MARINE BORING OF CARBONATE HARD SUBSTRATES ON SAN SALVADOR ISLAND, THE BAHAMAS

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The exposed intertidal and subtidal inorganic carbonate hard substrates on San Salvador Island are extensively bored by a variety of organisms. A study was conducted at four different modern boring environments found on the island. The macroscopic and microscopic features of each identified boring type were described with the purpose of eventually comparing these observations to those from the fossil record. In modern hard substrates the soft-body anatomy of each borer is still intact and can be used to decipher the boring mechanism. Hard substrates also offer a relatively consistent environment for analysis through geologic time. The environment of modern hard substrates is similar to ancient ones, thus evolutionary trends can be distinguished easier than when the environment is a variable. Finally, the detailed descriptions of modern borings can be used to identify boring organisms in ancient hard substrates.

The localities chosen for this study were North Point, Man Head Cay, Fernandez Bay, and French Bay on San Salvador Island. These localities were selected on the basis of substrate lithology and wave energy. The North Point substrate consists of Holocene aragonitic eolianite. The substrate at Man Head Cay is also an eolianite but is Pleistocene in age and has calcite as its main constituent. Both North Point and Man Head Cay offer a high energy environment for the boring community. The beach rock found at Fernandez Bay and French Bay is less cohesive than the eolianites, with the Fernandez Bay hard substrate somewhat more indurated than that at French Bay. French Bay and Fernandez Bay are relatively low energy environments.

Five phyla of boring organisms were studied at the localities. These phyla include: Annelida, Arthropoda, Sipunculida, Mollusca, and Porifera. A detailed description was made of each boring type by observing the following characteristics: size, shape, condition of grain boundaries at the boring wall, and boring wall structures. These descriptions were based on observations made by optical and scanning electron microscopy. An abbreviated version of the description for each boring type appears in Table 1. The boring mechanism for each phylum was hypothesized and can be found in the last column of Table 1.

Mechanisms employed by each endolithic borer are proposed in this study on the basis of textural and microstructural evidence from the boring surface. The polychaete worms of the phylum Annelida appear to create their excavations by chemical dissolution of the substrate. This habit leaves behind cut grains and indistinct grain boundaries along with an etched boring surface. The hypothesized mechanism used by the barnacle *Lithotrya dorsalis* to penetrate the carbonate hard substrate by physical abrasion. The boring surface has striations which match the size of the calcified teeth on the barnacle so it appears the barnacle abrades the substrate by movements of the capitulum. The sipunculid species described in this study appear to use a combination of chemical and mechanical methods to excavate a boring. The papillae located on the surface of the organism may be used to physically abrade the rock surface; epidermal glands may also secrete an enzyme or acid to soften the substrate. The examined substrate offers evidence to support both mechanisms. *Cliona dioryssa* a sponge, is a chemical borer which carves small carbonate chips from the substrate. The sponge uses an acid as a carving agent to dissolve the carbonate substrate. The bivalve *Lithophaga bisulcata* is believed to penetrate the substrate by using an acid or calcium complexing solution to dissolve the carbonate material.

Finally, the modern characteristics of borings were compared to those found in ancient hard substrates. Hardgrounds from the Cretaceous and Ordovican were examined to see if similar characteristics exist in the ancient borings. The observations suggest that most ancient hardgrounds have undergone enough diagenesis and weathering to obscure the microscopic structures produced by the borers. Therefore, little microscopic evidence can be found to link modern borings with their ancient counterparts. However, macroscopic features of borings appear to be preserved in many ichnospecies.

| Type of Boring | Substrate Bored | Wall Structure & Texture | Shape & Orientation | Grain Boundaries |
|---|---|---|---|---|
| **Phylum Annelida**<br>*Eunice vittata*<br>*Lumbrineris inflata*<br>*Lysidice sp.*<br>*Capitella capitata* | Aragonitic Eolianite<br>Calcitic Eolianite<br>Beach Rock | Microscopically, the surface appears etched with a smooth topography. Cut grains are found throughout boring with evidence of microborings (possibly from boring fungi). | Borings are well-rounded and highly sinuous with multiple apertures on the surface. They exhibit a macro-scopic boring pattern which concentrates in the less cohesive (coarser) lamina of the eolianites. | Majority of boring surfaces have grain boundaries masked by etched surface; however, boundaries are evident over some patches of the boring surface. Intergranular matrix is evident throughout the length of the boring. |
| **Phylum Arthropoda**<br>*Lithotrya dorsalis* | Aragonitic Eolianite<br>Calcitic Eolianite<br>Beach Rock | Grains appear cut throughout the boring.<br>Anterior: Intergranular porosity is filled with carbonate matrix, perhaps resulting from dissolution.<br>Middle: Striations parallel to longi-tudinal axis of boring present. Inter-granular matrix also present to less of a degree than anterior.<br>Posterior: No intergranular matrix evident; grains are cut. | Boring appears cylindrical to elliptical and straight throughout length. Capitulum of barnacle fits tightly into boring. Usually oriented in a horizontal plane with anterior aperture towards the coastline. | Anterior: Boundaries are indistinct in most cases; grains are cut; spaces between grains are filled with carbonate material, perhaps due to dissolution. Fine fractures in the surface where possible boundaries exist.<br>Posterior: Boundaries distinct and no carbonate material fills intergranular porosity. Grains appear cut with no added material. |
| **Phylum Sipunculida**<br>*Phascolosoma antillarum*<br>*P. scolops* | Beach Rock | Anterior: Etched surface; grains indistinguishable; smooth topography.<br>Posterior: Individual grains evident; grains do not appear cut in French Bay sample but are cut in Fernandez Bay sample, perhaps due to lithology differences. Borings show grains with calcite cement coating & evidence of microborers. | Flask shape. Straight; widening toward the base. Base is cup shaped & aperture of boring is circular in cross-section. | Anterior: Boundaries are not evident; perhaps due to dissolution effects near water-substrate interface.<br>Middle: Evident boundaries.<br>Posterior: French Bay samples have uncut grains; Fernandez Bay samples have cut grains with etching & microboring. |
| **Phylum Porifera**<br>*Cliona dioryssa* | Aragonitic Eolianite<br>Calcitic Eolianite | Shallow cup shaped microscopic pits that appear in concentrated regions. Small, smooth pits are nearly identical; each 30-40 μm in diameter. | Spherical chambers; high concentra-tion near water-substrate interface. Interconnections between boring chambers. Found in crevices or on the surface of other borings. Prefers fine-grained lamina in eolianites. | Boundaries are indistinct due to removal of uniformly shaped carbonate chips by acid etching process. Grains are cut. |

