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Keck Geology Consortium: Projects 2007-2008
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SEDIMENTARY CONSTITUENTS AS INDICATORS OF CHANGING ENVIRONMENTS: THE EVOLUTION OF SMUGGLER'S COVE, ST. CROIX, U.S.V.I.

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INTRODUCTION

Smuggler's Cove is part of Tague Bay Lagoon on the north side of St. Croix (see Fig. 1 in Hubbard et al, this volume). The lagoon reaches depths greater than 5m and is up to 1 km wide (shore to Tague Reef). Sedimentary environments within the lagoon include open sand with *Callianassa* shrimp mounds, bare and featureless sand, and varying densities of seagrass (dominantly *Thalassia* and *Syringodium*) and algae (*Halimeda* and *Penicillus*). The lagoon is bordered to the south by a series of pocket beaches. To the north, Tague Reef provides a barrier to open Caribbean waves. In Smugglers' Cove (Fig 1), the eastern half of reef is lower than the western part, and allows more wave energy into the lagoon. An unvegetated sand patch immediately behind the deeper section of reef crest is referred to in this paper as "the blowout".

Sedimentary data from the present lagoon bottom and cores from Smuggler's Cove allow us to interpret lagoon evolution. Surface sediments and sand-fraction constituents were used to characterize modern lagoon environments, and were compared to patterns seen down the cores. Sedimentary textures and compositions are discussed in the context of sea-level rise and changes in the wave energy passing over the reef.

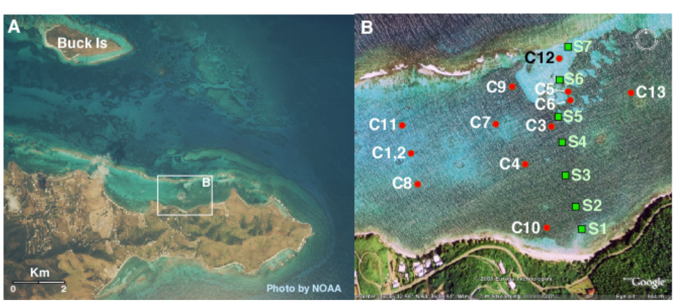

Figure 1. A) Vertical aerial photographs of eastern St. Croix. The field site in Smugglers' Cove is shown by the box. B) Smugglers' Cove photo showing core locations (e.g., C8; red dots) and surface sediment samples (e.g., S3; green squares). Dark areas are sea grass; lighter areas are sand. Photos from NOAA and Google.

METHODS

Twelve vibracore samples (7.6 cm diameter) were taken along two transects across the lagoon (shore to reef). Seven surface samples were taken along a separate transect that crosses all representative lagoon environments (Fig. 1). The vibracores varied in length from 1.5m-3.5m, with most cores encountering the underlying Pleistocene surface. Cores were cut open and visually analyzed on site, and then divided up in 20-cm intervals; the first 8cm of each interval was returned to Oberlin College for grain-size analysis. The remaining 12cm were sieved in the field to collect all shells larger than 2 mm. These were analyzed as part of other projects.

In the lab, samples taken every 20cm in cores plus those from the surface were washed, dried and sieved between –3.0 phi (8.00 mm diameter) and 4.0 phi (0.06 mm diameter), at 0.5-phi intervals. Samples were separated to >-3.0 phi (gravel), -3.0 to 4.0 phi (sand), and <4.0 phi (mud) categories. Thin sections were prepared from sand sub-samples obtained from cores and surface samples, and were point counted every 1.2mm for 150 points per slide.

RESULTS

Halimeda, bivalves, gastropods, upright calcareous algae, encrusting algae, benthic forams, encrusting forams, echinoderms, and bryozoans are the most common grains found in lagoon samples. Planktonic forams, coral, soft coral, sponges, tunicates, worm tubes, pellets, intraclasts and terrigenous rock fragments (TRF) are found in lesser amounts.

Surface sample constituents were used as controls for the spatial environments of the lagoon: 1) nearshore, 2) mid-lagoon, and 3) near-reef. Samples S1 and S2 are representative of nearshore environments, S4 and S5 are mid-lagoon, and S6 and S7 are near-reef (Fig. 1). *Halimeda* is the dominant grain in all samples, but is less prominent in near-reef samples. Higher percentages of gastropods, encrusting forams, coral and bryozoans are also near-reef indicators. Mid-lagoon samples have elevated bivalves, *Halimeda*, benthic forams, and calcareous algae. Nearshore samples contain more TRFs, calcareous algae, encrusting forams and gastropods, with fewer echinoderms, coral and bryozoans. Grain size patterns show that the largest grains are at the shore and reef, with finer grains near mid-lagoon (Fig. 2).

