

**PROCEEDINGS
OF THE THIRD SYMPOSIUM
ON THE GEOLOGY OF THE BAHAMAS**

Editor

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Sponsored by CCFL Bahamian Field Station

June 6 - 10, 1986

Cover photo: *Diploria strigosa*, the common brain coral, preserved in growth position at the Cockburn Town fossil coral reef site (Sangamon age) on San Salvador Island. Photo by Al Curran.

Articles in this volume should be cited as follows:

Author(s), 1987, Article title, in Curran, H.A., ed. Proceedings of the Third Symposium on the Geology of the Bahamas: Fort Lauderdale, Florida, CCFL Bahamian Field Station, p. xx-xx.

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ISBN 0-935909-24-9

Printed by Don Heuer in the U.S.A.

TRACE FOSSILS IN CARBONATE UPPER BEACH ROCKS AND EOLIANITES: RECOGNITION OF THE BACKSHORE TO DUNE TRANSITION

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ABSTRACT

The calcarenites of the Rice Bay Formation of Holocene age on San Salvador Island, Bahamas contain a distinctive suite of plant and animal trace fossils. Two ichnocoenoses are recognized. One is characterized by *Psilonichnus* *upsilon*, the fossil burrow formed by the ghost crab, *Ocypode quadrata*. This ichnocoenose occurs in the lower beds of the Hanna Bay Member and is interpreted to develop in upper foreshore-backshore deposits. The second ichnocoenose consists of *Skolithos linearis*, a cluster burrow, a small, irregular burrow, and plant trace fossils formed along bedding planes. Various elements of the ichnocoenose are found in the upper beds of the Hanna Bay Member and the beds of the North Point Member. This ichnocoenose formed in a proto-dune to dunal environment, and some of these trace fossils can be used to aid in reconstruction of ancient dunes. When possible, analog relationships between the trace fossils and modern plant or animal tracemakers are established. Such well documented analog relationships can be a significant aid in defining the backshore to dune transition in Bahamian calcarenites.

INTRODUCTION

Trace fossils of a variety of types and formed by both plants and animals can be a common component of the Pleistocene and Holocene calcarenites that cap the Bahama islands. When used in concert with physical sedimentary structures, the contained trace fossil assemblage or ichnocoenose of a given Bahamian calcarenite facies may be useful in characterizing the facies and in interpreting its depositional paleoenvironment (Curran, 1983, 1984). In the final section of this introduction, the differences between a trace fossil assemblage and an ichnocoenose are discussed briefly. If a given trace fossil or ichnocoenose can be shown to be indicative of a particular facies and paleodepositional environment, then the occurrence of that trace fossil or ichnocoenose will be an important interpretive

tool for the analysis of similar calcarenite sequences in other geographic/geologic settings. Documentation of analog relationships between modern tracemaker organisms and specific trace fossils strengthens greatly the interpretive significance of a given fossil, particularly when it can be shown that the tracemaker organism has a narrow zone of environmental occurrence.

The purpose of this paper is to examine the ichnocoenoses of the Holocene calcarenites that crop out along the northeastern coast of San Salvador Island, Bahamas. These rocks are interpreted as having been deposited as sediments in upper foreshore to backshore to dunal environments (Carew and Mylroie, 1985; White and Curran, 1985, 1987). Each trace fossil type that we have found in these rocks will be briefly described and its environmental significance evaluated. Furthermore, ichnocoenoses are defined herein that we think can be used for the recognition of the upper foreshore-backshore and dunal depositional environments in calcarenites of the Bahamas and other, similar, geologic/geographic settings.

The Physical Setting

The trace fossils described in this study are found in the rocks of the sea cliff exposures of Hanna Bay and North Point along Rice Bay, on the northeastern coast of San Salvador Island (Index Map 2). These rocks have been assigned to the Rice Bay Formation, named by Carew and Mylroie (1985) and radiometrically dated as Holocene in age. Carew and Mylroie subdivided the Rice Bay Formation into two parts, the North Point Member and the Hanna Bay Member.

The North Point Member consists of eolianites that mostly are composed of pelsparites with some ooids and skeletal fragments (Carew and Mylroie, 1985; White and Curran, 1987). Radiocarbon whole rock sample dates yielded an age of about 5,300 years for these rocks (Carew and Mylroie, 1985 and this volume). The sediments were deposited as lobate, parabolic-like dunes that coalesced to form an elongate, transverse dune ridge perpendicular to the prevailing

easterly wind direction during Holocene sea transgression. The physical sedimentary structures present in these eolianites have been described in detail by White and Curran (1987). In the exposures along Rice Bay, climbing wind ripple laminations and lee-side grainfall and sandflow bedding are the dominant mesoscale structures.

The sediments of the Hanna Bay Member were interpreted as having been deposited in equilibrium with modern sea level (Carew and Mylroie, 1985). In the cliffs of the type section at Hanna Bay, the lowermost rocks have bedding nearly parallel to present sea level, and they consist of coarse-grained, biopelsparites and pelbiosparites. Moving up the section, there is a decrease in grain size but composition remains essentially the same (Carew and Mylroie, 1985). Gently seaward dipping bedding gives way to more complex patterns of wedge-planar cross bedding. From cliff bottom to top, the paleodepositional environments are interpreted as representing foreshore to backshore to protodune and dunal rocks. Radiocarbon whole rock sample dating gives an age of about 3,200 years for these rocks (Carew and Mylroie, this volume).

