

Environmental Setting of Holocene Sabellariid Worm Reefs, Northern Belize

C.D. BURKE,
S.J. MAZZULLO,
W.D. BISCHOFF,
R.K. DUNN¹
Department of Geology,
Wichita State University,
Wichita, KS 67208

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Communities of sabellariid worms (Polychaeta) occur as areally discontinuous, unlithified reefs on an irregular depositional topography of Holocene and older sediments at the mouth of the Northern River Lagoon, Belize, Central America. They are found in nearshore marine, moderate energy, tidally influenced environments of normal to low salinity. These colonies, as much as 30 cm thick, are composed of dense thickets of agglutinated worm tubes (1.0 mm diameter, 3.0 cm length) that trap and bind sand- to silt-sized bioclastic debris, microorganisms, and micrite. Worm tube density in these communities averages 30 tubes cm⁻².

Based upon radiocarbon dating of peat deposits, and analyses of sediment cores, the worm reefs have flourished in the study area for at least 5100 years. This time span corresponds with sea level rise and transgression of the northern Belize coast. Initially, worms colonized drowned levees. Once established, the worm reefs stabilized these levees so that their original orientation normal to shore line is preserved today. Holocene paleoenvironments, interpreted from fossil assemblages

of ostracodes and foraminifera, were constant over the last 5100 years, and were characterized by fluctuating salinity which apparently was advantageous for the development of tube-building worms.

Sabellariid tubes in older Holocene deposits are clearly recognizable in the study area, and the existence of fossil reefs is readily indicated. Likewise, fossil worm reefs in the stratigraphic record may possibly be identified by the presence of rocks containing circular to longitudinal ichnofossils composed of agglutinated bioclasts surrounding circular openings.

INTRODUCTION

Long recognized as a component of modern intertidal communities, polychaete worms of the family Sabellariidae are among the most important "reef-building" agents in cold and warm water coastal environments. Although they span the latitude range from 53° S and 72° N (Kirtley and Tanner, 1968), they are concentrated in temperate to subtropical zones (Richter, 1921; Multer and Milliman, 1967; Gram, 1968; Wells, 1970; Wilson, 1971, 1974; Gore et al., 1978; Posey et al., 1984; Gore, 1986; Carey, 1987; Main and Nelson, 1988). The family Sabellariidae consists of at least 6 extant genera encompassing more than 50 species, approximately 20 of which are gregarious and construct reefs. Modern unlithified and partially consolidated reefs built by sabellariid worms occur most commonly in intertidal environments (Kirtley and Tanner, 1968; Pawlik, 1988). These reefs, composed of dense accumulations of

agglutinated worm tubes and associated sediments, form laterally extensive complexes along shorelines. In southeastern Florida, they extend as patches for 320 km along the shore (Kirtley and Tanner, 1968; Multer, 1977). The presence of such reefs may influence shoreline development, and they commonly serve as relatively stable habitats for other organisms in otherwise inhospitable environments (Gore et al., 1978; Carey, 1987).

Sabellariid worm reefs were discovered recently in Chetumal Bay in northern Belize (Fig. 1), where their presence has not been described previously. Modern, areally discontinuous, unlithified reefs occur in nearshore intertidal and shallow subtidal environments at Northern River Lagoon, Belize (Fig. 1). Reefs also are inferred in subsurface Holocene deposits here that are as much as 5100 years old. This study describes the occurrence of these Holocene, tropical-region reefs in terms of their effects on and response to coastline development.

