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Big Hatchet Mountains–key to Paleozoic stratigraphy in southwesternmost New Mexico.

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Stratigraphy of the Big Hatchet Mountains Area New Mexico

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Abstract

This stratigraphic study was concentrated in the Big Hatchet Mountains of southwestern New Mexico, where Paleozoic rocks are completely exposed, and in Mojado Pass to the south, where Cretaceous rocks crop out. Prior to the present study, only reconnaissance observations had been made of the stratigraphy of the Big Hatchet Mountains area.

A remarkably thick and complete sequence of sedimentary formations lies between Precambrian basement rocks and Tertiary volcanic rocks. The column of sedimentary rocks exposed is about 20,000 feet thick, half of which is Paleozoic and half of which is Lower Cretaceous. The lower 15,000 feet of rocks is almost entirely of marine origin; the upper 5000 feet is mostly terrestrial.

Paleozoic rocks rest upon an erosion surface cut on Precambrian granite and quartzite. Cambrian, Ordovician, and Devonian rocks represented by the Bliss, El Paso, Montoya, and Percha formations are similar to the corresponding formations elsewhere in southern New Mexico. Silurian rocks are absent. Mississippian rocks, divided into the Escabrosa Limestone below and the Paradise Formation above, take their names from the formations of southeastern Arizona which they strongly resemble. Likewise, the Pennsylvanian and Permian sequence in the Big Hatchet Mountains area resembles the corresponding sequence in southeastern Arizona. Therefore, it is assigned to the Naco Group and is divided into the Arizona formations, which in ascending order are Horquilla Limestone, Earp Formation, Colina Limestone, Epitaph Dolomite, Scherrer Formation, and Concha Limestone.

The Paleozoic section is truncated throughout the region by an erosion surface upon which rest Lower Cretaceous rocks. In the Big Hatchet Mountains, this erosion surface was cut to various depths into the Concha Limestone. Arkosic sediments of the basal Lower Cretaceous section were derived from granite that was exposed nearby because of orogeny during the Permian—Early Cretaceous hiatus.

The Lower Cretaceous section is divisible into three gross lithologic units or formations—red beds below, limestone in the middle, and sandstone above. Though these formations resemble certain others in the region in lithology and age, correlations cannot be confidently established because correlations are not possible at present with similar-appearing formations only a few miles away in the Little Hatchet Mountains. Thus, the formations are given new names, which in ascending order are Hell-to-Finish Formation, U-Bar Formation, and Mojado Formation. Steeply dipping Cretaceous rocks are overlain unconformably by gently dipping Tertiary fanglomerate followed upward by a thick pile of volcanic rocks.

During most of Paleozoic and Early Cretaceous time, the Big Hatchet Mountains area was the site of greater deposition and thus greater subsidence than bordering areas in New Mexico and Arizona. Paleozoic formations from Mississippian through Permian are thicker here than elsewhere, and Lower Cretaceous deposits are very thick. Such thicknesses suggest geosynclinal deposition.

Fossil collections from most of the formations were submitted to a number of specialists whose identifications and comments on the ages of faunas and floras are given. Correlations of formations are suggested. Stratigraphic sections are described and shown graphically.

Introduction

The Big Hatchet Mountains area covered in this study is in southern Hidalgo County of southwesternmost New Mexico. The area includes the Big Hatchet Peak quadrangle and the northern part of the Dog Mountains quadrangle. The picturesque Big Hatchet Mountains (frontispiece), which dominate the landscape and trend northwestward through the heart of the area, are part of a long block-faulted range that extends northward into the Little Hatchet Mountains and southward into the Alamo Hueco Mountains. Hachita Valley flanks the range on the east and Playas Valley on the west. Part of the Sierra Rica lies in the northeastern corner of the Big Hatchet Peak quadrangle. The Big Hatchet Mountains area is shown on Plate 1, and its location with respect to the surrounding region is shown in Figure 1.

Originally, this project was undertaken as a general geologic study of the Big Hatchet Peak quadrangle. It soon became apparent that detailed study of the stratigraphy was necessary to distinguish formations and thus to map the structural geology. Detailed Paleozoic stratigraphy had not been previously described within a distance of i oo miles of the area, and the only prior study made of the Cretaceous rocks was by Lasky (1947) in the Little Hatchet Mountains where the Cretaceous section as presently interpreted differs greatly from that of the Big Hatchet Mountains area. Therefore there was little precedent for subdivision of the geologic column.

Exposures of Paleozoic and Cretaceous rocks in this area are the finest found in southwestern New Mexico. Stratigraphic sections are unusually complete, unmetamorphosed, well exposed, and practically unfaulted. No other areas between the Rio Grande and the Arizona border have such complete stratigraphic sections, and in no other area were the rocks so little known.

Detailed study of the stratigraphy in the Big Hatchet Mountains area not only served to divide the geologic column into mappable units, but also provided a preliminary knowledge of the sedimentary rocks of this virgin region.

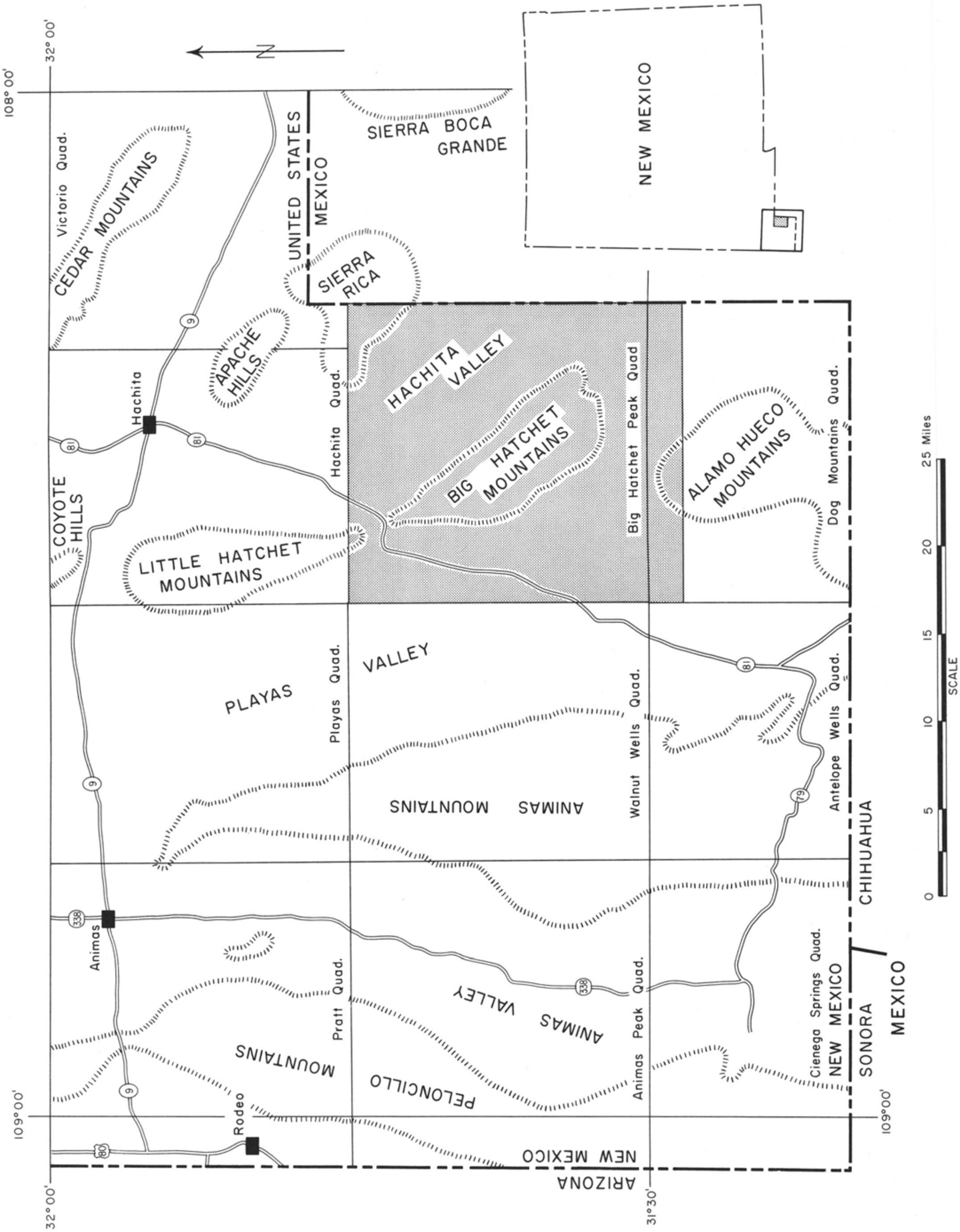

Figure 1

Index map of the Big Hatchet Mountains area and the chief geographic features of the region.

The general geology of the Big Hatchet Mountains area will be presented in another publication. Preliminary results were reported in the writer's dissertation (Zeller, 1958c).

This report presents detailed stratigraphic and paleontologic information concerning Paleozoic and Cretaceous sedimentary formations in the area of the Big Hatchet Mountains. Precambrian rocks are briefly described, and Tertiary rocks are only mentioned. It is hoped that this study will fill a gap in the hitherto incompletely known stratigraphy of southwesternmost New Mexico and that it will provide a basis for further stratigraphic studies. Between completion of the field work in the Big Hatchet Mountains area and publication of the results, several geologic studies of other areas in the region were published and are referred to herein.

Field work on this project was continuous from June 1951 until September 1953 and was intermittent from then until January 1964. Of the 33 months of field work in the Big Hatchet Mountains area, nearly half was devoted to stratigraphic studies.

To aid stratigraphic interpretation in the Big Hatchet Mountains area, field studies and observations were also made in the Little Hatchet, Animas, and Peloncillo Mountains, the Coyote and Apache Hills, the Sierra Rica, and Cooks Range, all in southwestern New Mexico; the Swisshelm, Mule, and Mustang Mountains and the Tombstone Hills in southeastern Arizona; and in Mexico in the Sierra Boca Grande, in ranges near Barreal, and in other localities in northwestern Chihuahua.

The initial field work was sponsored by the New Mexico Bureau of Mines and Mineral Resources under the direction of Eugene Callaghan. After Dr. Callaghan's departure from the Bureau in 1957, completion of the report and additional field studies were given only token financial support. The writer was obliged to finance most of this later work, a circumstance that delayed completion of the report by more than five years.

PREVIOUS WORK

Prior to this study, no detailed stratigraphic work had been done in the area. Darton (1928a) included the Big Hatchet Mountains in his reconnaissance geologic report on New Mexico. He mentioned the following formations as occurring in the Big Hatchet Mountains: Precambrian granite, Bliss Sandstone, El Paso Limestone, Montoya Limestone, Fusselman Limestone, Percha Shale, Lake Valley Limestone (probably), and Magdalena Group. The Fusselman, however, is not present. In the discussion of "Sarten sandstone and associated limestones (Comanche)," he noted limestone of Early Cretaceous age at the south end of the Big Hatchet Mountains.

Lasky (1947, p. 50-51) examined parts of the Big Hatchet Mountains to determine the relationship of the range to the Little Hatchet Mountains. He constructed a reconnaissance geologic map of the Big Hatchet Mountains (pl. 14 of his report) using his data and some of Darton's (1928b); in addition to Darton's formations, he recognized the "red shale and conglomerate (doubtfully of Cretaceous age)" which is the Hell-to-Finish Formation described in this report.

GEOGRAPHIC NAMES

The topographic maps of the Big Hatchet Peak and Dog Mountains quadrangles, published by the U.S. Geological Survey in 1918, were combined to make the base map used in this study (pl.). Because the original maps contained a number of incorrect geographic names and because named geographic features are so few that description of localities is difficult, certain revisions of and additions to the geographic names were made. Incorrect names were corrected, names now in local usage were added, and a few new names were introduced. These names have been submitted to the U.S. Board on Geographic Names for approval. In addition to the corrected and new geographic names, other cultural features of the base map were revised; the road pattern was brought up to date and new wells are shown. Changed and added geographic names are listed below:

Corrected names:

Badger Windmill changed to *Badger Well*
Benton Ranch changed to *Benton Well*
Chaineys Ranch changed to *Chaney Well*
Dallas Hatchet Ranch changed to *Hatchet Ranch*
Las Cienegas Spring changed to *Las Cienagas* Spring
Mengus Tank changed to *Mengus* Camp
Mosse Ranch changed to *Massey Well*
Petersons Ranch changed to *Peterson Farm*
Richens Ranch changed to *Richens Wells*
Robertsons Ranch changed to *Roberson Ranch*

Added names now in local usage:

Artesian Well	Little Tank
Badger Tank	Mine Canyon
Berts Well	Mine Canyon Tank
Big Tank	Muscratch Draw
Border Tank	New Well Canyon
Chaney Canyon	New Well Peak
Dark Canyon	Pierce Tank
Deep Well	Red Lake
Dishpan Tank	Red Lake Well
Double Tank	Romney Well
Double Wells	Sheep Tank
Hale Tank	Sheep Trap
Hell-to-Finish Tank	Sheridan Mine
Hell-to-Get-to Tank	Sheridan Tank
High Lonesome Well	South Sheridan Canyon
Horse Pasture Canyon	Thompson Tank
John Smith Ranch	Witch Well

New names with locations and histories:

Bighorn Canyon. Prominent canyon that lies chiefly in secs. 1, 2, and 12, T. 32 S., **R.** 15 W. This canyon is one of the main areas in which the

Mexican bighorn sheep ranged during the field study. It seems appropriate that this canyon should be named for this species, particularly as it is now near extinction.

Bugle Ridge. High ridge on the northeast flank of the Big Hatchet Mountains that lies between the mouths of Thompson and Sheridan Canyons. The name of this ridge commemorates a horse named Bugle, owned by the Hatchet Ranch, that lived about 40 years; its eventful life has become a local legend.

Mescal Canyon. Short canyon that lies on the northeast flank of the Big Hatchet Mountains in SE'% sec. 29, T. 3o S., R. 15 W. The canyon is named for a thick growth of mescal.

Mojado Pass. This name is applied to the broad, low pass between the Big Hatchet Mountains and the Alamo Hueco Mountains. The name is the Mexican word for "wetback," a Mexican national who enters the United States illegally. This pass is one of the chief routes of the "wetbacks."

Ram Gorge. Short, steep ravine that lies on the northeast flank of the Big Hatchet Mountains near the center of sec. 20, T. 3o, S., R. 15 W. This ravine is in the area in which several patriarch bighorn rams lived during the field work.

U-Bar Ridge. Prominent horseshoe-shaped ridge that lies off the southwestern flank of the Big Hatchet Mountains almost entirely on the U-Bar Ranch.

ACKNOWLEDGMENTS

I am most grateful to Dr. Eugene Callaghan, director of the New Mexico Bureau of Mines and Mineral Resources during the early part of the field work on this project, for granting me the financial aid of the Bureau, at first under the Ph.D. fellowship program and then as a member of the Bureau staff. Dr. Callaghan's realization of the importance of detailed stratigraphic studies in the area, his understanding of problems encountered in the field, and his counsel were indispensable to completion of the field studies.

Mr. Alvin J. Thompson, present director of the New Mexico Bureau of Mines and Mineral Resources, approved certain financial assistance that aided in completion of the report.

The hospitality and help of Mr. and Mrs. Mahlon T. Everhart, Jr., owners of the Hatchet Ranch, are appreciated. Mr. Everhart supplied me with horses during much of the field work and was helpful in many other ways.

John H. Rowland, A. J. Parker, and Arthur Rose assisted me in the field. I am indebted to them, particularly because much of their work was done without pay.

The many paleontologists who studied parts of my collections and furnished fossil identifications, age determinations, and environmental suggestions contributed an indispensable part to this study for which I am grateful. John W. Skinner and Garner L. Wilde, both of Humble Oil & Refining Company, studied the fusulinids. Alexander Stoyanow, University of California, Los Angeles, studied some of the Cretaceous fossils. Stuart A. Northrop, University of New Mexico, identified the Pennsylvanian and Permian megafossils. Rousseau H. Flower, New Mexico Bureau of Mines and Mineral Resources, studied some of the Cambrian and Ordovician fossils. Maxim K. Elias, University of Nebraska, studied fossils from the Paradise Formation and the lower beds of the Horquilla Limestone. Donald Baird, Museum of Comparative Zoology, Harvard University, identified Permian reptile and limuloid tracks. Russell M. Jeffords, Humble Oil & Refining Company, studied the Pennsylvanian and Permian corals. Robert F. Perkins, Shell Development Company, studied the Cretaceous rudistid pelecypods. Richard Rezak, Shell Development Company, examined samples of massive limestone from mounds in various formations for calcareous algae.

Many collections were studied by paleontologists of the U.S. Geological Survey and the U.S. National Museum. I am grateful to Charles B. Read, George 0. Bachman, and Sidney R. Ash, all of the U.S. Geological Survey, for arranging to have the collections studied. I wish to thank the following specialists for their assistance: Read identified plant fossils from the upper Paradise Formation, the Earp Formation, and Cretaceous rocks. The late John B. Reeside, Jr., identified many of the important fossils of the Mojado Formation. Ralph W. Imlay identified fossils from the upper U-Bar Formation. A. R. Palmer identified an important brachiopod from the Bliss Formation. G. A. Cooper confirmed identification of the brachiopod from the Bliss and examined brachiopods from the Percha Shale. W. J. Sando, in consultation with J. T. Dutro, Jr., identified corals and a brachiopod from the lower member of the Escabrosa Limestone. Raymond C. Douglass studied the orbitolinas. Norman F. Sohl identified gastropods from the U-Bar and Mojado Formations. Ruth Todd identified arenaceous foraminifers from the Mojado Formation, and Esther Applin confirmed the known maximum stratigraphic range of the same forms. I. G. Sohn studied ostracods from the Earp Formation. W. A. Cobban identified fossils from the Mojado Formation of the Animas Mountains, which are referred to in this report.

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Information on the deep oil test drilled southwest of the Big Hatchet Mountains was supplied by Richard D. Holt and Sam Thompson III, both of Humble Oil & Refining Company. Holt made available copies of the sample and geophysical logs; Thompson prepared a stratigraphic summary of the well included in this report. The cooperation of these geologists and of Humble Oil & Refining Company is appreciated.

Jess Coleman, Geological Sample Log Company, kindly made available the sample log of the oil test drilled east of the Big Hatchet Mountains.

I am grateful to Stuart A. Northrop for critically reading the manuscript and for offering many valuable suggestions. The manuscript was also read by Frank Kottlowski, New Mexico Bureau of Mines and Mineral Resources, Sam Thompson HI, and Charles B. Read.

Stratigraphy

A summary of the sedimentary formations in the Big Hatchet Mountains area is given in Figure 2. The geologic history pertinent to accumulation of the sedimentary formations and to their study is summarized below.

Eroded Precambrian crystalline rocks were inundated by the early Paleozoic sea, which advanced from the southwest. More than 1500 feet of Cambrian and Ordovician rocks were deposited. Any deposited Silurian rocks were removed by pre-Late Devonian erosion. An unbroken r 800-foot sequence of Devonian and Mississippian rocks accumulated, followed by a brief erosional break. About 3500 feet of Pennsylvanian and early Permian limestone was laid down in an unbroken sequence. This was followed by deposition of more than 4000 feet of Permian rocks. The 10,000 feet of Paleozoic rocks, most of which are of shallow-water marine limestone and dolomite, are the accumulations of more than one geosynclinal sea that reached this area at different times.

No Triassic or Jurassic rocks are preserved in the area. Fragmentary evidence of early Mesozoic history in the region indicates granitic intrusion, weak folding and faulting, and subaerial erosion. In Early Cretaceous time, the sea advanced from the south; a red-bed formation was deposited along the border of the sea. As the sea covered the area, 5000 feet of shallow-water marine sediments accumulated. After retreat of the sea, more than 5000 feet of terrestrial sediments accumulated in the Big Hatchet Mountains area.

Orogeny succeeded Cretaceous deposition, and the rocks of the area were strongly deformed by folds, high-angle faults, and overthrust faults. Elsewhere 'in the region, the intrusion of plutonic rocks caused metamorphism of sedimentary rocks. Though folding and faulting were strong in parts of the area of this study, satisfactory sections were preserved.

Following the orogeny, the region was above sea level and was eroded. Detritus accumulated on the flanks of residual high areas. Then volcanism started, and the region was covered by several thousand feet of volcanic flows, agglomerates, and tuffs. Finally, high-angle faulting and gentle tilting caused the uplift of mountain blocks with respect to the valley blocks; erosion produced the present land forms and created the excellent exposures of formations.

Many stratigraphic sections were measured in this study. The most important ones are described later in this report and are shown graphically. Study of the formations in the measured sections was supplemented by observations throughout the area and region. Stratigraphic studies in many other mountain ranges aided in identification and correlation of formations and in understanding regional depositional trends.

Comprehensive fossil collections were made to determine the age of rock units and to identify and correlate formations. Fossil groups having the greatest age significance, such as fusulinids in the Pennsylvanian—Permian rocks and ammonites in the Cretaceous rocks, were most completely collected; less important groups were incompletely collected. Most of the collections were made during study of stratigraphic sections, and each is numbered according to the stratigraphic section and bed from which it was collected. Important segments of faunas were sent to more than twenty different paleontologists for identification and age determination. Though study of entire faunas would have been more satisfactory, selection of only the significant elements of faunas for study was the most practical means under the circumstances of learning the age of the rock units in this study. Most of the fossil collections are retained by the institutions whose specialists made the identifications. The remaining fossil collections and lithologic samples are stored at the State Bureau of Mines and Mineral Resources in Socorro, New Mexico.

Problems of placing system and series boundaries are present here as in many areas. Notable of the problems are those between the Cambrian and Ordovician, the Devonian and Mississippian, and the Mississippian and Pennsylvanian, and between the series in the Cretaceous section. Several factors contribute to the problems. This is a relatively unknown region in which few paleontologic studies have been made. Many fossils have not been studied and are new forms whose ages and stratigraphic ranges are not known. Fossils occur together here that have not been found together elsewhere. In many instances, the faunas near a boundary in this project have not been collected or studied in sufficient detail to determine on which side of the boundary they belong. It seems axiomatic that the closer a fossil is found to a time boundary in a little-studied area, the greater the uncertainty as to which side of the boundary it should lie. However, as far as interpreting the stratigraphy of the region is concerned, such boundary problems do not seriously influence conclusions.

PRECAMBRIAN ROCKS

Paleozoic sedimentary rocks in the Big Hatchet Mountains area rest upon an erosion surface carved deeply in Precambrian rocks. The principal exposures of Precambrian rocks are on the small hills north of the highway in Hatchet Gap, on the southern end of the Little Hatchet Mountains, on the hill north of the mouth of Chaney Canyon on the west side of the Big Hatchet Mountains, and at the base of exposures in secs. 20 and 29, T. 3o S., R. 15 W. on the east side of the Big Hatchets. Other small exposures of Precambrian rock in fault blocks do not show the pre-Paleozoic erosion surface.

A mass of Precambrian quartzite, which was intruded by Precambrian granite, is exposed on the first hill north of the highway in Hatchet Gap. The Paleozoic Bliss Formation rests upon the quartzite for about i oo feet along the contact. Elsewhere on this hill and in other parts of the area where the unconformity is exposed, Paleozoic rocks rest upon Precambrian granite.

The Precambrian quartzite is massive but in places shows

Figure 2.—SUMMARY OF SEDIMENTARY ROCK FORMATIONS IN BIG HATCHET MOUNTAINS AREA.

Age			Rock units		Measured thicknesses (feet)	Lithology and remarks
TERTIARY						Basal unit consists of several hundred feet of limestone fanglomerate. This is overlain by thick sequence of volcanic tuffs and flows.
			Angular unconformity			
EARLY CRETACEOUS	Albian	Washita	Mojado Formation	Upper member	5195	Sandstone and shale. Thin to medium beds of strongly cross-laminated brown and gray sandstone are interbedded with thin units of shale. Lens-shaped sandstone masses probably represent channel fillings. Most of formation is of terrestrial origin. Calcareous fossiliferous marine beds are present in upper member and increase in number upward.
				Lower member		
		Fredericksburg	U-Bar Formation	Suprareef ls. mem.	3500	Limestone. Most of formation consists of medium and thin beds of bioclastic limestone alternating with thin gray shale beds. Lenses and thin beds of sandstone are found in lower part. Massive limestone near top of formation is a reef which ranges in thickness from 500 to 20 feet within the area.
				Reef ls. member		
	Aptian	Trinity		Ls.-sh. member		
				Oyster ls. member		
				Brown ls. member		
	?	?	Hell-to-Finish Formation		1274	"Red beds." Composed mostly of interbedded red arkose and sandstone, red and gray shale, and red siltstone. Basal bed is conglomerate composed of chert pebbles derived from Concha Limestone.
			Erosional unconformity			
PERMIAN	Leonard		Naco Group: Concha Limestone		1376	Limestone. Medium-bedded limestone characterized by abundance of purple chert nodules and silicified productid brachiopods. Upper beds often dolomitized. Pre-Cretaceous erosion removed varying amounts of upper beds.
	Leonard or Wolfcamp		Naco Group: Scherrer Formation		5-20	Quartz sandstone and limestone. Sandstone occurs as strata and lenses in limestone.
			Naco Group: Epitaph Dolomite		1480-1519	Dolomite. Medium-bedded light to dark gray dolomite with small knots of quartz. Lower part has a few lumpy limestone and dolomitic limestone beds. A red-weathered interval in lower part has red siltstone and, in one area, massive gypsum.
			Naco Group: Colina Limestone		355-505	Limestone. Thin-bedded limestone which is black on fresh fracture and which weathers light gray. Upper contact lies at different levels depending upon depth in section of Epitaph dolomitization.
			Naco Group: Earp Formation		997	Siltstone and claystone. Composed mainly of interbedded terrestrial brown-weathered cross-laminated siltstone and light gray claystone. Upper part contains marine limestone beds which increase in abundance upward.
			Local disconformity			
	Wolfcamp		Naco Group: Horquilla Limestone		3245-3530	Limestone. Lower third is medium-bedded bioclastic limestone which includes oolitic and crinoidal beds and some zones rich in gray chert nodules. Upper two-thirds is complicated by basin, reef, and shelf facies. The crest of the Big Hatchet Mountains in general follows the reefs; the basin lies southwest of the range; the shelf lies along the east side of the range. The reefs consist of massive bioclastic limestone with dolomitized areas. Basin deposits consist of dark shale and black thin-bedded limestone. The shelf beds consist of light-colored medium-bedded bioclastic limestone.
PENNSYLVANIAN	Virgil					
	Missouri					
	Des Moines					
	Derry					
	Morrow?					
?	?		*Erosional unconformity*			
MISSISSIPPIAN	Chester		Paradise Formation		318	Limestone. Thin-bedded yellowish-brown-weathered bioclastic and oolitic limestone rich in well-preserved fossils. Quartz sandstone beds and lenses near top have plant fossils. Pre-Horquilla erosion removed varying amounts of upper beds.
	Meramec		Escabrosa Limestone	Upper member	1261	Limestone. Lower member composed of thin-bedded limestone and a few shale beds. Middle member consists of rhythmic succession of thin limestone strata and nodular chert strata. Upper member composed largely of crinoidal limestone. Upper two members together usually form single cliff hundreds of feet high.
	Osage			Middle member		
	Kinderhook			Lower member		
?	?					
DEVONIAN			Percha Shale		280	Clay shale. Basal beds include a few strata of calcareous argillaceous siltstone and black shale. Upper beds include thin strata of nodular limestone. Bulk of formation is gray shale.
			Unconformity			
ORDOVICIAN	Cincinnatian		Montoya Dolomite	Cutter Member	385	Dolomite. Basal member consists of 10 to 20 feet of dolomitic quartz sandstone interbedded with dolomite. Aleman Member composed of rhythmic succession of dark gray dolomite strata and strata of black chert nodules.
				Aleman Member		
	Champlainian			Upham Member		
				Cable Canyon Mem.		
			Disconformity			
	Canadian		El Paso Formation	Bat Cave Member	916-1070	Limestone and dolomite. Sierrite Member composed of dolomite and dolomitic limestone; some strata rich in chert nodules and brown reticulated chert laminae. Bat Cave Member consists of bluish-gray-weathered bioclastic limestone. Uppermost beds dolomitized.
				Sierrite Member		
?	?					
LATE CAMBRIAN	Trempealeauian?		Bliss Formation		192-327	Arenaceous rocks. Basal beds composed of arkose and boulder conglomerate. Middle beds consist of white orthoquartzite. Upper beds composed of dolomite with varying quantities of quartz sand. Thickness and lithology of units variable.
	Franconian					
	Dresbachian?					
			Erosional unconformity			
PRECAMBRIAN						Coarsely crystalline porphyritic granite and quartzite.

bedding laminae. It is medium gray on fresh fracture and weathers brown. Sand grains consist of medium- to coarse-grained subrounded quartz and are silica-cemented. Megascopic examination of the quartzite near the granite contact shows quartz grains enclosed in feldspar crystals. This is apparently due to secondary feldspar growth associated with the intrusion nearby of Precambrian granite.

The granite is coarsely crystalline, porphyritic, and altered. Feldspar phenocrysts are rounded and average nearly half an inch in diameter. Fresh granite is medium gray, and the weathered surfaces are brown and rough. Petrographic descriptions of the Precambrian granite and quartzite are given by Lasky (1947; Precambrian granite described under heading "Porphyritic granite" on p. 32 and 33; description of Precambrian quartzite in first paragraph, p. 59*). The granite is less resistant than overlying Paleozoic rocks and, except for bold outcrops in Hatchet Gap and in the Little Hatchet Mountains, the rock is seldom exposed. Veins of milky quartz cut the Precambrian quartzite and granite; quartz veins are not found cutting younger sedimentary rocks of the immediate area.

Evidence of Precambrian age of the granite and quartzite is conclusive. Exposures of the erosion surface upon which Paleozoic rocks were deposited are abundant, and the character of the contact can be decisively determined. Basal beds of the Paleozoic section consist of arkose and coarse conglomerate derived from weathering of Precambrian rocks. Late Cambrian brachiopods are found in beds loo feet above the unconformity in the Hatchet Gap section.

Precambrian age of the granite is further confirmed by zircon age determinations. Jaffe and Schlecht (written communication, 1957) reported ages for the granite of 605 million years and 640 million years, which are late Precambrian and very close to the Cambrian boundary. They further remarked, "The zircon of sample 493-93o is purple in color. . . . Purple zircon is known only from Precambrian plutonic rocks."

The intrusive nature of the contact between the granite and quartzite, whether the quartzite be a large xenolith or a roof pendant of the pluton, proves that the quartzite is older than the granite and thus is of Precambrian age.

PRE-LATE CAMBRIAN UNCONFORMITY

The earliest Paleozoic rocks of the area, the Bliss Formation, rest with profound unconformity upon Precambrian rocks. Though fossils of specific age significance have not been found in the lower part of the Bliss, beds 100 feet above the unconformity have early Franconian (middle Late Cambrian) fossils. The period of erosion represented by the unconformity may have ceased in the area in about early Franconian time, or it may have ended earlier.

Throughout southern New Mexico and southeastern Arizona, early Paleozoic sandstone rests unconformably upon Precambrian rocks. Without exception, the lower part of the sandstone lacks useful fossils. The ages of the first fossils that appear above the unconformity become progressively younger eastward—Middle Cambrian in central Cochise County, Arizona; Late Cambrian in the Chiricahua and Big Hatchet Mountains; and Early Ordovician at El Paso, Texas. This suggests that the period of pre-sandstone erosion ceased at progressively younger times toward the east and that the basal sandstone was deposited by an eastward-advancing sea. But because of the unknown ages of the lowest beds and the possibility of undetected depositional breaks in these barren beds, this concept remains speculative.

In the Big Hatchet Mountains area, the pre-Bliss erosion surface has at least several tens of feet of relief, which is visible in Chaney Canyon and Hatchet Gap. Relief may have been greater, as indicated by the great size of boulders in basal Bliss beds and by sharp changes in lithology and thickness of the Bliss Formation over short distances.

CAMBRIAN AND ORDOVICIAN SYSTEMS

In the area of this study, the position of the Cambrian—Ordovician boundary is not precisely known and may lie within the upper part of the Bliss Formation. Rocks of these systems are divided into three formations. The basal arenaceous beds are assigned to the Bliss Formation; the predominantly limestone sequence above is called the El Paso Formation; and the upper unit of dolomite is assigned to the Montoya Dolomite.

BLISS FORMATION

The basal Paleozoic arenaceous formation in the Franklin Mountains east of Fort Bliss, Texas, was originally named *Bliss Sandstone* by Richardson (1904, p. 27). Kelley and Silver (1952, p. 33-34) summarized the history of use of the formation name and proposed that the name be changed from *Bliss Sandstone to Bliss Formation* " . . . because the lithology is diverse over the region and such a change will probably lead to more significant lithologic and thickness data and hence better paleogeologic interpretations."

The basal Paleozoic arenaceous formation in the Big Hatchet Mountains area is similar in lithology and age to the Bliss of south-central New Mexico and is assigned to that formation. The usage of Kelley and Silver, *Bliss Formation*, is followed in the Big Hatchet Mountains because here, though sandstone is the dominant rock type, the lithology of the formation varies.

West of the Big Hatchet Mountains, principally in Arizona, the basal Paleozoic sandstone is assigned to the Bolsa Quartzite. Although the basal part of the Bliss in the Big Hatchet Mountains is undoubtedly the lithogenetic equivalent of the Bolsa, the upper part of the formation is probably not correlative lithologically or timewise with the Bolsa. Therefore, as the sandstone unit in the Big Hatchet Mountains is more closely allied to the Bliss than to the Bolsa, the former name is more appropriate.

Distribution and Topographic Expression

The Bliss Formation is exposed in four places in the area. In the Sierra Rica, several outcrops are found on the south

* In Lasky's report, the Precambrian age of these rocks was not recognized.

sides of the hills in secs. 31 and 32, T. 29 S., R. 14 W. In Hatchet Gap, exposures are seen on the tops and southwest slopes of the three hills north of the highway. On the east side of the Big Hatchet Mountains, a belt of exposures extends southeastward from sec. 20 to sec. 33, T. 3o S., R. 15 W. On the west side of the range, the formation crops out on the top and north side of the small ridge that lies north of the mouth of Chaney Canyon.

In Chaney Canyon and Hatchet Gap, the Bliss Formation consists chiefly of thick-bedded sandstone, which is resistant and forms the tops of ridges and hills. In the Sierra Rica, the formation is also mostly sandstone, but areas of exposure are small and inconspicuous.

Along the east side of the Big Hatchet Mountains, the formation has little sandstone and consists largely of sandy dolomite and shale. Here the formation is nonresistant and is incompletely exposed in gullies and in small outcrops at the base of the range.

Stratigraphy

On the east side of the Big Hatchet Mountains, the Bliss Formation was studied in the Mescal Canyon and Ram Gorge sections. A few miles to the southwest, three closely spaced, overlapping stratigraphic sections were measured in Chaney Canyon to eliminate the effects of several faults. Two of these are combined to form the Composite Chaney Canyon section in which the Bliss Formation is included. A short section of the Bliss was measured in Hatchet Gap. The sections are described later and are shown graphically on Plate 2.

The lower contact of the Bliss with Precambrian rocks is definite, but the upper contact is not so clearly defined. In most sections in the Big Hatchet Mountains area, the upper part of the formation consists of dolomite containing varying amounts of quartz sand. Overlying dolomite of the El Paso Formation looks like the Bliss dolomite, but it lacks the sand. In the field study of the Bliss, the upper contact was chosen at the top of the highest bed in which quartz sand is obvious. This contact is somewhat indefinite and is difficult to choose with consistency in all sections.

The choice of the upper contact above the sandy dolomite is in variance with the usage of most authors, who place the contact above the highest sandstone and include overlying sandy dolomite in the El Paso Formation. However, sandy dolomite can be traced laterally into sandstone in the Big Hatchet Mountains; this indicates the equivalence of sandy dolomite in some sections with sandstone in others. Here no lithologic break is evident between the Bliss and El Paso. In the absence of such a break, the contact is chosen at the level above which quartz sand is not obvious. Besides being a useful field criterion for differentiating the two formations, it is genetically valid, for it marks the end of deposition of arenaceous sediments.

The lithologic sequence of the Bliss Formation is similar in gross aspect in all the areas studied, including the northern part of the Big Hatchet Mountains, Hatchet Gap, the Sierra Rica, and the northwestern part of the Animas Mountains. On the reconnaissance geologic map of the latter area (Zeller, 1958a), the Bliss is included in the map unit designated as "Undifferentiated Lower Paleozoic formations."

The general threefold sequence of rock units in the Bliss is as follows: The basal beds consist of arkose and of conglomerate composed of large boulders of Precambrian rocks in a coarse-grained arkosic matrix. A distinctive unit of white quartzite is next. The upper unit consists of dolomite in which some beds contain quartz sand. Although this generalized sequence applies throughout the region, many local variations were noted in the thicknesses and rock types of the various units, particularly in the lower and upper parts. These variations are described below.

In Hatchet Gap, the lithology of the Bliss Formation conforms well to the regional sequence. The basal 5o feet consists of arkose, arkosic sandstone, boulder conglomerate, and some quartzite. Rock units vary greatly in lithology and thickness along the strike. In the measured section, the lower 6-foot bed consists of coarse-grained arkose with some rounded pebbles of milky quartz and a few boulders of Precambrian granite. Above this are two lensing beds of conglomerate interbedded with sandstone. The conglomerate consists of boulders as large as 20 feet in length composed of Precambrian quartzite and granite; the matrix is of arkose having laminations upturned along the sides of the boulders in original depositional attitudes. Arkosic sandstone and quartzite beds within the lower 5o feet are strongly cross laminated and contain *Skolithos** tubes.

Above the variable lower part of the formation, white-weathered, silica-cemented, medium-grained, cross-laminated quartzite 43 feet thick forms the most prominent exposures in Hatchet Gap. The pure quartzite is overlain by 43 feet of less pure arkosic and dolomitic thin-bedded sandstone that is medium gray when fresh and brown when weathered. The proportion of dolomite cement progressively increases higher in the sandstone to 5o percent. Brown-weathered stringers in the upper part of the dolomitic sandstone represent irregular concentrations of silica cement. An early Franconian (middle Late Cambrian) brachiopod fauna is found near the base of this impure sandstone.

The upper 85 feet of exposed beds in the Hatchet Gap section consist of sandy or quartzose dolomite with the quantity of quartz sand varying from bed to bed; the more sandy beds weather brown in contrast to the gray color of the pure dolomite beds. Here, the top of the Bliss Formation is not exposed.

Along the northeastern flank of the Big Hatchet Mountains the character of the Bliss changes. The lower arkosic and conglomeratic beds vary sharply in thickness, the white quartzite is quite thin, and the upper sandy dolomite unit is thick.

In the Ram Gorge section, 3 1/2 miles southeast of Hatchet Gap, the basal 5o feet of the Bliss consists of arkose and boulder conglomerate with arkose matrix. One boulder measures 25 feet across. This is overlain by 16 feet of thin-bedded hematitic shale having some arkosic silt and including lenses and thin strata of partly leached oolitic hematite. The beds of light gray quartzite above are only 20 feet in thickness. The remaining 163 feet of the upper Bliss consists of

* *Skolithos* Haldeman, 1840 has priority over *Scolithus* Hall, 1847.

quartzose dolomite in which sand-rich beds weather brown. Nearly half of the rock consists of quartz sand. The contact with the El Paso Formation is not sharp and was chosen at the highest dolomite containing obvious quartz sand.

From Ram Gorge southward, the Bliss Formation is exposed for 1 1/2 miles. A few hundred yards south of Ram Gorge, Precambrian granite is overlain by 20 to 3o feet of arkose or very arkosic sandstone. Above the arkose, the white quartzite unit is very thin and in places is missing. The overlying sandy dolomite consists of nearly 5o percent quartz sand and includes some brown-weathered beds of dolomitic quartzite. Half a mile south of Ram Gorge, the basal arkose and conglomerate unit is missing, and a very thin unit of white quartzite—in one place only one foot thick—rests upon granite. This is succeeded upward by the sandy dolomite unit, which has less sand than in the Ram Gorge section.

About 1 1/2 miles south of Ram Gorge, the Mescal Canyon section was studied. Here a 4-foot basal bed of granite-arkose boulder conglomerate is overlain by 42 feet of arkose. This is succeeded by the remainder of the formation, 146 feet of sandy dolomite with some beds of dolomitic sandstone and some of dolomite. Quartz-free dolomite beds are light gray; those rich in sand weather brown. A single 22-foot bed of dolomitic sandstone near the middle of this unit contains 6o to 7o percent quartz sand. Because of its resistance and its dark-brown-weathered color, this bed is a prominent local marker which may be traced for more than a mile.

The Bliss Formation is exposed at the base of the spur a quarter of a mile southeast of the Mescal Canyon section. Here the basal beds, which rest upon granite, consist of granite-quartzite boulder conglomerate with arkose matrix. Boulders range in size to 20 feet in diameter. This is overlain by arkose. The combined thickness of the basal conglomerate and arkose units is 138 feet. A hundred yards to the north, these basal units are only a few tens of feet thick. The basal beds are overlain by 27 feet of white, very coarse-grained quartzite which becomes dolomitic upward. Above the quartzite, the remainder of the formation consists of interbedded sandy dolomite, dolomitic sandstone, and dolomite; the sand-rich beds weather dark brown.

On the west side of the Big Hatchet Mountains in Chaney Canyon, the Bliss Formation has its southernmost exposure in the area and, in fact, in New Mexico. The composite Chaney Canyon section lies five miles south of Hatchet Gap and two miles southwest of the Mescal Canyon section.

The lower part of the section, which includes the Bliss, was measured near the eastern end of the small ridge north of the canyon floor. Although a major fault lies nearby and minor faults are present on the ridge, the Bliss section is believed to be unfaulted.

Here the formation differs from other sections in having a much greater thickness of arkose in the lower part and in having little sandy dolomite in the upper part. The basal 8-foot bed consists of granite boulder conglomerate with arkose matrix. This is followed by 215 feet of arkose grit with some thin strata of coarse-grained arkosic sandstone and quartzite. The lower beds are weathered brown and may be distinguished from underlying granite by the presence of a few rounded milky quartz pebbles and crude bedding. The upper part of the arkose unit is finer grained, with grain sizes ranging from granule to medium sand; it is thin bedded and nonresistant. Some arkose beds are hematitic.

Above the arkose unit is 48 feet of silica-cemented arkosic sandstone, which is white when fresh and brown when weathered. The next and highest unit of the Bliss in the measured section is medium-bedded, medium- and coarse-grained, white, silica-cemented quartzite 56 feet thick. The contact of the quartzite with overlying carbonate beds of the El Paso Formation is sharp. It is believed to be a depositional, not a faulted, contact.

A few hundred yards west on the same ridge, the lower arkose beds are the same as those measured. The white quartzite, however, is thinner, and a few tens of feet of brown-weathered sandy dolomite lie between the quartzite and the base of the El Paso Formation. As the sandy dolomite beds are traced toward the measured section, they become increasingly more sandy and finally become quartzite, merging with the underlying unit.

The sections of Bliss Formation described are in the northern part of the Big Hatchet Mountains and Hatchet Gap; all are within a five-mile radius. Although the generalized threefold lithologic sequence mentioned earlier may be recognized through most of the area, there are notable variations in each unit which were described above and which are here summarized. Basal boulder arkose conglomerate is present in all the sections and in most of the exposures between sections. The arkose unit is thin in Hatchet Gap and thick in Chaney Canyon. On the east side of the range its thickness is intermediate but quite variable. The overlying white quartzite has similar thicknesses in Hatchet Gap and Chaney Canyon but is quite thin and locally missing on the east side of the Big Hatchets. The upper unit, sandy dolomite, has a moderate thickness exposed in Hatchet Gap, comprises the upper two-thirds of the Bliss on the east side of the range, and is very thin and wedges out in Chaney Canyon. Evidence in Chaney Canyon shows that the upper part of the white quartzite is the lateral equivalent of upper sandy dolomite. The thick sandy dolomite on the east side of the range may likewise be equivalent to much of the quartzite in the other sections.

High-angle, northwest-trending faults lie between exposures of Bliss in Hatchet Gap, on the east side of the range, and in Chaney Canyon (Zeller, 1958c, p. 169-173). Fragmentary evidence indicates possibly large lateral movement that could have shortened significantly the original distances between these areas. Thus, the changes in the formation seen within five miles may have taken place much farther apart during deposition.

The Bliss Formation is exposed in two other places within the region, in the Sierra Rica and in the Animas Mountains. On the northwestern spurs of the Sierra Rica nine miles east of Hatchet Gap, the Bliss is exposed in an overthrust fault sheet, but because of structural complications and incomplete sections, it was not studied in detail. The lowest Bliss exposed consists of several tens of feet of white quartzite with *Skolithos* tubes and several thin strata of argillaceous sandstone with linguloid brachiopods. This is overlain by brown-weathered sandy dolomite.

On the northwestern flank of the Animas Mountains 20 miles northwest of Hatchet Gap, lower Paleozoic formations rest upon Precambrian granite. Although the area is faulted, a complete section of Bliss Formation is present. The section was not measured or studied, but the lithologic sequence was noted. The basal part, at least 5o feet of brown-weathered thin beds, consists of arkose-pebble conglomerate, arkose, shale, and quartzite. Above this is a unit of white quartzite at least 6o feet thick. The quartzite is overlain by brown-weathered dolomite in which sand-rich beds are cross laminated.

Where the entire Bliss Formation was measured, its thicknesses are as follows: Ram Gorge section, 249 feet; Mescal Canyon section, 192 feet; Composite Chaney Canyon section, 327 feet. In the Hatchet Gap section where the top of the formation is covered, 223 feet of Bliss was measured. Its thickness in the Animas Mountains appears to be of the same order of magnitude. Because the Bliss was deposited upon an irregular surface and because choice of the upper contact is perhaps not consistent in all sections, the variations in thickness of the formation within the Big Hatchet Mountains area have no particular regional significance.

Conditions of Deposition

The Bliss Formation in this area was deposited upon an irregular surface eroded upon Precambrian rocks. Some tens of feet of relief were seen on the old surface in Hatchet Gap and in Chaney Canyon, and about 100 feet of relief in a distance of loo yards were noted south of the Mescal Canyon section. Judging from the 20-foot diameter boulders found resting on the surface, relief was probably even greater. That the boulders of the basal conglomerate beds were transported and were not merely blocks of rock weathered in place on the pre-Bliss erosion surface is shown by the inclusion of quartzite boulders in places where only Precambrian granite and no quartzite is presently exposed. The quartzite boulders were moved from nearby sources which are now covered or were eroded away.

Erosion of the pre-Bliss surface probably took place under land rather than sea conditions. Subaerial erosion would account for the sharp irregularities of the surface more readily than would marine erosion.

The Bliss Formation is a marine deposit probably formed along the shoreline of an advancing sea. Its marine origin is shown by marine brachiopods and other evidence of sea life, such as *Skolithos* tubes. Cross-lamination was caused by shifting of the sand by wave and current action. Depressions in the old erosion surface were filled with conglomerate and arkose derived from weathered Precambrian rocks. Coarse sediments of the basal Bliss may represent fillings of submerged channels, or they may be small deltas. Deposition upon this irregular surface accounts for the sharp variations in thickness and character of the lower Bliss sediments.

With the filling of depressions by arkosic sediments and the erosion of hills, the surface became relatively smooth. The white silica-cemented quartzite of the Bliss Formation present almost universally in this region was deposited. The sands were well worked by wave action which produced well-sorted, equidimensional, subrounded quartz sand free of feldspar.

The white quartzite is overlain by sandy dolomite. The origin of the sandy dolomite of the upper Bliss is thought to be as follows: As the margin of the sea advanced beyond the region and clean sands were left behind, the depth of water increased to below wave base. Lime mud was deposited, and currents from the shore carried varying quantities of sand which became incorporated in the mud. That the dolomite was deposited as lime mud is indicated by the preservation of fossil shell fragments as inclusions in chert nodules. Such fragments were also undoubtedly included in the mud, but during dolomitization they were destroyed. Also, some of the dolomite is finely brecciated, which indicates that the mud was at least partially hardened to limestone and that during later dolomitization, brecciation resulted from a volume change.

Variations in thickness of white quartzite and quartzose dolomite units were caused by slight changes in depositional environment. In Chaney Canyon, sandy dolomite beds traced along the strike become progressively more sandy, and within a few hundred yards become white quartzite. On the east side of the Big Hatchet Mountains north of Mescal Canyon the upper Bliss beds become more sandy. Some such sand may have been transported to deeper water by currents, but in Chaney Canyon the upper beds of white quartzite, which are lateral equivalents of sandy dolomite, probably represent deposits along a shoreline that existed here longer than elsewhere in the area. During late Bliss deposition, the depth of the sea probably remained close to wave base.

No interruption in sedimentation is apparent between the Bliss and El Paso Formations. As defined in this study, the top of the Bliss is the highest level at which quartz sand is obvious. When the sea became sufficiently deep and when the shoreline was sufficiently far that little or no quartz sand was deposited in the lime muds, deposition of the El Paso Formation commenced.

In southeastern Arizona, the conditions of deposition of the Bolsa Quartzite, in part the lithologic equivalent of the Bliss, were similar (Gilluly, 1956, p. 15). There the basal Paleozoic sands were deposited upon a smooth rather than irregular surface of Precambrian rocks; the coarse-grained arenaceous sediments were deposited in shallow water, and, according to Gilluly, deposition of the overlying limestone formation "was a direct continuation of sedimentation as the depth of the sea increased and the waves were no longer able to transport coarse detritus."

Age and Correlation

Though fossils are rare in the Bliss Formation, a significant brachiopod fauna was found in the Hatchet Gap section. It occurs above the white quartzite in thin-bedded gray and brown arkosic and dolomitic sandstone 102 feet above the base of the formation. Palmer (written communication, 1962) reported on the collection as follows:

> All of the brachiopod remains are of orthoid forms. The larger strongly ribbed specimens represent the genus *Eoorthis;* smaller specimens represent another eoorthoid that is not generically determinable. Both Dr. G. A. Cooper, who confirmed the identification, and I agree that this is certainly a fauna of Cambrian age. *Eoorthis* is widespread in the lower part of the

Franconian stage of the middle Upper Cambrian and this is most likely the age of the sample.

The collection was retained by the U.S. Geological Survey and was assigned U.S.G.S. collection number 3797.

Linguloid brachiopods and *Skolithos* found in the Bliss have no specific stratigraphic significance.

A small, semiconical form found higher in the Bliss and 20 feet below the top of the formation in the Mescal Canyon section was studied by Rousseau H. Flower (written communications, 1960 and 1962). He regards the specimen as an undescribed amphineuran, a form to which present-day chitons are related. Flower notes that an amphineuran occurs in the Oneota Dolomite of Wisconsin, which is of earliest Ordovician (earliest Canadian or Gasconadian) age. He believes that the form from the Big Hatchet Mountains is of the same age. Basing the age of the uppermost Bliss upon such a fossil is somewhat tenuous, but such an assignment is not unlikely because 63 feet higher in the Mescal Canyon section, a definite early Canadian fauna is found.

By using the scant fossil data and by extrapolation using lithologic information, the age of the Bliss Formation in the area may be tentatively surmised. No lithologic breaks are evident in the Bliss, but such breaks could be present and not apparent. The rates of deposition certainly were varied. Conglomerate and arkose in the lower part were probably deposited rapidly. The overlying white quartzite, a shoreline deposit, was probably deposited at a slower, moderate rate. The upper sandy carbonate rocks of the Bliss may have been deposited very slowly.

The conglomerate, arkose, and white quartzite that underlie the early Franconian *Eoorthis* fauna were probably deposited at rapid to moderate rates and therefore during a relatively short time. They may be of Dresbachian age (early Late Cambrian). However, if any unrecognized depositional breaks occurred, some of the lower beds may be older.

As no depositional breaks are apparent between the Eoorthis-bearing beds and the overlying sandy dolomite, and as the dolomite may have been deposited slowly over a long period, it seems probable that the dolomite is of Franconian and Trempealeauian (late Late Cambrian) age. If the enigmatic undescribed amphineuran of the uppermost sandy dolomite is of earliest Canadian age, Bliss deposition in the area extended into earliest Canadian time.

Thus, the age of the Bliss Formation in the Big Hatchet Mountains area is known to include early Franconian time, is thought to include most of the Upper Cambrian epoch, and may include pre-Upper Cambrian and earliest Canadian times. These conclusions are in accord with the age of the overlying beds in the area, and with the age of the Bliss and its correlative formations in the region.

The lower part of the Bliss Formation in the area of the Big Hatchet Mountains is probably the lithogenetic equivalent of part of the Bolsa Quartzite of southeastern Arizona, and as such it appears to represent the continued arenaceous deposition of an eastward-advancing sea. Inconclusive age information, derived mostly from fossils in beds overlying the basal sandstone, indicates that the Bolsa and lower Bliss become younger eastward.

The problem of correlation of the upper Bliss with formations in Arizona is discussed in a later section.

EL PASO FORMATION

Originally Richardson (1904, p. 29), in naming the El Paso Limestone for exposures in the Franklin Mountains north of El Paso, Texas, included all limestone of Ordovician age in the formation. Later he (Richardson, 1909, p. 3) divided the Ordovician limestone of the Franklin Mountains into two formations, stating that "the name El Paso is retained for the lower formation which contains Lower Ordovician fossils." Cloud and Barnes (1948, p. 61) commented, "The El Paso 'limestone' of previous authors contains limestone, dolomite, minor sandstone, and local shale beds and is therefore referred to as the El Paso formation in this report." Kelley and Silver (1952, p. 40-42) raised the El Paso to group status and divided it into the Sierrite Limestone and Bat Cave Formation.

In the Big Hatchet Mountains, the name *El Paso Formation* is used for the rocks lying between the highest sandy dolomite bed of the Bliss Formation and the lowest bed of the Montoya Dolomite in which quartz sandstone lenses are present. The El Paso is called "formation" rather than "limestone" because of the varied lithology. Since the formation is mapped as a single unit, it is assigned to formational rather than group status. The Sierrite and Bat Cave Members are recognized and, though they are not mapped separately, they are described below.

Distribution and Topographic Expression

The El Paso Formation is exposed on the west side of the Sierra Rica and in the northern part of the Big Hatchet Mountains. In the Sierra Rica, the formation occurs only in an overthrust fault plate mainly in the hills in secs. 31, 32, and 33, T. 29 S., R. 14 W. A very small exposure is found in SE1/4SE1/4 sec. 10, T. 30 S., R. 14 W.

In the Big Hatchet Mountains, an exposed band of El Paso Formation somewhat complicated by faults extends from sec. 13, T. 30 S., R. 16 W. southeastward to sec. 33, T. 30 S., R. 5 W. The formation also crops out on the north side of Chaney Canyon.

The lower part of the formation, composed of dolomite and dolomitic limestone, is nonresistant and forms moderate slopes. The upper part is composed of more massive limestone and is more resistant; on the ridge in sec. 19, T. 30 S., R. 15 W., it forms prominent cliffs. Elsewhere, erosion of the upper beds has developed a bluff-and-terrace topography where massive beds form the bluffs and thin-bedded limestones form the terraces.

Stratigraphy

The El Paso Formation was studied in three stratigraphic sections on the east side of the range and in three sections in Chaney Canyon on the west side. Later in this report, the formation is described in the Mescal Canyon, the Ram Gorge, and the Composite Chaney Canyon sections; these sections are shown graphically on Plate 2. The Mescal Canyon section is the most completely exposed and most carefully studied, and it is designated as the best reference section for the El Paso and other lower Paleozoic formations in the area. Figure 3 is a photograph that shows the location of the Mescal Canyon section.

The formation is divided into the Sierrite Member below and the Bat Cave Member above. In the Caballo Mountains where Kelley and Silver first defined these divisions of the El Paso, the Sierrite is distinguished from the Bat Cave by its rhythmic laminae of brown-weathered chert and gray limestone, weathered colors of dark gray and brown, crystalline rather than detrital texture, presence of dolomitic limestone, and absence of stromatolites. In the Big Hatchet Mountains, enough of these criteria are present to distinguish the Sierrite from the Bat Cave.

The Sierrite Member consists of dolomite and dolomitic limestone with rhythmic strata of chert nodules and fine chert laminae. The dolomitic rocks weather darker gray than the overlying blue-gray limestone of the Bat Cave Member, and the general appearance of the outcrop is brown due to abundant brown-weathered chert laminae. The basal contact with the Bliss Formation is gradational. The sandy dolomite of the basal contact zone is herein included with the Bliss rather than with the El Paso. The upper contact of the Sierrite Member is transitional with the Bat Cave Member and is chosen above the chert strata at the level above which limestone rather than dolomite predominates.

In the Mescal Canyon section on the east side of the range, the basal beds consist of about 50 feet of shale and thin interbedded dolomite. The shale is medium gray on

Figure 3

Mescal Canyon section on the northeastern flank of the Big Hatchet Mountains.

The following formations are indicated: Oep–El Paso Formation; Om–Montoya Dolomite; Dp–Percha Shale; Me–Escabrosa Limestone; Mp–Paradise Formation; and P IPh–Horquilla Limestone. The deep valley, which traverses the range, was eroded in Percha Shale; cliffs of Escabrosa Limestone tower above the valley. Air view northwestward.

fresh fracture, weathers light brown, is composed of clay firmly cemented with dolomite, is medium to finely fissile, and is thin bedded and nonresistant. The dolomite is light to medium gray on fresh fracture, weathers light brown, is medium crystalline with a residual elastic texture, occurs in lumpy beds from 1 inch to 2 feet thick, and has some bedding surfaces marked with oscillation-type ripple marks.

This basal unit of dolomitic shale and dolomite may be recognized throughout the area, though in places the thin shale beds are covered and exposed beds are of mottled dolomitic limestone. Cystoid plates, black glossy linguloid brachiopod shells, and trilobite fragments are an aid in recognition; the important *Kainella—Leiostegium* trilobite fauna, described later, is found in one of the shale beds. Small spherical concretions of limonite pseudomorphic after marcasite are common.

Above the shaly beds, the Sierrite Member consists of medium- and thin-bedded dolomite and dolomitic limestone rich in chert. The dolomite is medium crystalline, is often brecciated, is medium and light gray on fresh fracture, and weathers medium to dark gray and light brown where free of chert and light to dark brown where rich in disseminated chert particles or chert laminae.

The dolomitic limestone is finely speckled because of a mixture of gray-weathered limestone grains and brown-weathered dolomite grains. Originally a elastic limestone, the present rock was formed by selective dolomitization of scattered limestone grains. Small patches particularly rich in dolomite grains produce a mottled appearance on bedding surfaces.

A characteristic feature of the Sierrite Member here as in most places is the rhythmic alteration of reticulated laminae of brown-weathered chert with laminae of carbonate rock. Kelley and Silver (op. cit., p. 43) described such chert in the Sierrite of the Caballo Mountains and mentioned that earlier writers noted the chert. The laminae of chert average one half inch in thickness, are wavy and irregular, are interconnected, and weather in relief. Often they are concentrated in such numbers as to produce conspicuous dark brown bands on hill slopes. In some zones, the proportion of chert exceeds dolomite.

In the upper half of the Sierrite, chert lenses and chert nodules concentrated in certain strata alternate in rhythmic succession with dolomite and dolomitic limestone. The chert masses are one or two inches thick and range in length from a few inches to ten feet. Fresh surfaces of the chert are medium gray and show tiny grains and fossil fragments; weathered surfaces are light gray. Grains of disseminated brown-weathered chert are also common.

The measured thickness of the Sierrite Member in the Big Hatchet Mountains ranges from 345 feet in Mescal Canyon to 204 feet in Ram Gorge. This variation may be due partly to choice of the basal contact at slightly different levels. Possible structural complications concealed by talus in the Ram Gorge section may account for the apparent thinness of the member in that section.

The Bat Cave Member of the El Paso Formation is conspicuously elastic limestone that weathers light bluish gray. The basal contact, though transitional, may be chosen within a few feet; at the contact, dolomite and dolomitic limestone with regularly spaced chert-rich strata give way upward to light-bluish-gray-weathered limestone with no rhythmically distributed chert strata. The upper contact with the Montoya Dolomite, a disconformity, is marked by a lithologic break. About 18o feet above the base, a bed of black oolitic limestone conveniently divides the Bat Cave into lower and upper parts.

The lower part consists of thin- and medium-bedded elastic limestone with detritus ranging in size from clay to coarse sand. The grains consist of finely to coarsely crystalline limestone. When fresh, the rock is medium gray; when weathered, it is bluish gray. Fossil fragments are abundant.

Weathered rock slabs from the lower beds contain abundant markings tentatively thought to be worm trails or burrows. These are filled with hard orange-brown siliceous material, probably silica-cemented silt or chert. Such features are reported from equivalent beds in the El Paso from other localities in southern New Mexico.

Chert nodules and reticulated chert laminae similar to those of the Sierrite are found in the lower 12 feet of the Bat Cave in Mescal Canyon. These beds are assigned to the Bat Cave because they contain stromatolites, one of the most diagnostic features of the Bat Cave. In Mescal Canyon the stromatolites are rare, range in diameter to several feet, have rounded tops, and have closely spaced, scalloped and concentric laminae. Small, brown-weathered, silicified, elongate conical-shaped masses, which are siphuncles of straight cephalopods, are found in the lower beds and in various beds higher in the formation.

Above the basal few feet, the lower part of the Bat Cave consists of alternate beds of medium- to thin-bedded poorly stratified and finely laminated limestone. The massive beds, seldom more than a few feet in thickness, are mottled because of small irregular concentrations of different-sized detrital grains. Fine-grained areas weather light bluish gray, and coarser grained areas weather medium gray. As seen on weathered surfaces perpendicular to bedding, the fine-grained limestone appears to fill small erosional depressions cut in the coarser rock. Thin laminae in the fine-textured fillings are often curved over knobs of coarser textured rock in depositional conformity or because of compaction of the fine sediments upon an irregular surface. These cut-and-fill features are small, averaging only a few inches in breadth.

Thin, nonresistant intervals of finely laminated limestone separate the more massive beds. Fine laminae of silty limestone weather yellowish brown in contrast to the bluish gray color of pure limestone laminae.

Dividing the Bat Cave Member is a bed of oolitic limestone composed of calcareous oolites of medium sand size in black limestone matrix. The oolites are concentrated in strata and in irregular masses, and as they are more resistant than the matrix, they stand out in relief on weathered surfaces. Fresh oolitic limestone is black; weathered surfaces are dark gray with tints of brown. Strata of black limestone composed almost entirely of broken trilobite fragments lie between oolitic strata. Small, dime-sized gastropods are common in some trilobite coquina strata.

Where observed in the Big Hatchet Mountains, this unusual lithology is confined to a bed no more than seven feet thick. In Chaney Canyon, the bed is present but wedges out along the strike because of marine erosion prior to deposition of the succeeding bed. In Mescal Canyon, a bed of slightly oolitic limestone lies 14 feet above the main bed, but this one is only two feet thick and is not so conspicuously oolitic.

Because of its distinctive elastic composition and its dark color in a sequence of light gray limestone, the oolitic bed or zone is an excellent local marker. Depositional conditions responsible for such a deposit were no doubt unusual and probably occurred simultaneously throughout the small area of exposure of the El Paso Formation in the Big Hatchet Mountains. On Plate 2, the oolitic limestone bed is shown horizontally as a "time line" which serves to correlate three stratigraphic sections. Close agreement of lithologies above and below the marker bed in the sections confirms the use of the bed as a time-stratigraphic unit within the area. Similar distinctive oolitic limestone beds are recognized in other exposures of El Paso in southern New Mexico.

Above the oolitic limestone, the remaining 55o feet of the Bat Cave Member consists of limestone of which the upper beds are locally dolomitized. The limestone, like that of underlying beds, is elastic and weathers light bluish gray; it differs from lower strata in being thicker bedded and in containing amorphous limestone masses of various types.

This limestone in the Mescal Canyon section lies in ledges two to five feet thick separated by thin beds of nonresistant laminated limestone. All the rock is elastic with grain sizes generally ranging from clay to coarse sand. Edgewise conglomerate, which is common in Cambrian—Ordovician limestones in many places, occurs in several beds. Fossil shell fragments are common. Crystallinity, imposed upon the rock after deposition, produced crystal sizes from very fine sand to coarse sand, and though crystal size in the rock often matches the size of detrital grains, the two do not invariably coincide. Thin strata between massive beds have fine wavy laminae, some of which are silty and weather light yellowish brown. A few brown-weathered chert nodules are present.

Some beds of coarsely crystalline limestone in the Mescal Canyon section contain amorphous masses of dense limestone. A few such masses are stromatolites recognized by their finely laminated internal structures. Most, however, are irregular in shape, have no internal structure, have rounded borders, and are from two to five feet across. In shape and internal structure, they do not resemble stromatolites, nor do their shapes suggest organic origins. Rather, they are thought to represent fillings of irregularly shaped channels eroded upon the coarser crystalline limestone beds prior to deposition of overlying beds. In Chaney Canyon, similar masses of dense limestone have depositional laminae which curve over the tops of knobs on underlying beds and indicate deposition upon surfaces of slight marine erosion. This is probably the origin of the masses in Mescal Canyon. None of the masses have the characteristics of cavity fillings.

North of Mescal and Chaney Canyons on the ridge in section 19, T. 3o S., R. 15 W., the upper part of the Bat Cave Member includes a massive limestone unit displayed as a vertical cliff. On the west side of the ridge, the unit is duplicated by a fault to produce two cliffs. The unit is 1oo feet thick; 20o feet of beds lie between the top of the unit and the top of the El Paso Formation, but a small fault in this interval probably removed a few tens of feet of section. Comparison of these measurements with the stratigraphic sections on Plate 2 shows that this massive unit occupies about the same stratigraphic position as the more massive limestone of the Bat Cave in the Mescal Canyon section, the limestone which contains the enigmatic masses of dense limestone.

This unusually massive unit is responsible for the prominence of the ridge in the northern part of the range. Equivalent beds exposed on spurs both east and west of the ridge become less massive a short distance from the cliffs. The same beds exposed in Mescal and Chaney Canyons, though thicker bedded than underlying strata, are less massive than those in the area of the cliff. Whether the 100-foot massive unit represents a thickening of section due to excessive accumulation of detritus in the restricted area or whether it is simply the result of merging of normally medium-bedded units into a massive local sequence without thickening of the involved interval is not known. The massive unit, the core of the ridge, is confined to a northwest-trending zone more than a mile long and less than half a mile wide.

The limestone of this unit, like that of equivalent beds in the measured sections, is finely and coarsely elastic and weathers light bluish gray. Many beds of coarse-grained limestone have highly irregular upper surfaces, and succeeding beds of very fine grained limestone have laminae that bend around projections on the underlying beds with depositional or compactional attitudes. Some thin laminae are silty and weather yellow. Irregularities of such bedding surfaces could result from marine erosion prior to continued deposition or from local accumulations of detritus due to physical processes or organic growths.

Many isolated masses of unstratified amorphous limestone ranging in diameter from 6 inches to 20 feet are present. Some are of very finely crystalline limestone that have tiny involutions which appear on weathered surfaces. Although this limestone does not have the internal pattern commonly associated with stromatolites, it perhaps represents colonies of calcareous algae. Spaces between such masses are filled with coarser detrital limestone. Other masses are composed of calcarenite and have rounded tops; they resemble stromatolites in shape, but they show no internal structure. These may or may not be of organic origin. From a sample of the massive rock, Richard Rezak (written communication, 1962) identified the alga *Girvanella,* which is usually an indication of very shallow water depth during deposition.

The shape and distribution of the massive limestone unit is not unlike that of a bioherm. However, the entire unit cannot be a single bioherm because it is divided by bedding planes and persistant strata from 1 foot to 20 feet apart. Some or all the enigmatic masses may represent reefs formed about frameworks of calcareous algae. If this be true, environmental conditions confined to this small area during part of Bat Cave time favored growth of calcareous algae. In any event, concentration of the bodies of dense limestone in this area is responsible for the massiveness of the unit.

The upper beds of the Bat Cave, above the more massive part, consist of thin-bedded elastic limestone and dolomite. On the east side of the Big Hatchet Mountains and in some areas on the west side of the range, the uppermost beds are dolomite. The dolomite is light gray on fresh fracture, is finely to medium crystalline, weathers light gray and light brown, and contains a few thin, yellowish brown chert stringers. A few orange-brown-weathered beds of silty and sandy dolomite are present in the upper, poorly exposed part of the formation in Mescal Canyon. Silt is concentrated in thin wavy laminae and in small lenses; quartz sand of similar distribution ranges in grain size from very fine to medium and from angular to well rounded.

In the Mescal Canyon section, the upper 171 feet of the Bat Cave consists primarily of dolomite, and the contact between the dolomite and underlying limestone is irregular and passes stratigraphically lower to the southeast, even so low as to include the oolitic limestone bed. Near the contact, patches of dolomite are found in the limestone, and the dolomite has areas of limestone. Beds may be traced laterally from limestone to dolomite. Transgression of the contact across beds shows that dolomitization took place after deposition of the formation. In the Ram Gorge section, the upper 15 feet of the formation is dolomite. A mile to the northwest, the upper beds are not dolomitized.

The dolomitization appears to be related to the disconformable surface at the top of the El Paso Formation. Where the upper El Paso is dolomitized, rocks from the disconformity downward are usually completely dolomitized to the limestone contact.

The total thickness of the El Paso Formation in the Mescal Canyon section is 1070 feet. Only 916 feet of the formation was measured in the Ram Gorge section, but here talus which conceals the basal beds may conceal structural complications responsible for removal of beds. Also, choice of the lower limit of the formation based on sand content of the dolomite may not be consistent in the two sections. Inspection of the stratigraphic sections (pl. 2) shows that distinctive lithologic units in the Ram Gorge section lie at the same levels above the base of the formation in the Mescal Canyon section. The thickness determined for the El Paso in Mescal Canyon is considered reliable.

Age and Correlation

In the Big Hatchet Mountains, the El Paso Formation has an abundance of fossils, including trilobites, cephalopods, gastropods, cystoids, sponges, and algae. Unfortunately, many fossils are fragments inadequate for identification; some cannot be extracted from the matrix, and others are of undescribed forms. Only a few of the large number of fossils collected during this study are useful. The entire collection of El Paso fossils, except for algae, was submitted to Rousseau H. Flower. All fossil identifications, zonation, and age information given below are his (written communications, 1958, 1962).

The age of the El Paso Formation here, as elsewhere in southern New Mexico, is Canadian (early Ordovician). In the Big Hatchet Mountains area, El Paso deposition took place during nearly all of Canadian time with the following possible exceptions: During earliest Canadian time the upper Bliss may have been deposited instead of the lower El Paso; minor hiatuses may be present in the El Paso; and any beds of latest Canadian age deposited in the upper El Paso may have been removed during the time of the El Paso—Montoya disconformity. The precise age of the upper beds of the El Paso, though Canadian, is not known because in the studied sections dolomitization has destroyed the fossils, and where the rocks are not dolomitized, the fauna has not been studied.

Flower recognizes eight empirical zones based upon fauna and lithology in the El Paso of the Big Hatchet Mountains. Most of these are present in other sections of the formation in southern New Mexico and western Texas. Though this zonation has its greatest use within this region, it also helps in correlation of parts of the El Paso Formation with formations in the Cordilleran region and in areas to the east. Flower's zonation of the formation in the Big Hatchet Mountains, as evident from my collections, is given below in descending order with his comments on correlation. A few of the important fossils are indicated on Plate 2.

4

Upper Canadian

8. Upper dolomite zone. The upper beds of the El Paso Formation in the Big Hatchet Mountains are dolomitized to various stratigraphic levels from the top of the formation downward. In the studied sections, fossils have been destroyed by dolomitization. Fossils are present in some areas where only the upper few feet of beds are dolomitized, but these have not been studied. Flower presumes these beds to be of Jefferson City age.

7. Beds of Jefferson City age and faunal affinities (collections 21S through 21y of the Mescal Canyon section). Collection 2I s contains a small brachiopod of the genus *Archaeorthis*, which is diagnostic of Jefferson City age. Higher in the zone, siphuncles of endoceroid and piloceroid cephalopods appear. Massive beds from which collection 21y was taken contain the typical second piloceroid zone of other New Mexico sections. The diagnostic cephalopods *Allopiloceras* sp. and *"Mcqueenoceras" franklinense* are questionably present in the Big Hatchet Mountains. A few low-spired gastropods of *Maclurites* aspect are present.

Middle Canadian

6. Interval occupied by *"Orospira"* (new genus and new species of Flower) zone in other New Mexico sections. *"Orospira"* has not been collected from this interval in the Big Hatchet Mountains (collections 21j through 2x q), but Flower states that he has seen the form in the field. Some fossils from underlying "oolite" zone continue into these beds, especially the gastropods. Thus, this interval is more closely allied to beds below than to beds above.

5. "Oolite" zone (collections mg and 21h). Abundant trilobite fragments consist mostly of pygidia of *Megalaspis*, *Leiostegium manitouense*, and *Hystricurus* spp. Diagnostic low-spired gastropods of an undescribed genus are confined to this zone in the Big Hatchet Mountains and to the "oolite" zone in other southern New Mexico sections. A high-spired gastropod similar to *Hormotoma* is found in this zone and in higher beds. Also, the zone includes slender annulated cephalopod siphuncles that are probably of the genus

Rudolfoceras. Concerning the age and correlation of the "oolite" zone in the region, Flower (Kottlowski et al., 1956, p. 18) states, "No obviously similar faunas have been reported from either the eastern North American sections or those of the Cordilleran region.

4. First piloceroid zone (collection 21d). This zone contains several species of *Bisonoceras,* a large piloceroid with *a* strongly curved, horn-shaped siphuncle. Other cephalopods include endoceroid siphuncles which are larger and more varied in form than in the underlying first endoceroid zone. The endoceroid *Kirkoceras* sp. is present.

3. First endoceroid zone (collections 21a and 21b). The dominant cephalopod of this zone is *Proendoceras,* a simple endoceroid represented by silicified siphuncles. A varied gastropod fauna includes *Ozarkina,* Ozarkispira, *Ophileta, Lytospira,* and others which are undescribed and some which are not identifiable. A gastropod that Flower states has been widely but mistakenly identified as *Liospira gyocera* Meek is diagnostic of this zone here and elsewhere in the region. Small stromatolites are present. This zone is widespread in southern New Mexico and is present in the El Paso Formation of the Dos Cabezas Mountains of southeastern Arizona.

Lower Canadian

2. *Kainella* zone (collections 20f and 2og). Trilobite fauna includes the genera *Kainella* and *Leiostegium.* Also present is a brachiopod tentatively assigned to the genus *Finkelnburgia.* According to Flower, the trilobites are unquestionably those of zone D of Ross (1951) and Hintze (1952) of the Garden City Limestone of Utah.

1. Lowermost El Paso Formation which grades into uppermost Bliss Formation. No diagnostic fossils were collected from these beds.

The most complete section of El Paso Formation in the region is at the type locality in the southern Franklin Mountains. Here the formation, 1590 feet thick, was studied and zoned by Cloud and Barnes (1948, p. 72, 361-369). They restrict the Ellenburger Group of central Texas to rocks of early Ordovican age and assign the El Paso to that group.

Flower correlates parts of the El Paso Formation of New Mexico with formations in the Ozark region, in Utah, and elsewhere. For a discussion of regional relationships of the El Paso Formation to the east and north, the reader is referred to Flower's analysis (Kottlowski et. al., 1956, p. 21-22).

CORRELATION OF BLISS AND EL PASO FORMATIONS TO THE WEST

Near Bisbee in southeastern Arizona and in sections north and west of Bisbee, Precambrian rocks are overlain unconformably by Bolsa Quartzite followed without break by Abrigo Limestone. The upper Bolsa and the Abrigo contain Middle and Late Cambrian faunas. Lithologically the Bolsa-Abrigo succession resembles the Bliss—El Paso sequence of southern New Mexico, but fossils show the Bliss and El Paso to be younger than the Arizona formations. These observations led Kelley and Silver (1952, p. 55) to propose a hypothesis of advance from southeastern Arizona eastward of the Cambrian—Ordovician sea. According to this concept, the sandstone and quartzite of the Bolsa and Bliss represent the deposits of an eastward-advancing shoreline, and overlying carbonate rocks of the Abrigo and El Paso represent deposits in deeper water following passage of the shoreline to the east. This hypothesis is illustrated by Sabins (1957, p. 471).

Since proposal of this idea, new information reported by Epis and Gilbert (1957) and Epis (1958) in the Swisshelm and Pedregosa Mountains between formerly studied areas requires alteration of the concept of simple eastward advance of the early Paleozoic sea.

Sabins, Epis and Gilbert, and others show that the El Paso Formation of southern New Mexico passes a short way into southeastern Arizona. In the northern Swisshelm Mountains, Epis and Gilbert found that the El Paso overlies the Abrigo Limestone, an observation which destroys the earlier belief that the El Paso and Abrigo are lithologically equivalent rock units. Dolomitic sandstone lying between Abrigo beds and what they considered typical El Paso beds was believed to represent at least the upper part of the Bliss Formation. Their sequence from base upward was Bolsa, Abrigo, Bliss, and El Paso. According to their suggested correlations, the Abrigo Limestone wedges out under the Chiricahua Mountains east of the Swisshelms.

For several reasons, correlations of Cambrian—Ordovician formations in this region must at present remain speculative. Fossils having specific age significance have not been found below the uppermost Bolsa, and very few have been found in the Bliss. Although the Cambrian—Ordovician successions in Arizona and southwestern New Mexico show no physical signs of depositional breaks, absence of such breaks can not be proved without more complete fossil data from the basal sandstones. In view of the great changes in lithology of the Bliss Formation within a few miles in the Big Hatchet Mountains, it would be risky to suggest a positive lithologic correlation of the Bliss with rock units in Arizona. Of course, the many miles separating exposures in this region add to the difficulties.

Without implying positive correlations, I shall suggest some relationships based upon studies in the "panhandle" of southwestern New Mexico, observations in the northern Swisshelm Mountains, and analysis of the literature. Figure 4 illustrates pertinent information of stratigraphic sections from the Big Hatchet Mountains west to Bisbee and suggests relationships of the rock units. The sections are plotted using the occurrences of *Billingsella* and *Eoorthis,* early Franconian fossils, as a horizontal time line.