Ichnocoenoses

Definitions. An ichnocoenose is the natural association of lebenspuren (traces) or trace fossils reflecting the contemporaneous benthic activities of a given biologic community or biocoenose (Frey and Pemberton, 1985). By contrast, the term trace fossil assemblage is more general and refers to the activities recorded in the substrate of one or more benthic biocoenoses, possibly at different times. As an example from the Bahamian context, a facies representative of any shallow marine or terrestrial environment may contain as part of its trace fossil assemblage rhizomorphs formed by plant roots during a period of subaerial exposure. A given ichnocoenose from Bahamian rocks must be reconstructed with care, with the later formed rhizomorphs and possibly borings subtracted out.

Over the past two decades, ichnologists have recognized recurring associations of trace fossils that are thought to represent specific benthic environments. Such associations have been given formal names such as *Skolithos* ichnofacies or *Cruziana* ichnofacies (see Frey and Pemberton, 1984 and 1985 for tables listing formally described ichnofacies). In this paper, two ichnocoenoses are defined that are characteristic of Bahamian beach and dune environments, one representing the upper foreshore and backshore zone and the other representing the nearshore dunal zone.

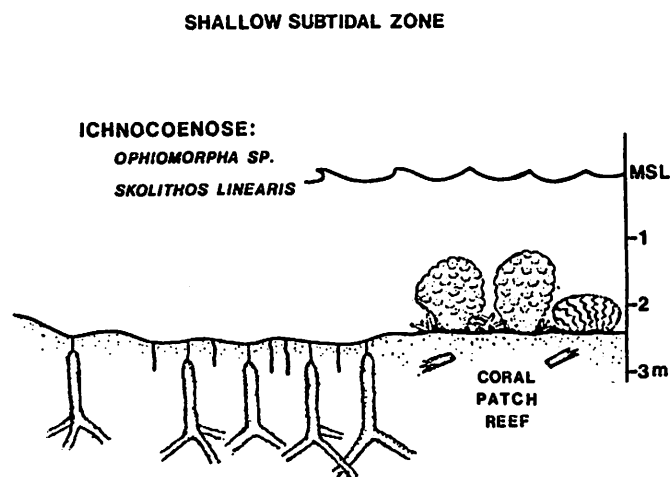


Fig. 1. Ichnocoenose of the Bahamian shallow subtidal zone.

The Subtidal Ichnocoenose. In earlier studies, Curran (1983, 1984) described the trace fossils that form an ichnocoenose characteristic of the shallow subtidal zone as preserved in marine calcarenites of the Bahamas (Fig. 1). The trace fossils of this ichnocoenose are *Ophiomorpha* sp. and *Skolithos linearis*, attributed to the burrowing activities of callianassid shrimp and polychaetes respectively. This ichnocoenose was shown to occur in Pleistocene calcarenite facies that interfinger with coral rubblestones at the Cockburn Town fossil reef site on San Salvador (Curran and White, 1985) and in similar, reef-associated facies and shallow marine facies landward of a fossil reef complex on Great Inagua (White and Curran, this volume).

Based on numerous observations of the modern, shallow subtidal zones off Bahamian beaches, Curran (1984) stated as a rule of thumb that modern callianassid shrimp are not found burrowing in Bahamian open shelf sands at a water depth of less than about one meter and that callianassid burrows are not found on beach lower foreshores. This is because Bahamian beaches tend to be narrow and steep, with shifting substrate conditions in the swash zone. Such conditions largely prohibit burrowing activity, and the result is that the lower foreshore-shoreface zone of Bahamian beaches largely is devoid of preservable traces. Accordingly, trace fossils should be expected to be absent to rare in the sediments of Holocene and Pleistocene rocks that were deposited in this zone. The possible exception would be a protected shoreline situation where a low-gradient beach could develop with relatively firm substrate conditions. Under such circum-

stances, one might expect to find burrowing with preservable traces being formed in the lower foreshore zone. However, in the experience of the authors, such beach conditions are not common in the Bahamas.

THE BEACH ICHNOCOENOSE

Introduction

As stated previously, the lower foreshore zone of modern Bahamian beaches and the ancient strata that formed in this zone largely are devoid of traces and trace fossils. This is not true for the upper foreshore and backshore zone, which is characterized by burrows of the ghost crab *Ocypode quadrata* and, in the rock record, by the trace fossil *Psilonichnus upsilon* (Fig. 2). Also commonly present in sediments of the landward edge of the backshore as it merges with at least partly vegetated proto-dunes are a variety of root molds, some of which have distinctive forms.

Psiloichnus upsilon

When walking on modern Bahamian beaches, even the casual observer will note that burrow holes are present and frequently common in the beach upper foreshore and backshore zones. These burrow openings (Fig. 3a) range from 1 to 2 cm to about 8 cm in diameter. The burrower is the ghost crab, *Ocypode quadrata* (Fig. 3b), found on sandy western Atlantic and Caribbean beaches from Rhode Island to Brazil (Williams, 1965), and the fossil burrow form has been named *Psiloichnus upsilon* (Frey and others, 1984).

Ocypode quadrata has been shown to construct a variety of burrow forms, ranging from steeply inclined shafts to J-, U-, and Y-shaped forms (Frey and Mayou, 1971; Hill and Hunter, 1973; Allen and Curran, 1974). The authors have made numerous casts of *O. quadrata* burrows from the beaches of San Salvador, and we find the most common forms to be steeply inclined shafts (Fig. 3c) and U-shapes or Y-shapes (Fig. 3d).

