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USING SEDIMENTS AND SUBSTRATES TO INTERPRET REGIONAL HYDRODYNAMICS AND ECOLOGY OF CORAL GARDENS, BELIZE

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INTRODUCTION

In Northern Belize, located between Ambergris Cave to the north and Cave Caulker to the south, the hydrologic setting of Coral Gardens is unique in many ways. The generally healthy condition of Acropora *cervicornis* and *palmata* patch reefs relative to the greater Caribbean region is hypothesized to be a result of the hydrodynamics of Coral Gardens and the surrounding lagoon region. The Coral Gardens study site, located ~200 m west of the Belize Barrier reef, lies between the Cave Caulker and Hol Chan marine protected zones (Figure 1, Greer et al., this volume). The corals at the study site and surrounding region deviate from the general trend of unprecedented dieoffs of acroporid reefs in the Caribbean throughout the past three to four decades (Gardner et al., 2003). Important factors contributing to overall growth rates of Acropora spp. include CO₂ saturation, presence of zooxanthellae, and available sources of food (Bender et al., 2014). Water currents also play a large role in the health of acroproids due to filter feeding of polyps when open. Therefore, Acropora spp. have been shown to thrive in shallower high energy hydrologic settings (Geister, 1980).

Depths in the Coral Gardens lagoon rarely exceed 10 meters and are as shallow as a few meters in some areas. Faults offshore of mainland Belize created horsts that resulted in the formation of the outer atolls and cayes. Northeast trending normal faults along the coast led to the formation of an uplifted carbonate platform on which the Belize Barrier Reef and lagoon was formed (Mazzullo & Dunn, 1990). The biodiversity of coral reefs and the overall ecosystem health in this area rely on the propagation of *Acropora*

spp. as framework corals (Harborne et al., 2012). Regional bathymetry within the lagoons of northern Belize is controlled by mud mound and sediment deposition overlain by largely by lithified carbonate "hard pan" and instances of mangrove peat substrate (Mazullo & Dunn, 1990).

Surface water currents in the study area could be largely affected by prevailing easterly trade winds (Belize National Meteorological Service, 2014). These winds would have a large impact in shallow water areas such as the lagoon in which the study site is located. Tidal current patterns follow this general trend with oscillation of flow in the east-west direction (Belize National Meteorological Service, 2014). Further controls that may affect the micro and macro currents of Northern Belize include the location of formations such as caves, barrier reefs, and channels. Local currents are present as water moves in and out of the lagoon via channels in the Belize Barrier Reef. The location of the study site between Ambergris Caye and Caye Caulker, provides a larger area in which currents can flow freely and sediment can be transported.

Using bathymetry, sediment texture, thickness, and sediment composition data, we can show the patch reef relationships to processes such as biological degradation by echinoderms as well as sediment removal and deposition by ocean currents. The "hard pan" substrate beneath the present-day sediment is used to investigate for proxies to past environments. Understanding the hydrologic and ecologic setting of the Coral Gardens study site can therefore elucidate relationships contributing to coral health.

METHODS

Sediment samples were collected using a syringe plunger, thin steel rebar measuring stick, plastic bags with labels, and a compass. At predetermined locations at the study site and adjacent lagoon, sediments were collected by scooping samples from the upper 1-2 cm of sediment while simultaneously pulling the plunger. This method enabled sampling without the loss of fine grained material. At sample sites, rebar was used to probe and measure the sediment thickness.

Sediment sample processing began by oven-drying samples with calcium sulfate desiccant at under 200 °F. Samples were sieved with sieves of 2 mm, 1 mm, 500 μ m, 250 μ m, 125 μ m, and 63 μ m mesh. The separated clasts of sediments were weighed individually on a balance with 1/1000thgram precision. The clasts were then separated between "allochems" (>500 μ m) and "fines" (<500 μ m) for microscopic analysis.

Transect profiles, showing bathymetry, were created using a depth gauge on a dive computer. By swimming the dive computer along the top of the coral surface with a sample intervals of 2 seconds, a profile of depth to coral was determined. Underlying lithified substrate height was determined using the rebar measuring stick.

