Sedimentology of the Cutoff Formation (Permian), western Guadalupe Mountains, west Texas

by Mark T. Harris, Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD 21218

Abstract

The Cutoff Formation (middle Permian) of the western escarpment of the Guadalupe Mountains was formed by alternating erosion and deposition over a drowned shelf margin. The underlying carbonate bank (Victorio Peak Formation–Bone Spring Limestone) was abruptly terminated by erosion of the shelf edge, which formed a 2-mile-wide escarpment. The fine-grained Cutoff strata mantled this escarpment locally removed Cutoff strata so that it occurs today in three discontinuous areas: shelf, shelf margin, and basin. Within this section, five lithostratigraphic units, consisting of alternating intervals of lime mudstone and shale, can be traced from the shelf edge to the basin. Recognition of these five units appears to resolve the uncertainty of correlating the Cutoff Formation into the basin area. Within these units, variations in the sedimentary structures, color, and fauna of the lime mudstones record anoxic basin conditions.

The upper and lower contacts of the Cutoff Formation are unconformities, and an intraformational unconformity separates upper and lower units of the Cutoff Formation. For all three unconformity surfaces, recognition of the Cutoff Formation into the basin area. Oriented parallel to the shelf edge, much of the margin is preserved. Flattened surface ranges from broad (180-300 ft wide), flat-sided scours to nonge (less than 10 ft wide), steep-sided channels. The primary channel fills are intrabasinal rudstones, megabrecia, and lutites. Clast lithologies indicate that the source was both underlying units and lithified Cutoff strata. The depositional geometries of the lutite beds and the interrelationship of channel fillings and erosion surfaces indicate that a model of a density-stratified basin with both bottom currents and interflows can be applied to deposition of Cutoff strata.

Previous faunal collections from the Cutoff Formation are largely allochthonous, reworked material. Fusulinids collected during this study from the upper Cutoff Formation are of Guadalupian age. The intraformational unconformity within the formation appears to be the first easily recognized, chronostratigraphic horizon below the reported Guadalupian fusulinids.

Introduction

The Cutoff Formation is a well-exposed drape of middle Permian basin-style facies that overlies the carbonate bank deposits of the Victorio Peak Formation. This facies records an 11-14 mi shelfward shift of basin sediments. At the Cutoff shelf-to-basin transition, the shelf margin is a paleoslope with a relief of 900-1,000 ft. This study concentrates on the facies at the shelf margin that contain a record of alternating deposition and submarine erosion.

The study area is located along the west escarpment of the Guadalupe Mountains, extending from the New Mexico–Texas border to the hills south of El Capitan (Fig. 1). The escarpment results from Cenozoic block faulting and exposes a little-disturbed, natural cross section oriented nearly perpendicular to the Permian shelf margin of the Delaware Basin.

Stratigraphy

Previous work by King (1942, 1948), Newell et al. (1953), and Boyd (1958) established the basic stratigraphic relationships (Fig. 2) of the Permian section. King (1948) established the Cutoff as a member of the Bone Spring Limestone, designating the type section at Cutoff Mountain (along the Texas–New Mexico border). Later, he changed the stratigraphic rank to formation, renaming the unit Cutoff Shale (King, 1965). In this report, the Cutoff Shale is redefined as the Cutoff Formation based on lithologic content. In the Guadalupe Mountains, the Cutoff strata consist of both limestone (60-70%) and shale (30-40%). Cutoff or Cutoff-age strata also occur in the northeastern Guadalupe Mountains (Hayes, 1959), Sierra Diablo Plateau (King, 1965), Wylie Mountains (Hay-Roe, 1957), and Apache Mountains (Wood, 1968). Correlation of Cutoff strata from shelf to basin has long been problematical (Wilde and Todd, 1968) because post-Cutoff erosion has removed Cutoff strata locally along the shelf margin. Preserved strata occur in three distinct areas, as defined by the pre-Cutoff shelf profile (Fig. 3): 1) a flat shelf (0°–1° dip), 2) a steeply dipping shelf margin (5–20° dip), and 3) a low relief basin that flattens out to a low angle (1–5° dip). Submarine erosion and shelfward retreat of the underlying Victorio Peak Formation and Bone Spring Limestone (Pray, 1971; Harms and Pray, 1974) formed this shelf profile with a relief of 900–1,000 ft (McDaniel and Pray, 1967).

