2010

Enigmatic Structures on Upper Pleistocene Laminar Caliche Surfaces of the Bahamas: Animal, Vegetable, or Mineral?

H. Allen Curran
Smith College, acurran@smith.edu

PROCEEDINGS OF THE 14TH SYMPOSIUM ON THE GEOLOGY OF THE BAHAMAS AND OTHER CARBONATE REGIONS

June 12-16, 2008

Edited by
Fredrick D. Siewers and Jonathan B. Martin

Gerace Research Centre
San Salvador Island, Bahamas
2010

ENIGMATIC STRUCTURES ON UPPER PLEISTOCENE LAMINAR CALICHE SURFACES OF THE BAHAMAS: ANIMAL, VEGETABLE, OR MINERAL?

H. Allen Curran
Department of Geosciences
Smith College
Northampton, Massachusetts 01063, USA

REPRINTED FROM:

Frederick D. Sievers & Jonathan B. Martin (eds.), 2010, *Proceedings of the 14th Symposium on the Geology of the Bahamas and Other Carbonate Regions*: San Salvador, Gerace Research Centre, p. 31-41.

(Cover photo: Kelly and the Veggiemorphs by Jon Martin)

ENIGMATIC STRUCTURES ON UPPER PLEISTOCENE LAMINAR CALICHE SURFACES OF THE BAHAMAS: ANIMAL, VEGETABLE, OR MINERAL?

H. Allen Curran
Department of Geosciences
Smith College
Northampton, Massachusetts 01063

ABSTRACT

Trace fossils are a common and important component of most Quaternary carbonate rock units of the Bahamas and other, similar tropical carbonate regions. In the Bahamas, the Pleistocene-Holocene boundary is typically marked by a calichified paleosol horizon that formed on the exposed limestone surfaces of the islands during the time of lowered sea level of the Last Glacial. On the north coast of San Salvador Island, an extensive horizontal surface of laminar caliche is exposed at Singer Bar Point and to the west. This surface formed on carbonate eolianite of Late Pleistocene (Eemian) age and is overlain by Holocene eolianite. The surface bears numerous and distinctive large, meandering structures that typically are preserved in half relief, with sharp, parallel ridge-like edges that slope inward to form a smooth, medial 'trough.' Widths of these trough-shaped structures mostly range between 1 to 3 cm, although some are wider, and individual structures commonly can be traced for lengths of several meters, with one specimen having a length of greater than 5 m. Patterns formed by the structures can be quite complex and unusual, with crossovers common but branching only occasionally present.

These enigmatic structures superficially resemble physical pedogenic structures such as the weathered forms of thin caliche dikes that filled fractures in the host-rock eolianite (the mineral origin). They also bear an uncanny resemblance to trails formed by several species of modern neritid snails that inhabit Bahamian rocky intertidal surfaces (the animal origin) as in the Singer Bar Point area. If fossilized, such trails could be assigned to the ichnogenus *Archaeonassa*. However, some features of the morphology of the structures and the geology of the setting do not support a snail trail origin. Instead, a plant root origin is favored; namely, that these structures formed by partial dissolution and re-precipitation of calcitic materials around roots that had penetrated downward through overlying Holocene eolianite or older substrate material and then spread laterally along the hard, laminar caliche surface. These structures thus can rightfully be considered trace fossils, as they represent a record of plant activity. Specific plants that might have root systems capable of generating these distinctive forms have not been identified, and this is a topic for future research.

Similar structures have been found on Upper Pleistocene laminar caliche surfaces at other coastal locations on San Salvador, and they likely are present on such surfaces throughout the Bahamas and beyond. This suggests that structures of this origin may be far more common and widespread in Quaternary and older carbonate rock sequences than previously recognized.

INTRODUCTION

Physical and biogenic sedimentary structures are a common and important component of the carbonate grainstone and packstone Quaternary rocks that cap the islands of the Bahamas. Biogenic structures, including a variety of animal

and plant trace fossils, have been used to characterize the facies of these rocks, ranging from shallow subtidal to beach to dune environments (Curran and White, 1991, 2001; Curran, 1994, 2007). These overview papers have established an ichnologic framework for Bahamian lithofacies, but there are numerous subfacies and bedrock surfaces that have yet to be studied in detail with respect to their contained biogenic and physical sedimentary structures.

The purpose of this paper is to describe large and enigmatic structures that occur on laminar caliche surfaces of the paleosol that marks the disconformity between rocks of the Grotto Bay Formation (Upper Pleistocene - MIS 5e, Eemian, or Last Interglacial) and Holocene rocks of the Rice Bay Formation on San Salvador Island (stratigraphy of Carew and Mylroie, 1995; Mylroie and Carew, 2008). These distinctive structures are best displayed on the high intertidal to supratidal surfaces of laminar caliche that occur in the Singer Bar Point area (Figure 1).