**Table 1**

| Type of Boring | Size | Mechanism of Boring |
|---|---|---|
| **Phylum Annelida**<br>*Eunice vittata*<br>*Lumbrineris inflata*<br>*Lysidice* sp.<br>*Capitella capitata* | Diameter range = 4-8 mm. Length ≥ 30 mm. Diameter remains constant throughout length of boring. | Possibly acid dissolution because of etched surface of boring. Setae are possible boring structures. However, previous studies show setae are often too weak for mechanical boring (Haigler, 1969). Another hypothesis is that polychaetes use chemical dissolution to bore into the substrate (Haigler, 1969). The cut grains and indistinct grain boundaries are evidence that chemical dissolution was used to create the excavations in this study. |
| **Phylum Arthropoda**<br>*Lithotrya dorsalis* | Diameter range = 7-9 mm; tapers down to 2-3 mm in posterior of boring. Length of boring 30 to 65 mm. | Larvae may use chemical dissolution (Tomlinson, 1969). Adults may use a combination of chemical activities & mechanical activities with chitinous teeth. Piles of powdered sediment were noted by Tomlinson (1969) around the aperture of a boring barnacle. Enzymatic softening of rock before mechanical abrasion has been suggested by the fact that the barnacle secretes carbonic anhydrase (Tomlinson, 1969). Ahr & Stanton (1973) state that the boring mechanism is strictly physical abrasion by calcified plates on capitulum and peduncle. Striations near the middle of the boring wall suggest abrasion by an anatomical external structure of this barnacle. Texture at the anterior of boring may have resulted from dissolution of carbonate material by direct circulation of sea water. |
| **Phylum Sipunculida**<br>*Phascolosoma antillarum*<br>*P. scolops* | Base 10 mm in diameter. Surface opening 5 mm in diameter.<br>Total length is 30 mm. | Possible use of papillae to abrade surface. Another possiblity includes secretion of an enzyme or acid from highly developed epidermal glands located at papillae pores. Microstructure of the boring suggests "burrowing" or grain plucking in French Bay instead of boring. Fernandez Bay samples show evidence of cut grains and dissolution of the substrate. |
| **Phylum Porifera**<br>*Cliona dioryssa* | Macroscopic boring up to 1.5 mm in diameter. Microscopic pits resulting from boring activity have a diameter range of 30-40 μm. | Chemical borer. The sponge contains etching cells which project part of their cytoplasm onto the substrate. Within the cytoplasm is a substance which is possibly an acid or enzyme that dissolves the surrounding substrate. This activity continues until the substrate is sliced in the shape of a shallow cup. The substrate above the etching cell is loosened and becomes a small carbonate chip which is carried out of the sponge. Thus, the sponge bores by carving out small carbonate chips from the substrate (Cobb, 1969). |

**Table 1**

| Type of boring | Substrate Bored | Wall Structure & Texture | Grain Boundaries |
|---|---|---|---|
| **Phylum Mollusca**<br><br>*Lithophaga bisulata* | Aragonitic Eolianite | Thin calcareous lining is produced by this bivalve. This laminated calcareous lining is uniformally distributed over the anterior surface of the boring. It tapers in thickness from 1 mm near anterior aperture to zero at a distance of 20 mm from surface opening. The posterior portion of the excavation has no apparent calcareous lining.<br>Anterior: Surface of calcareous lining exhibits a smooth topography. Patches exist where calcium carbonate crystals are well developed. These layered patches mimic the topography of the grains beneath it.<br>Posterior: Surface is without calcareous lining. Grains are evident but appear cut by the boring process. Intergranular porosity is apparent in some portion of this section. | Anterior: Boundaries are indistinct where thick calcareous lining exists. However, boundaries can be dististinguished when lining is a layer which covers the surface of the grains.<br>Posterior: Boundaries are evident over cut surface of the boring wall. Irregular surface of intergranular cement can be distinguished from smooth surface of cut grains. |

| Shape & Orientation | Size | Mechanism of Boring |
|---|---|---|
| Clavate in form. It tapers slightly toward the anterior aperture and is radially symmetrical around the longitudinal axis of boring. Borings are oriented with longitudinal axes at high angles to the surface of the substrate. | Diameter range = 10-11 mm.<br>Length = 40 mm.<br>Tapers anteriorly to 8 mm diameter at the opening. | Both mechanical and chemical methods have been suggested for this bivalve's boring mechanism. Most authors suggest that it employs acids to dissolve the substrate (Jones & Pemberton, 1988). Others hypothesize the use of a calcium complexing solution (Jaccarini et al., 1968). The bivalve has a well-developed periostracum which may help in protecting the shell from the acids or other chemical substances used to create the excavation. The process used to form the lining and encrusting carbonate is not well understood. It has been suggested by Jones & Pemberton (1988) to be related to the mucus secreted by the pallial glands. |

**Table 1**