King (1948) recognized upper and lower Cutoff units (informal names) at the shelf margin exposures based on lithologic variation and intervening unconformity surface. This report extends this informal division into shelf and basin areas (Figs. 3 and 4). The lower Cutoff Formation is black lime mudstone with abundant chert. The upper Cutoff Formation is predominantly black to medium gray lime mudstone and shale. Both units are bounded above and below by widespread unconformities.

As recognized by King (1948), the lower unit is best exposed in the shelf margin area as a large channel fill in south Shumard Canyon (King, 1948, pl. 12B). At the Cutoff Mountain type section (233 ft thick) only the lower 11 ft are assigned to the lower Cutoff Formation. This lower unit pinches out to the south, probably due to (erosional?) truncation along its upper surface. In the basin area, the lower Cutoff Formation appears 0.25 mi south of Bone Canyon, and reaches a maximum thickness (102 ft) an additional 0.25 mi south, just north of its disappearance into the subsurface. The overlying upper Cutoff strata make up the bulk of the formation and occur widely in basin, shelf margin, and shelf areas.
Rock types

Two major rock associations make up the Cutoff strata: 1) lime mudstone and shale (lutites) that comprise 95%+ of the strata exposed, and 2) coarser-grained lithologies that occur locally along the shelf margin and adjacent basin edge. Carbonate rock texture terminology follows Embry and Klovan’s (1971) modification of Dunham’s (1962) scheme. Bedding terminology is that of Ingram (1954).

Lutites

The lutites are suspension deposits that drape over pre-existing bottom topography. Slight bedding thickness variations indicate only minor current activity during deposition. Grain size of the lime mudstone ranges from fine silt to coarse clay. In places, calcareous sponge spicules (0.025 mm in diameter) are recognizable, but generally grain origin is indeterminant. Siliciclastic material is predominantly clay with minor quartz silt. Six lutite lithologies were recognized:

1. Black, cherry lime mudstone is medium bedded and contains abundant black chert (5-15%), which occurs in thin (about 2 inches thick) seams in nearly every bed. Typically, this lithology is thinly laminated, but laminations are faint or absent in the shelf area.

2. Thinly laminated, lime mudstone is dark gray and medium bedded with shaly partings and a very sparse brachiopod fauna.

3. Faintly laminated to nonlaminated lime mudstone is dark gray and medium bedded with shaly partings. Laminations are faint or absent. A very sparse brachiopod fauna occurs.

4. Medium-gray lime mudstone is medium bedded and nonlaminated. It contains scattered skeletals, predominantly brachiopods and echinoderms.

5. Medium-gray lime wackestone occurs as thin (about 1-2 inches thick) skeletal-rich layers within the medium-gray lime mudstone at the type section. These layers have sharp bases and irregular tops, and are interpreted as storm deposits.

6. Interbedded lime mudstone and siliceous shale are both dark brown to dark gray to black, unfossiliferous, thinly laminated, and fissile. The lime mudstone is commonly argillaceous. The shale is slightly calcareous and contains elliptical, football-sized concretions. Both lithologies are interbedded vertically and grade into each other laterally. In places, a few thin to very thin beds of unfossiliferous, thinly laminated siltstone occur.

Coarser rock types

Coarser-grained lithologies (coarser than lutites) occur either in lens-shaped channel or sheet-like bodies associated with truncation surfaces. These lithologies are limited to shelf margin and basin areas, but are distributed vertically throughout the Cutoff strata.

These rocks are all grain-supported and ungraded with either mud-filled or mud-free intergranular spaces. The megabreccias and most intraclastic rudstones are poorly sorted with a mud matrix. The skeletal rudstones, quartz sandstones, and some intraclastic rudstones are well sorted and mud-free. The grain-supported textures, erosive bases, and channel morphologies all suggest that these rocks are deposits from turbulent flows. In the megabreccias at the base of the Cutoff section along the shelf margin, the clasts are derived from the underlying Victoria Peak Formation and Bone Spring Limestone. Higher in the section, the principal clast source shifts to the lutites of the Cutoff Formation.
4. Quartz sandstone is tan, thinly laminated, thickly bedded, and fine grained. It occurs only as a channel fill at the base of the lower Cutoff strata in the shelf margin.

