IS THE CAPITAN LIMESTONE A FOSSIL REEF?†

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The occurrence of alleged fossil "reefs" in various portions of the geologic column is recognized by many observers to be a very difficult problem to reconcile with Biblical chronology. If accumulated at approximately the same rate as modern reefs, a single fossil "reef" would take thousands of years to form, and, therefore, could negate the Genesis implication of a young earth and also seriously question the role of the Noachian Flood in earth history.

The famous Capitan Limestone in the Guadalupe Mountains of southeastern New Mexico and western Texas is alleged by many geologists to be a classic example of a fossil "barrier reef." Study of the strata cast doubt on the various depositional and ecologic environments alleged to be associated with "Capitan Reef." So-called "backreef lagoon" and "forereef talus" deposits were not contemporaneous with "reef" accumulation. Furthermore, the Capitan lacks large, in situ, organically-bound framework and deposits of broken debris which can be shown to be derived from an organic framework.

The Capitan is composed primarily of broken fossil fragments in a fine-grained matrix of lime silt and sand which were not wave-resistant when deposited. The fossil flora and fauna of "Capitan Reef" represent a shallow water assemblage which was not especially adapted to a wave or strong current environment. Reef-forming organisms which could bind sediments and build frameworks are either altogether absent or largely inconspicuous.

The available data certainly do not require many thousands of years for the Capitan to accumulate, and, therefore, seem to present little problem for Biblical chronology. Instead, the lack of large organically-bound structures, which would grow during thousands of years, suggests that deposition was very rapid. It is proposed that the Capitan Limestone accumulated either during the last stages of the Noachian Flood or shortly thereafter.

Introduction

One has only to refer to the index of any recent historical geology text to find a number of examples of so-called fossil organic "reefs." These "reef" deposits, which are found in various portions of the geological column, have been recognized by many observers to be very difficult to reconcile with Biblical chronology.

The great thickness of calcium carbonate found in a single ancient "reef" appears to represent thousands of years of accumulation of coralline and algal organisms one on top of another if cemented at roughly the same rate as modern organic reefs. How then can the Noachian Flood be considered important in rapidly depositing certain portions of the geological record if strata implying very slow rates of accumulation are common? Doesn't the occurrence of so many fossil "reefs" require that many thousands of years be added to the relatively short duration of earth history implied in the book of Genesis?

That the so-called "reefs" of the fossil record provide difficulty for Biblical chronology was recognized by John C. Whitcomb and Henry M. Morris in *The Genesis Flood.*[1] They suggest that many of these fossil "reefs" are not *in situ,* organically-bound frameworks, but fossiliferous debris which has been transported in the waters of the universal Noachian Flood. Many structures which may appear to be *in situ,* they propose, are products of resedimentation.

Harold W. Clark[2] in his book *Fossils, Flood and Fire* considers that Permian "reefs" were growing before the Flood and, therefore, suggests that these structures are organically constructed in quiet water over a period of time longer than the year of the Flood. Clark argues that the rate of growth of Paleozoic "reefs" need not be as slow as the rate for modern reefs. He is not obligated to the long period of time advocated by uniformitarian geologists.

The problem of fossil "reefs" was also brought to many people's attention in an article by J. R. van de Fliert[3] written as a critique of *The Genesis Flood.* Van de Fliert advocates that strict adherence to the Biblical chronology is untenable because of the very long period of time necessary to form a single fossil "reef." He mentions several "barrier reefs" in the stratigraphic record as particular problems and insists that modern historical geologists are correct in estimating the age of many of the earth's sedimentary deposits in the order of hundreds of millions of years.

The problem of fossil "reefs" is therefore a crucial issue to Bible-believing Christians.

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EDITOR'S NOTE: A number of problems of interpretation from the creationistic point of view remain for discussion after further investigation of multiple layers of evaporites known to be associated with "Capitan Reef' and with similar formations in central Canada.

In response to a research challenge from several members of the Creation Research Society, an investigation was conducted into one of the so-called "barrier reefs" of the fossil record. This is the world famous "Permian Reef Complex" of the Guadalupe Mountains of southeastern New Mexico and western Texas (more commonly referred to by geologists as "Capitan Reef"). The purpose of the present research paper is to evaluate critically the stratigraphic, lithologic, and ecologic criteria which have led many modern geologists to consider the Capitan Limestone and associated sediments as an example of a fossil "barrier reef."

Terminology

To avoid confusion many terms must be defined. They are used widely by modern geologists. These definitions are found in the Appendix.

Definition of "Reef"

Before beginning an analysis of the data relevant to "Capitan Reef" it is necessary that agreement be obtained on the definition of the term "reef." Geologists of the past have used different criteria to define "reef," and the term has been misapplied to many fossil deposits which have since been understood to be deposits of tumbled debris, sheet-like strata, or of other non-reefal origin.

The layman usually pictures a reef as a massive structure composed of solid, organically-bound, *in situ* organisms on or near the shore of the ocean. He may recognize that a reef has a particular topographic expression (it rises above the surrounding depositional surface), has an internal structure which is largely unbedded or obscurely bedded, and is chemically composed mainly of calcium carbonate ($CaCO_3$). To those in the nautical profession, the term "reef" has very precise meaning denoting an organic structure which intercepts waves and is a hazard to navigation.

Present-day reefs have been grouped into three main classes: *fringing reefs* — linear reefs which occur at the shoreline; *barrier reefs* — linear or curved reef strips which follow the shoreline yet are separated from it by a lagoon usually many tens of feet deep; and *atolls* — circular reef strips which surround empty lagoons.

In the study of ancient "reefs" the historical geologist would be severely handicapped by definitions as specific as those just stated. When examining a stratum which is suspected to contain a "reef" deposit, it is often very difficult to determine whether the organisms were bound together at the time they lived. This is often due to recrystallization of the carbonate after deposition which obscures many of the features of the deposit. There is always extreme difficulty in estimating the depth of water and the position of the shoreline at the time the organisms lived mainly because these are rarely apparent in the stratigraphic outcrop.

The geometry of the suspected "reef" deposit is sometimes changed by erosion subsequent to the period of deposition. Also, the stratigraphic outcrop contains no isochronous datum lines which can tell the geologist what the characteristic topographic expression of the deposit was at a particular moment in time. For many reasons the historical geologist has been content with using a very vague definition of ancient "reefs."

W. C. Krumbein and L. L. Sloss in their text, *Stratigraphy and Sedimentation,* begin their discussion of fossil "reefs" with the following admission concerning the misuse of the term:

> Recognition of the oil-trapping potentials of mound-like carbonate masses and the relationship of some of these to modern organic reefs has led to the rather indiscriminate application of the term "reef" to almost any permeable carbonate mass that exhibits a degree of upward convexity. The development of a definition that would cover ancient organic reefs, but which would exclude unrelated masses of similar geometry, is hampered by a number of factors.[4]

The inappropriate use by geologists of the term "reef" which reflects a very poor definition is also emphasized by J. Keith Rigby:

> The term "reef" has been applied loosely to several structures by different workers. Locally, it has been used for merely a faunal association, even though the organisms are present as loose, discrete fragments and the rocks in which they occur are evenly bedded in moderately thin layers. The term also has been applied to carbonate lenses in noncarbonate sequences, even though these lenses are of bedded, unbound detritus, oolites, or crinoid columnals. It also has been applied to sheetlike deposits of *in situ* corals or algal crusts or other reef-associated organisms even though the deposit is widespread, thin, and with no demonstrable topographic expression. Massive tumbled blocks also have been considered to be reefs, particularly if the blocks are abundantly fossiliferous and occur in distinctly more thinly bedded rocks. The term "reef" also has been applied to large carbonate structures which may be truly of reef origin at their margins, but which are composed mainly of bedded, clastic debris.[5]

Thus, we see that part of the misconceptions associated with the "reef" problem comes from the vague definition of the term "reef." Since the term has been widely misapplied, we have abundant reason here to question the authenticity of the "reef' interpretation of many geologists. If we were to ask for a more strict definition of the term "reef," it is evident that many (and probably most) of these ancient deposits would not qualify for consideration as "reefs."

Probably the greatest difficulty in identifying so-called ancient "reefs" is that the modern examples generally have little resemblance to those of the past. Krumbein and Sloss recognize that modern and ancient "reefs" are products of different environments. They write:

> . . . much of our knowledge of modern reefs is derived from the study of oceanic realms in which reefs are found on seamounts or islands that rise from abyssal depths. The data have but little applicability to the majority of ancient reef masses available for investigation, since the latter are products of relatively shallow epicontinental seas, commonly associated with restricted euxinic or evaporitic environments that are not duplicated among modern settings. Finally, the dolomitization and recrystallization of carbonate rocks serve to obscure many of the details of structure, texture, and paleontology that would aid in relating ancient reefs to their modern counterparts.[6]

W. H. Easton in his popular text, *Invertebrate Paleontology,* has suggested that the reason for dissimilarity between modern and ancient "reefs" is also due to differences in the type of organisms forming each. Modern reef-forming organisms (mainly scleractinian corals and coralline algae) were not responsible for building Paleozoic "reefs."