Both lithologic and faunal evidence prove that the El Paso Formation extends as far west as the Swisshelm Mountains. Pre-Late Devonian erosion cut progressively deeper into Ordovician formations toward the west, and beyond the Swisshelms toward Bisbee and the Dragoon Mountains, all traces of the El Paso have been removed by the erosion. In Arizona as in New Mexico, the bulk of the preserved El Paso is of Canadian age. Beds included in the basal El Paso by some workers contain Late Cambrian fossils,

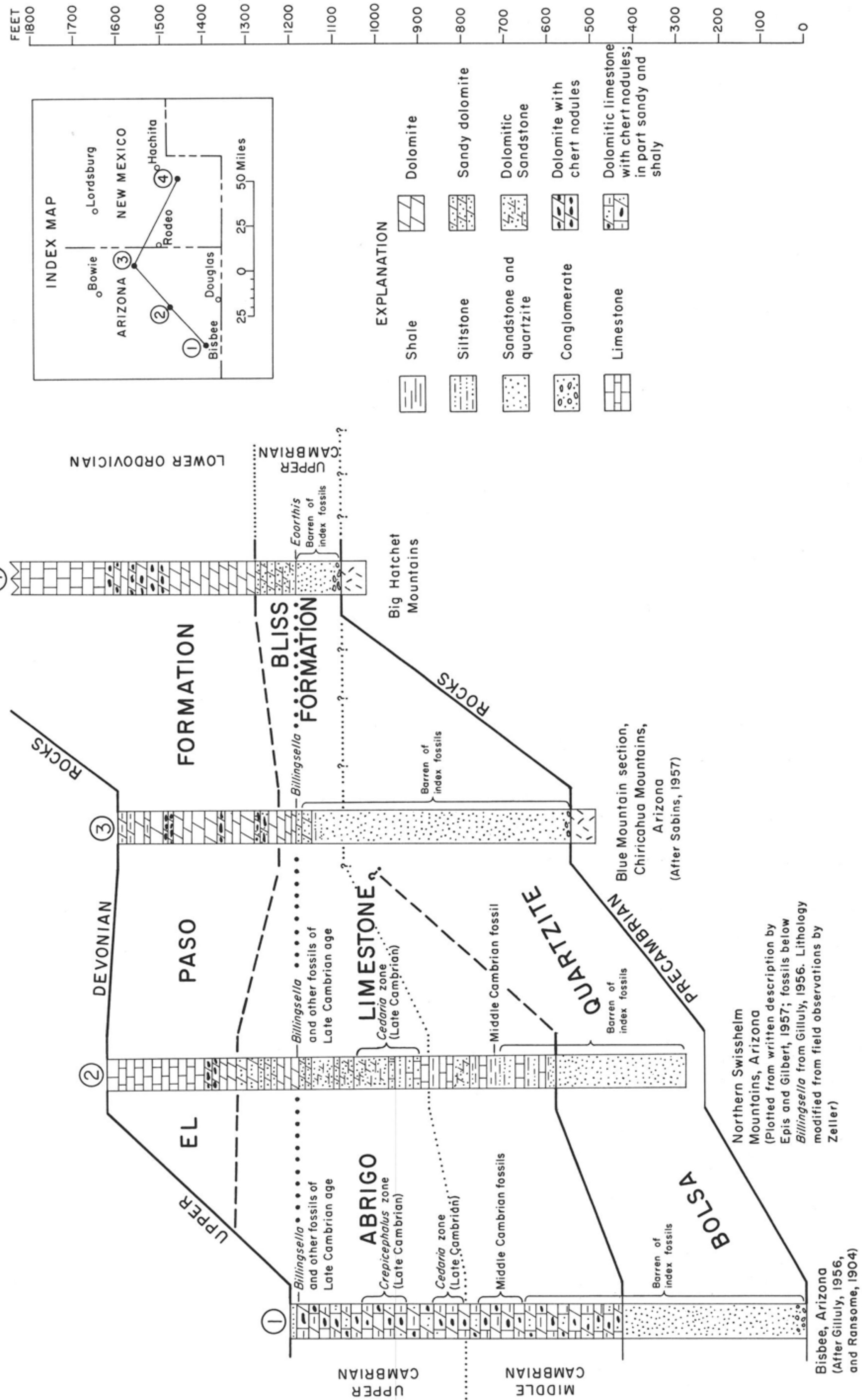

Figure 4

RELATIONSHIPS OF CAMBRIAN–ORDOVICIAN FORMATIONS IN SOUTHEASTERN ARIZONA AND SOUTHWESTERN NEW MEXICO but choice of the base of the formation could probably be made as well above the Cambrian faunas as below because of the gradational nature of the contact.

The hard white quartzites of the Bolsa and lower Bliss are probably lithologically equivalent. Slim faunal evidence, chiefly from overlying carbonate rocks, along with the absence of obvious depositional breaks in the quartzite and sandstone suggest that the rock unit becomes progressively younger eastward. Thus, there seems little reason to doubt that the Bolsa and lower Bliss represent the littoral deposits of an eastward-advancing sea.

The remaining problem is the relationship of the Abrigo to formations east of the Swisshelm Mountains. The dolomitic sandstone and sandy dolomite of the upper half of the Abrigo in the Swisshelm Mountains strongly resemble the sandy dolomite of the upper Bliss in the Big Hatchet Mountains. This lithology is very thin in the Chiricahua Mountains, but in view of the rapid lateral changes from sandy dolomite to quartzite known from the Big Hatchet Mountains, the lower part of the unit could be represented by sandstone in the Chiricahua Mountains. Thus, the upper sandy part of the Abrigo appears to be lithologically equivalent to the upper Bliss. The lower, less sandy part of the Abrigo conceivably may belong to the same unit, or it may wedge out east of the Swisshelm Mountains.

It seems to me that the gross Cambrian–Ordovician history of the region was a blending of the hypotheses of Kelley and Silver and of Epis and Gilbert. The quartzites of the Bolsa and lower Bliss were shoreline deposits of an eastward-advancing sea. As the shore moved into New Mexico, deeper water in Arizona was the site of carbonate deposition. Slight decrease in water depth to that of wave base or currents from the shore could account in part for sand in the Abrigo carbonate rocks. During that time, the sedimentary basin was subsiding more rapidly in Arizona than in New Mexico, a fact that accounts for the greater thickness of the Abrigo. Lack of noncalcareous sandstones in the Abrigo of the Swisshelm Mountains argues against regression of the sea during late Abrigo deposition. By early Canadian time, or perhaps latest Cambrian time in Arizona, the shoreline was so far removed from the region that the essentially sand-free carbonate sediments of the El Paso Formation were deposited. Pre-Late Devonian erosion cut deeply into the El Paso in Arizona so that the original thickness of the formation is not known, and since the El Paso is missing west of the Swisshelm Mountains because of the unconformity, the western limit of El Paso deposition cannot be determined.

POST-EL PASO—PRE-MONTOYA DISCONFORMITY

The contact between the El Paso Formation and the Montoya Dolomite is an unconformity in the Big Hatchet Mountains as it is in south-central New Mexico. Kelley and Silver (1952, p. 50-54) recognized a pre-Montoya erosion surface cut upon the El Paso in the Caballo Mountains. Kottlowski et al. (1956, p. 18) noted an unconformity between the El Paso and Montoya in the San Andres Mountains. In these ranges, pre-Montoya karst erosion produced cavities in the upper El Paso beds.

The age of the highest identified fossils in the El Paso of the Big Hatchet Mountains is equivalent to that of the Jefferson City, which is late but not latest Canadian. The age of the lowest identified fossils in the Montoya of the Big Hatchets is late Champlainian (middle Ordovician) or early Cincinnatian (late Ordovician). Between these fossil zones there are about zoo feet of beds from which fossils have not been studied. Therefore, either these beds represent deposition during latest Canadian and at least early and middle Champlainian times, or a hiatus embracing much of this period interrupted the depositional sequence. These beds of undetermined age are lithologically allied to the underlying El Paso beds and seem to represent continued El Paso deposition.

This erosional break in the Big Hatchet Mountains is classed as a disconformity because no angularity is noted between the beds below and above. Rocks below the contact in the Mescal Canyon section consist of light-gray-weathered dolomite, the upper dolomitized limestone of the El Paso sequence. Rocks above the contact are dolomite that weathers very dark gray. The sharp contact between light and dark dolomite is only rarely exposed because the beds of this interval are nonresistant and usually covered. A few feet above the disconformity, the dark gray dolomite contains scattered grains of well-rounded quartz sand and small lenses and laminae of sandy dolomite. The sand concentration increases upward to form the diagnostic sandstone unit of the lower Montoya.

In detail, the disconformity shows small erosion channels cut a few feet into underlying rocks. In places along the contact, small concentrations of limonite pseudomorphic after iron sulfide are noted. Of particular interest are thin tabular stringers of quartz sandstone perpendicular to bedding that extend a few feet downward from the disconformity. These features evidently represent sand fillings of cracks during the period of the disconformity. No solution cavities, collapse breccias, or other indications of karst erosion are present in underlying rocks.

Evidence of karst erosion in the El Paso under the pre-Montoya surface in south-central New Mexico shows that the surface in that region emerged above sea level. However, in the Big Hatchet Mountains, where some erosion occurred between El Paso and Montoya deposition, there is little indication that the area was above the sea and subjected to subaerial erosion.

MONTOYA DOLOMITE

Richardson (1904, p. 29) originally included all Ordovician beds of the Franklin Mountains with the El Paso Limestone. Later, he (1909, p. 3-4) divided the Ordovician rocks into two formations and retained the name *El Paso* for the lower one in which he found a lower Ordovician fauna. The upper formation, in which he recognized a later Ordovician fauna, he named *Montoya Limestone*, "from a station on the Santa Fe Railway in the Rio Grande Valley about 10 miles above El Paso." Dunham (1935, p. 42-43) recognized the dolomitic composition of the formation in the Organ Mountains, and therefore used the name *Montoya Dolomite.* Kelley and Silver (1952, p. 57-58), noting four distinct divisions of the Montoya in the Caballo Mountains, elevated the name *Montoya* to group status and divided the group into four formations; in ascending order, they are Cable Canyon Sandstone, Upham Dolomite, Ale-man Formation, and Cutter Formation.

In the Big Hatchet Mountains, the same four units are recognized but are not of sufficient thickness to be mapped as individual formations. 'Therefore, in this study, *Montoya* is used as a formational name and the four subdivisions of Kelley and Silver are considered as members. As the formation consists almost entirely of dolomite, Dunham's name, *Montoya Dolomite, is* most appropriate.

Different terminology used for Montoya divisions by other workers is discussed by Flower (1961, p. 7). I prefer use of the divisions of Kelley and Silver in the Big Hatchet Mountains area because their terminology has gained widest acceptance in the region and their lithologic division of the Montoya is most useful in the field.

Distribution and Topographic Expression

The Montoya Dolomite, like the El Paso Formation, is confined in distribution in this area to the west side of the Sierra Rica and the northern part of the Big Hatchet Mountains.

In the Sierra Rica, the Montoya Dolomite is found only in a thrust sheet. Its principal exposures are on the north sides of the hills in secs. 31 and 32, T. 29 S., R. 14 W. Three miles to the southeast a number of small exposures of the formation are found along a thrust, probably the same fault.

In the Big Hatchet Mountains, the formation is most prominently exposed in a belt extending diagonally across the range from southeast to northwest in secs. 19, 29, 3o, 32, and 33, T. 3o S., R. 15 W. North of this belt, patches of Montoya Dolomite are found along the crest of the range. It also crops out in a small area near the head of Chaney Canyon.

The Montoya Dolomite, composed principally of massive dolomite, is more resistant than enclosing formations. It commonly forms ridges between the moderately resistant El Paso Formation and the nonresistant Percha Shale. Along the belt of exposures cutting diagonally across the Big Hatchet Mountains the Montoya, which dips southwestward under the Percha Shale, forms a cuesta that bounds the deep valley eroded from soft Percha. The northeastern slope of the cuesta where the ends of beds are exposed is steep and craggy. The Cable Canyon and Upham Members combine to form a low cliff at the base of the formation, and the resistant Cutter Member forms bluffs at the crest of the ridge; the thin-bedded Aleman Member is less resistant and occupies a gentle slope between the more resistant members.

S tratigraphy

In the Big Hatchet Mountains area, the Montoya Dolomite was studied in detail only in the Mescal Canyon section, which is described later and is shown graphically on Plate 2. Where observed elsewhere in the area, its characteristics are essentially the same as in the studied section.

The basal contact of the Montoya, a disconformity, has already been described. The Cable Canyon Member in the Mescal Canyon section is composed of the following: The basal six feet of beds resting upon the disconformity consists of dolomite which is very dark gray on fresh fracture, is finely to medium crystalline, and weathers dark gray to black. This is overlain by five feet of medium gray, finely to medium crystalline dolomite with variable amounts of quartz sand in scattered grains, in thin laminae, and in small irregular lenses. The quartz sand is poorly sorted and is cemented with dolomite; grains range in size from fine to medium and are rounded. The concentration of sand increases progressively upward. The overlying 5-foot bed, the characteristic sandstone unit of the Cable Canyon Member, consists of quartz sandstone that is white to light gray on fresh fracture and weathers medium brown and mottled. The sandstone consists chiefly of quartz grains of two size ranges—fine and coarse. The fine-grained sand is sub-angular and forms the bulk of the detrital fraction. Coarse sand grains are well rounded, have frosted surfaces, and consist mostly of quartz but include a few scattered grains of blue translucent chert. The sandstone is cemented with dolomite, which varies in concentration but which averages nearly half of the rock composition. Some irregularities in the rock appear to be sand fillings of fossil molds; one seems to be of a large straight cephalopod.

This thin sandstone unit, an outstanding marker of the Cable Canyon, is readily visible from a distance because its brown-weathered color contrasts with gray-weathered beds below and above.

Two miles north of Mescal Canyon, the sandstone unit consists of two dolomitic sandstone beds separated by a bed of dolomite. On the northwestern flank of the Big Hatchet Mountains, the Cable Canyon Member is thicker and contains a higher proportion of sand than in Mescal Canyon. In one place in that area the sandstone unit of the member contains beds of quartzose dolomite between sandstone beds and is 13 feet thick. The distribution of sand is in lenses which produces a patchy and lumpy appearance on weathered surfaces. Another bed of brown-weathered quartz sand found about 5o feet below may lie in the upper El Paso Formation. In another place on the northwest flank of the range, z3 feet of brown-weathered dolomitic sandstone of the Cable Canyon rests with sharp contact upon light gray dolomite believed to be of the El Paso Formation.

The basal contact of the sandstone unit with underlying dolomite within the Cable Canyon is usually gradational. In the place noted above where the basal contact of the sandstone is sharp, the sandstone apparently rests directly upon the disconformity with no Cable Canyon dolomite between. Dolomite often found within the sandstone unit has the same dark weathered color as the dolomite of the basal Cable Canyon. The upper contact of the sandstone unit, which is the top of the Cable Canyon Member, is also gradational. In thickness, the Cable Canyon Member in the Big Hatchet Mountains ranges from 16 feet in Mescal Canyon to at least 23 feet on the northwestern flank of the range. The beds here assigned to the Cable Canyon Member represent a single continuous period of deposition that probably was not interrupted prior to Upham deposition.

The Upham Member is a massive, medium gray, medium to coarsely crystalline dolomite with lenses and strata of shell fragments and other detritus. It weathers light gray mottled with dark gray. The lower few feet contain a small quantity of quartz sand grains. Rounded inclusions of finely crystalline dolomite elongated parallel to the bedding are common in the lower part of the member, and these are partly to completely replaced by medium gray chert, the replacement of nodular inclusions becoming progressively more complete higher in the member. Nodules partly replaced with chert have spongy-looking brown-weathered chert borders. However, chert is not a conspicuous constituent of the member and chert nodules are quite rare.

Two strata near the top of the member in Mescal Canyon consist largely of brachiopod shells and echinoderm columnals replaced by white chert. Some brachiopods are beautifully preserved and stand out on weathered surfaces. Blocks of rock from these strata, as well as from fossiliferous strata higher in the formation, yield a rich fauna of silicified brachiopods when dissolved in acid.

The upper surface of the Upham contains a persistent half-inch layer of dark chertlike pellets. When weathered, the pellets have bluish white soft coatings and are thought to be phosphatic. The upper contact of the Upham with the overlying Aleman is sharp; the change from nearly chert-free elastic dolomite below to finely crystalline dolomite with abundant black chert nodules and strata above is conspicuous.

The Aleman Member in the Big Hatchet Mountains has the same distinctive lithology found in most areas throughout southern New Mexico. It consists of thin dolomite strata alternating in rhythmic succession with strata and thin elongated nodules of black chert. The dolomite is very dark gray or black on fresh surfaces, is finely crystalline, weathers dark gray, and is in strata from 1 to 10 inches thick. Chert is black when fresh and weathers mostly black and dark brown; some weathers white and gray. The chert occurs in strata and in smoothly rounded nodules concentrated in thin zones, the masses ranging in dimensions from 1/2 inch to 5 inches thick and from several inches to 25 feet in length parallel to bedding. At least 35 percent of this rock unit consists of chert.

Light-gray-weathered, finely laminated, rounded dolomite lenses or nodules elongated parallel to the bedding are common in the dark dolomite. Some have been replaced by chert to varying degrees, the replacement having proceeded from the outer border inward. No fossils were noted in this unit.

In the Mescal Canyon section, 48 feet of beds have the typical Aleman lithology. Above this is 28 feet of less resistant dolomite, mostly covered, that is included with the Aleman. However, this dolomite is lighter colored and chert is much less abundant. These beds appear to be transitional between the Aleman and Cutter Members. Some thin beds of this interval weather orange-brown and are silty dolomite.

The Cutter Member consists of massive dolomite which is medium to dark gray on fresh fracture, weathers light gray, and is finely crystalline. Some beds have light-gray-weathered chert nodules concentrated to as much as 20 percent in some beds, but in general chert nodules are not abundant. No chert nodules occur in these beds I% miles northwest of Mescal Canyon. Many strata are rich in brachiopods and shell debris replaced by white chert. Mottling of some beds may be caused by filled worm borings. The contact of the Cutter Member with the overlying Percha Shale is an unconformity.

My assignment of the upper part of the Montoya to the Cutter is challenged by Flower (personal communications, 1958-1962), who contends that these rocks in the Big Hatchet Mountains should be placed with the Aleman on lithologic grounds. My justification for assignment of these beds to the Cutter is that they are quite different lithologically from the underlying Aleman, and they are lithologically similar to the Cutter in south-central New Mexico.

The thickness of the Montoya Dolomite in the Mescal Canyon section is 385 feet. This compares favorably with the general thickness of the formation in the ranges of south-central New Mexico. West of the Big Hatchet Mountains, pre-Late Devonian erosion cut progressively deeper into the section. Only remnants of Montoya are preserved in easternmost Arizona (Kottlowski, personal communication, 1964), and farther west no Montoya or equivalent is found.

Age and Correlation

Dolomitization of the Montoya apparently destroyed many of the fossils. However, some strata bear brachiopods, bryozoans, and solitary and colonial corals which were replaced and preserved by white chert. Blocks of rock from these strata yield perfectly preserved fossils when dissolved in hydrochloric acid. Rousseau H. Flower (personal communications, 1958-1962), having freed the fossils from rock collected during this study, made a preliminary examination of the fossils and commented that all the forms require critical work at the specific level.

Flower's preliminary identifications are as follows:

Collection 22a:
tetracoral: *Streptelasma* sp.
brachiopods: *Rafinesquina* sp.
Sowerbyella (Thaerodonta) sp.
Rhynchotrema (Lepidocyclus) n. sp.

Collection 22b:
tetracoral: *Streptelasma* sp.
brachiopods: *Clitambonites?* sp.
Sowerbyella (Thaerodonta), apparently 2 species
Dinorthis cf. *subquadrata*
Austinella? sp.
Glyptorthis sp., close to *G. insculpta*
Hebertella sp.
Zygospira sp. 1
Onniella sp.
Plaesomys cf. *subquadratus*

Collection 22c:
ramose bryozoans
brachiopods: *Zygospira* sp. 2
Onniella sp. 2
Rhynchotrema (Hypsiptycha) argenturbicum
Rafinesquina sp., (fragments)

Collection 22d:
varied ramose bryozoans
brachiopods: *Rhynchotrema (Hypsiptycha) argenturbicum*
Onniella sp.
large orthid fragments

Collection 22e:
brachiopods: *Rhynchotrema (Hypsiptycha) argenturbicum*
Rhynchotrema (Lepidocyclus) perlamellosum
Dinorthis? sp. (fragments)
Hebertella? sp., (fragments)

Collection 22f:
bryozoans
brachiopods: *Rhynchotrema (Hypsiptycha) argenturbicum*
Rhynchotrema (Lepidocyclus) perlamellosum
Thaerodonta? sp.
Platystrophia sp., (fragments)

Collection 22g:
bryozoans
brachiopods: *Rhynchotrema (Hypsiptycha) argenturbicum*
Rhynchotrema (Lepidocyclus) perlamellosum
orthid fragments

Flower did not submit age assignments for the fossils identified. However, the genera listed for the Montoya of the Big Hatchet Mountains compare favorably with those from other studied areas. Judging from the faunal and lithologic similarities of the Montoya divisions in the Big Hatchet Mountains with the divisions of the formation elsewhere in southern New Mexico, age and correlation data published on other New Mexico sections are applicable in gross aspect to the Montoya of the Big Hatchet Mountains; there are probably small differences, however, that will appear when the Big Hatchet faunas are studied in detail.

Flower (1957, p. 20-22) presents age and correlation data for the Montoya. He states that " . . . the Montoya group embraces three widely separated intervals of deposition: First, a basal remnant of sandstones, probably to be correlated with the Winnipeg and Harding sandstones; second, a series of limestones and local basal sands of Red River age; and third, a sequence of Richmond strata. . . ." As shown in Figure 2 of Flower's (1957, p. 2o) report, the Harding—Winnipeg equivalents are represented by a very thin sandstone bed found locally below the chief sandstone of the Cable Canyon. The age is inferred, as no fossils have been found in this bed in New Mexico. Above are the Red River equivalents, which include the Cable Canyon and Upham. The diagnostic sandstone bed of the Cable Canyon represents the basal sandstone of a depositional sequence continuous with the beds above. The Richmond equivalents, consisting of the Aleman and Cutter, lie disconformably upon the Upham. In the Big Hatchet Mountains, the contact between the Upham and Aleman is a sharp division between different lithologies, and the basal inch of the Upham has pellets that may be phosphatic; these facts suggest the presence of a depositional break.

For further information on Flower's interpretation of the age and correlation of the Montoya Dolomite in southern New Mexico, the reader is referred to the following publications: Kottlowski et al., 1956, p. 22-26; Flower, 1957, p. 2o-22; Flower, 196r, p. 7-13.

PRE-LATE DEVONIAN UNCONFORMITY

In this area, the Percha Shale of Late Devonian age rests upon an erosion surface cut upon Montoya Dolomite. The hiatus represented by the unconformity includes the time from late Ordovician to Late Devonian. No angularity is noted between beds below and above; the contact is a plane surface with no channel cuts or irregularities. A thin basal sandstone of the Percha found in some exposures may represent reworked, insoluble detritus derived from the weathering of pre-Percha rocks.

In south-central New Mexico, an early Devonian unconformity is found that undoubtedly corresponds to the later Devonian unconformity of southwestern New Mexico. Devonian deposition commenced earlier in south-central New Mexico than in the southwestern area, but by Late Devonian time, deposition extended over all of southern New Mexico.

The Late Devonian unconformity cuts deeper into the sedimentary sequence west of the Big Hatchet Mountains. In the Peloncillo Mountains, Gillerman (1958, p. z6) found the Percha Shale resting upon the El Paso and a few possible remnants of the Montoya. The unconformity continues into southeastern Arizona where the Late Devonian Martin Limestone lies upon the Cambrian Abrigo Limestone. In central Arizona, the Late Devonian erosion surface is cut into Precambrian rocks.

Throughout most of southern New Mexico, the Montoya Dolomite is overlain by the Fusselman Dolomite of Silurian age. At the type locality of the formation in the Franklin Mountains, Kottlowski et al. (1956, p. 27) report a thickness of about 840 feet for the Fusselman. Kelley and Bogart (1952, p. 1646) report a thick section of Fusselman in the Florida Mountains. In the Sacramento, San Andres, and Caballo Mountains, the Fusselman Dolomite thins northward and pinches out in each range because of post-Fusselman erosion. From the regional distribution and southward thickening of the Fusselman Dolomite, one might expect it to be present in the Big Hatchet Mountains, but the formation is absent here. The uppermost beds of the Montoya were examined carefully to determine whether they might actually represent the Fusselman. Though barren of fossils, these beds were assigned to the Montoya with confidence because of their lithologic similarity to lower beds of known Montoya and because no depositional break is evident between these beds and known Montoya beds.

The absence of Fusselman Dolomite in the Big Hatchet Mountains may be due to nondeposition or to pre-Percha erosion. In view of the regional thickening of the Fusselman in the direction of the Big Hatchet Mountains, its absence here is most probably due to pre-Percha erosion.

DEVONIAN SYSTEM

In the Big Hatchet Mountains, about 30o feet of shale lies between the Montoya Dolomite of Ordovician age and the Escabrosa Limestone of Mississippian age. The few fossils found in the formation in the Big Hatchet Mountains have not been determined as to age, but from regional considerations, the formation here is thought to be Late Devonian.

Such a shale formation is found in the same stratigraphic position in other ranges in southern New Mexico where it is commonly called *Percha Shale*, a name that was first applied to the formation by Gordon and Graton (1907, p. 92). Kelley and Silver (1952, p. 68-78) reviewed the literature on the Percha Shale and concluded that "the prior and well-established term Percha formation should be retained and applied widely to this lithologically and topographically distinct unit as it crops out in New Mexico."

In the Chiricahua Mountains of southeastern Arizona, Sabins (1957, p. 475-480) described the Upper Devonian Portal Formation, which consists of about 30o feet of interbedded shale and limestone. The formation lies between the Ordovician rocks and the massive Escabrosa Limestone. Because the Devonian shale of the Big Hatchet Mountains resembles the Percha more than it does the Portal, and because Devonian faunas in the region have not been studied sufficiently to establish correlations, the name *Percha* is more justified for the shale formation in the Big Hatchet Mountains. Possible correlations of the Percha and Portal are mentioned later.

PERCHA SHALE

Distribution and Topographic Expression

The Percha Shale is exposed in two locations in the area, one in the prominent valley that cuts the northern part of the Big Hatchet Mountains diagonally from northwest to southeast in secs. 19, 29, 3o, and 32, T. 3o S., R. 15 W., and the other on the southwestern slope of the northernmost peak of the Big Hatchet Mountains mass, principally in sec. 13, T. 3o S., R. 16 W.

The soft Percha Shale is sandwiched between resistant formations, and therefore, where the rocks have moderate dips, erosion reduces its exposures to valleys lying between ridges. Its occurrences are covered with alluvium except for a few exposures in deep gullies. The most complete exposure of the formation is in Mescal Canyon where it was studied and measured. Figure 3 is a photograph showing the deep valley eroded upon the Percha Shale.

Stratigraphy

The Percha Shale, included in the Mescal Canyon section (pl. 2), rests unconformably upon Montoya Dolomite. The basal thin bed of the Percha is very fine grained, brown-weathered sandstone. The 20 feet of section that overlies the sandstone consists of alternating beds of black, finely fissile shale and beds of gray shale. In the type area of the Percha Shale and elsewhere in southern New Mexico, the lower beds are of black fissile shale; the lower black shale unit of the Big Hatchet Mountains is probably equivalent to the lower beds of the formation elsewhere in the region.

The main body of the formation consists of clay shale that is medium gray on fresh fracture, is weathered light gray with a yellowish brown cast, is slightly calcareous, is medium to finely fissile, and has a few 1- to 2-inch silty shale strata.

The upper contact with the Escabrosa Limestone is gradational. Limestone nodules appear in the shale near the top, and limestone nodules and thin nodular limestone beds progressively increase upward in abundance. The contact is chosen at the point where limestone becomes predominant over shale. A slight difference in bedding attitude above and below this contact in the Mescal Canyon section is due to a minor thrust fault. An undetermined but probably small thickness of the upper Percha may be missing along this contact because of the structure.

At the top of the formation in Mescal Canyon and in a gully half a mile to the south, thin sills of decomposed diorite are interlaced with the shale and nodular limestone. Several inches of the country rock on either side of the sills are baked and hardened.

As measured in the Mescal Canyon section, the Percha Shale is 28o feet thick.

Age and Correlation

The age of the Percha Shale in the Big Hatchet Mountains is not known from direct evidence. Fossils are rare. A fish plate was found in the basal sandstone bed; three specimens of *Conularia* sp. and several linguloid brachiopods were found in the middle of the formation. These fossils at present have no specific age significance. Brachiopods found in several nodular limestone beds near the top of the unit were submitted to Flower who sent them to G. A. Cooper. According to Flower (personal communication, 1962), Cooper reported them to be new forms which would require close study to determine their age.

Elsewhere in southern New Mexico where significant fossils are present, the age of the Percha is close to the Devonian—Mississippian boundary. Stainbrook (1947, P. 297-328) and Weller et al. (1948, p. 142 and chart) regarded the Percha as very early Mississippian. However, the latest and most convincing evidence, summarized by Bass and Northrop (1963, p. J25-J26), indicates a Late Devonian age for the Percha.

In southeastern Arizona (Gilluly, 1956, p. 29), the Martin Limestone is of Late Devonian age. Gilluly states that the Percha Shale of New Mexico seems to be younger. Stainbrook (op. cit., p. 298) made a small fossil collection from the type locality of the Martin Limestone near Bisbee; he found that "The Percha is younger than the Martin limestone carrying *Spirifer hungerfordi.*"

In the Chiricahua Mountains, Sabins (1957, p. 475-480) assigned a new name, *Portal Formation*, to beds of Late Devonian age that lie between the El Paso Formation and the massive shale-free Escabrosa Limestone. The Portal Formation is more calcareous than the Percha Shale and more argillaceous than the Martin Limestone; because of the difficulty in determining the lateral continuity of the formation with either the Percha or Martin, Sabins used the new name. Fragmental faunal evidence indicates that the Portal Formation is probably older than the Percha Shale.

Above the Percha Shale and below the massive shale-free limestone of the Escabrosa in the Big Hatchet Mountains, there is a 545-foot interval of limestone with interbedded shale. These beds are included with the Escabrosa because they are lithologically allied to it and because they are evidently of Mississippian age. This is the lower member of the Escabrosa, which is described later. Should the contact between the Percha and Escabrosa in the Big Hatchet Mountains be shifted up-section above the highest shale bed, so that the lower member of the Escabrosa would be assigned instead to the Percha, the lithology of the Big Hatchet Percha would be similar to that of the Portal Formation. The differences would then be that the Portal Formation has more thin limestone beds throughout, has a conspicuous black shale member near its middle, and is much thinner. However, despite similarity between the lower member of the Escabrosa in the Big Hatchet Mountains and the upper Portal, these rock units do not correlate at present because faunal information indicates that they are different in age. The Portal is Late Devonian and older than the Percha; the sequence in the Big Hatchet Mountains is evidently Mississippian. Any serious attempt to correlate the two must await comprehensive stratigraphic and paleontologic studies.

In the Peloncillo Mountains, Gillerman (1958, p. 25-27) recognized the Percha Shale which has a thickness of 23o feet. The formation is primarily shale but includes a significant quantity of interbedded limestone which increases upward. A thick bed of black shale is found in the lower part. Gillerman remarks that this section corresponds remarkably well to the section of Portal Formation measured by Sabins (1957, p. 476-477) at Blue Mountain in the Chiricahua Mountains, except that the lower (pre-black shale) unit was 100 feet thicker at Blue Mountain. He also remarks that the section in the Peloncillo Mountains corresponds to the Percha Shale that he observed in the Silver City area, except that there the formation is nearly 500 feet thick.

The Percha in the Peloncillo Mountains is generally similar to the Percha of the Big Hatchet Mountains except that there, as in the Portal Formation of the Chiricahua Mountains, it contains more limestone and has a thick bed of black fissile shale above its base. Black fissile shale found near the base of the Percha in the Big Hatchet Mountains may correspond to the black shale units found in the Peloncillo and Chiricahua sections.

MISSISSIPPIAN SYSTEM

ESCABROSA LIMESTONE

In the Big Hatchet Mountains, the limestone of Mississippian age that overlies the Percha Shale closely resembles the Escabrosa Limestone of southeastern Arizona and is quite different from the Mississippian formations of south-central New Mexico. Therefore I assign this formation in the Big Hatchet Mountains and elsewhere in nearby ranges (Sierra Rica, Animas Mountains, Sierra Boca Grande) to the Escabrosa.

Ransome (1904, p. 42-44) named the formation from Escabrosa Ridge, which lies about one mile southwest of Bisbee, Arizona. He summarizes the lithology as follows: "The characteristic rocks of the Escabrosa formation are rather thick-bedded, nearly white to dark gray, granular limestones, which close examination often shows to be made up very largely of fragments of crinoid stems."

Distribution and Topographic Expression

The most prominent exposure of Escabrosa Limestone in the Big Hatchet Mountains stretches diagonally from southeast to northwest across the northern part of the range. Along most of this band, the upper part of the formation forms a sheer cliff more than 500 feet in height. This cliff is one of the outstanding topographic features of the range, and the Escabrosa is one of the greatest cliff-formers of the area (fig. 3).

Near the western limit of this cliff, the head of a westward-draining valley has advanced along the nonresistant Paradise Formation and a fault zone to a place behind the cliff. This resulted in isolation of a high, thin, elongated remnant of the Escabrosa which, in end view as observed from the northwest or southeast, appears as a great spire.

The formation is exposed also on the south side of the northernmost peak of the range. Here the upper part also forms a sheer cliff.

Other exposures include only the upper few hundred feet of the formation; these do not form spectacular cliffs but instead produce moderate slopes with craggy and bedded exposures. The ridge and hills along the south side of the mouth of Chaney Canyon consist of Escabrosa Limestone. A small exposure is found in SW^{1}/4 sec. 28, T. 3o S., R. 15 W. In Hachita Valley, a low, inconspicuous knoll of Escabrosa is found 1 1 1/2 miles northeast of the Hatchet Ranch. A few small exposures occur in a thrust sheet in the northwestern part of the Sierra Rica.

Along the eastern flank of the Big Hatchet Mountains from near the mouth of Sheridan Canyon southward, Escabrosa Limestone is exposed in many places. Formations in this area dip southwestward, and Mississippian strata underlying the Horquilla Limestone crop out in discontinuous exposures.

The lower member of Escabrosa consisting of medium- and thin-bedded limestone and some shale is not resistant. It is generally covered with rubble from the cliffs that invariably tower above. Near the top of this part, however, two massive limestone beds each about 5o feet thick are exposed as small cliffs.

As mentioned, the upper part of the Escabrosa, about 700 feet thick, forms sheer cliffs in some exposures and in others, where only the upper few hundred feet are exposed, erosion has produced more subdued slopes. The factor determining the nature of the exposure—cliff or slope—is whether or not erosion has proceeded deep enough in the strati-graphic column to cut the soft, underlying Percha Shale. Where the Percha was exposed, a valley was produced that migrated downdip as erosion proceeded. The overlying Escabrosa, being more resistant than the shale, broke off along joints perpendicular to bedding as the shale was removed. The cliff was thus formed and perpetuated. Talus from the upper, more massive Escabrosa covered the less resistant lower beds at the base of the cliff. Throughout this region where the upper Escabrosa is exposed as a cliff, the Percha is invariably available to erosion, though much of it is concealed by rubble.

The upper part of the Escabrosa, though resistant with respect to underlying beds, is usually divided by bedding planes. In places where only these upper beds are exposed, erosion has produced craggy hillsides and moderate slopes formed of well-defined beds.

Stratigraphy

In the Peloncillo Mountains, Gillerman (op. cit., p. 28-29) divided the Escabrosa into three units which, from base to top, are the lower gray member, the black member, and the upper gray member. In the Big Hatchet Mountains, the Escabrosa Limestone lends itself to a similar threefold division. However, here the divisions are much thicker and have certain other differences, and therefore they may not correspond exactly to the members described by Gillerman. For convenience of description, the Escabrosa Limestone of the Big Hatchet Mountains is divided into three members called lower, middle, and upper. The formation was studied in the Mescal Canyon section, which is illustrated on Plate 2.

The lower member, which includes the rocks between the Percha Shale and the base of the massive limestone part of the Escabrosa, is assigned to the Escabrosa because it differs from the pure shale of the Percha and consists predominantly of crinoidal limestone, which is characteristic of the Escabrosa. The rock sequence from Percha into typical massive Escabrosa is transitional with no obvious breaks. Changes upward are gradual from shale to shale interbedded with limestone to limestone. The age of the Percha in the region and presumably in the Big Hatchet Mountains is very late Devonian. Fossils from high in the lower member of the Escabrosa are of early Mississippian age. Thus, lithologic and faunal evidence indicates continuous deposition from latest Devonian Percha to early Mississippian Escabrosa in the Big Hatchet Mountains.

Throughout southeastern Arizona, the base of the Escabrosa is chosen very near the base of a massive cliff-forming limestone which rests upon Late Devonian rocks. In the Big Hatchet Mountains, the thin-bedded lower member of the Escabrosa lies between the base of a cliff-forming limestone and Devonian rocks. Some observers are inclined to place the base of the Escabrosa in the Big Hatchet Mountains at the base of the cliff-forming limestone, and assign the underlying thin-bedded sequence to the Portal Formation. Present age information prohibits such assignment because these beds in the Big Hatchet Mountains are evidently early Mississippian and the Portal is evidently prePercha Late Devonian.

The lower member, though composed mainly of medium gray crinoidal limestone, includes a number of different lithologies. The basal part consists of interbedded gray clay shale and thin nodular gray limestone beds. The contact with the underlying Percha Shale is gradational from predominant shale below to predominant limestone above. Higher in the member, there are medium-bedded light gray and white crinoidal limestone beds and two diagnostic massive 8-foot beds of coarsely oolitic limestone. In the upper part, two 50-foot beds of massive calcarenite are separated by I oo feet of interbedded thin strata of shale and black limestone. The lower of the two massive beds contains curious, large, brown-weathered, masses of chert that Armstrong (1962, p. 27) declared bioherms without presenting evidence; the chert has selectively replaced elastic limestone grains. Except for the two massive beds near the top, this member is relatively nonresistant and is commonly covered with scree from the overlying cliff-forming rocks. The lower member has a thickness of 545 feet.

The remaining 716 feet of the Escabrosa comprising the middle and upper members often forms a sheer cliff. The middle member, about 35o feet thick in the Mescal Canyon section, consists of a rhythmic succession of thin strata of limestone, shaly limestone, and chert. The limestone is dark gray to black on fresh fracture, weathers light gray, is finely crystalline, has a elastic texture, has a hydrogen sulfide odor on fresh fracture, and occurs in strata averaging one foot in thickness. The shaly limestone, which has a minor quantity of clay and a shaly parting, occurs in laminae less than one inch thick that separate limestone strata; shaly limestone laminae diminish in number upward. Chert occurring as nodules within the limestone and as thin strata is distributed in bands alternating with chert-free limestone. The chert on fresh fracture is light gray to black, black predominating, and it weathers medium brown. Nodules average two inches in thickness and are greatly elongated parallel to the bedding. Some have concentric banding; some contain fossil fragments. The proportion of chert varies vertically from bed to bed and also laterally. Some zones particularly rich in chert may be traced laterally for only 100 or 200 feet, beyond which the chert abundance diminishes. In the upper two-thirds of the member, the strata rich in chert nodules give way to thin strata of black chert ranging up to two feet in thickness. In the upper 5o feet of the member, the black limestone is interbedded with light gray calcarenite. This member with its black limestone and rhythmic chert strata is strikingly similar to the middle (black) member of the Escabrosa in the Peloncillo Mountains.

The upper member, about 36o feet thick, consists of limestone that is light gray on fresh fracture and that weathers medium gray to almost white, light gray predominating. The rock is detrital, being composed largely of crinoid columnals; grain sizes range from coarse sand to granule. The limestone is crystalline, with crystal sizes the same as grain sizes. As exposed in cliffs, the rock is quite massive, although faint bedding planes are visible; where exposed on moderate slopes, individual beds are defined by erosion. White chert occurs in small quantities as strata, as nodules, and as replacements of individual crinoid columnals. The rhythmic banding characteristic of the lower member is not developed in the upper member. The crinoidal composition and coarse elastic texture of this member correspond more closely to the Escabrosa lithology typical of southeastern Arizona (Ransome, 1904, p. 43; Gilluly, Cooper, and Williams, 1954, p. 3-4; Sabins, 1957, p. 481) than do the lithologies of the lower members. In isolated exposures, crinoidal beds of the Escabrosa Limestone are difficult to distinguish from similar beds of the lower Horquilla Limestone.

The massiveness of the upper crinoidal member of the Escabrosa Limestone exposed in cliffs has suggested a bio-hermal or reef origin to some observers. However, evidence for the presence of reefs is slim. As described above, the cliffs owe their existence to erosion of the underlying Percha Shale' and not to the resistance of a supposedly thick homogeneous upper Escabrosa member. This fact is amply demonstrated by the absence of moundlike limestone masses in areas where Percha Shale is not exposed and where only the upper member of the Escabrosa is exposed; examples are each end of the great cliff of Escabrosa and the ridge on the southern side of the mouth of Chaney Canyon. Erosion has divided the individual beds of the member, which shows that the rock is not so homogeneous as it may appear on cliff faces.

Furthermore, if the Escabrosa cliffs represent mounds that are absent in places where the same stratigraphic interval is represented by evenly bedded limestone, the thickness of the interval at the supposed mounds should be greater than at evenly bedded places. Measurement of the upper member of the Escabrosa in the Mescal Canyon section where it is most boldly exposed and about a mile to the southeast where it is eroded into individual beds shows the thickness at each place to be the same. Observation of the formation from the air shows no increase of thickness in the cliff areas.

Although large mounds are not present in the upper member of the Escabrosa, small areas of apparently homogeneous limestone that are seen on cliff faces from a distance could represent small mounds. These are difficult to study because of their inaccessibility. Two rock samples from one of the most massive parts of the member were studied by Richard Rezak (written communication, 1962) who found no calcareous algae present.

The contact between the Escabrosa Limestone and the overlying Paradise Formation is gradational; it lies within a transition zone which seldom exceeds 10 feet in thickness. The uppermost beds of the Escabrosa, which are thin and nonresistant, consist of alternate dark gray, finely clastic limestone and medium gray crinoidal limestone. Such strata are interbedded with Paradise types, such as tan-weathered silty limestone, tan oolitic limestone, and tan shale. The contact is chosen at the base of the lowest tan-weathered limestone bed, which marks the division of predominance of the contrasting lithologies. In many parts of the Big Hatchet Mountains, such as in the Mescal Canyon section, a stratum of white chert lies at or a few feet below the top of typical Escabrosa lithology. Where the chert is seen and beds of the transition zone are poorly exposed, the top of the chert stratum is chosen as the contact.

Apparently the change from Escabrosa to Paradise lithology was produced by introduction of silt and clay in gradually increasing quantities as a result of shallowing of the sea and closer proximity of the shore.

The total measured thickness of the Escabrosa Limestone in the Mescal Canyon section is 1261 feet.

Age and Correlation

Fossils, though not abundant, are found throughout most parts of the formation. These include brachiopods, solitary corals, crinoids, trilobites, bryozoans, cephalopods, *Archimedes*, and fish teeth.

A small collection from near the top of the lower member (field number 55e; U.S.G.S. Loc. No. 20375-PC) was studied by W. J. Sando in consultation with J. T. Dutro, Jr. Sando 's identifications and remarks are as follows:

> *"Amplexus"* sp.
> *"Koninckophyllum"?* sp.
> *Zaphrentites* sp.
> *Syringopora aculeata* Girty
> *Punctospirifer aff. P. subtexta* (White)
>
> This faunule, although small and poorly preserved, is very similar to a faunule recently discovered a few feet above the base of the Redwall Limestone at Black River Crossing, sec. 11, T. 4 N., R. 20 E., Gila Co., Arizona. The fossils in these faunules are definitely Mississippian types and are strongly suggestive of an Early Mississippian (Kinderhook) age.

As these Mississippian fossils were collected from the upper part of the lower member of the Escabrosa, and as no lithologic break is evident within the member, the age of the entire lower member is probably Mississippian.

Other fossils collected in the Escabrosa have not been studied, but on preliminary examination, I have recognized the following: Spirifer sp., productid brachiopods, *Leptaena* sp., goniatites, fenestellid bryozoans, *Archimedes* sp, and *Taonurus* sp. Although the formation is of Mississippian age, its exact age within the system in the Big Hatchet Mountains is not yet known from direct evidence. However, the age of the Escabrosa Limestone in Arizona gives an approximation of its age in this area.

Williams (Gilluly, Cooper, and Williams, 1954, p. 9-13) discusses the age of the Escabrosa Limestone in southeastern Arizona and compares its fauna with that of other Mississippian formations. He agrees with the age of the formation as determined by Girty (Ransome, 1904, p. 46) and concludes that the Escabrosa Limestone is in general of early Mississippian (Kinderhook and Osage) age and locally may be younger than Osage age. Speaking of correlations, Williams says, "The writers believe that the long-held general correlation of the main body of the typical Escabrosa with the fauna of the main body of the Madison limestone is probably correct." Elsewhere, he says the brachiopods of the Escabrosa " . . . are, with relatively few exceptions, forms found associated in faunas in the West that are considered to be of the age of the Red Wall [sic], Leadville, and Madison limestones, as those formations are widely interpreted."

Speaking of zoning the Escabrosa and Madison Limestones Williams says:

> The fauna of the Escabrosa, as collected thus far, does not indicate that success would be obtained were attempts made to zone the Escabrosa. . . . The writer (Williams) believes that the Madison limestone fauna (and perhaps the Escabrosa fauna) existed during both Kinderhook and Osage time, and that the faunas in the West during these epochs did not change so rapidly as in the midcontinent region, because in the West ecological conditions were uniform longer. Some of the western species identified with species from the midcontinent may not actually be of those species; but even if they are, there is no reason that the

> species should have precisely the same ranges in the West where ecological conditions were different. The Madison (and Escabrosa) faunas are western faunas that cannot be as yet definitely identified with the faunas from the typical thin formations of the Kinderhook and Osage groups in the Mississippi Valley, where indeed the boundary between the Kinderhook and Osage is still in dispute.

Williams' comments on the age and correlation of the Escabrosa Limestone of southeastern Arizona are surely valid for at least the typical massive part of the Escabrosa Limestone of the Big Hatchet Mountains.

Correlation of the Escabrosa Limestone of the Big Hatchets with Mississippian formations to the northeast in New Mexico is not at present made with confidence. Laudon and Bowsher (1949) studied the Mississippian rocks of south-central New Mexico and subdivided the section into formations and members. They studied the faunas and were able to correlate the formations with the midcontinent Mississippian section. Their studies did not include the southwestern corner of New Mexico where the Escabrosa facies is dominant. Without fossil identifications from the Escabrosa Limestone of the Big Hatchet Mountains, and not having studied Mississippian sections east of the Big Hatchet Mountains, I am able only to speculate on the relationship of the Big Hatchet Escabrosa sections to eastern sections from information assimilated from published reports.

According to Laudon and Bowsher, the Caballero Formation of south-central New Mexico is a thin unit of shale and nodular limestone of Kinderhook age; it has not been recognized west of the Lake Valley area. Above this, the Lake Valley Formation of Osage age is widely distributed in southern New Mexico and has a thickness of as much as 450 feet in Cooks Range (Jicha, 1954, p. 18), the westernmost limit of its recognized exposure. The Lake Valley Formation, which Laudon and Bowsher divided into six lithologic members recognizable throughout much of south-central New Mexico, consists almost entirely of limestone. Black chert nodules similar to those of the middle member of Escabrosa Limestone in the Big Hatchet Mountains are found in various concentrations in the lower part of the formation; crinoidal limestone beds are found near the middle and in the upper parts. The formation is unlike the Escabrosa Limestone of the Big Hatchet Mountains in lithologic details; also, it is thinner and is not so massive. However, because of the age similarity of the Escabrosa and the Lake Valley, and because of a few lithologic similarities, the formations may be in part correlative. The lower member of the Escabrosa Limestone in the Big Hatchet Mountains is more similar in lithology to the Lake Valley and the Caballero Formations in south-central New Mexico than to basal Escabrosa or formations below the Escabrosa in southeastern Arizona (except for the Portal Formation of Devonian age). This lower 500 feet of beds may prove to be correlative with eastern strata. However, the views of Williams on the difficulty of faunal zoning of the Escabrosa may prove quite pertinent in future attempts to correlate the Big Hatchet Escabrosa with eastern sections, particularly since distances between exposures are great and many exposures are complicated by structure and metamorphism.

Armstrong (1962) in a reconnaissance study of the Mississippian System in southwestern New Mexico and southeastern Arizona elevated the Escabrosa Limestone to a group and divided it into two new formations, the Keating Formation and the Hachita Formation. The formations are not useful mapping units. As elevation of the Escabrosa to group rank and its division into two unmappable formations serves no useful purpose, this usage is rejected.

According' to Armstrong, the Escabrosa lies unconformably upon Upper Devonian strata, and prior to Mississippian deposition, Devonian rocks were exposed to subaerial erosion. In the Big Hatchet Mountains, he places this unconformity at the base of the lowest 50-foot limestone bed within what I call the lower member of the Escabrosa, and he assigns the underlying beds to the Upper Devonian Portal Formation. There is no lithologic evidence of the unconformity, as rocks below and above the contact have the same characteristics. Armstrong gives no evidence to support the presence of the unconformity in the Big Hatchet Mountains, and the base of the Escabrosa should not be placed within a uniform lithologic sequence without reason. He gives no evidence of Devonian age for the underlying rocks; my observations favor Mississippian age.

PARADISE FORMATION

The Paradise Formation, named by Stoyanow (1926, p. 316-318) from exposures near Paradise, Arizona, in the Chiricahua Mountains, is limited in distribution to southeastern Arizona, southwestern New Mexico, and northwestern Chihuahua. It is not known west of the Chiricahua Mountains. Gillerman recognized the formation in the central Peloncillo Mountains, which is its northernmost known occurrence. I found the formation in the Animas Mountains (Zeller, 1958a), the Big Hatchet Mountains, the Sierra Rica, and the Sierra Boca Grande in Chihuahua 25 miles east of the Big Hatchet Mountains. The Paradise may be related to the Helms Formation of southeastern New Mexico and western Texas. Studies of the formation have been made by Hernon (1935. p. 653-696) and Packard (1955)•

The Paradise Formation, consisting mainly of tan-weathered, thin-bedded elastic limestone and tan shale, lies conformably upon the gray-weathered massive Escabrosa Limestone and is overlain with erosional unconformity by gray-weathered, medium-bedded Horquilla Limestone. It is one of the distinctive lithologic units of the region.

Distribution and Topographic Expression

The largest exposure of the Paradise Formation in the Big Hatchet Mountains is in a diagonal northwest-trending band paralleling lower Paleozoic formations in the northern part of the range. Northeast of this band, it crops out in several small areas along the north and northeast sides of the range where late normal faults have placed it in contact with older formations.

The formation is also exposed on the south side of Chaney Canyon. From here southward for a mile along the west side of the range, it is distributed in a pattern complicated by tight folding and faulting. Along the eastern flank of the range, the formation crops out in a number of places from near the mouth of Sheridan Canyon southward. In the Sierra Rica, it is found in a small exposure in NW1/4 sec. 32, T. 29 S., R. 14 W.

The formation is thin bedded and nonresistant. Commonly, its exposure forms a swale between the bluffs of resistant limestones below and above. Identification of the Paradise is facilitated by its orange-brown or tan color, its nonresistance, its abundance of oolitic and fossiliferous limestone, and its position between two resistant gray limestone formations.

Stratigraphy

The Paradise Formation was measured and briefly described only in the Mescal Canyon section (pl. 2). Good exposures of the Paradise are found in several places to the southeast of Mescal Canyon, notably in S1/2 sec. 33, T. 3o S., R. 15 W., and in N1/2 sec. 29, T. 31 S., R. 14 W. Because time did not permit detailed study of these alternate sections, the following description of the stratigraphy is based upon the Mescal Canyon section and field observations from many other exposures.

The lithology of the lower few tens of feet of Paradise beds varies laterally. In the Mescal Canyon section, thin beds of dark gray, indistinctly cross laminated, finely detrital limestone are interbedded with tan calcareous silt and clay shale. The shale is covered but its presence and character are known from float. Overlying thin beds are of tan-weathered crystalline limestone. One and a half miles to the northwest, the basal beds consist of tan shale interbedded with thin beds of fossiliferous oolitic limestone that is gray and tan when fresh and tan or orange-brown when weathered. The only coarsely crystalline material in the oolitic rock consists of scattered crinoid columnals. In most places, basal Paradise beds are incompletely exposed.

The bulk of the formation consists of clastic limestone beds that are medium and dark gray on fresh surfaces and tan on weathered surfaces. Detritus, which ranges from fine sand to granule size, consists mostly of crinoid columnals but includes fragments of a great variety of other fossils. Freshly fractured rocks have a distinct hydrogen sulfide odor. Most beds are only a few feet thick, but in the Mescal Canyon area one limestone bed that is locally persistent has a thickness of 22 feet. Many beds are cross laminated.

Oolitic limestone is found throughout the Paradise but is most common in the upper part. The fresh rock is gray and tan, and the weathered rock is tan, orange-tan, and olive. Oolites are mostly medium and coarse sand size with nuclei composed of fossil fragments, mainly crinoids. Thinly distributed crinoid columnal fragments appear as coarse crystals on fresh surfaces. The matrix is extremely fine grained limestone. Well-preserved marine fossils, particularly fenestellid bryozoans and *Archimedes*, are abundant and conspicuous on weathered surfaces.

Limestone beds are divided by shale and mudstone beds, usually concealed, which average a few feet in thickness. The shale, composed mostly of silt and clay, is calcareous; it is tan on fresh and weathered surfaces; it fractures into flakes and chips 1/16 to I inch thick.

Several thin beds of intraformational conglomerate are present in the upper part. In one locality, a few of the uppermost beds consist of limestone-cobble conglomerate. In the Peloncillo Mountains, Gillerman (1958, p. 3o) noted conglomerate near the top of the Paradise Formation.

Chert is rare in the formation. A few stringers and nodules of light gray chert are sometimes present in the lower beds.

Thin lenses and beds of brown-weathered quartz sandstone containing plant fossils are infrequently interbedded with marine limestone in the upper part of the Paradise Formation in the Big Hatchet Mountains. Very commonly such a sandstone forms the highest bed of the formation in the area. Fossil tree roots and trunks, some of which are normal to bedding in apparent growth positions, indicate the terrestrial origin of the sandstone. Most of the lenses and beds are no more than a few feet in thickness, but half a mile south of the mouth of Chaney Canyon, a unit of sandstone at or very near the top of the Paradise is more than 5o feet thick.

The upper contact of the Paradise Formation is chosen at the level where the brown-weathered limestone or sandstone of the Paradise gives way to the gray limestone lithology of the overlying Horquilla. This contact between contrasting rock types is an erosional unconformity.

Because the depth of pre-Horquilla erosion varied throughout the range, various amounts of upper Paradise were removed from different sections. The measured thickness of the Paradise Formation in the Mescal Canyon section is 318 feet, which is probably its average thickness throughout the range.

In the Sierra Boca Grande 25 miles to the east, the Paradise Formation is much thicker than in the Big Hatchet Mountains. Much, but not all, of the greater thickness is due to the injection of many green-weathered diorite sills in the soft shale intervals. Curiously, a few thin diorite sills are also present in the Paradise of the Big Hatchets. In the upper part of the formation in the Sierra Boca Grande, thick beds of arenaceous limestone and calcareous sandstone are present; at the top of the formation, beds of brown-weathered quartz sandstone having plant fossils are quite thick and are interbedded with thin beds of tan oolitic limestone.

Packard, who made detailed lithologic studies of several sections of the Paradise Formation in southeastern Arizona and southwestern New Mexico, concluded that the marine portion of the formation was deposited in a shallow warm sea in which the sediments were subjected to agitation. Apparently the terrestrial sandstone beds and lenses in the upper part of the formation represent periods of deltaic deposition in which the area was above sea level and received fluviatile sands.

As no terrestrial sandstone is present in Arizona and as the sandstones thicken to the southeast in Mexico, it seems possible that the land area that supplied the sand lay to the southeast. After deposition of the Paradise Formation the area was subjected to erosion followed by marine flooding of the region and subsequent deposition of the Horquilla Limestone.

Age and Correlation

The Paradise fauna is rich both in quantities of fossils and in variety of forms. Marine invertebrate fossils include corals, bryozoans, crinoids, brachiopods, pelecypods, scaphopods, gastropods, cephalopods, and trilobites. Land plant fossils which I have recognized include *Calamites*, *Lepidodendron*, and *Stigmaria*.

A complete suite of fossils collected from each fossiliferous bed of the formation in the Mescal Canyon section was submitted to M. K. Elias, but these have not yet been studied. However, another collection of marine invertebrates collected from the formation as a whole and not separated according to stratigraphic level was studied by Elias. His identifications (written communication, 1956) are shown in Table I.

Elias commented on the fauna as follows:

> The identified fauna suggests that your fossiliferous beds correspond to the members 5, 6, and 7 of the Paradise of Arizona, as per Hernon's 1935 classification. The presence of *Goniatites choctawensis* permits their correlation with the Delaware Creek member of the Caney in the Arbuckle Mts. (Elias, 1956). Hernon's correlation of 5 to 7 members with the Fayetteville of Arkansas is generally acceptable, but I would somewhat lower it down to the basal part of the Fayetteville and the upper part of the Batesville. Hernon (1935, table, p. 667) is right in placing the Pitkin above the Paradise. It may be of interest to you also that I consider the Helms of Texas about equivalent to the Pitkin, both being near the top (but not quite at the top) of the Chester.

Fossils are more abundant in the upper half of the Paradise Formation in the Big Hatchet Mountains, and nearly all the forms listed in Table I came from this part. However, *Goniatites choctawensis* was collected from the basal beds. Elias noted that the fauna studied corresponds to Hernon's members 5, 6, and 7 of the type Paradise Formation. The lower, less fossiliferous beds of the formation probably will be found to correlate with the lower beds of the Paradise in the type locality, which there, incidentally, are also less fossiliferous than the upper beds.

Plant fossils are found in the sandstone beds and lenses that lie at and near the top of the Paradise Formation. Specimens from the uppermost bed of the formation on the east side of the Big Hatchet Mountains near the Mescal Canyon section were identified by Elias (written communication, 1955) as *Lepidodendron obovatum* Sternberg. Specimens collected later from the top of the formation on the west side of the range south of Chaney Canyon were identified as the same species by Charles B. Read (written communication, 196o). Read comments that *Lepidodendron obovatum* is very common in the Early Pennsylvanian. He further says that the genus *Lepidodendron* is present in rocks of Chester age, and although he does not recall having seen L. *obovatum* in rocks of Chester age, such an occurrence would not be surprising.

No fossils of indisputable Chester age have been found above beds containing L. *obavatum*, but indirect evidence suggests that these sandstone beds are of Chester age and that this occurence of L. *obovatum* is an unusually low one. Some plant-bearing sandstone beds below the top of the Paradise Formation are overlain by rocks of typical Paradise litholohy that contain marine faunas similar to those of

TABLE 1. FOSSILS FROM THE PARADISE FORMATION OF THE BIG HATCHET MOUNTAINS

Identifications by M. K. Elias

Genera and species	Known from Paradise Formation of Arizona: Hernon (1935)	Known from Paradise Formation of Arizona: Condra & Elias (1944)
Corals:		
Michelinia sp.		
Small horn coral	X	
Echinoderms:		
Pentremites cf. *pinguis* Ulrich and *cavus* Ulrich	X	
Bryozoans:		
Batostomella (?) cf. *armata* Ulrich	X	
Fenestella tenax Ulrich	X	
Fenestella cumingsi Condra and Elias		X
Fenestella rarinodosa Condra and Elias		
Archimedes proutanus Ulrich	X	X
Archimedes invaginatus Ulrich	X	X
Archimedes confertus Ulrich	X	X
Archimedes meekanus Hall		
Archimedes compactoides Condra and Elias		X
Polypora spinulifera Ulrich	X	
Polypora tuberculata Prout		
Thamniscus n. sp (?)	X	
Brachiopods:		
Orbiculoidea cf. *keokuk* (Gurley)		
Rhipidomella cf. *diminutiva* Rowley		
Orthotetes kaskaskiensis (McChesney)	X	
Chonetes cf. *oklahomaensis* Snider	X	
Echinoconchus biseriatus (Hall)[1]	X	
Echinoconchus rodeoensis (?) Hernon	X	
Linoproductus ovatus (Hall)[2]	X	
Linoproductus n. sp.[3]		
"*Dictyoclostus*" *inflatus* (McChesney)[4]	X	
"*Dictyoclostus*" *crawfordsvillensis* Weller		
"*Dictyoclostus*" n. sp.		
Dielasma illinoisensis Weller	X	
Dielasma cf. *osceolensis* Weller		
Spirifer pellaensis var. *cavecreekensis* Hernon	X	
Spirifer n. sp., cf. *striatiformis* Meek		
Spirifer n. sp.		
Cleiothyridina cf. *sublamellosa* (Hall)	X	
Composita cf. *corpulenta* (Winchell)		
Eumetria vera (Hall)	X	
Eumetria cf. *verneuiliana* (Hall)	X	
Pelecypods:		
Limipecten sp.	X	
Scaphopods:		
Laevidentalium sp.	X	
Gastropods:		
Patellostium cf. *aureyensis* Gurley		
Naticopsis n. sp., cf. *splendens* (Girty)		
Cephalopods:		
Cycloceras randolphensis (Worthen)	X	
New genus (?), aff. *Belemnites* and *Eobelemnites*		
Goniatites choctawensis Shumard		
Trilobites:		
Griffithides sp.	X	

[1] May be *Stegacanthia*, according to Muir-Wood and Cooper (1960, p. 199).
[2] *Ovatia ovata*, Muir-Wood and Cooper, p. 313.
[3] Probably *Ovatia*.
[4] *Inflatia inflata*, Muir-Wood and Cooper, p. 227.

lower beds. The sandstone beds at the top of the formation, those which contain *Lepidodendron obovatum,* are identical in character to those which occur below. It thus appears that the upper sandstone beds represent part of a continuous late Paradise phase of deposition and that no interruption occurred before deposition of the highest sands. As the somewhat lower sandstone beds are probably of Chester age, the uppermost sandstone beds are probably of the same age. Admittedly, the possibility exists that the Mississippian—Pennsylvanian boundary lies within the uppermost Paradise Formation,.even though no depositional breaks are apparent.

The tentative conclusion that the uppermost Paradise beds in the Big Hatchet Mountains are of Chester age is supported by my studies in Mexico. In the Sierra Boca Grande, the upper few hundred feet of the Paradise Formation contains terrestrial sandstone interbedded with oolitic marine limestone rich in Chester fossils. A sandstone bed 20 feet below the top of the Paradise has a large specimen of *Lepidodendron.* Beds above the one containing *Lepidodendron* are of tan oolitic limestone with a marine fauna that appears to be the same as that in lower beds of tan oolitic limestone of known Chester age.

Hernon (1935, p. 66o) found that the faunal zones of the Paradise Formation in the Chiricahua Mountains "indicate that the formation represents the time from St. Louis [middle Meramec] to Golconda of the middle Chester, inclusive." He chose the base of the formation (op. cit., p. 656) "at the first marked evidence of shallowing of the waters, where the moderately bedded limestones overlying the typical Escabrosa [15o feet of an 'unnamed formation' of St. Louis age which separates the Escabrosa and the Paradise] give place to shale and thinner-bedded limestones carrying limestone conglomerates near their base. The lithologic base is not marked by a sharp change in fauna. . . ." He implies that the Escabrosa, the unnamed limestone, and the Paradise Formation form an uninterrupted conformable sequence. Sabins (1957, p. 483) shows the base of the Paradise to be conformable with the top of the Escabrosa Limestone a few miles northwest of the type locality. Therefore, in the Chiricahua Mountains there is no appreciable hiatus at the Escabrosa—Paradise contact. The Escabrosa ranges in age through Osage and in some places is younger (Meramec), and basal beds of the type Paradise Formation and the unnamed limestone of Hernon that separates the two formations are of St. Louis age (middle Meramec).

In the Peloncillo Mountains, the Escabrosa—Paradise contact appeared to Gillerman (1958, p. 3o) to be conformable. In the Big Hatchet Mountains, the change from massive crinoidal limestone of the upper Escabrosa to the thinner beds of crinoidal limestone interbedded with other clastic limestone beds and shale in the Paradise Formation is gradational. There is no lithologic evidence of an unconformity.

The age of the Paradise Formation of the Big Hatchet Mountains may be summarized as follows: The lower half is thought to be of middle and late Meramec and early Chester age, and most of the upper half is known to be of Chester age. Lepidodendron-bearing sandstone locally present at the top is probably Chester but may be Pennsylvanian.

Packard measured a stratigraphic section in the Big Hatchet Mountains about one mile southeast of the Mescal Canyon section. He kindly authorized publication of his section and fossil identifications, which are shown in generalized form in Figure 5. The location at the section is the eastern slope of a large gully that runs approximately along the southern half of the boundary between secs. 32 and 33, T. 3o S., R. 15 W. Packard explains that he did not make exhaustive fossil collections because his purpose was only that of correlating the formation with the type locality.

Packard's conclusions concerning the nature of the Paradise Formation are in accordance with mine. The Paradise Formation of the Big Hatchet Mountains correlates with the type Paradise both lithologically and faunally. He interprets the basal contact as conformable. He found that the upper contact is everywhere unconformable, his chief evidence for this being that the overlying formation rests upon different horizons within the Paradise at different places. Packard dates the lower part of the Paradise as Meramec and the upper part as Chester, which conforms to Hernon's findings. With reference to the endothyroids and the fusulinids, Packard states that Chester age is indicated for the portion of the formation in which and above which *Millerella* is found and that Meramec age is indicated for the portion in which *Endothyra* is found.

Some workers have suggested correlation of the Paradise Formation with the Helms Formation of southeastern New Mexico and western Texas. Flower (1958, p. 76), speaking of the Escabrosa—Paradise succession of the Big Hatchet Mountains, observes that "Curiously, the upper Chester portion of the section shows prevailing olive tint, faintly reminiscent in color of the Helms of the Franklin and Hueco Mountains, but not nearly so shaly." Weller et al. (1948, p. 142-143 and correlation chart) show the Helms and the Paradise to be of approximately the same age. However, Elias considers the Helms Formation about equivalent to the Pitkin Limestone of the Oklahoma—Arkansas region, both of which are near the top of the Chester Series. He places the Pitkin above the Paradise Formation (as did Hernon, op. cit., p. 667), and thus he also places the Helms above the Paradise. Packard found that the upper part of the Paradise Formation is dissimilar to the Helms Formation, and he suggests that the Helms may be younger than any part of the Paradise.

In all places, the Paradise Formation has been cut by erosion before deposition of later rocks. Perhaps the Helms and Paradise Formations were once a continuous succession of rocks, but the younger Helms Formation was removed from southwestern New Mexico and southeastern Arizona by this period of erosion.

Concerning correlations with other formations, Packard suggests that faunal comparison may establish an age equivalence for the lower (Meramec) part of the Paradise with the Las Cruces and Rancheria Formations of the El Paso area, but lithologically the Paradise does not resemble those formations.

POST-PARADISE-PRE-HORQUILLA UNCONFORMITY

In the Big Hatchet Mountains, the contact between the Paradise Formation and the overlying Horquilla Limestone

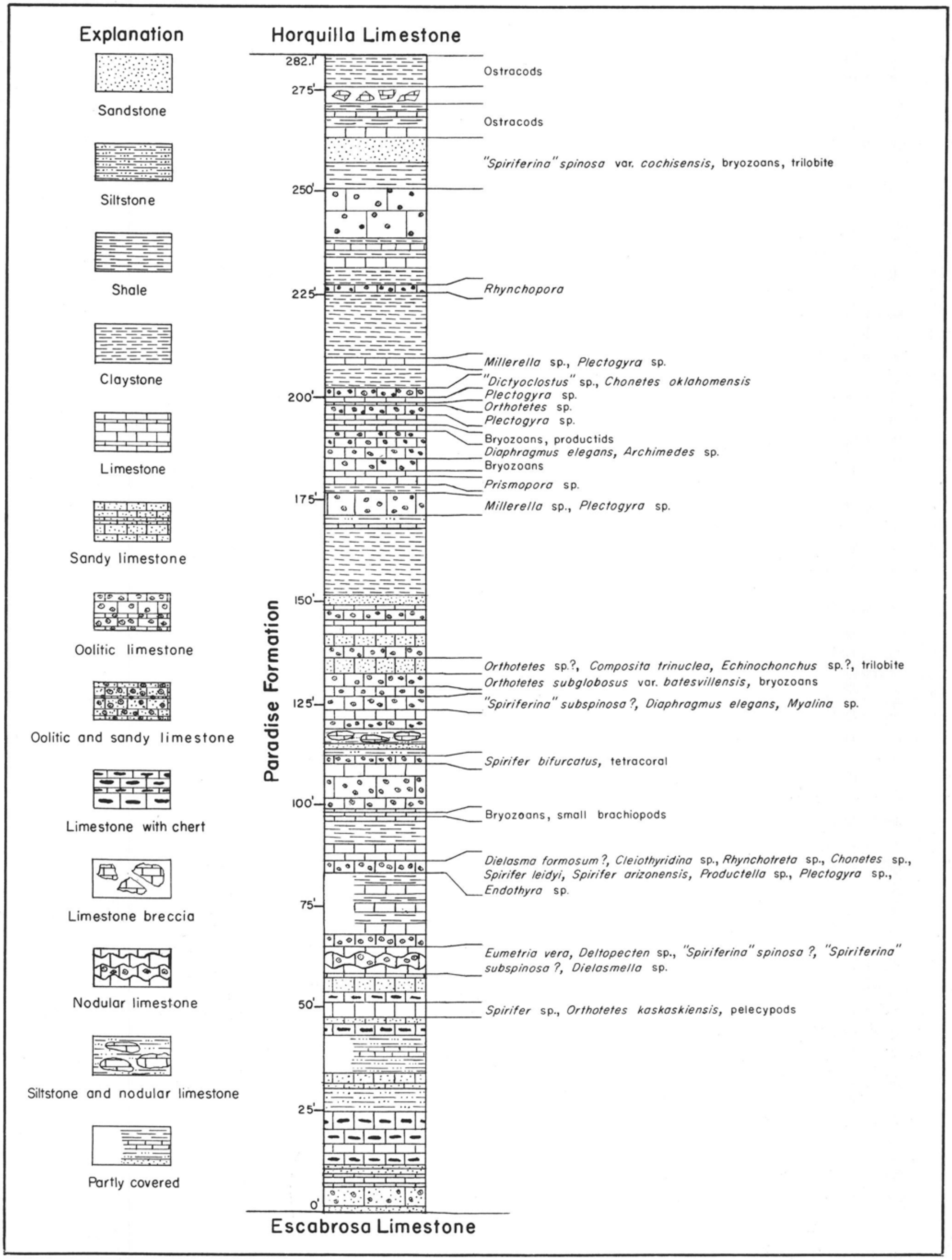

Figure 5

STRATIGRAPHIC SECTION OF PARADISE FORMATION IN THE BIG HATCHET MOUNTAINS.

Generalized from section measured and studied by Packard (1955) about one mile southeast of Mescal Canyon section. Fossils identified by Packard.

is an erosional unconformity. There is no obvious angularity between the beds above and below the contact. Evidence of the unconformity is as follows: (I) There is an abrupt change in lithology at the contact; (2) the upper part of the Paradise Formation containing beds and lenses of terrestrial sandstone is relatively thick in some places and missing in others; (3) the thickness of the Paradise Formation varies considerably within the range and, where it is thin, the upper beds are missing; (4) the detailed sequence of the lowermost Horquilla beds is nearly identical throughout the region in contrast to the varied lithology of the underlying Paradise beds.

A hiatus is undoubtedly present at the unconformity. Its magnitude depends upon the age of rocks above and below. The uppermost beds of the Paradise are probably of Chester age; the age of the lowermost Horquilla beds is not known at present. Elias examined a fauna from the lower 20 feet of the Horquilla and considered it as Morrow age (early Pennsylvanian). Northrop examined a fauna from the same interval, but collected at a different locality, and considered the fossils to be Chester in age. These comments are discussed further under *Harquilla Limestone.*

In the Sierra Boca Grande to the east, the unconformity is more obvious than in the Big Hatchet Mountains. There the unconformity progressively cuts out several hundred feet of the upper Paradise in half a mile.

Throughout the entire region, there is an erosional unconformity at the base of the Pennsylvanian System. In the Caballo Mountains, Kelley and Silver (1952, p. 91-92) found that the base of the Pennsylvanian section rests upon an erosion surface having a maximum stratigraphic relief of about 500 feet; Pennsylvanian rocks rest upon beds ranging from lower Upham to Lake Valley. Farther north, Pennsylvanian rocks rest upon Precambrian rocks. In the San Andres Mountains (Kottlowski et al., 1956, p. 35), Pennsylvanian rocks rest with erosional unconformity upon various Mississippian beds.

West of the Big Hatchet Mountains in central Cochise County, Arizona, Gilluly, Cooper, and Williams (1954, p. 15) recognized a disconformity between Pennsylvanian and Mississippian rocks. In the Chiricahua Mountains, Sabins (1957, p. 485-486) found that the contact between the Paradise Formation and the Horquilla Limestone is a minor disconformity indicated by an abrupt lithologic change and a hiatus representing late Chester time.

Thus, the contact between the Paradise Formation and the Horquilla Limestone in the Big Hatchet Mountains is an erosional unconformity. The Mississippian—Pennsylvanian boundary may or may not lie at this contact. Throughout the region, the unconformity is recognized at the base of rocks identified as Pennsylvanian.

PENNSYLVANIAN AND PERMIAN SYSTEMS—NACO GROUP

The predominantly carbonate rocks of the Pennsylvanian and Permian Systems in the Big Hatchet Mountains are readily divisible into formations based upon gross lithologic differences. These formations bear less resemblance to the upper Paleozoic formations of other parts of New Mexico or western Texas than to those of southeastern Arizona. In gross lithology, they match remarkably well those of central Cochise County, southeastern Arizona, as defined by Gilluly, Cooper, and Williams. Such similarity justifies the use of the upper Paleozoic terminology of southeastern Arizona in the Big Hatchet Mountains. Formations of the Pennsylvanian and Permian Systems are included together in the Naco Group.

The history of the term *Naco* is summarized by Gilluly, Cooper, and Williams (1954, p. 15-16). Ransome (19o4, p. 44) named the Naco Limestone from the Naco Hills in southeastern Arizona. His Naco Limestone included as much as 300o feet of Pennsylvanian limestone and possibly some Permian limestone truncated by a pre-Cretaceous erosion surface. Elsewhere in the region, the erosion surface did not cut so deeply into the section and thousands of feet of additional Permian rocks are preserved. Gilluly, Cooper, and Williams advanced the name *Naco* to group status and commented that " . . . it seems probable that a name will long be useful in southeastern Arizona for the entire assemblage of post-Mississippian Paleozoic rocks to which Ransome originally applied the name Naco." This usage is followed here.

Gilluly, Cooper, and Williams divided the Naco Group into six formations, which from oldest to youngest are Horquilla Limestone, Earp Formation, Colina Limestone, Epitaph Dolomite, Scherrer Formation, and Concha Limestone. All these formations are recognized in the Big Hatchet Mountains and are described below. The Scherrer, however, is too thin here to be classed as a true formation. Though it is called a formation in this study, it is grouped with the Concha Limestone for geologic mapping.

HORQUILLA LIMESTONE

Distribution and Topographic Expression

The Horquilla Limestone is the thickest and one of the most resistant and widely exposed Paleozoic formations in the region. I have mapped it in the Big Hatchet Mountains, the Little Hatchet Mountains (Dane and Bachman, 1961), the Animas Mountains (Zeller, 1958a, 1962), Antelope Pass in the Peloncillo Mountains (Dane and Bachman, 1961), the Cedar Mountains, the Sierra Rica, and the Sierra Boca Grande and other ranges in northwestern Chihuahua. In the Big Hatchet Mountains where its exposures cover half the range, the greatest area of outcrop is in the eastern half; it extends from the northern to the southern tip of the range. In the southwestern and western parts, it is found in many thrust plates. Scattered exposures occur along the flanks of the northern third of the range, on the northernmost peak of the mountains, and on the isolated hill south of the highway in Hatchet Gap. Small exposures of Horquilla Limestone are found in a thrust plate on the northwestern spurs of the Sierra Rica.

The Horquilla Limestone is resistant to erosion and forms most of the bold peaks and ridges that make up the backbone of the Big Hatchet Mountains. Thick, massive biohermal reefs locally present in the middle and upper parts of the formation account for the great cliffs found on Big Hatchet Peak and on other peaks in the center of the range.

In the south-central part of the mountains, local 200-foot shale beds between massive reef limestones in the upper part of the formation result in gentle slopes steepening upward to moderately high limestone-capped mountains. The lower third of the formation, and also the upper part in places where not complicated by reefs or local shale beds, is characterized by alternating thin and thick beds that form moderately steep mountain slopes with frequent ledges. Exposures of this lithology are characterized by light-colored and regularly stratified beds.

Stratigraphy

The Horquilla Limestone rests upon an erosion surface cut upon the Paradise Formation; the contact is distinct and sharp. Brown-weathered sandstone, oolitic limestone, and shale of the Paradise contrast with the overlying light-gray-weathered limestone of the Horquilla.

The basal 20 to 50 feet of Horquilla Limestone is a remarkably similar sequence of beds throughout the range and the entire region. Small flat shells of *Chonetes* are very abundant in some strata; the rock is crystalline clastic limestone which is dark gray on fresh fracture and light gray on weathered surface; black chert nodules having brown-weathered borders are abundant in some strata; and the rock is thin bedded. Where exposed elsewhere in the region, from the Animas and Big Hatchet Mountains to the Sierra Boca Grande, these beds have the same distinctive characteristics.

Oolitic limestone in lenses and strata is common in the lower 450 feet of the Horquilla in the Big Hatchet Mountains. The oolitic texture, which is not obvious, may be seen with the aid of a hand lens on fresh moist surfaces. Few of the oolitic grains are spherical; most are elongated because of precipitation of calcite around elongated shell fragments. Except for the oolitic texture, the rock has the same appearance as that of non-oolitic clastic rock in the lower part of the formation; fresh and weathered colors are medium to dark gray; clastic grains are medium sand size; cross-lamination is occasionally present; and beds range from 2 to Io feet in thickness. In the Horquilla Limestone, oolitic texture is present only in the lower part. I have noted oolitic limestone in the lower Horquilla beds in many ranges, including the type section in the Tombstone Hills, southeastern Arizona, and in the Sierra Boca Grande, Chihuahua.

Other lithologies are found in the lower oolitic part of the Horquilla. Some beds are of medium-grained calcarenite composed of fossil shell fragments. Dark gray and black, finely crystalline limestone is interbedded with medium gray calcarenite in the lower 100 feet. A few brownish-weathered limestone beds contain fine quartz sand, silt, and clay. Rarely, a few thin beds of brown-weathered siltstone are present near the base. Several persistent zones rich in silicified *Syringopora* and *Chaetetes* are conspicuous. The lowest fusulinids noted are about 230 feet above the base of the Horquilla, and above this they are abundant in many beds.

Throughout most of the lower half of the Horquilla Limestone, massive beds of crinoidal limestone are common. They are so similar to the crinoidal limestone beds of the Escabrosa that they can be distinguished only by their position in the stratigraphic sequence and by the presence of rare fusulinids. Much of the lower half of the Horquilla has a pink tint, a characteristic found in sections to the west.

Above the oolitic part and still in the lower half of the formation, black chert is conspicuous and abundant as thin strata, nodules, and disseminated grains concentrated in particular beds; some zones are nearly 5o percent chert. The host rock, fine- to coarse-grained calcarenite, was selectively replaced by chert. Individual elastic grains were replaced in various concentrations ranging from thinly disseminated chert grains to strata of solid black chert. Limestone nodules were replaced by silica to form chert nodules. Preserved limestone nodules are finer grained than the matrix, and sedimentary laminae in the matrix bend over the tops of the nodules; such nodules apparently were formed on the sea floor during deposition. Many limestone nodules are only partly replaced by chert; in some, only the exteriors are replaced, the chert forming rinds around limestone cores.

Fusulinids are abundant and comprise the greater proportion of some beds. The outcrop of a few limestone beds composed almost entirely of weakly cemented fusulinids is littered with fusulinids weathered from the rock.

The general diagnostic features of the lower half of the Horquilla Limestone are summarized as follows: regularly stratified thin and medium beds forming moderately steep mountain slopes; medium-gray calcarenites having varying proportions of oolite, crinoid columnal, fusulinid, and fossil shell detritus; conspicuous black chert in nodules and in thin strata; fusulinids abundant throughout many beds and forming the bulk of some of the less resistant beds; and almost no quartz sand, shale, or dolomite.

The upper half of the Horquilla changes in detail from place to place as a result of different facies. Its outstanding characteristic in the Big Hatchet Mountains is extremely thick and massive limestone beds separated by intervals of shale and thin beds of calcarenite. The massive limestone is light gray and lithographic; it has an abundance of recrystallized fossil shell detritus seen faintly with the aid of a hand lens on lightly etched moist surfaces. Some small and large irregularly shaped areas of the massive limestone were replaced by dolomite. The spectacularly abrupt cliffs on the west face of Big Hatchet Peak are composed almost entirely of such massive, partly dolomitized limestone. The change from the medium-bedded lower half of the formation to the massive upper part apparently is gradational.

