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Permian Sedimentary Facies, Central Guadalupe Mountains, New Mexico

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Abstract

The Permian rocks of the Guadalupe Mountains undergo striking changes in short distances between basin, basin-margin, and shelf facies. The upper Guadalupian Capitan reef, and equivalent shelf and basin deposits, have been studied intensively in the southern Guadalupe Mountains by many workers. This report is the first detailed study of the equally important facies changes within the Leonardian and lower Guadalupian strata north of the Texas-New Mexico border. Field work included the geologic mapping of El Paso Gap quadrangle.

The strata in the northern part of the area are shelf sediments, largely carbonates, and include the Yeso, San Andres, Grayburg, and Queen formations. In the southern part of the area the Grayburg formation, Queen formation, and Carlsbad group of the shelf phase overlie units of the basin and basin-margin phases (Victorio Peak and Cutoff members of the Bone Spring formation, and the Cherry Canyon sandstone tongue). The Queen formation and Carlsbad group pass into the Goat Seep reef and the Capitan reef, respectively, in this area.

Basin deposits encroached some 9 miles shoreward of the present Capitan reef front during deposition of the Cherry Canyon sandstone tongue and the Cutoff member of the Bone Spring formation. The upper part of the Cherry Canyon tongue grades into the lower Grayburg formation, but the remainder, together with the underlying Cutoff member, passes into a mile-wide transition facies of the San Andres formation. The southern part of this facies is characterized by patch reefs. The Victorio Peak member of the Bone Spring formation occurs farther north than was previously supposed. In the central part of the area studied, it underlies some 600 feet of San Andres strata and presumably passes into the lower San Andres in the subsurface.

The San Andres formation is one of the most persistent and uniform of the shelf units, extending over an area of hundreds of square miles in Texas and New Mexico. As the formation is only sparsely fossiliferous, its exact age with reference to the highly fossiliferous sequence of marginal and basin formations has always been debatable, even though the San Andres is a well-known stratigraphic datum in the subsurface. Some geologists believe that it is entirely Leonardian in age, but inconclusive available evidence indicates that the Leonardian-Guadalupian boundary lies within the San Andres formation.

Some of the dense dolomite which characterizes much of the Guadalupian shelf phase possesses a microcrystalline texture resulting from recrystallization, and some exhibits a fine primary detrital texture indicative of calcilutites. Many dolomite layers in the Guadalupian shelf deposits exhibit laminations similar to those in algal-controlled sedi-

ments now forming on tidal flats and in shallow water off the coasts of Florida and the Bahama Islands.

Large and diverse fossil collections were obtained from the Cherry Canyon sandstone tongue and the Cutoff member of the Bone Spring formation where these units pass into the shelf phase. Thus the basin-margin environment favored abundant invertebrate life in late Leonardian and early Guadalupian time. Although some patch reefs were formed along the basin margin at this time, a barrier reef was not established before middle Guadalupian time. A diverse invertebrate fauna was obtained from a thin bed in the Queen formation, but in general the Guadalupian shelf deposits were formed in an environment inhospitable to invertebrate life.

Introduction

GEOLOGIC IMPORTANCE OF THE GUADALUPE MOUNTAINS

The Permian reef complex of western Texas and south-central New Mexico is one of the most instructive examples known of intricate contrasts in stratigraphic and paleontologic facies. The broad relationships have become comparatively well known, because of long-sustained interest in this region by stratigraphers and paleontologists.

The Guadalupe Mountains (fig. 1 and pl. 1) are uplifted blocks of nearly horizontal Permian rocks, mainly limestone and dolomite. The area includes sedimentary facies of the stagnant Delaware Basin to the south, marginal reef and bank facies, and shelf or lagoonal facies to the north (fig. 2 and pl. 6E). The basin and marginal facies are highly fossiliferous and are the American standard Permian section. These facies are exposed widely in the southern Guadalupe Mountains, where they have been studied intensively by King (1948) and Newell et al. (1953). The relatively unfossiliferous shelf phase is widespread and contains many oil fields; therefore, is of great interest to geologists studying subsurface rocks.

This report is concerned largely with rocks of the shelf phase and with rocks transitional between the shelf and basin phases. The area studied is immediately north of the Texas-New Mexico border, in the central Guadalupe Mountains, and contains excellent outcrops but rather complex structure.

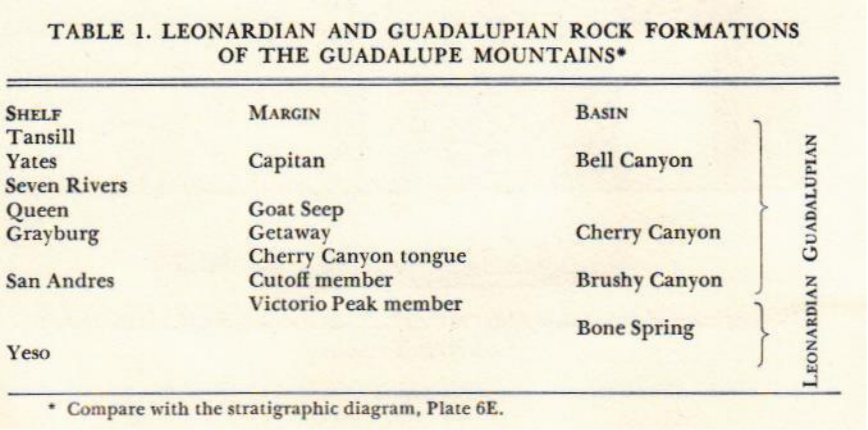
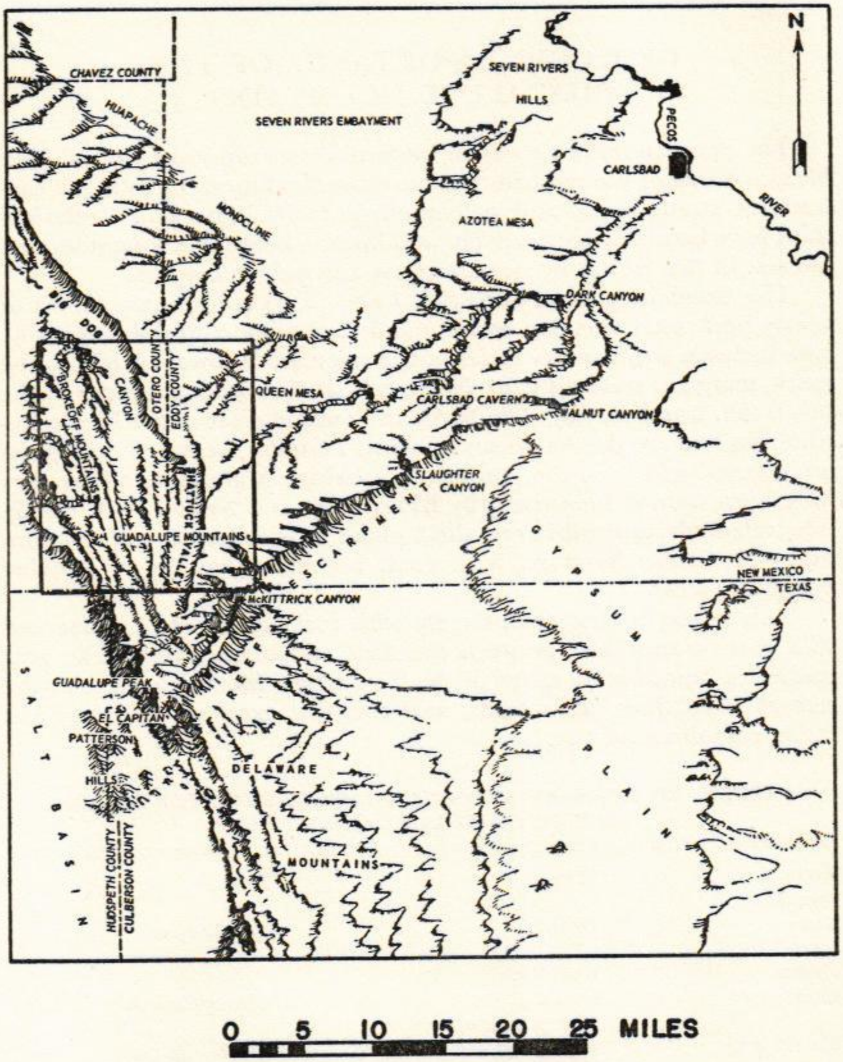


TABLE 1. LEONARDIAN AND GUADALUPIAN ROCK FORMATIONS OF THE GUADALUPE MOUNTAINS*

SHELF	**MARGIN**	**BASIN**	
Tansill			GUADALUPIAN
Yates	Capitan	Bell Canyon	
Seven Rivers			
Queen	Goat Seep		
Grayburg	Getaway	Cherry Canyon	
	Cherry Canyon tongue		
San Andres	Cutoff member	Brushy Canyon	
	Victorio Peak member		LEONARDIAN
		Bone Spring	
Yeso			

* Compare with the stratigraphic diagram, Plate 6E.

The geology of the central Guadalupe Mountains has been poorly known because of the relative inaccessibility and structural complexi-



GUADALUPE MOUNTAINS AND VICINITY IN SOUTHERN NEW MEXICO AND WESTERN TEXAS.

Figure 1

ties in an area of abrupt facies changes. Extensive and meticulous field observations are required to map the geology.

Stratigraphic details in the central Guadalupe Mountains are important for several reasons:

1. Transition of basin to shelf facies in the pre-Capitanian formations is exposed in the area. The lack of accurate knowledge of this transition has prevented detailed correlation of basin and shelf formations.
2. The type localities of two poorly defined shelf formations (Queen and Dog Canyon formations), and complete surface exposures of two other shelf formations whose type localities are elsewhere (San Andres and Grayburg formations), occur in the central Guadalupe Mountains. There has been much confusion over the mutual relationships of these formations and their lateral equivalents in the Delaware Basin. Lang (1937), DeFord and Lloyd (1940), and King (1942) noted the need for a thorough study of the central Guadalupe Mountains north of the New Mexico-Texas boundary to solve these stratigraphic problems.
3. The extensive exposures of bedded dolomites in the central Guadalupe Mountains supply clues concerning the genesis of the shelf sea deposits.

REGIONAL SETTING

GEOGRAPHY

The Guadalupe Mountains are triangular in outline, with the apex pointing south (fig. 1). Most of the mountain area is in southeastern New Mexico, but a bold promontory extends several miles south of the Texas-New Mexico border. Elevation and relief increase to the south, where Guadalupe Peak, 8,751 feet above sea level is the highest point in Texas.

El Paso Gap quadrangle includes most of the central Guadalupe Mountains. The quadrangle is bounded on the south by the New Mexico-Texas border and lies 40 miles southwest of Carlsbad, New Mexico, or 60 miles by road. The eastern third of the quadrangle is a flat plateau draining to the east and deeply dissected only in the southeastern part. The plateau, which extends north and east of the quadrangle, is known as Queen Mesa. The western two-thirds of the quadrangle contains numerous fault-block horsts of the Brokeoff Mountains, which trend north-northwest, and which are separated by valleys draining to the northwest into the Salt Basin west of the mountains.

Queen Mesa is separated from the Brokeoff Mountains by two north-south trending valleys, Big Dog Canyon to the north, and Shattuck Valley to the south.

The highest point, in the southeastern part of the quadrangle, has an elevation of 7,444 feet above sea level; the southwestern part contains the lowest elevation, 3,634 feet.

The area is served by one gravel road which connects El Paso Gap with New Mexico Highway 285, 14 miles north of Carlsbad. There are automobile trails in the larger valleys and several graded roads constructed by the U. S. Forest Service to cattle tanks scattered over Queen Mesa in Lincoln National Forest. Subsequent to publication of the topographic map of El Paso Gap quadrangle in 1940, the Carlsbad-El Paso Gap road has been partly relocated; in several places its present route is almost a mile from that indicated on the map.

The land is utilized for grazing, and there are several ranches within the quadrangle boundaries. Rainfall of 15 inches per year supports shrubs and grasses characteristic of the semiarid environment.

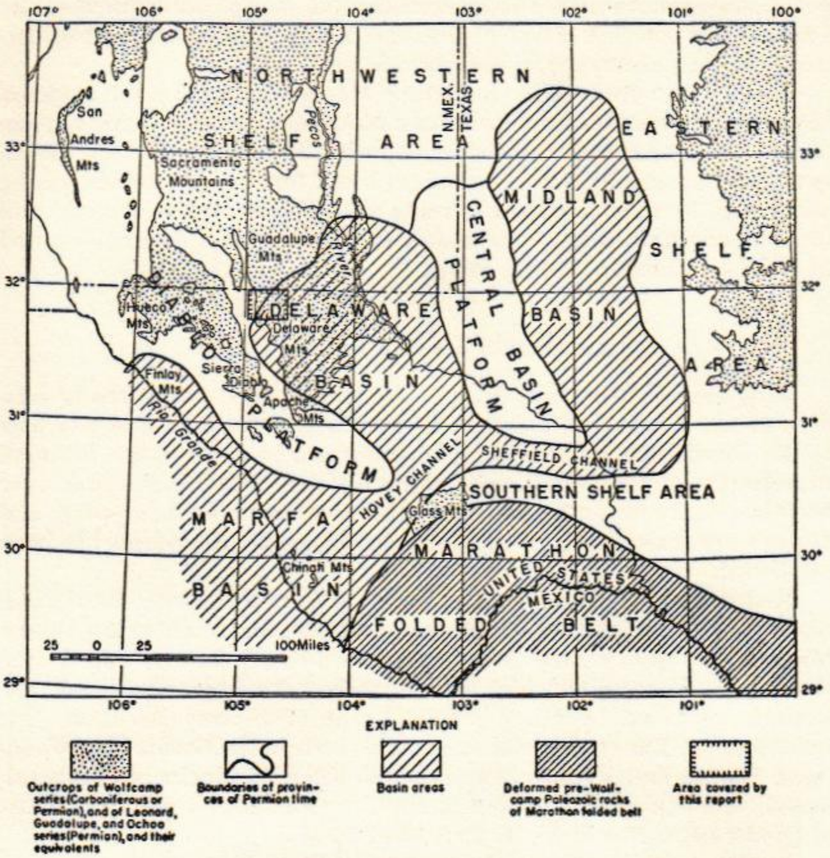
GEOLOGY

The Permian sedimentary rocks of western Texas and southern New Mexico are noted for abrupt lateral changes. About 25 years ago several geologists suggested that the thick, lenticular limestones of the southern Guadalupe Mountains are organic reefs. This suggestion was the key to correct interpretation of the Permian stratigraphy, and it is now generally agreed that these reefs greatly influenced Permian sedimentation over a large area.

The dominant Permian paleogeographic features of the western Texas-southern New Mexico area were the deep Delaware and Midland Basins, separated by the Central Basin Platform, all bordered on the north by shelf areas (fig. 2). Shallow seas covered the shelves, and the position of the shoreline fluctuated throughout Permian time. The existence in Permian time of three unlike environments of contiguous areas—basin, basin-margin, and shelf—greatly influenced sedimentation. The geographic limits of the three environments shifted with migration of the basin margin and the shoreline.

Early in the Permian period, during Wolfcampian time, organic reefs were initiated around the rim of the Delaware Basin. Reef building culminated during Capitanian time, when a great barrier reef, essentially continuous except for a southern channel to the open ocean, extended around the Delaware Basin. Dark-colored limestones and fine-grained sandstones were deposited in the basins, whereas thin-bedded carbonate rocks, grading into gypsum and red beds to the north, were laid down on the shelves. Reefs did not exist in the area after Capitanian time, apparently because of the hypersalinity of the seas. Thick evaporite deposits were formed at this time (Ochoan epoch).

Today the Permian shelf deposits are exposed widely in the San Andres, Sacramento, and Guadalupe Mountains, and adjacent areas of south-central New Mexico. The lowest Permian strata exposed (Wolfcampian) in the shelf area to the northwest are chiefly of continental origin, whereas the Leonardian beds contain many marine carbonates. Higher Permian (Guadalupian) shelf deposits cap the uplands in the central and southern Guadalupe Mountains. The eastern front of the



STRUCTURAL FEATURES OF PERMIAN AGE IN SOUTHERN NEW MEXICO AND WESTERN TEXAS.
(From King, 1948, p. 25.)

Figure 2

Guadalupe Mountains lies along the Capitan reef escarpment, so that the present topographic relief, at least locally, approximates the submarine topography of Permian time. Several canyons are cut into the mountain front and expose good cross-sections of the reef, allowing the lateral gradation among the shelf, reef, and basin facies to be seen in continuous exposures of the Capitanian formations.

The Capitan reef and associated deposits are broadly exposed in the southern Guadalupe Mountains. They have been the subject of numerous studies based mainly on the more accessible outcrops south of the Texas-New Mexico border. The stratigraphy of these Capitanian deposits has been worked out in considerable detail; consequently, the Capitan reef complex is one of the most widely known and best understood deposits of its type in the world.

The western part of the Guadalupe Mountains, termed the Brokeoff Mountains, consists of numerous fault blocks of Leonardian and Guadalupian shelf, marginal, and basin deposits. The mountains are terminated on the west by the downfaulted block forming the border of the Salt Basin. Permian basin-facies rocks are well exposed to the east and south of the Guadalupe Mountains, in the Delaware Mountains, and in the Sierra Diablo (Stehli, 1954).

PREVIOUS INVESTIGATIONS

King's excellent report (1948) on the geology of the southern Guadalupe Mountains includes the only published geologic map of any part of the Guadalupe Mountains. The numerous reports on the Permian stratigraphy of the Guadalupe Mountains and adjoining region have been based on reconnaissance rather than systematic field mapping, and no comprehensive study of the central Guadalupe Mountains has been published.

Richardson (1910) made a reconnaissance trip through the Guadalupe Mountains in an attempt to determine the relationship of the Manzano group of central New Mexico to the Permian sequence in the Guadalupe Mountains which had furnished the impressive fossil collections described by Girty (1908). Beede (1910) suggested the first correlation of Kansas Permian strata with beds in the Guadalupe Mountains. Darton and Reeside (1926, p. 426) listed 63 species of fossils collected from exposures in Last Chance Canyon, about 4 miles northeast of Queen (secs. 32 and 33, T. 23 S., R. 22 E.).

In the twenties, the need for detailed knowledge of the Permian formations encountered by drilling in the newly developed oil fields northeast and east of the Guadalupe Mountains focused interest on the outcrops in the mountains. The successful application of the reef concept to the interpretation of Permian stratigraphy aided the surface studies.

Most subsequent references to the geology of the central Guadalupe Mountains have discussed three problems: (1) correlation of basin equivalents of the San Andres formation, a persistent shelf unit; (2) subdivision of the 800 feet of interbedded sandstone and dolomite that overlie the San Andres formation; and (3) correlation of the southern New Mexico shelf units with those on the east side of the Midland Basin (fig. 2).

In 1929 six papers (Baker, Blanchard and Davis, Crandall, King and King, Lloyd, Willis) were published on the description and interpretation of rocks of the Guadalupe Mountains.

In a regional study by Lang (1937), which included the central Guadalupe Mountains, two shelf units were defined, the Chalk Bluff formation and the Dog Canyon limestone, neither of which has been widely used.

Papers by Dickey (1940) and Woods (1940) in a West Texas-New Mexico symposium include cross-sections, based on well logs, showing the characteristics of the San Andres and related shelf formations in the subsurface eastward from the Guadalupe Mountains over the Central Basin Platform and into the Midland Basin.

Lewis (1941), relying mainly on subsurface information, described the distribution of the San Andres sequence and traced the San Andres equivalents at the east margin of the Midland Basin southwestward and westward in the subsurface to the Glass Mountains and the Delaware Basin. This lengthy subsurface "route" was selected to bypass the poorly known central Guadalupe Mountains area, a principal obstacle to all surface correlations between pre-Capitanian basin and shelf units.

A widely recognized subsurface unit between the San Andres and the Queen formations, the Grayburg formation, was defined by Dickey (1940). His type section is in an oil well in northeastern Eddy County, New Mexico. Recently Moran (1954) has proposed new type sections for the Grayburg and the overlying Queen formations.

Skinner (1946) described the San Andres exposures in the northern Guadalupe Mountains and interpreted seemingly contradictory paleontologic evidence concerning the age of the San Andres and its equivalent units in the Midland Basin. King (1947) took exception to Skinner's paleontologic interpretations. The controversy has not been fully resolved.

Two papers that provided excellent syntheses of the Permian stratigraphy of west Texas and southern New Mexico are a comprehensive paper by King (1942), and an article by Adams and Frenzel (1950) that emphasizes the history of the Capitan barrier reef.

One of the most intensive studies of the Guadalupe Mountains is a work by Newell and his colleagues (1953). The emphasis of this book is on the paleoecology of the Capitan reef complex and associated rocks, but some chapters, especially those concerning Leonardian rocks and the shelf phase of the Guadalupian rocks, contain original contributions on the stratigraphy north of the Texas border.

OBJECTIVES AND PROCEDURE

The objectives of this report are:

1. The study of facies relationships and the establishment of accurate correlations between Permian basin and shelf formations of pre-Capitanian age.
2. Interpretation of the shelf and marginal sedimentary environments.

3. Analysis of the diagenesis of the shelf sediments.

A total of 7 months was spent in field studies of El Paso Gap quadrangle during the summers of 1950-52. Outcrop studies and the tracing of individual beds were emphasized.

The areal geology of the quadrangle was mapped at a scale of 2 inches to 1 mile on an enlargement of the topographic map.

The areas of facies changes received the most intensive study. This inequality of emphasis is reflected on the geologic map (pl. 1), especially in the portrayal of faults. For example, faults of small displacement are mapped in the areas where formations show progressive changes in facies, whereas only major faults are mapped in the northern Brokeoff Mountains.

The Guadalupe Mountains (fig. 1) are not subdivided formally into northern, central, and southern parts. King's report (1948) on the geology of the southern Guadalupe Mountains, Texas, deals primarily with that part of the mountains south of the New Mexico-Texas boundary. In this report, the term "central Guadalupe Mountains" refers to El Paso Gap quadrangle, plus an adjacent area to the northeast, drained by Last Chance Canyon, an area to the east around Queen, and the mountains between the west border of the quadrangle and the Salt Basin.

Laboratory work included spectrographic analyses, differential thermal analyses, staining tests, microscopic studies of thinsections and peels, and studies of silicified fossils leached from limestone. The names of rock colors used in this report are those of the Rock Color Chart distributed by the National Research Council (Goddard et al., 1948). The terms "dolomite," "dolomitic limestone," and "limestone" refer to uncrushed rocks distinguished by different degrees of reaction with cold dilute hydrochloric acid. Dolomite does not effervesce, whereas limestone effervesces readily, and dolomitic limestone reacts slowly.

ACKNOWLEDGMENTS

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Parts of fossil collections were identified by Roger Batten and Ellis Yochelson (gastropods); Robert Finks (sponges and corals); R. V. Hollingsworth, H. **L.** Williams, J. W. Skinner, and G. Marrall (fusulinids); A. K. Miller (cephalopods); N. D. Newell (pelecypods); Frank Stehli (brachiopods); and Heinrich Toots (bryozoans). Karl Turekian made the spectrographic analyses of carbonate rocks.

Many thanks are due the ranchers of the El Paso Gap area for their wholehearted cooperation and hospitality.

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Stratigraphy

For descriptive purposes, the stratigraphy is divided into a southern and a northern sequence. One characterizes the northern half of El Paso Gap quadrangle and the adjoining mountainous region to the north, whereas the other sequence characterizes the southern half of the quadrangle and the adjoining part of the southern Guadalupe Mountains.

THE SOUTHERN SEQUENCE

VICTORIO PEAK MEMBER OF THE BONE SPRING FORMATION

North of Bone Canyon, which cuts the west front of the Guadalupe Mountains 8 miles south of El Paso Gap quadrangle, King (1948, p. 17) reported that the black limestones of the Bone Spring formation are replaced laterally by "a succession of thick-bedded, gray limestones 800 feet thick, which are the northward equivalent of the upper part of the black limestones." The light-colored beds, some of which are from 50 to 100 feet thick, are known as the Victorio Peak member. This unit is restricted to a belt several miles wide along part of the Delaware Basin margin. King (1948) and Newell et al. (1953) interpreted these rocks as having been formed from a broad, low bank of calcareous sand.

The contrast between the massive light-colored carbonate rocks of the Victorio Peak unit and the overlying shaly dark-gray limestone of the Cutoff member is an excellent stratigraphic datum for tracing the associated lithologic tongues through the complex of rapidly changing facies.

The exceptionally thick beds in the Victorio Peak member probably do not persist as far north as the New Mexico border. Although the base of the unit is concealed north of the Texas line, King (1948, p. 164) measured 543 feet of the Victorio Peak member on the west slope of Cutoff Mountain, just north of the State line, and reported no beds over 7 feet thick. The upper part of the unit is exposed in many places along the west front of the mountains for several miles north of the State line. These beds are light gray to light olive gray, with chert nodules common in some places. The upper 50 feet of the beds contains abundant silicified crinoid columnals and brachiopods.

A good exposure of 340 feet of Victorio Peak beds occurs in the NE¼ sec. 12, T. 26 S., R. 19 E., where West Dog Canyon cuts a narrow horst. The lower 50 feet of section consists of an alternation of thin beds of grayish-orange fine-grained sandstone with thicker beds of dense very light-gray dolomite. This sequence is presumably equivalent to the sandstone-bearing "middle division" of King's Cutoff Mountain section. The overlying 290 feet of section is composed of light olive-gray to medium light-gray dolomite and limestone in beds 2 feet and less in thickness. Some beds have numerous chert nodules, but at least half the total thickness of carbonate rock is devoid of chert. Beds with abundant fossil molds and scattered silicified fossil fragments comprise the upper 50 feet of the section.

To the north, exposures of the upper part of the Victorio Peak and lower Cutoff members occur in Panther Canyon, near the mouth of West Dog Canyon, and near the mouth of Chosie Canyon (see pl. 1). The Victorio Peak member is represented by ledge-forming medium-gray beds, 1 to 7 feet thick, that closely resemble the beds in the upper part of the unit farther south. The thickest of the northern sections is in a narrow horst cut by Panther Canyon in the SW¼NE¼ sec. 35, T. 25 S., R. 19 E. At this locality, 150 feet of upper Victorio Peak dolomite, composed predominantly of bioclastic sediment, is exposed. Fusulinids are abundant in the lower 100 feet, but in the upper 50 feet, fragments of brachiopods and crinoids are numerous. Large chert nodules are common in the lower beds of this exposure, but silicified fossils are rare; in the upper two-thirds of the section, the reverse is true.

The lower part of the outcrop exposed in lower Chosie Canyon (pl. 3B) is mapped as the Victorio Peak member for several reasons. Its top is approximately the same distance below the base of the Grayburg-Queen sequence as is the top of the Victorio Peak member farther south. Furthermore, it is ledge forming, includes some 7-foot-thick beds, and in upper ledges has a silicified fossil assemblage characterized by the brachiopods *Dictyoclostus* and *Neospirifer,* corals, and euomphalid gastropods, as is the case farther south. Aside from these features, the section is indistinguishable from the lower San Andres formation as exposed in Big Dog Canyon, suggesting that the upper part of the Victorio Peak member grades laterally into the lower San Andres formation.

CUTOFF MEMBER OF THE BONE SPRING FORMATION

King (1948) designated some 233 feet of shale and thin-bedded limestone which overlies the Victorio Peak member in the west front of the Guadalupe Mountains, just north of the New Mexico-Texas border, as the type section of the Cutoff member of the Bone Spring limestone. He found that the Cutoff member is absent over the Bone Spring flexure, 6 miles south of the Texas border, as a result of intra-Permian erosion, but is present basinward from the flexure. Newell et al. (1953) disagreed with King as to the specific part of the southern section correlated with the type Cutoff.

In exposures along Cutoff Ridge, north of the type locality at Cutoff Mountain, the Cutoff member consists of dark-gray limestone in layers mostly less than 6 inches thick. The limestone beds are separated by thin beds of black papery shale, and 1-inch-thick layers of black chert are common. The limestones are fetid and characteristically weather light yellowish gray. A few beds of grayish-orange siltstone with calcite-lined vugs also occur in the Cutoff member.

