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Keck Geology Consortium: Projects 2007-2008
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SHELL BED FORMATION IN THE SUB-FOSSIL RECORD: USING MOLLUSCAN ASSEMBLAGES TO DISTINGUISH BIOTURBATION LAGS FROM STORM CONCENTRATIONS

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INTRODUCTION

Molluscan assemblages from sediment cores in Smuggler's Cove, St. Croix (USVI) represent Holocene paleo-environments present since the lagoon formed at least 7000 years ago. Three distinct environments exist on the surface at present: open sand with *Callianassa* shrimp mounds, seagrass (*Thalassia*) beds, and sandy areas containing neither *Callianassa* mounds nor grass (termed "blowouts" below). According to Hubbard (1989) distribution of sub-fossil assemblages may be diagnostic of specific depositional regimes. Near-surface molluscan assemblages within the lagoon environments of Smuggler's Cove have been compared to sub-fossil assemblages within thirteen sediment cores taken along transects in the same area (Figs. 1 and 3, Hubbard et al. this volume). Changes in individual cores are correlated between cores to assess major events and changes in sedimentological regimes influenced by Callianassa and storm events within the lagoon.

Shell lags, concentrated deposits of shelly skeletal material, are common sedimentological events in the marine rock record. A critical part of this research involves determining the different mechanisms of shell lag deposition within the lagoon. *Callianassa* shrimp move massive quantities of sediment during feeding and burrowing, ejecting fine grains to the surface. Coarser-grained material, mainly shell debris and coral fragments, is stored in chambers 1.5 m or more below the surface, erasing primary depositional structures within the sediment. These Callianassa burrows produce alternating layers of coarse shell lags and fine muds (Suchanek 1983).

Primary depositional features also are altered when large storm events occur, (e.g., Hurricane Hugo in 1989) causing strong currents, sediment re-working, and grain transport. In addition to re-suspending fine muds, these storm events can mobilize, transport, and re-deposit mollusks and other skeletal debris into layers of shell known as tempestites. Molluscan skeletal samples collected by Miller and others (1992) prior to and following Hurricane Hugo revealed that, although spatial patterns associated with environmental zones were not disturbed significantly, the importance of shell material from exotic species increased by ten percent. Consequently, storm events, while subtle, may be distinguished in the Holocene record. However, the recognition of critical differences between *Callianassa*-derived shell lags and shelly tempestites caused by storms has yet to be explored and is crucial for high-resolution paleoenvironmental reconstruction of shallow-water Caribbean environments.

METHODS

Thirteen sediment cores were collected across Smuggler's Cove in three main environments: Thalassia grass beds, open sand with *Callianassa* mounds, and sandy "blowout" sections. Cores were also recovered from transitional sites. Cores were recovered using a hydraulically driven vibro-core. A commercial cement vibrator, connected to a hydraulic motor on board a boat, was lowered into the water and attached to a section of 3-inch (diameter) aluminum pipe 4.57m in length. All coring was done underwater using SCUBA. Recovered core length varied from 1.02m to 3.48m. Sediment thickness was determined by probing at each core site and along a transect across the lagoon using a thin metal rod 4.0 meters in length, beginning near shore (northeast of core SC 10: Fig. 3, Hubbard et al., this volume), and extending across the lagoon to the back reef environment of Tague Reef. Core locations were determined using a handheld GPS receiver.

Cores were examined macroscopically on shore to identify major components: mollusk species, corals, organic matter, and overall grain size of siliclastic and carbonate material. Each core was photographed and described in a stratigraphic column before being sampled. The first 8-cm of sediment was collected and retained for grain-size analysis, and the next 12-cm was sieved using a 2-mm sieve. All constituents collected in the sieve were retained and the fines discarded. The remainder of each core was sampled in this manner, alternating between collection of 8cm of sediment and 12cm of sieved material. Each 8-cm interval was sieved at 0.5-phi intervals in the lab at Oberlin College to determine mean grain size and sorting. Mollusks from the 12-cm intervals and the bottom 30-cm of each core were identified to species level.

Two surface samples were collected at each coring site using an airlift powered by a SCUBA tank. The airlift collected surface sediment into a bag, much like a vacuum cleaner. A 5-mm mesh bag attached to the top of the airlift collected large allochems while eliminating the lime mud and sand. Each airlift sample was taken from a 0.5x0.5m quadrat placed near the coring location. Mollusks were separated from grass and other debris and the species assemblage was identified. Fauna from these known modern environments were then available for comparison with mollusk assemblages within the cores.