The massive limestones are thought to be biohermal reefs for a number of reasons. They are extremely massive and in general lack stratification; in some places, thin beds may be traced into massive areas having no stratification; some masses are flanked by foresetlike thin beds dipping away from the massive area; the upper thin beds arch over the tops of these massive limestones and dip away from them on the flanks (figs. 6 and 7); the rock is composed largely of recrystallized shell detritus; calcareous algae have been identified from the massive rock; and the relationship of these massive limestones to the basin deposits of the same age found in the Humble Oil & Refining Company well southwest of the range strongly suggests that the massive limestones are reefs along the margin of the basin. Facies interpretations are discussed later.

Thin and medium beds of calcarenite occur below, be-

Figure 6

THIN BEDS OF LIMESTONE RESTING UPON THE TOPS AND FLANKS OF UPPER HORQUILLA REEFS ON BIG HATCHET PEAK.

tween, adjacent to, and above reef masses. Where reefs are absent or sparse, most of the upper half of the Horquilla consists of such calcarenite. The rock is light and medium gray and is composed of fossil shell fragments. It was not recrystallized to lithographic texture as was the reef rock.

Shale beds ranging in thickness from a few inches to more than 30o feet separate many of the reef masses in the western and southwestern parts of the Big Hatchet Mountains (fig. 8), The shale is light to dark gray when fresh, weathers light to medium gray with a faintly brown tint, is composed mostly of clay but contains a minor quantity of silt, and breaks into small fragments with rounded edges.

In areas near the Big Hatchet Mountains, the Horquilla Limestone is overlain conformably by the Earp Formation. In the type area in the Tombstone Hills, in other ranges to the west, and also in the Sierra Boca Grande to the east, the contract is gradational and obviously conformable.

The Horquilla—Earp contact in the Big Hatchet Mountains is a sharp lithologic break and is interpreted as a local disconformity. The change from gray limestone below to brown arenaceous and argillaceous rocks above is abrupt, except that a thin bed of dolomitic siltstone occurs i6 feet below the contact in the Hale Tank section. The contact is also sharp and apparently disconformable in the well drilled by Humble Oil & Refining Company southwest of the Big Hatchet Mountains.

Three stratigraphic sections traversing the Horquilla Limestone were measured in the Big Hatchet Mountains. These are the Bugle Ridge, New Well Peak, and Borrego sections, which are described later and are shown graphically on Plate 3.

The Bugle Ridge section lies along the eastern flank of the Big Hatchet Mountains about midway along the mountain front. Its base is on the Paradise Formation, and it extends through most of the Horquilla Limestone. The section ends at the highest exposures of the formation on a

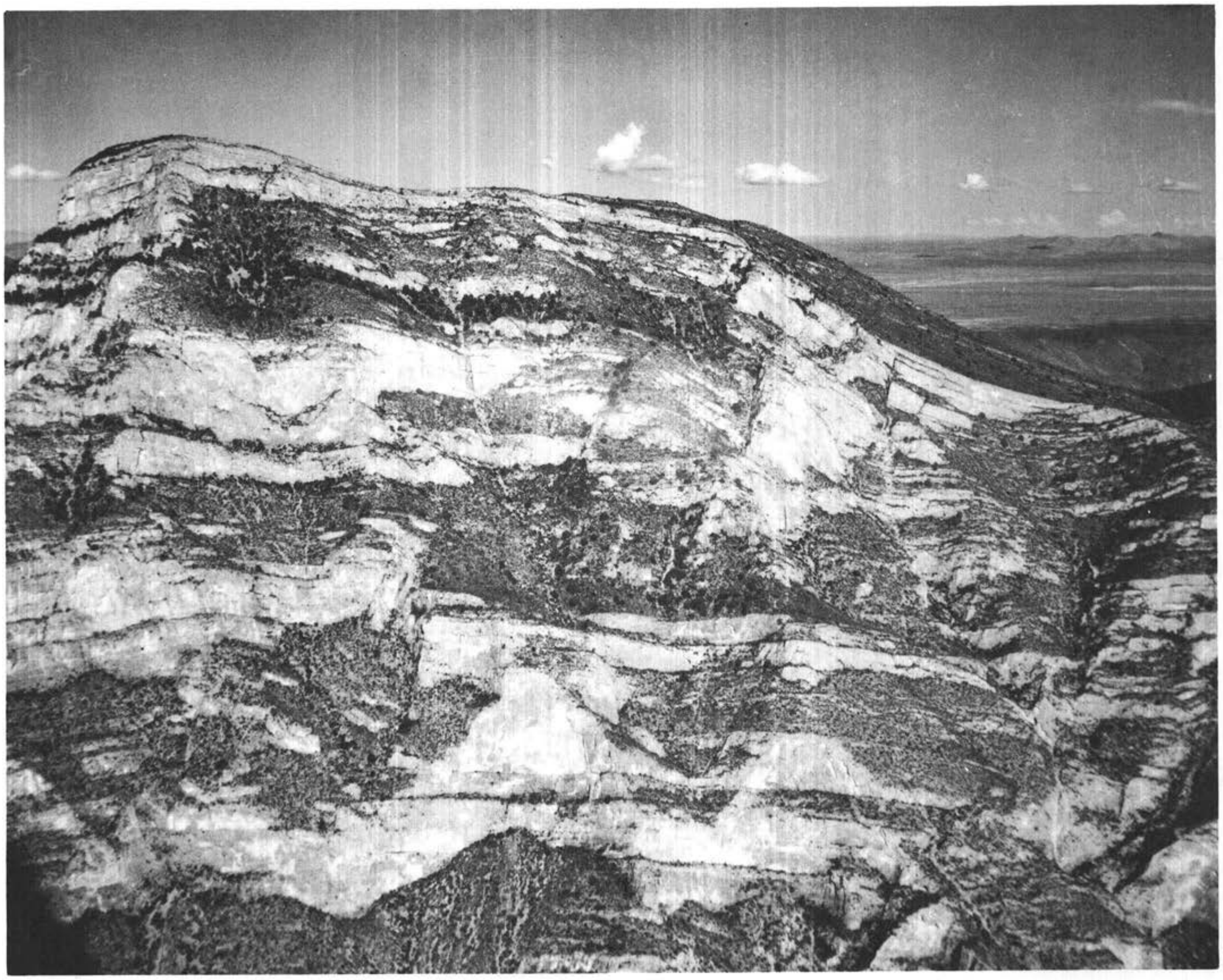

Figure 7

Compound upper Horquilla reefs on west face of Big Hatchet Peak.
Note thin beds to the right of the reefs.

peak. Judging from topographic relationships and fossil data, the end of the section is very near the top of the Horquilla Limestone.

The New Well Peak section lies about five miles southeast of the Bugle Ridge section in the southeastern part of the range (fig. 9). It starts at the base of the formation and ends at the highest exposure where alluvium conceals a fault. The highest beds measured are thought to lie close to the top of the Horquilla. Care was taken in measurement of the lower part of the section to eliminate the effects of several faults. The New Well Peak section is designated as the best reference section for the Horquilla Limestone in southwestern New Mexico because this section is the most complete and least disturbed.

The Borrego section traverses approximately the upper half of the formation in a locality where thick shale beds separate massive reef limestones (fig. 8). The end of this section is at the highest beds exposed on a peak and is stratigraphically close to the contact with the Earp Formation.

The top of the Horquilla Limestone is not present in any of the three measured sections. However, the disconformable contact between the Horquilla and Earp is exposed at other places within the range. The lithology and fauna of the uppermost Horquilla were studied in such places to determine the approximate amount of Horquilla that may be missing from the tops of the three measured sections. The upper 38 feet of the Horquilla Limestone described in the Hale Tank section is typical.

Immediately below the Earp contact, the Horquilla Limestone is massive and, in places, the uppermost foot is stained bright orange-red. It has small and large irregularly shaped patches of dolomite. An undetermined type of small coiled cephalopod is often found. A specific fusulinid fauna is present, which includes *Schwagerina huecoensis?,* other species of *Schwagerina, Triticites* sp. (very thick-walled), and *Ozawainella* sp.

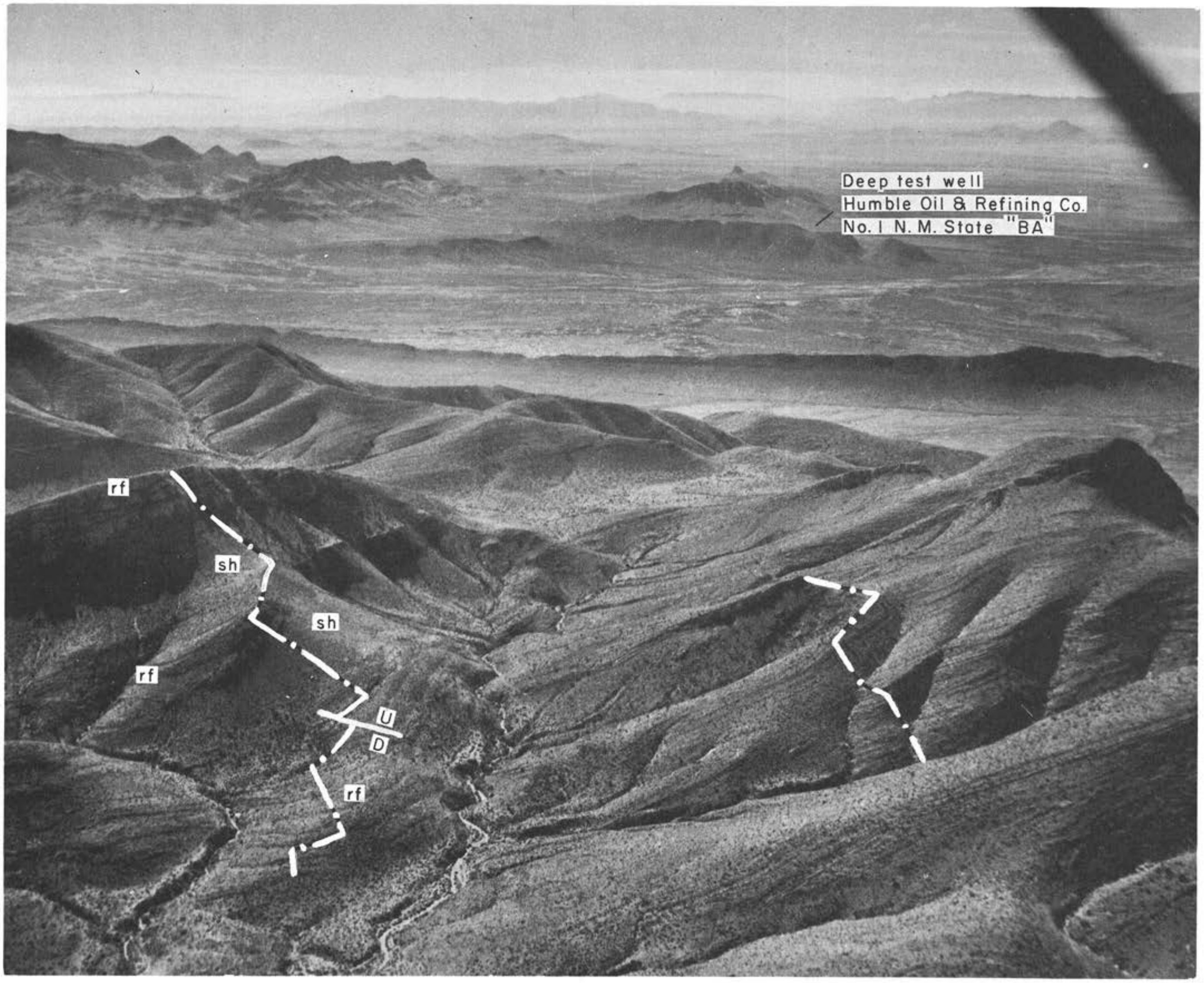

Figure 8

Borrego section, which traverses upper Horquilla Limestone.

The lower part of the section is to the right; the upper part is to the left. Humble Oil & Refining Company No. 1 N.M. State "BA" well, which is indicated seven miles southwest of the section, penetrated a basin facies including shale in the upper Horquilla. Shale of the basin facies (sh) is intertongued with limestone reefs (rf) in the upper part of the Borrego section. This southwestward view includes parts of U-Bar Ridge in the middle and the Alamo Hueco Mountains in the left background.

Fusulinid collections from the highest beds exposed in the measured sections of Horquilla include *Schwagerina* sp., *Pseudoschwagerina* aff. *beedei, Schwagerina franklinensis?, Rugosofusulina* sp., and *Pseudoschwagerina* sp. As this fauna is approximately of the same zone as that found below the unfaulted contact, and as the lithology of the highest beds of the sections is similar to that of the uppermost Horquilla, the assumption is made that only a few tens of feet of beds are missing from the tops of the measured sections.

Intervals between specific fusulinid zones in the Bugle Ridge and New Well Peak sections are nearly identical. However, correlation of the Borrego section with the corresponding intervals of the Bugle Ridge and New Well Peak sections based upon fusulinid zones indicates that in the Borrego section intervals between faunal zones are much thicker. If the shale beds were eliminated between the massive limestones, the thickness of the Borrego section would be about the same as the corresponding limestone beds of the other sections, and the intervals between fusulinid zones would then match. The shale beds lens out eastward along the strike. These observations could suggest that the shales were deposited in small local depressions during short time intervals. However, it seems most likely that the shale represents extensions of the basin deposits which lie mainly southwest of the mountain mass, and that the massive limestones represent reefs of the basin margin. The wedging out of the shale beds could be due to several periods of basinward advance of the reefs upon the basin deposits.

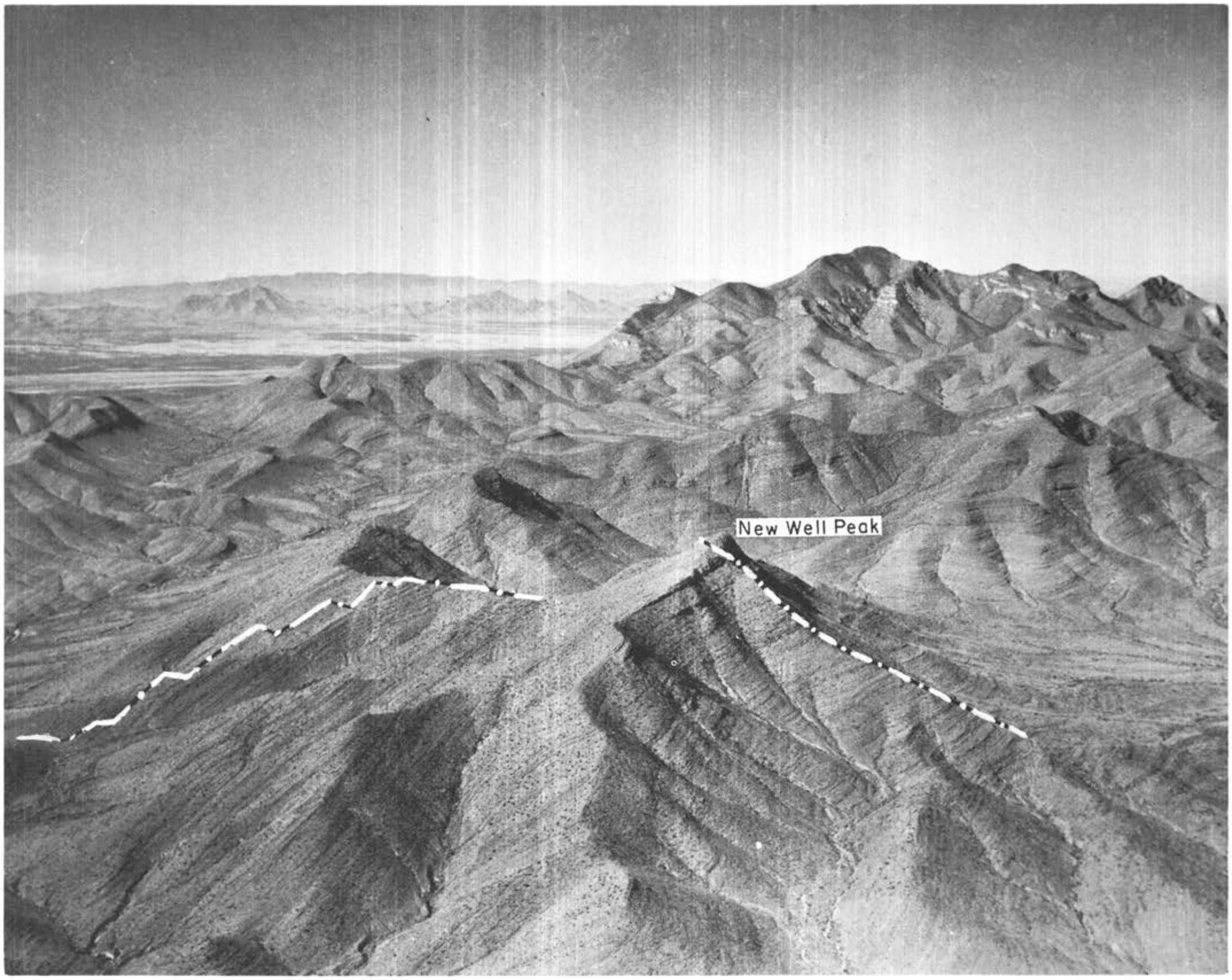

Figure 9

NEW WELL PEAK SECTION.

First part of the section lies beyond the right side of the photo. Air view toward the northwest of the interior of the Big Hatchet Mountains.

The thickness of the Horquilla Limestone measured in the New Well Peak section is 3245 feet and in the Bugle Ridge section is 353o feet. Allowing for the small thickness of beds assumed to be missing from the tops of each section, the true thickness is probably no greater than 360o feet.

Age

The Horquilla Limestone in the Big Hatchet Mountains ranges from latest Mississippian (Chester) age or earliest Pennsylvanian (Morrow) age, through Pennsylvanian, and into early Permian (Wolfcamp) age.

The fauna is rich and varied and includes fusulinids, brachiopods, gastropods, cephalopods, bryozoans, corals, crinoids, pelecypods, and sponges. Calcareous algae, "fucoidal" markings, rare trilobites, and large four-inch barbed echinoid spines are also found. Exhaustive collections of fusulinids were made because they are abundant and are of greatest value for zoning. Other fossils were collected where obvious or from intervals where fusulinids are lacking.

John W. Skinner and Garner L. Wilde (written communications, 1954-1964) made all fusulinid identifications, age determinations, and zonations in the fusulinid-bearing portion of the Horquilla. Stuart A. Northrop (personal communication, 1955) examined the megafossils, principally brachiopods, and made generic determinations. Russell M. Jeffords (written communication, 1955) determined many of the corals. Maxim K. Elias (written communications, 1955, 1956) studied fossils in the basal beds of the formation to determine whether these are of Mississippian or Pennsylvanian age.

Northrop examined a collection of fossils from the lowermost 20 feet of the Horquilla Limestone and tentatively identified the following forms:

Chonetes sp.
Orthotetes sp.
Orbiculoidea sp. (very large)
Schizophoria sp.
Cleiothyridina sp.
trilobite
crinoid basal plate.

He believed this fauna to be of Chester age.

Later, Elias and I collected fossils from a different locality but from approximately the same interval. According to Elias, the collection is quite different from that examined by Northrop. A partial list of Elias' (written communication, 1955) identifications and his remarks on the age of this fauna are as follows:

1. *Derbyia robusta* Hall, abundant form known from Morrow of Arkansas and Oklahoma (Mather, 1915), and particularly abundant in the Hale, as per my observations; none in the Chester or its equivalents.
2. *Chonetes dominus* King, very abundant, previously described and illustrated only from the middle part (Lemons Bluff) of the Marble Falls of Texas (King, R. H., 1938; Plummer, 1950).
3. *Buxtonia semicircularis* (Sutton and Wagner, 1931) *[=Flexaria semicircularis],* a* single but satisfactorily preserved individual; previously known only from the Kinkaid of Kentucky, but I am describing it now from the approximate equivalent of the middle Chester in the Ardmore Basin of Oklahoma.
4. A trilobite, insufficiently preserved for closer identification.

In spite of the presence of the late Mississippian species of *Buxtonia [Flexaria],* the fauna seems to belong to the Morrow, even if it does not represent the same facies of the Morrow that have been previously known from the Sandia and its equivalents in the North.

A brachiopod collected 93 feet above the base of the Horquilla Limestone in the Bugle Ridge section was identified by Northrop as a *Wellerella* of Pennsylvanian age. The lowest fusulinids discovered in the formation were about 230 feet above the base of the Horquilla in both the New Well Peak and Bugle Ridge sections. These were provisionally considered to be of Morrow age by Skinner and Wilde. Thus, the age of the lower 93 feet of beds may prove to be either Mississippian or Pennsylvanian, whereas the beds above are of Pennsylvanian age.

Skinner and Wilde divided the Horquilla of the Big Hatchet Mountains into six zones and three subzones based upon observed ranges of fusulinid genera. In ascending order, these are as follows: (a) *Millerella-Paramillerella* zone, (b) *Profusulinella* zone, *(c) Fusulinella* zone, (d) *Wedekindellina* subzone, (e) *Fusulina* zone, (f) *"Fusulinella"* sub-zone, (g) *Triticites* zone, (h) *Schwagerina* zone, (i) *Pseudoschwagerina-Parasch-wagerina* subzone.

In the Pennsylvanian part of the formation they recognize the following series: Morrow(?), Derry, Des Moines, Missouri, and Virgil. Concerning the Morrow Series, Wilde (written communication, 1954) says, "The oldest fusulinids may be Morrow in age. However, for the present time I have called everything Morrow merely on the absence of fusiform fusulinids (e.g. *Profusulinella).* The lower section may all be Derryan in age." In the Permian part of the Horquilla, Skinner and Wilde recognize the Wolfcamp Series.

The fusulinid identifications and remarks of Skinner and Wilde on the collections from the measured sections of Horquilla Limestone are given in Table 2. Wilde comments about the identifications:

> Let me point out that all the identifications are tentative; the same is true for series and systemic boundaries. However, I think you can feel safe in assuming that changes for the final report will be small and will differ only in the assignment of generic and specific names to the fusulinids and in raising or lowering series boundaries only slightly.

Four fusulinid collections were made from the uppermost beds of the Horquilla Limestone in the Hale Tank section where the disconformable contact between Horquilla Limestone and the overlying Earp Formation is exposed. The identifications of these faunas are as follows:

60d	*Schwagerina* spp., *Triticites* sp.
60c	*Schwagerina* spp., *Triticites* sp. (very thick walled)
60b	*Schwagerina* spp., *Triticites* sp. (very thick walled)
60a	*Schwagerina* spp., *Triticites?* sp., OzawaineUa sp. (Wolfcamp)

Wilde (written communication, 1959) states that the highest Horquilla fusulinids from the Big Hatchet Mountains are of late Wolfcamp age.

Tentative identifications of the megafossils from the measured sections of the Horquilla Limestone made by Stuart A. Northrop (personal communication, 1955) are listed in Table 3.

Russell M. Jeffords (written communication, 1955) studied some of the corals from the measured sections and made the following remarks and identifications:

> The fauna seems obviously from a different lithologic sequence than that where most described Pennsylvanian corals occur, but the generic occurrence seems approximately consistent. On a preliminary check of the assemblage using exteriors and natural sections the following genera were recognized.

BUGLE RIDGE SECTION

42δ	*Michelinia* (Missourian type)
42g	*Caninia* (s.l.)
42b	*Chaetetes*
	Syringopora
41j	*Syringopora*
40h	dibunophyllid
40c	*Caninia* (s.l.)
39α	sponge (?)
39y	*Chaetetes*
	Syringopora
39h	*Chaetetes*
39f	*Chaetetes*
39b	*Michelinia*

NEW WELL PEAK SECTION

57g	*Chaetetes*
56e	*Michelinia*

BORREGO SECTION

824	*Lophophyllidium* (s.s.) (Virgil-Wolfcamp species)
	sponge (?)

* According to Muir-Wood and Cooper, 1960, p. 259.

TABLE 2. HORQUILLA FUSULINIDS FROM BUGLE RIDGE, NEW WELL PEAK, AND BORREGO SECTIONS

Identifications and comments by Skinner and Wilde (written communication, 1954). Stratigraphic positions of collections shown on Plate 3.

BUGLE RIDGE SECTION

44z	*Rugosofusulina*? sp. (silicified)
44y	*Triticites* sp., *Schwagerina* cf. *laxissima*
44x	*Triticites victorioensis*, *Schwagerina* spp.
44w	*Pseudoschwagerina uddeni*, *Schwagerina* sp.
44v	*Pseudoschwagerina* sp. (very large), *Schwagerina* sp.
44t	Silicified specimens
44s	Silicified specimens—indeterminate
44r	*Paraschwagerina*? sp., *Schwagerina* sp., *Triticites* sp. (elongate, massive chomata)
44n	*Pseudoschwagerina* sp., *Paraschwagerina*? sp., *Schubertella* sp.
44m	(loose specimens)
44k	*Pseudoschwagerina* sp., *Paraschwagerina* sp., *Schubertella kingi*, *Rugosofusulina*? sp.
44j	*Pseudoschwagerina* sp., *Schwagerina* sp., *Schubertella kingi*, *Schubertella* sp.
44i	*Pseudoschwagerina* sp., *Paraschwagerina* sp.
44g and 44h	*Schwagerina* sp.
44f	*Schwagerina* cf. *huecoensis*, *Pseudoschwagerina* spp.
44e	*Schwagerina* spp., *Triticites* spp.
44d	*Schwagerina* spp., *Triticites* sp., *Pseudoschwagerina*? sp.
44c	*Schwagerina* spp.
44a	*Schwagerina* cf. *emaciata*, *Schubertella* sp.
43w	*Schwagerina* sp. (shaped like *S. thompsoni*), *Triticites* sp. (large, highly fluted, massive chomata)
43v	*Schwagerina* sp. (shaped like *S. thompsoni*)
43u	*Schwagerina huecoensis*
43t	*Schwagerina* sp., *Triticites ventricosus* var. *meeki*
43s	*Schwagerina* sp., *Triticites* sp.
43h to 43n	Loose specimens—all appear to belong to same genera as above and below.
43g	*Schwagerina* sp., *Triticites* sp.
43f	*Triticites* sp., *T. uddeni*, *Schwagerina* sp.
43e	*Triticites ventricosus* tribe, *Schwagerina* sp.
43c	*Triticites ventricosus* tribe, *Schwagerina* sp. (Wolfcamp)
43a	*Triticites* sp.
42u	*Triticites* spp., *Schubertella* sp.
42s and 42t	*Triticites* spp.
42r	*Triticites acutus*? (Virgil)
42p	*Triticites* spp.
42n	*Triticites ohioensis* type
42m	*Triticites pygmaeus*, *T. secalicus* var. *oriziformis*
42k	*Triticites neglectus*, *T. pygmaeus*
42j	*Triticites osagensis-irregularis* types
42i	"*Fusulinella*"? sp., *Triticites neglectus*
42h	"*Fusulinella*" spp. (elongate)
42g	"*Fusulinella*" sp. (Missouri)
42e	*Fusulina* spp. (large, elongate forms)
42c	*Fusulina* spp. (large forms)
41x	*Fusulina euryteines*, *Wedekindellina euthysepta*, *Pseudostaffella* sp.
41w	*Fusulina euryteines*, *Wedekindellina*? sp.
41v	*Fusulina* sp., *Wedekindellina*? *matura*
41u	*Fusulina* sp., *Wedekindellina minuta*?
41s and 41t	*Fusulina rockymontana*, *Wedekindellina euthysepta*
41r	*Fusulina* sp. (large form)
41p	*Fusulina* spp., *Fusulinella*? sp.
41n	*Fusulina* spp., *Wedekindellina* sp.
41k	*Fusulina* sp.
41j	*Fusulina* sp., *Wedekindellina*? sp.
41i	*Fusulina* spp. (elongate forms)
41h	*Fusulina* cf. *distenta*
41e	*Fusulina* spp., (numerous small fusulinids)
41d	*Fusulina novamexicana*
41b	*Fusulina* aff. *distenta*, *Wedekindellina*? *matura*
39μ	*Fusulina novamexicana*, *Fusulina* sp. (Des Moines)
39θ	*Fusulinella famula*?
39β and 39γ	*Fusulinella* sp.
39α	*Fusulinella* (advanced)
39z	*Fusulinella* sp.
39x	*Fusulinella famula*—*F. thompsoni* types
39w	*Fusulinella* aff. *juncea*, *Fusulina*? sp.
39v	*Fusulinella devexa*
39t and 39u	*Fusulinella* spp. (broad chomata group)
39s	*Fusulinella prolifica*?
39p and 39r	*Profusulinella* spp.
39n	*Profusulinella* spp., *Millerella* sp. (large form)
39m	*Profusulinella copiosa*, *Millerella* sp.
39j	*Millerella* sp.
39i	*Profusulinella copiosa*, *Profusulinella* sp., *Millerella marblensis*, *Paramillerella* sp., *Eoschubertella* sp. (Derry)
39d and 39e	*Millerella marblensis*, *Paramillerella circuli*, *Eoschubertella* sp. (Morrow)

NEW WELL PEAK SECTION

59j and 59h	*Rugosofusulina* sp., *Schwagerina* sp.
59f	*Pseudoschwagerina* fragments
59e	*Pseudoschwagerina beedei*, *Schwagerina* sp.
59d	*Pseudoschwagerina* sp., *Rugosofusulina* sp.
59c	*Pseudoschwagerina* sp., *Schwagerina* sp.
59b	*Pseudoschwagerina* sp. (squeezed somewhat)
59a	*Pseudoschwagerina* sp., *Schwagerina thompsoni*, *Schwagerina* sp. (elongate), *Schubertella kingi*, (numerous tiny fusulinids—juvenaria?)
58z	*Pseudoschwagerina* sp., *Paraschwagerina* sp.
58y	*Schwagerina huecoensis* (squeezed out of shape)
58x	*Schwagerina* sp., *Triticites* sp., *Paraschwagerina*? sp.
58w	*Schwagerina huecoensis*, *Pseudoschwagerina* sp., *Paraschwagerina* sp., *Triticites* sp.
58v	*Schwagerina huecoensis*, *S. thompsoni*?
58u	*Schwagerina* sp., *Triticites*? sp.
58t	*Schwagerina huecoensis-franklinensis*, *Triticites*? sp.
58s	*Schwagerina huecoensis-franklinensis*
58r	*Schwagerina huecoensis-franklinensis*, *Triticites* sp.
58q	*Schwagerina* sp., *Triticites* sp.
58p	*Triticites* spp., *Schwagerina* spp., *Rugosofusulina*? sp.
58n	*Triticites* aff. *pinguis* (smaller than typical)
58m	*Triticites* spp., *Schwagerina* (axial filling), *Rugosofusulina*? sp., *Schubertella* sp.
58k	*Triticites pinguis*, *T. ventricosus*
58j	*Triticites* sp., *Schwagerina* sp., *Rugosofusulina*? sp., *Schubertella kingi*
58i	*Triticites* sp., *Rugosofusulina*? sp.
58h	*Triticites* sp., *Schubertella kingi* (Wolfcamp)
58e to 58g	*Triticites* spp.
58d	*Triticites* spp. (Virgil)
58c	*Triticites* spp. (Missouri)
58b	*Triticites* spp., "*Fusulinella*"? sp., *Eoschubertella* sp.
57z	"*Fusulinella*" spp. (lower Missouri)
57y	*Fusulina* sp., *Bartramella* sp., "*Fusulinella*" sp.
57x	*Fusulina novamexicana*
57w	*Fusulina* spp., *Wedekindellina*? sp. (elongate, with little axial filling)
57v	*Fusulina* spp., *Eoschubertella* sp.
57u	*Fusulina* sp., *Wedekindellina* sp.
57t	*Fusulina* spp., *Wedekindellina euthysepta*, *W. excentrica* (Des Moines)
57r	*Fusulinella texana-iowensis*
57q	*Fusulinella texana*?, *F.* sp.
57n	*Fusulinella devexa*, *F.* sp. (small)
57m	*Fusulinella famula-iowensis*
57k	*Fusulinella devexa*?, *F. juncea*?
57j	*Fusulinella acuminata*
57i	*Fusulinella* spp. (broad chomata group)
57g	*Fusulinella devexa*?, *F. acuminata*?
56i	*Profusulinella apodacensis*?, *P. decora*
56h	*Millerella* sp., *Paramillerella* sp., *Eoschubertella* sp., *Ozawainella plummeri*, *Profusulinella copiosa* (Derry)
56g	*Millerella* (large form), *Paramillerella* sp. (Morrow)

BORREGO SECTION

834	*Schwagerina* sp., *Pseudoschwagerina* sp., *Rugosofusulina* sp. (specimens abundant but squeezed out of shape)
833	*Schwagerina* sp. (loosely coiled), *Pseudoschwagerina* sp. (large)
832	*Schwagerina* sp., *Rugosofusulina* sp.
831	*Schwagerina* aff. *nelsoni*
829	*Schwagerina* sp., *Pseudoschwagerina* sp.
828	*Schwagerina*? sp. (large, elongate, cuniculi present), *Rugosofusulina* sp., *Schubertella* sp. (intermediate form)
826	*Schwagerina* sp., *Rugosofusulina* sp.
825	*Pseudoschwagerina* sp., *Paraschwagerina* sp., *Schwagerina* sp., *Schubertella* sp. (intermediate between *S. melonica* and *S. kingi*)
824	*Pseudoschwagerina* sp., *Paraschwagerina* sp.
823	*Schwagerina* sp., *Pseudoschwagerina* sp.
822	*Schwagerina* sp.
821	*Schwagerina huecoensis*?, *Schwagerina* sp. (like *S. nelsoni* but small proloculus)
820	*Triticites*? sp., *Schwagerina* sp. (large, elongate)
819	*Triticites* sp., *Schwagerina* sp.
818	*Triticites* spp., *Schwagerina* sp.
815	*Triticites ventricosus*
814	*Triticites ventricosus* tribe
813	*Triticites* sp., *Schubertella* sp. (Wolfcamp)
812	*Triticites* spp. (large), *Schubertella* sp.
809 and 810	*Triticites* spp.
806	*Triticites* spp.
802	*Triticites* spp. *Dunbarinella* sp. (Virgil)
798	*Triticites* spp. (Missouri)

Jeffords further states, "A number of the specimens seem to be *Caninia (Campophyllum* of authors), but sections probably will show zaphrentoid or dibunophylloid structures." Collections 40c and Ooh are from part of the section that was duplicated in measurement but is neither shown on Plate 3 nor described. The *Caninia* of collection 40c is from the same bed as collection 41c. Collection Ooh is from about the same stratigraphic level as 41j.

Based upon the foregoing information, the age of the Horquilla Limestone in the Big Hatchet Mountains may be summarized as follows: The basal 93 feet may be either Chester or Morrow in age. The beds between 93 and about 23o feet above the base are Pennsylvanian and are probably Morrow age. Between 23o and about 33o feet above the base, the beds are also probably Morrow age but may be Derry in age. These beds are overlain by the remainder of the formation composed of a sequence of rocks of Derry, Des Moines, Missouri, Virgil, and Wolfcamp ages. The highest beds are of late Wolfcamp age.

Correlation

West of the Big Hatchet Mountains the lithology of the Horquilla Limestone is similar, except that no basin or reef facies are reported, the formation becomes thinner, and the upper contact becomes older.

In the Peloncillo Mountains, a complete section of Hor-

TABLE 3. HORQUILLA MEGAFOSSILS FROM BUGLE RIDGE, NEW WELL PEAK, AND BORREGO SECTIONS

Identifications and comments by Northrop (personal communication, 1955). Stratigraphic positions of collections shown on Plate 3.

Collection number	Identifications and Comments
	BUGLE RIDGE SECTION
44z	sponge
	Composita sp. (abundant)
	Wellerella sp. (abundant)
	Antiquatonia? sp.
	Condrathyris sp.
43n	productid brachiopod
42δ	unidentified brachiopod
	fish teeth
42g	*Antiquatonia?* sp.
42d	tetracoral
42c	*Antiquatonia?* sp. (large)
	Prismopora sp. (abundant)
	Straparolus (Euomphalus) sp.
42b	*Chaetetes* sp.
	Syringopora sp.
	Composita sp.
	Wellerella sp.
	star-shaped crinoid columnal
42a	large tetracoral
41y	*Composita* sp.
	Beecheria? sp.
	Punctospirifer sp.
	Spirifer sp.
	Prismopora sp.
	fish teeth
41m	minute gastropods
41j	*Rhipidomella* sp.
	Antiquatonia? sp.
	Syringopora sp.
41g	*Punctospirifer kentuckiensis* (abundant)
	Spirifer sp.
	Composita sp.
41c	*Neospirifer* sp.
	Hustedia mormoni (abundant)
	"Marginifera" sp.
	Derbyia sp.
	tetracoral
39ρ	large tetracorals
39π	large tetracoral
	Spirifer sp.
	Rhipidomella sp.
39φ	*Condrathyris* sp.
	ramose bryozoans of several species
	Rhombotrypella sp. (bryozoan determined by Elias)
39δ	*Juresania* sp.
39α	*Chaetetes* sp.
	Straparolus (Euomphalus) sp.
	sponge (?)
39y	*Chaetetes* sp.
	Syringopora sp.
39w	*Cancrinella boonensis*
	Straparolus (Amphiscapha) sp.
	bellerophontid gastropod
	Anthracospirifer opimus
39r	*Antiquatonia?* sp.
	Linoproductus sp.
	Composita sp.
	"Marginifera" ? sp.
	Cancrinella boonensis
	fenestellid bryozoan
39h	*Chaetetes* sp.
39g	2 genera of small gastropods, one of which is high-spired
39c	*Wellerella* sp.
39b	compound tetracoral, echinoid plates
	NEW WELL PEAK SECTION
59i	cephalopod (?)
59b	*Antiquatonia?* sp.
58a	*Composita* sp.
	enormous echinoid spines
57u	bryozoan
57p	*Prismopora* sp.
57g	*Chaetetes* sp.
	Syringopora sp.
56f	*Antiquatonia?* sp.
	BORREGO SECTION
824	sponge
	two genera of tetracoral
785	fenestellid bryozoan
784	*Neospirifer* sp.
	Spirifer sp.
	Ameura? sp. (abundant trilobite heads and tails)
801	pelecypod—genus undetermined
800	high-spired gastropod
796	minute high-spired gastropod, productid

quilla Limestone is lacking, but Gillerman (1958, p. 31-35) estimated a total thickness of 1350 to 1500 feet. The lithology is similar to that of the formation in the Big Hatchet Mountains, except that no reefs or thick shale beds are present. The age of the formation based upon fusulinid identifications ranges from late Derry and possibly pre-Derry age to early Wolfcamp age.

In the Chiricahua and the Dos Cabezas Mountains, Arizona, Sabins (1957, p. 484-488) measured a thickness of 1605 feet of Horquilla Limestone. The limestone beds are similar to those of the formation in the Big Hatchet Mountains; many are crinoidal or oolitic, contain chert nodules, and are thicker and more massive in the upper part. However, there the lower 835 feet of the formation (Morrow through Des Moines Series) contains much shale interbedded with the limestone. Sabins determined the age of the formation through his study of the fusulinids supplemented by the megafossils. He (op. cit., p. 488) reports that " . . . the Horquilla limestone ranges in age from the Morrow through the Missouri series within the area of this report. This age determination agrees in general with that made by Williams (Gilluly, Cooper, and Williams, 1954, p. 35) at the type region."

In the region of the type Horquilla Limestone in central Cochise County, Arizona (Gilluly, Cooper, and Williams, op. cit., p. 16-18; 31-35), the formation has a maximum thickness of about 160o feet. The lithology is similar to that of the Horquilla of the Big Hatchet Mountains, except that there it lacks the thick shale beds and the reefs. Curiously, the beds commonly have a pink tint, a characteristic that is diagnostic of the lower part of the formation in the Big Hatchet Mountains. Some of the thicker beds consist of crinoidal limestone. Thin shale beds are common in the upper part of the formation, and they increase in abundance upward until they become dominant over the limestone interbeds near the base of the Earp Formation. Concerning the *age* of the type Horquilla Limestone, Williams (Gilluly, Cooper, and Williams, op. cit., p. 34) states that the formation " . . . contains beds ranging in age from post-Morrow Pennsylvanian to middle late Pennsylvanian." In the basal beds of the formation, he recognizes certain fossils considered to be typical of Morrow age occurring with other fossils considered to be typical of Lampasas age (approximately equivalent to Derry) and Des Moines age. Williams recognizes the possibility that beds of Morrow age may be present. Fusulinids from the upper part of the formation are at least as young as Missouri and may prove to be Virgil.

Thus, from the Big Hatchet Mountains westward, the base of the Horquilla Limestone ranges from possibly Chester to Derry age, and the top ranges from Wolfcamp to Missouri age. The uppermost beds of the Horquilla Limestone in the Big Hatchet Mountains are of late Wolfcamp age represented by the fusulinid subzone of *Pseudoschwagerina-Paraschwagerina.* These beds are younger than the Wolfcamp of the upper Horquilla in the central Peloncillo Mountains. In the Chiricahua and Dos Cabezas Mountains and in central Cochise County, Arizona, the uppermost beds of the formation are of Missouri or early Virgil age.

In southeastern Arizona, Horquilla deposition ceased as terrestrial elastic sediments of the Earp Formation were carried into the region from the north and northwest. There the change from Horquilla to Earp deposition was gradual and took place in middle late Pennsylvanian time. Deposition of elastic sediments slowly extended eastward to mark the end of Horquilla deposition at successively later times. By late Wolfcamp time, land-derived sediments of the Earp Formation reached the area of the Big Hatchet Mountains.

The Horquilla Limestone of the Big Hatchet Mountains may be correlated in part with the Magdalena Group of central and northern New Mexico and with the Hueco Limestone of southeastern New Mexico and western Texas.

Thompson (1942) studied the fusulinids of the Pennsylvanian System in much of New Mexico and divided the system into four series: Derry, Des Moines, Missouri, and Virgil. Kottlowski et al. (1956, p. 35-47) divided the Pennsylvanian section of the San Andres Mountains on the basis of fusulinids into the same four series. Such division of the section into faunal zones based upon the same fossil group is most helpful in the detailed correlation of various stratigraphic sections. As the Big Hatchet Mountains sections have also been zoned on the basis of fusulinids, detailed correlations throughout the region can be made. Kottlowski (1959; 1960) has made such a study for the Pennsylvanian System in southwestern New Mexico and southeastern Arizona.

In the Hueco Mountains of western Texas, Richardson (1904, p. 32-38) applied the name *Hueco Formation* to the rocks that he interpreted as being of Pennsylvanian age. Later King (1942, p. 556-561) showed that the type Hueco included rocks now known to be of Mississippian, Pennsylvanian, and Wolfcamp ages, and in the Sierra Diablo it included beds now known to be of Wolfcamp and Leonard ages. He separated the parts of the formation belonging to the different systems and restricted the name *Hueco Limestone* to the Wolfcamp part; he placed the Pennsylvanian part in the *Magdalena Limestone.* The part of the Horquilla Limestone of the Big Hatchet Mountains of Wolfcamp age correlates with the restricted Hueco Formation of western Texas and southeastern New Mexico.

In the areas of southern New Mexico that lie north and northeast of the Big Hatchet Mountains and north of the Hueco Mountains, the limestone of the Pennsylvanian Magdalena Group is overlain by the red beds of the Abo Formation of Wolfcamp age. In the region separating the Abo and Hueco Formations, the red-bed facies of the Abo is intertongued with the limestone facies of the Hueco. The Earp Formation, which overlies the Horquilla Limestone in the Big Hatchet Mountains, probably correlates with the Abo Formation.

During the Pennsylvanian, limestone was deposited in the sea that covered most of the region of western Texas, southern New Mexico, and southeastern Arizona. During Wolf-camp time, land areas that lay principally to the north shed sand, silt, and clay into areas peripheral to the sea of the Big Hatchet area. These elastic sediments gradually encroached upon the marine deposits, and the Horquilla Limestone of southwestern New Mexico was covered by the land-derived elastic sediments of the Earp Formation.

Upper Horquilla Facies

In the area of the Big Hatchet Mountains, the upper two-thirds of the Horquilla Limestone embracing rocks of the upper Des Moines, Missouri, Virgil, and Wolfcamp Series is complicated by basin, reef, and shelf facies (Zeller, 196o). These facies and the indicated depositional environments are similar to those in the Permian rocks of western Texas and southeastern New Mexico. Principles described by King (1942) and by Newell et al. (1953) for the latter area are applicable to the area of the Big Hatchet Mountains.

Detailed study of basin, reef, and shelf relationships in southwestern New Mexico is retarded by several factors. Complete exposure of the Horquilla Limestone is found only in the Big Hatchet Mountains, and exposures of parts of the formation are found in widely separated localities. In many places, the formation was involved in post-Horquilla structural deformation which contorted original sedimentary features. Projection of reef and basin facies southward is retarded by meager knowledge of the Horquilla Limestone and its equivalents in Mexico.

The significance of the reef and associated facies was realized after completion of the field work and after the deep test well was drilled southwest of the range in 1958. Thus, certain data that would aid in the understanding of these problems were not collected. A concentrated study of the upper Horquilla facies within the region would be of value.

During late Pennsylvanian and Wolfcamp time, the region including southwestern New Mexico, southeastern Arizona, northwestern Chihuahua, and northeastern Sonora was the site of marine deposition. Subsidence was greater here than in neighboring areas, a fact that is indicated by the thick deposits of marine rocks found here compared to the thiner sections of rocks of the same age found in surrounding areas. Kottlowski (1959, P. 15o) shows that the thickness of the Pennsylvanian section in the Pedregosa Mountains of southeastern Arizona is about the same as that of the Pennsylvanian part of the Horquilla Limestone measured in the Big Hatchet Mountains, about 2500 feet.

Areas of even greater subsidence within the region produced local basins (analogous to the Delaware basin of western Texas). Areas between such local basins were the sites of deposition from an epicontinental sea and may be defined as shelf areas.

Such a local basin was discovered in the upper Horquilla Limestone in the well drilled by Humble Oil & Refining Company southwest of the Big Hatchet Mountains. Corresponding beds that crop out as extremely massive limestone on Big Hatchet Peak and southeastward along the crest of the range represent biohermal reefs along the basin margin. Medium-bedded limestones east of the reefs lie in the shelf area. These facies realms are shown in Figure 10.

The rock typically found in shelf areas is regularly bedded, light-colored limestone composed chiefly of fossil shell detritus. Even though the rock is composed mostly of shell remains, its light color indicates that bituminous matter is very minor. Evidently agitation and aeration of the sediments by wave and current action in shallow water destroyed such matter. Fossil shell detritus is partly composed of the remains of heavy-shelled animals that thrived in shallow, turbulent, aerated water, and fragmentation and abrasion of detritus further indicates deposition in water agitated by wave and current action.

In the Big Hatchet Mountains, the upper Pennsylvanian and Wolfcamp parts of the Bugle Ridge and New Well Peak stratigraphic sections measured on the southeast flanks of the range consist mostly of typical shelf limestones. Relatively thick deposits of light-colored, shallow-water sediments indicate that deposition kept pace with subsidence. Further evidence that these stratigraphic sections lie principally in a shelf area is seen in the relationship of the area to the reef-rich marginal facies and the basin facies found west and southwest of the measured sections. Examination of the figure in which Kottlowski (1959, p. 150) illustrates the Pedregosa Mountains section suggests that there the upper Pennsylvanian is represented also by a shelf facies.

Several relatively thin reefs in the measured sections in the Big Hatchet Mountains probably represent periods of eastward growth from the main reef mass. Large, irregularly shaped parts of these reefs are dolomitized, a phenomenon that is common in back-reef areas adjoining a shelf area. Study of polished surfaces of the reef limestone in these sections shows that they are somewhat dolomitic.

The area southwest of the Big Hatchet Mountains was the site during Wolfcamp time of a local basin which I call the Alamo Hueco basin. Evidence for the basin is from the logs of the test well drilled by Humble Oil & Refining Company about nine miles south of Big Hatchet Peak. The lithology of the well is summarized later in this report. The well penetrated a thick, complete, and apparently unfaulted section of Horquilla Limestone. Although the apparent thicknesses of stratigraphic units shown on the sample log should be corrected for bedding dips, the dips are believed to be small enough that the log thicknesses are only slightly greater than true unit thicknesses. The Wolfcamp interval in the well is about 1000 feet thicker than that of the measured sections in the shelf area on the eastern flank of the Big Hatchet Mountains. The Wolfcamp beds in the well consist mostly of dark gray and black shale; some limestone and sandstone are present. The dark color of the shale indicates a high content of bituminous material which may have been preserved under the quiet, sterile conditions of deep water in a basin. Thus the evidence for the presence of the Alamo Hueco basin is the abnormal thickness of Wolfcamp-age beds and the indication that the beds were deposited in deep water. Comparison of thicknesses of Wolfcamp-age beds in the shelf area and in the basin shows that the basin subsided more than I000 feet below the shelf.

The marginal area separating the basin from the shelf was the site of massive reef formation. The greatest reef development centered around Big Hatchet Peak; the topographic prominence of this part of the range results from the resistance of the reefs to erosion. From here, the reefs extend in a long, narrow band southeastward along the highest ridges of the range to the last exposures of upper Pennsylvanian and Wolfcamp rocks. Figure 10 illustrates the trend of the reefs in the Big Hatchet Peak quadrangle and shows the basin and shelf areas.

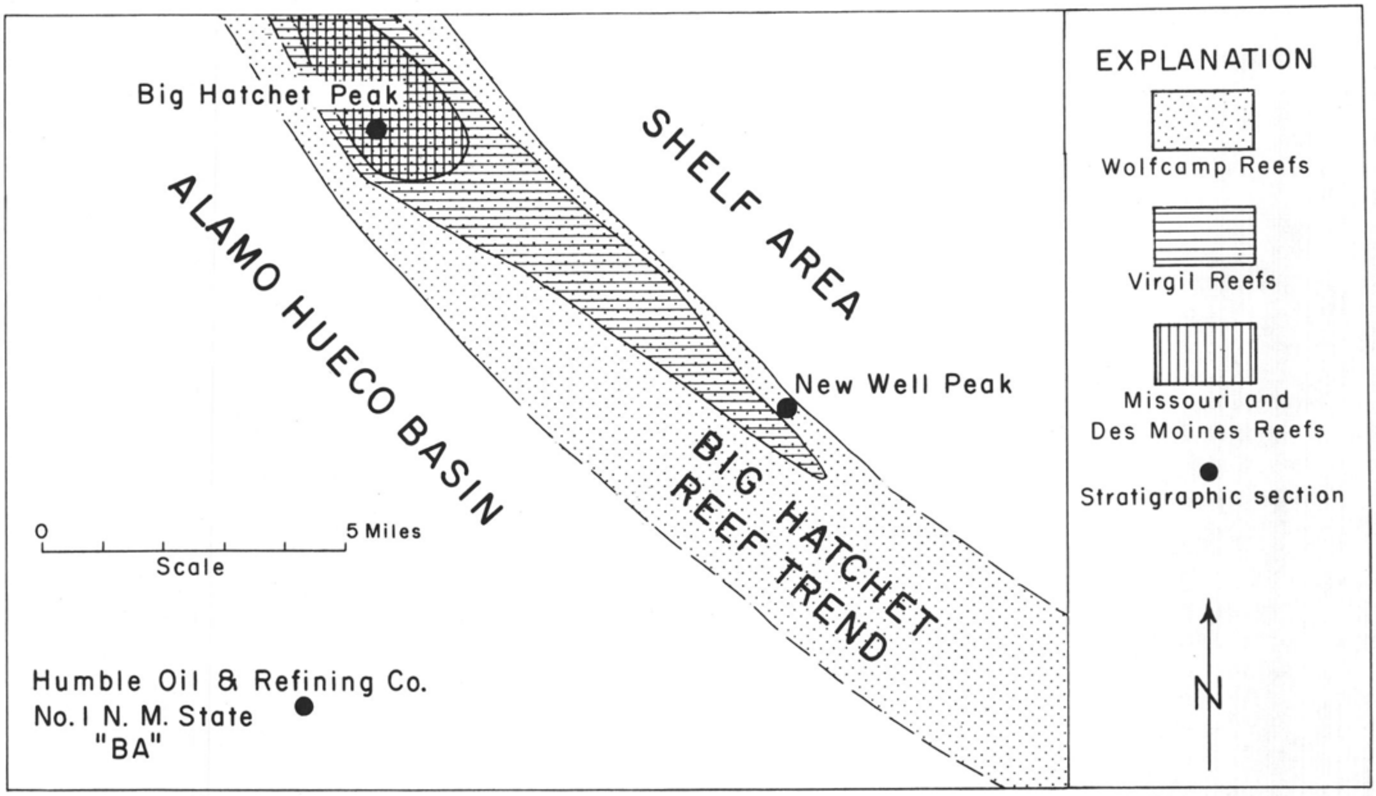

Figure 10
MODIFIED PALEOGEOGRAPHIC MAP OF UPPER HORQUILLA LIMESTONE, BIG HATCHET MOUNTAINS AREA.

Study of the photos of Figures 6, 7, and II reveals the form of the reef deposits. They consist of thick masses of limestone in which stratification is absent or sparse. Thin limestone beds on the flanks lap upon the sides of the reefs and dip away from them. Thin beds passing over the reefs are arched upward with original attitudes. Figure 11, which pictures the northwestern slope of the peak in SE1/4SE1/4 sec. 7, T. 31 S., R. 15 W., shows limestone beds that are less massive than the reef and which dip toward the Alamo Hueco basin to the right. These are foreset beds composed of detrital material. Reefs and less massive limestone beds that may represent submarine talus deposits of elastic material derived from the erosion of reefs extend into the edges of the basin and are interbedded with thick shale. Such features occur along the western base of the range and in the Borrego stratigraphic section. Some of the shale is black and is interbedded with thin beds of black limestone. However, the shale occurring in thick beds between reefs is medium to light gray. The deficiency of bituminous material indicated by the light color may have resulted from slight agitation of the sediments near the edge of the basin.

The limestone of the reefs is massive and is found in mounds ranging up to zoo feet or more in thickness. The rock is light gray and is composed mostly of fossil shell fragments. It was recrystallized and now has a lithographic texture. The original elastic texture of the rock before recrystallization may be seen on weathered surfaces, and with the aid of a hand lens it may be seen on moist, lightly etched fresh surfaces. Scattered crystals seen on fresh surfaces are usually of dolomite.

Reef rock was studied to identify any calcareous algae as an aid to interpreting the depositional environment. A suite of eight rock chip samples was collected at random locations from the most massive limestone beds on the north face of Big Hatchet Peak. Thinsections of the samples were examined by Richard Rezak (written communication, 1963), who identified the following forms:

1026A *?Girvanella* (blue-green alga) and encrusting foraminifers
1026B *Tubiphytes* (?hydrocoralline) and *?Girvanella* or encrusting foraminifers
1026C Possible *Ivanovia* (?codiacean alga)
1026D Possible *Dvinella* (dasyclad alga)
t10 26E *Tubiphytes—no* algae
1026G *?Ivanovia*, encrusting foraminifers
1026H No algae
1026I *Tubiphytes*

Concerning the significance of the algae, Rezak states, "These same algae occur elsewhere in non-reef deposits. The mere presence of calcareous algae is not evidence of reef environment." However, it seems to me that the presence of calcareous algae and hydrocorallines in a number of the specimens, when considered with the other evidence, supports a reef interpretation.

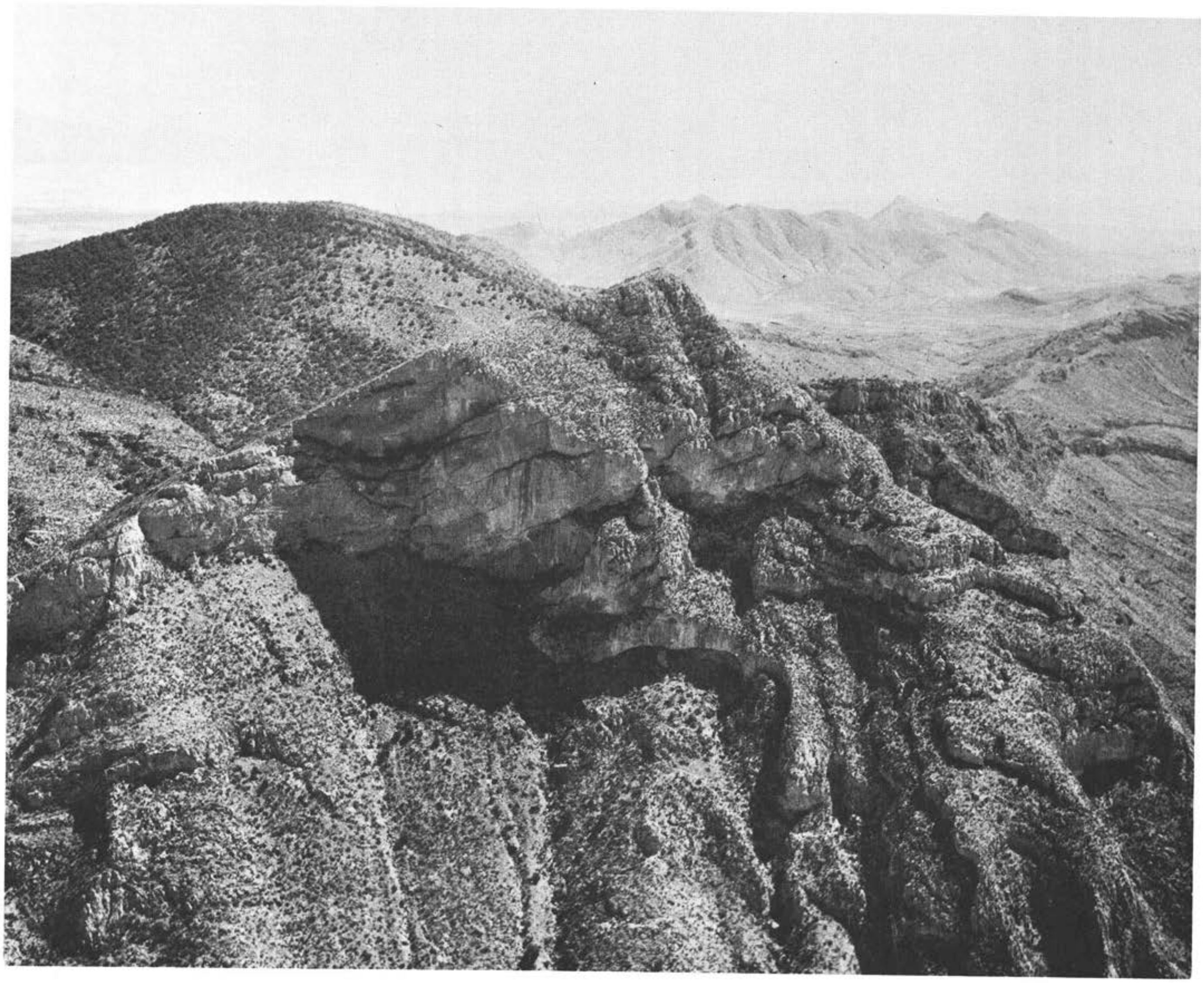

Figure 11

MARINE TALUS DEPOSITS OR FORESET BEDS FLANKING UPPER HORQUILLA REEFS AND DIPPING TOWARD ALAMO HUECO BASIN.

The massive limestone of the peak is a reef, and thinner beds lapping upon the right side of the reef are probably marine talus deposits; the basin lies to the right of the photo. This peak is one mile south of Big Hatchet Peak. View is toward the southeast.

Along the main trend of the reefs, the rock appears to be pure limestone, but analysis might prove the rock to be slightly dolomitic. Much of the reef rock on Big Hatchet Peak is partly dolomitized. A mass of dolomite capping the hill in the southeast corner of sec. 1, T. 31 S., R. 16 W. lies on the west (basinward) side of the main reef zone. Dolomitized massive limestone is common in the Sheridan Canyon drainage on the east (shelfward) side of the main reef zone.

The reefs on Big Hatchet Peak range from middle or late Des Moines through Wolfcamp age. Although a section was not measured on Big Hatchet Peak, an approximate thickness of 1200 feet for the composite reef mass was computed from the bedding attitude and measurements from the topographic map. Fusulinid faunas collected from the lowermost reefs on Big Hatchet Peak and from the top of the peak were compared with the fusulinid zones of the New Well Peak and Bugle Ridge sections. The thickness of shelf beds between the same fusulinid zones in the measured sections is of the same order of magnitude. In the direction of the basin where shale beds are interfingered with limestones of the marginal area, as in the Borrego section, the separation between specific fusulinid zones progressively increases.

The older reefs of Des Moines through Missouri ages are seen only within a radius of a little more than a mile from Big Hatchet Peak. The reefs exposed southeast of the peak are all of Virgil and Wolfcamp age, and any older reefs present are covered. Older reefs probably were not developed toward the southeast. If the older reefs existed far to the southeast,. it seems likely they would be exposed somewhere. The evidence thus indicates that reefs first started forming in the area of Big Hatchet Peak in middle or late Des Moines time; as they continued to grow through late Pennsylvanian and Wolfcamp time, they spread southeastward along the margin of the Alamo Hueco basin. Figure 10, a generalized map of late Horquilla paleogeography of the Big Hatchet area, illustrates the progressive growth of younger reefs along the margin of the basin. Projection of the reef trends beyond areas of exposure is, of course, speculative.

Wolfcamp-age reefs are exposed from Big Hatchet Peak southeastward to the vicinity of Mine Canyon Tank, beyond which the Horquilla Limestone of the reef trend is buried. Big Hatchet Peak is the northwesternmost exposure of the reef zone; north of the peak, the upper Horquilla was removed by erosion.

Extension of upper Horquilla facies beyond the area of the Big Hatchet Mountains is not attempted here. A number of exposures of these rocks in the region yield clues to facies distribution, but studies of those exposures are required before reconstruction of late Horquilla paleogeography of this region can be approximated. Data from test wells drilled in the future would be invaluable in accurate paleogeographic reconstruction.

Figures 12 and 13 summarize the facies interpretation of the upper Horquilla Limestone. Figure 12 shows three stratigraphic sections of Horquilla, each of which lies in a different facies realm. The Big Hatchet Peak section was not measured; lithology is generalized from field observations, and thickness is estimated from the topographic map and the dip of the formation. The lower third of the Horquilla is the same in all sections; the upper two-thirds show the different facies.

Figure 13 is a cross section from the Humble Oil & Refining Company well northeastward to the New Well Peak section. The Big Hatchet Peak section is projected southeastward along the reef trend from Big Hatchet Peak to the line of the cross section to show the maximum development of the reef. The stratigraphic sections are plotted in correct relative horizontal positions, showing correct thicknesses; horizontal and vertical scales are made equal to prevent distortion. The lithology and the relationships of the various facies are shown somewhat schematically. In construction of the figure, which shows the Horquilla prior to Earp deposition, the top of the Horquilla was plotted as a horizontal line.

EARP FORMATION

Distribution and Topographic Expression

The Earp Formation crops out in the southwestern part of the Big Hatchet Mountains. Its greatest area of exposure is on the floor of South Sheridan Canyon and in the topographic basin between Sheridan Wells and Sheridan mine. The Earp is exposed in several of the small canyons trending northwest from Sheridan Wells and in the long canyon extending from Hell-to-Get-to-Tank to a mile south of Big Hatchet Peak. It crops out through nearly the full length of Mine Canyon. In the steep, west-sloping area between Little Tank and Hell-to-Get-to-Tank, the formation is exposed in several bands where it has been involved in imbricate thrust faulting. Here, as in central Cochise County, Arizona, the Earp Formation served as a weak stratum along which thrusting of sheets of massive Horquilla Limestone occurred.

As the Earp Formation is less resistant to erosion than enclosing formations, canyons or valleys have been cut in areas of its exposure. Most of the canyons in the southwestern interior of the mountains were formed by erosion of southeast-trending belts of the Earp Formation. Since the formation is weak and occupies canyon floors, it is covered with alluvium, except for exposures in deep gullies and outcrops of certain resistant beds (fig. 14). Where typically exposed, the Earp Formation occupies canyons bounded by high mountains of Horquilla Limestone on one side and lower ridges of Colina Limestone and Epitaph Dolomite on the other.

Stratigraphy

The Earp Formation was measured in the Hale Tank section, which lies about half a mile northwest of Hale Tank. Here the formation is most completely exposed and is not faulted. This section, designated as the best reference section for the Earp in the area, is described later and is shown graphically on Plate 4.

The lower part of the formation is commonly faulted against the upper part of the Horquilla Limestone, which results in the removal of a small amount of section. However, the locally disconformable contact between the two formations may be seen in the Hale Tank section, in the area about one mile south of Big Hatchet Peak, and in the area of imbricate thrust faults between Little Tank and Hell-to-Get-to-Tank. In the Hale Tank Section (pl. 4), the basal bed is brown limestone-granule conglomerate, but elsewhere the basal beds consist of thin, brown siltstone interbedded with light gray soft claystone. The contact between the Horquilla Limestone and the Earp Formation is usually sharp with no interbedding of the limestone and siltstone-claystone lithologies. However, a thin bed of dolomitic siltstone lies 16 feet below the contact in the Hale Tank section.

The Earp Formation is characterized by resistant I- to 20-foot beds of brown-weathered siltstone interbedded with relatively thicker nonresistant beds of soft white claystone, which are largely concealed. The siltstone is medium to light gray on fresh fracture, calcareous, and medium and finely cross laminated; it breaks into 1- to 2-inch slabs and 2-to 6-inch blocks. The claystone is calcareous and commonly contains small, irregular, calcareous nodules. Beds of bright red, finely fissile shale are exposed near Sheridan Wells. Several thin beds of orange-weathered silty dolomite and a few inconspicuous beds of silty limestone containing marine fossils are found in the upper half of the formation. The upper 30o feet or more are mostly covered by talus, but sparse exposures in gullies indicate that this part of the formation consists mostly of claystone with some beds of siltstone and limestone.

In the uppermost few feet of the formation, beds of Earp lithology are interbedded with thin beds of black limestone typical of the overlying Colina Limestone. The rarely seen upper contact is conformable and is chosen where the Colina-

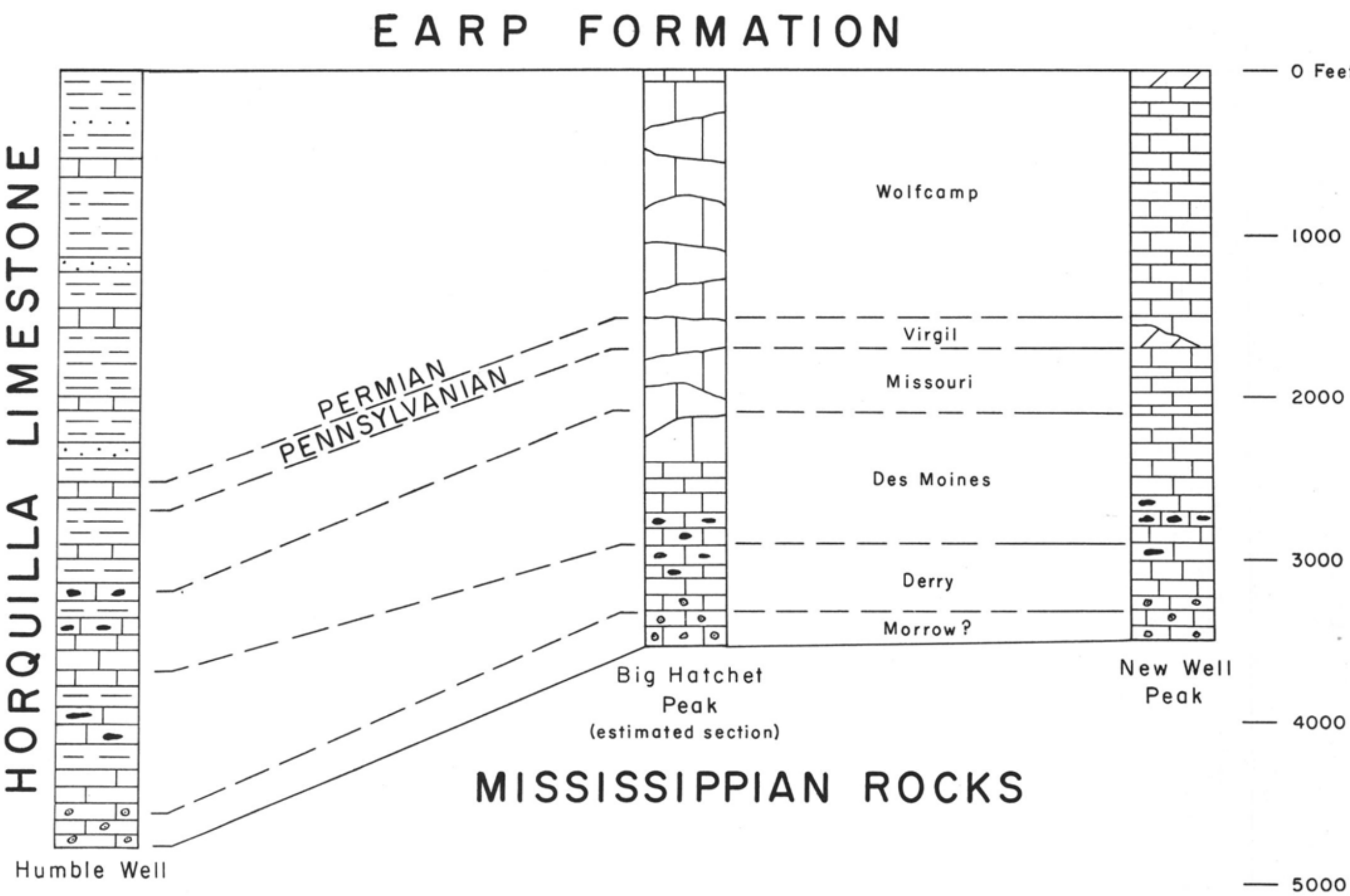

Figure 12

Stratigraphic sections of Horquilla Limestone that illustrate upper Horquilla facies in Big Hatchet Mountains area.

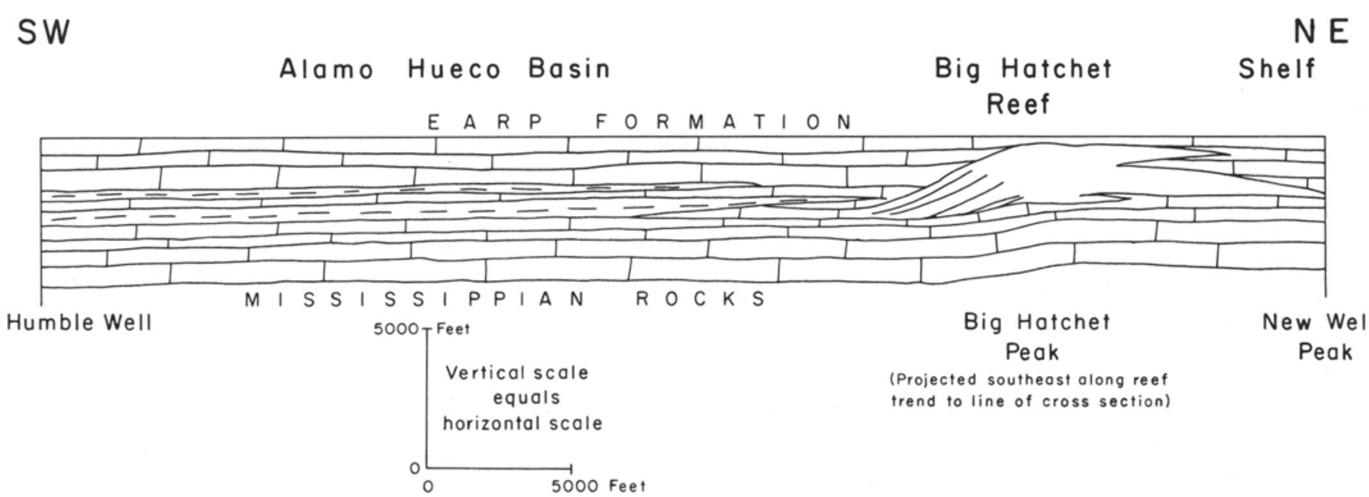

Figure 13

Generalized cross section from Humble well through Big Hatchet Mountains showing Horquilla Limestone prior to deposition of Earp Formation.

Figure 14

HALE TANK SECTION.

The following formations are indicated: P IPh—Horquilla Limestone; Pe—Earp Formation; and Pcl—Colina Limestone. Air view toward northwest of the interior of the Big Hatchet Mountains.

like limestone becomes predominant. This lies within a few feet of the base of the lowermost cliff-forming limestone of the Colina.

In the type locality of the Earp Formation in central Cochise County, Arizona, the contacts are gradational. In the Big Hatchet Mountains, contacts are relatively sharp and the lithology contrasts more sharply with the underlying and overlying formations. The Earp is an excellent mapping unit of value in deciphering the structural geology in this area of predominant limestone formations.

Animal tracks and fossil plants found in siltstone and shale indicate a terrestrial origin for most of the formation. A few limestone beds bearing marine fossils are interbedded with terrestrial beds in some places. This predominance of terrestrial beds contrasts with the chiefly marine character of the formation in areas to the west and east.

Age

Fossils in the Earp Formation are rare. In the Hale Tank section fossils, including ostracods and fragments of high-spired gastropods, were found only in bed 27. Ostracods (sample 61a) collected were examined by I. G. Sohn, who (written communication, 1955) reported that the genera represented have a stratigraphic range of Mississippian through Permian.

About 200 yards east of Sheridan mine, fossil fish scales and conifer branches are found in the Earp Formation. Charles B. Read (personal communication, 1958) identified the conifer as *Walchia piniformis* (Schlotheim) Sternberg; he commented that this fossil is most commonly found in rocks of Wolfcamp age but is also known from early Leonard rocks. It is presumed that the fish scales are from freshwater fishes. Fossil wood, which is common in the lower Earp, has not been studied.

Fossil footprints were found near the middle of the formation at a point about a quarter of a mile northwest of the mouth of Mine Canyon. These were examined by Donald Baird, who (personal communication, 1954) reported as follows:

> 493-835-A. Parts of two trackways of a small tetrapod, too indistinct for identification but suggesting a small reptile such as the captorhinomorph cotylosaurs *Protorothyris* and *Romeria.* A footprint species rather similar in size and form, *Varanopus curvidactylus* Moodie (1929), occurs in the Upper Clear Fork at Castle Peak, 1 10 miles south of Merkel, Texas. Another similar form is *"Hylopus" hermitanus* Gilmore (1927) from the lower Permian Hermit shale of the Grand Canyon National Park, Arizona. Even more comparable tracks, still undescribed, have been found by G. 0. Raasch in the Wellington formation of Garfield County, Oklahoma (Harvard MCZ 23o). This type of footprint thus corresponds in distribution to the redbeds vertebrate fauna of the Wolfcamp and lower Leonard.
>
> 493-835-B. Right half of a leftward-curving trackway of limulid xiphosuran, showing imprints of the ectognath pusher lateral to or superimposed on impressions of the ?fifth walking leg, and indistinct impressions of the third and fourth walking legs. The most lateral biramous impressions are directed anteriorly and are moderately deep, and thus appear to represent the outermost or fifth walking leg; but in most limuloid trackways this tends to impress lateral rather than medial to the ectognath.
>
> Several form-genera of horseshoe crab trackways have been proposed: *Paramphibius* Willard from the Upper Devonian (Caster, 1938), *Bipedes* Aldrich and Jones (1930) from the Lower Pennsylvanian, *Micrichnus [Artiodactylus]* Abel from the Upper Triassic (Caster, 1939), and *Kouphichnium* Nopcsa from the Upper Jurassic and Paleocene (Caster, 19410; 1944, pp. 81-82). The present tracks are too indistinct for positive generic assignment, but there is no mistaking their limuloid origin. They represent an animal considerably larger than *Paleolimulus avitus* Dunbar (1923; Raymond, 1944) from the Lower Leonard (Carlton limestone member of the Wellington shale) of Kansas, but well within the probable size range of *P. signatus* (Beecher) from the Upper Wolfcamp (Ft. Riley member of Barnes-ton limestone) of Kansas. Nothing in the limb structure of *Paleolimulus* would exclude it from correlation with the footprints. Any definite correlation, however, must await the discovery of additional and more diagnostic trackways.
>
> 493-835-C. Indeterminate impressions resembling the footprints of a lacertoid reptile. These are not actual footprints but "shadows" impressed into a layer of sediment below the one on which the animal walked.
>
> The ecological setting suggested by these trackways is the strand of a flood plain or delta. In Recent sediments the presence of a horseshoe crab would be taken to indicate marine or at least brackish conditions, but this deduction is not necessarily valid for the Lower Permian. Xi*phosura polyphemus,* though normally an inhabitant of marine and brackish water, is capable of living in fresh water (cf. Caster, 1939, p. 797); and there is a growing body of evidence (e.g., Russell, 19410) that at least some ancient limulids have been fresh water in habitat. On this point it may be noted that *Paleolimulus avitus* occurs near Elmo, Kansas, "associated with fragmentary plant remains, and with many remarkably preserved insects, both adults and aquatic larvae; that no fishes were present, and that the only marine elements of the fauna are two species of the clam *Myalina.* The water must have been sweet or slightly brackish, and was probably a fresh lagoon at the head of an inland sea." (Dunbar, 1923, p. 450).

As no fusulinids or other index fossils were discovered in the formation, its exact age is unknown. Based upon fusulinid information from overlying and underlying formations, John W. Skinner (written communication, 1954) comments concerning the age of the Earp Formation in the Big Hatchet Mountains: " . . . the highest fusulinids below . . . [the Earp Formation] are late Wolfcamp in age. The only ones above that we have seen are up in the Concha. They are probably about middle Leonard in age. Consequently, the red beds are either late Wolfcamp or early Leonard, or both. I'm inclined to believe they are early Leonard, but I couldn't prove it."

The elastic lithology, the oxidized iron in the rock indicated by the brown color, plant fossils, cross lamination, tetrapod and horseshoe crab tracks, and rarity of limestone beds and marine fossils all suggest that the Earp Formation in this area was deposited as a deltaic tidal-flat or shallow lagoonal deposit; the rare limestones were deposited during brief encroachments by the sea.

Correlation

The Earp Formation in the Big Hatchet Mountains differs from that of areas to the west and northwest in several respects, but its similar lithology and its position in the stratigraphic succession between the Horquilla and Colina Limestones indicate its lithologic equivalence to the type Earp. In the areas to the west and northwest and in the Sierra Boca Grande to the southeast, the Earp contains more marine limestone beds and more abundant marine fossils than in the Big Hatchet Mountains. The upper contact with the Colina Limestone appears to be the same throughout the region. However, the lower contact, chosen at the level above which shale or siltstone becomes dominant over limestone, is not well defined in most sections and varies in stratigraphic level throughout the region.

In the Big Hatchet Mountains, the measured thickness of the Earp Formation is 997 feet; in the type area, Gilluly, Cooper, and Williams (1954, p. 23) report a thickness ranging from 600 to 1126 feet; in the Chiricahua Mountains, Sabin (1957, p. 489) reports a thickness of 2710 feet; and in the Peloncillo Mountains where the top of the formation is missing, Gillerman (1958, p. 38) reports a thickness of 831 feet. It therefore appears that the Earp Formation is thickest in the Chiricahua Mountains and possibly in the Peloncillo Mountains, and that it thins toward the west and southeast. Variations in thickness, however, may be attributable partly to choice of the basal contact at different levels.

The age of the Earp Formation in the Big Hatchet Mountains is Wolfcamp or Leonard. With respect to the age of the formation in the type area, Williams (Gilluly, Cooper, and Williams, 1954, p. 38) concludes,

> From a study of all the evidence presented by those who have studied various groups and from a first-hand examination of the brachiopods and from other evidence, it appears to the writer that the age of the Earp is from middle late Pennsylvanian to and including beds of Wolf-camp (Permian?) age, with the possibility that beds at the

top of the formation in the Gunnison Hills may be younger than any beds in the Earp Hills and sections nearby.

Sabins (op. cit., p. 491) reports that the age of the Earp Formation in the Chiricahua Mountains is Virgil and Wolfcamp. Gillerman (op. cit., p. 37) reports that the age of the entire formation in the Peloncillo Mountains is Wolfcamp. Though the age of the upper contact is not known precisely, it is probably about the same throughout the region. The lower contact, though not a consistent stratigraphic level, appears to become younger toward the east.

