First documentation of tidal-channel sponge biostromes (upper Pleistocene, southeastern Florida)

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ABSTRACT

Sponges are not a common principal component of Cenozoic reefs and are more typically dominant in deep-water and/or cold-water localities. Here we report the discovery of extensive upper Pleistocene shallow-marine, tropical sponge biostromes from the Miami Limestone of southeastern Florida built by a new ceractinomorph demosponge. These upright, barrel- to vase-shaped sponges occur in monospecific aggregations constructed within the tidal channels of an oolitic tidal-bar belt similar to modern examples on the Great Bahama Bank. The biostromes appear to have a ribbon-like geometry, with densely spaced sponges populating a paleochannel along a 3.5 km extent in the most lengthy biostrome. These are very large (as high as 2 m and 1.8 m in diameter), particularly well-preserved calcified sponges with walls as hard as concrete. Quartz grains are the most common particles agglutinated in the structure of the sponge walls. Where exposed, sediment fill between the sponges is commonly a highly burrowed or cross-bedded ooid-bearing grainstone and, locally, quartz sand. It is postulated that the dense, localized distribution of these particular sponges was due to a slight edge over competitors for food or energy supply and space in a stressed environment of tidal-influenced salinity and nutrient changes, strong currents, and frequently shifting submarine sand dunes. To our knowledge, this represents the first documentation of sponge biostromes composed of very large upright sponges within high-energy tidal channels between ooid shoals. The remarkably well-preserved accumulations provide an alternative example of sponge reefs for comparative paleoenvironmental studies.

Keywords: sponges, biostromes, tidal channels, Pleistocene, Florida.

INTRODUCTION

Reef-building scleractinian corals and coralline algae construct the most widespread and volumetrically important reefs in the world's modern tropical oceans (James and Bourque, 1992). Although sponges regularly are faunal elements of coral-algal reefs, they characteristically are accessory (Rigby, 1969). Although sponges inhabit effectively all marine environments, they are generally dominant only in deep-water and/or cold-water settings (Gammon and James, 2003). Examples of modern shallow-marine, tropical, sponge reefs are relatively uncommon, but include small demosponge bioherms that occur on the Great Bahama Bank (GBB; Wiedenmayer, 1978). Calcified demosponges are the primary frame-building organisms of some modern coral reefs, but are in the deeper parts below the zone of active coral growth (Hartman and Goreau, 1970). Large, modern, cold, deep-water Hexactinellida sponge bioherms have been reported off the Canadian Pacific margin (Conway et al., 2001), the main setting for this class of sponge. In the Tertiary fossil record, extensive accumulations of sponges are uncommon and generally not reef related (Rigby, 1969); however, where reported as part of reef assemblages they are mostly associated with deep-water mounds (Perrin, 2002). Sponge reefs have not been substantially prevalent since the Late Jurassic (Stanley, 2001). Thus, the types and numbers of Cenozoic sponge reef analogs are limited for use in comparative paleoenvironmental and paleoecologic analyses with much older Mesozoic and Paleozoic sequences that contain stratigraphic intervals where sponges were important in reef building (Stanley, 2001).

Recently, four large upper Pleistocene, shallow-marine, tropical biostromes built of upright barrel- to vase-shaped demosponges were discovered in southeastern Florida (Cunningham et al., 2006a). These sponges are important because, to our knowledge, (1) they are the only sponge biostromes that occur in tidal channels cutting through a complex of ooid shoals and (2) they are large, outstandingly well preserved examples of shallow-marine, tropical sponge accumulations that contrast with much more common deep-water and/or cold-water Cenozoic examples. As such, the southeastern Florida biostromes are an alternative sponge aggregation that provides for comparative analysis of modern and ancient sponge reefs. We provide a general description of these newly discovered biostromes and a discussion of possible environmental controls on their developmental history.

GEOLOGIC SETTING

The Florida sponge biostromes are exposed along canal banks in the uppermost unit of the upper Pleistocene Miami Limestone (Figs. 1 and 2), variously designated (1) the oolitic facies by Hoffmeister et al. (1967); (2) the Q5 unit by Perkins (1977); and (3) the Q5e unit by Multer et al. (2002), because of its deposition during the last interglacial period (marine isotope stage 5e). Bedrock composed of the oolitic facies of the Miami Limestone forms the southernmost part of the Atlantic Coastal Ridge (ACR; Fig. 1), a southwest-trending, relatively high, but low-relief, topographic feature that has, at most, an elevation of 7.3 m (Hoffmeister et al., 1967).