Further reconnaissance study revealed the presence of similar structures on other laminar caliche surfaces around San Salvador. It is highly likely that these structures will be found on similar surfaces throughout the Bahamas and beyond. Hypotheses for the origin of these enigmatic structures are introduced and discussed, and a favored hypothesis is presented.

GEOGRAPHIC AND GEOLOGIC SETTING

The primary locality for this study is along the north coast of San Salvador to the west of Singer Bar Point (Figure 1). Access is easily gained via a small boat-launch ramp on the north side of the main road (N 24° 07.112'; W74° 28.711'), with parking space on the south side of the road. This is a low rocky coast with an obvious laminar caliche paleosol surface capping eolianites of the Grotto Beach Formation. Singer Bar Point can be seen to the east (Figure 2A).

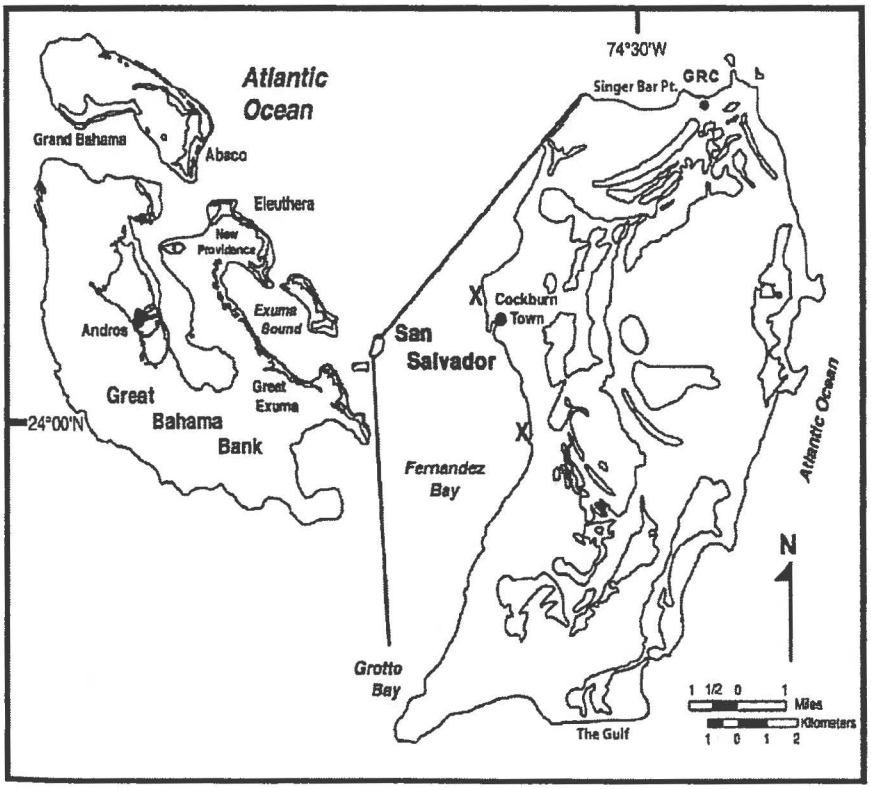

Figure 1. Index map to the Bahama Archipelago and study sites on San Salvador Island. The principal study site is along the north coast, just west of the Gerace Research Centre (GRC) and Singer Bar Point. Supplementary sites are on the laminar caliche surface on the south coast, a short distance west of The Gulf, and on the west coast (marked by Xs), with the northernmost X laminar caliche surface immediately north of the entrance to the Club Med marina and the southern X on the surface south of the entrance point to Telephone Pole Reef.

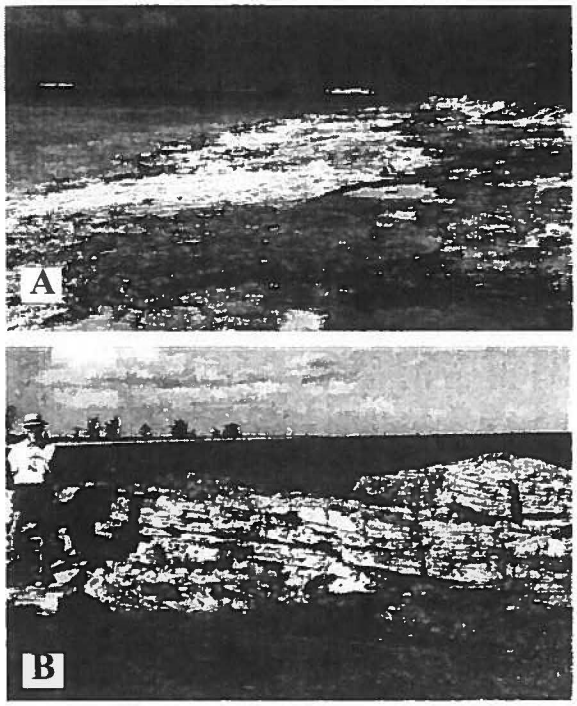

Figure 2. A) View of the laminar caliche surface looking east toward Singer Bar Point; photo taken east of the boat ramp entry point to the coast. B) Outcrop of the Holocene Rice Bay Formation overlying the laminar caliche surface and Upper Pleistocene eolianite of the Grotto Beach Formation; photo taken a short distance west of the entry point. Author of this paper for scale.