LOCATION AND METHODS OF STUDY

The climate of northern Belize is humid-tropical with mean annual water temperature and precipitation of 29° C and 127–152 cm, respectively (Purdy et al., 1975). Chetumal Bay is a large, shallow (2 m or less) back-reef lagoon (Fig. 1) affected by semi-diurnal tidal fluctuations of less than 0.5 m. Salinities in the bay vary seasonally from 19 to 41‰. During rainy seasons (June–July and November–March) low-salinity waters in the bay often are turbid because of the presence of suspended organic matter and clay-size carbonate and siliciclastic detritus derived from the adjoining mainland. During drier seasons the water is mostly clear and salinity varies from about 30 to 41‰. Easterly trade winds persist during the summer and alternate with northerly winds during the winter months. Holocene sediments in Chetumal Bay are composed wholly of calcium carbonate skeletal debris deposited on limestone bedrock identified region-

¹ Present address: Department of Geology, University of Delaware, Newark, DE 19716.

ally as Pleistocene in age (Ebanks, 1975; Pusey, 1975).

Thickness of Holocene sediments along the mainland coast and in some extensive mudbanks in the bay (e.g., Bulkhead Shoals; Fig. 1) varies between 3.0–3.7 m, whereas other areas are covered by only a veneer of sediment. These sediments are composed mostly of muddy sands and sandy muds dominated by miliolid and rotalid foraminifera, molluscs, and peloids, with minor admixture of terrigenous siliciclastic detritus. Worm reefs are found in the intertidal and shallow subtidal (0.5 m depths) zones at the entrance to Northern River Lagoon along the mainland coast of Chetumal Bay (Fig. 2). They occur as a series of discontinuous reefs along two topographic highs oriented normal to the shoreline and separated by a navigable tidal channel that is 1.0 m deep (Fig. 2). They are somewhat protected from storm surges by a broad, shallow (0.5 m) tidal shoal to the south-southeast (Fig. 2).

The worm reefs were examined and sampled in April 1989, 1990, and 1991 and in January 1991, periods of time corresponding to dry summer and rainy winter seasons. Holocene sediment thickness on and around the reefs was measured by probing to bedrock with a steel rebar. Four cores of Holocene unconsolidated sediments in the study area (Fig. 2) were recovered with a coring device constructed of PVC pipe. In the laboratory, the core samples were rinsed in a solution of Calgon and then distilled water and their textural compositions determined by wet-sieving. Particle types composing individual sediment size fractions (gravel, sand, and coarse silt) were tabulated. A sample of buried mangrove peat recovered in core 4 was sent to Geochron Laboratories in Cambridge, Massachusetts, for dating by the radiocarbon method.

Samples of ambient surface water collected during each field visit were analyzed immediately for temperature, salinity, and pH. Samples of worm tube colonies from reef surfaces were collected and preserved immediately in 95% ethanol. The worm

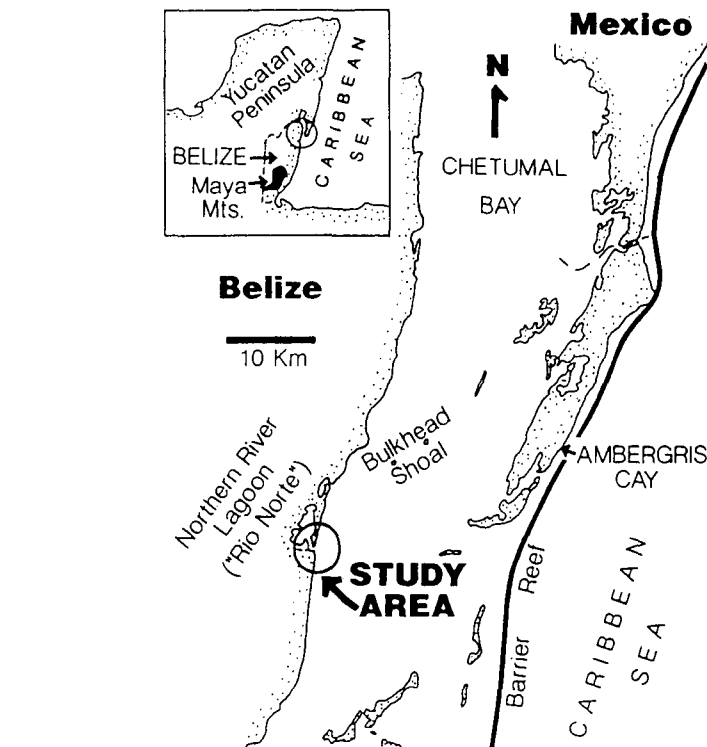


FIGURE 1—Locality map of study area in Belize. Note location of Maya Mountains on mainland Belize (inset map).

tubes were examined thereafter to identify the types of living organisms present. Population densities of worm tubes were measured in the field on several representative traverses across the reef trends.