Furthermore, most of the ancient "reef" organisms are extinct today and their ecologic affinities are to some degree unknown. Easton recommends that the ancient deposits should not be referred to as "reefs." Specifically,

> Recent coral reefs are not typical of coral growths in the past. Intergrown build-ups as large as the Great Barrier Reef east of Australia are unknown in the fossil record. Moreover, many tropical "coral reefs" of today actually consist of more than 50 per cent (some as high as 80 per cent) of calcareous red algae such as *Lithothamnium* and *Halimeda.* It is also true that ancient reefs commonly (or even mostly) consisted of less coralline material than other material. For instance, many Paleozoic reefs were composed largely of tabulate corals and stromatoporoids, or even of crinoids or brachiopods. For this reason it has seemed desirable for a word to be coined which has neither the connotation of corals nor of rocks and shoals such as mariners have in mind when they speak of reefs. The term *bioherm* has achieved wide acceptance by geologists for build-ups of any kind of organic skeletal material. In addition, the companion term, *biostrome,* refers to stratified deposits of fossils or fossil debris which do not stand in any appreciable relief above the general surface of deposition.[7]

Since the modern and ancient deposits differ, there are very few features of modern reefs which can be used to identify ancient "reefs." Thus the "reef complex" problem becomes very apparent because we do not know exactly what characteristics to expect in ancient "reefs."

In the previous discussion some of the problems relating to identification of fossil "reefs" have been presented. Yet, many geologists feel that ancient "reefs" exist in the stratigraphic record. How is this identification made? The recognition is based mainly on three logical schemes which come from different subfields of geology. These subfields are 1) stratigraphy, 2) lithology, and 3) paleoecology.

1) Stratigraphy, a discipline of geology which deals with the position and geometry of stratified rocks, is claimed by many geologists to prove the existence of "reefs" in the fossil record. These geologists say the presence of a reef should modify the sedimentation of an area to such an extent that three typical depositional environments (the "reef core," the "backreef," and the "forereef") should exist and be readily apparent from study of the strata.

Since a reef cannot exist without modifying surrounding sedimentation, the environments and strata associated with the alleged "reef" proper are termed a "reef complex." Very characteristic facies relationships should exist in an ancient "reef" and any synchronous depositional surface should change laterally in a seaward direction from "backreef" to "reef core" to "forereef." Furthermore, a study of the position of each environment of the so-called "reef complex" should show that the "reef core" rose topographically above the surrounding depositional surface.

2) Lithology, the megascopic and microscopic study of the composition and structure of rocks, is also alleged to be very useful in identifying different environments of an alleged fossil "reef complex." The "reef core," which represents the actual "reef" proper accumulated in the zone of breaking waves, is made of organically-bound sediments and precipitated calcium carbonate from *in situ* organisms. This unbedded framework must be wave-resistant and lack large bodies of mud, silt, or sand which could be easily eroded by waves. Cavities within the "reef core," however, could be filled with fine sediment which has been "baffled" down into the framework.

The "forereef" is on the seaward side of the "reef" and is located in deeper water. Here bedded deposits dipping at some angle away from the massive "reef core" form from fossil fragments and chunks of "core" which have been torn loose by waves and rolled downslope.

The "backreef" is thought to represent a broad and shallow lagoonal environment behind the "reef core" where there is little turbulence caused by waves. Here fine grained materials such as mudstone or siltstone, or chemical precipitates such as calcium carbonate or calcium sulfate are deposited.

3) Paleoecology, the study of the relationship between ancient organisms and their environment, is considered by many geologists to distinguish the various parts of the "reef complex." Thus, the "reef core" should be characterized mainly by rugged life forms which could bind themselves and other sediments. Thin-shelled or free-floating forms would be at a disadvantage. The "backreef" should logically contain fragile organisms and forms which could tolerate higher salinity. Due to the depth below the photic zone, the majority of the "forereef" environment should lack *in situ* growths of algae. Many of the organisms of the "forereef" could be expected to be out of place due to transportation from the "reef core."

Having discussed the problems and techniques used to recognize fossil "reefs," an attempt can now be made to formulate a definition of the term "reef" which will be both restrictive and useful to the geologist. J. Keith Rigby defines "reef" as follows:

> Reefs are considered as largely unbedded or obscurely bedded, massive structures which are composed of solid, organically bound, *in situ* organisms, and which were at least potentially wave-resistant structures that rose topographically above the surrounding depositional surface.[8]

Another excellent definition was made by William G. Hart who suggests that a "reef" is:

> . . . a wave-resistant organic build-up composed of frame-builders, cementing organisms, and detrital fill which modifies the surrounding sedimentation.[9]

Combining the better features of both Rigby's and Hart's definitions, we attempt a definition which clearly encompasses the stratigraphic, lithologic and ecologic criteria which have been useful in identifying so-called fossil "reefs." It is suggested that a "reef" is a largely unbedded, wave resistant structure composed of *in situ*, organically-bound, frame-building organisms, cementing organisms, and sediment filling which modifies the surrounding sedimentation. This definition can be used to assess the "reefishness" of many of the so-called "reefs" of the fossil record. It will be employed when examining "Capitan Reef" which is one of the most widely claimed examples of an ancient "barrier reef."

General Description of Capitan Limestone

While the Capitan Limestone is present in several areas in southeastern New Mexico and western Texas, one of the best exposures occurs in the Guadalupe Mountains southwest of Carlsbad, New Mexico. The very light gray limestone which is about 2,000 feet thick outcrops in a narrow strip up to five miles wide and about 47 miles long (See Figure 1).

This limestone tends to form the southeast escarpment of the northeast-southwest trending Guadalupe Mountains. Carlsbad Caverns and Guadalupe Mountains National Parks are located in the Guadalupe Mountains and the exceptional scenery and enormous caverns are due to the distinctive Capitan Limestone.

The Permian Capitan Limestone has been considered for the past 40 years by many geologists to be a classic example of a fossil "barrier reef." Probably more has been written on the Capitan than on any other ancient "reef" in North America. K. H. Crandall[10] was the first to publish data in 1929 advancing the "barrier reef" explanation.

Since then numerous authors have supported Crandall's idea. The "reef" interpretation has been solidly "enthroned" in the literature and in geologists' minds by popular guidebooks and textbooks. Only a few notable articles[11,12,13] have taken exception to the popular view.

According to advocates of the popular interpretation, one of the best exposures of Capitan Limestone illustrating the appropriateness of the "reef" view is in the Guadalupe Mountains. By far the greatest amount of data on the Capitan comes from this area.

In order to test the "reef" interpretation for the Capitan Limestone of the Guadalupe Mountains, extensive literature search and field investigation was conducted. Since the Capitan is most readily studied in the field where it is cut by canyons on the southeast side of the Gaudalupe Mountains, seven canyons were studied in the field research. These are Walnut Canyon, Bat Cave Canyon, Rattlesnake Canyon, Slaughter Canyon, Double Canyon, McKittrick Canyon, and Pine Spring Canyon (See Figure 1). The present research concentrated on the stratigraphy, lithology and to some extent the paleoecology of the Capitan Limestone.

Stratigraphy

Strata of the Permian System[14] and of the Guadalupian Stage of the Middle Permian are well exposed in southeastern New Mexico and

