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Keck Geology Consortium: Projects 2007-2008
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SEDIMENTARY CONSTITUENTS AS INDICATORS OF TROPICAL STORM VARIABILITY AND CHANGING HOLOCENE ENVIRONMENTS IN SMUGGLERS' COVE, ST. CROIX, USVI.

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INTRODUCTION

This study examines sediment cores taken from a reef-protected lagoon on the north shore of St. Croix, U.SV.I. (see Hubbard et al; this volume for background) to evaluate whether it is feasible to identify intense storm activity over the past 7,500 years. Previous studies (Liu and Fearn, 1993, 2000; Donnelly et al., 2001; Scott et al., 2003; Donnelly and Woodruff, 2007) successfully used exotic biological fauna in overwash from barrier/lagoon systems as proxies to past storms. In this study, grain size was compared to total carbon content based on a) coulometric analysis, b) loss-on-ignition, c) magnetic susceptibility, d) peroxide and acid digestion and e) percent weight within terrigenous gravel to determine their utility for identifying "tempestites" in a reef/lagoon setting. The spatial and temporal patterns observed in the cores also illustrates how sea level, reef development, wave energy and more recent human activities have influenced deposition in this mixed biogenic/siliciclastic sedimentary environment.

METHODS

Coring

Thirteen vibracores ranging in length from 1.5 - 4.5 m (7.6 cm diameter core barrel) and seven surface grab samples were collected from Smugglers' Cove (Fig. 1). The apparatus consisted of a hydraulically driven cement vibrator attached to a 3-inch (diameter) aluminum pipe. Cores were drilled to refusal or the ca. 4.0-m length of the core tube below the vibrator. Measurements in the field were used to compute compaction. GPS was used to locate each core, and digital depth gauges recorded water depth. Short (8 cm) cores were also collected along a transect from shore to the reef (Fig. 1). Sediment thickness was determined at each site by probing with a thin metal tube pushed to refusal. Cores were split, photographed and visually logged. Within the cores, the top 8 cm or each 20-cm interval was sampled for grain-size analysis. The remainder was sieved and used for studies of shell taxonomy and taphonomy in related studies. In the Oberlin College lab, samples were sieved at 0.5 phi intervals to determine mean grain size and sorting.

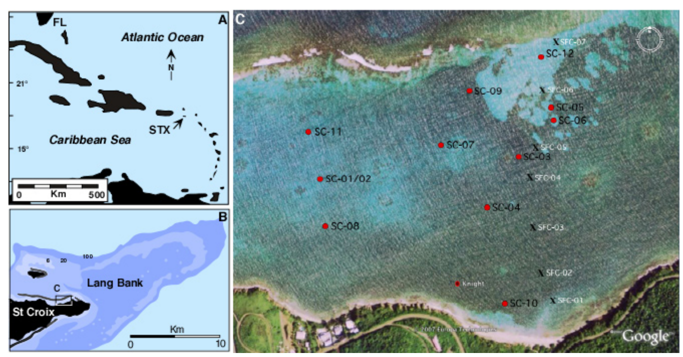


Figure 1. A) Map of the Caribbean showingthe location of St. Croix. B) Map of eastern St. Croix showing the location of the study area in Smugglers' Cove. C) Air photo (Google) of Smugglers' Cove showing the core and surface-sample locations.

Total Carbonate

Sand was split from a sub-sample from each 8-cm interval. The sample was bathed in hot 30% hydrogen peroxide to eliminate organic matter), rinsed, and subsequently digested in a 0.5M HCl solution to dissolve $CaCO_3$. The weights of the initial sample and the remaining insoluble residue were used to compute weight percent of terrigenous material.

Total Carbon within the sand and mud fractions was measured using a UIC Inc. CO2 Coulometer. Sand was ground to silt size by mortar and pestle; mud samples were left untouched. Initially, samples were ashed at 550°C to drive off organic carbon. Weight before and after heating were used to determine the percent of organic carbon (Loss-on-Ignition). Samples were then heated to 950° C to combust the remaining carbon, presumably from inorganic carbonate. Coulometric titration of the resulting CO2 yielded the weight percent of carbon in each sample. Because the nearby siliciclastic rocks onshore contain only minor carbon, samples with lower total carbon were assumed to reflect an elevated terrigenous contribution.