The landward part of the southern ACR is an assemblage of fossil oolitic shoals and channels (Hoffmeister et al., 1967) that Halley et al. (1977) interpreted as an ancient southwest-trending tidal-bar belt (Fig. 2), in the sense of Ball (1967). The long axis of the patchwork of shoals parallels the southwest-trending axis of the southern ACR (Figs. 1 and 2). The oolitic shoals correspond to low-relief topographic highs and are separated by lower topographic areas, which are a match for relict tidal channels (Halley et al., 1977). These channels are commonly oriented northwest-southeast, essentially perpendicular to the ACR axis, and an oolitic barrier bar (Fig. 2) that parallels the ACR (Halley et al., 1977). The ancient tidal-bar belt is similar to modern Bahamian ooid sand bodies (Halley et al., 1977).

Throughout an area northwest of the southern ACR (stippled area in Fig. 2), the Q5e unit is characterized by a *Schizoporella*-bearing peloid packstone and grainstone lithofacies (Cunningham et al., 2006b), which is dominated by an *Ophiomorpha* ichnofabric. Based on mapping by Cunningham et al. (2006b), the peloid packstone and grainstone lithofacies resembles the bryozoan facies described and interpreted by Hoffmeister et al. (1967) to represent an open-marine shelf lagoon (Fig. 2); Perkins (1977) and Evans (1984) interpreted the facies as an open-marine platform. This *Schizoporella*-bearing peloid packstone and grainstone lithofacies is similar to the Joulters Cay bioturbated ooid sand flats at the north end of Andros Island, GBB, that are commonly burrowed by callianassid shrimp (Boardman and Carney, 2000).

SPONGE BIOSTROMES

Detailed data collected from the sponge biostromes at two localities, two coreholes (G-3831, G-3831A) at site 1A and a 300-m-wide part of the outcrop at site 2 (Fig. 1), provide the primary basis for understanding the composition and spatial distribution of the lithofacies comprising the biostromes.

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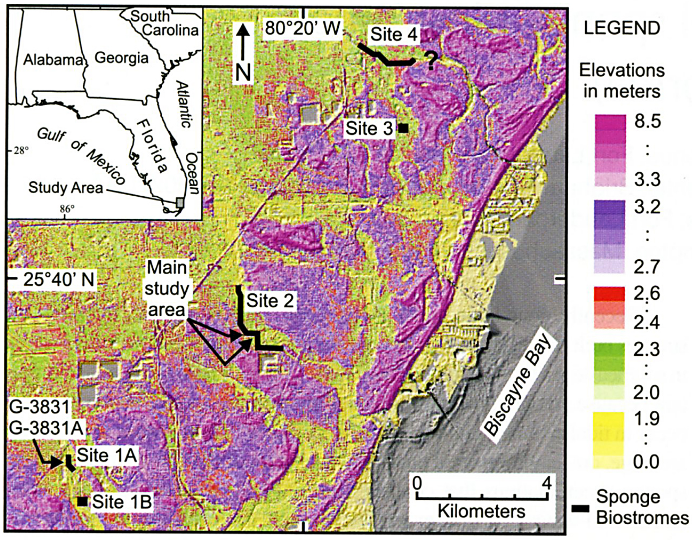

Figure 1. **Laser imaging detection and ranging (Lidar) digital elevation map with locations of sponge biostromes (wide black lines) superimposed. Lengths of biostrome exposures along canals are ~95 m at site 1A, 30 m at site 1B, 3.5 km at site 2, 30 m at site 3, and 2.1 km at site 4. Eastward limit of site 4 biostrome is unknown because biostrome outcrop is covered east of mapped area. Atlantic Coastal Ridge is generally area of relatively high elevations depicted as large patches of purplish colors trending NE to SW.**

