Holocene Coral Patch Reef Ecology and Sedimentary Architecture, Northern Belize, Central America

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PALAIOS, 1992, V. 7, p. 591–601

The biotic composition, growth and relationship to sea level history, and diagenetic attributes of a representative Holocene patch reef ("Elmer Reef") in the Mexico Rocks complex in northern Belize are described, and compared to those of Holocene patch reefs in southern Belize. Elmer Reef has accumulated in shallow (2.5 m) water over the last 420 yr, under static sea level conditions. Rate of vertical construction is 0.3–0.5 m/100 yr, comparable to that of patch reefs in southern Belize. A pronounced coral zonation exists across Elmer Reef, with Monastrea annularis *dominating on its crest and* Acropora cervicornis *occurring on its windward and leeward flanks. The dominance of* Montastrea *on Elmer Reef is unlike that of patch reefs in southern Belize, in which this coral assumes only a subordinate role in reef growth relative to that of* Acropora palmata. *Elmer Reef locally is extensively biodegraded and marine, fibrous aragonite and some bladed high-magnesium calcite cements occur throughout the reef section, partially occluding corallites and interparticle pores in associated sands.*

Patch reefs in southern Belize have developed as catch-up and keep-up reefs in a transgressive setting. In contrast, the dominant mode of growth of Elmer Reef, and perhaps other patch reefs in Mexico Rocks, appears to be one of lateral rather than vertical accretion. This style of growth occurs in a static sea level setting where there is only limited accommodation space because of the shallowness of the water, and such reefs are referred to as "expansion reefs".

INTRODUCTION

Coral patch reefs are major components of Holocene platform carbonate facies systems in tropical and subtropical areas (James, 1983). Many studies have been published on such reefs, and have focused on aspects of their environmental setting and morphology, biotic compositions and zonations, rates of growth, and synsedimentary diagenesis (reviews in James, 1983, 1984; James and Macintyre, 1985; Schroeder and Purser, 1986b; Fagerstrom, 1987; and papers in Frost et al., 1977 and Schroeder and Purser, 1986a). Similar studies of Holocene and Pleistocene patch reefs in Belize have also been done, and they have dealt exclusively with those on the southern shelf (Wantland and Pusey, 1971; York, 1971; Purdy, 1974a, b; York and Wantland, 1975; Halley et al., 1977; Miller and Macintyre, 1977; Shinn et al., 1979; James and Ginsburg, 1979; Choi, 1981; Choi and Ginsburg, 1982; Westphall and Ginsburg, 1984; Westphall, 1986) or on large atolls seaward of the continental margin (Wallace and Schafersman, 1977; James and Ginsburg, 1979). In contrast, there is no published information on patch reefs in northern Belize despite their abundance and importance to carbonate sedimentation here. Preliminary study (Anderson, 1990) has suggested some fundamental differences between Holocene patch reefs in northern and southern Belize in terms of depositional settings, ages, and biota. Furthermore, this study suggests that patch reef growth, and relationship to sea level history, are distinctly different in northern and southern Belize. However, the extent of these differences and their effects on reef development remain to be evaluated.

This paper presents the results of a detailed study of a single Holocene coral patch reef on the northern Belize shelf, one that is representative of the many such patch reefs that occur in this area. The age and geologic setting, relationship to Holocene sea level history, types of biota and associated sediments, rates of reef construction, and synsedimentary diagenetic attributes of this patch reef are described. This patch reef is compared to published descriptions of some Holocene patch reefs in southern Belize, and interpretations therefrom provide information critical to interpreting patch reef development in other areas of the world.

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0883-1351/92/0007-0591/$3.00

LOCATION AND METHODS OF STUDY

The study area is within the Mexico Rocks complex, seaward of Ambergris Cay in northern Belize (Fig. 1). Mexico Rocks covers approximately 1.5 km^2 on the shallow, outer-shelf lagoon to the lee of the Belize barrier coralgal reef, and includes scores of coral patch reefs (Fig. 2A). Moderate physical energy levels of the Mexico Rocks area result from wind-driven waves and deep-ocean swells which enter the lagoon through passes on the barrier reef (Fig. 1). Current and sediment transport directions here are to the northwest, and semi-diurnal tidal range is less than 0.3 m. Distribution of Holocene facies in the area is shown in Figure 1B. Holocene sediments are deposited on Pleistocene limestone bedrock (Ebanks, 1975; Pusey, 1975) dated at 125 Ka old (Lighty and Russell, 1985).

The patch reef examined in this study ("Elmer Reef") is located near the northeastern tip of Mexico Rocks (Figs. 1, 2). It was chosen for study because it appeared to be representative of the many patch reefs here in terms of geometry and biota. Elmer Reef is 16 m in length and a maximum of 8 m in width. Its thickness and height above the sea floor vary from 1.6–2.2 m, although deep crevasses are present locally (Fig. 2B). Water depths around Elmer Reef and throughout the Mexico Rocks area average 2.5 m, and the top surfaces of most of the patch reefs, including Elmer Reef, are within 0.3 m of mean sea level.

Identification of the invertebrate biota living on and around Elmer Reef was done during snorkel and SCUBA surveys. Determination of biotic distribution patterns was done by counting the number of different species present within each square (0.3 m^2) on grids placed across the reef. Because extensive coring and underwater excavations of reefs are not permitted in Belize, we were able to take only one core through Elmer Reef, at a locality near its seaward side (Fig. 2B). Samples recovered from this core were examined by thin section petrography and scanning electron microscopy. A sample from an unaltered (aragonitic) coral from near the base of the core was sent to Geochron Laboratories (Cambridge, Mass.) for radiocarbon dating.

Thickness of modern sediments and subsea depth to the top of the Pleistocene limestone were measured in Mexico Rocks, and specifically along two traverses around Elmer Reef (Fig. 1B), by probing to bedrock with a steel rebar (reinforcement bar). Twelve surface sediment samples were collected along the two traverses, within 20 m of the reef (Fig. 1B), in order to evaluate sediment budget in the immediate area. One additional sample was collected for comparison from the sand flat behind the barrier reef (Fig. 1B).

