VITA

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THE PERMIAN CAPITAN FORMATION OF THE GUADALUPE MOUNTAINS OF TEXAS AND NEW MEXICO

by

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figures

Table 1

Plates

THE PERMIAN CAPITAN FORMATION OF THE GUADALUPE MOUNTAINS OF TEXAS AND NEW MEXICO

ABSTRACT

The Capitan formation of the Guadalupe Mountain area may be divided into two distinct lithologic units: (1) the organic reef here defined as the Slaughter member, and (2) the fore-reef talus unit here defined as the Calamity member. The Capitan formation lies between, and is equivalent in time to, the Bell Canyon formation in the basin and the Carlsbad formation in the lagoon. It is limited below by the Goat Seep formation and above by the Castile gypsum.

The Slaughter member (reef) is a fossiliferous, white, semi-lithographic limestone containing quartz sandstone dikes and pods. The Calamity member (fore-reef talus) is composed of reef debris ranging from mud to boulder size. The reef grew by accumulation of skeletal remains at its front and top, extending itself basinward over its own talus. Growth was controlled along a subsiding flexure between the shelf and the basin. The principal components of the fauna are calcareous sponges, algae, bryozoans, brachiopods, crinoids, and fusulinids.

INTRODUCTION

This study of the Capitan formation in the Guadalupe Mountain area (Figure 1) was undertaken as part of a general investigation of the Permian reef complex in the Delaware Basin (Figure 2) under the direction of Dr. N. D. Newell. The investigation of the Capitan reef complex comprises three individual studies divided on the basis of formational boundaries; J. K. Rigby studied the Bell Canyon formation (basin), A. J. Whiteman the Carlsbad formation (lagoon), and the author the Capitan formation (reef and upper fore-reef talus).

On the basis of the stratigraphic, petrologic, and paleontologic relationships, this paper presents conclusions regarding the ecologic and sedimentary environments of the Capitan formation and its development as a part of a barrier reef complex.

ACKNOWLEDGMENTS

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PREVIOUS LITERATURE

The first observations on the geology of the Guadalupe Mountains were published by G. G. Shumard in 1858. He recorded a 3,000 foot section of four members, white limestone (Capitan and Carlsbad), upper dark limestone (Pinery), yellow sandstone (Brushy Canyon), and lower dark limestone (Bone Spring). His brother, B. F. Shumard (1860), who examined the fossils from the section, listed fifty-four species and noted that the fauna has a Permian aspect. R. S. Tarr (1890) of the Texas Geological Survey also visited the area and noted his observations.

In 1901 and 1903 G. H. Girty and G. B. Richardson of the United States Geological Survey visited the region and made extensive observations and collections. Subsequently Girty (1908) published his classic "Guadalupian Fauna" which listed 326 species, and Richardson (1904, 1910) published his stratigraphic papers in which the Capitan formation was originally defined.

Under the impetus of petroleum exploration the stratigraphy of the Guadalupe Mountains was intensively studied in the late 1920's. The massive Capitan limestone was found to occur as a barrier in a narrow belt between the bedded Carlsbad limestones to the northwest and the lower, but contemporaneous, sandstone formations to the southeast. From these stratigraphic relationships, Lloyd (1929) first interpreted the Capitan as a reef deposit. Crandall (1929) also noted that the Capitan appears to constitute a reef and the detritus deposited off the reef front, but did not delineate the boundaries involved.

In 1928 and 1930 P. B. King and R. E. King made a detailed investigation of the Glass Mountains which are stratigraphically similar to the Guadalupe Mountains. P. B. King, in his papers on the trans-Pecos region (1934) and west Texas and New Mexico (1942), and Lang on the Pecos Valley (1937), integrated the various Permian studies of the Delaware Basin and devised a usable stratigraphic nomenclature. In addition King (1942) proposed a method of accumulation for the Capitan formation.

In 1948 P. B. King published "The geology of the southern Guadalupe Mountains, Texas" which has served as the major reference work during the present investigation. This inclusive paper for the first time approaches the problem from an integrated areal, structural, stratigraphic, and paleontologic viewpoint. Although restricted to the Texas portion of the mountains, King's investigation solved many of the stratigraphic problems of the Guadalupian series, but did not include the correlation of fore-reef and back-reef members (through the reef), nor did it bring out the dual nature of the Capitan, with the resultant considerations involving detailed correlations and methods of accumulation.

J. E. Adams and H. N. Frenzel published a short paper on the paleo-ecology of the Capitan barrier reef in 1950. Although some of their conclusions are correct, little substantiating evidence is presented.

Paleontological studies, such as algal studies by J. H. Johnson (1942, 1943, and 1951), fusulinid reports by C. O. Dunbar and J. W. Skinner (1937), and ammonoid studies by A. K. Miller and W. M. Furnish (1940), have aided in forming an overall picture of Permian ecology in this region. In addition, the many excellent papers on Tertiary and modern reefs (Henson, 1950; Fairbridge, 1950; Ladd *et al*, 1950; and others) have aided in interpretation of the fossil reef.

ANALYSIS OF PREVIOUS WORK

In spite of the voluminous literature on the Capitan limestone, little has been presented to detail correlations, method of reef growth, and the ecologic and sedimentary environments. The major correlations for the Permian reef-complex, as well as detailed basin correlations, are given by King (1948), but no precise correlation from basin, through reef to lagoon is attempted. Adams and Frenzel (1950) detail the back-reef stratigraphy, but do not correlate into the basin.

King (1942) proposed a method of reef accumulation by increments on the reef front, but, as demonstrated later, this interpretation is not in agreement with the dual nature of the Capitan deposits. Moreover, it is not compatable with the known facts regarding reef building organisms and their environments. Crandall (1929) first recognized the dual origin, but the knowledge of the stratigraphy at that time was not adequate to provide a logical solution to the question of Capitan deposition. Adams and Frenzel (1950) have discussed Capitan deposition but much of their discussion is either contradictory or unclear. They do not illustrate their proposed mode of reef deposition and while some of their dimensions of the reef are applicable at a given locality, these dimensions do not hold elsewhere.

All investigators who have recognized the Capitan as a reef, have also interpreted it as a feature of overall subsidence. King has interpreted the reef as growing upward and outward in a stair-step fashion. Adams and Frenzel state that sea level "shifts in both directions are recorded" but no evidence is cited for this conclusion.

The sedimentary environments of the reef-complex are generally well documented. The three major areas of deposition, the lagoon, reef--fore-reef, and basin have been recognized by most authors. King and Adams and Frenzel have postulated water depths and other factors of the depositional environments for these areas. Nearly all authors have noted dolomite in the reef and Adams and Frenzel state that "many of the algae . . . of the reef wall have been partially destroyed by dolomitization."

The ecologic environment is also well documented in a general sense. However, no one has given a detailed account of fossil occurrences within the Capitan formation or its transitions into the lateral formations.

SUMMARY OF RESULTS OF THE PRESENT INVESTIGATION

Detailed correlations through the Capitan reef, from basin to lagoon, are proposed on the basis of a reconstructed succession of reef profiles. Accordingly, the base of the Hegler member (basin) is equivalent to the base of the Capitan formation (Figure 3) and the base of the Seven Rivers member (lagoon). The top of the Seven Rivers member (base of the Yates) correlates with the base of the McCombs member (basin). The top of the Yates member (base of the Tansill) correlates with beds in the upper Lamar member (basin). The top of the Tansill member is equivalent to the top of the Capitan and the base of the Castile formation (top of the post-Lamar sand-limestone member).

The Capitan reef is recognized as a subsidence feature, the subsidence being relatively slow and regular into Rader time and gradually increasing to a maximum at the end of the Capitanian interval. No "shifts" or "steps" are indicated.

The method of accumulation of the Capitan reef is comparable, in general, to the accumulation of modern reef limestones. The reef, at all times, consisted of a reef flat (its width varying inversely with the rate of subsidence), a low reef crest, and a rather short, steep reef front rising above a long slope of reef talus.

The sedimentary environments of the Capitan formation are distinguished, the formation being divided into its natural genetic (and petrologic) units, the reef and upper fore-reef talus, for which the new members, Slaughter and Calamity, are proposed. The petrology of the limestones supports the proposed method of reef accumulation. It is also notable that no dolomite was found in the reef limestones.

The ecologic environments within the Capitan formation likewise correspond to the two genetic units and corroborate the inferred method of accumulation of the reef. The large fusulinid *Polydiexodina* is believed to have been restricted to the reef flat environment. Finally, it is proposed that the reef may have died because increased subsidence "drowned" the reef organisms.

GEOLOGIC SETTING

The Capitan formation of late Guadalupian age (Permian) crops out along the Guadalupe Mountain front from El Capitan to the south of Walnut Canyon thirty-five miles to the northeast (Figure 1). The regional dip is less than 2° to the northeast, the elevation of the formation being 8,600 feet above sea level on Guadalupe Peak and 3,600 feet near Walnut Canyon. The relief in the area varies from 3,000 feet near El Capitan to 250 feet in the vicinity of Walnut Canyon (Figure 10). The topography is youthful and the climate semi-arid.

The Capitan formation as defined by Richardson (1904) is here determined to comprise the reef and upper fore-reef talus of a reef complex. Henson's (1950) following definition of a reef complex is used: "The term reef complex is applied to the aggregate of reef limestones and the calcareous rocks genetically (?) associated with them." The reef complex is subdivided on the basis of ecology and sedimentation into back-reef, reef, and fore-reef environments (Figure 5). The reef proper is restricted to that rock which actually grew in place (biogenic deposition). The reef profile approximated a broad reef flat extending to a low reef crest above a short reef front which intertongues with the fore-reef talus (Figure 4).

The formation is a tabular mass of white limestone, tilted slightly to the northwest. It lies between, and is contemporaneous with, the flat lying Carlsbad back-reef strata and the basin deposits of clastic limestone and quartz sandstone of the Bell Canyon formation (Figure 8). In depositional sequence the Capitan follows the Goat Seep reef and is followed by the Castile gypsum.

The Capitan formation contains two mappable lithologic units: (1) the semi-lithographic, fossiliferous limestone which actually grew in place as a reef, and which is here named the Slaughter member, and (2) the upper fore-reef talus of reef debris, defined as the Calamity member. The Carlsbad formation is made up of the Seven Rivers, Yates, and Tansill members (Figure 3). The Bell Canyon formation consists of the Hegler, Pinery, Rader, McCombs,[1] and Lamar limestone members and five unnamed sandstone members.

The Seven Rivers member is a medium to thick bedded dolomite; the Yates an alternating quartz sandstone-limestone section; and the Tansill a predominantly lime section with some quartz sandstone strata. All three members thicken and become almost entirely clastic limestone toward the reef.

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[1] McCombs has been introduced as the name for King's (1948) "flaggy" member by J. K. Rigby in an unpublished (as of June 1952) thesis (Columbia University). The type locality is McCombs Quarry.

Generally, fossils are restricted to within a mile of the reef. Dasycladacean algae, fusulinids, and mollusks are the major components of the fauna. Pisolites are found in some of the strata. Separating the reef from typical back-reef sediments are transition beds (thick bedded to massive calcareous sands) made up entirely of reef debris.

The Bell Canyon formation is predominantly sandstone in the basin, but the sands thin and disappear toward the reef, whereas the clastic (reef derived) limestones thicken and become coarser toward the reef. The fauna of the Bell Canyon formation approximates that of the reef except for more numerous cephalopods, a few additional genera of brachiopods, siliceous sponges, and echinoids. This fauna is much easier to study than the faunas of the Capitan and Carlsbad formations, because the fossils are silicified locally and may be extracted in practically the same condition in which they were buried by dissolving the lime matrix in hydrochloric acid.

The Bell Canyon-Capitan contact is located at the poorly defined surface where the basin sand members disappear and the thick bedded, white limestones of the fore-reef talus become thin bedded, gray basinal limestones (Figure 8). Individual beds of reef detritus extend across this contact into the Bell Canyon formation where they intertongue with the typical basin sands.

The area of reef growth was controlled along a subsiding flexure between the shelf and the basin, the reef growing by accumulation of skeletal remains of organisms at the front and top, thus extending it outward over its own talus (and maintaining it at sea level).

STRATIGRAPHY

General

The Capitan formation was originally defined as the massive white limestones above bedded black limestone on Guadalupe Peak (Richardson, 1904). It has come to be known as a reef facies between (and equivalent in time to) the Bell Canyon basin facies and the Carlsbad lagoon facies (King, 1948). Crandall (1929) and King (1948) state that the Capitan consists of both massive and bedded detrital rocks, but they neither delineate nor define these as units. Not only are two lithologies present, but also they occur as distinct mappable units of unlike origin. These are here defined as the Slaughter and Calamity members.

The Slaughter member is the reef unit, the rock which grew in place as an organic reef. It is typified by the reef rock, a semi-lithographic, white to cream limestone with conchoidal to splintery fracture. It contains abundant calcareous sponges, brachiopods, fibrous calcite, cavity linings and quartz sandstone pods. The Slaughter member accumulated throughout Capitan time. The member is from 400 to 1,200 feet thick (vertical measurement) and approximately 2½ miles wide (horizontal measurement) on outcrop. The type locality is Slaughter Canyon.

The Calamity member is the detrital unit, the talus off the reef front. It is entirely limestone, often dolomitic, massively to rudely bedded, varying from boulder breccias to mudstones, and invariably clastic. The Calamity is granular or sandy as opposed to the semi-lithographic reef rock. The Calamity member is about 2½ miles wide (horizontal measurement) at outcrop and varies from a few hundred to one thousand feet in thickness (vertical measurement). It extends throughout Capitan time and is limited laterally by the Slaughter boundary and the somewhat arbitrary Bell Canyon boundary (see Lateral Lithologic Variation). The type locality is Calamity Cove.

An ideal system of nomenclature would limit the Capitan formation to the reef rock. If this were done the three facies of the reef complex, back-reef, reef, and fore-reef, would correspond to the three formations, Carlsbad, Capitan and Bell Canyon. However, because "Capitan" has become an established term in the literature, it seems more appropriate to divide the formation than to restrict it. Therefore, as formerly, the basinward lateral limit of the Capitan formation is regarded as extending to the transition where the reef derived limestones become gray (rather than white) and well bedded, and the basin sands begin. This lower limit does not include all the reef derived limestone. It sometimes approaches the biofacies boundary between the fore-reef slope growth zone and the pontic (stagnant) facies, but, in general, the black limestones of the pontic facies are basinward from the Capitan-Bell Canyon contact. It is thus seen that this contact does not serve as a facies boundary.

There are no obvious lithologic or faunal boundaries through the Capitan. More detailed work will define the upper limit beyond which *Polydiexodina* does not occur. Bedding planes may be traced from the Bell Canyon formation into the Calamity member but they disappear in the Slaughter member. Stratification, sandstone pod zones, and breccia zones cannot be followed through the reef. Therefore exact correlations cannot now be made through the reef from the Bell Canyon formation to the Carlsbad formation.

The last (highest stratigraphic) occurrence of *Polydiexodina* may be traced across the reef near the mouth of McKittrick Canyon on the steep south wall under the three caves (Figure 8). In Slaughter Canyon also the final occurrence of *Polydiexodina* may be traced to the base of the cliffs along the south wall of the canyon opposite the mouth of West Slaughter Canyon. However, as the Carlsbad has not been mapped in this area and the Bell Canyon members do not outcrop, a profile cannot be checked through the reef.

Northeastward from Black Canyon, along the reef escarpment, the reef must be dated by reference to Carlsbad beds because the basin beds are not exposed. Southwest of Black Canyon both basin and lagoon beds are exposed and may be used to date parts of the reef. As growth profiles of the reef at any given time cannot be established with precision, correlations across the reef are only approximate. Wherever possible, basin correlations are given because the lagoon beds have not been accurately mapped.

Previous investigators have made only gross correlations across the Capitan reef. They are in general agreement that the Bell Canyon, Capitan, and Carlsbad formations are time-stratigraphic equivalents, but no detailed correlations have been presented. For example, King (1942 and 1948) defined and subdivided the Bell Canyon formation, but did not correlate these divisions across the reef to the members of the back-reef Carlsbad formation; while Adams and Frenzel (1950) recognize the Carlsbad subdivisions, but make no attempt to correlate through the reef into the Bell Canyon basin deposits. However, Adams and Frenzel include the Queen and Grayburg formations in the Capitanian back-reef equivalent, but the author and King (1942) agree, on the basis of lithologic and stratigraphic evidence, that these are Goat Seep equivalents.

King (1942) implies a correlation by extending the fore-reef bedding through the reef to the Carlsbad. In other words, these correlations agree with his conclusion that the Capitan accumulated by addition of "shingles" on the front. The Calamity fore-reef deposits do "shingle" in this way, but such a correlation does not take into account the reef proper

(Slaughter) and its accumulation by the addition of horizontal increments.

To obtain a correlation through the reef, the back-reef bedding is projected across the reef and then down into the fore-reef beds. This correlation is based on the author's interpretation of the reef profile as a wide reef flat (except in latest Capitanian), and a reef crest near and approximately 200 feet above the fore-reef talus.