Chonetid brachiopods and gastropods, scattered through the limestones, are the most common fossils of the Cutoff member. In a few places massive ledges of light olive-gray limestone contain relatively diverse faunas.

Several miles north of the State line, the Cutoff member is exposed in West Dog Canyon near the southern limit of the San Andres transition facies. The 100 feet of beds immediately overlying the Victorio Peak limestone compares closely with the typical Cutoff farther south. The upper part of the Cutoff member differs, however, from the type Cutoff Ridge exposures. The carbonate is dolomite rather than limestone and contains scattered, irregular masses of secondary silica. Quartz siltstone is common in some parts of the section, and small exposures of bedded gypsum were observed. Bedded gypsum was not seen in the Cutoff at other localities in the central Guadalupe Mountains. Secondary gypsum has been reported along Cutoff exposures of the Sierra Diablo by Newell et al. (1953, p. 21), which indicates that there may be bedded gypsum in the member in that area. Newell et al. suggest (p. 27) that the Cutoff member may be equivalent to the gypsiferous uppermost Yeso of the shelf phase, but evidence discussed below suggests that this correlation is not valid.

The transition of the Cutoff member into the lower San Andres formation takes place without an abrupt change. The distinctive colors, bedding, odor, and fossils of the type Cutoff are recognizable farthest north in the lowermost beds of the Cutoff sequence and occur in the lower San Andres formation as far north as the mouth of Chosie Canyon. The upper part of the Cutoff member passes into middle San Andres beds 5 or 6 miles farther south.

CHERRY CANYON TONGUE

The lower 200 feet of the Cherry Canyon sandstone spreads far shelfward from the Delaware Basin and is the only part of the 4,000-foot-thick Delaware Mountain group which reaches the central Guadalupe Mountains. In the Delaware Basin the group is made up of three formations; from oldest to youngest, they are the Brushy Canyon, Cherry Canyon, and Bell Canyon. The Bell Canyon formation, composed mainly of sandstone, passes into carbonate deposits at the margin of the basin, south of El Paso Gap quadrangle. The same is true for the entire Cherry Canyon formation except the lower portion. The underlying Brushy Canyon sandstone pinches out by overlap in the Guadalupe Mountains, south of the New Mexico line (King, 1948, p. 28). Thus the Cherry Canyon sandstone tongue rests unconformably on the Cutoff member in the Brokeoff Mountains. The two units are composed largely of nonresistant strata, so that the contact is covered on many slopes, and an unconformity was not recognized between the two units in El Paso Gap quadrangle.

The Cherry Canyon tongue is composed predominantly of soft irregularly bedded arkosic sandstone which is typically yellowish gray; other colors, however, are common, especially light brown and light greenish gray. Included beds of shale are light blue green, a very distinctive color in Brokeoff Mountains exposures, where grays and browns predominate.

Some beds within the sandstone are characterized by small, irregular masses of secondary silica, and in some cases the silica appears to line cavities, possibly molds of fossils. The Cherry Canyon tongue, unlike the shelf sandstones, contains many fossils; echinoid spines, fusulinids, sponges, and brachiopods are most common. Most of the fossils are either silicified or are preserved as molds. Fibers of the root tufts of siliceous sponges are distinctive fossils, which were not found in any other unit.

Primary structures are common in the upper part of the Cherry Canyon sandstone tongue. They include small reefs, channel fillings up to 20 feet thick, and large-scale crossbedding. These structures probably are indicative of deposition in shallow water.

The northward transition from sandstone to carbonate rocks takes place first in the upper part of the Cherry Canyon tongue, so that the upper beds are predominantly carbonates throughout much of the area studied. The medium light-gray color and fusulinid-bearing chert nodules are remindful of lower San Andres strata farther north. These rocks, however, are separated from the typical San Andres shelf facies by a 1-mile-wide transition belt of atypical dolomitic limestone. Furthermore, evidence discussed below indicates that the upper part of the Cherry Canyon tongue is equivalent to the upper San Andres and the lower Grayburg formations rather than to the cherty lower San Andres.

GRAYBURG-QUEEN SEQUENCE

On the west fault scarp of the Guadalupe Mountains, a few miles south of the Texas border, the Cherry Canyon sandstone tongue is separated from the base of the Capitanian shelf deposits by 1,200 feet of massive dolomite. King (1948) designated this sequence as the Goat Seep limestone. He recognized that it was part of the basin-margin phase and equivalent to most of the Cherry Canyon sandstone of the basin phase. Newell et al. (1953) emphasized the reeflike attributes of the upper half of the sequence and restricted the name Goat Seep to the upper part, proposing that the lower, thick-bedded half of the sequence be called the Getaway formation, whose type section is to the south.

The Getaway loses its distinctive, thick-bedded character near the Texas-New Mexico border. North of the border, the equivalent stratigraphic unit forms the lower half of the Grayburg-Queen shelf sequence.

The upper half of this sequence is the back-reef equivalent of the Goat Seep reef.

The lower half of the Grayburg-Queen sequence is composed largely of very light-gray dolomite but also includes thin, discontinuous quartz sandstone beds.

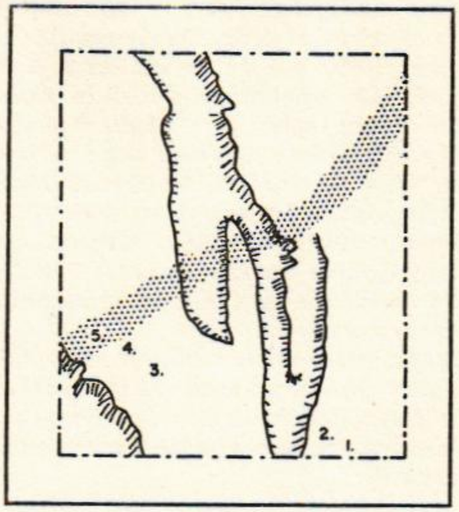
In the southwestern quarter of El Paso Gap quadrangle, a 75-foot-thick section of interbedded dolomite and moderate orange-pink to light-brown medium-grained sandstone forms a distinctive basal member of the Grayburg formation. Some of the sandstone beds contain many burrow fillings, whereas others contain scattered gypsum fillings of cavities once occupied by fusulinids, gastropods, and echinoid spines. The sandstone beds of this basal member seem to be limited to the outer margin of the shelf and pass into dolomite within a short distance north of the limit of the underlying Cherry Canyon tongue (fig. 3).

Thin beds (less than 10 inches thick) of conglomerate associated with sandstone layers were observed at several localities, mostly within the basal Grayburg member, although not at the base of the unit. The conglomerates are composed of angular pebbles of sandstone and dolomite of local origin.

A massive ledge of mottled medium light-gray dolomite forms a distinctive marker above the contact between the Cherry Canyon tongue and Grayburg. This ledge ranges from 8 to 30 feet in thickness, is homogeneous, and appears massive, although weathered surfaces locally reveal faint bedding lines. At the base the ledge is crossbedded and grades into the underlying sandstone.

A distinctive unit in the Grayburg-Queen sequence, noted at several localities in the southwestern quarter of El Paso Gap quadrangle, is composed of gypsum, soft siltstone, and dolomite. The beds are nonresistant and in most places covered. The best exposures are in narrow fault blocks cut by South Tank Canyon, at the western base of Big Ridge (sec. 29, T. 25 S., R. 20 E.). Here the section is composed principally of soft sandstone and thin-bedded dolomitic calcilutite. Some of the calcilutite beds contain numerous empty fossil burrows one-eighth inch in diameter and several inches in length. Other beds have surfaces covered by crisscrossing, straplike casts, one-fourth inch wide, of undetermined origin. Some beds of dolomite are flecked with pores, and some contain crystals of gypsum several inches long. Oolitic layers are present; some show crossbedding, as do many of the quartz sandstone layers. Some sandstone surfaces are rippled, and all the sandstone and siltstone layers are bright colored.

Beds of similar character crop out at two other localities. One is in a fault block, and the position of the interval relative to the base of the Grayburg formation is unknown. This exposure is one-half mile southwest of El Paso Gap (SE¼SW¼ sec. 32, T. 25 S., R. 21 E.). Varicolored shaly siltstone, with interbedded dolomite, is exposed in the



San Andres transition facies (stippled) in El Paso Gap quadrangle. The belt is parallel to the Capitan barrier reef, exposed at locality no. 1. Other numbers locate reefs of different ages described in the text.

Figure 3

stream cut, overlain by at least 10 feet of bedded gypsum, which forms the slope at the base of the small hill. Solution of part of the same layer has formed a small cave at the north end of the adjacent hill. The gypsum section exposed on the walls of the cave is interbedded with thin layers of dolomite and shale.

Poor exposures of similar strata crop out in gullies north of the Berlin tank (NE¼ sec. 7, T. 26 S., R. 20 E.). The upper and lower limits are difficult to determine, but the rocks consist of at least 50 feet of brightly colored siltstone, gypsum, and porous dolomite. The sequence is about 150 feet above the top of the Cherry Canyon tongue.

GOAT SEEP REEF

The Goat Seep reef, as defined by Newell et al. (1953), is exposed in North McKittrick Canyon in the central Guadalupe Mountains' and in the west fault scarp of the southern Guadalupe Mountains. These two localities are on the trend of the basin margin, along which the Goat Seep reef formed a barrier.

In North McKittrick Canyon, the abrupt change from bedded to nonbedded rock takes place one-half mile from the head of the canyon.

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1. Figure 26 of Newell et al. (1953, p. 43) gives the erroneous impression that the Goat Seep reef is exposed in Devil's Den Canyon. Section 1 of that figure should be labelled "North McKittrick Canyon" rather than "Devil's Den Canyon." The Devil's Den section appears in the figure as section 15.

The reef rock is medium light-gray to very light-gray dolomite containing many clusters of calcite crystals. Poorly preserved sponges, corals, and brachiopods are present but are not uniformly distributed through the rock. Much breccia overlies the reef rock in some areas, probably having been derived from higher parts of the reef a short distance to the southeast. The shoreward margin of the reef is characterized by cavity fillings as much as several feet in diameter. Many of the cavities were filled largely by fusulinid tests now represented by molds.

At several places in North McKittrick Canyon, basal exposures of the Goat Seep show distinct bedding surfaces. The beds have a steep primary dip and originated as beds of talus which flanked the reef and eventually were overgrown by it.

The Shattuck member, or upper sandstone unit of the Queen formation, is approximately equivalent to the highest part of the Goat Seep reef as mapped in North McKittrick Canyon. Newell et al. (1953) report the same correlation on the west face of the mountains several miles south of the Texas border.

CAPITAN REEF

Outcrops of the Capitan reef occur along the southeast front of the Guadalupe Mountains for 35 miles northeast from El Capitan, and for a much shorter distance on the west front of the mountains. In El Paso Gap quadrangle, the reef exposures are limited to North McKittrick and Big Canyons, where the Capitan formation includes nonbedded reef rock and bedded, reef-derived talus. The formation is composed of very light-gray limestone, some of which is recrystallized; fossils are moderately well to poorly preserved.

During deposition of the Capitan limestone, reef growth was generally more rapid on the basinward margin of the reef than at the top. As a result, the exposures of the formation in North McKittrick Canyon are of gently dipping talus beds several miles wide and several hundred feet thick.

A detailed discussion of the Capitan limestone, based in part on observations in North McKittrick and Big Canyons, is given by Newell et al. (1953), whose study was in part concurrent with this investigation. Thus, the writer did not make an extensive independent study of the formation.

THE NORTHERN SEQUENCE

YESO FORMATION

The oldest shelf deposit exposed in El Paso Gap quadrangle is the Yeso formation. The formation is well exposed in central New Mexico, where Lee (1909) reported 1,000 to 2,000 feet of interbedded sandstone, shale, limestone, and gypsum in which the elastic deposits vary in color from gray to red. Lang (1937) reported that the Yeso formation ranges in thickness from 600 feet to 2,000 feet and noted gastropods in some of the black limestones.

Skinner (1946, p. 1863-1865) traced the Yeso formation from the southern Sacramento Mountains southeastward toward the Delaware Basin along the east wall of Big Dog Canyon. He noted that southward there are more dolomitic limestones, and that the shales become more gypsiferous and gray.

The east wall of Big Dog Canyon is made up of progressively younger beds toward the south, so that the Yeso formation is exposed for not more than a mile in the northern part of El Paso Gap quadrangle. Beds of equivalent age crop out in the southwestern part of the quadrangle but are of different facies and are assigned to formations of the southern sequence.

About 200 feet of the upper part of the Yeso formation is exposed at the northern boundary of El Paso Gap quadrangle. Light-gray to light olive-gray thin-bedded dolomites and limestones make up most of the sequence. Thin intercalations of shale, grayish-yellow siltstone, and gypsum also occur, and chert nodules are numerous in some of the dolomites. Recognizable fossils are absent except for abundant crinoid columnals in a few beds of calcarenite, and poorly preserved fusulinids, which are restricted to a few thin layers. A few dolomitic limestone beds include thin layers of coarse &Mite, with oöids about 2 mm in diameter.

The Glorieta sandstone, a persistent unit in central New Mexico, where it overlies the Yeso formation, is absent in the central Guadalupe Mountains. According to Willis (1929, p. 1009), the Glorieta sandstone is nearly uniform over wide areas and can be traced eastward more than halfway across the Texas Panhandle, maintaining a thickness of 500 feet throughout this distance.

Skinner (1946, p. 18634864) found 25 feet of sandstone at the top of the Yeso formation east of Pinon, New Mexico. This sandstone thins southward to only 10 feet in the east wall of Big Dog Canyon, 3 miles north of El Paso Gap quadrangle. He concluded that the Glorieta sandstone grades into Yeso-type beds.

Evidence presented below indicates that the Yeso formation changes in facies in the subsurface and passes into the Bone Springs limestone of Leonardian age.

SAN ANDRES FORMATION

Lee (1909) named the San Andres limestone for exposures in the San Andres Mountains of south-central New Mexico. At the type locality, the formation is 600 feet thick, but the upper part has been removed by recent erosion. However, nearby oil tests penetrated only 650 to 700 feet of the San Andres formation beneath Triassic red beds (Kottlowski et al., 1956).

Eastward from the type locality, in the subsurface, and southward in the Guadalupe Mountains, strata younger than those of the type section are included in the formation. The problem is to define the upper limit of the formation to the south, where a more complete shelf section is exposed, and in the subsurface to the northeast and east.

Prior to 1940, the interval between the Yeso and the Queen sandstone generally was called the San Andres formation. Since 1940, the concept of an intermediate unit between the San Andres formation and the Queen sandstone has been widely accepted (Dickey, 1940). The change must be considered when comparing estimates of the thickness of the San Andres formation published before 1940 with those of recent years.

Other factors have contributed to inaccurate estimates of the thickness of the San Andres formation in the subsurface. Woods (1940, p. 33) mentioned the difficulty of determining the top of the formation in some areas. As King (1942, p. 692) pointed out, the limestone-evaporite contact, which some geologists regard as the top of the San Andres sequence, is not a time-stratigraphic horizon. The age of the contact varies from place to place. According to Jones (1953), the term "San Andres" is used broadly in the subsurface for the predominantly carbonate section above the Glorieta and is equivalent to the Cherry Canyon formation of the Delaware Basin.

The subsurface distribution of the San Andres formation eastward and northward from the central Guadalupe Mountains is well known from oil tests. It consists almost entirely of marine carbonates as far north as Roswell, 95 miles northeast of El Paso Gap. Blanchard and Davis (1929, p. 971) reported a thickness of 1,200 feet near Roswell. This figure, however, presumably includes several hundred feet of section which would now be assigned to the Grayburg formation.

Northward and northeastward from Roswell, the carbonates progressively pass into red beds and evaporites. Eighty miles north of Roswell, only the lower 275 feet of the formation is predominantly dolomite, according to Woods (1940, p. 33). Seventy miles farther northeast, in the Plainview Basin of northwestern Texas (Jones, 1951, p. 346), the formation is 1,100 feet thick and changes within a short distance from predominantly dolomite to predominantly evaporites and red beds.

Lewis (1941, p. 86) studied the subsurface San Andres sequence in the Midland Basin. He recognized an upper dolomitic member and a lower sandy member over most of the basin. In the Big Lake field of Reagan County, Texas, the upper division is sandy and about 600 feet thick, whereas the lower division consists of 1,000 feet of sandstone and shale. At the rim of the Central Basin Platform in west-central Upton County, Texas, the San Andres sequence thins to 1,450 feet, and both divisions appear to grade into dolomite. Page and Adams (1940, p. 57) described a disconformity at the top of the San Andres sequence in the Midland Basin and noted that it is more pronounced around the marginal areas than in the center of the basin.

North of the Central Basin Platform in Cochran County, Texas, Lewis (1941, p. 96) described the San Andres section as 1,300 feet thick, the upper part consisting largely of anhydrite with thin dolomite beds.

A line from the southwest to the northeast corners of El Paso Gap quadrangle roughly approximates the strike of facies changes south of which the San Andres formation is not recognizable (fig. 3). North of this line, the formation is exposed in the east scarp of Big Dog Canyon, in many of the ridges of the Brokeoff Mountains, and in part of Last Chance Canyon.

The fault scarp along the east side of Big Dog Canyon in the central Guadalupe Mountains steepens noticeably above the Yeso formation. Skinner (1946, p. 1864) examined the scarp as far south as section 3, T. 24 S., R. 21 E., just inside El Paso Gap quadrangle. At this locality, he divided the San Andres formation into a lower cherty member and an upper noncherty member. These two members can be traced several miles southward along the scarp until the lower member is concealed beneath alluvium and talus.

Three detailed sections were measured by the writer along this scarp. Although outcrops on the mesa east of this scarp dip a few degrees east, the outcrops at the scarp show great dips ranging from 5° to 33° E. This folding is due to differential movement along fault slivers associated with the major fault immediately west of the cliff. These faults provide potential sources of error in measurement of stratigraphic intervals. Furthermore, on that part of the scarp between the north border of El Paso Gap quadrangle and a point 3 miles farther north, the top of the lower San Andres appears to drop on the scarp from north to south, producing a thicker section of San Andres to the south. This appears to be the effect of a "scissors" fault rather than convergence of section.

The basal 40 feet of the San Andres above the gypsiferous Yeso formation consists of noncherty very light-gray dolomitic limestone similar to the carbonate beds of the Grayburg-Queen sequence. Some beds have a microcrystalline texture, and others are composed of irregular laminations. Some thin layers are characterized by abundant small pisolites. The unique aspects of these beds probably reflect depositional environment transitional from the hypersaline Yeso sea to the more normal marine conditions of deposition of the San Andres formation.

Above the light-colored beds are about 360 feet of cherty light olive-gray limestone and dolomitic limestone in tabular beds 4 to 12 inches thick. The chert is medium light gray and usually contains fusulinids, corals, productid brachiopods, fenestrate bryozoans, and crinoid columnals. In some layers, silicified brachiopods and corals separate from chert nodules. Other layers are characterized by numerous fusulinid molds, and calcarenite beds are present. Chert nodules are not equally abundant in all beds. They are mostly parallel to the bedding, but some beds are notable for elongated, anastomosing nodules without apparent orientation. A few beds characterized by closely spaced holes occur in the lower part of the San Andres formation. The holes are from one-half inch to 4 inches in diameter and are easily mistaken for chert nodules at a distance.

Above the cherty beds there is about 210 feet of light olive-gray beds flecked with fusulinid molds. The beds include limestone, dolomitic limestone, and dolomite. On fresh surfaces many of the fusulinid molds are partially filled with secondary calcite. Crinoid columnals are sparse, and other fossils are extremely rare. The beds of this upper member are thicker than the cherty beds below and form angular ledges which make steep slopes. The weathered surfaces are pitted by enlarged fusulinid molds, which are not equally abundant throughout. Some ledges are of dolomitic calcarenite, with few or no fusulinids.

The sequence above the fusulinid beds of the Big Dog Canyon scarp is lighter in color and lithologically different. The boundary between these two parts of the section is recognizable by the color change even at a distance. Skinner's photograph (1946, fig. 7) clearly shows the boundary. He included the light-colored beds in the San Andres formation, but the writer found the contact between dark and light rock useful in mapping, and designated the contact as the top of the San Andres formation. The light-colored beds are the highest distinctive and persistent stratigraphic unit below the Shattuck member (Newell et al., 1953) of the Queen formation. The thickness of strata separating this horizon and the top of the Shattuck member compares favorably with that for the Grayburg-Queen interval reported in the subsurface (Skinner, 1946) and at the surface (Moran, 1954). Furthermore, this unit is probably not far below the top of the Cherry Canyon sandstone tongue in the southern sequence (pl. 6D).

The San Andres formation, as restricted, is about 570 feet thick along the east wall of Big Dog Canyon. Published estimates of the thickness of the San Andres formation in the Guadalupe Mountains are much greater. Willis (1929, p. 1021) gave a thickness of 1,000 to 1,100 feet, and Dickey (1940, p. 43) a thickness of 1,250 feet. The discrepancy between these two estimates is even more significant in view of the fact that Willis did not recognize an intermediate unit between the San Andres formation and the Queen formation, whereas Dickey presumably took into account the Grayburg formation, for which he listed 300 feet.

The San Andres formation frequently is cited as being over 1,000 feet thick in the subsurface (Skinner, 1946). The top of the formation seems to be drawn at the contact between a carbonate sequence and an overlying section of sandstone and/or evaporites. No attempt seems to be made to subdivide the carbonate sequence in the subsurface, but the carbonates of the upper San Andres and Grayburg, as described herein, appear sufficiently distinct to be differentiated in well cuttings. The resulting boundary may be a true stratigraphic horizon, whereas the age of the carbonate-evaporite contact probably varies from place to place and the lateral persistence of sandstone beds (in this part of the lagoonal phase) is known to be erratic.

The change in lithologic character and color which marks the upper limit of the San Andres formation as recognized in this report is well defined in the Brokeoff Mountains in the northwestern quarter of El Paso Gap quadrangle. For example, the color change can be seen along the west wall of Big Dog Canyon (T. 24 S., R. 20 E.) from the opposite side of the canyon. Attempts, however, to divide the San Andres into two members based on presence or absence of chert were not always successful. In this area, chert nodules are scattered through the upper part of the formation. If the upper limit of the chert-bearing rock were a meaningful stratigraphic datum, the upper member would be missing entirely in some places and very thin in the rest of the area. However, the sporadic occurrence of the nodules in the upper part of the formation suggests that their presence or absence is not a reliable criterion for subdividing the San Andres formation; thus, the formation was mapped as a single unit.

The formation may be divisible into a lower member containing abundant chert and an upper member with relatively few and scattered chert nodules. Several sections measured in the Brokeoff Mountains show such a division. It is impossible, however, to be sure that the upper limit of the abundant chert defines a single stratigraphic horizon, because the upper limit is near the bottom of the exposures and its relationship to the base of the formation is unknown.

At several scattered localities in the central Guadalupe Mountains, a difference of 5 or 6 degrees dip exists between the lower cherty beds and the upper part of the formation. This angular relationship is most apparent from a distance. On close examination, an erosional break between the two parts of the section was found only at Last Chance Canyon, as discussed below. Elsewhere, the lower cherty beds grade imperceptibly upward into a gradational sequence, several feet thick, which lacks distinct stratification. Accurate measurement of the attitude of the beds on either side of the contact is difficult because the beds are not sharply defined, and because an angular relationship is usually recognizable only where broadly exposed on a cliff. The angular relationship is between very cherty beds below and sparsely cherty or noncherty beds above, except in an exposure on the south wall of Panther Canyon (SE¼ sec. 35, T. 25 S., R. 19 E.), where the beds below the contact contain only scattered chert nodules.

The thickness of the upper, noncherty part of the San Andres formation, as determined in the north-central Guadalupe Mountains, was used to draw an isopach map (pl. 6B). This map shows that the "upper member" of the San Andres formation is thickest in the northwestern part of El Paso Gap quadrangle and thins toward the Delaware Basin.

East of Big Dog Canyon, only one canyon cuts Queen Mesa deeply enough to expose the San Andres formation; this is Last Chance Canyon in the extreme northeastern corner of El Paso Gap quadrangle. There the section includes a maximum of 100 feet of noncherty San Andres strata overlying cherty beds. This area is in the zone of transition between basin and shelf deposits of San Andres age, as described below.

Subsurface information in the eastern part of El Paso Gap quadrangle was provided by water wells. Five wells encountered water in a "very hard black rock," which caused difficulty for the drillers. Drill cuttings of chert containing *Parafusulina* may still be seen at the Hamm tank well. These facts suggest that the "hard black rock" is the cherty lower San Andres. If this is the case, the altitudes of the five well bottoms[2] define the surface of a homocline dipping northeastward. A line connecting the Hamm and Thayer wells is nearly parallel to the dip of the homocline in that area, which is 42 feet per mile. If the same line and dip are projected toward the northeast, Last Chance Canyon is intersected at an altitude (5,175 feet) that coincides with the top of the lower member of the San Andres formation.

The two McCollaum wells are several miles south of the predicted southern limit of the San Andres formation. Nevertheless, the altitudes of the bottoms of the two wells fit the homoclinal structure. This may be coincidence, or the wells may have encountered cherty limestones of the Cutoff member (table 1).

The chemical composition of typical samples from the San Andres formation is given in Table 2.

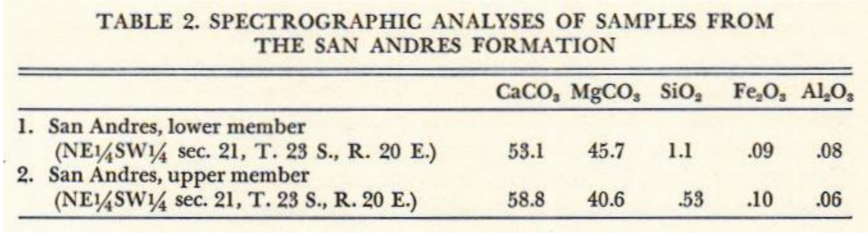

TABLE 2. SPECTROGRAPHIC ANALYSES OF SAMPLES FROM THE SAN ANDRES FORMATION

	$CaCO_3$	$MgCO_3$	SiO_2	Fe_2O_3	Al_2O_3
1. San Andres, lower member (NE¼SW¼ sec. 21, T. 23 S., R. 20 E.)	53.1	45.7	1.1	.09	.08
2. San Andres, upper member (NE¼SW¼ sec. 21, T. 23 S., R. 20 E.)	58.8	40.6	.53	.10	.06

SAN ANDRES TRANSITION FACIES

The transition between the San Andres shelf facies and the equivalent basin deposits is well shown in the lower part of West Dog Canyon (pl. 2). Correlation between the adjacent sections across a narrow transition belt a mile or so wide is difficult because of: (1) absence of distinctive beds which have lateral continuity, (2) diagenetic obliteration of textural details, and (3) displacement along several faults which cut the east wall of the canyon.

The full section of San Andres transition beds is not exposed, however, in West Dog Canyon. For the most part, unbroken sequences

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[2] The well locations are: Hamm tank, 688 feet deep (sec. 4, T. 25 S., R. 21 E.); Thayer ranch, 410 feet deep (sec. 23, T. 24 S., R. 21 E.); Shattuck ranch, 612 feet deep (sec. 10, T. 25 S., R. 21 E.); John McCollaum ranch, 650 feet deep (sec. 25, T. 25 S., R. 21 E.); and the McCollaum ranch in Carlsbad Caverns West quadrangle, 550 feet deep (sec. 20, T. 25 S., R. 22 E.).

exposed in the canyon are less than 500 feet thick, of which the upper 50 to 100 feet is of the Grayburg formation. Below the Grayburg, at least the upper 150 feet is equivalent to the Cherry Canyon sandstone tongue. The lower beds of the exposures, plus additional concealed strata, are equivalent to the Cutoff member of the Bone Spring formation. These lower exposures consist of light-gray dolomitic limestone in 1-foot-thick beds. Chert nodules, irregular patches of impure chert, and fusulinid molds are common in some strata. Other beds are very sandy and weather grayish orange. A few poorly preserved sponge bioherms, 2 to 10 feet thick, occur in this part of the section.

Higher in the section the beds are more massive. The rock is medium light-gray dolomite, much of which has a vestigial detrital aspect, but primary texture is not preserved. Many of the massive, irregular layers are distinctively mottled on weathered surfaces. Fusulinid molds occur in scattered lenses at the southern margin of the transition zone and are progressively more abundant toward the north in the upper part of the section.