On coasts dominated by siliciclastic sands, such as the Georgia coast, *Ocypode quadrata* is known to range well back into areas of unvegetated dunes (Frey and Mayou, 1971). Our observations on San Salvador indicate that the situation is not quite the same for the carbonate coastal regime. Here sandy backshores tend to merge sharply with well-vegetated proto-dunes and dunes. The ghost crab appears to shun vegetated areas, probably because dense, low-lying vegetation cuts

BACKSHORE—FORESHORE ZONE

ICHNOCOENOSE:

PSILONICHNUS UPSILON

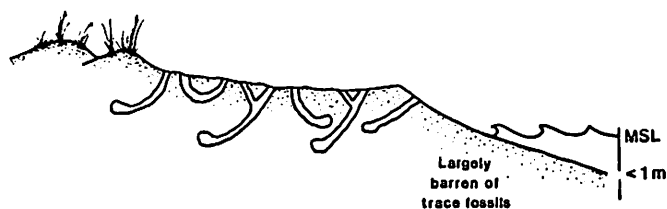


Fig. 2. Ichnocoenose of the Bahamian upper foreshore-backshore zone.

down its mobility and possibly also because of competitive pressure from the common land crab, *Gecarcinus lateralis*, which is a well-established burrower in vegetated dunal areas.

This is not to say that *Ocypode quadrata* cannot burrow in carbonate dunal areas. The crab probably would do so if such areas were largely unvegetated. However, since this normally is not the case, *O. quadrata* and its burrows largely are confined to the upper foreshore and backshore zones, and it is this narrow habitat preference that makes *Psilonichnus upsilon*, the fossilized burrow of *O. quadrata*, such a diagnostic trace fossil form.

The type specimen of *Psilonichnus upsilon* was formally described by Frey and others (1984) and occurs in the lower beds of the Hanna Bay Member in the cliffs at Hanna Bay (Fig. 4a). These burrows are unlined and unbranched to Y-shaped. Shafts are steeply inclined to bedding, typically 2.5 to 4.5 cm in diameter, and up to 1.2 m or more in length (Curran, 1984). Specimens of *P. upsilon* are fairly easily found in the lower to mid sections of the Hanna Bay cliffs, with most specimens occurring as segments of shafts (Fig. 4b).

In addition to the Hanna Bay cliffs, we have observed *Psilonichnus upsilon* specimens in presumed Holocene rocks of the cliffs on Catto Cay and White Cay and to the south of Grotto Beach on San Salvador and in the Pleistocene calcarenites of Bermuda. The well documented relationship between the trace fossil *P. upsilon* and its tracemaker, *Ocypode quadrata*, makes the occurrence of the trace fossil particularly

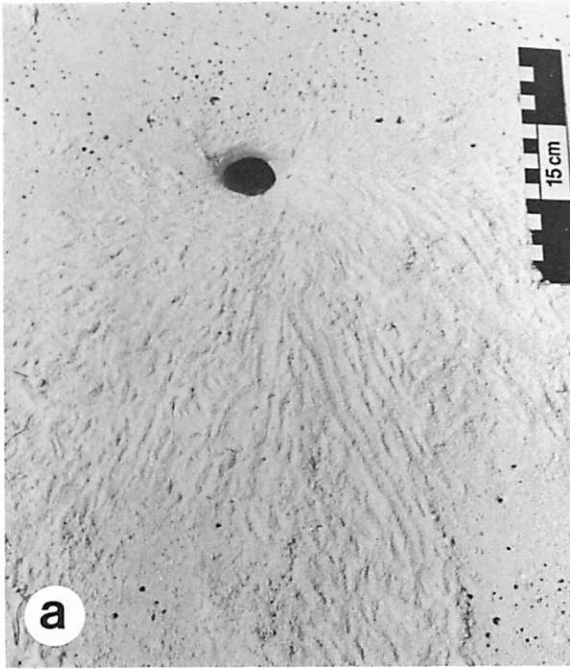


Fig. 3a. Burrow opening of the ghost crab, *Ocypode quadrata*.

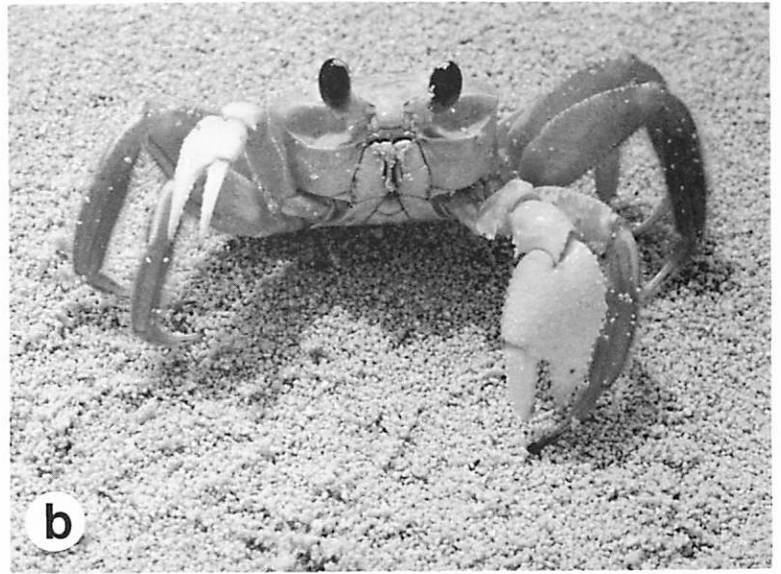


Fig. 3b. The ghost crab, *Ocypode quadrata* (Fabricus).