Live coral cover was measured at 1 m² quadrat intervals at each of the five numbered transects at Coral Gardens. Using MATLAB tracing and visual interpretation of live and dead coral cover, representative values of coral cover could be discerned along study transects.

Echinoderm counts along 1 m² quadrats in transects quantified the abundance of individuals at different points on patch reefs at the Coral Gardens study site (Bender, this volume). The density of echinoderms was also used by Bender (this volume) to determine relative carbonate sediment production rates. A similar survey of parrotfish abundance was conducted to quantify density on transects within the study site (Bender, this volume). Geospatial interpretation of collected datasets were mapped on the ArcMap GIS program according to GPS values determined using a Trimble unit. Interpolation techniques of 'Ordinary Kriging' and 'Empirical Bayesian Kriging' created filled contour plots of sediment textures, thickness, and bathymetry.

Collection of core samples from the underlying "hard pan" served to help characterize paleoenvironments that correspond with the Coral Gardens study site. Core samples were extracted using a 40 cm pneumatic drill with a hollow diamond-tipped drill bit. Two cores could be reasonably used in the context of this study, Core 2 (E side of T5) and Core 6 (E side of T1). Cores were used to produce 2 and 13 thin sections, respectively, along the length of the core. Petrographic slides were used to characterize composition of the "hard pan". Furthermore, two sample locations from C2 and four from C6 were marked for absolute age dating.

Standard petrographic analysis was conducted on thin sections and sediment samples using transmitted polarized light and reflected light microscopes.

Carbon and Oxygen isotope analysis was conducted on points of interest from samples corresponding with thin sections on C6. All samples represent material below the exposure surface. $100\mu g$ of substrate for each point was sampled using a diamond-coated drill bit ~1mm in diameter. Samples were analyzed on a Gasbench II in conjunction with ThermoFinnigan Delta +XP at University of Texas of San Antonio. Corrections using institutional and international standards of NBS-19 and NBS-18 produced corresponding δ^{13} C and δ^{16} O values.

RESULTS

Percent weight of various size fractions of sediment samples was spatially interpolated within the Coral Gardens study site. Grain size distribution profiles varied between sample sites. However, overarching trends can be seen in textural composition of these carbonate sands.



Figure 1. Fine grained sediment distribution map based on ordinary kriging interpolation. Relative amounts of fine grained sediment grains ($<63 \mu m$) are based upon weight percent after sieving samples taken at locations around the Coral Gardens study site. Three data control points to the west are not shown on map.

Figure 1 shows, through ordinary kriging interpolation, that a greater weight-percent of fines (<63 μ m) occurs towards the eastern side of the study site. However, the proportion of fine grained sediments is relatively low in the Coral Gardens study area and does not exceed 2% of the cumulative sediment sample weight.



Figure 2. Coarse grained sediment distribution map based on ordinary kriging interpolation. Relative amounts of coarse grained sediment grains (>500 μ m) are based upon weight percent after sieving samples taken at locations around the Coral Gardens study site. Three data control points to the west are not shown on map.

Coarse grained sediments (>500 μ m) constitute a greater percentage of sediment samples towards the middle of the study site (near T2, T3, and T4) compared to the Eastern and Western bounds (Fig. 2).





Figure 3. Plots showing the relationships between coral profile, underlying lithified substrate, live coral cover, and echinoderm densities (from Bender, this volume). Sediment thickness is less than 1 cm at all points along the transects. Transect 5 (Bottom) is shallower than Transect 1 (Top) and demonstrates significantly higher coral cover. Furthermore, little to no echinoderm presence is seen in Transect 5 compared to a much higher echinoderm densities in Transect 1.

Spatial trends of live coral cover values can be seen when comparing Transects 1 and 5. Live coral cover is greater (48-64%) at the eastern bound of the study site near Transect 5, with generally decreasing live cover (< 30%) trending to the NW towards Transect 1 (Fig. 3).

Echinoderm abundance (Bender, this volume) is inversely related to percentage of live coral cover (Fig. 3). Less than 3 echinoderms/m² are observed along Transect 5 compared with up to 49 echinoderms/m² along Transect 1 (Fig. 3).



Figure 4. Map showing sediment thickness according to empirical bayesian kriging. Thickness values are based off of measurements using a rebar probe. Three data control points to the west are not shown on map.