A few meters to the west, rocks of the Rice Bay Formation are well exposed above the Pleistocene-Holocene disconformity surface (Figure 2B). Enigmatic structures as described herein are well developed on the high intertidal to supratidal laminar caliche surface. Walk east along the coast and the surface structures become more common. The most concentrated area of their occurrence (N 24° 07.168'; W 74° 28.520') is just west of a very obvious clump of closely spaced rock-core drill holes where cores were taken for study of paleomagnetic properties (locally known to GRC geologists as 'Panuska holes'). This locality is about 100 m west of Singer Bar Point proper.

As pointed out by Wright and Tucker (1991) in the introduction to their edited volume titled *Calcretes*, the terms caliche and calcrete are synonymous in current usage, with 'caliche' favored by most authors of papers on Bahamas geology. Laminar caliche consists of microcrystalline carbonate material and refers to indurated sheets of carbonate, typically undulose, and usually forming over hardpans or indurated rock substrates (Wright and Tucker, 1991, p. 3). Surfaces of laminar caliche marking the Pleistocene-Holocene disconformity commonly occur at various areas along the coast on all sides of San Salvador, and similar surfaces are widespread throughout the Bahamas. Previous studies of laminar caliche and paleosols on San Salvador and beyond by Beier (1987) and Boardman et al. (1995) were directed primarily to the petrographic, geochemical, and stratigraphic aspects of Bahamian caliches and did not address their megascopic properties. In an initial survey of caliche surfaces around San Salvador, I found examples of structures as described in this study along the south coast of the island west of The Gulf and at two locations along the island's west coast (Figure 1). Yet to be investigated are surfaces along the east coast of San Salvador, but laminar caliche surfaces are present in the areas studied by Beier (1987), and it seems highly likely that similar structures will be found there as well as on other Bahamian islands and beyond.

DESCRIPTION OF THE STRUCTURES

Enigmatic structures on the laminar caliche surfaces of the Singer Bar Point area consist of meandering, trough-like forms typically preserved in half relief. Sharp and parallel, ridge-like edges slope inward to form a smooth, medial trough (Figures 3A-C). Width of the structures measured from ridge edge-to-edge ranges from about 1 to 5 cm, with the average between 2.0 to 2.5 cm (Figure 4). Individual structures can be traced over considerable distances, up to 5.5 m in one case, and complex meandering forms are present, including at least one near-circular form (Figures 3C, D).