Lutite distribution and interpretation

Vertical succession and lateral variations

The lutites occur in a vertical succession of five correlation units, each recognizable within the Cutoff Formation from shelf edge to basin. Recognition of this succession provides a stratigraphic framework within the Cutoff Formation that appears to resolve the shelf-to-basin correlation (Fig. 5). The fivefold succession is:

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>upper</td>
<td></td>
</tr>
<tr>
<td>Cutoff</td>
<td>Unit 5: Medium-bedded lime mudstone</td>
</tr>
<tr>
<td></td>
<td>Unit 4: Interbedded lime mudstone-shale</td>
</tr>
<tr>
<td></td>
<td>Unit 3: Medium-bedded lime mudstone</td>
</tr>
<tr>
<td></td>
<td>Unit 2: Interbedded lime mudstone-shale</td>
</tr>
<tr>
<td>lower</td>
<td></td>
</tr>
<tr>
<td>Cutoff</td>
<td>Unit 1: Black, cherty lime mudstone</td>
</tr>
</tbody>
</table>

Within the lime mudstone units (1, 3, and 5), four consistent lithologic relations occur (Fig. 5): 1) black, cherty lime mudstone is restricted to unit 1 (lower Cutoff Formation); 2) well-laminated lime mudstone occurs basinward and grades laterally into poorly laminated lime mudstone in the shelf margin (units 3 and 5) or shelf (unit 1) area; 3) lime mudstone in basin and shelf margin areas is dark gray to black, but grades laterally and vertically into medium-gray limestone on the shelf; 4) fossils are rare in shelf margin and basin lutites, but occur widely in low abundance in the medium-gray shelf limestone.

Within the interbedded lime mudstone-shale (units 2 and 4) no persistent variations are discernible, probably due to the diagenesis of these clay-rich rocks. Table 1 shows the correspondence of these five units to the stratigraphic terminology of previous workers.

Anoxic model

An anoxic basin model (Byers, 1977) best describes the variations of lamination quality, rock color, and fossil content that occur in the Cutoff limestones. Oxygen concentration, as a function of water depth, affects biologic activity and the resulting sediment texture, thus dividing the basin profile and sedimentary facies into three depth zones (Table 2): aerobic, dysaerobic, and anaerobic.

In the Cutoff limestones (Fig. 5) each of these three depositional environments are recognizable by the sediment structures (laminated or bioturbated), color (dark gray or black due to organic content), and the presence or absence of shelled fauna. The basal dark gray to black, laminated lime mudstones represent the anaerobic zone. The dark gray, faintly laminated to nonlaminated lime mudstones of the shelf margin are dys-

FIGURE 4—Geologic map of the shelf margin area.
TABLE 1—Comparison of stratigraphic terminology for the basin area. Note that King (1948, pl. 9) mapped limestones at the base of the Brushy Canyon Bone Spring Limestone Middle Bone Spring Limestone Bone Spring Limestone

<table>
<thead>
<tr>
<th>Stratigraphic Unit</th>
<th>King (1948)</th>
<th>Newell et al. (1953)</th>
<th>This report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brushy Canyon Formation</td>
<td>Brushy Canyon Formation</td>
<td>Brushy Canyon Formation</td>
<td></td>
</tr>
<tr>
<td>Upper Bone Spring Limestone</td>
<td>Cutoff Formation</td>
<td>Cutoff unit 5</td>
<td></td>
</tr>
<tr>
<td>Cutoff Formation</td>
<td>formation units 2-4</td>
<td>formation lower unit 1</td>
<td></td>
</tr>
<tr>
<td>Bone Spring Limestone</td>
<td>Middle Bone Spring Limestone</td>
<td>Bone Spring Limestone</td>
<td></td>
</tr>
</tbody>
</table>

unconformity, and Cutoff strata are consistently 200-240 ft thick from the type section to the basin edge. The intraformational unconformity is undulatory near the type section, and it entirely truncates lower Cutoff strata near the shelf edge.

Two miles north of the shelf edge (near Bartlett Peak) a large channel cuts through 240 ft of Cutoff strata and 100 ft into the Victorio Peak Formation. Filled with Cherry Canyon Sandstone and two megabreccia sheets, it may have served as a feeder channel into the Delaware Basin for sand during post-Cutoff time (Harms, 1974).

