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STRATIGRAPHIC CONTACT BETWEEN CORAL REEF COLONIES AND SERPULID TUBE/TUFA MOUNDS (MID-HOLOCENE) OF THE ENRIQUILLO VALLEY, DOMINICAN REPUBLIC: PALEOENVIRONMENTAL IMPLICATIONS

KELSEY WINSOR
Smith College
Sponsor: H. Allen Curran

INTRODUCTION

Located in the mountainous southwestern Dominican Republic, present-day Lago Enriquillo is a hypersaline lake with a surface 40 meters below sea level. As recently as five thousand years ago, the valley was a normal marine coastal embayment. In early- to mid-Holocene time, the shores of this large embayment hosted a diverse and healthy fringing coral reef. Following sediment accumulation at its mouth, the embayment's connection to the sea became blocked and ancient Lago Enriquillo was formed. Subsequent environmental change triggered the demise of the coral reef and the growth of the unusual mounds that are the focus of this study.

The large mounds of the Enriquillo Valley are composed primarily of serpulid worm tube aggregates and tufa. Serpulid worms can be opportunistic and are known to aggregate in waters of abnormal salinity, where competition is reduced. These sessile worms secrete calcareous tubes, attaching to any hard substrate and building on each other. Within the valley, worm tubes reach a length of 1-2 cm and a diameter of 1-2 mm. Yet, they are capable of producing aggregates up to 3 m in height.

Tufa is a carbonate precipitate normally found associated with groundwater springs and limestone bedrock. It is generally porous and microcrystalline, and its development is microbially-mediated (Berrios, 2002). Precipitating out of calcium-saturated waters, tufa grows after nucleating on a stable surface. In this case, serpulid aggregates provide the stable surface, and tufa composes up to 40 percent of mound material. The purpose of this study is to determine the rate and extent of environmental change between the time of coral growth and of serpulid tube/ tufa mound formation.

METHODS

GPS coordinates and elevations were recorded for serpulid tube/tufa mounds found around the periphery of the valley. Mound shape, size, and composition were noted, as well the characteristics of the underlying coral substrate. At Cañada Honda, our study site with the most extensive mound growth, a profile showing relationships between mound height, elevation, and shape was created (Fig. 1). Coral and mound samples were taken from Cañada Honda and four other locations around the valley rim: Cañada Honda West, Abuela Grande, Las Caritas, and Devil's Furnace. Most samples were collected at the coral-serpulid contact to determine the timing and rate of coral death and mound growth, as well as the extent of environmental change within Enriquillo Valley during this time period.

At Washington and Lee University, two *Montastrea annularis* coral samples were micromilled at one millimeter resolution for 2-5 cm along thecal walls of individual corallites. Carbon and oxygen stable isotope analyses were performed on these 160 subsamples at the University of Saskatchewan. In addition, 52 serpulid and coral subsamples have been powdered, roasted, and analyzed for carbon and oxygen isotopes. These samples were chosen either from locations that have been age dated, or from a variety of areas at different elevations around the valley.

Radiocarbon age dates were determined for ten samples from locations Cañada Honda, Cañada Honda West, and Abuela Grande. Serpulid and coral samples were chosen (with the exception of CH-1-5) from the coral-mound contact. Samples were sonicated and were then analyzed at Dr. Tom Guilderson's lab at Lawrence Livermore National Laboratory. All age dates were corrected for possible reservoir effects.

Three large samples of mound material were cut using a band saw. The cut surfaces were scanned and content proportions were examined. Also, twenty individual serpulid tubes were cleaned and photographed in detail; in addition, a number of mound and coral samples were photographed.

RESULTS

Serpulid tube/tufa mounds are located around the margins of present-day Lago Enriquillo both in terraces and in isolation. Mound circumferences range from a few tenths of a meter to 13 meters, with heights reaching up to about 3 meters. Isolated mounds are generally symmetrical, with variations dependent on the form and shape of the underlying substrate. Terraced mounds, located primarily at Devil's Furnace and Las Caritas, are elongate horizontal occurrences of the typical mound shape; frequently these terraces occur in distinct tiers (Figs. 1 and 2).