In the southern part of the transition area, the upper 250 feet of the transition beds on the east side of West Dog Canyon contains several large exposures of reef-derived rock. The masses are difficult to distinguish from surrounding nonreef rock. The massive irregularly bedded dolomite which forms much of the walls of West Dog Canyon for a mile north of Snow tank originated as clastic talus rather than as wave-resistant reef rock.

Several primary structures, noted on the west wall of the canyon, consist of sequences of beds with diverging surfaces. The structures are interpreted as beds of detritus which accumulated on the basinward flanks of nearby reefs to the northeast.

The upper part of the lateral transition between the Cherry Canyon sandstone tongue and the San Andres dolomite is exposed in two canyons which cut the west front of Big Ridge (SE% sec. 32, T. 25 S., R. 20 E.), and in one canyon which cuts the east front (NE% sec. 4, T. 25 S., R. 20 E.). In the latter, 120 feet of massive light-gray sandy dolomite is exposed below the Grayburg. Equivalent beds in the next exposure to the south are composed of the Cherry Canyon sandstone. The lower part of the transition beds is exposed in canyons on the west side of Big Ridge, where 300 feet of the transition sequence is exposed. This section resembles the one described for West Dog Canyon. The lowest beds are dense yellowish-gray dolomite, with small, irregular inclusions of secondary silica. The major part of the section, however, consists of light-gray dolomite in thick layers, many of which were calcarenite. Some beds have abundant fusulinid molds, and others contain chert nodules. The numerous diverging bedding surfaces of the beds in the upper 100 feet suggest that they were detrital beds flanking reefs now concealed in the graben to the west.

The San Andres formation is exposed in Last Chance Canyon. The lowest beds are lithologically unlike the San Andres farther west at the edge of the mesa. A massive ledge of dense medium-gray limestone, exposed at the canyon bottom, is very nodular and contains scattered silicified brachiopods, corals, cephalopods, and crinoid fragments. Nonresistant silty beds overlie the ledge and are in turn overlain by cherty dolomite similar to the lower San Andres farther west. An upper member of light-gray dolomite, flecked with fusulinid molds but lacking chert, occurs both in Last Chance Canyon and at the western margin of the mesa. It is only 65 feet thick in the canyon and up to 250 feet thick at the edge of the mesa.

Downstream in Last Chance Canyon, east of El Paso Gap quadrangle, anomalous dips appear in the cherty dolomites. Underlying and overlying beds, including the noncherty upper member of the San Andres, are unaffected. Some of these intraformational folds resulted from compaction of fine-grained carbonate sediments over rigid masses of probable reefs. The best exposures of the intraformational folding are more than a mile east of El Paso Gap quadrangle, in SW 1/4 sec. 32, T. 23 S., R. 22 E.

Last Chance Canyon crosses the San Andres-Cherry Canyon lateral transition obliquely; therefore, the apparent width of the belt in the canyon is greater than the true width. A section on the north wall of the canyon opposite the mouth of Whiteoaks Canyon (1.8 miles east of the northeast corner of El Paso Gap quadrangle) shows the basin-ward transition from carbonate to sandstone. Here only 25 feet of the upper member of the San Andres separates the Grayburg from the cherty San Andres. The cherty beds are 180 feet thick and differ from the more typical San Andres exposures farther upstream in color, fossil content, and amount of clastic fragments. Instead of the typical light olive gray, these beds are yellowish gray to grayish orange. Fossils are common, especially brachiopods, crinoid fragments, and echinoid spines; most are silicified. Many of the carbonate beds are arenaceous, and numerous beds of grayish-orange sandstone with spotty secondary silicification and scattered fossils are interbedded with the carbonate.

Several unusual beds are included in the underlying 150 feet of section. Shaly limestones containing trilobites, snails, and fusulinids are unlike anything observed elsewhere in El Paso Gap quadrangle, and a grayish-orange limestone bed, 15 inches thick, yielded an exceptionally diverse fauna. A few thin beds of sandstone occur in the section, as well as two massive ledges of medium-gray nodular limestone. One of the ledges is the massive bed described above as the base of the section upstream. The abrupt shelfward pinchout of this ledge is shown in several places along the north wall of Last Chance Canyon and in northern tributary canyons. Therefore, the lower, atypical beds in Last Chance Canyon may grade laterally and pinch out to a shelf facies, probably part of the lower San Andres, not far to the north.

The truncated compaction folds described above suggest subaqueous erosion followed by deposition of the youngest San Andres beds. Although this is the only unconformity clearly distinguishable at the surface in this part of the stratigraphic section, there have been numerous reports of an unconformity between the San Andres and the Gray-burg in the subsurface. King (1942, p. 703-704) noted reports of such an unconformity in fields in Lea County, New Mexico, in Ector County, Texas, on the Central Basin Platform, and along the south and east margins of the Midland Basin.

In Panther Canyon, at the northern margin of the San Andres transition facies, crossbedded fusulinid tests and channel fillings indicate shallow water conditions; none of these features were observed elsewhere in the San Andres exposures.

The thinner San Andres section at the basin margin in the Last Chance Canyon area, compared with the adjacent shelf section, contrasts with the situation in overlying formations. The basin-margin phase of the Getaway and Goat Seep limestones is 1,200 feet thick (Newell et al., 1953), whereas the shelf phase is less than 900 feet thick.

GRAYBURG-QUEEN SEQUENCE

The beds between the San Andres and Seven Rivers formations consist of dolomite, dolomitic limestone, and sandstone, about 800 feet thick. The proportion of sandstone increases upward. In the northeastern part of El Paso Gap quadrangle, the upper half of this sequence has been removed by erosion. Farther southeast, younger beds are preserved, and sandstone beds, as well as groups of 2 or 3 sandstone beds separated by thin dolomite beds, are abundant. The uppermost sandstone unit, about 100 feet thick, is the most distinctive and is persistent over a wide area. This sandstone is the Shattuck member of Newell et al. (1953).

In the twenties, petroleum geologists referred to the sandstone sequence underlying the Seven Rivers formation as the "Queen sandstone" in the subsurface. Since then, various authors have called this stratigraphic sequence a formation, a member, a "zone," and simply the "Queen sand." The top of the "Queen sandstone" is widely agreed upon, but the base is not. The lower limit is difficult to define because of the progressive downward decrease in the number of sandstone beds. Crandall (1929, p. 940) named the Queen for the sandstones underlying the Seven Rivers formation from "[their] extensive outcrops in the vicinity of Queen Post Office." No thickness was given. Blanchard and Davis (1929, p. 972) referred to the beds near Queen as several lenses of sandstone interbedded with limestone, about 200 feet thick, and placed them at the top of the San Andres formation. Willis (1929, p. 1013) referred to 400 feet of anhydrite and sand between the San Andres limestone and Seven Rivers gypsum as the Queen sand. The Shattuck member may be the equivalent of the "red sand bed" which was recognized in the subsurface as far east as the Texas boundary.

Lang (1937, p. 859) classified the Queen sand as a member of the Chalk Bluff formation, including therein only the upper 60 to 100 feet, the part now termed the Shattuck member. King (1948) mapped this sandstone unit in the southern Guadalupe Mountains and traced it into North McKittrick Canyon, where it pinches out between the Goat Seep and Capitan reefs. King assumed that this sandstone is the same unit exposed on Queen Mesa, but Newell et al. (1953) show about 200 feet of strata separating the two sandstones.

The unbroken depositional sequence between the San Andres and the Seven Rivers formations was divided into two formations by Dickey (1940). He named the lower formation the Grayburg from a well northeast of the Guadalupe Mountains and described it as 300 feet of dolomite and fine-grained sandstone between the San Andres and the Queen formations.

The boundary between the Grayburg and the Queen is difficult to recognize on the surface and in the subsurface. Jones (1953) suggested that the upper sandy zone of the type Grayburg be classed with the Queen. Moran (1954) has proposed new type sections for both the Grayburg and Queen formations. His total thickness of 896 feet is nearly the same as the writer's thickness of composite sections of the Grayburg-Queen sequence (pl. 6C).

The outcrops at Crandall's type locality of the Queen formation are several sandstone beds comparable to the Shattuck member, but with less distinct boundaries. The lower "boundary" of this zone is called the base of the Queen formation by Newell et al. (1953, p. 45). This boundary is difficult to map because other sandstones occur in the section 200 feet below the beds of the type locality. This lower part of the section is exposed on the Shattuck Valley scarp and northeast of the Thayer ranch, in Pine Canyon and Last Chance Canyon. Several of the lower sandstone beds were traced to test their persistence, but none proved continuous over a great distance. The lowest sandstone bed at any locality either grades into carbonate or overlies another sandstone in adjacent areas.

There is no evidence, in the area, of any pronounced interruption in the sequence between the San Andres and Seven Rivers formations. If the *sequence* is mapped as two units, the division is based on the greater amount of sandstone in the upper half of the sequence. Such distinction is difficult in the many fault blocks of the central and western El Paso Gap quadrangle. Therefore, the beds between the top of the Shattuck member and the top of the San Andres were mapped as one unit, called the Grayburg-Queen sequence.

The Grayburg formation has been traced in the subsurface across the Central Basin platform and the Midland Basin to outcrops on the east side of the Midland Basin. Dickey (1940) described the formation as overlain conformably by the predominantly elastic Queen but resting unconformably on the San Andres dolomites and limestones. The Grayburg varies laterally but consists predominantly of gray to pink dolomite interbedded with gray and red sandstone and local gray and green bentonite beds. Dickey reported the thickness as averaging 300 feet at the eastern side of the Midland Basin but varying, owing to the unconformable lower contact.

Page and Adams (1940) reported an angular unconformity separating Grayburg and San Andres beds in the Midland Basin and stated that the Grayburg is less fully developed near the margins of the basin than in the deeper parts. They reported frosted quartz grains to be the only distinctive feature of the Queen sandstones not possessed by the Grayburg sandstones. Dickey (1940), however, mentioned frosted quartz grains in the Grayburg type section.

Northward from the Guadalupe Mountains, the Grayburg carbonates change to evaporites. In a north-south cross-section based on well logs, Skinner (1946, p. 1872-73) portrayed the first appearance of bedded evaporites north of the Guadalupe Mountains in both the Grayburg and Queen formations in north-central Eddy County. To the east, in central Lea County, Woods (1940) reported a few thin beds of anhydrite in the Grayburg and noted that the dolomites grade into anhydrite farther north.

The "Queen sandstone" in the Midland Basin includes the sequence between the highest Grayburg dolomite and the base of the main Whitehorse salt, according to Page and Adams (1940). They describe it as largely fine-grained orange-red sandstone and interbedded anhydrite, which normally thicken toward the center of the basin and are 1,100 feet thick in one well. Farther west, the Queen on the Central Basin platform was described by Dickey (1940) as largely carbonate, with little sand.

The carbonates of the Queen formation grade into evaporites northward from the Guadalupe Mountains in a shorter distance than do the carbonates of the underlying Grayburg formation. Skinner (1946, p. 1870) showed that the Queen consists of 375 feet of interbedded sandstone and evaporites in northeastern Eddy County, whereas the underlying Grayburg is as thick but is made up of sandstone and dolomite.

In the central Guadalupe Mountains, the Grayburg-Queen sequence caps most of Queen Mesa, as well as many of the fault blocks west of the mesa. The top of the sequence is preserved in the southeastern quarter of El Paso Gap quadrangle, but elsewhere in the map area varying thicknesses have been removed by erosion.

The lower part of the sequence is well exposed along Big Dog Canyon. The strata are medium light-gray to yellowish-gray ledge-forming dolomitic limestone. The beds range from ½ to 2 feet in thickness; they are largely bioclastic, although beds of oölite are common. About 150 feet above the base, the ledge-forming bioclastic beds give way to thin-bedded dolomitic calcilutite, very light-gray and irregularly fractured. These upper beds crop out as alternating ledges and covered intervals. Many of the sublithographic beds contain gypsum inclusions about one-sixteenth inch in diameter, or iron oxide nodules from one-eighth to one-half inch long.

The carbonate rock of the Grayburg-Queen sequence is dolomite and dolomitic limestone (table 3). The carbonates change gradually upward in the sequence. In general, the upper beds are finer textured, weather smoother, and contain scattered cavity fillings of gypsum. Several of the upper dolomites and sandy dolomites contain cubic pseudo-morphs, about an inch square, after crystals of pyrite. These weather in relief from the enclosing rock. Thermal analyses by Peggy K. Hamilton and J. Laurence Kulp show the pseudomorphs to be about 65 percent goethite and 25 percent lepidocrocite.

Numerous beds of pisolite occur in the Queen Mesa exposures, with bedding surfaces a mosaic of polygons 1 to 12 inches in diameter, each showing concentric structure. In any one bed, the size of individual polygons is fairly uniform. These structures are believed algal, as presented below. The algal mosaics have not been observed in the lower half of the Grayburg-Queen sequence, although bedding surfaces are not so broadly exposed in the lower part of the section.

TABLE 3. SPECTROGRAPHIC ANALYSES OF SAMPLES FROM THE GRAYBURG-QUEEN SEQUENCE

	$CaCO_3$	$MgCO_3$	SiO_2	Fe_2O_3	Al_2O_3
1. Queen (NW¼ sec. 1, T. 25 S., R. 21 E.)	49.2	46.2	4.0	.27	.44
2. Queen (center of sec. 16, T. 25 S., R. 21 E.)	52.2	46.0	1.25	.49	.10
3. Queen (SW¼ sec. 6, T. 25 S., R. 22 E.)	57.0	42.2	.52	.21	.03
4. Queen (NE¼ sec. 6, T. 25 S., R. 22 E.)	56.6	40.8	2.2	.37	.15
5. Queen (SE¼SW¼ sec. 9, T. 25 S., R. 21 E.)	48.7	43.9	6.33	.49	.73
6. Queen (center of sec. 1, T. 25 S., R. 21 E.)	57.8	33.5	6.35	.56	1.82
7. Queen (NW¼SE¼ sec. 2, T. 25 S., R. 21 E.)	56.6	39.6	2.9	.37	.46
8. Queen (NW¼SE¼ sec. 2, T. 25 S., R. 21 E.)	52.1	46.9	.52	.48	.03
9. Queen (NW¼SE¼ sec. 2, T. 25 S., R. 21 E.)	61.1	36.6	1.95	.30	.13
10. Queen (SE¼NW¼ sec. 16, T. 25 S., R. 21 E.)	48.9	46.0	3.8	.51	.83
11. Queen (NE¼ sec. 34, T. 24 S., R. 21 E.)	54.2	41.8	3.2	.32	.47
12. Queen (SE¼NE¼ sec. 10, T. 25 S., R. 21 E.)	60.0	39.0	.73	.20	.09

The Grayburg-Queen beds contain many fossils, but few are well preserved. Fusulinids, mollusks, and algae are numerous. Striking changes in fossil preservation occur in short distances. A group of well-preserved fossils usually is surrounded in the same bed by molds, and a few feet away no fossils are present. The well-preserved fossils are in dolomitic limestone which grades into unfossiliferous dolomite within a short distance. Dolomitization appears to have destroyed many of the fossils.

Spotty silicification was noted in the Grayburg-Queen sequence at several different localities in El Paso Gap quadrangle; it is not common, however, and nodular chert is absent. At one locality only was silicification selective; here, individual fossils were replaced selectively.

The interval between the top of the San Andres formation and the lowest sandstone in the overlying Grayburg-Queen sequence ranges from 30 feet (Last Chance Canyon) to 170 feet (Big Dog Canyon, near Coats Lake). South of these localities and higher in the section, sandstone beds are numerous. The sandstones near the Queen Post Office site are fine to medium grained and moderate reddish brown. The same beds are very pale orange to yellowish gray where exposed on steep slopes. Current ripple marks and channel cuts are common primary structures in the quartz sandstones of the upper part of the GrayburgQueen sequence. Crossbedding is common in both quartz sandstones and calcarenites.

Argillaceous greenish-gray laminae less than half an inch thick are common in the parts of the Grayburg-Queen section that are composed predominantly of thin-bedded microcrystalline dolomite. The shaly material resembles altered bentonite beds of the Manzanita member of the Delaware Basin and is mainly illite, with some sericite and quartz.

The beds which form the lower part of the east wall of Shattuck Valley, near the head of North McKittrick Canyon, resemble the upper part of the San Andres formation but were mapped as Grayburg. The locality was close to the edge of the depositional basin, and conditions were different from those on the shelf, so that the deposits would be expected to be exceptional. The basin-margin sequence equivalent to the 900 feet of Grayburg and Queen beds was found by Newell et al. (1953) to be 1,200 feet thick on the western face of the Guadalupe Mountains, south of the Texas border. The shelf formations apparently thicken as they approach the basin margin, so that one would expect a thicker Grayburg-Queen sequence in the southern part of Shattuck Valley than farther north. The beds which most closely resemble the upper San Andres are not limited to the lowest part of the scarp. They are massive dolomites flecked with fusulinid molds; the highest such bed is only 300 feet below the top of the Queen. Also, the trend of the basin margin, as defined by exposures of the San Andres transition facies in West Dog Canyon and Last Chance Canyon, passes north of Shattuck Valley. If this interpretation is correct, the Cherry Canyon sandstone tongue, rather than the San Andres formation, underlies the Grayburg in the Shattuck Valley area. This is evident in a small inlier north of Sixshooter Canyon (sec. 18, T. 25 S., R. 21 E.), where the lowest exposed beds are interpreted as part of the San Andres transition facies and are overlain by basal Grayburg sandstone, which elsewhere overlies the Cherry Canyon tongue and the basinward part of the San Andres transition facies.

CARLSBAD GROUP

The only deposits of Capitanian age in El Paso Gap quadrangle are in the southeastern quarter of the map area. The Capitan reef is partially exposed in two canyons, and equivalent shelf deposits form the adjacent tableland.

The Capitanian shelf deposits are divided into the Seven Rivers, Yates, and Tansill formations. Each formation is composed of several facies in belts parallel to the reef front. Newell et al. (1953) distinguished the following facies in each of the formations: (1) dolomitized, reef-derived coquina and calcarenite, (2) pisolite, (3) fine-grained dolomite, (4) evaporites, and (5) terrigenous material. All these rock types occur in the underlying Queen formation; so no new depositional environments existed in the shallow sea behind the Capitan reef. However, the striking zonation in belts parallel to the reef is lacking in the preCapitanian back-reef deposits. Several miles shoreward from the reef, the shelf formations change from dominantly carbonate rocks to dominantly red beds and evaporites. The carbonate phase of the Capitanian shelf deposits usually is referred to as the Carlsbad group.

The Seven Rivers is the only one of the three Capitanian shelf formations represented by a complete section in El Paso Gap quadrangle. Near the head of North McKittrick Canyon, 500 feet of very light-gray thin-bedded dolomite, including a few thin sandstone layers, separates the prominent sandstone units which define the top of the Queen and the bottom of the Yates. According to Newell et al. (1953), the Seven Rivers thickens reefward to a maximum of 750 feet; the transition into reef rock of the upper beds of the formation takes place 8,000 feet basinward from the equivalent transition at the base. Northeast of Queen Mesa, the transition of Seven Rivers dolomite into gypsum and red beds is well exposed along Rocky Arroyo. The red bed facies and the transition beds have been removed from Queen Mesa by erosion; the northernmost Seven Rivers outliers which cap the hills overlooking Dark Canyon are predominantly dolomite.

Newell et al. (1953) report the Yates formation to be 350 feet thick in McKittrick Canyon. In El Paso Gap quadrangle, the basal sandstone unit of the Yates caps much of the north wall of North McKittrick Canyon, as well as the flat-topped drainage divides to the northeast. The western limit of Yates outcrops in this area is at an altitude of 7,300 feet on a plateau remnant overlooking the head of North McKittrick Canyon. The Yates sandstone beds are identical in appearance to those of the two underlying formations; also, like the latter, they weather to a distinctive moderate reddish brown in gentle slope exposures. In subsurface studies, the top of the Yates frequently is chosen as the highest bed, with large frosted sand grains below the base of the upper Castile salt (Woods, 1940, p. 34).

Rock Types

LIMESTONE AND DOLOMITE

STRATIGRAPHIC DISTRIBUTION

Most of the rocks exposed in the Guadalupe and Brokeoff Mountains north of the New Mexico-Texas border were deposited on a broad platform, covered by shallow water, which lay between the Delaware Basin to the south and the shore to the north. These sediments are predominantly dolomite and dolomitic limestone and range from sub-lithographic to arenaceous. Some of the carbonate rocks contain fossil molds or replacements. Such evidence indicates that the San Andres formation was formed largely of fossils. The Queen formation, however, contains relatively few fossiliferous layers, and the post-Queen beds are notably barren of fossils other than in the near-reef calcarenite phase.

The lack of fossils of some of the bedded shelf carbonate rocks is the result of recrystallization. Chert nodules in the San Andres formation show its original fossiliferous character, being packed with fusulinids, whereas the surrounding rock is usually barren. Silicification is rare in beds younger than the San Andres, although at one locality the Queen yielded a silicified fauna. This suggests that the post-San Andres shelf formations originally may have been more fossiliferous than they now appear.

The sediments which accumulated on the basin margin are predominantly of organic origin. In the Vittorio Peak member, fossil molds and fossiliferous chert are abundant. Younger basin-margin deposits are characterized by large and small reefs, which in the central Guadalupe Mountains have been recrystallized to some degree. In many cases, this alteration has nearly obliterated all trace of skeletal structure from the reef mass, and it usually was followed or accompanied by dolomitization. The notable exception is the Capitan reef, which, although extensively recrystallized, has not been dolomitized.

PRIMARY OR SECONDARY ORIGIN OF THE PERMIAN DOLOMITES

The best evidence for primary deposition of dolomite is limited to small-scale occurrences, such as the alternate coats of calcite and dolomite lining the walls of cavities in the Funafuti Atoll subsurface specimens (Cullis, 1904, p. 406); evidence cited in favor of large-scale direct deposition of dolomite is circumstantial. The Permian Goat Seep reef has been largely dolomitized (Newell et al, 1953), and Lowenstam (1948, p. 174) has described partially dolomitized Silurian reefs. The Funafuti Atoll boring passed through 1,114 feet of reef rock, of which the lower 660 feet is dolomitized (Judd, 1904, p. 373). According to Illing (1954,

p. 91), a well drilled through 14,587 feet in the Bahamas passed out of calcarenite at 400 feet and into dense dolomitic limestone, some of which shows relicts of original calcarenite.

The numerous dolomitic beds of coquina, calcarenite, and pisolite of the shelf phase in the map area, suggest that the dolomite content is probably of secondary origin. In some of the beds, dolomitization appears not only to have been secondary but also to have taken place later than silicification; for example, the dolomitic beds which exhibit well-defined fossils only in chert nodules or as selectively silicified individuals.

Sea water is probably the most important agent of dolomitization. There appears to be no other explanation for the shallow dolomitized reef cores of the Pacific and the buried calcarenites of the Bahamas. Steidtman (1917, p. 439) reported the experimental replacement of aragonite and calcite by dolomite at ordinary temperatures in solutions comparable to sea water. Skeats (1905, p. 131) noted that magnesium is "absorbed" by calcite up to 10 to 15 percent of its mass without visible change in form. Above that, dolomite crystallizes out.

The rarity of corals, bryozoans, and brachiopods from all the shelf units except the San Andres formation, suggests deposition in hypersaline waters. Sea water of above average salinity has been suggested as a factor stimulating dolomitization of sediments, but some of the most recent examples of dolomitization indicate that above-average salinity is not a prerequisite for dolomitization. Newell et al. (1953, p. 121) report salinities as high as 43 parts per 1,000 in waters near Andros Island; however, the upper 400 feet of sediment in the Bahamas shows no evidence of dolomitization.

The Capitan reef contains but little dolomite, in contrast with the underlying Goat Seep reef, which is almost entirely dolomitized. Newell et al. (1953, p. 178) attribute the dolomitization to lagoonal brines and suggest several reasons why the Goat Seep reef may have had more contact with such waters than the Capitan reef.

Structures permeable under marine conditions are most susceptible to dolomitization, according to Steidtman (1917, p. 444), who noted dolomitization in proximity to worm borings. The numerous dolomitized reefs, both fossil and recent, indicate that permeability is an aid to dolomitization. Laminated algal structures possessed of high permeability are abundant in some parts of all the post-San Andres shelf deposits. Although an aid to dolomitization, permeability is apparently not the main factor; if it were, the Goat Seep and Capitan reefs would be equally dolomitized.

Field evidence indicates that aragonite is more susceptible to dolomitization than calcite. Aragonite sand may have been a quantitatively important sediment in the Permian shelf sea, as it is now on the Bahama Banks (Illing, 1953). Steidtman (1917, p. 442) noted correlation between degree of dolomitization and abundance of pelecypod shells in some Ordovician limestone beds in Wisconsin. Aragonite is a common constituent of mollusk shells. In samples from the Funafuti boring, Skeats (1918, p. 192) noted that skeletal material had been dolomitized in a definite order, with aragonite dolomitized first.

A significant property of aragonite in regard to dolomitization is its lack of stability compared to calcite. Walther (1885), Lowenstam (1948), and Newell et al. (1953) have cited evidence that recrystallization precedes dolomitization. If recrystallization aids dolomitization instead of being its product, the greater susceptibility of aragonite than of calcite may be explained. However, dolomitization does not always involve extensive recrystallization. Newell et al. (1953) report retention of microstructure in dolomitic pisoliths, which were probably originally calcium carbonate; similar observations have been made by the writer.

FINE-GRAINED DOLOMITE

The post-San Andres shelf deposits are characterized by an abundance of fine-grained dolomite. The percentage of this rock increases upward in the section and is especially noteworthy in the Capitanian shelf deposits.

Thinsections show that some of the fine-grained dolomite possesses a primary texture little affected by recrystallization. Close-spaced, irregular bedding surfaces and numerous microscopic stylolites are visible. The thinnest definable laminations in this material are only 0.3 mm thick.

Most of the fine-grained dolomite, however, exhibits a secondary microcrystalline texture in thinsection and can be subdivided into three textural groups. One type exhibits no evidence of the original texture, and thinsections show only a mosaic of equal-sized crystals. Typical of this type are some of the patch reefs in the San Andres transition facies which have lost all primary internal features. They probably possessed a fairly coarse original texture, which was obliterated by re-crystallization. However, the original texture of some of the nonreefal fine-grained bedded dolomite is not known.

A second type of the microcrystalline dolomite exhibits scattered, but easily recognizable, fossils in thinsections. A third, intermediate, type is entirely crystalline, but scattered "ghosts" of fossils are composed of slightly larger crystals than those making up the groundmass (pl. 5C).

Much of the lower Carboniferous limestone in the Craven reef belt of northern England is described by Bond (1953, p. 328) as porcelaneous calcitic mudstone. Fossils are rare, and Bond suggests that the deposit was precipitated in a quiet lagoon. Unlike the porcelaneous beds of the Guadalupe Mountains, the English deposits are not dolomitized.

The Bahama Banks are one of the present major areas of accumulation of nonskeletal limestone. Illing (1954) recently published the results of a study of sedimentation in this region. Although mud composed of minute aragonite needles accumulates locally in the protected lagoons, tidal currents preclude mud accumulation on the major part of the banks, which is covered by dean calcareous sand composed largely of cryptocrystalline aragonite. This probably was true also of Permian shelf seas. thing attributes calcium carbonate precipitation to warming of relatively cool oceanic waters by the shallow sea bottom of the banks and to extraction of carbon dioxide from water by marine algae. The same conditions may have resulted in precipitation of aragonite in the Permian shelf seas.

The lack of evidence of compaction in the Capitanian shelf section precludes the proposed mud origin of the sublithographic dolomite. Terzaghi (1940) reported that calcareous muds compact as much as 50 percent. There appears to be no indication, however, that the back-reef section has decreased in thickness relative to time-equivalent reef units.

