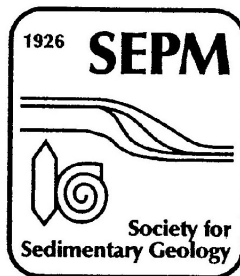


# **TECHNOLOGY OF HOLOCENE CARBONATE EOLIANITES OF THE BAHAMAS**

**H. ALLEN CURRAN AND BRIAN WHITE**



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# ICHOLOGY OF HOLOCENE CARBONATE EOLIANITES OF THE BAHAMAS

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**ABSTRACT:** Wind-deposited, terrestrial carbonate grainstones, formed concurrently with sea-level transgression, constitute the greater part of the Holocene rock record throughout the Bahama Archipelago and are particularly common along windward coastal reaches. Eolianite exposures of the Rice Bay Formation on North Point and along the Hanna Bay cliffs on San Salvador are characterized by well-preserved physical sedimentary structures, most notably large-scale cross-stratification and distinctive, millimeter-scale, inversely graded lamination couplets, along with other mesoscale structures. These carbonate eolianites also typically contain a diverse assemblage or ichnocoenosis of plant and animal trace fossils. Structures formed by plant roots are nearly ubiquitous in Bahamian Quaternary limestone facies and commonly occur in these Holocene eolianites. In addition, the above-ground parts of plants and trailing roots may form distinctive trace fossils along the bedding planes of eolianites. Animal trace fossils, including *Skolithos linearis* formed by tube-dwelling insects and/or arachnids, small, irregular burrows formed by insects or insect larvae, large cluster burrows formed by digger wasps, large stellate burrows probably formed by burrowing bees, and small burrows likely representing ant nests, also characterize these eolianites. Indeed, the dunal ichnocoenosis commonly exhibits a higher level of diversity than that found in adjacent shallow subtidal and intertidal-supratidal environments, and the burrowing activity of several tracemakers of the dunal ichnocoenosis can produce ichnofabrics distinctive to carbonate eolianites. In outcrops of limited exposure or in core samples, the occurrence of individual trace fossils generated by invertebrates or of an ichnofabric should not be used as evidence to rule out an eolian environment.

## INTRODUCTION

Carbonate eolianites are wind-deposited, terrestrial sedimentary rocks composed of sand-size grains and cement of calcium carbonate. Rocks of this origin make up the greater part of the Quaternary sequences that cap the islands of the Bahama Archipelago. In addition to the Bahamas, Pleistocene and Holocene carbonate eolianites form a major component of the shallowing-upward carbonate sequences in Bermuda, the Yucatan Peninsula of Mexico, and other, geologically similar tropical locations around the world. As recently as the early 1980s, however, pre-Quaternary carbonate rocks of eolian origin rarely, if ever, had been reported in the literature (McKee and Ward, 1983). This leads to the question of whether the apparent scarcity of carbonate eolianites in the more ancient rock record is real or simply a result of the failure to recognize such rocks. There has been growing interest among sedimentary geologists in carbonate eolianites and in developing criteria for their recognition in the pre-Quaternary rock record.

McKee and Ward (1983, p. 136–137) listed a number of criteria derived from the study of Quaternary carbonate eolianites that they deemed potentially useful for the recognition of more ancient eolian limestones. Most of these criteria relate to large-scale features such as bed geometry and associated facies or to microscopic features such as grain composition, size and sorting, and grain cements. Mesoscale physical sedimentary structures were mentioned only briefly, and it was stated that such rocks likely contained few, if any, trace fossils resulting from the activity of burrowing animals (McKee and Ward, 1983, p. 131). This dearth of knowledge about the mesoscale physical sedimentary structures and ichnology of carbonate eolianites motivated us to undertake a series of studies of Bahamian Quaternary eolianites.

An instructive succession of Holocene carbonate eolianites occurs in the sea cliffs and rocky shore platforms along the northeast coast of San Salvador Island. Eolianites are particularly

well exposed at North Point and along the cliffs of Hanna Bay on San Salvador (Fig. 1). In addition to displaying mesoscale physical sedimentary structures diagnostic of wind deposition and likely recognizable in core samples (White and Curran, 1988), Bahamian carbonate eolianites can contain a distinctive assemblage(s) of trace fossils generated by plants and the burrowing activities of invertebrates. Various aspects of this trace-fossil assemblage have previously been described and interpreted in some detail (Curran and White, 1987, 1991; Curran, 1994) and in a preliminary review and discussion of some new trace-fossil discoveries (Curran and White, 1999).

This paper reviews briefly the characteristics of the mesoscale physical sedimentary structures found in the carbonate eolianite exposures at North Point; a more detailed description and analysis was given by White and Curran (1988). Emphasis herein is on the ichnology of the eolianites exposed in the Hanna Bay cliffs. Characteristics of the previously described trace fossils of the dune-environment ichnocoenosis and findings from more recent research are presented, particularly regarding description and interpretation of the trace fossils attributed to the burrowing activity of bees. This paper highlights the ichnologic features of Holocene Bahamian eolianites as criteria for the recognition of pre-Quaternary carbonate eolianites.

## THE GEOLOGIC SETTING

The physical sedimentary structures and trace fossils described in this paper occur in carbonate eolianites of sea-cliff exposures along Hanna Bay and at North Point and Cut Cay along Rice Bay, on the northeastern coastal area of San Salvador (Fig. 1). These Holocene rocks were assigned to the Rice Bay Formation by Carew and Mylroie (1995 and earlier papers) and were subdivided into two parts, the older North Point Member and the somewhat younger Hanna Bay Member (Fig. 2). The general characteristics of the rocks of these members have been described in some detail by Carew and Mylroie (1995, p. 21–22).