The mounds formed on hard, stable substrates rising slightly above the surrounding topography. In most cases, *Montastrea annularis* colonies provided the growth substrate; on occasion, Miocene limestone bedrock, fragmented and cemented *Acropora cervicornis*, and *Siderastrea siderea* were also growth substrates. Terraced mounds occur on steeper slopes, whereas isolated mounds were observed on gentler slopes.

The mound interiors are a mix of calcareous serpulid tubes and tufa, with whole and fragmented shells of gastropods, bivalves, and barnacles also present (Fig. 3). The proportions of material differ between mounds, which are also internally variable; however, serpulid tubes always compose the largest portion of the whole. Layers of mussels and clusters of other bivalves are not uncommon within the mounds. Small cavities ranging up to several centimeters in diameter are scattered throughout the interior and provided a favorable location for serpulid

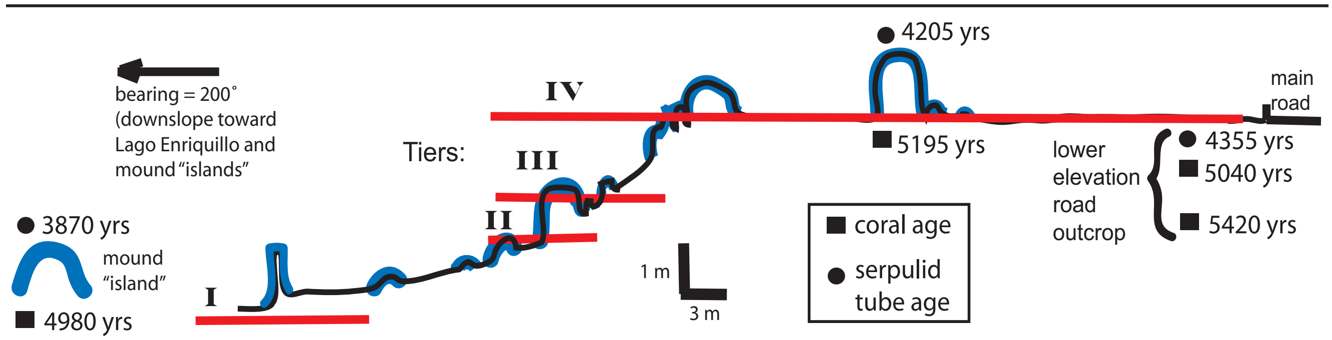


Figure 1: Profile of mound shape and elevation along a continuous line at Cañada Honda. Age dates for corals and serpulid tubes at corresponding elevations are shown. Tiers of distinct mound growth are labeled as roman numerals and are punctuated by layers of fragmented and cemented *A. cervicornis.*

Figure 2: Mounds at Cañada Honda. Note rounded, symmetrical shape and rough exterior.

growth. Serpulids grew within and over tufa, as well as being covered with the precipitate, indicating simultaneous development of both.

Figure 3: Interior of mound sample CHW-1-3. Millimeter scale serpulid tubes are visible in center. Note tufa crust at the bottom of the photo and the many associated gastropod and bivalve shells.

Radiocarbon age dates show a trend of younger ages associated with decreasing elevation (Table 1). This trend holds with both coral and serpulid samples. At coral-serpulid contacts, dates range from 5195 to 4975 years ago for corals and from 3700 to 4355 years ago for serpulids. A distinct, 700 to 1300 year hiatus between coral and serpulid growth was observed at all surveyed areas. Corals from the coral-serpulid contact are constrained to a 200-year period, and serpulids from the contact are constrained to a range of 650 years.

