Hardened Subtidal Stromatolites, Bahamas

Abstract. *Hardened, high-relief stromatolites have been discovered along the margins of some Bahamian platforms. They occur in high-energy (tidal) oolitic sand environments in waters ranging in depth from about 1 to 5 meters. Physical stress produced by actively migrating bed forms of oolitic sand appears to exclude grazing gastropods and subsequent community successions, permitting stromatolite growth.*

Phanerozoic carbonate rock sequences containing stromatolites are mostly considered to reflect nearshore depositional environments, with the stromatolites signifying tidal or shallow subtidal settings far removed from a platform margin (*1–5*). More specifically, it has been thought that depositional waters for subtidal sequences dominated by stromatolites must be hypersaline in order to preclude gastropods from grazing the algal material. The best modern analog is Hamelin Pool in Shark Bay, Western Australia, where subtidal columnar stromatolites presently form in hypersaline water (*6, 7*). Although hardened stromatolites produced by algal binding of sediment have not, to my knowledge, been documented in modern subtidal settings with normal marine waters, such stromatolites can develop under certain environmental conditions.

This report describes the occurrence of hardened subtidal stromatolites in a high-energy, oolitic sand environment along the platform margin of Eleuthera Bank, Bahamas (Fig. 1). The stromatolites are forming in normal marine waters ranging in depth from less than 1 m to at least 5 m (Fig. 2). Aerial reconnaissance of a similar oolitic sand complex along the southern edge of Tongue of the Ocean (Fig. 1) indicates that stromatolites are also present there.

The existence of normal marine subtidal stromatolites is traceable to the interrelation between organic activity, early marine diagenesis, and physical stress induced by mobile bed forms of oolitic sand. Their presence in this modern sedimentary environment dictates that caution now be used in interpreting the depositional setting of ancient stromatolitic sequences. Furthermore, it may explain some stromatolitic sequences in the rock record for which the Shark Bay analog seems inappropriate. A major implication of this study is that hypersalinity alone is not necessary for the occurrence of subtidal stromatolites in a particular depositional environment.

Eleuthera Bank is a shallow marine platform situated approximately 350 km east-southeast of Miami (Fig. 1). Its high-energy margin is dominated by the Schooner Cays oolitic tidal bar complex (*8*), in which ooids are actively forming from near the platform margin bankward for as much as 17 km (*9*). Maximum tidal current velocities are 2 to 3 knots (*8*). This laterally extensive oolitic sand facies, with longitudinal sand bodies oriented predominantly perpendicular to the platform margin (*8*), and the associated marine cementation and oolitic hardground formation (*9*) accurately reflect the high-energy character of the platform.

Oolitic stromatolites are forming in this depositional environment, but only in subtidal areas where low-relief oolitic hardground and actively migrating bed forms of oolitic sand (ripples, sand waves, megaripples) coexist. As with the Hamelin Pool stromatolites (*7*), the Eleuthera Bank stromatolites are always localized on preexisting hard substrates. As a result, they are widespread but areally restricted, a situation again similar to that of Hamelin Pool (*7*). They occur on the broad crests of tidal bars (less than 1 m in depth) and along the surfaces of deeper (at least 5 m) large-scale sand bodies. As discussed below, the morphology and internal sedimentary fabrics of these Bahamian stromatolites are strikingly similar to those of the Hamelin Pool stromatolites.

Subtidal oolitic stromatolites on Eleuthera Bank begin as columns a few decimeters or less in height but gradually evolve into hemispheroidal columns of 0.5 to 1 m (Fig. 2A). With continued growth, isolated columnar heads coalesce laterally into large rounded masses (common in deeper water) or into elongated ridges (common in more shallow water). The latter often exhibit preferred orientations in response to prevailing local tidal flow or wave action. [Hamelin Pool stromatolites grow similarly and often assume preferred orientations as well (*7*).] The Bahamian stromatolites and the areas between them are floored by continuous oolitic hardground covered by a veneer of mobile oolitic sand (Fig. 2A). The hardground is lithified by submarine aragonitic cement (*9*).