The lithographic dolomite outcrops exhibit characteristic randomly oriented grooves, which seem to be due to differential solution along fractures. Some of these markings were interpreted by Lang (1937, p. 870) as ice-crystal impressions. Such an origin seems improbable, since similar markings are found on all outcrop surfaces rather than solely on bedding planes. Also, great deposits of limestone are forming today only in the tropics. Furthermore, remains of green algae in the shelf formations suggest that above-freezing temperatures prevailed, since the calcareous green algae of today are restricted almost entirely to tropical and subtropical waters (Lowenstam, 1954, p. 290).

SEDIMENTS INFLUENCED BY ALGAL ACTIVITY

In present-day seas, algae influence sedimentation both directly and indirectly. Many lime-extracting red and green algae build calcium carbonate skeletal structures. Although none of the marine blue-green algae are known to build lime skeletons, they are important, where calcium carbonate is the dominant sediment, as collectors and binders of sediment (Black, 1933).

Many kinds of algal deposits are abundant in the Permian reef and back-reef phases. The calcareous red and green algae are represented by several genera (Johnson, 1942, 1951), and many laminated deposits have been referred to the blue-green algae. Pisoliths are common in some beds of the Queen formation, and they form the bulk of the rock in parts of the Capitanian near-reef lagoon deposits. Johnson (1942) and Newell et al. (1953) consider the pisoliths to be of algal origin.

On Queen Mesa, many bedding surfaces of carbonate-rock layers in the Queen formation are studded with disk-shaped structures brought into relief by differential solution. These usually show concentric laminations, though in most cases obscured by recrystallization. The structures are polygonal and range in diameter from less than 1 inch to 1 foot. These structures resemble Black's (1933) algal heads from ponds and swamps of Andros Island, Bahamas. He described the heads as low, rounded domes, 4-5 inches across, with concentric or parallel laminations. The structures occur on tidal mud flats where the dominant sediment is calcium carbonate. The heads may originate around some irregularity on the sediment surface or on polygons isolated by mud cracks. The blue-green algae produce a felt of filaments enclosed in mucilaginous sheaths to which fine limestone particles adhere. The lamination is due to sharp differences in grain size in successive layers. Black believed that the layers of fine material represent particles trapped by the mucilaginous sheaths, whereas the coarser layers, containing particles up to 1 mm in diameter and exhibiting graded bedding, represent material which settled over the algal heads after storms.

Many of the hemispherical and discoidal structures in the Queen formation are products of recrystallization. Thinsections of some, however, show alternating layers of transparent anhedral carbonate crystals and graded detritus (pl. 5B). The transparent material may have been very fine-grained calcium carbonate deposited around algal filaments. Johnson (1946, p. 1106) noted that such a spongy mass might easily be dissolved and recrystallized, masking details of the filaments.

The alternation in the Queen formation, of thin, roughly parallel layers of very fine-grained detrital carbonate with transparent anhedral carbonate crystals may be of algal origin. The latter material weathers more easily than the former; so weathered surfaces exhibit layers of small openings and pits, which leave the more resistant layers in relief. The more resistant layers appear in thinsection to be made largely of very fine-grained carbonate detritus arranged in many irregular laminae. Occasionally, pisoliths and calcified algal structures are included in these layers. The interbedded transparent carbonate shows no primary texture, and the surfaces of all the layers are very uneven. The accumulation of calcium carbonate may have been controlled by filamentous blue-green algae, such as those studied by Black (1933), who noted that the simplest form of algal-controlled sediment in the Bahamas consists of carbonate sediment layers. Perhaps the alternating layers in the Permian deposits represent repeated smothering and reestablishment of algal colonies on the sediment surface. The transparent calcite may represent recrystallized calcium carbonate mud which accumulated on the algal filaments during the periods when the colonies covered the surface, or it may represent secondary filling of space occupied originally by organic material.

Ginsburg (1955) reports that similar laminated sediments cover hundreds of square feet on intermittently flooded mud flats in southern Florida. Millimeter-thick laminae rich in blue-green algae alternate with layers composed of particulate calcium carbonate. The sediment is mostly bioclastic debris, "and abundant carbonate precipitated by algal photosynthesis is not present."

The similarity of these structures described from the intertidal zone in the Bahamas and Florida to those in the Grayburg-Queen sequence suggests that all were formed in a similar environment.

DETRITAL CARBONATE

Calcarenite and coquina are found in all the shelf formations, as well as in the Victorio Peak member of the marginal facies. However, the percentage of these rock types varies greatly in the different units. Newell et al. (1953, p. 94) note that beds of obvious shell debris compose much of the Victorio Peak member. In contrast, the Yeso formation contains very few such rock types. Throughout most of its outcrop area in the Guadalupe Mountains, the upper half of the San Andres formation is characterized by an abundance of fusulinid molds; much of this rock originally must have been composed primarily of fusulinid tests.

The lower Grayburg beds are frequently calcarenitic and are composed chiefly of well-sorted clastic material, usually altered by recrystallization. Partially recrystallized calcarenite and coquina are found in the upper Grayburg and Queen formations throughout the Queen Mesa area. Many dolomitic limestone units within the Queen formation show prominent crossbedding and must have been calcarenitic, although the original texture was destroyed by recrystallization. In the Capitanian shelf formations, coquina and calcarenite are restricted to a belt near the reef, as described by Newell et al. (1953).

(Rate is abundant in some outcrops of the Queen and Grayburg formations and in some areas takes the place of calcarenite in the lower Grayburg. For example, in sec. 20, T. 25 S., R. 20 E., the lower 60 feet of the Grayburg formation contains many beds of oölite. Willis (1929, p. 1014) reported that production in the Big Lake pool was obtained from, among other beds, "oolitic horizons" near the top of the San Andres formation. Willis did not utilize an intervening unit between San Andres and Queen; since he described the Queen formation as about 400 feet thick, the oolitic beds are in the Grayburg formation.

Many impure carbonate beds in the Queen are mixtures of oölite, calcarenite, and quartz sand; such units are commonly crossbedded.

Oöids are forming at the present time on the Bahama shelf (Newell et al., 1951; Illing, 1954), in Great Salt Lake (Eardley, 1938), and as a byproduct of certain commercial operations (Kemp, 1934). The oöids form where calcium carbonate is being precipitated in waters sufficiently agitated to keep the sediment particles which serve as nuclei, and the adds themselves, in motion. Illing (1954, p. 44) believes that the backand-forth tidal movement of water in a shallow sea is an important factor in the origin of the oolite of the Bahama shelf. The oolite in the Grayburg and Queen formations probably was deposited under similar conditions.

QUARTZ SANDSTONE

At various times during the accumulation of the Permian shelf deposits, quartz sand was the dominant sediment and was widely distributed over the shelf, presumably by strong currents such as those which distribute terrigenous material over the entire shelf between Australia and the Great Barrier Reef today (Fairbridge, 1950).

The Glorieta sandstone is a widespread shelf unit overlying the Yeso in the New Mexico subsurface, as well as in outcrops to the northwest. However, the Glorieta is not present in El Paso Gap quadrangle, having graded into Yeso-type beds north of the quadrangle border (Skinner, 1946). In contrast, some sandstone beds in the shelf phase seem to be restricted to a belt bordering the basin margin.

In the southwestern quarter of El Paso Gap quadrangle, the lower 75 feet of the Grayburg-Queen sequence includes many quartz sandstone beds. The sandstone beds grade laterally into carbonate rocks along a line roughly coincident with the line of transition betwen the San Andres formation and the Cherry Canyon tongue; north of this line, the lower Grayburg is comparatively free of quartz sandstone. The northward transition from sandstone to carbonate rock occurs in some beds in as short a distance as 50 feet. Furthermore, many individual quartz sandstone beds in the upper and middle parts of the GrayburgQueen sequence in the central Guadalupe Mountains grade into carbonate rocks along the outcrop.

The unequal lateral distribution of quartz sand in many beds suggests that the sand was distributed in the shelf seas by currents whose orientation varied from time to time.

Beds of quartz sandstone are not equally distributed vertically in the shelf phase. For example, geologists working the subsurface have subdivided the Grayburg and Queen formations on the basis of the more abundant quartz sandstone in the upper part. Within the Queen formation, moreover, more quartz sandstone beds occur in the upper part of the section than in the lower part. The unequal vertical distribution is not due to masking of quartz sand by carbonate sand, because many of the dolomite beds in the Queen do not contain even scattered quartz grains. Quartz grains have not been observed in the laminated detrital beds, which are thought to owe their origin to sediment-binding algae. If quartz sand had been carried across the sea bottom during formation of these beds, some quartz should have been trapped in the algal mat and incorporated in the laminated sediment.

Thus, the writer suggests that the supply of sand to the shelf sea fluctuated locally through time. This could have been the result either of a changing source or of fluctuations in current direction.

The Cherry Canyon sandstone tongue is the only part of the great sandstone deposits of the Delaware Basin which extends as far north as El Paso Gap quadrangle. In this area, the Cherry Canyon sandstone

is impure, often fossiliferous, and poorly bedded, thus differing from the quartz sandstone beds of the shelf section. It should be regarded as part of the basin facies.

A prominent sandstone sequence makes up the lower part of the Grayburg formation where that unit overlies the Cherry Canyon sandstone tongue in the southwestern quarter of El Paso Gap quadrangle. The even-bedded lower Grayburg sandstone beds are not a northern extension of the Cherry Canyon formation but are part of the shelf phase. Neither King (1948) nor Newell et al. (1953) reported a similar member overlying the Cherry Canyon tongue in the Bush Mountain area, a few miles south of the Texas-New Mexico border.

Fifteen sandstone samples from the central Guadalupe Mountains were studied by Joseph P. Hull as part of an investigation of the petrology of the Permian sandstones. The samples included representatives from the Yates formation, Grayburg-Queen sequence, and the Cherry Canyon tongue. Heavy minerals identified were zircon, tourmaline, rutile, garnet, epidote, sphene, leucoxene, and apatite. Each of these minerals was present in at least one of the samples from each of the three formations, except that apatite was found only in the Cherry Canyon rocks. However, Hull did not consider this important owing to the instability of apatite under ordinary weathering conditions. The relative proportions of the heavy minerals vary in the same formation and even in the same rock sample; therefore, no information useful in separation of the beds or in interpretation of source areas is gained. The lighter minerals of these samples are almost entirely quartz, according to Hull. This is surprising, as the fine-sand and coarse-silt fractions of samples of the Delaware Mountain sandstone are from 20 to 40 percent feldspar, and the same fractions in sandstone samples from the Northwestern Shelf are from 5 to 41 percent feldspar (Hull, 1955). Pennsylvanian and lower Permian arkoses of northern New Mexico have been suggested by Hull (1955) as sources of the feldspathic sand.

One distinctive feature in many of the shelf sandstone beds is the frosted appearance of many of the medium- and large-size quartz grains. King (1942, p. 703) reported that the Yates is the highest formation with frosted sand grains, but an editorial note (by DeFord and Lloyd) indicated their presence in the younger Dewey Lake formation. Frosted quartz grains have been reported in pre-Yates sandstones from the Glorieta (Skinner, 1946), the Grayburg (Dickey, 1940), and the Queen (Page and Adams, 1940). Hull (personal communication, 1955) reported that the frosted appearance of some of the larger quartz grains from the Grayburg-Queen sequence is due to quartz overgrowths.

SHALE

Argillaceous gray-green rock, usually in layers less than half an inch thick, is common in the parts of the Grayburg-Queen section made up dominantly of thin-bedded microcrystalline dolomite. Specimens of the shaly material contain sericite and quartz grains and are similar to altered bentonite beds of the Manzanita formation in the Delaware Basin (Newell et al., 1953). Thermal curves and X-ray patterns, determined by Peggy K. Hamilton, show that the major constituent is the clay mineral illite. Montmorillonite, identified elsewhere in altered bentonites, is not present. Grim (1942) believed that illite is the dominant clay mineral in most argillaceous marine sediments, although Pettijohn (1949) believes that montmorillonite can be converted to illite. There is no conclusive proof either for or against a volcanic origin of the thin shale beds in the shelf section.

CHERT

The stratigraphic distribution of chert in the central Guadalupe Mountains is noteworthy. Hardly any chert has been observed in deposits of Capitanian age. Although all pre-Capitanian units contain some chert, it is rare in the Grayburg-Queen sequence. Abundant chert occurs in some beds of the Cutoff and Victorio Peak members of the Bone Spring formation, the Yeso formation, the Cherry Canyon sandstone tongue, and the San Andres formation. Where the San Andres is exposed on the east wall of Big Dog Canyon, it is divisible into a lower 300 feet of beds with abundant chert nodules and an upper 300 feet of noncherty beds, characterized by abundant fusulinid molds. In the Brokeoff Mountains, however, scattered chert nodules occur in the upper part of the San Andres formation, and they are abundant in some beds of the upper part of the formation in the area of transition between the San Andres and the Cherry Canyon tongue (pl. 6C). The assumption that the upper limit of chertification in the San Andres sequence is a stratigraphic horizon creates more problems than it solves.

Practically all the pre-Capitanian chert is in nodules, 2 to 6 inches long, that show evidence, such as replacement of fossils, of epigenetic origin. In some cases, the nodules are scattered through thick beds with no particular orientation, but more frequently they parallel the bedding. In the Brokeoff Mountains, some beds in the lower San Andres formation and the Cutoff member contain tubular anastomosing nodules which transect lines of stratification, and which are clearly epigenetic.

The upper division of the Victorio Peak member, according to King (1948) and Newell et al. (1953), is characterized by absence of chert in the southern Gaudalupe Mountains. Near the Texas-New Mexico border, however, some beds in the upper Victorio Peak include chert nodules, and in the central Guadalupe Mountains, where almost all the exposed Victorio Peak represents the upper part of the member, some cherty beds occur in almost every outcrop of the Victorio Peak.

Beds of chert are present in the Cutoff member but are not abundant; individual layers are irregular and not more than 2 inches thick.

The Cherry Canyon sandstone tongue includes solid chert nodules, especially near its northern limit. It also contains numerous small patches of silicification too irregular to be called nodules. These patches are porous, with the open spaces surrounded by botryoidal chert, and show fibrous structure similar to the bundles of root tufts of siliceous sponges found in the same strata. They probably are recrystallized sponges.

Although chert nodules were not found in the post-San Andres beds, there are rare occurrences of silicification in the Grayburg-Queen sequence. In the east part of the quadrangle, a diverse fauna of silicified fossils was obtained from this sequence by etching limestone blocks in acid. Wherever the fossils were not crowded, they were silicified individually; in coquina layers, on the other hand, the fossils are welded together by chert. Silicification was concentrated in the coquina beds, probably owing to the relative ease with which silica-bearing solutions could migrate through such permeable layers.

The evidence indicates that most of the chert of the central Guadalupe Mountains is epigenetic. Silicification occurred in some cases after the sediments had been buried to a sufficient depth to cause compaction, as several gastropod shells from the silicified Queen fauna are crushed. If this had not occurred before silicification, the various pieces of each shell would probably not have fused at points of mutual contact. On the other hand, closely spaced bedding surfaces in the Cherry Canyon tongue were observed to part around a chert nodule. The section apparently thinned by compaction after the nodule was in place.

Silicification occurred before dolomitization wherever chert contains well-preserved fossils in contrast to molds and fossil "ghosts" in the surrounding dolomitic limestone. There are no cases where dolomitization appears to have preceded silicification.

If silicification precedes dolomitization, it may be least likely to occur where dolomitization closely follows deposition, other factors being equal. Two conditions which seem to favor dolomitization are aragonitic composition and high permeability. Perhaps silicification is lacking in most reefs of the Guadalupe Mountains because dolomitization occurred early in these permeable structures. Early dolomitization might explain the absence of silicification in the microcrystalline dolomite of the Capitanian shelf section, as this rock may originally have contained much aragonite.

There is evidence, however, that silicification occurs very early in diagenesis (Newell et al., 1953), whereas dolomitization probably occurs sometime after burial to depths of hundreds of feet (Newell, 1955). Furthermore, fossils in the relatively nondolomitized Capitan reef are not silicified. Newell and coworkers (1953) postulate that decomposition and elimination of organic matter from the highly permeable reef was accomplished by scavengers and aerobic bacteria. They suggest that these processes continued at appreciable depths in the rock, with a resulting low hydrogen-ion concentration, which is most likely responsible for the lack of diagenetically precipitated silica.

Chert nodules which transect lines of stratification, and which contain fossils, are clearly epigenetic features. According to Newell et al. (1953, p. 162), "no compelling evidence of primary deposition of chert was recognized, but evidence for replacement of limestone by silica is abundant." The statement applies to observations made in El Paso Gap quadrangle.

GYPSUM

All the shelf formations include evaporites, but there is comparatively little gypsum in the central Guadalupe Mountains. The site of evaporite accumulation during deposition of the older shelf formations was mainly farther north. The evaporite beds of the Capitanian shelf units have been stripped away from the Guadalupe Mountains by erosion.

Gypsum was observed in El Paso Gap quadrangle in the Yeso formation, in the Grayburg-Queen sequence, and in the Cutoff member of the Bone Spring formation. Beds of gypsum as much as 5 feet thick occur in the Yeso outcrops along the east side of Big Dog Canyon. The gypsum in many places includes thin intercalations of dolomitic limestone. In the northeast corner of sec. 12, T. 26 S., R. 19 E., several thin lenses and small pockets of gypsum are exposed in thin-bedded dolomite of the Cutoff member. There is a similar occurrence in the Grayburg formation in South Tank Canyon.

The pockets of gypsum are irregular and small, the greatest diameter not exceeding a few inches. A few oöids of carbonate are scattered through the gypsum. Gypsum is also found as small cavity fillings in many layers of the Grayburg-Queen sequence. The lower Grayburg sandstones in the southwestern quarter of El Paso Gap quadrangle contain numerous gypsum casts of fusulinids and small gastropods. The dolomitic limestones of the Grayburg-Queen sequence contain many tiny inclusions of gypsum 1 or 2 mm in diameter.

Structural Geology

PRIMARY STRUCTURES

DEFINITION

As used in this report, primary structure refers to structures resulting directly from deposition, such as reefs and crossbedding, and to structures formed soon after deposition, such as glide folds.

REEFS AND REEFLIKE STRUCTURES

Ladd (1944) and Lowenstam (1950) emphasized that the term "reef" should be applied only to structures built of fossils which show evidence of wave-resistant qualities. The reef, therefore, rose above the surrounding sea bottom and grew, or was capable of growing, against wave erosion.

Several structures within El Paso Gap quadrangle offer evidence of growth above wave base. These reefs are surrounded by beds of reef talus. The primary dip of beds indicates that the fragmental material accumulated around the margins of structures which rose above the surrounding sea floor. Many of the fossils in the detrital beds were broken from the adjacent reef by wave action.

The reefs vary greatly in size. The Capitan reef, which is exposed in the canyons of the southeastern quarter of El Paso Gap quadrangle (fig. 3, locality 1), has been traced in the subsurface around most of the margin of the Delaware Basin. The underlying Goat Seep reef, which is exposed in North McKittrick Canyon (fig. 3, locality 2) is probably almost as extensive.

In addition to these two barrier reefs, several patch reefs were observed in and near the zone of transition between the upper San Andres formation and the Cherry Canyon tongue exposed in the southwestern quarter of El Paso Gap quadrangle. One of the patch reefs (fig. 3, locality 3) is 56 feet thick, contains no trace of fossils, and contrasts sharply with the slope-forming surrounding sandstone. A narrow marginal area between reef and sandstone consists of bedded carbonate rock, with chert and brachiopods. The small amount of marginal debris, the thickness as compared to width, and the vertical sides of the reef suggest that the reef top was below the water surface. Either the reef growth started in water deeper than 56 feet, or the base of the reef changed relatively to sea level during reef growth. Whereas the growth in this patch reef was chiefly vertical, the Capitan reef shows both horizontal and vertical components of growth, the former being of greater importance.

A large patch reef marks the northern limit of the Cherry Canyon tongue in this area (sec. 12, T. 26 S., R. 19 E.; see fig. 3, locality 4). Poor exposures and several faults obscure the form and size of this structure. The marginal zone, with prominent forereef beds dipping away from the structure, is exposed in the northeast corner of sec. 12. Here, the basal sandstone beds of the Grayburg pinch out on the top of the reef, which is about 70 feet thick. The reef rock is massive dolomitic limestone, moderate orange pink on fresh surfaces and light olive gray on weathered surfaces. No fossils were observed. A light-colored lens of quartz sandstone, 6 feet thick at the thickest point and dipping southeast, occurs in the nonbedded reef rock. Small pockets and thin layers of quartz sand cover irregular surfaces and fill crevices as far as 6 feet below the lens. Some quartz sand entered the reef as the reef was being buried, and some was washed over the reef during its growth. In both cases, sand filtered down through the porous framework and was trapped in cavities. Sand was washed from the shelf area over the reef and into the adjoining basin, as postulated by Newell et al. (1953) for the quartz sand in the Capitan reef. The southeast (basinward) dip of the sand lens and of the forereef beds, and the fact that the reef separates the Cherry Canyon tongue of basin-facies sandstone from the San Andres formation of the shelf facies, favor this interpretation. One might expect the reef to be similar in form to the Capitan reef, instead of localized on the basin margin. Examination, however, of the belt of gradation between the San Andres and the Cherry Canyon tongue in the few places where it is exposed in the central Guadalupe Mountains provided no evidence of a continuous reef.

The above patch reef may be considerably larger than the described exposure would indicate, as other exposures of reef rock in the area may represent parts of the same reef. About 500 yards northeast of the locality described above, 40 feet of nonbedded dolomitic limestone, containing a few indistinct fossils and some small patches of sedimentary breccia, was measured. This rock does not persist laterally but gives way to bedded carbonate. South of the outcrop, the beds at the same strati-graphic horizon dip 12° SE. The reef rock is separated from the basal Grayburg sandstones by 50 feet of poorly bedded dolomite, with abundant fusulinid molds. The basal Grayburg sandstones grade downward into the carbonate reef rock and show a small but distinct dip away from the area on both sides.

Four hundred yards to the west of the patch reef, an exposure of thick reef rock may represent a more central part of the same structure. The reef rock is exposed in a small northwest-southwest trending gully in the center of the south line, sec. 1, and is 200 feet thick. This rock contains numerous indistinct fossils and is separated from the base of the Grayburg formation by about 70 feet of bedded dolomite. Less than one-half mile farther west on the same slope, the stratigraphic horizon of the reef rock is of calcarenite beds with a primary dip of 17° S. These are probably forereef beds, indicating an unexposed reef immediately to the north. Thus, if the exposure in sec. 6 is part of the same structure, the reef is nearly a mile long in its southwest-northeast trend. The stratigraphic position of the reef rock in the three localities indicates that the reef was growing upward and southward toward the basin during deposition of the upper half of the San Andres formation.

A small patch reef is exposed at the base of the west wall of West Dog Canyon, in the northwest corner of sec. 2, T. 26 S., R. 19 E. (fig. 3, locality 5). This reef is moundlike; its greatest width 60 feet, along the base, and its greatest thickness 28 feet. The reef is in the transition belt between the San Andres formation and its basin-margin equivalents, either the lower part of the Cherry Canyon tongue or the upper part of the Cutoff member, and appears to be older than any of the reefs discussed above. It consists of nonbedded porous rock which is medium light gray to light olive gray on weathered surfaces. Fossils, chiefly as molds, are most common in the lower part. With the exception of a few molds of *Leptodus,* the recognizable fossils are calcareous sponges. The reef rock on the flanks of the structure grades into poorly bedded dolomite. On the south flank, these beds contain many molds of brachiopods *(Leptodus* and productids), whereas on the north side, fusulinid molds are more abundant than brachiopods. Chert nodules occur in the flank beds but not in the reef. A good exposure at the same stratigraphic horizon, 100 feet south of the reef, shows bedded dolomitic limestone of the same color as the reef rock, with a primary dip of 15° SW. The beds range from 1 to 2 feet in thickness and contain abundant irregular light-brown chert nodules alined parallel to the bedding. The lower part of this exposure contains abundant crinoid columnals, whereas the upper part has many molds of fusulinid and fossil fragments.

Although the reefs of the central Guadalupe Mountains vary considerably in size and form, all have several features in common. The reef rock is nonbedded dolomitic limestone or dolomite that is flanked by bedded dolomitic limestone, with primary dips away from the reef of 4 to 15 degrees. The reef rock contains no chert, whereas the flanking beds commonly are cherty. The flanking beds have calcarenitic or coquinoid texture, whereas the reef rock commonly shows evidence of in situ construction by frame-building organisms, such as indistinct skeletal outlines and molds scattered through the rock. In places, however, the original fabric is entirely lacking. The reef rock frequently is characterized by scattered cavities and cavity fillings of calcite crystals. Irregular pockets of sand and sedimentary breccia show that the reefs were effective sediment traps.

A few reeflike structures in the central Guadalupe Mountains lack evidence that they were wave-resistant structures. Aside from the absence of bioclastic material around the margins, they closely resemble the patch reefs discussed above. They may have been formed by communities of lime-secreting organisms which were perpetuated in the same locality for considerable time. A thick deposit of such rocks might never have risen far above the sea floor if the accumulation of organic material did not appreciably exceed that of surrounding sediments.

Several examples of reeflike structures are exposed in Last Chance Canyon (SW¼ sec. 32, T. 23 S., R. 22 E.). The rock is nonbedded and porous, and contains scattered brachiopods and solitary corals, with a small amount of chert. The surrounding beds are cherty dolomitic limestones of the San Andres formation. Beds are draped over the structure, apparently as a result of differential compaction (p1. 3A). Like the patch reefs, these structures are in the transition belt between the San Andres formation and the Cherry Canyon tongue, and originated at the same time and in a similar environment as most of the patch reefs described above.

Another small reeflike mass is partially exposed in the gully in the center of the south line of sec. 1, T. 26 S., R. 19 E. It is 30 feet below the base of the thick section of reef rock described above. This lenticular mass is 17 feet thick and contains many indistinct fossils. It is formed of dolomite, with scattered traces of fossils and pockets of breccia. Calcite has filled numerous small cavities. There is no chert in the reeflike body nor in the surrounding bedded dolomite. The beds above and below show effects of differential compaction, the enclosing beds being slightly warped in accommodation to the form of the reeflike mass.

RIPPLE MARKS

Many of the quartz sandstone beds in the Grayburg-Queen sequence exhibit ripple marks. Newell et al. (1953, p. 126) note the rarity of ripple marks and crossbedding in the rocks immediately behind the Capitan reef. However, the older sandstone beds of the shelf facies exhibit these structures, which are indicative of deposition in agitated waters. Of the rippled surfaces observed in place, the orientation of the ripples in 8 of 9 cases is in the northwest quadrant, with one 10 degrees east of north. The ripples observed were current ripples; so the distribution suggests that currents in the shelf sea during deposition of the Grayburg and Queen formations were approximately parallel to the basin margin rather than normal to it.

Beds of detrital carbonate rock are common in the shelf deposits, but ripple marks were not observed. Clifton (1944, p. 1017) observed ripple-marked calcarenite in the Blaine and Dog Creek formations on the east side of the Midland Basin. Black (1933) noted of modern algae near the Bahama Islands, that "*Chlorophyceae* bind the sediment without producing any banded or radial structure." Perhaps the growth of algal or other vegetation in the Permian shelf seas during times of carbonate deposition prevented rippling of the surface by current action. According to N. D. Newell (personal communication, 1955) bottoms near the Bahamas, with even scattered vegetation, are usually free of ripples, because the plants break up the regular oscillations of bottom currents, producing turbulent effects.

CROSSBEDDING

Although ripple marks were observed only in quartz sandstone, in the quadrangle, crossbedding in the shelf deposits is as common in calcarenite as in quartz sandstone. Crossbedding of pure quartz sandstone is found only in beds a few inches thick; the larger scale crossbedding involves arenaceous calcarenites or pure calcarenite. The Grayburg-Queen sequence includes numerous crossbedded units involving calcarenite and calcareous sandstone, as well as oolite. At one locality (NW¼ sec. 4, T. 26 S., R. 20 E.) a 6-foot bed of oolite exhibiting torrential crossbedding is exposed in a canyon bottom and appears from a distance to mark an angular unconformity.

Some of the crossbedded carbonate rock shows no megascopic sandy texture, suggesting that the original texture was modified during diagenesis. Since this rock, aside from the crossbedding, appears similar to much of the carbonate rock of the Grayburg-Queen sequence, details of original texture may have been lost in much of the shelf carbonate rocks.

