PROCEEDINGS OF THE 11TH SYMPOSIUM ON THE GEOLOGY OF THE BAHAMAS AND OTHER CARBONATE REGIONS

Edited by
Ronald D. Lewis and Bruce C. Panuska

Production Editor:
Ronald D. Lewis

Gerace Research Center
San Salvador, Bahamas
2004

Front Cover: Close-up view of a patch-reef coral head in Grahams Harbor, north of Dump Reef. As shown here, Caribbean shallow-water reefs have declined since the mid-1980s and are now largely overgrown by fleshy green macroalgae and a variety of encrusting organisms. See Curran et al., "Shallow-water reefs in transition," this volume, p. 13. Photograph by Ron Lewis.

Back Cover: Dr. A. Conrad Neumann, University of North Carolina, Chapel Hill, NC, Keynote Speaker for the 11th Symposium and author of "Cement loading: A carbonate retrospective," this volume, p. xii. Photograph by Mark Boardman.

ENVIRONMENTAL INDICATOR PROXIES FROM A MID-HOLOCENE CORAL REEF, ENRIQUILLO VALLEY, DOMINICAN REPUBLIC

Gala M. M. Guerard
Department of Geology
Smith College
Northampton, MA 01063

Lisa Greer[1]
Department of Geosciences
Pennsylvania State University
University Park, PA 16802
greerl@wlu.edu

H. Allen Curran
Department of Geology
Smith College
Northampton, MA 01063

ABSTRACT

The excellently preserved fossil reef deposits in the Enriquillo Valley, southwestern Dominican Republic, reveal a complex history of alternating salinities and environments including a fringing coral reef community that thrived during mid Holocene time, from at least 7.2 to 5.2 ka before present. Stratigraphic, microfossil, and isotopic data were gathered from four measured sections of the Enriquillo Valley deposits. These indicators of environmental conditions reveal rapid transition from a normal marine environment to one of highly variable salinity.

Reefal beds are exposed in gullies located around the margins of present-day Lago Enriquillo, at elevations ranging from approximately 3 to 30 meters below present sea level (bsl). Hemispherical, tufa-coated serpulid worm mounds commonly cap the sequences, with their tops reaching elevations of up to 2.3 m above present sea level. Serpulid layers 1-3 cm thick are also found within the reef sequences, first occurring at an elevation of 18.5 m bsl. Our data suggest that the serpulid layers and mounds formed under predominantly brackish water conditions, with the stratigraphy of the layers and mounds indicating multiple transitions in the salinity history of the area. Stable carbon and oxygen isotope data from samples of serpulids encrusted on corals, serpulid aggregate layers, and serpulid mounds, indicate a sharp decrease in salinity following the decline of the fringing coral reef (~5.2 to 4 ka).

The salinity changes are mirrored in the microfossil assemblages found in the reefal deposits. Marine deposits in the lower part of the sequence are dominated by a microfossil assemblage indicative of normal marine conditions (ostracodes: *Bairdia* sp. and trachyleberidids; foraminifera: *Pyrgo* sp. and *Triloculina* sp.). Microfossil assemblages from deposits closer to the top of the section indicate brackish conditions (ostracodes: *Cypria* sp., *Cyprideis* sp.; foraminifera: *Ammonia beccarii*; hydrobiid gastropods: *Littoridnops monroensis*; charophytes: *Chara* sp.).

Salinity fluctuations in the paleoembayment seem to have been controlled primarily by the progressive restriction of the mouth of the Enriquillo Seaway. As the rate of sea-level rise slowed in mid to late Holocene time, continued alluvial shedding from the surrounding mountains closed the eastern end of the seaway at 4.2 ka. The Enriquillo Valley received water from the drainage basin of the Rio Yaque del Sur. High levels of precipitation created influxes of isotopically light freshwater and terrestrial carbon

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1. Current address: Department of Geology, Washington and Lee University, Lexington, VA 24450

Figure 1. Location of Hispaniola and the Dominican Republic. The island lies southeast of Cuba and is part of the Greater Antilles. Lago Enriquillo is in the southwestern part of the country, near the border with Haiti.

Figure 2. Index map to the Lago Enriquillo area. The principal study site, Abuela Grande gully (AG), is marked with a star.

into the newly formed lake. Arid conditions prevailed after closure of the seaway, resulting in evaporation of the lake to its present level of ~ 42 m bsl.

INTRODUCTION

Beginning with the close of the last glacial stage, global sea level began to rise as polar ice decreased. The resulting rapid marine transgression crossed the shelf-slope break of Hispaniola near Bahía de Neiba in early Holocene time and flooded the Enriquillo Valley (Figure 1). This created a fully marine gulf or seaway connecting the area now occupied by Lago Enriquillo with the sea (Mann et al., 1984; Taylor et al., 1985). Circulation within the seaway became adequate to support coral reef development, and fringing coral reefs flourished along its margins from at least 7.2 to 5.2 ka (Greer, 2001).

