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Front Cover: Rice Bay Formation, looking southwest along Grotto Beach. Photograph by Sandy Voegeli.

Back Cover: Dr. John Milliman, The College of William and Mary. Keynote Speaker for the 13th Symposium. Photograph by Sandy Voegeli.

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# FOSSIL PALM FROND AND TREE TRUNK MOLDS: OCCURRENCE AND IMPLICATIONS FOR INTERPRETATION OF BAHAMIAN QUATERNARY CARBONATE EOLIANITES

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## ABSTRACT

Molds of palm fronds and vertical, cylindrical structures interpreted as molds of palm tree trunks were reported from Holocene and upper Pleistocene carbonate eolianites on several islands in the Bahamas in the early 1990s. As a result of recent discoveries described herein, palm frond and tree trunk molds are now known to be widespread in Bahamian eolianites, including Holocene beds on Cat Island, Eleuthera, Lee Stocking Island of the Exuma Cays, Long Island, and Stocking Island offshore from Georgetown, Exuma. Late Pleistocene occurrences are known from Eleuthera, Long Island, Norman's Pond Cay of the Exuma Cays, and San Salvador Island. Both palm frond and trunk molds also occur in upper Pleistocene eolianites of Bermuda.

Beds with prolific tree trunk molds comprise an eolianite facies that is interpreted to have formed when drifting sands of coastal dunes encroached on and over the trees of a coastal coppice community dominated by the silver thatch palm, *Coccothrinax argentata*. Rapid cementation of these sands by meteoric waters and decay of palm trunks created the large, cylindrical trunk-mold structures and spongiform texture of this distinctive facies, best represented in Holocene strata exposed along the windward coasts of Eleuthera, Long Island, Lee Stocking Island, and Stocking Island.

## INTRODUCTION

Quaternary carbonate eolianites are the dominant rock type capping the islands of the Bahama Archipelago (Figure 1), with virtually all bedrock above 7 meters elevation and much of that at lower elevations, even below sea level, being of eolian origin (Carew and Mylroie, 2001). In recent years, interest in carbonate eolianites has grown, as geologists have come to recognize that an eolian interpretation for grainstones may be more commonly warranted than previously thought (Abegg et al., 2001). For the Bahamas, the meso- and macro-scale physical sedimentary structures and trace fossils that characterize the Quaternary eolianites have been described in some detail from various island localities (e.g., White and Curran, 1988; Caputo, 1995; Kindler, 1995; Curran and White, 2001).

Nonetheless, much remains to be learned about Bahamian eolianites, including better characterization of the various facies that may