Oxygen and carbon isotopes ($\delta^{18}O$ and $\delta^{13}C$) from the two micromilled *M. annularis* samples show little change throughout the top few centimeters of corallite before their death (Figs. 4a and b). For sample CH-6-3, $\delta^{18}O$ values fall between -4 and -5‰ VPDB, while $\delta^{13}C$values cluster between -2 and -5‰. Sample CHW-1-2 yielded $\delta^{18}O$ values between -3 and -4‰, consistently more positive than the first coral. Values of $\delta^{13}C$ range from -2 to -4‰.

DISCUSSION

Age dates from serpulid tube/tufa mounds in the Enriquillo Valley, Dominican Republic indicate that these mounds developed between 4.5 and 3.5 thousand years ago. Conditions of lowered salinity allowed serpulids to aggregate in the absence of competition, along with several species of bivalves. Aggregation was, in most places, coupled with tufa precipitation.

Both coral and serpulid ages become younger with decreasing elevation. A period of approximately 700 to 1300 years separates the time of coral death and the formation of serpulid aggregates. Average $\delta^{18}O$ and $\delta^{13}C$ isotopic compositions for the two micromilled coral samples show a trend toward increasingly negative values of both $\delta^{18}O$ and $\delta^{13}C$ with decreasing elevation toward Lago Enriquillo. This indicates a decrease in salinity and an

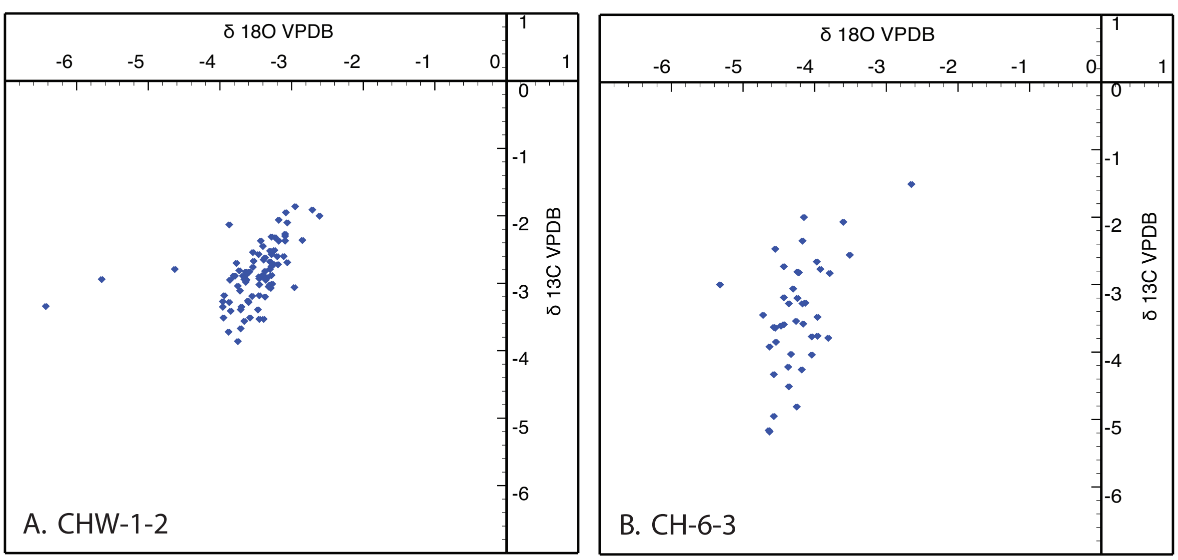
Location	Sample	Type	^{14}C Age Date	^{14}C +/-	Notes
Cañada Honda	CH-1-7-10a	Serpulid tube	4355	35	At road cut. Attached to CH-1-7-10b.
Cañada Honda	CH-1-7-10b	*A. cervicornis*	5040	35	Contacting serpulid tubes.
Cañada Honda	CH-1-5	*A. cervicornis*	5420	30	.5 m below CH-1-7-10.
Cañada Honda	CH-3-4	Serpulid tube	4205	35	Attached to CH-3-2.
Cañada Honda	CH-3-2	*M. annularis*	5195	35	Tier 4. Contacting serpulid tubes.
Cañada Honda	CH-6-1	Serpulid tube	3870	35	Attached to CH-6-1.
Cañada Honda	CH-6-3	*M. annularis*	4980	30	Mound "island". Contacting serpulid tubes.
Cañada Honda West	CHW-1-2	*M. annularis*	5175	30	Tier 4. 1 km west of Cañada Honda
Abuela Grande	AG-1-1	Serpulid tube	3700	35	Attached to AG-1-6.
Abuela Grande	AG-1-6	*M. annularis*	4975	35	Contacting serpulid tubes.