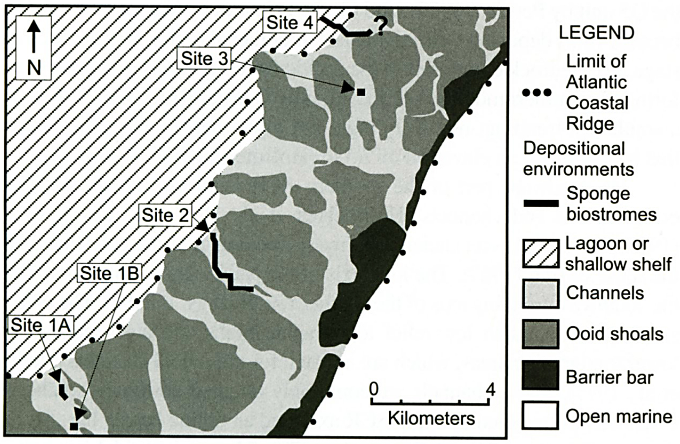

Figure 2. **Locations of sponge biostromes relative to conceptualized late Pleistocene paleoenvironments of last interglacial period (marine isotope stage 5e). Each biostrome appears to occur within relict channels; part of site 4 biostrome extends westward into lagoonal or shallow-shelf environment (adapted from Halley et al., 1977).**

Biostromes

The biostromes are composed of a sponge bafflestone with the sponges mostly in situ (Figs. 3–5A). The external geometry of the accumulations of sponges probably has a narrow, ribbon-like shape, as though the ribbon is flat within the ancestral tidal channel, with bends and straight stretches of the biostrome conforming to the original tidal-channel course. The large upright sponges are generally closely spaced, but typically not in contact (Figs. 3–5A). Sediments between the sponges are commonly fine to medium sand-sized ooids (Fig. 5B) and, locally, quartz grains, with minor coarser skeletal debris. The total height of individual sponges is not commonly exposed in outcrops, but excavations at site 2 and digital optical borehole data (Fig. 3) from site 1A indicate that typical sponge heights are almost all within the range of 1–2 m. Thus, the biostromes are commonly 1–2 m thick.

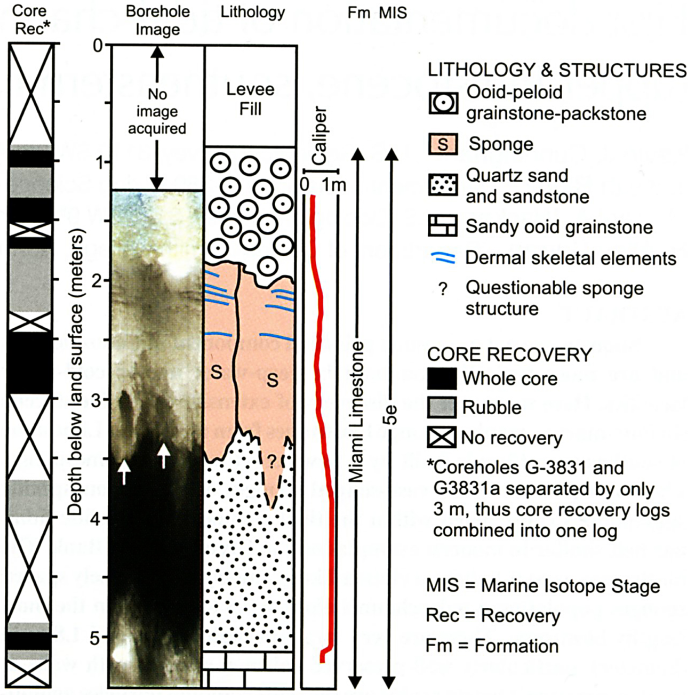

Figure 3. **Digital borehole image from corehole G-3831 and interpreted lithofacies from coreholes G-3831 and G-3831a (Fig. 1) at site 1A. Sponge height approaches or possibly exceeds 2 m. Initial sponge growth was within and/or on quartz sand. Quartz sand represented on lithology log was extruded from around borehole by air-induced well development, creating dark cavity on image log between ~3.4 and ~5 m depths. Stacked dermal skeletal elements probably resulted from concurrent pulses of vertical growth in two adjacent sponges (S). Note large ovoid openings (white arrows) that are central spongocoels of each sponge.**