During late Holocene time and concurrent with sea level rise, the baselevel of the Rio Yaque del Sur rose, and large amounts of fluvial sediments were dumped at the entry point of the seaway (Mann et al., 1984). As this area became choked with sediment, the greater part of the seaway was cut off. Large serpulid-worm mounds began to form on the dead coral substrates (Curran and Greer, 1998). These mounds occur sporadi-
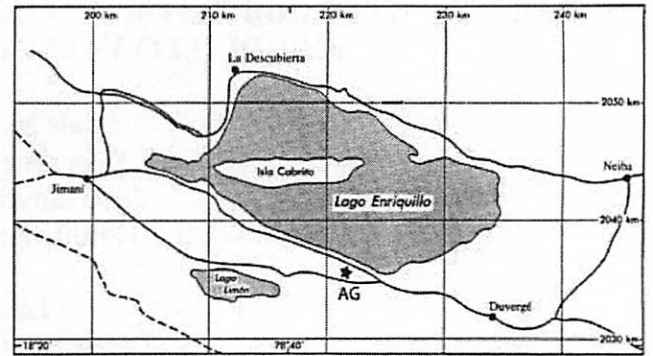
cally around present-day Lago En-riquillo and lie above the fringing coral reef deposits. On steeper slopes, a well-developed two-tiered line of mounds is visible (Mann et al., 1984; Curran and Greer, 1998).

Once the seaway closed, the newly formed Lago Enriquillo began to evaporate to its present level of about 42 m bsl (Figure 2). The lake level fluctuates with annual precipitation and storm events, especially hurricanes, which bring heavy rainfall. Evaporation has exposed the fossil reef sequence in many areas around the lake. The climate of the Enriquillo Valley is semi-arid, and this has aided in the preservation of the reef (Greer and Swart, 1999). Erosional gullies, road cuts, and outwashes permit three-dimensional studies of vertical sections of the reef and reveal thick sequences of corals in growth position. Over 30 species of fossil scleractinian corals were identified from the Holocene sections. The dominant corals are Acropora cervicornis, Agaricia spp., Colpophyllia sp., Montastraea spp., and Siderastrea sidereal; all of which are present in modern Caribbean reefs, as noted and discussed by Stemann and Johnson (1992).

This study presents a detailed look at the stratigraphy of a fossilized mid- to late- Holocene reefal sequence. We have used various paleoenvironmental proxies found in the Enriquillo deposits as evidence for abrupt environmental changes, from normal marine to variable salinity. Knowledge and utilization of such proxies should aid in characterizing similar Quaternary and older deposits elsewhere around the globe.
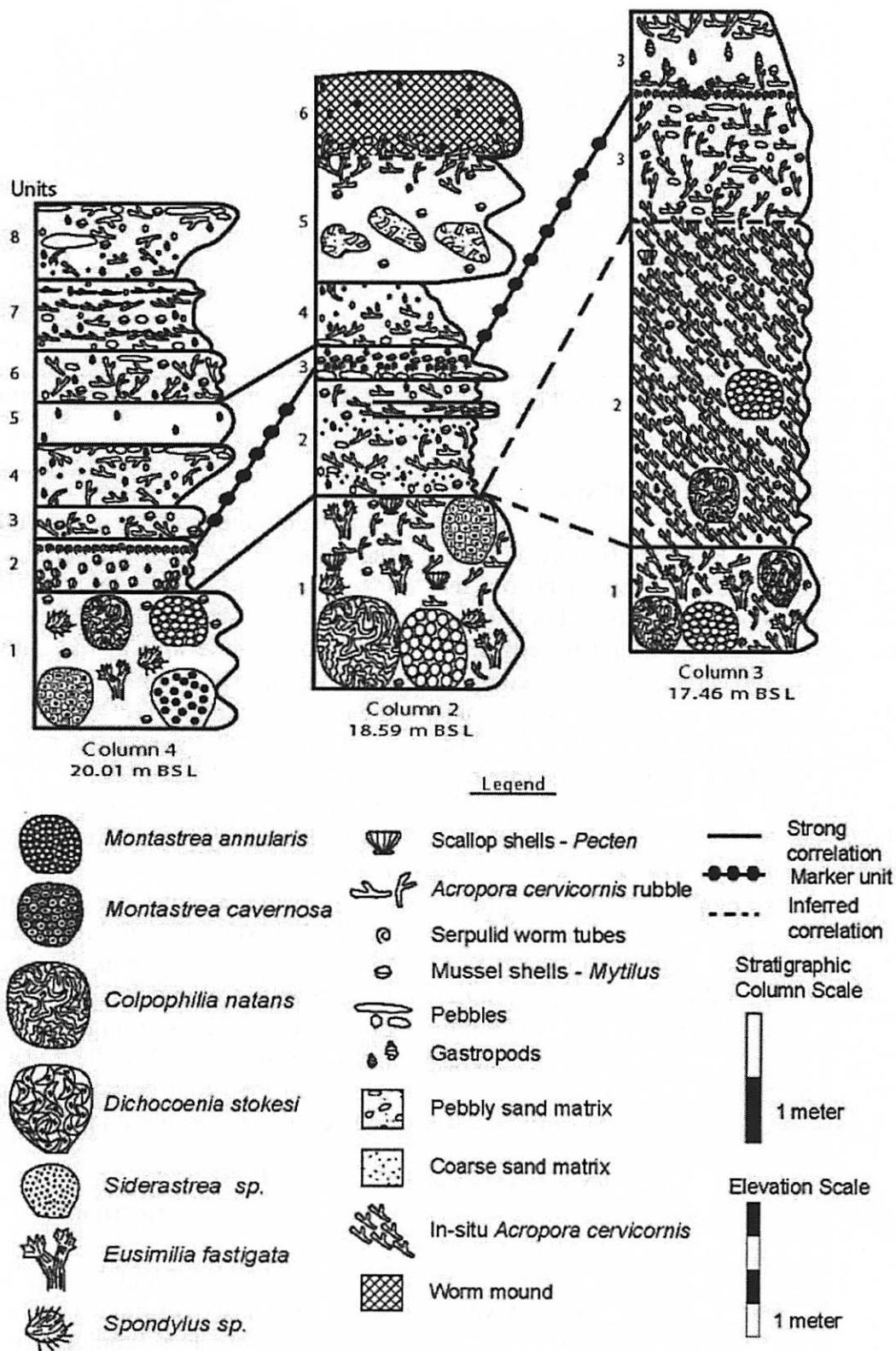
Figure 3. Correlation of stratigraphic sections from the Abuela Grande study area showing strati-
graphic units with major fossils and a key marker unit, which separates the fully marine facies below
from the variable salinity facies above. BSL = elevation below present sea level of bases of the sections.
More complete descriptions of these sections are given in Guerard, 2001.