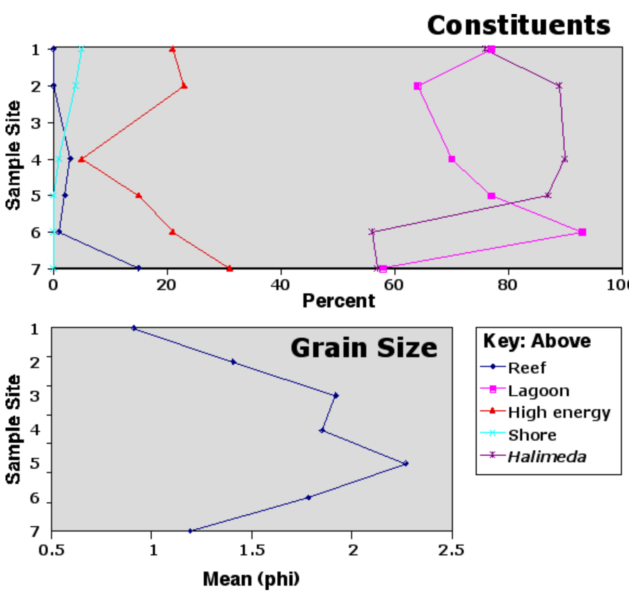

Figure 2. A – upper) Sedimentary constituents found in the sand fraction of the surface samples from Smugglers' Cove (see Fig. 1 for locations). B – lower) Mean grain size for surface samples. See Figure 1b for locations of samples on the y-axis.

Based on surface-sample analyses and the environments in which they are found, grain types have been grouped for comparison to the cores: 1) near

Figure 3. Shell-hash layer at base of core C2. Note terrigenous pebbles (dark grey).

reef—bryozoan, coral; 2) mid-lagoon—bivalve, benthic foram, upright coralline algae; 3) shore—terrigenous; 4) high energy—encrusting foram, calcareous algae, gastropod. Nearshore and near-reef sites are exposed to higher energy, and have similar grains, but the nearshore environments have more TRFs and near-reef samples have more coral and bryozoans. Echinoderm fragmnents are problematic, because they can be either rocky bottom dwellers (reef) or sandy bottom grazers (lagoon), Because fragments cannot be identified as environment-specific species in thin section, they were not assigned a specific environment.

Halimeda is the dominant grain in all thin sections except those in core C5, where mid-lagoon grains dominate. In cores C9 and C11, mid-lagoonal grains are the second most common, coming close to *Halimeda*. Encrusting/high energy grains show the most fluctuation in thin sections (1 - 20% range) in all cores. In the majority of cores, Halimeda increases as other lagoonal grains decrease; this mirroring pattern is also seen between *Halimeda* and high-energy grains. TRF never appear more than 6 times in a thin section (usually 0-1 grains). The small percentage of coral grains was unexpected due to the presence of the reef. However, most of the coral found on the present reef was a soft coral variety (sea whips), which disaggregates upon death. Bryozoans were the other common reef organisms observed in thin sections. Unknown mollusc fragments were also common, but unfortunately cannot be used as environmental indicators because bivalves and gastropods might be contributed from

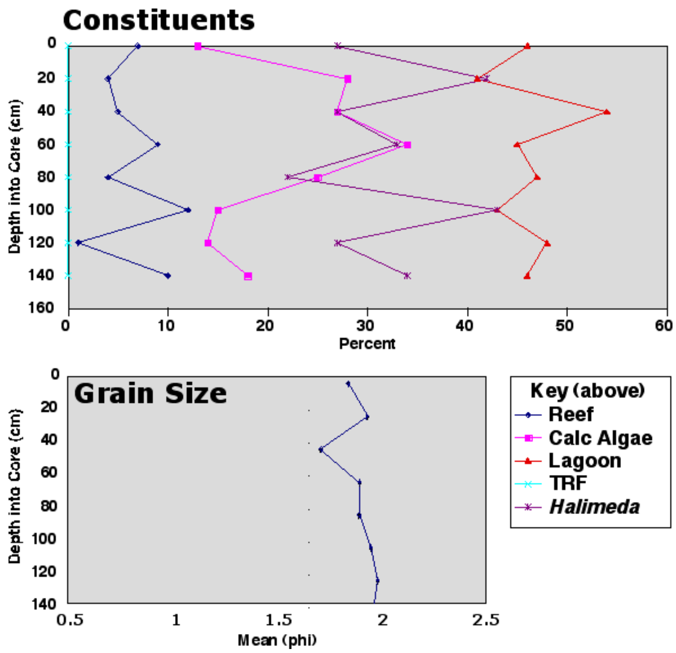

Figure 4. A - upper) Grain constituents for the "blowout" core C5. 0 = top of the core. Note change at interval 40 for Halimeda and "high-energy" grains. B – lower) Grain size data for core C5. Note interval 40 in comparison to the change in constituents seen in (A).

different paleoenvironments. Unidentified grains were typically small and rounded, and were a minor part of the total counts.

Almost all cores bottomed out in a shell-hash layer (Fig. 3). Point counts show most cores ending with increased lagoon grains, which include bivalves and forams contributing to this shell layer. Visual inspection in the field indicated an increase in terrigenous rock fragments at the base of several cores. However, this was not reflected in point counts. TRFs from visual inspection were pebble size (Fig. 3) and only the sand fraction was analyzed in thin section. Between 140 and 150cm in core SC13 two large coral fragments were identified, which correlates to a sudden increase in mean grain size between 140 and 160 cm samples. Several large gastropods and bivalves were observed during visual inspection, as well as seagrass rhiozomes and anoxic areas; both represent grass beds, but would not show up in thin section. We think a hard ground, pre-lagoon surface stopped the vibracore, but it is possible that the shell hash layer at the base of most cores became too thick for the core to penetrate or the composition became more rocky.