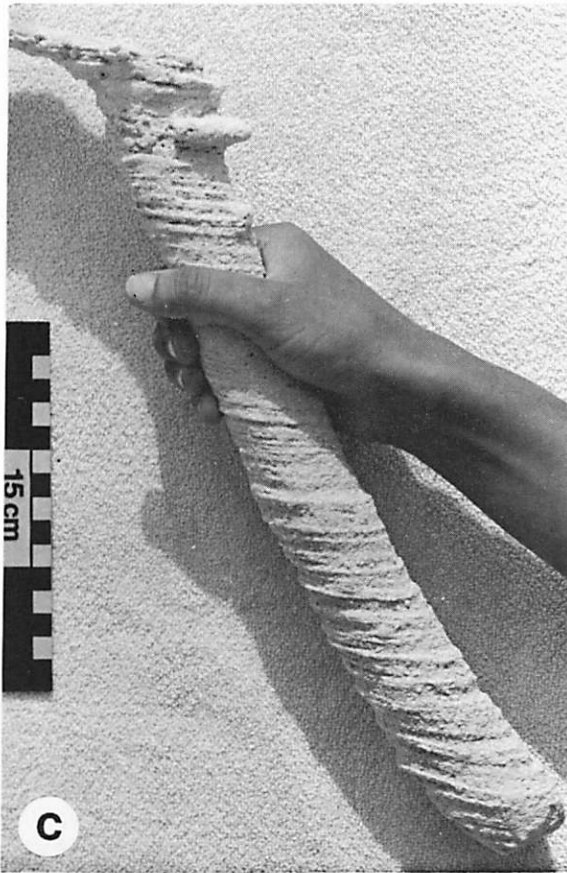


Fig. 3c. Cast of an *Ocypode quadrata* burrow showing the simple, steeply inclined form.



Fig. 3d. Cast of an *Ocypode quadrata* burrow showing the Y-shaped form.



Fig. 4a. The type specimen of *Psilonichnus upsilon*, Hanna Bay Member, Hanna Bay cliffs. Burrow length = 1.2 m.

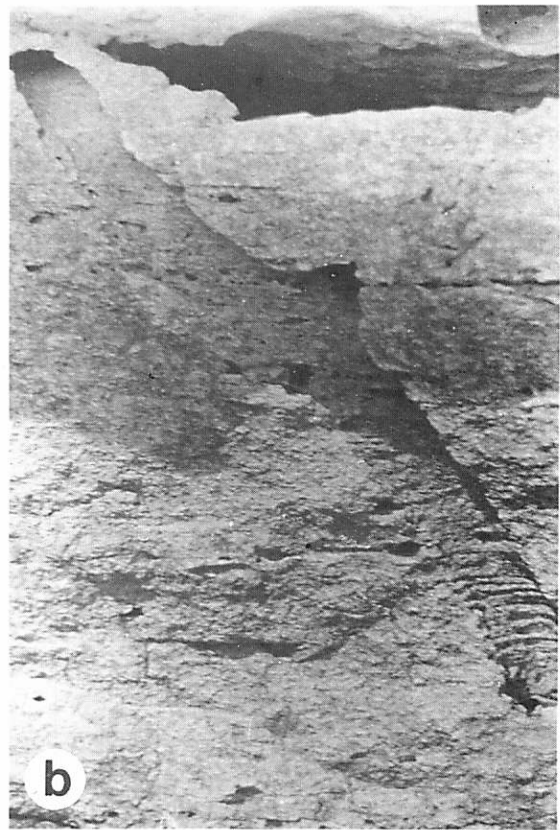


Fig. 4b. Typical segment of *Psilonichnus upsilon*, Hanna Bay Member, Hanna Bay cliffs. Burrow diameter = 2.5 - 3 cm.

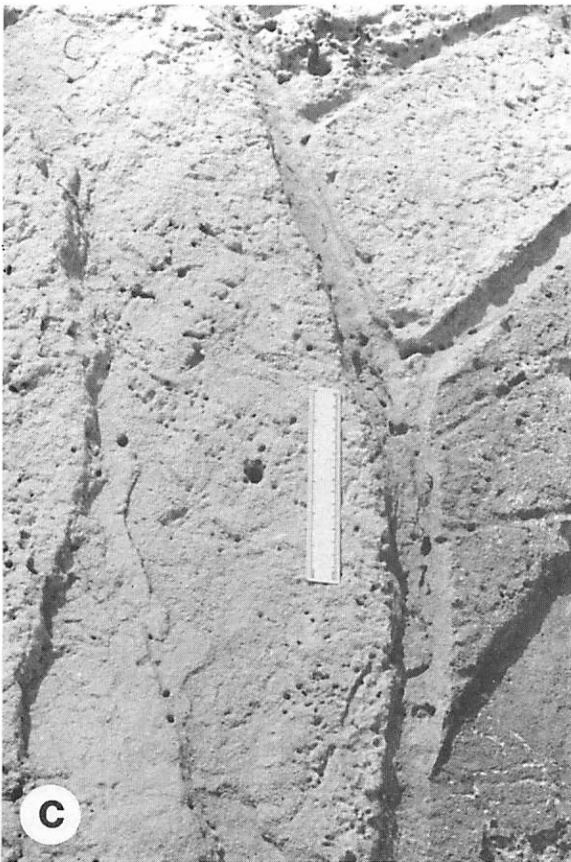


Fig. 4c. Fossil root mold with Y-shaped branching, Hanna Bay Member, Hanna Bay cliffs. Scale = 15 cm.