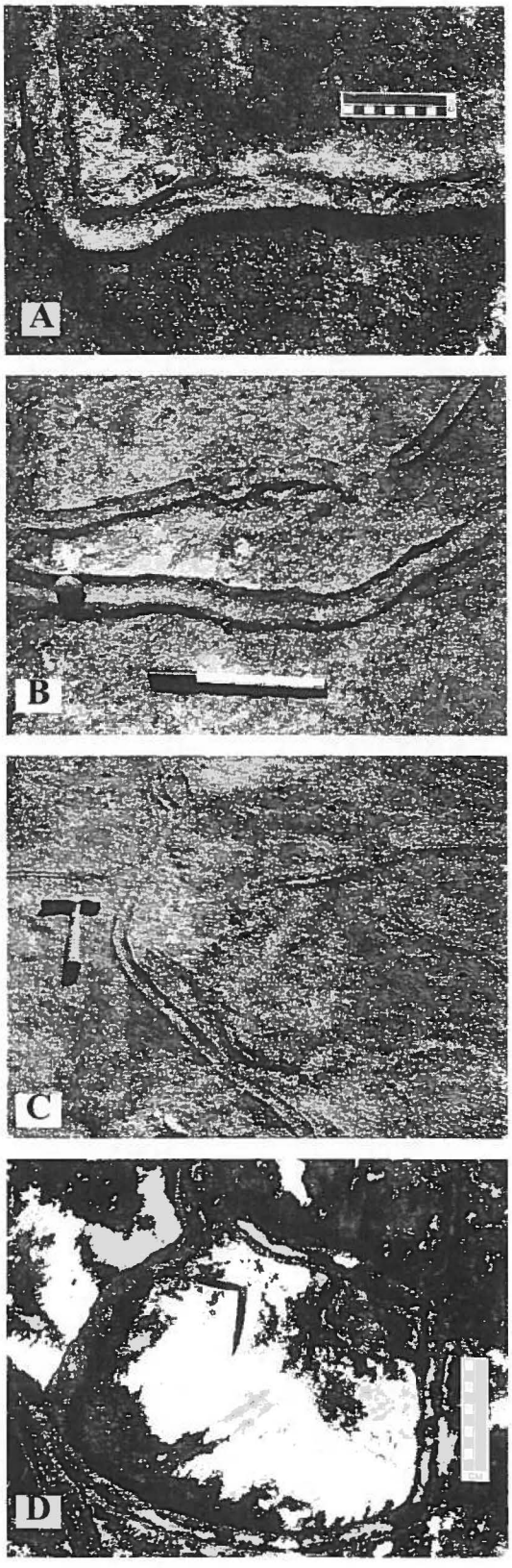

Figure 3. Views of the large enigmatic structures exposed on the laminar caliche surface a short distance west of Singer Bar Point: A) Typical structure exhibiting parallel, ridge-like edges with a smooth 'trough' in the middle. B) Parallel structures with a modern neritid snail in the trough of the lower specimen; pen = 15 cm. C) Overview of several large, meandering structures; hammer = 27 cm. D) Structure with a circular form; note that several crossovers are present and an older structure bisects the circle. E) Close-up of a complex intersecting of structures. F) Neritid snail crossing over a fossil structure and making a trail of similar form; snail diameter = 2 cm.

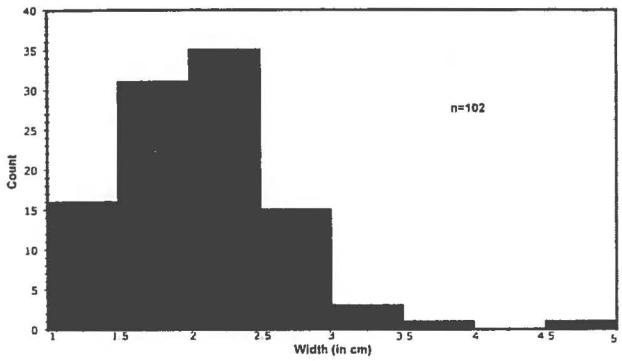

Figure 4. Histogram plot of the maximum widths of structures measured at the Singer Bar Point study area.

The larger structures branch only rarely, but cross-over intersections are common and sometimes complex (Figures 3D, E). Several species of neritid snails are present on the intertidal surfaces of the laminar caliche, and they appear to show a preference for movement along the smooth troughs of the structures (Figure 3B). Snail trails are common and distinct in areas where a thin layer of moist sand is present, and these trough-like trails commonly cross over the fossil troughs, leaving a form suggestive for origin of the latter (Figure 3F).

At first viewing, one is taken with the large, trough-like forms and their complex meandering and crossover patterns. However, more careful observation reveals the presence of a variety of forms beyond the half-relief troughs. Smaller, less obvious forms are preserved as partial or complete tubes of laminar caliche, and branching is present. Some areas have small-diameter rhizomorphs that resemble root mats.

At Singer Bar Point, the rock beneath the thin, laminar caliche layer consists of very fine to fine skeletal sand. Individual grains tend to be rounded. For the most part, the beds are gently seaward dipping and dunal bedforms are not obvious, but the absence of shell layers and the overall fine-grained texture of the rock suggest an eolian depositional origin. It is difficult to sample the actual trough structures, and no thin sections have been made, but several rock samples were cut to reveal trough structures in cross section. The rust-colored laminar caliche layers are very thin, discontinuous, and inter-layered with fine sand grains. In short, it was surprising to find just how thin the veneer of laminar caliche layer actually is. Information from the other areas of coastal laminar caliche surveyed to support the findings from Singer Bar Point will presented in the following sections of this paper.

HYPOTHESES FOR ORIGIN OF THE ENIGMATIC STRUCTURES

Three hypotheses, representing animal, vegetable, and mineral themes, are offered to explain the origin of the enigmatic structures found at Singer Bar Point. The bottom line is that these structures are variable, complex, and merit further study. Similar structures have been found elsewhere on San Salvador, as reported herein, and they likely occur throughout the Bahamas and beyond on coastal laminar caliche surfaces.

A Physical Origin – The Mineral Hypothesis

This is a 'straw-man' hypothesis in that structures of obvious inorganic origin are present and sometimes common on the Bahamian laminar caliche surfaces. These typically are caliche-filled fractures (Figure 5), and they bear superficial res-

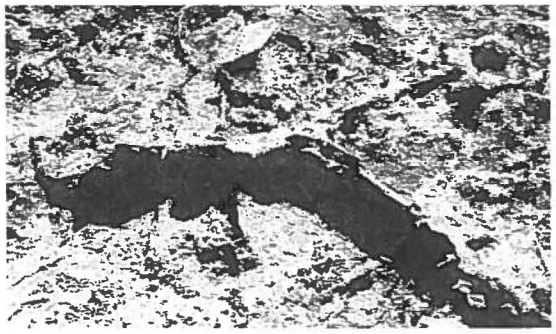

Figure 5. Caliche-filled fractures weathered out in positive relief bear superficial resemblance to the enigmatic structures. This example is in The Gulf study area; pen = 15 cm.

emblance to the meandering, trough-shaped forms found at Singer Bar Point. The inorganic structures differ from the forms at Singer Bar Point in that they exhibit irregular, zig-zag horizontal patterns, not smooth, meandering forms, and there is no true trough development. In addition, caliche-filled fractures typically are branched (Figure 5), and do not commonly reach the widths of the trough-shaped structures.