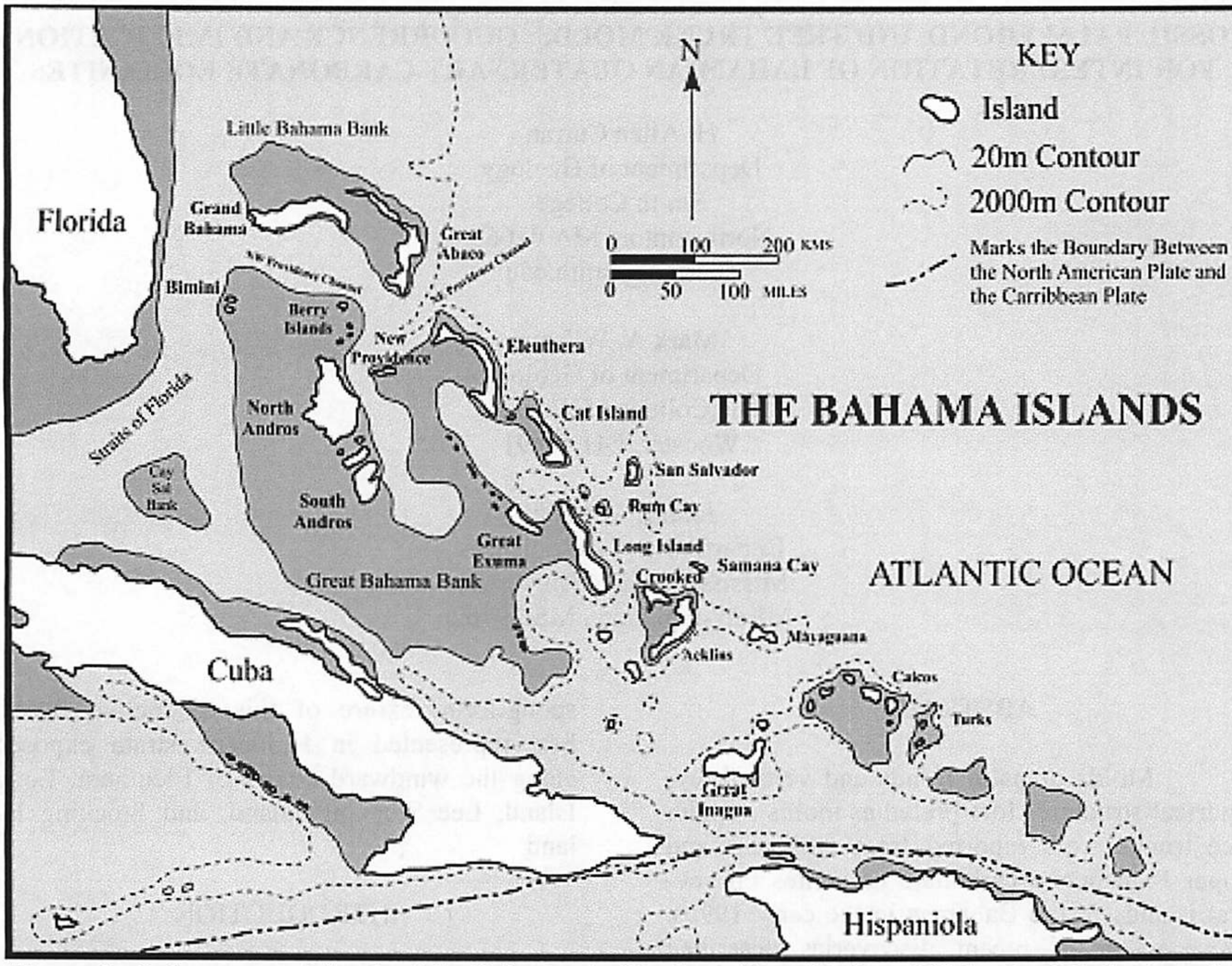


*Figure 1. Index map to islands of the Bahama Archipelago (from Walker, 2006). In alphabetic order, fossil palm frond molds presently are known to occur in Quaternary carbonate eolianites on Cat Island, Lee Stocking Island and Norman's Pond Cay of the Exuma Cays (both just north of Great Exuma), and San Salvador Island. Fossil tree trunk molds (and some casts) occur on Cat Island, Eleuthera, Lee Stocking Island, Long Island, and Stocking Island (Atlantic side of Great Exuma, offshore from Georgetown).*

be present within any given eolianite unit. The goals of this paper are to describe the occurrence and nature of palm frond and tree trunk molds in eolianites from previously reported and newly discovered localities throughout the Bahamas, to offer an explanation for the formation of such fossils, and to evaluate their implications for paleoenvironmental interpretation.

## GEOLOGIC SETTING AND OCCURRENCE

Palm frond and tree trunk molds occur in both upper Pleistocene and Holocene eolianites and have been reported from several of the Bahama islands (Figure 1). Following the Bahamas stratigraphy of Carew and Mylroie (1995, 1997), fossil frond and tree trunk molds are known from Holocene rocks of both the North Point and Hanna Bay members of the Rice Bay Formation, from the regressive eolianites of the Cockburn Town Member of the upper Pleistocene Grotto Beach Formation, and also from transgressive eolianites of the French Bay Member (Figure 2).

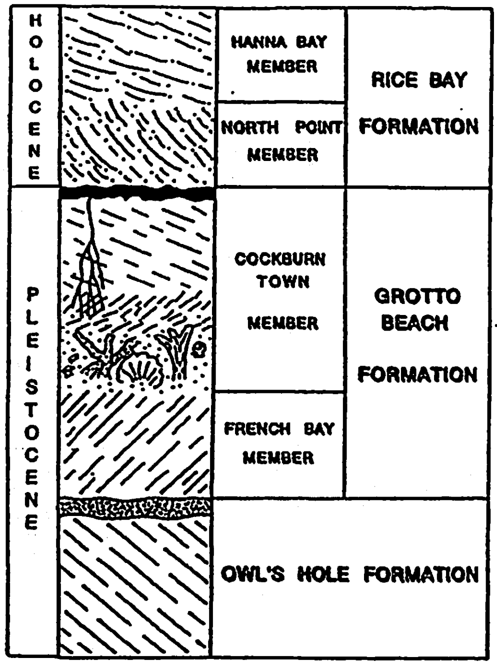


*Figure 2. The Carew-Mylroie stratigraphy of the Bahamas (Carew and Mylroie, 1995, 1997).*

Interestingly, in occurrences described to date, fossil palm frond molds are not commonly found in direct association with fossil tree trunk molds. Frond molds have been reported previously from Holocene eolianites on Lee Stocking Island of the Exuma Cays (White and Curran, 1993; Kindler, 1995) and Cat Island (Mylroie et al., 2006) and from upper Pleistocene strata in a submarine cave on Norman's Pond Cay of the Exuma Cays (Curran and Dill, 1991). Carew and Mylroie (1994) noted the presence of frond molds in upper Pleistocene beds of the walls of Triple Shaft Cave, a pit cave in the southwestern part of San Salvador, and JEM believes that trunk molds also may be present here. If so, this would mark a first occurrence of both palm frond and trunk molds in close proximity at a single locality.

Fossil tree trunk molds, presumably also from palms, as will be discussed, have been reported from Holocene eolianites on Lee Stocking Island (White and Curran, 1993; Kindler, 1995) and Long Island (Curran et al., 2004). One of us (HAC) found trunk molds similar to those on Long Island in Holocene eolianites of the windward coast of Stocking Island, offshore from Georgetown, Great Exuma. Holocene tree trunk molds also recently were discovered by HAC on the windward coast of Eleuthera, a short distance north of Governor's Harbour, and by JEM on the southern coast of Cat Island. Kindler and Hearty (1996) reported a single trunk mold in upper Pleistocene strata on Eleuthera, also near Governor's Harbour, and JEM found a site on the windward coast of the mid-part of Long Island where trunk casts were common in upper Pleistocene eolianites.

Fossil palm frond and tree trunk molds long have been known to occur in the Pleistocene eolianites of Bermuda (Vacher and Rowe, 1997, and earlier references cited therein). The palm frond and tree trunk molds illustrated by Vacher and Rowe (1997, Fig. 2.7) in the upper Pleistocene Rocky Bay Formation are very similar to those of the Bahamas. Other cylindrical structures, as figured by Vacher and Rowe (1997, Fig. 2-9), were termed soil pipes by Vacher et al. (1995; see Vacher and Rowe, 1997, p. 47-48, for a list of previously applied names). The origin of these structures is more problematic and will be discussed briefly later.