Stratigraphic Column	In-Situ Corals	Stratigraphic Column	In-Situ Corals
Column 1 Unit 1	Eusimilia fastigiata Montastraea annularis M. cavernosa Siderastrea radians	Column 3 Unit 1	Acropora cervicornis Colpophyllia natans Dichocoenia stokesii Eusimilia fastigiata Montastraea annularis
		Unit 2	Acropora cervicornis Colpophyllia natans Montastraea annularis
Column 2 Unit 1	Acropora cervicornis Colpophyllia natans Eusimilia fastigiata Montastraea annularis M. cavernosa	Column 4 Unit 1	Colpophyllia natans Eusimilia fastigiata Montastraea annularis M. cavernosa

Table1. In-situ *corals found in unit 1, at the base of each stratigraphic section.*

GEOGRAPHIC SETTING

The Dominican Republic (Figure 1) occupies the eastern two-thirds of the island of Hispaniola and is the second largest island in the Caribbean Greater Antilles. The island is geographically and geologically varied and has a complex tectonic history, with four major mountain chains trending approximately northwest to southeast, separated by three extensive valleys, one of which is the Enriquillo Valley (Figures 1, 2). Beginning in the Bahía de Neiba, the Enriquillo Valley trends northwest and extends to the Cul de Sac Valley in Haiti (Lewis et al., 1990). Situated in the lowest part of the valley is Lago Enriquillo, the largest of several lakes that occur in the region. Lago Enriquillo is a saline lake with salinities sometimes exceeding 80 ppt. Conversely, salinities can be greatly reduced by episodic rainfall and flooding from the Rio Yaque del Sur.

SECTIONS STUDIED

Four stratigraphic sections were measured, described, and analyzed in detail for this study. All of the stratigraphic columns are located within the same gully, off the main road from Duvergé to Jimaní, 17.5 km west of the Chief Enriquillo statue found at the intersection with the road to Neiba (Figure 2). The elevations of the columns were obtained using GPS points from a pin located at the base of column 2. Column 1 is located ~3 m below the road cut in the gully. The base of the column is 24 m bsl. Column 2 is ~13 m basinward of the "Abuela Grande" coral, an exceptionally large *Montastraea annularis* colony that nearly blocks the axis of the gully. The base of this column is at 18.6 m bsl. Pin 8216 is located at the base of column 2 (18.4°N, 71.6°W). Column 3 is located 1.5 m upgully from the "Abuela Grande" coral; base of the column is 17.5 m bsl and column 4 is located between columns 1 and 2, 1.4 m downgully from the elevation pin. The base of the column is 20 m bsl.

Figure 3 shows the correlation of units between three of the stratigraphic sections illustrating the sequence as it is found in the Abuela Grande area. Column 1 is not correlated with the others because it is stratigraphically lower. than the other sections. The field data and samples taken from the four sections comprise the major sources of data for this study.

METHODS

The four sections from the Abuela Grande gully were closely examined in the field and sampled in detail. The lithology of the sediment, structure of the coral reef, fossils, and sedimentary features were described and sampled for each stratigraphic unit. Laboratory analyses of the samples took place at both the Rosenstiel School of Marine and Atmospheric Science (RSMAS) of

the University of Miami and at Smith College. At RSMAS, microfossils from washed samples were picked from the 180 micron size fraction. Representative samples of serpulid worm tubes were analyzed for stable isotopes using a Finnigan MAT 251 mass spectrometer. Analytical precision was monitored through analysis of a lab standard, and the carbon and oxygen isotope values are reported relative to the Vienna PeeDee Belemnite (VPDB) standard. Isotopic compositions were corrected for drift using standard methods. Isotopic compositions ($\delta^{18}O$ and $\delta^{13}C$) are reported in per mil (‰) units.

At Smith College, the sample sets were picked for microfossils from the 250 micron and 500 micron size fractions. Two 4x3-inch trays of each sample were prepared for picking. If the sample had an abundance of microfossils, a random sample of 300 microfossils was picked. More commonly, microfossils were sparse, and all microfossils from both trays were picked. Both macro- and microfossils were identified and categorized according to their salinity range as determined from the literature. The paleosalinity of the sample was then assessed. The following paleoecolgic criteria were used to categorize each assemblage: 1) the dominant species and diversity of microfossils found, and 2) the presence or absence of other fossil groups.