Cluster analysis using the program PCOrd was used to test for similarities between mollusc assemblages and depositional environment. PCOrd groups samples together based on similarities, not differences, of the constituents in a sample. Data presented here are based on presence-absence of species in each sample; species abundance is not taken into account.

To reduce the number of samples, increase sample size volume to more accurately equate the surface airlift samples to the core sample, and to observe clearer clustering patterns of the core sections samples from each core were divided into three sections. The sections included (1) the top of the core, including sections 8-20-cm and 28-40-cm (2) middle of the core, including 48-60-cm to the bottom 30-cm of the core (differed for each core) and (3) the bottom of the core, including the bottom 30 cm of the core and the additional shell lag.

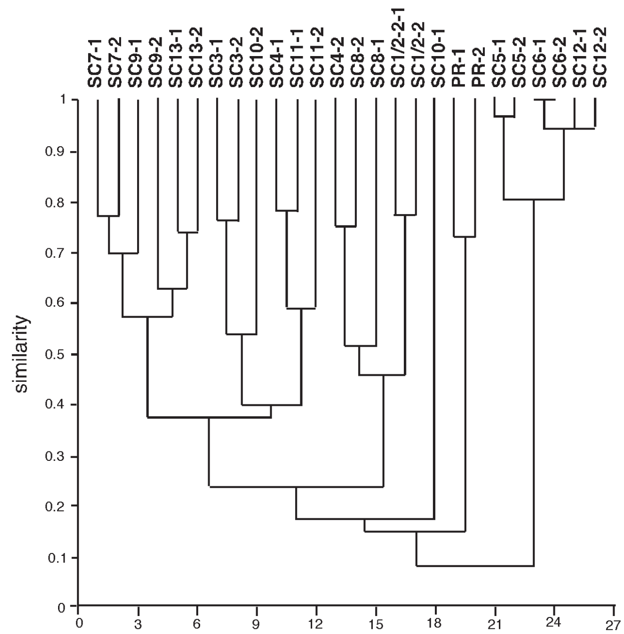

Figure 1. Cluster dendrogram based on species level differentiation of molluscan assemblages found within the surface airlifts taken at each coring location. Multiply similarity measure by 100 for percent similarity. Two additional airlifts were collected on a Patch Reef (refer to Fig. 1 Hubbard et al. this volume for location). Environment associated with each sample location is included in Table 1.

RESULTS

Samples with similar molluscan assemblages (identified to species level) clustered together. More specifically, surface airlifts taken in comparable environments clustered together (Fig. 1 and Table 1); samples taken in carbonate sandy blowouts have similar molluscan assemblages to the other carbonate sandy blowout environments, while samples taken in *Callianassa* mounds group with the other samples from *Callianassa* mounds, etc. Analysis