## THE FOSSIL PALM FROND AND TREE TRUNK MOLDS

### Palm Frond Molds

The most prolific occurrence of fossil palm frond molds reported to date from the Bahamas is within a Holocene eolianite outcrop at Alligator Point on Cat Island. This site was discovered by the Gerace Research Center reconnaissance team in preparation for the 2006 Bahamas Geology Symposium field trip to Cat Island. As Stop 6 of the field trip, details on the location of the outcrop and its description are given in the guidebook (Mylroie et al., 2006, p. 29-33).

This outcrop was generated by excavation for an access road to new home sites, and it cuts the long axis of a fossil dune, revealing a section of well-bedded oolitic eolianite up to 4 m in thickness. There is no calichified paleosol

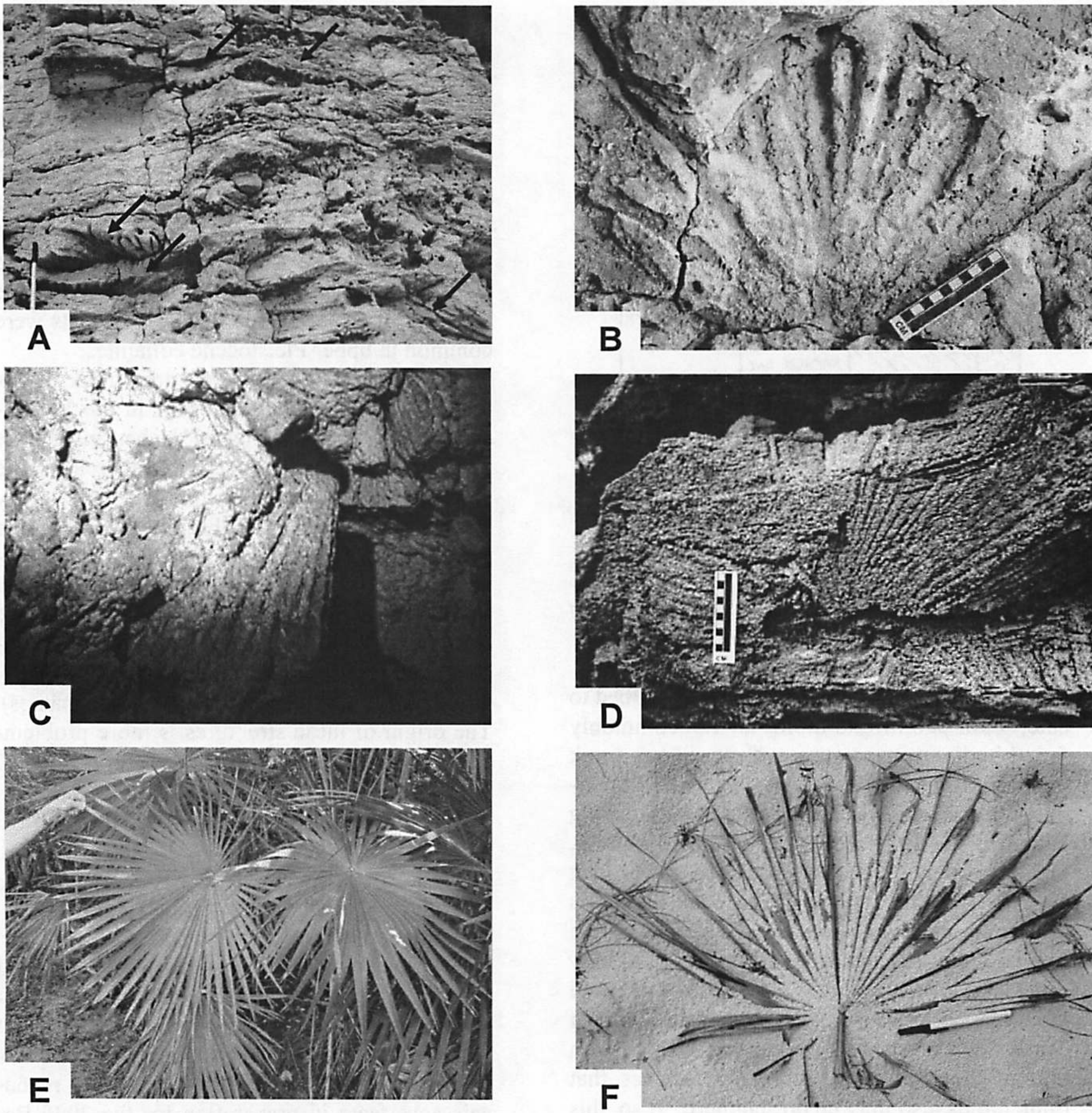


*Figure 3. A) Vertical exposure of eolianite beds, North Point Member of Rice Bay Fm., Alligator Point, Cat Island. Arrows indicate palm frond mold fossils. Pen =15 cm. B) Plan view of palm frond mold at Alligator Point. Scale = 10 cm. C) Palm frond molds in late Pleistocene eolianite beds exposed in walls of a submarine cave, Norman's Pond Cay, Exuma Cays. Length of molds up to 40 cm. D) Palm frond mold in the Devonshire Member, late Pleistocene Rocky Bay Fm, Bermuda. Scale = 10 cm. E. Living silver thatch palm fronds, Cat Island. Arm for scale = about 30 cm. F. Silver thatch frond partially buried in proto-dune sands, Cat Island. Pen = 15 cm.*

at the top of the dune ridge, confirming a Holocene age for these beds of the North Point Member of the Rice Bay Formation.