Sponges

The sponges of the biostromes are monospecific upright aggregations of a new ceractinomorph demosponge (Rigby and Cunningham, 2007). In general, the morphology of the sponges can be either barrel or vase shaped (Figs. 3–5A). The exposed tops of the sponges range in diameter from ~3 cm to 1.8 m (mean = 0.6 m). Counts of sponges along 10 m horizontal increments of the biostrome outcrop at site 2 indicate that the density of sponges varies throughout the span of the biostrome, with sponges uncommonly absent and as many as 1.8 visible sponges per meter outcrop length (mean = 0.5 sponges/m).

Irregular canals occur in outer or dermal parts of the sponges, and are somewhat less prominent in inner or gastral parts of the skeletons. Large bifurcating root-like structures extend outward and downward from the dermal walls of some of the sponges and probably functioned to steady these large sponges in the shifting sediment and strong currents (Fig. 5C). Walls of the sponges are calcified, and almost everywhere are as hard as concrete. Our collection of sponges shows that the walls of sponges most commonly contain agglutinated quartz grains, regardless of vertical position within the sponge wall and sediment type surrounding the dermal side of walls (Fig. 5D). Uncommon peloids, ooids, bivalve fragments, gastropods, and *Halimeda* also occur within the wall structure. Epibionts, such as bivalves, *Schizoporella*, and other bryozoans, commonly encrust parts of the dermal wall.

Lithofacies Surrounding the Sponges

Although the lateral variations in lithofacies are complex, an idealized vertical succession of the sediments that surround the sponges at site 1A and the main study area of site 2 (Fig. 1) is, from base to top (Figs. 3 and 4), (1) quartz sand and sandstone, (2) sandy skeletal grainstone,

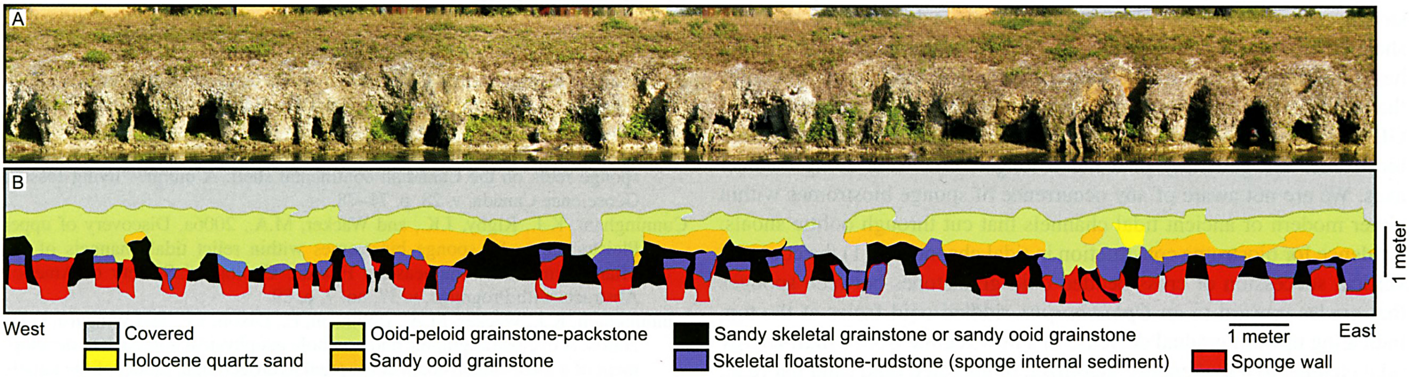

Figure 4. A: Outcrop photomosaic of part of sponge biostrome along wall of canal included in main study area of site 2 that is shown in Figure 1. B: Drawing of lithofacies represented in A.