Sabins (op. cit., p. 50o) and other writers have suggested that the Earp Formation of southeastern Arizona inter-fingers with the Supai Formation of the Colorado Plateau and that the two formations are at least in part equivalent in age.

Throughout much of central and southern New Mexico, the Pennsylvanian limestone of the Magdalena Group is overlain by red beds of the Abo Formation of Wolf camp age. The Abo is recognized as far west as the Silver City area.

It seems probable that the Abo, Earp, and Supai Formations are lithologically equivalent to one another, even though they differ in details. They all include deposits shed from land areas that lay predominantly toward the north and northwest during late Pennsylvanian and Wolfcamp time. From southeastern Arizona to southwestern New Mexico, the basal beds become younger, indicating that the land-derived elastics progressively encroached upon the sea in which the marine limestones of the Horquilla Formation were being deposited.

COLINA LIMESTONE

Distribution and Topographic Expression

In the Big Hatchet Mountains, the Colina Limestone is exposed only in the southwestern part. As it overlies the Earp Formation, its distribution is similar to that of the Earp except that it occupies the updip sides and rims of canyons in which the Earp is found. In addition, it is found in several narrow outcrop belts on the steep southwestern slopes of the range.

Because the Colina Limestone is medium bedded, it is only moderately resistant to erosion. It ordinarily is carved by erosion into high hills and spurs intermediate between canyons formed of the Earp Formation on one side and high hills and mountains formed of resistant higher Permian formations on the other side. In some places, the Colina is less resistant to erosion, and alternating thin and medium beds form stepped hillsides. In other places, it becomes more massive, forming several prominent bluffs. A prominent and persistent 25-foot bed, which may be distinguished by a 15-inch stratum near its middle, commonly forms a cliff near the base of the formation and is a useful marker bed throughout much of the range. This is unit 3 of the Lower Sheridan Tank section.

Stratigraphy

For mapping purposes, the base of the formation is chosen at the base of the marker bed just mentioned because the underlying beds are usually concealed. However, in a few places where the lower beds are exposed, the basal contact of the formation is placed about 35 feet below the marker bed. Colina-like limestone and Earp-like claystone and shale are interbedded in a thin transition zone, and the contact, which is conformable, is chosen where limestone becomes predominant.

Most of the Colina Limestone consists of thin beds of limestone that is dark gray and black on fresh surfaces and that weathers medium to light gray with a smooth surface. The rock is very finely crystalline, shows a residual elastic texture on fresh moist surfaces, and has almost no chert. Small knots or geodes of intergrown quartz and calcite, common in the overlying Epitaph Dolomite, are found in the upper beds of the Colina Limestone. A few beds contain echinoid spines and gastropods. Thin concealed intervals in the lower half of the formation are occupied by brown-weathered, thinly cross laminated siltstone beds similar to those in the Earp Formation. In the upper part, limestone is interbedded with dolomite that is identical to the dolomite of the overlying Epitaph. The upper contact is arbitrarily chosen where the predominance of limestone gives way to dolomite.

The Lower Sheridan Tank and the Mine Canyon stratigraphic sections were measured across the Colina Limestone. The locations of these sections are shown on Plate 1, and their lithologies are shown graphically on Plate 4. The Lower Sheridan Tank section is described later.

In the Lower Sheridan Tank section the thickness of the Colina Limestone is 355 feet, whereas in the Mine Canyon section less than a mile away, its thickness is 505 feet. This difference of thickness over so short a distance is due to variation in the stratigraphic level of dolomitization; individual limestone beds of the upper Colina traced from the Mine Canyon section to the Lower Sheridan Tank section change to dolomite as successively lower beds become dolomite. Thus, the Colina—Epitaph contact does not represent a stratigraphic plane, but instead it shifts in stratigraphic position. The relationship of the two formations is discussed further under Epitaph Dolomite.

Characteristics of the Colina Limestone that serve to distinguish it from other limestone formations are black fresh color, light gray and smoothly weathered surfaces, lack of chert, thin-beddedness, gastropod-echinoid fauna, quartz-calcite knots, and interbedded dolomite.

Age

The fauna of the Colina Limestone consists mostly of bellerophontid and high-spired gastropods and large echinoid spines and plates. No fusulinids or brachiopods were found, although they were diligently sought. The few fossils collected have not been identified, and therefore the exact age of the formation is unknown. However, since the formation lies in the interval between late Wolfcamp fusulinids in the Horquilla Limestone and Leonard fusulinids in the Concha Limestone, the age of the Colina Limestone is either late Wolfcamp or Leonard.

In the type area in the Tombstone Hills in Arizona, the formation is Wolfcamp and Leonard(?) in age (Williams in

Gilluly, Cooper, and Williams, 1954, p. 41). Sabins (1957, P. 494-495) found that in the Chiricahua Mountains, the base of the Colina may be of Wolfcamp age, but fossil evidence shows that most of the formation is of Leonard age.

Correlation

The identification of the formation with the Colina Limestone in the type locality south of Tombstone, Arizona (Gilluly, Cooper, and Williams, op. cit., p. 23-25), is made with confidence because of its identical lithology and its position in the stratigraphic sequence. The Colina Limestone is also reported from the Chiricahua Mountains by Sabins (op. cit., p. 491-495) and from the Peloncillo Mountains by Gillerman (1958, p. 38-39). The thickness of the formation in the areas to the west is of the same order of magnitude as in the Big Hatchet Mountains.

The lower part of the Colina Limestone is present 15 miles to the west in the Animas Mountains. Also, it crops out in Mexico in the Sierra Boca Grande and in hills near the village at Barreal, 75 miles southeast of the Big Hatchet Mountains.

EPITAPH DOLOMITE

Distribution and Topographic Expression

The Epitaph Dolomite is exposed only in the southwestern part of the Big Hatchet Mountains in the area bounded on the northeast by South Sheridan Canyon, on the southwest and south by the foot of the range, and on the north approximately by lat. 31° 37' N. Unfaulted exposures along the southwestern side of South Sheridan Canyon are the best for study. A long belt of faulted exposures of the formation extends northwestward from near the head of Bighorn Canyon.

The formation is moderately resistant to erosion and therefore crops out on relatively high hills and mountains. Slopes on the formation are craggy and moderately steep, but cliffs are rare. Thinner beds in the lower half produce bluff-and-terrace slopes.

Stratigraphy

The Epitaph Dolomite was measured in the Lower Sheridan Tank and the Mine Canyon stratigraphic sections, the locations of which are shown on Plate 1 and the lithologies of which are shown graphically on Plate 4. The Lower Sheridan Tank section is described later.

The lower contact of the formation with the Colina Limestone was arbitrarily chosen where dolomite becomes predominant; this varies within wide limits as the stratigraphic level of dolomitization shifts.

About the lower 400 feet of the formation on the southwest side of South Sheridan Canyon consists of thin-bedded dolomite interbedded with red shale, claystone, and siltstone. These beds are relatively nonresistant, and most of the fine elastic beds are concealed. Where exposed, the elastic beds are contorted and shattered. The over-all weathered color of this zone is reddish brown. The dolomite is dark gray on fresh fracture and weathers from light to dark gray with brownish cast and a rough, gashlike surface; the rock is finely to very finely crystalline and is internally brecciated; knots and small geodes of intergrown quartz and calcite are conspicuous; the dolomite is thin bedded, many beds being only 1 or 2 inches thick. A few thin beds of lumpy, brecciated, light gray, finely crystalline elastic limestone are interbedded with the dolomite.

The lower beds of the Epitaph Dolomite are exposed in the short valley on the western slopes of the range in which is the corner common to secs. 20, 21, 28, and 29, T. 31 S., R. 15 W. Here thick massive deposits of white and light gray gypsum are found interbedded with the thin beds of dolomite and red shale. As this area lies immediately below a system of imbricate thrust faults, it seems likely that the stresses that produced the thrusting also caused the flowage of the gypsum into this concentration. The soft gypsum is exposed here only because of the relatively recent removal by erosion of the overlying protective thrust sheet. In the measured stratigraphic sections on the southwestern side of South Sheridan Canyon, gypsum was not recognized, but it may be present in thin beds that are concealed or it may have been squeezed from between the beds. Brecciation, minor faulting, and contortion of beds favor the latter possibility.

Above the lower zone of argillaceous rocks and gypsum, the formation is composed entirely of uniformly bedded dolomite in beds with thicknesses ranging from 1 to 10 feet and averaging 2 or 3 feet. The dolomite is medium and light gray on fresh fracture and weathers medium gray to white with a rough surface. The texture is finely crystalline to lithographic, but remnants of an original elastic texture may be seen on moist fresh surfaces. The dolomite of many beds is finely brecciated; it is rich in knots and small geodes having quartz shells and calcite cores concentrated in some beds up to 3o percent. Light gray dolomite is interbedded with medium gray dolomite; the light gray dolomite increases in proportion upward and becomes predominant in the upper 200 feet. Very few chert nodules are found in the formation.

The upper contact of the Epitaph Dolomite with the Scherrer Formation is sharp and was chosen where quartz sand grains appear. The thickness of the formation is about 1500 feet.

In the well drilled by Humble Oil & Refining Company southwest of the Big Hatchet Mountains, anhydrite was found throughout the lower 1000 feet of the Epitaph. Dolomite is the dominant rock type noted throughout the anhydrite zone; black, gray, and brown shale and red and gray fine-grained sandstone are also present. In the sections measured on the surface, the corresponding zone containing shale, siltstone, dolomite, and gypsum was found about 600 feet above the top of the Earp Formation and was only about 400 feet thick. Pinpoint porosity and subcommercial shows of oil and gas were reported from the Epitaph in the well.

Age

No fossils were found in the Epitaph Dolomite, which lies in the undated interval between the upper Horquilla Limestone of Wolfcamp age and the Concha Limestone of Leonard age. As the lithology is more closely allied to the overlying Concha Limestone, the Epitaph Dolomite is likely to be of Leonard age. In the Gunnison Hills, Arizona, Williams (Gilluly, Cooper, and Williams, 1954 p. 41) shows that the Epitaph Dolomite is probably of Leonard age.

Correlation and Stratigraphic Interpretation

In spite of the lack of fossils in the formation in the Big Hatchet Mountains, the Epitaph Dolomite may be correlated with confidence with the formation in the type area in the Gunnispn Hills, southeastern Arizona, on the basis of similar lithology and its position in the stratigraphic succession.

In the type area, Gilluly, Cooper, and Williams (op. cit., p. 27) discuss the problem of the stratigraphic interpretation of the Epitaph Dolomite. There the formation overlies the Colina Limestone in the north end of the Dragoon Mountains but only about five miles away at Schemer Ridge in the Gunnison Hills, the Colina beds are overlain directly by sandstone of the Scherrer Formation, and beds of Epitaph lithology are missing. Gilluly, Cooper, and Williams suggest three possible interpretations:

> 1. The Epitaph dolomite has been eroded in the Gunnison Hills area, and the Scherrer formation is an overlapping formation younger than the Epitaph. This interpretation requires an unconformity at the base of the Schemer formation. The base of this formation is well exposed on Schemer Ridge but no evidence of angular or erosional unconformity was noted.
> 2. The Epitaph dolomite is equivalent to beds in the concealed interval between the lower and upper parts of the Colina limestone of the Gunnison Hills. Lack of exposures of the Epitaph in the Gunnison Hills would probably require a change in lithology or down-faulting of the ridge-forming part of the formation.
> 3. The lower part of the Epitaph is the dolomitized equivalent of beds referred to the Colina limestone in the Gunnison Hills and the upper part of the Epitaph is equivalent to part or all of the Scherrer formation. This would require a more rapid change of facies in the Epitaph than is indicated in the Tombstone Hills—Dragoon Mountains area.

The problem of stratigraphic interpretation of the Colina, Epitaph, and Scherrer formations is not confined to central Cochise County, Arizona, but applies to the entire region where formations of the upper Naco Group are found. In the Chiricahua Mountains, Sabins (1957, p. 492-494) found the Scherrer Formation resting upon Colina Limestone with no Epitaph Dolomite between. He discussed the three hypotheses of Gilluly, Cooper, and Williams as they apply to the Chiricahua Mountains, and he concluded that the third hypothesis is probably the correct one. In the Peloncillo Mountains, Gillerman noted that the Epitaph Dolomite is absent.

Bryant (1959, p. 4o) recognized that the Epitaph Dolomite of the type section " . . . is gradational from the Colina below." He considered as Epitaph the upper, somewhat dolomitic limestone of the sequence assigned by Williams to the Colina Limestone in the Gunnison Hills. Also, he divided the section lying between the Horquilla and Scherrer in the Chiricahua Mountains differently than did Sabins, and he assigned 800 feet of sub-Scherrer section to the Epitaph. Bryant believed that the upper beds of the Colina—Epitaph sequence throughout the region are equivalent.

My observations in the Big Hatchet Mountains, in the Mustang Mountains west of Tombstone, Arizona, in the hills a few miles southwest of Barreal, Chihuahua, and in the Sierra Boca Grande, Chihuahua, indicate that the Colina and Epitaph represent an unbroken sequence of deposition; only in areas where the upper beds are dolomitized is the Epitaph distinguishable from the Colina.

In the Big Hatchet Mountains, the difference in the stratigraphic depth of dolomitization in two nearby stratigraphic sections is clearly visible. In the Humble Oil & Refining Company well southwest of the Big Hatchet Mountains, the contact between the Colina and Epitaph is stratigraphically higher than in the surface sections. In the Mustang Mountains, a considerable thickness of limestone below the sandstones of the Schemer Formation apparently represents undolomitized Epitaph; although only a few beds of dolomite are present, silica knots in the limestone and the thinness of beds are characteristics found in the Epitaph Dolomite. Similarly, a few miles southwest of Barreal, Chihuahua, some hundreds of feet of beds below sandstones identified as Scherrer consist mostly of limestone, but this section also has a few beds of dolomite and contains silica knots. In both the Mustang Mountains and the Barreal areas, the sub-Schemer rocks are equivalent to the Epitaph, even though in gross lithology they more closely resemble the Colina Limestone.

In the Sierra Boca Grande 25 miles east of the Big Hatchet Mountains, the Horquilla, Earp, Colina, Epitaph, and Scherrer represent a continuous sequence of deposition unbroken by any obvious disconformities. Dolomitization of the Epitaph extends from the Scherrer downward nearly to the top of the Earp. Beds that correspond to the Colina in other sections throughout the region are almost completely dolomitized.

Thus, the regional evidence clearly favors the hypothesis that the Epitaph Dolomite represents a locally dolomitized portion of the upper part of the Colina—Epitaph sequence; only in areas where dolomite predominates in the upper part is the Epitaph clearly separable from the Colina. For stratigraphic purposes, the Colina and Epitaph should not be divided because the only difference between the two is the depth of dolomitization below the top of the sequence, a factor that varies greatly and without regional trend from place to place. However, for the purpose of geologic mapping in restricted areas, the division of the sequence into Colina Limestone and Epitaph Dolomite is useful, even though the contact dividing the formations varies somewhat in stratigraphic level.

As rocks below the base of the Scherrer Formation in many areas are solidly dolomitized downward to various depths in the section, it appears that dolomitization may be related in some way to the Epitaph—Schemer contact.

The anhydrite and gypsum found in the Epitaph Dolomite in the Big Hatchet Mountains area may have formed in lagoons separated from the sea by reefs. In the Mustang

Mountains, lens-shaped masses of unstratified carbonate rock in the upper part of the Epitaph Dolomite and in the Concha Limestone appear to be biohermal reefs. Bryant (1959, p. 4o) mentioned that about 200 feet of gypsum is found in the upper part of the Epitaph in the Whetstone Mountains a few miles north of the Mustang Mountains. This close association of possible reefs and gypsum deposits in southeastern Arizona suggests that reefs also may have been associated with the evaporite deposits in the area of the Big Hatchet Mountains. The analogy between these rocks and those of the Permian "basin" of southeastern New Mexico and western Texas is striking and warrants further investigation, particularly by those interested in oil and gas exploration.

Besides the obvious lithologic correlation of the formation with the Epitaph Dolomite of the type area, which is based upon lithologic similarity and similar position in the stratigraphic succession, its correlation with formations of neighboring regions is hindered by lack of fossils and accurate age information. The red shale and evaporite zone may represent a tongue of the Supai Formation of central Arizona, and that zone may be equivalent to the Yeso Formation of central and southwestern New Mexico.

Correlation of the Epitaph with the Yeso has three points in its favor. First, both contain evaporite deposits interbedded with red shale, siltstone, and sandstone. Second, the ages of each are approximately the same; the Epitaph may be either Wolfcamp or Leonard in age, but it is most likely to be Leonard. The Yeso Formation in the San Andres Mountains and in southeastern New Mexico (Kottlowski et al., 1956, p. 59-6o) is classified as Leonard age. And third, they each underlie sequences of thin beds of sandstone overlain by limestone that probably correlate with one another.

SCHERRER FORMATION

In the Big Hatchet Mountains, the Scherrer Formation is between 5 and 20 feet in thickness. Though this is too thin to be properly classed as a formation, it is nevertheless called a formation here because it cannot be properly included with either neighboring formation and because it is a distinct division of the Naco Group in the type area. However, for geologic mapping in the Big Hatchet Mountains, it is grouped with the Concha Limestone.

The distribution of the Scherrer Formation is similar to that of the upper Epitaph Dolomite. It is nonresistant and is commonly concealed. The Scherrer is described in the Upper Sheridan Tank section, and it is shown graphically in the Upper Sheridan Tank and the Mine Canyon sections on Plate 4.

The formation is characterized by medium- and fine-grained subrounded quartz sand in a limestone matrix. In most places, the proportion of sand is great and the formation becomes a white calcareous quartz sandstone. However, the sand concentration and the thickness vary, and where the formation is 20 feet thick, several beds of quartz sandstone are interbedded with sandy limestone. The limestone is similar to that of the overlying Concha Limestone.

The basal contact of the Scherrer is sharp in the Big Hatchet Mountains, as it is in the type section in the Gunnison Hills of southeastern Arizona. Gilluly, Cooper, and Williams (op. cit., p. 28) remark that although the contact is knife-sharp in the type section and that it . . . obviously represents a great change in conditions of deposition, no evidence of either angular or erosional unconformity was detected." This observation applies as well to the contact in the Big Hatchet Mountains.

Evidence from the Sierra Boca Grande in Mexico suggests that the basal contact of the Scherrer is conformable and does not represent a regional disconformity. In that range, the Scherrer consists of sandstone with a faintly purple color. A few thin strata of identical purplish sandstone occur in the upper 400 feet of the Epitaph Dolomite. Within the Scherrer, there are thin beds of Epitaph-like dolomite. Commingled Epitaph and Scherrer lithologies indicate a normal contact. This evidence from Mexico and the lack of evidence of a regional disconformity in New Mexico and Arizona suggest that the basal contact of the Scherrer is conformable even though the contact is sharp in most places.

The upper contact of the Scherrer is also conformable. In the Big Hatchet Mountains, as in the type section in Arizona, quartz sand gradually diminishes upward as the proportion of limestone increases. In the Big Hatchet Mountains, the contact was chosen at the level where obvious quartz sand disappears.

As no fossils were found in the formation, its age in the Big Hatchet Mountains is not definitely established. Like the Earp, Colina, and Epitaph, the Scherrer lies in the interval between Wolfcamp- and Leonard-age rocks. The conformable relationship of the Scherrer with the overlying Concha of Leonard age suggests that the Scherrer also is of Leonard age.

In the type area in southeastern Arizona, no fossils with specific age significance were found in the Scherrer Formation, and there its age must be surmised from its position between the underlying Colina of Wolfcamp and Leonard (?) age and the Concha Limestone believed by Williams (Gilluly, Cooper, and Williams, op. cit., p. 43) to be of Leonard age. In the Chiricahua Mountains, the Scherrer is of Leonard age (Sabins, op. cit., p. 496).

Lithologic correlation of the formation in the Big Hatchet Mountains with the type Scherrer Formation of the Gunnison Hills, southeastern Arizona, is established by its similar lithology and its position in the stratigraphic succession.

In the type area, the maximum measured thickness of the Scherrer Formation is 687 feet. In the Chiricahua Mountains, it is between 12o and 15o feet thick. In the Peloncillo Mountains, its thickness ranges from o to 5o feet. The formation therefore thins toward the east, and the thickness found in the Big Hatchet Mountains conforms to the regional picture. Apparently the source of the Scherrer sediments was from the northwest, as described by Sabins (1957, p. 496).

Williams (Gilluly, Cooper, and Williams, op. cit., p. 42-43) shows that, although not conclusive, correlation of the Concha Limestone with the Kaibab Limestone is indicated. The relationship of the sandstone of the Scherrer Formation to the overlying Concha and of the Coconino Sandstone to the overlying Kaibab suggests correlation of the Scherrer and the Coconino, a possibility recognized by Sabins (op. cit., p. 49[6]).

The Concha Limestone may correlate with the San Andres Formation of central and southeastern New Mexico. If so, the Scherrer Formation may be equivalent to the Glorieta Sandstone, which underlies the San Andres Formation.

CONCHA LIMESTONE

The Concha Limestone, which overlies the Scherrer Formation, was named by Gilluly, Cooper, and Williams (op. cit., p. 29) for Concha Ridge in the Gunnison Hills of southeastern Arizona. Williams, in discussing the fauna of the formation, recognized that the Concha Limestone is probably equivalent to the Chiricahua Limestone, which was first recognized by Stoyanow in 1926 and named by him in 1936 (Stoyanow, 1926, p. 318-319; 1936, p. 532-533).

Sabins (op. cit., p. 498) chose to suppress the name *Chiricahua Limestone* in favor of the name *Concha Limestone* because "no type section was ever named or described and the name has seldom been used by later writers." Gillerman (op. cit., p. 41-42), recognizing that the two names are probably used for the same formation, chose to use *Chiricahua Limestone* because of its priority. He stated that Sabins ignored Stoyanow's earlier name for the formation, but to the contrary, Sabins fully discussed the relative merits of the two names.

I prefer the name *Concha Limestone* for the reasons stated by Sabins. Also, as the subdivisions of the Naco Group proposed by Gilluly, Cooper, and Wiliams are used here for pre-Concha formations, it seems best to adhere to this nomenclature for the entire group. Use of the name *Chiricahua Limestone* could lead to certain ambiguities unless the formation were restudied and completely defined in the type area.

Distribution and Topographic Expression

The Concha Limestone crops out in two northwesterly-trending belts in the southwestern part of the Big Hatchet Mountains. One belt caps the ridge between South Sheridan Canyon and Bighorn Canyon; it extends down the dip slope of the ridge to the floor of Bighorn Canyon and is terminated by a fault at the head of the canyon. It is covered by valley fill on the south end of the ridge. The other belt caps the ridge on the west side of Bighorn Canyon and extends southwestward down the dip slope to the edge of the mountains. It extends northwestward along the foot of the range for about five miles in exposures narrowed by faulting and valley fill. A portion of this belt was offset by a high-angle fault, which accounts for the Concha on the ridge principally in the northeastern part of sec. 4, T. 32 S., R. 15 W.

The Concha Limestone is moderately resistant and forms the tops and dip slopes of several ridges. Where exposed on ridge tops, it weathers into small bluffs, and on the dip slopes its alternating thin and medium beds weather into a gentle step topography.

Stratigraphy

The Concha is readily recognized throughout the region by its distinctive lithology. The outstanding features are the abundance of chert nodules and silicified robust productids, and the lavender color of much of the chert. The field term used for the formation was "cherty limestone."

The lower half of the formation consists of limestone that is medium and light gray on fresh fracture, weathers medium bluish gray, varies from lithographic to coarsely crystalline, is composed largely of fossil shell detritus, and occurs in beds ranging in thickness from 6 inches to 8 feet with an average of about 3 feet. The formation contains abundant medium-gray, light-gray, red, and lavender irregularly shaped, brown-weathered chert nodules and silicified brachiopods concentrated in strata alternating with limestone. Many beds are composed of 3o percent chert nodules, and in a few, the chert makes up 65 percent or more of the rock.

The upper half of the formation consists mostly of dolomite that is light gray on fresh fracture, weathers light gray, is finely crystalline, and has a residual elastic texture. It contains the same type of chert nodules and silicified fossils in similar abundance and distribution as the underlying limestone. Beds of limestone and partly dolomitized limestone are found interbedded with the dolomite.

Erosion prior to deposition of Lower Cretaceous rocks removed parts of the upper Concha Limestone, and in many places the upper dolomite beds are missing. The contact between Concha Limestone and the overlying Lower Cretaceous rocks is therefore an erosional unconformity, but no noticeable angularity is seen where the contact is exposed in the Big Hatchet Mountains.

The Upper Sheridan Tank section and part of the Mine Canyon section were measured across the formation (pl. 4). Mine Canyon section traverses the lower 342 feet of the Concha Limestone and ends at the highest exposures on a peak. Field relations suggest that only a small amount of Concha lies between the top of the section and the Cretaceous beds. In the Upper Sheridan Tank section, 1376 feet of the Concha Limestone were measured, which is the maximum exposed thickness of the formation in the area. Thus, in a distance of about 1 1/2 miles along the Permian—Cretaceous contact on the northeastern side of Bighorn Canyon, the Concha Limestone apparently was thinned about 1000 feet by erosion prior to Cretaceous deposition.

Age

The fauna of the Concha Limestone is rich in silicified brachiopods, including *"Dictyoclostus"* sp.*, *Spirifer* sp., and *Composita* sp. These forms have not been studied, but the fauna is similar in appearance to that of the Concha

* Northrop (personal communication, 1963) notes that Muir-Wood and Cooper (1960, p. 269) accept the splitting of the genus by Russian authors and the restriction of *Dictyoclostus* to three species found in the Mississippian of Great Britain and Europe. As restricted, *Dictyoclostus* does not occur in North America and does not occur in the Pennsylvanian or Permian.

Limestone of central Cochise County, Arizona, and the Chiricahua Mountains, Arizona. Williams (Gilluly, Cooper, and Williams, op. cit., p. 42-43) discusses the age of the Concha Limestone in southeastern Arizona based on a study of the megafossils and concludes, "At present the writer is inclined toward a correlation with the Leonard, but it must be admitted that there are also elements that suggest correlation with the Word." In the Chiricahua Mountains, Sabins (op. cit., p. 498) describes the age of the Concha Limestone as Leonard and Guadalupe (?), and in the Peloncillo Mountains, Gillerman (op. cit., p. 43) states that the formation is the same age. Bryant (1959, p. 42) reports that a species of *Parafusulina* of lower Guadalupe (Word) age has been identified from the Concha Limestone of the Empire Mountains, Helmet Peak, Tucson Mountains, and Waterman Mountains, all in south-central Arizona.

In the Big Hatchet Mountains, a half dozen fusulinid horizons were found; collections from these beds were identified by Skinner and Wilde (written communication, 1954) as follows:

63c	*Parafusulina* sp. (middle to upper? Leonard)
63d	*Parafusulina sp.*
63e	*Parafusulina* sp.
63«	*Parafusulina?* sp. (may be *Schwagerina* of S. *setum* type)
63g	*Parafusulina* sp.
63j	*Parafusulina* sp.

Commenting on the age of these fossils, Wilde states, "The youngest fusulinids appear to be upper Leonard at most. I see none in your collection as young as Guadalupian." Thus, fusulinid evidence establishes the age of the Concha Limestone in the Big Hatchet Mountains as middle to late (?) Leonard. This agrees with the age of the Concha Limestone in central Cochise County, Arizona, as determined by Williams.

Correlation

The Concha Limestone of the Big Hatchet Mountains is correlated with the "Chiricahua" Limestone of the Peloncillo Mountains, the "Chiricahua" Limestone and Concha Limestone of the Chiricahua Mountains, and the Concha Limestone of central Cochise County, Arizona, because of its position above the Scherrer Formation, its nearly identical and distinctive lithology, and the general aspect of its fauna.

Concerning the correlation of the Concha Limestone, Williams (Gilluly, Cooper, and Williams, op. cit., p. 43) states:

> The Concha limestone, on the basis of its brachiopod fauna, is probably the equivalent of the Chiricahua limestone of Stoyanow. The Chiricahua is correlated by Stoyanow (1936, p. 532) with member Beta of the Kaibab, as restricted by McKee, of the Grand Canyon region, a correlation that the writer believes is probably as nearly correct as can be made on evidence now available. The fauna of the Concha is not of sufficient size to support a positive correlation with the Kaibab, but such a correlation is indicated.

Williams continues by discussing the correlation of the Kaibab with the west Texas section, and he states that the correlation is in dispute. The discovery of *Parafusulina* sp. with Concha brachiopod faunas in the Big Hatchet Mountains, an area that lies about midway between the west Texas and Kaibab areas, should help to settle the matter.

Correlation of the Concha Limestone with the San Andres Formation of central and southeastern New Mexico is here suggested, but such correlation cannot be proved until the faunas of the formations are studied in greater detail. Similarities of the two formations are that (1) both consist predominantly of limestone; (2) each is underlain by quartz sandstone; (3) evidence from different faunal groups shows each formation to be of Leonard age; and (4) certain fossils present in the San Andres Formation of the San Andres Mountains are characteristic of the Kaibab; they are found in the Concha Limestone of southeastern Arizona, and they are tentatively recognized in the Concha Limestone of the Big Hatchet Mountains.

The Concha Limestone is found in other localities near the Big Hatchet Mountains. It is exposed on the low hill east of the Young Ranch in the Animas Mountains. The small, isolated hill in sections 23 and 24, T. 29 S., R. 15 W., west of the Sierra Rica consists of Concha Limestone. South of the Alamo Hueco Mountains, it crops out in the hills near Rancho las Palmas a few miles south of the international boundary. The first mountains north of the river in the Sierra Boca Grande in Mexico consist chiefly of Concha. About 75 miles southeast of the Big Hatchet Mountains, the Concha is exposed near the village of Barreal, Chihuahua. In all these localities, the Concha Limestone is characterized by an abundance of lavender chert nodules and silicified productid brachiopods.

POST-PALEOZOIC—PRE-CRETACEOUS UNCONFORMITY

The contact between Paleozoic rocks and the overlying Lower Cretaceous rocks is seen in a few small exposures in the southwestern part of the Big Hatchet Mountains. Here the conglomerate and red beds of the Hell-to-Finish Formation rest upon the Concha Limestone. The Hell-to-Finish Formation is regarded as Early Cretaceous in age.

The contact is an erosional unconformity representing a hiatus that includes post-Leonard Permian, Triassic, Jurassic, and possibly earliest Cretaceous time. The red-bed lithology above the contact contrasts sharply with the gray limestone and dolomite below. In the Big Hatchet Mountains, no angular divergence is seen between beds above and below the contact. Erosion prior to deposition of the Hell-to-Finish Formation cut deeply into the Concha Limestone and produced a surface of great relief. Such relief is indicated by the difference in thickness of Concha Limestone preserved below the contact in two nearby measured sections. Thickness variations of the Hell-to-Finish Formation may be due in part to deposition upon the irregular surface. The basal bed of the Hell-to-Finish Formation resting on the contact is conglomerate composed of chert granules, fusulinid-bearing chert pebbles, and limestone and dolomite pebbles—all derived by erosion of the Concha Limestone.

In the well drilled by Humble Oil & Refining Company about five miles southwest of the surface exposures of Concha Limestone, several cavities ranging from 3 to 27 feet in height were encountered within the upper 85 feet of the Concha Limestone. These are apparently solution cavities which formed below the pre-Cretaceous erosion surface by karst erosion.

The contact between the Concha Limestone and the basal Cretaceous beds, which undoubtedly are equivalent to the Hell-to-Finish Formation, is exposed at Rancho las Palmas in Mexico about 18 miles south of the Big Hatchet Mountains. There the contact is an angular unconformity.

About 18 miles west-northwest of the exposures of Concha Limestone in the Big Hatchet Mountains, the pre-Cretaceous erosion surface is seen in the Animas Mountains (Zeller, 1962). Here it was cut into the lower part of the Colina Limestone and the upper part of the Earp Formation; the Epitaph, Scherrer, and Concha were removed by erosion. In this restricted area, deposition was upon an anticline that started its growth prior to Cretaceous sedimentation, and a slight angular divergence is visible between beds below and above the unconformity (Zeller and Alper, in press).

The unconformity is visible in the Sierra Boca Grande east of the Big Hatchet Mountains. Lower Cretaceous rocks rest upon an erosion surface cut to varying depths upon Concha Limestone, and no angular discordance is noted between the Permian and Cretaceous beds.

In the Peloncillo Mountains, Gillerman (1958, p. 46-47) found the same unconformity at the base of the Cretaceous rocks. The pre-Cretaceous surface had cut into the Earp Formation and higher Permian rocks. In some places, beds above and below the unconformity are parallel, but elsewhere angular discordance is seen.

The pre-Cretaceous unconformity is found throughout southeastern Arizona. Ransome (1904, p. 57-58) recognized the structure in the Bisbee area. Gilluly (1956, p. 67-68) found the unconformity in the northern end of the Mule Mountains, the Tombstone Hills, and the Dragoon Mountains. He shows that here, as at Bisbee, strong orogenic disturbance occurred between deposition of the Paleozoic and Cretaceous rocks and that erosion removed amounts of the section ranging downward from Epitaph Dolomite to Precambrian schist. Taliaferro (1933, p. 19-21) shows that in Sonora about 25 miles southwest of Douglas, Arizona, the unconformity is angular. Sabins (1957, p. 502-506) found that in the Chiricahua and Dos Cabezas Mountains, the unconformity is angular and that, in places, Cretaceous sediments have filled valleys formed upon the deeply dissected erosion surface.

Lower Cretaceous limestone is exposed in many ranges in western Texas, and where the basal contact is seen, it rests unconformably upon the Hueco Formation. Thus, the pre-Cretaceous unconformity is recognized in southwestern New Mexico, in southeastern Arizona, in western Texas, and in neighboring parts of Mexico.

From the Big Hatchet Mountains area toward the north, Lower Cretaceous sections progressively thin and disappear (the Little Hatchet Mountains sections are excluded from this statement for reasons mentioned later). In the Burro Mountains area, rocks interpreted as Late Cretaceous in age are found resting unconformably upon Paleozoic and older rocks. These facts imply that while the area of southwestern New Mexico and southeastern Arizona was receiving Early Cretaceous sediments, areas bordering this depositional basin on the north were still positive. Gradually, the limits of the basin advanced northward and successively younger beds were deposited upon the erosion surface. The pre-Late Cretaceous unconformity in the Burro Mountains therefore may be continuous with the pre-Early Cretaceous unconformity to the south.

Orogeny affected the region during the hiatus between Concha and Hell-to-Finish deposition. Angularity of the pre-Cretaceous unconformity in some exposures is evidence of this activity. Deformation in southeastern Arizona may have been stronger than in the area of the Big Hatchet Mountains because there the unconformity is angular and cuts more deeply into the geologic column. Near the Big Hatchet Mountains angular discordance at the unconformity is seen only in two areas, and elsewhere Cretaceous beds rest with concordance upon Concha Limestone. However, the arkose of the Hell-to-Finish Formation shows that deformation was strong near the Big Hatchet Mountains. Angular grains of quartz and fresh pink feldspar in the formation were derived from a nearby elevated granitic mass, which was exposed following orogenic activity but which is now concealed.

CRETACEOUS SYSTEM

Lower Cretaceous rocks crop out in many of the ranges of southeasternmost Arizona, southwesternmost New Mexico, and adjoining areas in Mexico. Upper Cretaceous rocks, which have not been identified in this restricted region, are known only in the peripheral zone extending from south-central Arizona to north of Lordsburg and Deming, New Mexico, and to El Paso, Texas. Only Lower Cretaceous rocks are recognized in the area covered by this report. Prior to initiation of the present study, Lower Cretaceous rocks of the region were given detailed attention by Ransome (1904) and Stoyanow (1949) near Bisbee, Arizona, and by Lasky (1947) in the Little Hatchet Mountains.

In the area covered by this report, Lower Cretaceous rocks are exposed in the Sierra Rica and in Mojado Pass south of the Big Hatchet Mountains. Because the rocks in the Sierra Rica are faulted and silicified, complete and satisfactory stratigraphic sections are lacking. In Mojado Pass, exposures are more complete and less deformed. Therefore, detailed study of Lower Cretaceous rocks was confined to Mojado Pass.

Here about 10,000 feet of sedimentary rocks are exposed that rest upon an erosion surface cut upon Permian Concha Limestone and that are truncated by an erosion surface formed before Tertiary deposition. Fossils prove Early Cretaceous age for all but the lowermost beds, but even though index fossils are lacking in these beds, their conformable relationship with overlying Lower Cretaceous beds indicates their probable Early Cretaceous age.

The Lower Cretaceous section in Mojado Pass lends itself to a natural threefold division based upon gross lithology. Each division, an excellent mapping unit, is designated as a formation. Because problems prevent identification or correlation of these formations with other described formations in the region, the Lower Cretaceous formations of Mojado Pass are here assigned new names. Problems of correlation and interpretation of the Lower Cretaceous rocks are discussed later.

The Lower Cretaceous sequence in the area of the Big Hatchet Mountains is divided into the following new formations: the lower, Hell-to-Finish Formation, which is a clastic unit composed mainly of red arkosic sandstone and red shale; the middle, U-Bar Formation, which is predominantly limestone; and the upper, Mojado Formation, which consists mostly of sandstone and shale.

HELL-TO-FINISH FORMATION

The Hell-to-Finish Formation is here named from exposures near Hell-to-Finish Tank, which lies at the southern end of the Big Hatchet Mountains in NE1/4NW1/4 sec. II, T. 3z S., R. 15 W. The Hell-to-Finish Tank section, which is described later and shown graphically on Plate 5, is designated as the type section. Figure 15 shows the location of the section.

Distribution and Topographic Expression

The Hell-to-Finish Formation is exposed in several places on the southern and southwestern flanks of the Big Hatchet Mountains. The largest and most complete exposure ex-

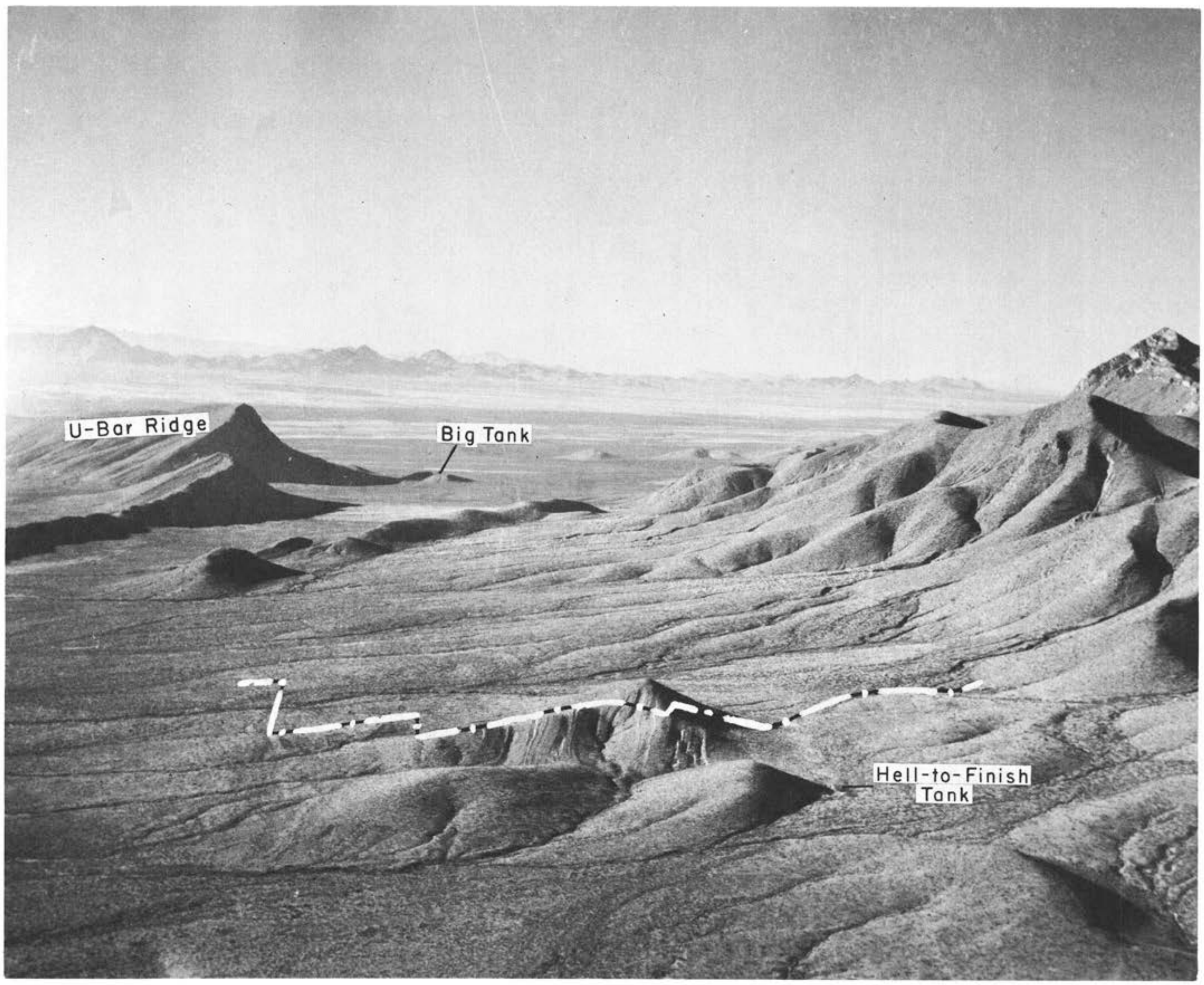

Figure 15

HELL-TO-FINISH TANK SECTION.

U-Bar Ridge is to the left of center. Big Tank, near which two short Cretaceous sections were measured, is indicated. View is toward the northwest.

tends from about a quarter of a mile north of Hell-to-Finish Tank to the south side of the hill south of the tank. This hill is capped with Tertiary fanglomerate, but the Hell-toFinish Formation crops out on all sides. The formation is exposed in a few gullies from the tank northwestward about a mile and a half to the head of a short valley. It crops out on the hill in NW1/4 sec. to, T. 32 S., R. 15 W.; from here it is exposed in a few places along a narrow belt extending northwestward to near the center of N1/2 sec. 29, T. 31 S., R. 15 W. A sequence of chert conglomerate, red clastic sediments, and andesite flows in Bighorn Canyon is tentatively assigned to the Hell-to-Finish Formation.

Since the formation is nonresistant to erosion, its exposures are rare and are seen mostly where a protective blanket of Tertiary fanglomerate has recently been eroded. Basal beds resting upon relatively resistant Concha Limestone are exposed in gullies that traverse the contact. Where exposed, the more resistant beds of sandstone form small bluffs on hill slopes, but interbedded shale is mostly concealed.

Stratigraphy

The Hell-to-Finish Formation on the southern flank of the Big Hatchet Mountains rests upon the irregular erosion surface cut upon the Concha Limestone. Relief on the surface was probably as much as I000 feet in a mile. Where the Hell-to-Finish Formation was deposited in deep depressions in the erosion surface, it is thick; where the formation was deposited on topographic highs, it is thin. Although the formation is characterized by red clastic sediments, a great variety of rock types is present. Such varied lithology is not surprising in view of the deposition upon a surface of such high relief.

The basal bed of the formation is conglomerate, and in places conglomerate is interbedded with other lithologies in the lower hundred feet of the formation. The conglomerate consists chiefly of light-gray chert granules and pebbles which, as shown by enclosed fossils, were derived by erosion of chert nodules from the underlying Concha Limestone. A few pebbles and cobbles of limestone and dolomite are present locally. Coarse detritus varies from rounded and polished to subrounded. Matrix consists of red arkosic sandstone. The conglomerate is usually well indurated, coarsely cross bedded in places, weathers from gray to dark brown, and occurs in beds as thick as 4o feet. Conglomerate, though locally conspicuous due to its greater resistance, is a relatively minor constituent of the lithologic sequence.

In the lower 400 feet of the type section, a few beds of sandy limestone and chert sandstone crop out between concealed intervals probably occupied by shale. The limestone is dark gray on fresh fracture, weathers light gray and brown, contains a large proportion of angular chert sand, and has irregularly shaped globules of nondetrital chert. A few limestone strata contain arkosic detritus. The sandstone of this lower part of the type section consists chiefly of light-gray chert sand; quartz sand is rare. The rock is light gray when fresh and dark brown when weathered. Strata, lenses, and cross laminae consist of sand of different grain sizes and o a few light-gray chert pebbles. The sandstone is cemented with calcite.

The bulk of the Hell-to-Finish Formation consists of shale, mudstone, and siltstone which are soft and seldom exposed. The shale is mostly red, although some beds are reddish brown and others are green. Mudstone, which has the same colors, lacks the fissility of the shale and is weakly indurated. Siltstone is chiefly red, but some is reddish brown, gray, and green. In composition, the silt is arkosic and the cement is calcareous.

Resistant beds of indurated arkose are conspicuous in the middle and upper parts of the type section of the formation. The arkose consists of angular grains of quartz and pink feldspar cemented with calcite and silica. Most of the arkose weathers brown. However, one bed of arkose near the top of the type section weathers white and is useful as a local marker. Grains in this bed are mostly coarse sand to granule in size, but lenses contain quartzite pebbles as much as 2 inches in diameter.

Exposed thin beds in the upper too feet of the formation in the type section consist of gray arkose, quartz sandstone, siltstone, gray shale, and limestone that weathers pink and bright orange; concealed intervals between exposed beds are undoubtedly occupied by argillaceous rocks. Several foot-thick, orange-weathered silty limestone beds at the top of the formation contain abundant minute fossil shells. The limestone is dense with a lithographic texture, and it includes scattered subangular grains of quartz and feldspar sand.

The clastic lithology of the Hell-to-Finish Formation is transitional upward with the marine limestone lithology of the U-Bar Formation. The contact is taken at the level above which limestone predominates. Thin beds of gray and red shale, chert and quartz sandstone, and arkose are interbedded with brown-weathered impure limestone in the lower 200 feet of the U-Bar Formation.

Rocks exposed in Bighorn Canyon are tentatively identified as the basal part of the Hell-to-Finish Formation. Basal chert conglomerate is visible in several places where it rests upon the Concha. Approximately 10o feet of beds that lie above the conglomerate consist of red shale, red mudstone, red arkosic sandstone, chert-pebble conglomerate, and thin volcanic flows of andesite. About zoo feet of andesite flows separated by thin strata of red shale lies stratigraphically above the predominantly sedimentary sequence. The andesite is overlain by red shale and red soft mudstone. Higher parts of the formation are not exposed because of a fault on the west side of the canyon. These beds are overlapped with angular unconformity by Tertiary fanglomerate near the mouth of the canyon, and hills of andesite are capped by the fanglomerate.

The andesite flows are vesicular, particularly near the upper and lower surfaces. "Dikes" of red shale and red arkosic sandstone that cut the andesite normal to bedding were formed as the joints in solidified andesite were filled with sediment during deposition of overlying beds. Flow structure within the andesite and the flows themselves lie parallel to the steeply dipping bedding of enclosing red clastic sediments. The andesite weathers dark purple-gray, which is the characteristic color of Cretaceous andesite flows in the region.

This sequence of rocks in Bighorn Canyon is thought to belong to the Hell-to-Finish Formation because it lies only a mile east of the type Hell-to-Finish Formation and is lithologically similar. However, andesite flows are not found elsewhere in the Hell-to-Finish Formation. Two thrust faults, one cutting the other, lie between the exposures in Bighorn Canyon and the type Hell-to-Finish Formation. Possibly, the areas were much farther apart prior to faulting.

The Hell-to-Finish Formation and the lower part of the U-Bar Formation are exposed in the deep saddle of the ridge a mile west of Hell-to-Finish Tank. Here the Hell-to-Finish Formation is no thicker than 30o feet, and the lower several hundred feet of the U-Bar Formation, as represented in the Hell-to-Finish Tank section, are missing. The thinning of more than 1000 feet in a mile from the measured section to this locality could be stratigraphic thinning due to deposition upon a surface of high relief. Though the evidence favors removal of part of the Hell-to-Finish and basal U-Bar Formations by faulting, the known irregularities of the pre-Cretaceous erosion surface and the probable thickness variations in formations equivalent to the Hell-to-Finish in the region show that such abrupt stratigraphic thinning is not improbable.

The thickness of the Hell-to-Finish Formation in the type section is 1274 feet. On the ridge a mile to the west, about 30o feet of the formation is present, but whether this represents the total original thickness of the formation here or whether part of the formation was displaced by faulting is not known. The entire formation is not exposed in any other place near the Big Hatchet Mountains.

Age and Correlation

Fossils occur only in the upper part of the Hell-to-Finish Formation. Abundant, small pelecypods in several limestone beds at the top of the type section have not been identified and probably would not be useful in determination of age. Fossil wood collected from the upper beds of sandstone and shale might be helpful in age determination. A fossil cycad was collected 42 feet above the prominent white arkose marker bed. At present, the age of the formation is not known from direct fossil evidence.

The probable age of the formation may be surmised from indirect evidence. The formation is overlain conformably by the U-Bar Formation in which the earliest identified fossils are of Early Cretaceous Aptian age. As these fossils are found in several exposures separated from one another and from the Hell-to-Finish Tank section by broad areas of alluvium, their precise positions above the top of the Hellto-Finish Formation are not known. However, consideration of spatial relationships of the exposures and probable concealed structure would place these zones no more than 900 feet stratigraphically above the contact (pl. 5). The fact that no breaks in deposition are known from the Hell-toFinish Formation into Aptian parts of the U-Bar Formation indicates that the two formations represent continuous deposition and are therefore closely related in age. Thus, it seems probable that the Hell-to-Finish Formation is of Early Cretaceous age.

Intensive collecting in the Hell-to-Finish Formation might yield small fossils, such as ostracods, spores, or pollen, that might aid in determination of the age. Also, a greater effort to collect fossils from the lowermost beds of the U-Bar Formation would probably yield more precise data on the age of the base of that formation.

Attempts to correlate the Hell-to-Finish Formation chronologically with other formations in the region are hazardous when the age of the formation is not known precisely. However, red shale and red arkosic sandstone commonly found at the base of the Lower Cretaceous section throughout the region correspond to the Hell-to-Finish Formation in depositional history and in lithologic character. On the eastern end of the Apache Hills near the International mine, red beds are found below Cretaceous limestone. In the northern part of the Animas Mountains, red shale is interbedded with limestone in the lower part of the Cretaceous section. A thin sequence of conglomerate and of red shale and arkose lies at the base of the Cretaceous section in the east-central part of the Animas Mountains. An excellent basal Cretaceous section lying upon Concha Limestone is exposed north of the river in the Sierra Boca Grande. Here red shale and red arkose are interbedded upward with marine limestone containing Early Cretaceous ammonites. In general aspect, this section is strikingly similar to the type section of the Hell-to-Finish Formation. A thin sequence of red shale and oyster-bearing limestone rests with angular unconformity upon the Concha Limestone near the headquarters of Rancho las Palmas, which is in Mexico about three miles south of the international boundary and about four miles south of Dog Spring in the Alamo Hueco Mountains. The presence of fossiliferous marine limestone within a few tens of feet of the basal contact indicates that the equivalent of the Hell-to-Finish Formation here is thin.

The lowest beds of the Cretaceous section in the Little Hatchet Mountains, which are exposed east of Old Hachita, consist of red shale and mudstone, red arkose, limestone conglomerate, and thin beds of limestone containing Early Cretaceous fossils. This sequence of red beds may be equivalent to the Hell-to-Finish Formation. In the Bisbee area, the Glance Conglomerate and red beds in the Morita Formation suggest a lithologic correlation with the Hell-to-Finish Formation.

That red beds are found at the base of the Cretaceous section throughout the region is genetically significant and implies lithologic equivalence. Though fossils are rare, detailed paleontologic studies may yield data on the age of the Hell-to-Finish Formation and its probable lithologic equivalents throughout the region.

Conditions of Deposition

From Concha to Hell-to-Finish time, the area had a long history of which little record remains. The angular unconformity found in places at the base of the Cretaceous beds and the arkosic composition of the Hell-to-Finish Formation are evidence of mountain-building activity during the long hiatus. Regional evidence shows that the Mexican sea advanced northward and that as it advanced, successively younger beds were deposited. Terrestrial sediments of the Hell-to-Finish Formation were deposited as the Big Hatchet area started subsiding and the Cretaceous sea approached from the south; when the sea reached the area, the marine U-Bar Formation was deposited.

The Hell-to-Finish Formation and equivalent red-bed formations in the region represent a facies of terrestrial rocks that was deposited near the margin of the advancing Cretaceous sea prior to marine deposition. Deposition was probably in river deltas and flood plains close to the coast, and as the sea approached, the upper beds were probably deposited in estuaries. Advance of the sea was rapid; had it been slow, the elastic beds would have been reworked and quartz sandstone would have been deposited instead of arkose.

Features of the Hell-to-Finish deposits provide clues to its history. Terrestrial origin is indicated by the red color and by fossil wood in the upper part. Red coloration probably was due to oxidation of iron in the sediments under subaerial conditions; gray and green beds may represent periods of submergence. Gray chert derived from the Concha Limestone supplied the coarse detritus of the basal conglomerate and lower sandstone of the formation. Rounded and subrounded chert pebbles indicate that the chert was abraded, possibly during river transport. However, angular grains of quartz and feldspar sand could not have traveled far from the source. Marine limestone interbedded with elastic sediments in the upper part of the formation shows brief periods of marine inundation. Near the close of Hell-toFinish time marine invasions increased in frequency until finally limestone deposition predominated and U-Bar time began. The erosional surface upon which the Hell-toFinish was deposited had sharp depressions in which thick deposits accumulated. Irregularities were covered by the Hell-to-Finish beds, and the way was cleared for deposition of the U-Bar Formation upon a relatively uniform surface.

U-BAR FORMATION

The U-Bar Formation is here named for exposures on U-Bar Ridge, the prominent synclinal ridge that lies off the southwestern flank of the Big Hatchet Mountains. The formation consists of the dominant limestone part of the Lower Cretaceous section that lies above the red beds of the Hellto-Finish Formation and below the sandstone of the Mojado Formation.

Because a complete and continuous stratigraphic section of the U-Bar Formation is not exposed, the upper part of the Hell-to-Finish Tank section, the Big Tank Southeast section, and the lower part of the U-Bar Ridge section are designated as the composite type section. Other stratigraphic sections measured across parts of the U-Bar Formation are the Roberson Ranch section, the Big Tank Southwest section, the Little Hat Top section, and the Pierce Tank section. Locations of the sections are shown on Plate I; descriptions of each are given later; they are shown graphically on Plate 5 in relative vertical positions that are as nearly correct as can be determined.

Choice of component sections for the composite type section is not ideal but is the most satisfactory of several alternatives. The upper part of the Hell-to-Finish Tank section includes the only undisturbed exposures of the lower part of the formation in the area. The U-Bar Ridge section includes the typical reef of the upper part of the formation. The Big Tank Southeast section is chosen as the type for the middle part of the formation because the rocks exposed are typical of that part and because the section is geographically between the lower and middle parts of the composite section. Minor faults may be present in the Big Tank Southeast section, but any such complications do not change the general aspect of the rock sequence. The combination of the Little Hat Top and Pierce Tank sections constitutes an excellent reference section. However, this combined section is not entirely satisfactory because it does not include the base of the U-Bar Formation, and because the massive reef that is so typical of the upper part of the formation is very thin.

Distribution and Topographic Expression

The most extensive exposures of the U-Bar Formation in the area lie off the southwestern and southern flanks of the Big Hatchet Mountains in and west of Mojado Pass. Spectacular U-Bar Ridge is composed of the formation. Small exposures occur on isolated hills north of U-Bar Ridge, on the southwest side of the ridge that lies northeast of U-Bar Ridge, and on the southwestern flank of the hill in SW1/4 sec. 3, T. 32 S., R. 15 W. A broad band of low exposures extends a total distance of about five miles from sections 13 and 14, T. 32 S., R. 15 W. southeastward into the Dog Mountains quadrangle. The extension of this band of exposures is shown on the reconnaissance geologic map of the Dog Mountains quadrangle (Zeller, 1958b) as "Cretaceous limestone." This map also shows exposures of the U-Bar Formation in the area of Sentinel Butte south of the extension of U-Bar Ridge.

In the Sierra Rica, the U-Bar Formation occurs in two northwest-trending outcrop bands duplicated by a fault in approximately the six sections of the northeasternmost corner of the Big Hatchet Peak quadrangle.

Except for the massive reef limestone near the top of the formation and several oo-foot-thick units of massive calcarenite near the middle, the formation consists of thin alternating beds of limestone and shale. Thin-bedded parts crop out with a ribbed pattern of exposed and covered beds on exhumed pediments and low hills. The massive units near the middle of the formation form long ridges which are low but conspicuous. The massive reef limestone, which ranges in thickness from 20 to 500 feet and which has a moderate dip where exposed, produces prominent high ridges where thick. Such ridges are capped with reef limestone which produces a vertical cliff on one side of the ridge and a dip slope on the other side. U-Bar Ridge and some ridges near the international boundary in the Sierra Rica are examples of reef exposures. The extraordinary horseshoe shape of U-Bar Ridge is the erosional expression of the thick, resistant reef limestone enclosed in weaker rocks folded into a syncline.

Stratigraphy

The U-Bar Formation rests conformably upon the Hell-to-Finish Formation. The contact lies within a transition zone in which elastic beds characteristic of the Hell-to-Finish Formation are interbedded with limestone characteristic of the U-Bar Formation. Within the zone of intermingled lithologies, which is several hundred feet thick, the contact was taken at the stratigraphic level above which limestone dominates. The contact probably traverses time lines because marine deposition became dominant in some areas before others.

For convenience of description, the U-Bar Formation is divided into five members, which from base to top are brown limestone member, oyster limestone member, limestone-shale member, reef limestone member, and suprareef limestone member.

The Hell-to-Finish Tank section extends across the only unfaulted exposure of the lower U-Bar Formation known in the area. This is designated as the type section for the lower 900 feet of the formation which includes the brown limestone member and the lower part of the oyster limestone member.

The brown limestone member includes the lower 387 feet of the formation in the type section. The over-all color of the outcrop is tan in contrast to the gray- and tan-streaked color of the higher beds. The tan color is due to the weathering of limestone containing clay and silt impurities and to the color of weathered sandstone. That the limestone may have been chemically precipitated is indicated by the lithographic texture, the lack of fossil shell detritus, the lack of fossils except for tiny pelecypods, and the presence of oolites in some beds. Angular grains of quartz and feldspar sand are scattered through some limestone beds. Beds and lenses of brown-weathered and white-weathered quartz sandstone and arkose are common but diminish in number upward. Some sandstone beds contain black fossil wood. Exposed ledges of limestone and sandstone, which are mostly I to 5 feet thick, are separated by thicker covered intervals occupied by gray and red shale. No significant fossils were collected from this member, but well-preserved pelecypods noted in the upper part may be useful in determining its age. The lithology of this member grades imperceptibly into that of the overlying oyster limestone member, the dividing line being drawn where tan-weathered beds give way upward to alternating gray and tan beds. In the Hell-to-Finish Tank section, the contact is at the base of unit 95, which is the first prominent gray-weathered limestone bed in the section. At the base of the Little Hat Top section, 25o feet of beds, mostly concealed, are assigned to this member.

The overlying oyster limestone member of the U-Bar Formation, named for an abundance of large oysters, may be distinguished by the following characteristics: Most exposed rock is thin-bedded limestone except for one or two massive beds in the upper part. It is composed almost entirely of fossil shell fragments, giving the rock a conspicuous elastic texture. Oysters and other fossils are abundant. A few arkosic and quartz sandstone beds are present and are particularly obvious in the lower part. Shale is exposed between some limestone ledges, although most intervals between limestone ledges are covered. The member crops out on low hills ribbed evenly by steeply dipping, thin beds of limestone separated by thicker bands of concealed shale. Massive limestone beds in the upper part form prominent but low ridges. The over-all color of the outcrop is gray with a few tan streaks caused by tan-weathered limestone. This member has a greater variety of lithologies than other parts of the formation. Its thickness is about z000 feet.

Basal thick beds of the oyster limestone member consist of massive gray limestone containing 3-foot-thick lentils of half-inch silicified *Exogyra* shells which weather brown and in relief. Such *Exogyra* lentils are a distinctive feature not found in other parts of the formation. Some of these limestone beds are lens shaped; some contain lenses of quartz sandstone. With the aid of these characteristics, these beds may be recognized and correlated in the upper part of the Hell-to-Finish Tank section, in the Big Tank Southeast section, and in the Little Hat Top section.

A mile west of Hell-to-Finish Tank, two beds of gypsum 20 and 5o feet thick are intertongued with basal U-Bar limestone beds containing *Exogyra* lentils. The gypsum is white and contains thin strata of limestone and dolomite and laminae of clay. Concealed intervals in this part of the section may obscure other gypsum beds.

The bulk of the oyster limestone member consists of a variety of lithologies. Most conspicuous are beds of limestone with silt concentrations and an abundance of large oyster shells. Large *Pecten* shells are present but not abundant. The color of the fresh and weathered rock is medium gray due to oyster shells and mottled with orange-brown due to silt. Surfaces weather lumpy and are rough because of partial silica replacement of oyster shells. Beds range from I to about 6 feet in thickness, averaging about 3 feet. Such oyster-rich limestone beds are particularly abundant in the upper two-thirds of the member.

Also common in the member are beds of bioclastic limestone that contain small fossils other than oysters. The rock has various amounts of silt and fine quartz sand in irregular concentrations which produce orange-brown streaks in the fresh gray limestone. Weathered surfaces are gray mottled with orange-brown patches due to the silt concentrations, and many surfaces are lumpy because of differential weathering of pure limestone and silty bodies. The proportion of silt and sand is so great in some beds that the rock weathers brown, is cross laminated, and has a blocky fracture. A few thin beds of brown-weathered siltstone and white, fine-grained, quartz sandstone are present. Fossil wood is found in some of the sandstone beds. Gray and brown clay shale with septarian limestone concretions occurs as thin units between limestone beds; near the middle of the Little Hat Top section, one such shale unit is 155 feet thick. Surfaces of concretions in some of the shale beds have small, brown, glossy pelecypod and gastropod shells.

Units of massive limestone occur in the middle and upper parts of the oyster limestone member. A single massive limestone unit loo feet thick is found in the Pierce Tank section (fig. 16; the massive limestone forms part of the Pierce Tank dam). The same one may be identified by detailed matching of underlying and overlying beds and of faunal zones in the Little Hat Top section (fig. 17) and in the

Figure 16

Pierce Tank section.

Steeply dipping Cretaceous rocks are blanketed by gently dipping Tertiary fanglomerate; the contact is an angular unconformity. Recent erosion near Pierce Tank removed the fanglomerate and exposed the pre-fanglomerate pediment surface; the eroding edge of the fanglomerate forms a prominent escarpment. Formations indicated on the photo are as follows: Ku—U-Bar Formation; Km—Mojado Formation; and Tfg —Tertiary fanglomerate. Section is indicated by heavy dot-dash line. View is toward the southeast.

exposures about midway between Little Hat Top Butte and Hell-to-Finish Tank. Two massive limestone units are present a mile west of Hell-to-Finish Tank; three such units are present in the Big Tank Southeast section, although one that is 34 feet thick in the section wedges out in a distance of 15o feet along the strike. Where present and persistent, these massive units form low but distinct ridges that may be traced for long distances.

The rock of each massive limestone unit is the same. It is calcarenite, medium gray on fresh and weathered surfaces, finely crystalline, and composed mainly of fossil shell fragments. Weathered surfaces have a finely speckled appearance due to the shell detritus, a feature that distinguishes these limestones from the lithographic limestone of the reef member higher in the formation. Some fossils and fossil fragments are replaced by brown-weathered chert. Small, brown-stained crystals of authigenic quartz, which sparkle in the sun, are dispersed through some beds. Oolitic limestone occurs in a few strata and lenses. Complete fossils are not abundant, but a few heavy-shelled pelecypods and colonies of coral and rudistids are present. Beds are 5 to 20 feet thick; some are coarsely cross laminated. The general lithology of beds that lie above each massive limestone is the same as that of beds below. Though these units of thick bedded calcarenite have some of the features of biohermal reefs, such factors as bedding, cross lamination and apparent absence of a solid organic framework do not support a reef interpretation.

Figure 17

LITTLE HAT TOP SECTION.

This northwest view in Mojado Pass shows the small thrust plate in which the section is located. Section is indicated by dot-dash line. The following formations are indicated: Ku—U-Bar Formation; and Km—Mojado Formation. U-Bar Ridge is seen in the left background.

This richly fossiliferous member of the U-Bar Formation may be a source for petroleum. Oil and gas content of the rock is indicated by the strong petroliferous odor of freshly broken limestone and sandstone and by a strong natural gas odor noted while digging with a prospect pick in shale rich in pelecypods. In collecting fossils from a dense limestone bed, a pelecypod was broken that had a small, central cavity from which a drop of liquid petroleum flowed.

The limestone-shale member, next in the sequence, was studied in the U-Bar Ridge and Pierce Tank sections. Where the overlying reef limestone is thin, as at Pierce Tank, the limestone-shale member is thick; where the reef is thick, as on U-Bar Ridge, the underlying member is correspondingly thin. The total thickness in each measured section from the base of the limestone-shale member to the top of the formation is the same.

On U-Bar Ridge, the lower 200 feet of the member is brown-weathered clay shale which breaks into fine, equidimensional fragments. It includes a few beds of calcareous siltstone and a few peculiar 6-inch nodules of silty limestone that have large-diameter, silt-filled worm borings on the surfaces and crystalline calcite and celestite in the cores. The shale rests upon the relatively smooth bedding surface of the highest limestone bed of the oyster limestone member. Within the lower few feet of shale, perfectly preserved large oyster shells weather free from the soft matrix. Exposures are found only where deep gullies have cut through overburden on the steep slope of the ridge. The thick shale at the base of the member is either thin or missing in the Pierce Tank area where a thin sequence of beds of this interval is covered.

The remainder of the limestone-shale member consists of alternating beds of dense limestone and of shale and claystone. The thickness of the limestone beds ranges from 10 inches to 15 feet and averages about 3 feet. Shale and claystone beds have a similar range of thickness but average about 6 feet. The fresh limestone is usually dark gray; in some beds it has a faintly brown tint. Weathered surfaces are light bluish gray and smooth. A few beds have rough surfaces. The texture is very finely crystalline to lithographic. Fossil shell detritus, though visible with a lens on moist, fresh surfaces, is not abundant or conspicuous. Fossils commonly seen include echinoids, small oysters, the foraminifer *Orbitolina*, and the 8-inch-diameter gastropod *Lunatia? praegrandis* Roemer.

In the U-Bar Ridge section, fissile shale is exposed between the limestone beds of the member. The shale is light gray and is composed entirely of clay. Echinoid tests preserved in minute detail weather from the shale and are abundant on the outcrop. Intervals between limestone ledges in the Pierce Tank section are covered, but 2-foot holes dug in some of the intervals exposed light-gray, soft, silt-free claystone. Shale may be present in these intervals at greater depths, and the claystone may represent weathered shale.

The alternating beds of limestone and shale are overlain by the reef limestone member, which forms conspicuous cliffs where thick as on the crest of U-Bar Ridge. The massive limestone of the member has a thickness of 218 feet in the U-Bar Ridge section; it thickens to a maximum of about 500 feet on the prow of U-Bar Ridge a mile to the north. From here southeastward, the massive limestone progressively thins to about 100 feet at the end of the ridge; about five miles farther southeast in the Pierce Tank section, the member is only 19 feet thick.

The limestone is light gray on fresh fracture; weathered surfaces, which are as rough as sandpaper, are light gray with a blue tint in some parts and a brown tint in others. Surfaces of the reef-rock etched by weathering reveal its original elastic texture composed of sand-sized grains of fossil shells. Laminae and lenses of such detritus are obvious. However, the texture of freshly fractured rock is finely crystalline to lithographic and dense because of recrystallization that obscured the original elastic texture. The rock is massive, it has no clearly defined stratification, and bedding-plane fractures are rare and widely separated. Fossils include rudistid pelecypods, other heavy-shelled pelecypods, colonial corals, and gastropods.

This limestone member is interpreted as a fossil biohermal reef. The unit is massive limestone that has practically no stratification. It progressively thickens from 19 to 500 feet in about eight miles. The top of the massive rock is undulating; thin beds lying between 50-foot high projections on the surface bend upward, thin, and disappear adjacent to projections. The rock consists mostly of fossil shell detritus, and as in many fossil reefs, the rock was recrystallized to a lithographic texture (*see* Newell et al., 1953, p. o9; "The primary organic structures [of fossil reefs] are generally obliterated by recrystallization, and the secondary texture is exceedingly fine."). Small areas of dolomite are present in the massive rock in the Roberson Ranch section. Faunas, including rudistids and colonial corals, are types that are common in fossil reefs and much less common in rocks formed in other environments. Rudistids are present in all the Early Cretaceous reefs in this region.

To add further information on the biota of the rock and its possible depositional environments, rock samples were collected at irregular intervals throughout the massive limestone unit in the U-Bar Ridge section. Thinsections of these specimens were examined for calcareous algae by Richard Rezak (written comunication, 1963), whose identifications are as follows:

1024B Fragments of *Boueina* (codiacean alga) and recrystallized coralline algae?
1024D No algae; stromatoporoid on rudistid
1024F Possible coralline algae
o24H No algae
1024J Indeterminate coralline algae
1024L No algae
o 24N Cf. *Cayeauxia* and indeterminate coralline algae
o 24R Abundant stromatoporoids encrusting rudistids; no algae
1024S No algae
1024U *Acicularia, Terquemella* (green, dasyclad algae)

Concerning the interpretation of the collection, Rezak says, "The only algae in the list that might support a reef interpretation are the corallines. Other evidence that gives stronger support to your argument is the presence of rudists encrusted by stromatoporoids." Such forms apparently contributed to the construction of the solid framework about which the reef was built.

Specimen 1024U was collected from one of the first distinct beds above the massive reef; *Orbitolina* is present in this bed, as well as green dasyclad algae. Concerning the depositional environment indicated by the green dasyclad algae, Rezak comments, "These are indicators (when abundant) of extremely shallow (wading) depths and tropical to sub-tropical water temperatures." He further states that these would indicate a back-reef facies and that they did not grow in abundance in a reef environment. These beds immediately above the reef may be a back-reef facies deposited as the site of reef growth shifted laterally.

Thinner limestone beds that lie between the reef and the top of the U-Bar Formation are assigned to the suprareef limestone member, which is about 25o feet thick in the U-Bar Ridge and Roberson Ranch sections; it appears to be of similar thickness along the full length of U-Bar Ridge. Beds of this member occupy the dip slopes of U-Bar Ridge. In the Pierce Tank section where the reef member is thin, the suprareef limestone is only 2 feet thick.

This member consists of limestone beds between 5 and 15 feet in thickness. Bedding planes are distinct, and many limestone beds are separated by thin, shaly partings. Most of the limestone is dark when fresh and light bluish gray when weathered. Beds rich in silicified fossils weather to shades of brown. The rock consists primarily of fossil shell detritus, although in some beds the limestone has been recrystallized and has a finely crystalline texture; one bed is oolitic. Petroliferous odor is strong on freshly broken rock of many beds. Fossils are abundant and varied in type in some strata. Rudistids, which I tentatively called *Toucasia*, and miliolid foraminifers are found together and in abundance in some beds; other beds are rich in *Orbitolina* that comprise nearly all of the rock. A few shale and claystone beds were noted in the upper part.

The contact between the U-Bar Formation and the overlying Mojado Formation is transitional and conformable. Limestone of U-Bar type is interbedded with sandstone of Mojado type. The contact was arbitrarily chosen at the base of the lowest sandstone bed, which is also the boundary dividing the predominance of limestone below and sandstone above in all places noted. The contact is exposed in many places near Pierce Tank but is concealed at the base of U-Bar Ridge.

The total thickness of the U-Bar Formation is about 3500 feet.

A Lower Cretaceous limestone formation is found in the Sierra Rica, which is equidistant from Cretaceous exposures in the Little Hatchet Mountains and in Mojado Pass south of the Big Hatchet Mountains. From spatial relationships, it could as well represent the U-Bar Formation as one of the several similar limestone formations in the Little Hatchet Mountains. However, this limestone is confidently identified as the U-Bar Formation on the strength of three factors. First, the formation in the Sierra Rica is lithologically similar to the U-Bar; each member of the U-Bar Formation is present in the Sierra Rica. Second, the faunas, though not studied, are similar in aspect; the index fossil *Lunatia? praegrandis* Roemer, which is present in the limestone-shale member in Mojado Pass, was found in the corresponding member in the Sierra Rica. Third, the limestone in the Sierra Rica is overlain by a sandstone formation that is identified on good fossil evidence as the Mojado Formation; since the limestone underlying the Mojado in the type area is the U-Bar Formation, the limestone underlying the Mojado in the Sierra Rica should also be the U-Bar Formation. The U-Bar Formation was not studied in the Sierra Rica because it is faulted and because it is strongly silicified near igneous intrusions.

The U-Bar Formation is exposed in the east-central part of the Animas Mountains where the formation was deposited during growth of the anticline southwest of the Winkler Ranch (Zeller and Alper, in press). Identification of the formation here is based upon the same criteria used in its identification in the Sierra Rica. It is lithologically similar to the type U-Bar; its fauna, though not studied, resembles that of the U-Bar; and, like the type U-Bar, it is overlain by a sandstone formation that is identified by conclusive fossil evidence as the Mojado Formation.

Age

The U-Bar Formation has a rich and varied marine fauna, which includes pelecypods, gastropods, echinoids, corals, ammonites, nautiloids, and foraminifers. Fossils that are abundant and obvious, such as *Ostrea*, are usually long-ranging forms that are useless for precise age determination or for zoning the formation. Rare but useful fossils, such as ammonites, are very difficult to find and, when found, many are too poorly preserved to be serviceable.

Because of the importance of the U-Bar Formation in interpreting regional Lower Cretaceous stratigraphy, a special effort was made to collect enough significant fossils to date and zone the formation. Many months were devoted to the collection of fossils and the study of stratigraphic sections; slopes were combed for loose specimens of ammonites; trenches were excavated in some ammonite-bearing beds; one ammonite the size of an automobile wheel required several days of careful drilling and blasting to remove it from bedrock. These efforts yielded disappointingly few specimens of identifiable significant fossils, and most of these are only fragments. However, this collection is sufficient to provide the age of parts of the formation, which is valuable in correlation.

Most of the collections from the subreef part of the U-Bar Formation were submitted to Alexander Stoyanow, who selected the significant fossils for study. Small fossil collections from the reef and suprareef members of the formation, in which no ammonites were found, were sent to Ralph W. Imlay, who studied some of the pelecypods, to Norman F. Sohl, who studied some of the gastropods, and to Robert F. Perkins, who studied the rudistid pelecypods. The orbitolinas were studied by Raymond C. Douglass.

The subreef part of the U-Bar Formation may be classified according to European stages by using a few ammonites, and according to Gulf Coastal Plain terminology by using a few regional index fossils. Comparison of the European and Gulf Coastal Plain classifications may be seen in the Cretaceous correlation charts by Cobban and Reeside (1952). Although the two classifications are hardly compatible, both are used in this report to aid students of international and of regional Cretaceous stratigraphy.

No fossils of specific age significance were found in the lower 1200 feet of the U-Bar Formation, which includes the brown limestone member and the lower part of the oyster limestone member. A number of ammonites were found in the lower part of the oyster limestone member in the Little Hat Top section, but they are fragments that are corroded beyond the point of determining the genera with certainty. As overlying beds contain late Aptian index fossils and as no depositional breaks are evident, this lower part of the U-Bar Formation is probably Aptian in age.

The part of the formation from the lower oyster limestone to the base of the reef limestone is partly zoned on the basis of ammonites, the universal medium for Cretaceous zonation. Ammonites and a few regional index fossils from these beds were studied by Stoyanow (personal communications, 1952-1964), who supplied the identifications and age information. Based upon study of the ammonites, Stoyanow chose the position of the Aptian—Albian boundary in the U-Bar Formation. His identifications are shown on Plate 5.

Two significant ammonite faunulae are present in the upper part of the oyster limestone member. Stoyanow's conclusions regarding the late Aptian age of these are summarized as follows: The lower faunule is represented by new genera and species of parahoplitan ammonites found in both the Pierce Tank and Little Hat Top sections in the same bed (collections 7b and 75g). Though the specimens are only fragments, their identification as parahoplitids is certain, and they are definitely of Aptian age. The upper faunule, collection 73a from near the base of the Big Tank Southwest section, is represented by several species of *Immunitoceras* of very late Aptian age. The specimens are numerous and well preserved. The *Immunitoceras-bearing* strata of the Big Hatchet Mountains area are equivalent in age to division 3b of the Quajote Member of the Lowell Formation in southeastern Arizona. That division in Arizona contains *Immunitoceras immunitum* and several species of *Acanthohoplites.* The two Aptian ammonite faunulae of the Big Hatchet Mountains area are affiliated with the parahoplitids described from the Caucasus—Transcaspian region of Russia and of southeastern Arizona.

Early Albian age of the limestone-shale member is indicated by the ammonite *Douvilleiceras mammillatum,* which is a standard Albian index fossil. It was found in place in the Pierce Tank section. Loose specimens of the ammonites *Douvilleiceras mammillatum, Prolyelliceras?* sp. and *Protanisoceras* cf. *hourcqi* derived from the limestone-shale member in the U-Bar Ridge section further indicate early Albian age for the member.

As selected by Stoyanow, the Aptian—Albian boundary in the U-Bar Formation lies within a 400-foot stratigraphic interval between highest Aptian and lowest Albian ammonites. The highest Aptian fossil lies near the top of the oyster limestone member. The Aptian—Albian boundary may coincide with the lithologically sharp contact between the oyster limestone and the limestone-shale members, or it may be somewhat higher.

In terms of Gulf Coastal Plain nomenclature, the part of the U-Bar Formation from the lowest significant fossil through the *Douvilleiceras mammillatum* zone correlates with the Trinity Group. *Douvilleiceras mammillatum* has been found in the Trinity of western Texas. Other Trinity fossils present in these beds and shown on Plate 5 support this equivalence. *Pterotrigonia stolleyi* occurs in the Glen Rose Formation of Texas; *Exogyra quitmanensis* is present in the Cuchillo Formation of the Quitman Mountains of western Texas. The Cuchillo and Glen Rose Formations are in the Trinity Group.

A float specimen of *Pinna guadalupae* found in the U-Bar Ridge section was derived from the uppermost beds of the limestone-shale member. This pelecypod, previously found in Texas, is not known from beds older than Fredericksburg. Either the upper beds of the member are of Fredericksburg age or the range of the fossil is lower here than in the Texas occurrences.

The remainder of the U-Bar Formation, the reef and suprareef members, has yielded no ammonites. Certain significant fossils in these members suggest a Fredericksburg age.

A fauna chiefly of pelecypods collected from the supra-reef member in the Roberson Ranch section was sent to Ralph W. Imlay for study. His identifications and comments (written communication, 1962) are as follows:

collection 2m:
Neithea irregularis (Bose)
Protocardia texana (Conrad)
Lima wacoensis Roemer

collection 2k:
Neithea irregularis (Bose)

collection 2j:
Neithea irregularis (Bose)
Lima wacoensis Roemer
Lima (Plagiostoma) sp.
Nucula? sp.
Protocardia cf. *P. texana* (Conrad)
Modiolus? sp.
Ostrea sp.
Brachiopod undetermined

collection 2e:
Monopleura?

collection 2d:
Pinna guadalupae Bose
Neithea irregularis (Bose)

collection 2g:
Rudistid undetermined

Adkins (i928) lists *Neithea irregularis* (Bose) from the Fredericksburg group and questionably from the Glen Rose limestone. He lists *Pinna guadalupae* Bose, *Lima wacoensis* Roemer, and *Protocardia texana* (Conrad) from both the Fredericksburg and Washita groups. As *Neithea irregularis* (Bose) is the most common species present, a Fredericksburg age is more likely than a Washita age for the collections in which it occurs.