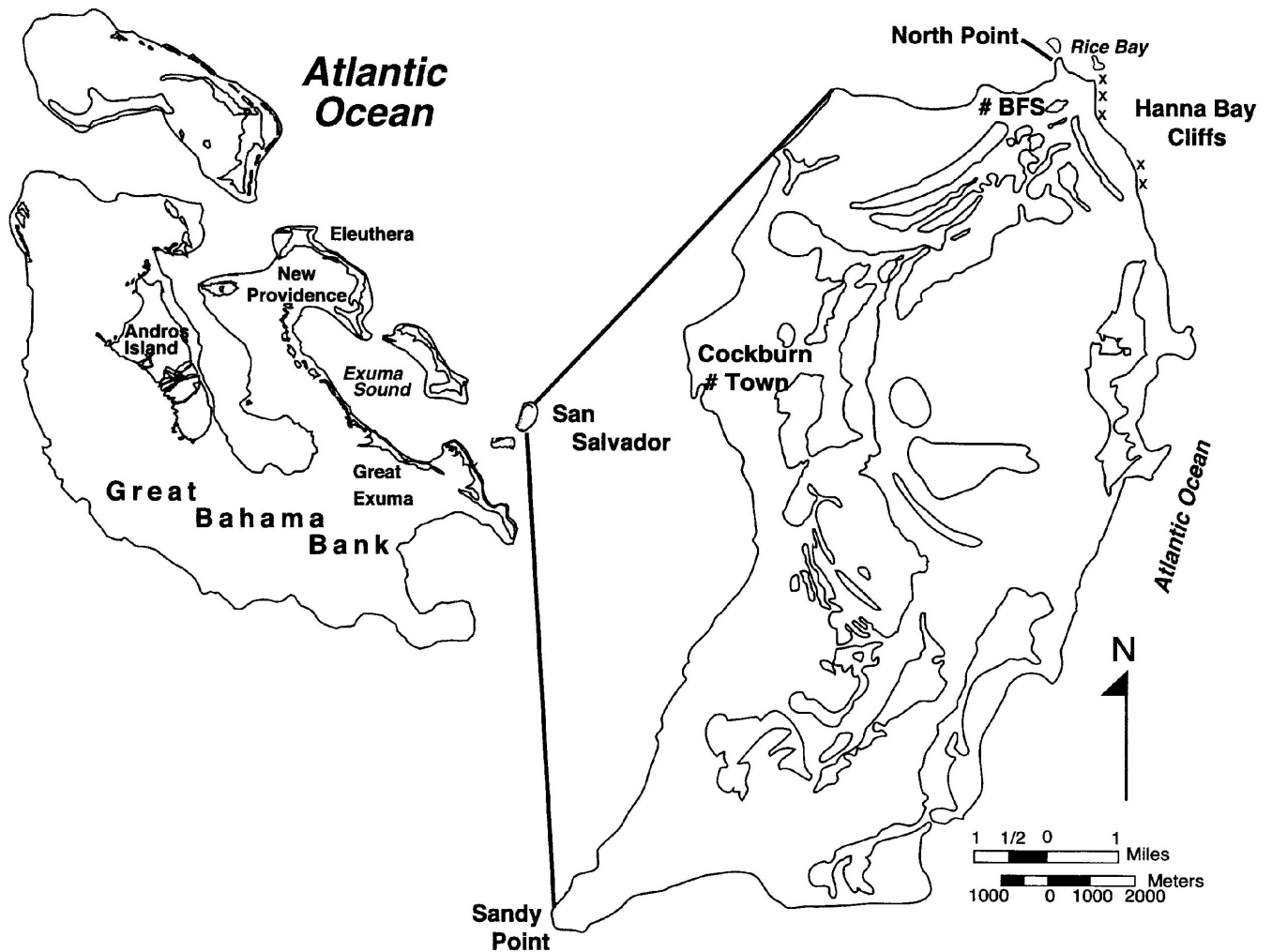


FIG. 1.—Location of San Salvador Island within the Bahama Archipelago and the study sites for the Rice Bay Formation at North Point (North Point Member) and along the Hanna Bay cliffs (Hanna Bay Member). Small xxxs mark the approximate location of the Hanna Bay Member exposures described in this study.

Both members are well represented by equivalent eolianites on other Bahamian islands, as indicated by references cited in Carew and Mylroie (1995, 1997). Field localities for study of features of the North Point Member and Hanna Bay Member rocks discussed herein have been described in chapters of several geology field guides available from the Bahamian Field Station (most recently in Curran, 1997).

The North Point Member eolianites are generally fine-grained sands, mostly pelsparites with some ooids and skeletal fragments. The sediments constituting these eolianites were deposited during the Holocene transgression as the sea flooded the San Salvador shelf (sea-level curve of Boardman, et al., 1989). Peak deposition of these eolian sediments occurred around 5,000 years before present (whole-rock radiocarbon dates from Carew and Mylroie, 1995, p. 24–25). The sediments of the eolianites that form the present-day North Point were deposited as lobate, parabolic dunes that coalesced to form an elongate dune ridge

perpendicular to the direction of the prevailing easterly trade winds. The lowermost beds of the North Point Member dip below present sea level, indicating deposition prior to the ongoing sea-level transgression of late Holocene time.

In contrast, the eolianites of the Hanna Bay Member have been interpreted as deposited essentially in equilibrium with modern sea level, between about 3,200 to 300 years before present. Most such deposits in the Bahamas are younger than 2,500 years before present (Carew and Mylroie, 1995). In the cliffs in the vicinity of the member's type section at Hanna Bay, the lowermost rocks have bedding essentially parallel with present sea level. The sediments of these rocks were deposited in a beach backshore environment (Fig. 3; Curran and White, 1987, 1991), and they consist of generally coarse-grained biopelsparites and pelbiosparites. Moving up the section (Fig. 3), grain size decreases but composition remains essentially the same. The backshore bedding quickly gives way to more



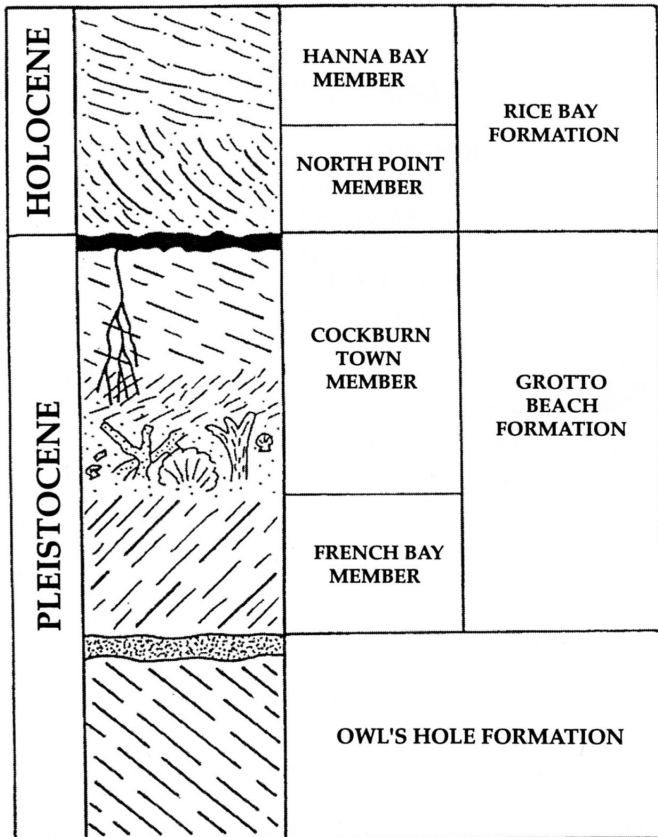


FIG. 2.—Physical stratigraphic column for San Salvador and other Bahama islands. Note that a well-developed terra rossa paleosol separates the latest Pleistocene unit from the Holocene Rice Bay Formation. From Carew and Mylroie (1995).