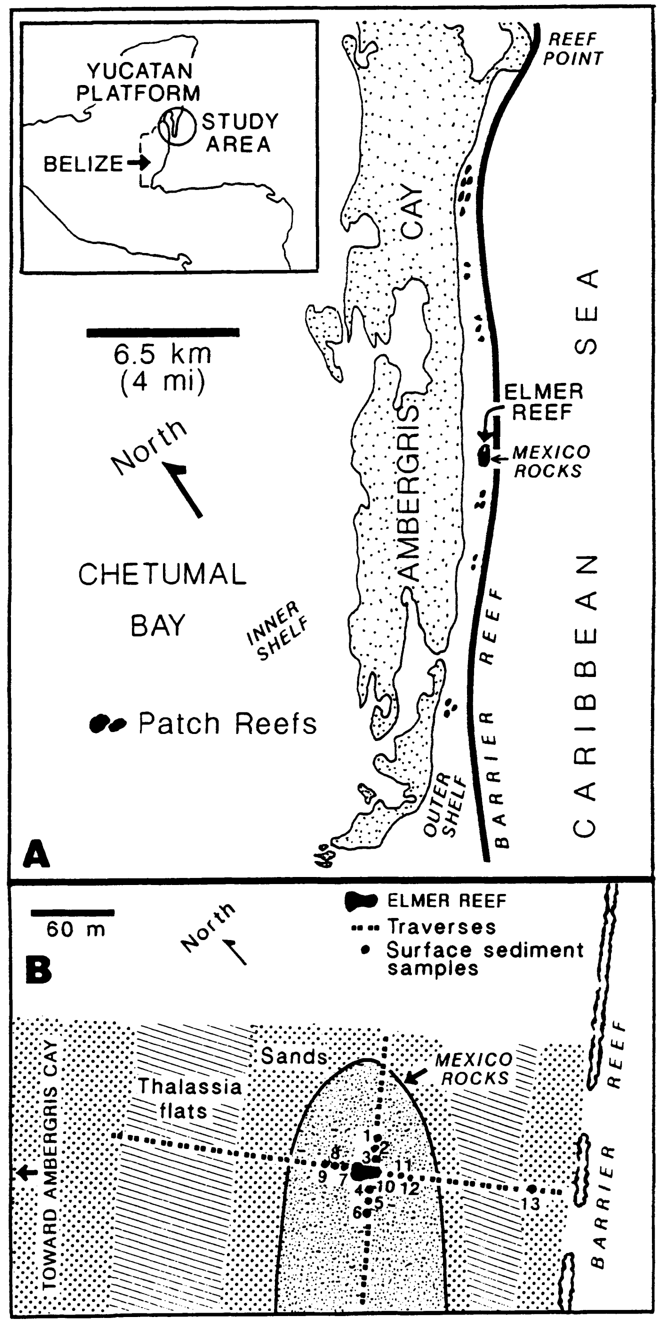

FIGURE 1—**A)** Location of Elmer Reef in Mexico Rocks complex, Belize. **B)** Areal view of Holocene facies around Elmer Reef. Locations of traverses and surface sediment samples 1–13 shown.

PATCH REEF ARCHITECTURE

Reef Foundation

Thickness of unconsolidated, Holocene marine sediments in the study area varies from about 370 cm along the coast of Ambergris Cay, 440 cm in the sand flat immediately behind the barrier reef, to only 10–20 cm around Elmer Reef (Fig. 3A). Sediment thickness in the study area is the inverse of topography on the underlying Pleistocene limestone, and the entire Mexico Rocks complex has formed on a NE-trending bedrock ridge of considerable areal extent (Fig. 3). Elmer Reef is situated on a 0.35 m high bump on this larger bedrock ridge (Fig. 4).

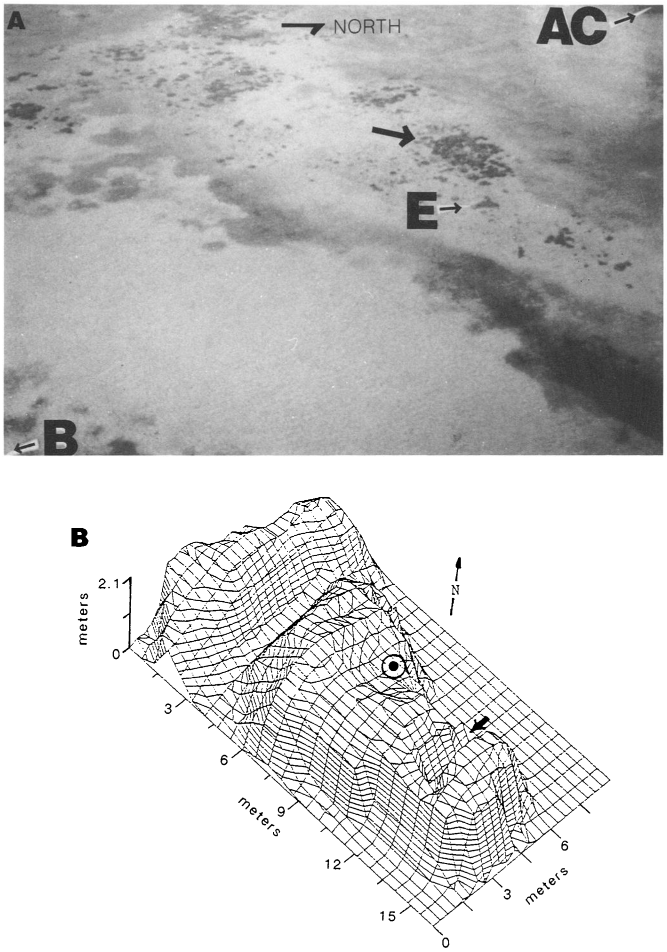

FIGURE 2—A) Areal view of Elmer Reef ("E") within northeastern part of Mexico Rocks complex. Ambergris Cay ("AC") to the northwest, barrier reef ("B") to the southeast. Note coalescence of individual patch reefs into larger, composite patch reefs (arrow). Darker areas landward and seaward of the patch reef complex are *Thalassia* meadows; light areas are mobile sand. **B**) Three-dimensional representation of geometry of Elmer Reef. Location of core shown by circled dot; arrow points to deep crevasse in the reef.

