RECOGNIZING TILEFISH MOUNDS IN THE ROCK RECORD: IMPLICATIONS OF SAND ACCUMULATION TO THE FOSSIL RECORD

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INTRODUCTION

The creation, transportation, and deposition of sediment in a reef system differ from other marine environments. The sediment of reef systems is typically generated *in situ* through biologically and chemically induced precipitation and bioerosion. Sediment transport is controlled by both the activities of certain fauna and by local currents and waves. We studied the difference between mechanical movements of oceanic sediment versus the biological transport of clasts by the sand tilefish, *Malacanthus plumieri*. This species of tilefish builds nearly horizontal dwelling-mounds using various types of clasts (see, Leven and Waldron, this volume) on sandy flats near reef systems in areas of both calm water and migrating channels. The clast-gathering behavior of this fish (see, Diggins and Feucht, this volume) facilitates the trapping of sand deposits and helps shape reef environments. This paper will identify the likely fabrics contained within and around modern tilefish mounds by studying sand size and composition data collected in transects across these mounds. The identification of characteristic features will allow for the recognition of ancient tilefish lebensspuren in the rock record.

Methods and Analyses

Using SCUBA, a total of 21 tilefish mounds were investigated and 126 sediment samples taken from eight different dive sites. The northernmost collection site in the study was located on Villa Blanca Reef (20º29"17.6'N, 86º58"7.3'W), and the southernmost site at Paso del Cedral Reef (20º22"8.2'N, 87º01"39.9'W). Mounds were selected based on their size, location, depth and distance from the nearest reef system. Five groups composed of two researchers each collected data.

Groups 1 and 2 collected mound data using a 0.25 m^2 grid with crosshairs spaced 10 cm apart. Groups 3 and 4 gathered data along a mound-centered north/south transect line with a 0.25 m^2 grid divided into quadrangles. Groups 1 through 4 identified clasts within their grids and recorded the long, intermediate, and short axes of the random samples with standard calipers. Group 5 used a 2.5 cm diameter tube to gather 15 cm sediment samples along each transect line at 2.5 m, 5 m, and 12 m, due north and south.

Mound sediment samples were transferred to Ziploc Baggies and transported to shore. Fifty-seven wet samples were sieved using a US Standard Sieve Series to retain particles of pebble (≥ 4 mm; -2 phi) through very fine (≥ .0625 mm; 4 phi) size. Samples were dried and weighed on site for later analysis where -2_ and -1_ fractions of all samples were macroscopically viewed for content, and several full-series sediment samples were examined with a light-refracting microscope. A scanning electron microscope (SEM) analysis was also performed on one of the samples. Statistical data was analyzed, graphed, and augmented with digital photos taken at each dive site.

Sediment Analysis

Sample 22-02 contained foraminifers in all phi fractions (-2_ to 4_). The coarsest fractions (-1_ and -2_) contain whole segments, large fragments, and holdfast remnants of skeletal *Halimeda*. Every phi fraction contains shell fragments of various kinds; most often classified as either bivalve or gastropod. Fragments of worm tubes and casings are in the -1 to 1 phi range. Coral fragments are the major component of all phi fractions, but *Halimeda* fragments are also present. The 0_ fraction shows grains with possible rasping marks (Frydl and Stearn, 1978; Ogden, 1977) of unknown origin. The smallest fraction (4_) contains curved grains that may be shell fragments, or possibly, grains produced by the boring action of sponges (Warme, 1977). Photographs from SEM in the 3_ fraction reveal a questionable holothurian, soft coral, or tunicate ossicle (Deichmann, 1954; Mankiewicz, personal communication). The majority of fragments in sample 2202 are angular in shape, regardless of their phi size (Fig. 1).