Randomly oriented fusulinid tests are the major component of many upper San Andres beds, but the fusulinid deposits are crossbedded at only one locality (Panther Canyon, in NW¼ sec. 35, T. 25 S., R. 19 E.).

Large-scale crossbedding occurs in the upper part of the San Andres formation in the west-central and central parts of El Paso Gap quadrangle,[3] within about 8 miles of the southern limit of the San Andres formation (fig. 3). In some localities, the foreset beds are overlain by the light-colored Grayburg formation. In other places, they are separated from the Grayburg by as much as 140 feet of upper San Andres beds.

The crossbedded foreset beds have a relief of at least 100 feet and differ in dip by 5 to 9 degrees from the overlying beds. Individual foreset beds are of relatively uniform thickness throughout and are not often strongly concave. In limited exposures they might be mistaken for the lower of two sequences separated by an angular unconformity. The foreset beds in several localities are not sharply truncated at their upper limit but grade upward into several feet of rocks with indistinct bedding. The foreset beds dip southeast or southwest in all exposures, indicating that sediment was swept basinward by the shelf sea currents.

Large-scale crossbedding of arenaceous calcarenite is common in the upper half of the Cherry Canyon tongue. These cherty strata, containing beds of recognizable calcarenite and fusulinid molds, resemble the San Andres formation more closely than the Cherry Canyon sandstone. This fact, plus the attitude of the bedding, suggests a delta of carbonate detritus built basinward from the shelf margin.

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[3] In Panther Canyon, sec. 35, T. 25 S., R. 19 E.; near the mouth of Chosie Canyon, which leaves El Paso Gap quadrangle in sec. 3, T. 25 S., R. 19 E.; in NW¼ sec. 34, T. 24 S., R. 19 E.; in SW¼ sec. 32, T. 24 S., R. 20 E., and in SE¼NW¼ sec. 35, T. 24 S., R. 20 E.

CHANNEL FILLINGS

A sea bottom subjected to differential current action might undergo alternate deposition and erosion, or both processes at the same time, in different areas. If the sediments deposited over a period of time exceeded the quantity eroded, the resulting strata should show evidence of penecontemporaneous scour and fill. Such evidence, in the form of buried filled channels, was observed in several places in the Queen-Grayburg sequence. The channels generally were cut in beds of quartz sandstone and were usually less than 2 feet deep. They are filled by sandy carbonate rock or by quartz sandstone.

Only one channel filling was observed in the San Andres formation. It is similar in dimensions to those described above, but the channel was cut in carbonate sediments and was filled with fusulinid tests. This is the crossbedded deposit of fusulinid tests described above.

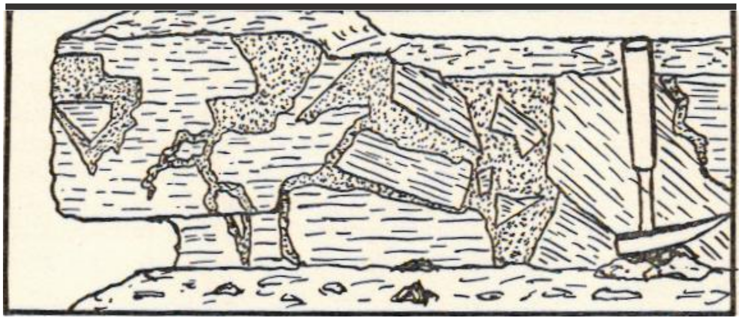
SHRINKAGE CRACKS

A polygonal pattern resembling that formed in muds by desiccation cracks is exposed on dolomite bedding surfaces at several localities in the northeastern quarter of El Paso Gap quadrangle. These beds, in the Grayburg-Queen sequence, show other evidence of shallow-water deposition. Possibly these shelf sediments were exposed occasionally to sub-aerial drying. Most desiccation cracks forming at the present time are the result of subaerial drying, although under certain conditions (Twenhofel, 1950) cracks may be produced in muds beneath water. Expansion of bentonite buried beneath mud may cause cracks in the overlying layer. Also, mud may crack under water if the water in the mud drains out at the bottom.

In some cases, the polygonal pattern is produced by cracks in narrow troughs on the surface. Occasionally the cracks are not visible, and the pattern is produced by the troughs alone. In a few exposures, the cracks follow low ridges which separate polygonal areas. Thinsections show the rock to be composed of particulate carbonate and anhedral carbonate crystals, with the latter grouped in pockets alined parallel to the bedding. The particles include shell fragments and tiny pellets, and the rock is the type described above as reflecting sediment-binding algae. Perhaps the algal incrustations were built up on polygonal blocks separated by shrinkage cracks. R. N. Ginsburg (personal communication, 1955) has noted crusts of laminated sediment and organic matter covering polygonal blocks in mud flats along the Florida shore.

FRACTURE FILLINGS

At two localities, sandstone was observed to have filled fractures between displaced blocks of bedded dolomite. The most extensive of the two disturbed zones is restricted to a stratigraphic interval of 25 feet and a horizontal exposure of 15 feet. Overlying beds were not disturbed.



SANDSTONE-FILLED FRACTURES IN CALCARENITE OF THE GRAYBURG FORMATION, BROKEOFF MOUNTAINS.

Figure 4

Both occurrences are near reefs, and the dislocations may have been caused by subsidence of the nearby reefs. Since the disturbance caused the bedded dolomite to break into blocks, the sediment was well consolidated and rigid, although still near the surface of deposition. One of the disturbed areas (NE¼SE¼NE¼ sec. 1, T. 26 S., R. 19 E.; fig. 4) extends downward from the basal Grayburg sandstone, whereas the top of the other is 10 feet below the Shattuck sandstone member of the Queen formation (SE¼SW¼NW¼ sec. 28, T. 26 S., R. 21 E.).

These features differ from the sandstone dikes noted by Newell et al. (1953) in the Carlsbad group, in that they include breccia as well as sandstone and show no evidence of injection of material from below. Breccias formed by intrastratal flowage in partially lithified basin limestones differ from the fracture fillings in being lenticular, with the long axis parallel to the enclosing bedding.

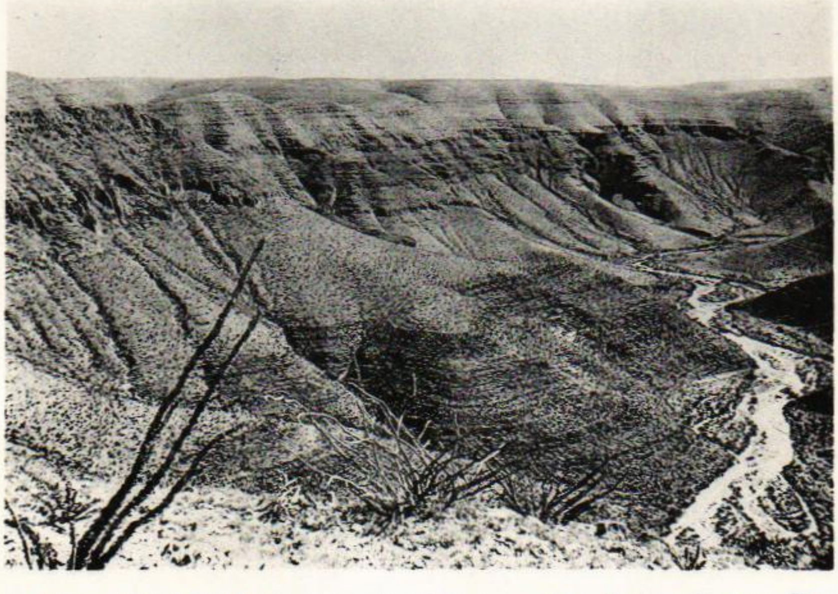
TEPEE STRUCTURES

Small primary chevron folds in the Capitanian backreef deposits were designated "tepee structures" by Adams and Frenzel (1950, p. 308). Newell et al. (1953) devote considerable attention to these features, emphasizing the symmetrical form, lack of compressional features, and undeformed nature of the underlying beds.

Several similar structures were noted in the Grayburg-Queen sequence, both in the northeastern and west-central parts of El Paso Gap quadrangle. The tepee structures are 1 to 4 feet high and are found only in thin-bedded carbonate rock. Occasionally some of the carbonate layers are silty. Most of the structures observed had been extensively leached, so that the relationship of the beds in the structure to the overlying beds is obscure. One well-preserved tepee structure in South Tank Canyon (pl. 4A) permits deductions concerning its origin. The beds in this structure were originally horizontal, but if they could be

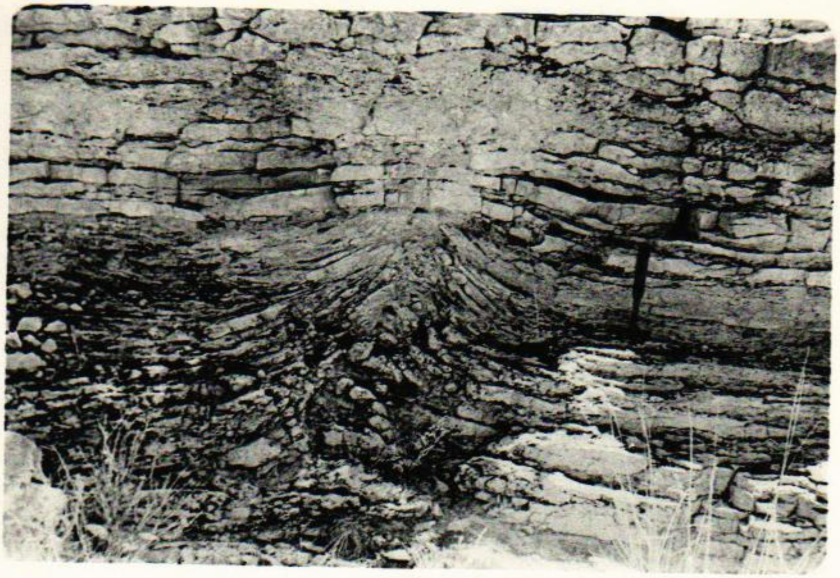
Plate 2. West Dog Canyon area.

A. Truncated compaction folds in Last Chance Canyon. Cherty San Andres beds are folded. Upper San Andres and Grayburg beds are horizontal. Note horizontal beds near canyon bottom.

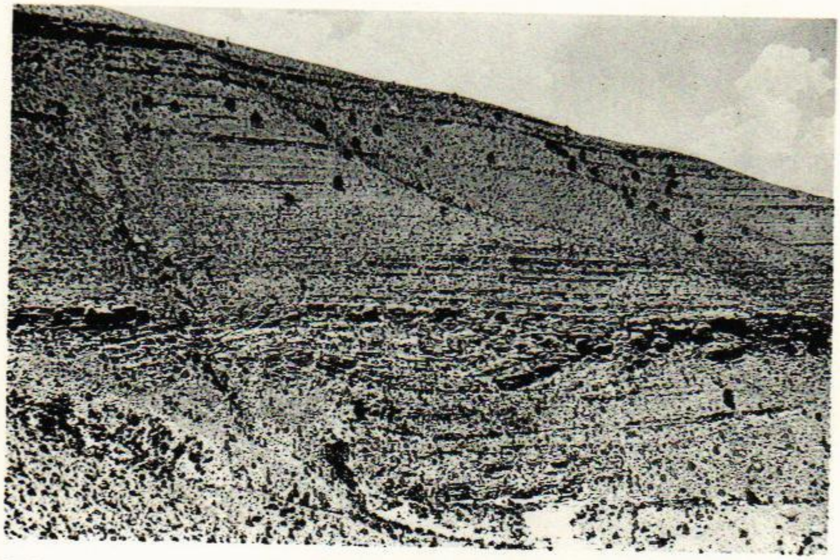


B. View northeastward of north wall of lower Chosie Canyon. The contact between lower ledge-forming beds and middle slope-forming beds is correlated with the Victorio Peak-Cutoff contact in the southern Guadalupe Mountains. The contact between the upper interval of ledge-forming beds and the slope-forming strata which cap the canyon wall is correlated with the San Andres-Grayburg contact in the central Guadalupe Mountains.

Plate 3. San Andres formation.



A. Tepee structure in Grayburg-Queen sequence, South Tank Canyon.



B. Large channel filling in upper Cherry Canyon tongue exposed in Cork Draw. Prominent ledge across middle of picture marks base of Grayburg formation.

Plate 4. Sedimentary structure.

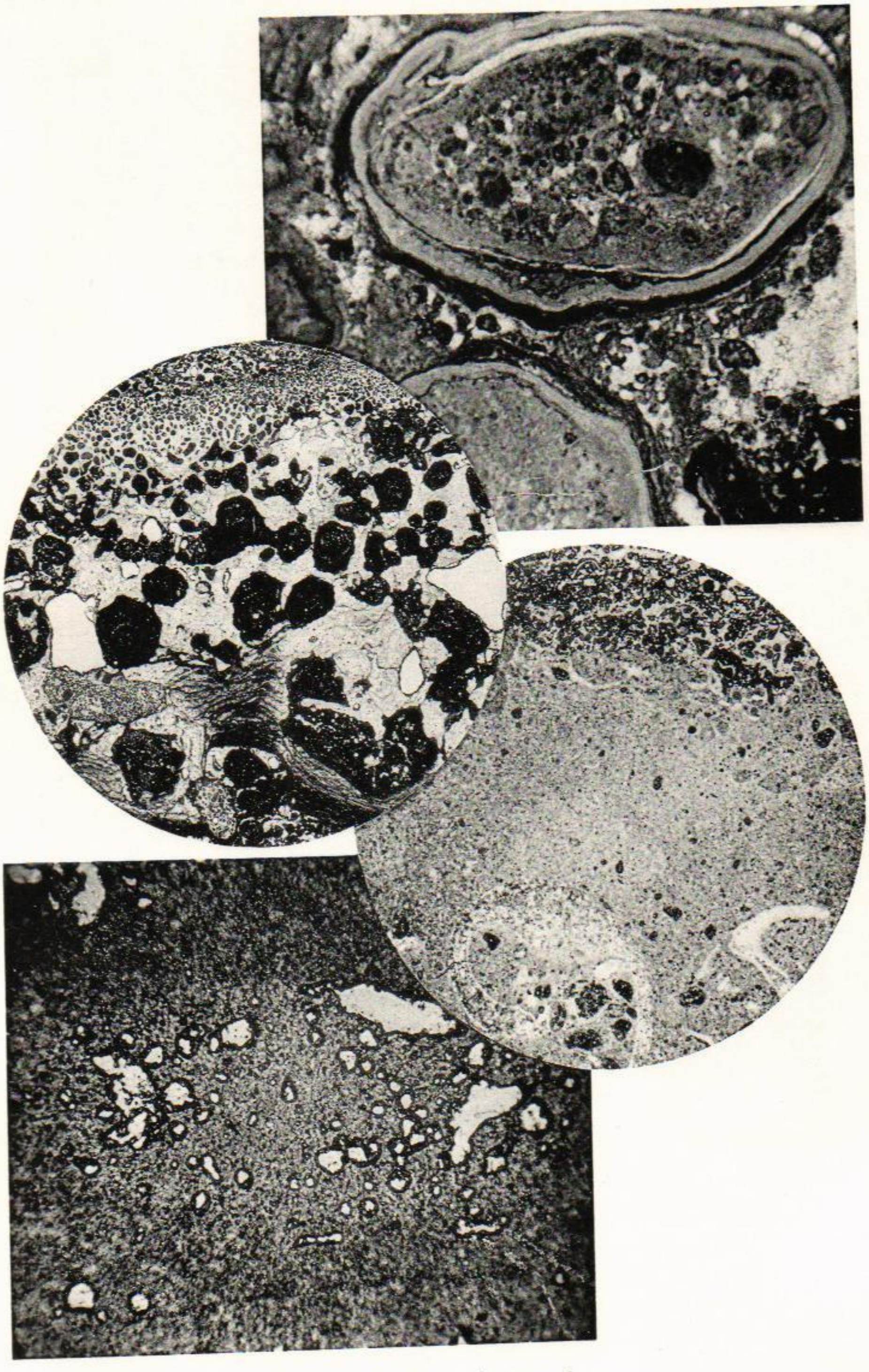


Plate 5. Photomicrographs.

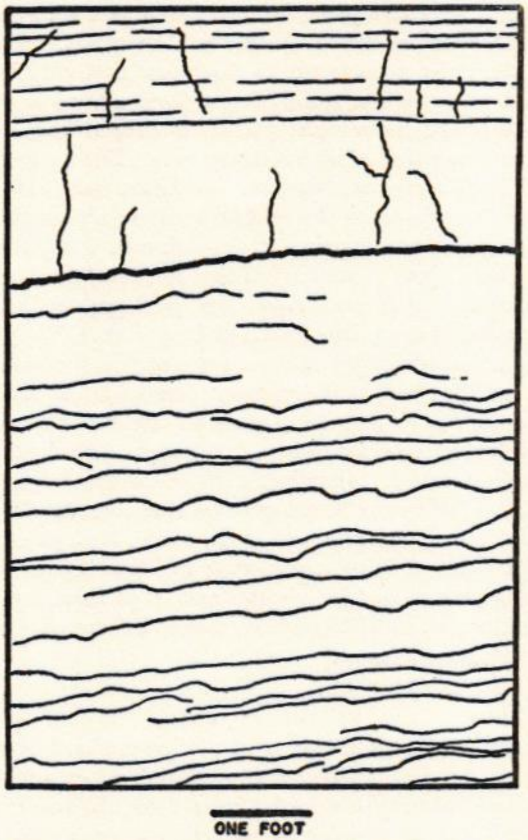
returned to their original position, they would overlap, and appear, therefore, to have been stretched during diagenesis. This could have been accomplished by a decrease in thickness through flowage of material in each bed toward a zone of weakness where material escaped upward. The upward movement probably caused the arching of the beds and the destruction of their continuity. The truncation of beds in the South Tank Canyon structure indicates removal of the top of the arch before deposition of the overlying beds, although Newell et al. (1953) report that such a situation is exceptional. They suggest that the "tepees" in the Carlsbad group may have formed "during the Permian period by expansion of crystallizing salts, perhaps the inversion of anhydrite to gypsum, along joints and bedding planes."

Expansion of crystallizing salts is responsible for some surface deformation in arid regions at the present time. The addition of sodium chloride from the air to a surface crust in the Peruvian coastal desert results in buckling of the surface into hummocks, observed by the writer, with up to 1 foot relief. Likewise, surface deformation of laminated sandstones in the Delaware Basin may be due to crystallization of salts in joints and between beds (Newell et al., 1953). No evidence was found, however, during the present study, that the folding in the GrayburgQueen sequence was caused by crystallization of salts. Intrastratal flowage of material in unconsolidated beds due to differential loading merits equal consideration as a cause.

WAVY BEDDING

Newell et al. (1953) note outcrops of fine-grained basin limestones characterized by hummocky bedding surfaces. They conclude that the uneven surfaces probably resulted "from unequal reaction to loading and from adjustment by flowage in waterladen, fine-grained sediments." Similar wavy bedding occurs in a 10-foot-thick bed of dense limestone (fig. 5) exposed near the floor of Last Chance Canyon, opposite the mouth of Whiteoaks Canyon. This bed is some distance below typical San Andres beds, although not necessarily pre-San Andres in age. The locality is in the transition belt between the basin and shelf phases, and there is reason to believe that the transition beds were deposited on a slope. Patch reefs occur nearby, and one 20-foot bed wedges out shelf-ward as a result of nondeposition. The stratum with wavy bedding may have been laid down on a slope under conditions of loading similar to the loading conditions which occurred at the foot of the Capitan reef talus.

Another type of wavy bedding characterizes some horizons of thin-bedded microcrystalline dolomite within the Grayburg-Queen sequence. The beds are a few inches thick and are bounded above and below by thicker, undeformed layers of dolomite. Some of the thin beds appear to have been thickened and thinned from place to place by internal flowage, although the majority of the thin beds merely flexed sufficiently



WAVY BEDDING IN FINE-GRAINED LIMESTONE, LAST CHANCE CANYON.

Figure 5

to accommodate these changes in thickness. The resulting structures are symmetrical chevron folds a few inches from crest to trough. They differ from tepee structures in size and in continuity of the folded beds. They differ from the wavy bedding described above in symmetry and in the fact that the small chevron folds involve similar behavior of several very thin beds.

GLIDE FOLDS

The many examples of intraformational deformation in the Bone Spring formation of the southern Guadalupe and Delaware Mountains are attributed by Newell et al. (1953) to creep and slump of poorly consolidated sediments on slopes. Glide folds in the Vittorio Peak member of the Bone Spring formation involve a body of strata at least 75 feet thick, in the NW¼ sec. 30, T. 26 S., R. 20 E. Near the lower limit of the mass, the beds dip 16° W. and are truncated along an underlying plane which dips much less steeply in the same direction. This plane is conformable with the underlying beds. Both these and the slumped beds are light-gray cherty limestone. This structure probably represents the upper limb of a primary recumbent fold which parted and slid along the axial plane.

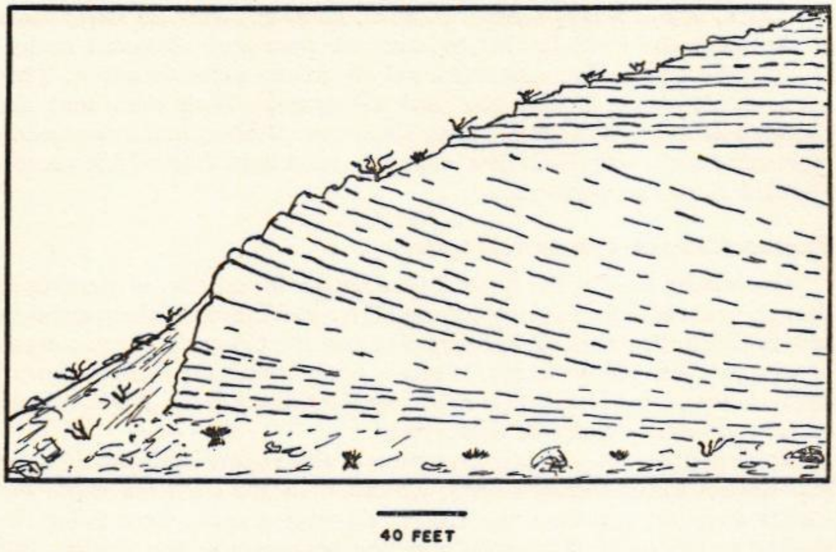
PRIMARY DIPS OF UNCERTAIN ORIGIN

Discordant dips in the central Guadalupe Mountains of uncertain, though probably diverse, origins, are all located either in the transition belt between the San Andres formation and the Cherry Canyon tongue or within a few miles thereof. It seems likely that some environmental condition peculiar to this belt might be recognized if the origins of the various structures could be determined.

Evidence presented in a later section of this report indicates that the San Andres formation was being deposited in the shelf sea while the Cutoff member, and later the Cherry Canyon tongue, were being deposited to the south. The transition belt between the San Andres and the basin units is several miles wide and trends roughly parallel to the Capitan reef. In the central Guadalupe Mountains, the belt is partially exposed in Last Chance Canyon in the area adjoining the northeast corner of El Paso Gap quadrangle. More extensive exposures of the transition belt are in the fault blocks of the west-central and southwestern parts of the quadrangle. Between this area and Last Chance Canyon, the transition belt is concealed except for a small exposure in the NW¼ sec. 18, T. 25 S., R. 21 E.

Four different types of discordant dips have been recognized in El Paso Gap quadrangle, their origins being ascribable respectively to: (1) more deposition in one area than in another, (2) deposition on an uneven surface, (3) penecontemporaneous tilting of the surface of deposition, and (4) deposition on truncated compaction folds.

More deposition in one locality than in the surrounding area resulted in thickening of the section by increase both in number of beds and in thickness of individual beds. Where these changes take place within a short distance, discordant dips can be recognized, as along the west front of Big Ridge, in SE¼ sec. 32, T. 25 S., R. 20 E., and NW¼ sec. 4, T. 26 S., R. 20 E. For the most part, the beds are nearly horizontal; however, the beds of a part of the section, about 100 feet thick, strike N. 50° E. and dip 18° SE. (fig. 6). Many of the discordant beds contain abundant fusulinid molds; others are composed of shell fragments and contain large crinoid columnals. A mold of *Leptodus* was identified in one of the wedge-shaped beds. These bioclastic beds dip and thin away from a fault-line scarp; they may be forereef deposits from reefs which are in the downthrown fault block. Exposed reefs at the same strati-graphic horizon and in the same facies a few miles farther west were



PRIMARY DIPS IN UPPER SAN ANDRES TRANSITION FACIES, BROKEOFF MOUNTAINS.

Figure 6

described above; they have associated discordant dips like those in Big Ridge.

The west wall of lower West Dog Canyon contains structures similar to those exposed in Big Ridge. The primary dip is toward the south and southwest away from the canyon. If the dipping beds are forereef talus, the reef either has been removed by erosion or is east of the canyon. Reefs were not recognized on the east wall of West Dog Canyon, although indistinct, irregular bedding characterizes much of the massive dolomite exposed there, and rare isolated sandstone lenses were noted. However, a large patch reef occurs nearby to the east, as noted previously in the discussion of reefs.

Attitudes of beds known or suspected to be flanking reefs in the San Andres transition facies were measured at 11 localities; 8 strike N. 42° to 73° E. and dip southeast; 3 strike N. 20° to 85° W. and dip southwest. A barrier reef was not yet in existence during deposition of the San Andres formation, but the detritus from the numerous small reefs was deposited in a basinward direction, suggesting that the area sloped toward the basin.

In Last Chance Canyon, just northeast of El Paso Gap quadrangle (fig. 1), the abrupt pinchout of one layer of limestone causes a discordance in dips at its margin. This massive ledge-forming bed is a distinctive unit in the canyon walls from the point of its first exposure, at the spring one-half mile beyond the boundary of El Paso Gap quadrangle, to its pinchout about 2 miles downstream. The medium-gray nodular limestone maintains a uniform thickness of 55 feet and contains a few silicified corals, brachiopods, and crinoid columnals. The limestone nodules are surrounded by silty limestone, which weathers grayish orange. Several exposures of the wedge-shaped margin of this unit occur in sec. 32, T. 23 S., R. 22 E., of Bandanna Point quadrangle. The location on the north side of Last Chance Canyon in this area indicates that the limestone is a basin deposit which pinches out a short distance to the north.

Much of the upper part of the Cherry Canyon tongue exposed in upper West Dog Canyon and Cork Draw (secs. 8 and 17, T. 26 S., R. 20 E.) shows evidence of deposition on uneven surfaces formed by current scour. The best exposed structures are large channel fillings (p1. 4B) in the upper 100 feet, and at the top, of the Cherry Canyon tongue. The "filling" is sandstone identical to the overlying basal Gray-burg sandstones. Some of these lenticular bodies are over 100 feet wide and 50 feet thick.

The uppermost Cherry Canyon beds are characterized also by primary dips discordant with the overlying horizontal Grayburg beds. In several localities beds converge upward into the massive ledge of sandy carbonate rock which occurs between the Cherry Canyon and the Grayburg in this region. The converging bedding surfaces are curved, convex upward. The surface of deposition toward the margin of the basin during deposition of the upper part of the Cherry Canyon tongue perhaps was tilted, causing subaqueous slumping and subsequent redistribution of sediments over an uneven surface.

Exposures in Last Chance Canyon, bordering El Paso Gap quadrangle on the northeast, show apparent truncated compaction folds (pl. 3A). The folded beds are cherty dolomitic limestone characteristic of the lower San Andres and include reeflike structures described above. These resistant bodies probably caused differential compaction. The beds underlying the folded sequence are horizontal, and the folds are truncated by overlying horizontal dark-colored dolomitic limestones containing abundant fusulinid molds. About 50 feet of such beds occurs here, compared to 200 feet in Big Dog Canyon, the next exposure to the west. This thinning and the truncated folds suggest that the shelf margin in the Last Chance Canyon area was subjected to subaqueous erosion during deposition of the upper San Andres formation elsewhere on the shelf.

SECONDARY STRUCTURES

FOLDS

A few structures in the central Guadalupe Mountains were formed by secondary flexing of strata. A southward plunging syncline occurs between Queen Mesa and Shattuck Valley, in secs. 20, 17, and 8, T. 25 S.,

R. 21 E. This structure is not the result of lateral compression but is a rotated fault block which sagged at its southern end. The eastern limb was formed by drag along the major fault which bounds Shattuck Valley on the east.