Extant Reef Biota and Ecology

Montastrea annularis is the principal framebuilder on the living surface of Elmer Reef, composing approximately 70% of the total biota (Table 1). Other corals living on the reef include *Diploria* sp., *Agaricia agaricites, A. purpurea, Porites furcata, P. porites,* various octacorals (*Plexaura* sp., *Plexaurella* sp., and *Gorgonia* sp.), and rarely,

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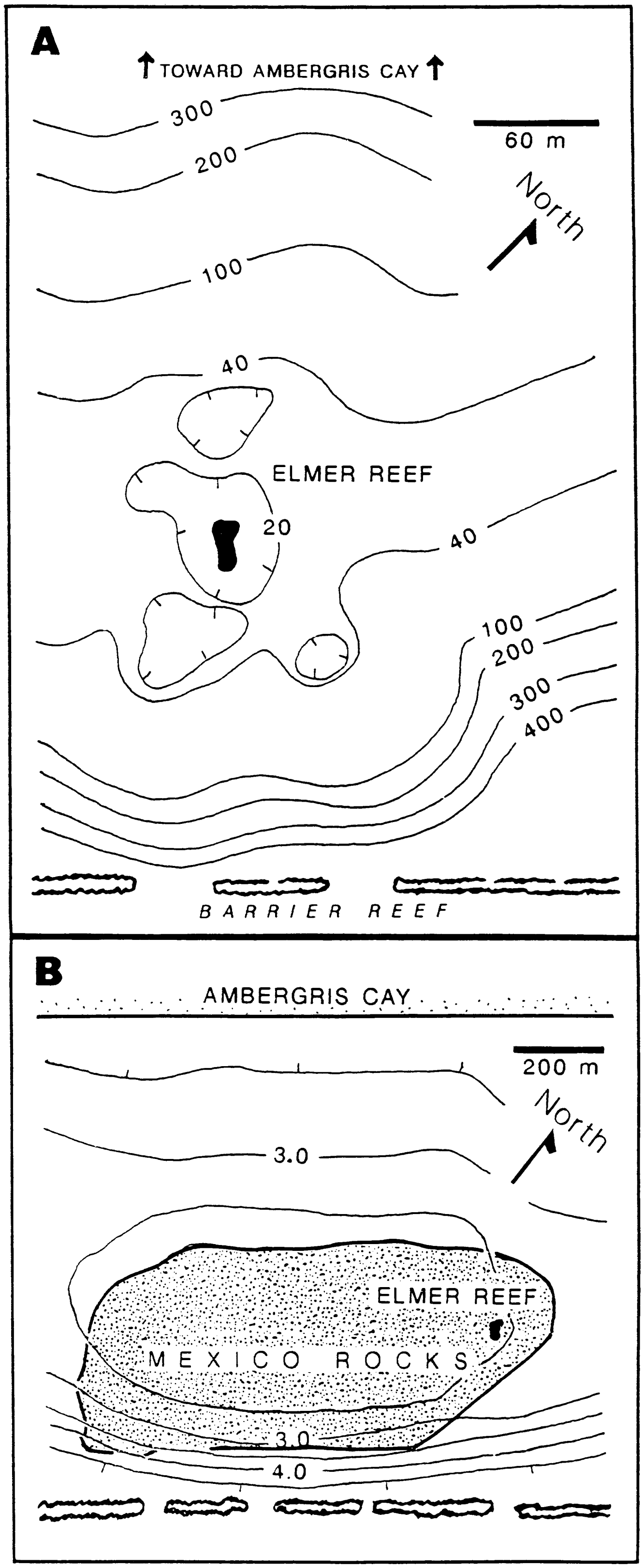
FIGURE 3—A) Thickness of Holocene sediment in study area (CI = 20 cm around Elmer Reef and changes to 100 cm away from it). **B**) Depth to top of Pleistocene limestone, datum mean sea level (CI = 0.5 m).



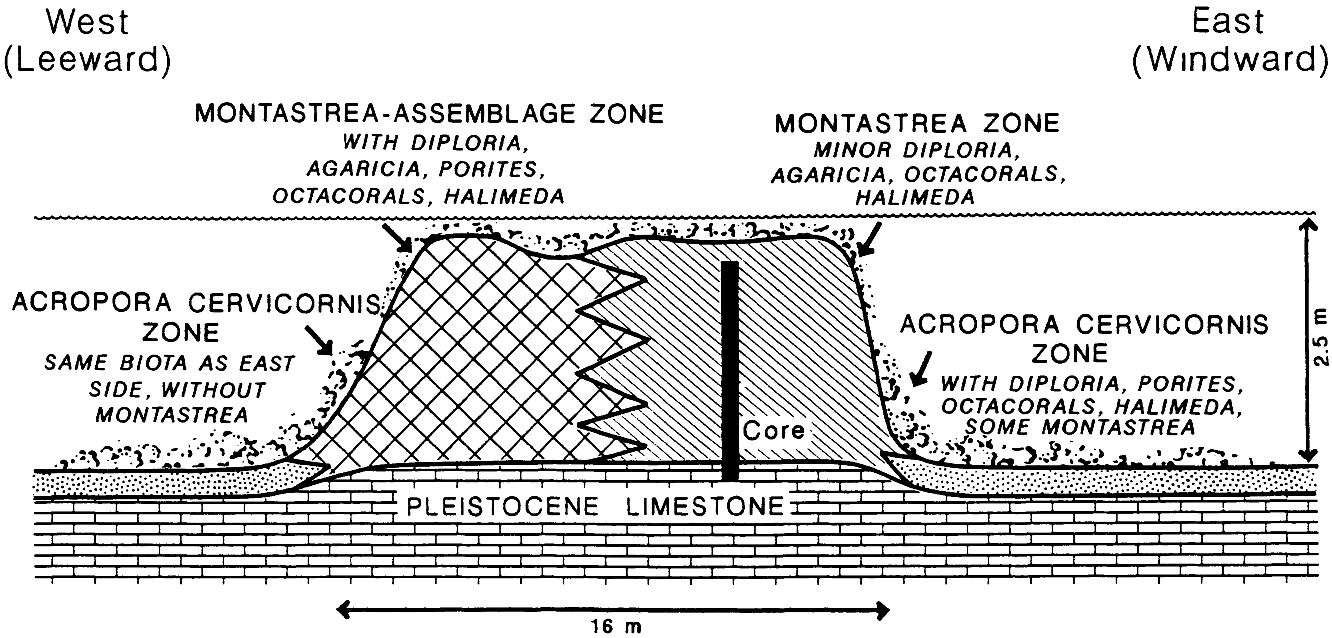


FIGURE 4—Schematic of extant coral zonation on and around Elmer Reef. Dominance of *Montastrea* in older Holocene sediments on the seaward side of the patch reef is suggested by core study (Fig. 5); *Montastrea* assemblage zone in older sediments on the leeward side of the reef is inferred.