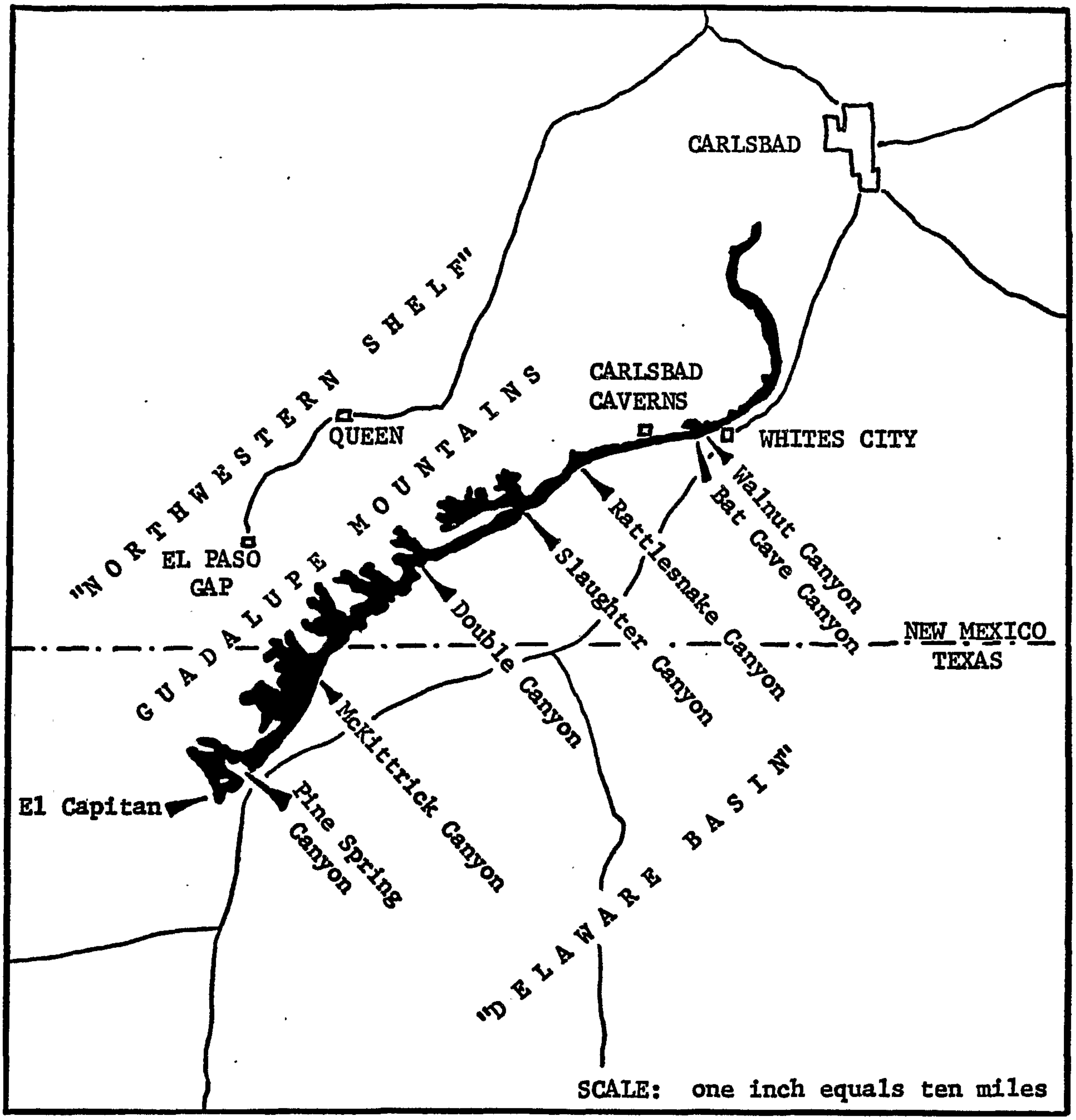

Figure 1. Location map of Guadalupe Mountains in southeastern New Mexico and western Texas. The zone of outcroppiags of Capitan Limestone is blackened.

western Texas. For a number of years many geologists have attempted to interpret the environment of deposition of these strata.

To the southeast of the Guadalupe Mountains the Bell Canyon and Cherry Canyon formations (predominantly strata of fine grained quartzose sandstone with some beds of limestone) are present over wide areas. Because of the regular bedding of the fine material in widespread strata and the lack of fossils, the Bell Canyon and Cherry Canyon formations are interpreted to be deposited in a marine basin (called the "Delaware Basin") which was about one to two thousand feet deep.

To the northwest of the Guadalupe Mountains strata of dolomite, sandstone, and evaporite of the Tansill, Yates, Seven Rivers, Queen, and Grayburg formations are present. These are presumed to have been deposited at the same time as the Bell Canyon and much of the Cherry

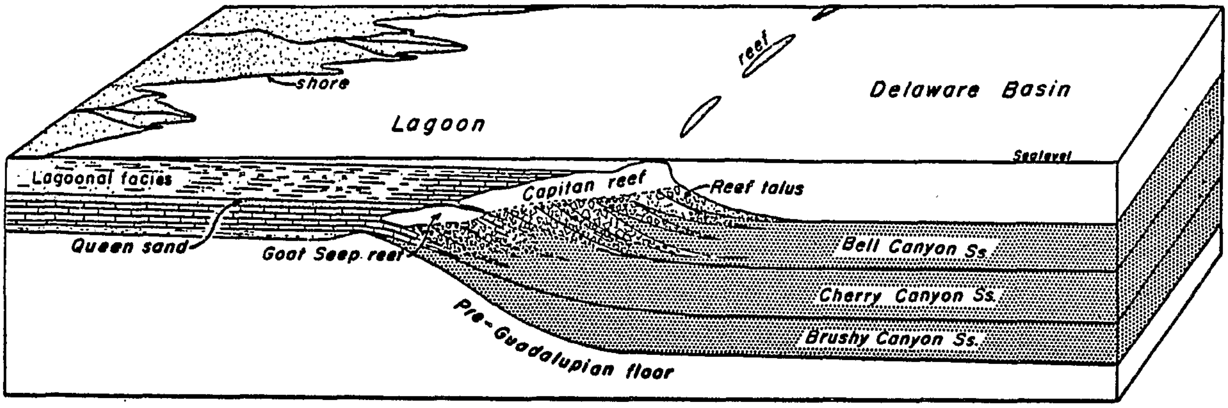

Figure 2. Block diagram showing different ecologic and depositional environments alleged to be associated with "Capitan Reef." (After Carl O. Dunbar and Karl M. Waage.[15])

Canyon formations. These strata of dolomite, sandstone, and evaporite to the northwest of the Guadalupe Mountains are considered by many geologists to have been deposited in a shallow sea or broad lagoon (called the "Northwestern Shelf") because of the chemical characteristics of the rocks and presence of rare shallow marine fossils.

Thus, many geologists envision the existence of an oceanic basin, (the "Delaware Basin") to the southeast of the Guadalupe Mountains, and a shallow sea or broad lagoon (the "Northwestern Shelf") to the northwest during the Guadalupian Stage of the Permian. The Guadalupe Mountains, then, are of particular interest because they are generally considered to have been an area of transition between the shallow sea and the deep ocean.

The alleged transition zone is represented by a distinctive type of limestone and dolomite known as the Goat Seep Limestone (dolomitized limestone with rare fossils) and the Capitan Limestone (limestone and dolomitized limestone with common shallow marine fossils). The Capitan Limestone and Goat Seep Limestone, which are thought to represent a "barrier reef," intertongue laterally to the northwest with the Tansill, Yates, Seven Rivers, Queen, and Grayburg formations. To the southeast the Goat Seep Limestone and Capitan Limestone intertongue laterally with the Bell Canyon and Cherry Canyon sandstones and limestones. The interpreted environments and facies relationship between formations are shown in Figure 2.

Many geologists who hold to the above interpretation have also speculated on how the strata and depositional environments developed over millions of years. A common explanation given to students is that at the beginning of the Guadalupian Stage a shallow sea covered much of the area. To the northwest was a land area which continually supplied sediments to the sea. At or near the shore of this sea, "Goat Seep Reef" began to grow and trap sediments on its shoreward side. This started a differentiation between "shallow sea" and "deep-sea basin."

Because of nutrient-rich waters upwelling from the stagnant basin to the highly saline shallow sea, "reef" growth was ideal and a linear "barrier reef" ("Capitan Reef") developed. Waves tore chunks of "reef core" loose and these rolled down the steep slope on the basinward side of the "reef" to form vast "talus" deposits.

Supposedly, while sea level rose gradually over millions of years, "Capitan Reef" could not grow upward at a fast rate but grew basinward over the talus deposits. A broad and shallow lagoon existed behind the "barrier reef" which trapped sediments coming from the land. Basin sediments may have come from the land through narrow breaks in the "reef." "Reef" construction was concluded when sea level began to lower.

After the Guadalupian Stage was deposited, the sea occupied "Delaware Basin" and was very shallow. As the sea dried up it left vast amounts of evaporites (anhydrite, gypsum, salt, etc.) comprising the Castile Formation which exists to the southeast of the Guadalupe Mountains. The southeast escarpment of the Guadalupe Mountains is the shelf-basin margin caused by the Permian "reef complex."

Figure 3 shows two different stratigraphic interpretations through the Guadalupe Mountains. The top illustration displays the conventional diagram advocated by geologists who hold the "barrier reef" view. Notice that the Capitan Formation is divided into two units—a "reef core" unit above a "reef talus" unit.

The "reef core" unit is thought to represent the organically-bound build-up which formed a wave-resistant "reef." The "reef talus" unit is considered to represent the "forereef" deposits which accumulated on the seaward side of the "reef core." Thus, P. B. King[17] and P. T. Hayes

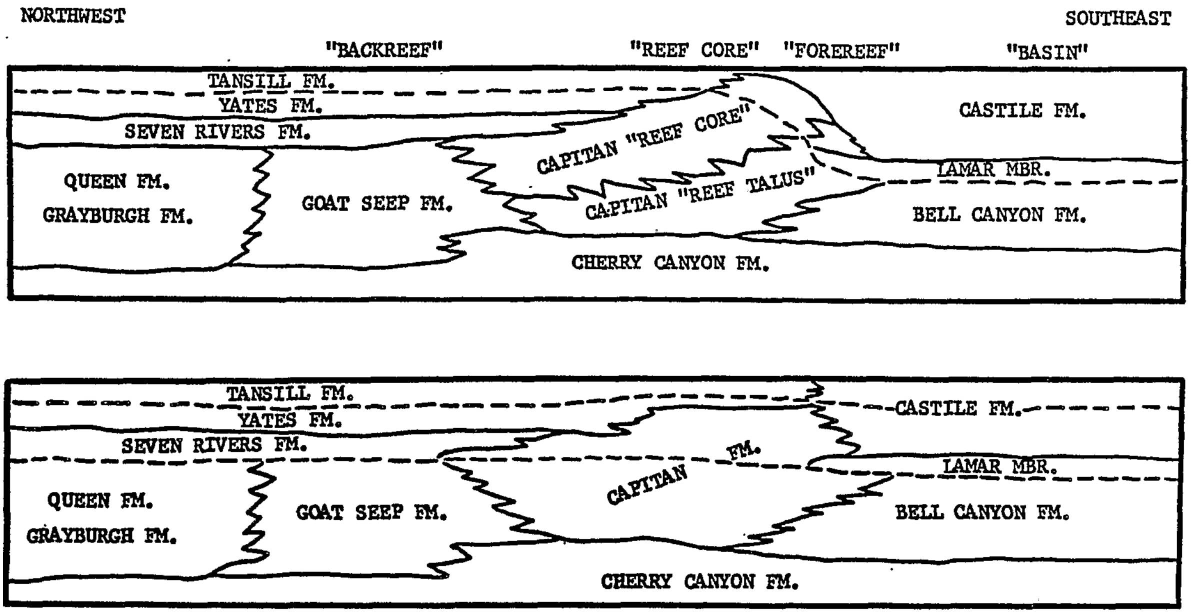

Figure 3. Two generalized cross-sectional diagrams through the Guadalupe Mountains showing different stratigraphic interpretations before any flexure or erosion of strata. Top, diagram suggested by advocates of the "barrier reef" view (modified from P. T. Hayes and R. L. Koogle[16]). Bottom, diagram proposed from our research. Dashed lines are interpreted to be synchronous depositional surfaces. Vertical thickness of strata is variable but approximately 3,000 feet; horizontal width of diagrams is about nine miles (note the use of extreme vertical exaggeration).

and R. L. Koogle[18] of the U. S. Geological Survey differentiated the two units in their geological mapping. They map the boundary between the two units of the Capitan Limestone at a prominent topographic break.