Gastropods from the reef and suprareef members of the U-Bar Formation in the Roberson Ranch section were examined by Norman F. Sohl, who (written communication, 1963) reports on them as follows:

collection 2M:
Indeterminate internal molds of a naticid snail

collection 2j:
Turritella seriatimgranulata Roemer cf.
Aporrhais? subfusiformis (Shumard)
Tylostoma cf. regina (Cragin)

collection 2i:
Cerithium cf. C. *quitmanense* Stanton

collection 2c:
Nerinea incisa Giebel—N. bicoriensis
Cragin group

collection 2a:
Cerithium cf. C. *quitmanense* Stanton

collection 1 h:
Cassiope sp.

The state of preservation of the material does not allow for precise determination. My overall feeling is that there are no Washita beds involved in the sequence from which the collections were made. I suggest that the nerineas of collection 2c are Trinity to low Fredericksburg. The higher collections especially 2i and 2j are most likely Fredericksburg.

Rudistid pelecypods collected from the Roberson Ranch and U-Bar Ridge sections were studied by Robert F. Perkins. Collections 2f, 4c, 4p, and 1025 were from the suprareef limestone member of the U-Bar Formation; the other collections were from the reef limestone member. Perkins' identifications (written communication, 1962) are as follows:

Note: Specimens for which thinsections were made are indicated by (TS).

collection 1a:
1. monopleurid or primitive caprotinid (TS)
2. ? (TS)
3. Same as 1a-1

collection id:
I. monopleurid? (TS)
2. ? (crushed)
3. ? (crushed)
4. fragments
5. caprotinid
6. caprotinid? (TS)
7. caprotinid

collection le:
I. caprinid? (TS)
2. caprinid? (TS)
3. caprinid (Fredericksburg type) (2 TS)
4 ?

collection if:
I. ?
2. caprotinid?
3. caprotinid?
4. caprotinid?
5. ? (fragment)

collection 2f:
1. radiolite

collection 4p:
I. requieniid (not necessarily *Toucasia)*
2. requieniid (not necessarily *Toucasia)*

collection 4c:
I. radiolite (Fredericksburg type)

collection o 5 :
x. radiolite, possibly *Eoradiolites* sp. (Fredericksburg type)

Most of the specimens are too poor to be used for age determination. However, two of them may be dated as Fredericksburg. Perkins states that "The first (e-3) is a caprinid lower valve. I cannot be sure of a generic assignment but the canals in the shell wall are of a type which is not known below the Fredericksburg in Texas." The other one is collection 1025, of which Perkins says, "There is no question about the Fredericksburg age of this radiolite colony. I would tentatively identify the fossil as *Eoradiolites* sp."

The large conical and discoidal foraminifer *Orbitolina* is conspicuously abundant in some beds of the upper U-Bar Formation. The lowest occurrence is in the middle of the limestone-shale member; they are extremely abundant in some beds near the top of the member. Isolated specimens occur in the overlying reef limestone. Orbitolinas are present in great numbers in some thin beds of the suprareef limestone member and are found at the very top of the U-Bar Formation.

The lowest Orbitolina-bearing strata lie between beds containing Trinity ammonites and therefore are of Trinity age. Somewhat higher beds contain *Orbitolina* but no other fossils of definitive age. The suprareef limestone member in the Roberson Ranch section contains the molluscs of presumed Fredericksburg age listed above. A limestone bed composed almost entirely of *Orbitolina* lies about 35 feet stratigraphically above the stratum from which the molluscs of collection 2m were taken.

Raymond C. Douglass (1960) studied the genus *Orbitolina* in North America. He indicated that the absolute strati-graphic range of the genus is still unknown, although the presently reported range is from late Neocomian (early Early Cretaceous) to Cenomanian (early Late Cretaceous). In North America, *Orbitolina* is known only from rocks considered to be of Trinity age; it has been used as a Trinity index fossil in the Southwest.

Thus, the indicated age of the suprareef limestone member is Fredericksburg according to the molluscs and Trinity according to the orbitolinas.

Though *Orbitolina* is currently considered as a more reliable age indicator than the identified molluscs, the stratigraphic range of *Orbitolina* in this region should be reexamined in the light of this occurrence. Many of the species of *Orbitolina* known in southeastern Arizona and southwestern New Mexico occur above the highest beds having fossils of definite Trinity age. For instance, no fossils restricted to the Trinity are known in or above the Orbitolina-bearing strata of the Mural Limestone in southeastern Arizona or the Playas Peak Formation of the Little Hatchet Mountains. As no Fredericksburg fossils are known in these beds, and as other species of *Orbitolina* are of Trinity age, these species were thought also to be Trinity.

However, the following evidence suggests that some of the highest orbitolinas of southeastern Arizona and southwestern New Mexico could be Fredericksburg age; the highest orbitolinas in the Big Hatchet Mountains area occur above molluscs of presumed Fredericksburg age; no evidence in the region disputes Fredericksburg age for the highest orbitolinas; and post-Trinity age would not be extraordinary as *Orbitolina* is known to range into the Late Cretaceous in the Mediterranean region.

Prior to the identification of the molluscs from the suprareef limestone member, my collections of *Orbitolina* from the reef and suprareef limestone members of the U-Bar Formation were studied by Douglass (1960, p. 5). He reported that they are similar to the orbitolinas of the Mural Limestone. This suggests correlation of the upper U-Bar Formation with the Mural, which is not unlikely.

The age of the U-Bar Formation may be summarized as follows: In terms of European stages, it ranges from Aptian to early and possibly middle Albian. In terms of Gulf Coastal Plain terminology, it ranges through Trinity and probably into Fredericksburg. The Aptian—Albian boundary lies near the contact between the oyster limestone and limestone-shale members; the Trinity—Fredericksburg(?) boundary is close to the contact between the limestone-shale and reef limestone members.

Correlation

Correlation of the U-Bar Formation with other Lower Cretaceous limestone formations in the region is complicated because of the several similar limestone formations in the Little Hatchet Mountains. To which one or ones does the U-Bar Formation correlate? Until correlation of the Cretaceous formations is possible between the Big Hatchet and Little Hatchet Mountains only a short distance apart, correlations of the U-Bar Formation with other formations in the region cannot be firmly established. The problems of Cretaceous correlations are discussed later.

Even though confident correlations are not possible at present, the similarity of lithology and of faunas suggests correlations of the U-Bar Formation with other formations in the region. Several such possible correlations are as follows:

The Broken Jug Limestone in the Little Hatchet Mountains has index fossils that are present in the U-Bar Formation. Stoyanow (written communication, 1955) identified from my Broken Jug collections the nautiloid *Cymatoceras neohispanicum* and the ammonite *Douvilleiceras mammalatum,* both of which are found in the U-Bar Formation. Lithologically, the two formations are similar.

The Lowell Formation of southeastern Arizona, which was named and described by Stoyanow (1949), has a number of regionally significant fossils in common with the U-Bar Formation. The lithology of the Lowell together with the overlying Mural is similar to that of the U-Bar Formation.

Some regional index fossils of the Glen Rose Formation of Texas are found in the middle part of the U-Bar Formation. *Douvilleiceras mammillatum* is found in the upper Cuchillo Formation in the Quitman Mountains and in the lower Glen Rose of the Solitario in central Texas. *Pterotrigonia stolleyi* and *Lunatia? praegrandis*, which are present in the U-Bar Formation, are Glen Rose fossils. Both the Glen Rose and the U-Bar are predominantly limestone.

The Carbonate Hill Limestone of the central Peloncillo Mountains (Gillerman, 1958) has a fauna containing fossils found in the U-Bar Formation. The parahoplitids found in each formation are of the same faunal zone. The lithology of the formations is similar, but the Carbonate Hill Limestone is only about 200 feet thick.

MOJADO FORMATION

The Mojado Formation, the uppermost division of the Lower Cretaceous sequence in the Big Hatchet Mountains area, is here named for Mojado Pass in which it is exposed. It consists of more than 5000 feet of interbedded sandstone and shale that rests conformably upon the limestone of the U-Bar Formation and that is overlain with angular unconformity by Tertiary fanglomerate. The Mojado Formation was studied in the U-Bar Ridge and the Pierce Tank sections, which are described later and are shown graphically on Plate 5. The upper part of the U-Bar Ridge section is designated as the type section.

Distribution and Topographic Expression

Within the area covered by this report, the formation is exposed in Mojado Pass south of the Big Hatchet Mountains and in the Sierra Rica. The formation is nonresistant in the Mojado Pass area and is exposed chiefly in places where a protective blanket of resistant Tertiary fanglomerate has been stripped off by recent erosion. It is resistant in the Sierra Rica because of silicification and is exposed in hills and low mountains.

The most complete exposure of the formation in Mojado Pass is on the west, north, and northeast flanks of the hill in S1/2 sec. 20, T. 32 S., R. 15 W., where it has been protected by the overlying fanglomerate that caps the hill. The type section traverses this exposure. A small inconspicuous exposure in NW1/4 sec. 9, T. 32 S., R. 15 W. is marked only by an area of sandstone rubble. A similar rubble-marked exposure of the formation is found near the corner common to secs. 13, 14, 23, and 24, T. 32 S., R. 15 W. Another exposure encircles Little Hat Top Butte, which lies just south of the boundary of the Big Hatchet Peak quadrangle in NE1/4 sec. 25, T. 32 S., R. 15 W. The butte is capped by cemented Tertiary fanglomerate; recent erosional recession of the capping has exposed the Mojado Formation. From here southeastward for several miles into the Dog Mountains quadrangle, the formation crops out in low hills in a wide band from which the overlying fanglomerate has been stripped. This band of exposures is shown on the reconnaissance geologic map of the Dog Mountains quadrangle (Zeller, 1958b) as "Cretaceous sandstone."

In the Sierra Rica, the principal exposure of the Mojado Formation is in a 1 1/2-mile-wide band along the southwestern side of the range. Northeast of here, a narrow strip of the formation is duplicated by a large high-angle fault.

The formation is poorly resistant to erosion in the Mojado Pass area, and its exposures lie at the base of hills capped by the fanglomerate or on low-lying exhumed pediment surfaces. Here it is characterized by long ribs of steeply dipping sandstone beds separated by partly covered intervals of shale. On the north side of the hill on which the type section lies, the formation dips steeply toward the east, and long sandstone ribs extend for some distance northward.

In the Sierra Rica, silicification has uniformly hardened the formation; as a result, the rib-and-trough topography is subdued. Several thick quartzite beds are prominent. The drainage of the area trends at right angles to the strike of the formation, which produces southwestward-trending high spurs in the southwest part of the range.

Stratigraphy

The conformable relation of the Mojado Formation and the underlying U-Bar Formation is indicated by the mingling of limestone and sandstone beds in a thin transition zone. The base of the Mojado is selected at the base of the lowest sandstone, which is also the division between the predominance of limestone below and sandstone above. The contact is exposed in the Pierce Tank section, but it is concealed under a 660-foot interval in the U-Bar Ridge section. That the contact lies at the base of the concealed interval in the latter section is indicated by the abruptness with which the slope of the upper U-Bar Formation rises from the valley. Because the U-Bar Formation is resistant and the Mojado Formation is weak, the contact probably lies at the sharp change in slope at the base of U-Bar Ridge.

A thickness of 5195 feet of Mojado Formation was measured in the U-Bar Ridge section. For convenience of description, the formation in this stratigraphic section is divided into two members: the lower one, 4109 feet in thickness, consists chiefly of unfossiliferous sandstone and shale; the upper one, 1086 feet in thickness, is also composed mainly of sandstone and shale but includes thin beds of sandy limestone and calcareous sandstone in which marine fossils are abundant.

The lower member is composed of a rather uniform sequence of interbedded sandstone and shale. The sandstone occurs typically in thin, lensing, cross-laminated beds. Fresh rock is gray. Most rock surfaces are stained to shades of brown by various types of limonite concentrations, but some beds are white or light gray; weathered color often changes along the strike of a bed. The sandstone is composed mainly of angular to subangular quartz of medium and fine sand size; a few beds contain small amounts of feldspar and biotite. Much of the rock is only weakly cemented, but in resistant beds, the sandstone is firmly cemented by calcite. In some beds, the calcite cement is in optical continuity over areas of up to a square inch in diameter; freshly broken sandstone rotated in sunlight shows flashes of light reflected from the cleavages of the large calcite crystals. Intervals between sandstone beds, though usually concealed, are occupied by unconsolidated clay and silt and by more firmly consolidated shale and siltstone. Channel cut-and-fill structures are common; channels in argillaceous rocks are filled with sand. Several of the clay beds in the lower part of the member are unconsolidated and have small limestone nodules. Underlying sandstone beds have concentrations of limonite on their upper surfaces in contact with the clay zones. These clays are thought to represent "fossil" soil zones. Although this part of the formation is not conspicuously fossiliferous, a few fossil oysters, other pelecypods, and fossil wood fragments are found in the upper beds.

The upper member of the formation is much like the lower member in that interbedded brown-weathered sandstone and argillaceous beds are predominant. It differs from the lower member in having calcareous beds rich in marine fossils; some beds are of calcareous sandstone, some are of brown-weathered quartzose and silty limestone, and others are of brown-weathered limestone. The proportion of calcareous beds increases upward to the highest exposure of the formation beyond which alluvium covers bedrock. Marine fossils, especially pelecypods, gastropods, and the foraminifer *Haplostiche texana,* are concentrated in strata and lenses in such quantity as to produce coquinas. In a few strata, the fossils are replaced by white chert. Fossil plants occur in several shale interbeds. One of the uppermost, profusely fossiliferous limestone beds has a distinct petroliferous odor on freshly fractured surfaces.

In the Pierce Tank section where only the lower 175o feet of the Mojado Formation is exposed, the contact with the underlying U-Bar Formation is visible. Above the base of the lowest sandstone, which is chosen as the contact, U-Barlike limestone beds are rare, but a few are found through the lower 185 feet of the Mojado Formation

In this section, the formation is steeply dipping and is exposed on a surface of little relief, which is an exhumed pediment formed prior to deposition of the Tertiary fanglomerate (fig. 16). Ledges of sandstone are exposed between concealed intervals presumably occupied by soft argillaceous sediments. The sandstone is thin bedded, strongly cross laminated, and lensing. Pod-shaped sandstone exposures in the midst of alluvium-covered areas evidently represent the cemented sand fillings of channels cut into argillaceous sediments. One such lens has a length of 120 feet and a maximum thickness of about Io feet. The thinly cross laminated sandstone breaks into flagstone slabs. The sandstone consists of fine- and medium-grained subangular to subrounded medium- to well-sorted quartz sand which is both poorly and well cemented. Silica cement produces resistant lenses within poorly cemented quartz sandstone, and it also produces resistant sandstone beds. However, most of the rock is indurated to various degrees by calcite cement, and poorly cemented portions are quite porous. Fresh sandstone is medium and light gray or white; weathered rock is white, gray, and brown. The well-cemented sandstone and some of the poorly consolidated sandstone weather white.

Throughout this stratigraphic section, fossils are rare in the Mojado. Marine pelecypods occur in a few sandstone beds and in a few thin beds of sandy brown- and gray-weathered limestone distributed through the section. Fragments of fossil wood are found in the rubble of some of the concealed intervals. In one such interval near the top of the section, a fossil log two feet in diameter was noted. Exposures of the Mojado Formation in the Pierce Tank section are terminated upward by Tertiary fanglomerate, which lies upon the Cretaceous rocks with sharp angular unconformity.

In the Sierra Rica where the formation was silicified, the sandstones were converted to quartzite and the shales were hardened to hornfels. The formation is cut by a great number of post-Early Cretaceous latite porphyry dikes and sills, which probably are related to the monzonite stock exposed several miles to the north in the Apache Hills. The introduced silica was apparently derived from such igneous intrusions. In some places, the hornfels is more resistant than the sandstone. Some of the uppermost beds of the formation exposed in E1/2 sec. 32, T. 29 S., R. 14 W. are massive white quartzite which contains hollow molds of marine pelecypods. Fossils were not found below this bed. North of the boundary of the Big Hatchet Peak quadrangle in NE1/4 sec. 3o, T. 29 S., R. 14 W., beds of fossiliferous calcareous sandstone and thin beds of fossiliferous, sandy, brown-weathered limestone are exposed in a zone that lies between 4000 and 5000 feet above the base of the formation. The diagnostic Washita foraminifer *Haplostiche texana* is present in these beds. The lithologic character, composition of the fauna, and the position of these beds above the formation's base show that this zone corresponds to the fossiliferous calcareous Washita zone that lies about 4200 feet above the base of the formation in the type section. The uppermost part of the formation is concealed by an overthrust sheet and alluvium in the Sierra Rica.

The Mojado Formation was probably deposited on the coastal plain of the Cretaceous sea. Argillaceous sediments were deposited upon flood plains and sands were deposited in stream channels which migrated laterally. The fluviatile origin of the sandstones is indicated by the channel cutand-fill structures, the lensing of beds, and the pronounced cross-lamination. Subrounding of the sand grains shows that the sediments were abraded through transport. General lack of coarse detritus shows the area to have been of low relief and the streams to have had gentle gradients. The few conglomerate beds may be the records of floods. Probable "fossil" soil zones found in the lower part of the type formation are compatible with a coastal-plain origin. The rare occurrences of marine fossils in the lower 400o feet of the formation resulted from brief periods of marine inundation. The increasing frequency upward of calcareous marine beds shows that the advances of the sea became more common in late Mojado time. That these marine beds are found in the Mojado Pass area and in the Sierra Rica at about the same stratigraphic level, and that each contains the same fauna, shows that increased frequency of marine flooding became widespread in late Mojado time. Plant remains found associated with marine beds may have been carried to the sea from nearby land by flooding streams. After the wood became waterlogged and sank, it was buried by argillaceous sediments.

Age

In the type section, the lower member of the Mojado Formation has only a few thin beds containing marine fossils and a few with fossil wood. The most common shells are of poorly preserved oysters and other pelecypods; no fossils with specific age significance were found. The fossil wood occurs in small fragments and offers little hope for precise dating. In the Pierce Tank section, only the lower part of the formation is exposed and no significant fossils were found.

The upper member of the formation in the type section, though largely concealed, contains useful fossils. A few exposed calcareous beds are rich in marine invertebrates, and one bed contains a significant plant. Fossils were collected primarily from the lower 334 feet of beds of the member; collections are numbered in ascending order as follows: 5h, 5i, 5j, 5k, and 5m *(see pl.* 5). The faunas found from the base to the top of this 334 feet of beds have many fossils in common, all of which have similar age assignments; as the faunas cannot be divided into clearly defined zones, these beds were probably deposited during a very short interval of time.

Portions of the faunas of this zone were submitted for identification to paleontologists of the U.S. Geological Survey. Carle H. Dane and the late John B. Reeside, Jr., accompanied Charles B. Read and the writer at different times to study and collect additional material from these beds. The identifications of the collections and the comments of the paleontologists are given below.

Collections of gastropods were studied by Norman F. Sohl; he (written communication, 1955) reported on them as follows:

Collection 5i:
Nerita sp.
Turritella seriatimgranulata Roemer
Nerinea cf. *N. geminate* Stanton
Pyrazus (Echinobathyra) cf. *P. pecoense* (Stanton)
Cassiope sp.

Mixed collection from throughout fossil zone (5i through 5m):
Turritella seriatimgranulata Roemer
Pyrazus (Echinobathyra) cf. *P. pecoense* (Stanton)

Concerning the fossils and their age significance, Sohl commented:

> *Turritella seriatimgranulata* Roemer ranges through both the Fredericksburg and lower Washita. The specimens here placed in this species bear a closer resemblance to those assigned by Stanton to the variety *gainsvillensis* of the lower Washita than to the holotype from the Walnut Clay. The specimens of *Nerinea* do not preserve the external ornamentation in sufficient detail for confident identification but in shape, whorl profile and sutural characteristics appear close to the type of *N. geminata* found in the Edwards limestone. *Pyrazus (Echinobathyra) pecoense* (Stanton) also occurs in the. Edwards limestone.
>
> The known stratigraphic ranges of the individual species substantiates a Fredericksburg age assignment and further suggests that the sandstone may be of late Fredericksburg (Middle Albian) age correlative with the Edwards formation of Texas.

Specimens of an ammonite from collection 5k were examined by the late John B. Reeside, Jr., who (written communication, 1956) reported that "The ammonite seems to me to be *Engonoceras serpentinum* (Cragin), which has been reported from the Pawpaw and seems to be only of late Washita age. The material is good and the identification should be reliable."

A later collection of silicified molluscs (collection 5j) made from a bed only a few feet below the one from which significant plant remains were found was studied by Norman F. Sohl, who listed the fossils and commented as follows (written communication, 1956):

Breviarca sp.
Ostrea sp.
Pelecypods indet.
Nerita (Theilostyla?) sp.
Turritella seriatimgranulata Roemer
Pyrazus (Echinobathyra) n. sp.
Cassiope cf. C. *hyatti* Stanton
Pseudonerinea sp. ?
Nerinea cf. *N. geminate* Stanton
Aptyxella (Nerinoides) **n.** sp.
Acteonella? sp.
Shark tooth

> In a recent report, Mr. J. B. Reeside, Jr., assigned the [overlying] *Engonoceras-bearing* beds to the Washita. Many of the molluscs are new forms and others specifically indeterminate. In addition a restricted age identification on the basis of the molluscs is difficult due to the lack of published information as to the total range of the few species previously described. Taken collectively the identifiable material ranges in age from late Fredericksburg to early late Washita.
>
> *Breviarca* has never been identified in the Lower Cretaceous but is known from the Woodbine of Texas, and its presence in the Washita would not necessarily be inconsistent. Among the gastropods, as noted in the report of November 23, 1955, *Turritella seriatimgranulata* Roemer has a wide range but the specimens in these collections appear to be closest to Stanton's variety *gainsvillensis* from the lower Washita. *Pyrazus (Echinobathyra)* n. sp. is close to *Cerithium pecoense* Stanton from the Fredericksburg of the Quitman Mountains area but differs in having a

slimmer outline and additional sculpture elements. *Cassiope* cf. C. *hyatti* Stanton compares rather well with the paratype from the Purgatorie formation (Washita) of Mesa Tucumcari, New Mexico. *Nerinea* cf. *N. geminata* Stanton externally is similar to Stanton's variety *glabra* of the Edwards but internally is closer to *N. shumlensis* Stanton from the upper part of the Devils River limestone (Georgetown). The remainder of the identifiable material has little in common with previously described species.

The two most abundant species in the fauna are *Turritella seriatimgranulata* and Pyrazus *(Echinobathyra)* sp. The latter is typically a littoral to estuarine, brackish water form. A .shallow water near short environment of deposition is in keeping with the remainder of the assemblage as well as the physical wear and breakage exhibited by much of the material and detrital nature of the sediment.

Throughout the entire zone of the above-described faunas (collections 5h through 5m), arenaceous foraminifers are found. Specimens of these forms from collections 5h, 5k, and 5m were studied by Ruth Todd, who reported as follows (written communication, 1955):

These arenaceous foraminifera range from cylindrical individuals to flattened ones (as much as 3 to 1). In the cylindrical individuals the aperture consists of a group of openings between the sand grains at the top of the final chamber. In the flattened individuals the aperture consists of a string of slits at the top of the final chamber. Two generic names have been applied to forms like these: *Haplostiche* Reuss 1861 for the cylindrical ones and *Polychasmina* Loeblich and Tappan 1946 for the flattened ones. So far as I can determine, cylindrical and flattened specimens have not previously been found occurring together. Their presence together here, with numerous examples of gradational forms from cylindrical to flattened, throws doubt upon the validity of the generic separations as resting upon flattening of the test and consequent rearrangement of apertural pores.

Comparisons have been made with types of *Haplostiche texana* (Conrad) and *Polychasmina pawpawensis* Loeblich and Tappan and all these specimens can be included in these two species. It seems likely, however, that the earlier name, *H. texana,* should be used for all the specimens.

Without settling the question of whether one or two genera are represented here, the following notes include the age indications given by both *Haplostiche texana* and the genus *Polychasmina* (which is represented by only one species).

Haplostiche texana (Conrad):
- In Grayson, Weno, and Maness? of Washita age (Frizzell, 1954, p. 58)
- In Washita group (except for Fort Worth); Fredericksburg and Trinity records doubtful (Lozo, 1944, p. 547-548)
- In strata of upper Albian age in Colombia (Petters, 1954, p. 134)

Polychasmina pawpawensis Loeblich and Tappan:
- In Pawpaw and Weno of Washita group (Loeblich and Tappan, 1946, p. 242-243)

The above records of occurrences elsewhere seem to indicate Washita equivalent for the age of the strata containing these large arenaceous foraminifera.

Because of the widespread occurrence of the foraminifer *Haplostiche texana* in other Mojado exposures throughout the region, I have relied heavily upon the form for dating rocks in which it is found. To further confirm the known range of this form, I wrote to Esther R. Applin, who replied (written communication, 1959):

. . . regarding the vertical range of *Haplostiche texana* (Conrad), I have seen specimens of *Haplostiche texana* only in outcrop samples of sediments of Washita age in Texas and, so far as I know, this fossil is restricted in its range to the upper half of the Washita group. In Texas it has been reported from the Grayson marl and the Weno clay, and some questionable specimens were also recorded from the Maness shale.

Fossils collected later from these beds by John B. Reeside, Jr., Charles B. Read, and the writer were given U.S. National Museum numbers 26111 and 26215 and are retained by that institution. Reeside made the following identifications (written communication, 1956):

Collection 26215 [from the same bed as collection 5h]:

pelecypods: *Arca?* sp.
Ostrea perversa Cragin
Plicatula? sp.
Brachydontes? sp.
Protocardia texana (Conrad)
"Tellina" sp.

gastropod: *Cassiope?* sp.

Collection 26111 [from the same bed as collection 5k]:

foraminifera: *Haplostiche texana* (Conrad), probably including *Polychasmina pawpawensis* Loeblich and Tappan

worm: *Serpula* sp.

pelecypods: *Nucula* sp.
Yoldia sp.
Ostrea perversa Cragin
Lopha quadriplicata (Shumard)
Neithea texana (Roemer)
Camptonectes inconspicuus (Cragin)
Plicatula sp.
Lima? sp.
Anomie? sp.
Cardium aff. C. *kansasense* Meek
Protocardia texana (Conrad)
Cyprimeria gigantea Cragin
"Tellina" sp.
Cymbophora? sp.
Corbula sp.

scaphopods: *Cadulus?* sp.
Dentalium sp.

gastropods: *"Lunatia,"* several species
Turritella seriatimgranulata Roemer
Anchura aff. mudgeana White
Cinulia? sp.

cephalopod: *Engonoceras serpentinum* Cragin

The distances between fossiliferous beds were estimated by Reeside; the beds from which these fossils were collected are the same from which the earlier collections were made; numbers of collections from corresponding beds are shown in brackets. Measured distances separating fossiliferous beds are shown on Plate 5 and in the U-Bar Ridge section. Reeside commented as follows:

The collection of invertebrates (26111) [5k] 3o feet above the horizon of fossil plant remains confirms the indication of the ammonite previously examined that the level is about the age of the late Washita in terms of the Texas sequence, and late Albian in terms of the European stage sequence. Some of the fossils have sufficiently marked characters to permit fairly assured determination. Others suggest generic assignment that seems well assured, but do not warrant the effort to find a rational specific name. Others permit only a guess at a generic assignment or are completely indeterminable. The fauna is certainly an extensive one and though the matrix is extremely hard and tough would be worth further study.

The most abundant forms in the collection are the foraminifera, the *Camptonectes*, and the Cyprimeria. In previous reports N. F. Sohi has listed forms from the horizon of silicified gastropods that lies below the plant remains. These are in reasonable agreement with an assignment to a late Albian age. Lot 26255 [5h], which is around 30o feet below the plant remains, would still be of Washita age.

The horizon of fossil plant remains to which Reeside referred is at the top of the bed from which collection 5j was made (unit number 203 of the U-Bar Ridge section). This horizon lies 45 or 5o feet below the bed that yields *Engonoceras serpentinum* (Cragin). The beds immediately below the fossil plant horizon include the silicified gastropods that Reeside mentioned above and that Sohl described; in the original collections, the invertebrates and the plants from this thin unit 203 were given the same collection number, 5j.

The most significant plant remains from this horizon were identified by Charles B. Read (Zeller and Read, 1956) as *Tempskya minor* Read and Brown. In a letter to Read concerning the age of this form, Reeside (written communication, 1956) stated, "Regarding the age of *Tempskya*, I think you are right about putting it in the Albian. There is no undisputed evidence of later age for the American records and much in favor of Albian."

Age determinations of different elements in the marine invertebrate fauna and of the fossil plant of this biotic zone high in the Mojado Formation are all in close agreement. The gastropods range in age from late Fredericksburg to early late Washita. The ammonite is of late Washita age. The foraminifers are restricted to late Washita age. Collections of mixed types of invertebrates studied by Reeside are about of late Washita and of late Albian age. Thus, the age of this biota may be summarized as of middle to late Washita in terms of the Gulf Coastal Plain and Texas terminology and of late Albian in terms of European stages of the Cretaceous System. This is very close to the boundary between Lower and Upper Cretaceous.

The 752 feet of Mojado Formation that was measured above the described biotic zone is apparently of the same age. Though the fossils have not been studied, I have recognized *Haplostiche texana* (Conrad) in certain beds throughout the entire interval. Thus, there can be little doubt of its middle or late Washita age.

The lower member of the Mojado Formation, which is barren of index fossils, lies below the described faunal zone of middle or late Washita age and above the U-Bar Formation, the upper beds of which are thought to be of Fredericksburg age. This lower member of the formation, therefore, encompasses the equivalents of some of the Fredericksburg and the lower and possibly the middle Washita.

Correlation

The Cretaceous sandstone of the Sierra Rica is identified as the Mojado because of several similarities to the type Mojado Formation. After making due allowances for silicification of the formation in the Sierra Rica, its original lithology was the same as that of the type Mojado. Its exposed thickness of between 4000 and 5000 feet is of the same order of magnitude. It overlies a thick limestone unit, part of which is of Trinity age. And, most significant of all, calcareous sandstone and impure limestone near the highest exposures have an abundance of silicified fossils similar in general aspect to those of the Washita faunal zone high in the Mojado Formation at the type locality. I recognized *Haplostiche texana* (Conrad) in this zone, which clearly indicates its middle or late Washita age and its equivalence to the Washita faunal zone of the type section. The Mojado Formation was not studied in detail in the Sierra Rica nor was a stratigraphic section measured there; the approximate stratigraphic position of the faunal zone above the base was computed from the bedding attitude of the formation and from measurements from the topographic map. The Washita faunal zone lies about the same distance above the base of the Mojado Formation in the Sierra Rica as in the type area.

In the east-central part of the Animas Mountains (Zeller, 1962), a thick Cretaceous sandstone formation was identified as the Mojado Formation for the same reasons as was the sandstone formation of the Sierra Rica. It is lithologically indistinguishable from the type Mojado Formation, and it overlies a Lower Cretaceous limestone formation that has a zone of reefs at its top, as does the U-Bar Formation. Its thickness cannot be determined because of concealed faults, but making allowance for structural complications and considering the average attitude and the width of its outcrop, its thickness is similar to the exposed thickness of the Mojado Formation in the type section. In this part of the Animas Mountains, the formation is conformably overlain by a limestone-cobble conglomerate formation, but as the uppermost beds of the Mojado Formation of the type area are concealed and are of unknown character, this fact does not hinder the correlation. Of greatest significance in proving the equivalence of this sandstone ,formation with the type Mojado are the fossils high in the-formation, many of which are the same as those of the diagnostic Washita biotic zone high in the type Mojado. These occur here in the same lithology as in the type section, calcareous sandstone and sandy limestone interbedded with shale. This exposure is about 16 miles west-northwest of the type section of the Mojado Formation and about half a mile east of Cowboy Spring. I recognized *Haplostiche texana* (Conrad), *Engonoceras* sp., and *Tempskya* sp. Charles B. Read examined the plant, which he recognized as a new species related to *Tempskya grandis* Read and Brown. Fossils identified by W. A. Cobban (written communication, 1959) from these beds in the Animas Mountains are listed below; those that have also been identified in the diagnostic faunal zone of the type Mojado Formation are indicated by an asterisk (*).

**Haplostiche texana* (Conrad)
*Ostrea sp.
Exogyra sp.
Trigonia emoryi Conrad
**Lopha* cf. L. *quadripticata* (Shumard)
**Protocardia texana* (Conrad)
Corbula basiniformis Adkins
**Cadulus* sp.

*Dentalium sp.
Turritella kansasensis Meek
Actaeonella sp
Drepanocheilus kiowana (Cragin)
**Engonoceras serpentinum* (Cragin)

Cobban remarked that the fauna is of Washita age, and from the number of significant forms that are in common with the faunal zone high in the type Mojado, it is obviously a contemporaneous one. Thus, identification of this Cretaceous sandstone formation in the Animas Mountains as the Mojado Formation is well substantiated.

Attempts to correlate the Mojado Formation with any part of the stratigraphic sequence in the Little Hatchet Mountains meet with difficulties. All of the Cretaceous formations in that range are considered to be of Trinity age (Lasky, 1947). The only formation that has both the right lithology and the right order of thickness to suggest correlation with the Mojado Formation is the Corbett Sandstone. Its lithology is closely similar, and it is underlain by a limestone formation that has a reef zone at its top. However, it is supposedly overlain by the Playas Peak Formation, which at present is dated as Trinity. No fossils of restricted age significance have been found in the Corbett Sandstone. If the Playas Peak Formation actually overlies the Corbett Sandstone in normal sequence and if the age of the Playas Peak Formation is Trinity, then the Corbett Sandstone cannot be correlative with the post-Trinity Mojado Formation. However, the contact between the Corbett Sandstone and the Playas Peak Formation may be a major fault, and the Playas Peak may actually be older than the Corbett. Should such a fault be present, and should additional paleontologic study indicate a Fredericksburg—Washita age for the Corbett Sandstone, the Mojado Formation and Corbett Sandstone could then be correlated.

Cretaceous sandstone similar in appearance and thickness to the Mojado Formation is found also in the Apache Hills, in the northern part of the Animas Mountains (Zeller, 1958a), on the northeastern side of the Coyote Hills, in the Brockman Hills, and in Antelope Pass in the Peloncillo Mountains. Fredericksburg or Washita fossils have not been found in these sandstones. In view of the difficulties of correlating the Mojado Formation with the Corbett Sandstone over a distance of only 20 miles, it is unwise to speculate on the correlation of similar sandstones in the vicinity with the Mojado unless Fredericksburg or Washita faunas are discovered in them or unless future studies prove the Corbett Sandstone and the Mojado Formation to be correlative.

A section of rocks that is in part equivalent in age to the Mojado Formation is exposed around the base of the sharp peak on the west side of the city of El Paso, Texas. The peak, which is traversed by the international boundary, was originally known as Cerro de Muleros, but present-day El Pasoans call it Cristo Rey Peak because of the statue of the Crucifixion of Christ that stands at the summit. The rocks, calcareous sandstone, shale, and argillaceous limestone, are similar to those of the upper calcareous beds of the Mojado Formation. The proportion of limestone increases upward. Bose (1910) estimated the total thickness of the section at between 1700 and 2200 feet. Fossils are not rare; I recognized *Haplostiche texana* (Conrad) in beds below the middle of the section. These rocks were studied by Stanton and Vaughan (1896) and by Bose (9 0) and were divided into a number of faunal zones. Zones 5 and 6 of both Stanton and Vaughan and of Bose are the same, and these two zones contain a number of fossils also found in the Washita faunal zone of the type Mojado Formation. Using modern nomenclature for the fossils, the ones common to zones 5 and 6 of the Cerro de Muleros section (as listed by Stanton and Vaughan and by Bose) and the Washita zone of the Mojado Formation are as follows:

Haplostiche texana (Conrad) *Lopha quadriplicata* (Shumard) *Neithea texana* (Roemer) *Turritella seriatimgranulata* Roemer
Protocardia texana (Conrad)

Bose (1927, p. 152) shows that bed 5 is equivalent in age to the Fort Worth beds and bed 6 is equivalent in age to the Denton, Weno, and Pawpaw beds of central Texas, all of which are of Washita and late Albian age. Thus zones 5 and 6 of the Cerro de Muleros are equivalent in age and similar in lithology to the late Washita faunal zone of the Mojado Formation. The Cerro de Muleros section continues upward into rocks of Late Cretaceous age.

Darton (1917, p. 6) described a Cretaceous sandstone formation from the southern spur of Cooks Range that he named Sarten Sandstone; it resembles the Mojado Formation in lithology. Darton lists fossils that were collected from one bed and were identified by T. W. Stanton; some of these fossils are found in the Washita faunal zone of the Mojado Formation. Stanton's faunal list is shown below, and the forms that are found in the type Mojado Formation are indicated by an asterisk (*).

Cardita belviderensis Cragin
**Cardium kansasense* Meek
**Protocardia texana* (Conrad)
Protocardia quadrans Cragin
Tapes belviderensis Cragin?
**Turritella* cf. T. *seriatimgranulata* Roemer
**Ostrea* sp.
**Nucula* sp.
Trigonia sp.
**Lunatia* sp.
**Cyprimeria* sp.
Anchura sp.

Darton commented, "This fauna, which is nearly the same as that found in the marginal beds of Comanche age in southern Kansas and near Tucumcari, N. Mex., is regarded by Stanton as indicating that the beds are of the age of the Washita group of the Comanche series of Texas. In addition, I recognized *Haplostiche texana* in the Sarten Sandstone a short distance from Darton's fossil locality.

Thus, the Sarten Sandstone in its type locality is of similar lithology and at least in part of the same age as the Mojado Formation. However, the type Sarten is only about 300 feet thick in contrast to the mile-thick Mojado. Darton applied the name *Sarten Sandstone* widely throughout southwestern New Mexico to exposures of Cretaceous sandstone. Were it not for the complexities of correlation in the Little Hatchet Mountains, the name *Sarten Sandstone* could probably still be applied to many if not all these exposures.

Correlation of the Mojado Formation with formations to the west and northwest may eventually be possible. The thick arenaceous Cintura Formation of southeastern Arizona is lithologically similar to the Mojado and it overlies the Mural. Limestone, the upper part of which is variously dated by different workers as Trinity or Fredericksburg. As index fossils have not been found above the basal beds of the Cintura, its age is not known. The Johnny Bull Sandstone, described by Gillerman in the Peloncillo Mountains, is similar to the Mojado in lithology and stratigraphic position. Sabin speculates on the correlation of the sandstone unit at the top of the Cretaceous section in the Chiricahua Mountains with the Cintura and Mojado Formations on the basis of lithologic character and stratigraphic position. Admittedly, such correlations are suggestive, but they cannot be firmly established until the Cretaceous System of the Little Hatchet Mountains is more thoroughly understood.

CORRELATION AND INTERPRETATION OF LOWER CRETACEOUS ROCKS

The Lower Cretaceous formations of Mojado Pass south of the Big Hatchet Mountains cannot be correlated with the Lower Cretaceous formations as interpreted by Lasky (1947) in the Little Hatchet Mountains a short distance to the north. Lasky divided the Cretaceous section of the Little Hatchet Mountains into seven formations, which in ascending order (fig. i8) are Broken Jug Limestone, Ringbone Shale, Hidalgo Volcanics, Howells Ridge Formation, Corbett Sandstone, Playas Peak Formation, and Skunk Ranch Conglomerate. Certain lithologic and faunal similarities exist between the formations of Mojado Pass and the Little Hatchet Mountains. For instance, the Broken Jug Limestone resembles the sequence of Hell-to-Finish and U-Bar beds. In both areas, basal rocks are red beds that include conglomerate. Thin-bedded limestones above the red beds in each area have certain Trinity index fossils in common. The uppermost rock unit of the Broken Jug and the U-Bar is a massive reef limestone. However, formations overlying these sequences in the two areas are quite different. The reef limestone in Mojado Pass is overlain conformably by sandstone and shale of the Mojado Formation, but the reef at the top of the Broken Jug is overlain with apparent unconformity by Ringbone Shale and Hidalgo Volcanics.

Another strikingly similar lithology is the thick sandstone of the Mojado Formation and the Corbett Sandstone. Both are identical lithologically, both are thousands of feet thick, and both conformably overlie a massive reef limestone. Still another lithology that is the same in the two areas is the reef limestone. In Mojado Pass, a single reef-limestone unit is found in the U-Bar Formation. In the Little Hatchet Mountains, Lasky shows four massive reef limestones in the section, all of which are identical lithologically and faunally to one another and to the one at the top of the U-Bar Formation.

Despite such similarities, the sequences of gross rock units in the two areas are very different. In Mojado Pass, the Lower Cretaceous section is divisible into a lower red clastic unit, a middle limestone unit, and an upper clastic unit. In the Little Hatchet section, clastic and volcanic units separate three limestone units, any one of which, all of which, or none of which could be equivalent to the single limestone unit in Mojado Pass. Correlation of formations of such vastly different sequences is not possible.

Likewise, the relatively simple Lower Cretaceous sequences of other places in the region do not match the complex sequence in the Little Hatchet Mountains. The lithologies and faunas of Lower Cretaceous formations at Mojado Pass and near Bisbee are so similar that correlations might be suggested, but the inability to correlate Bisbee or Mojado Pass formations with Little Hatchet formations casts a shadow of doubt upon Mojado Pass—Bisbee correlations. The Lower Cretaceous stratigraphic sequence in the Little Hatchet Mountains, as currently understood, is thus an obstacle to regional correlation.

Lasky (1938, p. 535) found that certain lithologies and faunas are repeated through the section in the Little Hatchet Mountains. He noted, for instance, that "There are four zones of massive limestone, perhaps of reef origin, containing many specimens of the foraminifer *Orbitolina,* the mollusks *Toucasia* and rudistids, and perhaps less commonly the large gastropod *Tylostoma*. . . . After considering the possibility of fault repetition, he concluded that the repetition was not due to faulting but instead to normal deposition (op. cit., footnote, p. 535). According to his (1947) determinations, the entire sequence was deposited during Trinity time and had a total thickness of between 17,000 and 21,000 feet; as much as 17,000 feet of rock was deposited during the Glen Rose part of the Trinity. He attributed this tremendous thickness of rocks to deposition in a rapidly subsiding geosyncline.

Lasky's stratigraphic sequence in the Little Hatchet Mountains is viewed with suspicion because of two major regional observations. The first is that the total thickness of the section seems excessive. Many observers are reluctant to believe that as much as 21,000 feet of rock was deposited in the relatively short time span of the Trinity. Furthermore, this thickness does not fit the regional pattern of progressive thinning of the Lower Cretaceous from south to north. Figure 18 shows Lower Cretaceous sedimentary sections of the region, and though the uppermost Lower Cretaceous beds are not preserved in any of the sections, the general thinning from the more active part of the geosyncline in the south toward the edge of the geocyncline in the north is nevertheless apparent from thinning of the lower formations. The stratigraphic section in the Little Hatchet Mountains does not fit the regional trend. The Cretaceous section in Mojado Pass, which includes rocks of probable pre-Trinity age, of Trinity and Fredericksburg ages, and of early and middle Washita age, is Io,000 feet thick. Only 20 miles to the north in the northern Little Hatchet Mountains, the exposed Cretaceous section of Lasky is twice as thick and includes beds of only Trinity age. If pre-Trinity and post-Trinity rocks were originally present there as in Mojado Pass, the total thickness would have been much greater than 21,000 feet.

A second regional observation makes the Little Hatchet stratigraphic sequence suspect. In the chief areas where Lower Cretaceous rocks have been studied in the region, the lithologic sequence is divisible into three gross divisions:

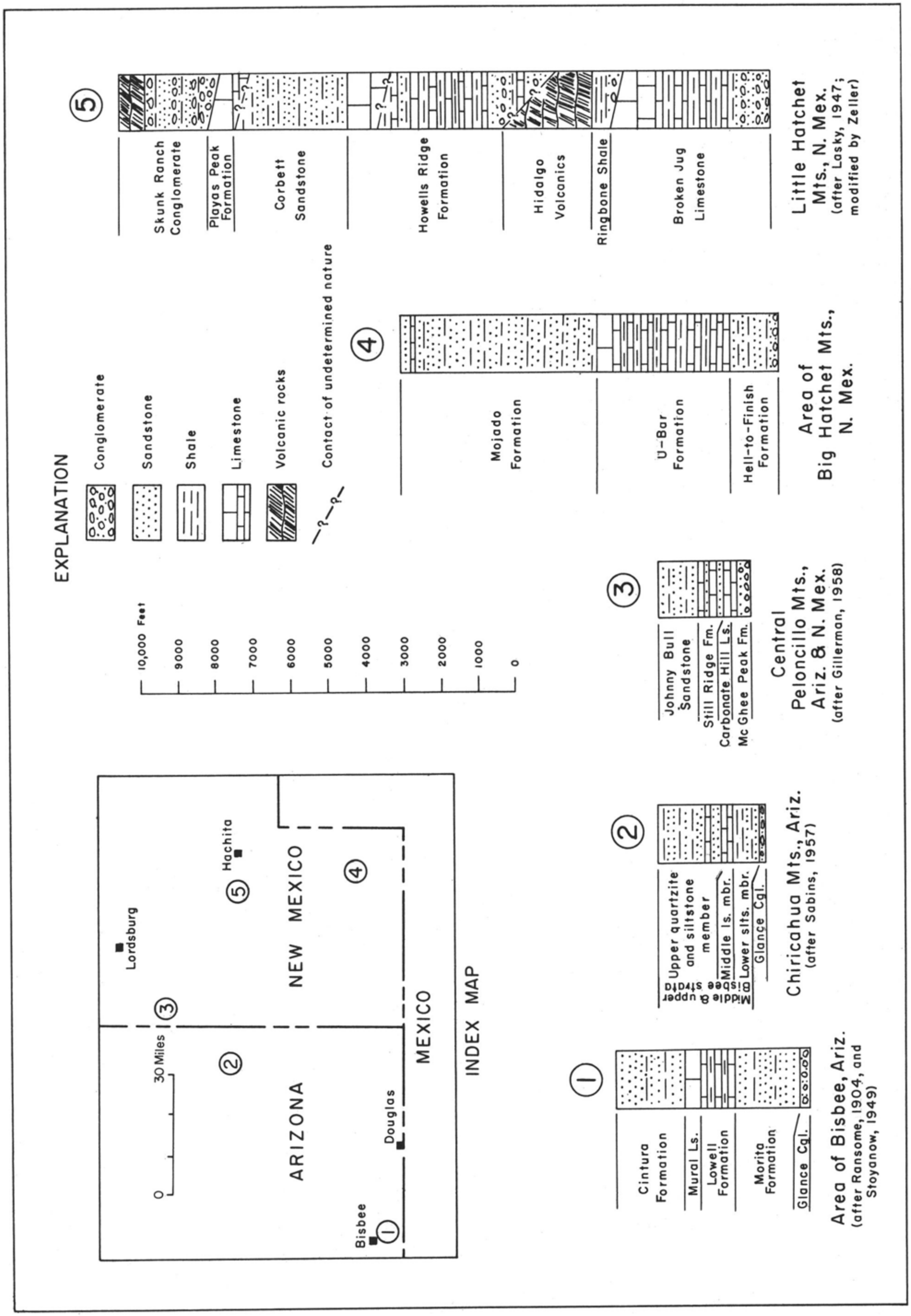

Figure 18

GENERALIZED LOWER CRETACEOUS STRATIGRAPHIC SECTIONS, SOUTHEASTERN ARIZONA AND SOUTHWESTERN NEW MEXICO.

a lower sandstone and shale unit, a middle limestone unit, and an upper sandstone and shale unit. This threefold division, which is recognized in Mojado Pass, in the Sierra Rica, at Bisbee, in the northern Chiricahua Mountains, and in the central Peloncillo Mountains, is indicated in Figure 18. As index fossils have not been found in the upper and lower clastic units of the region, except for the Mojado Formation, their precise ages are not known. However, index fossils from the middle limestone units of all studied sections are of the same age—Trinity and possibly Fredericksburg. Such similarity of lithology and age suggests correlation that further suggests a simple gross Early Cretaceous history for the region. As subsidence of the Mexican geosyndine started here and the sea advanced from the south, the lower terrestrial clastics were deposited along the coast. As subsidence continued and the shallow Mexican sea invaded the region, the limestone of the middle unit was deposited. And as the rate of subsidence slackened, terrestrial deposits from the north were brought to the region by streams and the upper clastic unit was deposited as the sea retreated. The fact that the Little Hatchet stratigraphic section does not fit this regional picture casts doubt on its validity.

Although such regional observations are useful in suggesting that something is amiss in the Little Hatchet strati-graphic section as presently interpreted, the answers can be found only by further field study in the Little Hatchet Mountains. Solution of the stratigraphic puzzle in the Little Hatchet Mountains should simplify regional Cretaceous stratigraphy and may permit regional correlation of formations.

Descriptions of Stratigraphic Sections

During this work, more than 20 stratigraphic sections were measured. Most of these are described below and are shown graphically on Plates 2, 3, 4, and 5; locations of the sections are shown on Plate 1.

Care was taken to choose the stratigraphic sections that are best exposed, most complete, and least faulted; with few exceptions, the sections studied represent the best available. Measurements in faulted sections were carefully adjusted to eliminate omission or duplication of beds. Occasionally, the lines of section were shifted laterally along prominent beds so that optimum exposures were crossed.

The study of stratigraphic sections extended over a period of ten years, during which time a uniform system of describing rock units was evolved. As most of the rocks studied are carbonates, the system was tailored to describe these rocks most completely. The general order of data in rock unit descriptions is rock name, fresh and weathered color, composition, texture (crystal and elastic), description of chert, bedding and lamination, other data, and fossil types present. The beds or stratigraphic units are numbered consecutively from base to top. Abbreviated fossil collection numbers follow descriptions of rock units from which they were collected; the positions of the collections above the bases of the thicker units are indicated. Most fossils were collected from in place; float specimens are indicated by the letter "f" following the collection number (example, 3t-f).

Nearly all the carbonate rocks of the area have an original elastic texture that often is obscured by postdepositional recrystallization. The grains of elastic or detrital limestone consist of limestone fragments, fossil shell fragments, or oolites. The original elastic texture may usually be seen on weathered rock surfaces and may be brought out on fresh surfaces by light etching with acid. Original texture and crystallinity are independent variables that are described separately for many units.

All sections were measured using the special staff and method described by Kummel (1943). This method was adopted because it is fast, accurate within 5 percent, and well suited to measurement of moderately dipping strata. Detailed stratigraphic descriptions are facilitated because thin units may be easily measured. The angle of the instrument may be constantly changed to compensate for changes in dip. Measurements are made directly in feet; no computations are necessary. An assistant may make the measurements while the stratigrapher takes notes and collects samples.

MESCAL CANYON SECTION

The Mescal Canyon section, which traverses the lower Paleozoic formations of the Big Hatchet Mountains, starts at the erosional unconformity upon Precambrian granite, includes the Bliss Formation, El Paso Formation, Montoya Dolomite, Percha Shale, Escabrosa Limestone, and Paradise Formation, and ends 1024 feet above the base of the Horquilla Limestone. Faulting is minor and exposures of lower Paleozoic formations are more complete than in any other place in the range. Therefore, this is designated as the best reference section for pre-Pennsylvanian Paleozoic formations in the Big Hatchet Mountains. The section is shown graphically on Plate 2. Figure 3 is a photograph showing the section.

The base of the section is at the contact of the Precambrian granite and Bliss Formation in an arroyo in the NE1/4 SE1/4 sec. 29, T. 3o S., R. 15 W., north of the mouth of Mescal Canyon. Measurement continues up the northwest side of the arroyo with minor offsets along beds, proceeds up the southeasternmost prominent spur to the top of the hill, and continues down the southwest (dipslope) side of the hill to the floor of the valley in which the Percha Shale is found. The section is offset about 200 yards southeastward and continues southwestward in a deep wash, in which the Percha Shale is exposed, to a point in the lower Escabrosa Limestone beyond which exposures are poor. It is offset a few hundred feet to the north along a distinctive oolitic limestone bed. The section proceeds upward along the south side of a great cliff of Escabrosa Limestone and passes to the top of the formation through a cleft, the only place in the vicinity where the cliff can be scaled. The section is shifted a short distance northward along the distinctive white chert bed at the top of the Escabrosa Limestone to the crest of the spur and continues southwestward up the spur to the end of the section on the peak at the corner common to sections 29, 3o, 31, and 32, T. 3o S., R. 55 W.

	Thickness (feet)
Top of peak; no higher exposures.	
Horquilla Limestone:	
80. Limestone, weathered medium gray, elastic, some beds finely crystalline, others coarsely crystalline and coarsely elastic with crinoid detritus, and others oolitic; some zones rich in black chert nodules, but generally chert is not abundant; fossiliferous throughout; petroliferous odor in some beds on fresh fracture. Coll. 36m, from 739 feet above base; coll. 36k, from 711 feet; coll. 36j, from 661 feet; coll. 36i, from 600 feet; coll. 36h, from 501 feet; coll. 36g, from 471 feet; coll. 36f, *Prismopora* from 258 feet; coll. 36e, from 200 feet; and coll. 36d, from 93 feet	973
79. Limestone, black, very finely crystalline, abundant black chert nodules, thin-bedded. Coll. 36c .	5
78. Limestone, elastic, fine-grained, massive, with corals; forms ledge. Coll. 36b	34
77. Limestone, black, very finely crystalline, thin-bedded, with abundant *Chonetes.* Coll. 36a	12
Total Horquilla Limestone measured	1024
Erosional unconformity.	
Paradise Formation:	
76. Sandstone, weathered light brown, quartz, fine-grained, with abundant plant fossils. Coll. 35j, *Calamites*	2
75. Conglomerate, weathered very dark brown, limonitic	2
74. Limestone, dark gray, weathered brown, elastic, mostly composed of fine-grained detritus; many	

beds medium-grained oolitic, some beds of limestone-chip conglomerate, and some shaly beds with much clay; thin-bedded, nonresistant, many short concealed intervals, some strata cross laminated; very fossiliferous, including profuse bryozoans, trilobites, brachiopods, cephalopods, and pelecypods. Coll. 35h, from 177 feet above base; coll. 35g, from 164 feet; coll. 35f, from 152 feet; coll. 35e, from 122 feet; coll. 35d, from 69 feet; and coll. 35c, from between 40 and 60 feet 180

73. Limestone, medium gray, weathered brown, coarsely clastic, detritus largely crinoid debris, fetid odor on fresh fracture; resistant, forms prominent local cliff; upper part fossiliferous .. 22

72. Limestone, dark gray, weathered medium gray and light and medium brown with an over-all aspect of brown, clastic, same lithology as in unit 74; some strata cross laminated; thin-bedded, nonresistent, many intervals concealed; fetid odor on fresh fracture; many beds fossiliferous; lower contact at white chert bed at top of Escabrosa Limestone. Coll. 35b, from upper 30 feet 112

Total Paradise Formation 318

Conformable contact.

Escabrosa Limestone:

Upper member:

71. Limestone, weathered light to medium gray, clastic, detritus coarse sand size and composed largely of crinoid columnals; a few white chert beds, nodules, and replacements of crinoid fragments; very massive, resistant, forms upper half of great cliff; no thickening or thinning suggestive of biohermal development; upper beds thinner and less resistant, and interbedded with brownish limestone beds of the type found in overlying Paradise Formation; upper contact chosen at top of 3-foot white chert bed that is underlain by a bed of limestone conglomerate containing a few fish teeth. Coll. 35a, fish teeth from near top .. 364

Middle member:

70. Limestone, shaly limestone, and chert in remarkable rhythmic succession. Limestone: dark gray to black, weathered light gray with a faint bluish cast, fine-grained, clastic, some fossil detritus, H_2S odor on fresh fracture, 1-foot beds, interbedded with crinoidal limestone in upper 50 feet. Shaly limestone: very thinly laminated, with little clay, occurs as very thin partings between limestone beds, more abundant in lower half. Chert: light to dark gray and black, weathered medium brown, in rounded nodules 2 inches thick and greatly elongated parallel to bedding; some with concentric banding; near top, nodules contain fossil fragments; in upper two-thirds, nodules tend to form thin chert beds ranging to 2 feet in thickness. Unit is massive and resistant, and forms lower half of great cliff. It is fossiliferous and contains spirifers, *Leptaena,* other brachiopods, goniatites, solitary corals, crinoids, trilobites, fenestellid bryozoans, and *Archimedes*. Coll. 33e, from 160 feet above base; coll. 33d, from 113 feet; coll. 33c, from 38 feet; coll. 33b, from 31 feet; and Coll. 33a, from 28 feet . 352

Lower member:

69. Limestone, black, finely crystalline and dense, H_2S odor on fresh fracture; massive, forms upper of two small distinctive cliffs that underlie great 700-foot cliff; a few gray chert nodules in upper part, limy shale and shaly limestone at top; fossiliferous 40

68. Limestone, black, weathered medium gray, fine-grained and finely crystalline, thin-bedded; interbedded with shale, weathered medium brown, argillaceous and limy, in thin beds; nonresistant, forms partly concealed interval between two small distinctive cliffs; fossiliferous 112

(Section is offset a few hundred feet to the north from unit 67 to unit 68.)

67. Limestone, weathered medium gray, clastic, medium to coarsely crinoidal; crinoid detritus averaging 3 mm, broken and rounded; masses of disseminated chert replacements of fossil debris; ¼ mile to the south this unit contains several large, lens-shaped, brown-weathered areas of chert that have replaced fossil detritus; massive, bedding indistinct and shown only by alignment of detritus and by a few bedding-plane joints, forms lower of two small distinctive cliffs, base of unit here chosen at base of cliff, but elsewhere base of cliff is stratigraphically lower; fossiliferous. Coll. 32b, *Spirifer, Archimedes,* and other fossils; and coll. 32a, *Taonurus* ... 38

66. Limestone, white, weathered light and medium gray, clastic, composed almost entirely of coarse crinoid fragments, coarsely crystalline, weathered to grains and lumps, nonresistant and largely concealed; interbedded with a few beds of limestone, weathered light brown, argillaceous, partly dolomitized, rich in fenestellid bryozoans; two 8-foot beds of massive oolitic limestone, weathered medium gray, one at base, the other at 70 feet; medium-bedded. Coll. 31r, bryozoan from 40 feet above base; coll. 31q, brachiopods, bryozoans, and crinoids from 32 feet; and coll. 31p, from lowermost oolitic bed 178

65. Limestone and shale, interbedded; in basal part, clay shale is nearly 50% and limestone occurs in thin, nodular beds 1½ to 2½ inches thick; upward, limestone becomes progressively more abundant and is in thin and medium beds; near top, shale intervals are very few and thin, and limestone beds average 1 foot and are composed largely of crinoid detritus; upper contact chosen above highest obvious shale interbeds which is at base of oolitic limestone; nonresistant; fossils common in upper part but less abundant in lower part; uppermost bed contains fish teeth. Coll. 31n, from 177 feet above base; coll. 31m, fish teeth from 158 feet; coll. 31k, *Archimedes* and bryozoan from 137 feet; coll. 31j, from 133 feet; coll. 31h, from 94 feet; coll. 31g, from 80 feet; coll. 31f, from 71 feet; coll. 31e, from 68 feet; coll. 31d, from 64 feet; coll. 31c, from 60 feet; coll. 31b, from 50 feet; and coll. 31a, float specimens from 40 feet 177

Total lower member 545

Total Escabrosa Limestone 1261

Conformable contact.

Percha Shale:

64. Lit-par-lit intrusion of diorite sills into nodular limestone and shale. 21

63. Shale, medium gray, weathered light brown, clay, fissile, fractures into 1/16-inch-thick flakes; with some beds of silty shale and some 1-inch beds of silty limestone; fossils rare, several fossiliferous lenses in upper half. Coll. 30d, linguloid brachiopods from 165 feet above base; coll. 30c, productid brachiopods from 140 feet; coll. 30b, productid brachiopods from 131 feet; coll. 30a, linguloid brachiopods from 108 feet 178

62. Shale, weathered yellowish brown, clay, mostly concealed 65

61. Concealed. Along strike of beds basal contact of Percha Shale is exposed. Lower few feet of Percha contains siltstone and very fine grained sandstone, medium gray, weathered brown, calcareous and argillaceous. Above this is a few feet of black finely fissile clay shale. 16

Total Percha Shale 280

Unconformity.

(Section is offset about 200 yards southeastward on the projection of the highest measured bed of the Montoya Dolomite, and it continues southwestward up deep wash in which Percha Shale is exposed.)

Montoya Dolomite:

Cutter Member:

60. Dolomite, mostly concealed; some light gray, finely crystalline dolomite with 10% chert 28
59. Dolomite, light gray, weathered light gray, finely crystalline; with chert, medium gray, weathered light gray, 20%, in irregularly shaped nodules . 12
58. Dolomite, weathered light gray, finely crystalline . 5
57. Dolomite, dark gray, weathered light gray with mottled appearance, finely crystalline; local concentrations of chert nodules, never exceeding 20% of rock; resistant; zones of fossils partly silicified with white chert 64
56. Dolomite, dark gray, weathered light gray, finely crystalline; some beds contain up to 35% chert nodules; silicified fossils; resistant, forms uppermost cliff and crest of hill. Basal few feet silty and nonresistant. Coll. 22g, from 100 to 128 feet above base; coll. 22f, from 70 to 100 feet; coll. 22e, from 50 to 70 feet; coll. 22d, from 24 to 50 feet; and coll. 22c, from lower 24 feet 128

Total Cutter Member 237

Aleman Member:

55. Dolomite, medium gray, medium crystalline, thin-bedded, nonresistant, mostly concealed; with chert, 10%, in nodules; contacts gradational with overlying and underlying units 28
54. Dolomite, dark to very dark gray, finely crystalline, unfossiliferous; with chert, black, weathered dark brownish gray, 30 to 40%, occurring in masses ranging in size from rounded nodules ¼ inch thick to 5-inch strata 25 feet long; resistant, forms upper part of cliff. Dolomite and black chert nodules are in fine rhythmic bands that produce a unique lithology characteristic of the Aleman throughout southwestern New Mexico. Lower contact sharp. . . 48

Total Aleman Member 76

Upham Member:

53. Dolomite, medium gray, weathered light gray mottled with medium gray, medium to coarsely crystalline, no quartz grains; fossiliferous, two zones rich in brachiopods and crinoids silicified with white chert; resistant, forms bulk of cliff; lower two-thirds of unit contains rounded nodules of finely crystalline dolomite elongated parallel to bedding that are partly to completely replaced by medium gray chert; replacement by chert is more complete in upper part of unit. Locally silicified coquina in upper 2 or 3 feet. Top surface of unit contains persistent ½-inch layer of chert pellets believed to be phosphatic because of bluish white stains. Coll. 22b, from upper 16 feet; and coll. 22a, from lower 3 feet 56

Cable Canyon Member:

52. Quartzite, dolomitic, fresh surfaces white to light gray with glassy quartz grains, weathered surfaces mottled medium brown with quartz grains in relief; quartz grains are fine and coarse sand; fine sand subangular and forms bulk of detrital fraction; coarse sand well rounded, frosted, includes a few grains of blue translucent chert; dolomite cement; proportion of quartz appears high on weathered surface, but may average less than 50%; suggestions of filled, large, straight cephalopod and other fossil molds. In measured section upper contact irregular and not gradational, lower contact sharp plane surface. Along strike, both lower and upper contacts are transitional with underlying and overlying beds 5
51. Dolomite, medium gray, weathered medium gray, finely to medium crystalline; with quartz sandstone, grains medium to fine, rounded, poorly sorted, dolomite cement, in 1- to 3-inch irregular lenses and stringers elongated parallel to bedding; lower contact gradational 5
50. Dolomite, very dark gray, weathered dark gray to black, finely to medium crystalline 6

Total Cable Canyon Member 16

Total Montoya Dolomite 385

Disconformity.

El Paso Formation:

Bat Cave Member:

49. Dolomite, weathered light gray, finely crystalline, with residual clastic texture, some grains composed of fossil detritus 10
48. Dolomite, gray, weathered light brown, medium crystalline, thin-bedded; interbedded with sandy dolomite, quartz grains fine to medium, poorly sorted, subrounded; thin-bedded; chert in thin, yellowish brown stringers; unit nonresistant and 90% concealed. 56
47. Dolomite, medium to light gray, weathered light gray, finely crystalline, with residual clastic texture shown on freshly etched surfaces; no chert, quartz grains, or fossils; bedding indistinct with 1-foot beds in lower part and 2-foot beds in upper 20 feet 105

(Limestone-dolomite contact is irregular and passes stratigraphically lower to the southeast. Areas of dolomite are found in the upper limestone and areas of limestone are found in the lower dolomite along contact. Contact appears to be one of postdepositional dolomitization.)

46. Limestone, weathered light bluish gray, clastic texture, material medium- and fine-grained composed of limestone and fossil debris; some beds have irregular masses of fine-grained limestone embedded in matrix of coarse-grained and coarsely crystalline limestone detritus (channel fillings as described in unit 41); irregular bedding laminae; massive, resistant, forms ledges; fossiliferous. Coll. 21y, cephalopod from 12 feet above base 51
45. Limestone, same type as in unit 46, but less massive and resistant, beds average 2 feet thick, thinner beds have wavy laminae; shaly limestone rubble in thin concealed intervals suggests very thin-bedded strata 60
44. Limestone, weathered light bluish gray, fine-grained clastic texture; with chert, weathered yellowish brown, 10%, in nodules and in stringers which fill "worm trails," less chert in upper quarter of unit; in 2- to 5-foot beds alternating with thinner beds. Coll. 21x, from 25 feet above base; and coll. 21w, from 12 feet 68

43. Limestone, weathered light bluish gray, most beds dense and very finely crystalline but with numerous beds coarsely crystalline, clastic texture; 2- to 5-foot beds, resistant, forms ledges; silicified siphuncles of straight cephalopods at several horizons; lower contact gradational. Coll. 21v, from 17 feet above base; and coll. 21u, from 2 feet 28

42. Limestone, weathered light bluish gray, dense, very finely crystalline, clastic texture, thin-bedded, with some 1-inch laminae separated by 1/16-inch irregular sheets of light yellowish brown silt-rich limestone. Alternating with limestone, weathered light yellowish brown, silty, coarsely crystalline, coarse clastic texture composed of angular chips of light-bluish-gray-weathered finely crystalline limestone and fossil fragments; a few nodules of chert, medium gray, weathered brown; partly concealed. Coll. 21t, from dense bed 12 feet above base 54

41. Limestone of two types; one is dense and weathers light bluish gray and the other is coarsely crystalline, clastic, somewhat silty, and weathers yellowish brown; coarsely crystalline limestone predominates and contains rounded irregularly shaped masses of the dense limestone from 2 to 5 feet across that appear to be slightly later fillings of irregularly shaped channels eroded in the coarsely crystalline limestone. Origin of the two types of limestone appears to have been as follows: a bed of coarsely crystalline clastic limestone was deposited, and the surface was then slightly eroded by marine currents. Fine lime mud was deposited upon the irregular surface, which produced the dense limestone. Such scour-and-fill features are common in this part of the El Paso Formation 12

40. Limestone, weathered light bluish gray, dense, very finely crystalline; several beds of coarsely crystalline limestone, and several beds of edgewise conglomerate; thin-bedded, mostly concealed; fossils common on weathered slabs. Coll. 21s, from 8 feet above base 12

39. Limestone, medium gray, weathered light bluish gray, dense, very finely crystalline; massive, forms prominent bed; stromatolites 2 feet in diameter 4

38. Concealed. Float specimens indicate presence of diorite dike 38

37. Limestone, weathered light bluish gray with yellowish brown silty stringers, finely crystalline, medium-grained clastic texture; thin-bedded, nonresistant, partly concealed, forms saddle on hill slope; very fossiliferous; a few nodules of chert, weathered light gray. Coll. 21q-f, float specimens from upper part; coll. 21q, from 17 feet above base; coll. 21p, from 9 feet; and coll. 21n, from 6 feet 31

36. Limestone, weathered light bluish gray, medium- and fine-grained clastic texture; 2-foot beds; fossiliferous, trilobite fragments common; upper 2 feet limestone, dark gray, slightly oolitic. Coll. 21m, from top; coll. 21k, from 14 feet above base; and coll. 21j, from 4 feet 16

35. Limestone, dark gray to black, weathered dark gray with faint brownish cast, partly oolitic; oolites are medium sand size, stand out in relief on weathered surfaces because they are more resistant than matrix, are weathered light brown, and occur in beds and irregularly shaped masses; zones of limestone, black, composed almost entirely of trilobite debris; one such zone at base, and another 4 feet above base contain gastropods. Unit is excellent marker. To the southeast this bed passes into an area of dolomitization and is partly and completely dolomitized. Contact of dolomitization interfingers with limestone along favorable and less favorable beds. Coll. 21h, trilobites and gastropods from 4 feet above base; and coll. 21g, trilobites from base 7

34. Limestone, weathered light bluish gray and mottled with darker gray due to concentrations of different sized grains, clastic, fine to coarse sand size material composed mostly of fossil shell debris; thin-bedded; fossiliferous, with gastropods in lower half and brachiopods and trilobites in upper half. Coll. 21f, brachiopods from upper half 10

33. Limestone, gray, weathered light bluish gray in fine-grained areas, mottled with medium gray in medium-grained areas, medium- and fine-grained clastic; with small particles and laminae of limestone, silty, weathered yellowish brown; massive, with 2- to 5-inch laminae showing on weathered edges of strata. Coll. 21e 12

32. Limestone, weathered light bluish gray, upper 5 feet weathers yellowish brown and banded due to silt content, clastic, medium sand size detritus; thin-bedded with beds 1 inch to 1½ feet, nonresistant; fossils present 25

31. Limestone, medium gray, weathered light bluish gray with reticulated thin laminae of yellowish brown silty limestone, clastic, fine to coarse sand size detritus; massive, with thin beds near middle producing a concealed interval; chert stringers in upper 6 feet; fossils throughout, but not common; lower contact gradational. Coll. 21d, cephalopods from 20 feet above base; and coll. 21c, trilobite from 2 feet 100

30. Limestone, medium gray, weathered light bluish gray, coarsely clastic, most detritus less than ½ inch but a few scattered larger fragments up to 6 inches; "worm trails," especially in lower 6 feet, filled with silt that weathers light brown and in relief; chert laminae, weathered dark brown; and zones of chert nodules, light gray, weathered dark brown, confined to lower half and resembling chert of underlying unit; fossiliferous, cephalopod siphuncles in lower 4 feet, a few stromatolites. Coll. 21b, cephalopod siphuncles from base collected in gully south of section; and coll. 21a, cephalopod siphuncles from base 26

Total Bat Cave Member 725

Sierrite Member:

29. Dolomite, medium to light gray, weathered light brownish gray, medium crystalline; small quantity of light gray chert nodules 55

28. Dolomite, same type as in unit 24; chert, weathered very light gray, nodules abundant 36

27. Dolomite, same type as in unit 24; chert, weathered dark brown, in small globular and thin reticulated laminae and in disseminated grains, very abundant, gives entire unit an over-all characteristic dark-brown-weathered color; also numerous chert nodules, weathered very light gray; contacts with overlying and underlying units gradational 12

26. Dolomite, light gray, weathered light brown, medium crystalline; with chert, weathered dark gray, in thin ½-inch irregular laminae or ribbons, present but not conspicuous; also chert, medium gray, weathered very light gray, in masses averaging 2 inches thick and from 1 to 10 feet long typically forming elongated chert nodules and strata, very abundant; massive 6

25. Dolomite, same type as in unit 24 below; with 40% reticulated chert laminae as found in unit 23, which gives unit dark-brown-weathered color; a few chert nodules similar to those of unit 24; massive	5
24. Dolomite, light gray, weathered light brown, medium crystalline; chert abundant and conspicuous; brown-weathered reticulated chert laminae as found below in unit 23 common, but chert nodules and strata become more common above base; chert nodules and strata are medium gray on fresh fracture, weathered very light gray, masses average 2 inches in thickness and are elongated parallel to bedding from 1 foot to more than 10 feet	52
23. Dolomite, light gray, weathered light brown, medium crystalline; abundant ½-inch, irregularly shaped, reticulated laminae of chert that weather dark brown; concentrations of chert laminae produce dark brown zones; beds in lower part 2 to 3 feet in thickness; in upper part bedding not obvious and rock massive	122
22. Shale, dolomitic; and dolomite, finely crystalline and shaly; beds average 1 foot, several thicker dolomite beds	6
21. Dolomite, light gray, weathered medium brown, medium crystalline; a few chert nodules, medium gray; resistant	2
20. Shale, light to dark gray, weathered light brown, dolomitic, becoming more argillaceous upward, shaly fracture; two trilobite zones. Coll. 20g, *Kainella* sp. from 4 feet above base; and coll. 20f, from 3 feet	9
19. Concealed	4
18. Dolomite, medium gray, medium crystalline, residual clastic texture shown on weathered surface, composed largely of fossil detritus including cystoid stem segments, no quartz grains, massive. Coll. 20e	2
17. Dolomite, weathered light brown, finely crystalline, argillaceous, thin-bedded, concealed intervals strewn with 1- to 2-inch fragments of lumpy dolomite, bedding planes marked with oscillation-type ripple marks; upper half dolomite, finely crystalline, more resistant, in 1-foot beds. Coll. 20d, from trilobite zone at 25 feet above base on north side of gully; and coll. 20c, from trilobite and brachiopod zone at 4 feet on north side of gully	28
16. Concealed	6
Total Sierrite Member	345
Total El Paso Formation	1070

Conformable contact.

Bliss Formation:

15. Dolomite, medium gray, weathered light brown, finely crystalline, some quartz sand, fossiliferous, linguloid brachiopods. Coll. 20b, from 15 feet above base	35
14. Dolomite, finely crystalline, argillaceous, nonresistant, in thin lenticular beds that weather to small 1-inch lumps, partly concealed, a few linguloid brachiopods. Coll. 20a	11
13. Dolomite, medium gray, weathered light brown, medium and finely crystalline; with quartz sand, subrounded, 30%, in thin streaks parallel to bedding near base of unit; very little quartz sand in upper part; massive, resistant	27
12. Quartzite, weathered dark brown, dolomitic; quartz sand is medium- to coarse-grained, subrounded, and dolomite-cemented; over-all abundance of sand 60 to 70%, in varying concentrations, some thin dolomite beds deficient in sand and other beds almost entirely sand; forms ledge, excellent local marker bed, cross lamination prominent; lower contact irregular, upper contact gradational into dolomite deficient in sand	22
11. Dolomite, light gray, weathered light gray, medium crystalline, very little quartz sand	13
10. Dolomite, light and medium gray, weathered light gray, medium crystalline, quartzose; quartz sand, medium-grained, subrounded, mostly disseminated, but also concentrated in layers; 1- to 2-foot beds	16
9. Dolomite, dark gray, weathered medium to dark brown, medium crystalline, quartzose; quartz sand, coarse- to medium-grained, angular, 20% in lower part, diminishing upward to sand-free dolomite; bed characterized by dark-brown-weathered color	8
8. Dolomite, light gray, medium crystalline, nonresistant	2
7. Concealed	4
6. Dolomite, light gray, weathered yellowish brown, finely crystalline, no sand; contact with underlying arkose irregular	8
5. Arkose, medium- and fine-grained with carbonate cement	6
4. Concealed	16
3. Arkose, grains medium to coarse, subrounded, in distinct beds	8
2. Arkose, fine- to coarse-grained, a few subrounded quartz pebbles; granite-boulder conglomerate at base; in crude bedding planes	12
1. Boulder conglomerate; boulders of medium-grained granite and of cross-laminated arkose, up to 3 feet across, angular, in jumbled arrangement with respect to internal boulder structure, matrix of arkose gravel; a few thin beds of quartzite; lower contact very irregular with 10 feet of relief	4
Total Bliss Formation	192

Erosional unconformity.

Precambrian granite:

Granite, weathered reddish brown, coarsely crystalline, average crystal size 10 millimeters, strongly altered, soft, feldspars weathered to soft clay.

RAM GORGE SECTION

This stratigraphic section, which lies about 11/2 miles north of the Mescal Canyon section, starts at the base of the Paleozoic section on Precambrian granite, traverses the Bliss and El Paso Formations, and ends in the Montoya Dolomite. The principal reasons for measuring this section were to learn what stratigraphic units of the Mescal Canyon section persist over the distance between the sections and to determine the thicknesses of the Bliss and El Paso Formations in order to compare them with the thicknesses found elsewhere in the range. The section is shown graphically on Plate 2.

The section starts in an arroyo in the NW1/4SE1/4 sec. 20, T. 3o S., R. 15 W., and proceeds westward up the slope to the base of prominent cliffs in the lower El Paso Formation. The section is then offset northwestward a few hundred feet along a distinct bedding plane to a deep narrow wash that I call Ram *Gorge.* The section continues up this gorge and ends in the NE1/4SW1/4 sec. 20, T. 3o S., R. 15 W.

	Thickness (feet)
Higher beds exposed but not measured.	
Montoya Dolomite:	
22. Dolomite, dark grey, with abundant strata of dark gray chert nodules; not measured.	
21. Dolomite, weathered light gray, no quartz sand, fossiliferous, silicified fossils in upper 18 feet	68
20. Quartzite, dolomitic, sand grains medium, subrounded; upper contact sharp	6
19. Dolomite with quartz sand stringers	4
Total Montoya Dolomite measured	78
Disconformity.	
El Paso Formation:	
Bat Cave Member:	
18. Dolomite, weathered light gray, medium crystalline	15
17. Limestone, medium-bedded, nonresistant, partly concealed, with stringers of chert and dolomite in upper quarter of unit	140
16. Limestone, weathered light bluish gray, clastic; some beds contain both dense limestone and coarsely clastic limestone in irregular concentrations; some chert nodules in middle part, chert stringers in some beds; upper 200 feet forms massive cliff; fossiliferous	392
15. Limestone, dark gray, clastic, fossiliferous	17
14. Limestone, dark gray, oolitic, with some oolites dolomitized, abundant trilobite debris. This is same bed as unit 35 of Mescal Canyon section	7
13. Limestone, clastic, some yellowish stringers, a few chert nodules in lower part, medium- and thin-bedded	117
12. Limestone, coarsely clastic, with disseminated dolomite grains, yellowish brown "worm-trail fillings," chert nodules, straight cephalopod siphuncles	24
Total Bat Cave Member	712
Sierrite Member:	
11. Limestone, clastic, dolomitized to varying degrees because of various concentrations of dolomitized grains; most beds only partly dolomite, but a few are almost entirely dolomite; many 1- to 2-inch strata rich in nodules of chert, very light gray, weathered light gray; also dark-brown-weathered reticulated chert laminae; lower contact at lowermost chert nodules; upper contact chosen where chert nodules diminish in abundance and "worm trails" become common	112
10. Dolomite, weathered brown; patches of limestone, weathered gray, clastic, with disseminated dolomitized grains in various quantities, dolomite grains weathered brown; abundant reticulated chert laminae, weathered dark brown, concentrated in some zones producing prominent dark brown strata; resistant, lower beds form upper part of 30-foot cliff	40
9. Dolomite and limestone: dolomite weathered brown, clastic; limestone, weathered medium gray, occurs in patches 1 to 2 inches across; thin reticulated laminae of chert; strata average 1 inch in thickness and have a coarsely lumpy, shaly habit; fossiliferous, with linguloid brachiopods, other types of brachiopods, large trilobites, and cystoids. Lumpy and shaly character, stratigraphic position, and similar if not identical faunas suggest that this unit is equivalent to units 19 through 22 in the Mescal Canyon section and to unit 11 in Composite Chaney Canyon section	28
8. Concealed; probably occupied by rock similar to that of unit 9	20
7. Dolomite, weathered brown, no quartz sand	4
Total Sierrite Member	204
Total El Paso Formation	916
Conformable contact.	
Bliss Formation:	
6. Dolomite, with quartz sand; also several beds of chert, weathered white, in angular fragments	20
5. Quartzite, weathered dark brown, composed of medium-grained subangular quartz sand cemented by dolomite; proportion of sand varies considerably and is concentrated in pods; cross-laminated; probably correlates with quartzite bed in Mescal Canyon section, unit 12	25
4. Dolomite, weathered brown, with varying proportions of quartz sand; lower part more sandy and has several sand-rich beds; beds 2 feet, forms low ledges; much of unit covered; possible minor faults may be concealed	118
3. Quartzite, weathered light gray; sand composed of quartz and some feldspar, medium- and coarse-grained subangular sand cemented with dolomite; beds 18 inches thick. A few beds of hematitic arkosic shale are present near the base of the unit. Upper and lower contacts are gradational	20
2. Shale, brilliant red with a few light gray, orange, brown, and brownish red beds; argillaceous, hematitic, silty, with 20% disseminated arkosic sand detritus; hematite disseminated and locally concentrated in lenses of leached oolitic hematite; beds average 6 inches in thickness and are lenticular	16
1. Arkose: Upper part is medium-grained arkose which has 5 to 8 mm subrounded grains of quartz weathered in relief; bedding distinct, several 2-inch strata of hematitic shale. Lower part consists of medium- and coarse-grained matrix and scattered pebbles and boulders of granite and arkose (one granite boulder 25 feet across); also contains pebbles of milky quartz and many subangular quartz granules; massive, very crude bedding. Lower contact with granite is difficult to locate because of similar appearance of granite and arkose	50
Total Bliss Formation	249
Erosional unconformity.	
Precambrian granite.	