Millepora sp. (Table 1). *Montastrea* dominates on the eastern (windward) half of the patch reef proper, where it composes nearly 90% of the total biota. In contrast, *Montastrea* makes up about 50% of the total biota on the western (leeward) side) of the reef proper, and is associated with a more diverse assemblage of other corals which altogether compose 77% of the total biota (Fig. 4 and Table 1). *Agaricia* occurs mainly on the undersides of and between larger coral heads on the patch reef. Isolated stands of *Acropora palmata* are found on some patch reefs in the Mexico Rocks complex, but do not occur in Elmer Reef. Encrusting foraminifera (*Homotrema rubrum*) and coralline algae (*Lithothamnion*) are found locally on the corals. Calcareous algae (*Halimeda incrassata, Penicillus capitatus, Udotea flabellum,* and locally *Padina* sp.), anemones, fan worms and featherworms, sponges (*Callyspongia* sp. and *Verongia* sp.), echinoderms (*Diadema* sp.), and various molluscs inhabit sheltered areas between corals and crevasses within the reef. Coral growth at Elmer Reef has resulted in a steep-walled accumulation that is a maximum of 2.2 m high (Fig. 2B). Our observations suggest that such a geometry is characteristic of most of the patch reefs in Mexico Rocks.

Acropora cervicornis is the dominant coral flanking Elmer Reef. It is more abundant on the somewhat protected, lower-energy western (leeward) flank of the reef than on its eastern (windward) flank, composing 75% versus 50% of total biota, respectively (Table 1). *Diploria, Gorgonia, Agaricia, Porites,* octacorals, and some *M. annularis* also occur in these areas, together with the same taxa of calcareous algae, sponges, molluscs, and echinoderms as are found on the reef (Fig. 4 and Table 1). Large blocks of *M. annularis* dislodged from the Elmer Reef proper occur locally in areas flanking it.

The activities of parrot fish, clinoid and siphonodictid sponges, echinoids, boring pelecypods, rasping gastropods, and endolithic algae have resulted in locally extensive degradation of the reef. Bioerosion, likely along with periodic physical erosion, produce sediments which are deposited within crevasses and growth-framework voids, and partially cover eroded areas on Elmer Reef. These sediments are similar compositionally to sediments around the reef (discussed below).

Sediments Around Elmer Reef

Sediments around the reef (samples 1–12) consist of unconsoliated, poorly sorted, gravelly sands and slightly gravelly sands composed mainly of *Halimeda* and coral fragments, with lesser amounts of miliolid and rotaliid foraminifer, molluscs, *H. rubrum,* ostracodes, sponge spicules, and echinoderm fragments (Table 2). Peloids appear to be mostly micritized coral and *Halimeda* fragments. Sediments from the sand flat behind the barrier reef (sample 13) are similar compositionally to those around Elmer Reef (Table 2). Therefore, it is not possible to discern how much of the sediment surrounding Elmer Reef is actually derived from it versus having been transported there by currents from the sand flat.

Internal Structure and Composition

The top 0.19 m of Elmer Reef was not cored so as to avoid damage to living corals. Instead, the core was spud-

TABLE 1—Estimated average percentages of biota living on and surrounding Elmer Reef. "VB" refers to mostly vagrant benthos for which percentages were not tabulated.

	Elmer Reef			Off-reef (within 5 m)		
Biota	East side	West side	Total average	East side	West side	Total average
Corals						
Agaricia agaricites	1	4	2.5	2	0	1
A. purpurea	1	4	2.5	1	0	0.5
Acropora cervicornis	0	0	0	50	75	62.5
Diploria sp.	2	5	3.5	9	3	6
Gorgonia sp.	0	2	1	4	4	4
Montastrea annularis	89.5	50	69.7	3	0	1.5
Plexaura sp.	0	4	2	0	0	0
Plexaurella sp.	0.5	4	2.25	0	0	0
Porites furcata	0	2	1	2	0	1
P. porites	0	2	1	5	2	3.5
Algae						
Lithothamnion sp.	3	2	2.5	0	0	0
Halimeda incrassata	2	14	8	8	8	8
Penicillus capitatus	0	3	1.5	5	3	4
Udotea flabellum	0	2	1	2	3	2.5
Worms						
Fanworms (*Sabella* sp.)	0	0.5	0.25	0.5	0.5	0.5
Featherworms (*Spirobranchus* sp.)	0.5	0.5	0.5	0.5	0.5	0.5
Sponges						
Callyspongia sp., *Verongia* sp.	0.5	1	0.75	8	1	4.5
Various molluscs (pelecypods, gastropods)	VB	VB	—	VB	VB	—
Echinoderms						
Diadema sp.	VB	VB	—	VB	VB	—
Totals	100	100	99.95	100	100	100

ded in a void between growing coral heads, and penetrated 1.41 m of Holocene section overlying Pleistocene limestone (Fig. 5). The upper few centimeters of Pleistocene limestone recovered at the base of the core consist of well indurated coralgal sands of low-magnesium calcite composition. Based on limited core recovery in the Pleistocene limestone section, it is not presently possible to determine if Elmer Reef developed on an older patch reef. Although the Pleistocene was exposed subaerially prior to Holocene submergence (Ebanks, 1975; Pusey, 1975), any physical evidence of exposure that may have been present has been obliterated by bioerosion.

In addition to coral growth-frameworks, Holocene samples in the core mainly included fragments of partially lithified sediments, and most of the unconsolidated sediments in the section were flushed from the core barrel during drilling. However, some of these sediments were collected (Fig. 5) when rates of drilling could be reduced. Numerous cavities were encountered in the section (Fig. 5) as indicated by the unimpeded drop of the core barrel during drilling.

The cored section above the Pleistocene limestone consists entirely of layers with in situ growth-framework corals, dominated by *M. annularis* and minor recognizable *Diploria,* admixed and interbedded with lenses and layers of gravelly sands (Fig. 5). Thickness of fossil coral colonies on the core varies from 0.025 m to 0.1 m, and like their living counterparts, the corals are encrusted locally by *Homotrema rubrum* and *Lithothamnion,* and are biomicritized. An unaltered (aragonitic) sample of *M. annularis* collected from the stratigraphically lowest recognized in situ coral colony at 0.19 m above the base of the core (Fig. 5) yielded a radiocarbon date of 420 ± 130 BP.