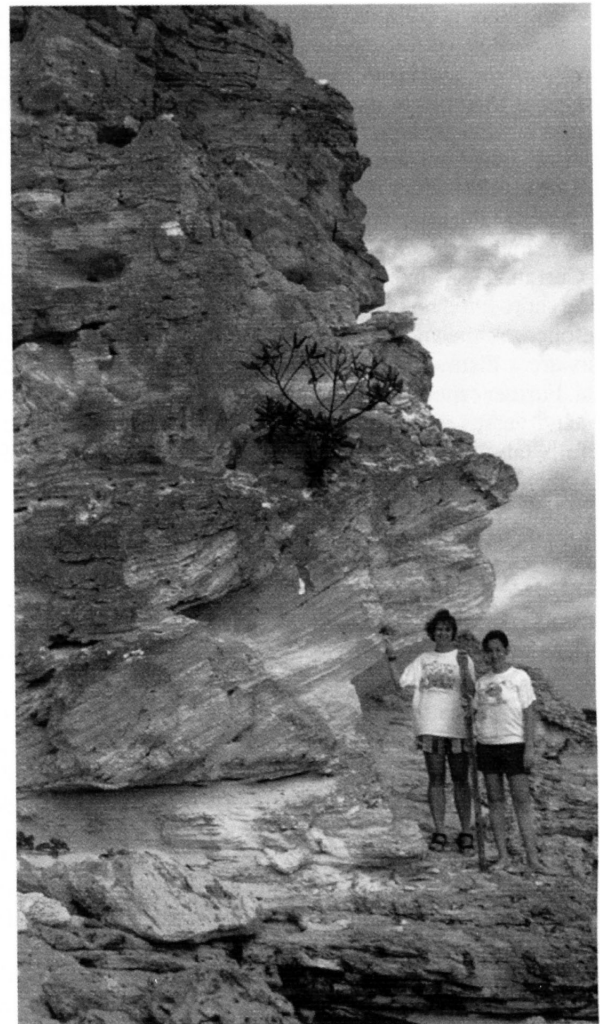


FIG. 3.—Cliff exposure of the Hanna Bay Member of the Rice Bay Formation at Hanna Bay. Geologists are standing on backshore beds that quickly grade upward to protodune and dunal beds (carbonate eolianites).

complex patterns of wedge-planar cross-stratification, indicative of an eolian environment.

THE PHYSICAL SEDIMENTARY STRUCTURES

Both the North Point Member and Hanna Bay Member eolianites display well-preserved physical sedimentary structures. We have studied these structures in detail, primarily along the windward coast of North Point. There, we particularly emphasized the mesoscale physical sedimentary structures, previously unreported from carbonate rocks (White and Curran, 1988), and compared them with essentially similar features described by Hunter (1977) from siliciclastic coastal dunes. Detailed descriptions of these characteristic, small-scale structures provide useful criteria for the recognition of more ancient carbonate eolianites, particularly in core samples where the larger-scale aspects of dunal structure are not visible. Physical sedimentary structures similar to those described here likely are widespread in Holocene carbonate eolianite deposits throughout the Bahamas. Certainly that was the case with Holocene strata that we studied on Lee Stocking Island in the Exuma Cays (White and Curran, 1993).

Large-scale cross-stratification structures tend to dominate one's initial view of these dunal deposits, particularly for the exposures on the west (lee) side of North Point (White and Curran, 1988, their fig. 3). However, closer examination of the stratification of these rocks reveals that distinctive fine/coarse-grained couplets characterize these deposits. These couplets were formed by the migration of wind ripples (climbing wind ripples). These migrating and accreting ripples produced millimeter-scale, fine (migrating trough)—coarse (migrating crest) couplets that form the distinctive laminae visible in outcrop, hand sample, and thin section (White and Curran, 1988, their figs. 6, 7). Similar couplets have been described from Pleistocene eolianites on San Salvador (Caputo 1989, 1995, his fig. 3). Greater than 90% of the North Point eolianites reflect reworking and redeposition of previously accumulated wind-deposited sands by the movement of climbing wind ripples.

The remaining eolianite strata contain other distinctive structures including centimeter-scale grainfall layers of homogeneous, nonlaminated sands deposited from suspension on sheltered lee-side slopes of the dunes. In some cases, these grainfall deposits avalanched down lee slopes to produce distinctive lenticular grainflow structures a few centimeters across (White and Curran, 1988, their figs. 8, 9). In addition, micrite crusts and associated plant trace fossils (as described briefly below) are common in the eolianite beds of the Rice Bay Formation (White and Curran, 1988, their fig. 10). These crusts formed quickly, during short-lived breaks in sediment accumulation as the dunes developed. White and Curran (1988, p. 175) suggested that these crusts are a distinctive aspect of transgressive carbonate dune strata. Further criteria for the recognition of transgressive versus stillstand versus regressive carbonate dune deposits have been carefully tabulated and discussed by Carew and Mylroie (1997, 1998, this volume).

#### THE DUNAL ICHNOCOENOSIS

##### *Background*

The carbonate eolianites of the Rice Bay Formation contain a distinctive and surprisingly diverse assemblage of plant and animal trace fossils. This assemblage clearly qualifies as an ichnocoenosis; namely, as defined by Bromley (1996), it represents an ecologically pure assemblage of trace fossils resulting from the activities of a single community of organisms. In other words, these organisms, both plants and animals, were living together within the dunal environment and performing their trace-making activities at essentially the same time. The dunal ichnocoenosis is represented in Figure 4. Undoubtedly there were subenvironments within the dunal zone, and these environments likely hosted their own sub-ichnocoenoses of trace-making organisms. For instance, we suspect that some of the trace fossils most commonly occur in dune lee slope areas owing to the requirement of the trace-making organisms for protection from the wind and/or requirements for moisture, as discussed below.

The ichnology of the Rice Bay Formation strata has previously been described and discussed in detail by Curran and White (1987, 1991), White and Curran (1988), and Curran (1997), so the following discussions of each element of the dunal ichnocoenosis are brief. Recent work on the rocks of the Hanna Bay Member has revealed the common occurrence of burrows attributable to the activity of bees, so those trace fossils receive special attention.