The organisms primarily responsible for stabilizing and trapping oolitic sand on accreting stromatolites are a noncalcareous dasycladacean alga, *Batophora*, and blue-green algal scum mats (*10*). Suspended oolitic sediment is supplied to the stromatolite surface by daily tidal agitation or periodic storm activity. Oolitic sediment trapped by these organisms is much finer and more poorly sorted than the oolitic sediment transported along the sea floor, supporting its derivation as a suspension load. *Batophora* and blue-green algal scum serve only to trap and stabilize this sediment. They do not bind the grains into the coherent, hardened substrate characteristic of these stromatolites.

Effective binding and cementation of oolitic sediment supplied to stromatolite surfaces is achieved by swarms of calcified algal filaments (*9*). These filaments, presumed to calcify after death of the algal material, are believed to be those of a chasmolithic or endolithic chlorophyte (*9*). Binding and filament calcification cement ooids to create the rigid frame-

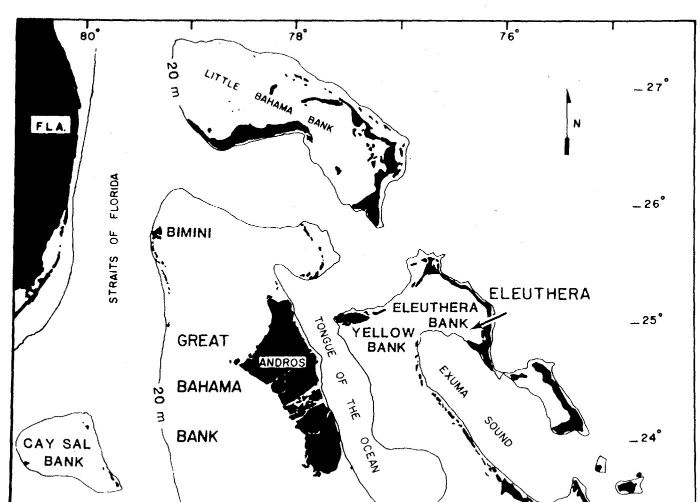

Fig. 1. Map of the Bahamas showing the location of Eleuthera Bank and the southern end of Tongue of the Ocean. Both areas are high-energy settings exhibiting broad, active oolitic sand complexes and associated subtidal oolitic stromatolites. Arrows denote the approximate locations where stromatolites have been observed.

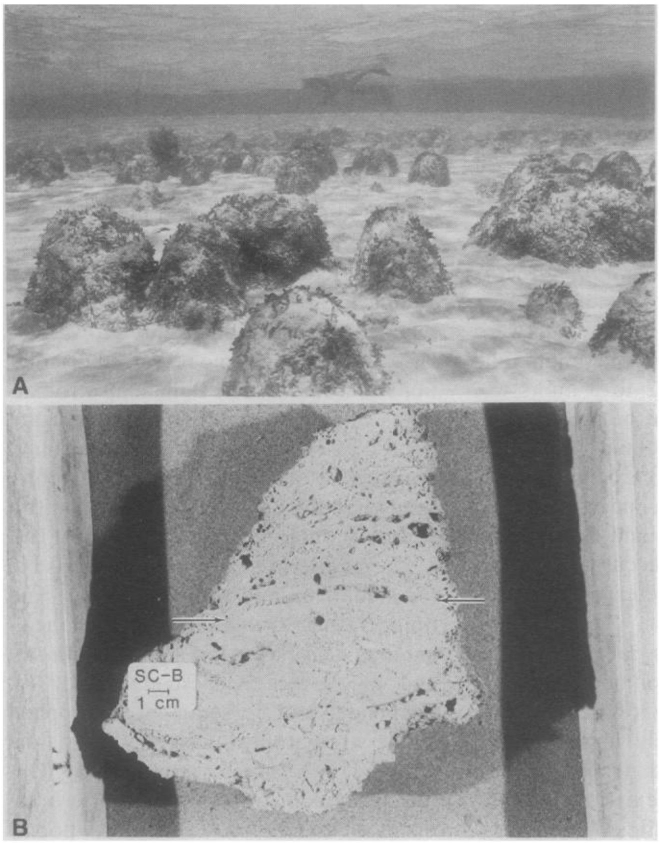

Fig. 2. (A) Subtidal oolitic stromatolites on the crest of an oolitic tidal bar on Eleuthera Bank. Most are 0.5 to 1.0 m high. The stromatolites in the foreground are colonized by *Batophora* and blue-green algal scum. Both trap suspended sediment on the stromatolites. (B) Section through a columnar stromatolite. The arrows denote the sharp contact between stromatolite and hardground. Typically, stromatolites exhibit crude laminations with fenestral porosity. Larger holes are a result of boring activity.

work of the stromatolites. Staining reveals that the calcified algal filaments always possess a high magnesium calcite mineralogy.