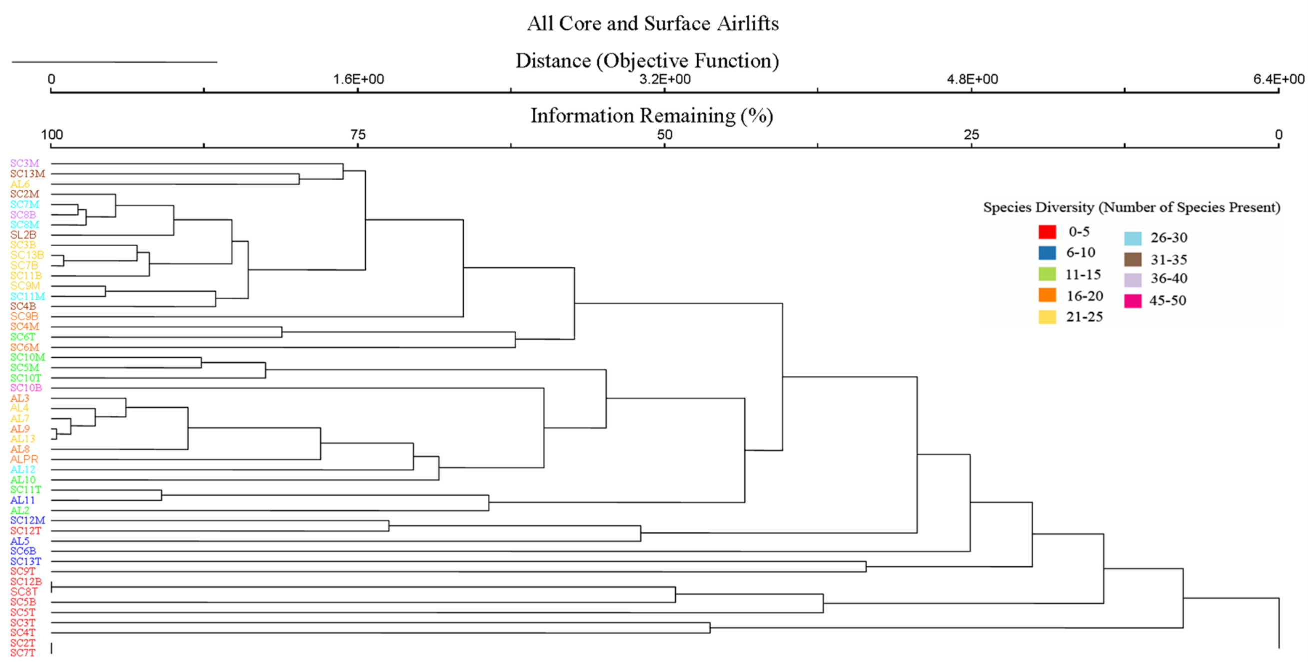

Figure 2. Cluster dendrogram based on species level differentiation of molluscan assemblages. Cores are individually labeled as SC and number and T, M, or B, referring to top, middle and bottom respectively. The color of each core or airlift section corresponds to the diversity of species present in that sample.

shows that the airlift surface samples taken at each core location contain significantly different molluscan assemblages than those found deeper in the cores (Fig. 2), however, samples within different cores correlate. Middle sections of the cores taken at different locations (surface environments) and depths in Smuggler's Cove are similar to other middle sections of cores collected across the lagoon. .Individual samples consist of anywhere between zero and forty-seven different species (Samples are coded for their species diversity by colors in Figure 2). Similarity cluster analysis not only grouped samples based on the similarity of the identity of species, but also seemed to incorporate the total number of different species (diversity) within samples into the way it grouped samples.

Core Number	Environment
SC 1 and SC 2	*Callianassa* mounds
SC 3	*Thalassia* beds
SC 4	*Thalassia* beds
SC 5	Sand Blowouts
SC 6	Sand Blowouts
SC 7	*Callianassa* mounds and *Thalassia* beds
SC 8	*Callianassa* mounds and *Thalassia* beds
SC 9	*Thalassia* beds
SC 10	*Thalassia* beds
SC 11	*Callianassa* mounds and *Thalassia* beds
SC 12	Sand Blowouts
SC 13	*Thalassia* beds

Table 1. Surface environment at each core location.

Substantial lags in the upper section of the cores did not exist. Shell "beds" ranged only a few shells in thickness, however, most cores penetrated to a shelly lag in the bottom twenty to forty centimeters (Fig. 3). Rare species provided a means to differentiate between tempestites and shell lags due to *Callianassa* burrowing. Species were considered to be rare if they appeared in three or fewer samples (Table 2).

DISCUSSION

Molluscan assemblages unique to the surface samples and seemingly not found in the subsurface may be due to invasive species introduced to the modern environment through alternative transport mechanisms, such as boats. The surface assemblages collected from environments of *Thalassia* beds, *Callianassa* mounds, and sandy carbonate blowouts

Rare Genera

Sample	Genera (number of times seen in all samples)
SC2. 88-100cm	Agriopoma (1)
	Batillaria minima (2)
SC2.188-200cm	Diplondonta (3)
SC3. 88-100cm	Diplodonta (3)
SC3.228-240cm	Anodontia (2)
	Diplodonta (3)
SC4. AL4.2	Astraea (3)
SC4. 8-20cm	Cantharus cancellarius (1)
SC4. SL4	Baliya (1)
	Prunum (1)
	Batillaria (2)
SC6. AL6.1	Rissonia (3)
SC6. 28-40cm	Zebina (1)
SC6. 68-80cm	Sinum (1)
SC8. AL8.2	Arca (2)
SC8. 148-160cm	Arca (2)
SC9. AL9.1	Andodontia (2)
SC10. 88-102cm	Mactra (1)
	Pseudochama (2)
SC10. SL10	Petricola (1)
	Astraea (3)
	Pseudochama (2)
SC11. 288-320cm	Eudolium (1)
SC12. 8-20cm	Lottia pustulata (1)
SC13. AL13.2	Astraea (3)
SC13. 8-20cm	Vermicularia (1)
SC13. 68-80cm	Rissonia (3)
SC13. 108-120cm	Coralliophila (1)
	Rissonia (3)
SC13. 288-300cm	Dosina (1)
SC13. 288-300cm	Rhizorus (1)
SC13. 308-320cm	Cyclostremiscus (1)

Table 2. Below are listed the rare genera present in the samples, the sample in which they were found, and the number of samples in which they appear. A genus is considered rare if it appears in 3 or fewer samples.