A monocline, broken in places by faults, forms the eastern front of Martine Ridge, in secs. 13, 24, and 25, T. 25 S., R. 20 E. Many of the fault scarps in the region are bordered by tilted segments of the down-thrown mass. Deformation in these cases probably began by flexing and was continued by normal faulting along major breaks in the monoclines.

FAULTS

The major valleys which border Queen Mesa on the west originated from faulting, and there are many normal faults in the mountains west of the valleys. These faults, some of which can be traced for miles, strike north to northwest, and their traces form a fan-shaped pattern that converges toward the south (see pl. I). The major displacement, which is as much as hundreds of feet, is dip-slip. The greatest displacements were on the major faults along the west margin of Queen Mesa.

Minor faults in many places cut large upthrown blocks near and parallel to the major bounding fault. The small downthrown blocks in most cases are downdropped on the same side of their faults as in the case of the nearby major fault. An exception is the western part of Big Ridge, a large horst, where two subsidiary faults outline a graben. The estimated throw is 250 feet on the east margin of the graben and 130 feet at the west margin.

Numerous segments of the downthrown block west of Queen Mesa are left on the major fault scarp, especially along the west margin of Shattuck Valley, and dip as much as 60° W. Some of these segments are easily recognized, but most of the blocks of westward dipping strata "hug" the fault scarp and are difficult to recognize from a distance. These westward dipping strata extend in places almost to the top of the scarp and in places are cut by strike faults of small displacement.

Toward the north end of Shattuck Valley, displacement of the major fault decreases. The scarp does not extend north of the Carlsbad-El Paso Gap road, but the fault probably continues along the western edge of Pickett Hill, which trends north-south. Also, a well drilled for water 1 mile northwest of Pickett Hill was dry and was abandoned 1,250 feet below the surface (Mr. Elmer Hepler, personal communication), whereas wells drilled east of the fault on Queen Mesa have been successful at much shallower depths. For example, a water well at Hamm tank is 688 feet deep.

The attitude of a sharply defined layer of breccia at the base of the eastern wall of Big Dog Canyon (NW¼ sec. 23, T. 24 S., R. 20 E.) may be similar to that of the major fault plane nearby. The breccia layer strikes N. 1° W., and dips 77° W.

The close coincidence of fault blocks and topography indicates that faulting occurred relatively recently in the region. King (1948) discussed at length the timing of deformation in the Guadalupe Mountains, concluding that most of the faulting took place in late Pliocene or early Pleistocene time.

Many of the stream courses of the central Guadalupe Mountains are consequent on downthrown fault blocks, but some were established before the faulting. For example, Panther Canyon cuts through many fault blocks, and North McKittrick Canyon appears to have been beheaded by the Shattuck Valley fault. At least some of the streams have had a change in gradient during Recent time, since thick deposits of alluvium in several canyons and along the fronts of escarpments are cut by V-shaped gullies up to 15 feet in depth. The alluvium may be post-Pleistocene in age, since a flint spearhead was found projecting from a gully wall (NW¼ sec. 18, T. 26 S., R. 21 E.) 2 feet below the surface of the enclosing gravel.

Paleontology

FOSSIL PRESERVATION

Most of the fossils in the central Guadalupe Mountains are either molds or silica replacements; many have been partially or totally destroyed during diagenesis. At some localities in the Queen formation, coquina with well-defined fossils grades within a short lateral distance into dolomite with either indistinct fossils or none at all. This progressive change from sharp to indistinct outline was observed also in concentric structures of algal(?) origin. Walther (1885) and Newell et al. (1953) recognize gradations in other formations from unaltered algae and other fossils to recrystallized, relatively featureless limestones. Well-preserved molds, not visible on weathered surfaces, were found in some beds.

Poor preservation of fossils in dolomitic rock frequently has been attributed to dolomitization. Nonsilicified fossils, other than algae, were collected from the Queen formation at seven localities on Queen Mesa, and fossil detail is notably better preserved at three of the localities. Analyses of samples from these seven localities are shown in Table 3. Samples 1-4 are from the poor-preservation localities, and nos. 5-7 from the good-preservation localities. These analyses show that, in general, the amount of magnesium carbonate is greater where the fossils are poorly preserved. However, since the opposite extremes in magnesium carbonate content differ by only 16 percent, the evidence is insufficient to warrant the conclusion that poor preservation in dolomites is a function of dolomitization. Also, Newell (1940) collected molds from the Dozier dolomite of the Whitehorse formation in Texas which show excellent detail.

Silicified fossils were collected from all the formations containing chert nodules except the Yeso, but selective silicification of fossils took place in beds where chert nodules were not formed, and a good silicified fauna was obtained from the Queen formation, which contains no chert nodules. These silicified fossils are of special interest, because secondary silica and well-preserved fossils are rare in the Queen formation.

The absence of silicification in reefs is noteworthy, especially in the many cases where chert occurs in surrounding bedded deposits. Newell et al. (1953) suggest that lack of silicification in some of these cases may be due to low hydrogen-ion concentration resulting from activity of scavengers and aerobic bacteria.

Silicification was apparently an early diagenetic event; in many localities, fossils replaced by silica are well preserved, whereas nonreplaced fossils have been partially destroyed. Some compaction occurred, however, before silicification of the Queen fauna mentioned above, as several of the specimens, mostly gastropods, appear to have been crushed prior to silicification.

Color markings, which may represent the original color pattern, were noted on several shells. Of the silicified specimens from the Queen formation, some *Bellerophon* fragments and one good specimen of *Bucanopsis modesta* have color markings, as does a calcareous specimen of *Chonetes* from the Cutoff member.

BASIN FAUNAS

Fossils were collected from the Cutoff member of the Bone Spring formation and the Cherry Canyon sandstone tongue. These units are represented in the Delaware Basin section south of the Texas border but grade into shelf facies in El Paso Gap quadrangle.

CUTOFF MEMBER

Table 4 shows the major taxonomic categories represented in the collections made during this investigation. The collections are detailed in the check list of species in the appendix.

The Cutoff member in the Brokeoff Mountains contains many specimens of the brachiopod *Chonetes* and of three gastropod genera, two of which have not been found in Last Chance Canyon. A few ledge-forming limestone beds are more fossiliferous than the more common slope-forming platy limestone and contain silicified fusulinids, corals, brachiopods, and crinoid columnals.

In Panther Canyon (SW¼NE¼ sec. 35, T. 25 S., R. 19 E.), several molds and casts were obtained from an 8-inch-thick bed in a narrow fault block about 50 feet wide. The bed is thought to be part of a tongue of the Cutoff member which extends into the lower part of the San Andres transition fades. A mold of the dental armor of the shark *Helicoprion* was observed in this bed by N. D. Newell. A fragment of a shark's tooth (Bobb Schaeffer, personal communication) was collected in Last Chance Canyon from a bed believed laterally equivalent to the Cutoff formation.

Other fossils in the Panther Canyon bed include the ammonoids *Pseudogastrioceras* sp. and *Perrinites hilli*. The former genus was not reported from the Bone Spring or Leonard formations by Miller and Furnish (1940). Since the discovery of the specimen in Panther Canyon, however, W. C. Warren and C. R. Grice collected a specimen of *Pseudogastrioceras* from 20 feet above the base of the Cutoff member, south of the Texas border (W. C. Warren, personal communication, October 27, 1955). According to A. K. Miller (personal communication, May 11, 1953), *Pseudogastrioceras* has a wide stratigraphic range in the Permian, ranging throughout almost the entire system. He considers *Perrinites* to be limited, however, to Leonardian beds, except for the first Word limestone in the Glass Mountains, where it is associated with

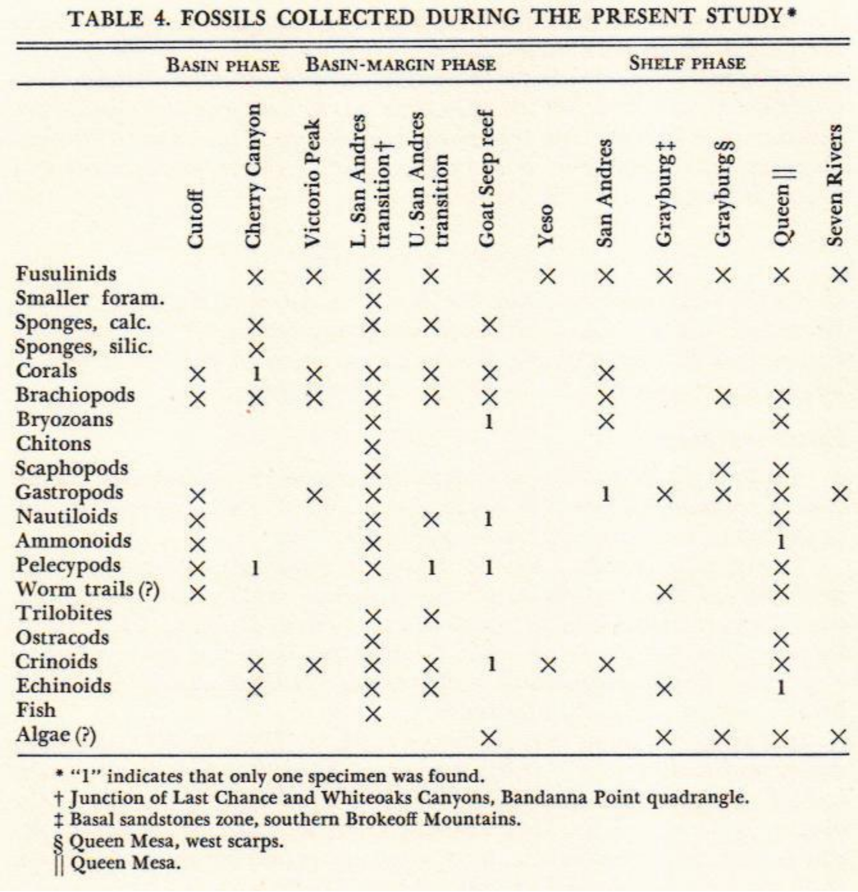


TABLE 4. FOSSILS COLLECTED DURING THE PRESENT STUDY*

	Basin phase		Basin-margin phase				Shelf phase					
	Cutoff	Cherry Canyon	Victorio Peak	L. San Andres transition†	U. San Andres transition	Goat Seep reef	Yeso	San Andres	Grayburg‡	Grayburg§	Queen‖	Seven Rivers
Fusulinids		×	×	×	×		×	×	×	×	×	×
Smaller foram.				×								
Sponges, calc.		×		×	×	×						
Sponges, silic.		×										
Corals	×	1	×	×	×	×		×				
Brachiopods	×	×	×	×	×	×		×		×	×	
Bryozoans				×		1		×			×	
Chitons				×								
Scaphopods				×						×	×	
Gastropods	×		×	×				1	×	×	×	×
Nautiloids	×			×	×	1					×	
Ammonoids	×			×							1	
Pelecypods	×	1		×	1	1					×	
Worm trails (?)	×								×		×	
Trilobites				×	×							
Ostracods				×							×	
Crinoids		×	×	×	×	1	×	×			×	
Echinoids		×		×	×				×		1	
Fish				×								
Algae (?)						×			×	×	×	×

* "1" indicates that only one specimen was found.
† Junction of Last Chance and Whiteoaks Canyons, Bandanna Point quadrangle.
‡ Basal sandstones zone, southern Brokeoff Mountains.
§ Queen Mesa, west scarps.
‖ Queen Mesa.

Leonardian brachiopods. Of the two nautiloid genera identified from the Panther Canyon outcrop, specimens of *Foordiceras* are similar to species from the Leonard formation of the Glass Mountains, according to Miller.

King (1948) designated the Cutoff member of the Bone Spring formation as Leonardian in age and is supported by the cephalopod evidence cited above. However, Hollingworth and Williams (personal communication, August 24, 1955) consider the Cutoff to be lower Guadalupian in age, on the basis of fusulinids from the type section.

A few poorly preserved fusulinids collected from the Cutoff member in the Brokeoff Mountains, north of the Texas border, were identified by Hollingsworth and Williams (personal communication, September 26, 1955) as probably of Guadalupian age. A collection obtained by H. N. Frenzel (personal communication, August 30, 1955) from the Cutoff member about 1 mile north of the Texas border, on Cutoff Ridge, yielded forms of *Parafusulina* said by Hollingsworth and Williams to be closer to Getaway (Guadalupian) types than to any others in their collections.

There are at least two possible explanations for the conflicting interpretations as to the age of the Cutoff member. First, *Perrinites hilli* may occur well into the Guadalupian series. Second, different lineages of fusulinids may have passed through the same developmental stages at different times. Since *Perrinites* has not been found with established Guadalupian index fossils (e.g., *Waagenoceras, Parafusulina rothz),* there is no conclusive proof that it occurs in strata younger than the first Word limestone. This suggests that our present knowledge of fusulinid evolution may be unsatisfactory for precise determination of the Leonardian-Guadalupian boundary in areas where the better known species are absent.

CHERRY CANYON TONGUE

The soft Cherry Canyon sandstone beds, which overlie the Cutoff member in the southern Brokeoff Mountains, contain silicified fusulinids, sponges, brachiopods, and echinoid spines. Silicification is imperfect, and only the external details of the fossils usually are preserved. The lyssacine hexactinellid sponge *"Hyalostelia"* is common. The bundles of fibers, which served these sponges as anchoring devices, usually are poorly preserved. Commonly only the exterior of the bundle is preserved, the original structure of the interior having been destroyed. The sponges may be mistaken for irregular porous chert nodules, when seen in cross-section in an outcrop. Silicified sponges are common in some of the Cherry Canyon beds. The genus *Defordia* is noteworthy because it, like the hexactinellids, was not found in any other formation. The only inarticulate brachiopod collected in El Paso Gap quadrangle is poorly preserved as a mold in the base of a silicified *Defordia.*

The south wall of West Dog Canyon (sec. 12, T. 26 S., R. 19 E.) exposes the Cherry Canyon tongue at its northern margin, where the tongue contains much sandy dolomite and dolomitic limestone as well as sandstone. The upper part of the Cutoff member is transitional between basin and shelf fades in this area, and the criteria used in differentiating the two units farther south are not applicable. Thus, a fossiliferous dolomitic limestone bed, 5 feet thick and 280 feet below the top of the Cherry Canyon tongue, cannot be assigned with certainty to either unit. It is thought, however, to be equivalent to part of the lower Cherry Canyon tongue, because thin underlying sandstone beds closely resemble those of the Cherry Canyon tongue farther south. The small but diverse fossil assemblage collected from the bed is unlike any other found in the Cutoff, the Cherry Canyon, or the San Andres. It probably represents a fauna restricted by environment to the edge of the basin. Brachiopods, trilobite pygidia, pelecypods, and several specimens of the coiled nautiloids *Stearoceras* and *Tainoceras* were collected. All the fossils are preserved as molds; weathered surfaces of the layer offer only a faint indication that it is fossiliferous.

On the south wall of Cork Draw (NW¼SW¼ sec. 17, T. 26 S., R. 30 E.), about 11/2 miles south of the northern limit of the Cherry Canyon tongue, a massive dolomite is exposed in the upper part of the slope-forming Cherry Canyon sandstone (fig. 3, locality 3). The dolomite is apparently the result of a concentration of lime-secreting organisms in this spot on the sandy Cherry Canyon sea bottom. The main part of the mass was probably a patch reef which rose above the surrounding sea floor.

Calcareous sponges were the first organisms to populate the spot; their dolomitized remains, mostly indistinct in outline, form a thin lenticular deposit, the lowest resistant bed, 60 feet long and as much as 13 feet thick. Exposures at the eastern limit of the lens show that the sponges give way to siltstone and sandstone which contain silicified brachiopods *(Composita* and spiriferids) and crinoid stems. These fossils are common for 50 feet away from the edge of the sponge-bearing lens, but beyond that distance the sandstone is unfossiliferous.

The lens is separated from the overlying reef by 5 feet of sandstone, which contains abundant remains of the aberrant brachiopod *Leptodus.* The sand evidently accumulated too rapidly for sponge growth but occasionally decreased sufficiently to allow population of the area by *Leptodus.* Some large spiriferids and a few productids were noted toward the margins of this deposit.

The overlying lens of massive dolomite, 56 feet thick, does not contain recognizable fossils; presumably they were destroyed by diagenesis. On the eastern flank the nonbedded rock grades into poorly bedded dolomitic limestone containing brachiopods *(Leptodus,* spiriferids, and productids) and chert nodules; farther east, the carbonate rock gives way to sandstone.

REEF AND BANK FAUNAS

VICTORIO PEAK MEMBER

Fusulinids, crinoid columnals, and brachiopods are the most common fossils in the Victorio Peak limestone. Some beds are composed largely of fusulinids. Euomphalid gastropods and solitary corals are common in some layers near the top of the formation. Many of the corals, brachiopods, and gastropods are silicified.

Fusulinids collected by the writer from the Victorio Peak member in West Dog Canyon, about 1 mile northwest of Berlin tank, were identified by Hollingsworth and Williams as upper Leonardian forms of *Parafusulina* (R. V. Hollingsworth, personal communication, September 26, 1955). These authorities also identified Leonardian forms in samples collected by H. N. Frenzel (personal communication, August 30, 1955) from the Victorio Peak member in Cutoff Ridge.

Frenzel and the writer independently collected fusulinids from the lower ledge-forming beds near the mouth of Chosie Canyon, 10 miles north of the Texas border (pl. 3B). These beds are thought by the writer to be laterally equivalent to the Victorio Peak member, for reasons already discussed. Hollingsworth and Williams report (H. N. Frenzel, personal communication, August 30, 1955) that the fusulinids in Frenzel's collection are poorly preserved but appear to be lower Guadalupian or upper Leonardian forms of *Parafusulina.* From the writer's collection, Gerald E. Marrall identified several forms of *Parafusulina*[4] which he regards as of lower Guadalupian age. He states, however, that the stage of evolution of these forms is not so far advanced as that of many lower Guadalupian specimens. The Chosie Canyon beds may not be laterally equivalent to the Victorio Peak member farther south; a time-transgressive contact may be involved. On the other hand, it is possible that the change in character of the fusulinid assemblages from south to north is a reflection of control by environment rather than by time.

SAN ANDRES TRANSITION FACIES

The most significant paleontological feature of the transition facies is the evidence afforded by the fossil patch reefs and reeflike structures of local concentration of lime-secreting organisms. The structural aspects of these reefs, as well as some possible reasons for their lack of well-preserved fossils, have been discussed previously.

Poorly preserved molds are scattered through most of the reefs. Thinwalled calcareous sponges are the most common fossils. Laminated deposits (possibly of algal origin), solitary corals, specimens of *Leptodus,* and crinoid columnals have been identified in one or more of the reefs.

In the interreef areas of the transition sequence, fusulinid molds are the most common fossils, but all the types of fossils found in the reefs have been collected also from nonreef beds. In addition, a few pelecypods, trilobite fragments, and echinoid spines were collected from exposures near the southern limit of the transition facies.

In Last Chance Canyon, the lower 150 feet of the exposure opposite the mouth of Whiteoaks Canyon is dissimilar in fauna and in many lithologic characteristics to all units mapped in El Paso Gap quadrangle. From its stratigraphic position it is considered probably part of the San Andres transition facies and equivalent to part of the Cutoff member farther south. Darton and Reeside (1926, p. 426) identified 28 species from these limestones and shaly limestones. The writer collected 20 genera of brachiopods, 11 of gastropods, 6 of cephalopods, and 6 of ostracods from these strata, as well as other fossils. Gastropods, brachiopods, and fusulinids are the most common fossils in the shaly limestones. One 15-inch-thick limestone bed contains an extraordinarily diverse

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[4] Personal correspondence, December 15, 1955. The forms identified are: *Parafusulina* ~~*splendens?, P. bosei?, P.* sp. (resem~~bles *P. bosei* var. *attenuate).*

fauna. Most of the fossils are silicified, and several hundred pounds of rock etched with hydrochloric acid yielded fusulinids, sponges, corals, bryozoans, brachiopods, chitons, scaphopods, gastropods, pelecypods, nautiloids, ammonoids, ostracods, and trilobites. A shark's tooth, one of two specimens of vertebrate material observed during this study, was obtained from the same layer.

GOAT SEEP AND CAPITAN REEFS

Newell et al. (1953) have published a detailed description of the reef complex of the Guadalupe Mountains. They conclude that the Permian reefs were formed mainly by algae, calcareous sponges, bryozoans, and organisms tentatively referred to as hydrocorallines. Other groups, such as the brachiopods, made relatively minor contributions to the reefs. No representatives of groups other than those reported by Newell and associates were found in the Capitan reef.

The fauna of the Goat Seep reef is not so well known as that of the overlying Capitan reef. Thus, some effort was made to locate and collect fossils from the exposures of the Goat Seep reef (fig. 3, locality 2) in North McKittrick Canyon (sec. 28, T. 26 S., R. 21 E.). Although most of the reef rock examined contained no recognizable fossils, a few limited exposures yielded abundant molds. Many of these fossils did not seem to be in growth position and thus may represent debris in cavities found in the reef framework or reef talus. Brachiopods are the most common fossils found in the reef; 10 species have been identified from the collections (see appendix). In addition to pelecypods, bryozoans, and sponges, all of which are reported by Newell et al. (1953, p. 178), corals, crinoid fragments, and an orthoconic nautiloid were collected from the Goat Seep reef.

SHELF FAUNAS

YESO FORMATION

Outcrops of the Yeso formation in the central Guadalupe Mountains are limited to the lower part of the east wall of Big Dog Canyon. Fusulinids and crinoid columnals were the only fossils found in the Yeso. Each type is abundant in a few thin beds, but neither is quantitatively important throughout the formation. No gastropods were found in the Yeso, although Lang (1937) found specimens of *Bellerophon* and *Euomphalus* in black limestones of the formation.

The rarity of fossils in the Yeso is probably the result of deposition in a hypersaline sea. The bedded gypsum in the formation is direct evidence for this theory.

SAN ANDRES FORMATION

The San Andres formation is the only shelf unit of the central Guadalupe Mountains whose fauna suggests prolonged presence of a sea of normal salinity. Brachiopods and corals, two groups restricted today to sea water of normal salinity, are common in the formation. Fusulinids and crinoid fragments are numerous in the central Guadalupe Mountains area; bryozoans, gastropods, pelecypods, and echinoid spines are rare. Many of the fossils are imperfectly preserved by silicification.

As mentioned above, the upper 200 feet of the San Andres formation exposed on the east wall of Big Dog Canyon is different from the lower part, being characterized by an abundance of fusulinid molds; no other fossils were observed.

Much has been published concerning the age of the San Andres formation and the correlation of the San Andres with units on the east side of the Permian Basin. The age of the San Andres has been considered: (1) Leonardian, (2) Wordian, and (3) Leonardian for the lower part and Wordian for the upper part.

The fossils most frequently mentioned in literature concerning the age of the San Andres formation are the fusulinid species *Parafusulina rothi* and the ammonoid genera *Pseudogastrioceras* and *Perrinites.*

The fusulinid species *Parafusulina rothi,* considered by Skinner (personal communication, August 19, 1955) to range through the upper Brushy Canyon and lower Cherry Canyon formations, has been identified from San Andres strata in several localities. Lewis (1941, p. 99-100) summarized the occurrences of *Parafusulina rothi* in the subsurface; the lowest was 675 feet below the top of the San Andres. Lewis also noted the presence of *Dictyoclostus bassi* and *Parafusulina fountaini,* the latter a common fossil in the Victorio Peak limestone, in beds just above the "Holt Pay" and 1,000 feet below the top of the San Andres, in Ector County, Texas, wells. The "Holt Pay" is a limestone zone about 140 feet above the top of the subsurface Glorieta. Lewis theorized that the lower San Andres is Leonardian in age. Since the subsurface San Andres commonly includes about 1,200 feet of strata, King (1942, p. 694) suggested that the upper part of this sequence is not properly part of the San Andres formation.

Needham (1937, p. 17) described *Parafusulina dunbari,* which he interpreted as of Wordian age, from Last Chance Canyon, near Sitting Bull Falls. His description of the Ethology indicates that the collections came from the lower San Andres. According to Skinner (personal communication, August 19, 1955), Needham's *Parafusulina dunbari is a* synonym of *P. rothi* and is accompanied in Last Chance Canyon by *P. lineata* and *P. deliciasensis,* which Skinner regards as confined to the Cherry Canyon formation and equivalents.

Skinner (1946, p. 1865) collected *Parafusulina rothi* from the lower (cherty) San Andres of the Big Dog Canyon fault scarp, near the north boundary of El Paso Gap quadrangle. In 1946, H. N. Frenzel and W. C. Warren collected fusulinids from San Andres beds 190 feet above the Glorieta sandstone, a few miles north of El Paso Gap quadrangle. Hollingsworth and Williams identified the specimens as elements in the

Parafusulina rothi-maleyi assemblage and regarded them as lower or middle Guadalupian in age (H. N. Frenzel, personal communication, August 30, 1955).

Fusulinids found in the lower part of the San Andres formation in NW¼SW¼ sec. 21, T. 23 S., R. 20 E., were identified by Hollingsworth and Williams as *Parafusulina.* They resemble *P. splendens* and may be a new variety of that species, or a new species. At any rate, they are reported to be of lower Guadalupian age. Chert chips containing fusulinids were found in drill cuttings beside the water well at Hamm tank. Hollingsworth and Williams state that this material contains *Parafusulina* sp. insufficient for specific identification, but of Guadalupian types. The chert came from the San Andres formation, probably from the lower part.

Perrinites was widely used as an index fossil diagnostic of Leonardian age until Clifton (1954) found it in the lowest limestone member of the Word formation, in the Glass Mountains of Texas. King (1947, p. 775-776) pointed out that Perrinites occurs only 150 feet from the base of the Word formation, and not in association with the *W aagenoceras* ammonoid assemblage nor with the *Parafusulina rothi* fusulinid assemblage, both of which are considered diagnostic of Guadalupian age. This observation is still valid, not only for the Glass Mountains but also for the Permian Basin.

Although some geologists believe that the stratigraphic ranges of *Perrinites* and of some Guadalupian fusulinids overlap, their evidence is not condusive. For example, Skinner (1946) noted the occurrence of *Perrinites* in the "Blaine of Texas," at the eastern margin of the Permian Basin, and stated that subsurface beds containing Wordian fusulinids can be traced into the "Blaine of Texas" outcrop. He also cited Clifton's (1945) report of *Perrinites* in the upper San Andres some 35 miles west of Artesia, New Mexico, and noted that *Parafusulina rothi,* a Guadalupian species, was known from the lower San Andres farther south, in the northern Guadalupe Mountains. The stratigraphic location of Clifton's *Perrinites* needs confirmation. The collecting locality may be in the lower rather than upper San Andres formation, for according to H. N. Frenzel (oral communication, October 1955), the lower San Andres is brought to the surface by faulting in some places west of Artesia.

Pseudogastrioceras had not been reported from Leonardian beds in this country when Miller and Furnish (1940) published their study of Permian ammonoids of the Guadalupe Mountains. King (1947), however, pointed out that the genus was known from beds of Leonardian age in the Eastern Hemisphere. Two specimens were subsequently obtained from two localities from the Cutoff member of the Bone Spring formation.

Miller now believes that *Pseudogastrioceras* has a long range in the Permian system and that Leonardian forms cannot be distinguished from Guadalupian specimens (letter from A. K. Miller to W. C. Warren, October 31, 1955). In view of this decision, one notes that several authors previously cited the association of *Pseudogastrioceras* with *Perrinites as* evidence that the range of the latter genus extends into the Guadalupian series. Clifton (1945) cited the presence of *Pseudogastrioceras beedei* in the San Andres of the Sacramento Mountains as evidence of Guadalupian age for the enclosing strata, and Skinner (1946) emphasized the association of *P. texanum* and *P. roadense* with *Perrinites* in the "Blaine of Texas" for this reason.

