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Deep reef sedimentology: Impact on the structural sustainability of mesophotic coral reefs in the U. S. Virgin Islands

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Mesophotic coral ecosystems (MCEs), deep reef communities (30-150 m) found in low light, low energy environments (Lesser, Slattery, & Leichter, 2009), have recently recaptured the attention of the scientific community (Puglise et al., 2009) as a result of the global decline in the health of shallow water reefs (Gardner et al., 2003; Hughes et al., 2003) and the mesophotic refugia hypothesis (Glynn, 1996; Riegl & Piller, 2003). Often comprised of surprisingly high levels of coral cover (Bak et al., 2005; Smith et al., 2010), mesophotic reefs are valued as: (1) renewable sources of larvae that could contribute to shallow water reef resiliency (Hughes et al., 2003; Lesser et al., 2009); (2) locations with potentially high levels of undiscovered biodiversity; and (3) critical habitats for commercially important fish (Nemeth, 2005; Kadison et al., 2006). The study of mesophotic reefs could also serve as a valuable method for developing new, deeper reef carbonate facies models, given the successful application of comparative sedimentology towards modeling and predicting reservoir properties of shallow tropical reef deposits (Ginsburg, 1974; Wilson, 1975). Early mesophotic reef research focused on wall and slope ecosystems (Goreau & Goreau, 1973; James & Ginsburg, 1979; Hubbard, 1989; Grammer & Ginsburg, 1992). However, a few recent studies have shown that different types of MCEs exist and may be composed of a variety of distinct, geomorphic habitats (Armstrong, 2007; Smith et al., 2008), implying a high level of complexity, diversity and functionality.

While recent technological advances in deep sea diving have greatly increased the number of MCE biology and ecology studies conducted (Bak et al., 2005; Armstrong, 2007; Menza et al., 2007; Rooney et al., 2010; Smith et al., 2010), there remains a critical gap in the knowledge of MCE sedimentary processes, and how the variability of these processes affects the sustainability and architectural structural integrity of mesophotic reefs. There is also little understanding of how early depositional processes might affect key reservoir properties of ancient mesophotic reef deposits. Developing proper environmental management strategies as well as the ability to predict the reservoir potential of mesophotic reef deposits will require a fundamental understanding of principal mesophotic sedimentary processes, specifically bioerosion, sediment production, and cementation.

The *long-range goal* of my research is to identify the significance and variability of primary sedimentary processes involved in the development, maintenance, and preservation of mesophotic reef ecosystems, and at the same time contribute to the exploration of near-horizontal MCEs. The *objective of this research*, which is the next step in pursuit of that goal, is to determine how bioerosion rates and intensity, reef sediments, and cementation vary between structurally different MCE habitats and their shallow water counterparts. My *central hypothesis* is that variations in these three sedimentary processes result in differing levels of structural sustainability per habitat.

To test the central hypothesis and achieve my *long-range* research objective, I am pursuing two *specific aims* at each habitat: (1) determining the distribution of bioeroders and the total rate of bioerosion; and (2) categorizing sediment composition, grain-size distribution, and cementation. The working hypothesis for the first aim is that excavating sponges are the dominate macroborers in MCEs and that bioerosion rates, abundance distributions, and taphofacies will be significantly heterogeneous between the different MCE habitats. To test this hypothesis, I am characterizing and quantifying bore holes found in mesophotic coral rubble samples and calculating bioerosion rates by analyzing previously dispatched coral substrate disks that I collect annually. The working null hypothesis for the second aim is that no significant difference in sediment grain size and composition or cementation exists between the studied mesophotic habitats. To test this hypothesis, I will conduct grain-size and petrographic analyses of sediments from all sites and also examine reef cements in thin sections made from framework collected at each site.

The proposed research is *innovative* because no studies have examined near horizontal MCE sedimentology, specifically how sedimentary processes influence how MCEs should be managed and protected. My *expectations* are that the resultant approach will identify significant variations in bioerosion, sediment production, and cementation between different geomorphic MCE habitats. I also expect that the results will identify specific reef habitats with more substantial framework accretion potential. These results will be *significant* because they will provide a new level of knowledge into mesophotic geology and in turn will supply future researchers with important data needed to help assess the complete functionality, preservation potential, and reservoir properties of MCEs. The study will also continue to increase awareness of mesophotic reefs.

Background

Bioerosion is a fundamental process that plays a critical role in the modification of reef environments through the redistribution of calcium carbonate (Kiene & Hutchings, 1994). The significant role bioeroding organisms play in modifying the carbonate budget of a coral reef (Scoffin et al., 1980) implicates the bioerosional process as a primary control on reef accretion, destruction, and preservation (Hutchings, 1986). Given the importance of bioeroders in reworking reef material, there exists a vital need to study how bioerosion affects the development of different benthic habitats in a reef, the overall structure of an autonomous reef ecosystem, and the amount of reef material that can potentially preserve as structure-forming framework (Kiene, 1988).