The lithified, gravelly, skeletal sand layers in the core vary in thickness from 0.25 m to nearly 0.5 m (Fig. 5). These deposits, as well as samples of unlithified sediments that were collected, consist of particles of the same biotic types as are found living on the modern reef surface and

TABLE 2—Particle composition in different size fractions of Holocene sediments versus distance from Elmer Reef, given in averages for respective sample suites (see Fig. 1B for locations of samples).

	Immediately surrounding the reef (5.0 m): samples 3, 4, 7, 10		Distal from the reef (20 m): samples 1, 6, 9, 12, 13	
Particle types	Gravel and coarse sands	Medium to very fine sand	Gravel and coarse sands	Medium to very fine sand
Corals	21.5	66.1	12.2	72
Halimeda	62	25	63.6	18.3
Miliolids and Rotaliids	6.5	3.3	11.9	4.1
Molluscs	5.8	0.3	6.3	0.2
Homotrema rubrum	3.0	0.7	2.3	2.1
Ostracodes	0	0.2	0	0.4
Sponge spicules	0	0.5	0	0.2
Echinoids	1.2	1.5	1.9	0.7
Peloids	0	2.4	1.8	2.0
Totals	100	100	100	100

around it. Coarse sand and gravel size fragments of *M. annularis* and *Halimeda* dominate in these sediments.

Interpretation of Core

We interpret the cored section as being of patch reef origin based on the abundance of coral framestones and associated coralgal sand and gravel. Reefs and patch reefs typically consist of abundant rubble together with in situ reef framework (Friedman, 1970; James, 1983). Cavities in this section are interpreted as being large growth-framework voids which are common in modern and ancient reefs (James, 1983).

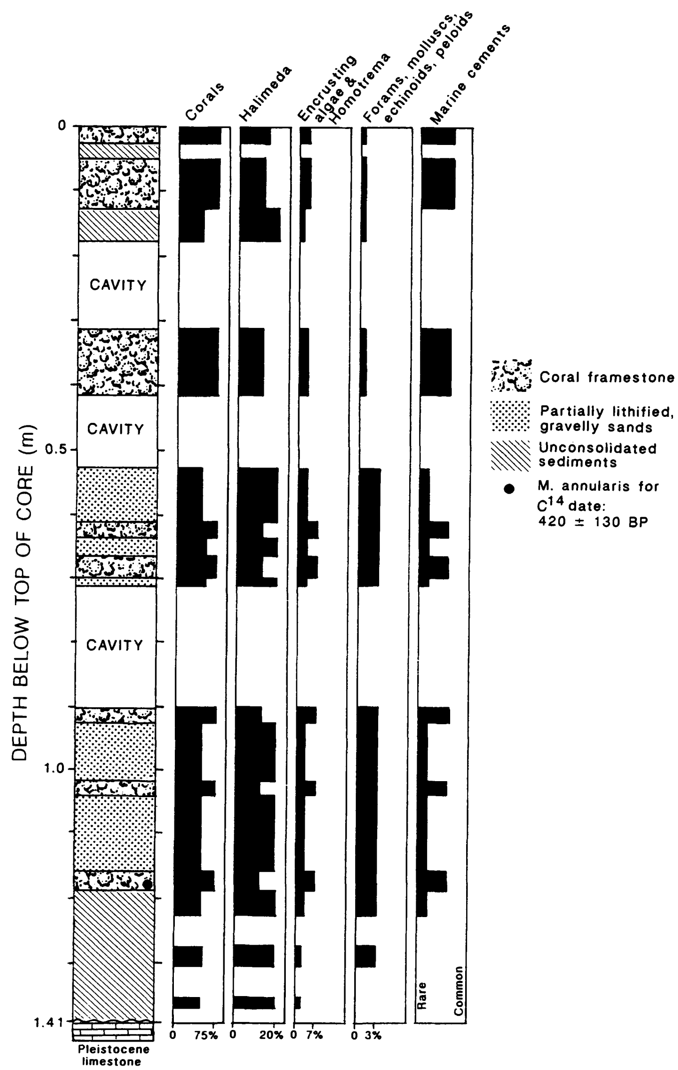


FIGURE 5—Holocene facies in core through Elmer Reef (depth below top of core; see Fig. 2B for location) showing relative proportions of principal biota and abundance of marine cements; the composition of unconsolidated sediments that were recovered during drilling is shown. Location of ^{14}C-dated *M. annularis* shown. The top 0.19 m of living reef was not cored here; core begins 0.8 m below mean sea level.

Diagenesis

All skeletal components on and around the reef and in the core are composed of either aragonite or high-magnesium calcite, the exception being ostracodes which are primary low-Mg calcite. Aside from biodegradation, the most conspicuous diagenetic aspect of Elmer Reef is the presence throughout the core (Fig. 5) of syndepositional marine cements and internal sediments. Internal sediments occur within corals, and consist of pockets of crystal silt and micrite that locally are graded and laminated (Fig. 6A).

Marine cements occlude from 10–15% of primary porosity in the core. The most abundant cement mineralogy encountered is aragonite, as confirmed by XRD and the occurrence of prominent Sr peaks on EDAX scans. The abundance of aragonite cement in Elmer Reef contrasts with the overall dominance of high-magnesium calcite cements in reef and fore-reef settings in southern Belize (James and Ginsburg, 1979; Shinn et al., 1982). Aragonite cements occur most commonly as isopachous druses of needles and square-tipped fibers 100 to 500 μm long and 3 μm wide (Fig. 6B). Crystals typically have nucleated syntaxially on corallite walls, and also occur in interparticle pores in partially lithified sediments. Also present, but less abundant, are isopachous druses of acicular aragonite crystals 15 to 20 μm in length and 3 μm in width (Fig. 6C). These crystals are commonly found in small corallites where they also have precipitated syntaxially on skeletal aragonite substrate, and also in interparticle pores in associated sands and internal sediments. These arago-