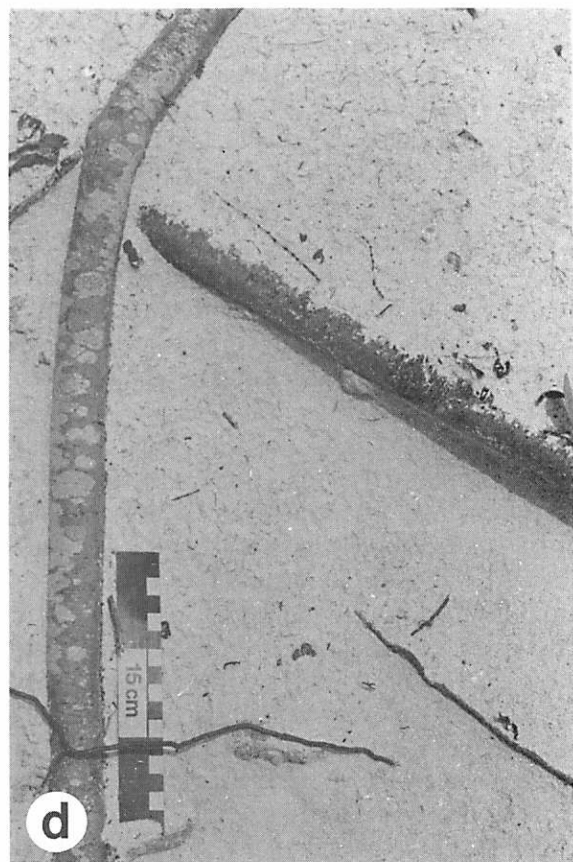


Fig. 4d. Root of the sea grape, *Cocoloba uvifera*, on proto-dune surface.

useful. Its presence should be a reliable indicator of backshore beds in Bahamian-style carbonate sequences. As such, the trace fossil can be used as an indicator of past sea level position and of the close proximity of the sea, because the tracemaker crab must moisten its gills periodically in salt water.

Plant Root Molds

Molds of external root surfaces are body fossils, not trace fossils. Nonetheless, they can be a prominent element in rocks of the Rice Bay Formation, particularly the Hanna Bay Member, and they merit brief mention here. Such molds have a variety of diameters and shapes, but they differ from rhizomorphs in being smooth-sided and having no calichified tubular lining or core, as is characteristic of rhizomorphs. Root molds such as are found in the Hanna Bay cliffs were formed by sand packing around the root, and then lithification of the packed sediment with simultaneous or later decay of the root material. The process is passive in that there is no chemical interaction between the root and surrounding sediment and pore waters to create a calichified structure or rhizomorph.

Root molds of the type shown in Figure 4c occur in the mid part of the Hanna Bay Member beds in the Hanna Bay cliffs. The molds are smooth-sided, can have multiple Y-shaped branches, and diameters of about 1.5 to 6 cm (Fig. 4c). At Hanna Bay, root molds of this type are found in beds that overlap with the upper level of occurrence of *Psilonichnus upsilon*. Comparison of Figures 4a-c will show morphologic similarity between *P. upsilon* and the root mold, but *P. upsilon* occurs in vertical section whereas the root molds are found on horizontal bedding plane exposures and commonly show multiple branches.

The form of the root molds of Figure 4c shows close similarity with the roots of *Coccoloba uvifera*, the sea grape (Fig. 4d). This plant is a common inhabitant of modern proto-dunes and dunes on San Salvador (Smith, 1982). In the Hanna Bay cliffs, we think that the initial presence of root molds as shown in Figure 4c indicates the transition from backshore to proto-dune/dune conditions. There are many other, smaller and less distinctive root mold forms in the rocks of the Rice Bay Formation. It may be possible to match some of these forms with the root systems of modern plants, and the topic deserves further study.

DUNAL ZONE

ICHNOCOENOSE:

1. Cluster burrow
2. Small, irregular burrow
3. *SKOLITHOS LINEARIS*
4. Rhizomorphs

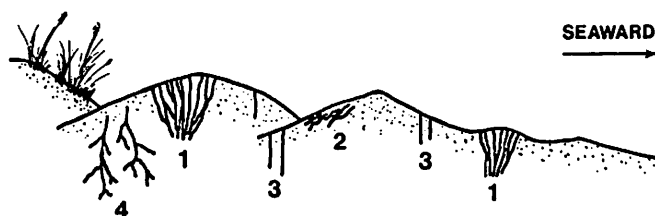


Fig. 5. Ichnocoenose of the Bahamian dunal zone.

THE DUNE ICHNOCOENOSE

Introduction

Although a general survey of past literature would indicate that trace fossils largely have been unreported from carbonate eolianites, recent studies by White and Curran (1985, 1988) have shown that both plant and animal trace fossils can be reasonably common in such rocks. A distinctive ichnocoenose occurs in the eolianites of the North Point Member (Fig. 5). However, the interpretive value of the trace fossils of the dunal ichnocoenose is in part limited by the lack of knowledge of tracemaker organisms that inhabit modern carbonate dunes. Ahlbrandt and others (1978) and Ekdale and Picard (1985) have compiled useful tables listing animals that form traces and trace fossils in dunal environments. However, the effects of animals on and within coastal dune complexes, and particularly carbonate dunes, have received little attention, and the modern carbonate dune ichnocoenose certainly warrants future study.

Skolithos linearis

Skolithos linearis burrows (Fig. 6a) are common in the eolianite beds of the Hanna Bay Member in the Hanna Bay cliffs. These burrows consist of lined, unbranched shafts with vertical orientation and are commonly 2 to 4 mm in diameter and up to 30 cm long. We have seen similar *S. linearis* burrows in Holocene eolianites in the Yucatan and in Pleistocene eolianites on Sand Cay, Turks and Caicos.