Figure 4 shows the mouth of Slaughter Canyon and the supposed lithologic boundary between the unbedded (massive) "reef core" and the bedded and steeply dipping rocks of the "reef talus" unit.

Our field work does not support the above division of the Capitan. Lithologic data presented later in the paper will be used to show the absence of lithologic change at the topographic break. Furthermore, we will show that the alleged "reef core" lacks large masses of framebuilding organisms and, therefore, is a poor example of the wave-resistant portion of the proposed "reef complex."

Also, it will be suggested that there is absence of demonstrable "reef-derived" talus in what is interpreted to be the "forereef" portion of the Capitan. The distinction of a massive "reef core" unit from a bedded and steeply dipping "reef talus" unit is therefore *imaginary*.

In our interpretation of the stratigraphy (See Figure 3, bottom diagram) we have avoided making the division. The Capitan Formation is shown as a single unit. It is noteworthy that C. W. Achauer,[19,20] a petroleum geologist, refuses to make the distinction between "reef core" and "reef talus" for similar reasons.

Advocates of the "barrier reef" interpretation also imagine characteristic facies relationships to exist. Thus, "backreef," "reef core," "forereef," and "basin" sedimentation are considered to be coeval. In Figure 3 (top diagram) the dashed line is used to indicate a synchronous depositional surface. The base of the Tansill Formation is correlated in time with the Lamar

Figure 4. Capitan Limestone at the mouth of Slaughter Canyon. The massive cliff-making limestone alleged to be "reef core" is above beds thought to be "reef talus" which dip steeply toward the camera. At the extreme left are "backreef" beds of the Yates and Tansill formations. Vertical exposure is about 1,000 feet.

Limestone Member (calcilutite) of the "basin" deposited Bell Canyon Formation.

According to W. W. Tyrell[21] the Tansill-Lamar correlation is based on the presence of common species of fusalinids (small planktonic animals the size and shape of a grain of wheat) in both units. This time correlation surface is considered to pass through both the alleged "reef core" and "forereef talus" of the Capitan.

C. W. Achauer,[22] however, disputes this paleontological correlation with stratigraphic evidence. His field work seems to indicate that the Lamar Limestone Member passes into the upper part of the Capitan Limestone but does not pass into the Tansill Formation. Achauer correlates the Lamar Member through the upper Capitan with the Seven Rivers Formation. Harold S. Cave,[23] a geologist who is also critical of the "barrier reef" view, correlates the Lamar Member with the Grayburg Formation.

Our field work also does not substantiate the Tansill-Lamar correlation. In the stratigraphic diagram presented in Figure 3 (bottom diagram) we correlate the Lamar through the upper Capitan with the Seven Rivers or Queen formations. Figure 5 shows alleged "backreef," "reef core," and "forereef" beds in McKittrick Canyon. The "talus" of the "forereef" Capitan in the foreground is stratigraphically above beds which correlate in time with the Lamar Member, yet, these foreground beds appear to merge into the massive "reef core" Capitan and not into the Tansill Formation above the Capitan. The Tansill seems to consistently cap the "reef core" Capitan (except where removed by erosion). To suggest the Lamar-Tansill correlation here seems inappropriate.

The Tansill Formation in a southeast direction must be correlated in time with the Castile Formation because of the presence of intertongueing between Capitan and Castile as noted by C. L. Jones[24] and H. S. Cave.[25] Yet, advocates of the "barrier reef" view commonly place the deposition of the evaporites of the Castile Formation (gypsum, anhydrite, salt, and limestone—See Figure 6) after the entire Guadalupian Stage. Thus they deny Capitan-Castile intertongueing to any large extent. The evidence which suggests simultaneous evaporite-carbonate deposition is difficult for the "reef" view. Could ocean waters which had reached a high enough concentration to precipitate calcium sulfate have been conducive to reef growth?

Advocates of the "barrier reef" interpretation also suppose that considerable topography existed at the junction of the "Northwestern Shelf" and "Delaware Basin." The dashed line in Figure 3 (top diagram) is thought to represent a synchronous depositional surface. Notice that the surface rises about one thousand feet as it passes through the Capitan Limestone.

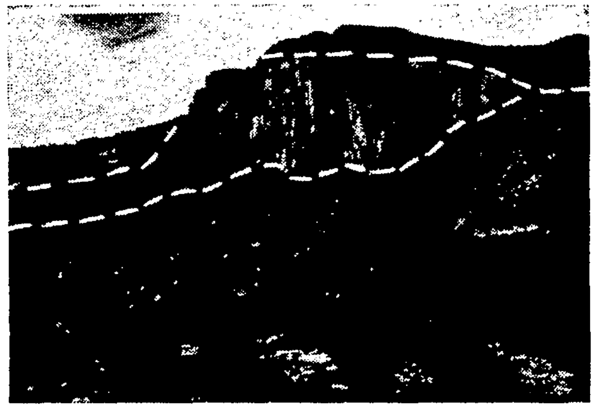

Figure 5. "Backreef," "reef core," and "forereef talus" in McKittrick Canyon. The massive cliff-making "reef core" (calcisiltite) is above so-called "reef talus" (sponge-algal limestone). "Backreef" beds of Yates and Tansill overlie the "reef core."

The need for this topography is seen in Figure 7. Here beds of "Delaware Basin" rocks are seen approaching the alleged "reef" to the northwest. In the right foreground of Figure 7 are sandstones of the Brushy Canyon Formation, and in the center left are sandstones of the Cherry Canyon Formation. The peak at the right is El Capitan; the upper portion of which is Capitan Limestone.

While the Brushy Canyon and Cherry Canyon formation pass under the Capitan Limestone, the Bell Canyon Formation, which lies above the Cherry Canyon and below the Capitan, intertongues with the Capitan. There seems to be a rise in altitude of synchronous beds through the Capitan. Upholders of the "reef" view who endorse the Tansill-Lamar correlation must imagine Bell Canyon strata correlating in time with strata which overlie the Capitan—hence a change in altitude of synchronous beds of about one thousand feet.

Since our field work does not suggest the Tansill-Lamar correlation, but that the deposition of the Lamar Member of the Bell Canyon Formation is contemporaneous with the upper Capitan, we see considerably less change in altitude of synchronous beds. Yet, even our interpretation must allow for some change in altitude. How is this accounted for?

Those who hold the "barrier reef" view maintain that the change in altitude is due largely to the depositional slope which existed during Guadalupian time between the supposed "shelf" and the "basin." They tend to deny evidence of large tectonics (deformations by folding). But, if the southeast side of the Guadalupe Mountains where the Capitan outcrops is a zone of flexure of strata, the change in altitude of synchronous

Figure 6. Laminated gypsum of the Castile Formation.

strata need not be caused by original deposition along a junction between "shelf" and "basin." Harold S. Cave says:

> Since publication of the paper entitled, "Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of Western Texas," by K. H. Crandall, . . . it seems to have been a generally accepted fact by many geologists that the generally southeast dips shown in the Capitan limestone outcrops in the general Carlsbad Cavern area are the result of fore-setting in reef building. It is herein suggested that the dips in question are, in large part at least, comparable with other formational dips coming off the southeast and east flanks of the Guadalupe Mountains. Hence said dips could well be perfectly normal inclinations resulting from the post-Cretaceous orogeny that built the mountains.[26]

Our field work showed evidences of tectonics (orogeny). Probably the most obvious evidence of flexure through the Capitan comes from the steep angle of dip of the alleged Capitan "reef talus." In some places these beds dip at angles of 45° away from the supposed "reef core." (Commonly encountered dips are usually about 20°.)

Due to the buoyancy of rocks and sand in water it is nearly impossible to accumulate mate-

Figure 7. Strata of sandstones of Brushy Canyon, Cherry Canyon, and Bell Canyon formations below the prominent peak (El Capitan); the upper portion of which is Capitan Limestone.

rials at such steep angles. Tectonics seems at least in part necessary to imagine formation of this slope. Achauer[27] observes that some rock fragments in the Capitan "reef talus" can be fit together along fracture planes, and such is evidence of tectonics.