Statistical Analysis

Site photos were used to determine the degree to which mounds were trapping agents. Of the 21 mounds in this study, four showed strong accumulations of sand and five showed slight sand covering. The remaining mounds lacked significant sand accumulation and displayed a clast-supported matrix. The randomness of sand-covered tilefish mound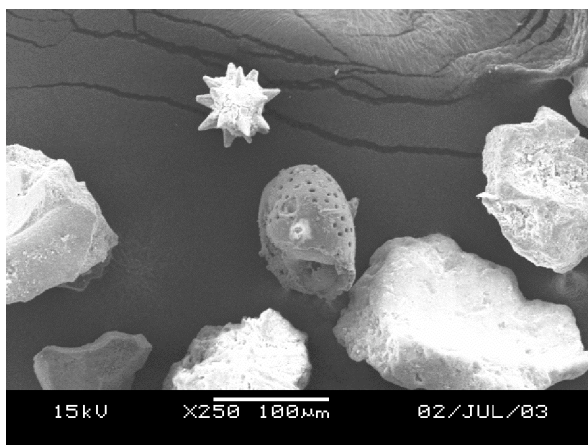s was found using Poisson (P) and Chi Square ($\_^2$) test of independence. The calculated value of $\_^2 = 72.44$ exceeds the 95% confidence level and is well beyond the critical value for the 0.005 confidence level at 7.879, indicating a significant difference between the observed and expected frequencies of Poisson's distribution of randomness.

Histograms of grain size with either normal or positive skewness distributions are most often from samples taken from clast-supported mounds and northern locations (Fig. 2a). A slight negative skewness (mode of 2_) is typically inferred at sites of active sand accumulation and most southern locations (Fig. 2b). Additionally, histograms, site
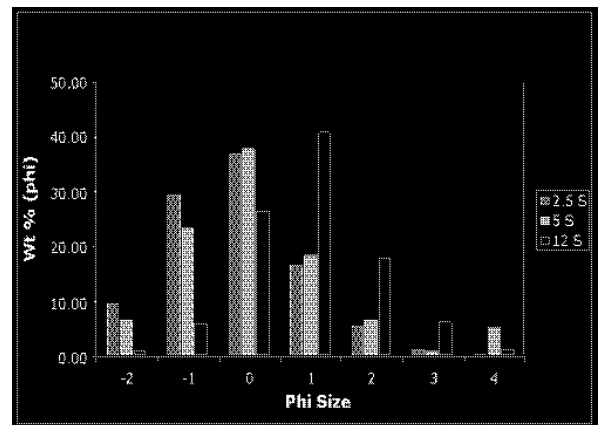
Figure 2a: Villablanca 1102. Histogram shows poor sorting and the high variance common between samples from a single transect line. The 12 meter-south sample shows a normal distribution, but closer to the mound, at 5 S and 2.5 S, samples are positively skewed. This graph is representative of many northerly dive sites, and sites of clast-supported mounds.

Figure 1: A scanning electron microscope image of 3_ grain size from sample 2201, Chankanaab Bowl. Image shows a variety of *in situ* grains.
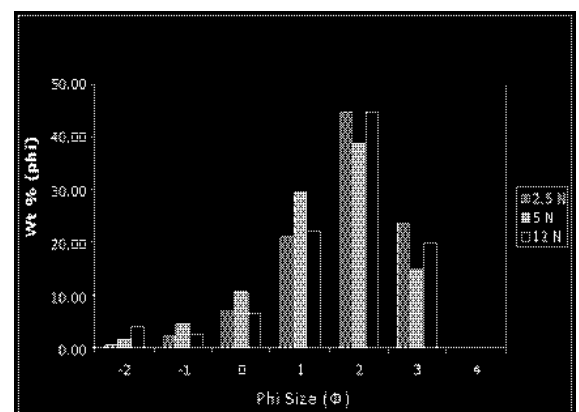
Figure 2b: Yucab 1802. Histogram shows poor sorting and a negatively skewed grain size distribution. Shape is typical of mounds located in areas near active sand channels. Hydrologic marine processes have selectively sorted highest percentiles centered on modes +1, +2, and +3.

photography, and dive logs show that the highest _ fractions in the pebble to granule size are observed at sites rich in living *Halimeda*, while the highest amount of very fine size fractions (4_) are from samples taken near areas of refracted wave energy and reduced current.

Figure 3a shows graphic phi means (Mz) and it indicates that transects of southern locations have higher percentages of grains in the very coarse to medium size range (0_ to 2_), and that transects from northern locations have greater percentages of very coarse to pebble size grains (0_ to -2_). The inclusive graphic means sorting (_I) of Figure 3b shows that 91% of the surviving samples are poorly sorted, regardless of location. While inclusive graphic skewness (Sk$_I$) in Figure 3c shows that 63% of samples are strongly coarse-skewed to coarse-skewed, 8% are near symmetrical, and 29% of the samples are strongly fine-skewed to fine-skewed. Interpretation of grain-size data is complicated because large variations commonly exist between samples from the same transect line (Fig. 2a).