Figure 3. Shell lag (72-102-cm) from bottom of core SC10 (See Figure 3, Hubbard et al., this volume, for location).

cluster according to their present, modern environment (see Figure 2), indicating that different environments are distinctive with regard to specific species. Assemblages within mixed *Thalassia* beds and Callianassa mounds represent transitional regimes between respective environments, and will cluster with assemblages found in a variety of surface environments.

Samples containing a higher degree of species diversity cluster together at greater levels of similarity. Samples containing zero to five different species (shown in red in Fig. 2) are not as similar to each other or any other clusters than the samples with higher species diversity, i.e. samples containing fifteen to twenty species (orange) and twenty-one to twenty-five species (yellow) as seen in two discrete clusters the first of which contains samples SC3B, SC7B, SC11B, and SC13B, all of which are the bottom sections of cores found in either Thalassia beds or mixed Thalassia and Callianassa beds, and the second contains airlift samples from core locations 3, 4, 7, 8, 9, and 13. Interestingly the clusters are centered on the sample containing the highest amount of diversity, SC10B.

Correlation of molluscan assemblages within the cores shows evidence of the progression of environments throughout the lagoon. Assemblages of the middle section of SC7 correlate with the bottom section of SC8 at a 95% similarity indicating a common environment of deposition at differing levels in the lagoon. The contour of the lagoon is not uniform (Fig. 4 in Hubbard et al., this volume) indicating that this sample was not deposited simultaneously in these cores.

A high percentage of similarity between molluscan assemblages is seen in different samples throughout the cores, representing similar depositional environments. The middle sections of SC5 and SC10 and the top section of SC10 all correlate at 80% similarity. The surface environment of the two cores is different; SC5 was drilled in a sandy carbonate blowout while SC10 was taken near shore in dense Thalassia beds. In addition to having similar molluscan assemblages the core sections have similar species diversity with all three sections containing ten to fifteen different species.

Shell lags below both *Callianassa* burrows and other lagoon environments differ from the normal or "background" sedimentary processes and, therefore, differ from surface shell accumulations in *Thalassia* seagrass beds, sand blowouts, and transitional environments. Environmental data is used not only to identify geographic shifts among key environments through the Holocene, but also to identify the differences between native mollusk assemblages versus those with exotic rare shells transported into the lagoon by storm events.

SC10, the shortest core and the core taken nearest to shore in Thalassia beds, is characterized by over forty centimeters of shelly hash at the bottom of the core. The shell lag and final section of the core both contain rare species that appear in less than three other samples. These genera, including Mactra fragilis, Pseudochama radians, Petricola pholadiformis, and Astraea phoebia, are all commonly found in shallow marine environments but not in the airlifts or other sections of cores. The variation may be due to local extinction of these species or storm activity because the assemblages do not resemble molluscan assemblages characteristic of *Callianassa* deposits.

Not all cores with substantial shell lags contained rare species, the shell lags can also represent average lagoon shell material accumulation. The bottom remainder of cores 3, 7, 11, and 13 cluster together at a high measure of similarity to each other and to middle sections of cores at a 80% rate. This might be expected if it is a lag produced over time by bioturbation or by concentration of local shells during storms. At this time it is difficult to differentiate between the possible mechanisms of secondary deposition. However, the bottom section of SC10 stands alone in the cluster analysis, only clustering with other sections of samples at less than 60% similarity. Considering the abundance of rare species, high species diversity, and distinctive clustering pattern, it is most-likely that this lag represents a tempestite.

CONCLUSIONS

The differences between tempestites and shell lags created by *Callianassa* shrimp activity have gone unrecognized; studying modern mollusk assemblage distribution enhances recognition of specific shell lag deposits, and thus fine-scale environmental events in the rock record. This study showed that the fauna present today at the surface of a tropical lagoon are poorly represented in the subsurface sedimentary accumulation. The typical high diversity assemblage at the surface drops to low diversity assemblages that occur in poorly defined shell beds at best. Cores show a return to higher diversity assemblages in shelly lag accumulations at the bottom near, or lying directly over, the Pleistocene bedrock. These lags may reflect accumulated lags produced over the history of sedimentation in the lagoon by deep-burrowing shrimp in environments where shrimp are active. Elsewhere, the lags may represent tempestite deposits and/or the presence of deep bioturbation in the past. The recognition of shell lags deposited by biotic versus abiotic processes is applicable to deep time paleoenvironmental reconstruction.

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