COMPOSITE CHANEY CANYON SECTION

Three stratigraphic sections were measured on the ridge on the north side of the mouth of Chaney Canyon on the west side of the Big Hatchet Mountains. None of the sections is completely reliable because of faulting and abrupt changes in bedding attitudes. However, parts of two of the sections are here combined into what represents as complete a section as can be measured on this ridge.

The lower part of the composite section starts at the Precambrian granite—Bliss contact in the saddle near the center of the S1/2NW1/4 sec. 31, T. 30 S., R. 15 W.; the section proceeds southward over the ridge and ends at a distinctive brown-weathered chert bed. This bed was traced northwestward about 300 yards along the southern slope of the ridge to a point at which the upper part of the composite section starts. Measurement proceeds southwestward down the slope to the alluvium near the center of the eastern boundary of sec. 36, T. 30 S., R. 16 W. The composite section traverses the Bliss Formation and two-thirds of the El Paso Formation. In the area between the two parts of the composite section, the Bliss Formation is duplicated by a fault. The section is shown graphically on Plate 2.

	Thickness (feet)
Alluvium.	
El Paso Formation:	
Bat Cave Member:	
22. Limestone: irregularly shaped masses of coarsely crystalline and coarsely clastic dark-bluish-gray-weathered limestone are separated and overlain by finely crystalline and finely clastic bluish-gray-weathered masses of limestone. The fine-grained limestone appears to represent detrital deposits and fillings deposited upon scoured and channeled surfaces cut upon coarser clastic beds; the fine-grained limestone has thin laminae that have compaction structures; these features are a few inches to a foot in size. The unit is massive, especially in the upper 85 feet; some parts are concealed; beds are irregular; fossils are common and include brachiopods, straight cephalopods, and sponges. Coll. 26c, from upper 50 feet	185
21. Limestone, dark gray, weathered light yellowish gray, very finely crystalline, thinly laminated. It lies upon an irregularly scoured surface of coarse-grained clastic limestone and has compaction structures; its upper surface is scoured and irregular, and it is overlain by coarse clastic limestone	5
20. Limestone, very dark gray, weathered light bluish gray with some yellowish gray; occurs in thinly laminated irregular beds and also as fillings of channels cut into coarse-grained clastic limestone. Some beds 2 feet thick; a few faint "fucoidal" markings. A short distance to the east of the measured section, the diagnostic black oolitic limestone bed (unit 35 of Mescal Canyon section) commonly found throughout the region is exposed at a stratigraphic level about 30 feet above the base of this unit. The oolitic bed was removed by marine erosion prior to deposition of the overlying bed at the place where the section was measured	75
19. Limestone, weathered light bluish gray, very finely crystalline; and limestone, weathered dark gray, coarsely clastic; finely crystalline limestone apparently fills irregularly shaped channels in coarsely crystalline limestone. A few yellow silt-rich stringers in lower part; a few 6-inch irregular chert nodules in upper part concentrated in particular strata; massive; rare "fucoidal" markings; fossil sponges in upper part	28
18. Limestone, interbedded coarse and fine clastic strata as in overlying units; coarse-grained limestone predominates; thin-bedded, "fucoidal" markings and fillings common. Coll. 26b, piloceroid siphuncles from 16 feet	46
Total Bat Cave Member measured	339
Sierrite Member:	
17. Dolomite and limestone: dolomite and limestone grains mixed in nearly equal proportions, a few chert nodules	12
16. Dolomite, abundant heavily silicified dark-brown-weathered fillings of "worm trails," silicified cephalopod siphuncles and gastropods. Coll. 26a	1
15. Dolomite; chert nodules, weathered white, elongated parallel to bedding, abundant through most of unit but fewer in upper part	60

(Lower part of section shown below was measured near the east end of the ridge. Correlation between upper and lower parts of section was made on the diagnostic chert bed, unit 14. The base of the upper part of the section is at the top of the chert marker bed.)

14. Chert, weathered dark brown, in reticulated laminae, forms 80% of rock; limestone 20% of rock; excellent local marker bed	10
13. Dolomite and limestone, clastic; limestone grains weathered dark gray, dolomite grains weathered light brown or brownish gray; limestone and dolomite grains in varying proportions in different beds, dolomite predominates; abundant chert nodules, weathered white, elongated parallel to bedding; chert nodules concentrated in particular beds and distributed in rhythmic succession with thin dolomite strata	39
12. Limestone and dolomite, medium-grained clastic; limestone grains weathered dark gray, dolomite grains weathered light brown or brownish gray; proportions of dolomite and limestone vary in individual beds; over-all weathered color is medium to dark gray; reticulated laminae of chert, weathered dark brown; fossiliferous, small gastropods and trilobites; thin-bedded; chert laminae and dolomite less abundant in lower part	80
11. Limestone, weathered light bluish gray; and dolomite, weathered yellowish brown; in lensing relationship that resembles thin-bedded dolomite and shale beds in Mescal Canyon section (units 19 through 22); thin-bedded, strata 1 to 4 inches; very fossiliferous, trilobites; concretions of limonite pseudomorphic after marcasite. Coll. 25a	22
10. Dolomite, weathered brown, with much quartz sand; irregular chert stringers not parallel to bedding	5
9. Limestone and dolomite in lensing relationship; thin-bedded, fossiliferous	12
8. Concealed	15
Total Sierrite Member	256
Total El Paso Formation measured	595
Conformable contact.	
Bliss Formation:	
7. Quartzite, white, weathered white; composed mainly of clean medium-grained subrounded quartz sand that is cemented with silica; a few feldspathic quartzite beds; very resistant, beds 2 feet thick	56
6. Arkosic sandstone, white, weathered brown, silica-cemented, in 1-foot beds	48
5. Arkose and arkosic sandstone: grain size ranges from granule to medium sand; some beds have hematite cement; nonresistant, beds average 6 inches thick, mostly concealed; contacts of unit arbitrarily chosen because of poor exposures	112
4. Arkose-granule conglomerate and arkose grit, weathered brown, grit predominating; resistant, beds 1 foot thick	20
3. Arkose, weathered white, medium-grained, with silica cement; interbedded with arkose-granule conglomerate and grit, weathered light brown and crumbly, calcite cement; cross-bedded	4
2. Arkose grit, weathered brown, composition is of arkose and arkosic sandstone, grain size about 5 mm, grains equidimensional and subangular; unit resistant, in 2-foot beds, forms ridge top; some crude cross-bedding; a few thin beds of white quartzite; upper contact transitional; some weathered surfaces hematitic	79

1. Conglomerate, with rounded granite boulders up to 4 feet across and arkose matrix 8

Total Bliss Formation 327

Erosional unconformity.

Precambrian granite.

HATCHET GAP SECTION

Exposures on the several small hills north of the highway in Hatchet Gap show the Bliss Formation resting unconformably upon Precambrian rocks. The Bliss was measured in the Hatchet Gap section because here the Bliss is lithologically different from other exposures in the area, and it contains an important brachiopod fauna.

The section lies on the first hill north of the highway in the S1/2 sec. 1, T. 3o S., R. 16 W. The Bliss caps the hill and dips about 35 degrees southwest. The section starts at the base of the formation high on the east side of the hill, proceeds southwestward over the crest, and continues to the last exposures at the southwestern toe of the hill. It is shown graphically on Plate z.

Thickness (feet)

Alluvium.

Bliss Formation:

12. Dolomite, medium to dark gray, weathered mostly dark gray with gashed surfaces, sandy beds weathered brown, texture saccharoidal with dolomite crystals the size of medium-grained sand; some beds have varying amounts of quartz sand, medium- to coarse-grained, angular to subrounded, weathered brown in contrast to the gray color of pure dolomite beds, in strata and in irregular concentrations distributed throughout unit, about 10% of composition of unit; upper 30 feet of unit more sandy and resembles unit 11, but this may be a fault duplication; beds 6 inches to 1 foot thick; "fucoidal" markings on a few bedding planes 85
11. Sandstone; medium gray, weathered medium brown with dark-brown-weathered reticulated stringers; sand grains subangular to subrounded, equidimensional, fine to very coarse, mostly of quartz, a few grains of feldspar; a few small pebbles of milky quartz and of feldspar; cement chiefly dôlomite that averages nearly 50% of rock, irregular stringers of silica cement produce reticulated dark-brown-weathered pattern in some beds and also produce small nodular masses of silica-cemented sandstone within dolomitic sandstone; a few beds are of sandy dolomite; beds from 6 inches to 1½ feet thick, finely stratified, unit nonresistant; dimples on some bedding surfaces suggest *Skolithos* sp. 20
10. Sandstone, medium gray and brown, weathered brown, sand sizes range from fine to very coarse, a few pebbles, arkosic, dolomite cement in varying quantities increasing upward, beds 1 to 6 inches thick, unit nonresistant and mostly covered. Brachiopods, including *Eoorthis* sp., collected 7 feet above base of unit (U.S.G.S. collection number 3797) 23
9. Sandstone, fresh and weathered colors medium to light gray, grains similar to those of unit 8 except none of strata are of arkose and only a few are arkosic; more resistant and fewer laminae than in unit 8; slightly porous; a few rounded pebbles of arkose or granite; beds average 2 feet in thickness 6
8. Sandstone, medium gray, weathered medium gray, sand mostly of quartz, a few thin strata have composition of arkose and arkosic sandstone, grain sizes in different strata range from sand to small pebble but medium-grained sand predominates; less strongly cemented with silica than neighboring units, some strata porous, nonresistant and partly concealed; finely laminated and cross-laminated; a few widely scattered rounded pebbles of milky quartz 5
7. Quartzite, light gray to white, sparsely speckled with limonite flecks, weathered light gray to white, over-all appearance of exposure white; quartz grains equidimensional, equigranular, medium sand size, subangular to subrounded, firmly cemented with silica; massive, beds 2 to 10 feet thick, laminated and cross-laminated, *Skolithos* tubes and "fucoidal" markings, tiny pores lined and filled with limonite, little limonite staining along joints 32
6. Partly concealed. Quartzite, light gray with disseminated limonite specks, weathered light brown, sand grains same as in unit 5 except some strata are weakly cemented and slightly porous, *Skolithos* tubes normal to bedding, beds 6 inches to 1 foot thick. A few feet south of the section, unit contains boulders of Precambrian granite, and farther south unit thickens and becomes a boulder conglomerate having the same characteristics as unit 3 6
5. Quartzite; light gray to white, weathered light gray to white with brown specks due to limonite lining small scattered pores and with some limonite-stained joints and laminae; medium-grained quartz sand, subangular to subrounded, equigranular, silica-cemented; massive single bed with bedding laminae and cross-laminae 11
4. Quartzite; light gray with orange and yellow streaks parallel to strata, weathered light gray and light brown; medium-grained quartz sand subrounded, equigranular, and silica-cemented; laminated, some porosity due to 5-mm cavities mostly concentrated along certain strata 5
3. Partly concealed. Scattered exposures and rubble of boulders indicate the unit to be boulder conglomerate. Boulders consist mostly of Precambrian granite but include a minor quantity of Precambrian quartzite boulders; all are subrounded to well rounded, and diameters range up to 20 feet. Granite boulders weather light gray instead of the brown of recently exposed Precambrian granite, but in texture and other respects the granite is the same. Matrix is of arkose and arkosic sandstone, distinctly cross laminated, laminae curved in conformity with boulder tops and sides. Unit lenses and probably represents a channel fill 17
2. Quartzite, white, weathered light gray with numerous limonite stains along joints, medium-grained quartz sand, a few strata arkosic, grains subrounded to rounded, equigranular, silica-cemented, strongly cross-laminated 7
1. Arkose, arkosic sandstone, and quartzite; fresh and weathered color light gray, coarse-grained; includes some granule size detritus, some boulders of Precambrian granite that weather light gray perhaps because of long exposure to weathering and leaching prior to Bliss deposition, and some subrounded to subangular 1-inch pebbles of milky quartz; some strata cross-laminated; thickness of unit varies 6

Total Bliss Formation measured 223

Erosional unconformity.

Precambrian rocks:

The Bliss Formation rests with erosional unconformity upon Precambrian quartzite and granite. At the base of the section, the Bliss rests upon Precambrian quartzite along 100 feet of the contact, and elsewhere on this hill and on the two hills to the northwest the Bliss rests upon Precambrian granite. Several tens of feet of relief are seen on the pre-Bliss erosion surface, but relief must have been greater judging from the large boulders in the lower Bliss. The lower beds in the section apparently represent a channel fill, which is indicated by the local depression on the erosion surface and by the boulder conglomerate beds in the lower Bliss.

The Precambrian quartzite is massive, but at one place where bedding is visible it dips steeply to the east in contrast to the southwestern dip of the Bliss Formation. The quartzite is medium gray, weathers brown, and is silica-cemented. Sand grains are medium to coarse and subrounded. In some beds, feldspar crystals enclose quartz grains and appear to be secondary growths associated with the intrusion of Precambrian granite. The exposed quartzite mass is 300 feet long and at least 100 feet thick.

The Precambrian granite is coarsely crystalline, porphyritic, medium gray on fresh exposure, and brown-weathered. Feldspar phenocrysts are one-half inch in diameter and are rounded. The granite has the same characteristics here as in the Big Hatchet and Little Hatchet Mountains and in the Sierra Rica. Scattered veins of milky quartz cut the Precambrian rocks but are not found in the Bliss Formation.

NEW WELL PEAK SECTION

This represents the most complete and least disturbed section of Horquilla Limestone in the Big Hatchet Mountains and southwestern New Mexico, and therefore it is designated as the best reference section for the formation in southwestern New Mexico. The base of the section is at the contact of the Horquilla Limestone with the underlying Paradise Formation north of the center of the SW1/4 sec. 28, T. 31 S., R. 14 W. on the northeast slope of the hill that lies southeast of the mouth of New Well Canyon. The section continues southwestward to the top of this hill. It is then offset about three-fourths mile southwestward to bypass several small faults and one large fault. Measurement of several hundred feet of beds was duplicated, and diagnostic beds, megafossil zones, and fusulinid zones were matched in the duplicated parts in order to properly shift the line of section. The duplicated beds are not included in the description. The section continues in a southwestern and western direction up a long prominent spur nearly to the top of New Well Peak. The section is then offset about half a mile southwestward to the high saddle at the head of the south fork of New Well Canyon. This is accomplished without omission or duplication of beds by tracing individual strata between the two parts of the section. The section then trends in a southern and southwestern direction and follows close to the crest of a prominent spur. Many small offsets in the line of section are made upon individual beds. The section ends at the alluvium on the northeast side of South Sheridan Canyon in the SW1/4NW1/4 sec. 5, T. 32 S., R. 14 W. Here the alluvium conceals a fault, but comparison of fusulinids and other fossils in the highest beds exposed in this section with those in the uppermost beds of the Horquilla Limestone where not disturbed by faulting indicates that the highest beds measured here are near the top of the formation. This section was measured cooperatively with J. P. Fitzsimmons and H. P. Bushnell. The New Well Peak section is shown graphically on Plate 3; its location is shown on the photograph of Figure 9.

	Thickness (feet)
Fault concealed by alluvium.	
Horquilla Limestone:	
129. Dolomite and limestone; uppermost beds almost entirely dolomite with crinoid columnals replaced by white chert, patches of dolomite in limestone in upper 167 feet; below the dolomite there is limestone, medium and light gray, weathered medium and light gray, medium-grained clastic, finely crystalline, in 1-foot beds; lower beds limestone, light gray, coarse-grained crinoidal, in 2-foot beds separated by concealed intervals; a few dark gray chert nodules at 32 feet above base; fossiliferous, with small coiled cephalopods at 142 feet above base that resemble those found elsewhere in limestone beds immediately below base of Earp Formation. Coll. 59k, from 169 feet above base; coll. 59j, from 167 feet; coll. 59i, from 142 feet; coll. 59h, from 88 feet; coll. 59g, from 47 feet; coll. 59f, from 32 feet; and coll. 59e, from 22 feet	237
128. Limestone, medium gray, weathered medium gray, medium-grained clastic with small flecks of white chert; patches of dolomite; a few white chert nodules near top. Coll. 59d, from top	21
127. Limestone, light gray, weathered light gray, finely crystalline matrix with much crinoidal debris; a few white chert nodules	12
126. Limestone; upper half dark gray, weathered dark gray, medium-grained clastic; lower half crinoidal limestone, light gray, weathered light gray, coarse-grained	10
125. Limestone, light gray, weathered light gray, coarse-grained crinoidal; with chert nodules, light gray to white, 20 to 30%. Coll. 59c, from 10 feet above base	15
124. Limestone, light gray, weathered light gray, medium and coarsely crinoidal with columnals as wide as one-half inch; a few patches of dolomite near top; a few white chert nodules with molds of crinoid columnals, some fusulinids and columnals replaced by white chert; beds 5 feet, bedding-plane joints 1 foot apart. Coll. 59b, from 7 feet above base	22
123. Limestone, light gray, weathered light gray, finely crystalline, medium sand size clastic grains faintly visible; a few beds of limestone, medium to dark gray, weathered dark gray and mottled, medium-grained clastic; a few beds of coarse-grained crinoidal limestone; white chert nodules at 120 feet above base; massive, beds 5 feet, with several 3-foot concealed intervals. Coll. 59a, from 155 feet above base; and coll. 58z, from 93 feet	158
122. Concealed	5
121. Limestone, light gray, weathered light gray, very finely crystalline; with 1-foot dark gray coarse-grained calcarenite bed at top; many large bellerophontid gastropods	5
120. Concealed	8
119. Limestone, light gray, weathered light gray, very finely crystalline, massive, with strata rich in fusulinids. Coll. 58y, from top; coll. 58x, from 15 feet above base; and coll. 58w, from near base	32

118. Limestone, light gray, weathered light gray, medium- and coarse-grained crinoidal, massive; with 10% large chert nodules; fusulinids 17
117. Limestone, dark gray, weathered dark gray mottled with medium gray streaks, medium-grained clastic, sublithographic; upper part partly dolomitized; massive; fusulinids in upper part weathered to dark gray spots against brownish dolomite background. Coll. 58v, from 5 feet above base; and coll. 58u, from base 23
116. Limestone, light brownish gray, weathered light gray and smoothly rounded, lithographic, a few crystals and fossils, nonresistant; middle bed 4 feet thick and medium gray on fresh surface; upper half of unit nonresistant and contains from 20 to 50% clastic debris that gives rock dark mottled appearance 15
115. Limestone, light gray, weathered light gray, finely and very finely crystalline, some clastic material that shows up on weathered surface; beds 1 foot thick. Coll. 58t, from 12 feet above base; coll. 58s, from 5 feet; and coll. 58r, from 3 feet 30
114. Limestone, medium gray, weathered medium gray mottled, very finely crystalline, medium-grained residual clastic texture; some beds mottled dark gray and similar to those in unit 113; massive, beds 5 feet 40
113. Limestone, medium gray and some beds light gray, weathered medium to dark gray, most beds conspicuously medium-grained clastic with much very finely crystalline cement; some beds of coarse crinoidal limestone; one zone of chert nodules, medium gray, weathered brownish gray; nonresistant, beds 1 foot separated by short concealed zones, fusulinids abundant. Coll. 58q, from 30 feet above base; coll. 58p, from 24 feet; and coll. 58n, from 20 feet 40
112. Limestone, dark gray mottled, weathered dark gray mottled, medium-grained clastic with much very finely crystalline matrix; some beds oolitic; beds 5 feet separated by nonresistant thin beds. Coll. 58m, from 17 feet above base 52
111. Limestone, light gray, weathered light gray, very finely crystalline, with some clastic material . . 23
110. Limestone, light gray, weathered light gray, very finely crystalline, in 1-foot beds. Coll. 58k, from 7 feet above base 12
109. Limestone, light gray, weathered light gray, very finely crystalline; massive, forms single ledge; fusulinids. Coll. 58j, from 5 feet above base . . 13
108. Concealed 5
107. Limestone, light gray, weathered light gray, very finely crystalline with a trace of clastic debris; massive with bedding joints 2- to 5-feet apart. Coll. 58i, from 27 feet above base; and coll. 58h, from near base 62
106. Concealed 13
105. Limestone, medium gray, weathered medium gray mottled, medium-grained clastic, some beds very finely crystalline; massive, beds 5 to 8 feet with thin nonresistant interbeds. Coll. 58g 55
104. Limestone, medium to dark gray mottled, weathered dark gray mottled, matrix very finely crystalline with variable but large quantity of medium- and coarse-grained detritus 15
103. Limestone, medium and light gray, weathered medium gray, very finely crystalline, some beds of medium-grained detritus; beds 2 feet 39
102. Limestone, medium gray mottled, weathered medium gray mottled, some beds dark gray, finely crystalline, medium-grained clastic texture; some beds mostly clastic; a few widely scattered globules of chert. Coll. 58f, from 24 feet above base 25
101. Concealed 3
100. Limestone, medium gray, weathered dark gray mottled, medium-grained detritus and finely crystalline matrix; beds 2 to 5 feet 13
99. Limestone, light gray, weathered light gray mottled, very finely and finely crystalline, with medium- and fine-grained residual clastic texture; no chert or dolomite; beds 5 feet 50
98. Concealed 10
97. Limestone, medium gray, weathered medium and light gray mottled, finely crystalline, fine clastic grains; some black streaks 13
96. Limestone, light gray, weathered light gray with reddish brown streaks, very finely clastic, very finely crystalline to lithographic with a few larger scattered crystals; changes laterally to dolomite, small patches of dolomite in limestone produce mottling; contains large chert nodules, very light gray, weathered white, 5%; massive, bedding strata 5 feet; some silicified fossils including fusulinids, bellerophontid gastropods, and productid brachiopods 107
95. Limestone, medium gray, weathered medium brownish gray, medium and coarsely crystalline, patches of dolomite similar to those in unit 94; medium-gray chert nodules; some silicified detritus in dolomite 25
94. Dolomite, light brownish gray, weathered medium brownish gray, finely crystalline; composition variable, crystals of calcite and patches of limestone, unit changes to limestone along strike; chert nodules, light and medium gray, 1% 25
93. Limestone, light gray, weathered light gray, very finely crystalline, in 5-foot beds, a few white chert nodules. Along strike there are great masses of finely crystalline dolomite which have no traces of bedding. This is the same unit that caps New Well Peak. Coll. 58e, from 55 feet above base; and coll. 58d, from 35 feet 70

(Line of section is offset about half a mile southwestward from units 92 to 93. This was accomplished by carefully tracing beds from near the top of New Well Peak to the point where section is continued; there is no duplication or omission of beds.)

92. Limestone, medium and light gray, weathered light gray, finely and very finely crystalline; a few beds of crinoidal limestone, medium- and coarse-grained, poorly cemented; chert nodules, 10%; differs from unit 91 only in forming an upper cliff near top of New Well Peak 45
91. Limestone, light gray, weathered light gray, very finely crystalline to lithographic; some beds of limestone, medium gray, weathered light gray, finely crystalline, medium-grained clastic; chert nodules, white with yellowish brown stain, 10%, large (10 inches by 2 feet); massive, forms cliff on crest of ridge extending south from New Well Peak 90
90. Limestone, medium gray, weathered medium gray, medium-grained clastic, finely crystalline; some patches of dolomite; in 2-foot beds 18
89. Dolomite, light gray, weathered light gray, finely crystalline, very rough weathered surface due to silicified particles 9
88. Limestone, dark gray, weathered medium gray, finely crystalline, medium-grained clastic, some 1-foot beds of crinoidal limestone, nonresistant 10
87. Dolomite, light gray, weathered light gray, finely crystalline, very rough weathered surface due to silicified fossil and breccia fragments 8
86. Limestone, light gray, weathered light gray, very finely crystalline; a few beds of limestone, medium gray, weathered light gray, medium-grained clastic; some beds rich in crinoid detritus; dolomite and silica crenulations 22

85. Dolomite, light gray, weathered light gray, finely and medium crystalline, many very large diameter crinoid columnals; some disseminated chert; chert nodules, 20%; strata 1 foot. This is probably a lens-shaped mass rather than a bed . . . 8
84. Limestone, light gray, weathered light gray, very finely crystalline, traces of medium-grained clastic texture; light gray chert nodules, less than 1%; forms single massive cliff . . . 40
83. Limestone, light gray, weathered light gray, very finely crystalline, some medium-grained calcarenite zones; chert nodules, 8 by 15 inches, light gray, weathered white, 30%; stringers of dolomite; nonresistant, beds 1 foot . . . 15
82. Limestone, light gray, weathered light gray with some mottling and with rough surface, very finely crystalline to lithographic, residual medium-grained clastic texture; a few thin beds of dark gray medium-grained calcarenite; several beds of limestone, light gray, weathered light gray, medium-grained clastic with very finely crystalline matrix; a few zones of chert nodules, 6 by 12 inches, white to light gray, less than 1%; with chert and dolomite crenulations; massive, forms bold slope; a few silicified brachiopods. Coll. 58c, from 80 feet above base . . . 95
81. Limestone, dark gray, weathered dark gray, medium-grained clastic, forms top of cliff of unit 80 . . . 3
80. Limestone, light gray, weathered light gray, very finely crystalline, with stringers of crinoidal limestone; chert nodules, very light gray, brown-stained, 1 to 5%; small dolomite stringers throughout; forms single cliff . . . 28
79. Limestone, medium gray, weathered medium gray, clastic, massive, with fusulinids. Coll. 58b . . . 7
78. Limestone, weathered dark gray, a few chert globules and nodules . . . 2
77. Limestone, dark gray, weathered medium gray, finely crystalline, medium-grained clastic, with fossils on weathered surfaces, forms single ledge, bedding joints 1 foot; echinoid spines 6 inches long and ¼-inch diameter in basal 1 foot. Coll. 58a . . . 5
76. Concealed . . . 5
75. Limestone, light gray, weathered light gray, coarse-grained crinoidal, in single ledge . . . 3
74. Limestone, medium brownish gray, weathered light gray, finely crystalline, with patches of dolomite . . . 2
73. Limestone, light gray, weathered light gray, finely crystalline matrix with medium-sized crystals; silicified and dolomitized streaks; massive ledge; abundant silicified solitary corals . . . 5
72. Limestone, light gray, weathered light gray with rough surface, lithographic . . . 7
71. Limestone, medium gray, weathered medium gray, finely crystalline with fine-grained clastic texture; minor chert in brown globules and nodules; fusulinids. Coll 57z, from 3 feet above base . . . 7
70. Limestone, medium and dark gray, weathered medium gray, fine- and medium-grained clastic, finely crystalline; with chert, 20%; nonresistant, beds 6 inches to 1 foot . . . 35
69. Limestone, light gray, weathered light gray, lithographic, with some crystals scattered sparsely throughout; a few thin beds of calcarenite; several zones of chert nodules, light gray, weathered light brownish gray; surface weathers very rough because of small silicified streaks and areas that are partly dolomitized; massive, boldly exposed in cliff; *Chaetetes* zone at 87 feet above base . . . 101
68. Limestone, light gray, weathered light gray, medium- and coarse-grained clastic; streaks of silicified material and concentrations of dolomite; some 3-foot zones have 20% chert nodules; beds 3 to 5 feet, forms base of cliff; some silicified brachiopods . . . 25
67. Limestone, light gray, weathered light gray, very finely crystalline, in 2-foot beds; streaks of dolomite in random orientations; very little chert . . . 11
66. Limestone, light gray, weathered medium gray, medium-grained clastic, in 2-foot beds; alternating with limestone, dark gray, weathered light gray, finely crystalline, with 2 to 5% chert nodules . . . 24
65. Limestone, dark gray, weathered medium and light gray, finely crystalline, fine-grained residual clastic texture; a few beds of medium-grained crinoidal limestone; chert, dark gray, weathered dark brownish gray, 35 to 40%; 6-inch strata, 10- to 15-foot ledges separated by concealed zones. Coll. 57y, from 8 feet above base . . . 33
64. Concealed . . . 6
63. Limestone, medium to dark gray, weathered medium to dark gray, finely clastic with faint fine mottling; chert, in brown-weathered globules and large globular masses, 10%; 1- to 2-foot beds 7
62. Concealed . . . 7
61. Limestone, dark gray, weathered medium gray, finely crystalline, fine clastic texture; a few small particles and streaks of dolomite; weathered surface suggests abundance of bryozoans; single bed; bellerophontid gastropods. Coll. 57x, from near base . . . 5
60. Limestone, medium gray, weathered dark to light gray, medium- and coarse-grained crinoidal; alternating with and predominated by limestone, smooth-textured, finely clastic, and finely crystalline; chert nodules, black and dark brown, 20 to 30%, form beds of light-brown-weathered color; nonresistant, beds 6 to 12 inches, forms low slope and is half covered . . . 60
59. Limestone, medium gray, weathered medium gray, coarse-grained crinoidal; forms massive cliff, with 1-foot strata in upper part . . . 17
58. Limestone, medium gray, weathered medium gray, medium- and coarse-grained clastic, 1-foot beds; alternating with limestone, dark gray, weathered medium to light gray, finely clastic and finely crystalline, 1-foot beds with 2-inch laminae; fossiliferous . . . 18
57. Limestone, medium to dark gray, weathered medium to dark gray, coarse-grained clastic, H_2S odor, single massive ledge . . . 22
56. Limestone, weathered medium and light gray, medium- and coarse-grained clastic, 2-foot beds; alternating with limestone, medium gray, weathered medium and light gray with some beds having brownish cast, 6-inch beds, a few chert nodules . . . 35
55. Limestone, medium gray, weathered medium gray, medium-grained clastic; with spongy-looking chert masses, 1%; single ledge, with 2-foot strata . . . 5
54. Concealed; probably underlain by shale . . . 10
53. Limestone, medium gray, weathered medium gray mottled, medium-grained clastic; with spongy-looking chert masses, weathered brown and lumpy, 20% . . . 4
52. Concealed; underlain at least in part by shale, very light gray, weathered very light gray, clay, with a little very fine-grained quartz sand . . . 16
51. Limestone, medium and dark gray, weathered medium gray with rough surface, medium- and coarse-grained crinoidal, with a few nodular areas of brown porous-looking chert, 1%, in 3- to 5-foot ledges; alternating with limestone, medium to dark gray, weathered mottled light gray with smooth surface, finely crystalline,

much medium- and fine-grained detritus, 6-inch beds, nonresistant; silicified fossils include *Prismopora, Syringopora,* brachiopods, and fusulinids. Coll. 57w, from 22 feet above base 42

50. Concealed 5

49. Limestone, medium to dark gray, weathered medium and light gray and some beds mottled, finely crystalline, fine-grained clastic, in 3-foot beds, with black "fucoidal"-like blotches on light-gray-weathered areas, no chert. Coll. 57v, from 20 feet above base 23

48. Limestone, dark gray, weathered light gray, with much detritus; a few 6-inch beds of coarse-grained crinoidal limestone; chert nodules, weathered dark brownish gray, 30%; more massive than unit 47, 6-inch strata 5

47. Limestone, dark gray, weathered medium gray and mottled and with fine-textured lumpy surface, finely crystalline with clastic streaks; chert nodules, black, 20 to 40%; nonresistant, 6-inch beds, half covered; with medium-gray-weathered crinoids, fusulinids, solitary corals, brachiopods, and *Prismopora.* Coll. 57u 23

46. Limestone, medium gray, weathered medium gray and some beds having reddish brown tinge, mostly medium- and fine-grained clastic with little finely crystalline dark gray limestone, less than 1% black chert, in 1-foot beds. Coll. 57t, from 25 feet above base 27

45. Limestone, medium gray, weathered medium gray with reddish brown streaks, finely and very finely crystalline, clastic streaks visible on weathered surface, no chert, 6-inch to 1-foot beds; alternating with and predominated in upper part by limestone, light gray, weathered medium gray, medium- and coarse-grained crinoidal, a few silicified solitary corals and brachiopods, 2-foot beds; calcarenite at 40 feet above base has limy incrustations (oolite-like) on grains; very coarse-grained crinoidal limestone with ¼-inch diameter detritus from 63 to 68 feet above base 70

44. Limestone, fresh color medium gray with reddish brown streaks, weathered medium gray, finely crystalline, clastic stringers; chert nodules medium gray, weathered brownish gray, 6 by 12 inches, 20% 8

43. Limestone, medium gray, weathered medium gray with hematite stain, medium-grained clastic, partly covered 11

42. Limestone, light gray, weathered medium gray with hematite stain, very coarsely clastic, ¼-inch detritus common, massive but nonresistant, beds 15 inches, mostly covered; brachiopods and crinoids 11

41. Limestone, medium and light gray with a few brownish beds, weathered medium gray, fine-grained clastic, minor parts finely crystalline; chert, medium and light gray, weathered brown, in large somewhat irregular nodules, 6 by 10 inches, 45%, evenly dispersed to make a prominent zone 27

40. Limestone, medium gray, weathered gray, medium-grained clastic, a few silicified solitary corals 3

39. Limestone, dark and medium gray, weathered medium and light gray, finely crystalline, a few beds of crinoidal limestone; near top is 2-foot bed of limestone, weathered light gray mottled, containing "fucoidal" markings; chert, medium gray, 20%; most beds 1 foot 25

38. Limestone, medium gray, weathered medium gray, finely crystalline, some chert, massive, many solitary corals 5

37. Limestone, medium gray, weathered gray, mostly finely crystalline, some chert, massive 5

36. Limestone, medium gray, weathered medium gray, medium-grained crinoidal; chert, medium gray, in large nodules, 10%; massive ledge. Coll. 57s 10

35. Concealed 30

34. Limestone, medium and light gray, weathered medium gray, medium- and coarse-grained crinoidal; chert, light gray, weathered light gray; some beds have large, spongy-looking chert nodules containing fusulinids; chert absent in upper two-thirds 55

33. Limestone, medium gray, weathered medium gray, medium clastic with variable quantities of finely crystalline cement; chert, dark gray, weathered dark brownish gray, nodules 3 by 12 inches, distributed throughout; nonresistant, beds 6 inches 25

32. Limestone, medium gray, weathered medium gray, finely crystalline, some clastic beds; massive beds 5 feet. Coll. 57r, from top 25

31. Limestone, medium gray, weathered medium gray, finely crystalline, beds 1 foot. Coll. 57q 12

30. Limestone, medium gray with faint brownish cast, weathered medium gray, very finely crystalline, residual clastic texture; one 6-inch bed of medium-grained crinoidal limestone; chert nodules, dark brownish gray, 30%; *Composita, Prismopora,* and other fossils. Coll. 57p, from near middle 8

29. Limestone, medium to dark gray, weathered medium gray, medium-grained clastic, finely crystalline; almost no chert; massive, beds 4 feet; upper half concealed. Coll. 57n, from 4 feet above base 21

28. Limestone, medium gray, weathered light gray mottled, finely crystalline, much crinoidal debris; beds 2 feet; *Chaetetes* and *Prismopora* 12

27. Limestone, medium gray, weathered medium gray, finely crystalline, medium-grained clastic, little chert; massive, beds 3 to 5 feet; *Chaetetes* zone at 37 feet above base, many fusulinid horizons. Coll. 57m, from 50 feet above base; coll. 57k, from 40 feet; coll. 57j, from 30 feet; and coll. 57i, from 13 feet 52

26. Limestone, medium gray, weathered medium gray mottled, finely crystalline, some clastic debris; black chert nodules; beds thin. Coll. 57h . . 10

25. Limestone, medium gray, weathered medium gray, finely crystalline, medium-grained clastic; chert nodules, dark gray, weathered light gray; beds 6 to 12 inches 7

24. Limestone, medium gray, weathered medium gray, very finely crystalline; single ledge; fusulinids, silicified *Chaetetes* abundant and silicified *Syringopora* present. Coll. 57g 8

23. Limestone, light gray, weathered medium gray, lithographic to very finely crystalline, massive ledge 13

(Section is offset approximately ¾ mile southwestward from unit 22 to unit 23 to bypass several minor faults and one major fault. The offset was made upon the top of the distinctive brownish-weathered limestone of unit 22. Measurement of several hundred feet of beds was duplicated, and diagnostic beds, megafossil zones, and fusulinid zones were matched in the duplicated parts to confirm the identification of the brown-weathered marker bed. The duplicated section is not shown here or on Plate 3, and the section continues without interruption.)

22. Limestone, light gray with light brownish tint, weathered medium gray with light brownish tint, lithographic, a few crystals, probably slightly dolomitic; massive, single bed 22

21. Limestone, medium gray, weathered medium gray, medium- and fine-grained oolitic; a few beds of limestone, lithographic; upper part massive; up-

permost beds mottled, bearing chert, and mostly concealed. Coll. 56i, from 110 feet above base; and coll. 56h, from 95 feet 120

20. Limestone, same type as in bed 19; sheared brown chert, 50% 5
19. Limestone, medium gray, weathered medium gray, lithographic and very finely crystalline; a few beds of oolite and medium-grained clastic limestone; some chert globules 15
18. Limestone, medium gray, weathered medium gray, medium-grained clastic, with oolites and detrital grains incrusted with calcite; 30% of bed composed of silicified *Chaetetes* 4
17. Dolomite, medium gray, weathered light pinkish gray with gashed surface, finely crystalline, resistant, beds 1 foot 8
16. Limestone, medium gray, weathered light brownish gray, finely crystalline, somewhat dolomitic, nonresistant, beds 1 foot 8
15. Limestone, weathered medium gray, lithographic to very finely crystalline; less than 10% black chert nodules; massive, beds 10 feet 20
14. Limestone, medium gray, weathered medium gray, finely crystalline, with some medium- and fine-grained calcarenite beds, some of which are oolitic; beds 1 to 2 feet; a few black chert nodules near top; fusulinids (lowest observed in Horquilla Limestone). Coll. 56g, from 20 feet above base 60
13. Limestone, medium gray, weathered medium gray with rough surface, finely crystalline; chert, in small ½-inch globules, 15%; massive bed 5
12. Limestone, medium gray, weathered medium gray, medium-grained clastic; upper half finely crystalline with some mottling; *Chonetes* present but not common, productid brachiopods. Coll. 56f 22
11. Limestone, dark gray, weathered light gray with smooth surface, very finely crystalline with 5% clastic limestone grains, beds 6 inches 5
10. Limestone, medium gray, weathered medium gray, medium sand-sized oolitic; beds 2 to 3 feet; a few zones rich in brachiopods silicified with brown-weathered chert; *Michelinia, Derbyia,* and productid brachiopods. Coll. 56e 24
9. Limestone, medium gray, weathered medium gray, finely crystalline, fine- and medium-grained clastic; chert, medium to dark gray, weathered brown, occurs in calcarenite as spongy-looking nodules produced by replacement of some of clastic grains, and also occurs as solid chert masses which partly replaced limestone nodules up to 18 inches in diameter, 40%; beds 6 inches; spirifer brachiopods and large 4-inch barbed echinoid spines. Coll. 56d 11
8. Limestone, dark gray to black, weathered dark gray to black, very finely crystalline, little chert, massive 22
7. Limestone, medium gray, weathered medium gray, medium-grained oolitic; stringers of brown-weathered disseminated chert grains 3
6. Limestone, dark gray to black, weathered dark gray to black, very finely crystalline; chert nodules, medium gray, 10%; very massive 13
5. Limestone, medium gray, weathered light gray mottled and with smooth surface, finely crystalline; chert, black, in 6-inch irregular nodules with ½-inch brown spongy-looking rinds, 30% 8
4. Limestone, dark gray, weathered dark gray and slightly mottled, finely crystalline, concentrations of oolites; stringers and ½-inch globular masses of brown-weathered chert; massive, beds 5 feet 15
3. Limestone, medium gray, weathered light gray with smooth surface, finely crystalline, clastic streaks; a few beds of black chert nodules; beds 6 inches; *Chonetes*. Coll. 56c 15
2. Limestone, dark gray to black, weathered dark gray, some beds oolitic and others finely crystalline; oolites concentrated with other detritus in bands, some of which are cross laminated; massive, beds 10 feet; concentrations of fossils silicified with brown-weathered chert 22
1. Limestone, dark gray, weathered light gray with smooth surface, very finely crystalline, in 1-foot beds; alternating with siltstone, light reddish brown, shaly, nonresistant; some beds of medium-grained calcarenite; upper part contains black chert nodules; nonresistant; *Chonetes* at base, trilobites, productid brachiopods, and fish teeth in higher beds. Coll. 56b, from 20 feet above base; and coll. 56a, from 10 feet 45

Total Horquilla Limestone measured 3245

Erosional unconformity.

Paradise Formation:

Upper 4 feet consists of quartz sandstone.

BUGLE RIDGE SECTION

This stratigraphic section, which lies mainly on Bugle Ridge, traverses nearly the entire Horquilla Limestone. Its starting point is at the contact of the Horquilla with the underlying Paradise Formation near the foot of a spur on the northeast side of Bugle Ridge in the SE1/4E1/4 sec. II, T. 31 S., R. 15 W. The section continues southwestward along the crest of the spur to a diagnostic zone of brown-weathered silicified corals. Because of a fault higher on this spur, the section is offset on the coral zone a quarter of a mile southeastward to the next spur. The section continues up the slope to the crest of Bugle Ridge and then proceeds northwestward with several minor offsets to the highest peak. To measure stratigraphically higher beds, the line of section is offset about three-fourths mile along a distinctive zone of fusulinid limestone to a point in the SE1/4SE1/4 sec.

o, T. 31 S., R. 15 W., which is on the east side of the spur that divides the east and west forks of Dark Canyon. The section continues southwestward up the slope with one minor offset to the crest of the spur, and then it proceeds southeastward to the peak in the NE1/4NE1/4 sec. 15, T. 31 S., R. 15 W., where it ends. No stratigraphically higher beds are exposed. The lithologic and faunal similarities of the highest beds measured in the section with those known to lie at the top of the Horquilla Limestone elsewhere in the mountain indicate that these beds are very close to the top of the formation. The Bugle Ridge section is plotted on Plate 3.

Thickness (feet)

Top of peak; no higher exposures.

Horquilla Limestone:

146. Limestone, medium and light gray, weathered medium and light gray, finely crystalline, abundant well-cemented detritus; patches of dolomitic limestone; lenses of fossils replaced by white chert, basal part rich in crinoid columnals replaced by chert; beds 6 inches; unit nonresistant. Coll. 44z, from 50 feet above base; coll. 44y, from 44 feet; coll. 44x, from 42 feet; coll. 44w, from 40 feet; coll. 44v, from 38 feet; and coll. 44u, from 10 feet 92

145. Dolomite, light gray, weathered light gray, medium crystalline; patches of dolomitic limestone; chert, light gray, weathered white and light gray, less than 5%, robust irregular-shaped and smooth-surfaced nodules found in lower 6 feet and upper 15 feet, and clusters of chert-replaced fusulinids at 20 feet; upper and lower contacts sharp; masses of coarse calcite crystals near top. Coll. 44t, from 28 feet above base; and coll. 44s, from 20 feet . . . 40
144. Limestone, medium gray, weathered medium gray, medium-grained clastic texture with finely crystalline cement, abundant fusulinids, beds 6 inches, nonresistant; alternating with limestone, light gray, weathered light gray, finely crystalline, medium-grained clastic texture, beds 4 to 8 feet, strata 1 foot, resistant; bed of limestone, weathered brown silty, between 28 and 30 feet; small patch of dolomite near top. Coll. 44r, from 60 feet above base; coll. 44p, from 30 feet; coll. 44n, from 24 feet; and coll. 44m, from 16 feet . . . 72
143. Limestone, medium gray, weathered medium gray, finely crystalline, with large *Pseudoschwagerina;* beds 6 to 10 inches. Coll. 44k, from 8 feet above base . . . 20
142. Limestone, light gray, weathered medium gray, finely crystalline, residual clastic texture, abundant fusulinids, beds 6 inches. Coll. 44j, from top . . . 8
141. Limestone, medium gray, weathered medium gray, coarsely crystalline (½-inch crystals), patches of dolomite . . . 8
140. Limestone, light gray, weathered medium gray, finely crystalline. Coll. 44i, from 8 feet above base . . . 24
139. Limestone, medium gray, weathered medium gray, composed almost entirely of fusulinids . . . 8
138. Concealed; rubble of lumpy fusulinid limestone with some detritus replaced by orange-weathered chert in concentric concentrations. Coll. 44h . . . 4
137. Limestone, dark gray, weathered medium to dark gray, composed almost entirely of fusulinids. Coll. 44g, from top . . . 6
136. Limestone, medium gray, weathered medium gray, medium-grained oolites composed of shell fragments coated with calcite; some beds light gray and finely crystalline with less detritus; massive cliff. Coll. 44f, from 24 feet above base . . . 32

(Section offset a few hundred feet to the northwest along top of unit 135 and continued southeastward along crest of spur.)

135. Limestone, lumpy, with 2-inch fusulinid beds, thin-bedded. Coll. 44e . . . 5
134. Limestone, medium gray, weathered medium and light gray, finely crystalline, some detritus, massive. Coll. 44d, from 10 feet above base . . . 36
133. Limestone, light gray, weathered light gray, finely crystalline, massive . . . 24
132. Limestone, medium gray, weathered medium gray, finely crystalline, much detritus, thin-bedded, nonresistant . . . 9
131. Limestone, light gray, weathered light gray, finely crystalline . . . 8
130. Limestone, medium gray, weathered medium gray, finely crystalline, much detritus, contains possible algae, thin-bedded, nonresistant, wedges out along strike. Coll. 44c, from top; and coll. 44b, from base . . . 8
129. Limestone, light gray, weathered light gray, massive 15
128. Limestone, medium gray, weathered medium gray, finely crystalline, large but varying amounts of medium- and coarse-grained detritus; contains possible algae; beds 6 inches to 1 foot, nonresistant, unit thins and disappears 20 feet to the north. Coll. 44a . . . 9
127. Limestone, light gray, weathered medium to light gray, finely crystalline and lithographic, residual medium-grained clastic texture seen on moist surface; several 1- and 2-foot beds of coarse-grained crinoidal limestone near base; large and small irregular-shaped masses of dolomite common; minor amount of chert in subspherical crusts about limestone nodules; fossil fragments, fusulinids, and possible algae; massive with no stratification, forms cliff; unit is probably biohermal . . . 148
126. Limestone, medium gray, weathered medium gray, finely crystalline, medium-grained detritus variable in quantity but less than 50%; chert, dark gray, weathered dark brown, 20%, in 2-inch nodular strata with wavy banding that appears to preserve original clastic structure, a few white silicified fusulinids; dolomite, in a few small irregular masses; stratification 1 foot. Coll. 43w, from 5 feet above base . . . 20
125. Limestone, medium gray, weathered medium gray, finely crystalline, variable amounts of medium-grained detritus; a few 6-inch beds of coarse-grained crinoidal limestone; several beds of limestone, light gray, lithographic; dolomite, weathered brown, in irregular masses of all sizes; massive, 1- to 4-foot strata; thin concealed intervals underlain by soft limestone rich in fusulinids; forms steep craggy slope. Coll. 43v, from 70 feet above base; coll. 43u, from 60 feet; coll. 43t, from 25 feet; and coll. 43s, from 20 feet . . . 95
124. Limestone, medium gray, weathered medium gray, finely crystalline, minor amount of medium-grained detritus; chert, weathered brown, in porous or granular-looking spheroidal shells about limestone nodules, found in upper 5 feet; single ledge, 10-inch stratification in lower 5 feet . . . 20

(Because no higher beds are exposed on Bugle Ridge, the line of section is offset about three-fourths mile northwestward to the east side of the mountain that lies between the east and west forks of Dark Canyon. Several of the last-measured beds composed almost entirely of fusulinids form a distinctive zone that was traced to the point where the section continues with unit 124. There is no duplication or omission of beds.)

123. Concealed; rubble of free fusulinids. Coll. 43n . . . 7
122. Limestone, mottled . . . 2
121. Concealed, rubble of free fusulinids. Coll 43m . . . 8
120. Limestone, medium gray, weathered medium gray with mottling in upper half, composed almost entirely of fusulinids with very little finely crystalline cement . . . 19
119. Concealed; rubble of lumpy fusulinid limestone. Coll. 43k . . . 5
118. Limestone, medium gray, weathered medium gray and mottled. Coll. 43j . . . 15
117. Concealed; rubble of limestone, medium gray, weathered medium gray, finely crystalline, composed mostly of fusulinids, lumpy. Coll. 43i . . . 8
116. Limestone, medium gray, weathered medium gray mottled with 1-inch irregular light gray patches, finely crystalline, substantial quantity of medium- and coarse-grained detritus, beds 2 feet. Coll. 43h, from 12 feet above base . . . 25
115. Concealed; rubble of lumpy fusulinid limestone. Coll. 43g . . . 7
114. Limestone, medium to light gray with brown tint on damp fresh surface, weathered medium gray, finely crystalline; upper half is limestone, light gray, mottled on weathered surface due to abundant fossils, lithographic; lower half rich in fusulinids; single massive ledge; probably biohermal. Coll. 43f, from 54 feet above base; coll. 43e, from 32 feet; coll. 43d, from 24 feet; and coll. 43c, from base . . . 238

113. Limestone 40%, chert 20%, shale 40%. Limestone, black, weathered light gray, but weathered light brown where rich in silt. Chert, black, weathered black with brown rinds that grade imperceptibly into limestone, in irregular nodules and strata alternating in rhythmic succession with limestone; strata 6 inches thick. Shale, gray, weathered light brownish gray, clay and silt with much calcite, thinly laminated, *Taonurus*. Proportions of limestone and shale vary along strike . . . 35

112. Limestone, medium gray, weathered medium gray, finely crystalline, no stratification, forms cliff . . . 32

111. Limestone, black, weathered light gray, finely crystalline; chert, black, weathered dark gray, 50%, in 3-inch strata in rhythmic succession with limestone; a few beds of shale . . . 34

110. Limestone, medium gray, weathered medium gray with rough surface due to chert replacements of fossil fragments, finely crystalline, coarse-grained-sand- and pebble-size limestone fragments, no stratification, possible algae, appears to be biohermal . . . 27

109. Shale, light gray, clay, thinly laminated; interbedded with limestone, black, weathered light gray, finely crystalline, beds 8 inches to 1 foot; *Taonurus* . . . 13

108. Limestone, medium gray, weathered medium gray, finely crystalline; 30% detritus, some coarse-sand- and pebble-size limestone fragments; massive. Coll. 43b, from top; and coll. 43a, from 12 feet above base . . . 44

107. Shale, light and medium gray, clay and silt, calcareous, thinly laminated; interbedded and interfingered with lesser amounts of limestone, black, weathered light gray, finely crystalline; a few 1-foot dark gray chert strata separated by 1-inch shale strata; units vary in thickness along strike . . . 25

106. Limestone, medium and light gray, weathered medium gray and with rough surface caused by silicified fossil debris and other fragments, finely crystalline and lithographic, some detritus; 8-inch beds of black finely crystalline limestone and coarse clastic limestone between 20 and 30 feet from base. Coll. 42u, from 130 feet above base; and coll. 42t, from 102 feet . . . 144

Crest of Bugle Ridge at 92 feet above base of unit 106.)

105. Limestone, black, weathered medium brown and brownish gray, finely crystalline, 40% silt, shaly with ¼- to 10-inch laminae, 10% black chert, nonresistant . . . 10

104. Limestone, medium gray, weathered medium gray, finely crystalline and lithographic, much detritus; massive, beds 2 to 10 feet, forms low cliff; large solitary corals at 44 feet and at top. Coll. 42s, from 14 feet above base . . . 80

103. Limestone, medium gray, weathered medium gray with some brown specks, mostly coarsely clastic, beds 6 inches; interbedded with silty limestone, weathered brown and lumpy, thin-bedded and nonresistant. Coll. 42r from base . . . 15

102. Limestone, medium to dark gray, coarsely crystalline, in two ledges . . . 5

101. Limestone, light gray, weathered medium gray with rough surface due to small bits of silica and possible small concentrations of dolomite, lithographic, residual clastic texture shown on etched surface . . . 36

100. Limestone, same type as in unit 94 except this has smooth weathered surface; lower 10 feet has coarse detritus and 1-foot beds . . . 22

99. Limestone, medium gray, weathered medium gray, finely crystalline, much medium- and coarse-grained detritus; beds 2 to 5 inches, nonresistant; beds near top composed almost entirely of fusulinids. Coll. 42p . . . 14

98. Limestone, same characteristics as limestone in unit 94; lens 18 feet above base rich in fine quartz sand, forms single craggy cliff . . . 60

97. Limestone, medium gray, weathered medium gray, finely crystalline, residual clastic texture, with 20% silt and some fine quartz sand in varying proportions; chert, medium gray, weathered light brownish gray, 40%, in large irregular nodules; beds 10 inches, laminae bend around chert nodules . . . 19

96. Limestone, same characteristics as unit 94 . . . 14

95. Limestone, medium to dark gray, weathered with smooth surface, finely crystalline, much medium- and coarse-grained detritus; beds 1 foot, nonresistant. Coll. 42n, from 21 feet above base; and coll. 42m, from 14 feet . . . 26

94. Limestone, light gray, weathered medium gray with rough surface due to small bits of silica and possible small concentrations of dolomite, lithographic, residual clastic texture shown on etched surface; forms single bluff . . . 48

93. Limestone, black, weathered medium brown, finely crystalline, 40 to 50% silt in lower part, shaly with ½- to 4-inch laminae . . . 9

92. Limestone, medium to dark gray, weathered medium gray, mostly finely crystalline, much medium- and coarse-grained detritus, 1-foot stratum of coarse calcarenite; chert, black, 15%, in nodules; 1-foot stratification, forms single ledge 23

91. Limestone, mostly black but parts dark gray, weathered medium gray, finely crystalline, some detritus, H_2S odor; chert, black, 20%, in nodules; beds 1 foot with thinner strata between. Coll. 42k, from 12 feet above base . . . 61

90. Limestone, medium gray, weathered medium gray, finely crystalline, variable amounts of detritus; some brown chert globules in basal 2 feet; beds 1 to 4 feet, forms single ledge . . . 13

89. Limestone, black, weathered medium gray, 10% chert, thin-bedded, nonresistant. Coll. 42j . . . 8

88. Limestone, medium gray, weathered medium gray, finely clastic, concentrations of brown-weathered chert globules, beds 1 foot, forms single ledge. Coll. 42i . . . 8

87. Limestone, black, weathered medium gray, finely crystalline, H_2S odor, 20% black chert nodules in lower 15 feet, possible algae, strata from less than 1 inch to 2 feet, nonresistant . . . 40

86. Limestone, medium gray, weathered medium gray, finely crystalline; in upper half chert, weathered brown, 50%, in 1-inch globules . . . 5

85. Limestone, black, weathered medium bluish gray, finely crystalline, H_2S odor; basal part shaly and in 6-inch beds, 2-foot bed in middle, near top 1-foot beds; *Syringopora* at 12 feet. Coll. 42h, from top; and coll. 42g, from base . . . 16

84. Limestone, medium gray, weathered medium gray, finely crystalline; chert, medium gray, weathered light brown, 20%, in nodules; strata 6 to 8 inches, lower 6 feet nonresistant, forms upper half of cliff; abundant *Chaetetes* in upper 1 foot 42

83. Limestone, medium to light gray, weathered medium gray, mostly finely crystalline, detritus; beds 8 feet, forms lower half of cliff. Coll. 42δ . . 40

82. Limestone, medium gray, weathered medium gray, finely crystalline; 8 feet of coarse calcarenite at top; nonresistant . . . 40

81. Limestone, medium to light gray, weathered medium gray, finely crystalline, up to 30% detritus; chert, medium to light gray and black, weathered light brown, less than 5%, occurs in 1-foot beds of lighter gray limestone; beds average 6 feet, forms cliff broken by thinner beds of light gray limestone; great abundance of *Chaetetes* about 60 feet above base. Coll. 42f, from top; and coll. 42e, from 42 feet above base 76

80. Limestone, medium gray, weathered medium gray, finely crystalline, abundant small solitary corals. Coll. 42d 1

79. Mostly concealed; sparse exposures of limestone, light brownish gray, weathered light brownish gray, finely clastic, argillaceous material in some beds, shaly structure with ½- to 1-inch laminae; also limestone, medium gray, weathered medium gray, finely clastic, in 2- to 6-inch beds, rich in fossils including *Prismopora,* fusulinids, and productids, Coll. 42c 20

78. Limestone, medium to dark gray, weathered medium to dark gray, medium- and fine-grained clastic texture; chert, weathered brown to black, 2%, in nodules 3 by 15 inches, found at a few horizons; large solitary corals silicified with brown-weathered chert between 30 and 40 feet, sparse *Chaetetes* and *Syringopora* at top. Coll. 42b, from top; and coll. 42a, from 30 feet above base 48

77. Limestone, medium gray, weathered medium gray, coarsely clastic 25

76. Limestone, medium gray, weathered medium gray, medium- and fine-grained clastic texture, in 2-foot beds 59

75. Limestone, light gray with faint brownish tint, weathered light gray, finely clastic, some clay, shaly fracture; near middle 1-foot bed of limestone, light gray, medium-grained crinoidal, massive 9

74. Limestone, medium gray, weathered medium gray, fine- to coarse-grained clastic texture 18

73. Limestone, medium gray, weathered medium gray, coarse-grained clastic texture; chert, in nodules ranging up to 10 inches by 3 feet in size, which are spongy-looking chert replacements of coarse-grained detritus, occurs at top 3

72. Limestone, medium brownish gray, weathered light brown due to finely disseminated chert and mottled, coarse-grained crinoidal; interbedded with gray, finely crystalline limestone; brown-weathered chert bands 10

71. Limestone, medium gray, weathered medium gray; lens of limestone granule conglomerate at top; *Prismopora.* Coll. 41y, from top 2

70. Limestone, medium gray, weathered dark medium gray with slightly mottled surface, finely crystalline, variable amounts of fine-grained detritus . . 23

69. Limestone, medium gray, weathered medium gray, finely crystalline, some fine-grained detritus indicated by laminae seen on etched surfaces; chert, light gray, weathered light brownish gray, 20%, in nodules 6 by 15 inches. Coll. 41x, from middle 14

68. Limestone, medium gray, weathered medium gray, coarsely clastic 3

67. Limestone, medium gray, weathered medium gray, finely crystalline, 10 to 20% fine- and medium-grained detritus; chert, light to medium gray, weathered light brownish gray, 30%, nodules 6 by 15 inches 8

66. Limestone, medium gray, weathered medium gray, clastic, finely crystalline cement, 1-foot beds . . . 12

65. Limestone, fresh and weathered color medium gray, composed mainly of fusulinids. Coll. 41w 2

64. Limestone, medium gray, weathered medium gray, clastic, finely crystalline cement. Coll. 41v, from top 8

63. Limestone, medium gray, weathered medium gray, clastic, finely crystalline cement; chert, weathered brown, in ½-inch globules 3

62. Limestone, medium gray, weathered medium gray, medium- and fine-grained clastic, with varying but large proportion of finely crystalline cement. Coll. 41u, from 48 feet above base; coll. 41t, from 40 feet; coll. 41s, from 36 feet; coll. 41r, from 32 feet; coll. 41p, from 24 feet; and coll. 41n, from 15 feet 50

61. Limestone, medium gray, weathered medium gray, medium- and fine-grained clastic texture; chert, weathered light gray and brown, 30%, in irregular nodules 2 by 8 inches 8

60. Limestone, medium gray, weathered medium gray, medium- and fine-grained clastic texture, little chert, massive 15

59. Limestone, medium gray, clastic texture, finely crystalline cement; chert, dark gray, weathered brown, in nodules 8 inches by 4 feet showing cross lamination. Coll. 41m 4

58. Limestone, medium gray on fresh and weathered surfaces, medium-grained clastic texture. Coll. 41k, from top 12

57. Limestone, medium gray, on fresh and weathered surfaces, finely clastic, thin-bedded; chert, black, with brown-weathered rinds, 30%, in nodules 5

56. Limestone, medium gray, weathered medium gray, coarsely clastic, finely crystalline cement 2

55. Limestone, medium gray, weathered medium gray, medium-grained clastic texture, finely crystalline cement, massive 20

54. Limestone, fresh and weathered color medium gray, clastic texture; chert, weathered dark gray, ½-inch irregular globules, abundant 3

53. Limestone, fresh and weathered colors medium gray, medium-grained clastic texture 6

52. Limestone, medium gray, weathered light gray mottled with medium gray streaks, clastic texture, finely crystalline; chert, black, 10% 6

51. Limestone, medium to dark gray, weathered medium gray with light gray mottling suggestive of an original conglomeratic texture, finely crystalline, some fine- to coarse-grained detritus, a few thin beds of medium- and coarse-grained calcarenite especially in upper 40 feet; chert nodules, black, weathered black in cores and brown and spongy-looking on exteriors, some white silicified fusulinids, nodules average 4 inches thick, chert varies from 30 to 50% along strike; laminae in limestone bend around chert nodules; strata 6 to 8 inches, forms gentle mountain slope. Coll. 41j, from 84 feet above base; coll. 41i, from 68 feet; and coll. 41h, from 62 feet 112

50. Limestone, medium gray, weathered medium gray, coarse-grained clastic texture, a few beds of limestone pebble conglomerate near top; lower 6 feet has sparse chert, weathered medium gray, in strata 5 inches by 4 feet; near middle is bed of perfectly preserved brachiopods lying in positions suggesting living attitudes. Coll. 41g, from 50 feet above base; coll. 41f, from 25 feet; and coll. 41e, from 6 feet 73

49. Partly concealed; limestone, medium gray, weathered light gray, finely crystalline, residual clastic texture; chert nodules, black, weathered black with brown rinds, 20 to 40%. Coll. 41d 12

48. Limestone, medium gray, weathered medium gray mottled with light gray, abundant solitary corals replaced by brown-weathered chert 1

47. Limestone, medium gray, weathered medium gray, mostly finely crystalline, lenses of medium-grained detritus; chert nodules, dark gray to black in centers and brown porous rinds on exteriors, 30%, nodules 3 by 20 inches 25

(Because of a fault higher on this spur, the section was offset about a quarter of a mile southeastward to the next spur. The shift was made on the distinctive zone of brown-weathered silicified corals and frayed-looking chert nodules at the top of unit 46. To confirm recognition of this zone in each part of the section, measurement of the more than 1000 feet of beds was duplicated so that other diagnostic lithologic units and fusulinid zones could be matched. The duplicated part is not described here nor shown on Plate 3. Section description continues without duplication or omission of beds.)

46. Limestone, medium gray, weathered light and medium gray, finely crystalline, fine-grained clastic texture; chert, medium gray, weathered brown with spongy appearance, 40%, in nodules 1½ by 12 inches and as replacements of solitary corals; laminae in limestone bend around chert nodules and silicified corals, suggesting that fossils and original lime mud balls were later replaced by chert. In upper 5 feet there are silicified solitary corals and frayed-looking chert nodules (1 by 15 inches) that together make up 50% of bed. Abundant silicified solitary corals near middle of unit. Lower 6 feet is rich in chert nodules. Coll. 41c 17
45. Limestone, medium gray, weathered medium gray, finely clastic with some medium-grained detritus; chert, dark gray to black, replaced fusulinids white, weathered dark brownish gray, in rounded nodules 6 by 15 inches; abundant fusulinids. Coll. 41b 11
44. Concealed; rubble of limestone, medium gray, weathered light gray, finely crystalline, thin-bedded 10
43. Limestone, medium gray, weathered medium gray and mottled due to concentrations of various grain sizes, fine- to coarse-grained detritus in lenses; chert, medium gray, weathered brown, 10%, in nodules 4 by 10 inches with concentric banding, concentrated in one bed; beds 2 feet . . 11
42. Limestone, medium gray, weathered light gray and brown, finely crystalline, clastic; in upper half chert, weathered brown, 50%, in nodules and as finely disseminated grains; beds 6 inches; ramose bryozoans common. Coll. 39μ 9
41. Limestone, medium gray, weathered medium gray, coarse-grained clastic, forms ledge, solitary corals in upper half. Coll. 39ρ 2
40. Limestone, medium gray, weathered light gray, lithographic, finely clastic; chert, medium gray, weathered brown, 10%, in irregular-shaped, smooth-surfaced nodules 1 by 2 inches; beds 8 inches. Coll. 39π 10
39. Limestone, medium gray, weathered medium gray, coarse-grained clastic texture; chert, dark gray, 10%, in nodules; forms ledge 3
38. Concealed. The following lithology assumed present from study of rubble: limestone, medium to light gray, weathered light gray, fine-grained detritus, lithographic cement; chert, dark gray and black with white fossil replacements, in nodules with ¼-inch brown-weathered rinds and in 6-inch strata, probably nearly half of unit; nonresistant; abundant ramose bryozoans silicified with white chert and enclosed in black chert in upper half. Coll. 39φ, from upper half 21
37. Limestone, medium gray, weathered medium gray, medium-grained clastic with a few reworked oolites; chert, medium gray, weathered brown, 10%, in nodules; massive ledge with 1- to 2-foot stratification. Coll. 39θ, from top 32
36. Limestone, medium to light gray, weathered light gray, lithographic, with fine-grained detritus; chert, dark gray, 50%, in nodules up to 4 by 18 inches in size and with ¼-inch brown-weathered rinds; nonresistant, beds 2 to 4 inches. Coll. 39δ 7
35. Limestone, medium gray, weathered medium gray, medium- and fine-grained clastic; chert, light gray, weathered brown, 10%, in 2-inch nodules; beds 6 inches. Coll. 39γ 12
34. Limestone, medium gray, weathered partly medium gray but predominantly light brownish gray due to finely disseminated chert replacements of detritus and fusulinids in 2- to 10-inch bands, medium-grained clastic; forms massive ledge with 1-foot stratification; *Chaetetes* and *Syringopora* in lower 2 feet. Coll. 39β 7
33. Limestone, dark gray, weathered dark gray, medium-grained clastic, in 1-foot beds; alternating with limestone, dark gray, weathered brown, fine-grained clastic, with much finely disseminated chert, in 6-inch strata; nonresistant and mostly concealed. Coll. 39α, from near top; and coll. 39z, from base 14
32. Limestone, medium gray, weathered medium gray with mottling due to concentrations of detritus of different grain sizes, medium-grained clastic, forms ledge, abundant *Chaetetes* in middle 2 feet, *Composita* noted. Coll. 39y 9
31. Limestone, medium gray, weathered light gray, lithographic cement with less than 50% medium-grained detritus, nonresistant, in 3-inch beds. Coll 39x 7
30. Limestone, medium gray, weathered medium gray, coarse-grained clastic texture, in 2-foot beds . . 8
29. Limestone, medium gray, weathered medium gray with slight mottling due to concentrations of detritus of different grain sizes, medium-grained clastic texture; chert, dark gray, weathered dark brown, less than 10%, in globules; beds ½ to 1 foot. Coll. 39w, from 20 feet above base; and coll. 39v, from 16 feet 21
28. Limestone, medium gray, weathered medium gray, medium- and coarse-grained clastic texture, large proportion of finely crystalline limestone showing residual medium-grained clastic texture; chert, medium gray, weathered brown, 2 to 10%, in irregular 1-inch nodules concentrated in bands, and as replacements of fossils; forms ledge with 1-foot stratification 12
27. Limestone, medium gray, weathered medium gray, clastic, nonresistant, in 1-foot beds, large gastropods at top 16
26. Limestone, medium gray, weathered medium gray, medium-grained clastic texture; a few strata of chert, dark gray, weathered brown; single bed; abundant *Chaetetes*. Coll. 39u 4
25. Limestone, medium gray, weathered medium gray, medium-grained clastic; chert, dark gray, weathered brown, less than 5%, in bands; beds 4 feet with 1-foot strata. Coll. 39t 19
24. Concealed; rubble indicates covered rock is limestone, medium gray, weathered medium gray with light brown cast, coarse-grained clastic texture, in 8-inch beds. Coll. 39s 8
23. Limestone, medium gray, weathered medium gray, medium-grained clastic texture; chert, dark gray, weathered brown, sandy, small amount, in nodules 6 by 10 inches and as replacements of solitary corals; forms ledge 4
22. Concealed, rubble of thin-bedded, light-gray-weathered limestone with brown silty stringers. Coll. 39r 4
21. Limestone, medium gray, weathered medium and light gray mottled, medium-grained clastic texture 2

20. Concealed	4
19. Limestone, medium gray, weathered medium gray, medium-grained clastic texture due to abundance of oolites and other detritus, in 1½-foot ledges; alternating with limestone, weathered light gray, finely clastic, beds 2 to 6 inches, forms 1- to 2-foot nonresistant intervals; chert, less than ½%, nodules 6 inches by 1 foot, with concentric banding, found in several 1-foot beds; unit forms more gentle slope than underlying oolite beds; *Chaetetes* at 120 feet. Coll. 39p, from top; coll. 39n, from 148 feet above base; coll. 39m, from 112 feet; coll. 39k, from 92 feet; coll. 39j, from 77 feet; and coll. 39i, from 7 feet	164
18. Limestone, medium gray, weathered medium gray, oolitic, with abundant dark-brown-weathered silicified *Chaetetes*. Coll 39h	5
17. Limestone, medium gray, weathered medium gray, medium-grained clastic texture, with fine-grained oolites, in 2- to 4-foot ledges; alternating with limestone, in 3-foot nonresistant beds with 3- to 6-inch strata; lenses of coarse fossil detritus; small amount of dolomite throughout; *Chaetetes* at 100 feet, lowermost fusulinids collected in Horquilla Limestone. Coll. 39g, from 114 feet above base; coll. 39f, from 100 feet; coll. 39e, from 88 feet; and coll. 39d, from 60 feet	173
16. Limestone, medium gray, weathered medium gray, medium-grained oolite, in 18-inch beds	22
15. Dolomite, medium to light gray, weathered light brownish gray, finely crystalline, some medium gray chert, in 2-inch beds	4
14. Limestone, medium gray, weathered medium gray, oolitic with many oolites formed by accretion of calcite around thin shell fragments, 8-inch beds of black chert	10
13. Concealed	4
12. Limestone, medium gray, weathered medium gray, finely crystalline, a few beds of oolite; chert, black, 3-inch nodules, white fossil inclusions	17
11. Limestone, dark gray, weathered light gray, finely crystalline; chert, black, 30%, in concentrically banded nodules; nonresistant, 6-inch strata. Coll. 39c	3
10. Concealed; rubble of limestone, dark gray, weathered light gray, finely crystalline, many black chert nodules	8
9. Limestone, medium gray, weathered medium gray, oolitic, massive, forms upper part of ledge	3
8. Limestone, medium gray, weathered medium gray, finely crystalline; lenses of siltstone, weathered dark brown, calcareous; chert, black, 10%, in nodules; massive, forms ledge	9
7. Concealed	10
6. Limestone, medium gray, weathered medium gray, composed of grains of which 90% are oolites; massive, beds 4 feet, forms rounded ledges. Coll. 39b	10
5. Concealed; rubble of limestone, light gray, weathered light gray, finely crystalline; some brown-weathered sandy limestone; a few chert nodules	25
4. Limestone, light gray, weathered light gray, finely crystalline, with variable amounts of quartz silt; nonresistant, in 6-inch strata; brachiopods and crinoids weathered in relief	4
3. Limestone, black, weathered brown, finely crystalline, with nearly 50% fine angular quartz sand, irregular laminae	4
2. Concealed	17
1. Limestone, medium gray, weathered light gray, mostly finely crystalline, small concentrations of oolite; chert, black, weathered brown, in strata and nodules; nonresistant, 4-inch laminae; *Chonetes* abundant. Coll. 39a	3
Total Horquilla Limestone measured	3530

Erosional unconformity.

Paradise Formation:

Upper unit consists of limestone, dark gray, weathered brownish gray, oolitic, with 30% quartz grains; 2-foot beds; some beds of sandstone, weathered dark brown, quartz, calcareous, with some thin lenses of quartzose oolitic calcarenite; fossils abundant, including *Archimedes*.

BORREGO SECTION

This stratigraphic section, which traverses the upper part of the Horquilla Limestone in the south-central part of the Big Hatchet Mountains, is of particular interest because it shows the intertonguing of the massive reef limestone facies with the shale of the basin facies. Figure 8 is a photograph of the section. The base of the section is at the lowest beds exposed in an arroyo slightly north of the center of the NW¼ sec. 27, T. 31 S., R. 15 W. The section continues southward up the slope to the top of the small sharp peak at the middle of the southern border of the NW¼ sec. 27, T. 31 S., R. 15 W. Then the section is offset about a half mile eastward to the SW¼NE¼ sec. 27, T. 31 S., R. 15 W. on the southeast side of the main canyon. In making this offset distinctive beds were traced and projected between the two parts of the section; thus, there is no duplication or omission of measured beds. In the graphic section on Plate 3, this offset is not shown. The line of section continues southward up the slope and has many small offsets along particular beds. The section passes over the high ridge and continues for a short distance down the southern (dip-slope) side of the ridge to a point beyond which no higher beds are exposed; the section ends near the center of the southern boundary of sec. 27, T. 31 S., R. 15 W. The stratigraphic plane at which the section ends, if projected southward down the slope to the talus-covered contact of the Horquilla Limestone with the overlying Earp Formation, would be within a few tens of feet of the contact.

	Thickness (feet)
No stratigraphically higher exposures on peak.	
Horquilla Limestone:	
45. Limestone, dark gray, weathered medium gray, very finely crystalline, medium-grained clastic, nonresistant, strata 6 inches; a few beds of limestone, light gray, weathered light gray, sublithographic, massive. Coll. 834, from 28 feet above base; and coll. 833, from 24 feet	80
44. Limestone, light gray, weathered light gray, sublithographic, clastic, with small masses of dolomite, massive. Coll. 832, from 12 feet above base	14
43. Limestone, dark gray, weathered medium gray, finely crystalline with medium-crystalline areas, medium-grained clastic, few chert nodules, beds 6 inches to 1 foot, slight petroliferous odor on fresh fracture. Coll. 831, from near base; and coll. 830, from 4 feet above base	15
42. Limestone, light gray, weathered light gray, sublithographic, clastic, massive. Coll. 829, from 14 feet above base	48
41. Limestone, medium gray, weathered light gray, very finely crystalline, clastic, massive, stratification 1 to 3 feet; some beds of limestone, dark gray, weathered medium gray; some brown-weathered chert nodules. Coll. 828, from 6 feet above base	32

40. Limestone, very light gray, weathered light gray, lithographic with scattered dolomite crystals, residual clastic texture formed by calcareous algae (?) and shell fragments, massive, unstratified, forms boldest part of cliff; biohermal. Coll. 827, from 68 feet above base; and coll. 826, from base 74

39. Limestone, dark gray, weathered light gray, very finely crystalline, some detritus, massive with 6-inch to 1-foot strata, forms basal unit of cliff. Coll. 825, from base 31

38. Mostly concealed; exposures in gullies show interval to consist of shale, light gray with faint brownish cast, weathered light gray with faint brownish cast, clay, with much silt, rounded fracture. Coll. 840 335

37. Limestone, medium gray, weathered medium gray, very finely crystalline, medium-grained clastic, little chert, upper 80 feet light-gray lithographic limestone (same type as unit 40), massive with 1-foot strata in lower part, forms cliff, fusulinids common in lower part but rare in upper part, silicified sponges in uppermost beds; biohermal. Coll. 824, from 168 feet above base; coll. 823, from 113 feet; coll. 822, from 86 feet; coll. 821, from 53 feet; coll. 820, from 44 feet; and coll. 819, from 12 feet 184

36. Mostly concealed; exposures in gullies show interval to consist of shale, same type as unit 38 . . 340

35. Siltstone, black, weathered light brownish gray, beds 1 foot, shale interbeds, resistant 3

34. Shale, black, weathered medium gray with trace of brown, clay, with much silt, ½- to 1-inch partings, partly concealed 22

33. Concealed; probably shale 17

32. Conglomerate, weathered with rough surface and orange spots, limestone pebbles and cobbles, some angular fragments, fusulinids in cement. Coll. 818, from base 4

31. Concealed 8

30. Shale, dark gray to black, weathered brownish gray, clay, with much silt, hackly fracture. Coll. 817 4

29. Concealed 14

28. Siltstone, black, weathered brown, calcareous, dense, conchoidal fracture. Coll. 816 1

27. Conglomerate, cobbles and boulders (up to 3 feet) of limestone with a few small brown chert pebbles; limestone detritus is medium gray, weathered medium gray, finely crystalline, clastic; matrix is limestone, medium gray, weathered medium gray, medium-grained clastic, with fusulinids; moderately massive; 10 feet of shale at base. Coll. 815, from 15 feet above base; and coll. 814, from 8 feet 44

26. Limestone, medium gray, weathered medium gray with rough surface, very finely crystalline, medium- and fine-grained clastic; chert, less than ½%, in small globules and replacements of crinoidal and fusulinid detritus; massive, 10- to 20-foot beds; in upper part limestone becomes coarse calcarenite with some limestone pebble conglomerate, beds become distinct and separated by shale intervals. Coll. 813, from 238 feet above base; coll. 812, from 172 feet; coll. 811, from 144 feet; coll. 810, from 50 feet; coll. 809, from 32 feet; and coll. 806, from near base 244

(Top of small sharp peak. Section is offset from unit 25 to unit 26 eastward about half a mile to southeast side of main arroyo. It is shifted on the top of the distinctive sandstone and shale units; there is no duplication or omission of beds in section because of offset. Section continues southward up spur with many small offsets along particular beds.)