**Shelf margin**

The truncation surfaces along the shelf margin vary widely in scale and type. The preserved Cutoff strata are bounded by marked angular unconformities and channel forms. The pre-Cutoff unconformity shapes the shelf margin by truncating 900-1,000 ft of the underlying Bone Spring Limestone and Victorio Peak Formation carbonate bank (McDaniel and Pray, 1967).

At the shelf margin, the upper Cutoff Formation is largely missing and limited to the more basinward portion of the shelf margin (Fig. 4), and the lower unit is restricted to a single channel fill (Fig. 6). This channel is predominantly filled with black, cherty lime mudstone with minor basal beds of intraclastic rudstone and quartz sandstone. The intraformational unconformity truncates this channel fill and is overlain by upper Cutoff strata (units 2, 3). The post-Cutoff unconformity cuts into the Cutoff Formation throughout the shelf margin area, in places completely removing the formation.

At the shelf edge, 150 ft of Cutoff strata and 150 ft of underlying Victorio Peak Formation are truncated by a half-channel. The initial Cutoff shelf edge was probably farther basinward than at present. The redeposited clasts of the megabreccia and intraclastic rudstone deposits record the shelfward retreat of this edge. At the northern (shelfward) extent of the preserved shelf margin, upper Cutoff strata overlie a second 300-ft-deep half-channel cut into the Victorio Peak Formation. Both half-channels are spoon-shaped, dip steeply (>20°) basinwards at their shelfward head, and strike parallel to the shelf edge. The origin of these surfaces and similar Guadalupian surfaces is not well understood (Pray et al., 1980).

**Truncation surfaces**

Truncation surfaces, which occur at many horizons throughout the Cutoff Formation, are concentrated at the shelf margin. Most surfaces laterally merge to form three widespread shelf-to-basin unconformities. These occur at the base and top of Cutoff strata (Pray, 1971) and between the lower and upper units of the Cutoff Formation.

Truncation surfaces occur in these forms: 1) channel cross sections with a relief ranging from a few inches to 150 ft, 2) spoon-shaped "half-channels" that truncate more than 300 ft of strata at the shelf edge (Pray et al., 1980), and 3) low-angle (1-5°) truncation of strata in shelf and basin areas over a distance of several miles. Examples of these surfaces are described below (see Figs. 3, 4, 6, and 7).

**Shelf**

The predominant truncation feature in the shelf area is low-angle truncation of strata along the three unconformity surfaces. The post-Cutoff surface runs parallel to the basal aerobic in nature. The initial shelf sediments are also dysaerobic, but they grade upward and shoreward into medium-gray lime mudstones of aerobic nature. These low-energy shelf deposits grade into the San Andres Formation (Boyd, 1958), probably a shallower water, higher energy shelf deposit, ~11-14 mi north of the shelf margin (southern New Mexico).

**TABLE 2—Anoxic model summary, after Byers (1977)**

<table>
<thead>
<tr>
<th>Oxygen level</th>
<th>Aerobic</th>
<th>Dysaerobic</th>
<th>Anaerobic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundant</td>
<td>Low</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Shelled</td>
<td>Soft bodied</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Sediment texture</td>
<td>Bioturbated</td>
<td>Bioturbated</td>
<td>Laminated</td>
</tr>
<tr>
<td>Shelled fossils</td>
<td>Present</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Organic content</td>
<td>Low</td>
<td>Variable</td>
<td></td>
</tr>
<tr>
<td>Color (generally)</td>
<td>Light</td>
<td>Medium</td>
<td></td>
</tr>
</tbody>
</table>

Dark
Channel forms are best exposed at the basinward edge of the shelf margin (Bone Canyon; Fig. 7). Two types of channels occur: 1) broad (180-600 ft) forms with flattened (<10°) sides predominantly filled with lutites and minor intraclastic rudstone lenses, and 2) narrow (<100 ft), steep-sided (>10°) forms with megabreccia channel fillings. Most broad channels do not occur along major unconformity surfaces; however, some locally truncate stratigraphic units. In contrast, narrow megabreccia-filled channels (Pray and Stehli, 1963; the “patch reefs” of Newell et al., 1953) are limited to the unconformity surfaces. This variety of channel shape and filling is duplicated in the more poorly exposed strata in the basin area. It also occurs on a smaller scale of channels a few inches deep.