IDENTIFICATION OF ENVIRONMENTAL FACIES

Various lines of evidence were used to identify two distinct paleoenvironmental facies in the stratigraphic sections studied. These facies are (1) normal marine beds and (2) beds characterized by serpulid worm aggregates and variable salinities.

Normal Marine Facies

The normal marine facies is defined by a pristinely preserved coral fauna indicative of healthy fringing-reef growth in a normal marine environment. This facies occurs at the base of each of the stratigraphic sections and can be used as a marker for correlation (Figure 3).

Macrofossils

There is a wealth of stratigraphic evidence suggesting fringing coral-reef growth in a normal marine environment. Each of the marine units identified in columns 1-4 contains similar species of *in-situ* corals, indicating a fringing reef environment (Table 1). These corals are largely preserved in growth position and show few signs of mechanical weathering or transport, as would be evidenced by broken or fractured coral pieces, rounded or worn edges, or generally dulled features. The position of these corals and the lack of evidence indicating post-mortem transport signify preservation dominantly in growth position. The bivalves *Chama* sp. and *Spondylus* sp. and serpulid worm tubes are prominent encrusters found on the corals and are excellently preserved, with little breakage or abrasion.

Some of the most spectacular evidence for largely *in-situ* preservation comes from the non-coral macrofossils found in the normal marine units. Whole specimens of small regular echinoids (including articulated parts of the Aristotle's lantern) were found in the basal unit of section 1. In sections 2 and 3, large, articulated Princess clams were found *in situ* (Figure 4). Also found in section 2 was an articulated *Lyropecten nodosa* (Lion's Paw scallop). A pristine, articulated specimen of the spiny scallop *Spondylus* sp. with most of the spines intact was found in section 3. The preservation of the delicate structures of fossils such as these demonstrates a general lack of transport and mechanical destruction.
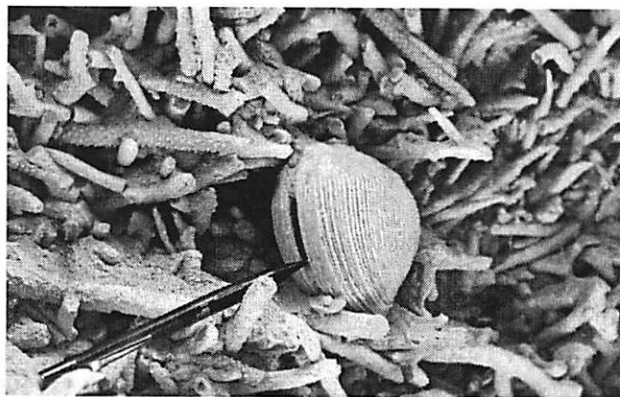

Figure 4. In-situ *Princess Venus clam found in the* Acropora cervicornis *thicket, stratigraphic column 2. Pen = 15 cm in length.*

SAMPLE	AGS2#3	AGS2#4	AGS3#5	AGS3#6	AGS3#8	AGS3#9	AGS3#10
Gastropods							
Hydrobiids		E	E		E	E	E
Foraminifera							
Ammonia beccardii		E					
Elphidium	E	E		E		E	E
Quinqueloculina	M	M			M		
Triloculina		M	M		M	M	M
Pyrgo			M	M	M		M
Ostracodes							
Bairdia	M	M	M	M	M	M	M
Cypria	E						
Cytherura	M/E	M/E	M/E	M/E	M/E	M/E	M/E
Cytherella		M					
Gomphocythere	M						
Trachyleberids	M	M	M	M	M	M	

Table 2. Microfossils found in samples from the normal marine facies. An E signifies euryhaline species occurrence and an M represents typically marine species found within each normal marine sample collected.

Microfossil Evidence

The microfossils found in these beds are useful paleoenvironmental indicators and aid in revealing the salinity history of the Enriquillo seaway to lake transition. Ostracodes are among the most useful microfossils found in these beds. Ostracodes are present in nearly all aquatic environments from freshwater lakes to abyssal depths in the oceans, thus making them advantageous over other groups (Colin and Lethiers, 1988). Ostracodes are very sensitive to variations in salinity and have well-defined salinity tolerances. Individual taxa are not universally distributed over the whole salinity range, and this preference for certain salinities makes ostracodes particularly useful in establishing the paleosalinities of ancient sedimentary environments (Neale, 1988). Foraminifera are also useful, although they are generally more stenohaline than ostracodes.

Microfossil evidence from the lower units of these deposits strongly supports an interpretation of normal marine salinity conditions. Two samples from section 2 and five samples from section 3 were analyzed for microfossil assem-

blages. From these samples several trends are apparent (Table 2). Most of the ostracode species are paleoindicators of a marine environment (e.g., *Bairdia* sp., *Gomphocythere* sp., and Trachyleberids). When found together, these ostracodes constitute a typical marine assemblage, as recognized by Brasier (1980). Some of the other ostracodes (e.g., *Cypria* sp. and *Cytherura* sp.) have varying salinity preferences, but they occur in small numbers only.

The foraminiferan assemblages, which are dominated by *Pyrgo*, *Triloculina*, and *Quinqueloculina*, are also consistent with a normal marine environment. *Ammonia beccarii* and *Elphidium* sp. prefer euryhaline conditions but occur in smaller numbers only.