Evidence is available to suggest uplift of the Capitan "reef core" and/or downwarping near the base of the "reef talus." Thus, in Figure 8; beds of Yates and Tansill formations can be seen dipping at 8° toward the northwest away from the "reef core." When Tansill beds are present on top of Capitan "reef core," they usually dip toward the "basin" (southeast) at 5° or more. Bell Canyon beds are also warped upward as they approach the Capitan "reef talus."

Since our field work indicates that at least a major part of the structural features associated with the Capitan Formation are post-depositional, we have avoided including these on our stratigraphic diagram (Figure 3, bottom diagram). Thus, our time lines pass through the Capitan horizontally (or nearly so) with little distortion.

In the previous discussion several stratigraphic objections have been presented to the classical "barrier reef" interpretation of the Capitan Limestone. Those who maintain that the Capitan Limestone and associated strata represent a fossil "reef complex" with simultaneous deposition of "backreef," "reef core," and "forereef" do so on very scanty evidence.

Lithology

One of the best ways to disprove the young age of the earth's sedimentary deposits implied by Biblical chronology would be to find evidence of long history within the stratigraphic record. Such an evidence would be a large organically-bound framework composing the "reef core" of a fossil 'barrier reef." It would take thousands of

Figure 8. Beds of Yates and Tansill formations in Rattlesnake Canyon dipping at 8° toward the northwest away from the "reef core."

years to cement a framework of algal and coralline organisms one on top of another if deposited at roughly the same rate as modern reef core.

If several fossil "reef cores" could be found at various levels in the stratigraphic succession, evidence for slow accumulation over long periods of time would be well documented. Lithology should either substantiate or refute the presence of these alleged "reef cores" in the ancient sedimentary deposits.

When geologists first suggested the "barrier reef" interpretation for the Capitan Limestone 40 years ago, they were primarily impressed by the stratigraphy. Since the Capitan had massive limestone above steeply dipping beds of brecciated material, the proposal was that it represented a "reef" on the junction between "shelf" and "basin" environments. Little consideration was given to the lithology of the Capitan at that time. The lack of large organically-bound frameworks was known, but it was reasoned that recrystallization had destroyed them, or that future field investigations would find some.

Today there is wide agreement among geologists that the alleged Capitan "reef core" lacks large organically-bound frameworks. One of the first geologists to clearly note the absence of "reef core" was Donald L. Baars:

> In cross-section the Capitan complex . . . is composed of steeply dipping "fore-reef" beds of skeletal sands and gravels that interfinger basinward with clastics of the relatively deep Delaware Basin. The skeletal particles deposited on the basinward slope grade abruptly to a massive limestone facies in a shelfward direction. *This so-called "reef core" is, upon close inspection, massive but composed of calcilutites (lithified lime muds) which would not now be considered "frame-built" or particularly wave resistant in the unlithified state.*
>
> This facies is narrow, and in some places is lacking. Core sediments (or, in some cases, the fore-slope skeletal sands) grade abruptly shelfward to beds of definite intertidal character, demonstrating very shallow water to mud-flat environments. *Diligent search has shown that reefoid structures are rare indeed, and are not responsible for the shelf construction but occur only as superficial small structures.*[28] (Emphases added.)

Probably the most qualified person to speak concerning Capitan "reef core" is C. W. Achauer who has examined hundreds of slabbed and etched samples and hundreds of thin sections under the microscope. He agrees with Baars concerning the lack of framework, but correctly observes that the "reef core" is not mostly clay-size materials as Baars suggests, but predominantly silt- and sand-size debris, as follows:

> Most of the Capitan lacks reef cores or large masses of colonial frame-building organisms. . . . Primarily the Capitan consists of silt- and sand-size skeletal debris derived from many kinds of organisms that thrived along the edge of the Northwest shelf.[29]

Examination of the so-called "reef talus" should also provide clues about the supposed binding of the "reef core." Achauer says, "The Capitan lacks stratified deposits of bioclastic debris which can be shown to have been derived from reef cores."[30] And R. J. Dunham says:

> Use of this criterion [examination of the binding of the "reef talus"] on the surface Capitan reef and on the subsurface Scurry reef indicates that the binding was wholly or largely inorganic, which accords with other evidence. . . . The Capitan reef and the Scurry reef thus are examples of a large class of stratigraphic reefs that are not ecologic reefs, not "really reefs." Organisms provided their skeletal debris, their bulk; but organisms did not provide their rigid framework (except perhaps locally, and incidentally).[31]

Based on our field work, we can conclude that the Capitan Limestone lacks an organically-bound framework. The Capitan is composed largely of calcarenite and calcisiltite. Fossils, except where noted in the discussion on paleoecology, are usually fragments and are not cemented in an organic framework.

The massive so-called "reef core" limestone tends to be very hard and poorly stratified due to some recrystallization of calcite. The lower portion of the Capitan has been partially dolomitized. Calcirudite "fossil hash" is sometimes found in both the "reef core" and "reef talus."

Figure 9 shows what may be called typical Capitan "reef core" from McKittrick Canyon.

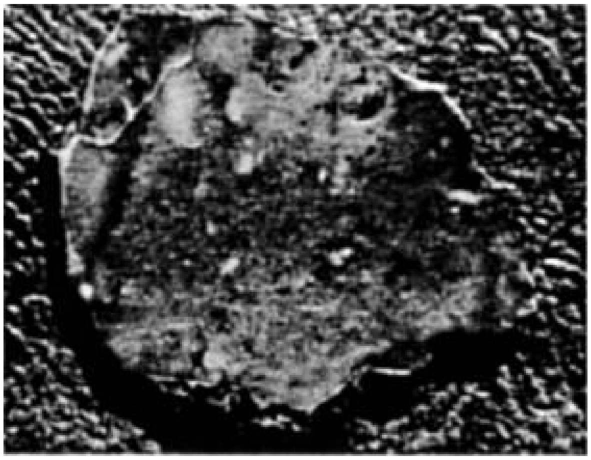

Figure 9. Cut and polished slab of typical Capitan "reef core" rock from McKittrick Canyon. It is calcisiltite which was not wave-resistant. Structure is blurred due to recrystailization. An encrusting bryozoan is present in the upper left (2X actual size).

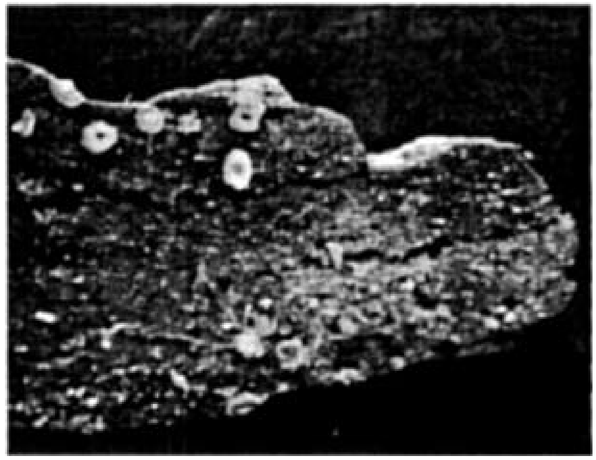

Figure 10. Cut, polished, and etched slab of Capitan Limestone from Pine Spring Canyon containing pisoliths (large concentrically laminated spheres) and ooliths (small gray spheres) (1.5X actual size).

The sample comes from the lower part of the massive cliff in the center of Figure 5. The limestone (calcisiltite) is composed mainly of silt-size particles of broken skeletal calcite and calcite of nonorganic origin. There is no wave-resistant framework present! A small encrusting bryozoan cemented in the silt matrix is present in the upper left.

There is some evidence of recrystallization of the calcite (a characteristic of "reef core" limestone) which tends to obliterate fossils and make the rock extremely hard. Some geologists have actually maintained that recrystallization has destroyed the framework which is postulated to have existed, but this view seems rather extreme because of the presence of unrecrystallized fossils.

Many of the most perfect fossil specimens presented later come from the "reef core" and these are also cemented in calcisiltite or calcarenite matrix. Arguing for destruction of the organic framework by recrystallization therefore seems pointless.

Figure 10 shows Capitan from Pine Spring Canyon near the boundary between Capitan and Tansill formations. The limestone is composed predominantly of pisoliths (the larger concentrically layered spheres) and oolitlhs (the smaller, gray, pellet-like spheres). The origin of the two are still uncertain. Some geologists speculate that both objects formed from sticky particles which have rolled collecting clay- and silt-size particles. Other geologists postulate that the pisoliths formed from weathering and recrystallization around nucleii. One thing seems certain, they are not evidence for an organic framework.

A sample of what may be considered somewhat representative of Capitan "reef talus" is seen in Figure 11. It was collected in McKittrick Canyon near the foreground in Figure 5. The term "reef talus" is certainly misleading because this sample shows no evidence of having originated from the destruction of "reef core." It is very much like what has been called "reef core" as it is composed of calcisiltite matrix with abundant broken fossils.

The only notable lithologic difference between this sample and the "reef core" sample of Figure 9 is the presence of recrystallization in the latter. A cross-section of a whole, thin-shelled brachiopod is seen in the lower right of Figure 11. To the left of center is an encrusting bryozoan. No organic binding is evident.