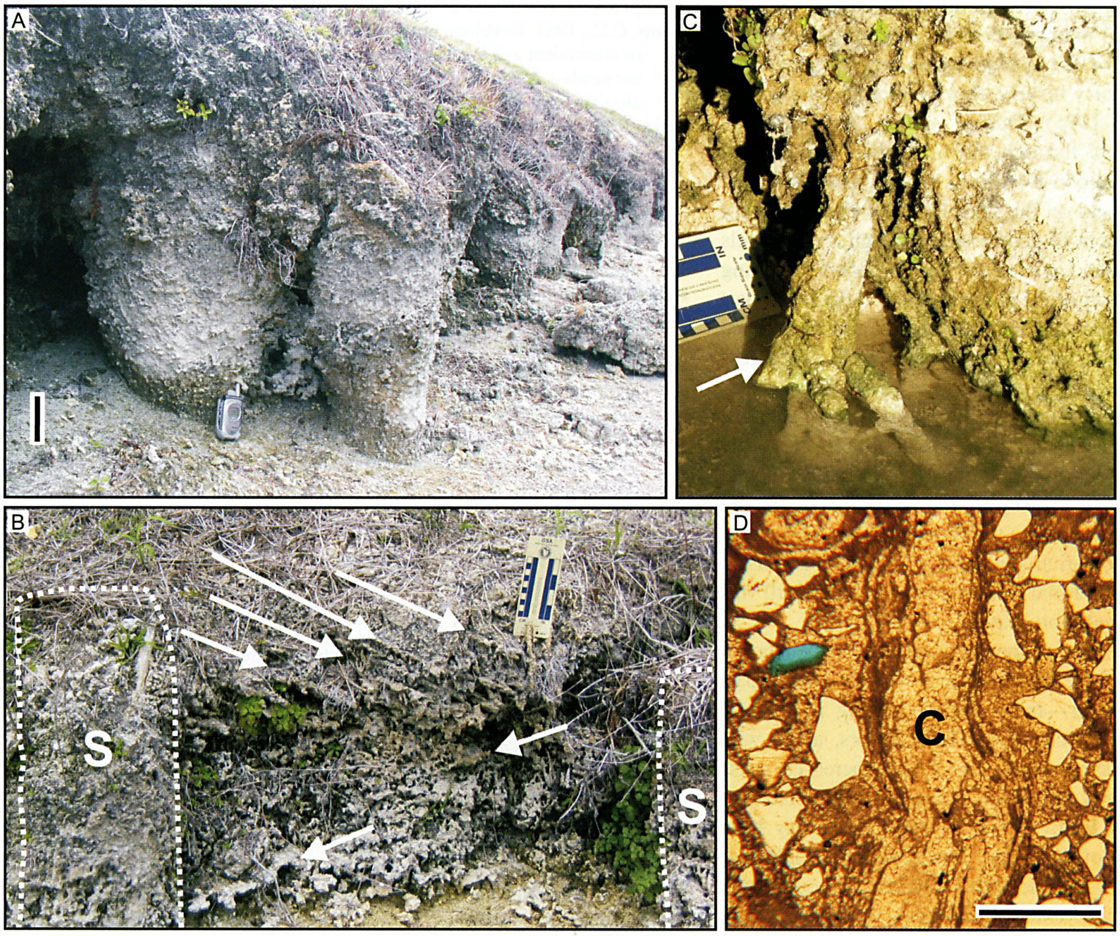

Figure 5. Photographs from site 2. A: Densely spaced, well-preserved sponges in growth position. Black bar scale = 10 cm. B: Photograph of burrowed high-energy cross-bedded (arrows) ooid-bearing fill between upright sponges (S) at site 2. Dip on upper cross beds is 23°SE and on lower cross beds is 18°SW. C: Large branching root-like structure (arrow) that bifurcates downward (as many as five branches) from dermal wall of large upright demosponge. D: Thin-section photomicrograph in plain light of sponge wall with canal (C) surrounded by agglutinated quartz grains within wall structure. Black bar scale = 1 mm.

(3) sandy ooid grainstone, and (4) an ooid-peloid grainstone-packstone lithofacies. Scarce, small, *Schizoporella* bryozoan colonies and uncommon coral colonies contribute minimal large-scale paleobiomass to these mostly monospecific sponge biostromes.