REEF MORPHOLOGY AND ECOLOGY

Modern sabellariid reefs in the study area (Fig. 3A) inhabit a near-shore, shallow subtidal and intertidal environment whose salinity fluctuates seasonally from 2‰ during rainy months due to heavy river discharge, to 38‰ in drier months. The reefs cap topographic highs that stand about 1.0 m above the channel floor (Fig. 3A). They are elliptical in plan view, and average approximately 3.0 × 5.0 m in dimension. Reef communities are about 30 cm thick, and occur as dense thickets of worm tubes and admixed sandy carbonate muds. Worm tube density averages 30 tubes cm⁻².

Unlike some sabellariid reefs, Belizean worm reefs are unconsolidated

in that tubes do not share walls. In other areas in the world, however, worm tubes lithify and form 'honeycomb' rocks over time either by cementing tubes to neighboring tubes or by replacement of proteinaceous binding material in the tube walls by calcium carbonate (Kirtley and Tanner, 1968; Wells, 1970; Kirtley, 1971; Wilson, 1971, 1974). In Belize, the worm colonies consist of separate, unbranched, vertical, relatively straight but flexible tubes that average 3.0 cm in length and 1.0 mm in diameter (Fig. 3B). No modern, lithified reef rock has been found in the study area, and only concentrations of individual tubes are preserved in the subsurface, indicating that older reefs also were not consolidated. Perhaps this lack of reef lithification is a result of species-specific growth and dispersion patterns or relationship to the sediment.

Modern and buried worm tubes typically are pigmented by alternating laminae of light colored, skeletal carbonate grains and dark colored,

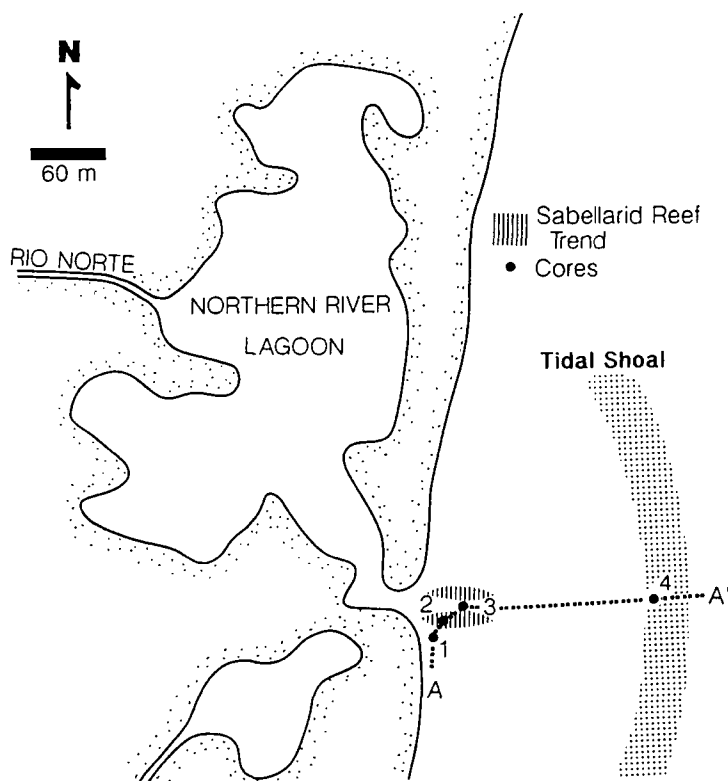


FIGURE 2—Locality map of entrance to Northern River Lagoon, showing: orientation of worm reef trends, locations of cores, and cross section of Figure 4.