Littoridinops monroensis, the hydrobiid gastropod found in these samples (Figure 5), is predominantly a brackish water species, but it can tolerate higher salinities and is known to occur in tidal marshes in Florida (Thompson, 1968). The small numbers of these low-salinity to non-marine species suggest that they may not have lived in their optimal environment and/or were occa-
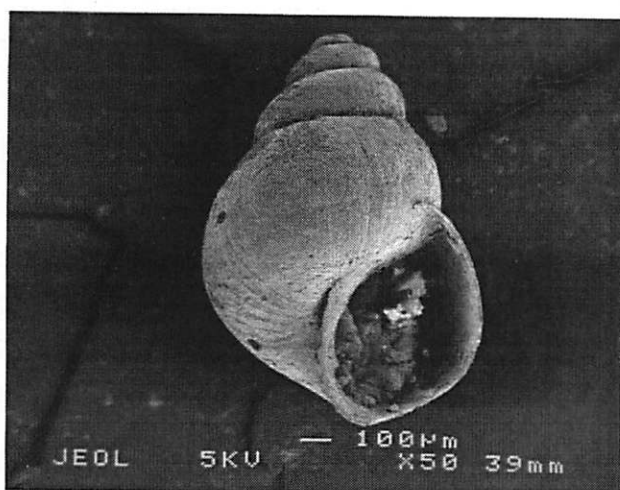
Figure 5. SEM image of one of the common hydrobiid gastropods found in the samples. Bar scale = 100 microns.

sionally washed in from shallow, low-salinity areas marginal to the marine seaway.

Variable Salinity Facies

The other facies recognized in these deposits was the serpulid facies, interpreted as representing variable salinity conditions. Indications are that approximately 4.2 ka before present (L. Greer, unpublished radiocarbon data), there was a change in the normal marine environment of the seaway. Stratigraphically, units characterized by this facies are quite distinctive and are marked by layered aggregates of serpulid worm tubes.

Serpulid Worm Aggregates

In the Enriquillo deposits, serpulid aggregates manifest themselves in two different forms. The first is as very thin layers (Figure 6). These thin serpulid layers were found in sections 2, 3, and 4 and form a marker bed (Figure 3). The serpulid layers can pinch out laterally, but the marker bed for section 3 was prominent and positioned by leveling and sighting across the gully. Variation in the elevation of this serpulid marker bed (and possibly others like it) is likely attributable to topographic relief on the surface of the reef deposits. The marker bed lies above *in situ* reef deposits and is overlain by a mussel bed layer and a massive muddy layer.

The second form of serpulid development present in the Enriquillo deposits is as large, meter-high, serpulid-tufa mounds that cap the reef sequence (Figure 7). The tops of these mounds occur approximately 2.3 m above sea level around the lake margin. They are hemispherical in shape and commonly are coated with a rind of porous tufa material. On the northern or northeast side of Lago Enriquillo, the mounds commonly coalesce to form a wall-like, two-tier structure (Mann et al.,1984; Curran and Greer, 1998). Further description of these large and spectacular mounds can be found in Glumac et al. (this volume).

The serpulid tubes in both the layer and mound-aggregate forms occur in random growth patterns and typically are 0.5 to 1 mm or slightly

Figure 6. Close up view of serpulid layer located in stratigraphic column 2. Pen cap = 6 cm in length.

Figure 7. Large serpulid-tufa mound located along the northern shore of Lago Enriquillo. Mound is approximately 2 m in height; intervals on Jacob's staff = 10 cm.

SAMPLE	AGS2#13	AGS2#14	AGS2#15	AGS2#20	AGS4#3	AGS4#6	AGS4#7
Gastropods							
Hydrobiids	E	E	E	E	E	E	E
Foraminifera							
Ammonia beccarii	E	E				E	E
Elphidium	E	E		E		E	E
Quinqueloculina	M						
Triloculina	M	M			M	M	M
Pyrgo							M
Ostracodes							
Bairdia					M		
Candona			E			E	
Cypria	E		E			E	
Cyprideis			E		E	E	E
Cytherura			M/E		M/E	M/E	
Gomphocythere			M				
Paracypris					M		
Trachyleberids					M	M	M

Table 3. Microfossils found in samples from the variable salinity facies. E signifies euryhaline species and O represents fully marine species; table shows the various species found within each sample interpreted as representing a variable salinity environment.

larger in diameter. Serpulids are common marine organisms and are present in the normal marine facies but not in massively aggregated forms.

Modern serpulids are generally considered to be eurytopic (Ten Hove and Van den Hurk, 1993). Serpulid aggregate behavior is enhanced by environmental conditions such as lack of predation and/or competition for food, lack of water circulation, and deviation from normal salinity and temperature ranges (Ten Hove, 1979; Ten Hove and Van den Hurk, 1993). Modern serpulid worm aggregates have been found in various locations around the world, including Baffin Bay, Texas (Andrews, 1964; Berrios, 2002; Glumac et al., this volume), Tunisia, and Ireland among other areas (Ten Hove and Van den Hurk, 1993). The common theme of these occurrences appears to be variable salinity (Ten Hove and Van den Hurk, 1993), specifically mesohaline to hyperhaline environments, including lagoonal settings.