A Snail Trail Origin – The Animal Hypothesis

Modern snails that graze on intertidal sandy and smooth rock substrates with a thin cover of moist sand make trails that bear striking resemblance to the trough-shaped structures at Singer Bar Point. In the Bahamas, these trails are made by neritids (Figure 3F). A higher latitude, temperate climate example would be the intertidal zone of siliciclastic-sand beaches of Cape Cod Bay, Massachusetts. Littorinid snails are common in this setting, and they make abundant, long, meandering trails with trail crossover intersections (Figures 6A, B), very much like the Bahamian trough-shaped forms. Such trails are known from the fossil record and are most commonly assigned to the ichnogenus *Archaeonassa*. Similar trails also can be formed by polychaete worms foraging in intertidal sands (Figure 6C).

This hypothesis is appealing, but it can be rejected for at least three reasons: 1. Snail trails do not branch, i.e. the snails forage by moving ahead, and do not back up and move in another direction. Although branching is not common with the trough-shaped forms at Singer Bar Point, branching does occur and is present in examples from laminar caliche surfaces elsewhere (see below). 2. Snail trails always display only half-relief form, whereas examples of trough-shaped forms morphing to a tubular form can be cited from Singer Bar Point and elsewhere, as will be discussed below. 3. Finally, the underlying geology of the Singer Bar Point locality and other, similar localities on San Salvador do not support the possibility of a snail origin for these structures. The laminar caliche surfaces at Singer Bar Point formed on eolianites, not sediments deposited in an intertidal zone. More importantly, the caliche surface, upon which the structures were formed, developed in a fully terrestrial environment during the Last Glacial when sea level was significantly lower than at present.

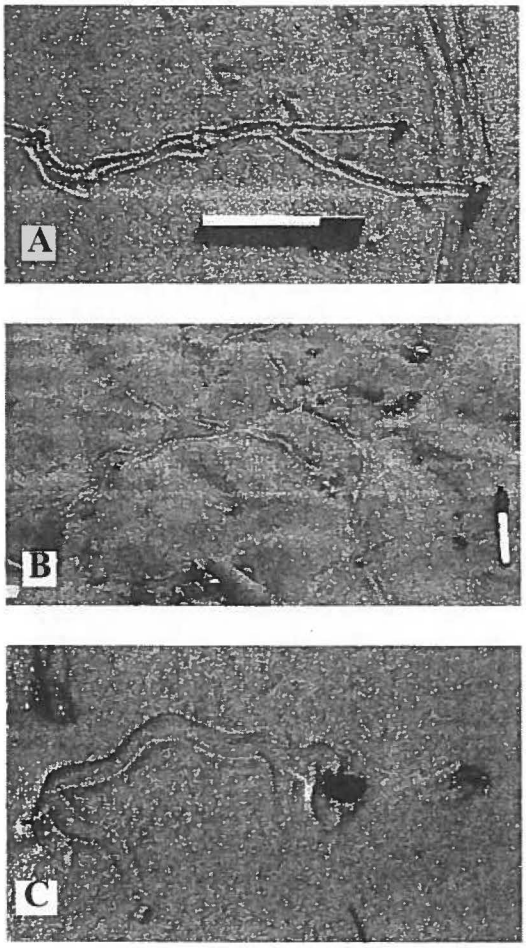

Figure 6. Intertidal zone of a siliciclastic sand beach at Duck Harbor, Wellfleet, Cape Cod Bay, Massachusetts: A) Littorinid snail trails. These trails bear close morphologic similarity to the form of the enigmatic structures; pen = 15 cm. B) Snail trails everywhere! Marker = 14 cm. C) A foraging polychaete worm ('blood worm') makes a similar trail; width of trail = 1.2 cm.

A Plant Root Origin – The Vegetable Hypothesis

Root structures, usually referred to as rhizomorphs, rhizocretions, or vegemorphs in Bahamian literature (see White and Curran, 1997, for a comprehensive review of terminology), are a common feature of Bahamian eolianites and can occur in virtually all Bahamian lithofacies. The root origin hypothesis for the trough-shaped structures at Singer Bar Point is that they represent root tubules in the sense of Klappa (1980). The tubules are preserved in half-relief, with the upper half of tubules having been eroded away with subaerial exposure of the laminar caliche surfaces on which they occur. The tubules presumably formed by partial dissolution and re-precipitation of calcitic materials around roots as they penetrated downward through overlying sediment cover and then moved laterally along the hard laminar caliche surface (see Klappa, 1980, p. 625-628, for a review of rhizomorph-formation geochemistry). It seems reasonable to assume that gravity played a role with migration of fluids generating a thicker rind of tubule material on the lower hemisphere of a given tubule, thus making the trough form thicker and more readily preserved with exposure of the laminar caliche surfaces. A few specimens at Singer Bar Point are suggestive of complete tubule formation, and I discovered an excellent example of a root tubule on a sloping laminar caliche surface on Rum Cay (Figure 7). The upper part of this specimen is a complete tubule, but the tubule was preserved only in half relief on the fully exposed lower part of the slope.