organic matter-rich rings (Fig. 3B) that represent annular growth increments. Sabellariid larvae construct tubes once they settle from the water column on suitable, hard substrate. During construction the worm filters and traps silt and sand-sized skeletal particles and binds them with a protein-mucous compound. This mixture is molded into a collar located below the head and then attached to the top of the tube as the worm rotates inside, thus producing the annular bands. SEM examination reveals that the tubes are agglutinated rather than cemented by calcium carbonate, and consist of whole and comminuted, sand- and silt-sized skeletal fragments including diatom frustules, miliolid and rotalid tests, ostracode valves, and sponge spicules (Fig. 3C).

Sabellariid worms were not found in the tubes during previous visits to the reefs in April and January. However, worms must colonize the reefs at other times of the year because

damage done to the reefs during coring in April 1989 was found in April 1990 to have been repaired by the growth of new colonies of tubes. According to Carey (1987), periods of dormancy and recolonization of worm reefs are not unusual. Periodic recolonization occurs after breeding seasons as a result of spawning, and both laboratory and field observations suggest that sabellariid spawning may be controlled by seasonal changes in water temperature (Wilson, 1971; Eckelbarger, 1976; Curtis, 1978). Breeding season may also be related to latitude in that populations living in cool waters tend to spawn in the summer, whereas warm-water populations tend to spawn in the winter (Eckelbarger, 1976; Curtis, 1978). Although we are presently uncertain of exactly when spawning and recolonization occur in the study area, our observations suggest that the worms breed sometime between January and March.

Living shrimp, diatoms, and other

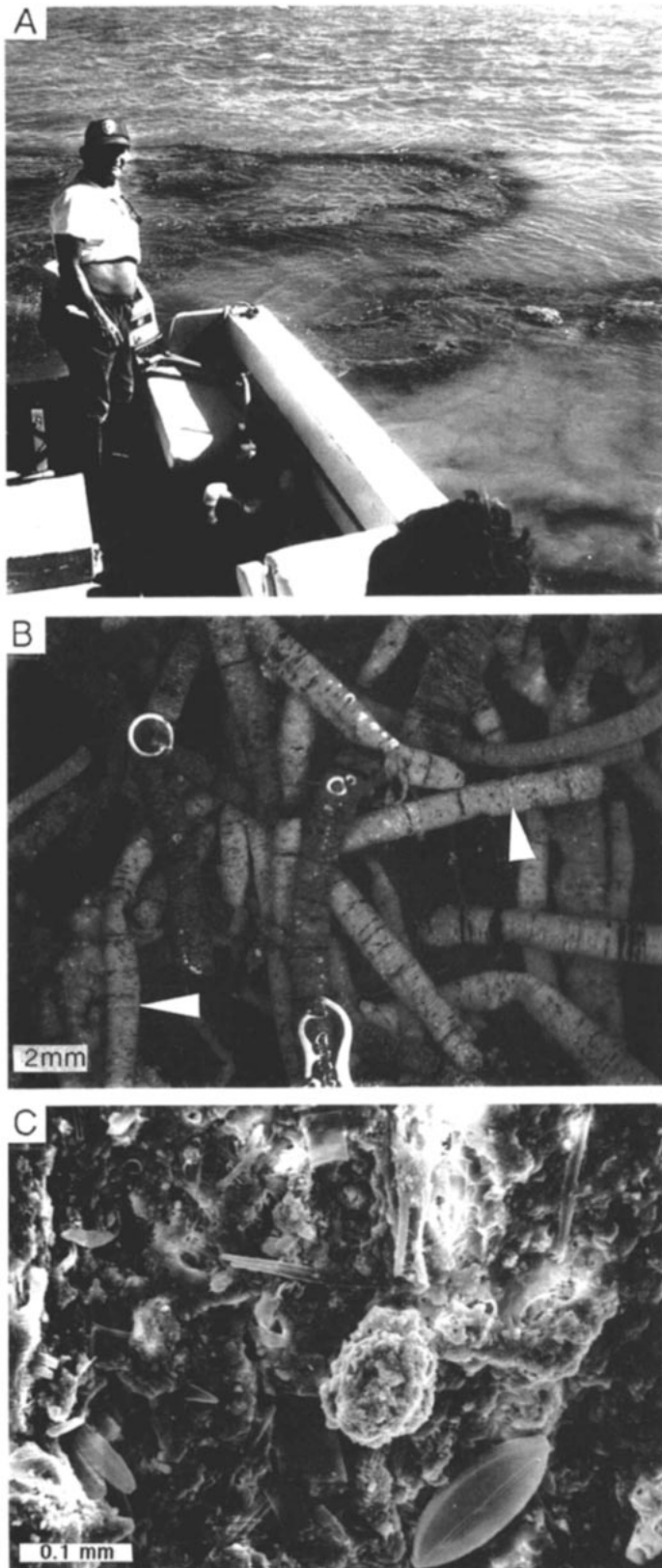
organisms were found in the worm tubes during our field investigations. These organisms probably enter vacated tubes on feeding excursions as well as for shelter. Gore et al. (1978) noted that trophic partitioning among macrocrustaceans exists within stable sabellariid communities. Furthermore, community diversity generally is significantly higher in and around worm reefs as compared to other intertidal environments. This higher diversity results because mature reefs provide attachment and shelter sites for organisms that otherwise would not typically be found in such environments. In the stratigraphic record, an increase in fossil diversity and fossilized worm tubes may be a useful guide to the recognition of former reef sites in otherwise low-diversity, nearshore marine deposits.