Correlation

Hegler reef equivalent is found only in North McKittrick Canyon (Figure 8). It probably crops out in Pine Spring Canyon, but the stratigraphy is complicated here by faulting and the Hegler member cannot be traced directly into the reef. The Hegler member may be seen grading into the reef on the inaccessible cliffs of the west side fault scarp (Figure 11). The back-reef equivalent of this part of the reef is the lower part of the Seven Rivers member. The upper sandstone of the Queen formation correlates with the top of the Goat Seep reef and the base of the Hegler member.

Reef equivalent of the Pinery member is found in Pine Spring and McKittrick Canyons. This portion of the reef crops out at the heads of the larger canyons to the north, although the Pinery member itself is not exposed. The part of the reef of Pinery age seems to correspond to the middle part of the Seven Rivers formation. This portion of the reef is exposed to the north in Slaughter, Double, Gunsight, Black, and Big Canyons.

Reef equivalent of the Rader member is shown along the escarpment in Pine Spring Canyon and occurs progressively farther up each of the canyons to the northeast as far as Slaughter Canyon. The back-reef equivalent apparently is the upper Seven Rivers formation.

The reef equivalent of the McCombs member, King's (1948) "flaggy" member, is exposed in all the major canyons from McKittrick to Slaughter Canyon. The back-reef equivalent is the lower part of the Yates formation.

The Lamar equivalent reef is found in all canyons from McKittrick to Rattlesnake Canyon. The back-reef equivalent is the middle and upper Yates and perhaps the lower part of the Tansill formation. The top of the Lamar member and equivalent reef, together with the back-reef equivalents, are not shown in any single canyon. In McKittrick Canyon most of the reef of Lamar age has been removed by erosion whereas in Slaughter Canyon the top of the Lamar member is not recognizable.

That part of the reef of post-Lamar age (equivalent to quartz sandstone in the basin) corresponds to the Tansill formation in the back-reef. The reef of Tansill age occurs from Rattlesnake to Walnut Canyons. The outcrops at the mouth of Dark and Jurnigan Canyons are interpreted as near-reef Tansill beds.

The relationship between the Capitan formation and the overlying Castile formation is not clear because of poor exposures. The Castile formation appears to lap onto, but not over, the reef escarpment.

The base of the Capitan formation is best seen in the head of North McKittrick Canyon (Figure 8). The basal relationships are also visible on the west side fault scarp (Figure 11). The basal Slaughter member in North McKittrick Canyon is, as elsewhere, composed of white semi-lithographic limestone. It rests on brecciated dolomite which grades into sucrose, white dolomite of the Goat Seep reef. The brecciated dolomite may mark a submarine erosion surface representing a hiatus of short duration separating the Goat Seep and Capitan reefs. No recognizable unconformity occurs in the basin or lagoon beds.

DEVELOPMENT OF THE REEF

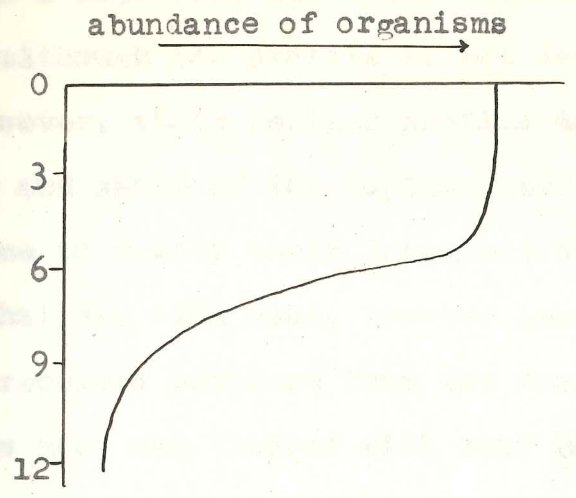
Method of Accumulation

The Capitan reef complex compares in general overall features with modern reef complexes, but it differs in detail as modern barrier reefs differ among themselves. Many of the features noted on modern reefs are masked in the Capitan by subsequent sedimentation, crystallization, and physical changes. For instance, the reef profile is interpreted as approximating the Bikini atoll profile of Ladd, *et al* (1950) with a lagoon, reef flat, lithothamnion ridge (reef crest), and sea terrace (reef front), although none of these is visible in the Capitan as a profile feature. Rather, they are interpreted on the basis of stratigraphic and structural relationships, as they must be in the case of all ancient reef complexes. Even though individual profiles may in general be comparable, the reef section and its behavior under subsidence cannot be compared in detail to modern reefs because no modern reef with a similar history is known. Unlike modern barrier reefs and atolls, the Capitan reef grew on the basinward margin of a shelf which almost completely encircled the Delaware basin (King, 1948). Thus the open circulation basin was almost completely encircled by the reef, which in turn was surrounded by the lagoon. This pattern, which is the opposite of the atoll, is unknown among modern reefs. In addition, as pointed out by King (1948), most modern barrier reefs have relatively narrow lagoons as compared to the Capitan lagoon which may have been several hundred miles in width. King (1948) suggested that the Andros reef, Bahama Islands, around the Tongue of the Ocean might be comparable to the Capitan around the Delaware Basin. However, the Andros reef, where studied by the author, was found to be a relatively small, minor feature growing back on the shelf rather than at the edge of the shelf as the Capitan reef was situated. Also the biofacies, lithofacies, and reef complex profile are not comparable in detail (Newell, *et al*, 1951).

The Capitan reef began its growth on the top of the ancestral Goat Seep reef. On the basis of lithologic differences and the presence of intervening breccias, an interval of non-deposition (non-growth) is believed to have occurred between the two reefs. Undoubtedly the new reef started as a series of patch reefs but quickly became a relatively continuous barrier. Although modern reefs are somewhat discontinuous, and the Capitan reef is probably analogous in this respect, no evidence of reentrants or channels through the reef has been recognized. Possibly the modern canyons occupy zones of weakness representing channels through the reef, which have been destroyed by stream erosion. On the spur between Black and Gunsight Canyons a submarine mudflow and fore-reef beds of post-Lamar age apparently extend farther into the reef escarpment than on the adjoining spurs. This may indicate the presence of a channel in the reef. Adams and Frenzel (1950) describe and discuss reentrants, gaps, and channels, and give their dimensions. However, they then state that "the section is too poorly exposed to permit recognition of surge channels, grooves, tunnels, or blow holes."

The Goat Seep reef had approximately 1,000 feet of relief when the first Capitan limestone was deposited. Adams and Frenzel (1950) give 600 feet of relief on "early Capitan basins." With growth of the reef and differential subsidence, the total relief reached 2,000 feet by the end of Lamar time. Adams and Frenzel (1950) give the basin depth as 1,800 feet and King (1948) gives 1,000 feet. At the mouth of McKittrick Canyon the Tansill stands at an elevation of 7,050 feet, while to the east, within a mile, the top of the Lamar is at 5,000 feet. Subtracting 150 feet for the eastward tilt gives a minimum relief of 1,900 feet. With approximately 100 feet of Tansill removed by erosion at this locality, the total relief is approximated at 2,000 feet.

Theoretically, an ideal growth curve of reef organisms, plotted against depth of water, would show a zero at low tide level, a maximum from low tide level to about three fathoms, and a rapid diminishment to about ten fathoms where the curve would become asymptotic. On Andros reef, Bahama Islands, maximum growth occurs within two fathoms of the surface. Reef



growth is non-existent below six fathoms.

Thus it is reasoned that, as the shelf subsided, the Capitan reef grew up and out at or near the surface of the sea. All authors who have discussed the Capitan reef have interpreted it as a feature of subsidence and have postulated upward and outward growth, but, heretofore, none have presented the necessary correlations through the reef as a basis for treating the mode of such growth. The reef profile at any given time is interpreted, by the author, as consisting of a short, steep reef front rising from the fore-reef talus to a low reef crest at the forward margin of a broad reef flat. As the reef grew upward and outward it continuously masked the previous crests. The earlier reef profiles were likewise masked by later growth, and thus no bedding or lamination would be expected in the reef. Adams and Frenzel (1950) imply a profile with a reef flat 1,000 feet wide and a reef front 350 feet high, although the profile is not detailed or illustrated. However, their implied profile does not correspond to the size and shape of the Capitan reef, nor do they present evidence to verify their interpretation.

A shallow, wide moat, located immediately behind the reef flat, received sediment from the reef, and from the lagoon. The moat was floored with reef rock and shifting sands which are now seen as the back-reef transition strata.

The evenly graded reef--back-reef contact (Figure 8) and the absence of intertonguing between reef rock and lagoonal strata indicate wave erosion on the back edge of the reef flat. The inclination of this contact should reflect the rate of subsidence (and the rate of accumulation) modified by the rate of erosion at the back edge of the reef flat. With increased rate of subsidence the contact would steepen, but this change of slope would not be directly proportional to the rate of subsidence and accumulation, since the erosional rate would also increase with the steepening of the slope.

The slope of the reef--fore-reef contact should also be a function of the rate of subsidence, but in this case modified only by the rate and direction of reef accumulation. In other words, the reef would grow upward at a rate directly proportional to the rate of subsidence, while it would grow laterally at virtually a constant rate for all rates of subsidence. Thus the altitude of the contact would be the resultant of two vectors; the rate of vertical accumulation and the rate of lateral accumulation.

Thus it may be seen that both the back-reef and fore-reef contacts should increase in slope with increased subsidence. The width of the reef would therefore be a function of the rate of subsidence; with a low rate of subsidence the reef would tend to increase in width, but with an increased rate of subsidence the reef would narrow and grow upward, maintaining itself at the surface.

These theoretical considerations may be tested by their application to the Capitan reef. The reef widened rapidly from its start in Hegler time and maintained a wide flat through Pinery and Rader time, which indicated uniformly slow subsidence. At the end of Rader time the reef flat gradually became narrower until it disappeared in Lamar time. The reef of post-Lamar age was only a few hundred feet across and grew nearly vertically. This indicates relatively rapid subsidence toward the end of Capitan time.

The back-reef--reef contact varied from 5° to 10° from the horizontal (assuming that the Carlsbad strata were deposited horizontally) and although there are slight breaks in slope on the Carlsbad-Capitan contact, no definite periods of up-growth as opposed to out-growth are indicated until post-Lamar (Tansill) time when the rate of subsidence increased and the reef grew up at a high angle. In North McKittrick Canyon Adams and Frenzel (1950) and King (1948) report "steps" along the reef--back-reef contact. They interpret these as indicating periods of up-growth as opposed to out-growth. The actual Capitan-Carlsbad contact is a relatively evenly graded surface throughout (Figure 8), rather than step-like as stated by Adams and Frenzel. Detailed examination of the outcrops indicated that the rocks which appear massive at a distance (and thus reef-like) are actually distinctly bedded Carlsbad strata.

The reef formed a barrier for the deposition of the Tansill strata but its effect on the basin was less than in the preceding depositional intervals because it shed a relatively small amount of talus. In the basin this period is represented by only thirty feet of post-Lamar sandstone and limestone which grade into the Castile gypsum.

It has been suggested that the Delaware Sea was sealed and that increased salinity killed the reef (Adams and Frenzel, 1950). If this were true, impoverished and dwarfed faunas should occur in the latest Capitan. However, normal sized Porifera, Brachiopoda, Bryozoa, Coelenterata, and Algae continue in abundance into the youngest known reef rocks (Walnut Canyon). On the contrary, the shape of the Capitan reef indicates a more rapid subsidence toward the end of Capitan time and the final pinch off of the reef may well be the result of this subsidence. Thus the reef appears to have died because it could not "keep up" with the rate of subsidence.

The attempt of Adams and Frenzel (1950) to classify the natural growth of a reef into arbitrary stages (youth, mature, and decadence) is not applicable to this barrier reef. No field evidence was found by the author to substantiate these growth stages. In fact, their "youth" stage (Grayburg) and early "mature" stage (Queen) are Goat Seep equivalents, and as such are pre-Capitanian, and thus represent no part of Capitan history. Their "mature" stage (Seven Rivers, Yates, and lower Tansill) is stated to have been a period "dominated by upward growth." Actually this stage is marked by relatively slight upward growth, the reef expanding by growing primarily forward into the basin (Figure 8). Adams and Fenzel give as their last period a stage of "decadence and death" (Tansill). On the contrary, the Tansill equivalent reef was the most vigorous of all the stages, growing upward rapidly to maintain itself against the increasing subsidence.

Some differential subsidence is indicated along the reef trend. The bottom of the reef is not found in Slaughter Canyon, but a thickness of 1,200 feet of reef is measured near the mouth of the canyon (Figure 8). This greatly exceeds the thickness of the complete section of the reef in McKittrick Canyon. Thus the Slaughter Canyon areas subsided more than the areas to the southwest.

The West Texas Geological Society Guide Book (1948) gives a total reef width (Goat Seep to post-Lamar) of 7½ miles (perpendicular to the reef trend) in the subsurface near Carlsbad. The maximum width exposed at the surface is about 2½ miles (McKittrick Canyon). This indicates that the reef to the southwest was higher topographically (the basin being relatively deeper) so that outward growth required the deposition of more talus. In other words, in the north it was easier for the reef to maintain itself near the surface of the sea.

No lagoonal patch reefs, such as are found on Andros Island (Newell, Rigby, Whiteman, and Bradley, 1951), on the Great Barrier Reef (Fairbridge, 1950), and on the Pacific atolls (Ladd, Tracey, Wells, and Emery, 1950, are found in the Carlsbad formation. Adams and Frenzel (1950) mention an occurrence, but documentation is lacking. No evidence of patch reefs was found by Whiteman or the author.

Sedimentary Environment

General Petrology

The Slaughter member, the reef unit of the Capitan formation, is remarkably uniform. No definite sedimentary pattern occurs within the reef; apparently all changes are gradual. No bedding is discernible.

Almost the entire reef is made up of semi-lithographic limestone, which locally may contain sponges, brachiopods, bryozoans, mollusks, and other marine organisms. There are pockets of calcarenite and breccia, some of which are composed entirely of fossil remains, while others consist of clastic, semi-lithographic limestone. All gradations between these two types are found. Pods and dikes of quartz sandstone occur in abundance but with no definite pattern. They cannot be directly correlated with sandstone beds of the basin or lagoon. Fibrous calcite halos usually surround the sandstone inclusions.

The youngest part of the reef, i.e., Tansill or post-Lamar equivalent, differs slightly from the rest of the reef. This section is much narrower (200-300 feet wide) and contains many vermiculate and "bird's nest" structures (encrusting algae?). The rock of this portion of the reef, although semi-lithographic, is browner than that of the earlier parts of the reef, and contains relatively abundant bryozoans. The changes are gradational from Lamar to post-Lamar reef equivalents.

Dolomitic limestones occur in both fore-reef and back-reef strata, but the reef rock is almost pure limestone. Although Adams and Frenzel (1950) state that many fossils in the reef have been destroyed by dolomitization, no dolomite is found in the Slaughter member (Table 1). Johnson (1943) and Adams and Frenzel (1950) noted that a high algal content might be expected to give a high primary magnesium ion content. However, the patchy dolomitization in the Capitan formation (see Descriptive Petrology) indicates secondary origin.

In describing the "reef-wall" (reef) of Cretaceous and Tertiary reefs, Henson (1950) states:

> Vigorous vertical, and in some places lateral, growth of reef-building organisms with cavities filled in by reef-breccia and by rapid biochemical and physico-chemical precipitation of lime. In many places volume proportion of matrix greatly exceeds that of organic structures. Resulting rock mass is unstratified, very irregular and lithologically heterogeneous, with dense, commonly porcellaneous matrix, but with zones and channels of high porosity due to coral structures etc. Algal reefs are much less porous in this respect and do not as a rule form reef-walls without supporting corals.

This statement may be applied to the Slaughter member if calcareous sponges are substituted for corals and if it is realized that there is less porosity because of greater recrystallization and cementation. These differences are to be expected in comparing Permian reefs with those of the Cretaceous and Tertiary.

The widespread occurrence of quartz sandstone dikes and pods in the reef indicates that lagoon sands were at least occasionally swept across the reef flat during most of Capitan time. The sand pods are evidently fillings in the top of the porous reef mass (see Descriptive Petrology). The dikes are sand fillings in joints or fractures believed to have been formed by settling of the reef. In the few good exposures, the dikes strike parallel to the reef front. The tops of the dikes, where visible, occur at various time-stratigraphic horizons, and thus the dikes evidently were formed at different times.

The Calamity member, the Capitan talus unit, is composed of rudely bedded detrital limestone varying in texture from boulder breccias to mudstones. It contains the fossil remains of all the reef organisms. Dolomitization is patchy and erratic in the Calamity member.

Lateral Lithologic Variation

The basin, fore-reef talus, reef, and lagoon sediments correspond respectively to the Bell Canyon, Calamity, Slaughter, and Carlsbad lithostratigraphic units.

The contact between the Calamity and Slaughter members which is within an intertonguing zone about 100 yards wide along the projected fore-reef bedding, is mapped at approximately the middle of this intertonguing rather than by delineation of individual tongues (Figure 10).