**Basin**

In the basin area, Cutoff units thicken uniformly away from the shelf margin due to both stratigraphic thickening and decreasing truncation along unconformity surfaces. The lower Cutoff Formation appears 0.25 mi south of Bone Canyon. It increases in thickness from its truncated feather edge to 102 ft (beneath the intraformational unconformity) over a distance of 0.25 mi, and disappears southward into the subsurface. The upper Cutoff Formation thickens basinward from 122 ft, in the south wall of Bone Canyon, to 283 ft over a distance of 1.1 mi to the south (sec. 17 of King, 1948). This expanded upper Cutoff section can be traced to the south where it forms the low black hills south and southwest of El Capitan, which King (1948) and Newell et al., (1953) considered Bone Spring Limestone.

Small, poorly exposed channels with a relief of up to 2-3 ft occur in low abundance within the basinal Cutoff strata. These are inferred to be similar in their geometry to the well-exposed channels in the shelf margin area.

**Formation of truncation surfaces**

Cutoff truncation surfaces are believed to be of subaqueous origin because of 1) the lack of features typical of vadose, subaerial, or shallow marine environments; 2) the typically basinal nature of the Cutoff strata; and 3) the similarity of these surfaces to features in the overlying deep-water deposits of the Delaware Mountain Group (Harms and Pray, 1974).

The occurrence of channel forms along truncation surfaces, the coarse clasts in the channel fills, and the similarity of features from top to base of the shelf margin and over a range of scales imply that the surfaces are, at least in part, erosional in origin. The enigmatic “half-channels” truncate more than 300 ft of shelf edge strata, and shape the shelf margin profile (Fig. 3). They may be the result of large-scale slumps or gravity-slide features, as recorded along modern carbonate margins (for examples, see Mullins, 1986). However, the erosional features and lack of any fault scarp or notable slump features (only two small slump-fold features occur in the basin) indicate significant modification of any such features.

**Depositional model**

The depositional style of the Cutoff strata and the associated erosion surfaces are well described by the density current model proposed by Harms (1974) and Harms and Pray (1974) for the basinal sands and silts of the overlying Brushy Canyon Formation. In contrast, the Cutoff strata reflect similar processes in a carbonate anoxic basin setting. Lutites, carried in suspension by interflows over density stratified basin waters, alternate with erosional features and traction deposits deposited by denser bottom-hugging currents, as presented by Harms (1974). Graded beds, indicative of turbidity flows and deep-sea fan geometries, are absent. In contrast to the siliciclastic Brushy Canyon Formation, the Cutoff rocks are predominantly carbonates. The greater predominance of lutites is probably due to the lack of sand-sized particles (which are limited to the shallow-shelf equivalent, San Andres Formation); thus, bottom currents are recorded largely by erosion surfaces. The anoxic basin conditions recorded in the lime mudstone units indicate that a stable, stratified water column existed throughout Cutoff deposition. This setting is ideal for separation of density interflows and bottomflows, but the cause of the scarring episodes is unclear.

Megabreccias and intraclastic rudstones are numerous, probably because of the availability of lithified carbonate clasts. Initially, the retreat edge of the Victorio Peak bank served as the major source of clasts. As the Cutoff Formation blanketed the 900-1,000 ft paleoscarp, the main clast source shifted to lithified Cutoff strata of the upper shelf margin and shelf edge. The coarse deposits always overlie erosional features, and are concentrated at the shelf margin along the shelf-to-basin unconformities. Erosion and deposition alternated along the shelf margin, producing the complex of truncation surfaces (and missing section) that make direct physical correlation impossible.