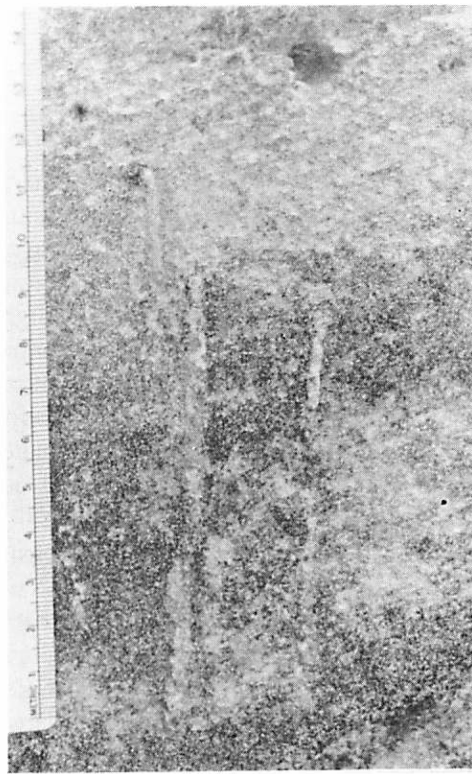
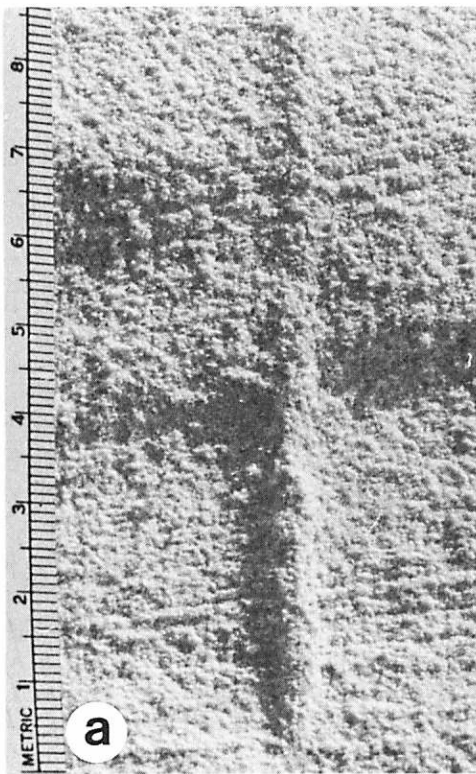


Fig. 6a. *Skolithos linearis* specimens, Hanna Bay Member, Hanna Bay cliffs.



Fig. 6b. The cluster burrow trace fossil in vertical section, North Point Member, Rice Bay cliffs. Height of burrow = 1.4 m.

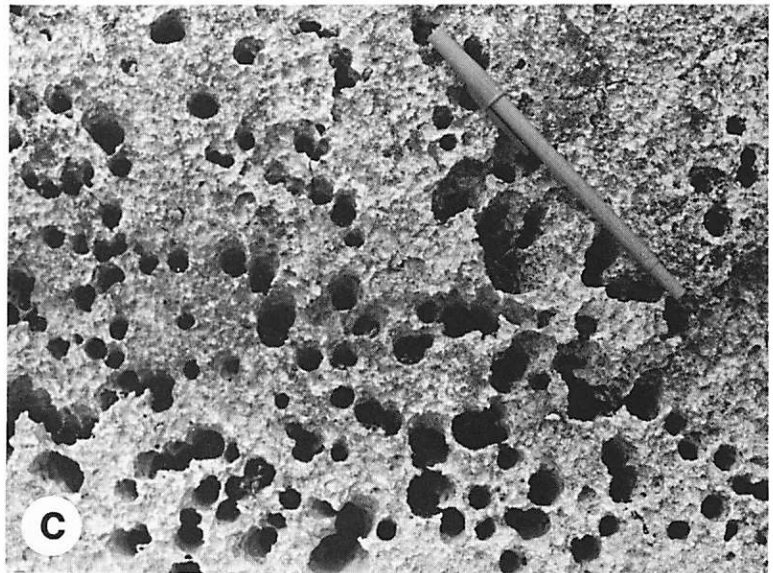


Fig. 6c. Openings of cluster burrow shafts on a horizontal surface, North Point Member, Rice Bay cliffs. Pen = 15 cm.

The *Skolithos* tube, most often used as a dwelling burrow, undoubtedly has been constructed by many different types of invertebrates through its long geologic history (late Precambrian to Recent). The ichnogenus is one of the most typical representatives of the *Skolithos* ichnofacies, characteristic of shifting substrates of lower intertidal to shallow subtidal environments (Frey and Pemberton, 1984, 1985). Nonetheless, *Skolithos* is known to have a much broader range of environmental occurrence, from floodplain deposits (Ratcliffe and Fagerstrom, 1980) to deep-sea fans (Crimes, 1977). More recently, Frey and Pemberton (1987) have reported *Skolithos* from the backshore and dune zones of the Georgia coast.

Modern burrows of the form *Skolithos*, made by insects and by arachnids, were reported common by Ahlbrandt and others (1978) in siliciclastic inland dune fields. Frey and Pemberton (1987) also noted a variety of insects and arachnids capable of making *Skolithos* tubes in siliciclastic washover fans and coastal dunes. Our observations extend the already wide range of *Skolithos* to the carbonate coastal dune environment. By comparison with burrows in modern carbonate dunes on San Salvador and elsewhere, we suggest that the tracemaker animals were insects or arachnids, or both.