If the trough-shaped structures at Singer Bar Point are indeed half relief root tubules, they can rightfully be considered trace fossils, as they record plant activity. However, the timing of their formation is not easy to determine. It is tempting to think that the structures had a Holocene origin, with formation by plant roots penetrating down through the overlying beds of the Rice Bay Formation and moving laterally over the impenetrable laminar caliche surface, with this surface then exposed by coastal erosion stripping away the weakly lithified Holocene beds with rising sea level. However, it also is possible that the structures formed under a sediment/soil cover that developed during the long expanse of the Last Glacial. An answer to this question will not be easily determined.

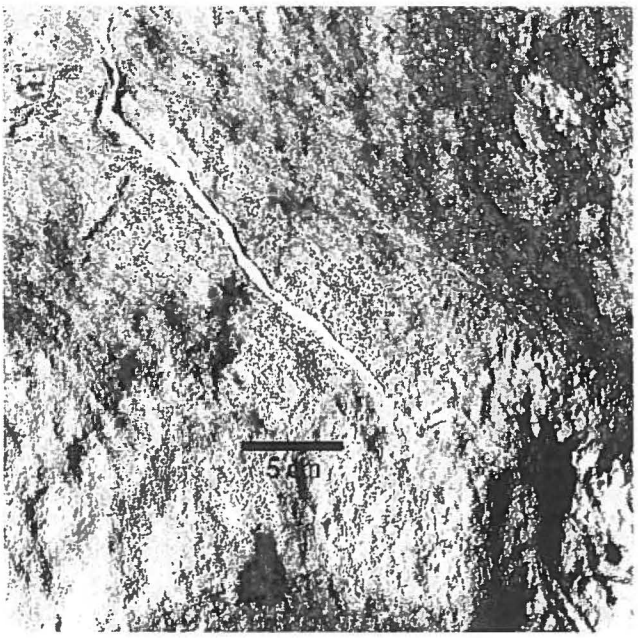

Figure 7. Long structure on a sloping laminar caliche surface on the north coast of Rum Cay. The upper end of this structure is tubular, whereas the lower two-thirds are trough-shaped. Presumably the upper part of the tubule has been eroded away. This form would be termed a root tubule following the Klappa (1980) classification of rhizoliths or rhizomorphs.

Additional evidence for a plant root origin for the structures in question is the fact that surfaces with closely spaced, mat-like masses of rhizomorphs are present at Singer Bar Point (Figure 8). These masses are not extensive, and they are not always easy to find, but they do give solid evidence of plant root activity on and just below the laminar caliche surface.

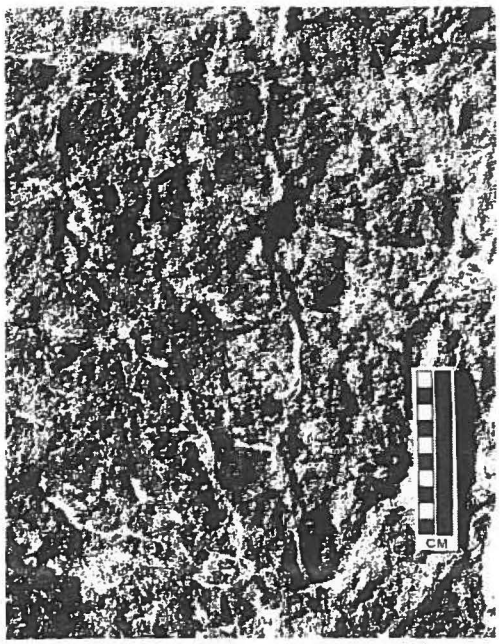

Figure 8. Horizontal surface in the Singer Bar Point study area with numerous small rhizomorphs forming what appears to be a fossil root mat.

DISCUSSION WITH EVIDENCE FROM OTHER LOCALITIES

Although I favor a root tubule origin for the structures at Singer Bar Point, a primary argument against this hypothesis might be their lack of branching. Roots typically branch, and these trough-shaped structures can extend for long distances over the laminar caliche surfaces without branching. The limiting factor at present is our lack of knowledge about the specifics of root geometries for most of the larger plant species of the Bahamas. One potential candidate for formation of these structures is roots of the sea grape (*Coccoloba uvifera*). This plant is common along the coasts of the islands of the Bahamas. Its roots are typically smooth, have diameters within the range of diameters for the trough-shaped structures, and branching, while present, can be infrequent, as might be expected with roots moving over a hard surface with minimal available nutrients and even moisture. Further research is needed before a conclusion on this trace-maker possibility can be reached.