Sediment thickness varies considerably across the study site. In general, very little sediment occurs within coral patches, but sediment cover increases between coral patches and sediment shows a regional trend of increasing thickness to the west (Fig. 4).

Sediment samples taken from sample sites are expectedly carbonate dominated in composition and contain fossil remains of flora and fauna indicative of a lagoon environment. Clasts include foraminifera, halimeda, coralline algae, echinoderm, coral, and shell fragments. A majority of the clasts, especially on the eastern side of the study site, are unidentifiable likely due to abrasion from transport.

Thin section samples from core C6 are mostly composed of micritic and skeletal material, demonstrating textural characteristics of a wackestone. Corals, coralline algae, and skeletal fragments/ shells are allochems. Diagenetic features including dissolution vugs and circumgranular cracks were observed in thin section. No discernable differences in micrite percentage or allochem composition can be seen along the length of the core. C6 core dating constrain the age to less than 39,090 +/- 440 ybp (Busch, this volume).



Figure 5. (Left) Vertical plots of $\delta 13$ carbon and $\delta 16$ oxygen isotope concentrations collected along samples of Core 6 taken from the East side of Transect 1. Core 6 age is constrained to younger than $39,090 \pm 440$ ybp (Busch, this volume). Phases are denoted by colors.

(Right) Crossplot comparing negative values of carbon and oxygen isotopes within Core 6 taken from the East side of Transect 1. Groupings of phases demonstrating differential uptake of environmental isotopes.

Carbon and oxygen isotope values are negative throughout the length of core C6 but fluctuate throughout, showing no discrete zones or abrupt changes of isotopic concentrations. δ^{13} C values range from -2.4 to -7 ‰ while δ^{16} O values range from -2. 5 to -5.7 ‰ (Fig. 5).Vertical plots and a crossplot show that there may be differential uptake between phases that are more negative (micrite) and phases that are more positive (corals) (Fig. 5). Two-tailed t-Test of variability of isotope uptake between the coral and micritic phases of the core indicate that the difference in δ^{13} C isotope uptake is significant, while the differences in δ^{16} O isotope uptake are not.

INTERPRETATION

Both sediment texture and composition of sediment samples collected in the study site and on a regional scale could provide insight into the ecologic composition and influences of herbivory on the patch reefs. Furthermore, the data might also shed light on regional and local hydrodynamic currents.

Spatial trends of sediment texture and thickness indicate greater influence of hydrologic currents to the East of the patch reef system. Thinner sediments between patch reefs and lower proportion of fines to the east indicate winnowing of grains closer to the barrier reef on the east bound of the study site (Fig. 1). This may suggest that the main hydrologic flow and sediment transportation would trend from the Belize Barrier Reef (east) toward mainland Belize (west).

A greater proportion of coarse grained sediments (>500 μ m) in the center of the study site (Fig. 2) is not consistent with an interpretation of higher current energy toward the east and decreasing energy westward toward the interior of the lagoon. It is hypothesized that this inconsistency could be due to increased bioerosion and fragmentation of dead coral within the center of the study site.

The greater live coral cover and thinner sediment cover toward the eastern margins of the study site could result in an increased ability of Acropora spp. to anchor themselves on lithified substrates with a lesser veneer of sediment. This would be a hydrologic positive control increasing likelihood of acroporid colonization. Furthermore, indications of a higher energy environment on the eastern side of the study site would also benefit Acropora spp. affinity for high energy feeding environments (Geister, 1980). Similarly, shallower coral depth could contribute to high live coral cover of patches (Fig. 3). These interpretations are corroborated by general observations of increased abundance and health of Acropora spp. stands in the eastern bound of the study area near the Belize Barrier Reef.

Figure 3 shows that the profile of the top of the coral cover follows general topography of the underlying lithified substrate. Transect 5 has a shallower coral profile and higher live coral cover than Transect 1 (Fig. 3), indicating that depth of corals may have an inverse relationship with live coral cover.