Microfossil Evidence

Samples from two serpulid layers (AGS2#13 and ASG4#6) were analyzed and are characterized by non-marine and euryhaline ostracodes, as indicated in Table 3. Sample AGS4#6 contained 81% euryhaline forms (*Cyprideis* sp. and *Cytherura* sp.), 16% freshwater forms (*Cypria* sp. and *Candona* sp.), and only 3% marine forms. Assemblages containing *Candona* sp. and *Cypria* sp. are characteristic of oligo-mesohaline waters (Gliozzi and Mazzini, 1998). *Cyprideis* sp. has been identified by Teeter (1995) as an indicator of euryhaline environments, and significant numbers of *Cyprideis* sp. and *Cypria* sp. potentially signal an environment with variable salinities.

The foraminifera also point to a varied salinity environment. *Ammonia beccarii* is a euryhaline species that is found in greater numbers in the serpulid layers than in the normal marine units. *Ammonia beccarii* is unique in its prefer-

ence for varying salinities, living mainly in hyper- to hypohaline lagoons (Almogi-Labin et al., 1992).

Variation from the normal marine environment is recorded in the microfossil assemblage changes shown in Figure 8. The major transition occurs in the middle of the section, beginning at ~2.3 m through 4.3 m, and is characterized by a particularly sharp increase in hydrobiid gastropod numbers. These fluctuations are coincident with the serpulid layers found in sections 2 and 4. Samples AGS2#13, AGS2#14, AGS2#15, and AGS4#6 contained the brackish-water hydrobiid species *Littoridinops monroensis* in percentages up to 98% or higher. (Two of these samples contained only *Littoridinops monroensis*).

This paleoenvironmental change is mirrored (to a lesser extent) in the numbers of ostracodes and foraminiferans present. The low diversity, high dominance, and large populations of the brackish species found in these units are similar to microfossil assemblages from modern ecosystems where physical and chemical conditions are unstable (Tibert and Scott, 1999). Similarly, when a few species flourish in an extreme or stressed environment, they often occur in very large numbers (Ten Hove, 1979). The beds associated with the serpulid layers also have a strong brackish signature. The mussel shell beds (AGS2#14 and AGS4#7) have microfossil evidence indicating variable salinity conditions similar to those of the serpulid units (Table 3). Many of the ostracodes (*Cyprideis* sp. and Trachyleberidids) and foraminifera (*Ammonia beccarii, Elphidium* sp., and *Triloculina* sp.) are found in both the serpulid-bed and mussel-bed units. The brackish-water hydrobiid *Littoridinops monroensis* is also a prominent microfossil in these units.
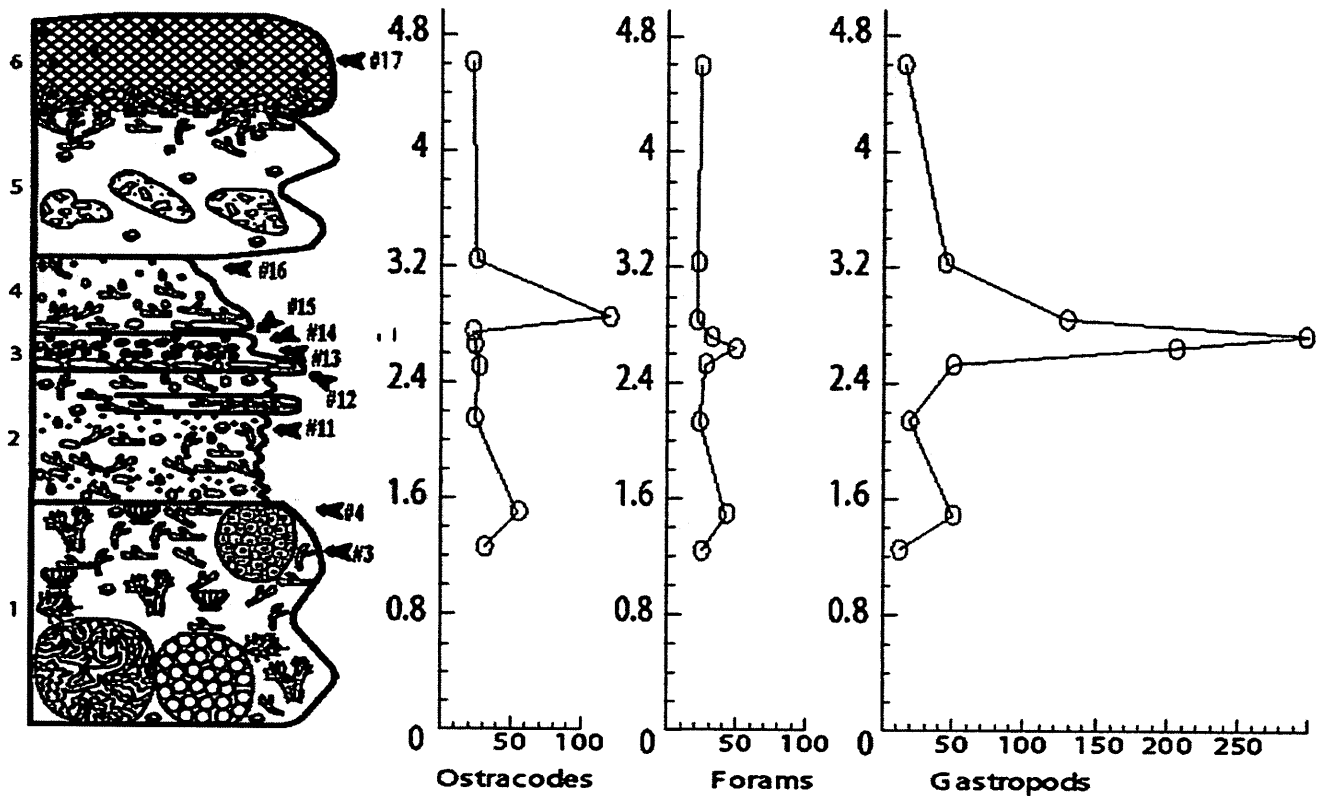

Figure 8. Stratigraphic column 2, with graphs for the numbers of microfossil types found in each sample. Samples 12-15 are from the serpulid-mussel shell marker bed.