##### *Plant Trace Fossils*

Structures attributable to the activities of plants, exhibiting a variety of morphologies, likely formed by various parts of plants and under differing circumstances, can be found in virtually all facies of Quaternary Bahamian limestones. Such structures are most common in eolianites.

Initially the term rhizomorph, introduced by Northrop (1890), was used to describe the cylindrical root-like masses found in Bahamian limestones. This term has a checkered history in that it has been modified, rejected, replaced, and reintroduced in the literature over the years. A lengthy discussion of past usage of the

## DUNAL ZONE

### ICHNOCOENOSIS:

1. Rhizo- and Thallo- ichnomorphs
2. *Skolithos linearis*
3. Small, irregular burrows
4. Cluster Burrows
5. Stellate Burrows

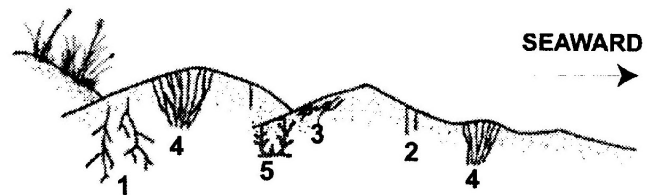


FIG. 4.—Model of the dunal ichnocoenosis characteristic of Holocene carbonate eolianites in the Bahamas.

term rhizomorph was given by White and Curran (1997) in the context of presenting a classification scheme for all types of plant-related features found in Bahamian Quaternary rocks. Carew and Mylroie (1995) pointed out that not all fossilized plant features represent roots; other vegetative parts also can be preserved in Bahamian rocks in some fashion. They proposed the term vegemorph and suggested that it replace all previously used terms having rhizo as a prefix. Given that “rhizo” structures truly are a common component of Quaternary Bahamian limestones and that they exhibit a range of distinctive morphologies, we offered a new classification scheme for such structures (White and Curran, 1997).

Probably the most common types of plant trace fossils found in Bahamian rocks, particularly those of late Pleistocene age, are those formed by plant roots. Following the White-Curran classification scheme, such structures are rhizo-ichnomorphs (Fig. 5A). Rhizo-ichnomorphs are present in the Holocene rocks of the Rice Bay Formation, but they are of secondary importance to the horizontally oriented structures formed by plants, as described below.

Plants with runners extending for several meters across the surfaces of modern sand dunes are abundant on San Salvador, for example the railroad vine (*Ipomoea pes-caprae*) and the bay geranium (*Ambrosia hispida*). These runners can induce lithification, resulting in distinctive, preservable structures, as discussed by White and Curran (1988, 1997). We have termed these structures thallo-ichnomorphs (Fig. 5B). Such thallo-ichnomorphs are common on the numerous micritic crusts of the North Point Member, as exposed along the coast of Rice Bay, and their occurrence on the crusts indicates that they developed contemporaneously with the accumulation of sediments in the ancient dunal environment. The presence of such thallo-

ichnomorphs can serve as another specific criterion for the recognition of eolian deposition.

*Animal Trace Fossils*

*Skolithos linearis*.—

*Skolithos linearis* burrows (Fig. 5C) are common in the eolianite beds of the Hanna Bay Member, as exposed in the Hanna Bay cliffs. These burrows consist of simple, lined, unbranched shafts typically 2 to 4 mm in diameter and sometimes up to 45 cm in length. This occurrence of *S. linearis* and its significance was discussed at some length by Curran and White (1987, 1991) and White and Curran (1988). These are dwelling burrows, likely formed by insects, arachnids, or both.

Recently, we conducted a survey of a 120-meter-long section of the Hanna Bay cliffs, counting, identifying, and measuring all burrows in the eolianites section of the cliffs, from the base of the exposures to upward arm's-reach level. Although not conclusive, the data for *Skolithos linearis* burrow diameters suggest that two size classes exist, supporting the idea of more than one tracemaker invertebrate for these burrows (Fig. 6).

*Small, Irregular Burrows*.—

These burrows are the most abundant animal trace fossils in the Rice Bay Formation, and they are particularly common in the North Point Member in exposures on North Point and Cut Cay. The burrows are easily visible on the upper surfaces of the eolianite strata, where they meander irregularly (Fig. 5D). They have a uniform diameter of 3 to 4 mm along their length, which commonly exceeds 20 cm. The burrows have an outer wall that is paler than the enclosing sediment and a fill that is like the surrounding sediment. No branching has been observed, but crossovers are common.

In vertical exposure, these burrows can extend 2 to 3 cm into the strata and sometimes are in sufficient density to cause burrow mottling, resulting in a distinctive ichnofabric [after Bromley (1996) "all aspects of the texture and internal structure of a sediment that result from bioturbation at all scales"], as was observed in the Holocene eolianites of Lee Stocking Island (White and Curran, 1993, their figs. 6, 7). Larval or adult insects were the probable tracemaker organisms, but no specific modern counterpart has yet been identified. These trace fossils are most common in grainfall and sandflow strata in the North Point Member rocks, suggesting that their makers preferentially inhabited sheltered dune lee slope areas (White and Curran, 1988).

*Cluster Burrows*.—

Clusters of unlined, vertical burrows radiating upward from a common area of origin form the largest and most distinctive trace fossils in the Rice Bay Formation. We have informally referred to these impressive burrow systems as cluster burrows and have described them in some detail (Curran and White, 1987, 1991; White and Curran, 1988). These large burrows consist of numerous, straight to gently curved, unlined shafts (average diameter 1.2 to 1.4 cm); the shafts are closely packed in cross section, and they can be 1.4 m or more in length. Each cluster

consists of tens to hundreds of individual shafts, creating an overall cone-shaped structure that may reach a diameter of 1 m or more (Fig. 7A, B). Curran and White (1987) interpreted the cluster burrow as representing the brooding and hatching activities of a species of burrowing (digger) wasp of the Family Sphecidae, with each shaft being the escape pathway of a young wasp, formed as it moved to the sediment surface.

Previously we had identified at least 15 cluster burrows in the Rice Bay Formation rocks on San Salvador, with most found in the North Point Member beds. This was a very conservative count. Our more recent work on the Hanna Bay Member exposures along the Hanna Bay cliffs has revealed that cluster burrows are more common there than we originally thought; there were at least 13 clusters in the 120 m stretch of Hanna Bay exposures that we surveyed. In addition, we found cluster burrows to be well developed and reasonably common in the Holocene eolianites of Lee Stocking Island in the Exuma Cays (White and Curran, 1993, their figs. 11, 12), and Curran and Dill (1991) reported cluster burrows in late Pleistocene eolianites in a submarine cave on Norman's Pond Cay, also in the Exumas. The indication is that this spectacular trace fossil is widespread in Bahamian Quaternary eolianites, and similar cluster burrows very likely occur in tropical eolianites elsewhere in the world. As with the small, irregular burrows, cluster burrows can produce a distinctive ichnofabric.