OLDER HOLOCENE SABELLARIID REEFS

Sedimentologic Framework

Local concentrations of sabellariid worm tubes are found in the subsurface Holocene section in cores 1–3 in the study area (Fig. 4). They are interpreted as either buried sabellariid reefs or detritus derived therefrom. Carbonate sediments compose the bulk of the Holocene section recovered here, which is about 3.5 m thick (Fig. 4). The lithology of the basal 0.8 m of sediment directly overlying the Pleistocene limestone section is uncertain, however, because of lack of sample recovery. Carbonate sediments recovered consist of unconsolidated muddy sands and sandy muds with some admixed quartz and feldspar sand and gravel-sized clasts of older limestone (Fig. 4). The Holocene sediments are interpreted to represent nearshore, shallow marine and intertidal deposits of schizohaline (fresh to slightly hypersaline) environments. Similar environments exist today throughout northern Belize (Pusey, 1975; Wantland, 1975).

A prominent lens of siliciclastic sand was encountered at a subsea depth of 1.8 to 2.4 m in core 3 (Fig. 4) located within the present-day tid-



al channel (Fig. 2). The sand is composed dominantly of quartz and accessory feldspar, mica, and chert grains derived from erosion of the Maya Mountains to the south (Fig. 1). This sand unit is interpreted as a tidal channel or fluvial deposit. Similar deposits of siliciclastic sand amidst nearshore carbonate sediments are described from along the mainland Belizean coast (High, 1975; Purdy et al., 1975). The sand and underlying carbonate sediments in core 3 contain abundant discoidal crystals of gypsum as much as 2.0 cm in length. We and others (Ebanks, 1975; Pusey, 1975; Mazzullo and Reid, 1987) have not found any evidence of evaporite deposition and hypersalinity in modern or older Holocene sediments anywhere in Belize. Therefore, this gypsum is not believed to have formed in a hypersaline depositional environment. Instead, we suspect it is a later diagenetic phase that possibly formed as a consequence of oxidation of sulfides (perhaps pyrite, which occurs in the sands) in the presence of oxygen- and bicarbonate-rich interstitial fluids (cf., Bain, 1990). Alternatively, it could have formed by reactions of Ca-rich interstitial fluids and dissolved sulfate (cf., Siesser and Rogers, 1976). In any event, the environment of reef growth was schizohaline, but did not reach levels of hypersalinity that would have induced evaporite deposition.