RESULTS AND DISCUSSION

Malacanthus plumieri dwellings can gather sediment as calcareous sand migrates northward with the current across the terraces. Results of P and _^{2} tests show evidence that these sites are not randomly distributed, but clumped and localized to areas of active marine processes. In areas of slight
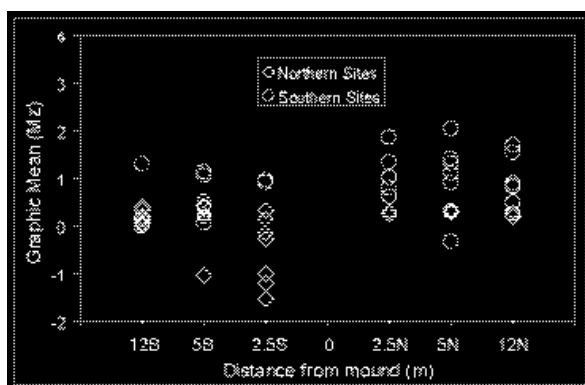

Figure 3a: Graphic grain-size means [Mz = _$_{16}$ + _$_{50}$ + _$_{84}$ / 3] of all 57 samples. Of the 29 samples from southern transect lines 21 were gathered at northern dive locations. The remaining 28 samples were gathered along north-strung transect lines and 21 of these came from southern dive locations.
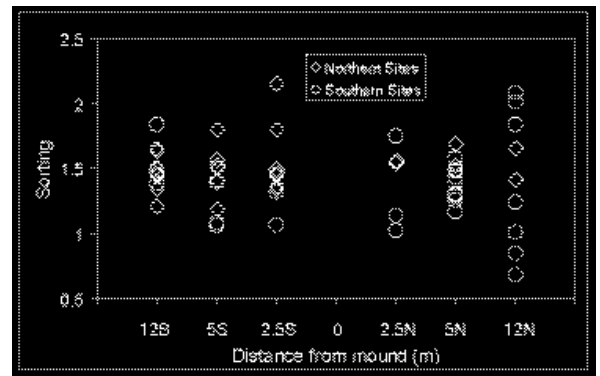

Figure 3b: Inclusive graphic standard deviation of all samples [_$_i$ = (_$_{84}$ − _$_{16}$) / 4 + (_$_{95}$ − _$_5$) / 6.6]. Sorting classification: 0.50 to 0.71_, moderately well sorted; 0.71 to 1.0_, moderately sorted; 1.0 to 2.0_, poorly sorted; and 2.0 to 4.0_, very poorly sorted. Graph shows majority of all samples (91%) are poorly sorted.
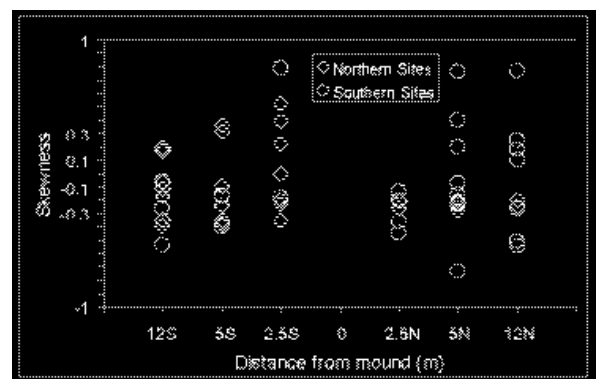

Figure 3c: Inclusive graphic skewness of all samples [Sk$_i$ = (_$_{16}$ + _$_{84}$ − 2_$_{50}$) / 2(_$_{84}$ − _$_{16}$) + (_$_5$ + _$_{95}$ - 2_$_{50}$) / 2(_$_{95}$ − _$_5$)]. Calculation includes 90% of area under curve for best determination of critical differences between right and left tails. Skewness classification: -1.00 to -0.30, strongly coarse-skewed; -0.30 to -0.10, coarse-skewed; -0.10 to +0.10, near symmetrical; +0.10 to +0.30, fine-skewed; +0.30 to +1.00, strongly fine-skewed.