DISCUSSION

Based on the depth of the presumed Pleistocene surface and available Caribbean sea-level data, deposition in the lagoon probably began about 6,000 to 7,000 years ago as sea-level rise was starting to slow down. This correlates to the oldest radiocarbon ages recovered from Tague Reef (Burke et al, 1989). With development of a barrier reef, average wave energy and grain size may have decreased. This is consistent with up-core decrease in mean grain size in most cores. Exceptions are cores C5 and C6, located at "the blowout" with an overall coarsening trend. Thus the increase in reef and high-energy grains here correlates with a lower reef crest. Core C5 reflects this with coarser grain size grains (Fig. 4).

Cores C2, C8, C7, and C11 are in *Callianassa* shrimp mounds, built by burrowers that create intricate chambers > 1.5m into the sediment. Shrimp bioturbation creates a lag deposit at the base of the chambers as they excavate and feed on smaller grains. Mounds occur in light seagrass areas and open sandy areas. Suchanek (1983) noted that the bioturbation deposits are stratified—thin coarse beds and thick fine-grained beds. This stratification is likely to show up as abrupt changes in grain size down core. Significant variation in grain size in C7, C8 and C11 could represent this biostratification; C2 does not show this variation. The light to moderate seagrass in C7, C8 and C11 represents a change from mound-dominated to seagrass-dominated, where past shrimp activity would have slowed down. Core C2 could be representative of new shrimp colonization, with less distinct stratification at this time. If this is true, there is no way to know if the seagrass in C7, C8 and C11 is waxing or waning without monitoring the area for a period to observe shrimp colonies.

It would be helpful to know if the seagrass/mound combination represents a change in environments. Most likely the mound/seagrass communities have migrated within the lagoon. If there were a recognizable signature to define shrimp mounds covered by seagrass, this change could be identified down core in other locations. A sequence of mounds over grass would be difficult to document because the sedimentary structures beneath the mounds would be altered. Cores C3, C4 and C9 are located in moderate to dense seagrass respectively. Core C3 shows abrupt changes down core that are observed in the shrimp mound cores. Core C4 does not show much abrupt change and SC-9 shows some at the bottom of the core. It is possible that Core C3 and the base of C-9 are representative of past *Callianassa* mounds. There is no consistent pattern of grain types within the mounds, but this may be due to shrimp reworking the sediment, with grain size as their only priority (i.e. they can only pump finer grains back up to the surface).

Changes in grain type within the sand fraction are not great enough in the cores to determine past environments with confidence, e.g., a change from grass, to mounds, to open sand. However, near-shore, mid-lagoon, and near-reef environments can be generally interpreted. Because the reef has not moved laterally, the near-reef environment of the lagoon was logically constant over time. However, the near shore environment probably moved progressively up the gentler slope toward the present shore. Core C10 has the largest mean grain size of any core at its base, and sediment remains coarser in general compared to other cores. Among surface samples, S1 has the largest size (Fig. 2). Both also have the largest percentage of terrigenous rock fragments, a trend seen at the base of most cores. This increase is not always noted in thin section, but was obvious during visual field inspection.

All cores except for SC-13, SC-9 and SC-8 show a decrease in high-energy constituents between the base sample and the one above; only C6 has increasing grain size. A decrease in wave energy and its representative grains could represent southward beach migration as sea level rose. The overall, up-core decrease in grain size at most sites suggests the reef kept up with sea level rise, forming a barrier from the beginning that may have become more effective over time. The resulting sequence at any core site would have been: 1) an initial high-energy base with TRF close to the beach, 2) an overlying layer of early lagoonal sediments, and 3) increasing low-energy grains deposited as the reef grew and the shoreline moved southward. While there are fluctuations, the range in mean grain size does not seem large enough to support an initially exposed environment changing to a protected lagoon environment. Instead, we see one thick shell hash layer and TRFs at the base of cores followed by lagoon environment grains. The presence of reef grains in the base of the core supports this idea; if there were no reef present during early lagoon evolution, there would be no source of reef grains. Thus, the reef appears to have formed coincident with earliest lagoon evolution.

CONCLUSION

Halimeda and lagoon grains are the largest contributors to sediment in Smuggler's Cove. It is difficult, if not impossible, to determine the location and change in sedimentary environments within the lagoon using thin sections and grain identification. Some shell layers can be seen in shrimp mound cores, but only grain size evidence can be interpreted; sedimentary constituents are not adequate to make this interpretation. However, spatial relations (near shore, mid-lagoon, near reef) can be determined from the sand fraction. Due to terrigenous input in the base layer and the large grain size, the bottom of the cores may represent a transgressive shore sequence. It appears that Tague Reef formed early and kept up with sea-level rise to maintain a protected lagoon from the very beginning.

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