Magnetic Susceptibility & % Terrigenous

The sand and mud fractions were analyzed using a Kappabridge KLY-3 meter (Agico Corp.). The sand and mud fractions of each sieved sample were weighed and poured into 2.5-cm cubes. Magnetic susceptibility was measured five times; values were averaged and then standardized by mass and volume using the equation:

$$((M+0.0000048)*0.8*(H/2))/W \qquad (1)$$

where:
M = measured magnetic susceptibility
H = height of the sample in the cube (a proxy to volume)
W = sample weight

Terrigenous content in the gravel fraction was determined directly. In the sieved gravel, terrigenous and carbonate clasts were visually identified and weighed. Additional gravel data for the 12-cm intervals between the 8-cm sieved sections in cores SC 03, 07 and 13 were provided by Tems (this volume).

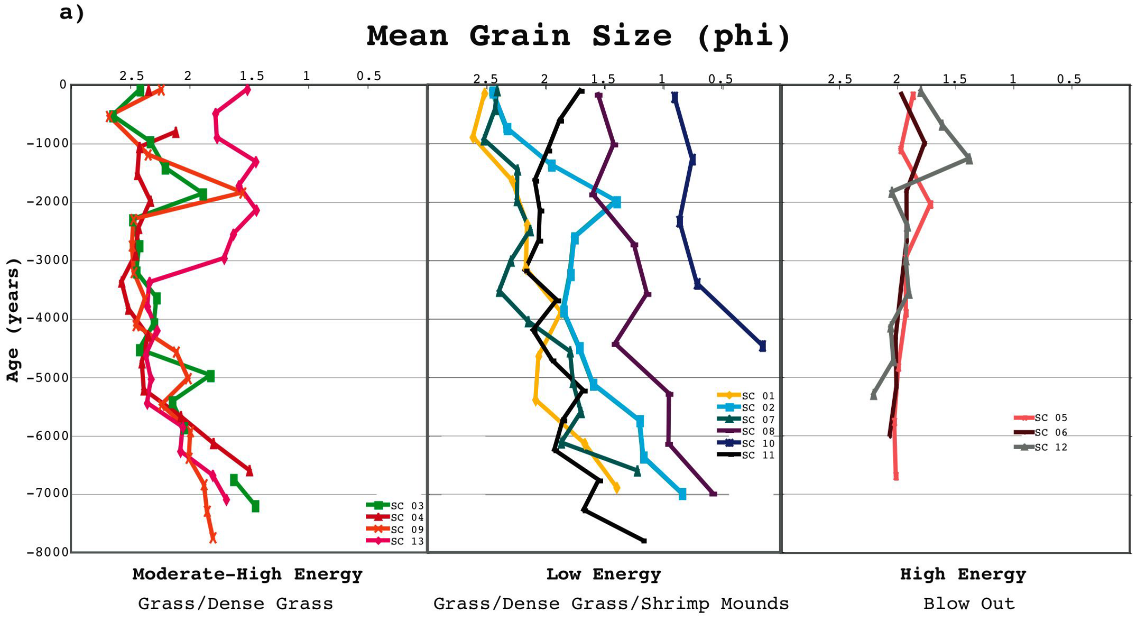
RESULTS

A total of 161 samples were analyzed from the13 cores and the surface sediments from the shore-to-reef transect (See Hubbard et al, this volume for core statistics). The core sites can be divided into three general regions based on grain-size and sorting (Fig 2): 1) low-energy –core sites in the western part of the study area that either sit behind the highest section of the reef (cores SC 01, 02, 07, 08, 11) or close to shore (SC-10); 2) high-energy sites to the east and directly behind a lower stretch of reef that lets in more wave action (cores SC 05, 06, and 12 in a sandy "blow-out" area with minimal vegetation), and 3) moderate-energy sites behind the lower section of the reef but somewhat shielded from the waves that directly impact higher-energy sites. Site SC-13 sits in the high-energy zone but is adjacent to a patch reef.
Loss-on-ignition data showed no consistent pattern in organic carbon. This is probably due to the loss of organics during rinsing. Likewise the coulometric analyses did not produce reliable results for reasons that are less clear. Neither method was shown to provide significant insights into patterns of terrigenous versus carbonate sedimentation either today (surface samples) or in the past (cores). Percent terrigenous gravel provided a good proxy for elevated runoff in cores SC-03 and SC-07, but the larger analysis suffered from a lack of samples. Insoluble residues were likewise derived from a number of samples that is probably insufficient to produce reliable results.