*Stellate Burrows*.—

Several new exposures of Hanna Bay Member beds along the Hanna Bay coast, combined with our recent reexamination of these beds with fresh eyes and, possibly, a greater sense of ichno-awareness, has led to our recognition of large, well-formed burrows that we have informally termed stellate burrows for the stellate pattern formed by obliquely oriented shafts that radiate out and upward from a large central shaft (Figs. 8, 9A, B). A well-developed stellate burrow has a U-shaped main shaft to which literally hundreds of smaller burrows connect (Fig. 8). Stellate burrows are patchily distributed in the Hanna Bay eolianites. They seem to be most common in the lower half of the eolianite sequence. We found three areas of bedding-plane exposure that revealed abundant stellate-burrow cross sections and that were sufficiently large to permit census measurements (Fig. 9A). Our counts averaged 20 stellate burrow cross sections per square meter in these areas.

Typical height of the main shaft of the stellate burrow is 50 cm or more, with average shaft diameter being 5 to 7 cm. The smaller, obliquely and mostly upward-oriented, unlined shafts that branch off from the main U-shaft have an average maximum diameter of 1 cm. In full longitudinal view, they are flask-shaped (Fig. 8), with the entry to the main shaft noticeably constricted (Fig. 9B). Our interpretation of these burrows is preliminary, but we believe that they represent the nesting activity of bees of the Family Halictidae (sweat bees). Michener (1974) illustrated nests made by modern halictid bees that bear close resemblance to those described here.

From the fossil record, Thackray (1994) described nests attributed to halictids from Miocene paleosols of Kenya that have an overall burrow architecture generally similar to the Bahamian stellate burrows. More recently, Elliott and Nations (1998) described burrows from the Upper Cretaceous Dakota



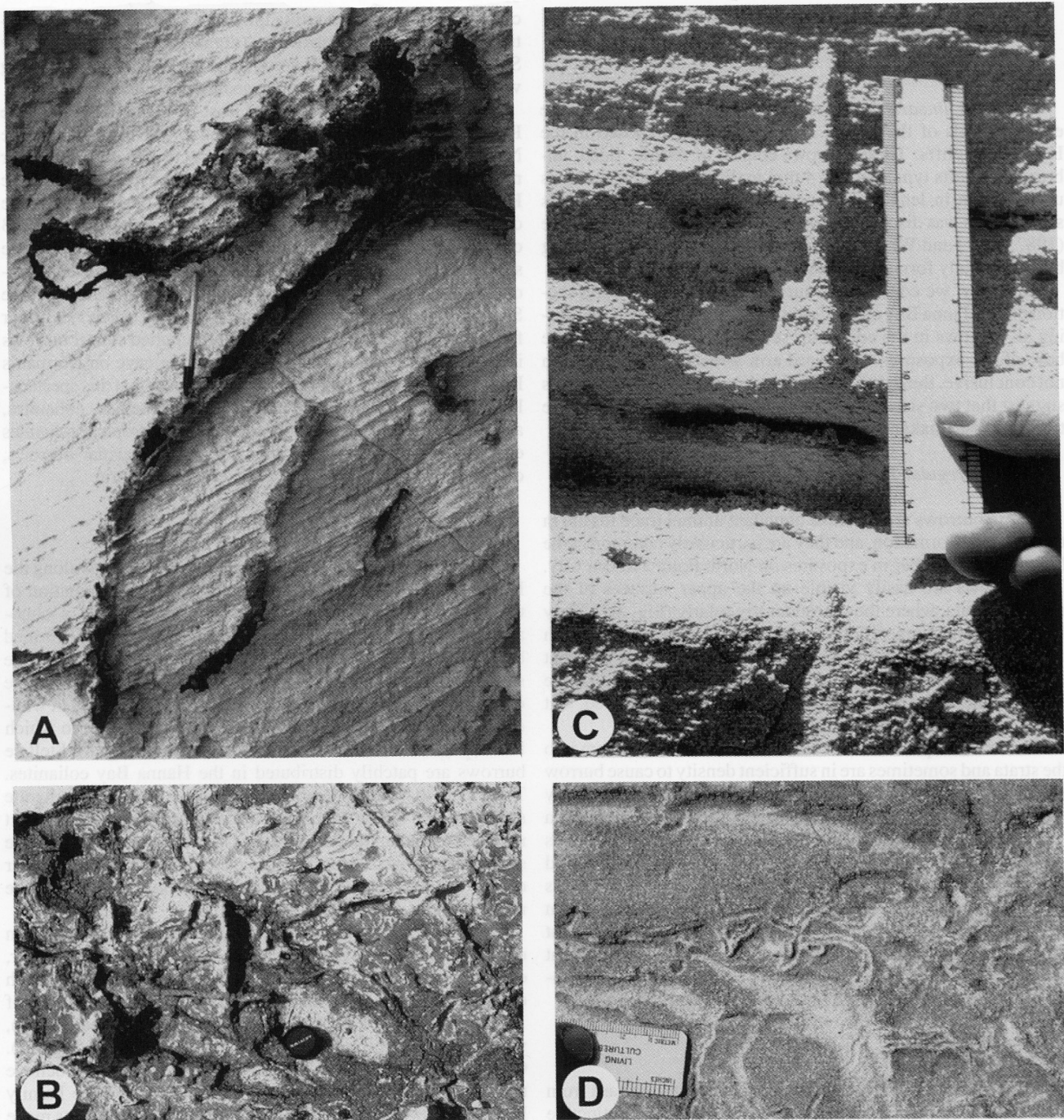


FIG. 5.—A) Typical rhizo-ichnomorph produced by the biogeochemical action of plant roots, which also modified the original sedimentary structures in late Pleistocene eolianites, The Gulf, San Salvador Island. Pen = 15 cm. B) Thalio-ichnomorphs developed on the surface of a micritic crust on beds of the North Point Member of the Rice Bay Formation, North Point. Lens cap = 5.5 cm in diameter. C) Typical specimen of *Skolithos linearis* in eolianite beds of the Hanna Bay Member, Hanna Bay. D) Typical small, irregular burrows on upper surface of sandflow strata, North Point Member, North Point.