According to Mazzullo and Reid (1987), initial inundation of the study area during the Flandrian transgression occurred approximately 5500 BP when sea level was approximately 3.5 m below present stand. We were unable to recover sediment from the top of the Pleistocene limestone to the base of the peat or equivalent unit

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FIGURE 3—A) View of sabellariid reefs at low tide, view to the east. The channel separating the levee ridges on which the reefs are located is to the left of the boat. [Tomas Paz for scale.] **B)** Photograph of un lithified worm tubes from modern reef. Note annular rings (arrows) and color banding on tubes. **C)** SEM micrograph of tube wall showing agglutinated skeletal fragments.

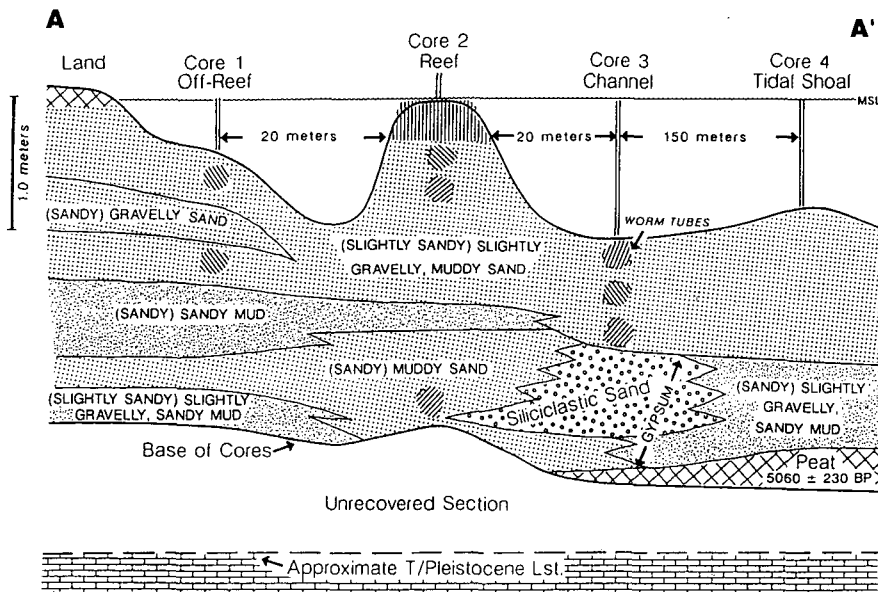


FIGURE 4—Cross section of modern and older Holocene sedimentary facies in the study area. Note locations where abundant worm tubes were found in the cores.

that occurs at 0.8 m above the Pleistocene (Fig. 4). This unrecovered section, however, likely represents an initial transgressive and then aggradational nearshore sequence because it is capped by peritidal mangrove peat composed dominantly of *Rhizophora mangle* (Fig. 4). This peat was dated by the ^{14}C method at 5060 ± 230 BP (^{13}C -corrected). Insofar as mangrove peat accumulates essentially at sea level, its occurrence indicates that sea level in the study area was approximately 3 m below present stand about 5060 BP. This calculation is in agreement with the sea level curve for northern Belize constructed by Mazzullo and Reid (1987). Hence, average rate of sedimentation of this unrecovered unit and the peat is about 2.0 m/1000 yrs, and average rate of sea level rise at this time was 1.25 m/1000 yrs. The section overlying the peat likewise consists of coastal marine facies deposited during ensuing decelerated sea level rise (0.75 m/1000 yrs) which attained present stand about 1000 BP. After that time there is local evidence of coastal erosion and shoreline retreat throughout northern Belize (Mazzullo and Reid, 1987). In fact, the topographic highs that are the substrate for modern sabel-

lariid reef growth in the study area are believed to be remnants of modern coastal erosion (Mazzullo et al., 1990). Because they adjoin a modern and ancient (sand-filled) channel or river, these topographic highs likely are relict levees that may have been preserved throughout the Holocene by the stabilizing presence of the worm reefs. Average rate of Holocene coastal sedimentation in the study area over the last 5100 years, assuming a maximum sediment thickness above the peat of 2.7 m, is about 0.5 m/1000 yrs.