Table 1: Radiocarbon age dates for ten coral and serpulid tube samples. Note sample location within the Enriquillo Valley and contacts between corals and serpulid tubes.

increase in terrestrial water influx as time progressed.

Following cutoff from the sea, Lago Enriquillo collected freshwater runoff which decreased lake salinity. Lake salinity decreased below a level capable of supporting coral colonies. Water level rose rapidly, reaching at least as far up slope as the highest mounds. Serpulids aggregated and tufa formed as lake level dropped back down toward its present-day position.

Because tufa formation precipitates most easily on older tufa that has already initiated nucleation (Glover and Robertson, 2003), and because initial serpulid aggregation encourages further aggregation due to rapid reproduction, the primary control on mound location must affect mound initiation. Individual mound "islands" downslope at Cañada Honda formed on the available hard topographic highs provided by *M. annularis* colonies. The control for terraced mound location may come from groundwater influx via springs.



Figures 4a and b: Carbon and oxygen isotope comparison of a). Cañada Honda West *M. annularis* sample CHW-1-2 and b). Cañada Honda *M. annularis* sample CH-6-3.

Most literature (Pedley, 1990; Glover and Robertson, 2003) discussing tufa formation states that freshwater springs containing high quantities of dissolved calcium carbonate are the source of tufa material. Today, many springs run into the Enriquillo Valley; in the past locations of ancient springs may have dictated the locations of tiers of mounds. While individual springs are likely not associated with individual mounds, a lack of freshwater mixing may have created pockets of mesohaline, calcium-saturated water appropriate for tufa precipitation. Along steep slopes, these pockets may have been focused in the shallow, near-shore area; this would explain the laterally extensive terraced tiers.

If springs are a major factor in tufa formation, they may also heavily influence serpulid aggregation. Serpulids are filter feeders and could possibly benefit from nutrients carried in by springs (Ten Hove and Van Den Hurk, 1993; Andre, 2004). If springs can cause serpulid aggregation, any combination of low salinity, increased nutrients, and high levels of dissolved carbonate may be responsible. In this circumstance, tufa and serpulids would prefer the same locations.

It is also possible that wave action contributed to mound formation. Calcium-saturated waves would facilitate formation of films of tufa on hard surfaces after evaporation in the arid climate, starting tufa nucleation. *M. annularis* colonies, rising above the lake floor would be exposed to more wave action. Furthermore, the steep slopes of Las Caritas, where tufa "laps" up the bedrock, would experience wave activity. Hence, tufa would form more readily on these surfaces; at these sites, tufa formation may have preceded serpulid aggregation.

While the previous interpretation that mound material is a core of aggregated serpulid tubes coated by a distinct layer of tufa (Berrios, 2002) may apply to some locations within the valley, mound composition generally appears to be more complex. Causes for mound material may involve more than one factor within the paleoenvironment; groundwater springs, mesohaline lake water, and the marine setting implied by certain gastropod species are all possible contributors to mound formation. Nevertheless, there is a distinct trend toward decreasing salinity and increasing terrestrial water input as ages for coral and mounds decrease. Further stable isotope analyses, petrographic work, and literature review will provide more information needed to assess more fully this interpretation.

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