The chronology for each core was calculated using the *Acropora*-based sea-level curve for the Caribbean Sea presented by Hubbard et al. (2005). The age model assumes that the basal elevation at the bottom of each core represents a stratigraphic horizon coinciding with the onset of Holocene marine sedimentation in response to initial flooding due to sea-level rise. It is further assumed that sedimentation has continued, at each core site, through to the present and, as such, the top of each core can be assigned an age of zero. The basal (bottom) age of each core is assigned based upon the initial marine flooding time for its elevation (water depth plus core penetration depth). Because no additional age-depth control points are available, a constant, linear sedimentation rate throughout the core from initial flooding through to the present is used.

Figure 2

a)



b)

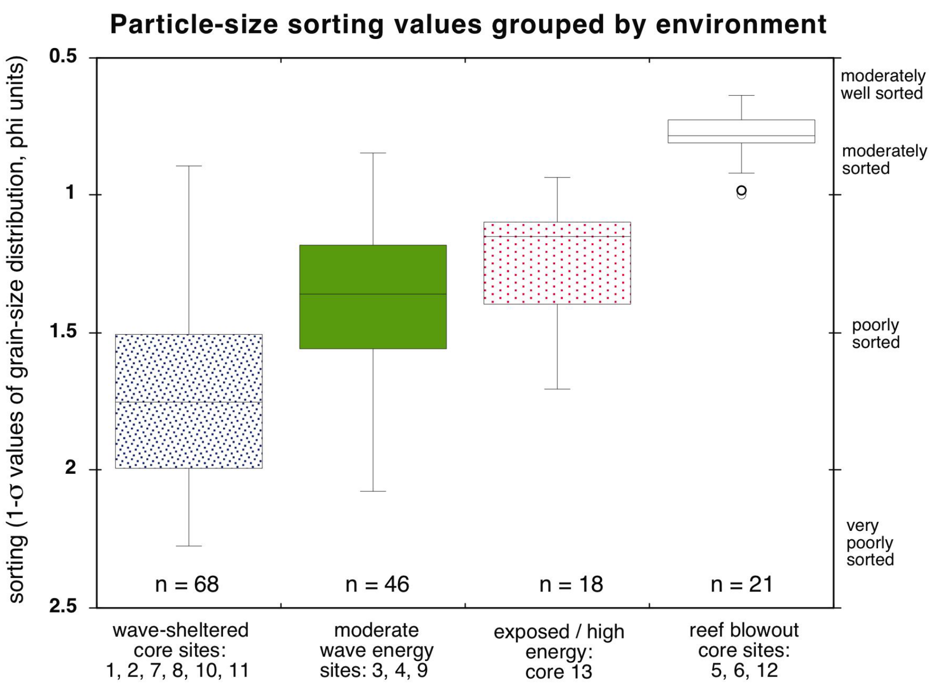


Figure 2. A) Mean grain size down the Smugglers' Bay cores. B) Sorting within cores from different modern lagoon types.

DISCUSSION

COMPARISON OF METHODS

Given the successful core-to-core correlation of the magnetic susceptibility (MS) records (based on event markers), and the subsequent success in correlating the core-to-core grain size records based on the MS stratigraphy, this paper concludes that MS is one of the more accurate and precise analytical methods for studies of both the sand and mud size fraction of these mixed carbonate/clastic lagoon sediments. As discussed further in a later section, MS also proved to be an effective proxy for anthropogenic influence via increased runoff and terrigenous input to the lagoon-reef system. Lastly, MS provides a rapid and suitable method of discerning chronologies, or at least correlating stratigraphic events among cores in studies lacking other chronological control data (e.g., radiometric dates). Additionally, percent terrigenous gravel material yielded accurate results, however significant data was only present for three cores.

MODERN ENVIRONMENT

Figure 3a shows that mean grain size reaches two maxima, with coarser particles at the most shallow landward sample location and also the most seaward site, closest to the reef front. These locations correspond to where the seafloor currents would be strongest, as a result of shallow water depth and greater wave exposure, respectively.