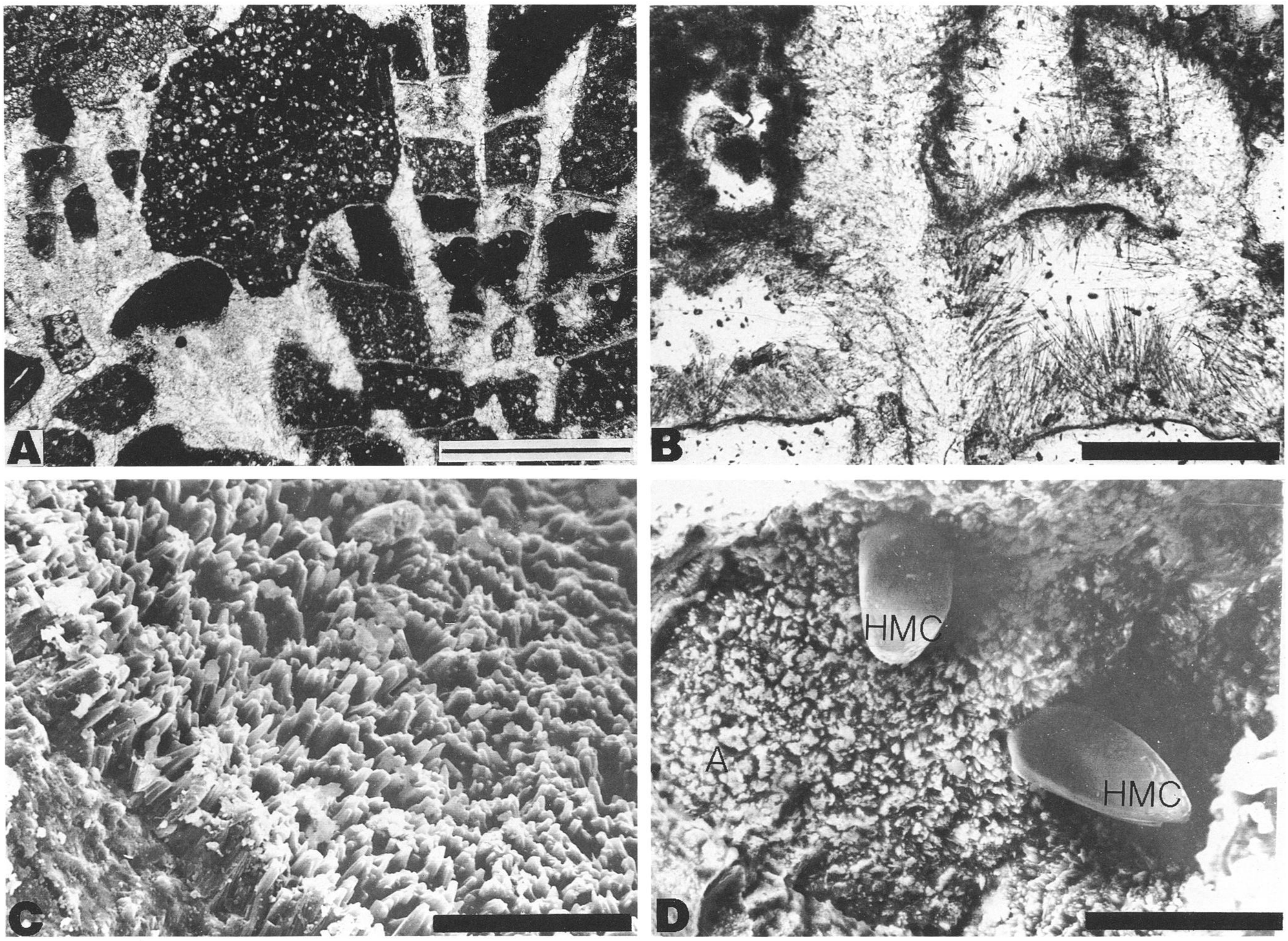


FIGURE 6—Syndepositional diagenetic fabrics: **A**) Thin section photomicrograph of internal sediments in large bore (center-left) and within corallites (right); length of scale 1400 μm, crossed polars. **B**) Thin section photomicrograph of coarse crystalline aragonite needle cement in corallite; length of scale 400 μm, plane light. **C**) SEM micrograph of fine crystalline aragonite cement in corallite; length of scale 50 μm. **D**) SEM micrograph of bladed high-magnesium calcite cement ("HMC") overlying fine crystalline aragonite ("A") in corralite; length of scale 80 μm.

nite cement fabrics are similar to those described in Holocene and Pleistocene reefs by many workers (Friedman, 1974; Macintyre, 1977; James and Ginsburg, 1979; Bathurst, 1983).

Large (60–75 μm), bladed cement crystals occur rarely within some corallites, where they have precipitated on substrate of acicular aragonite cement (Fig. 6D). A magnesian calcite mineralogy of these cements is suggested by the presence of subdued Mg peaks and corresponding absence of Sr peaks on EDAX spectrum scans. The $MgCO_3$ concentrations of these cements could not be determined by this technique with available equipment, or by other techniques, because of inadequate supplies of samples. However, they resemble marine, bladed HMC cements described by several workers from Holocene and Pleistocene reefs (Schroeder, 1973; James et al., 1976; Bathurst, 1983; Pierson and Shinn, 1985). Equivocal examples of micritic HMC cements were not found in any of the samples examined.

DISCUSSION

Rates of Construction

Elmer Reef is 1.6 m thick at the locality where the core was taken (Fig. 2B), and the coral that was dated at 420 ± 130 BP was from 0.19 m above the top of the Pleistocene limestone (Fig. 5). Hence, average rate of vertical construction (total mass balance between coral growth and destruction: Schlager, 1981) of the upper 1.41 m of the reef here is approximately 0.3 m/100 yr. The maximum thickness of the patch reef is 2.2 m. Assuming that the 0.19 m of unrecovered sediment section in the core beneath the dated coral (Fig. 5) is also about 420 yr old, a maximum rate of

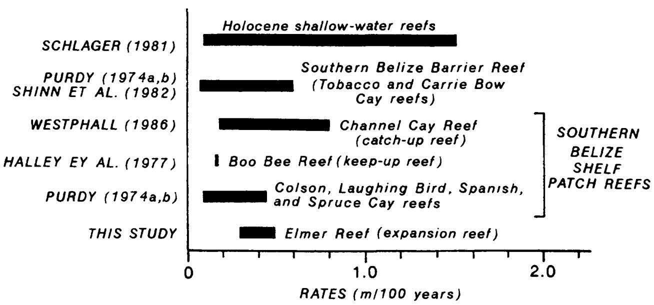


FIGURE 7—Growth rates of patch reefs in the study and in southern Belize, and comparative data for Belize barrier reefs and typical Holocene, shallow-water reefs.