At site 2, most of the sponge bases are embedded in limestone; however, in the main study area of site 2 and at coreholes G-3831 and G-3831a at site 1A, they are within the upper part of the quartz sand and sandstone lithofacies (Figs. 1 and 3). Above the sand, the sponges are entombed by the progression of the remaining three lithofacies with the ooid-peloid grainstone-packstone lithofacies surrounding and covering the upper part and tops of the sponges (Figs. 3 and 4). Common particles within the sandy skeletal grainstones are *Halimeda*, bivalves, bryozoans, and large benthic foraminifers. The sandy ooid grainstone lithofacies is locally cross-bedded (Fig. 5B), indicative of high flow regimes and probably migrating dunes or sand waves within the tidal channels. Small abundant trace fossils with average interior diameters of 4.7 mm are locally common within the sandy ooid grainstone lithofacies. The ooid-peloid grainstone-packstone lithofacies commonly forms a very hard, resistant cap around the upper part of the sponges and above the sponges. The principal trace fossil of this lithofacies is ubiquitous *Ophiomorpha* with interior diameters of the tubes averaging ~1.7 cm.

DISCUSSION

The tidal-channel environmental setting for the southeastern Florida sponge biostromes is novel. These sponge biostromes are primarily located in major tidal channels of a tidal-bar belt, with one biostrome extending westward of a channel into a lagoonal or shallow-shelf environment. The overall late Pleistocene environmental setting has similarities to that of the modern columnar subtidal stromatolites that grow among migrating ooid sand dunes within tidal channels of the GBB, such as at Adderly Cut (Dill et al., 1986), although the sponge biostromes are generally of a much longer dimension along channel axes. We are not aware of any occurrence of sponge biostromes within either modern or ancient tidal channels that cut through oolitic shoals. Evidence for biostrome construction in tidal channels is (1) the common vertical succession of cross-bedded ooid grainstones between sponges that grades upward to an *Ophiomorpha*-riddled ooid facies at the top, indicating upward gradual decrease in a flow regime from a high-energy tidal channel to a low-energy, stabilized bioturbated ooid sand flat (e.g., Joulters Cay), and (2) the coincidence of biostrome occurrence with topographic lows interpreted to be the locations of relict tidal channels (Halley et al., 1977).

We propose that the sponges were opportunists within the tidal channels and grew to their full maturity prior to substantial sediment infilling the channels. Some of the sponge aggregations grew on a quartz sand bottom. In their early history, they were epifaunal and/or infaunal (Ilan and Abelson, 1995). During sponge growth, large amounts of quartz sand moved through the tidal channels, derived from riverine sources on the lagoon-ward side of the channels and/or from long-shore transported sand on the seaward side. Contemporary growth of sponges and movement of quartz sand through the channels is evidenced by (1) the quartz sand and sandstone lithofacies occurring locally only in the lowermost part of the channel fills and the lower part of some sponges embedded in the sand and (2) the common occurrence of quartz sand within the full height of the sponge walls regardless of the relatively sparse quartz sand content of the surrounding upper ooid-rich sediment. Dill et al. (1986) described "dusting" of modern tidal-channel stromatolites by ooid sand during each tidal cycle in the Exuma Cays, GBB. An analogous situation during the last interglacial period could have provided a steady supply of quartz grains for the agglutination of particles into the sponge walls during the early history of the tidal channels. More ooid-rich sediment filled the channels in the later stages of sedimentation. Final covering of the channel fill was by lateral migration of stabilized bioturbated sand flats.

The generally closer connection of sponge biostromes to the lagoon-ward, or platform-ward, side of the tidal channels between ooid shoals (Fig. 2) is suggestive of seawater—frequently fluctuating in velocity and salinity—flowing through the channels. These factors, along with frequently shifting submarine sand dunes, could have increased stress on competitors for food or energy and space, important determinants in sponge distribution (Finks and Rigby, 2003). Further, there may have been a relation between growth of the sponge biostromes and spilling of nutrient-rich water derived from riverine and/or submarine groundwater discharge into the lagoon, and movement of nutrients through the tidal channels during falling tides. Wilkinson (1987) described a direct relation between present-day Caribbean sponge biomass and land-derived nutrients: as nutrients increase, sponge biomass increases. Thus we postulate that (1) stressed environmental conditions that reduced competition for food or energy supply and space and (2) increased nutrients in the ancient tidal channels contributed to opportunistic densely distributed monospecific aggregations of demosponges.

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