The magnetic susceptibility data for the sand fraction of the surface samples are shown in Figure 3b. A clear trend is observed wherein high MS values, reflecting high terrigenous sediment content occur close to the shoreline and decrease with seaward distance. While this is not surprising, it is important when combined with the observation that the majority of cores show a substantial increase in terrigenous input over roughly the past 400 years, particularly in the mud section. This coincides well with increasing human activity on St. Croix and leads to the conclusion that the magnetic susceptibility data is registering anthropogenically increased sediment

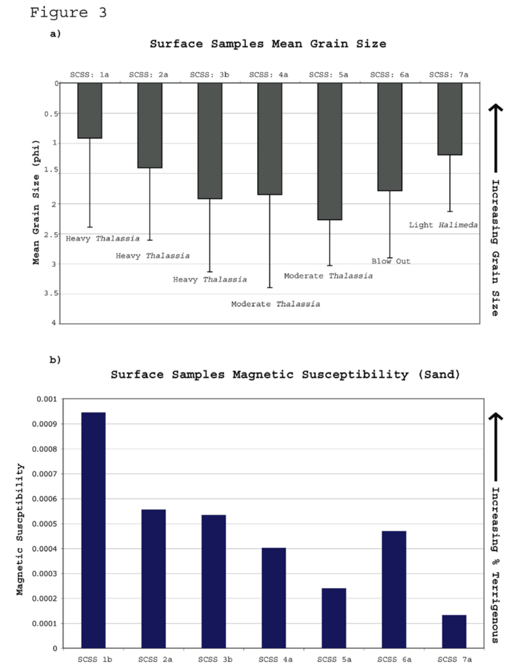


Figure 3. A) Mean grain size for the surface samples along to beach-to-reef transect. B) Magnetic susceptibility data for the same samples.

input to the lagoon.

This finding is significant given that increased terrigenous sediment flux into a reef system has been shown to have a detrimental effect on coral growth (McCulloch et al. 2003). Recent studies estimate that live coral cover in the Tague Bay Reef system is 12.4%. This value represents a significant decline since St. Croix's reef systems were first monitored in 1976 (Arienzo and Hubbard et al. 2005; Fisco, Arienzo, this volume

PALEOENVIRONMENT

Down-core grain size data are plotted together in Figure 2a. Cores SC 05, SC 06, and SC 12 show little variation in grain size down core; the mean grain size values more or less remain constant at around 2 phi. Also, all three cores show moderately sorted to moderately well sorted grain size distributions (Fig. 2b). All three of the cores are from the "high-energy reef blowout" part of the study area. Several possibilities exist for the formation of these areas. These areas could represent locations where a recent