It is most evident that "Capitan Reef" is very different from modem reefs when careful lithologic examination is conducted. Since "Capitan Reef" does not contain large masses of demon-

Figure 11. Cut, polished, and etched slab of Capitan "reef talus" (calcisiltite) from McKittrick Canyon. Many different fossils are evident due to the absence of recrystallization (1.5X actual size).

strated "reef core," and "reef talus" which can be shown to be derived from destruction of "'reef core," there is ample justification in denying its alleged reefal origin.

"Capitan Reef" in the Guadalupe Mountains did not build large organically-bound, wave-resistant, colonial frameworks and therefore did not *require* thousands of years of *in situ* growth. The presence of calcisiltite, calcarenite, and calcirudite in the alleged "reef core" suggests that the broken fragments were transported and deposited. *In situ* material is very rare if it exists. The rate of deposition need not be anything comparable to modern reefs.

Paleoecology

Many factors hinder proper ecologic interpretation of "Capitan Reef." The fact that most Paleozoic "reef-building" organisms are extinct restricts our knowledge of any biological affinities of these organisms. Recrystallization and dolomitization also tend to obscure some fossils and their matrix. The presence of exotic organisms transported from different environments to a single portion of the "reef" also presents problems.

What is known about the ecology of Capitan organisms does not lend exclusive support to the "barrier reef" interpretation. Concerning the ecology of Capitan organisms, P. B. King says:

> From a study of the calcitic limestone, it is clear that lime-secreting organisms contributed to the formation of the rock. Brachiopods, various molluscs, and some other groups are very abundant in certain beds. These organisms, however, do not show any special adaptation to a reef environment. There is not, for example, a noteworthy abundance of thick-shelled forms that would thrive in strong currents and pounding waves of the exposed parts of a reef and would, therefore, contribute a considerable amount of limestone to the deposit; instead, the assemblage seems to be a normal neritic fauna, such as would grow in any region of clear, shallow water.[32]

The possibility that organisms found in the Capitan were capable of withstanding the turbulence of a wave environment is denied by Achauer. Of the alleged "reef-building" Capitan organisms he says:

> . . . the most prominent forms are calcareous sponges and bryozoans. These organisms may have been capable of forming, and actually may have formed, sediment baffles in the Capitan; however, they did not build a wave-resistant structure in the Capitan, nor probably did they have the ecologic potential to do so.[33]

Figure 12. Cut and polished slab of spherical, concentrically laminated algae from Capitan "reef talus" of Slaughter Canyon. Nucleii are commonly a broken piece of bryozoan or other fossil fragment. Rolling of the spheres is evident and there is little evidence of organic framework or wave-resistant characteristics.

According to advocates of the popular "reef" view, algae were responsible for the major part of sediment trapping and binding, and, hence, are thought to be the major "reef-forming" organisms. Our field work and subsequent laboratory analysis of rock samples gave special attention to algae.

Figure 12 shows the commonest type of algae observed. These are small, spherical, cabbage-like (although of smaller size) colonies which tend to be crowded together. They seem to be composed mainly of filamentous green and blue-green algae which formed crude laminations around a bryozoan or other fossil fragment.

The majority of the structure, however, is not algae but frequently lime mud which was trapped between algal laminations. Promoters of the "barrier reef' interpretation feature this type of rock as a prime example of "reef core." Samples very similar to Figure 12 are on display at the exhibits at Carlsbad Caverns National Park labeled as "reef core" rock.

What is interesting about these algal structures is that they are most common in the so-called "reef talus" with sponges as stratified beds between layers of calcisiltite (such as Figure 11), calcarenite, and calcirudite. The "reef talus" beds in the foreground of Figures 4 and 5 are composed largely of this type of algal structure.

That this type of algae composes an *in situ* "reef core" within the "reef talus" deposits is most unlikely because of its position in the alleged "'reef complex." Algae can grow only in shallow water where sunlight is available and should not live hundreds of feet below the alleged wave intercepting portion of the "reef." Since these algae are filamentous and build structures by trapping mud between calcareous lami-

Figure 13. Photomicrograph of Capitan "reef core" algal sphere (right) in a nonorganically-bound matrix of silt-size particles (left). Algal structures have dominant orientation of calcite crystals that is not found in the matrix (35X actual size).

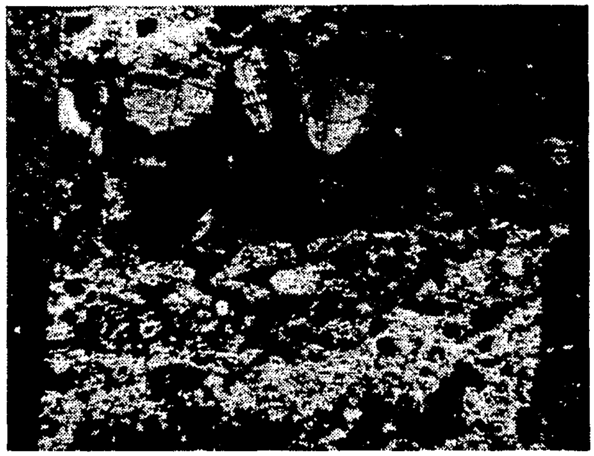

Figure 14. Cut, polished, and etched slab of Capitan "reef core" showing "stromatolitic algae" structure apparently in growth position over nonorganically-bound calcarenite with abundant dasyclad algae (1.5X actual size).

nations, there is little evidence of rigid framework or wave-resistant characteristics.

Some geologists may argue that these colonies of algae are not *in situ* "'reef cores" when found in the "reef talus," but are transported from the wave-intercepting "core" of the deposit where they are truly *in situ*. Careful mapping by Achauer of this algal and sponge deposit shows that it is characteristic of the "forereef" position and is sometimes in the "reef core" area. Both the "reef core" and the "reef talus" of Figure 4 in Slaughter Canyon, according to Achauer,[34] are composed of this association.

This algae and sponge relation is found with the Lamar Limestone in McKittrick Canyon which has been considered a deep water deposit and proceeds up the sloping beds of "reef talus" to near the massive "reef core" in Figure 5. The "reef core" in Figure 5 is not characterized by algae or sponges but by calcarenite and calcisiltite.

Such data are most perplexing. Achauer[35] correctly observes that the algae and sponge association common to the alleged "forereef" is the most "reef-like" structure in the entire Capitan complex. The most "talus-like" part of the Capitan in McKittrick Canyon seems to be the alleged "reef core!"

There is good evidence that even these "reef-like" algal structures are of transported origin. The characteristic roundness of these structures with enclosed fossil fragment nucleii suggests that they have been rolled. Also, microscopic examination (See Figure 13) shows that colonies are usually in a matrix of nonorganically-bound calcisiltite.

Evidences of what may be a sediment trapping organic framework are seen in Figure 14. This rock is from the Capitan "reef core" just below the Tansill Formation in Slaughter Canyon. What appears to be "stromatolitic algae" occur as a mat in growth position over nonorganically-bound calcarenite bearing abundant dasyclad algae.

According to John M. Cys,[36] some stromatolitic structures in the Capitan have been shown to be of inorganic origin. Several features of Figure 14, to the contrary, indicate algal origin.

If these are *in situ* algae, then the Noachian Flood evidently was not responsible for depositing them. However, it is possible that resedimentation (transport, deposition, and burial) has occurred with the mat of algae being redeposited in appearance of growth position.

If many more mats could be found in the appearance of growth position, then *in situ* growth would seem necessary. At the present time it seems appropriate to reserve judgment about the *in situ* character of these algae.

The dasyclad algae, a green algae forming a nonorganically-bound structure in the bottom of Figure 14 and in Figure 15, are distinctive forms common in the Capitan. While alive, their thalli were composed of a central fleshy stem with branches arranged in whorls. Calcite was secreted as a cylinder enveloping the central stem and the bases of the branches. After fossilization the only remaining parts are the hollow lime cylinders with pores in the walls where branches penetrated.

The presence of dasyclad algae in the "reef core" and "forereef" as well as in the "backreef" seems to present problems for the "reef" view. How could algae of such delicate structure have survived in a wave environment?

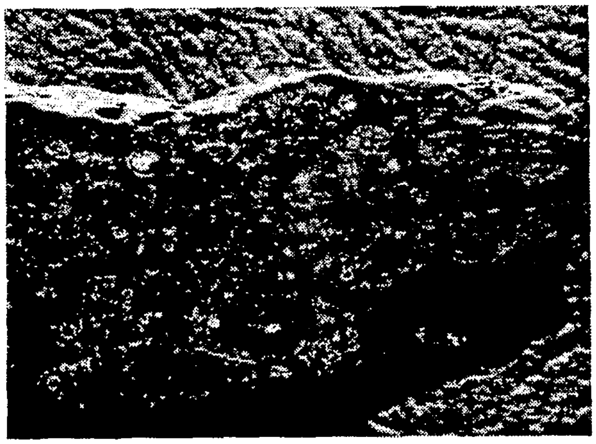

Figure 15. Cut, polished, and etched slab of Capitan Limestone from Walnut Canyon which is vary closely associated with "backreef" beds. Dasyclad algae (left) and cross-sections of brachiopods (right) are in a nonorganically-bound matrix (2x actual size).