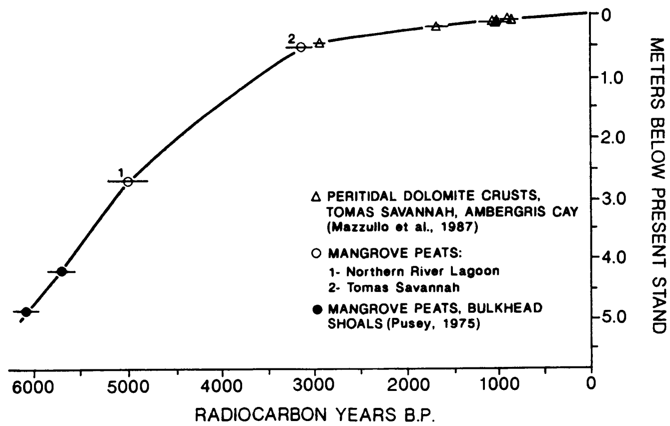


FIGURE 8—Sea level curve for northern Belize during the last 6100 yr, based on uncalibrated radiocarbon dates of buried mangrove peats (new data and data from Pusey, 1975), and shallow-buried dolomite crusts on peritidal flats on Ambergris Cay (from Mazzullo et al., 1987). Error bars for individual dated samples indicated; dates based on half-life of 5570 yr (from Geochron Laboratories, Krueger Enterprises).

vertical construction of 0.5 m/100 yr is indicated for Elmer Reef. These construction rates (0.3–0.5 m/100 yr) are within the range of values reported for patch reefs on the southern Belize shelf, which are generally lower than those of Holocene platform margin reefs (Fig. 7). We can not estimate rates of lateral accretion of the reef because we were able to take only one core through it. However, work in progress on other reefs in Mexico Rocks is attempting to resolve this matter.

Rate of accumulation of sediment surrounding Elmer Reef, based on a maximum thickness of 20 cm, is 0.05 m/100 yr, and is comparable to that reported by Halley et al. (1977) for sediments surrounding Boo Bee patch reef in southern Belize (0.4–0.5 m/100 yr). The order of magnitude difference between accumulation rates of patch reef and off-reef deposits in the study area is similar to that of platform reef and lagoonal accumulation rates in Holocene sediments in Belize (Purdy, 1974a).

Relationship to Sea Level and Mode of Growth

Sea level on the northern Belize shelf stood about 4.9 m below present stand at 6100 yr BP (Pusey, 1975), and reached present stand about 1000 yr BP (Fig. 8). There is no evidence on the northern Belize shelf of sea levels lower or higher than present in the last 1000 yr. Hence, Elmer Reef has developed a shallow water (2.5 m) during the last 420 yr or so, in a static sea level setting, during which time the reef grew rapidly to near sea level. The undated 0.19 m-thick sediment section beneath the dated coral in the core (Fig. 5) was deposited on top of the Pleistocene limestone which is at a depth of 2.3–2.5 m below sea level. Inundation of the Pleistocene limestone here occurred about 4500 yr ago, and sea level had risen to 2.3 m below present stand about 4400 yr ago (Fig. 8). Hence, initiation of patch reef growth apparently lagged by as much as 4100 yr after initial transgression, probably as a result of environmental conditions not conducive to coral growth (Schlager, 1981). As is the case with many patch reefs in southern Belize (Purdy, 1974a, b; Purdy et al., 1975; Halley et al., 1977; Westphall, 1986), Elmer Reef was initiated on an underlying topographic high, albeit a subtle one.

Lateral rather than vertical accretion appears to be the dominant mode of growth of Elmer Reef and other patch reefs in Mexico Rocks. This suggestion is supported by the observation that individual, closely spaced reefs throughout Mexico Rocks typically have grown to near sea level, and then have coalesced to form larger, composite patch reefs (Fig. 2A). Such a growth mode likely is a response to the lack of accommodation space, where vertical growth is limited by shallow water under static sea level conditions. Hence, Elmer Reef and other patch reefs in the study area do not fit readily into the "keep-up", "catch-up", or "give-up" classification proposed by Neumann and Macintyre (1985), which describes reef growth in transgressive situations only. We suggest the use of the term "expansion reef" to refer to a dominant lateral mode of patch reef growth in static sea level settings in shallow water environments. Lateral accretion is known to be occurring in modern reefs, under relatively static sea level conditions of the present itme, that have either kept up with or have caught up to Holocene sea level rise (Davies and Kinsey, 1977; Schlager, 1981; Davies and Hopley, 1983; Neumann and Macintyre, 1985).

In contrast, many patch reefs on the southern Belize shelf were formed initially in relatively deep water (20–35 m: Wantland and Pusey, 1971; York, 1971; Purdy et al., 1975; Miller and Macintyre, 1977; Westphall, 1986), or began to grow in shallow water and are now surrounded by deep water (Halley et al., 1977). Because growth of these patch reefs began several thousands of years ago, they have been affected by Holocene sea level rise (Purdy, 1974a, b). Accordingly, mainly catch-up and keep-up reefs rather than expansion reefs have developed, although under present static sea level some of these patch reefs are beginning to accrete laterally. The Channel Cay patch reef complex, for example, is dominantly a catch-up reef, with some component of lateral accretion, that began to grow about 3300 yr ago (Westphall and Ginsburg, 1984; Westphall, 1986). Boo Bee patch reef was initiated about 8000 yr ago, and appears to be a keep-up reef (Halley et al., 1977).

Purdy (1974a, b) provided little information on growth modes of the large patch reefs in southern Belize which he studied. According to him, however, these reefs began to grow 4000–6700 yr ago, and at least one of them (Laughing Bird Cay) appears to be a catch-up reef (see descriptions of facies in cores through this cay in Wantland and Pusey, 1971, p. 74–75). Despite different environmental settings and modes of origin (e.g., relationship to sea level), there is no apparent difference in rates of construction between keep-up, catch-up, and expansion type patch reefs in northern and southern Belize (Fig. 7). However, patch reefs in the latter area are thicker and areally more extensive than in northern Belize because: 1) they have been growing for a longer period of time, generally on antecedent topographic highs of larger dimension than in the study area, and; 2) many started in relatively deep water, and hence there was greater accommodation for vertical growth than on the northern shelf. The net result is that southern patch reefs have either caught up or kept up with a sea level rise of as much as 15 m in the last 8000 yr (Halley et al., 1977).