A reconnaissance study of several other areas of coastal laminar caliche exposure on San Salvador revealed that structures similar to those at Singer Bar Point are present on the extensive surface to the west of The Gulf, with numerous structures present just east of the coastal reentrant feature informally referred to as 'The Cut,' located very close to the south side of the road to Pigeon Creek. Scattered structures also are present on the laminar caliche surface along the south end of Fernandez Bay and on the surface of the coast just north of the entrance to the Club Med marina (Figure 1).

Structures on the Fernandez Bay surface are less common, have smaller widths than the average at Singer Bar Point, and are in low relief (Figure 9A). A relatively flat caliche surface caps the high cliffs of Upper Pleistocene eolianite along the south coast of San Salvador between the Gulf and The Cut. Here the trough-shaped structures are common (Figure 9B), although not as large and well formed as those at Singer Bar Point. Nonetheless, these sites indicate that these structures are likely present on similar surfaces elsewhere on San Salvador and beyond. Figure 9C shows a branching root tubule in full relief on the south coast. This specimen clearly demonstrates that branching plant roots were present on these laminar caliche surfaces and supports the hypothesis that all of the trough-shaped structures had a root origin.

Finally, I recently found a large structure on the laminar caliche surface along the reach of coast just north of the Club Med marina (Figure 10). This is one of the longest and most intricate forms recorded to date. It does not have the raised half-relief edges typical of the Singer Bar Point specimens, probably owing to a higher degree of surface scouring by wave action at this location, but in all other respects it is identical to previously described specimens. If one looks closely at Fig-

ure 10, one will see a thin, branching rhizomorph in the upper left central area of the figure.

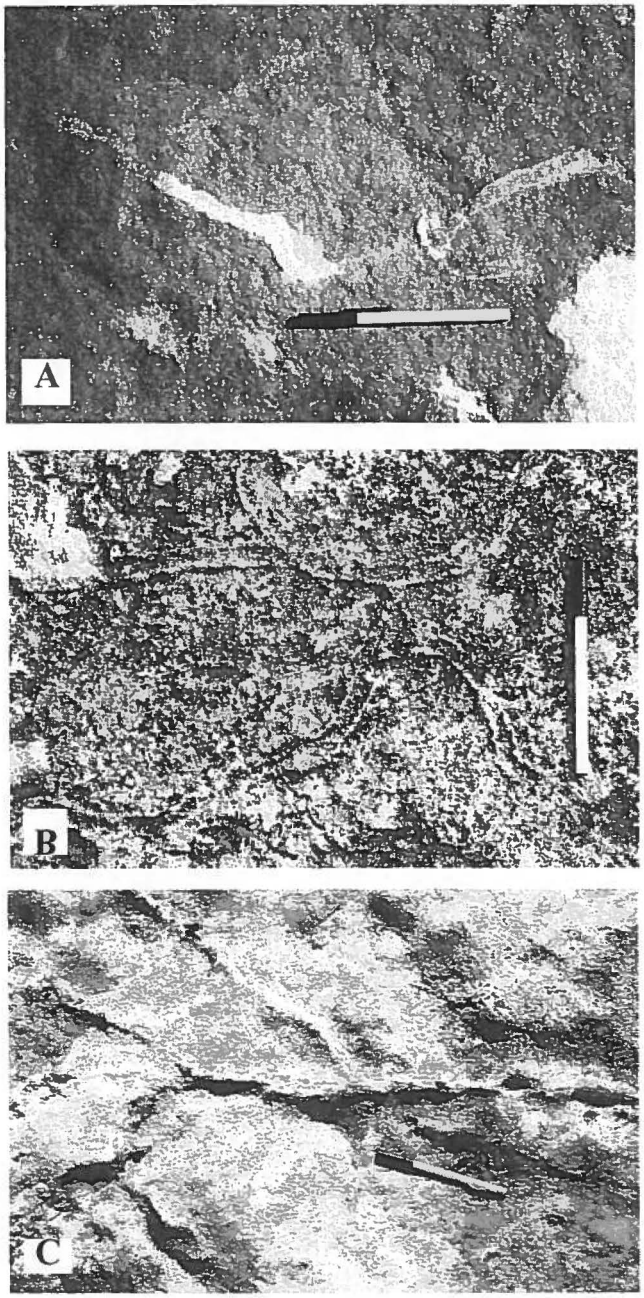

Figure 9. More enigmatic structures: A) Example from the laminar caliche surface at the south end of Fernandez Bay; pen = 15 cm. B) Intersecting structures from the surface of The Gulf study area. C) A branching root tubule from the same surface.