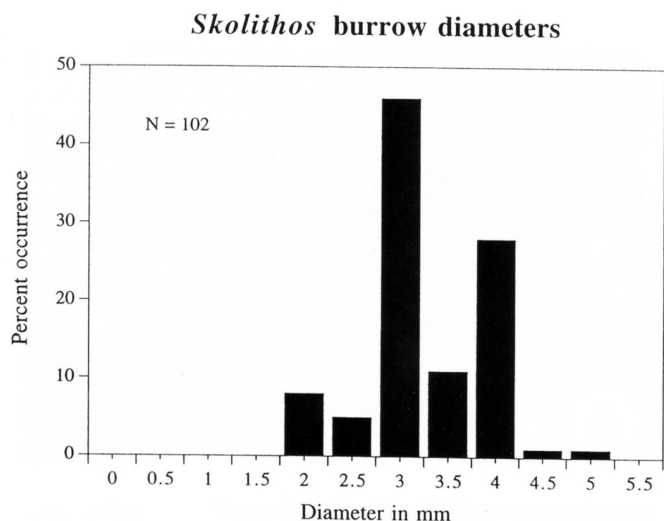


FIG. 6.—Histogram of *Skolithos linearis* burrow diameters measured from eolianite exposures of the Hanna Bay Member of the Rice Bay Formation, Hanna Bay.

Formation in Arizona that they interpret as halictid nests formed in fluvial channel-bar sands. Although these burrows are smaller and differ in overall architecture from the stellate burrows, in cross section they resemble very closely the stellate form of the Hanna Bay burrows (compare Fig. 9B with Elliott and Nations, 1998, their fig. 5A). This is at least somewhat amazing given that the burrows from the Dakota Formation are approximately equivalent in age to the oldest known bee body fossil (Elliott and Nations, 1998).

Both Thackray (1994) and Elliott and Nations (1998) assigned their fossil bee nests to the ichnogenus *Celliforma*. This may be the appropriate ichno-taxonomic assignment for the stellate burrows, but pending further research, it seems advisable to use the informal name for now. These burrows can be sufficiently numerous to impart a signature ichnofabric to the eolianites in which they occur.

*Possible Ant Nesting Activity.*—

Another new observation from the Hanna Bay Member eolianite beds exposed at Hanna Bay is that some cluster burrows show clear evidence of extensive secondary burrowing activity (Fig. 10A, B). Stephen Hasiotis (personal communication, 1997) noted that some cluster burrows were infested with smaller, interconnecting burrows (Fig. 10B). These burrows may represent chambers of large ant nests. As with the three previously described burrow types, the burrowing represented by this likely ant activity can impart a distinctive ichnofabric to the eolianites in which it occurs.

CONCLUSIONS

There are several notable aspects of the ichnocoenosis and physical sedimentary structures found in the Holocene carbonate eolianites of the Rice Bay Formation on San Salvador. The first and most obvious point is that these rocks contain a distinctive

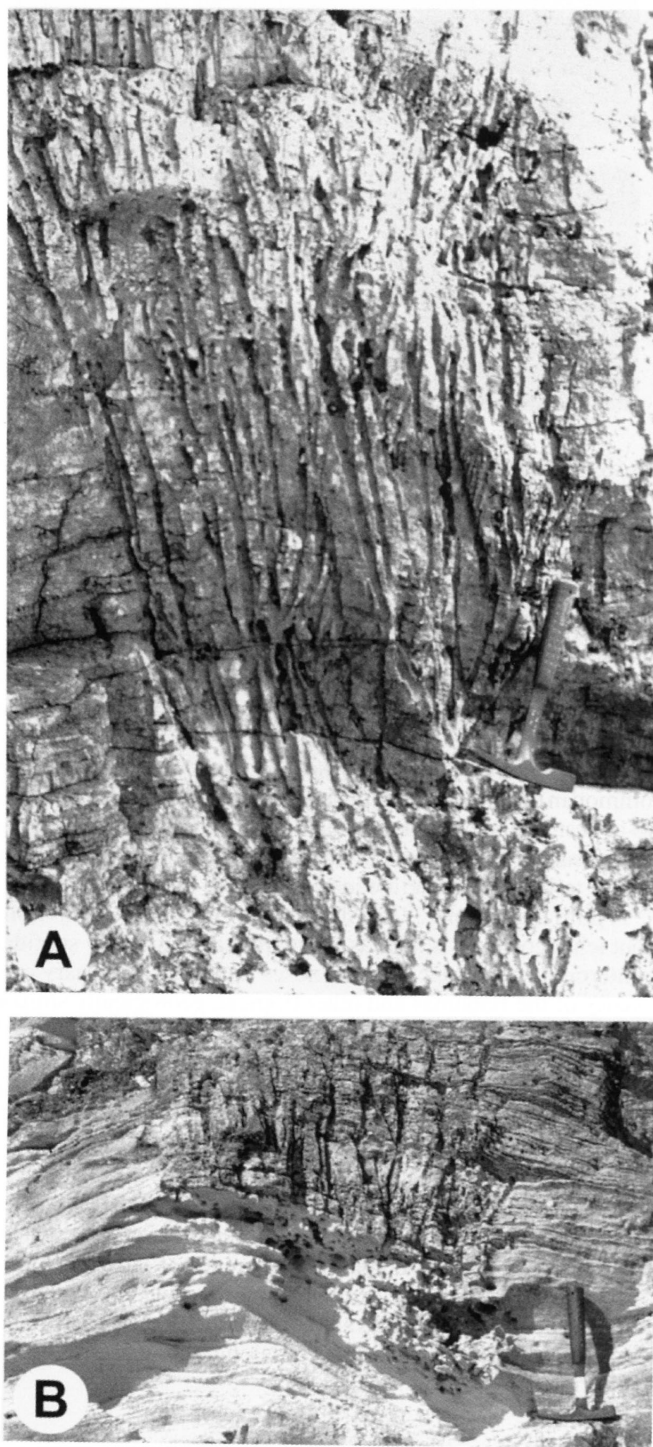


FIG. 7.—A) Large cluster burrow in vertical dune face exposure, North Point Member of the Rice Bay Formation, North Point. Rock hammer for scale. B) Another cluster burrow in vertical section in eolianite beds, Hanna Bay Member, Hanna Bay. Rock hammer for scale.