25. Concealed; rubble of shale and sandstone similar to that of unit 24 26

24. Sandstone, light brown, weathered light brown, medium angular-grained quartz and chert sand, calcite cement, beds 4 inches, cross-laminated. Coll. 805 12

23. Sandstone and conglomerate, weathered brown; texture ranges from coarse-grained sandstone through coarse-grained conglomeratic sandstone to coarse pebble conglomerate; detritus mostly angular quartz and chert with some limestone; proportions of various grain sizes and thicknesses of beds change along strike; resistant 4-foot beds separated by thin nonresistant beds. Coll. 804 44

22. Concealed; probably shale 20

21. Limestone, black, weathered light gray and orange-brown with smooth surfaces, very finely crystalline; interbedded gray calcareous shale; chert, black mottled with brown and white, coarse granular appearance, in large nodules; beds 6 inches to 1 foot, unit thins along strike. Coll. 803 8

20. Concealed 16

19. Limestone, dark gray, weathered light gray with rough surface, very finely crystalline; chert, small amount, weathered white, in large nodules; large nodular-shaped limestone masses partly replaced by chert; massive, beds 4 feet. Coll. 802 20

18. Concealed; rubble of limestone, black, some pieces weathered light bluish gray and others orange-brown, thin-bedded; shale interbeds; 2 feet of brown-weathered very coarse-grained quartz sandstone near top; trilobites. Colls. 784 and 785 36

17. Limestone, black, weathered orange-brown, massive bed, fossiliferous 2

16. Mostly concealed; sparse exposures of limestone, black, weathered light gray and orange-brown with smooth surface, very finely crystalline, thin-bedded; interbedded with gray shale; fossils include large fenestellids. Coll. 801 12

15. Mostly concealed; probably underlain by same rock types as found in unit 16 12

14. Limestone, medium gray, weathered medium gray, very finely crystalline, clastic, thin chert stringers, massive bed 3

13. Concealed 6

12. Limestone, dark gray with yellowish brown grains, weathered brownish gray, medium-grained clastic, beds 1 foot, fossiliferous 3

11. Concealed; in part underlain with limestone, black, weathered with smooth surface, very finely crystalline, clastic, thin-bedded; and with shale interbeds. Coll. 800 19

10. Limestone, dark gray, weathered medium gray, medium-grained clastic, very finely crystalline; chert, a few white-weathered nodules and brown-weathered globules; beds 1 to 2 feet; fusulinids. Colls. 799 and 798 28

9. Mostly concealed; rubble of limestone, black, weathered light brownish gray with smooth surface, finely crystalline, fine-grained clastic texture, beds probably 6 inches to 1 foot; interbedded with gray shale; chert, weathered brown, disseminated as replacements of detritus; "fucoidal" markings. Coll. 797 140

8. Limestone, medium gray, weathered medium gray, very finely crystalline, clastic, beds 1 to 2 feet; interbedded with shale mottled by "fucoidal" markings; large silicified solitary corals and *Syringopora* common; unit is transition between underlying massive limestone and overlying thin-bedded limestone. Coll. 796 . . 28

7. Limestone, medium gray, weathered medium gray, very finely crystalline, massive, forms upper half of small cliff 12

6.	Limestone, light gray, weathered light gray with smooth surface, very finely crystalline, worm trail fillings; chert, light gray, weathered very light brown, 50%, in nodules	14
5.	Limestone, medium gray, weathered medium gray, finely crystalline, some parts lithographic, lenses and beds of crinoidal limestone; chert, 10%; massive, strata 5 feet	82
4.	Limestone, dark gray, weathered medium gray, finely crystalline, some beds of crinoidal limestone; chert, dark gray, weathered light brown, in spongy-looking strata; thin beds of gray shale; nonresistant, beds 1 foot; *Prismopora, Composita,* and large solitary corals	52
3.	Limestone, medium gray, weathered medium gray with rough surface, very finely crystalline with varying amounts of larger crystals; chert, medium gray, weathered medium brown, 10%, in nodules; massive	44
2.	Limestone, dark gray, weathered medium gray, very finely crystalline; shale interbedded; nonresistant, beds 1 foot; *Syringopora,* small brachiopods, and large solitary corals. Coll. 795	24
1.	Limestone, medium gray, weathered medium gray with rough surface, very finely crystalline with varying amounts of larger crystals; chert, medium gray, weathered medium brown, 10 to 20%, in nodules concentrated in certain strata; beds 5 to 10 feet	80
	Total Horquilla Limestone measured	2257

Base of arroyo; no stratigraphically lower beds exposed.

HALE TANK SECTION

This section, which lies a little more than a quarter of a mile northwest of Hale Tank (fig. 14), starts in the uppermost beds of the Horquilla Limestone and traverses the entire Earp Formation. Here, the Earp Formation is not disturbed by faulting and all but its uppermost 264 feet of beds are well exposed. Therefore, this section is designated as the best reference section of the Earp Formation in the Big Hatchet Mountains. The base of the section is at the road in the NW¼NE¼ sec. 26, T. 31 S., R. 15 W., and the section continues southwestward to the contact of the Earp Formation with the overlying Colina Limestone in the SE¼NW¼ sec. 26, T. 31 S., R. 15 W. It is plotted on Plate 4. This section was measured cooperatively with J. P. Fitzsimmons and H. P. Bushnell.

Thickness (feet)

Colina Limestone.
Conformable contact.
Earp Formation:

50.	Concealed	264
49.	Siltstone, light gray, weathered brown, finely fissile	1
48.	Concealed	18
47.	Siltstone, light gray, weathered brown	2
46.	Concealed	35
45.	Siltstone, light gray, weathered brown, calcareous, beds 1 to 2 feet, forms resistant rib	15
44.	Mostly concealed; several exposed beds of brown-weathered siltstone and lumpy calcareous mudstone	80
43.	Siltstone, light gray, weathered brown, fissile and finely cross laminated, with 3-inch resistant beds	30
42.	Mostly concealed; interbedded limestone and shale, beds 6 inches; shale exposed at 9 feet above base is pinkish brown, clay, with lumpy fissility; also white clay, thinly laminated and very fissile	49
41.	Limestone, medium gray, weathered light yellowish brown, silty	1
40.	Mostly concealed; near top are exposures of limestone, silty, lumpy; and claystone, white	115
39.	Limestone, light gray, weathered light brownish gray to brown with rounded surface, nearly 50% silt, no obvious laminae, beds 1 to 2 feet separated by concealed intervals	15
38.	Siltstone, brown, in 2-foot beds; alternating with 2-foot concealed intervals	39
37.	Concealed	16
36.	Siltstone, medium gray with a few light yellowish brown streaks, with much but varying amounts of calcite cement, coarse lamination, massive, beds 2 feet, forms upper of the two prominent ridges	48
35.	Concealed; probably underlain by white clay	32
34.	Siltstone, light gray and white, weathered brown and white, with patches of loosely consolidated white siltstone or very fine sandstone, beds 6 inches to 1 foot	23
33.	Siltstone, brown, beds 1 to 2 feet; upper part concealed and underlain by white clay	9
32.	Concealed	15
31.	Siltstone, medium brownish gray, weathered reddish grown, cross-laminated	5
30.	Concealed	10
29.	Siltstone, light gray, weathered brown, very calcareous, cross-laminated	5
28.	Concealed	4
27.	Limestone, dark gray, black on moist fresh surface, weathered medium gray, composed mostly of thin shell fragments, very finely crystalline, fossiliferous with ostracods and high-spired gastropods. Coll. 61a	2
26.	Siltstone, brown	4
25.	Concealed	15
24.	Siltstone, brown, breaks into 2-inch slabs	6
23.	Concealed; lower part underlain by beds of unconsolidated white clay and loosely consolidated siltstone	11
22.	Siltstone, light gray with some red and brownish gray parts, weathered brown, with much calcite cement, ½-inch cross-lamination, beds 1 to 2 feet, massive, forms lower of the two prominent ridges	11
21.	Concealed	20
20.	Siltstone, light brownish gray, weathered brown, with much calcite cement, cross-laminated, resistant, beds 1 foot	7
19.	Concealed	14
18.	Siltstone	2
17.	Concealed	1
16.	Siltstone	1
15.	Concealed	20
14.	Siltstone, light gray, weathered brown, calcite cement, finely cross laminated, beds 6 inches, separated by 1-inch strata of shale and clay	10
13.	Mostly concealed; several exposures of white clay and nodular calcareous siltstone beds	17
12.	Siltstone, light gray, weathered brown, cross-laminated, with much calcite cement, breaks into 4-inch blocks	3
11.	Clay, light gray to white, with 1-inch irregular nodules, and with some calcareous nodule beds, nonresistant	15
10.	Siltstone, medium gray, weathered brown, with calcite or dolomite cement, cross-laminated, resistant, rubble 8 inches in diameter	3
9.	Conglomerate, reddish brown, limestone granule, nonresistant	4
	Total Earp Formation	997

Local disconformity.

Horquilla Limestone:

8. Dolomite, light brownish gray, weathered light gray and light tan mottled, lithographic; upper part limestone, lithographic, clastic, with patches of oolite and dolomite; fusulinids 3
7. Limestone, light gray, weathered medium gray, very finely crystalline, with residual clastic texture. Coll 60d 2
6. Dolomite, light brownish gray, weathered very light tan with smoothly rounded and gashed surface, very finely crystalline 6
5. Limestone, dark gray, weathered dark gray, finely crystalline, clastic texture 3
4. Limestone, light gray, weathered light gray, with streaks of dolomite; fusulinids. Coll. 60c 2
3. Siltstone, red or reddish brown, weathered light brown with smooth surface, dolomitic, beds 3 feet 12
2. Limestone, dark gray, weathered dark gray, very finely crystalline, medium-grained clastic; lower 4 feet single ledge; fusulinids. Coll. 60b, from 5 feet above base; and coll. 60a, from 3 feet .. 8
1. Limestone, medium gray, weathered light gray, very finely crystalline, with patches of dolomite 2

Total Horquilla Limestone measured 38

LOWER SHERIDAN TANK SECTION

This section lies two miles northwest of Sheridan Tank on the ridge southwest of South Sheridan Canyon. It extends from the top of the Earp Formation both stratigraphically and topographically upwards through the Colina Limestone and Epitaph Dolomite to the base of the Scherrer Formation. The section has no major faults, although a zone of red siltstone and brecciated dolomite low in the Epitaph Dolomite may have originally contained gypsum which was squeezed out of these rocks by tectonic forces. The base of the section is on the southwest side of South Sheridan Canyon at the base of a small cliff of gray-weathered Colina Limestone in the NW¼SE¼ sec. 36, T. 31 S., R. 15 W. From exposures seen along the strike of this limestone bed, this stratigraphic plane is known to lie within a few feet of the contact with the underlying Earp Formation. The section continues in a general southwestern direction up the slope to the base of the Scherrer Formation, which is near the top of the mountain northwest of the center of the N½ sec. 1, T. 32 S., R. 15 W. The section is shown on Plate 4. This section was measured cooperatively with J. P. Fitzsimmons and H. P. Bushnell.

Thickness (Feet)

Scherrer Formation.

Concordant contact.

Epitaph Dolomite:

49. Dolomite, light and medium gray, weathered to various shades of light and medium lead-gray, sublithographic to very finely crystalline; light-gray-weathered dolomite more prominent upward; many beds show brecciated or coarsely clastic texture on weathered surfaces, and weathered surfaces smooth with shallow gashes; beds 10 feet with 4-inch strata, beds in upper part 18 inches and dense 315
48. Dolomite, same type as in unit 49, with general light gray aspect; some zones of light gray chert nodules, many zones rich in knots and globular clusters of quartz; beds average 15 inches 115
47. Concealed; rubble of siltstone, light gray, weathered light gray; and dolomite, weathered orange-brown, in rounded chunks 15
46. Dolomite, light gray, weathered light to medium gray, finely crystalline, resistant, in 1-foot beds 10
45. Dolomite, light gray, weathered very light gray to white, very finely crystalline, with quartz knot concentrations, nonresistant 10
44. Dolomite, medium, light, and dark gray, weathered very light and medium lead-gray with gashed surface, with quartz geodal knots, and less than 1% chert nodules; beds average 10 inches 160
43. Limestone with patches and interbeds of dolomite; limestone, medium and dark gray, weathered medium gray, finely crystalline, 60%; beds 4 feet 65
42. Dolomite, light gray, weathered white, finely crystalline, with quartz geodes, in 6-inch beds; alternating with dolomite, dark gray, weathered medium brownish gray, finely crystalline, with small quartz geodes, in 2-foot beds; with patches and thin beds of limestone, dark gray, weathered dark gray, finely crystalline, with residual clastic texture 60
41. Limestone, light gray, weathered light gray, massive, forms 3- to 4-foot ledges; interbedded with 4-foot concealed intervals of lumpy and brecciated limestone; a few patches of dolomite .. 40
40. Dolomite, light gray, weathered light to medium gray, very finely crystalline, in 8-inch beds; with patches of limestone; small geodal masses 24
39. Limestone, in 4-inch beds; with stringers and patches of dolomite of same type as in unit 38 1
38. Dolomite, light gray, weathered light to medium gray, very finely crystalline; with geodal masses having quartz shells and calcite interiors; some dolomite, dark gray, weathered medium gray; a few fossils 25
37. Limestone, light gray, weathered light gray, finely crystalline, 50%; and dolomite, light gray, weathered light gray, very finely crystalline, 50%; beds 15 feet 20
36. Dolomite, light gray, weathered light lead-gray, very finely crystalline, with small calcite geodal masses, nonresistant and in 1-inch beds in lower 8 feet, in 1-foot beds above; with several beds of limestone and several beds with patches of dolomite crystals; uppermost bed has a few chert nodules, light gray, weathered brown .. 55
35. Limestone, light gray, weathered light gray, finely crystalline, brecciated, beds 1 foot; a few beds of dolomite and with dolomite crystals throughout 10
34. Limestone, light gray, weathered light gray with red patches, finely crystalline, internally brecciated, with many calcite veinlets; several 4-foot ledges with concealed intervals underlain by thinner beds and with soft lumpy beds; general color of outcrop is reddish gray 140
33. Partly concealed; lower part dolomite and limestone, light- and dark gray, internally brecciated, beds 1 to 2 inches and becoming lumpy upward; interbedded with red shale having wavy fissility. Upper 40 feet almost entirely shale, red, clay, calcareous, shattered, in gray angular fragments, nonresistant. Some zones of siltstone, mostly red, 1-foot gray lenses, calcareous, massive; rocks folded, faulted, and brecciated. This zone is believed to be equivalent to the zone rich in gypsum on the southwest side of the range 212
32. Concealed; underlain by claystone, light gray, weathered light gray 8

31. Dolomite, dark gray, weathered medium gray with gashed surface, very finely crystalline, in beds 6 inches to 2 feet; alternating with 4-foot concealed intervals underlain in part by shale and claystone, light gray, weathered light gray, clay, with some silt 52
30. Dolomite, dark gray, weathered medium gray with gashed surface, very finely crystalline, in single ledge 5
29. Mostly concealed; thin beds of dolomite, yellow and brown fissile shale, and yellow-weathered laminated siltstone 18
28. Dolomite, dark gray, weathered dark and light gray, finely crystalline, beds average 2 to 3 feet with 5-foot concealed intervals; some fossil fragments 83
27. Dolomite, dark gray, weathered dark brownish gray with gashed surface, finely crystalline, partly laminated; geodal masses having milky quartz shells and calcite fillings, 1/16 inch to 1½ inches across; echinoid spines and other fragments composed of silica and calcite 37

Total Epitaph Dolomite 1480

Conformable contact.

Colina Limestone:

26. Limestone, dark gray, weathered medium gray, very finely crystalline, beds 6 inches; alternating with dolomite, medium gray, weathered light gray with gashed surface, very finely crystalline, beds 6 inches to 2 feet 15
25. Limestone, dark gray, weathered medium gray mottled with light gray patches, very finely crystalline, with streaks of clastic debris, a few "fucoidal" markings; massive, forms cliff 25
24. Mostly concealed; exposure of limestone, black, weathered light gray, sublithographic, beds 1 inch 10
23. Limestone, dark gray, weathered medium gray, very finely crystalline, in massive bed 3
22. Concealed 12
21. Limestone, dark gray, weathered light gray, very finely crystalline, beds 1 to 3 inches 5
20. Dolomite, light brownish gray, weathered light gray and light brownish gray, sublithographic, some fine silt, beds average 1 foot 12
19. Concealed 12
18. Limestone, dark gray, weathered medium gray mottled, very finely crystalline, beds 4 inches 1
17. Concealed 10
16. Limestone, dark gray, weathered medium gray with smooth surface, very finely crystalline, with irregular concentrations of clastic debris; high-spired gastropods. Coll. 62b 3
15. Concealed; in part underlain by siltstone, light brownish gray, weathered brown, calcareous, laminated, beds 6 inches 19
14. Limestone, dark gray, weathered medium gray mottled with patches of light gray, medium-grained clastic texture 3
13. Concealed 12
12. Limestone, dark gray, weathered light gray, finely laminated, with much silt, massive, beds 6 to 10 inches; upper part dolomite, light brown, weathered light yellowish brown with gashed surface, very finely crystalline 3
11. Dolomite, light brownish gray, weathered light brownish gray, very finely crystalline, with partly silicified echinoid spines and geodal masses; a few irregular porous chert masses, dark gray, weathered brown, 1%; beds 1 foot 12
10. Limestone, dark gray, weathered light gray with smooth surface, dense, very finely crystalline, with some silt 3
9. Concealed 5
8. Limestone, dark gray, weathered medium gray, with some beds conspicuously clastic and others very finely crystalline; 1-foot beds separated by concealed intervals 20
7. Dolomite, light brownish gray, weathered light brownish gray with smooth surface, very finely crystalline, with a few partly silicified fossil fragments 6
6. Limestone, dark gray, weathered medium to light gray, medium-grained clastic, with oolites or ostracods, with much finely crystalline cement; fossiliferous, with bellerophontid gastropods and large echinoid spines and plates. Coll. 62a 39
5. Limestone, dark gray, weathered light gray with smooth surface, with fossil detritus and silt in most beds, 1-foot beds with 2-foot concealed intervals, 3-foot bed at top 15
4. Limestone, dark gray, weathered light gray, very finely crystalline, clastic streaks bearing small black shell fragments, nonresistant, beds 6 to 18 inches 50
3. Limestone, dark gray, weathered light bluish gray with rough surface on cliff face but smooth surface on beds exposed on slope, very finely crystalline, some silt shows on etched surface, 1-foot strata, locally forms cliff with diagnostic 15-inch break in middle 24
2. Limestone, dark gray, weathered light gray, very finely crystalline 11
1. Limestone, dark gray, weathered light gray, very finely crystalline with a few medium-sized crystals; beds 6 inches to 2 feet, forms massive outcrops. Coll 61b, ostracods 25

Total Colina Limestone 355

Conformable contact with Earp Formation covered by alluvium.

UPPER SHERIDAN TANK SECTION

This section, which lies a little more than one mile west of Sheridan Tank, includes the Scherrer Formation and the Concha Limestone and is shown on Plate 4. The base of the section is near the center of the SW¼ sec. 6, T. 32 S., R. 14 W. and near the top of the ridge on the southwest side of South Sheridan Canyon. The section continues southwestward over the ridge and down the crest of the spur to the alluvium in the NE¼NE¼ sec. 12, T. 32 S., R. 15 W. on the northeast side of Bighorn Canyon. The section is offset several hundred feet southeastward parallel to the strike of the beds and continues for some 60 feet across a small exposure of the Concha Limestone on the southwest side of the arroyo. The point at which the section ends near the center of the eastern boundary of the NE¼ sec. 12, T. 32 S., R. 15 W. is the highest exposure of the Concha Limestone, and judging from exposures elsewhere along the northeast side of the valley and the abruptness of termination of exposures of the limestone, this upper end of the section probably lies within a few feet of the contact of the Concha Limestone with the overlying nonresistant beds of the Cretaceous Hell-to-Finish Formation. This section was measured cooperatively with J. P. Fitzsimmons and H. P. Bushnell.

Thickness (feet)

Alluvium.

Concha Limestone:

40. Dolomite, medium and light gray, weathered light gray with some beds weathered brown, lithographic, some chert, with single bed of limestone 60

(Line of section is offset several hundred feet southeastward parallel to strike of beds in order to measure unit 40.)

39. Concealed 130
38. Dolomite, light gray, weathered light gray, finely crystalline; a few beds of limestone, light gray, weathered medium gray, very finely crystalline, some detritus; upper 40 feet mostly concealed but occupied by dolomitized limestone; chert, light gray, weathered white, 20% of unit, scattered nodules throughout unit and near base, some concentrated in certain strata; silicified fossils. Coll. 63k, *"Dictyoclostus"* sp., from 125 feet above base; and coll. 63j, *Parafusulina* sp., from 50 feet 275
37. Limestone, medium gray, weathered medium gray, finely crystalline, chert nodules 10
36. Limestone, medium gray, weathered light gray, finely crystalline, medium-grained detritus 7
35. Chert, medium gray, weathered brown, 60% of rock, in irregularly shaped nodules; and limestone, same type as unit 36 3
34. Limestone and dolomite in patchy distribution 35
33. Dolomite, light gray, weathered light gray, finely crystalline 10
32. Chert, occurring in 1-foot beds and in porous nodular masses; dolomite, 30%; most of interval concealed 30
31. Dolomite, light gray, weathered light gray, finely crystalline; chert, 20% evenly distributed nodules 20
30. Chert, light gray, weathered light to medium gray, occurring in massive 1-foot bed at base and as porous brown-weathered nodules in upper part; some dolomite 2
29. Dolomite, light gray, weathered light gray with brownish cast and with gashed surface, finely crystalline; small patches of limestone; chert, light gray with lavender tint, weathered white, 10%, nodules and replacements of fossil fragments; some quartz geodes; beds massive 48
28. Dolomite, light gray, weathered light gray, finely crystalline; interbedded with limestone, light gray, weathered medium gray, coarsely crystalline, in several 1-foot beds, 30% of unit; chert, 20%; silicified fossils 12
27. Dolomite, light gray, weathered light gray, finely crystalline; chert, 45% 6
26. Dolomite, light gray, weathered light gray, finely crystalline; chert, red, weathered white, 15%, silicified fossils 22
25. Dolomite, light gray, weathered light gray, finely crystalline; several beds and masses of limestone, some coarsely crystalline near limestone-dolomite contacts; chert, red, weathered white, 1 to 20%, nodules and silicified fossils; quartz geodes; beds 1 foot 70
24. Limestone, dark gray, weathered dark gray, finely crystalline, beds and lenses of calcarenite; areas of dolomite 6 feet in diameter; chert, 1 to 10%, nodules. Coll. 63i, from near top 50
23. Limestone, medium gray with some light gray beds, weathered medium gray and mottled, finely to very finely crystalline, small amount of detritus seen on fresh moist surfaces; several 1-foot beds of dolomite near middle of unit; chert, 10%, in elongated rod-shaped nodules; 5-foot bed near middle of unit has chert, red, weathered white, 20% 100
22. Limestone, dark gray, weathered dark gray, very finely crystalline, fossil shell detritus in some beds; chert, red, 1%, in nodules 1 by 4 inches and as rinds around limestone nodules. Coll. 63h, from 48 feet above base; and coll. 63g, from 12 feet 68
21. Dolomite, light gray, weathered gray with gashed surface, finely crystalline; a few white chert nodules and silicified brachiopods. Coll. 63f, from base 22
20. Limestone, light gray, weathered light gray, coarsely crystalline, patches of dolomite 10
19. Limestone, medium gray, weathered medium gray and mottled, very finely crystalline with many scattered coarse crystals, residual clastic texture; also limestone, light gray, weathered medium gray, coarsely crystalline; dolomite beds in upper 20 feet; chert, red, weathered brown, 1 to 5% but concentrated to 15% in one 10-foot bed, scattered throughout in nodules and in silicified fossil fragments; beds 2 feet. Coll. 63α, from top; coll. 63e, *Parafusulina* sp., from 64 feet above base; coll. 63d, *Parafusulina* sp., from 48 feet above base; and coll. 63c, *Parafusulina* sp., from 45 feet above base 80
18. Limestone, dark gray, weathered light gray, very finely crystalline; chert, red, 20%; thin-bedded 20
17. Limestone, medium gray, weathered medium gray mottled with light gray in coarsely crystalline areas, very finely crystalline, concentrated and disseminated coarse crystals that give weathered rock coarse-grained appearance, residual clastic texture seen on fresh etched surface; chert, red and purple, 1%, in nodules and as replacements of small rock fragments; beds 1 foot 30
16. Limestone, dark and medium gray, weathered light bluish gray and mottled with very light gray patches, weathered surface smooth, very finely crystalline, with little detritus; near base several beds of coarsely crystalline rough-surfaced limestone; chert, red and reddish brown, weathered brown, 40%, irregularly shaped nodules in rhythmic concentrations throughout unit, some chert near middle of unit is lavender to purple; beds 6 to 8 inches; silicified fossils, brachiopods, ramose bryozoans. Coll. 63b 90
15. Limestone; light gray, weathered medium gray with rough surface, finely crystalline, little chert 20
14. Limestone, light gray with a few medium gray beds, weathered medium gray, mostly medium and coarsely crystalline, a few beds finely crystalline, residual clastic texture; chert, light gray, weathered light brownish gray, 30%, nodules 2 by 6 inches; beds 1 to 3 feet, some beds concealed; fossiliferous 27
13. Limestone, light gray, weathered medium gray, finely crystalline; chert, 40%, in small spongy-looking nodules; silicified productids 3
12. Limestone, light gray, weathered medium gray, finely crystalline with scattered medium-sized crystals, medium-grained clastic, very little chert, beds 1 foot 13
11. Chert, light gray, weathered light brownish gray, 90% of unit, spongy appearance; with 10% limestone 9
10. Limestone, medium gray, weathered medium gray, very finely crystalline, nonresistant, abundant flat fossil shells 4
9. Limestone, light gray, weathered medium gray, very finely crystalline, 30% of unit composed of silicified productids. Coll. 63a 2
8. Limestone, light gray, weathered medium gray, very finely crystalline, fossil shell detritus, very little chert 11
7. Limestone, light gray, weathered medium gray, very finely crystalline; chert, light gray, weathered light brownish gray, 50% of unit, nodules 1 to 2 inches by 4 to 6 inches; single ledge; a few silicified fossils 10

6.	Limestone, light gray, weathered medium gray, coarsely crystalline, 50% medium-grained detritus, no chert, beds 2 feet	12
5.	Limestone, light gray, weathered medium gray, very finely crystalline, many medium and coarse crystals; chert, light gray, weathered light brownish gray, 40%; massive bed, conspicuous because of chert	11
4.	Limestone, light gray, weathered medium gray, coarsely crystalline (3mm), residual clastic texture seen on etched surface, chert not conspicuous, a few silicified fossils	20
3.	Limestone, light gray, weathered medium gray with bed near base having reddish streaks, very finely crystalline with scattered large crystals, residual medium-grained clastic texture; chert not conspicuous, several strata with light gray chert nodules and others with fossil shells replaced with white chert, disseminated chert produced rough-weathered surface; beds 6 inches to 3 feet with average of 2 feet	24
	Total Concha Limestone measured	1376

Conformable contact.

Scherrer Formation:

2.	Limestone, light gray, weathered medium gray, very finely crystalline, medium-grained clastic; stringers and lenses of quartz sand, quartz about 20% of unit; massive	9
1.	Limestone, dark red, weathered dark red, coarsely crystalline, coarse-grained clastic, some quartz sand	5
	Total Scherrer Formation	14

Concordant contact.

Epitaph Dolomite.

MINE CANYON SECTION

This section, which lies on the southwest side of South Sheridan Canyon about half a mile northwest of the Lower Sheridan Tank section, traverses the uppermost Earp Formation, the Colina Limestone, the Epitaph Dolomite, the Scherrer Formation, and the lower part of the Concha Limestone. The base of the section lies on the northern side of the hill east of the mouth of Mine Canyon in sec. 36, T. 31 S., R. 15 W., and the section continues southwestward along the prominent spur to the Scherrer Formation. It is offset a few hundred feet southeastward along the base of the Scherrer Formation and continues to the top of the peak near the center of the southern boundary of the SW¼ sec. 36, T. 31 S., R. 15 W., where the section ends. The section is shown graphically on Plate 4; its description is omitted. All pertinent information is shown on the graphic section.

HELL-TO-FINISH TANK SECTION

This section, which is in the vicinity of Hell-to-Finish Tank, is the type section for the Hell-to-Finish Formation and for the lower part of the U-Bar Formation. The base of the section is at the unconformable contact of the Hell-to-Finish Formation upon the Concha Limestone in the SW¼ sec. 2, T. 32 S., R. 15 W. The section continues in a general south-southwest direction across a narrow valley, along the northern and eastern flanks of the prominent hill in the NW¼ sec. 11, T. 32 S., R. 15 W., and along the southwestern spur of the hill. It is offset northwestward to the small area of exposure in the NE¼ sec. 10, T. 32 S., R. 15 W., and it continues to the highest bedrock exposures in the SE¼NE¼ sec. 10, T. 32 S., R. 15 W. The section is plotted on Plate 5, and its location is shown in the photograph of Figure 15.

Thickness (feet)

Alluvium.

U-Bar Formation:

Oyster limestone member:

108.	Limestone, medium gray, medium-grained clastic, medium- to thick-bedded	30
107.	Mostly concealed; lower third underlain by limestone, weathered gray, medium-bedded; lenses of calcareous quartz sandstone occur within massive limestone of this unit west of section	125
106.	Limestone, weathered orange-brown, rich in ½-inch shells of *Exogyra*	1
105.	Limestone, massive, a few small *Exogyra*	61
104.	Mostly concealed; underlain by limestone, ½-foot beds, rich in ½-inch shells of *Exogyra*	51
103.	Limestone, gray, medium-crystalline, clastic, massive	5
102.	Concealed	30
101.	Concealed; underlain in part by contorted limestone, weathered gray with orange-brown tint, massive	55
100.	Limestone, weathered gray and orange-brown, massive	16

(Line of section shifted a few hundred feet westward to low hill and continues south-southwestward to highest exposure.)

99.	Limestone, gray, mottled with orange-brown, massive	12
98.	Sandstone, quartz, with some white chalky grains, medium-grained, calcareous, thinly stratified, massive	12
97.	Limestone, medium gray, clastic, rich in ½-inch shells of *Exogyra,* beds 1 foot; upper 12 feet consists of calcarenite weathered to orange-brown color due to orange silty limestone matrix around brown-weathered fossils standing out in relief. Coll. 6k	48
96.	Concealed	12
95.	Limestone, weathered medium gray and brown, clastic, profusely fossiliferous, in 2-foot beds; abundant small (½-inch) *Exogyra,* which weather in brown relief against the medium gray limestone background, and which are concentrated in 3-foot-thick lenses or lentils. Coll. 6j	21
	Total oyster limestone member measured	479

Brown limestone member:

94.	Limestone, medium gray, weathered in 1-inch lumps, finely crystalline, massive	24
93.	Concealed; underlain in part by limestone, weathered brown, thin-bedded, clastic, small fossils	16
92.	Limestone, medium- and coarse-grained clastic	4
91.	Concealed; probably underlain by shaly-weathered limestone	14
90.	Limestone, white, lumpy, with abundant chalcedony, probably some shale. Coll. 6i	1
89.	Mostly concealed; lower half is underlain by light gray limestone that weathers into a lumpy and vuggy material; upper half is underlain by shaly limestone with some fossiliferous beds	38
88.	Limestone, dark gray, weathered dark gray, medium-grained clastic	1
87.	Limestone, weathered faint orange-brown, finely crystalline, clastic, composed of fossil fragments and limestone granules	1
86.	Concealed	11

85. Limestone, medium brown, containing 30 to 40% angular quartz grains 3
84. Concealed 7
83. Limestone, brownish gray, sand-sized clastic grains, some limestone pebbles, fossiliferous. Coll. 6h .. 1
82. Limestone, reddish brown, weathered orange, lithographic, quartz sand in several beds, thin-bedded, some beds resistant 48
81. Limestone, weathered brown, with thin lenses of silicified globules 1
80. Limestone, weathered orange-brown, very finely crystalline 1
79. Concealed 4
78. Limestone, weathered medium to dark brown, finely crystalline, medium- to coarse-grained clastic, 30% medium-grained and angular quartz sand concentrated in stringers; fossils abundant, including oysters, *Inoceramus(?)* sp., and vertebrate bone fragments. Coll. 6g 5
77. Concealed; to the west along strike is a lens of brownish-weathered sandstone containing limestone pebbles 10
76. Sandstone, weathered white, medium- to coarse-grained, subangular-grained, arkosic, calcareous, thick-bedded, cross-laminated 5
75. Sandstone, weathered reddish brown and gray, medium-grained quartz and chert sand, calcareous, thin-bedded, cross-laminated; upper 4 feet is sandy limestone 15
74. Concealed 7
73. Limestone, weathered reddish brown and slightly mottled, fine-grained, in 6-inch beds; upper 3 feet weathered to orange-brown 11
72. Concealed; probably underlain by red shale 17
71. Limestone, reddish brown, finely crystalline; clastic texture, composed of shell fragments 3
70. Concealed; interbedded brown limestone and shale 12
69. Limestone, weathered light brown, silty, fossiliferous; stringers of chert, dark reddish brown, in upper 3 feet. Coll. 6f 7
68. Limestone, silty, thin-bedded; alternating with shale; general weathered color is brown with red mottling. Coll. 6α 24
67. Limestone, light gray-brown, silty, oolites, fossiliferous. Coll. 6e 8
66. Concealed; probably underlain by shale 7
65. Arkose, weathered dark brown, medium-grained 3
64. Concealed 8
63. Limestone, weathered dark brown, silty; contains sand, medium- and fine-grained, angular; gastropods and pelecypods. Coll. 6d 2
62. Limestone, lumpy 6
61. Limestone, weathered light brown, silty, with oolites and minute silicified fossils. Coll. 6c .. 6
60. Limestone, gray, lumpy 4
59. Limestone, weathered light gray and light gray-brown, silty, fossiliferous, in 10-foot beds; alternating with 3-foot concealed intervals of gray shale; small fossils; one bed oolitic; upper limestone weathered lumpy. Coll 6b 52

Total brown limestone member 387

Total U-Bar Formation measured 866

Gradational contact.

Hell-to-Finish Formation:

58. Limestone, weathered bright orange-brown, silty, fossiliferous, in 1-foot beds; alternating with 3-foot concealed intervals of gray shale; minute pelecypods. Coll. 6a 20
57. Concealed; underlain by beds of shale, gray; with interbeds of limestone, weathered pink 22
56. Arkose, weathered light gray with brown areas, medium-grained 15
55. Mostly concealed; exposed patches of gray shale, thin sandstone, and arkose siltstone 36
54. Arkose, light gray, weathered gray-brown 8
53. Partly concealed; underlain by siltstone, quartz sandstone, arkose, and white clay and shale 58

(Section shifted a few tens of feet southeastward on top of bed 52 and continues with bed 53. Section passes southeast of small peak and continues south-southwestward along crest of ridge.)

52. Arkose, weathered white, grains from coarse sand size to granule size, fine-grained quartzite pebbles up to 2 inches in diameter in lenses and sporadic distribution; bed changes character and is stained by limonite in places along strike; bed very prominent 16
51. Partly concealed; underlain by alternating beds of light green shale, and tan calcareous siltstone .. 33
50. Siltstone, weathered tan, calcareous, with irregular dark resistant blobs 2
49. Concealed; underlain by green shale 8
48. Conglomerate, medium gray, weathered tan, composed of limestone pebbles and matrix of medium-grained arkose 8
47. Shale and siltstone, red with patches of green; beds of shale and siltstone alternate; calcareous lumpy nodules found in shale; several 2-foot beds of arkose, weathered brown, fine-grained 62
46. Arkose, weathered light gray, medium- and fine-grained, resistant 20
45. Partly concealed; underlain by red, gray, and green shale, calcareous; a few thin nonresistant beds of red siltstone 31
44. Arkose, light gray, weathered light brown, medium- and fine-grained, well-cemented, resistant 4
43. Mostly concealed; red and green shale, and thin siltstone beds 56
42. Sandstone, gray, weathered light greenish gray, fine-grained, calcareous; and siltstone 8
41. Shale and siltstone, red with patches of green; some of shale very dark red and finely broken .. 10
40. Siltstone, red, nodular, calcareous 5
39. Siltstone and shale, light green and gray, nonresistant 12
38. Siltstone, weathered gray and green, calcareous, resistant 4
37. Concealed 7
36. Siltstone, reddish brown with irregular patches of green, calcareous 9
35. Shale, weathered dark reddish brown, finely fractured 4
34. Siltstone, reddish gray; and sandstone, fine-grained, calcareous; separated by concealed intervals; nodular limestone with irregular patches of green-weathered shale in upper 2 feet 16
33. Concealed; probably underlain by red shale and siltstone 236
32. Arkose, weathered dark brown, medium- and fine-grained, resistant; alternating with concealed intervals occupied in part by arkose, medium- and coarse-grained, loosely cemented; and by arkosic limestone 62
31. Mostly concealed; occupied in part by arkose, weathered light gray, coarse-grained, loosely cemented; some lenses of granule conglomerate 16
30. Arkose, weathered dark brown, coarse-grained, calcareous 3
29. Arkose, weathered gray, coarse-grained, nonresistant 1
28. Limestone, weathered bluish gray, sandy, chert stringers 1
27. Concealed 12
26. Arkose, weathered dark brown mottled with gray; dark brown areas are due to irregular concentrations of silica cement and gray areas are due to concentrations of calcite cement 3
25. Arkose, weathered dark brown, medium-grained, calcareous 16

24. Concealed	10
23. Sandstone, light gray, weathered dark brown; composed of fine, medium, and coarse chert sand cemented by calcite; sand of different grain sizes in lenses; medium-grained sand predominates in lower half; in upper half, sand is coarse-grained and arkosic with lenses of granule arkose conglomerate	7
22. Concealed; one exposure of limestone, light brownish gray, finely crystalline, with stringers of chert	12
21. Sandstone, weathered dark brown, quartz, fine-grained, calcareous	3
20. Arkose, weathered pinkish gray, grains coarse sand size and subrounded, well-cemented	2
19. Concealed	14
18. Sandstone, weathered brown, medium-grained, calcareous, with a few pebbles of gray chert	3
17. Concealed	2
16. Limestone, weathered light brown, with stringers of chert	2
15. Concealed	10
14. Sandstone, weathered dark brown, composed of medium-grained angular chert grains, strata of granule conglomerate, calcareous, cross-laminated	4
13. Concealed	8
12. Limestone, weathered light gray, with chert sand grains	1
11. Concealed	10
10. Sandstone, weathered light brownish gray, calcareous, with stringers of chert and scattered lenses of conglomerate	13
9. Sandstone, weathered dark brown, composed of medium grains of light gray chert, calcareous, strata and lenses of conglomerate composed of subrounded light gray chert pebbles, resistant	4
8. Concealed; rubble of limestone, weathered dark brown, sandy; and much chert, light gray	24
7. Limestone, light gray, weathered light gray, silty, with stringers of chert	4
6. Limestone, dark gray, weathered light gray and brown, finely crystalline; large amount of light gray angular chert sand; irregular globules of chert	12
5. Concealed	16
4. Limestone, dark gray, weathered light gray and brown, finely crystalline; large amount of light gray and angular chert sand; irregular masses and stringers of chert; bed changes character along strike	3
3. Concealed	248
2. Conglomerate, pebble, weathered gray; pebbles range from granule size to 2 inches, are composed mostly of light gray chert, and are subrounded; matrix is reddish arkosic sandstone	28
1. Concealed	10
Total Hell-to-Finish Formation	1274

Erosional unconformity.

Concha Limestone.

U-BAR RIDGE SECTION

This stratigraphic section is located on U-Bar Ridge and along the northern flank of the hill in the S½ sec. 20, T. 32 S., R. 15 W. It is the type section of the upper part of the U-Bar Formation and of the Mojado Formation. Although this is described as a single section, it was measured in two parts in areas about three miles apart. The locations of the lower and upper parts of the section are described below and are shown on Plate 1. The section is shown graphically on Plate 5.

The lower part of the section starts near the southeastern corner of sec. 1, T. 32 S., R. 16 W. where shales are exposed in a long prominent gully. The section proceeds eastward up the gully nearly to the base of the massive limestone cliff that caps the ridge. The section is offset southward a few hundred feet along a particular bed to a point below the first cleft in the cliff, and it continues through the cleft to the top of the ridge in the NW¼NW¼ sec. 7, T. 32 S., R. 15 W. where the lower part of the section is discontinued.

The upper part of the U-Bar Ridge section starts at the top of U-Bar Ridge in the SE¼ sec. 19, T. 32 S., R. 15 W., a place which is 2¾ miles south of the end of the lower part. The continuation of the section is in beds that are approximately equivalent to those where the section was discontinued, but there may be a duplication of measurement of a few tens of feet of section. From the ridge top, the section continues eastward down the dipslope. It crosses a narrow valley in which bedrock is covered, and it proceeds along the northern slope of the low hill in the S½ sec. 20, T. 32 S., R. 15 W. The section ends at the stratigraphically highest exposures, which are in the SW¼SW¼ sec. 21, T. 32 S., R. 15 W.

	Thickness (feet)
Tertiary fanglomerate.	
Angular unconformity.	
Mojado Formation:	
Upper member:	
223. Concealed; exposure of fine-grained, calcareous, brown-weathered sandstone 100 yards south of line of section	48
222. Sandstone, weathered light brown and light gray, fine-grained, thin-bedded, nonresistant. Coll. 5r, *Haplostiche texana*	32
221. Concealed; off line of section gullies show exposures of shale, light yellowish brown, granular; diorite dike 25 feet wide	272
220. Sandstone, weathered light brown and gray, quartz, fine-grained, thin-bedded, nonresistant; interbedded shale in upper 8 feet; worm borings in upper part	52
219. Sandstone, medium brown, quartz, fine-grained	4
218. Concealed; upper part underlain by variegated shales	44
217. Limestone, weathered dark brown, silty, profusely fossiliferous with oysters and shark teeth; petroliferous odor; rare quartzite pebbles. Coll. 5q	20
216. Concealed	164
215. Siltstone, weathered medium brown with smoothly rounded surface, calcareous, several 1-inch strata of small gastropods. Coll. 5p	28
214. Limestone, medium brown, silty, abundant pelecypods and large gastropods. Coll. 5n	4
213. Concealed; rubble of sandstone, dark brown, fine-grained, calcareous	20
212. Sandstone, weathered dark brown, quartz, fine-grained, calcite cement in optical continuity	2
211. Concealed; rubble of calcareous siltstone or silty limestone, weathered dark brown	14
210. Concealed	48
209. Concealed; rubble of siltstone, dark brown, calcareous; foraminifers, oysters, and other fossils. Coll. 5m	12
208. Sandstone, light tan, quartz, fine-grained, partly massive, partly thin-bedded and cross-laminated	8
207. Concealed	112

147.	Sandstone, dark brown, weathered very dark brown, a few fossil oysters. Coll. 5a	1
146.	Siltstone, dark brown, crumbly	1
145.	Silt, white and yellowish brown, weakly consolidated	7
144.	Concealed	18
143.	Sandstone, fine-grained, thin-bedded, cross-laminated	16
142.	Sandstone, quartz, weathered light brownish gray, fine-grained, cross-laminated, massive	16
141.	Concealed	28
140.	Sandstone, weathered light and medium brown but upper half darker, medium-grained, cross-laminated, massive	27
139.	Sandstone, light brownish gray, weathered light brownish gray, medium- and coarse-grained, massive except for lower 4 feet	16
138.	Concealed; rubble of sandstone, light gray, weathered chocolate-brown, fine-grained, angular-grained	168
137.	Sandstone, light brown, weathered light brown, fine-grained, thin-bedded, cross-laminated; brown color due to evenly disseminated sand-size specks of limonite	17
136.	Concealed; underlain in part by clay, gray, unconsolidated	36
135.	Sandstone, light brown, weathered white or light brown, sand grains fine and angular	20
134.	Concealed	188
133.	Concealed; probably underlain by the same resistant sandstone that projects from under alluvial fan to north	20
132.	Concealed	52
131.	Sandstone, light brownish gray, fine-grained, massive	1
130.	Silt and siltstone, unconsolidated and weakly consolidated	8
129.	Sandstone, gray, fine-grained, graywacke composition; interbedded and lensing with shale and silt	10
128.	Silt, gray, partly unconsolidated	7
127.	Sandstone, gray, fine-grained, brown tube fillings, massive	1
126.	Clay and shale, light gray	10
125.	Sandstone, dark brown with darker brown tube fillings, massive	2
124.	Shale, light gray, silt	2
123.	Clay, light gray	4
122.	Sandstone, brown, thinly laminated; changes to 30-foot bed of massive white sandstone 100 feet southward along strike; such changes of color and thickness common in these beds	7
121.	Sandstone, light gray, thinly laminated	4
120.	Clay, light gray	8
119.	Sandstone, light brownish gray, weathered white, quartz, medium-grained, massive, one 2-foot bed finely laminated, upper inch limonite-stained	30
118.	Concealed	12
117.	Sandstone, gray, weathered brownish gray; sand is of graywacke composition, fine-grained, subangular to angular; unit nonresistant	8
116.	Sandstone, gray, weathered brownish gray, medium-grained, cross-laminated in lower 2 feet, massive; several 6-inch silty shale breaks divide unit into 4-foot beds	12
115.	Siltstone, gray, loosely consolidated; channel cut-and-fill relationship with overlying sandstone	2
114.	Sandstone, dark brown with coloring evenly disseminated through the rock, massive	2
113.	Clay, gray, weakly consolidated	8
112.	Sandstone, weathered dark reddish brown due to limonite, numerous limonite specks, massive	4
111.	Concealed; occupied by same material as unit 109	36
110.	Sandstone, very light brownish gray, weathered white; sand grains are of quartz, medium-grained, subangular, and equidimensional; calcite cement; massive; some zones of limonite speckling; upper several feet of unit stained dark brown; upper surface irregular	78
109.	Clay, gray, unconsolidated, contains limestone nodules from sand size to 6 inches; interpreted as possible "fossil" soil zone	60
108.	Sandstone, weathered light reddish brown or orange-brown due to great concentration of limonite specks; limonite may bear some genetic relation to the probable "fossil" soil zone overlying this unit	1
107.	Sandstone, weathered light brownish gray, quartz, medium-grained, cross-laminae 1 inch thick, contorted	24
106.	Sandstone, weathered dark brown, quartz, 10% feldspar, massive	32
105.	Sandstone, weathered various shades of reddish brown; grains mostly quartz but some feldspar, medium-grained, weakly cemented, strongly cross-laminated, bedding irregular	80
104.	Sandstone, dark gray, quartz, shaly (¼-inch partings)	16
103.	Sandstone, light gray, quartz, massive	8
102.	Conglomerate, dark gray, limestone granule	3
101.	Sandstone, light brownish gray, quartz, massive	12
100.	Sandstone, weathered light brownish gray, quartz, medium-grained; lower half thin-bedded, upper half massive	44
99.	Sandstone, quartz, fine-grained; siltstone and shale	8
98.	Sandstone; white, brown, and gray beds separated by short concealed intervals; somewhat arkosic, a few biotite flakes	68
97.	Conglomerate, limestone-granule, fine quartz sand matrix	2
96.	Concealed; underlain in part by quartzite weathered white with limonite speckling; sand medium-grained, subangular, and weakly cemented; torrential cross lamination, beds average 1 foot	152
95.	Sandstone, weathered brown with limonite speckling, quartz, fine-grained	10
94.	Sandstone, weathered tan with limonite speckling; sand is quartz, medium grained, and subangular; massive, cross-laminated	10
93.	Concealed	16
92.	Sandstone, weathered tan with limonite speckling; sand is quartz, medium grained, subangular	12
91.	Concealed beneath valley fill	660
	Total lower member	4109
	Total Mojado Formation measured	5195

Conformable contact concealed.

U-Bar Formation:

Suprareef limestone member:

90.	Limestone, dark gray, weathered light gray with smooth surface, miliolids, pertroliferous odor. Coll. 4y	8
89.	Limestone, light gray, weathered light gray, coarse-grained clastic, large rudistids in basal 2 feet. Coll. 4x	16
88.	Limestone, light gray, weathered light gray, lithographic; a few fossil fragments and miliolids	8
87.	Limestone, light gray, weathered light gray, lithographic; a few rudistids and miliolids. Coll. 4w	16
86.	Limestone, dark gray, weathered light gray; basal foot is miliolid calcarenite, middle 2 feet has medium-sized rudistids, upper foot is miliolid calcarenite. Coll. 4v	4
85.	Limestone, dark gray, weathered light gray with smooth and spheroidal surface, finely crystalline; upper half less resistant and darker gray; miliolids. Coll. 4u	8

84. Limestone, dark gray, weathered light gray; miliolids and rudistids. Coll. 4t	5
83. Concealed	3
82. Limestone, dark gray, weathered light gray; miliolids and small rudistids. Coll. 4s	4
81. Limestone, light gray, weathered light gray, a few zones of rudistids	4
80. Limestone, dark gray, weathered medium gray, clastic; a few fossiliferous beds and shell concentrations; petroliferous odor. Coll. 4r	12
79. Concealed	2
78. Limestone, dark gray, weathered light gray with smooth surface, rich in miliolids. Coll. 4q	2
77. Limestone, dark gray, weathered light bluish gray, finely crystalline, resistant; rich in large rudistids and miliolids; petroliferous odor; may be same bed as unit 72 in lower part of section. Coll. 4p	3
76. Limestone, dark gray, weathered light bluish gray, finely crystalline, rich in miliolids	5
75. Limestone, dark gray, weathered light bluish gray, finely crystalline, fossil shell calcarenite lenses; rich in miliolids, a few turritelloid gastropods. Coll. 4n	2
74. Limestone, light gray, weathered light brownish gray with very rough surface, finely crystalline; several foot-thick beds of fossils, one with large gastropods (¼ mile north of line of section); fossiliferous beds all have petroliferous odor. Coll. 4m	4

(Crest of U-Bar Ridge. Line of section shifts about 2¾ miles to the south from unit 73 to unit 74. It continues on crest of ridge in the beds rich in rudistids; possible duplication of measurement of between 20 and 40 feet of beds.)

73. Limestone, dark gray, weathered light bluish gray, finely crystalline; 2-foot bed rich in miliolids at base overlain by 2-foot bed of large rudistids, upper beds have several zones of miliolids and rudistids. Coll. 4l, from near top; coll. 4k, from 4 feet above base; and coll. 4j, from 2 feet	28
72. Limestone, dark gray, weathered light bluish gray, rich in 6-inch-long rudistids. Coll. 4i	6
71. Limestone, dark gray, weathered light bluish gray, clastic, petroliferous odor, rich in miliolids. Coll. 4h	1
70. Limestone, dark gray, weathered light bluish gray, rich in small rudistids that weather brown and in relief. Coll. 1025	2
69. Limestone, dark gray, weathered light bluish gray, lenses of rudistids, miliolids	6
68. Limestone, dark gray, weathered light bluish gray, petroliferous odor, abundant large rudistids. Coll. 4f	5
67. Limestone, dark gray, weathered light bluish gray, clastic, with many small fossils including *Orbitolina* sp.	17
66. Limestone, dark gray, weathered light gray, shaly, nonresistant, petroliferous odor, *Orbitolina* sp. Coll. 4e	5
65. Limestone, dark gray, weathered light bluish gray, finely crystalline; zone 16 feet above base rich in 1½-inch-long rudistids; higher in unit there are several more rudistid horizons. Colls. 4d and 4α, samples of rudistids collected at about this stratigraphic level from ridge top, about 1 mile north of section	72
Total suprareef limestone member measured	248

Reef limestone member:

64. Limestone, light gray, weathered light brownish gray with rough surface, finely crystalline, lenses of shell calcarenite, massive; fossil pelecypods, particularly silicified rudistids, weathered dark reddish brown and in relief; upper 28 feet rich in pelecypod shells. Coll. 4c, from 50 feet above base	52
63. Limestone, light gray, weathered light brownish gray with sandpaperlike surface, finely crystalline, lenses of shell calcarenite; rich in heavy-shelled clams, several horizons rich in large oysters, upper 1 foot rich in brown-weathered rudistids oriented perpendicular to the bedding as though in positions of growth	21
62. Limestone, light gray, weathered light brownish gray with sandpaperlike surface, finely crystalline, laminae of calcarenite composed mainly of shell fragments, massive; unit forms base of great cliff; pelecypods weathered out in relief. Coll. 4b, from 50 feet above base	145
Total reef limestone member	218

Limestone-shale member:

61. Limestone, light yellowish gray, coarse calcarenite composed of shell fragments. Coll 4a	4
60. Limestone, dark gray to black, weathered light gray with faint yellowish brown tint, massive; fossils include brachiopods, *Gryphaea* sp., *Orbitolina* sp., and possible ammonite. Coll. 3θ, from 16 feet above base; coll. 3φ, from 20 feet; and coll. 3λ, from approximately same horizon 1 mile to north	64
59. Concealed; probably underlain by limestone	17
58. Limestone, dark gray to black, weathered light gray with faint yellowish brown tint, massive, stratified; fossils include *Orbitolina* sp., brachiopods, and others	8

(Section is shifted southward about ¼ mile along the top of brownish-weathered unit 57; section is continued with unit 58, and it proceeds up the ridge through a prominent break in the cliff that caps the ridge.)

57. Limestone, dark gray to black, weathered light brownish gray with rough surface, finely crystalline, very massive, with *Orbitolina* sp.	4
56. Limestone, dark gray, weathered light gray with smooth surface, finely crystalline, massive; echinoids and *Orbitolina* sp.	11
55. Shale, medium gray, finely fractured	9
54. Limestone, same type as in unit 9; in lower 3 feet limestone alternates with thin shale beds; upper 2 feet massive; small thin *Orbitolina* sp. Colls. 3γ and 3γ-f	5
53. Shale, medium to dark gray, finely broken, tube fillings ¼ inch in diameter	17
52. Limestone, same type as in unit 9. Coll. 3δ-f	3
51. Shale, medium gray, finely broken, upper 2 feet calcareous and nodular	7
50. Limestone, same type as in unit 9, fossiliferous. Colls. 3β and 3β-f	3
49. Limestone, same type as in unit 9, interbedded with shale	15
48. Limestone, same type as in unit 9, fossiliferous. Colls. 3α and 3α-f	2
47. Limestone, same type as in unit 9, beds 1 foot interbedded with 1-foot beds of shale. Colls. 3z and 3z-f	6
46. Limestone, same type as in unit 9, fossiliferous. Colls. 3y and 3y-f	2
45. Limestone, same type as in unit 9, beds 10 inches; interbedded with 10-inch beds of limestone, medium gray, shaly; echinoids	10
44. Limestone, same type as in unit 9, fossiliferous. Colls. 3x and 3x-f	5
43. Shale, light gray, finely broken, beds 6 inches; interbedded with limestone, dark gray, weathered light gray, crumbly; with *Orbitolina* sp., echinoids, and other fossils	6

42. Limestone, same type as in unit 9, fossiliferous. Coll. 3w and 3w-f	1
41. Shale, light gray; thin beds of limestone, same type as in unit 9	6
40. Limestone, same type as in unit 9, *Orbitolina* sp. and echinoids. Colls. 3v and 3v-f	3
39. Limestone, dark gray, weathered light gray with smooth surface, shaly and nodular	2
38. Shale, light gray, finely broken	5
37. Limestone, same type as in unit 9, fossiliferous. Colls. 3u and 3u-f	2
36. Shale, same type as in unit 18	7
35. Limestone, same type as in unit 9, fossiliferous. Colls. 3t and 3t-f	4
34. Shale, gray, granular fracture. Coll. 3s	3
33. Shale, weathered light gray, calcareous, hard and compact, fractures into small nodular fragments. Colls. 3r and 3r-f	2
32. Shale, weathered light gray, calcareous, fractures into 1-inch fragments	4
31. Limestone, same type as in unit 9, nodular. Colls. 3q and 3q-f	3
30. Shale, light gray	5
29. Limestone, same type as in unit 9. Colls. 3p and 3p-f	4
28. Shale, same type as in unit 18	6
27. Limestone, same type as in unit 9, fossiliferous	2
26. Shale, same type as in unit 18	5
25. Limestone, same type as in unit 9, fossiliferous. Colls. 3n and 3n-f	2
24. Shale, same type as in unit 18	3
23. Limestone, same type as in unit 9, fossiliferous. Colls. 3m and 3m-f	1
22. Shale, same type as in unit 18	4
21. Limestone, same type as in unit 9, fossiliferous	2
20. Shale, same type as in unit 18	2
19. Limestone, same type as in unit 9, fossiliferous. Colls. 31 and 31-f	2
18. Shale, light gray, clay, finely broken	5
17. Limestone, same type as unit 9, fossiliferous. Colls. 3k and 3k-f	1
16. Shale, medium gray, clay, finely broken, small well-preserved *Gryphaea* sp. and other pelecypods. Coll. 3j	8
15. Limestone, same type as in unit 9, fossiliferous. Coll. 3i and3i-f	2
14. Shale, medium gray, clay, finely broken	5
13. Limestone, same type as in unit 9, fossiliferous	1
12. Shale, gray, brownish gray on moist surface, clay, broken finely	5
11. Limestone, same type as in unit 9, somewhat nodular, small fossils. Coll. 3h	4
10. Limestone, dark gray, weathered light gray, dense, beds 2 feet. Colls. 3g and 3g-f	7
9. Limestone, dark gray, weathered light gray, finely crystalline, dense; beds 1 to 5 feet separated by 1-inch shale intervals, *Orbitolina* sp. and other fossils. Colls. 3f and 3f-f	10
8. Limestone, weathered yellowish brown, dense, massive, fossiliferous. Coll. 3e	2
7. Shale, weathered gray, broken into fine fragments	7
6. Limestone, hard, fissile. Coll. 3d	1
5. Shale, greenish brown, clay, broken into fine fragments	5
4. Limestone, dark gray, dense, brachiopods. Coll. 1012, *Cymatoceras* sp.	1
3. Shale, greenish brown, clay, broken into equidimensional fragments up to ½ inch in diameter; intervals of silty limestone nodules having fossil shells on their surfaces and celestite cores. Colls. 3c and 3d-f	65
2. Concealed; rare outcrops indicate that the interval is occupied by shale, brown, granulated, with limestone nodules	100
1. Concealed; float indicates that interval is underlain by 6-inch beds of medium brown calcareous siltstone interbedded with brown clay shale; some limestone nodules present that have celestite cores and large diameter silt-filled worm borings on their surfaces; reworked oyster shells have parasitic growths. Coll. 3b	20
Total limestone-shale member measured	527
Total U-Bar Formation measured	993

Fault.

ROBERSON RANCH SECTION

About 2 miles east-southeast of Roberson Ranch, a spur extends northwestward from the toe of U-Bar Ridge. This spur is a downfaulted block in which the upper beds of the U-Bar Formation are well exposed. A short stratigraphic section was measured here because some beds contain well-preserved and significant fossils not discovered elsewhere in the upper part of the formation.

Dips are gentle to the south and southwest. The section starts within the reef limestone member of the formation and proceeds stratigraphically upward to the highest U-Bar beds exposed in the fault block. These beds lie within about 100 feet of the top of the formation, a fact that is indicated by small exposures of sandstone and shale of the Mojado Formation a short distance beyond the end of the section. In preparation of the stratigraphic chart (pl. 5), the relative vertical position of this section and the U-Bar Ridge section was approximately determined by matching the massive limestone beds and the U-Bar—Mojado contact.

The base of the section is at the lowest exposures of massive limestone near the northwestern end of the spur near the center of the N½NE¼ sec. 1, T. 32 S., R. 16 W. The section extends eastward to the top of the spur. It is offset southward for short distances along several distinctive beds and continues southward to the highest exposed U-Bar beds in the SE¼ sec. 1, T. 32 S., R. 16 W.

	Thickness (feet)
Mojado Formation.	
Concealed interval.	
U-Bar Formation:	
Suprareef limestone member:	
33. Limestone, weathered brownish gray with rough surface, with rudistids (1½ to 2 inches and borings filled with brown silt	10
32. Shale, white, soft	1
31. Limestone, composed almost entirely of small *Orbitolina* sp.	27
30. Limestone, weathered brownish gray with rough surface, pelecypods include oysters	12
29. Limestone, hard, nodular, fossiliferous	2
28. Claystone, white, semiconsolidated, many fossils. Coll. 2m, from upper 2 feet	7
27. Limestone, weathered dark bluish gray, composed mostly of shell fragments, large pelecypods and gastropods. Coll. 2k	3
26. Limestone, soft and lumpy	1
25. Shale, yellow, unfossiliferous	1
24. Limestone, light gray, weathered very light gray to white and mottled, lumpy with clay between concretionary masses, nonresistant, pelecypods include oysters	5
23. Limestone, weathered dark bluish gray, clastic, resistant, *Inoceramus* sp. Coll. 2j	2

22. Limestone, weathered dark bluish gray and lumpy, medium-grained clastic texture, non-resistant, pelecypods	2
21. Limestone, weathered light gray, finely crystalline, clastic texture, small fossils and fossil fragments	10
20. Limestone, mottled, coarse corals and large calcite clam shells 4 inches in diameter and ½ inch thick	4
19. Limestone, weathered light bluish gray, finely crystalline, several beds rich in fossils in which are found turritelloid gastropods, pelecypods including rudistids, and coral masses of the size and shape of cabbage heads	9
18. Limestone, weathered light bluish gray, finely crystalline, massive, forms prominent cliff, scattered fossils	31
17. Limestone, dark gray, weathered light bluish gray and lumpy, clastic texture	7
16. Limestone, massive, with lenses rich in shells, mostly rudistids	5
15. Limestone, weathered light gray with rough surface, numerous tubular fossils (¼-inch diameter) perpendicular to bedding. Coll. 2i	10
14. Limestone, dark gray, weathered brownish gray, rich in large (3- to 4-inch) rudistids. Coll. 2h	1
13. Limestone, dark gray, weathered bluish gray, few fossils	5
12. Limestone, dark gray, weathered brownish gray, rich in small rudistids	2
11. Limestone, dark gray, weathered mostly bluish gray but brown in fossil horizons, rough-surfaced, massive, forms cliff; basal 5 feet has many tubular fossils that weather out in relief; near middle of unit there is a zone rich in large (2- to 3-inch) rudistids that weather brown and in relief; at 25 feet from base of unit there is a zone of small (1-inch) rudistids. Coll. 2g, from 25 feet above base; coll. 2f, from 17 feet; and coll. 2e	26
10. Limestone, dark gray, weathered light bluish gray, very finely crystalline, clastic texture, profuse *Orbitolina* sp. and a few echinoids, nonresistant. Coll. 2d	10
9. Limestone, medium-grained clastic texture, some pebble-size fragments of limestone, fossils, nonresistant	5
8. Limestone, dark gray, weathered light bluish gray and into small spherical fragments, lumpy, nonresistant, a few large *Orbitolina* sp.	13
7. Limestone, weathered brown, forms prominent terrace; rich in gastropods of many species, very large (up to 18½ inches in length) turritelloid gastropods common, other fossils include 4-inch pelecypods and rudistids. Coll. 2c	1
6. Limestone, weathered light bluish gray, mottled brown due to brown siltstone fillings of tubes that constitute 50% of rock; bed forms prominent terrace on hillside	1
5. Limestone, weathered light bluish gray, massive with 5-foot strata, several 1-foot beds rich in rudistids. Coll. 2b	16
4. Limestone, dark gray, weathered light bluish gray, very fossiliferous	10
3. Limestone, light gray, weathered light bluish gray, with rudistids and gastropods. Coll. 2a	5
Total suprareef limestone member measured	244

Reef limestone member:

2. Limestone, light gray, weathered medium and light gray with rough surface, very fine grained and lithographic with some coarser grained parts massive with no stratification; fossils not numerous, include *Orbitolina* sp., rudistids, small bivalves, large oysters, small and varied forms of gastropods, several types of corals. Coll. 1i, from top; coll. 1h, from 23 feet above base; coll. 1g, from 18 feet; coll. 1f, from 13 feet; and coll. 1e, from 5 feet	33
1. Limestone, light gray, weathered brownish gray, rough-surfaced, finely crystalline, massive; concentrations of more resistant calcite and chert replacing fossil fragments add to the roughness of the weathered surface; irregular patches of dolomite, weathered brownish gray, medium-crystalline, one patch 30 x 200 feet, distributed at random in upper beds; fossils include *Orbitolina* sp., rudistids, small bivalves, and large oysters. Coll. 1d, from 35 feet above base; coll. 1c, from 30 feet; coll. 1b, from 20 feet; and coll. 1a, from 10 feet	49
Total reef limestone member measured	82
Total U-Bar Formation measured	326

Alluvium.

PIERCE TANK SECTION

This stratigraphic section, which includes parts of the U-Bar and Mojado Formations, lies approximately half a mile south of Pierce Tank in the northern part of the Dog Mountains quadrangle. Figure 16 is a photograph showing its location. The section starts at the road in the NW¼SE¼ sec. 29, T. 32 S., R. 14 W., and proceeds southwestward over the first low ridge to an alluvium-covered valley. The section is then offset several hundred yards northwestward along a marker bed and the section continues, with several minor offsets, in a general west-southwest direction over an exhumed pediment surface of low relief. The section ends at the stratigraphically highest exposures of the Mojado Formation, where it is overlain unconformably by Tertiary fanglomerate at the center of the boundary between secs. 30 and 31, T. 32 S., R. 14 W. The beds in the lower part of the section dip steeply southwestward and those in the upper part have an overturned dip steeply northeastward. The section is plotted on Plate 5.

	Thickness (feet)
Tertiary fanglomerate.	
Angular unconformity (concealed by alluvium).	
Mojado Formation:	
190. Sandstone, brown, weathered dark brown, blocky fracture, fine-grained, silica cement, marine fossils. Coll. 9a	3
189. Concealed; underlain by sandstone, brown, weathered dark brown, blocky fracture, fine-grained, silica cement	8
188. Concealed	20
187. Sandstone, brown, weathered dark brown, fine-grained	1
186. Concealed	13
185. Quartzite, light gray, weathered light brown, fine-grained, cross-laminated, breaks into 1-inch slabs, resistant low ridge, marine fossils	25
184. Mostly concealed; underlain by quartzite, medium brownish gray, weathered light brownish gray, fine-grained, cross-laminated	45
183. Sandstone, light brown, weathered dark brown with limonite stain on surfaces, fine-grained, graywacke composition, a few gray chert pebbles	1

182.	Conglomerate, weathered gray; pebbles of chert, subrounded, mostly gray but with some black, cream, and white	2
181.	Sandstone, brownish gray, coarse subangular chert and quartz grains with some pebbles, some resistant beds	17
180.	Concealed; fossil log 2 feet in diameter	3
179.	Sandstone, gray, weathered dark brown, medium-grained, chert with some quartz, massive	2
178.	Concealed	18
177.	Sandstone, yellow, weathered dark brown, grains medium to fine and rounded, 6-inch to 1-foot beds; lenses of poorly cemented quartzite, white, resistant; oysters	13
176.	Concealed	59
175.	Sandstone, fine-grained; interbedded with siltstone, gray, yellowish gray, and brownish gray, over-all weathered color medium brown, 6-inch beds, marine fossils. Coll. 9b	10
174.	Sandstone, white and light gray, weathered light tan-gray, grains medium and subrounded, weakly cemented, massive, resistant; with lenses of sandstone, medium gray, weathered dark brown, medium-grained, silica-cemented; whole unit cross-laminated	55
173.	Limestone, medium gray, weathered dark brown, coquina composed of *Exogyra;* interbedded with sandstone, yellow, weathered medium brown, fine-grained quartz sand. Coll. 9c	5
172.	Concealed	12
171.	Sandstone, medium gray, weathered medium gray, medium-grained quartz with some chert grains	3
170.	Concealed	100
169.	Concealed; rubble of sandstone and fossil wood. Coll. 9d	5
168.	Sandstone, white, weathered white; sand is quartz, fine-grained, subrounded; cross-laminated	10
167.	Limestone, gray, weathered brown, oyster coquina with much medium-grained quartz sand. Coll. 9e	3
166.	Concealed	12
165.	Sandstone, brown, weathered dark brown, grains fine and subrounded, nonresistant	1
164.	Concealed	20
163.	Sandstone, medium gray, weathered medium gray, quartz and some chert, grains fine and subrounded, silica cement	14
162.	Sandstone, white, weathered white, quartz, grains medium and fine and subrounded, weakly to moderately cemented, 1-inch cross laminae, in 3- to 5-foot lenses between 3-foot concealed intervals; several lenses of sandstone, white, weathered dark brown, silica cement	55
161.	Siltstone, dark gray, weathered dark gray, much limonite	5
160.	Concealed; underlain by sandstone, medium gray, weathered brown, quartz, grains medium in size and subrounded, cross-laminated	20
159.	Sandstone, white, weathered white, a few beds weathered dark brown; composed of very fine grained subangular quartz and some white grains of undetermined composition; interlensing with quartzite, weathered light gray and yellow; mostly nonresistant, cross-laminated	70
158.	Concealed; rubble of very fine-grained quartzite	100
157.	Sandstone, medium gray, weathered black to very dark brown, poorly sorted subrounded quartz, silica cement, very resistant	2
156.	Concealed; rubble of quartzite, white, weathered white, grains fine and subrounded	88
155.	Sandstone, medium gray, weathered very dark gray, medium- and coarse-grained, subrounded quartz grains, silica cement; mostly concealed, but several very resistant 6-inch beds crop out; granules and a few pebbles seen along strike; fossil wood fragments; some parts calcareous	10
154.	Sandstone, white, weathered white, fine-grained quartz	35
153.	Sandstone, white, weathered white, fine-grained quartz, red fossil wood. Coll. 9f	5
152.	Sandstone, white, weathered white, fine-grained quartz, strongly cross-laminated, mostly concealed, fossil wood fragments	80
151.	Sandstone, white, weathered white, fine-grained quartz, strongly cross-laminated, in lenses; fossil wood; silica-cemented lenses resistant. Coll. 9g	25
150.	Sandstone, medium gray, weathered light gray, fine-grained subrounded quartz, thinly laminated (¼ to ½ inch), probably strongly cross-laminated	10
149.	Mostly concealed; rubble of sandstone, white, weathered white and light brown, fine- and very fine-grained, subrounded quartz; white-weathered sandstone is massive, mostly weakly cemented, in lenses; some lenses are well cemented and crop out boldly in pod-shaped exposures	35
148.	Sandstone, white, weathered white, fine-grained, in 120-foot long lens that may represent a stream channel deposit	10
147.	Concealed	15
146.	Sandstone, white, weathered white, fine-grained subrounded quartz, thinly laminated (¼ inch), cross-laminated	5

(Stratigraphic section passes through corner common to secs. 29, 30, 31, and 32, T. 32 S., R. 14 W., which is marked with an iron post and brass cap.)

145.	Concealed; rubble of sandstone, white, weathered white, fine-grained, weakly cemented, porous	110
144.	Concealed	25
143.	Sandstone, medium gray, weathered brown; sand of graywacke composition, fine-grained, subangular	1
142.	Concealed; rubble of sandstone, white	9
141.	Conglomerate, limestone-granule	5
140.	Concealed, rubble of sandstone, white, weathered white and into slabs, fine-grained subangular, clean and well-sorted quartz, strongly cross laminated, laminae ¼ to ¾ inch, weakly cemented, generally nonresistant; some exposures of more resistant silica-cemented parts, also rubble of brown-weathered sandstone	143
139.	Sandstone, white, weathered white; sand is quartz, fine-grained, subangular, weakly cemented; cross-laminated, weathered into 1- to 1½-inch flagstone slabs	17
138.	Concealed; rubble of sandstone, white and light gray; weathered white, light brown, and gray; breaks into slabs; a few large quartzite pebbles	65
137.	Mostly concealed; exposed patches of sandstone, white, weathered white; sand is quartz, fine-grained, subrounded, well-sorted; weakly cemented; strongly cross-laminated; breaks into slabs	35
136.	Concealed; rubble of sandstone, fine-grained	20
135.	Concealed; rubble of limestone, medium gray, weathered brownish gray, finely crystalline, massive, very fossiliferous. Coll. 9h	2
134.	Concealed; rubble of sandstone, white and light gray, weathered white and brown, fine-grained, with strongly and weakly cemented parts; breaks into slabs	23
133.	Limestone, medium gray, weathered medium brownish gray, finely crystalline, contains 30% of fine quartz grains, fossils include turritelloid gastropods and pelecypods	1
132.	Concealed; rubble of sandstone, white and light gray, weathered white and brown, sand grains fine and subrounded, breaks into slabs; white-	

	weathered rock poorly cemented; brown-weathered rock silica-cemented, cross-laminated; fossil wood collected at top replaced partly by calcite and partly by chert. Coll. 9j	50
131.	Concealed; rubble of sandstone	9
130.	Concealed; rubble of limestone, dark gray, weathered medium bluish gray, lithographic; broken into rounded, smooth fragments	5
129.	Sandstone, medium gray, weathered brown, fine-grained, calcareous	10
128.	Sandstone, medium gray, weathered brown, fine-grained, calcareous, cross-laminated	1
127.	Limestone, weathered light bluish gray, dense, a large proportion of quartz sand appears along the strike, fossiliferous. Coll. 9k	2
126.	Mostly concealed; rubble of sandstone, medium-gray, weathered brown, fine-grained, calcareous, cross-laminated, weathered into 2-inch slabs, a few outcrops of strongly cemented lenses, oysters and fossil wood	27
125.	Limestone, dark gray with light brownish tint, weathered light bluish gray, smoothly rounded rubble; fossils include oysters	3
124.	Sandstone, white, weathered white, fine-grained, weakly cemented, cross-laminated	2
123.	Concealed; rubble of sandstone, medium gray, weathered brown and slabby, fine-grained, highly calcareous, finely cross-laminated	44
122.	Sandstone, medium gray, weathered brown, 6-inch blocks, fine-grained, calcareous	1
121.	Concealed	10
120.	Concealed, rubble of limestone, dark gray, weathered light bluish gray, weathered to smoothly rounded rubble. Coll. 9m	7
119.	Concealed; rubble of sandstone, medium gray, weathered brown, calcareous	13
118.	Limestone, medium gray, weathered light bluish gray, lithographic, a few marine fossils	5
117.	Concealed; quartz sandstone rubble	55
	Total Mojado Formation measured	1750

U-Bar Formation:

Suprareef limestone member:

116.	Limestone, dark gray, weathered medium gray; composed almost entirely of whole and broken *Orbitolina*. Coll. 10a	2

Reef limestone member:

115.	Limestone, dark gray, weathered light bluish gray, lithographic, massive; though the dip is nearly vertical the rock is eroded to a flat pavement-like surface; miliolids and rudistids replaced by yellow-weathered calcite; unit is identified as the reef limestone member that caps U-Bar Ridge. Coll. 10b	19

Limestone-shale member:

114.	Limestone, dark gray, weathered light bluish gray with a few dark gray beds and with smoothly rounded surfaces, lithographic, abundant *Orbitolina*	2
113.	Concealed; rubble of limestone, medium-grained clastic, rich in *Orbitolina*	17
112.	Limestone, dark gray, weathered bluish gray with rough surfaces, coarse rudistids and other pelecypods. Coll. 10c	10
111.	Limestone, dark gray with slight brownish tint, weathered light bluish gray, smoothly rounded rubble, lithographic, abundant *Orbitolina;* several resistant 3-inch beds of bluish-gray limestone separated by 12-foot concealed intervals	45
110.	Limestone, dark gray with faint brownish tint, weathered light bluish gray with smoothly rounded surfaces, lithographic, resistant, rich in *Orbitolina* and other fossils. Coll. 10d	25
109.	Concealed; probably underlain by shale	19
108.	Limestone, dark gray, weathered light bluish gray, lithographic, echinoids and a few large gastropods (*Lunatia? praegrandis*). Coll. 10e	16
107.	Concealed; probably underlain by shale	6
106.	Limestone, dark gray, weathered light bluish gray, lithographic, massive, echinoids and a few large gastropods. Coll. 10f	6
105.	Claystone, light gray, soft, lies beneath concealed interval at depth of 1½ feet	6
104.	Limestone, dark gray, weathered bluish gray, smoothly rounded rubble, lithographic, abundant large gastropods identified as *Lunatia? praegrandis*. Coll. 10g	2
103.	Limestone, brownish medium gray, weathered light gray, rich in echinoid spines	3
102.	Concealed	22
101.	Limestone, dark gray, weathered light bluish gray with smooth surfaces, lithographic. Coll. 10h	3
100.	Claystone, nonresistant and forming concealed interval	15
99.	Limestone, dark gray, weathered light bluish gray, lithographic, fossiliferous. Coll. 10j	24
98.	Claystone, light gray, soft, no silt	11
97.	Limestone, dark gray, weathered light bluish gray with smoothly rounded surfaces, lithographic, echinoids and large gastropods (*Lunatia? praegrandis*)	3
96.	Claystone, light gray, soft	12
95.	Limestone, dark gray, weathered light bluish gray with smooth surfaces; with fossils, some of which are replaced by orange silty limestone	2
94.	Concealed; probably underlain by claystone	10
93.	Limestone, dark gray, weathered light bluish gray with smooth surfaces, lithographic, single ledge. Coll. 10k	4
92.	Concealed; rubble of limestone, dark gray, weathered light bluish gray, smoothly rounded rubble, lithographic	11
91.	Concealed; probably underlain by claystone	11
90.	Limestone, dark gray, weathered light bluish gray with smooth surfaces, lithographic, forms single ledge	9
89.	Concealed; rubble of limestone, dark gray, weathered light bluish gray with smooth surfaces, lithographic	5
88.	Concealed; underlain by claystone. Coll. 10m	5
87.	Limestone, dark gray, weathered light bluish gray, lithographic, massive	10
86.	Concealed; probably underlain by claystone	10
85.	Concealed; underlain mostly by claystone with several 6-inch to 1-foot beds of limestone weathered bluish gray	20
84.	Limestone, dark gray, weathered light bluish gray with smoothly rounded surfaces, lithographic, fossiliferous, echinoids and abundant giant gastropods (*Lunatia? praegrandis*). Coll. 10n	2
83.	Claystone, light brownish gray	13
82.	Limestone, dark gray, weathered light bluish gray, lithographic, with abundant large gastropods and echinoids. Coll. 10p, from which Stoyanow identified *Cymatoceras neohispanicum* and *Lunatia? praegrandis*	5
81.	Claystone	30
80.	Limestone, dark gray, weathered light bluish gray, lithographic, massive, fossiliferous	5
79.	Claystone	17
78.	Limestone, dark gray, weathered light bluish gray with smoothly rounded surfaces, lithographic, 1-foot beds, echinoids. Coll. 10r	5

77.	Concealed; underlain by claystone	13
76.	Limestone, dark gray, weathered light bluish gray with smoothly rounded surfaces, lithographic	10
75.	Claystone, very soft, no silt	30
74.	Limestone, medium to dark gray with faint bluish tint, weathered light bluish gray with smoothly rounded surfaces, lithographic; fossils include ammonites. Coll. 10s, from which Stoyanow identified *Douvilleiceras mammillatum* and *Pterotrigonia stolleyi*	2
73.	Concealed	23
72.	Limestone, dark gray with brown tint, weathered light gray, lithographic, massive ledge	3
71.	Concealed	9
70.	Limestone, dark gray with brownish tint, weathered light gray with brownish tint, massive ledge, fossiliferous	2
69.	Concealed; claystone, medium gray, soft, no silt	31
68.	Limestone, dark gray, weathered light bluish gray with smoothly rounded surfaces, lithographic, fossiliferous. Coll. 10t	2
67.	Concealed	16
66.	Limestone, dark gray with brownish tint, weathered light gray with faint orange-brown tint, lithographic, massive ledge, fossiliferous	2
65.	Concealed	15
64.	Limestone, dark gray with faint brownish tint, weathered light gray with faint brownish tint, lithographic, in 18-inch beds	5
63.	Concealed	13
62.	Limestone, dark gray, weathered light gray, lithographic, massive ledge, fossiliferous	2
61.	Concealed	10
60.	Limestone, dark gray, weathered light gray, lithographic, massive ledge, fossiliferous	5
59.	Concealed	9
58.	Limestone, dark gray, weathered light gray, massive ledge, fossiliferous	3
57.	Concealed	11
56.	Limestone, dark gray with brownish tint, weathered light gray with light orange tint along joints, weathered surface rough, lithographic, fossiliferous	3
55.	Concealed	12
54.	Limestone, dark gray with brownish tint, weathered light gray and with rough surface, lithographic, fossiliferous	2
53.	Concealed	8
52.	Limestone, dark gray, weathered light gray with rough surface, lithographic, massive	7
51.	Concealed; underlain by claystone	10
50.	Limestone, dark gray, weathered light gray with rough surface, lithographic, massive	8
49.	Concealed	4
48.	Limestone, dark gray, weathered light gray with rough surface, lithographic, massive	13
47.	Claystone, light gray, soft, no silt, concealed	16
46.	Limestone, dark gray, weathered light gray with rough surface, lithographic, forms single ledge	2
45.	Concealed	3
44.	Limestone, dark gray, weathered light gray with rough surface, lithographic	3
43.	Concealed; underlain by claystone	16
42.	Limestone, dark gray, weathered light gray with rough surface, lithographic, fossiliferous. Coll. 10u, from which Stoyanow identified *Douvilleiceras mammillatum*	1
41.	Concealed	6
40.	Limestone, dark gray, weathered light gray with rough surface, lithographic	3
39.	Concealed	12
38.	Limestone, dark gray, weathered light gray with rough surface, lithographic	8
37.	Limestone, dark gray, weathered light gray with smoothly rounded surface, lithographic, in 15-inch beds; 1-foot concealed intervals	45
36.	Concealed	21
35.	Limestone, dark gray, weathered light gray with smooth surface, lithographic, in single ledge	3
34.	Concealed	9
33.	Limestone, dark gray, weathered light gray with smooth surface, lithographic, in single ledge	4
32.	Limestone, dark gray, weathered light gray, lithographic, in 2-foot ledges; thin concealed intervals	16
31.	Concealed	11
30.	Limestone, dark gray, weathered light gray, lithographic, in single ledge	2
29.	Concealed; rubble of limestone, dark gray, weathered light gray, lithographic	14
28.	Limestone, dark gray, weathered light gray, lithographic, in 1½ to 2-foot beds, echinoids	50
27.	Concealed	7
26.	Limestone, dark gray, weathered light gray, lithographic, in single ledge	3
25.	Concealed	8
24.	Limestone, dark gray, weathered light gray, lithographic	4
23.	Concealed	13
22.	Limestone, dark gray, weathered light gray, lithographic, in single ledge	10
21.	Mostly concealed; a few exposures of limestone, dark gray, weathered light gray, lithographic, 2-foot beds; alternating with 4- to 6-foot concealed intervals	55
	Total limestone-shale member measured	1049

(Line of section is shifted several hundred yards northwestward and continues in southwest direction with unit 21.)