accumulation, mounds have sand only on their southwest slopes, reflecting the current's dominant direction to the northeast. Petrologic examination of a fossilized mound from an environment such as this could have a textural fabric of calcareous grains similar to those shown in Figure 1. If so, then a sandy matrix will surround larger clasts of transported rhodoliths, corals and shells and be more developed on the up-current side of a mound. Conversely, mounds constructed in sheltered areas would lack this sandy matrix and display a clast-conglomerate fabric composed of fish-transported materials. Modal percentages of grain sizes found in the

matrix of tilefish mounds will therefore reflect mound position to ancient currents.

Most work in Cozumel was performed on the second terrace, and neither depth of mound or distance from reef system appears to be a determining factor for the presence or lack of sand accumulation at mound sites. However, areas of high wave energy and current velocity typically contained larger percentages of grains in the fine to coarse sand size, and lack significant fractions of very fine (4_) sand sediment (Fig. 2b). The highest percentages of 1_ to 3_ grain sizes may be reflective of wave fronts that bend into the coast north of Bahia Columbia and the many meandering counter-currents that run over the island's narrow leeward platform (Muckelbauer, 1990). Hydrologically driven marine processes provide good explanations for the grain-size distributions found at southern dive sites.

Grain-size distribution reflects processes and areas of reduced wave refraction and weakened or diverted currents can also explain the high fraction of very fine sand (4_) content, and poor sorting in general, observed in Figure 2a. At many northern dive sites grain-sizes show a grain-size distribution in the 0 to -1_ modal range. This pattern arises because sedimentation of a reef system is largely biokinetic (Clifton, 1973), and occurs where current and wave energy is typically low. Research from Cocos-Keeling, Bermuda, Panama, and Barbados have shown that biologically generated sediment, by parrotfish alone, ranges between 20 to 49 kg/ha, and that a parrotfish's gut-turnover occurs ~8 times a day (Frydl and Stearn, 1978). With the species richness seen in Cozumel, large amounts of sediment are contributed into a reef system. As a result, samples with either normal or positively skewed grain-size distributions are expected where suspended sediment accumulates. The areas of positive skewness with high percentages of -2 to -1_ sediment may reflect high abundances of *Halimeda*, with its short life span. These larger grains of skeletal *Halimeda* are most likely too heavy for saltation under local conditions, and are deposited *in situ*.

Muckelbauer (1990) suggested that mounds built by *Malacanthus plumieri* as dwellings "can function as a solid base for future patch reefs." Many tilefish mounds were observed by our group to serve as a mini-reef systems and nurseries (Clifton and Hunter, 1972), with new growth sponges and soft corals commonly colonizing the mound. If reef development occurs on tilefish mounds, future researchers should look for fossilized mounds, i.e., life marks or lebensspuren, at the base of fossilized patch reefs. For Cozumel, the examination of stratigraphy found around the few accessible outcrops and within the Island's limestone quarries is important if fossilized sand tilefish mounds are to be found here.

CONCLUSION

The southerly Gulf Current and biogeneration control sediment transport off the leeward coast of Cozumel. Sediment here is texturally diverse from south to north, and grain-size distributions within this reef system reflects site-specific marine processes and environments. The many types of flora and fauna found here create *in situ* accumulations of sand. In addition, certain types of fish selectively transport rubble and living clasts to chosen locations. The sand tilefish, *Malacanthus plumieri*, observed in this study is a major contributor of sediment transport and capture. Further study of this species will aid in the future interpretation of their mounds once found in the rock record.

The terraces of the Island's leeward shelf provide abundant supplies of building materials, sand flats, temperate waters, and food that supports *Malacanthus plumieri's* lifelong building behavior. Modal percentages of sand within a fossilized mound will reflect its position to paleo-coastlines and -currents. In areas of actively migrating sand mounds undergo burial at faster rates, and there should be a sandy matrix in lebensspuren from areas influenced by currents. Mounds from calm areas will lack a developed sandy matrix. It is our intent that the information presented here will assist others in the identification of exogenic trace fossils produced by *M. plumieri* and its predecessors.

ACKNOWLEDGMENTS

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