The presence of siliciclastics in the tidal or fluvial channel above the peat (Fig. 4, core 3) indicates that rivers draining the Maya Mountains were discharging along the southern and northern mainland coast of Belize during the Holocene. Stream piracy and eventual southern diversion of streams is known to have occurred sometime during the Holocene (Purdy et al., 1975). Cored sediments (Fig. 4) suggest that such diversion may have occurred about 4000–5000 BP because siliciclastic sediments that overlie the peat layer pass upward to dominantly carbonate sediments in the remainder of the cores. Except for the presence of reworked silici-

clastics, modern coastal deposits along northern Belize, including extant tidal channels, are dominated by calcium carbonate sediments. In contrast, mixed siliciclastic-carbonate deposits presently are accumulating only in southern coastal Belize (Purdy et al., 1975). Sabellariid worm reefs developed in the coastal setting of the study area over the last 5100 years (Figs. 2, 4). The modern reefs apparently have stabilized relict levee ridges on which they occur from further coastal erosion.

Paleontologic Framework

Generic composition and diversity-dominance patterns of fossil foraminifera and ostracodes substantiate paleoenvironmental interpretations of the older Holocene section based on sedimentologic criteria. In cored sediments, fossil foraminiferan genera include *Ammonia*, *Criboelphidium*, *Heterellina*, *Miliolinella*, *Quinqueloculina*, *Triloculina*, *Archaias angulatis*, *Peneroplis* sp., and other genera listed in Wantland (1975). These same foraminifera occur in Chetumal Bay today, and are indicative of nearshore marine environments of fluctuating salinity (Wantland, 1975), as are associated molluscs such as *Chione cancellata*, *Anomalocardia* sp. and cerithid and batillariid gastropods. Ostracode genera in the buried Holocene section consist of a variety of taxa that are also indicative of similar paleoenvironments (Teeter, 1975). Genera that represent this variable-salinity, shallow water ostracode biofacies include, for example, *Aurila*, *Megacythere*, *Paracyprina*, *Perissocytheridea*, *Cyprideis* and *Pteratocytheridea* (*Haplocytheridea* of Teeter, 1975). Ostracode assemblages are generally similar in taxonomic composition in the Holocene section in all cores, indicating that environmental factors similar to those existing presently dominated throughout much of the past. However, the total number of genera decline with depth in seaward cores 3 and 4 (Fig. 5). This decrease suggests that these older Holocene deposits were more restricted in the past than in more recent times, i.e.,

when sea level was lower, shoreline farther seaward, and rivers were seasonally discharging more fresh water into the marine environment. Alternatively, the decrease in the number of genera in core 3 (Fig. 5), in the siliciclastic section (Fig. 4), may have resulted from the dissolution of shells, perhaps accompanying the formation of diagenetic gypsum in this portion of the sediments. Some genera, such as *Paracyprina*, disappear with depth in the cores. This genus is found today living in nearshore environments where salinity is as low as 2‰ during rainy seasons. It is found in only the upper part of the buried Holocene section, in association with other euryhaline taxa, in cores 1 and 2, which represent the most nearshore paleoenvironments in the study area (Fig. 2). Its absence deeper in the cores is not believed to be the result of different paleoenvironments during the early Holocene, but rather, because its thin shell likely was dissolved by interstitial fluids.