Figure 10. A large and complex structure from the laminar caliche surface on the coast just north of channel entrance to the Club Med marina. Note also the thin, branching rhizomorph present in the upper left-central part of the photo.

CONCLUSIONS

1. Large, highly distinctive, trough-shaped structures occur commonly on the laminar caliche surface near Singer Bar Point and other similar coastal localities on San Salvador.

2. Mineral and animal origin hypotheses for these structures can be rejected; a plant root origin is favored and supported by several lines of evidence indicating that these structure are root tubules, following the classification of Klappa (1980), eroded to half-relief form or less by coastal wave-erosion processes. Nonetheless, important questions remain, such as why branching is so infrequently observed with the majority of these structures, and just what kind(s) of plant roots might have been responsible for their formation.

3. These trough-shaped structures likely are widespread on coastal laminar caliche surfaces throughout the Bahamas and beyond. The time of origin for these structures may be highly disconnected from the geologic ages of the bedrock and caliche surfaces on which they formed. The time disconnect may not be easily recognized and appreciated in more ancient carbonate sequences where similar forms might occur.

ACKNOWLEDGMENTS

I am indebted to Jim Carew for originally directing my attention to the enigmatic structures present at Singer Bar Point. My thanks to Fred Siewers and Jon Martin for their excellent work with producing this volume and for their patience and good assistance with editing of the original manuscript. Anna Dustira conducted a preliminary study of the structures at Singer Bar Point, and Andrea Gohl and Madeline Weigner (all Smith College) helped with drafting of figures. Jane Curran assisted greatly with field investigations, and Deedie Steele aided with preparation of the photo figures. Fieldwork for this project was funded in part by the Smith College Committee for Faculty Compensation and Development and by the Smith Department of Geosciences. I am grateful to the staff of the Gerace Research Center for full logistical support of my research on San Salvador Island.

REFERENCES

Beier, J.A., 1987, Petrographic and geochemical analysis of caliche profiles in a Bahamian Pleistocene dune: Sedimentology, v. 34, p. 991-998. (This paper reprinted in the Wright and Tucker volume as below.)

Boardman, M.R., McCartney, R.F., and Eaton, M.R., 1995, Bahamian paleosols: origin, relation to paleoclimate, and stratigraphic significance, *in* Curran, H.A., and White, B., eds., Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda: Boulder, Colorado, Geological Society of America, Special Paper 300, p. 33-49.

Carew, J.L., and Mylroie, J.E., 1995, Depositional model and stratigraphy for the Quaternary geology of the Bahamas Islands, *in* Curran, H.A., and White, B., eds., Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda: Boulder, Colorado, Geological Society of America, Special Paper 300, p. 5-32.

Curran, H.A., 1994, The palaeobiology of ichnocoenoses in Quaternary, Bahamian-style carbonate environments: the modern to fossil transition, *in* Donovan, S.K., ed., Palaeobiology of Trace Fossils: Chichester, England, John Wiley & Sons, Ltd., p. 83-104.

Curran, H.A., 2007, Ichnofacies, ichnocoenoses, and ichnofabrics of Quaternary shallow-marine to dunal tropical carbonates: a model and implications, *in* Miller W. III, ed., Trace Fossils: Concepts, Problems, and Prospects: Amsterdam, Elsevier B.V., p. 232-247.

Curran, H.A., and White, B., 1991, Trace fossils of shallow subtidal to dunal ichnofacies in Bahamian Quaternary carbonates: Palaios, v. 6, p. 498-510.

Curran, H.A., and White, B., 2001, Ichnology of Holocene carbonate eolianites of the Bahamas, *in* Abegg, F.E., Harris, P.M., and Loope, D.B., eds., Modern and Ancient Carbonate Eolianites: Sedimentology, Sequence Stratigraphy, and Diagenesis: Tulsa, Oklahoma, SEPM (Society for Sedimentary Geology) Special Publication 71, p. 47-56.

Klappa, C.F., 1980, Rhizoliths in terrestrial carbonates: classification, recognition, genesis and significance: Sedimentology, v. 27, p. 613-629. (This paper reprinted in the Wright and Tucker volume as below.)

Mylroie J.E., and Carew, J.L., 2008, Field Guide to the Geology and Karst Geomorphology of San Salvador Island: San Salvador, Bahamas, Gerace Research Centre, 88 p.

White, B., and Curran, H.A., 1997, Are the plant-related features in Bahamian Quaternary limestones trace fossils?: discussion, answers, and a new classification scheme, *in* Curran, H.A., ed., Guide to Bahamian Ichnology: Pleistocene, Holocene, and Modern Environments: San Salvador, Bahamian Field Station, p. 47-54.

Wright, V.P., and Tucker, M.E., eds., 1991, Calcretes: Reprint series volume 2, International Association of Sedimentologists: Oxford, England, Blackwell Scientific Publications, 352 p.