Cluster burrows

The largest, most complex, and most distinctive trace fossil found in the North Point Member of the Rice Bay Formation consists of a cluster of shafts radiating upward from a common area of origin. This trace fossil herein is referred to by the informal name cluster burrow. We plan to propose a formal name for this trace fossil in a future publication. The largest and best preserved specimen of the cluster burrow (Fig. 6b,c) occurs in a small sea cliff that begins some 60 m from the most southeasterly rock exposures on the Rice Bay side of the North Point peninsula (White and Curran, 1985). This is not an isolated specimen; some fifteen other, similar trace fossils, all smaller in overall size, have been discovered in the North Point Member cliffs along Rice Bay. Approximately 50 m northwest of the figured specimen, another cluster burrow is exposed in horizontal view where it can be seen to contain several hundred shafts. These two specimens occur in a fossil dune that is about 85 m wide and up to 5 m high, and it is enclosed in dune rocks that contain micrite crusts, rhizomorphs, sandflow strata, grainfall strata, wind ripples exposed on bedding surfaces, and wind ripple laminations (White and Curran, 1988).

The cluster burrow trace fossil consists of numerous, straight to gently curved shafts that have no lining. Individual shaft diameters range from 1 to 2 cm (average 1.2 to 1.4 cm), and they can be 1.4 m or more in length. In some cases shaft diameters narrow slightly towards their upper ends. A few of the shafts branch upwards, and definite crossovers occur. Each trace fossil consists of a cluster of tens to hundreds of individual shafts that radiate upward from an approximately common point of origin, creating a cone-shaped structure that may reach a diameter of 1 m or more.

This trace fossil does not resemble any previously reported form. It bears a superficial resemblance to a buried shrub; however, closer observation suggests that this is an unlikely explanation. The shafts are not preserved by concretionary micrite as is usually the case with true rhizomorphs, and their verticality and close proximity are unlike most plants. Branching of the shafts is minimal, and there is not much variation in diameter, unlike most plants that have abundant branches and show significant differences in diameter between older, thicker branches and younger, thinner twigs. We have never found any evidence of a root system radiating downward from the base of the upwardly radiating structure, nor any sign of a paleosol; both of which ought to be evident in a buried bush.

Our interpretation for the origin of this trace fossil is that it represents the brooding and hatching activity of a species of burrowing (digger) wasp of the Family Sphecidae, with each shaft representing the escape pathway of a young wasp as it made its way to the sediment surface. Our scenario for the origin of the cluster burrow is portrayed in Figure 7.

There are numerous species of modern digger wasps, and some of these are known to make extensive and deep (greater than 1 m) burrows (Iwata, 1976). Unfortunately, precise information on the form of such burrows largely is unknown or scantily reported in the zoological literature. Several species of digger wasps have been reported from San Salvador (Salbert and Elliott, 1979; Elliott and others, 1981), and one of these, *Cerceris watlingensis*, is known to burrow to depths of 30 cm, although it does not inhabit coastal dunes (Salbert and Elliott, 1979). Females of this species also were reported to share nests. Such nest sharing behavior could be the explanation for the large number of shafts found in some of the fossil cluster burrows. We have observed small-scale burrowing by digger wasps in modern carbonate dunes on San Salvador, but we have seen no modern counterpart with the large size and cluster form of the trace fossil found in the North Point Member. In this case, we may have an

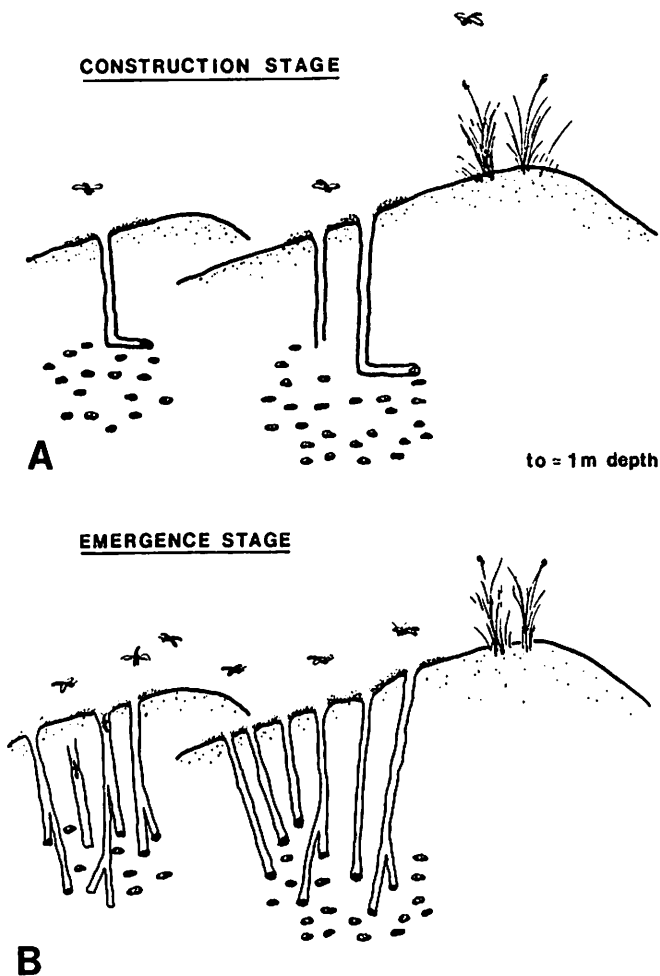


Fig. 7. Scenario for the formation of the cluster burrow by digger wasps. **A.** Females excavate a main shaft to their nests. Cells are formed, provisioned with insect prey, eggs are laid, and the cells closed. At a later time the entire nest may be closed. **B.** Following an incubation period, eggs hatch, juveniles eat cell provisions, and grow. At the proper time individuals, now of full size, burrow upward and emerge at the surface.

excellent example of a trace fossil providing significant information about the burrowing activity of an extant animal.