SUMMARY AND CONCLUSIONS

Sedimentology and analysis of generic diversity and dominance of fossil assemblages from Holocene sediments in the study area indicate that sabellariid worm reefs have grown over the last 5100 years in shallow, nearshore environments of variable salinity. Such an environment was ideal for the development and maintenance of these reefs. Some researchers contend that worm reefs require such relatively harsh intertidal conditions for successful development (Gore et al., 1978; Gore, 1986). However, most agree that the general factors contributing to their geographical distribution include reproductive fecundity and ample supply of food and sediments with which to build their tubes (Richter, 1921; Multer and Milliman, 1967; Gram, 1968; Kirtley and Tanner, 1968; Wells, 1970; Wilson, 1971, 1974; Main and Carey, 1987; Nelson, 1988). The presence of worm reefs throughout the Holocene in the study area indicates their reproductive success through time. Initial development of the worm

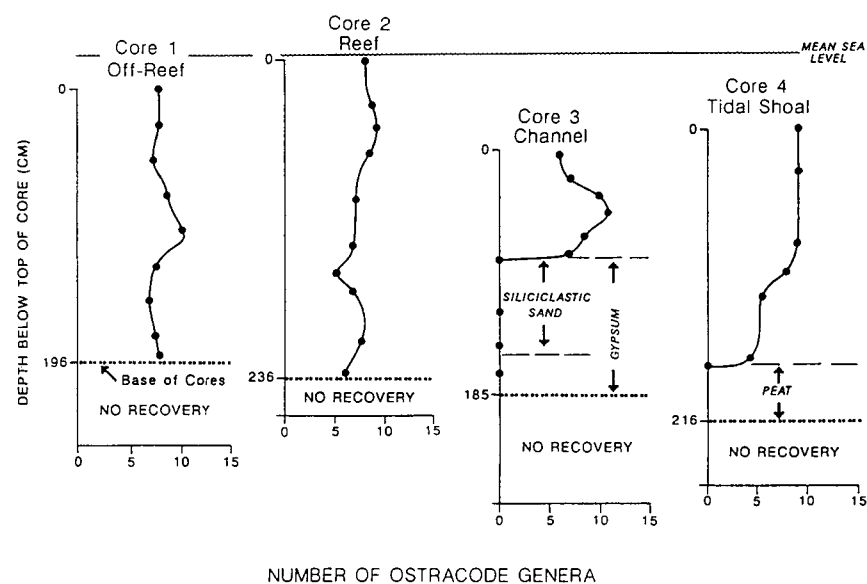


FIGURE 5—Down-core variation in abundances of ostracode genera that include *Aurila*, *Caudities*, *Cytheromorpha*, *Loxochonca*, *Cytherura*, *Megacythere*, *Paracyprina*, *Perissocytheridea*, *Cyprideis*, *Pteratocytheridea*, *Triangulocypris*, and *Xestoleberis*. Note decrease in ostracode abundance in cores 3 and 4. Sections hung on positions of tops of cores with respect to sea level.

reefs generally requires firm substrates (Wilson, 1971, 1974; Eckelbarger, 1976; Pawlik, 1988). The modern reefs in the study area colonized drowned levees that acted as firm substrates. Continual recolonization of these reefs probably is facilitated by the prior presence of adult worms insofar as existing colonized areas have a greater probability of attracting new larvae than do areas devoid of worms (Pawlik, 1988). Once settled, attached larvae metamorphose and construct new tubes. Food and sediment is easily supplied to the worms by wave and current activity.

As soft-bodied organisms, the preservation potential of worms generally is precluded. However, sabellariid tubes are preserved in older Holocene deposits in the study area, and the existence of fossil reefs is therefore indicated. Likewise, fossil worm reefs in the stratigraphic record possibly may be identified by the presence of rocks containing circular to longitudinal ichnofossils composed of agglutinated bioclasts surrounding circular openings. On the basis of tube morphology, for example, Richter (1921) speculated that

sabellariid worm tubes may have some affinity to the enigmatic *Skolithos* that have similar tube characteristics and are common in many lower Paleozoic rocks. An unlikely, yet intriguing example of possible fossil sabellariid recognition is *Zoophycos*. On the basis of prostomium morphology, the anterior portion of the worm that includes the oral aperture, Plicka (1968) classified the ichnofossil *Zoophycos* as having origins in sabellariid worms. The spiral trace fossil purportedly represents imprints of the feeding fans of fossil sabellariids.

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