Oyster limestone member:

20.	Concealed by valley fill; an exposure of limestone near top of unit west of the line of section is shown in graphic section, Plate 5	770
19.	Mostly concealed; underlain by limestone, weathered light gray and lumpy, fossiliferous, massive beds with 1-foot strata; upper third of unit underlain by limestone, weathered brown, silty	80
18.	Concealed; underlain by limestone, weathered light gray and lumpy, fossiliferous, abundant large oysters and clams, many 3/16-inch-diameter worm tubes. Coll. 7k	40
17.	Limestone, weathered light gray, concentrations of brown-weathered quartz sand, fossiliferous, petroliferous odor. Coll. 7j	1
16.	Concealed	20
15.	Limestone, weathered light gray, concentrations of brown-weathered quartz sand, fossil oysters and clams, petroliferous odor. Coll. 7i	2
14.	Mostly concealed; a few beds of limestone, weathered light gray, lumpy, fossiliferous	70
13.	Limestone, weathered brown and with blocky fracture, silty, cross-laminated, with patches and a few beds of gray fossiliferous limestone. Coll. 7h, from 25 feet above base	30
12.	Mostly concealed; many 1-foot beds of limestone, weathered light gray, composed of sand-size detritus, fossiliferous. Coll. 7g, from 15 feet above base	46
11.	Limestone, weathered light gray and lumpy, some stringers of brownish gray-weathered sand, fossiliferous	1
10.	Limestone, weathered brown and slabby, fine-grained clastic texture, with much fine quartz and black chert sand concentrated in irregular stringers; also small areas of gray limestone. Coll. 7f	25
9.	Concealed. Coll. 7e	10

8. Limestone, weathered light gray, massive, fossiliferous. Coll. 7d	2
7. Mostly concealed; several 1-foot beds of limestone, weathered light gray and lumpy; also rubble of limestone, weathered orange-brown, sandy, cross-laminated; probably some interbeds of shale or clay; ammonites, especially in lower 35 feet. Coll. 7c	78
6. Limestone, weathered light gray and lumpy; fossiliferous, with small ammonites. Coll. 7b, from which Stoyanow recognized new genera and species of parahoplitids	2
5. Limestone, weathered gray, conspicuous clastic texture due to medium sand size shell fragments, massive, petroliferous odor; lower 8 feet forms a prominent ledge, higher beds massive with concealed intervals. Units 3, 4, and 5 form a low ridge that is part of the Pierce Tank dam and that makes a prominent dark band on the aerial photographs	80
4. Concealed	21
3. Limestone, gray, clastic texture due mostly to shell fragments, in part oolitic, resistant; fossils include thick-shelled pelecypods, *Ostrea* sp., *Cucullaea* sp., and 3-inch turritelloid gastropods	31
2. Concealed; rubble of gray massive limestone blocks	40
1. Mostly concealed, particularly the lower half. Exposed beds of limestone, weathered brown, silty, slabby; interbedded with limestone, weathered gray and lumpy, finely crystalline, medium-bedded, abundant fossils, mostly pelecypods. Coll. 7a, from 108 feet above base	128
Total oyster limestone member measured	1477
Total U-Bar Formation measured	2547

Alluvium.

LITTLE HAT TOP SECTION

This stratigraphic section, which is about one mile east of Little Hat Top Butte, lies mostly on the small crescent-shaped hill at the center of the northern end of sec. 30, T. 32 S., R. 14 W., along the southern border of the Big Hatchet Peak quadrangle. Its location is indicated on the photograph of Figure 17. The section is about eight miles southeast of the two Big Tank sections and the U-Bar Ridge section and about three-fourths mile northwest of the Pierce Tank section. The section traverses parts of the brown limestone and oyster limestone members of the U-Bar Formation.

The hill over which the section passes is a thrust plate bounded on the west, south, and southeast by a thrust fault (fig. 17). Older U-Bar strata were thrust upon younger U-Bar strata. A short distance northeast of the stratigraphic section, a large northwest-striking high-angle fault has emplaced Tertiary volcanic rocks against the Cretaceous rocks. The purposes of measuring the section were to collect potentially significant fossils in the lower part of the U-Bar Formation and to study the lower beds, which are better exposed here than elsewhere.

The base of the section is in the low area in the SE¼ sec. 19, T. 32 S., R. 14 W. The section trends southwestward over the hill at the center of the northern boundary of section 30; it ends at the highest exposures in the thrust plate approximately at the boundary between the Big Hatchet Peak and Dog Mountains quadrangles. The beds of all but the base of the section are overturned. Units 1 through 8 were measured in normal order, but to facilitate measurement, the overturned beds were measured from top to bottom. In the following description of the section, units are shown in normal sequence. The section is shown graphically on Plate 5.

	Thickness (feet)
Upper part of U-Bar Formation.	
Thrust Fault (concealed by alluvium).	
Lower part of U-Bar Formation:	
Oyster limestone member:	
57. Mostly concealed; three beds of exposed limestone, fresh and weathered colors medium gray and mottled, rich in large oysters and other fossils, beds 1 to 1½ feet, weathered lumpy. Concealed intervals between limestone ledges underlain by shale of type described in unit 52. Ammonite collected 3 feet above base of unit. Coll. 75a	28
56. Concealed. Single 6-inch stratum of brown calcareous siltstone exposed	25
55. Limestone, medium brownish gray, weathered light tan, rich in angular sand grains of quartz and chert, contains abundant pelecypods including *Trigonia* sp. and very large pectens. Coll. 75b	1
54. Concealed; single exposed bed of limestone, medium gray, weathered medium gray mottled with irregularly shaped nodules of brown-weathered chert, abundant oysters, 1½ feet thick. Remainder of unit underlain with shale of type described in unit 52	17
53. Sandstone, brown, weathered light brown, very fine angular quartz grains, calcareous cement, occurs as lens within shale	3
52. Shale; light gray and tan; weathered white, light gray, and tan; argillaceous; very finely fissile to unconsolidated; unit soft and nonresistant, exposed only in gullies east of the line of section; includes a few thin, oyster-rich limestone beds similar to those above and below; strong natural-gas odor is released by digging into fresh shale; shale includes zones rich in well-preserved, somewhat squeezed pelecypods composed of limestone. Coll. 75c, pelecypods	31
51. Limestone, medium gray mottled with dark gray, weathered light brownish gray mottled with the black color of abundant large oyster shells, limestone matrix medium-crystalline and clastic, petroliferous odor. Along strike to east of the line of section, bed thickens because of several 3- to 5-foot oyster "reefs." Variety of oysters, from small to 10-inch diameter; some pectens. Coll. 75d, oysters	6
50. Mostly limestone, medium gray mottled with the dark gray color of abundant oyster shells, weathered light brownish gray mottled with black, medium-crystalline matrix between abundant large oysters; some oyster beds have soft matrix, weather lumpy, and yield perfectly preserved oysters through weathering of matrix; some irregularly shaped masses of brown-weathered chert; oyster-rich beds average from 1 to 2 feet in thickness; single 1-foot bed of limestone, medium gray with brownish tint, weathered light gray with tan areas, somewhat silty, a few oysters; one small exposure of thin strata of siltstone and shale, both of which are brown, weather brown, and are finely fissile; some beds concealed and probably underlain by shale of the type described in unit 52	26

49. Calcareous sandstone and arenaceous limestone; limestone is medium gray and weathers light gray; sandstone weathers brown and is composed of medium-grained, subrounded quartz grains with a small amount of feldspar; sand occurs in stringers and proportion of sandstone to limestone varies with each lamination; numerous large oysters in lower part; single bed with bedding joints 1 foot apart 4
48. Mostly limestone; medium gray with faint brown tint; weathered light gray and tan, the tan color occurring in laminae rich in silt; cross-laminated; thin beds of light gray limestone have abundant small pelecypods; a few thin beds of fine quartz sandstone; beds average 6 inches to 1 foot in thickness, concealed intervals between exposed ledges; a few brown-weathered strata of calcareous sandstone within limestone beds; petroliferous odor on fresh fracture of fossiliferous beds 45
47. Limestone; black to dark brownish gray; weathered light gray with faint brownish tint and mottled by abundant tiny, thin-shelled, medium-gray-weathered pelecypod shells; petroliferous odor on fresh fracture; dense; ammonites abundant but because of density of rock, they cannot be extracted from the matrix in the field; same bed from which earlier collection no. 922 was made. Coll. 75e 2
46. Limestone, medium gray, weathered medium to light gray and mottled with dark gray by abundant oyster and other pelecypod shells, some areas brown-weathered due to chert, unit weathered lumpy, beds 1 foot, petroliferous odor, some fine quartz sand, concealed intervals between exposed ledges, some fossils silicified with brown chert, one 6-inch bed of fine-grained sandstone 35
45. Limestone, medium gray with brown tint, weathers medium orange-brown and included fossils weather medium gray; unit prominent because of brown-weathered color, which is caused by large proportion of fine-grained angular sand and silt of graywacke composition; beds 6 inches to 1 foot, unit partly concealed; high-spired gastropods abundant and other fossils common 25
44. Limestone, medium gray, weathered light gray with the medium gray color of oyster shells and also mottled with brown-weathered chert in irregularly shaped masses, weathered lumpy, chert partly replaces fossils, single bed 5
43. Concealed 10
42. Limestone, medium gray, weathered light gray mottled with dark gray by large oyster shells, some oyster shells partly replaced with brown-weathered chert, massive, single bed 3
41. Concealed; exposures along strike of lumpy-weathered fossiliferous limestone similar to that of unit 40. Collection of fossils from this unit made along strike. Coll. 75f 37
40. Limestone, medium gray with faint brown tint, weathered light gray mottled brown by concentrations of silt and also mottled dark gray by oyster shells, weathered lumpy, limestone matrix dense and finely crystalline, fossils include ammonites. This unit is identified by its position in the lithologic sequence as unit 6 of the Pierce Tank section. In both sections, this unit contains ammonites which Stoyanow recognized as the same new genera and species of parahoplitids. Coll. 75g 4
39. Concealed 13
38. Limestone, medium gray, weathered medium gray, finely to very finely crystalline, bioclastic texture throughout, some lenses of oolites, authigenic quartz crystals 1 mm long, fossils in a few beds replaced with chert, lensing rudistid "reef" near middle of unit, massive, beds 10 to 20 feet thick; fossils include white cross sections of pelecypod thought to be *Cucullaea* sp., 6-inch turritelloid gastropods, and colonial corals. This massive unit is the same as units 3, 4, and 5 of the Pierce Tank section, a fact which is indicated by similar lithology and fauna, the lithologic and faunal similarity of beds above and below in each section, the massiveness of the unit within a thin-bedded sequence in each section, and the distinctive appearance of the bed on aerial photographs. The unit forms the crest of the ridge here as in the Pierce Tank section 95
37. Concealed 22
36. Limestone, medium gray, weathered medium and light gray mottled, rich in fossil shell detritus, some small *Exogyra* (1 inch diameter) replaced with brown-weathered chert 3
35. Mostly concealed; several exposures of siltstone and very fine sandstone that are medium gray with brown tint, weather orange-brown, are composed of angular grains of graywacke composition, have calcite cement, and contain fossils including oysters 33
34. Limestone, medium gray, weathered orange-brown, rich in silt in irregularly shaped concentrations, a few large oysters 1
33. Mostly concealed; exposures of 1-foot beds of limestone separated by 10- to 15-foot concealed intervals. Limestone is medium gray, weathered medium gray mottled with orange-brown and lumpy, silt grains, rich in oysters, some fossil shells silicified 48
32. Sandstone, white, weathered white, medium-grained subangular quartz sand, poorly cemented, porous, nonresistant 6
31. Concealed on line of section, but exposed in gully to the east. Consists of light gray and light brown finely fissile shale and brown, calcareous, thinly laminated siltstone 16
30. Limestone, same type as that described in unit 33, in 1-foot beds; concealed intervals near middle of unit 13
29. Concealed; several small exposures of lumpy silty limestone bearing small oysters; most of unit probably consists of shale 25
28. Limestone, medium gray, weathered medium gray mottled with dark gray by included oyster shells, silty, weathered lumpy, beds 6 inches to 1 foot, rich in large oysters, a few thin concealed intervals 12
27. Mostly concealed; a few 6-inch exposed beds of lumpy, oyster-bearing limestone and of dense light-gray-weathered, thin-bedded limestone rich in small, thin, black fossil shells. Coll. 75h, from base of unit 16
26. Limestone, medium brownish gray, weathered bright orange-brown, somewhat argillaceous, rich in very small (⅛-inch diameter) perfectly preserved pelecypods that weather in relief, strata 1 to 6 inches. This lithology is repeated at several levels in underlying section. Coll. 75i 3
25. Shale, medium gray, weathered medium gray, argillaceous, finely fissile, with a few 2-inch strata of nodular fossiliferous limestone 10
24. Limestone, medium gray with faint brownish tint, weathered light gray and finely mottled by the medium gray color of very abundant thin-shelled small pelecypods, dense, in 1-foot beds, with large ammonites having complex sutures. Coll. 75j 4

23. Limestone, medium gray, weathered light gray, mottled with brown areas, slightly silty, rich in oysterlike fossils that are largely silicified, massive, single bed 3
22. Largely concealed; exposure 14 feet above base of unit consists of limestone, brownish gray, weathered orange-brown, argillaceous, rich in perfectly preserved small pelecypods, includes *Trigonia* sp. and large ammonite (collected). Other exposed beds include limestone, medium gray with brownish tint, weathered light gray mottled with medium gray by small fossils, overall weathered appearance of beds is lumpy but individual "lumps" are smooth-surfaced. Coll. 75k 24
21. Limestone, medium gray with faint brown tint, weathered medium gray with light gray strata, mottled due to reddish-brown-weathered irregularly shaped patches of dark gray chert, pelecypods replaced with reddish-brown-weathered chert 3
20. Mostly concealed; shale, medium gray, clay; abundant 6-inch diameter spheroidal septarian limestone concretions; the limestone of the concretions is dark gray and dense, the fractures are filled with calcite, surfaces of concretions have thin, brown-weathered, silty "skins" with a few small pelecypods and gastropods 4
19. Concealed; mostly brown and gray clay shale . . 10
18. Mostly concealed, but rubble shows nature of underlying rock; limestone, medium gray mottled with orange-brown, weathered bright brown or orange-brown; rich in small (⅛- to ¼-inch) perfectly preserved turritelloid gastropod and pelecypod shells of calcite that weather in relief; limestone matrix and fossil fillings are brown apparently because of included silt; a few large pelecypods collected; float sample of ammonite found a few feet down-slope was obviously derived from this bed, as is indicated by its unique lithology; strata 1 inch; this unit has the same lithology as unit 26. Coll. 75m 7
17. Concealed; exposures in gullies along strike show this unit to consist almost entirely of finely fissile, medium-gray clay shale. A bed near top of unit is of the same lithology as that described in units 18 and 26. A zone at the base is rich in large (20-inch) spheroidal septarian concretions of dark gray, dense limestone having fractures filled with calcite 155
16. Limestone, fresh and weathered color medium gray mottled with orange-brown; rich in small (½-inch) *Exogyra* that have black shells partly silicified with brown chert and that have orange-brown, silty limestone fillings. This *Exogyra*-rich limestone is the same type as that in the lower part of the U-Bar Formation in the Hell-to-Finish Tank section (units 95 through 106) 1
15. Concealed 13
14. Limestone; medium gray mottled with small streaks of orange, some beds have brown tint; weathered medium and light gray with some fine brown mottling; bioclastic texture; a few oysterlike fossils; 3- to 5-foot concealed intervals between 1- to 1½-foot exposed beds 40
13. Concealed; a few exposures of lumpy, *Exogyra*-rich limestone 69
12. Limestone, medium gray, weathered medium gray with some mottling due to patches of brown-weathered chert, finely crystalline, clastic texture, beds 1 foot thick and separated by concealed intervals 8
11. Concealed 38
10. Limestone, medium gray, weathered medium gray, bioclastic texture, a few silicified, small *Exogyra* shells 1
9. Limestone, brown, weathered yellowish brown, silty, silicified, small medium-gray *Exogyra* shells 1
8. Concealed; scattered exposures show the attitude of the beds to be steep and contorted; assuming vertical dip and no faulting, the measured thickness represents the maximum for the covered beds 305
7. Limestone; dark gray mottled with orange-brown due to abundant small (½-inch) *Exogyra* which are largely silicified with brown chert; weathered dark and medium gray mottled with orange-brown due to the fossil shells; unit composed mostly of lentils of the *Exogyra* shells; some shells have light brownish gray, dolomitic-looking fillings; beds 1 to 2 feet thick; this lithology is identical with *Exogyra*-lentils of lower part of U-Bar Formation in Hell-to-Finish Tank section. (This unit exposed west of the line of the section.) 15

Total oyster limestone member measured 1324

Brown limestone member:

6. Concealed; lower 30 feet of unit has a few exposures of brown sandstone and limestone of the types described in units 1, 2, 4, and 5 150
5. Sandstone, medium gray, weathered brown, very fine grained angular sand of graywacke composition, calcite cement, finely cross laminated, bedding joints 6 inches apart 4
4. Limestone, orange, weathered orange-brown, finely crystalline; composed largely of tiny, thin, fossil shell fragments some of which are silicified; the tiny shells are similar to those in units 58, 59, and 61 of the Hell-to-Finish Tank section, and the general characteristics of the lithology are the same as in those beds 1
3. Concealed 60
2. Limestone, light brown and orange, weathered light brown, very finely crystalline with scattered larger crystals that may be of dolomite, residual clastic texture, some oolites, some angular arenaceous detrital grains, beds 6 inches to 1 foot, resistant 15
1. Sandstone, limestone, and concealed intervals: sandstone, medium gray, weathered brown, very fine grained, angular sand of graywacke composition, calcite cement, cross-laminated, single 4-foot bed with 2- to 6-inch bedding joints; limestone, orange, weathered orange-brown, composed partly of dark gray, small, oysterlike shell fragments, some fine sand, beds 1 foot; concealed intervals between exposed beds. This unit is thought to be very close to the base of the U-Bar Formation 20

Total brown limestone member measured 250

Total U-Bar Formation measured 1574

Concealed.

High angle fault (concealed by alluvium).

Tertiary volcanic rocks.

BIG TANK SOUTHWEST SECTION

This stratigraphic section, which lies about a quarter of a mile southwest of Big Tank and north of U-Bar Ridge, traverses beds of the upper oyster limestone member of the

U-Bar Formation. The section was measured mainly to place certain index fossil zones in their correct stratigraphic position with respect to the other measured sections. It is plotted on Plate 5.

The section starts at the stratigraphically lowest beds exposed in the SW¼NW¼NE¼ sec. 31, T. 31 S., R. 15 W., and proceeds southeastward up a steep gully to the saddle in the NE¼SW¼NE¼ sec. 31, T. 31 S., R. 15 W., beyond which the rocks are covered with rubble from U-Bar Ridge. The section ends in the diagnostic thick shale unit that corresponds to units 1 through 3 of the U-Bar Ridge section. This shale unit has been traced through scattered exposures in deep gullies along the slope of U-Bar Ridge for more than six miles southward from the Big Tank area.

	Thickness (feet)
Alluvium.	
U-Bar Formation:	
Limestone-shale member:	
15. Shale, fresh and weathered colors medium gray with faint brownish cast, clay, very finely fissile to granular (fragments average about 1/16 inch in diameter), soft, very uniform throughout exposure except for a few 6-inch strata of fossiliferous limestone in lower part. Thickness not measured; about 30 feet exposed. Coll. 73i, from 2 feet above base of shale.	
Oyster limestone member:	
14. Limestone, medium gray with faint brown cast, weathered light to medium gray with brown cast, clastic texture, quartz sand present in minor quantity, profusely fossiliferous with mostly pelecypods including scattered large oysters, a few fossils silicified with brown-weathered chert, weathered surface has lumpy appearance due to fossil shells, petroliferous odor, beds from 1 to 4 feet thick; largely concealed intervals between limestone beds occupied by light gray, soft, fossiliferous claystone. Coll. 73h, ammonite more than 2 feet in diameter from 95 feet above base; coll. 73g, ammonite from 94 feet; coll. 73f, from 92 feet; coll. 73e-f, float specimens from 58 feet; coll. 73d-f, float specimens from 20 feet; coll. 73c-f, float specimens from 10 feet; and coll. 73c, from 10 feet	95
13. Mostly concealed; upper part has small exposures of orange-brown finely fissile shale and orange-brown-weathered quartzose limestone in thin strata; lower part has exposures of thin beds of gray quartzose limestone with abundant pelecypods and gray fossiliferous claystone	57
12. Limestone, fresh and weathered colors light gray, rich in quartz sand throughout, in some strata sand concentrated to more than 50%, many white-shelled pelecypods, strong petroliferous odor, single prominent bed with 1-foot bedding joints	5
11. Partly concealed; exposures of the following lithologies: limestone, medium gray, weathered medium brown, large proportion of quartz sand, very fossiliferous, oysters and other pelecypods, petroliferous odor, beds 6 to 18-inches thick; limestone beds separated by wider partly concealed intervals occupied by claystone, light gray with brown cast, soft, fossiliferous; some beds of fissile brown shale; upper 10 feet of unit has a few 6-inch strata of sandstone, medium gray, weathered orange-brown, calcareous. Coll. 73b, *Pecten* from 35 feet above base	44
10. Mostly concealed; exposures of soft claystone and shale; line of section shifted slightly and measured thickness of unit may be slightly in error	15
9. Sandstone, light gray, weathered brown, calcareous, a few marine shells, petroliferous odor, beds 6 inches thick	5
8. Sandstone, light gray and light brown, weathered light orange-brown, fine-grained quartz sand, most of unit weakly cemented and partly concealed, some strata firmly cemented with calcite, thinly laminated and cross-laminated, no fossils noted	29
7. Mostly concealed; the following lithologies are exposed: light gray and brown soft claystone; shale; 6-inch beds of sandstone; limestone, weathered orange-brown and gray, rich in oysters, beds 6 to 10 inches thick	21
6. Concealed; probably underlain by soft claystone and shale	10
5. Limestone, medium gray with brown cast, weathered orange-brown, some grains of quartz sand; profusely fossiliferous with small, medium, and large oysters and probable *Exogyra*, petroliferous odor	2
4. Sandstone, medium gray with brown cast, weathered orange-brown, fine-grained, quartz, calcareous and argillaceous, somewhat shaly fracture	3
3. Limestone, dark gray with brown areas, weathered medium brown, clastic texture due to fossil shell detritus, abundant perfectly preserved pelecypods of great variety, ammonites, strong petroliferous odor, and liquid petroleum noted in hollow interior of fossil pelecypod; unit is short lens that disappears within a few feet laterally. Coll. 73a, several new species of *Immunitoceras* (identification by Stoyanow)	1
2. Shale, weathered light brown, clay, calcareous; thin strata of calcareous quartz sandstone and siltstone, several of highly calcareous strata are fossiliferous	4
1. Shale, medium gray, weathered light brown, clay, calcareous, finely fissile, with a few 2- to 6-inch strata of light-brown-weathered argillaceous limestone; interval partly concealed	8
Total oyster limestone member measured	299
Total U-Bar Formation measured	299
Alluvium.	

BIG TANK SOUTHEAST SECTION

This stratigraphic section, which lies about half a mile southeast of Big Tank and north of U-Bar Ridge, includes most of the oyster limestone member of the U-Bar Formation. It is designated as part of the composite type section of the formation.

The section starts at the stratigraphically lowest beds exposed in the SE¼NW¼ sec. 32, T. 31 S., R. 15 W. and proceeds southwestward over the crests of the low hills to a point near the southwest corner of the NW¼ sec. 32, T. 31 S., R. 15 W. It ends at the top of the oyster limestone member where it is overlain by shale of the limestone-shale member. The shale is concealed along the line of section. From here the limestone-shale contact was traced through exposures in gullies westward and southwestward to the Big Tank Southwest section and to the U-Bar Ridge section, and it is used on Plate 5 as a stratigraphic plane to show the relative stratigraphic positions of the three sections.

All beds northeast of the wash in the SW¼NW¼ sec. 32, T. 31 S., R. 15 W. are overturned with a dip of about 72° northeast. Southwest of the wash, 124 feet of normal-dipping beds were measured. Making appropriate allowances for changes of dip of the beds concealed near the wash, approximately 230 feet of beds are thought to be covered. A fault may be concealed beneath the alluvium near the wash.

	Thickness (feet)
Alluvium.	
(Diagnostic, persistent, thick shale beds (units 1 through 3 of U-Bar Ridge section and unit 15 of Big Tank Southwest section) lie immediately above highest exposure of limestone, as is seen by tracing the limestone bed several hundred yards westward where shale is exposed.)	
U-Bar Formation:	
Oyster limestone member:	
41. Limestone, medium gray, weathered medium gray, clastic texture due to fossil shell detritus, petroliferous odor, abundant fossils include oysters and other pelecypods, some fossil shells silicified, beds massive and from 1 to 4 feet in thickness	8
40. Coquina composed of large oyster shells, bed soft and lumpy	4
39. Mostly concealed; many exposures of light gray to white, soft, lumpy mudstone with scattered oyster shells	50
38. Limestone, medium gray, weathered medium gray, clastic texture due to fossil shell detritus, some beds rich in silicified pelecypods, in 2- to 3-foot massive beds	10
37. Concealed; a few exposures of white, soft mudstone	15
36. Limestone, clastic texture due to abundant fossil shell detritus, rich in oysters, single resistant bed	2
35. Concealed; a few exposures of white, soft mudstone	13
34. Limestone, medium gray, weathered medium gray, clastic texture due to abundant fossil shell detritus, a few large pelecypods, single resistant bed	2
33. Mostly concealed; a few exposures in nearby arroyo of soft, lumpy, white fossiliferous mudstone	18
32. Limestone, medium gray, weathered medium gray, with orange-colored silty limestone patches between oyster and other large pelecypod shells, large *Pecten* noted; bed is hard but has lumpy appearance due to large oyster shells	2
31. Concealed. (Beds change dip from normal to overturned within this interval. Assuming no faulting, the measured thickness shown for the concealed beds should be accurate within 20%. However, there is a possibility that a fault lies in this concealed interval.)	230
30. Sandstone, light brown, weathered light tan, fine-grained, composed of angular quartz grains, proportions of calcite cement varied in different beds; greater thickness of sandstone exposed off the line of section	8
29. Concealed	61
28. Limestone, light gray, weathered light gray, large proportion of well-rounded medium- and coarse-grained quartz and chert sand, some strata rich in tiny, thin, silicified pelecypod shells which weather in relief, cross-laminated	3
27. Mostly concealed by slope rubble; small, scattered exposures of the following lithologies noted: limestone, medium to light gray, rich in oysters, with orange-brown patches of silty limestone between oyster shells, in 1-foot beds; limestone, dense, with medium and small fossil shells; limestone, weathered orange-brown, silty, with oysters	45
26. Sandstone, white, weathered white, weathered surface roughened by concentrations of fossils silicified by orange-gray-weathered chert, medium-grained, grains of white subangular quartz, quite weakly cemented and porous, scattered fossil shells throughout, petroliferous odor. Coll. 74a, float specimen of ammonite	5
25. Concealed; float suggests that the following lithologies occupy this interval: limestone, medium gray, weathered orange with gray streaks due to numerous small thin pelecypod shells, thin-bedded; limestone, orange-brown, silty; limestone, gray, with large proportion of angular and medium-grained quartz sand; possibly some calcareous sandstone	52
24. Limestone, medium gray, weathered medium gray with orange-colored areas of chert that partly replace numerous large oyster shells, single massive bed	5
23. Concealed	20
22. Sandstone, weathered brown, quite calcareous, fossiliferous; limestone, sandy and silty, in thin beds	4
21. Concealed; float and exposures along strike of beds show the interval to be composed largely of limestone, gray with silty orange-colored patches, rich in oysters, hard, thin-bedded; a few beds of limestone, medium gray, weathered orange-brown, silty, with some partly silicified fossils. Ammonites collected from base of unit are from an orange-brown silty limestone bed. Coll. 74b	55
20. Concealed. Coll. 74c, float sample of large ammonite	24
19. Limestone, medium gray, weathered medium gray, pronounced medium-grained clastic texture due to fossil shell detritus, fossils not abundant, a few silicified fossils in some strata, coarsely cross-laminated, massive, in 5- to 8-foot beds, unit thickens and thins due to addition and subtraction of lensing beds at top; though thick-bedded and bioclastic, unit does not have other characteristics of a reef deposit; basal 2-foot bed is oolitic; lower part of unit forms crest of southwesternmost ridge.	70
18. Mostly concealed; float and exposures along strike indicate the following lithology: Limestone, medium gray with orange streaks and irregularly shaped patches due to concentrations of silt, weathered medium to light gray with orange patches, some fine-grained sand of apparent arkosic composition, thin-bedded, breaks into 6-inch blocks, many internal casts of large robust pelecypods weathered free of matrix, petroliferous odor, some fossils silicified. Coll. 74d, pelecypods	35
17. Limestone, medium gray, weathered light gray with sandpaperlike surface due to silicification of some detrital grains, clastic texture due to fossil shell detritus throughout but not readily obvious, strong petroliferous odor, abundant fine anastomosing calcite-filled fractures, beds 1- to 5-feet in thickness and massive, beds lens out along strike so that unit disappears about 150 feet southeast of the line of section	34
16. Mostly concealed; character of float and exposures near top of interval indicate the following lith-	

ology: limestone, medium gray with orange areas due to concentrations of silt and silicification of the silty areas, weathered medium to light gray with orange patches, abundant large oyster and other pelecypod shells give rock mottled lumpy appearance 15

15. Partly covered; exposures of sandstone, siltstone and shale found in gullies along strike. Sandstone is light brown, weathered medium to light brown, sand grains fine to very fine and angular to subangular, arkosic composition, varying proportions of calcite cement, thin-bedded, some beds of sandy limestone; siltstone is similar to sandstone in all characteristics except grain size; shale is reddish brown and finely fissile 52

14. Limestone, fresh and weathered colors are medium gray with orange-brown areas of calcareous siltstone, rich in oyster shells, weakly consolidated; silt occurs as fillings in shells and as matrix between shells 6

13. Sandstone, some beds are light brown but most are white, coarse- and medium-grained quartz sand with minor amounts of feldspar and rock detritus, grains well rounded and frosted, cemented to varying degrees with calcite, finely cross laminated, white fossil shells abundant in some strata, petroliferous odor, very porous; basal 6-foot bed is sandstone, white, coarse-grained, quartz, poorly consolidated, very porous, abundant white fossil shells, strong petroliferous odor 26

12. Siltstone, brown, weathered light brown, calcareous, thin-bedded, partly concealed 3

11. Limestone, light gray with orange-colored silt concentrations, very fossiliferous, many thin-shelled pelecypods, rich petroliferous odor, beds 8 inches to 1 foot; some beds more silty than others and have light orange-brown-weathered color, fewer strata of orange-colored silty limestone near base of unit; several 20-foot concealed intervals lie between 1- to 2-foot beds of resistant limestone; fine-grained quartz sand is found in several gray limestone beds; some thin beds of sandstone, brown, very fine grained, calcareous, broken into 1-inch thick slabs; basal beds rich in large oysters and include strata rich in fossils silicified with brown-weathered chert; this thin-bedded unit forms the main part of the saddle between the two prominent ribs on this hill. Coll. 74e, ammonite from 22 feet above base 162

10. Concealed; rubble and small exposures along strike indicate that this interval is occupied by thin strata of gray fossiliferous limestone mottled by orange silt concentrations, and also by fossiliferous claystone; loose specimens of pelecypods are common. Coll. 74f 14

9. Limestone, medium gray, weathered medium gray with rough surface, coarsely clastic texture; abundant small fossil shells and fragments, some of which are silicified with brown-weathered chert; 10 to 20% of well-rounded medium-grained quartz sand distributed throughout; single massive bed 4

8. Partly concealed; upper two thirds of unit occupied by limestone, medium brownish gray mottled with orange silt concentrations, weathered light gray with orange patches, broken to rounded chunks, probably has strata of soft claystone, abundant oysters and other pelecypods weather out of rock, petroliferous odor; lower third of unit, which is more resistant and more completely exposed, consists mostly of limestone, medium gray, weathered medium to light gray with orange-colored silty areas, very fossiliferous with abundant large oyster shells, includes several 3-foot concealed intervals; near the middle of this unit from the upper of the two wide concealed zones, *Acanthohoplites* sp. (?) was collected; this ammonite aids in correlating this section with the Pierce Tank section. Colls. 915, 74g 34

7. Limestone, medium gray, weathered medium gray, conspicuous medium-grained clastic texture due to predominance of fossil shell detritus, some beds oolitic, coarsely cross laminated, some strata rich in oysters (possibly some *Exogyra*) silicified with brown-weathered chert, weathered surface like sandpaper due to selective replacement of some detrital grains by silica, beds 2 to 10 feet thick, massive; unit forms northeasternmost prominent ridge. 65

6. Concealed 29

5. Mostly concealed; rubble of limestone, medium gray with orange silty patches, some quartz sand, abundant oysters and other pelecypods . . 75

4. Limestone, medium gray, clastic texture, some quartz sand, a few silicified fossils; unit is single lens only 50 feet in length 8

3. Mostly concealed; rubble and a few thin exposed beds indicate the following lithologies: limestone, medium gray with orange silty patches, clastic, rich in oysters, thin-bedded; calcareous siltstone; arenaceous limestone; sandstone, fine-grained, quartz, thin-bedded; beds contorted in part of interval, thickness measured may be somewhat excessive. Coll. 74h, large ammonite from 35 feet above base 305

2. Limestone, medium gray, weathered medium gray, clastic texture due to fossil shell detritus, some beds finely crystalline, fossils not abundant, a few small concentrations of orange-weathered silicified detritus, petroliferous odor strong in some beds, beds average 1 to 2 feet in thickness; some thin beds are rich in *Exogyra* silicified with brown-weathered chert, the lithology and fossils of which look identical to those in the lower part of the U-Bar Formation in the Hell-to-Finish Tank section; several 10- to 20-foot concealed intervals 128

1. Mostly concealed; rubble and a few exposures indicate the following lithologies: limestone, gray, clastic, fossiliferous, thin-bedded; sandstone, medium to light gray, weathered medium brown, fine to very fine subrounded equidimensional grains composed mostly of quartz but including some feldspar, firmly cemented with calcite, cross-laminated; limestone with strata rich in *Exogyra* replaced with orange-brown-weathered chert 150

Total oyster limestone member measured 1851

Total U-Bar Formation measured 1851

Alluvium.

Lithology of Deep Oil Tests

HUMBLE OIL & REFINING COMPANY NO. 1 N.M. STATE "BA"

This test well is located 990 feet from the north line and 1980 feet from the east line of sec. 25, T. 32. S., R. 16 W. (Plate 1). Sam Thompson III, Humble Oil & Refining Company, studied the samples from the well, the various logs, and the surface geology of the area. He kindly prepared the following stratigraphic summary of the well.

> Operations began on the Humble No. 1 State "BA" on May 15, 1958. It was completed as a dry and abandoned hole on December 24, 5958 after reaching a total depth of 14,585 feet.
>
> The following logs were run: induction-electrical survey, gamma ray—neutron, microlog, and a continuous dipmeter. A mudlogging unit was employed. Eight cores and five drill-stem tests were taken during the course of drilling.
>
> Samples are excellent over nearly the entire length of this rotary-mud well. However, no cuttings are available from 996 feet to 1490 feet as three cavities in the upper part of the Permian Concha Limestone were encountered from 998 feet to 1080 feet. Based on analysis of the samples and logs the following formation tops are presented: (Kelley bushing elevation was 4587 feet).

Depth	*Formation*
surface	Quaternary gravels, etc.
230′	Lower Cretaceous U-Bar Formation
648′	〃 Hell-to-Finish Formation
995′	Permian Concha Limestone
1522′	〃 Scherrer Formation
1532′	〃 Epitaph Dolomite
4450′	〃 Colina Limestone
5258′	〃 Earp Formation
6265′	Permo-Pennsylvanian Horquilla Limestone (Tentative correlations based on fusulinid identifications by Garner L. Wilde are: top Wolfcampian at 6265′, top? Virgilian at 8755′, top? Missourian at 8935′, top Desmoinesian at 9425′, top Derryan at 9910′, top Morrowan? at 10,800′.)
10,995′	Mississippian Paradise Formation
11,425′	〃 Escabrosa Limestone
12,500′	Devonian Percha Shale
12,830′	Ordovician Montoya Dolomite; Cutter Member
12,985′	〃 〃 〃 Aleman Member
13,097′	〃 〃 〃 Upham Member
13,155′	〃 〃 〃 Cable Canyon Member
13,214′	〃 El Paso Formation
14,120′	Mississippian Escabrosa Limestone (below reverse fault)
14,585′	Total depth in Escabrosa

> Most of the formations are quite similar in facies to the sequence exposed in the Big Hatchet Mountains. However, the thick shale section in the upper part of the Horquilla formation in this well lies within the Alamo Hueco basin as defined by Zeller (1960). Unconformities are noted at the tops of the U-Bar, Concha, Horquilla, Paradise, and Montoya formations.
>
> The No. 1 State "BA" was drilled on the Alamo Hueco surface anticline. Two significant reverse faults were crossed. One is at about 3310 feet in the Epitaph Dolomite, and the marker horizon at 2850 feet is repeated at 3820 feet. The second reverse fault is at about 14,120 feet where El Paso is displaced over Escabrosa. The marker horizon at 12,230 feet is repeated at 14,440 feet.
>
> Appreciation is expressed to Humble Oil & Refining Company for permission to publish this information.

The following brief description of gross rock units in the well is condensed from the good sample log by American Stratigraphic Company (log number D-1357), and discussion with Sam Thompson III (oral communication, 1963), who made a detailed analysis of the drill cuttings and the electrical-radioactivity surveys.

Depths from surface (in feet)	*Descriptions of gross lithologic units (within each description lithologies, colors, etc. are listed in order of decreasing abundance)*
0- 230	Quaternary alluvium: Gravel composed of limestone and volcanic rock.
	U-Bar Formation:
230- 648	Limestone, shale, and sandstone interbedded. Limestone, yellow and brown to gray, dense to finely crystalline. Shale, mostly yellow in upper part and gray to brown in lower part. Sandstone, quartz, yellow to clear, mostly fine-grained, some coarse-grained.
	Hell-to-Finish Formation:
648- 995	Red shale dominant; some gray shale and sandstone interbedded; small amounts of limestone and chert may be from conglomerate. Sandstone; light gray, tan, brown, and red; composed mostly of quartz but has some feldspar and chert; grains very fine to coarse and average fine. Limestone, brown to gray, dense to finely crystalline.
	Concha Limestone:
995- 996	Limestone, tan to white, finely crystalline; and tan translucent chert.
996- 1490	No samples. Two cores mostly of limestone; tan, light brown and brown; dense to finely crystalline, cherty. Chert is light blue and translucent. Large cavities penetrated in upper 85 feet.
1490- 1522	Basal Concha is limestone, tan to light brown and light gray, fine- to medium-crystalline, sandy. Sand grains are of quartz, clear, medium to coarse.
	Scherrer Formation:
1522- 1532	Sandstone, white, medium grained, quartz, calcareous, well cemented; grains well sorted and rounded.
	Epitaph Dolomite:
1532- 2310	Dolomite dominant; some sandstone, shale, and chert. Dolomite, tan to light brown, dense to finely crystalline. Sandstone, light gray to gray with some white, quartz sand, dolomite cement, very fine grained to medium-grained. Shale, light gray. Chert, tan to brown, bluish, translucent.

2310- 2850 Dolomite dominant; anhydrite throughout occurs in thin beds and as inclusions in many dolomite beds; small amounts of shale and sandstone. Dolomite; dark brown, brown, and tan; dense to finely crystalline. Anhydrite, brown to white. Shale, gray to black, some brown. Sandstone, gray to green, very fine grained to fine-grained.

2850- 2930 Sandstone dominant; minor amounts of dolomite and other lithologies as described in overlying unit. Sandstone; red, light gray, and green (highest occurrence of red sandstone in Epitaph Dolomite); quartz; fine-grained.

2930- 3310 Dolomite dominant; much anhydrite; minor amounts of shale and sandstone. Dolomite; dark brown, brown, and gray; dense to finely crystalline; some is anhydritic; small amount of silty dolomite at top. Anhydrite, gray to brown and white. Shale; gray, dark brown, and black. Sandstone, gray and green, very fine-grained, quartz.

3310 Fault.

3310- 3820 Dolomite, anhydrite, etc.; similar to interval 2310-2850.

3820- 3890 Sandstone, etc.; same as interval 2850-2930.

3890- 4260 Dolomite, anhydrite, shale and sandstone; similar to interval 2930-3310.

4260- 4450 Dolomite dominant, some shale, traces of anhydrite. Dolomite, dark brown to brown, dense to finely crystalline. Shale, dark brown to gray.

Colina Limestone:

4450- 5258 Limestone dominant. Some shale and dolomite interbedded. Limestone, dark brown to brown, dense to finely crystalline. Shale, dark brown and gray. Dolomite, light brown, finely to very finely crystalline.

Earp Formation:

5258- 6265 Mostly interbedded shale, sandstone, and siltstone; small amount of limestone may be from conglomerate. Shale; red, purple, gray, and dark gray. Very fine grained sandstone and siltstone; light gray to white, red; quartz. Limestone; gray to light brown, dark gray to brown in lower part; dense; shaly; small amount is sandy.

Horquilla Limestone:

6265- 9400 Shale dominant; some interbedded limestone and sandstone. A few thin sills of green to white felsite (Tertiary?). Shale; dark gray, black, and dark brown; calcareous. Limestone, various shades of brown and gray, dense to finely crystalline, some beds rich in fragments of many types of fossils. Sandstone; light gray to gray; quartz; grains fine, very fine, and medium (some siltstone); some is siliceous, some is calcareous.

9400- 9700 Limestone dominant; minor amounts of shale and chert. Limestone, brown to light brown, dense to finely crystalline, some beds rich in fossil fragments. Shale, dark brown to black, calcareous. Chert, light blue to tan, translucent.

9700-10,995 Limestone with much interbedded shale and minor amount of chert; a few thin sills. Limestone; mostly dark brown to dark gray and black, some light brown and gray; dense to finely crystalline; some beds rich in fossil fragments; many beds fine to very fine grained oolitic in lower part (from 10,390 to base of unit). Shale, dark brown to black, calcareous. Chert, tan with bluish tint, some dark gray to black. Trace of light gray very fine grained sandstone or siltstone 10 feet above base. Thin sills of green to white felsite (Tertiary?).

Paradise Formation:

10,995-11,070 Sandstone, shale, and limestone interbedded. Sandstone; light gray to dark gray, some yellow; very fine grained (some siltstone); quartz. Shale, dark gray. Limestone, dark gray and brown, dense to very finely crystalline, many beds oolitic, oolites same colors as matrix.

11,070-11,425 Limestone dominant, some interbedded gray shale; single thin sill of light green to white felsite. Limestone, dark brown to dark gray, dense to very finely crystalline, many beds medium- to coarse-grained oolitic, some beds of crinoidal limestone.

Escabrosa Limestone:

11,425-11,520 Limestone, some interbedded shale, minor amount of chert. Unit is transitional between typical Paradise and Escabrosa lithologies. Limestone, light brown to dark brown, dense to finely crystalline; some beds oolitic, some composed of crinoid fragments. Shale, dark brown to gray. Chert, white to light blue, translucent.

11,520-11,840 Limestone dominant, some chert. Limestone; tan, white, and light brown; dense to finely crystalline; oolitic texture rare; many crinoid fragments throughout. Chert; white, light blue, light gray; translucent.

11,840-12,230 Limestone dominant, significant amount of chert, minor amount of shale. Limestone; dark brown to black; dense, finely crystalline, and very finely crystalline. Chert, dark gray to light brown. Shale, dark brown.

12,230-12,350 Limestone; white, tan, and light gray; dense to finely crystalline; some beds with crinoid fragments; one bed oolitic and dark brown.

12,350-12,500 Limestone, gray to brown, in lower 50 feet dark brown to dark gray, dense to finely crystalline, some crinoid fragments.

Percha Shale:

12,500-12,830 Shale dominant, single thin bed of limestone, single thin sill of light green felsite (Tertiary?). Shale, dark brown to black, slightly calcareous, hard, fissile. Limestone, black to dark gray, dense to very finely crystalline.

Montoya Dolomite:

Cutter Member:

12,830-12,985 Dolomite, light gray to gray, coarsely crystalline at top but dense to finely crystalline through remainder of unit.

Aleman Member:

12,985-13,097 Dolomite dominant with much chert that is probably interstratified. Dolomite, dark gray to black, dense to finely crystalline. Chert, dark brown to dark gray, opaque to translucent.

Upham Member:

13,097-13,155 Dolomite, gray to dark gray, fine to medium crystalline.

	Cable Canyon Member:
13,155-13,170	Sandstone, dolomitic. Sand grains are of quartz with some chert, clear to light gray, fine- to coarse-grained, and rounded.
13,170-13,214	Shale, dark gray and dark brown, very slightly calcareous.
	El Paso Formation:
	Bat Cave Member:
13,214-13,850	Limestone, brown to gray, some dark brown to dark gray, lithographic, very minor amount of quartz grains in some beds.
	Sierrite Member(?):
13,850-14,120	Limestone dominant, very small amount of sandy limestone, single dolomite bed, and chert stringers at base of unit. Limestone, same as in overlying unit. Sandy limestone contains very fine grained quartz. Dolomite, black, dense to very finely crystalline. Chert, white to light blue, translucent; may be secondary chert associated with fault.
14,120	Fault.
	Escabrosa Limestone, middle part:
14,120-14,440	Limestone dominant, some thin interbedded shale, thin laminae of chert in upper part, and single sill of green felsite. Limestone; dark brown to dark gray, some brown to gray; dense to very finely crystalline. Shale, dark brown to dark gray, very slightly calcareous. Chert, tan to light gray, translucent; may be secondary chert associated with fault.
14,440-14,585	Limestone; light brown to gray; dense to finely, medium, and coarsely crystalline, some fossil fragments. Some limestone is sandy or siliceous and contains very fine grained quartz sand or silica.
14,585	Total depth of well.

Plate 6 illustrates graphically and in summary the composite surface stratigraphic column and the stratigraphic sections penetrated in the two deep test wells. The plotted section of No. 1 State "BA" is corrected for the two recognized faults; duplication of beds is eliminated.

Thicknesses and lithologies of most formations in No. 1 State "BA" are similar to those studied on the surface. A few formations, however, appear to change. Some observed differences may be due to such factors as weathered outcrop samples in contrast to the fresh surfaces of drill cuttings and apparent thickening of dipping formations in the well. Also, the comparison of the independent works of different geologists may introduce some apparent discrepancies. However, some real and important differences in lithology and thickness take place between the exposures in the Big Hatchet Mountains and No. 1 State "BA". These are described below in the order encountered in the well, from youngest to oldest.

The basal part of the U-Bar Formation penetrated in the well consists of interbedded limestone, shale, and sandstone of yellow, brown, and gray colors. This lithology is typical of the basal brown limestone member of the type formation.

The rocks of the Hell-to-Finish Formation in the well, predominantly red shale and including interbedded arkosic and cherty sandstone, are like those found in the type section. The formation is thinner in the well.

Concha Limestone in the well is lithologically similar to the formation on the surface but is thinner due to deeper erosion on the pre-Hell-to-Finish surface. Significantly, several large cavities penetrated in the upper 85 feet of the Concha apparently represent caverns formed by karst erosion related to the old erosion surface. Scattered sand grains in the basal Concha indicate a transitional contact with the underlying ten feet of sandstone of the Scherrer Formation.

Part of the Epitaph Dolomite in the well was duplicated by a fault. After the duplicated beds are eliminated from the section, the Epitaph of the well is still several hundred feet thicker than on the surface. This may be only an apparent thickening due to the dip of the formation in the well or due to minor faults; or it may be a real thickening caused by depositional conditions. Lithologically the formation is similar in the surface and subsurface sections, except that in the well much more anhydrite was found through a great thickness of section, and some sandstone and black shale beds are present throughout. Dead oil stain, shows of oil and gas, and pinpoint porosity were reported in the Epitaph.

Throughout the region, the Colina Limestone is an undolomitized basal part of the Colina-Epitaph sequence. In the well, the total interval of limestone designated as Colina is somewhat thicker than that measured in the Big Hatchet Mountains.

The Earp Formation of the well and surface sections is the same in thickness and is very similar in lithology.

One of the most important discoveries made in No. 1 State "BA" was the basin facies penetrated in the upper two-thirds of the Horquilla. These beds, more than 1000 feet thicker in the well than in the Big Hatchet Mountains, consist predominantly of dark gray, black, and dark brown shale; limestone and sandstone are also present. Missouri to late Wolfcamp beds are included. This middle Pennsylvanian—early Permian basin is named Alamo Hueco basin earlier in this report. Beds of corresponding age in the mountains are represented by reef and shelf facies (*see* p. 42). The lower third of the Horquilla Limestone is similar in lithology and thickness in the well and on the surface.

The Paradise Formation in the well, as in the Big Hatchet Mountains, has sandstone at the top and much oolitic and some crinoidal limestone throughout. The slightly different thickness is attributable to varying depths of pre-Horquilla erosion.

Escabrosa Limestone in the well and on the surface is essentially the same in lithology and thickness. The three distinctive members recognized in the Big Hatchet Mountains are present in the well. The upper member of chiefly crinoidal limestone was penetrated in the interval 11,425 to 11,840 feet below the surface. The middle member characterized by thin alternating strata of dark limestone and chert, occupies the interval 11,840 to 12,230 feet. Beds of the lower member lie below.

The lithology and thickness of the Percha Shale in the well and in the surface section are the same.

The Montoya Dolomite with the Cutter, Aleman, Upham, and Cable Canyon Members is similar in the well and on the surface. However, about 45 feet of shale that is present at the base of the Cable Canyon in the well is absent on the surface.

The lithology of the El Paso Formation may change because the texture of the limestone is described as lithographic in the well with no fossil fragments, whereas on the surface the limestone consists largely of fossil fragments and is finely crystalline. The lower part of the El Paso in the well may be equivalent to the Sierrite Member, but the chert near the base may be of secondary origin associated with the large fault. Similar chert is present immediately below the fault in the top of the repeated' section of the middle Escabrosa. The well was bottomed in the repeated Escabrosa.

HACHITA DOME COMPANY NO. 1 TIDBALL-BERRY "FEDERAL"

This wildcat well was drilled with a cable tool rig in the Hachita Valley on a small isolated exposure of Escabrosa Limestone about a mile northeast of the Hatchet Ranch from 1954 to 1957. The location is 1655 feet from the south line and 2012 feet from the west line of sec. 12, T. 3o S., R. 15 W. Mr. Jess Coleman, Geologic Sample Log Company, prepared a lithologic log of the well that was used in the following summary. Thicknesses are not corrected for dip, which at the surface is 24 degrees southwest. I chose the formation boundaries from information shown on the log. The lithology is shown graphically on Plate 6.

Depths from surface (in feet)	*Descriptions of gross lithologic units*
0- 21	Alluvium.
	Escabrosa Limestone:
21- 230	Limestone: mostly light gray; finely to coarsely crystalline but chiefly coarsely crystalline; crinoid columnals common throughout; some samples fragmental; tight fractures, some filled; trace of hematite.
230- 480	Limestone: chiefly medium to dark gray, a few samples with pink tints; very finely crystalline and dense; fragmental and fractured; no crinoid columnals noted except in upper 70 feet. Unit rich in chert: gray-pink, pink, gray-red, yellow-brown, brown-gray, yellow, and yellow-gray; opaque; some calcitic, some fragmental, and some fractured. One sample near top of unit contains small quantity of sandstone, dark red, grains fine to coarse and subrounded, very calcitic.
480- 800	Limestone: dark gray predominant but some samples are dark gray, gray, pink, brown, yellow, and white; very finely crystalline in upper part, lower part medium to coarsely crystalline and includes abundant crinoid fragments; fossiliferous, fragmental, dense; many samples argillaceous. One sample of limestone at top is oolitic. No chert. In lower 100 feet in which limestone is predominant, a few individual samples include siltstone, light brown, calcitic; dolomite, very light brown, finely to very finely sucrose, calcitic; sandstone, gray-red, very fine-grained; and shale, dark gray, calcitic.
	Percha Shale:
800-1255	Shale, limestone, and sills of diorite. Shale: mostly dark gray, some samples gray-green, red-brown, and black; flaky, some samples hard; calcitic. Limestone: dark gray to black, dense, very argillaceous; nodules of light gray fossiliferous limestone in upper part; diorite: gray-green to black; dense, finely crystalline; some contains pyrite; in small amounts in many samples.
1255-1395	Almost entirely shale: dark gray, gray-black, and black; carbonaceous; trace of pyrite. One sample contains black, dense, very argillaceous limestone; another contains gray-black, dense, very argillaceous dolomite.
	Montoya Dolomite:
1395-1510	Dolomite: white to very light gray, basal samples light to medium gray and brown-gray; finely to coarsely crystalline; contains traces of pink dolomite, white opaque chert, hematite stain, intercrystalline porosity. Small amount of chert, blue-white to very light gray, translucent to opaque.
1510-1640	No samples.
1640-1653	Dolomite: white to very light gray, finely to very finely crystalline. Also some sandstone: white to red-brown, fine-grained, loose.
	El Paso Formation:
1653-2240	Limestone: mostly medium to dark gray, a few samples light gray; dense to very finely crystalline; slightly to very fragmental, slightly to highly fractured, many fractures filled with calcite, some hematite stain, fossiliferous. Rare, thin, black shale partings. Very small quantity of chert, white and light gray, opaque. In lower 150 feet there are small amounts of dolomite: gray to black; finely crystalline, very finely crystalline, and dense.
2240-2590	Limestone, some dolomite, and notable amount of chert. Limestone: mostly medium to dark gray, some samples light gray, white, pale red, pink; dense to very finely crystalline; very fragmental; certain limestone samples have slight amounts of sand, silt, silica, and hematite. Dolomite: light to dark gray, finely to very finely crystalline, fragmental. Chert: blue-white, gray, very light gray, and white; translucent and opaque. Many zones slightly sandy. Limestone predominates in samples except for lower 40 feet which is entirely of dolomite. Poor samples in lower 60 feet.
	Bliss Formation:
2590-2723	Samples poor. Quartzite, sandstone, and dolomite. Quartzite: gray to light gray to white; fine- to medium-grained, some possibly coarse-grained; siliceous. Sandstone: white to light gray, medium-grained to very fine grained, grains subangular, dolomitic to siliceous. Dolomite: dark, medium, and light gray and white; finely to very finely crystalline; fragmental; slightly sandy.
2723-2726	Granite (?)
2726	Total depth of well

The succession of formations penetrated appears to be normal, but the thicknesses are somewhat different from those in the nearby Big Hatchet Mountains. The formations of the well should not be appreciably different from those in the Mescal Canyon section five miles to the southwest.

The part of the Escabrosa Limestone penetrated appears to have the same general lithology as in the surface section. The upper member, the middle chert-rich member, and the lower member are recognized. The middle and lower members are thinner in the well than in the mountains.

The Percha Shale in the well is 595 feet thick, which is twice as thick as in the mountains. This may be due to a combination of several factors. First, I may have chosen the upper contact higher in the well than in the Mescal Canyon section. Second, the significant amount of diorite in the samples is undoubtedly from sills, which may have thickened the formation. Third, part of the excessive thickness may be due to the dip of strata, although the thinness of the other formations does not suggest a high dip angle. Fourth, the greater thickness may be due to minor faulting or to plastic flowage of the shale near the axis of a fold.

The Montoya Dolomite of the well is more than loo feet thinner than on the surface. Sandstone at the base marks the Cable Canyon Member.

The El Paso Formation is more than 100 feet thinner in the well. The upper part represents the Bat Cave Member; the lower unit, which contains some dolomite and a notable amount of chert, represents the Sierrite Member.

Apparent thicknesses of the Montoya and El Paso in the well should be greater than in the surface section to account for the probable dip of the formations. However, both formations are thinner in the well than in the mountains. This may be due to minor faults.

The Bliss Formation is also thin, but it is within the limits of thickness variation found in surface sections. The sample of the lowest three feet of the well is shown on the log as possible granite.

Minor shows of oil and gas in the well were reported by the operators.

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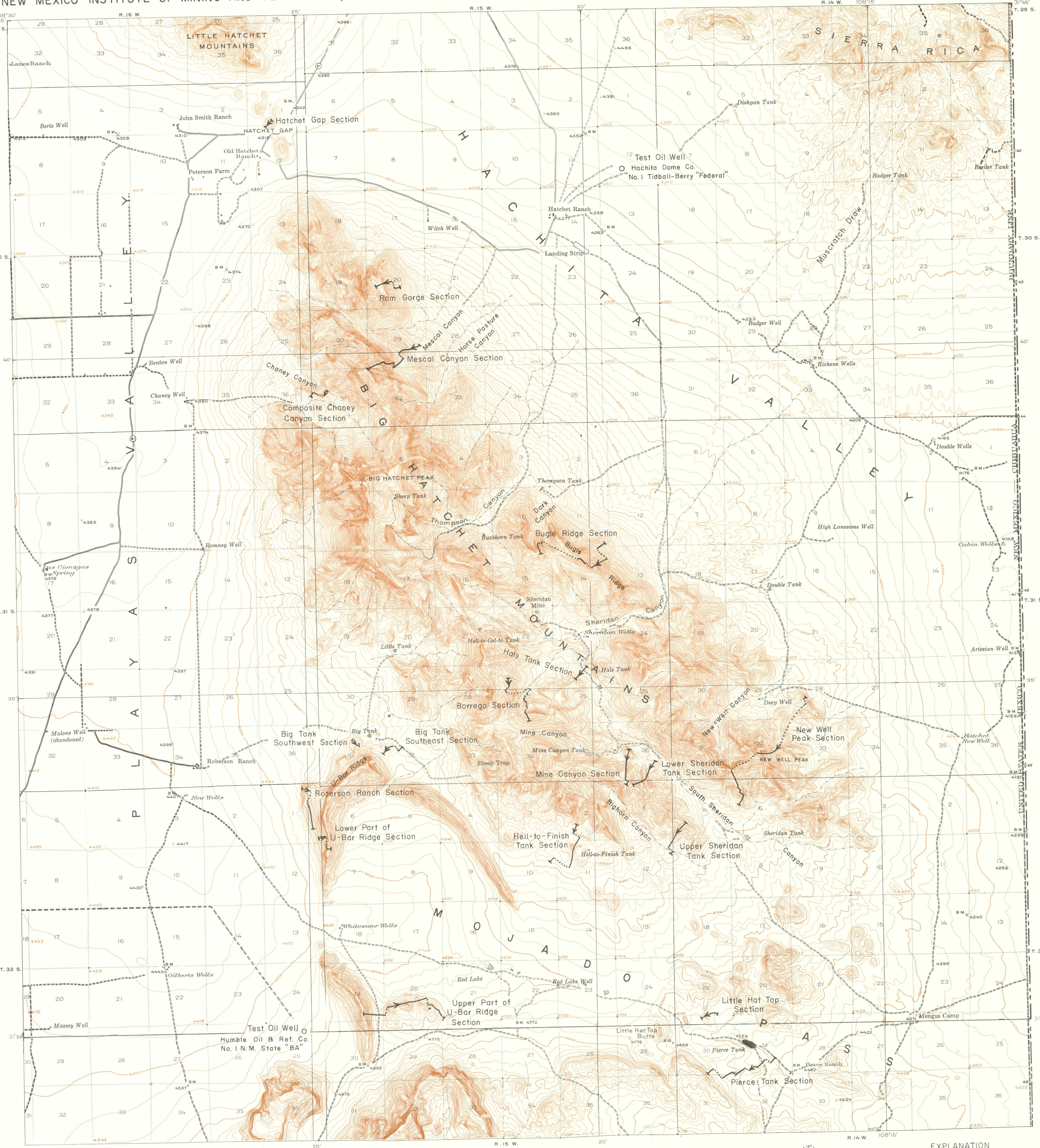
Numbers in **boldface** indicate main sections



Base from Big Hatchet Peak and Dog Mountains Quadrangles, surveyed by the U. S. Geological Survey in cooperation with the War Department in 1917-1918. Culture revised by R. A. Zeller, Jr., in 1960.

Scale 1:62500

1 0 1 2 3 4 Miles

Contour interval 25 feet
Datum is mean sea level

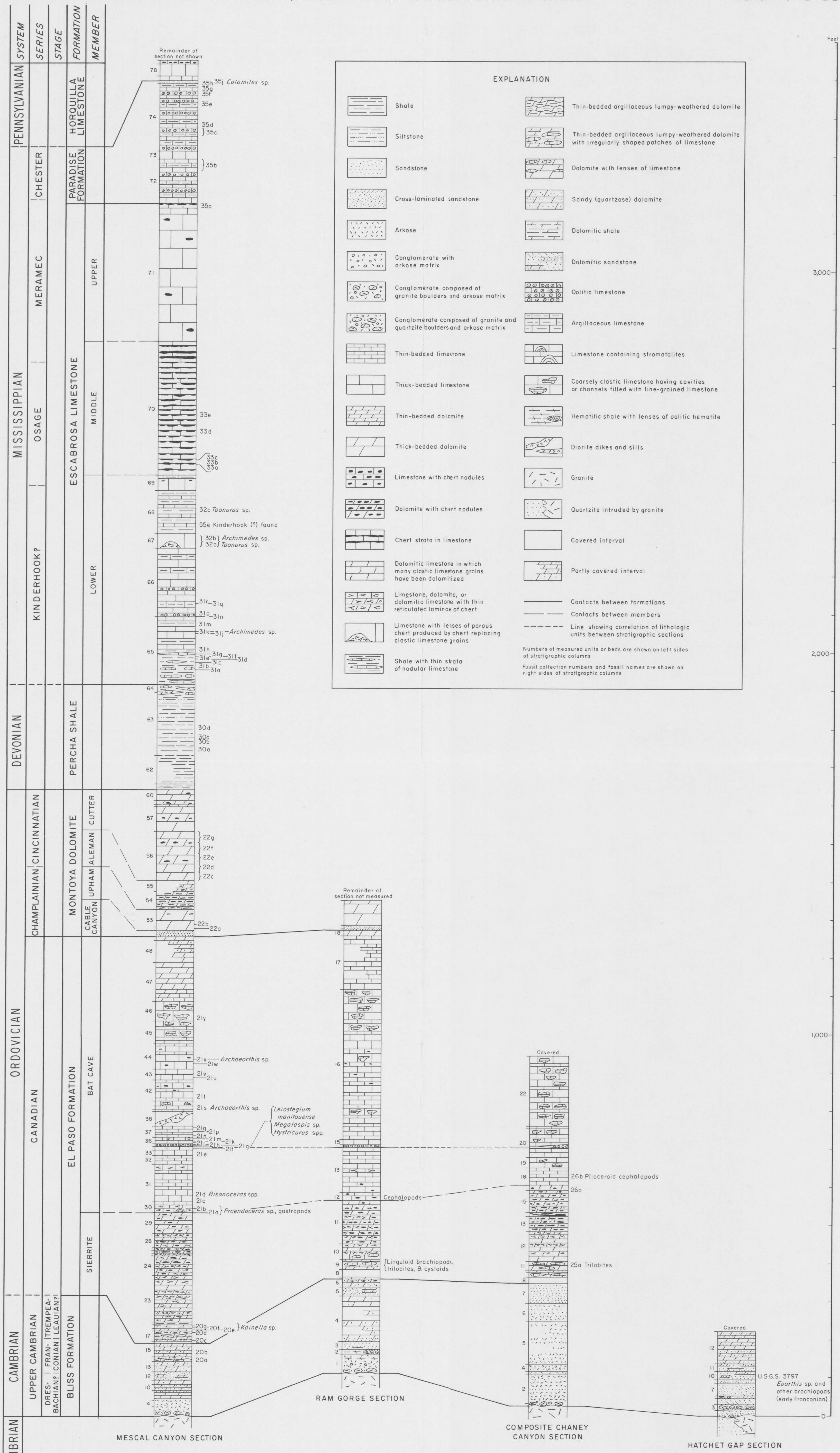
APPROXIMATE MEAN DECLINATION, 1950

EXPLANATION

Locations of measured sections
Arrow indicates direction of younger beds

Offsets of measured section

MAP OF BIG HATCHET MOUNTAINS AREA AND LOCATIONS OF MEASURED SECTIONS



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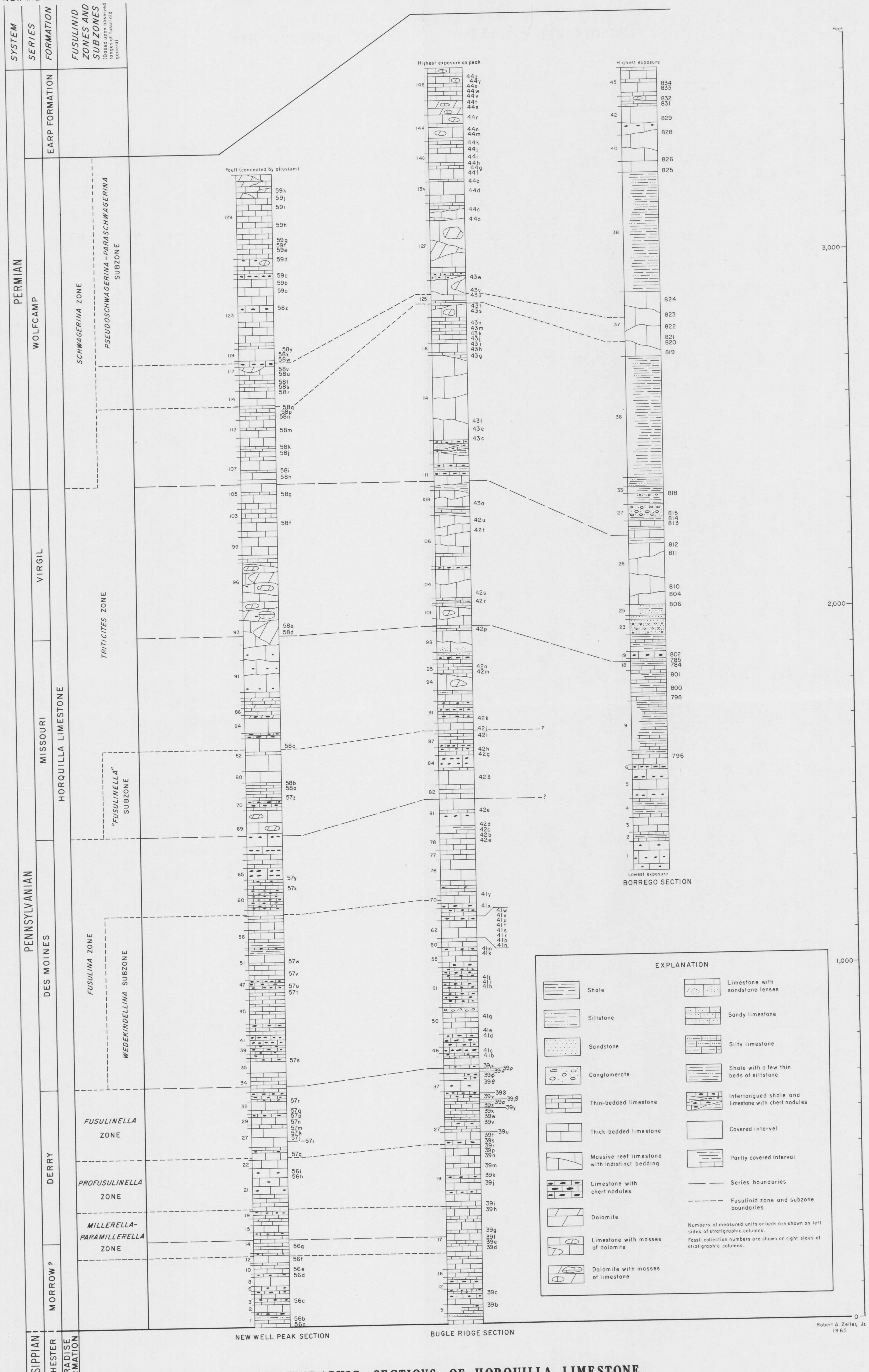

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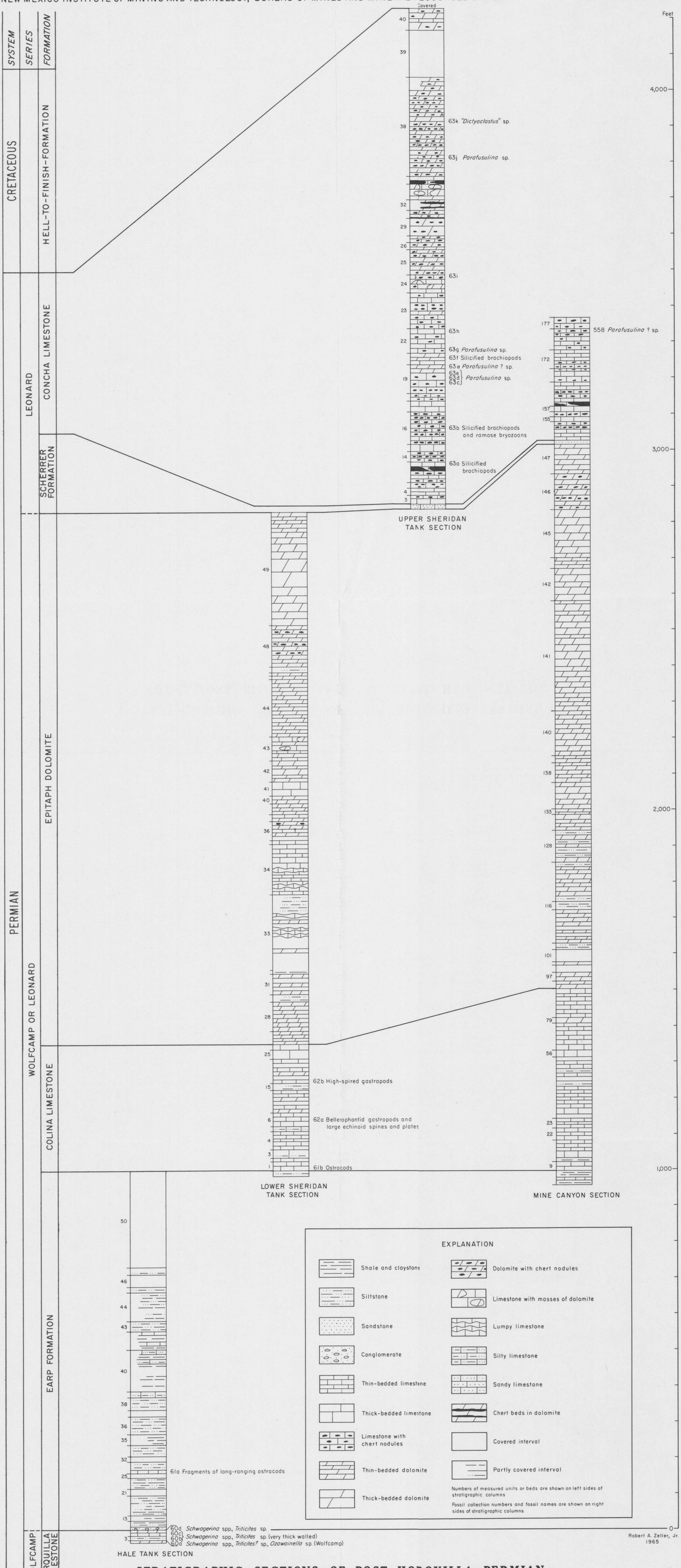

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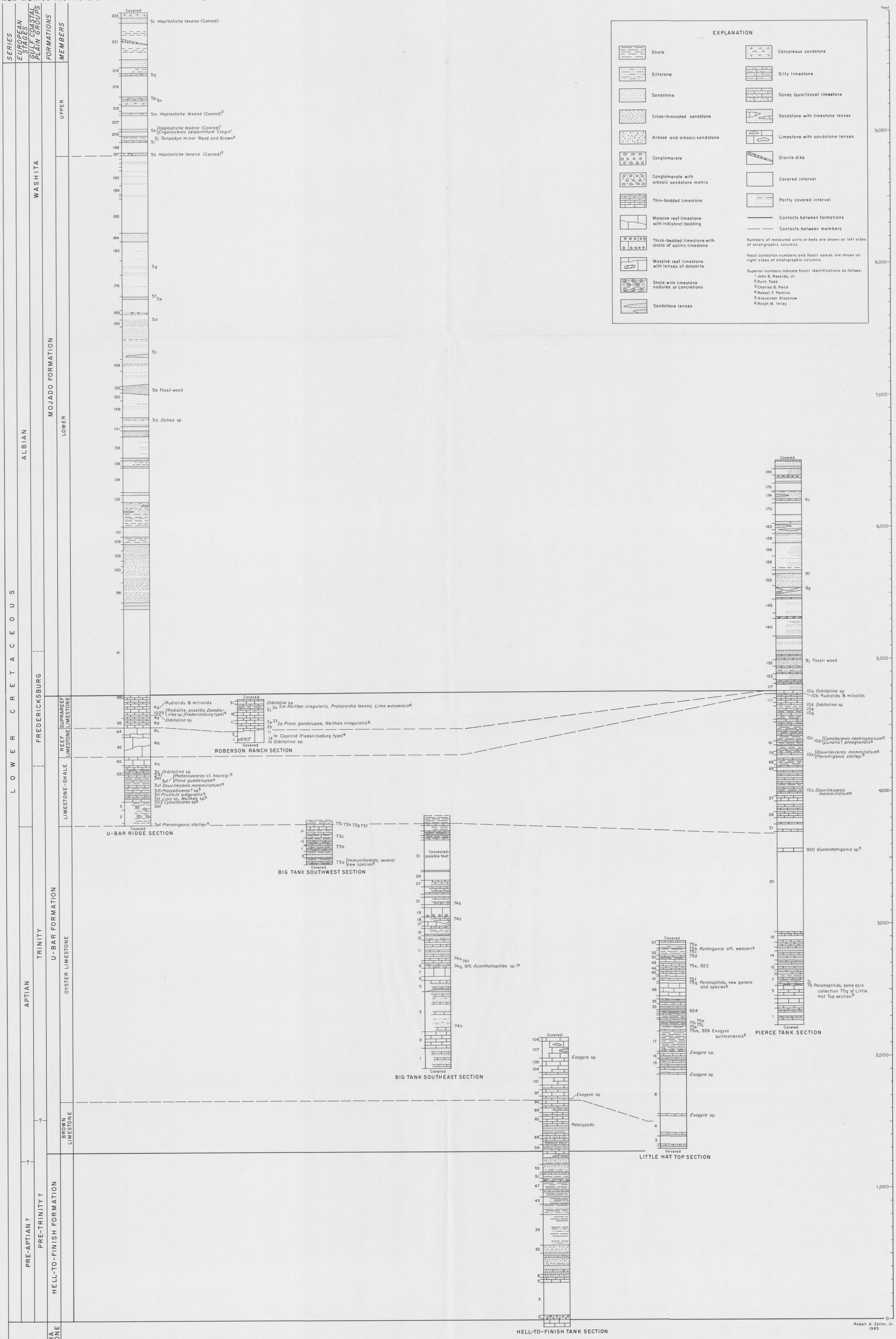

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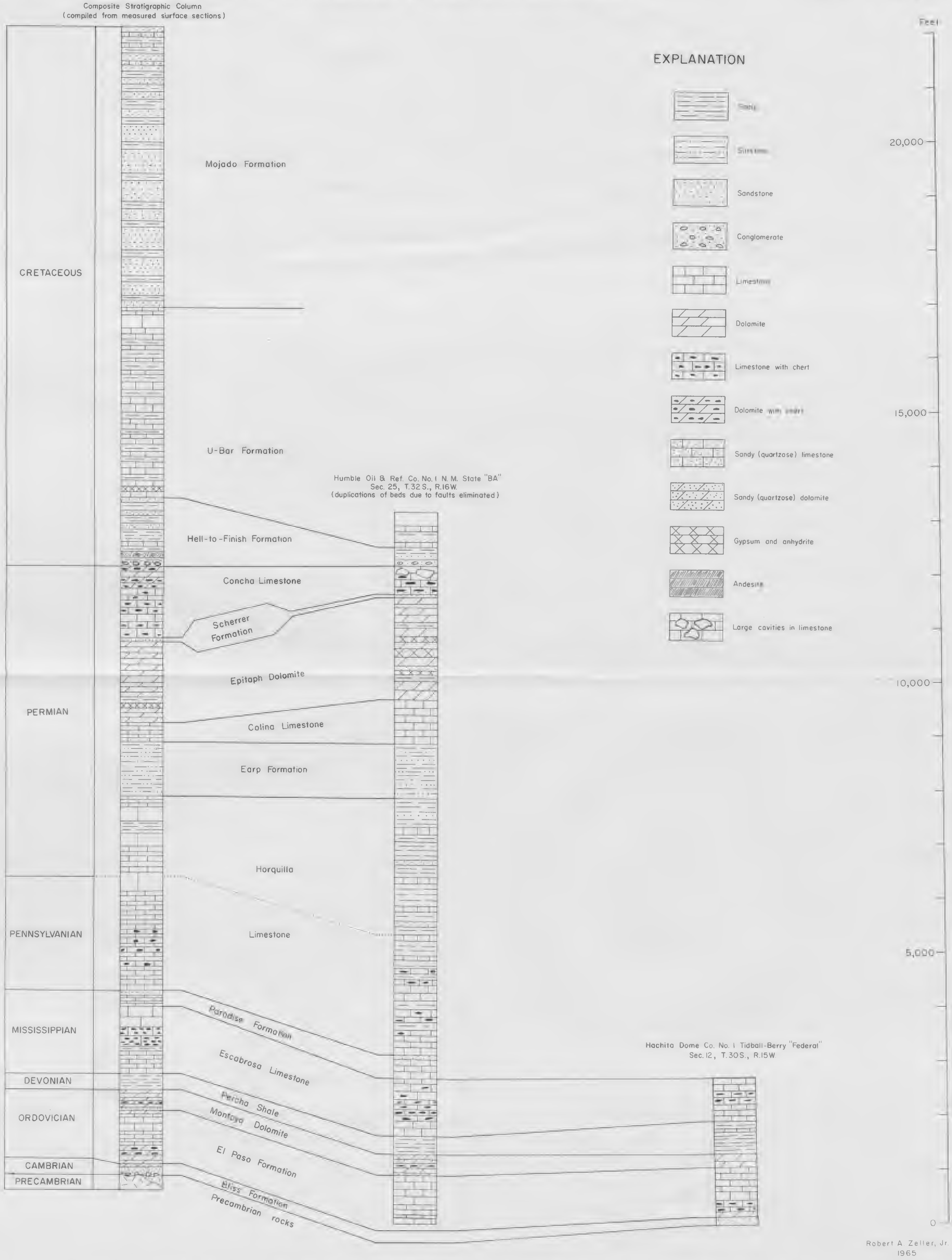

COMPOSITE SURFACE STRATIGRAPHIC COLUMN AND SUBSURFACE SECTIONS FROM TWO DEEP WELLS, BIG HATCHET MOUNTAINS AREA, NEW MEXICO