Transitional units occur between the Capitan and the adjacent formations. The transition between the Carlsbad formation and the Slaughter member is a poorly and thickly bedded fossiliferous calcarenite, and is usually confined to a zone less than 100 yards wide (horizontal) and 25 feet thick (vertical). These transitional rocks are mapped with the Carlsbad formation. In some places, as on Guadalupe Peak, the reef--back-reef contact is readily discernible where fusulinid conglomerate lies directly on reef rock. In many places, where reef-derived calcitic sand lies directly on the reef, the contact is not so clearly defined.

The contact between the Calamity member and the Bell Canyon formation of the basin is arbitrarily established at the zone where the quartz sandstones of the basin first appear and white, thick bedded, fore-reef limestones change to gray, well-bedded, basinal limestones. This transition zone is about 100 yards in width, measured down dip parallel to the bedding.

Ecologic Environment

General

As previously stated, the purpose of this paper is primarily to determine the sedimentary and ecologic environments, and the mode of development of the Capitan reef. In order to pursue this aim the fauna was examined to determine both temporally significant forms and forms which might serve as environmental indices. Only the fusulinid genus _Polydiexodina_ is thus far determined to have a time range restricted to only a portion of the sequence under consideration. With regard to the fossils which indicate environmental conditions, only the larger taxonomic categories are significant.

Biofacies

Although nearly all major biologic groups are represented in all the rock units, there does seem to be a concentration of certain groups in specific environments (Figure 6).

The Porifera are found everywhere in the reef, but apparently become sparse down the reef front. Although

Bryozoa occur throughout the Slaughter, they appear to be concentrated at the front of the reef on and below the reef crest. Crinoids are best preserved in the back-reef transition beds, but columnals are found throughout the Slaughter member. Brachiopods are found in all three major environments, back-reef, reef, and fore-reef. Fusulinidae occur in all parts of the reef and fore-reef, but there are large concentrations in the back-reef transition and near-reef Carlsbad strata. Abundant Gastropoda, particularly large bellerophonts, characterize the back-reef transition, but they are not evenly distributed through the temporal sequence. Dascycladacean algae are abundant in the transition beds, and they also vary in abundance through the sequence. Forms which are designated as probable algae are found throughout the reef.

With the exception of calcareous sponges, most forms occurring in the Slaughter are also found in abundance in the Calamity. However, nearly all specimens collected in the fore-reef are crushed, worn, or broken, and thus are believed to have been transported downward from the reef front.

It is further evident that since, in overall aspect, the fauna extends beyond the limits of the Slaughter environment, biofacies differentiation within the Slaughter does not occur. Instead this biostratigraphic unit, which roughly corresponds in dimension to the Slaughter member, is regarded as a single biotope.

Biostratigraphy

Genera of brachiopods and bryozoans apparently are not restricted to any given part of the reef. The Porifera do not lend themselves to zonation. Mollusca and Coelenterata are too rare to be of value. However, the fusulinid genus *Polydiexodina* was found to extend from the base of the Capitan upward to the top of its McCombs (lower Yates) equivalent. The top of this zone is the only paleontologic datum which has been traced through the Capitan formation.

Because of the difficulties of collecting identifiable fossils from the reef, and because most of the well preserved silicified fossils of the basin facies are transported, statistical analysis of these faunas is thought to be of dubious value. Certainly the silicified forms of the basin represent reef dwellers, but the percentages are subject to the chances of size selection by winnowing, selective silification, and perhaps other processes.

Ecology

The reef biota is rich in variety and numbers, indicating favorable living conditions so that types of even small ecologic valence (Hesse, Allee, Schmidt, 1949) could thrive. The biotope extends throughout Capitan time and indicates relatively constant ecologic conditions.

Salinity, oxygen and carbon dioxide content, and temperature were probably controlled and stabilized by currents along and across the reef. The currents should have brought fresh plankton to the living reef and the organisms of the reef itself provided food for scavengers. Algae were restricted to the zone of photosynthesis, probably within sixty meters of the surface.

The type of bottom may have been a controlling factor in the distribution of the reef organisms. Rock, or at least firm, bottom is indicated between the back-reef calcarenites and the fore-reef breccias. Attached forms, Porifera, Brachiopoda, Crinoidea, Bryozoa, and Coelenterata, which are found throughout the reef (Figure 6), should occur in greatest abundance on the type of bottom suitable for attachment.

Ladd (1950) summarizes:

> As has long been recognized, reef organisms need warm water and strong light. They also require some agitation or circulation of the water because they are fixed and the water must bring food to them. These three conditions are most widely developed in the tropical areas at shallow depths. They must also, of course, have water of near-normal salinity and a type of bottom suitable for fixation.

The type of bottom and its distribution was in turn controlled by the rate of subsidence. With an increased rate of subsidence (Lamar time) the reef became narrower, and the organisms were restricted to the most favorable zone near the reef crest.

<u>Polydiexodina</u> is believed to have been a benthonic form of rather limited ecologic valence. It lived on the

reef flat and perhaps in the immediate back-reef. Large concentrations of *Polydiexodina* in the back-reef beds, however, may represent an environment of death rather than of life.

The disappearance of *Polydiexodina* at the end of McCombs time may give a clue as to their ecologic requirements. By the end of McCombs time the broad reef flat had narrowed and through the later Capitanian the reef was a comparatively narrow ridge. No other faunal change is noted, and none of the ecologic factors are known to have changed other than the restriction of the rock bottom. Therefore it might be postulated that a reef flat environment was required for *Polydiexodina*. This restriction to a reef environment is in agreement with the known occurrences of the genus in North America. However, additional stratigraphic information on its occurrences in Afghanistan, Darwas, and Burma (Thompson, 1948) may make this hypothesis untenable. The other Fusulinidae, *Leela*, *Staffella*, *Codonofusiella* (all small, light forms), did not seem to be affected by the narrowing of the reef flat.

Although the reef flat was restricted in Lamar and post-Lamar time, there is no evidence that this change affected the back-reef sedimentary or biologic environments other than by the elimination of *Polydiexodina*. Insofar as this interpretation is correct, the presence of *Polydiexodina* in the back-reef sediments would appear to represent purely mechanical concentrations of tests derived from the reef flat.

CONCLUSIONS

The Capitan is divided into two distinct members; the Slaughter or organic reef member, and the Calamity or fore-reef talus member.

The reef is an unbedded mass of fossil remains in a matrix of semi-lithographic white limestone. Porifera, Brachiopoda, and Bryozoa are the most abundantly represented faunal elements. Quartz sandstone similar to that in the fore-reef and back-reef strata occurs in dikes and pods throughout the reef. The limestone matrix may have originated as encrusting, lime-depositing algae.

The upper fore-reef talus (Calamity member) is composed of rudely bedded detrital limestones varying in texture from boulder breccias to mudstones. It contains the fossil remains of all reef forms. The basinward limit of the Calamity member is placed in the zone where basin sands first occur rather than at the basinward limit of the fore-reef detritus.

The Capitan reef grew on top and in front of the ancestral Goat Seep reef after a short(?) interval of non-deposition (non-growth).

Reef growth was by accumulation of the skeletal remains of organisms on the reef front and flat, which extended it outward and upward over its own talus. The upper limit of growth was sea level. The death of the reef is believed to have been caused by rapid subsidence which resulted in the drowning of the environment required for reef building organisms.

Sponges, bryozoans, brachipods, crinoids, and algae, all attached forms, are concentrated on or near the reef. Thus rock bottom seems to have been a controlling ecological factor for the reef organisms.

The zone of reef growth was controlled along the subsiding flexure between the shelf and the basin. When subsidence slowed, the reef widened and grew out; when subsidence increased, the reef narrowed and grew up. The rate of subsidence progressively increased in later Capitan time.

The time of deposition of the Capitan formation is equivalent to Bell Canyon deposition in the basin and Carlsbad deposition in the lagoon. It is limited below by the Goat Seep formation and its time equivalents and above by the Castile gypsum.

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ILLUSTRATIONS

Figures 1 and 2 are directly from King (1942). Figure 4 was prepared from photographs by Newell. Figure 10 is plotted on a U. S. Geological Survey Quadrangle base and the geology in the Texas portion of the map is largely from King (1948). Plates 11 and 12 were made up by Rigby, and Plates 1, 2, 9, and 10 were prepared by Newell. The remainder of the plates and figures were prepared by the author. The illustrations are selected from a group of forty plates and ninety-five figures prepared for the joint Permian reef project.

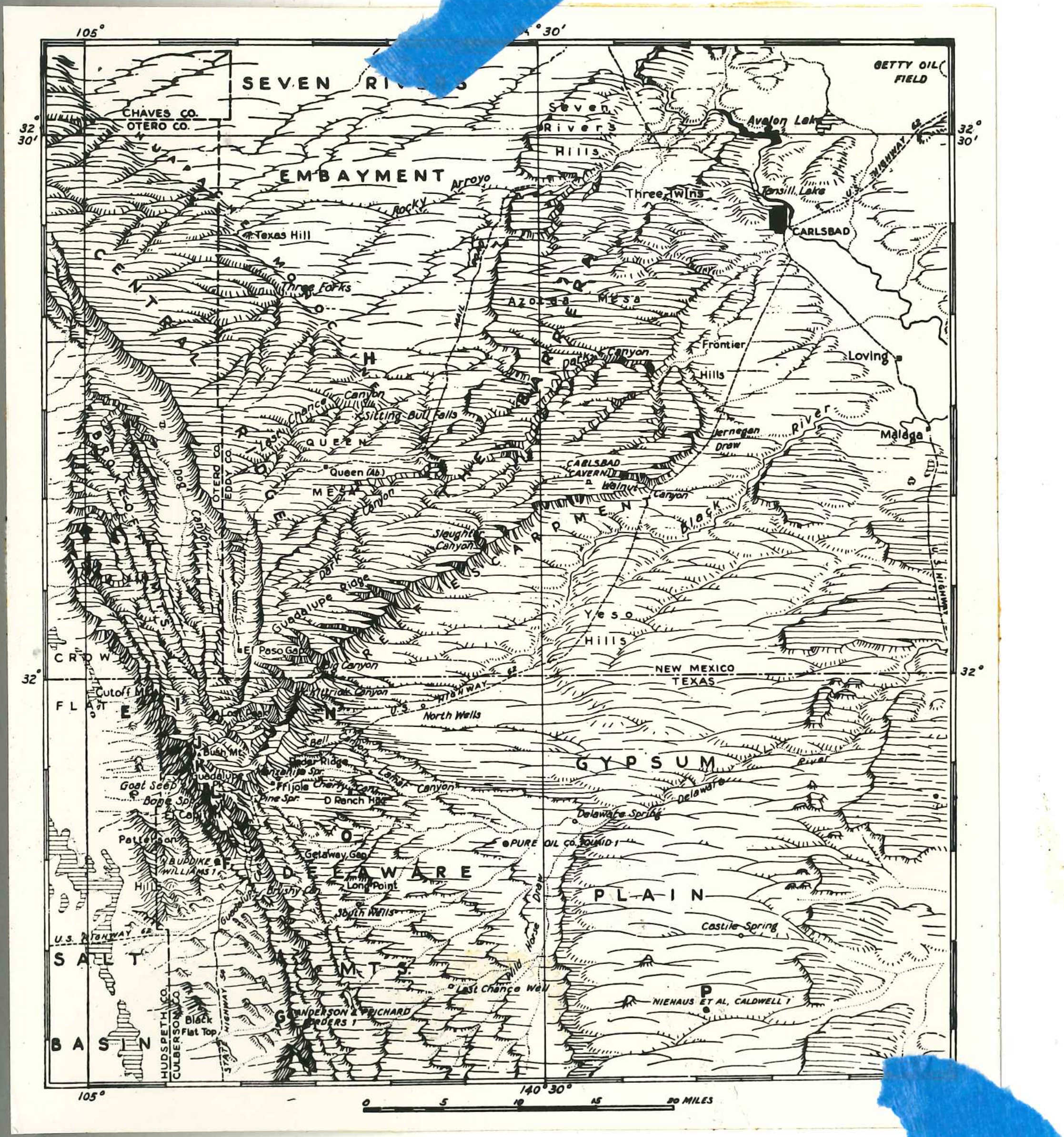
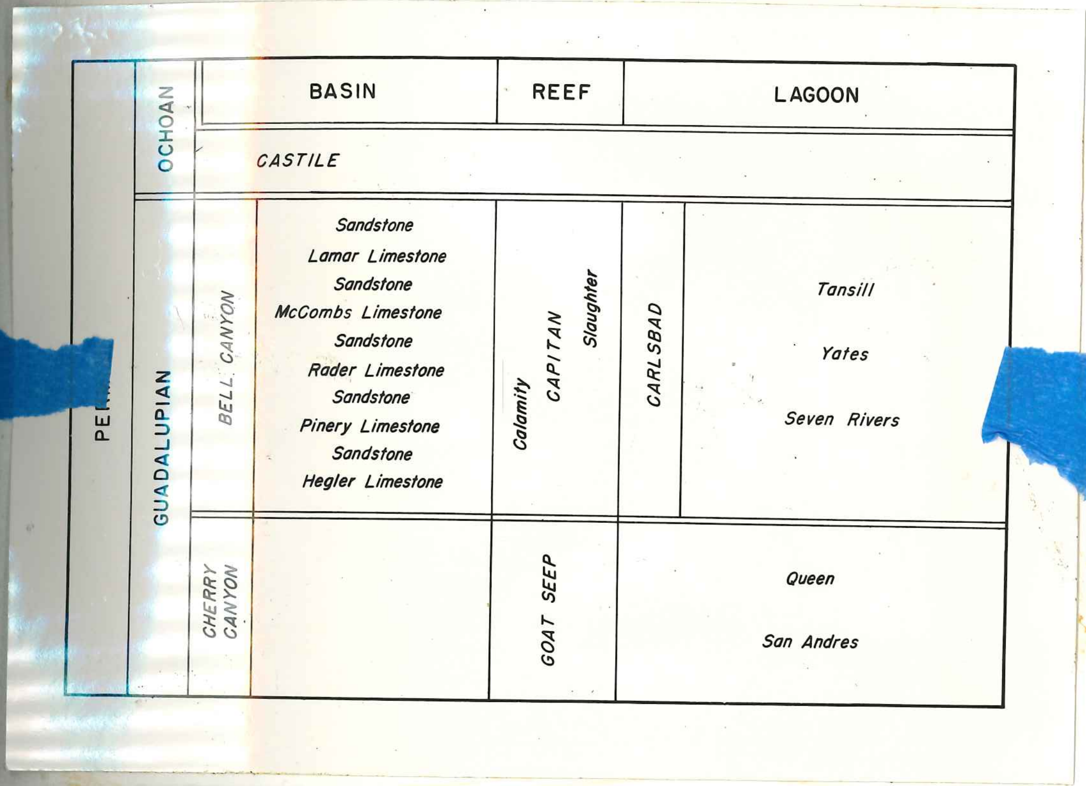
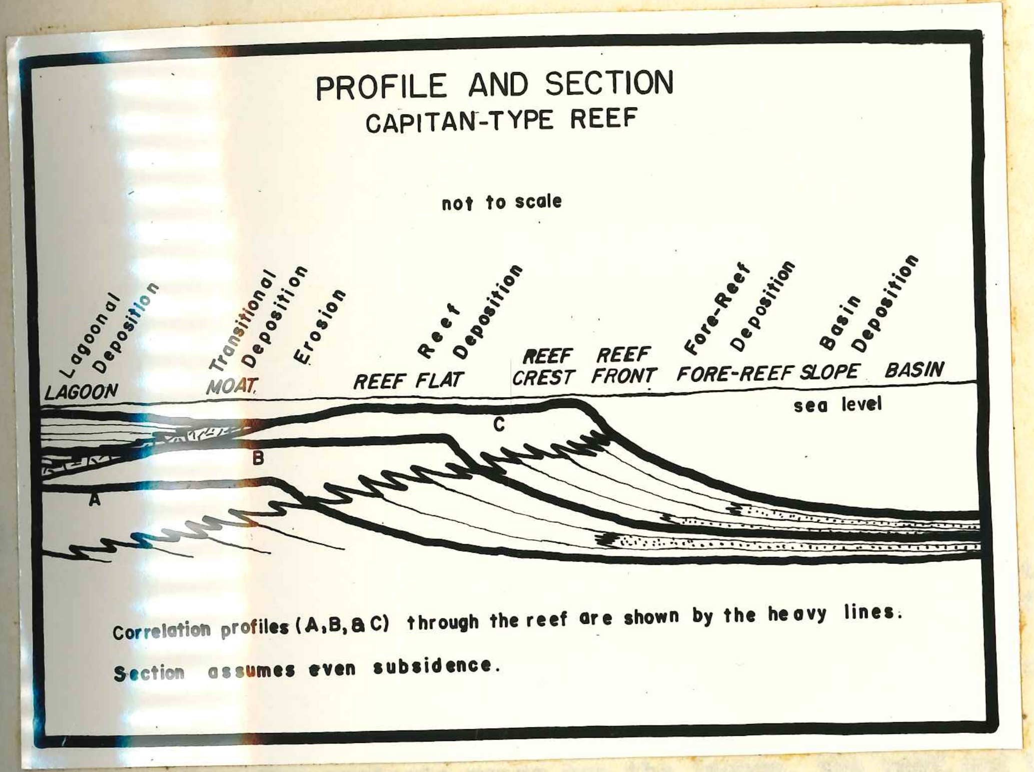


Figure 1. - Area of study. From King (1942).