Within the outcrop, the palm frond molds are numerous and manifested as coarsely crenulated surfaces along bedding planes (Figure 3A). Parts of frond molds occur commonly in blocks of eolianite lying near this outcrop and along the access road. They can be recognized by the distinctive subparallel to radiate, ridge and groove structure found on the eolianite bedding plane surfaces. A near- perfect palm frond mold fossil (Figure 3B) was found by HAC close to Stop 6 on a bedding plane surface on the Exuma Sound side of Alligator Point during further field study in early 2007.

Similar structures have been found in Holocene eolianites on Lee Stocking Island of the Exuma Cays (White and Curran, 1993, Figure 15; Kindler, 1995). Palm frond molds in upper Pleistocene eolianites also are known to occur in the walls of a submarine cave (Figure 3C) on Norman's Pond Cay of the Exuma Cays, as described by Curran and Dill (1991, Figure 3). On San Salvador, in the walls of Triple Shaft Cave, Sandy Point Pits area, Carew and Mylroie (1994, p. 18), reported the occurrence of palm frond molds in what are thought to be beds of the French Bay Member of the Grotto Beach Formation. Possible trunk molds also may be present in this cave (JEM, not yet described). On Bermuda, similar palm frond molds (Figure 3D) are known from the upper Pleistocene eolianites of the Rocky Bay Formation (Vacher and Rowe, 1997, Fig. 2-7A) and have been observed by HAC in the Southampton Formation.

These fossil molds are interpreted as having formed by the burial of palm fronds in drifting dune sands. With lithification of the dune sediment and decay of organic matter of the frond, the frond mold is generated. As will be discussed further, a likely palm candidate for the frond and tree trunk molds is the silver thatch palm (*Coccothrinax argentata*), common in coastal areas throughout the Bahamas. The fronds of the silver thatch palm are large (can be up to about 1 m in diameter; Figure 3E), accordion-like in form, pliable, and tough. Dead fronds commonly litter the surface around living trees, and easily could be buried in drifting sand (Figure 3F; compare with the fossil mold of 3B).

## Trunk Molds

Although fossil tree trunk molds were reported from the Bahamas, on Lee Stocking Island, in the early 1990s (White and Curran, 1993), reconnaissance by a Gerace Research Center team in preparation for a Bahamas Geology Symposium field trip was again the catalyst for a new discovery – this time on Long Island in 2004. The key outcrop section is on the Atlantic side of Long Island, at the north end of Cabana Beach of the Stella Maris Resort (Curran et al., 2004, Stop 3, p. 12-15). A similar sequence of beds occurs at the rocky coast exposures of Stop 1 (Cave Point) of the Long Island field trip guide (Curran et al., 2004), although access to this site is not so easy.

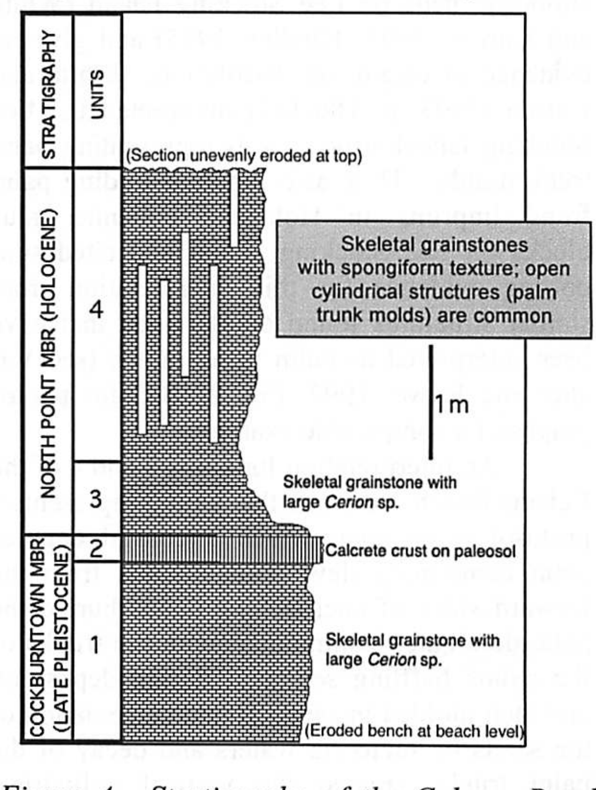


*Figure 4. Stratigraphy of the Cabana Beach section, Stella Maris Resort, Long Island, Bahamas (modified from Curran et al., 2004).*

The Cabana Beach exposure provides a classic view of the Upper Pleistocene/Holocene contact, as shown in the stratigraphic column of Figure 4. Here Holocene strata of the North Point Member of the Rice Bay Formation lie above a thick, continuous, and very hard caliche layer marking the top of the Pleistocene sequence. The skeletal grainstone beds of Unit 4 of this section are fine grained, not distinctly laminated, and have a friable, spongiform texture (Figure 5A). In addition, they contain numerous well-developed vertical, open cylindrical structures (Figure 5B, D). These cylindrical holes have inside diameters of up to 12 cm, lengths of up to 1.3 m, and are prolific in occurrence. In 2006, HAC measured all holes with inside diameters (not including rind material) of 5 cm or more on several bedding plane surfaces. A total area of 16 $m^2$ was surveyed, and 44 holes were encountered, for an average of 2.75 holes per $m^2$.