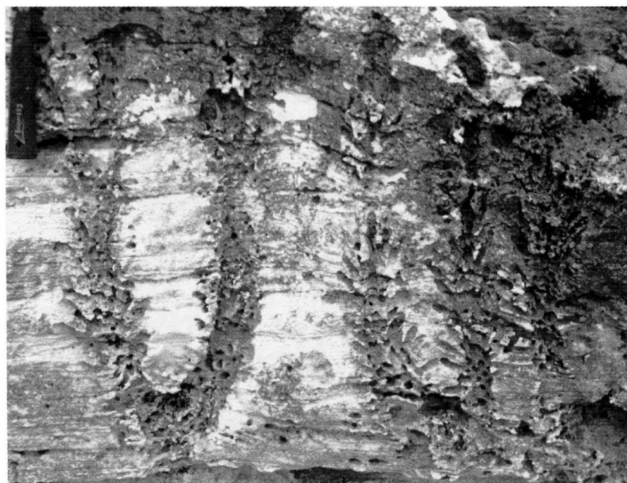


FIG. 8.—Well-developed stellate burrows in eolianites of the Hanna Bay Member of the Rice Bay Formation, Hanna Bay. Rock hammer handle in upper left = 15 cm.

suite of physical sedimentary structures, particularly at the mesoscale. The inversely graded lamination couplets produced by wind ripples are pervasive and distinctive and should be identifiable in cores and small hand specimens from more ancient carbonate rocks.

Secondly, trace fossils formed by burrowing animals are common in these rocks, thus dispelling earlier views that burrows are at best rare in carbonate eolianites. Furthermore, burrowing by several different types of invertebrates can be sufficiently intense to impart distinctive ichnofabrics to these eolianites.

A third major point is that the diversity of this dunal environment ichnocoenosis is high as compared to the shallow subtidal to intertidal–supratidal ichnocoenoses found in Quaternary carbonates of the Bahamas and other tropical, geologically similar areas (Curran and White, 1991; Curran 1994). Further study of this ichnocoenosis likely will yield much more information about the burrowing activities of a variety of invertebrates in the tropical, carbonate dunal environment. Such information will shed light on the habits of similar, more ancient invertebrates, as well as their modern counterparts.

Sedimentary geologists working with more ancient carbonate rocks, particularly with core samples, should not rule out an eolian interpretation based on the occurrence of individual burrows or of an ichnofabric. Rather, the occurrence of a suite of animal-generated trace fossils and of different ichnofabrics should be expected in carbonate eolianites, along with trace fossils of plant origin.

#### ACKNOWLEDGMENTS

We are indebted to the staff of the Bahamian Field Station for full logistical support of our field work on San Salvador, and we thank Don and Kathy Gerace, Dan and Nicole Suchy, and Kenny Buchan for their encouragement and facilitation of our research over the years. Smith College students Lauren McDonald and

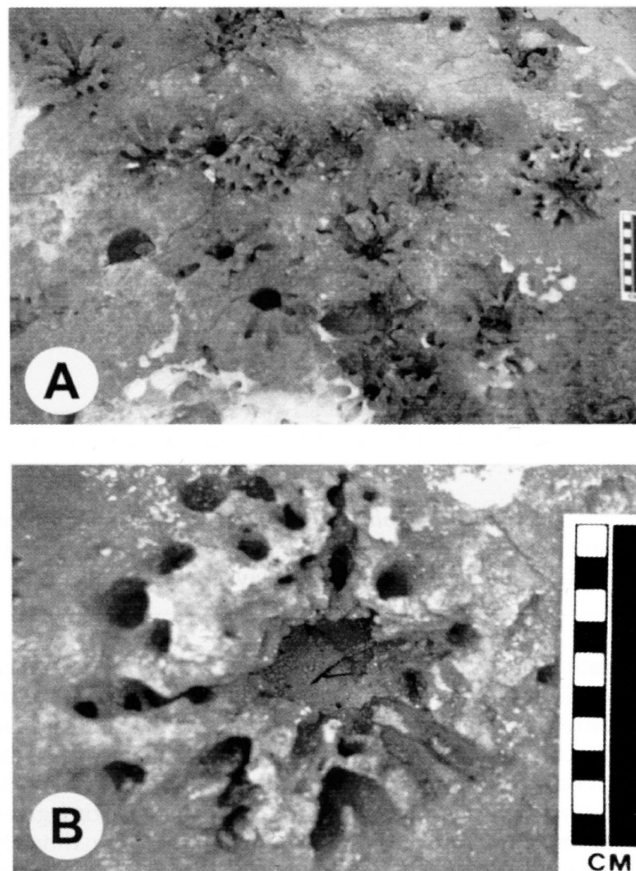


FIG. 9.—**A**) Numerous cross sections of main shafts of the stellate burrow on a nearly horizontal bedding surface; eolianites of the Hanna Bay Member of the Rice Bay Formation, Hanna Bay. Scale = 10 cm. **B**) Close-up view of a cross section of the main shaft of a stellate burrow. Note that the smaller, radiating shafts are constricted at their juncture with the main shaft. Same location as in Part A.

Jessica Linzmeier contributed to this research by assembling field observations and size data on several of the trace fossils that occur in the Hanna Bay cliffs in an excellent research report prepared for our Smith College Bahamas carbonates geology course. Shannon Ristau, also of Smith College, assisted with preparation of the figures. We thank Anthony Martin of Emory University for assistance in gathering field data from the Hanna Bay cliffs with the first author and for stimulating discussions about the trace fossil occurrences there. Stephen Hasiotis, Indiana State University, aided significantly with observations at Hanna Bay and with useful insights on the trace fossils and their possible insect tracemakers during the Fourth International Ichnofabric Workshop held on San Salvador in March, 1997. The first author thanks Nancy Elliott, an entomologist at Siena College, for her patience over the past decade or more in answering numerous questions about the habits of tropical burrowing wasps and bees and for her willingness to visit the field sites and