		BASIN		REEF	LAGOON	
PE	OCHOAN	CASTILE				
	GUADALUPIAN	BELL CANYON	Sandstone Lamar Limestone Sandstone McCombs Limestone Sandstone Rader Limestone Sandstone Pinery Limestone Sandstone Hegler Limestone	Calamity CAPITAN Slaughter	CARLSBAD	Tansill Yates Seven Rivers
		CHERRY CANYON		GOAT SEEP		Queen San Andres

Figure 3. - General correlation chart.



Correlation profiles (A,B,& C) through the reef are shown by the heavy lines.

Section assumes even subsidence.

Figure 4. Profile and Section.

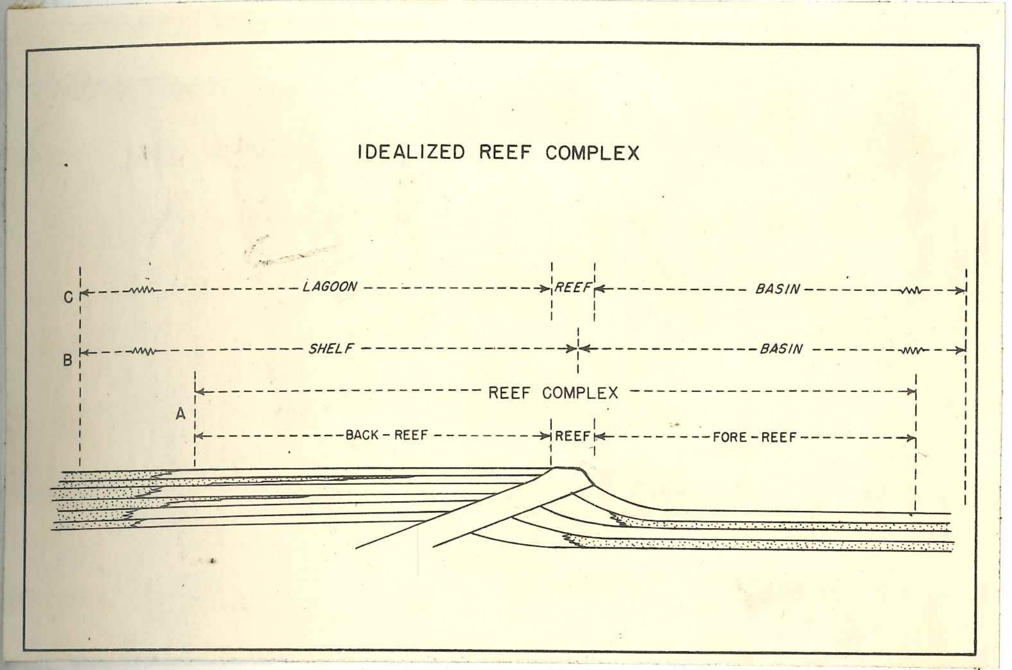


Figure 5. - Idealized reef complex

A. The reef complex embraces all reef derived limestones. It is divided into reef, back-reef, and fore-reef.

B. The physiographic or topographic nomenclature includes shelf and basin.

C. The ecologic zones are the lagoon, the reef, and the basin.

Note that there is no boundary within the reef complex (A) at the bottom of the reef talus slope. Although quartz sandstones appear, the tongues of reef derived limestone extend far into the basin. The Capitan formation does not correspond to the reef complex boundaries.

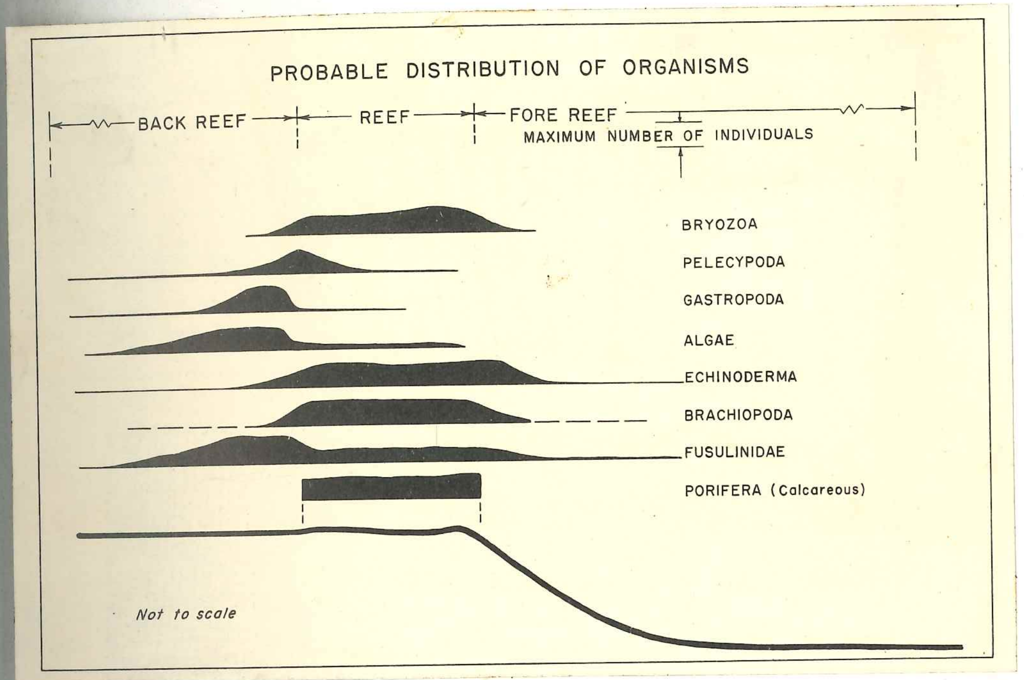


Figure 6. - Probable faunal distribution

Although this diagram is prepared to represent life distribution, it is possible that environments of death are represented. The Fusulinidae (principally Polydiexodina) may have been reef dwellers and the huge concentrations in the immediate back-reef are merely "cemeteries". The diagram was drawn from field observations and from specimens collected. It in no way represents a statistical study.

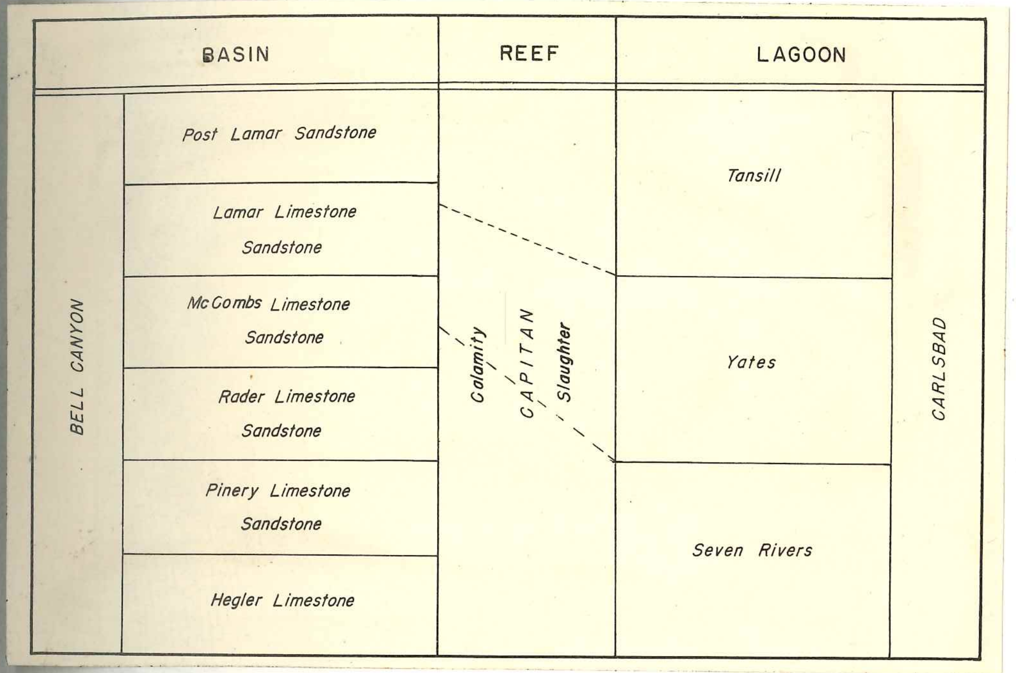


Figure 7. - Detailed correlation chart.

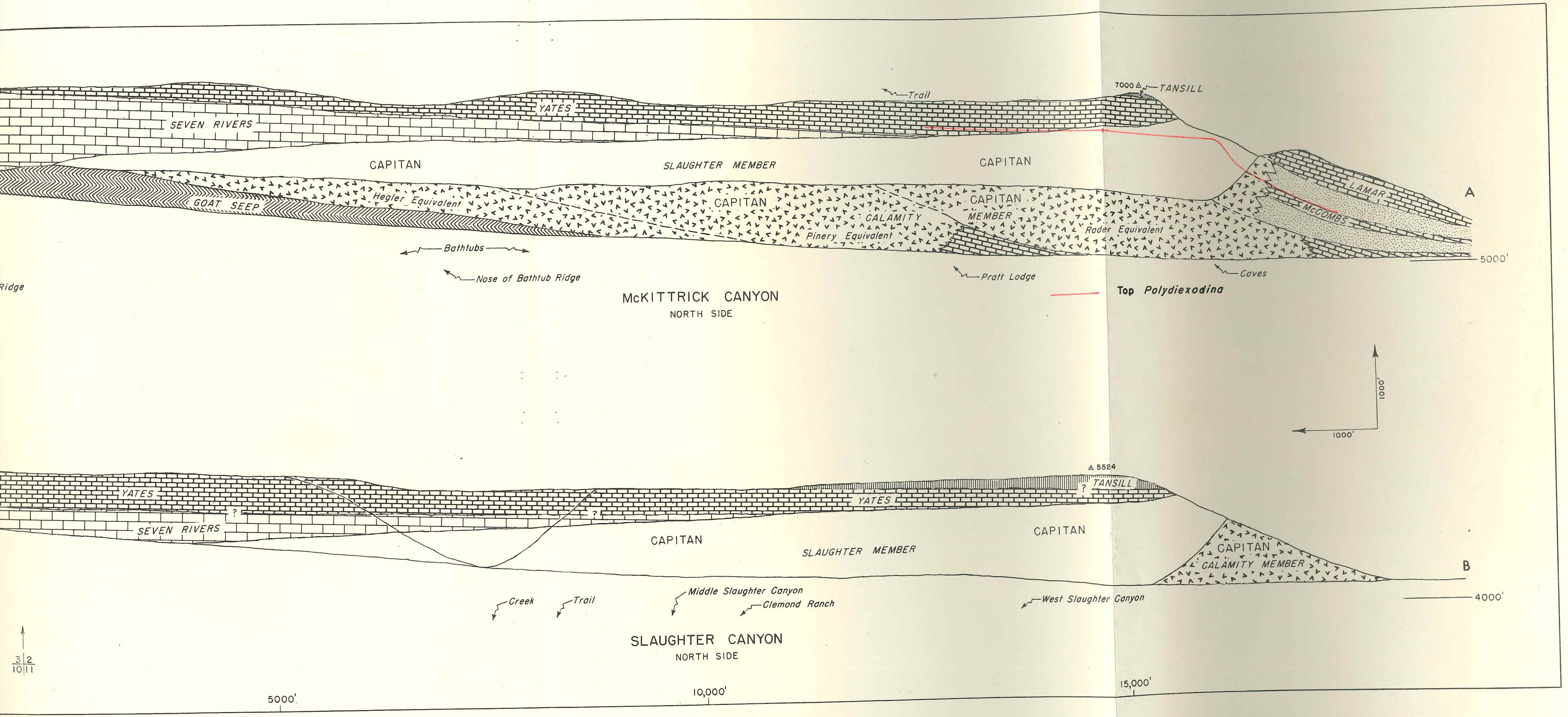

7000 △ TANSILL
Trail
YATES
SEVEN RIVERS
CAPITAN
SLAUGHTER MEMBER
CAPITAN
LAMAR
McCOMBS
A
GOAT SEEP
Hegler Equivalent
CAPITAN
CALAMITY
CAPITAN
MEMBER
Pinery Equivalent
Rader Equivalent
5000'
Bathtubs
Nose of Bathtub Ridge
Pratt Lodge
Caves
Ridge
Top Polydiexodina
McKITTRICK CANYON
NORTH SIDE
1000'
1000'
△ 5524
TANSILL
?
YATES
YATES
?
?
SEVEN RIVERS
CAPITAN
SLAUGHTER MEMBER
CAPITAN
CAPITAN
CALAMITY MEMBER
B
4000'
Creek
Trail
Middle Slaughter Canyon
Clemond Ranch
West Slaughter Canyon
SLAUGHTER CANYON
NORTH SIDE
3 2
10 11
5000'
10,000'
15,000'

Figure 8

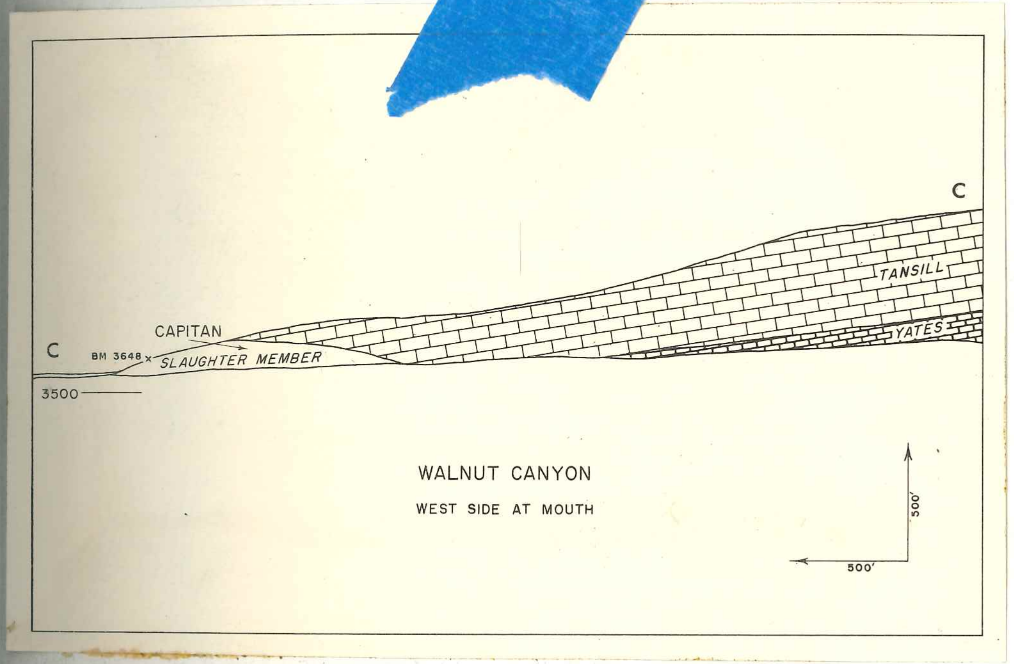


Figure 9. - Cross section through Walnut Canyon.