These cylindrical structures are very similar to the structures reported in equivalent Holocene beds on Lee Stocking Island (White and Curran, 1993; Kindler, 1995) and give no evidence of origin via dissolution. White and Curran (1993, p. 186-187) interpreted the Lee Stocking Island structures as representing palm trunk molds. They also reported finding palm frond imprints in Holocene eolianite talus blocks on Lee Stocking Island and cited supporting evidence for this interpretation from similar structures found on Bermuda that have been interpreted as palm trunk molds (see Vacher and Rowe, 1997, Fig. 2-7B,C for photographs of a comparable example).

An interpretation for Units 3 and 4 of the Cabana Beach section is that Unit 3 represents a protosol layer upon which a coastal coppice palm community developed. Sands from the leeward sides of encroaching dunes buried the palm-dominated community, with the trunks of the palms baffling sediment during deposition and then molded in sand. Rapid cementation of the sands by meteoric waters and decay of the palm trunks created the vertical cylindrical structures (tree trunk molds) and spongiform texture of Unit 4. The hard calichified rind that commonly lines trunk molds likely begins to form early in the burial process, with cementation and diagenesis as meteoric waters run down tree trunks and into the host sediment (Figure 5C). Beds lying above Unit 4 have typical eolianite lamination, contain numerous rhizomorphs, and represent the continued migration of dunes over the coastal palm community.

Several more localities of prolific occurrence of cylindrical structures or palm trunk molds have been discovered in the Bahamas since 2004. These include at Newton Cay on the far north end of the Atlantic coast of Long Island, where HAC found numerous trunk molds in Holocene Hanna Bay Member beds, as well as a similar sequence at Poseidon Point to the south, between Newton Cay and Stella Maris. HAC also observed palm trunk molds on the Atlantic coast of Stocking Island, offshore from Georgetown, Exuma and on the Atlantic side of Eleuthera, just north of the Twin Coves beach estate (on the coast and very near the Two Pines section of Kindler and Hearty (1996) a short distance north of Governor's Harbour). At this locality, trunk molds are prolific in North Point Member beds (Figure 5E). As at the Cabana Beach section on Long Island, the molds occurred in essentially unlaminated skeletal grainstones with a spongiform texture.

Likewise, in a reconnaissance study of the south end of Cat Island, JEM and his students recently discovered numerous trunk molds in Hanna Bay Member beds near Devil's Point, on the southwest coast of the island (Figure 5F). On the mid-Atlantic coast of Long Island, from another reconnaissance study, JEM reported a similar find of trunk molds and casts in upper Pleistocene strata of the Grotto Beach Formation (Figure 5G). This site merits further study because trunk casts have not been observed to date in Holocene strata. Comparison also needs to be made with the fossil tree trunk reported by Kindler and Hearty (1996, Figure 11) in upper Pleistocene eolianites at the Two Pines dune section on Eleuthera and with possibly similar structures on Bermuda. Beyond the Vacher and Rowe (1997) example of a trunk mold cited earlier, most of the "solution pipe" Bermudan