Reefs are unique depositional systems primarily comprised of allochthonous sediments. The analysis of this sediment is useful for resource managers, providing a bioindicator to evaluate ecosystem health (Daniels, 2005). Sediment analysis is also used to identify the heterogeneity of energy regimes in the reefs, and quantify sedimentary contributions to the carbonate budget. With over half the original carbonate material of a reef transformed into sediment by bioerosional processes (Stearn & Scoffin, 1977; Hubbard et al.,1985), sedimentation and bioerosion are intricately linked. Sediment (matrix), *in situ* framework, and cement constitute the three main sedimentary components that provide reefs with the structural support that makes them such vital ecosystems (Riding, 2002; Hubbard, 2008). Along with bioerosion, these components not only help to define and control the architectural integrity of a reef, but help dictate the preservation potential of the reef complex.

Methods

With a ban on benthic fishing and anchoring, and with collaborator support from colleagues at the University of the Virgin Islands, the Hind Bank Marine Conservation District and Grammanik Bank provide ideal, easily accessible locations to study the depositional environment of a MCE. Located approximately 11 km south of St. Thomas, U.S. Virgin Islands, these highly representative near-horizontal banks contain distinct MCE habitats identified based on bathymetric geomorphic classifications and biological differences (Smith et al., 2008). Five mesophotic sites were chosen for this study: (1) primary high bank (127`); (2) deep patch (135`); (3) secondary high bank (111`); (4) hillock basin (138`); and (5) flat basin (142`). Three other sites in close proximity to the mesophotic sites were included to provide a shallow water comparison: (6) mid-shelf patch reef; (7) shallow patch reef; and (8) fringing/patch reef.

The inherent nature of this study is potentially hazardous because of the deeper depths and extended bottom times needed to complete research tasks. To ensure safety, all divers were certified in first-aid and completed advanced diver training courses at the University of Miami (UM) for technical decompression and tri-mix diving, following the standards set by the American Academy of Underwater Sciences (AAUS). Divers are equipped with Halcyon SCUBA gear fitted with double tank air cylinders filled with a tri-mix gas and a small decompression cylinder filled with 50% oxygen, intended for required decompression stops. All dives are conducted in pairs following a pre-planned conservative dive profile from a 30´ vessel that has passed all safety guidelines and is stocked with all required life-support equipment.

-Bioerosion and Growth Rates

To obtain time-averaged abundance macroboring distributions, divers collected 5 to 8 random-sized coral rubble samples at each site. For studying long-term bioerosion rates, coral substrate disks were cut from pristine *Montastraea faveolata* cores. After drilling a hole through the center, disks were numbered, weighed, and photographed. Twelve disks were mounted to each PVC quadrant with nylon bolts. Due to a limited supply of coral substrate disks, all sites except the deep basin and the shallow patch reef were chosen for PVC quadrant deployment. In August 2010, divers used reinforced steel to attach 3 quadrants to the seafloor approximately 10 m apart, at each site. Three random disks from each quadrant are scheduled for collection once a year for 3 years. The last set will be collected after 10 years, providing one of the longest bioerosional data sets available for future study of long-term bioerosion in mesophotic reefs.

All coral rubble collected were left to dry in the sun over the course of 2 days. The samples were then cut into slices parallel to their assumed growth axis with a rock saw. Digital photographs were taken of each smooth cut surface. Spatial coverage and relative abundances of macroborings within each sample were calculated through point-count analysis on 3 slice surface photographs per sample using CPCe V3.6. Macroborers and their borings were identified using published descriptions (Pang 1973; Rützler, 1974; Bromley, 1978; Rice & MacIntyre, 1982; Scott, 1988; Perry, 1998, Macdonald & Perry, 2003). Preparations for a publication describing the results and implications of this part of the study are currently underway.

The first collection of substrate disks occurred in August 2011. Collected disk samples were first soaked in a weak bleach solution, dried, and weighed. The top and bottom of each disk were photographed to calculate changes in surface areas. Next, the disks were cut through the middle hole into 8 triangular slices. Each cut surface was photographed for image analysis using Adobe Photoshop and NIH image J to calculate the surface area of all borings. Grazing was calculated by measuring the change in surface area of each slice surface from the original dimensions. The same methodology will be used for the remaining substrate disks yet to be collected. Following the methodology of Kiene (1998), data from each collection period will be saved and used to calculate total bioerosion rates and rate changes for each site location.

-Sediment and Cementation

To study reef sediment variability, divers scooped the top 2 to 3 cm of sediment at random points at each site into plastic labeled jars. Additionally, divers used a hammer and chisel to remove underlying coral framework. Sediments are being analyzed at the University of Miami following standard wet sieving techniques (Folk, 1974). Subsamples of the bulk sediment from each site will be mixed with epoxy to create thin sections that will be analyzed using an Olympus BH2 series microscope. Using point-count analysis, grain composition will be quantified. Thin sections will also be made from the collected framework and examined under a microscope to determine the types of cement found in the reef framework at each site.

Conclusions

Reef architectural integrity is primarily dependent on bioerosion, cementation, and sedimentation. Therefore, studying the variability of sedimentary processes is fundamentally important when considering the sustainability of coral reef ecosystems. The results from the coral rubble section of this study identify distinct preservation zones (taphofacies) at different deep reef habitats. These taphofacies may eventually be utilized to better understand the degree of structural and habitat complexity and diversity of ancient reefs preserved as geological limestone deposits. The completion of the rest of this study will provide previously unknown insights into the principle structural components of near-horizontal MCEs, greatly advancing our understanding of the importance and ecological potential of these deep reefs.

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