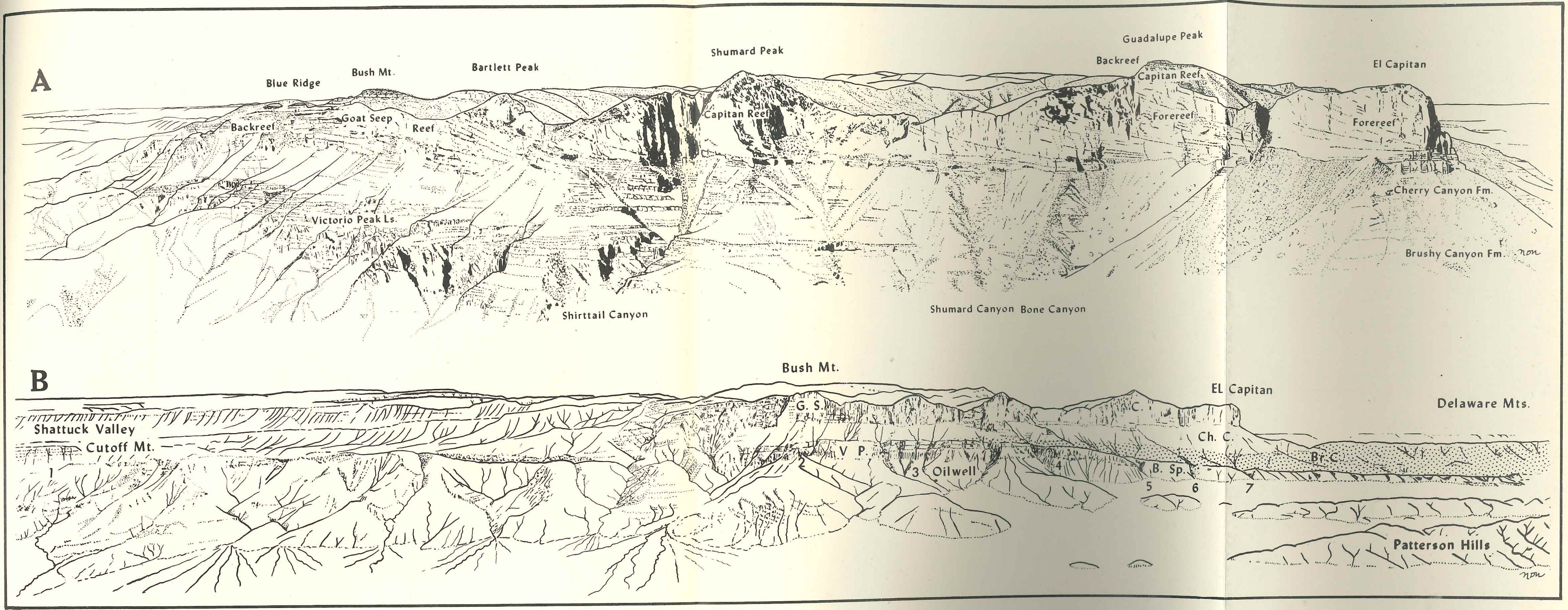

A
Blue Ridge
Bush Mt.
Bartlett Peak
Shumard Peak
Guadalupe Peak
Backreef
El Capitan
Backreef
Goat Seep
Reef
Capitan Reef
Capitan Reef
Forereef
Forereef
Victorio Peak Ls.
Cherry Canyon Fm.
Brushy Canyon Fm.
non
Shirttail Canyon
Shumard Canyon
Bone Canyon
B
Bush Mt.
EL Capitan
Delaware Mts.
G. S.
C.
Shattuck Valley
Cutoff Mt.
Ch. C.
V. P.
Br. C.
1
2
3
Oilwell
4
B. Sp.
5
6
7
Patterson Hills
non

Figure 11

PLATE 1

REEF AND WEST SIDE SCARPS

PLATE 1

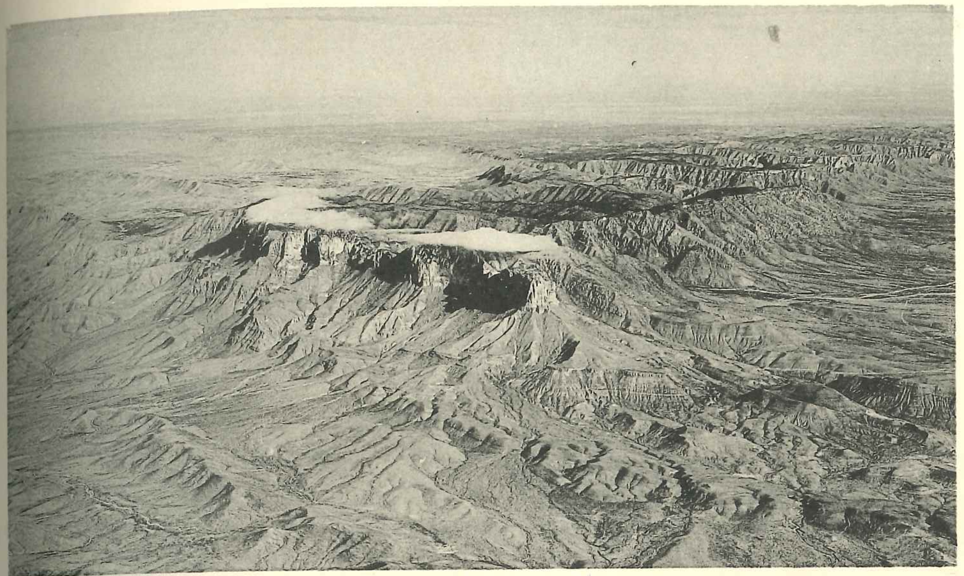


Figure 1. Southern Guadalupe Mountains
View toward the north-northeast. El Capitan near center; reef scarp on right, west side fault scarp on left. (*Muldrow photo*).

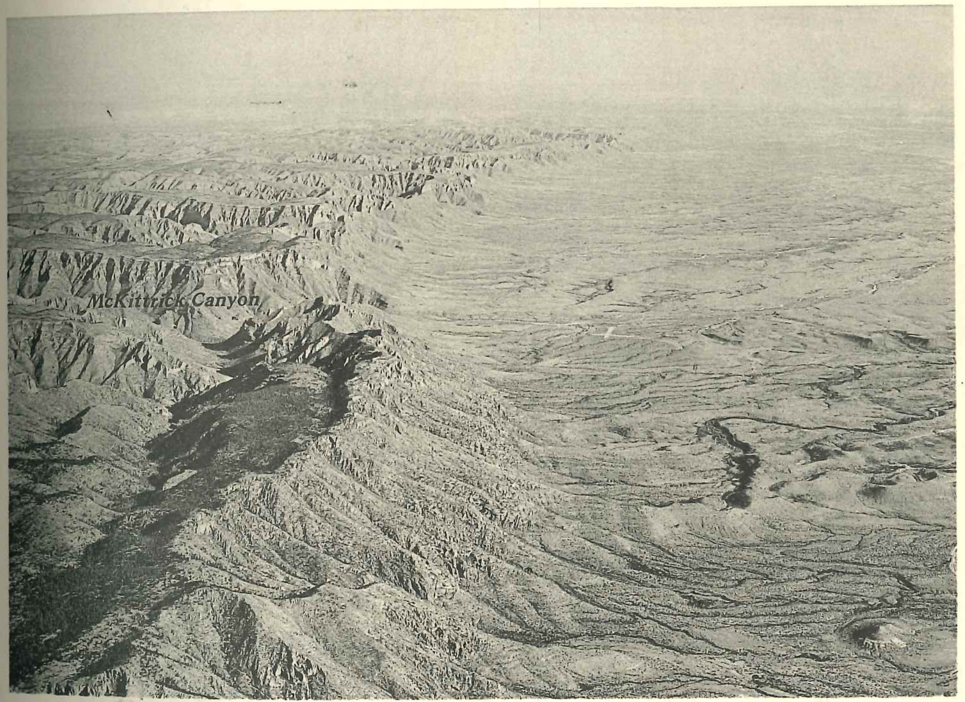


Figure 2. View Northeastward Along Capitan Reef Scarp
Well-defined embayment in the reef near mouth of McKittrick Canyon. Abrupt transition from reef to basin deposits in foreground. (*Muldrow photo*).

REEF AND WEST SIDE SCARPS

PLATE 2

REEF AND REEF TALUS

PLATE 2

REEF AND REEF TALUS

Figure 1. Algal head, family Spongiostroma, in fore-reef mud flow, post-Lamar equivalent. Slaughter Canyon at mouth. Locality 796.

Figure 2. Crinoid stems in near-reef Tansill strata. Dark Canyon at mouth. Locality 822.

Figure 3. Sandstone pods in reef rock weathered to show lacy pattern. Double Canyon. Locality 852.

Figure 4. Sandstone dike in reef rock. North Slaughter Canyon. Locality 843.

PLATE 3

REEF FACIES

Figure 1. Radial structure in fibrous calcite. X 5. Locality 833.

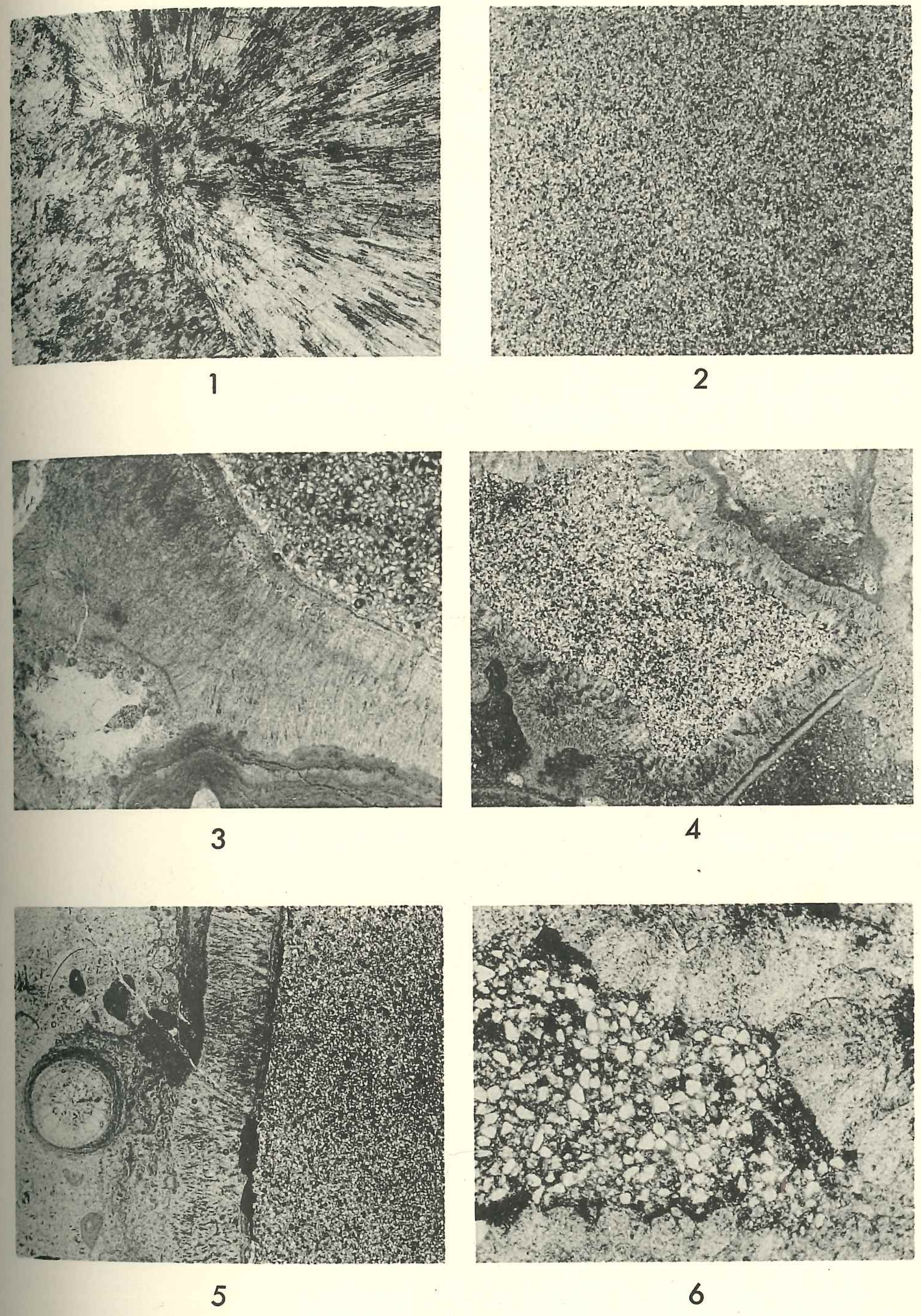
Figure 2. Quartz sandstone dike. X 5. Locality 770.

Figure 3. Sandstone pod showing fibrous calcite halo and encrusting algae. X 10. Locality 836.

Figure 4. Sandstone pod with calcite halo. X 5. Locality 789.

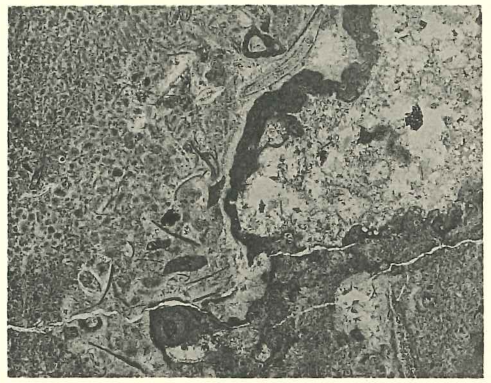
Figure 5. Sandstone pod, fibrous calcite, coral, and matrix of reef rock. X 5. Locality 836.

Figure 6. Sandstone pod with fibrous calcite. X 25. Locality 790.



REEF FACIES

PLATE 4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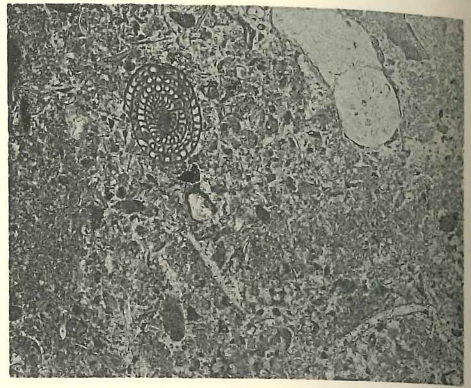
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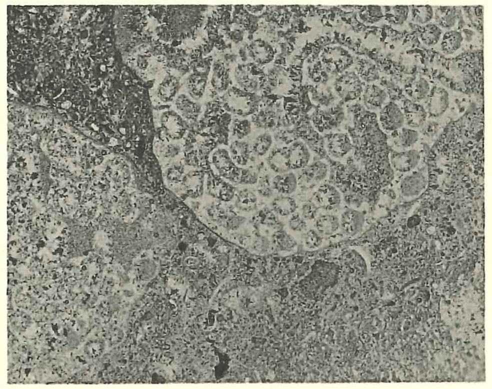
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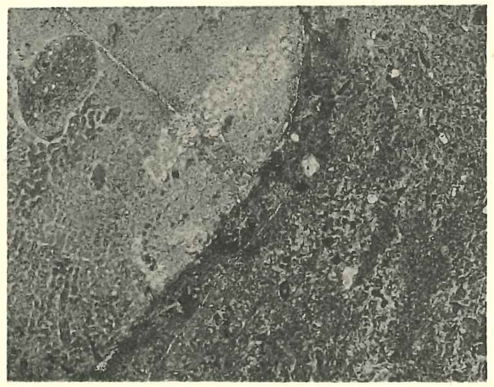
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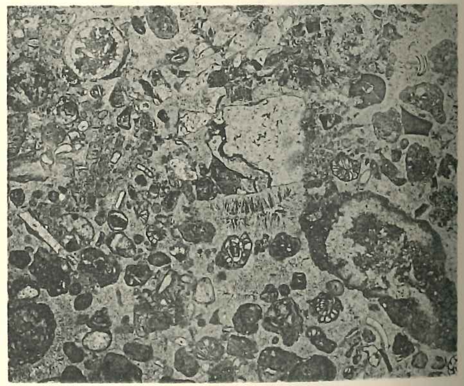
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REEF FACIES

PLATE 4

REEF FACIES

Figure 1. Fossil debris in matrix with encrusting algae. X 5. Locality 775.

Figure 2. Reef rock showing fusulinid and sponge in matrix of shell debris and fine-grained calcite. X 5. Locality 813.

Figure 3. Two calcareous sponges in reef rock. X 5. Locality 803.

Figure 4. Calcareous sponge, algae (*Solenopora texana* Johnson 1951), vug linings, and radial fibrous calcite in reef rock. X 5. Locality 845.

Figure 5. Calcareous sponge in reef rock. X 5. Locality 683.

Figure 6. Reef rock. All reef rock appears semi-lithographic in hand specimen and has a splintery to conchoidal fracture. X 5. Locality 856.

PLATE 5

REEF ORGANISMS

Figure 1. Hydrocorallines (fide J. H. Johnson). "The encrusting coatings on some of them are probably low lime-depositing algae." (J. H. Johnson, pers. com.). X 10. Locality 799.

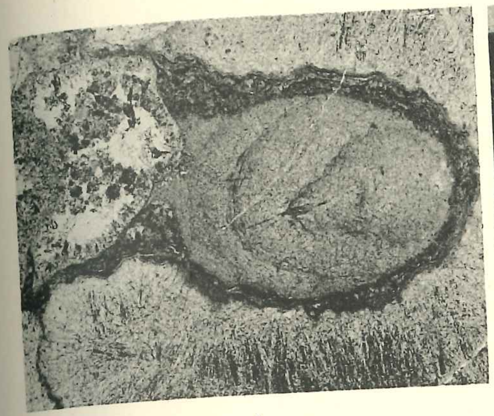
Figure 2. Algae (*Solenopora texana* Johnson 1951). X 25. Locality 845.

Figure 3. Same as Figure 2. X 10.

Figure 4. Same as Figure 1. X 25.

Figure 5. Same as Figure 1 (different specimen). X 25.

