Bioturbation of Carbonate Reef Sands

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Time-lapse photography and sediment analyses were used to compute the rate of sediment reworking by *Balanoglossus*, *Holothuria*, and *Callianassa* in a carbonate sand backreef environment. Burrowing organisms disrupt the stratigraphy of sediment deposits and may mix relatively young and old sediment, making interpretation of the geological history of sedimentation difficult. The extent of mixing and the resulting changes are important factors in geological interpretation. The patterns left by different animals are unique and may themselves be useful in interpretation of ancient environments.

*Balanoglossus* and *Holothuria* ingest the sediment to obtain nourishment. *Callianassa* displaces the sediment both in feeding and in burrow construction and builds an elaborate burrow system that may be more than a meter in diameter and a meter deep.

The study site, Enrique reef, is approximately 800 meters long and is aligned approximately east-west (Figure 1). It is on a shallow carbonate shelf that averages 18 to 20 meters deep except for reef areas. The diurnal tides of the southwest coast of Puerto Rico are less than 0.25-meter amplitude, allowing a distinct zonation of coral species and definite stable zonation of the environment. Sessile organisms in the shallow reef apron benefit because they do not have the stress of exposure at low tide. Waves approach Enrique reef from the southeast and wash over it, assuring mixing on the reef apron that prevents marked temperature or salinity differences. There is a low velocity current system over the reef.

Figure 1. La Parguera shelf bathymetry and geological environment of study area
Saunders and Schneidermann \cite{saunders:1973} divided the area from the shore to Enrique Reef into six environments on the basis of physiographic position, gross sediment type, and characteristic bottom communities. The bioturbation was done in the environment that they describe as reef apron, which is a shoal area of sand deposition lying leeward of the living coral-reef structure. The maximum width of this zone is 200 meters and the water depth varies from 0.3 to 3 meters. The reef apron is bordered on the south by the Porites reef flat and the reef structure and on the north by a barren lagoon and slope. The lagoonal bottom is dominantly silt and clay. The slope of approximately 25° between the lagoon and apron is medium- to coarse-grained sand. There is extensive burrowing activity on this slope.

The sand apron is thoroughly reworked by burrowing organisms. The topographic lows between burrows are filled with coral rubble, whole shells, and some silts. The reef apron can be divided into three zones: barren sand, coral patch reef, and *Thalassia* meadows (Figure 2).

![Figure 2. Zonation of the Enrique Reef apron](image)

The *Porites* flat is discontinuous across the length of the reef. It consists of dense colonies of *Porites porites* with adjacent areas of coral rubble and clumps of *Halimeda*. (Morelock et al., 1977).

Time-lapse underwater photography, underwater observations, sediment collection, and aquarium studies were used to compute the rate of sediment reworking and to observe its effects. The time-lapse sequences were taken with a 16-mm camera in a Sea Research and Development Underwater Housing (Figure 3).

![Figure 3. Underwater time-lapse movie camera set up in an area of Holothuria burrows](image)

Night sequences were shot with movie lights powered by two 12-volt car batteries modified for submersion. These were pulsed by the time-lapse system. Periods of sediment reworking and frequency were computed from frame by frame examination. These data were combined with collection and weighing of sediment deposited by *Callianassa* during a 24-hour period and by removal and weighing of sediment in the digestive tracts of *Holothuria* to obtain accurate values.
A population survey of *Balanoglossus*, *Callianassa*, and *Holothuria* was made, and as the following tabulation shows, *Callianassa* is the dominant burrowing organism (Table 1):

**Table 1. Population survey**

<table>
<thead>
<tr>
<th>Organism</th>
<th>Individuals per square meter</th>
<th>Grams of sediment reworked per day</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Callianassa</em></td>
<td>1.9</td>
<td>120</td>
</tr>
<tr>
<td><em>Holothuria</em></td>
<td>0.23</td>
<td>34</td>
</tr>
<tr>
<td><em>Balanoglossus</em></td>
<td>0.1</td>
<td>280</td>
</tr>
</tbody>
</table>

An individual *Callianassa* reworks an average of 120 grams of sediment per day, and *Holothuria* and *Balanoglossus* rework 34 and 280 grams per day, respectively. Based on the population density and rates of reworking, the reef-apron sediments could be completely reworked in 17 years to a depth of at least 1 meter.

*Callianassa* is present in all parts of the reef apron but has a higher concentration in the sand and coral areas (Figure 4). *Holothuria* are almost exclusively in areas with a *Thalassia* bottom. There were very few *Balanoglossus* burrows present, and all were in sand areas. In the Thalassia meadows, the densities of *Holothuria* and *Callianassa* populations were the same, 0.76 individual per square meter, but because of the difference in rate of sediment reworking, *Callianassa* is responsible for 78 percent of the reworked sediment.

**Figure 4. Location of Holothuria and Callianassa burrowing activity on Enrique**

The extrusion of sand from the excurrent opening of the *Callianassa* burrow is frequent, but the mounds reach a limiting maximum size owing to wave forces. The size of the mounds varies across the reef apron in direct relationship to measured wave forces. The development of *Callianassa* mounds and rate of mound building were studied by leveling a 4-meter-square area, which was observed, photographed, and measured over a 3-week period following the leveling. The leveled area was largely rebuilt after only 4 days, but was still distinguishable from the surrounding mounds. By the end of 19 days, no difference could be distinguished between the leveled area and the surrounding undisturbed mounds. The mounds that appeared after leveling were the result of normal daily activity of the animals that were already occupying the underlying burrow system. This demonstrates that the mounds are continuously replenished with sediment and are not just the product of construction of the original burrow.

Disruption of strata by burrowing *Holothuria* was studied in partitioned aquaria that were floored with an alternation of light and dark sediment layers. The maximum depth of sediment disruption was 15 centimeters. The disruption varied from bending of the sediment layers to complete mixing of particles (Figure 5).
Figure 5. Disruption of sediment stratification by Holothuria burrowing activity

As the following tabulation of grain and sediment characteristics shows, the mean grain size of reef-apron sediments is relatively uniform except for material from Holothuria mounds, which are composed of significantly finer sediment. The Holothuria are either selectively choosing smaller grains to ingest or reducing the size of grains that pass through the digestive tract. Since these are carbonate sediments, the pH of the tract may be sufficiently acid to cause grain-size reduction. To test this possibility sediments were collected and screened through a 0.50-millimeter and a 0.35-millimeter pair of sieves to obtain a uniform sand with a range of 0.35- to 0.5-millimeter diameter. This sand was used to floor an aquaria occupied by Holothuria.

Comparison of the amount of sediment by weight in each of the sieve classes for reworked and control samples of this sediment shows that Holothuria reworked material contains comparatively less sediment in the larger-sized classes and more sediment in the classes smaller sized than the control sample (Figure 6). This strongly suggests that size reduction has taken place during a relatively short period of sediment reworking.

Figure 6. grain size changes after Holothuria residence in sand tank

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