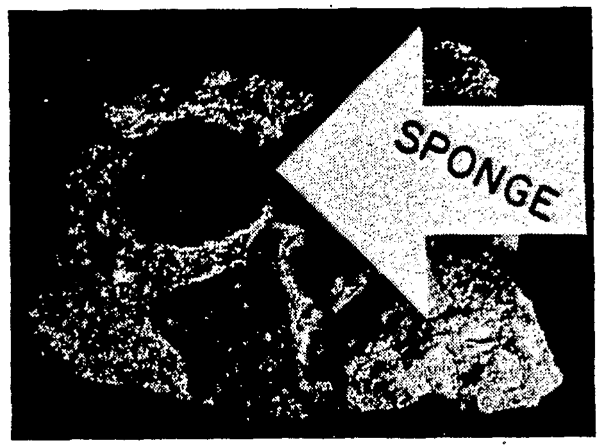

Figure 16. Naturally weathered rock surface showing cross-section of a sponge from Capitan "reef talus" in McKittrick Canyon. Matrix is nonorganically-bound calcarenite (actual size).

Another type of algae found in the Capitan belongs to the extinct family of lime-secreting red algae called Solenoporaceae. This family very closely resembles the modern calcareous red algae of the family Corallinaceae which commonly from 50% to 80% of reefs at the present.

What is amazing in our study of the algae of the Capitan is the unimportance of Solenoporaceae as a "reef-builder." It was not found as a frame-builder or as a sediment-binder but simply as an encrusting form often around fenestrate bryozoans. Thus, one of the organisms which should have been well adapted to a wave environment, building strong organic structures and binding sediments, is relatively insignificant in the so-called "Capitan Reef."

Calcareous sponges are found in the "reef core" and "forereef" areas. They have the ecologic potential to build frameworks and bind sediments to form a "reef." But the sponges are usually small, the largest being up to two or three centimeters in diameter and not more than ten or twenty centimeters long (Figure 16 shows a cross-section of a sponge).

The sponges are not found in colonial frameworks, but are usually separate from each other embedded in a nonorganically-bound matrix of calcarenite. They, therefore, do not seem to have formed wave-resistant frameworks in the Capitan. Attempts to determine if these sponges are in growth position (in situ) seem to be somewhat subjective although. Achauer[37] thinks that some are in position of growth.

As noted earlier, sponges are associated with transported algal spheres in deposits which are somewhat typical of the "forereef" or "reef talus" environment. The "reef core" as stated earlier is dominantly calcisiltite or calcarenite with a characteristic lack of what are considered to be wave-resistant, frame-building sponges or algae.

Two general types of bryozoans are very common in the Capitan. First there are small encrusting forms which are usually found as fragments. These are found embedded in calcisiltite or calcarenite "reef core" rock (See Figure 9), or in the central part of concentrically laminated algal spheres (See Figure 12), or in supposed "reef talus" beds (See Figure 11). Encrusting bryozoans were evidently shallow marine creatures, but they show little ability to build wave-resistant frameworks and could not bind sediments.

The second variety are the fenestrate bryozoans (See Figure 17). They are large fans having a lacy, net-like frame which has great delicacy and beauty. When alive, the fans stood erect attached to the substrate by a flimsy base. Fenestrate bryozoans, which are common to the Capitan "reef core," most certainly could not withstand a wave environment and they could not bind sediment. They are mute testimony of the inadequacy of the "reef" interpretation.

Fusalinids are also common to the Capitan (See Figure 18). They are the size and shape of a grain of wheat and form by coiling around a central axis. These are planktonic animals which show no special adaptation to a "reef" environment. When observed in the "reef core," fusalinids are usually cemented by calcarenite or calcisiltite, and their tests often show preferred orientation, an evidence of current action during deposition.

Brachiopods are very frequently encountered in "backreef," "reef core," and "forereef" deposits, Many of the skeletal fragments making up the limestone are pieces of broken brachiopods. Whole brachiopods are fairly common (See

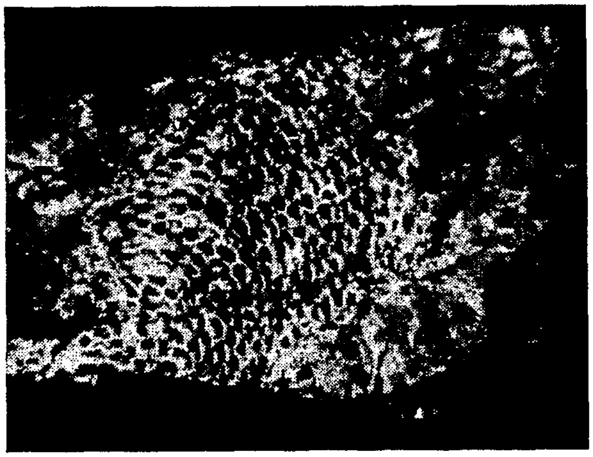

Figure 17. Fenestrate bryozoan from Capitan "'reef core." This fragile creature could not have survived in a wave environment, Matrix is calcisiltite (actual size).

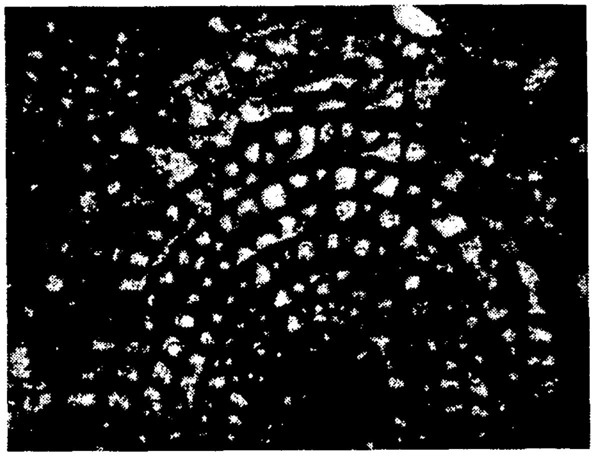

Figure 18. Photomicrograph of fusalinid in silty matrix from Capitan "reef core." The sample is from Carlsbad Caverns National Park elevator shaft #2 at a depth of 499 feet below the surface (35X actual size).

Figure 19) and just a few species comprise the majority of those observed. These brachiopods were sessile, bottom dwelling creatures which could not bind themselves to the substrate and show no special adaptation to a wave environment.

Other fossil forms found in the Capitan Limestone include crinoids (animals with a floating "head" having numerous radiating arms and long jointed stem which attached to sea floor—not frame-builders and not able to thrive in surf environments), cephalopods (chambered, coiled mollusks which could swim—not a "reef-builder"), pelecypods (thin shelled clams which are not especially adapted to surf zones), and trilobites (arthropods characterized by a body having three parts or lobes—probably not a surf animal). *Corals, creatures which could be considered ideally adapted to a reef environment, are very rare in "Capitan Reef."*

From the above discussion it appears that the fossil flora and fauna of "Capitan Reef" represent a shallow water assemblage which was not especially adapted to a wave or strong current environment. "Reef-forming" organisms which could bind sediments and build frameworks are either altogether absent or largely inconspicuous.

Other Alleged Fossil "Reefs"

Are the stratigraphic, lithologic, and ecologic characteristics of "Capitan Reef," as described. above, also found in other alleged Late Paleozoic "reefs"—or is the Capitan somewhat unique?

The lack of frame-builders is noted in "Goat Seep Reef" by P. B. King:

> Like the other limestones along the margin of the Delaware Basin the Goat Seep limestone is quite generally dolomitized, with the result that many of the details of its original structure are now lost. Not many reef-building organisms have been collected from it. No corals have been found, but Dr. Girty reports the presence of sponges. It is not possible, therefore, to determine whether the Goat Seep reef was built by organisms or by inorganic growth.[38]

Oil companies have been intensely interested in Pennsylvanian and Permian rocks in the subsurface in northern Texas. Here the so-called "Horseshoe atoll" (also known as "Scurry Reef") has been penetrated numerous times by drill bit. Concerning this limestone deposit P. T. Stafford says:

> Because of certain characteristics of the Horseshoe atoll, applicability of the terms "reef" or "atoll" to this carbonate mass may be questioned. The relationships of the different lithologic types in the Horseshoe atoll are unlike those of any reef described in the

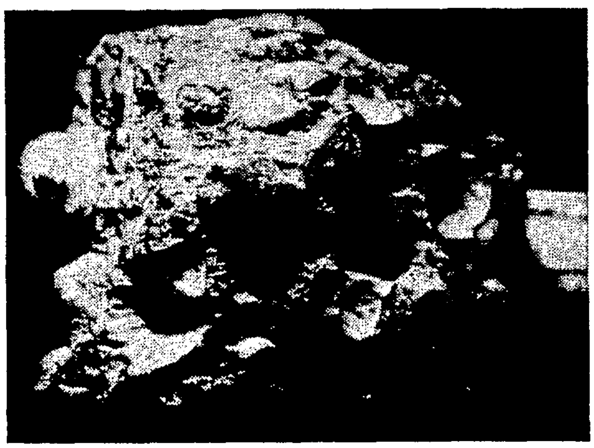

Figure 19. Brachiopods *(Squrmularia guadalupensis)* in Capitan calcarenite from Carlsbad Caverns elevator shaft #2 (½X actual size).