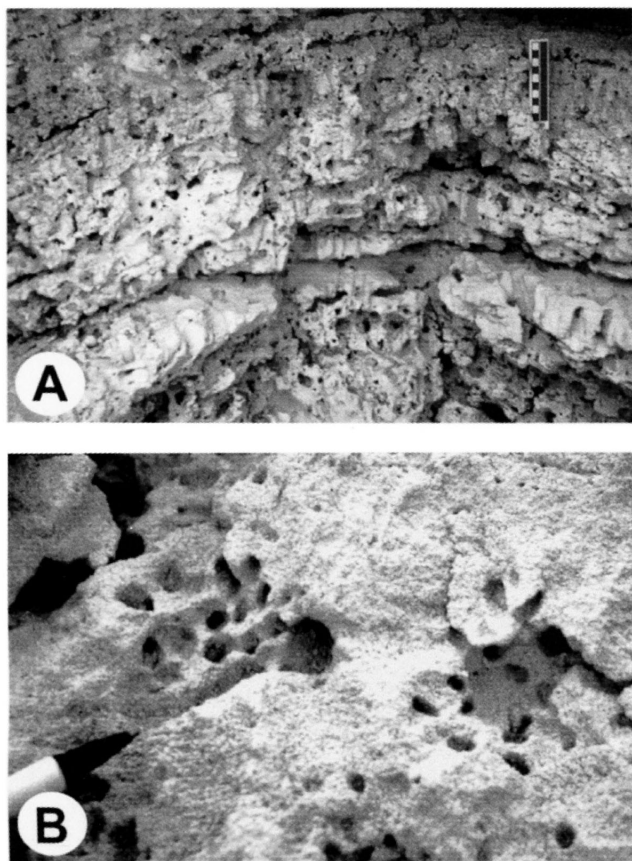


FIG. 10.—A) Cluster burrow infested by smaller burrows likely formed by ants; eolianites of the Hanna Bay Member of the Rice Bay Formation, Hanna Bay. Scale = 10 cm. B) Close-up view of these smaller burrows, likely fossil chambers formed by ants. Same location as in Part A; pen point for scale.

offer helpful comments about the trace fossils. We both gratefully acknowledge the Committee on Faculty Compensation and Development at Smith College for partial support of our field work expenses associated with this research. Helpful critical reviews of an initial version of this paper were provided by A. A. Ekdale, University of Utah, David Loope, University of Nebraska, Lincoln, and Mitch Harris, Chevron Petroleum Technology Company. Finally, we thank Rick Abegg, Chevron USA Production Company, David Loope, and Mitch Harris for organizing the SEPM symposium on carbonate eolianites held at the 1998 AAPG annual meeting in Salt Lake City and for all of their hard work and patience with the editing of this volume.

REFERENCES

BOARDMAN, M.R., NEUMANN, A.C., AND RASMUSSEN, K.A., 1989, Holocene sea level in the Bahamas, *in* Mylroie, J.E., ed., 4<sup>th</sup> Symposium on the Geology of the Bahamas, Proceedings: San Salvador, Bahamian Field Station, p. 45–52.

BROMLEY, R.G., 1996, Trace Fossils: Biology, Taphonomy and Applications, 2<sup>nd</sup> Edition: London, Chapman & Hall, 361 p.

CAPUTO, M.V., 1989, Selective cementation of eolian stratification in Pleistocene calcarenites, San Salvador Island, Bahamas, *in* Mylroie, J.E., ed., 4<sup>th</sup> Symposium on the Geology of the Bahamas, Proceedings: San Salvador, Bahamian Field Station, p. 61–72.

CAPUTO, M.V., 1995, Sedimentary architecture of Pleistocene eolian calcarenites, San Salvador Island, Bahamas, *in* Curran, H.A., and White, B., eds., Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda: Geological Society of America, Special Paper 300, p. 63–76.

CAREW, J.L., AND MYLROIE, J.E., 1995, Depositional model and stratigraphy for the Quaternary geology of the Bahama islands, *in* Curran, H.A., and White, B., eds., Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda: Geological Society of America, Special Paper 300, p. 5–32.

CAREW, J.L., AND MYLROIE, J.E., 1997, Geology of the Bahamas, *in* Vacher, H.L., and Quinn, T.M., eds., Geology and Hydrology of Carbonate Islands: Amsterdam, Elsevier, p. 91–139.

CAREW, J.L., AND MYLROIE, J.E., 1998, Quaternary carbonate eolianites: useful analogues for the interpretation of ancient rocks?: American Association of Petroleum Geologists, Annual Meeting, Extended Abstracts, no. A110, 4 p.

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., ED., 1997, Guide to Bahamian Ichnology: Pleistocene, Holocene, and Modern Environments: San Salvador, Bahamian Field Station, 61 p.

CURRAN, H.A., AND DILL, R.F., 1991, The stratigraphy and ichnology of a submarine cave in the Exuma Cays, Bahamas, *in* Bain, R.J., ed., 5<sup>th</sup> Symposium on the Geology of the Bahamas, Proceedings: San Salvador, Bahamian Field Station, p. 57–64.

CURRAN, H.A. AND WHITE, B., 1987, Trace fossils in carbonate upper beach rocks and eolianites: recognition of the backshore to dune transition, *in* Curran, H.A., ed., 3<sup>rd</sup> Symposium on the Geology of the Bahamas, Proceedings: Fort Lauderdale, Florida, CCFL Bahamian Field Station, p. 243–254.

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., 1999, Ichnology of Holocene carbonate eolianites on San Salvador Island, Bahamas: Diversity and significance, *in* Curran, H.A., and Mylroie, J.E., eds., 9<sup>th</sup> Symposium on the Geology of the Bahamas and Other Carbonate Regions, Proceedings: San Salvador, Bahamian Field Station, p. 22–35.

ELLIOTT, D.K., AND NATIONS, J.D., 1998, Bee burrows in the Late Cretaceous (Late Cenomanian) Dakota Formation, northeastern Arizona: *Ichnos*, v. 5, p. 243–253.

HUNTER, R.E., 1977, Basic types of stratification in small eolian dunes: *Sedimentology*, v. 24, p. 361–387.

MCKEE, E.D., AND WARD, W.C., 1983, Eolian environments, *in* Scholle, P.A., Bebout, D.G., and Moore, C.H., eds., Carbonate Depositional Environments: American Association of Petroleum Geologists, Memoir 33, p. 131–170.

MICHENER, C.D., 1974, The Social Behavior of the Bees: Cambridge, Massachusetts, Harvard University Press, 404 p.

NORTHROP, J.I., 1890, Notes on the geology of the Bahamas: New York Academy of Sciences, Transactions, v. 10, p. 4–22.

THACKRAY, G.D., 1994, Fossil nest of sweat bees (Halictinae) from a Miocene paleosol, Rusinga Island, western Kenya: *Journal of Paleontology*, v. 68, p. 795–800.

- WHITE, B., AND CURRAN, H.A., 1988, Mesoscale physical sedimentary structures and trace fossils in Holocene eolianites from San Salvador, Bahamas: *Sedimentary Geology*, v. 55, p. 207-250.
- WHITE, B., AND CURRAN, H.A., 1993, Sedimentology and ichnology of Holocene dune and backshore deposits, Lee Stocking Island, Bahamas, *in* White, B., ed., 6<sup>th</sup> Symposium on the Geology of the Bahamas, Proceedings: San Salvador, Bahamian Field Station, p. 181-191.
- 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.