Figure 6. Same as Figure 5. X 10.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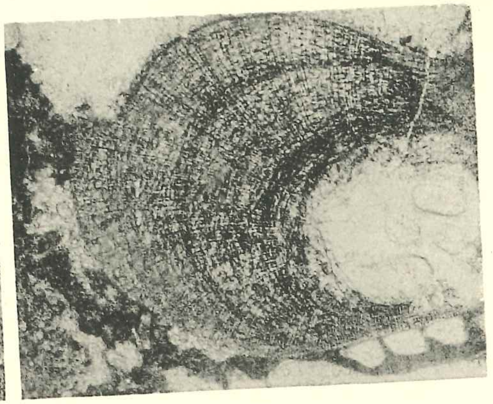
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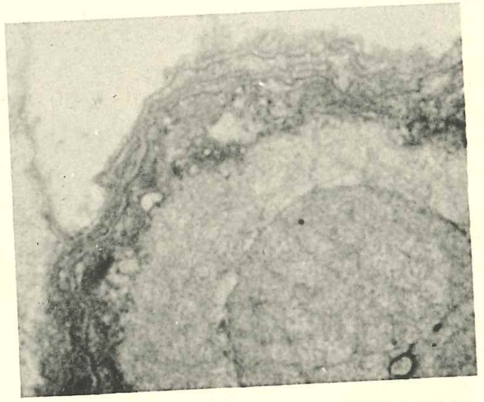
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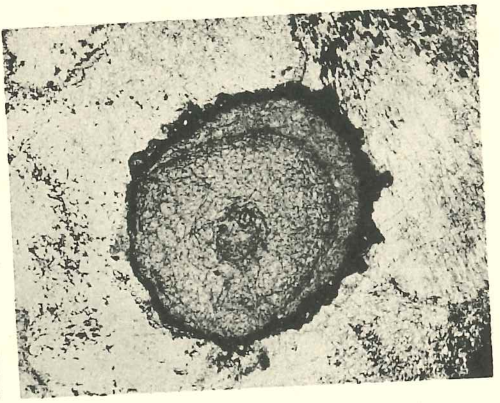
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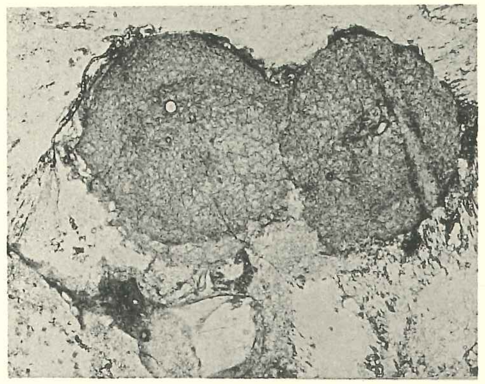
REEF ORGANISMS

PLATE 6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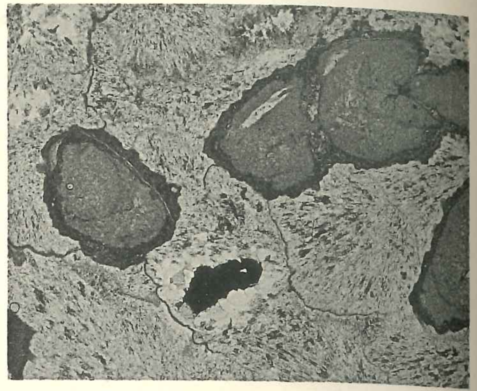
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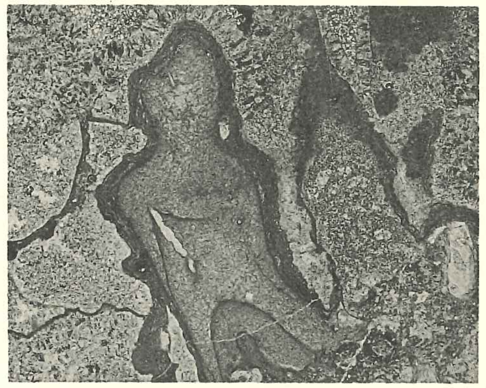
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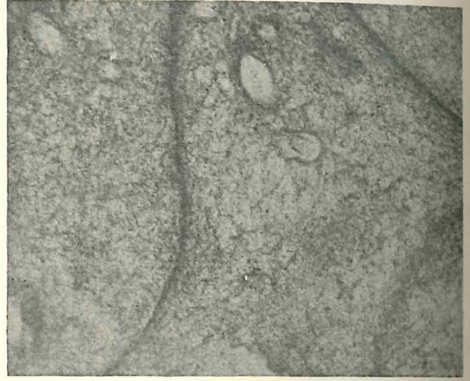
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5


6

REEF ORGANISM

PLATE 6

REEF ORGANISM

Figure 1.	Hydrocorallines (see Plate 5, Figure 1). X 10. Locality 799.
Figure 2.	Same as Figure 1. Note fibrous calcite. X 5.
Figure 3.	Hydrocorallines and encrusting algae. Note fibrous calcite and sandstone stringers at top. X 5. Locality 790.
Figure 4.	Hydrocorallines. X 25. Locality 794.
Figure 5.	Same as Figure 4. X 10.
Figure 6.	Same as Figure 4. X 5.

PLATE 7

REEF ALGAE

Figure 1. Collenella guadalupensis Johnson 1942, calcareous algae. X 1. Locality 815.

Figure 2. Same. Field occurrence on old stage road above White City. Locality 815.

REEF ALGAE

PLATE 8

1

2

REEF SPONGES

PLATE 8

REEF SPONGES

Figure 1. Reef rock. X 1/2. Locality 420.

- a. *Polyphymaspongia* sp.
- b. *Cystothalamia* sp.
- c. *Amblysiphonella* sp.
- d. *Cystauletes* sp.
- e. *Guadalupia* spp.
- f. Fibrous lining of cavities.

Figure 2. Large calcareous sponge (*Cystothalamia* sp.) Locality 823.

PLATE 9

WEST SIDE SCARP

PLATE 9

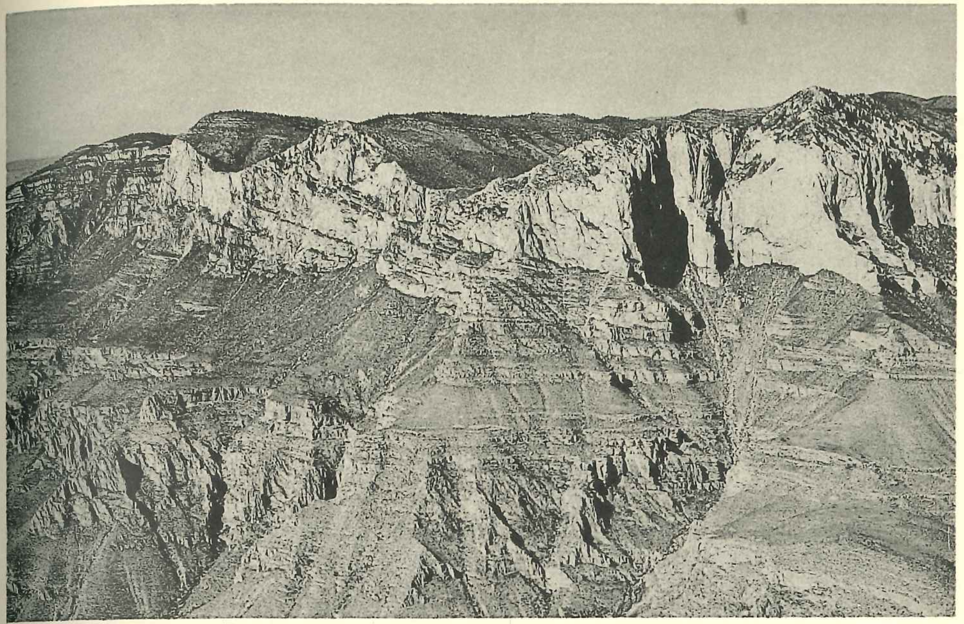


Figure 1. Blue Ridge, Left, to Shumard Peak, Right
Inclined forereef bedding planes are conspicuous on Bartlett Peak, upper left, but Shumard Peak is composed of very massive rock.

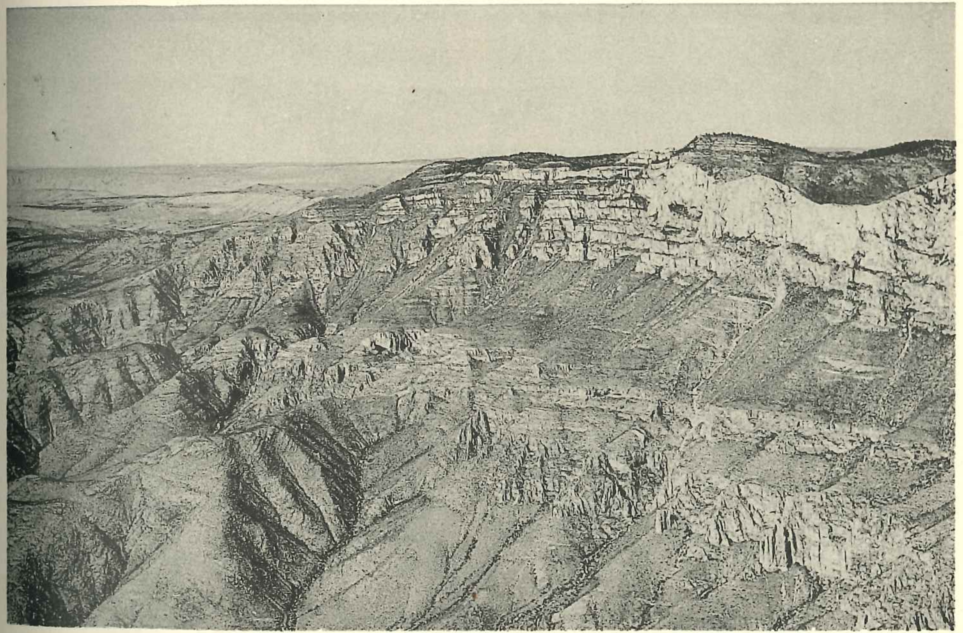


Figure 2. Blue Ridge Area
Massive Goat Seep reef, upper right, passes abruptly into bedded backreef to left. Lower cliffs formed by Victorio Peak member of Bone Spring formation.

WEST SIDE SCARP

PLATE 10

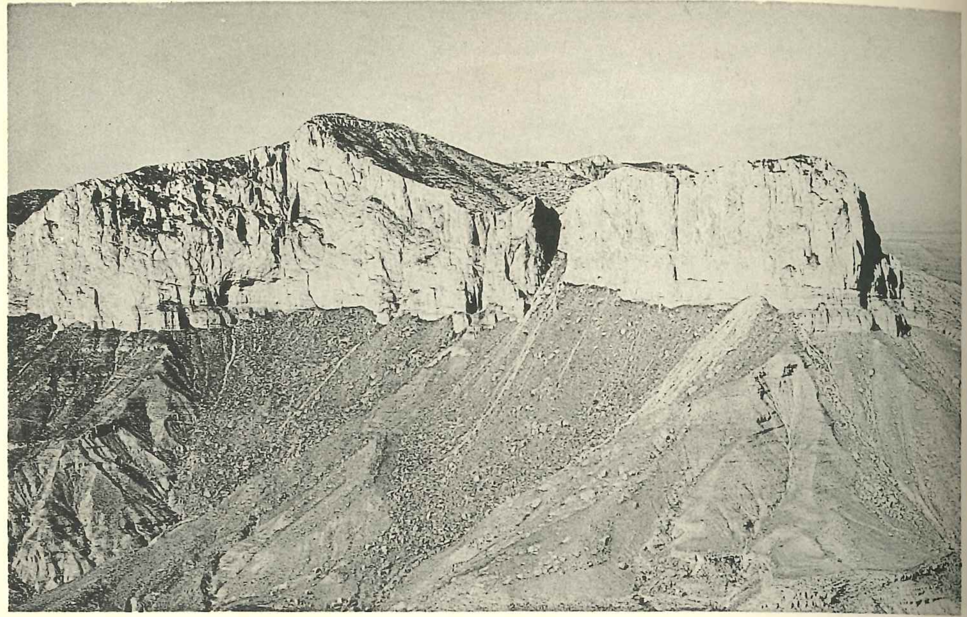


Figure 1. Guadalupe Peak, Left, and El Capitan, Right
Forereef inclined beds reach high toward the summit of Guadalupe Peak which is capped by horizontal backreef beds.

Figure 2. Shumard Peak, Left, to Guadalupe Peak, Right

WEST SIDE SCARP

PLATE 10

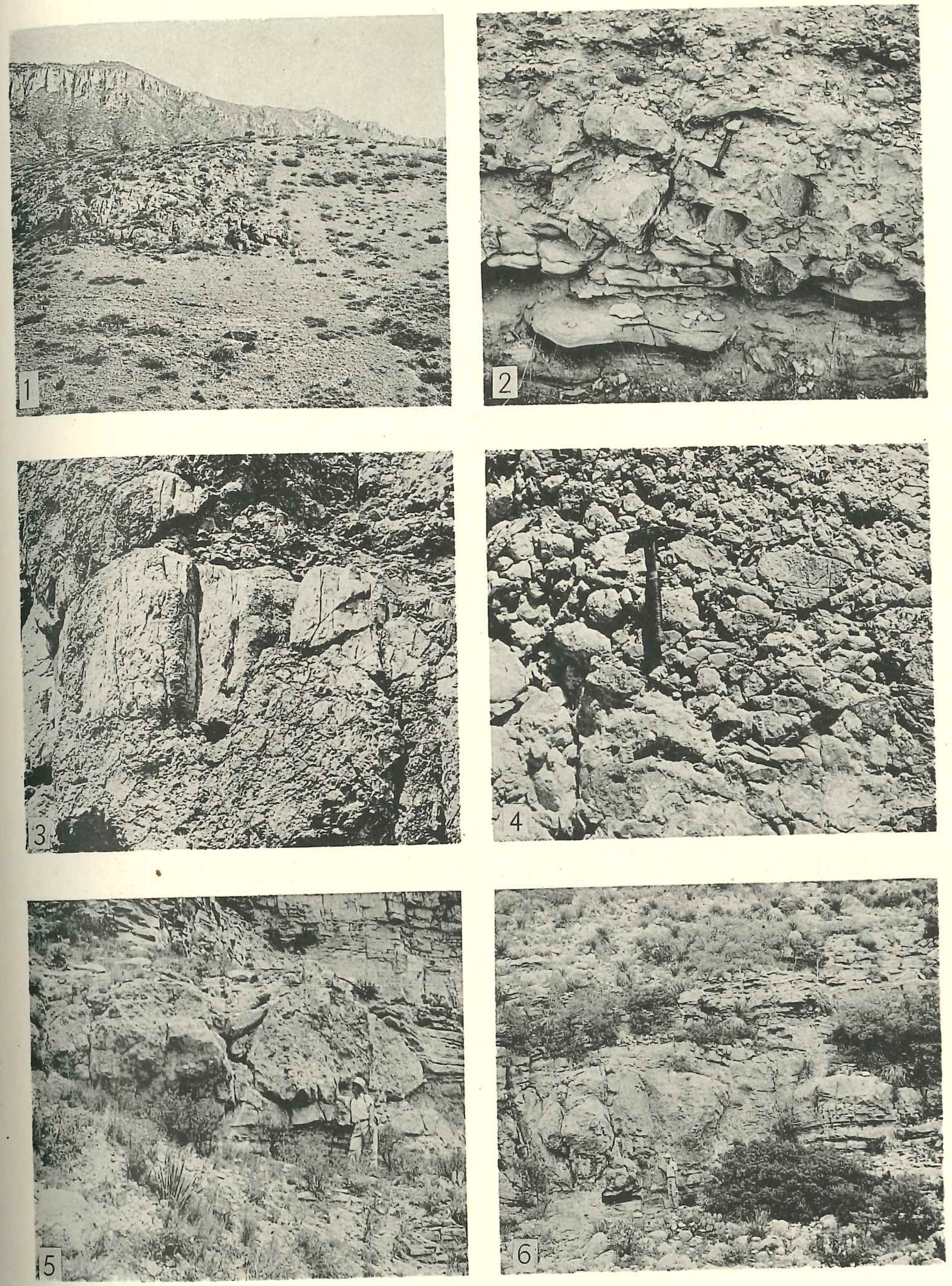
WEST SIDE SCARP

PLATE 11

FORE-REEF TALUS

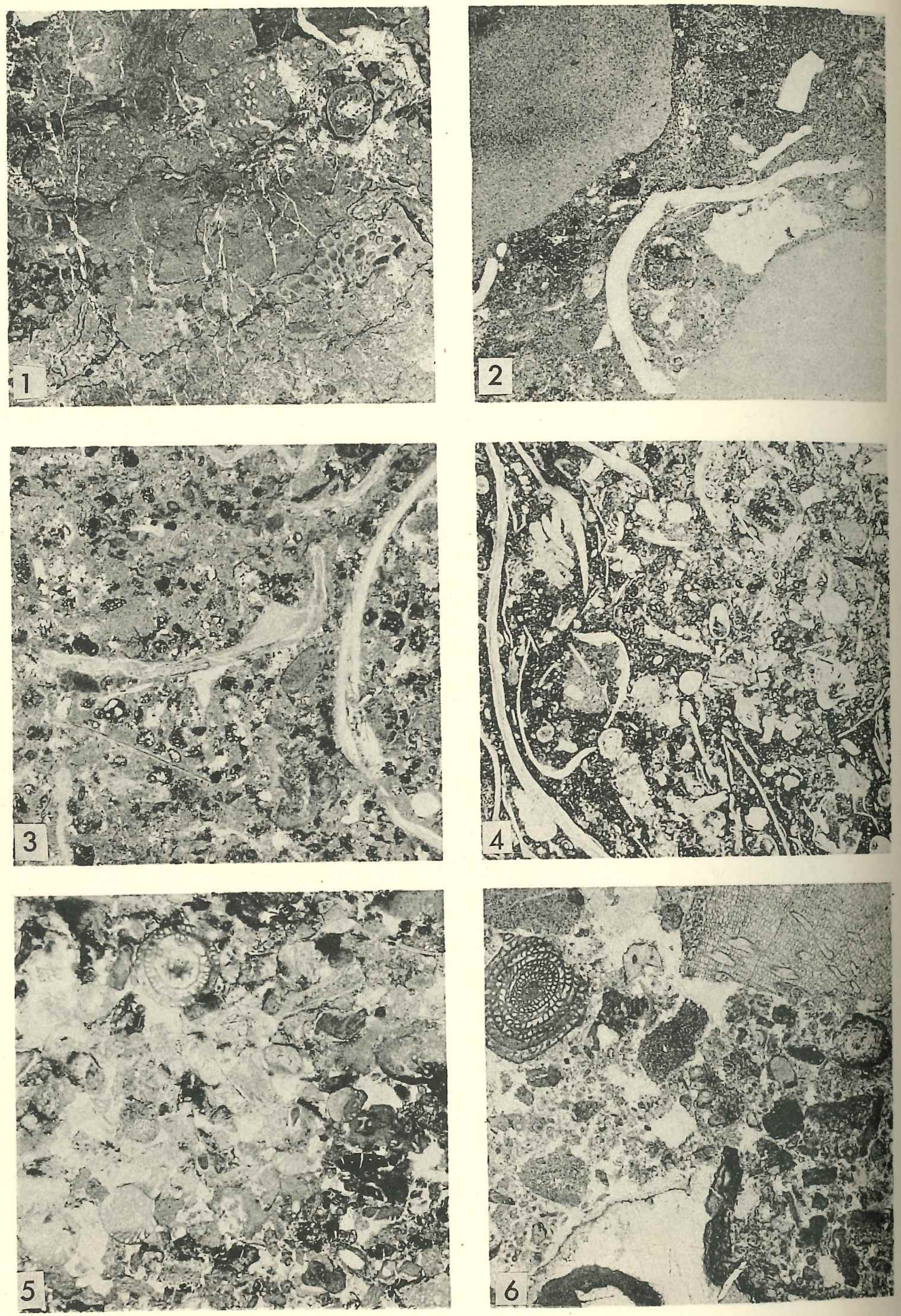
Field views of fore-reef breccias, mud lumps, boulders, and mud flows in the Calamity member.