According to Neumann and Macintyre (1985), an internal facies architecture composed of shallow water, framebuilding biota and associated sediments characterizes keep-up reefs which, in turn, indicates deposition in transgressive settings. The stratigraphy of the core taken through Elmer Reef (Fig. 5), however, indicates that its facies architecture is similar to that of many keep-up reefs, for example, Boo Bee patch reef in southern Belize (Halley et al., 1977). Hence, a facies stratigraphy composed entirely of framebuilding corals and associated sediments cannot be used in ancient reefs to imply the existence of keep-up reefs deposited in transgressive settings.

Patch Reef Zonations and Biota

Coral zonation is a major attribute of many modern patch reefs (James, 1983), and Elmer Reef is no exception (Fig. 4). However, similarities as well as differences exist in the specific types of biota between Elmer Reef and some patch reefs on the southern Belize shelf because of their contrasting environmental settings. Wantland and Pusey (1971), York (1971), York and Wantland (1975), Halley et al. (1977), Westphall and Ginsburg (1984), and Westphall (1986) described important biotic attributes of patch reefs in central portions of the southern Belize shelf, discussed below.

Patch reefs in southern Belize are developed in a high-energy environment, and generally are surrounded by deep water. They contain a diverse coral community that is dominated by *Acropora palmata* and associated *Montastrea annularis* and *Diploria* on their windward sides, and locally on their tops (e.g., on Boo Bee reef: Halley et al., 1977), and also on their leeward sides when the reefs adjoin deep intra-shelf channels. *Acropora cervicornis* typically occurs in sheltered areas behind these reefs. Coral communities dominated by *Porites, Montastrea, Diploria,* and *Manicina,* associated with *Neogoniolithon,* occur in the interiors of many of these patch reefs (Westphall, 1986). In contrast, these biota are not the major reef builders on Elmer Reef, which instead, is dominated by *Montastrea annularis.* Except for several patch reefs on Glovers Atoll (Wallace and Scafersman, 1977), the dominance of this coral as a major patch reef builder is unique in Belize. Wallace and Schafersman (1977) suggested that the dominance of *Montastrea* in some patch reefs on Glovers Atoll is due to the fact that they represent a mature stage of recolonization following the catastrophic demise of coral communities dominated by *Acropora.* However, they did not provide any core data with which to substantiate this contention. The dominance of *M. annularis* on Elmer Reef clearly is not explained by the model proposed by Wallace and Schafersman (1977) because this coral occurs throughout the core to the virtual exclusion of other coral genera. Instead, the dominance of *Montastrea* and the absence of *A. palmata* here likely reflects environmental controls on their distribution. In Holocene reefs in Belize and elsewhere, *Montastrea* is more common in somewhat less energetic environments, such as exist in the study area, than *A. palmata* which generally favors higher-energy environments along reef crests (Wantland and Pusey, 1971; Miller and Macintyre, 1977). In southern Belize, *A. palmata* is abundant in shelf patch reefs because high energy conditions prevail due to wind-generated currents across the wide platform and the presence of the deep Victoria Channel which funnels currents into adjoining shallower water areas (Wantland and Pusey, 1971; Miller and Macintyre, 1977). As noted above, however, *A. palmata* does occur on some patch reefs in Mexico Rocks, although its distribution on and relative contribution to these reefs have yet to be studied. The occurrence of *Acropora cervicornis*-dominated communities along the shallow-water leeward and windward flanks of Elmer Reef is similar to their occurrence in protected environments around patch reefs in southern Belize.

CONCLUSIONS

Elmer Reef is a Holocene coral patch reef representative of the many patch reefs that occur in the Mexico Rocks complex in northern Belize. It was initiated on a topographic high on the underlying Pleistocene limestone bedrock, and has grown in a shallow water (2.5 m), moderate-energy environment during the last 420 yr, in a static sea level setting. Pronounced coral zonation is evident across Elmer Reef as it is across many patch reefs on the southern Belize shelf. However, some differences in specific coral taxa make this patch reef somewhat unique. *Montastrea annularis* dominates on Elmer Reef, in contrast to the *Acropora palmata-Diploria-Montastrea-Porites-Manicina* assemblage typical of southern shelf patch reefs. Associated biota on Elmer Reef include *Diploria, Agaricia, Porites,* octacorals, calcareous algae, *Homotrema, Lithothamnion,* sponges, and worms, and there is somewhat greater biotic diversity on its leeward side relative to its windward side. As in southern shelf patch reefs, *Acropora cervicornis*-dominated communities flank the reef, although they are better developed along its leeward flanks in somewhat protected, lower-energy environments. The extant patch reef, as well as older Holocene patch reef facies identified in a core, are extensively biodegraded. Syndepositional marine cementation is dominantly by fibrous aragonite, with minor bladed high-magnesium calcite, that partially occludes primary porosity throughout the patch reef section.

Rates of vertical construction of Elmer Reef range from 0.3–0.5 m/100 yr, and are comparable to those of patch reefs on the southern Belize shelf. Dominant mode of growth of this northern shelf reef, however, appears to be one of lateral rather than vertical accretion because of its initial development in shallow water and growth in a static sea level setting. Internal facies architecture of Elmer Reef, composed of a section dominated by framebuilding corals and associated sediments, mimics that of keep-up reefs in southern Belize deposited in deeper water in a transgressive setting.

ACKNOWLEDGMENTS

The following sources of funding for support of this study are gratefully acknowledged: American Association of Petroleum Geologists for a Grant-in-Aid of Research, and a Federal Indian Education Bureau Fellowship Award, both to Anderson-Underwood; Colin McMillan and Jim Manatt, Permian Exploration Corporation, Roswell, New Mexico, and Robert Leibrock Jr., Amerind Oil Company, Midland, Texas, for support of field research; Dr. A.M. Reid, Geological Consultant, Midland, Texas, for funding the ^{14}C date. We thank two anonymous PALAIOS reviewers for their comments on this manuscript.

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ACCEPTED JANUARY 6, 1992