In summary, Guadalupian fusulinids have been reported by reliable investigators in the San Andres formation. *Pseudogastrioceras* and *Perrinites* have been identified from the formation in the Sacramento Mountains. The former genus has a wide range in the Permian, but the latter genus is not known positively to occur above the Leonard series except in the first limestone of the Word formation in the Glass Mountains. The reported occurrence of *Perrinites in* the upper San Andres is subject to question, and the oldest Guadalupian fusulinids known to the writer occur 190 feet above the base of the formation. The faunal evidence suggests that the Leonardian-Guadalupian boundary lies within the lower part of the San Andres formation, at least in the central Guadalupe Mountains region.

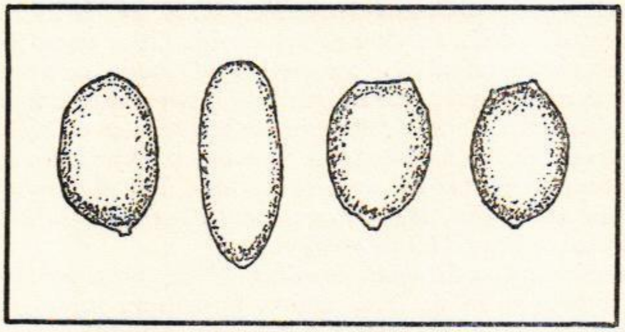
In the type section of the San Andres formation, Flower (in Kottlowski et al., 1956) identified *Perrinites* and *Pseudogastrioceras* from beds about 550 feet above the base of the formation. This indicates a Leonardian age for most of the type San Andres.

GRAYBURG AND QUEEN FORMATIONS

Newell et al. (1953) were the first to publish a description of a varied fauna from the Grayburg-Queen sequence, although Newell (1940) had previously described the Whitehorse fauna, which is of about the same age. They found representatives of eight classes (four phyla), as well as several types of algae. Blanchard and Davis (1929, p. 972) earlier reported that Beede had collected fossils from the Queen and considered the fauna to resemble that of the Whitehorse sandstone.

Molds of mollusks and fusulinids are scattered through the carbonate rocks of the Grayburg-Queen sequence, but well-preserved fossils are rare. Collections were made from five new fossil localities at various horizons. The highest of these, from the north side of Hamm Draw (NW¼SE¼ sec. 2, T. 25 S., R. 21 E.), provided the most diversified and numerous assemblage (see appendix, collection 0101). The collection was largely from a partially silicified coquina, itself of interest, because secondary silica is rare in post-San Andres beds of the shelf phase.

Nine hundred pounds of the dolomitic limestone was leached with hydrochloric acid, the fauna obtained being dominantly molluscan. Gastropods, pelecypods, and scaphopods are abundant. *Bellerophon majusculus,* a gastropod, is the most common species in the assemblage.



SILICIFIED PROBLEMATICA, QUEEN FORMATION.

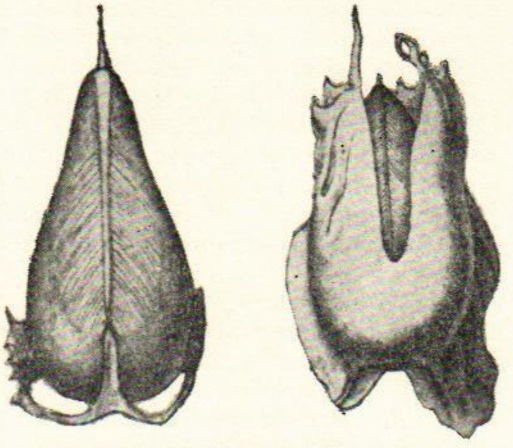
Figure 7

Most of the specimens of this species are worn and abraded fragments; their abundance is at least partially the result of sorting. Of the 13 gastropod genera identified, bellerophontids and representatives of *Cyclites* and *Callistadia* are most abundant. Of the 10 pelecypod genera identified, 2 are quantitatively important (see appendix).

Cephalopods are rare in the Grayburg-Queen sequence, but several were found at the Hamm Draw locality. One fragment of a coiled nautiloid *(Metacoceras?)* was recovered from the etched material, and several nonsilicified specimens of a small orthoconic nautiloid *(Mooreoceras?)* were collected from the same locality. Likewise, a nonsilicified ammonoid was collected by William Wiles but is too poorly preserved for generic identification. This is the only ammonoid known from post-San Andres shelf beds and as such is the youngest Permian ammonoid reported from New Mexico.

Rare fragments of siphonous algae, corals, bryozoa, and ostracods were found in the material from Hamm Draw but not elsewhere in the Grayburg-Queen sequence. However, no fusulinids, crinoid fragments, or brachiopods were found at Hamm Draw, although they were observed at other localities. The three last-mentioned groups, plus gastropods, nautiloids, and scaphopods, account for all the types of animal remains found in the Grayburg-Queen sequence, exclusive of the Hamm Draw locality.

One 100-pound block of silicified dolomite from this locality yielded 75 peanut-shaped problematica concentrated in one layer (fig. 7). They are 5 to 12 mm long and 2 to 5 mm wide. Most are entirely or partly filled with quartz crystals, but some are hollow. The "shell" thickness is about that of a sheet of paper. Most of these objects have one or two tiny protuberances on each end. Some were crushed before silicification took place, as were some of the gastropods from the same locality. Several dozen similar objects were collected from a lower bed of the Grayburg-



EGGS OF *Nautilus macromphalus.*

Figure 8

Queen sequence, about 3 miles north of Hamm Draw. They are also silicified but are packed together and superficially resemble pisolite. Several tiny orthoconic nautiloids, 3 to 15 mm long, are scattered through the group. At the Hamm Draw locality, silicified nautiloids were not obtained, but numerous nonsilicified orthocones, 1 to 5 inches long, were found nearby in the same bed.

The peculiar objects may be nautiloid egg cases, although comparison with the egg of the living *Nautilus* is not conclusive. The ovum of the living *Nautilus* is enclosed in a double casing made up of an inner and an outer capsule (fig. 8). Willey (1897, p. 467) noted that the capsules consist of a firm material of "cartilaginoid consistency," which retains its shape when dry. Although Willey did not actually observe *Nautilus* embryos in various stages of development, he believed that the shell and several chambers are formed while the embryo is still in the egg capsule (1902, p. 809).

The inner capsule resembles the objects from the Queen formation in general shape and in possession of a protuberance, but the size is three times that of the fossils. Furthermore, the fossils do not show a dorsal ridge or suture lines. The fossils lack the ridges and fenestrations that characterize the outer capsule of the recent eggs.

Brachiopods are rare in post-San Andres beds of the shelf phase, but four genera were collected from the Grayburg-Queen sequence. Only one genus, *Hustedia,* was found at more than one locality. The northernmost locality yielding brachiopods is 120 feet above the top of the San Andres formation, in NW¼ sec. 23, T. 24 S., R. 20 E. A chonetid was found here associated with gastropods and scaphopods. *Worthenia* sp. and *Euomphalus kaibabensis* are the most common gastropods. Ellis

Yochelson, of the U. S. Geological Survey, believes that the latter species may be indicative of upper Leonardian or lower Guadalupian age.

The exact stratigraphic position of the southernmost locality is unknown; it is in a small fault block tilted against the west-bounding fault scarp of Queen Mesa, in SW¼ sec. 4, T. 26 S., R. 21 E. The brachiopod *"Horridonia" walcottiana* was found here with representatives of 8 gastropod genera, pelecypods, scaphopods, and 1 coiled nautiloid *(Foordiceras?)*. Of the gastropods, *Goniasma, Murchisonia, Meekospira,* and a subulitid genus are most abundant. A new pleurotomarian genus is represented by a few specimens.

Only one locality (SW¼SW¼ sec. 9, T. 25 S., R. 21 E.) *yielded* two genera of brachiopods. *Composita* and *Hustedia* were found associated with numerous gastropods, including 1 bellerophontid species, 2 subulitid species, and 1 naticopsid species, which was represented by more individuals than were all the other species combined. The fossils were collected from a 1-inch-thick dolomite bed between calcarenite beds and show no evidence of transportation. The brachiopods are the youngest yet found in the shelf phase. *Hustedia* was collected at one other locality (NWIA sec. 33, T. 25 S., R. 21 E.), about 500 feet below the top of the Queen formation.

Fusulinid molds are common in some beds of the Grayburg-Queen sequence, but well-preserved forms are rare. Several good specimens collected from the lower part of this sequence on the Shattuck Valley east wall (SW¼ sec. 16, T. 25 S., R. 21 E.) were identified by Hollingsworth and Williams as *Parafusulina* cf. *bosei.* They noted that the specimens are more loosely coiled than is normal for the species. *Parafusulina is* the only fusulinid genus reported by Newell et al. (1953) from the Grayburg and Queen formations.

Many of the carbonate beds of the Grayburg-Queen sequence show distinctive laminations readily visible as a result of differential weathering. These laminations are similar to structures forming today through action of sediment-binding algae. It appears, therefore, that blue-green algae were abundant in the central Guadalupe Mountains region during deposition of the Grayburg-Queen sequence, and that the water during much of this time was less than 5 feet in depth.

The scarcity of fossils in the sandstones suggests that deposition was rapid. Aside from a few sinuous trails of problematical origin, no fossils were observed in the Queen sandstones. The sandstone beds of the lower Grayburg in the southwestern quarter of El Paso Gap quadrangle contain scattered gypsum fillings of fusulinid molds, echinoid spines, and gastropods; trails 20 mm wide were observed on several bedding planes.

The Whitehorse fauna described by Newell (1940) is a shelf fauna of about the same age as that of the Queen formation. Two assemblages are compared in the appendix.

In summary, the fossil collections from the Grayburg-Queen sequence are dominantly molluscan. Stenohaline organisms such as corals, bryozoans, and brachiopods are rare, and one may assume that the shelf seas were in the process of transition from normal salinity, in which the San Andres formation seems to have been deposited, to the hypersaline condition which characterized subsequent shelf seas.

SEVEN RIVERS FORMATION

Fossils are rare in the Seven Rivers formation except near the Capitan reef; even there the fauna is not diverse. Large bellerophontid gastropods 2 inches in diameter, fusulinids, and pisoliths were the only fossils found. Newell et al. (1958) also collected pelecypods and the alga *Mizzia.* The fusulinids, some of which are surrounded by algal(?) deposits, are all of the genus *Polydiexodina.*

General Facies Relationships

CORRELATION OF FORMATIONS

INTRODUCTION

Correlation of the Permian shelf and basin sections in the western Texas-southeastern New Mexico area has been hindered by insufficient knowledge of the San Andres formation in the critical area of changing facies.

Speculation as to the basinward equivalent of the San Andres first favored the Capitan formation. This theory was popular in 1929 (e.g., Willis, 1929) but proved untenable. Subsequent debate centered around the Cherry Canyon sandstone and the upper Bone Spring formation. Bybee et al. (1931) and Newell et al. (1953) are among those who favor the Cherry Canyon formation as the basin equivalent of the San Andres. P. B. King and R. E. King (1929) and P. B. King (1948), on the other hand, favored the upper Bone Spring. Lewis (1941) concluded that the San Andres is equivalent to part of the Cherry Canyon and Brushy Canyon formations, and Dickey (1940) stated that the type locality section, the lower 500 feet of the formation, is probably Leonardian in age, whereas the remainder is equivalent to the middle Delaware Mountain sandstone (Cherry Canyon).

None of the above conclusions were based on field mapping in the central Guadalupe Mountains. The present study of the transition belt between the San Andres formation and its basin equivalents in the central Guadalupe Mountains showed that field mapping could solve some of the Permian correlation problems.

Geologic mapping of El Paso Gap quadrangle included excellent exposures of the San Andres transition facies, although many normal faults in the quadrangle trend nearly at right angles to the margin of the Delaware Basin, and the transition facies occurs within a number of horsts. Over 60 sections were measured in El Paso Gap quadrangle (several only a few hundred yards apart) in the transition belt between shelf and basin phases. Excellent exposures of nearly horizontal strata enabled correlations of many critical sections by following beds between sections.

IMPORTANT STRATIGRAPHIC BOUNDARIES

The main objectives of the field mapping were the determination of relationships between Leonardian and Guadalupian shelf units and the correlation of these with basin units. Some of the formation contacts are of special interest because they have been recognized over wide areas and are mentioned frequently in geological literature of Texas and New Mexico.

In the shelf phase, the Yeso and San Andres formations, separated by the thin Glorieta sandstone, are widely recognized in the subsurface. Although the type localities of these formations are far north of the Guadalupe Mountains, the Yeso and San Andres equivalents have been recognized by many geologists in the northern Guadalupe Mountains. In the central Guadalupe Mountains, the Glorieta sandstone has not been recognized, and the San Andres formation lies directly on the Yeso (Skinner, 1946). The two units differ greatly in resistance to erosion, so that the contact is distinctive.

Another important horizon in the shelf section is the top of the Queen formation. In the surface studies of King (1948) and Newel et al. (1953), the top of the Queen formation is placed at the top of a distinctive sandstone sequence (the Shattuck member), which pinches out at the base of *the* Capitan reef. The top of the Queen formation is also an important subsurface datum plane, but some geologists have suggested that the top sandstone bed of the subsurface Queen is stratigraphically higher than the top of the Shattuck member (e.g., Frenzel, 1955). Newell et al. (1953) name King's (1948) distinctive sandstone member, which caps the pre-Capitanian shelf sequence in the central Guadalupe Mountains, the Shattuck member. The top of this member was used as the top of the Queen formation by the writer.

Of the stratigraphic boundaries mapped by King (1948) as far north as the southern border of El Paso Gap quadrangle, one of the most distinctive is the contact between two members of the Bone Spring formation, the ledge-forming Victorio Peak member and the overlying slope-forming Cutoff shaly member. The writer mapped this contact from the State line to the west-central part of El Paso Gap quadrangle. No evidence was found of interfingering between the two members, such as would be expected if the contact were time-transgressive. This casts uncertainty on the use of fusulinids in differentiating Leonardian and Guadalupian age, since fusulinid evidence can be cited to indicate that the contact is progressively younger from south to north in the central Guadalupe Mountains.

Field tracing of the stratigraphic boundaries clarified the relationship between the units of the shelf and basin phases, but not all problems of correlation have been solved. For example, the upper boundary of the Victorio Peak and the lower boundary of the San Andres are distinctive horizons in the southern and northern sequences, respectively. If the two boundaries could be traced into a single locality, the relationship of the two would be seen. However, the top of the Victorio Peak is concealed by alluvium north of Chosie Canyon, and the nearest exposure of the base of the San Andres is 9 miles to the northeast. Thus, the critical horizons are concealed under Big Dog Canyon and the northern Brokeoff Mountains, so that the location and nature of the passage of Victorio Peak beds into the shelf facies, or of the Yeso formation into the basin sequence, are not known. Although these two units are dissimilar at surface exposures, evidence discussed below indicates that much of the Victorio Peak member grades laterally into the Yeso formation beneath the northern Brokeoff Mountains.

The top of the San Andres formation was defined locally for the purpose of field mapping. Only one datum plane between the base of the San Andres and the top of the Queen is sufficiently distinctive to be mapped. This is the boundary between dark- and light-colored carbonate rocks, approximately 800 feet below the top of the Queen and 700 feet above the base of the San Andres. Although the contact is gradational, the transition takes place within a few feet.

The thickness of strata between the top of the San Andres, as herein defined, and the Queen formation is about the same as that commonly reported for this sequence in the subsurface. However, the thickness of the San Andres is several hundred feet less at the outcrop than usually reported from the subsurface, to the east and northeast. Selection of a higher datum plane for the top of the San Andres would merely transfer the discrepancy in thickness to the Grayburg-Queen sequence.

The light-colored rocks above the San Andres formation are laterally continuous with those overlying the Cherry Canyon tongue in the southern Guadalupe Mountains. Although the lower boundary of the light-colored rocks appears to be about 100 feet lower stratigraphically in the northern sequence than in the southern sequence, the light-colored rocks blanket the older rocks of both shelf and basin phases and make the division valuable for correlation of the northern and the southern sequences. This is the only distinctive stratigraphic boundary found in both the Brokeoff Mountains and Big Dog Canyon scarp.

SURFACE CORRELATIONS

The deposits laterally transitional between the San Andres formation and its basin equivalents, exposed in the fault blocks of the Broke-off Mountains, were mapped as a facies of the San Andres formation (see pl. 1).

Two localities are critical for an understanding of the stratigraphic relationships. In a fault block cut by Panther Canyon, in SE¼ sec. 35, T. 25 S., R. 19 E., the San Andres is underlain by characteristic beds of the Victorio Peak member of the Bone Spring formation (pl. 2). This member, a unit of the basin-margin facies, is reported at this vicinity by Newell et al. (1953, pl. 4, fig. 2). However, some of the exposures designated by them as Victorio Peak are considered by the writer to be equivalent to the Cutoff member farther south.[5] This is founded on their position below the base of the Grayburg formation, which overlies both shelf and basin units. Ledge-forming beds thought by the writer to be equivalent to the upper Victorio Peak are exposed beneath the

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[5] In Plate 4, figure 2 (Newell et al., 1953), the Victorio Peak member is identified at four localities. The present writer agrees with the identification of the northernmost and southernmost of these but believes that the Victorio Peak is not exposed at the other two localities.

San Andres in Chosie Canyon, about 5 miles north-northwest of the Panther Canyon locality. In both localities, the San Andres is overlain by light-colored calcarenites which grade upward into thinbedded microcrystalline dolomite with a few interbedded thin sandstones. These light-colored beds are a southern extension of the Grayburg formation.

North-south correlation of closely spaced sections through the San Andres transition facies indicates that the base of the distinctive light-colored sequence is about 100 feet lower stratigraphically where it overlies the San Andres formation than it is in the area where it overlies the Cherry Canyon tongue. Apparently, the upper part of the Cherry Canyon tongue grades northward into the lower part of the light-colored sequence (pl. 6A,D). Furthermore, where this sequence overlies the Cherry Canyon tongue, the lower 75 feet is characterized by numerous even-bedded medium-grained quartz sandstone beds. Aside from these two changes in character, the light-colored sequence continues southward beyond the Texas line.

Some 600 feet of San Andres beds near the southern limit of the formation (e.g., in Panther Canyon) is bracketed, as is the sequence composed of the Cutoff member and the Cherry Canyon tongue farther south, by the Victorio Peak member below and the Grayburg formation above. The lower half of the 600-foot sequence is laterally equivalent to the Cutoff member. The thickness of the San Andres between the Victorio Peak and the Grayburg in Panther Canyon is close to that of the interval between the Yeso and the Grayburg on the east wall of Big Dog Canyon. The two sequences are similar, but there are three notable differences.

First, the upper unit of the San Andres is of different thickness in the two localities. In Big Dog Canyon, the upper part consists of noncherty dolomitic limestone characterized by abundant fusulinid molds; it ranges from 175 to 250 feet in thickness in three measured sections. In Panther Canyon, it is thinner, ranging from 140 to 180 feet in short distances.

Second, the Panther Canyon section is characterized by large-scale crossbedding in the upper part of the lower San Andres. Although recognized at some other localities in the Brokeoff Mountains, the large-scale crossbedding was not noted along the Big Dog Canyon east wall except at the southern end of the canyon.

Third, the beds overlying the Victorio Peak in Panther and Chosie Canyons are similar to the Cutoff member farther south not only in stratigraphic position relative to the top of the Victorio Peak and the base of the Grayburg formation (pl. 6D), but also in lithology. Thus, although the Cutoff member and the Cherry Canyon tongue of the basin phase both grade laterally into the San Andres formation of the shelf phase, the lower part of the Cutoff member retains its identity several miles farther shoreward than does the rest of the sequence.

The combined thickness of the Cutoff member and the Cherry Canyon tongue just south of the Texas border, at Cutoff Mountain, is about 500 feet (Newell et al., 1953, p. 22). Sandstones overlying the lower Cherry Canyon tongue are included in the Goat Seep formation by King (1948) and are part of the Grayburg formation as interpreted herein. The upper part of the lower Cherry Canyon tongue is progressively less arenaceous northward from the State line, and the entire Cherry Canyon sequence is predominantly dolomite in West Dog Canyon, 5 miles northwest of Cutoff Mountain. Here, the sequence between the Victorio Peak and the basal sand of the Grayburg, 600 feet thick, was mapped as the San Andres transition facies. The lower 75 feet of the Grayburg formation here, as well as to the south, is composed of interbedded light-colored dolomite and even-bedded sandstone. North of this locality, however, the lateral change of these sandstones into carbonate is largely accomplished within one-half mile, and they disappear north of the transition facies of the San Andres formation. Correlation of sections north and south of the transition facies of the San Andres was accomplished by following ledges toward the basin margin between closely spaced measured sections.[6] As shown in Plate 6A,D, the top of the San Andres is below the horizon of the top of the Cherry Canyon sandstone. The San Andres transition facies occupies a belt about 1½ miles wide. At the northern margin of this belt, the base of the Grayburg lies from 110 feet (Big Ridge) to 150 feet (Panther Canyon) stratigraphically below the horizon with which it coincided at the southern margin of the transition facies.

Since the interval between the top of the Victorio Peak and the base of the Grayburg is 600 feet at both margins of the transition facies, the additional Grayburg section at the northern margin is probably due to slight downwarping of the shelf north of the basin during deposition of the lower Grayburg.

In the highly fossiliferous basin sequence of the southern Guadalupe Mountains, the Leonardian-Guadalupian boundary is placed (King, 1948) at the contact of the Bone Spring limestone (Leonardian) and the overlying Brushy Canyon sandstone (Guadalupian). King (1948) and Newell et al. (1953) agree that the Brushy Canyon pinches out by northward overlap several miles south of the Texas-New Mexico border and consider the resulting unconformity to represent the Leonardian-Guadalupian boundary in the marginal phase.

Although some geologists recently have expressed the opinion that the Cutoff member at its type locality is of Guadalupian age (e.g., Lloyd, 1954), no compelling evidence has been cited for such a conclusion. Newell et al. (1953, p. 23) found evidence, however, that the upper several hundred feet of the Bone Spring formation in the Delaware Basin is younger than the Cutoff member at its type locality, near the

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[6] E.g., from the center of sec. **36,** T. 25 S., R. 19 E., to SW¼ sec. 6, T. 26 S., R. 20 E.; the west side of Big Ridge, in sec. 4, T. 26 S., R. 20 E., and sec. 32, T. 25 S., R. 20 E.

Texas-New Mexico border. Paleontological evidence of the age of the Cutoff member is inconclusive but suggestive of Leonardian age. On paleontological grounds, the Bone Spring formation is generally believed to be entirely Leonardian in age within the Delaware Basin.

Since the writer's study indicates that the Cutoff member is equivalent to part of the lower San Andres formation, the Leonardian-Guadalupian boundary in the shelf phase must lie within the San Andres formation.

A composite section of the interval between the top of the San Andres formation and the top of the Queen formation was compiled by "walking out" a succession of sandstone beds between Last Chance Canyon, in the northeastern corner of El Paso Gap quadrangle, and the head of North McKittrick Canyon (p1. 6C). This section, 675 feet thick, establishes a relationship between the Last Chance Canyon San Andres exposures, Crandall's (1929) type locality for the Queen sandstone, and the top of the Queen formation as defined by Newell et al. (1953).

Sandstone beds were followed from Last Chance Canyon upstream to the center of sec. 25, T. 24 S., R. 20 E., and thence northwest along a tributary valley, thereby establishing the relationship between the Big Dog Canyon section near Coats Lake and the composite section (pl. 6C).

As shown in Plate 6C, the top of the San Andres in the Big Dog Canyon section is stratigraphically 225 feet below the top of the formation 7 miles to the east-northeast, in Last Chance Canyon. This conclusion is based on the assumption that the individual sandstone beds are synchronous throughout; no contrary evidence was found. Part of the difference in stratigraphic position may be due to cumulative errors in field tracing, but much of the difference is probably real and analogous to that in the southwest quarter of El Paso Gap quadrangle, where the bottom of the Grayburg is stratigraphically lower north of the San Andres transition facies than south of it. The San Andres exposures in the northeast quarter of El Paso Gap quadrangle are near the transition belt, whereas the Coats Lake section is several miles north of it. Furthermore, the truncated compaction folds and the thin upper San Andres (fusulinid dolomite) section in Last Chance Canyon suggest that the top of the San Andres is stratigraphically higher in that area than where such features do not occur.

Lang (1937) proposed the name "Dog Canyon limestone" for the light-colored carbonate rocks exposed in Upper Dog Canyon and at the top of the east wall of Big Dog Canyon, but he did not define limits for the unit. The unit has been little used, as the relationships to the San Andres and Queen formations are uncertain. These rocks have been classed with the Grayburg formation. Although the term "Dog Canyon limestone" has priority over "Grayburg formation" (Dickey, 1940), the latter name has been adopted by those working on subsurface geology. The Grayburg type section is in the subsurface, where specific horizons were defined as its top and bottom. Moran (1954) recently designated a measured section in Carlsbad Caverns West quadrangle as a surface reference section for the Grayburg formation.

King (1948) mapped the Goat Seep and Capitan reefs in North McKittrick Canyon. His map shows the basal sandstone member of the Carlsbad limestone pinching out on top of the Goat Seep reef. The sandstone was named the Shattuck member of the Queen formation by Newell et al. (1953). Moran (1954) recognizes the Shattuck member as the uppermost 100 feet of his type section of the Queen. Thus, in surface exposures, the Queen formation is equivalent to the upper part of the Goat Seep reef, and the Seven Rivers formation is the oldest Capitanian shelf deposit.

The maximum thicknesses of the San Andres formation and the Grayburg-Queen sequence in the area were found to be 700 feet and 900 feet, respectively. The sections measured by Moran (1954) as type sections for the Queen and Grayburg formations total 896 feet, the Queen being 421 feet thick, and the Grayburg 475 feet thick.

The 900 feet of the Grayburg-Queen sequence passes laterally into the Getaway limestone and the Goat Seep reef. These basin-margin units are exposed on Bush Mountain, several miles south of the Texas border; their total thickness there is estimated at 1,200 feet by Newell et al. (1953).

SUBSURFACE CORRELATIONS

Although the composite section of this report includes 1,600 feet of strata between the top of the Yeso and the top of the Queen, a much greater thickness usually is reported for this interval in the subsurface. For instance, cross-sections by Skinner (1946) from wells southwest of Carlsbad show 1,200 feet of San Andres, 380 feet of Grayburg, and 650 feet of Queen. A well in southeastern Chaves County, New Mexico, includes 1,250 feet of San Andres, 300 feet of Grayburg (the same thickness as at the subsurface Grayburg type locality), and 325 feet of Queen.

Although Dickey (1940, p. 43) gave a thickness of 1,250 feet for the San Andres in the northern Guadalupe Mountains, this includes several hundred feet of beds mapped by the writer as part of the GrayburgQueen sequence. The great thickness commonly reported for the San Andres in the subsurface probably includes beds which would be mapped as Grayburg in the Guadalupe Mountains.

Lewis (1941, p. 95) cited the Henderson No. 1 Wyatt well in west-central Lea County, a few miles east of the subsurface Grayburg type locality, which penetrated 800 feet of section below the Grayburg. The lower 300 feet is chiefly sandstone, although in another well (Transcontinental No. 1 Robbins), 30 miles to the northwest, the San Andres is 1,460 feet thick, with only a thin sandstone near the middle. The top of the sandstone in the Wyatt well is 960 feet above the horizon of the base of the San Andres in the Robbins well. Perhaps the sandstone is equivalent to the lower Cherry Canyon tongue, and the overlying 500 feet of section is part of the Grayburg-Queen sequence as defined on the surface.

Subsurface thicknesses reported for the Grayburg and Queen formations are variable throughout the Permian Basin. Page and Adams (1940) stated that the Grayburg is only fully developed in the deeper parts of the Midland Basin and cited a thickness of 1,100 feet for the Queen formation in one Midland Basin well.

The subsurface San Andres-Grayburg-Queen sequence has been traced to the section at the eastern margin of the Permian Basin. Skinner (1946) traced the San Andres into the "Blaine of Texas" in the subsurface. Dickey (1940) traced the Grayburg in the subsurface across the Central Basin Platform and the Midland Basin eastward into the clastic Whitehorse outcrops in Fisher County, Texas. In Texas, the interval from Grayburg to Tansill inclusive is considered to be equivalent to the Whitehorse group.