PLATE 11



FOREREEF TALUS

PLATE 12



FOREREEF DETRITUS

PLATE 12

FORE-REEF DETRITUS

Thin sections (X 5) of the fine grained fore-reef detritus of the Calamity member. Note the brecciated and broken fossils typical of the fore-reef. This material may form massively bedded deposits or be a matrix for larger breccias.

APPENDIX

METHODS OF STUDY

Field work was carried on during the summer of 1950 and was restricted to the area of Capitan outcrop between El Capitan and Walnut Canyon (Figure 1). Lithologic and paleontologic samples were collected from 110 localities (Figure 10 and Appendix), contacts and lithologies were noted on each locality traverse, and panoramic photographs were taken where applicable. From these notes and from aerial photographs, a geologic map of the Capitan formation (Figure 10) was prepared on a U. S. Geological Survey Quadrangle map base. In the area south of the Texas-New Mexico state line the faults and formation boundaries are largely from King (1948). The collections were generally made from the most fossiliferous localities in the reef rather than as typical or line samples. Thus no quantitative study may be based on the collection. The entire sample collection is deposited at Columbia University.

Laboratory work and writing were done during the winter of 1950 and the spring of 1951. Paleontologic examination was made of the entire collection, whenever possible in collaboration with a student of the particular fossils under consideration. The petrologic aspect of the collection was studied from hand specimens, field notes, field photographs, polished sections, thin sections, etched surfaces, acetate peels, stained surfaces, and by chemical and spectrographic analyses. Spectrographic quantitative analyses (Table 1) were made by Karl Turekian under the direction of Dr. J. L. Kulp (Columbia University). Chemical analyses for dolomite were based on the differential solubilities of calcite and dolomite with respect to acetic and hydrochloric acid.[1] Two stain tests for differentiating calcite and dolomite were used; (1) ferric chloride - ammonium polysulphide, and (2) silver nitrate - potassium chromate (Holmes, 1921). Both tests are applicable to relatively coarse-grained limestones, but the dolomite tends to be masked in fine-grained limestones. Selected samples were tested with ether for soluble hydrocarbons. Thin sections and photographs are filed at Columbia University.

---

[1] Grams sample - grams $HC_2H_3O_2$ insoluble = grams $CaCO_3$

Grams $HC_2H_3O_2$ insoluble - grams HCl insoluble = grams $CaMg(CO_3)_2$

$$100 \times \frac{\text{grams } CaMg(CO_3)_2}{\text{grams sample}} = \% \text{ dolomite}$$

DESCRIPTIVE PETROLOGY

Slaughter Member

Approximately eighty per cent of the reef is semilithographic to lithographic, white to cream limestone with conchoidal to splintery fracture. In thin section the rock is seen to be an agglomeration of very fine fossil debris in a matrix of felt-like calcite crystals (Plate 4). The debris is composed of skeletal remains of all types of fossil forms known in the reef. In most cases the matrix comprises more than half the total and is sometimes recrystallized in radial patterns of calcite fibers (Plates 4, Figure 6 and 5, Figure 1). Openings in the reef rock may be lined with fibrous calcite, filled with quartz sand, or filled by secondary calcite.

The youngest known reef rock (Walnut Canyon) is brown, rather than almost white as in the older portions of the reef. This color is due to the presence of light yellow-brown crude oil.

Sandstone dikes which occur throughout the Slaughter appear to be somewhat more abundant in the older portions. The sand grains appear identical to those of the back-reef sandstones which consist of fine, very angular, frequently conchoidally fractured quartz. Some of the quartz grains superficially resemble glass shards in form and luster. The dikes consist of fifty to sixty per cent quartz sand in a calcite matrix. The matrix may be dolomitized locally, especially at the limestone-sandstone contact. A few dikes may be traced fifty to one hundred feet along the outcrop. These dip almost vertically, strike parallel to the reef front, and vary from a few inches to several feet in width.

Sandstone pods, which occur throughout the reef, are highly irregular, with a maximum dimension of one to two inches and are, in many cases, dolomitized at their contacts. On outcrops they form an anastomotic to lacy pattern (Plate 2). The quartz grains of the pods are like those of the dikes.

Fibrous calcite, which is common throughout the reef, is shown in photomicrographs (Plates 3, 6, 8). In some cases this calcite is cavity filling, while in others it represents recrystallization of the matrix. Fibrous calcite also surrounds each sand pod and is present at dike boundaries, and is slightly more dolomitic than the surrounding reef rock (Table 1, locality 836).

Spectrographic quantitative analyses show very slight, if any, dolomitization in the reef rock. Thirteen sample localities show a minimum of 93.7 per cent $CaCO_3$ with a majority showing 98-99 per cent $CaCO_3$ (Table 1).

TABLE 1

CHEMICAL ANALYSES OF REEF ROCK

Loc.	$CaCO_3$ %	$MgCO_3$ %	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	Remarks
xxx	99.4	.3	.05	0	0	control-stalactite
856	99.0	.7	.3	0	0	Slaughter member
853	99.0	.7	.3	0	0	" "
845	99.2	.5	.3	0	0	" "
836	96.4	3.6	.1	0	0	" "
833	99.4	.4	.2	0	0	" "
818	98.9	.8	.3	0	0	" "
813	98.0	1.9	.1	0	0	" "
814	93.7	6.0	.3	0	0	Calamity "
803	97.0	2.6	.3	0	0	Slaughter "
799	97.6	1.9	.2	.5	0	" "
796	77.3	22.4	.2	.1	.1	Calamity "
794	99.3	.5	.3	0	0	Slaughter "
789	97.4	.9	1.8	0	0	" "
775	96.0	3.8	.1	.1	0	Calamity "
688	55.4	44.3	.3	0	0	Goat Seep Reef

Anions only were measured. All calcium is reported as calcium carbonate, all magnesium as magnesium carbonate, etc.

Calamity Member

The reef talus is made up solely of reef debris; it is rudely stratified in massive beds with a primary basinward dip of five to thirty-five degrees. Near the reef, beds may be fifty to one hundred feet thick, but they are five to twenty feet thick at the basinward margin where they are recognized as part of the Bell Canyon formation. The debris varies texturally from mudstones to boulder breccias. The rocks are not easily characterized, but most of the Calamity member consists of a very coarse calcitic sand made up of fragments of fossils and reef rock. The amount of matrix varies up to eighty per cent. The interstices of some breccias are filled with a quartz sand-calcite matrix or with secondary calcite, but the usual matrix is fine debris and lithified calcitic mud. Although some quartz sand is found there is much less than in the reef. No pods occur in the Calamity member and few of the sandstone dikes extend down into the detritus. Oil stains occur in some brown, post-Lamar equivalent, Calamity limestones.

Dolomitization is patchy and erratic in the Calamity member. More dolomitic patches were observed in the older talus than the younger talus. In the Rader equivalent the dolomite varies from zero to seventy-five per cent (differential insolubles test). There are no visible boundaries between the calcite detritus and the dolomitized patches, but the gradation may be observed with hydrochloric acid tests.

The fusulinid tests were dolomitized first. King (1948) gives two fore-reef analyses. The Lamar equivalent limestone at the mouth of McKittrick Canyon is 71.47 per cent $CaCO_3$ and 27.84 per cent $MgCO_3$; a fore-reef limestone (probably Rader equivalent) from Pine Spring Canyon is 92.06 per cent $CaCO_3$ and 7.23 per cent $MgCO_3$.

FAUNA

Because the detailed problems of systematic paleontology are being pursued by other members of the research group, only the occurrence and distribution of previously determined forms are treated in this report.

PHYLUM PROTOZOA

CLASS SARCODINA

The large cylindrical fusulinids, _Polydiexodina capitanensis_ Dunbar and Skinner 1931 and _P. shumardi_ Dunbar and Skinner 1931, are found from the base of the Capitan to the top of the McCombs (lower Yates) equivalent of the Capitan. _Polydiexodina_ is identified in thin and polished sections from numerous localities throughout the sequence.

The small fusulinids, _Staffella fountaini_ Dunbar and Skinner 1937, _Leela bellula_ Dunbar and Skinner 1937, and _Codonofusiella paradoxica_ Dunbar and Skinner 1937 appear in some of the thin sections, becoming relatively more abundant in Lamar time.

PHYLUM PORIFERA

CLASS CALCAREA

Anthracosycon

Locality 856

Amblysiphonella							
Localities	420	693	784	796	808	815	
Cystauletes							
Localities	420	780					
Cystothalamia							
Localities	420	683	774	776	778	784	786
	788	789	803	824	849		
Girtycoelia							
Localities	420	776	796	803	812	813	815
	823	855	856				
Guadalupia							
Localities	420	690	691	693	695	771	775
	780	784	785	797	799	803	808
	815	819	823	825	828	830	837
	845	847	849	850	852	855	856
Heliospongia							
Localities	774	845	856				
Laubenfelsia							
Locality	803						
Polyphymospongia							
Localities	420	691	693	771	774	790	792
	794	797	808	815	823	828	829
	845	847	856	857			
Pseudopemmatites							
Localities	808	811	831	856			
Stylopegma							
Localities	788	792	823	830	845	856	
Talpospongia							
Localities	789	856					
Virgula							
Localities	420	683	691	693	771	772	774
	775	776	778	780	782	784	785
	786	788	790	793	794	796	797
	808	819	823	825	828	830	833
	835	845	847	852	855	856	857

Calcareous sponges are the most important rock building organisms in the reef formation. They occur throughout the Slaughter member, but are rarely found in the Calamity member.

From this preliminary study the sponges do not appear to have any time-stratigraphic significance within the Capitan formation.

The sponges were identified by Robert Finks and the author. Because these specimens were not studied in thin section, some generic identifications are questionable; however, some specimens could be specifically determined. Most questionable genera have been placed with Virgula as many calcareous sponges without defining characteristics resemble that genus.

PHYLUM COELENTERATA

CLASS HYDROZOA

Hydrocorallines occur in a few of the thin sections, localities 799, 790, and 794 (Plates 5 and 6). They were originally thought to be algae by the author, but J. H. Johnson (personal comment) states:

> The principal organisms, that is, the conical forms that are oval or round in section are what I have previously interpreted as hydrocorallines. They have suffered considerable recrystallization, but the preservation and alteration is very similar to that which I find in some of the corals and hydrocorallines from the Tertiary reef limestones I am now studying from the Pacific. However, I am not an expert on the group, so I would suggest that you have them checked by someone who is. In any case, I do not consider them to be algae.

CLASS ANTHOZOA

Corals occur throughout the reef as a very minor constituent. Most of the forms are small horn corals (Lophophyllidium and Caninia), although one specimen is two inches in diameter and six inches long. Only one genus of colonial coral, Cladopora, was noted in the reef although several genera, found in the silicified basin collections, are believed to have been reef dwellers. Corals were collected at the following localities:

695 776 780 788 790 792 801 809 820
821 822 824 826 835 842 856 857

PHYLUM ECHINODERMA

CLASS CRINOIDEA

Crinoid debris is found throughout the Capitan formation. The only complete stems were found on top of the reef and in the immediate back-reef in Dark Canyon (Plate 2).

Fragments of crinoid stems and plates were collected from the following localities:

695 770 771 773 774 775 788 790 792
796 801 814 822 824 829 830 833 837
843 847 850 856 857

PHYLUM BRYOZOA

CLASS ECTOPROCTA

Acanthocladia
Localities 771 772 774 775 783 786
788 793 797 800 808 812
815 819 823 827 831 830
847 856 857

Batostomella
Localities 809 853

Domopora
Localities 683 693 765 770 772 775
776 780 781 783 787 788
790 794 796 799 800 808
812 815 819 824 825 842
845 850 856 857

Fenestrellina
Localities 683 774 775 776 778 780
783 853 856

Fistulipora
Localities 772 792 808 812

Meekopora
Localities 781 856

Polypora
Localities 775 776 778 783 786 855
856

The Bryozoa are distributed throughout the Capitan formation and are present in the basin sediments as well. In Lamar and post-Lamar reef equivalents the bryozoans seem relatively more abundant than in the older portion of the reef.

The Bryozoa were identified by Roger Batten, J. K. Rigby, and the author. Some few specimens could be specifically identified, but the species do not appear significant in establishing biostratigraphic zonation.

PHYLUM BRACHIOPODA

CLASS ARTICULATA

Aulosteges guadalupensis (Shumard) 1858
Locality 774

Chonetina cf. *C. hillana* (Girty) 1909
Locality 847

Composita emarginata affinis Girty 1909
Localities 803 804 843 853

Composita gigantea Branson 1930
Locality 806

Composita mexicana (Hall) 1857
Locality 837

Derbya sp.
Locality 820

Dictyoclostus capitanensis (Girty) 1909
Localities 774 847

Dielasma prolongatum Girty 1909
Locality 801

Dielasmina guadalupensis Girty 1909
Locality 847

Hustedia meekana (Shumard) 1858
Locality 804

Leptodus nobilis americanus Girty 1909
Locality 771

Marginifera sp.
Localities 837 847

Martinia rhomboidalis Girty 1909
Localities 817 820 830

Martinia shumardiana Girty 1909
Localities 817 820

Neospirifer mexicanus (Shumard) 1858
Localities 830 847

Orthotetes guadalupensis Girty 1909
Locality 804

Punctospirifer billingsi (Shumard) 1858
Localities 804 806 830 847

Squamularia guadalupensis (Shumard) 1859
Localities 817 830 840 843 847

Stenosciema daloi (King) 1931
Locality 847

Stenoscisma identata (Shumard) 1859
Localities 799 806 847 853

Stenoscisma venusta (Girty) 1909
Locality 830

Wellerella bidentata (Girty) 1909
Locality 847

Wellerella elegans (Girty) 1909
Localities 801 804 847

Wellerella osagensis (Tschernyschew)? 1902
Locality 847

Wellerella shumardiana (Girty) 1909
Localities 774 804

Wellerella sp.
Locality 837

The Brachiopoda are distributed throughout the Slaughter member, the Calamity member, and into the Bell Canyon formation. In places pockets of brachiopods make up approximately eighty per cent of the rock, but their usual occurrence in the reef is as scattered individuals in position of growth. The shell is often empty but the spirallae may be calcified and preserved. In the reef talus the shells are worn, broken, and filled. The brachiopods were identified by Frank Stehli.

PHYLUM MOLLUSCA

CLASS PELECYPODA

Pelecypoda are rare in the reef. They were found at only twelve widely scattered localities; therefore, they appear to be of no stratigraphic importance.

CLASS GASTROPODA

Bellerophontid and naticoid gastropoda are somewhat more abundant than pelecypods but because the forms show no distinguishing characteristics, they are not regarded as stratigraphically diagnostic. They were collected from localities 693 776 811 822 824 830 839 856 857

CLASS SCAPHOPODA

The scaphopod, *Plagioglypta canna* (White) 1874, was noted at several localities and collected from locality 843.