Comparison of percent live coral cover and corresponding echinoderm density (#/m²) shows that they are inversely related (Fig. 3). This could indicate that echinoderms prefer patch reefs with lower live coral cover, possibly due to higher algal growth. As a direct competitor to *Acropora* spp. for space and resources, macroalgae abundance also shows an inverse relationship with coral cover (Martin, this volume). Alternatively, high echinoderm abundance could correlate with low coral cover because they are destroying corals.

Carbon and oxygen isotope analysis performed on samples from core C6 provide evidence of probable subaerial exposure due to consistently negative isotope values compared to neutral values indicative of modern seawater (Scholle & Scholle, 2003). The isotopic signatures of δ^{16} O and δ^{13} C values show evidence of sediment litification and subaerial diagenesis by meteoric water (Scholle & Scholle, 2003, Allan & Matthews, 1982). It is hypothesized that the variability in isotope values in the "hard pan" formed during sea level fall and partial vadose diagenesis beneath a soil later that was later stripped away by erosion during subsequent transgression. Some evidence of patchy dissolution of cement fabrics and circumgranular cracks supports this hypothesis.

Less negative δ^{13} C values could have been a result of preferential photosynthetic uptake of δ^{12} C by coexisting zooxanthellae, leaving δ^{13} C enriched substrate. Similarly, organic matter within micritic sediment could facilitate pathways inducing carbonate precipitation. This authigenic carbonate could contribute to the significant differences in $\delta^{13}C$ concentrations. Paired with age date constraints of the core (Busch, this volume), we can deduce that this meteoric diagenesis could been a result of the last glacial maximum. Due to high growth rates of acroporid corals, the isotope results and petrographic analysis corroborate steady abundance of Acropora spp. and little change in corresponding paleoecology through the Pleistocene and Holocene (Aronson & Precht 1997).

CONCLUSION

While it is difficult to quantify all the hydrologic controls and biotic influence in this locality, it is clear that hydrologic conditions and the presence of bioeroders influence sediment distribution and coral cover within the Coral Gardens study site. Ideal conditions of high energy, shallow environments with little sediment interference enables patch reefs such as those in Transect 5 to thrive. Local fauna effecting competition dynamics and physical alteration of acroporid corals is demonstrated through correlation of low live coral cover, coarser sediments, and high echinoderm abundances. Environments conducive to coral growth, such as Coral Gardens, provides a context for general studies of environmental effects on patch reef ecosystems in the Caribbean.

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REFERENCES

- Allan, J. R., and R. K. Matthews., 1977, "Carbon and oxygen isotopes as diagenetic and stratigraphic tools: surface and subsurface data, Barbados, West Indies." *Geology* 5.1: p. 16-20.
- Aronson, R.B., and Precht, W.F., 1997, Stasis, biological disturbance, and community structure of a Holocene coral reef: Journal Information, v. 23.
- Belize National Meteorological Service., 2014, Belize weather trends, http://www.hydromet.gov.bz/ (2014)
- Bender, D., Diaz-Pulido, G., and Dove, S., 2014, The impact of CO2 emission scenarios and nutrient enrichment on a common coral reef macroalgae is modified by temporal effects. *Journal of Phycology, 50*(1), p. 203-215.
- Gardner, T. A., Cote, I. M., Gill, J. A., Grant, A., and Watkinson, A. R., 2003, Long-term region-wide declines in Caribbean corals: Science (New York, N.Y.), v. 301, p. 958-960.
- Geister, J., 1980, Calm-water reefs and rough-water reefs of the Caribbean Pleistocene. ACTA Palaeontologica Polonica, 25, p. 3-4.

- Harborne, A., Mumby, P., and Ferrari, R., 2012, The effectiveness of different meso-scale rugosity metrics for predicting intra-habitat variation in coral-reef fish assemblages. Environmental Biology of Fishes, 94(2), p. 431-442.
- Mazzullo, S. J., and Dunn, R. K., 1990, Holocene evolution of a carbonate barrier island, ambergris cay, northern shelf of belize. Abstracts with Programs - Geological Society of America, 22 (1; 1), p. 27-27.
- Scholle, Peter A, and D S. Ulmer-Scholle, 2003, A Color Guide to the Petrography of Carbonate Rocks: Grains, Textures, Porosity, Diagenesis. Tulsa, Ok: American Association of Petroleum Geologists.