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The thick, muddy layer associated with the serpulid units also has similar microfossil assemblages. AGS4#3 is characterized by the euryhaline ostracodes *Cyprideis* sp. and *Cytherura* sp. Sample AGS2#15 clearly has a strong non-marine signature: 69% of the ostracodes are freshwater forms (*Cypria* sp. and *Candona* sp.), 23% are euryhaline (*Cyprideis* sp. and *Cytherura* sp.), and only 8% are marine (*Gomphocythere* sp.). This sample, as well as sample AGS4#6, also contains fossil charophytes (*Chara* sp.). Specimens of *Chara* sp. are fossilized gyrogonites, the zygotes of freshwater green algae (Brasier, 1980; Delwiche, personal comm.). The presence of *Chara* sp. is recognized as a limnetic environment indicator (Rasmussen et al., 1990). These massive, muddy units have diverse microfossil assemblages, but very little macrofossil diversity. The only macrofossils found were particularly large (fully mature) specimens of the hydrobiid *Littoridinops monroensis*.

We found no microfossils in samples taken from the serpulid mounds. There was almost no loose sediment within the mounds, making sampling difficult. It is possible that this lack of microfossils may be due to the particular mounds sampled, and further investigation of this point is warranted.

Stable Isotope Data

Information from carbon and oxygen stable isotopes is another important tool that can be used to define salinity and paleoenvironmental conditions. Carbon and oxygen from coral skeletons or microfossils can be used as proxies for a range of environmental factors such as salinity, temperature, and precipitation. The oxygen isotopic composition of corals and other fossils is determined by the temperature and salinity environment of their development (Leder et al., 1996). Carbon isotopic composition of.
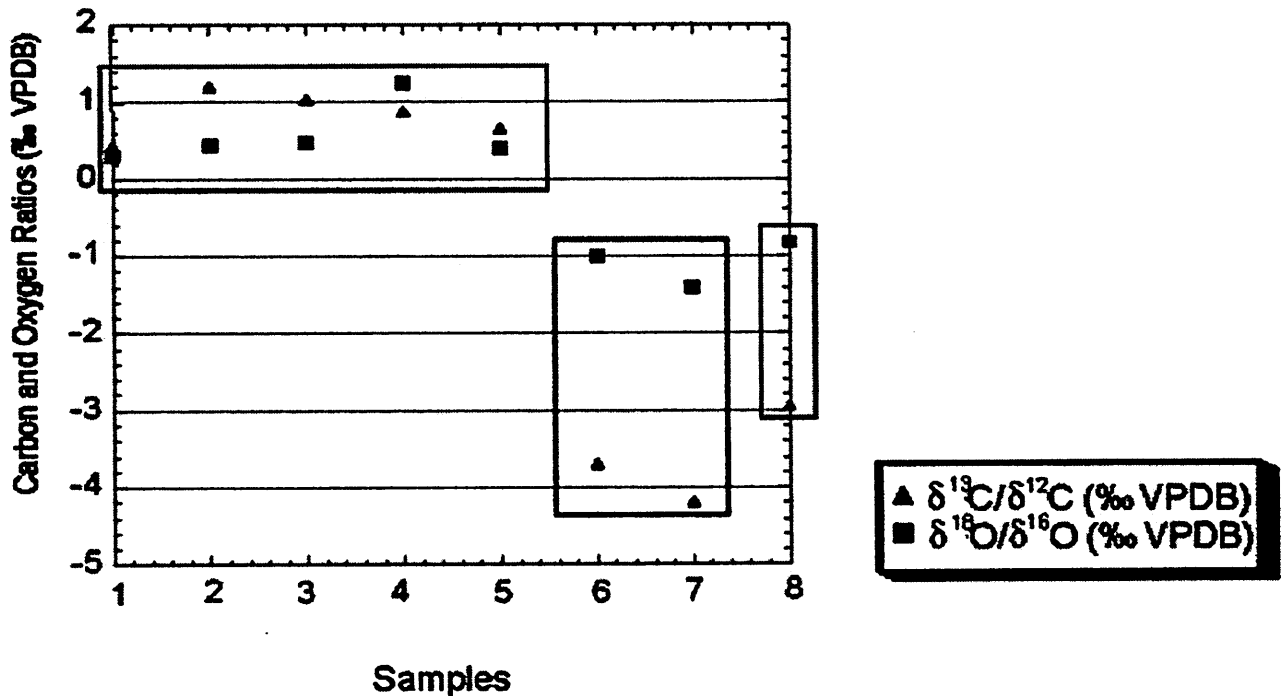