Figure 4

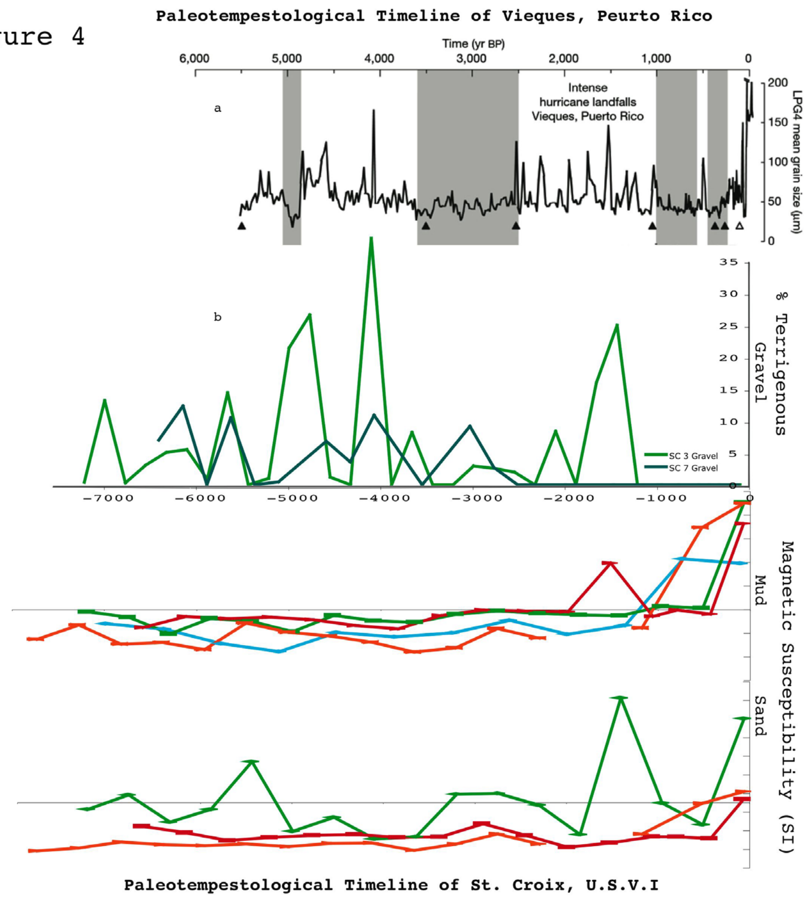


Figure 4. Comparison of hurricane landfall data from Vieques to inferred paleo-tempestites based on core data.

large storm has "blown-out" a *Thalassia* patch and completely reworked and homogenized all of the sediment from the core top to the refusal depth at these sites. Alternatively, these areas may have consistently received relatively high levels of wave energy levels since flooding of the basal elevations of these sites occurred 5300-6700 years ago. The continuous lack of shelter due to the lower reef crest may perhaps have rendered the area unsuitable for plant (*Thalassia*), algal (*Halimeda*), or shrimp (*Callianassa*) colonization and growth. There may also have been a combination of these two scenarios, with a major event blowing out this section of reef a few thousand years ago thereby resulting in consistently high wave energy since then. Nevertheless, given the remarkably consistent moderate-sorted to moderately well-sorted nature of the sediments at these sites, this paper argues that these areas have been characterized by consistently high energy since initial flooding. That is, rather than a "blow out" event that reduced the sheltering effect of a formerly taller frontal reef segment, the grain size data imply that the reef crest seaward of these core sites never grew to the height observed in the adjacent, western reef crest segments.

Strong lithological differences in the down-core grain size patterns is clearly correlated with the variation in energy levels between the low wave energy western part of the lagoon and the higher wave energy eastern side of the lagoon. Cores SC 03, SC 09, and to a lesser extent SC 04, show that this has been most pronounced for the last 2000 years. These cores appear also to record a background change in sedimentation due to the gradual slowing of the rate of relative sea-level rise during the last 7,000 years in this region. During the earlier interval, when rising sea level caused water levels over the core sites to become deeper, the increasing water depth gradually reduced wave energy and produced the observed fining upward trend. An alternative interpretation of the fining upward trend in the earlier part of the record is that the development of the reef and its sheltering effects on the lagoon reduced wave energy levels. In either scenario, however, as sea level rise slowed and/or the reef crest stabilized and ceased to build upward, sedimentation in the lagoon ceased its upward fining trend, and became more variable. This part of the record should theoretically be more responsive or more sensitive to short-term changes in energy levels, e.g., during major storms. It is unclear what the peak in grain size around 2000 ya represents however it is theorized in this paper that it represents some large-scale event that further delayed reef accretion relative to the western portion of the reef.

PALEO-TEMPESTITE CHRONOLOGY

Using magnetic susceptibility and terrigenous gravel fractions, a low-resolution paleo-tempestite chronology has been developed. Prominent intervals of greater than average terrigenous influx to the lagoon are shown in most of these data sets at roughly 1500, 2800-3100, 4100, 4500-5000 and 5400-5800 years before present.

Figure 4 shows the magnetic susceptibility data and gravel fractions of the Smugglers' Cove cores compared with the reconstructed timeline of intense hurricane landfalls in Puerto Rico (Donnelly and Woodruff, 2007). The data presented generally agree with the Donnelly and Woodruff (2007), record, particularly in the intervals around 1500 and 4100 years ago and to a lesser extent around 4500-5000 years ago. Given the low temporal resolution of the Smugglers' Cove data, its not certain whether these records are showing the same major hurricanes or episodes of enhanced storm intensity or frequency. The data presented, however, leads the author to strongly recommend further study in this area using the methods proven successful in this study at higher resolutions.

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