**Fossil collections and age relations**

The position of the boundary between the Guadalupian and Leonardian stages is uncertain, largely because of previous uncertainties over the correlation and age of the Cutoff Formation (Wilde and Todd, 1968). Cutoff fauna is difficult to interpret because the fauna is very sparse, almost all fossils are allochthonous, and shelf-to-basin correlation problems resulted in attribution.
of key fauna collections to incorrect stratigraphic units. Based on their sample locations (for a detailed list of sample locations see Cooper and Grant, 1972-1977), many of the Bone Spring Limestone fauna collections of King (1948) and Newell et al. (1953) were from the basinal upper Cutoff Formation (the lime mudstone hills south and southwest of El Capitan). Because these collections were from the Bone Spring Limestone (the Cutoff was a member of the Bone Spring Limestone according to workers in the 1940’s and 1950’s), the fauna was assigned to the Leonardian. However, these collections were probably from small channel fills within the Cutoff Formation of this report. This fauna is allochthonous and includes material reworked from the Victorio Peak Formation, Bone Spring Limestone, and parts of the Cutoff Formation, similar to the fauna of the marl-brecia lenses in Bone Canyon (Wilde and Todd, 1968). Garner Wilde (pers. comm. 1986) identified fusulinids from the upper Cutoff Formation (a small channel fill at the base of correlation unit 5 in the basin) as Guadalupian in age. Previously, Guadalupian fusulinids were recognized by Hollingworth and Williams (Boyd, 1958, p. 60) and Wilde (Wilde and Todd, 1968) from Cutoff strata to the north.

Brachiopods are the most abundant macrofauna in the Cutoff Formation, but other groups reported or observed are ammonites, nautiloids, pelecypods, gastropods, bryozoa, crinoids, fusulinids, corals, conularids (Conularia) and dasycladacean algae. Boyd (1958) provided a detailed fauna listing for the New Mexico exposures, and Cooper and Grant (1972-1977) summarized the brachiopod occurrences. Trace fossils are rare. At the basin edge, flattened horizontal burrows occur in the upper Cutoff Formation. Bioturbation is inferred to be intensive in the sediments of the shelf margin, but individual traces are not apparent.

The age of the upper Cutoff Formation is Guadalupian, on the basis of the reported fusulinid occurrences. The age of the lower Cutoff Formation is uncertain because it contains a largely allochthonous fauna, and no datable fusulinids are reported. For convenience, I suggest the stage boundary be taken at the unconformity surface between lower and upper Cutoff Formation. This is the first widespread surface below Guadalupian fauna that is both easily recognizable lithologically and nearly a chronostratigraphic surface (almost everywhere overlain by Cutoff correlation unit 2).

Conclusions

The Cutoff Formation is a drape of fine-grained basinal sediments over a shelf margin, representing an 11-14 mi shift of this lithofacies into shelf and basin. The post-Guadalupian lithologies are lutes, deposited in an anoxic basin with rocks recording aerobic, dysaerobic, and anaerobic environments. Within these strata, a vertical succession of five correlatable units is recognized, facilitating lithostratigraphic correlation of shelf-to-basin strata.

Erosional features (channels, half-channels) are concentrated at the shelf margin. Many of these features combine to form three major shelf-to-basin unconformities that truncate pre-Cutoff and Cutoff strata, with the maximum removal being at the shelf margin. The truncation surfaces, inferred to be submarine in origin, shape the shelf-to-basin profile.

These Cutoff lithologies and the erosion surfaces appear to be formed in a density-stratified basin with density flows scouring the shelf margin and carrying fine material out into the basin. This is a carbonate version of Harms’ (1974) model for the Delaware Mountain Group.

The two informal units of King (1948), upper and lower, can be traced from shelf to basin within the Cutoff Formation. This distinction is based on lithographic differences and the intraformational unconformity.

Many of the previously reported Cutoff fauna are allochthonous, reworked from either the Bone Spring Limestone, Victorio Peak Formation, or the Cutoff Formation. Previous collections from “Leonardian-age” strata appear to be from the upper Cutoff Formation, from which Guadalupian-age fusulinids have been reported. Based on the fusulinids, the upper member is of Guadalupian age, but the age of the lower member is uncertain.

ACKNOWLEDGMENTS—This report is based on a Master’s thesis (Harris, 1982) completed at the University of Wisconsin (Madison) under the direction of Professor Lloyd C. Pray. I wish to thank him for his guidance, encouragement, and suggestions. Field work was supported by a grant from the New Mexico Bureau of Mines and Mineral Resources, and conducted with the permission of the Guadalupe Mountains National Park. Mr. Windy Lewis and Mr. Ed Hammond kindly granted permission to cross their property. My wife Nancy has made this work possible by her suggestions, encouragement, and patience.

References


Hay-Roe, H., 1957, Geology of the Delaware Mountains and vicinity, Culberson and Jeff Davis Counties, Texas: Bureau of Economic Geology, University of Texas (Austin), Geologic Quadrangle Map 21.