> literature. Rock composed of a growth lattice of organisms was not observed; only detrital limestone has been noted. In areas that would commonly be considered reef core, calcirudite is found. Furthermore, the slopes on the flanks of the Horseshoe atoll are generally low compared to those of the so-called Capitan reef of western Texas and New Mexico or the Quaternary reefs in the Pacific.[39]

Donald L. Baars comments on some alleged "reefs" of the Pennsylvanian System of New Mexico, and that a demonstrated "reef core" is absent:

> Banks composed of carbonate sediments are present in rocks of Upper Pennsylvanian (Virgil) age in both the Sacramento and San Andreas Mountains of south-central New Mexico. . . . The bioherms are made up of skeletal debris and carbonate muds, with the chief constituent being codiacean algae. . . . Although some geologists have argued for a reefal origin of these buildups, there is no evidence of a rigid framework or wave-resistant characteristics.[40]

Mississippian bioherms in New Mexico were studied by Lloyd C. Pray. He begins his paper with the following statement:

> Abrupt mound and ridge-shaped carbonate masses of Mississipian (Osagian) age that are up to 350 feet thick crop out in southern New Mexico where they were first reported and described in considerable detail by Laudon and Bowsher (1941). These structures and apparently similar ones in the subsurface of north-central Texas have commonly been referred to as "crinoidal bioherms." Although the New Mexico occurrences have been known and examined by many geologists, including the writer, since 1941, their genesis has remained obscure, particularly the nature of the core facies. *The most enigmatic aspect has been the identity of the frame-builders, if indeed frame-builders were ever present.*[41] (Emphasis added.)

Thus, it seems that many highly fossiliferous limestones of the Late Paleozoic are in no sense organic frame-built reefs. Since general characteristics can be associated among fossiliferous limestones of the Late Paleozoic, it would seem logical to seek a common mode of origin.

Capitan Limestone: What Is It?

The above comments on the Capitan Limestone have shown the inadequacy of the "barrier reef" interpretation. So far remarks on what the Capitan is have been very brief. In a word the Capitan is here considered to be a *biostrome* — a highly fossiliferous stratified deposit which shows little topographic relief and is surrounded mostly by nonfossiliferous strata.

To the southeast of the Guadalupe Mountains the Capitan intertongues with gypsum, limestone, and sandstone, while to the northwest it intertongues with dolomite, siltstone, sandstone, and limestone. The lower dolomitized unit of the Capitan appears to be very continuous to the northwest where it passes laterally into the dolomitized Goat Seep Limestone and then into the Queen and Grayburg formations. Thus, the Capitan is not a narrow facies from 3 to 5 miles wide but a portion of a widespread layer of limestone. The formation names seem to confuse the true geometry of the deposits.

When was the Capitan Limestone deposited relative to the Noachian Flood? Did it accumulate before, during, or after? In our opinion some of the most obvious evidences of the universal Noachian Flood occur in Late Precambrian and Early and Middle Paleozoic strata. Here are found vast blanket-like marine sediments covering entire continents with a lack of subaerial deposits such as widespread lava flows. When volcanics are found in the Late Precambrian and Early and Middle Paleozoic strata, they show many evidences of submarine extrusion.

In a previous paper[42] it was shown that most of the Cenozoic strata (which were deposited after both the Paleozoic and Mesozoic strata) could not have been deposited during the Flood and they were interpreted to be post-Flood. This conclusion was based on the observation that Cenozoic lava flows in the northwestern United States are commonly subaerial.

The Mesozoic strata also seem to be post-Flood as subaerial lava flows are well documented. Thus, in the Meridian Formation (Triassic) of central Connecticut, basalt strata with manifold evidences of subaerial flow are up to 500 feet thick and are continuous laterally over distances up to 30 miles. Sedimentary strata between and above the Meridian flows contain abundant dinosaur footprints.[43]

Also, enormous Triassic or Jurassic lava flows of the Parana Basin of Brazil probably covered at least 375,000 square miles to a depth of up to 2,000 feet.[44] Similar flows to those in Brazil deposited about the same time are found in South Africa.

It is our opinion at the present time that the Late Paleozoic strata are associated with the final stages of the Noachian Flood. Thus, the Capitan Limestone, which is among the youngest of the Late Paleozoic strata, could be either deposited during the last part of the Flood or shortly thereafter. If fossils such as Figure 14 can be well documented as *in situ* occurring on several horizons, then the Capitan would have to belong to our post-Flood era.

Since the Capitan is composed largely of loose, unbound sediments and fossils, much of the material could have been transported by flood waves. Studies on the texture of the Bell Canyon and Cherry Canyon sandstones show that the grain size *increases* toward the southeast (toward the Gulf of Mexico and this indicates the source direction of the sand.[45]

It is possible that much of the Capitan sediment was washed into its present location by tidal waves from seismic disturbances or meteorite impact immediately after the Noachian Flood. The data certainly do not *require* many thousands of years for the Capitan to accumulate and, therefore, seem to present little problem for Biblical chronology. Instead, the lack of large organically-bound structures, which would grow during thousands of years, suggests that deposition was very rapid.

Acknowledgments

I wish to thank the Creation Research Society Research Fund chairman for amply funding field investigations during the summer of 1971 in southeastern New Mexico and western Texas. The permission of Carlsbad Caverns and Guadalupe Mountains National Parks to collect hand specimens of limestone was essential to completion of the project. I am grateful for the cooperation of Carlsbad Caverns National Park and Humble Oil Company for graciously allowing me to examine well cores and rock thin sections of Capitan Limestone.

Appendix: Terminology

General terms:

Reef: a largely unbedded, wave-resistant structure composed of *in situ*, organically-bound, frame-building organisms, cementing organisms, and sediment filling which modifies the surrounding sedimentation.

Reef Complex: the suite of environments and resulting sediments associated with a reef.[46]

Terms relating to stratigraphy:

Stratigraphy: a discipline of geology which deals with the position and geometry of stratified rocks.

Reef Core: the wave-resistant, *in situ*, organically-bound portion of a reef complex.

Forereef: the sediments on the seaward side of the reef core which are composed largely of transported debris (also known as "reef talus").

Backreef: the sediments on the shoreward side of the reef core often deposited in a lagoon.

Biostrome: a nonorganically-bound fossiliferous limestone which has no appreciable topographic relief but tends to be a widespread layer.

Bioherm: a nonorganically-bound fossiliferous limestone which rose topographically above the surrounding depositional surface.

Formation: a mappable rock unit.

Member: a subdivision of a formation.

Facies: refers to lateral variance in rock type within a stratigraphic interval.

Cenozoic Strata: the most recently deposited strata noted for fossil mammals.

Mesozoic Strata: strata deposited immediately before Cenozoic strata and are known for dinosaur fossils.

Paleozoic Strata: strata deposited immediately before Mesozoic strata and have abundant marine organisms.

Precambrian Strata: the oldest strata which have few fossils.

Tectonics: deformational processes in the earth's crust.

Terms relating to lithology:

Lithology: a discipline of geology which deals with the megascopic and microscopic composition and structure of rocks.

Limestone: a sedimentary rock composed chiefly of calcium carbonate—$CaCO_3$.

Dolomite: a sedimentary rock composed chiefly of calcium-magnesium carbonate—$CaMg(CO_3)_2$.

Calcite:. a mineral composed of calcium carbonate.

Calcilutite: limestone composed chiefly of clay-size particles.

Calcisiltite: limestone composed of chiefly silt-size particles.

Calcarenite: limestone composed of chiefly sand-size particles.

Calcirudite: limestone composed chiefly of particles larger than sand-size.

Dolomitized: refers to limestone which has been partially changed to dolomite through the addition of magnesium ions.

Recrystallized: refers to limestone in which the original crystal structure of calcite has been modified.

Calcareous: containing calcium carbonate.

Anhydrite: mineral composed of calcium sulfate—$CaSO_4$.

Gypsum: mineral composed of calcium sulfate and water—$CaSO_4 \cdot 2H_2O$.

Evaporite: rock composed of anhydrite, gypsum, or salt.

Pisolith: a sphere of concentrically laminated limestone or dolomite generally larger than 2 mm.

Ooliths: a sphere of limestone or dolomite usually smaller than 2 mm.

Terms relating to paleoecology:

Paleoecology: the study of the relationship between ancient organisms and their environment.

Stromatolitic algae: algae which build structures which have more or less planar lamination.

Dasycladaceae (Dasyclad): family of fragile green algae which construct calcareous tubes.

Solenoporaceae: extinct family of calcareous red algae having the ability to construct organically-bound frameworks.

Corallinaceae: modern family of calcareous red algae which build modern reefs.

Scleractinida: order of modern corals which build modern reefs.

Bryozoan: member of phylum of colonial animals which build calcareous structures.

Fusalinid: extinct animal about the size and shape of a grain of wheat.

Brachiopod: member of phylum of marine shelled animals with two unequal shells or valves.

Crinoids: marine animals with a floating "head" having numerous radiating arms and long jointed stem which attaches to the sea floor.

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[45]Advocates of the "barrier reef" view need to have the sand coming from the northwest and must be able to explain how it escaped being trapped in the "backreef." Where in any modern environment are limestones and evaporites being deposited behind a barrier reef while sand from the shore is being deposited in widespread strata in deep water beyond the reef?

[46]The term "reef complex" may also have meaning to the psychologist when describing a geologist's tendency to indiscriminately call *any* highly fossiliferous and unbedded limestone deposit a "reef." A geologist encumbered with such a bias may be said to possess a "reef complex."