Figure 9. Plot of the ratios of heavy to light carbon and oxygen isotopes found in the serpulid samples (each point represents an average of at least 5 isotopic measurements). Samples 1-5 were collected from serpulids encrusting corals in the normal marine facies. Samples 6 and 7 are from the serpulid layer in section 2, unit 3 (marker unit of Figure 3) at Abuela Grande. Sample 8 is from a serpulid mound on the northern side of the lake (Figure 7). The depleted signatures (samples 6-8) reflect a freshwater influence (oxygen) and a terrestrial influence (carbon) when compared to the normal marine samples..

pristine calcareous fossils can be a proxy for the degree of terrestrial precipitation and runoff. Serpulid samples from the layers and mounds and from tubes attached to the surfaces of corals and shells of the fringing reef facies were analyzed for their stable isotopic compositions. These data offer strong evidence for a low salinity to non-marine environment of deposition during the terminal history of the Enriquillo Seaway.

Figure 9 presents the summary of the isotopic data. The first five serpulid samples, collected from the fringing coral reef beds, have very similar isotopic values (close to 0 ‰), which we interpret to reflect normal-marine conditions.

Samples 6 and 7 are from the serpulid layer in section 2, unit 3. These are isotopically depleted compared to normal marine signatures. Sample 8 is from serpulid worm tubes of a large mound located on the northern shore of Lago Enriquillo (Figure 7). Its isotopic signature is very close to those of the serpulid layers, indicating that the mounds were deposited in an environment similar to the serpulid/mussel layers but very different from the normal marine facies. An explanation for the depleted serpulid signatures can be found by looking at freshwater and terrestrial carbon signatures. Carbon found in terrestrial runoff is lighter than in fully marine waters, so a more negative isotopic signature occurs. The depletion of both $\delta^{18}O$ and $\delta^{13}C$ within samples 6, 7, and 8 indicates an influx of both isotopically depleted terrestrial sediment and freshwater, and is interpreted as indicating an environmental change from the normal marine environment to one of dominant hyposalinity.

In this study, changes in the oxygen isotopic composition are correlated to changes primarily in salinity, not temperature. This is because a change of 1 ‰ = ±4°C. Figure 9 shows a $\delta^{18}O$ change of about 2 ‰, which would equate to about an 8°C change in temperature. The shift in the $\delta^{18}O$ isotopic compositions is greater than can be accounted for by temperature alone, and a temperature fluctuation of this amplitude would be highly unlikely in this tropical setting. Therefore, this shift is interpreted as a change in salinity. Given that there is no photosynthetic effect for serpulids we have thus ruled this out as a factor in interpreting the isotopic signatures.

DISCUSSION AND CONCLUSIONS

The history of the reef deposits marginal to present-day Lago Enriquillo began with the formation of a seaway extending from the Caribbean Sea, with normal marine salinities and temperatures supporting the growth of a healthy fringing reef beginning by at least 7.2 ka before present (Greer, 2001).

As sea-level rise slowed in later Holocene time (about 5.2 ka; Greer, 2001), continued alluvial shedding overcame the rising sea and cut off the Enriquillo Seaway. Concurrently, the Rio Yaque del Sur was diverted from its previous course and began to empty into the newly formed saline lake. Meander scars of fluvial channels between Lago Enriquillo and the river are still visible today (Mann et al., 1984). Waters from the Rio Yaque and precipitation filled the lake. The presence of fresh and brackish water ostracodes (*Cypria* sp. and *Cypredeis* sp.) indicates that the waters changed from marine to brackish (Tables 2, 3). Lack of circulation and the change to brackish water likely killed the coral reefs, but euryhaline invertebrates such as mussels and serpulid worms persisted. Continued drainage of the Rio Yaque del Sur into the lake introduced the freshwater charophyte (*Chara* sp.) and hydrobiid gastropod (*Littoridinops monroensis*), which were found in the serpulid units.

The brackish environment of the newly formed lake allowed serpulid growth to flourish after 4.5 ka (Curran and Greer, 1998). With particularly favorable conditions, the serpulids formed thin, layer-like aggregates. High levels of nutrition and reduced predation enhanced aggregate growth and lead to the proliferation of hydrobiid snails. The freshwater influence from the river continued for some time, as evidenced by the massive muddy layers found above the

serpulid layers (Figure 3). The serpulid mounds that cap the sequence likely indicate the high-water mark of the lake and the last evidence of a prolonged brackish-water environment prior to the beginning of profound evaporation leading to lowering of the lake level. The elevation of the mound tops (~2.3 m above present sea level) also would seem to indicate that they are not normal marine in origin, although neotectonic uplift may be a factor. Random growth positions of the serpulid tubes suggests episodes of rapid development in conditions of extreme salinity variation.

The serpulids grew and mound development prospered in a fluctuating salinity (dominantly brackish) environment until the Rio Yaque del Sur was diverted away from the lake to its present location. The semi-arid climate of the area prevailed and soon evaporation lowered the lake level, creating a hypersaline environment. Over time, the lake has evaporated to its present level (~42 m bsl), revealing the fossilized remnants of the fringing reef sequence.

Study of the history of this unique mid-Holocene fringing reef sequence and its associated serpulid occurrences has broadened our understanding of variable salinity environments and their complexity, and should help to characterize environments in similar Quaternary and older deposits elsewhere around the globe.

ACKNOWLEDGMENTS

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