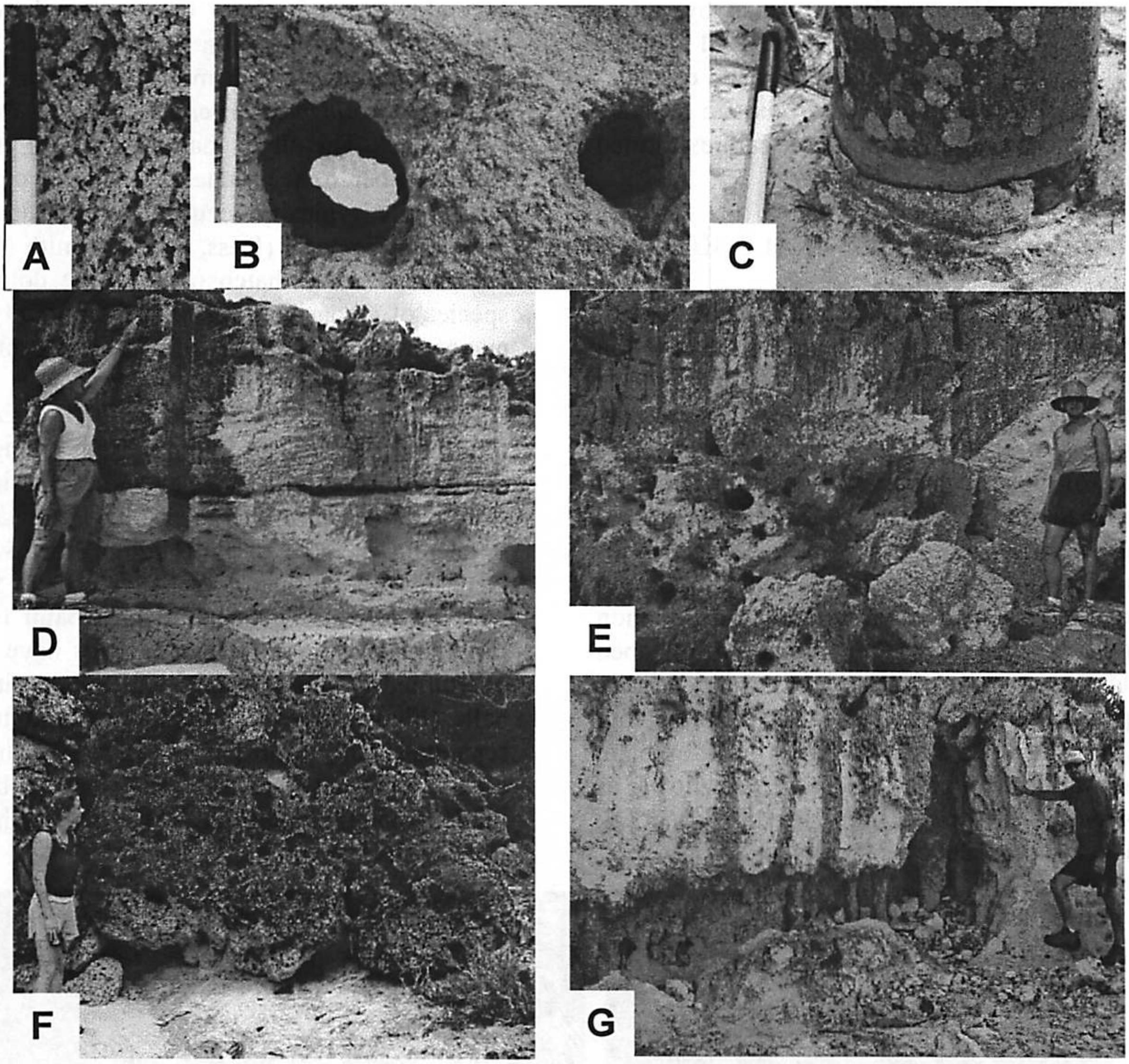


*Figure 5. A) Spongioform texture of grainstones, Unit 4 beds, North Point Member, Rice Bay Fm., Cabana Beach section, Long Island. Pen top = 4 cm. B) Open holes of tree trunk molds at Cabana Beach. Pen = 15 cm. C) Silver thatch palm tree with base of trunk encased by a calcified rind and growing in Hanna Bay Member beds of the Rice Bay Fm., Cape Santa Maria, NW Long Island. Pen = 15 cm. D) Multiple tree trunk molds in Unit 4, Cabana Beach section. Trunk molds commonly reach 2-m-length at this site. E) Prolific occurrence of tree trunk molds in beds of the North Point Member, Rice Bay Fm., exposed along the Atlantic coast north of Twin Coves near Governor's Harbor, Eleuthera. F) Tree trunk molds in cross-section of block of Hanna Bay Member eolianite near Devil's Point, Cat Island. G) Tree trunk molds and casts in Upper Pleistocene strata, Grotto Beach Fm., mid-Atlantic coast of Long Island.*

examples were reinterpreted by Herwitz (1993) as structures formed by stemflow phenomena, not as the molding of tree trunks by eolian sands. Thus, there is need for critical analysis of all localities where trunk molds and casts occur in the Bahamas and on Bermuda to evaluate further the ways in which these features formed and were preserved.

## A MODERN PALM ANALOGUE

Many examples of the occurrence of buried trees, even forests, have been reported in the geologic literature, beginning with the oldest known trees of the Gilboa forest that are preserved *in situ* in middle Devonian sedimentary rocks of upstate New York (Meyer-Berthaud and Decombeix, 2007). Tree trunks preserved in upright position are known to occur in sediments ranging from terrestrial siliciclastics to volcanic ash, with rapid burial as a common theme. Burial with the formation of open molds, as is the case for all of the Holocene examples cited herein, seems less common, but can include interesting examples such as palm preservation as molds in basaltic lava flows, as was recently described from Hawaii (Woodcock and Kalodimos, 2005).

In their field guides to the vegetation of San Salvador, Smith (1993) and Kass (2005) list several species of palms. Our best modern analogue for the fossil palm frond and tree trunk molds found in the Bahamas is the silver thatch palm, *Coccothrinax argentata*, of the Family Arecaceae. The silver thatch palm is a prominent member of the Bahamian coastal coppice community, typically occurring in dry, open areas along the coast (Kass, 2005). Smith (1993) recognized silver thatch palm as the dominant species of a coastal coppice subcommunity and mapped several locations of this subcommunity on San Salvador.

One area of occurrence of the *Coccothrinax argentata* subcommunity is along the northwest coast of San Salvador, just inland from the beach immediately east of Barkers Point and the site of the Haitian boat wreck. Here there is an open silver thatch palm forest with considerable ground litter of palm fronds (Figure 6A). In some places trees have been overturned by storm winds, exposing their root balls (Figure 6B). Interestingly, palm trunks separate cleanly from the root balls. At this location, it is not hard to envision wind-blown sands moving inland from the nearby beach and burying the forest.