CLASS CEPHALOPODA

The Cephalopoda are represented by a few gyrocone to ophicone nautiloids at localities 773 799 850 855. The genus *Foordiceras* is represented.

PHYLUM ARTHROPODA

CLASS TRILOBITA

Only a few trilobite fragments were found in the reef. Several pygidia, and one cephalon of *Anisopyge perannulata* (Shumard) 1858 were collected from locality 803.

PHYLUM THALLOPHYTA

Only two species of algae have been definitely located within the reef, *Collenella guadalupensis* Johnson 1942 (Class Cyanophyta) (Plate 7) and *Solenopora texana* Johnson 1951 (Class Rhodophyta) (Plate 5). Occasionally dasycladacean algae (Class Chlorophyta) are forms, but these were probably transported from the lagoon where they occur in great abundance. However, much of the reef is made up of vermiculate, "bird's nest," and "cabbage head" structures which are believed to be of algal origin. Of the "cabbage head," locality 796 (Plate 2), J. H. Johnson (personal comment) says:

> The dark cloudy patches are algal . . . It belongs to the general family Spongiostroma, of which the colonies are made up of molds of a felt-like mass of thread-like filaments. These develop growth zones, and in the larger colonies, the outer surface is covered by turrets and digitate protuberances. They are separated into genera and species on the basis of the growth zone of the colonies.
>
> The genus Collenella belongs to this same family, and show about the same type of microstructure. They could form masses as large as that shown in your photograph 796. Usually, the larger the colony, the more foreign material is used.

Encrustations believed to be algae are found on many of the other forms. Johnson states:

> The encrusting coatings on some of them are probably low lime-depositing algae. (Plates 5 and 6.)
>
> A few of the dark patches present in the slide probably represent masses of low lime-depositing algae. (Not illustrated)

The algal structures appear to be more abundant in the younger part of the reef but are found throughout the Slaughter member.

LOCALITIES

Collecting localities in the Guadalupe Mountains.

683 North McKittrick Canyon - north side on east side of large ravine section 27 at base of cliff. S88W 7327 at 6600'.

684 North McKittrick Canyon - north side 100' below 683.

685 North McKittrick Canyon - north side 100' below 684.

686 North McKittrick Canyon - north side 100' below 685.

687 North McKittrick Canyon - north side 100' below 686. (pre-*Polydiexodina*)

688 North McKittrick Canyon - in creek bottom below 687. (pre-*Polydiexodina*)

689 Guadalupe Peak - due east of BM8761 and 150' below top of peak.

690 Guadalupe Peak - east of BM8761 and 30' below 689.

691 Guadalupe Peak - east of BM8761 and 100' below 690.

692 Guadalupe Peak - east of BM8761 and 100' below 691.

693 Guadalupe Peak - east of and 100' below 692.

694 Guadalupe Peak - east of and 100' below 693 at head of Guadalupe Canyon.

695 Guadalupe Peak - float 200' below 694 in Guadalupe Canyon.

764 Pine Spring Canyon - in bottom of canyon upstream from first tributary above Devil's Hall N8E BM8761 at 7100'. (pre-*Polydiexodina*)

765 Pipe Canyon - on trail north side 500' above point where trail crosses canyon.

766 Rattlesnake Canyon - north side near mouth at valley level under first coxcomb. (post-*Polydiexodina*)

767 Gunsight Canyon - north side near mouth at lowest outcrop under high cliff below 768. (post-Polydiexodina)

768 Gunsight Canyon - north side under point of highest cliff near mouth at 5300'. (*post-Polydiexodina*)

769 Black Canyon - south side at valley level at base of first coxcomb above Franks Spring at 5000'. (post-*Polydiexodina*)

770 North McKittrick Canyon - north side first major spur above Pratt Lodge (Bathtub Ridge) in the saddle on the crest of the ridge at 6000'.

771 North McKittrick Canyon - Bathtub Ridge on nose overlooking saddle at 6150'.

772 North McKittrick Canyon - Bathtub Ridge at base of cliff on crest of ridge at 6300'.

773 McKittrick Canyon - on large spur halfway between mouth and Pratt Lodge (above Manzanital Ranch fence line) on crest of ridge above unmapped knob at base of cliff at 6500'.

774 McKittrick Canyon - on large spur halfway between mouth and Pratt Lodge on crest of spur 150' above knob at 6350'.

775 Double Canyon - east side of canyon at stream level S59W of BM6225 at 5050'. (post-*Polydiexodina*)

776 Double Canyon - bedrock under caliche at stream level west side S43W BM6225 at 5000'. (post-*Polydiexodina*)

777 Double Canyon - at stream level under first nose south side of stream S11W BM6225 at 4900'. (post-*Polydiexodina*)

778 Lefthook Canyon - 100' east of draw west of first large coxcomb on north side of canyon on level of Manzanita clump S89E BM6225 at 5300'. (post-*Polydiexodina*)

779 Lefthook Canyon - prospect pit in cave north side of canyon. (post-*Polydiexodina*)

780 Lefthook Canyon - on sheeting below and east of coxcomb north side of canyon 100' above alluvial terrace S72E BM6225 at 5150'. (post-*Polydiexodina*)

781 Slaughter Canyon - east of coxcomb mouth of canyon north side S12W BM5524 at 4500'. (post-*Polydiexodina*)

782 Slaughter Canyon - under coxcomb north side at mouth at valley level west of 781 at 4300'. (post-*Polydiexodina*)

783 Slaughter Canyon - under spire in front of coxcomb north side at mouth 100' east of 781 at 4350'. (post-*Polydiexodina*)

784 Slaughter Canyon - at base of first low spur north side at mouth 300' east of 783 at 4300'. (post-*Polydiexodina*)

785 Slaughter Canyon - south side at mouth on road level 300' in from 797 and 300' out from 786 at 4250'. (post-*Polydiexodina*)

786 Slaughter Canyon - at base of low spur south side near mouth at road level 300' west of 785 and 500' east of 787 at 4300'. (post-*Polydiexodina*)

787 Slaughter Canyon - south side at base of first spur east of mine dump house on road at 4350'. (post-*Polydiexodina*)

788 Slaughter Canyon - prominent nose between Slaughter and West Slaughter Canyons on top of major knob just below Calrsbad formation at 5200'.

789 Slaughter Canyon - on ridge between West Slaughter and Slaughter Canyons about 200' above valley on Slaughter Canyon sub-spur nose at 4250'.

790 Slaughter Canyon - on ridge between West Slaughter and Slaughter Canyons about 200' above valley on Slaughter Canyon sub-spur nose at 4250'.

791 Slaughter Canyon - on nose between West Slaughter and Slaughter Canyons on top of lowest prominent knob above 790 and below 789 at 4700'.

792 Slaughter Canyon - north side at base of cliff in gully opposite Ogle Cave S75W BM5524 at 5150'. (post-*Polydiexodina*)

793 Slaughter Canyon - north side at base of cliff on spur on east side of Ogle Cave gully (east of 792) S74W BM5524 at 5100'. (post-*Polydiexodina*)

794 Slaughter Canyon - north side 200' below base of cliff (793) at 4900'. (post-*Polydiexodina*)

795 Midnight Canyon - south side at mouth lowest outcrop at 4300'. (post-*Polydiexodina*)

796 Slaughter Canyon - north side at mouth at valley floor S16W BM5524 at 4200'. (post-*Polydiexodina*)

797 Slaughter Canyon - south side at mouth lowest outcrop at front 300' east of 785 at 4250'. (post-*Polydiexodina*)

798 McKittrick Canyon - north side near mouth at base of cliff under three caves S21E triangulation station at 6250'. (post-*Polydiexodina*)

799 McKittrick Canyon - north side at mouth at base of first cliff S40E triangulation station at 6500'. (post-*Polydiexodina*)

800 McKittrick Canyon - north side at mouth in saddle just east of first cliff S42E triangulation station at 6600'. (post-*Polydiexodina*)

801 McKittrick Canyon - north side 300' west of crest of ridge above Pratt Lodge at base of cliff at 6300'.

802 McKittrick Canyon - north side 100' west of crest of ridge above Pratt Lodge at base of cliff at 6200'.

803 McKittrick Canyon - north side at crest of ridge above Pratt Lodge at base of cliff at 6300'.

804 McKittrick Canyon - north side 300' east of crest of ridge above Pratt Lodge at base of cliff in ravine at 6350'.

805 McKittrick Canyon - north side on nose north of saddle in ridge above Pratt Lodge at 5900'.

806 McKittrick Canyon - north side on flat above saddle on crest of ridge above Pratt Lodge at 6050'.

807 McKittrick Canyon - north side 300' east of crest of ridge above Pratt Lodge 150' below 804 at 6200'.

808 White City (stage road) - on old stage road south side of spur south of Bat Cave Canyon at 3700'. (post-*Polydiexodina*)

809 White City (stage road) - 100' up stage road from 808 at 3725'. (post-*Polydiexodina*)

810 White City (stage road) - at top of stage road cut at 3950'. (post-*Polydiexodina*)

811 White City (stage road) - on crest of spur above stage road at 3875'. (post-*Polydiexodina*)

812 North McKittrick Canyon - on crest of spur south side N14W Pratt Lodge at 5900'.

813 North McKittrick Canyon - south side on crest of spur top of nose above 812 at 6150'.

814 North McKittrick Canyon - on crest of spur south side below 812 at 5600'.

815 White City (stage road) - in stage road cut half way between 809 and 810 at 3800'. (post-*Polydiexodina*)

816 White City (Walnut Canyon) - south side at valley floor 100' inside National Park fence at 3680'. (post-*Polydiexodina*)

817 White City (Walnut Canyon) - south side 200' up canyon from 816 and 100' above valley floor at 3800'. (post-*Polydiexodina*)

818 White City (Bat Cave Canyon) - slump block 300' into canyon on valley floor south side at 3675'. (post-*Polydiexodina*)

819 White City (Bat Cave Canyon) - on crest of spur south side at lowest outcrop at 3700'. (post-Polydiexodina)

820 White City (Walnut Canyon) - on crest of spur between Walnut and Bat Cave Canyons just above BM3648. (post-*Polydiexodina*)

821 Jurnigan Canyon - west of highway north side in bottom of canyon. (post-*Polydiexodina*)

822 Dark Canyon - north side at mouth at lowest outcrop. (post-*Polydiexodina*)

823 White City (Bat Cave Canyon) - south side at mouth on lowest outcrop at valley bottom at 3640'. (post-*Polydiexodina*)

824 Dark Canyon - north side 100' up the canyon from 822 at valley level. (post-*Polydiexodina*)

825 Escarpment - lowest outcrop on escarpment S36E Pipkin Ranch at 3775'. (post-Polydiexodina)

826 Escarpment - base of escarpment on east side of canyon (Hackberry?) with Carlsbad Cavern power line at 3900'. (post-Polydiexodina)

827 Rattlesnake Canyon - north side at stream level 600' downstream from Stone Ranch at 4050'. (post-Polydiexodina)

828 Rattlesnake Canyon - low point of spur between Rattlesnake Canyon and the first tributary to the south at 4000'. (post-Polydiexodina)

829 Rattlesnake Canyon - north side half way up first ridge at mouth at 4000'. (post-Polydiexodina)

830 Rattlesnake Canyon - north side at mouth 150' west of 829 in draw at 4000'. (post-Polydiexodina)

831 Rattlesnake Canyon - on crest of escarpment south of mouth S18W Stone Ranch at 4750'. (post-Polydiexodina)

832 Rattlesnake Canyon - crest of escarpment south of mouth due south of Stone Ranch 400' east of 831 at 4650'. (post-Polydiexodina)

833 Rattlesnake Canyon - half way down spur below BM4659 south side of mouth at 4250'. (post-Polydiexodina)

834 Slaughter Canyon - north side base of cliff opposite West Slaughter Canyon due east of BM5524 at 4950'.

835 Slaughter Canyon - north side 300' north 834 at low point of cliff at 4900'.

836 Slaughter Canyon - north (east) side at low point of cliff across draw north of 835.

837 Slaughter Canyon - north (east) side at base of last cliff (three draws north of 836) N62W BM5524 at 5050'.

838 Slaughter Canyon - north (east) side at natural bridge at end of cliff at 5100'.

839 Nuevo Canyon - on spur north side of first canyon east of Nuevo Canyon at mouth on first flat above valley N54E BM5524 at 4550'. (post-Polydiexodina)

840 Nuevo Canyon - spur at mouth north side first canyon east of Nuevo Canyon second knob from top 150' above 839. (post-*Polydiexodina*)

841 Nuevo Canyon - north side at mouth of canyon east of Nuevo 20' under nose at top of spur above 840. (post-*Polydiexodina*)

842 Nuevo Canyon - north side of canyon north of Nuevo S40W of spire north of Nuevo at 4700'. (post-*Polydiexodina*)

843 North Slaughter Canyon - east side on trail above confluence of North and Middle Slaughter Canyons N32W BM5524 at 5050'.

844 North Slaughter Canyon - east side on trail 100' above 843.

845 North Slaughter Canyon - east side on trail 100' below 843.

846 North Slaughter Canyon - east side on trail 75' above lowest outcrop.

847 North Slaughter Canyon - east side on trail 100' above 846.

848 Midnight Canyon - east side at mouth half way up dip slope. (post-*Polydiexodina*)

849 Midnight Canyon - east side at mouth at top of slope under cliff which caps the hill. (post-*Polydiexodina*)

850 Midnight Canyon - east side on top of ridge between Midnight and Slaughter Canyons directly above New Cave. (post-*Polydiexodina*)

851 Double Canyon - at base of coxcomb south side opposite Double Trail at 5200'.

852 Double Canyon - south side opposite Double Trail 200' above 851 on coxcomb.

853 Double Canyon - south side opposite Double Trail 100' above 852 at base of cliff.

854 Double Canyon - north side on Double Trail at 5600'.

855 Rattlesnake Canyon - in saddle on crest of east side of canyon at mouth at 4300'. (post-*Polydiexodina*)

856 Double Canyon - near head of canyon at Falls in bottom of valley.

857 White City - in creek bottom just across road from lower water tank. (post-*Polydiexodina*)

858 McKittrick Canyon - north side at mouth 100' below top of nose on crest of ridge at 6250'. (post-*Polydiexodina*)

859 McKittrick Canyon - north side at mouth top of nose S50E Triangulation station at 6350'. (post-*Polydiexodina*)

860 Yucca Canyon - north side above turn in canyon at base of nose of cliff N62E 5071 at 4850'. (post-*Polydiexodina*)

420 Big Canyon - traverse up the north side of ridge to the north of the Gray Ranch, at the eastern end of Lonesome Ridge. (Collected by Blake, Fisher, and Whiteman)

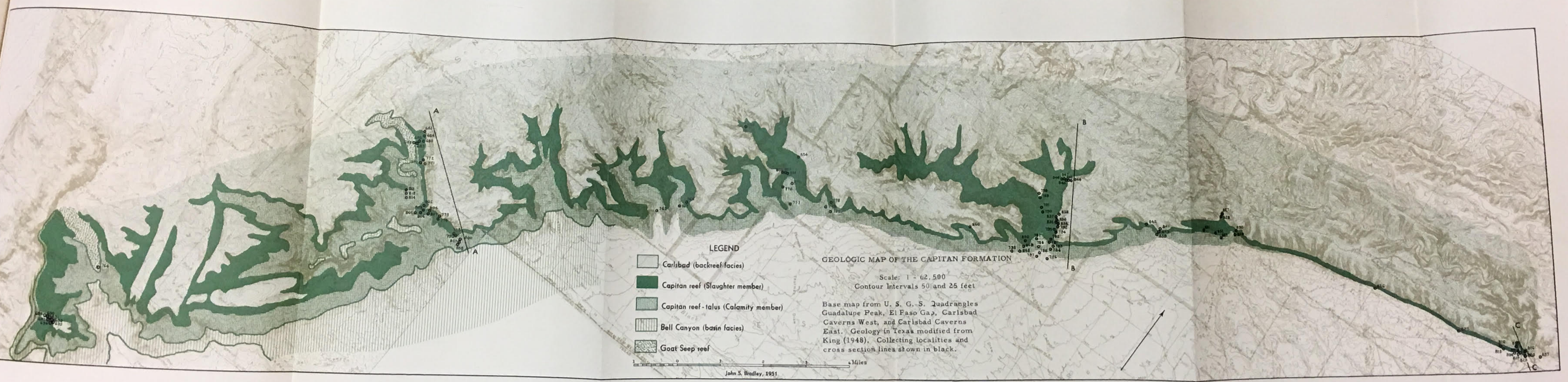


Figure 10

GEOLOGIC MAP OF THE CAPITAN FORMATION

Scale: 1 - 62,500
Contour Intervals 50 and 25 feet

Base map from U. S. G. S. Quadrangles Guadalupe Peak, El Paso Gap, Carlsbad Caverns West, and Carlsbad Caverns East. Geology in Texas modified from King (1948). Collecting localities and cross section lines shown in black.