Many petroleum geologists (e.g., Adams and Frenzel, 1950, p. 296; Jones, 1953, p. 30) consider the San Andres formation equivalent to the Goat Seep reef, and the Grayburg and Queen formations as grading laterally into the Capitan reef. These correlations are contradicted by the field relationships in the Guadalupe Mountains. The conflicting surface and subsurface correlations may be due to different interpretations of the Goat Seep reef. The Goat Seep and Capitan reefs of the Guadalupe Mountains may unintentionally be combined in the subsurface, and the name "Goat Seep" may also be extended to part of the underlying bank deposits designated as the lower Getaway limestone by Newell et al. (1953).

The influence of correlation of formations on paleogeographic interpretations is illustrated by a deduction made by Adams and Frenzel (1950, p. 294). They note that the clastics of the San Andres formation are largely colloidal shale, whereas fine sand replaces the shale in the basal Grayburg. Since they correlate the San Andres formation with the Goat Seep reef and consider the Grayburg to be the lowest unit of Capitanian age, they interpret the change in sediments above and below the Grayburg base to indicate that "the Capitan was introduced by a pronounced downwarping of the basinal areas and a corresponding upwarp of the landward margins of the basins."

MIGRATION OF THE BASIN MARGIN THROUGH TIME

The different geographic and stratigraphic positions of transition zones between basin and shelf facies indicate that the margin of the Delaware Basin changed position several times during the Permian period.

At the close of Capitanian time, the basin margin was defined by the Capitan reef front, which trends southwest-northeast through the southern Guadalupe Mountains. The basinward margin of the Capitan reef is a convenient reference line for locating the positions of preceding transition facies. The Goat Seep reef is 3 miles shoreward from the basinward margin of the overlying Capitan reef. This change in location of the basin margin during Capitanian time was a result of basinward growth of the Capitan barrier reef (pl. 6E).

The basin margin seems to have been defined less sharply during deposition of the Getaway limestone which underlies the Goat Seep reef. The belt of patch reefs described by Newell et al. (1953) in the lower Getaway is 4 miles wide. They estimate the depth of water 2 miles southeast of the rim of the basin to have been 800 feet during deposition of the upper Getaway limestone but less than 50 feet during deposition of the lower Getaway.

The lower 200 feet of the Cherry Canyon sandstone extends as a tongue under the Getaway limestone; 12 miles shoreward (pl. 6E) from the Capitan reference line, it passes into a transition belt, with patch reefs, as it grades into part of the San Andres formation. This northwestward extension of a basin sandstone deposit contrasts with the underlying Brushy Canyon sandstone, which pinches out only 3 miles northwest of the reference line. Patch reefs in the Brushy Canyon, described by Newell et al. (1953), are 2½ miles basinward from the Brushy Canyon pinchout.

The Cutoff member of the Bone Spring formation extends shoreward far beyond the Brushy Canyon pinchout (pl. 6E). The upper part of the member changes from basin to shelf facies in the West Dog Canyon exposures, about 12 miles northeast of the Capitan reef front. The lower part of the Cutoff member, however, retains the characteristics of the southern basin facies as far north as Chosie Canyon, in the Brokeoff Mountains, 19 miles shoreward from the reference line. Deposition of the Cutoff member, like that of the upper Getaway limestone, seems to have taken place during a period when the Delaware Basin was not sharply differentiated in elevation from the shelf area to the north.

The upper beds of the Victorio Peak member of the Bone Spring formation are also exposed in Chosie Canyon, though more typically developed farther south. The upper beds possess many of the characteristics of the San Andres formation and appear to be transitional between Victorio Peak and San Andres. The lower part of the Victorio Peak is not exposed as far north as Chosie Canyon. It presumably grades, however, into the Yeso formation within a few miles north of Chosie Canyon, because Yeso exposures underlie the San Andres formation at the north border of El Paso Gap quadrangle.

The northeast-southwest trend of the Goat Seep and Capitan reefs are shown on King's (1948) map of the southern Guadalupe Mountains. The basin-margin facies of the San Andres formation is exposed in the southwest quarter of El Paso Gap quadrangle and in Last Chance Canyon, in the northeast quarter of Carlsbad Caverns West quadrangle.

These localities define one segment of the Delaware Basin margin as it existed during deposition of the upper San Andres formation. The trend of the segment is parallel to that of the Capitan reef but is about 9 miles northwest of it. After deposition of the San Andres formation, the basin margin was established farther southeast. As a result, shelf deposits (Grayburg formation) overlie both the San Andres and the Cherry Canyon tongue.

In summary, basin-margin deposits of different ages in the Guadalupe Mountains are separated by as much as 19 miles along a line perpendicular to the trend of the Capitan reef front. However, trends of successive basin margins, where enough evidence is available to establish a trend, are parallel and strike northeast-southwest through the Guadalupe Mountains.

SUMMARY OF ENVIRONMENTS

The oldest marine shelf deposits (Yeso formation) in the central Guadalupe Mountains were deposited in a sea of above normal salinity, as shown by evaporite deposits. The waters were inhospitable to animal life and occasionally became supersaturated with calcium sulfate when the rate of evaporation was greater than the influx of water from the basin to the south. Between the basin and the shelf sea, a long, gentle slope was the site of much organic activity, although no reefs were formed. Currents distributed quantities of fusulinid tests, crinoid columnals, and other organic debris in extensive layers (Victorio Peak member) over this slope. Occasionally, basinward subaqueous slumping took place in these bank deposits.

Decrease in salinity of the shelf sea allowed occupation by a fauna which included several stenohaline invertebrate groups, such as corals and articulate brachiopods, which are common in the lower part of the San Andres formation. At the same time, an environment characterized by reducing conditions encroached far north of its previous extent, and dark fetid limestones (Cutoff member) were deposited over the Victorio Peak beds. During brief intervals, the environment in which the black muds were accumulating became temporarily hospitable to invertebrate life. Such intervals are represented by beds of light-colored limestone with a diverse fauna rather than the snails and chonetids which characterize the dark beds.

The Cutoff member was subjected to either subaerial or subaqueous erosion while the Brushy Canyon sandstone was deposited on a subsiding surface to the south. Sandstone deposition later extended northward as the Cherry Canyon sandstone tongue was deposited over the Cutoff limestones. During this interval of sandstone deposition in the southern part of the El Paso Gap quadrangle area, patch reefs flourished in a belt along the margin of the higher sea floor to the north. Along this margin, deposits of detrital calcium carbonate accumulated, and deltas were built southward. Meanwhile, on the shoreward side of the mile-wide belt of transition between shelf and basin deposits, many beds composed of fusulinid tests accumulated (upper San Andres formation).

These shelf deposits were followed by more detritus, in the form of calcarenite and sandstone (lower Grayburg formation). Inasmuch as the basin margin was several miles southeast of its former position, these deposits extend farther to the southeast than the preceding shelf deposits. The amount of calcarenite diminished with time, so that limy mud and quartz sandstone became quantitatively important as shelf sediments (Queen formation).

Current action resulted in crossbedding, channel cuts, and ripple marks. During deposition of the Grayburg-Queen sequence, the shelf sea was frequently 5 feet or less in depth. During such periods, some of the shelf area may have been out of water at low tide, and some of the channels may have been cut on tidal flats. The upper layer of sediment frequently was permeated by the filaments of blue-green algae. Such mats of sediment-binding algae resulted in laminated beds of detrital carbonate rock.

While animal and plant life flourished on the barrier reef (Goat Seep and Capitan reefs) which rimmed the basin, the fauna in the shelf seas became progressively less diverse, owing to continued increase in salinity. In time, carbonate deposition on the shelf was restricted to a belt adjacent to the barrier reefs, while evaporites and red beds were accumulating on the remainder of the shelf.

Appendix

CHECK LIST OF FOSSIL SPECIES

- SOUTHERN SEQUENCE
  - Victorio Peak member of the Bone Spring formation
    - Fusulinids
      - *Parafusulina bosei*
      - *Parafusulina splendens?*
      - *Parafusulina* sp. aff. *P. bosei* var. *attenuata*
      - *Parafusulina* sp.
    - Brachiopod
      - *Neospirifer* sp.
    - Gastropod
      - *Babylonites turritus*
    - Echinoderms
      - Crinoid columnals
  - Cutoff member of the Bone Spring formation
    - Fusulinids
      - *Parafusulina* sp.
    - Brachiopods
      - *Chonetes permianus*
      - *Chonetes* sp.
      - *Meekella* sp.
      - *Muirwoodia?* sp.
    - Ammonoids
      - *Perrinites hilli*
      - *Pseudogastrioceras* sp.
    - Nautiloids
      - *Domatoceras* sp.
      - *Foordiceras* sp.
    - Gastropods
      - *Babylonites turritus*
      - *Euphemites* sp.
      - *Platyzona* sp.
  - Cherry Canyon sandstone tongue
    - Fusulinids
      - *Parafusulina* sp.
    - Sponges
      - *Amblysiphonella* sp.
      - *Defordia* sp.
      - *Girtyocoelia* sp.
      - *Hyalostelia* sp.
    - Brachiopods
      - *Composita* sp.
      - *Derbyia nasuta?*
      - *Leptodus?* sp.
      - *Streptorhynchus* sp.
      - A neotremate valve
    - Nautiloids
      - *Stearoceras* sp.
      - *Tainoceras* sp.
    - Echinoderms
      - Crinoid columnals
      - Echinoid spines
  - Grayburg-Queen sequence
    - Gastropods
      - *Goniasma* sp.
      - *Meekospira* sp.
      - *Worthenia* sp.
    - Echinoderm
      - Echinoid spine
  - Goat Seep reef
    - Sponges
      - *Amblysiphonella* sp.
    - Coral
      - *Amplexus* sp.
    - Brachiopods
      - *Composita* aff. *emarginata*
      - *"Dielasmina" guadalupensis*
      - *Hustedia meekana*
      - *"Marginifera"* cf. *popei*
      - *Meekella* cf. *attenuata*
      - *Meekella* sp.
      - *Neospirifer* cf. *mexicanus*
      - *Pseudocameratus* sp.
      - *Stenoscisma?* sp.
      - *Waagenoconcha* sp.
    - Nautiloid
      - *Mooreoceras?* sp.
    - Pelecypod
      - *Girtypecten sublaqueatus*
    - Echinoderms
      - Crinoid columnals
  - Capitan reef
    - No collections
- NORTHERN SEQUENCE
  - Yeso formation
    - Fusulinids
      - Unidentified forms
    - Echinoderms
      - Crinoid columnals
  - San Andres formation
    - Fusulinids
      - *Parafusulina* sp. aff. *P. splendens*
    - Corals
      - Fragmental solitary rugosans

  - Bryozoans
    - Cryptostome fragments
  - Brachiopods
    - *Derbyia* sp.
    - *"Marginifera" popei*
    - *"Marginifera"* sp.
    - *Meekella* sp.
  - Gastropods
    - Unidentifiable molds
  - Echinoderms
    - Crinoid columnals
- San Andres transition facies
  - Fusulinids
    - *Parafusulina bosei*
    - *Parafusulina* sp. aff. *P. apiculata*
    - *Parafusulina* sp. aff. *P. splendens*
  - Sponges
    - *Amblysiphonella* sp.
    - *Girtyocoelia* sp.
  - Corals
    - *Cladopora spinulatum*
    - *Lophophyllidium* sp.
  - Bryozoans
    - *Acanthocladia* sp.
    - *Fistulipora* sp.
    - *Hemitrypa* sp.
    - *Septopora* sp.
    - *Thamniscus* sp.
  - Brachiopods
    - *Anidanthus waagenianus*
    - *Chonetes* sp.
    - *Composita* aff. *emarginata*
    - *Composita mexicana*
    - *Crurithyris sulcata*
    - *Derbyia* sp.
    - *"Dictyoclostus"* sp.
    - *Dyoros* sp.
    - *Enteletes dumblei*
    - *E. wordensis?*
    - *"Horridonia" walcottiana*
    - *Hustedia meekana*
    - *Kozlowskia kingi*
    - *Leptodus? americanus*
    - *"Marginifera" popei*
    - *Martinia* sp.
    - *Meekella attenuata*
    - *Meekella* sp.
    - *Neomartinia?* sp.
    - *Neospirifer* sp.
    - *Productus bassi*
    - *Prorichthofenia* sp.
    - *Psilonotus transversalis*
    - *Rhynchopora* sp.
    - *Spinifrons* sp.
    - *"Spiriferina"* sp.
    - *Stenoscisma* sp.
    - *Streptorhynchus* sp.
    - *Waagenoconcha* sp.
    - *Wellerella elegans*
    - *Wellerella* sp.
  - Chitons
    - Isolated plates
  - Scaphopod
    - *Plagioglypta canna?*
  - Nautiloids
    - *Cooperoceras* sp.
    - *Foordiceras?* sp.
    - *Metacoceras* sp.
    - *Mooreoceras* sp.
    - *Stearoceras?* sp.
  - Ammonoid
    - *Paraceltites elegans*
  - Gastropods
    - *Babylonites* sp.
    - *Bellerophon* sp.
    - *Callistadia* sp.
    - *Discotropis kingorum*
    - *Meekospira* sp.
    - *Worthenia* sp.
    - *Worthenia?* sp.
  - Pelecypods
    - *Astartella subquadrata*
    - *Aviculopecten* sp.
    - *Bakevellia* sp.
    - *Dozierella?* sp.
    - *Goniophora* sp.
    - *Grammatodon politus*
    - *Nuculana obesa*
    - *Palaeonucula levatiformis*
    - *Pernopecten symmetricus*
    - *Pleurophorus albequus*
    - *Pleurophorus* sp.
    - *Schizodus* cf. *oklahomensis*
  - Ostracods
    - *Amphissites* sp.
    - *Bairdia* sp.
    - *Hollinella* sp.
    - *Kirkbya* sp.
    - *Macrocypris* sp.
    - *Paraparchites* sp.
  - Trilobites
    - *Anisopyge perannulatum*
    - *Delaria antiqua*
  - Echinoderms
    - Crinoid columnals
    - Echinoid plates and spines

- Grayburg-Queen sequence
  - Fusulinids
    - *Parafusulina* cf. *P. bosei*
  - Brachiopods
    - *Composita* cf. *mexicana*
    - *"Horridonia" walcottiana*
    - *Hustedia* sp.
    - A poorly preserved chonetid
  - Ammonoid
    - One fragment
  - Nautiloids
    - *Foordiceras*?
    - *Metacoceras*?
    - *Mooreoceras*
  - Scaphopod
    - *Plagioglypta canna*?
  - Echinoderms
    - Crinoid columnals
    - Echinoid spine
  - Gastropods
    - *Baylea* sp.
    - *Bellerophon majusculus*
    - *Callistadia* sp. 1
    - *Callistadia* sp. 2
    - *Cyclites multilineata*
    - *Cyclites* sp.
    - *Euphemites* sp.
    - *Glabrocingulum* sp. 1
    - *Glabrocingulum* sp. 2
    - *Goniasma* sp. 1
    - *Goniasma* sp. 2
    - *Knightites* sp.
    - *Meekospira* sp.
    - *Murchisonia* sp.
    - *Naticopsis* sp.
    - *Phymatopleura*? sp.
    - *Portlockiella* sp.
    - *Soleniscus*? sp.
    - *Stegocoelia*? sp.
    - *Straparolus kaibabensis*
    - *Taosnia* sp. 1
    - *Taosnia* sp. 2
    - *Worthenia* sp.
  - Ostracods
    - Unidentified silicified valves
- Carlsbad group
  - Fusulinid
    - *Polydiexodina* sp.
  - Gastropods
    - Bellerophontid molds

FOSSILS FROM LOCALITY 0101 (Queen formation)

Locality 0101 is on Queen Mesa in NW¼SE¼ sec. 2, T. 25 S. R. 21 E. One bed in the Queen formation at this locality yielded the largest and most diverse collection of invertebrates yet obtained from the formation.

Column 1 indicates the relative number of individuals of each species found at locality 0101 (A, abundant; C, common; F, few; 1, one specimen).

Column 2 indicates those forms found at locality 0101 which are known from the Blaine and Dog Creek formations (Clifton, 1942). In this and subsequent columns, an "X" indicates that the same species is reported from the formations being compared, and a "Y" indicates that the genus, but not the species, is represented in both formations.

Column 3: San Andres formation (Girty, 1939).
Column 4: San Andres formation (Lee and Girty, 1909).
Column 5: Whitehorse formation (Newell, 1940).
Column 6: Kaibab formation (Chronic, 1952).

	1	2	3	4	5	6
Phylum Coelenterata						
Class Anthozoa						
Coenites spinulata (Girty)	F					
Phylum Bryozoa						
Fistulipora?	1					
Cryptostome fragment	1					

	1	2	3	4	5	6
Phylum Mollusca						
Class Gastropoda						
Bellerophon majusculus Walcott	A	X		X		
Naticopsis cf. *transversus* (Beede)	F				X	
Naticopsis sp.	F				Y	
Goniasma cf. *lasallensis*	F		X			
Murchisonia gouldii Beede	F				X	
Meekospira sp.	1					
Cyclites cf. *depressus* (Beede)	C				X	
Cyclites sp.	1				Y	
Bucanopsis modesta Girty	F			X		
Pseudozygopleura sp.	1					
Phymatopleura? sp.	1		Y			
Streptacis permiana (Beede) ?	F				X	
Baylea capertoni (Beede) ?	1				X	
Class Cephalopoda						
Subclass Nautiloidea						
Mooreoceras sp.	C	Y				
Metacoceras?	1	Y				
Subclass Ammonoidea						
Fragment	1					
Class Pelecypoda						
Labayaphorus sp.	F					
Bakevellia cf. *sulcata* (Geinitz)	1					X
Myochoncha sp.	F			Y		
Palaeonucula levatiformis (Walcott)	C					X
Pleurophorus cf. *albequus longus* Beede	F	Y			X	
Pleurophorus sp.	F	Y			Y	
Schizodus cf. *oklahomensis* Beede	F	X			X	
Dozierella cf. *gouldii* (Beede)	C	X			X	
Parallelodon sp.	1				Y	
Class Scaphopoda						
Plagioglypta sp.	1	Y				
Fragments of unidentified scaphopods are common						
Phylum Arthropoda						
Class Crustacea						
Subclass Ostracoda						
Bairdia cf. *rhomboidalis* Hamilton	F			Y		

SELECTED STRATIGRAPHIC SECTIONS

SECTION 20

Measured on the north wall of Last Chance Canyon, in SE¼ sec. 32, T. 23 S., R. 22 E., opposite mouth of Whiteoaks Canyon.

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Grayburg-Queen sequence	
17	Very light-gray dolomite in thin beds forming receding ledges, separated by short covered intervals, to top of slope. Small amount of sandstone float	*
16	Sandstone	6
15	Very light-gray dolomitic limestone forming low ledges separated by covered intervals	35

14	Yellowish-gray sandstone in 2- to 12-foot intervals, separated by short covered intervals and very light-gray dolomite, limestone, and dolomitic limestone in thin beds. Six sandstone intervals are included in this unit. Some of the sandstone beds exhibit crossbedding, some of the limestones are oölitic	79
	San Andres transition facies	
13	Light olive-gray to yellowish-gray dolomitic limestone forming high ledges. Some beds have considerable quartz sand content, as evidenced on weathered surfaces. Small iron oxide concretions common	45
12	Light olive-gray limestone flecked with fusulinid molds	26
11	Grayish-orange dolomite and dolomitic limestone; light olive-gray on fresh surfaces; numerous pores and molds filled with calcite. Chert nodules vary in abundance. Silicified brachiopods, crinoid columnals, and echinoid spines most abundant in upper part of unit; fusulinids in chert nodules and as molds	105
10	Grayish-orange sandstone with some silicification; scattered brachiopods	15
9	Grayish-orange sandstone in 1- to 6-foot intervals, separated by 3-inch beds of fossiliferous chert and by some 1- to 5-foot beds of grayish-orange sandy limestone. Chert nodules and silicified fossils in both limestone and sandstone; silicified fossils include fusulinids, crinoid columnals, and brachiopods	30
8	Grayish-orange dolomite with chert nodules and great numbers of silicified crinoid stem segments	1
7	Very pale-orange to yellowish-gray limestone with elongate branching chert nodules	32
6	Medium dark-gray to grayish-orange nodular limestone; lower 3-foot interval very silty and not nodular; shell fragments and silicification rare	55
5	Light olive-gray limestone, very shaly in some beds; well-preserved fusulinids and gastropods common	33
4	Grayish-orange limestone; exceptionally diverse silicified invertebrate fauna	1
3	Medium-gray limestone with wavy bedding	10
2	Grayish-orange dolomitic limestone in uneven beds; scattered chert nodules; covered in part	48
1	Grayish-orange fine- to medium-grained sandstone	9
	Base concealed	

* Not measured.

SECTION 23

Measured on north side of West Dog Canyon, where canyon cuts horst in NE¼ sec. 12, T. 26 S., R. 19 E.

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	San Andres transition facies	
5	Yellowish-gray to light-gray thin-bedded dolomite with chert nodules; forms slope	*
	Bone Spring limestone, Victorio Peak member	
4	Light olive-gray dolomite in thick ledge-forming beds containing many shell fragments, some of which are silicified; chert nodules rare	42

3	Medium light-gray to light olive-gray dolomite in even 1- to 3-foot ledge-forming beds; chert nodules vary in quantity from bed to bed; shell-fragment molds abundant in many beds; petroliferous odor from fresh surfaces	250
2	Very light-gray dolomite with small pores marking the weathered surfaces	6
1	Very light-gray unfossiliferous dolomite and grayish-orange fine-grained sandstone. The dolomite is dense in some beds, whereas others are marked by holes in the weathered surface. The sandstone is in eight 1-foot beds separated by dolomite; sandstone and dolomite beds have transitional contacts	52
	Base concealed	

* Not measured.

SECTION 37

Measured on south side of West Dog Canyon, in SE¼SE¼ sec. 8, T. 26 S., R. 20 E.

UNIT. NO.	DESCRIPTION	THICKNESS (feet)
	Grayburg-Queen sequence	
7	Very light-gray dolomite; forms receding 6-inch to 2-foot ledges separated by short covered intervals to top of hill	*
6	Pale-red to moderate orange-pink ledge-forming sandstone in 1- to 3-foot layers, separated by short slopes covered by dolomite float	84
	Cherry Canyon sandstone tongue	
5	Light-gray massive dolomite, with only faint traces of bedding; weathered surface mottled; forms cliff	50
4	Grayish-green to light-brown crossbedded siltstone	45
3	Slope-forming siltstone and fine-grained sandstone, pale blue-green in lower half of unit and dominantly light-brown in upper half. Silty limy beds in upper one-fourth of unit; also chert nodules and silicified fusulinids and brachiopods	140
2	Slope-forming yellowish-gray to light-brown sandstone; some silicification in upper part	140
	Bone Spring limestone, Cutoff member	
1	Light olive-gray limestone in thin, uneven beds; many holes ½-inch in diameter in weathered surfaces; black chert nodules in upper beds	56
	Base concealed	

* Not measured.

SECTION 63

Measured on south side of Panther Canyon, starting in canyon bottom in SW¼NE¼ sec. 35, T. 25 S., R. 19 E.

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Grayburg-Queen sequence	
20	Very light-gray dolomitic calcarenite in 6-inch to 2-foot beds; forms receding ledges at top of slope	78

	San Andres formation	
19	Light-gray dolomite, with scattered fusulinid molds in 1- to 3-foot beds; transitional between overlying and underlying units	11
18	Medium light-gray dolomite in 1- to 3-foot beds; most beds contain abundant fusulinid molds. From a distance, this unit is recognizable on the canyon walls as a distinct band somewhat darker and more homogeneous in appearance than the overlying and underlying strata	134
17	Light-gray dolomitic limestone in 1- to 1½-foot beds with poorly developed bedding surfaces; outcrop surface marked by scattered pits from ⅛ to ½ inch in diameter; irregular chert masses common	7
16	Medium light-gray to light olive-gray dolomite in 1- to 2-foot beds with irregular surfaces	28
15	Medium light-gray to light olive-gray dolomite in 1- to 2-foot uneven beds; fusulinid molds and irregular pale reddish-brown chert masses common	45
14	Light-gray dolomite in 1-foot-high ledges separated by short covered intervals; fusulinid molds and chert nodules common	28
13	Light-gray dolomitic limestone, with many tiny pores and scattered pits ¼ inch in diameter; beds 1-foot thick, mostly covered in upper part of unit; some silicification	22
12	Light-gray slope-forming dolomite, with many holes ¼ inch in diameter; some silicification	11
11	Greenish-gray to light-gray silty dolomitic limestone in irregular beds which form receding ledges on the slope; many holes from ¼ to 1 inch in diameter, some of which resemble burrows; some silicification	3
10	Very light-gray dolomitic limestone in 1-inch-thick, irregular, slope-forming beds; many flattened openings from ¼ inch to 1 inch in width	28
9	Greenish-gray slope-forming dolomitic limestone, with no well-developed bedding surfaces; irregular chert masses common	17
8	Very light-gray dolomite forming low ledges; some chert	2
7	Greenish-gray slope-forming dolomitic limestone, with no well-developed bedding surfaces; irregular chert masses rare	17
6	Yellowish-gray slope-forming siltstone in ½-inch to 1-foot beds; some irregular areas of secondary silicification; rests with even contact on underlying unit where contact is exposed in a gully	6
	Bone Spring limestone, Cutoff member	
5	Greenish-gray to light-gray dolomite in irregular 1-foot beds forming narrow ledges on a largely covered slope; medium light-gray chert common in some beds as almost continuous layers of nodules; some irregular layers of chert (up to 3 inches thick). Weathered surfaces of some beds show considerable silt content. Scattered holes several inches in diameter mark the weathered surfaces of some beds. Trails ½ inch wide occur on a few bedding surfaces	140
4	Light-gray to light olive-gray dolomite in 4-inch beds separated by 2-inch partings of calcareous shale; irregular chert nodules	28
3	Light-gray to light olive-gray dolomite in 1- to 3-inch uneven beds; abundant medium-gray chert nodules elongated parallel to bedding surfaces	56
2	Very pale-orange dolomite; pale yellowish-brown and darker on fresh surfaces. The 1-inch dolomite layers are separated by thin shaly beds. The dolomite yields a strong petroliferous odor from a fresh surface. Silicified chonetids are common	22

	Bone Spring limestone, Victorio Peak member	
1	Medium-gray to medium light-gray dolomite in 1- to 3-foot, even beds; calcite fills numerous pores and fusulinid molds. The beds consist of shells and shell debris; the detritus is composed largely of fusulinid molds in the lower two-thirds of the unit. In the upper third, brachiopod fragments and crinoid columnals predominate. Large chert nodules are common in the lower one-third of the unit; selective silicification in the upper beds has replaced numerous brachiopods, solitary corals, and euomphalid gastropods	151
	Base concealed	

SECTION 67

Measured on the north wall of Chosie Canyon, about one-fourth mile west of the west border of El Paso Gap quadrangle.

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Grayburg-Queen sequence	
4	Very light-gray dolomitic calcarenite in 2- to 6-inch beds; crossbedding common; transitional contact with underlying unit; forms receding ledges at top of slope	132
	San Andres formation	
3	Medium light-gray dolomite in 1- to 3-foot beds; fusulinid molds are abundant in most beds, and ellipsoidal chert nodules are scattered through the lower half of the unit; forms cliffs easily visible in aerial photographs	248
2	Light-gray dolomite in thin, irregular beds forming slope. Irregular, closely spaced chert nodules are abundant in some beds; silicified brachiopods, crinoid columnals, and shell fragments in lower portion, which has dark color on fresh surfaces. Most beds in upper part are unfossiliferous, but one 3-inch bed contains abundant molds of fusulinids, brachiopods, gastropods, solitary corals, and trilobites	226
	Bone Spring limestone, Victorio Peak member	
1	Light olive-gray dolomitic calcarenite in 1- to 3-foot ledge-forming beds. Gypsum inclusions of sand-grain size are brought into relief on weathered surfaces. Petroliferous odor from fresh surfaces. Scattered irregular chert nodules in many beds, especially in upper one-third; upper 30 feet of unit includes numerous silicified and nonsilicified solitary corals, not in growth position; euomphalid gastropods in uppermost ledge	220
	Base concealed	

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Numbers in **boldface** indicate main references.