The Bahamian subtidal stromatolites possess internal fabrics that are strikingly similar to those of their Hamelin Pool counterparts. Like the Hamelin Pool stromatolites (*7*), many exhibit crude laminations because of algal trapping and binding and possess coarse fenestrae (presumably left by dasycladacean algae) (Fig. 2B). Because they develop in normal marine waters, Bahamian stromatolites are highly susceptible to intense organic boring activity, which can obliterate most primary internal fabrics. Principal borers are mollusks, worms, sponges, and blue-green algae.

Both the Eleuthera Bank and Hamelin Pool stromatolites invariably develop on hard substrates (*7*). On Eleuthera Bank these hard substrates consist of oolitic hardground (*9*). The contact between an Eleuthera Bank stromatolite and its underlying hardground typically is very sharply defined (Fig. 2B). This transition is marked by a textural change in the oolitic sediment, coarse fenestrae, intense bioerosion, and grain micritization along the hardground surface. There is also a pronounced change in cementing agents across this contact, from aragonite cement in the hardground to algal filaments calcified by magnesium calcite in the stromatolite.

The hardground consists mainly of medium-grained, well-sorted ooids with preserved, well-developed aragonitic lamellae. Grain micritization, except along the hardground's upper surface, is not prevalent. This composition, texture, and degree of ooid preservation is identical to that found for oolitic sediments forming and accumulating in this environment today. The hardground is initially cemented by cloudy, isopachous, fibrous aragonite, although calcified algal filaments can be present (*9*).

The stromatolites themselves are composed of much more finely grained and poorly sorted oolitic sediment in which ooids have poorly developed aragonitic lamellae. Many of the ooids are highly micritized and have degenerated to peloids. Grains are bound and cemented by algal filaments, which become calcified to magnesium calcite. Despite the fact that this is an environment of widespread aragonite cementation (*9*), the remaining pore space in the stromatolite heads tends to remain open and not be occluded with aragonite cement.

The Hamelin Pool stromatolites reflect the effect of hypersalinity, which limits grazers and permits development (*6, 7*). The stromatolites are areally restricted to rocky headland areas along the margins of Hamelin Pool, where exposed bedrock or submarine hardground provides the hard substrate required for colonization. These boundstones are also closely associated with active ooid or skeletal sands (*7*).

The association of Eleuthera Bank stromatolites with high-energy oolitic sands in actively agitated normal waters on the platform margin may seem puzzling. Also, it may be wondered what environmental factors, in the absence of hypersalinity, limit gastropod grazing and subsequent benthic community succession to allow subtidal stromatolites to develop (*1*).

Stromatolites on Eleuthera Bank occur only where oolitic hardground and actively migrating bed forms of oolitic sand intimately coexist. This association implies that the environmental factor responsible for limiting grazing activity is physical stress, not salinity. I suggest that periodic inundation of stromatolite heads by oolitic sediments sufficiently excludes grazing gastropods from the immediate environment to allow stromatolite development. Stromatolite growth ceases during shallow burial, but once the stromatolites are uncovered by a migrating bed form they are quickly recolonized by algae and begin accreting again. Bed-form migration occurs in response to local hydrographic conditions or periodic storm activity. The veneer of unconsolidated oolitic sand shifting daily between stromatolite heads in response to tidal currents is also detrimental to gastropod activity. Migrating bed forms also inhibit subsequent encrusting, attaching, and boring detrimental to stromatolitic development.

With permanent termination of this physical stress, however, these topographically higher stromatolitic hardgrounds should serve as inviting substrates for coralgal reefs. This succession is extremely likely because the stromatolites are developing along a steeply dipping platform margin in shallow, well-circulated marine waters.

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References and Notes

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