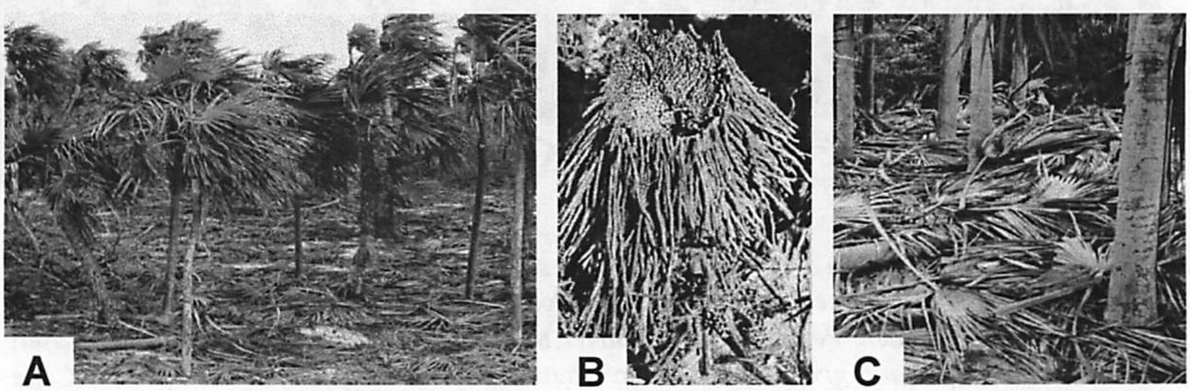


*Figure 6. A) Silver thatch palm (*Coccothrinax argentata*) coastal coppice, northwest coast of San Salvador (just inland from beach immediately east of Barkers Point and site of the wrecked Haitian boat). Note near monospecific occurrence of palm trees (about 3 to 5 m height) and the ground litter of fronds. B) Root ball of a silver thatch palm, showing clean break from the trunk. Diameter at top is about 15 cm. C) Silver thatch coppice just south of Club Med beach, near Governor's Harbour, Eleuthera. Tree trunk diameters here are significantly larger than at the San Salvador site and average about 17 cm. Note the dense litter of fronds. These two sites were used to gather statistical data displayed in Figure 7.*

This is the scenario we propose for formation of the fossil palm frond and tree trunk molds described here. With the formation of eolianites in earlier Holocene and interglacial Pleistocene times, intervals of drifting sand in large quantities must have been much more common throughout the Bahamas than is the case today. This would make the coastal coppice vulnerable to burial, with the fronds and tree trunks of the silver thatch palm being prime candidates for fossilization. Are all fossil trunk molds those of palms? Likely not, but at this stage in our investigations, it is not possible to identify different forms of trunk molds, and palm trunks are the best match for the characteristics of the cylindrical structures that we have observed and measured.

In order to test the coastal coppice burial scenario, HAC and field assistants measured the inside diameters (not including rind material) of fossil trunk molds from five study sites on Long Island and Eleuthera. These data were compared with measurements of modern silver thatch trunk diameters from forest sites on San Salvador and Eleuthera (Figure 6A,C).

The results are shown in Figure 7. Mean diameters for the five fossil sites are similar and

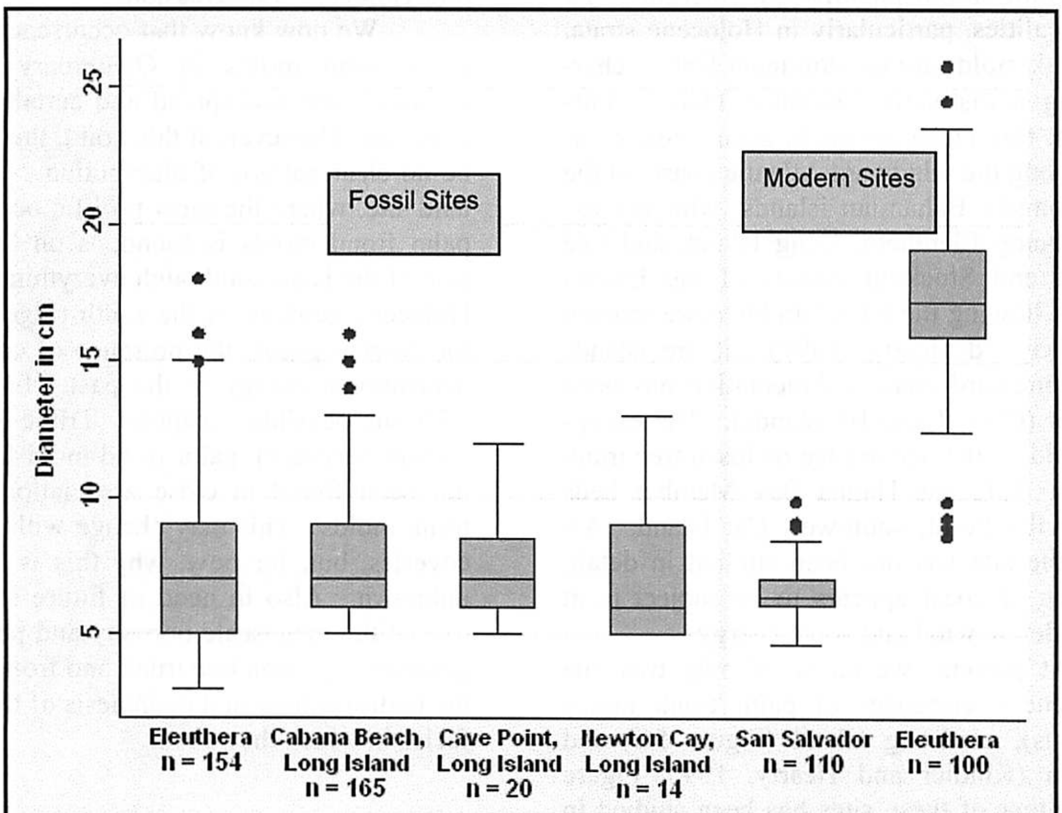


*Figure 7. Box plots for counts of diameters of fossil tree trunk molds and modern silver thatch palm (*Coccothrinax argentata*) trunks at selected sites on Eleuthera, Long Island, and San Salvador.*

suggest a single species of origin. The mean diameters of the fossil sites also matched closely with the mean diameter of the trees at the San Salvador site, supporting silver thatch palm as the modern analogue. However, the modern Eleuthera site does not match well. It was obvious when the measurements were made that this was a much more mature forest with bigger trees than those measured on San Salvador. So, while these results are suggestive, they are by no means conclusive in favor of the silver thatch palm as the one and only analogue. Nonetheless, one might speculate that in environmental settings of highly mobile sands, coastal coppice forests would be highly vulnerable to burial. With shorter amounts of time for development, the palm trees would not reach full maturity and would be expected to have and smaller diameter trunks, as at the San Salvador forest site.

## DISCUSSION

Although the full distribution and significance of the occurrence of fossil palm tree trunk and frond molds in the carbonate eolianites of the Bahamas remains to be determined, some initial patterns are emerging. At many localities, particularly in Holocene strata, palm trunk molds are the dominant feature characterizing a distinctive eolianite facies. Furthermore, this facies seems to occur most commonly along the windward Atlantic coasts of the more elongate Bahamian islands, with the examples being Eleuthera, Long Island, and Lee Stocking and Stocking islands of the Exuma Cays. Following the island architecture scheme of Kindler and Hearty (1997), all are islands where windward coast sedimentation has been dominant (Class I and III islands). The exception would be the occurrence of fossil tree trunk molds in Holocene Hanna Bay Member beds near Devil's Point, southwest Cat Island. Although the site has not been studied in detail, this reach of coast appears to be subject to at least moderate wind and wave energy.

At present, we know of only two late Pleistocene occurrences of palm trunk molds (and casts), on Long Island (Figure 5G) and Eleuthera (Kindler and Hearty, 1996, Figure 11). Neither of these sites has been studied in detail from the prospective of the significance of palm trunk mold and cast fossils, so it is too early to draw conclusions. Nonetheless, it seems likely that more sites of trunk mold and cast occurrence will be found in upper Pleistocene eolianites with further reconnaissance along the extensive windward coast of Long Island and elsewhere.

Rapid burial by dune sands migrating inland from adjacent beaches during transgression is the most likely explanation for the Holocene sites with prolific occurrences of tree trunks molds as described herein. However, caution is warranted because, as emphasized by Carew and Mylroie (2001), Bahamian eolianites form complex topographies with transgressive, stillstand, and regressive phases. Therefore each case must be evaluated individually with respect to depositional history. The Cabana Beach section on Long Island (Figure 4) is an excellent example of rapid burial of a coastal coppice forest, probably dominated by silver thatch palms (*Coccothrinax argentata*), during mid-Holocene transgression.

We now know that occurrences of fossil palm frond molds in Quaternary Bahamian eolianites are widespread and certainly not uncommon. However, at this point, there seems to be no clear pattern of distribution. The Cat Island site, where the most prolific occurrence of palm frond molds is found, is on the leeward side of the island, although everything about the Holocene geology of the south ridge of Alligator Point suggests the presence of considerable depositional energy in the past. Interestingly, with one possible exception (Triple Shaft Cave on San Salvador), palm frond mold fossils have not been found in close association with tree trunk molds. This may change with future discoveries, but, for now, why this is so remains unknown. Also in need of future study is the role of the megascale porosity and permeability generated by open tree trunk and frond molds on the hydrogeology and diagenesis of the eolianite facies in which they occur.

## CONCLUSIONS

As a result of several recent discoveries, fossil palm frond and tree trunk molds now are known to be widespread in the Holocene and upper Pleistocene eolianites of the Bahamas. When occurring in abundance, tree trunk molds form a distinctive facies, as shown by the Holocene examples cited herein, and this also is likely the case for trunk molds and casts in upper Pleistocene eolianites, although only one site on Long Island with numerous specimens is presently known, and it has not been studied in detail.

The prolific occurrence of trunk molds indicates depositional conditions of rapid burial by drifting dune sands, most likely covering coastal coppice forests dominated by the silver thatch palm, *Coccothrinax argentata*. The Holocene examples that occur on Long Island, Eleuthera, and Lee Stocking and Stocking islands of the Exuma Cays are a direct result of eustatic sea-level transgression. Nonetheless, caution is warranted in the detailed interpretation of depositional environment at any given site because conditions of drifting eolian sands can be present in times of sea-level highstand, still-stand, and regression as well.

Fossil palm frond molds, also attributed to the silver thatch palm, now have been reported from numerous islands and a variety of settings throughout the Bahamas. The most prolific occurrence known to date is in Holocene eolianites at Alligator Point on Cat Island. Interestingly, with one exception (Triple Shaft Cave on San Salvador), fossil palm frond molds have not been found in close association with tree trunk molds.

A number of questions related to the occurrence and significance of fossil palm frond and tree trunk molds remain and should be investigated in the future, including:

1. How widespread is the tree trunk mold facies and does it have a consistent stratigraphic position within Bahamian eolianite sequences?

2. How widespread is palm frond mold occurrence, and why aren't fossil frond and trunk molds consistently found together? Where are the tree root balls, and, if not preserved, why not?

3. What are the implications of the porosity and permeability generated by fossil tree trunk molds for the hydrology and diagenetic processes within the carbonate eolianites in which they occur?

4. How closely do palm frond molds and tree trunk molds and casts from the Bahamas compare with those of Bermuda?

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