Small, Irregular Burrows

The most abundant animal trace fossil in the Rice Bay Formation, particularly common in the windward cliff exposures of the North Point Member at North Point and Cut Cay, consists of small, irregular burrows. These are best seen on the upper surface of strata (Fig. 8a), where they are revealed as irregularly

meandering burrows that retain a uniform diameter of 3 to 4 mm along their length, which commonly exceeds 20 cm. The burrows consist of an outer wall that is noticeably paler than the enclosing sediment, and a sediment fill that is like the enclosing matrix. No branching was observed for these burrows, but cross-overs occur commonly, giving rise to an appearance of branching and radiate structure. The burrows are exposed most abundantly in vertical profile, where they can be seen to extend 2 to 3 cm into the strata, in some cases with sufficient density to cause burrow mottling of the sediments (Fig. 8b). An interesting feature of these burrows is that they only have been found in the grainfall and sandflow strata of the North Point Member (White and Curran, 1988), although not all such strata contain them. This indicates that the tracemaker animals preferred the shelter of lee slopes. We have observed a preferential distribution of insects on the lee side of modern carbonate dunes, and we suggest that these burrows may have been made by insects or insect larvae, but the specific modern tracemaker for this burrow type has not been identified.

Plant Trace Fossils

In many eolianite outcrops of the North Point Member at North Point, very thin, hard micritic crusts cap bedding planes and laminations at intervals of approximately 10 to 15 cm (White and Curran, 1988). On vertical faces these crusts stand out as thin, resistant layers, while their upper surfaces commonly bear plant trace fossils and narrow micrite ridges up to 1 cm high (Fig. 8c). Analogous crusts commonly occur on modern dune surfaces on San Salvador, and the mode of formation of such crusts was discussed by White and Curran (1988). The plant trace fossils associated with the micrite crusts represent both lateral root systems and the long, trailing stems characteristic of plants such as railroad vine (*Ipomoea pes-caprae*) and bay geranium (*Ambrosia hispida*) that extend, commonly for several meters, across the surface of modern carbonate dunes on San Salvador.

As stated earlier, the presence of rhizomorphs in a carbonate rock does not necessarily mean that the sediments were deposited in a terrestrial environment, only that they were subaerially exposed at some time during or after deposition. However, the preservation of plant trace fossils on and in the micritic crusts of the North Point Member rocks did occur contemporaneously within a dunal environment, and such trace fossils do provide a specific criterion for the recognition of eolian deposition.



Fig. 8a. Small, irregular burrows on horizontal surface of sandflow strata, North Point Member, Rice Bay cliffs. Scale bar = 2 cm.

Fig. 8b. Vertical surface of sandflow and grainfall layers showing mottling produced by the organisms that formed the small, irregular burrow, North Point Member, Cut Cay cliffs. The overlying wind ripple laminations have not been bioturbated.

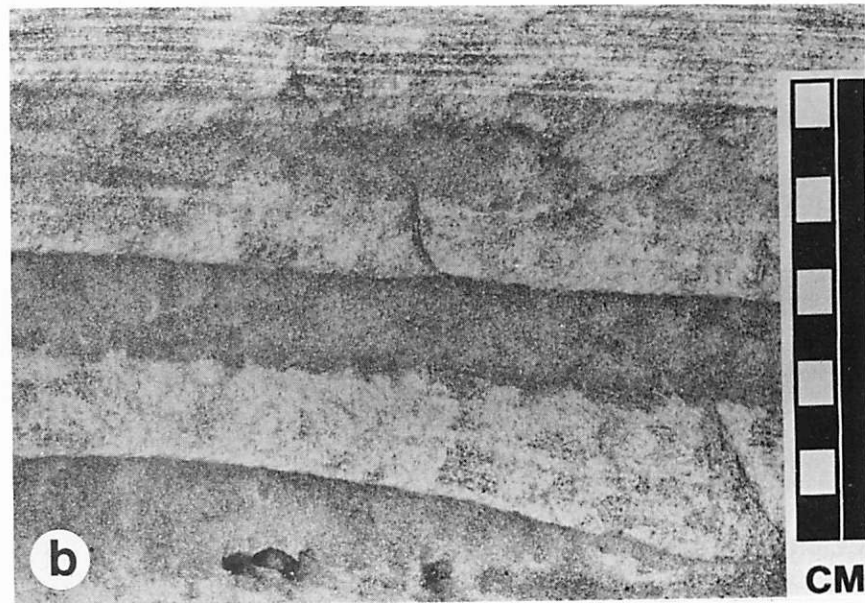


Fig. 8c. Upper surface of micrite crust showing plant trace fossils interpreted as having been formed by runners of dune plants like *Ambrosia hispida*, North Point Member, Rice Bay cliffs. Lens cap = 5.5 cm diameter.

CONCLUSIONS

Two distinctive ichnocoenoses, characteristic of the upper foreshore-backshore zone and dunal zone respectively, have been recognized in the Holocene calcarenites of the Rice Bay Formation on San Salvador, Bahamas. The principal trace fossils are *Psilonichnus* *upsilon*, most prominent in upper foreshore-backshore beds, and *Skolithos* *linearis*, a cluster burrow, a small, irregular burrow, and certain plant trace fossils, found in eolianites. Specific conclusions concerning these trace fossils are as follows:

1. The burrow-tracemaker relationship between the trace fossil *Psilonichnus* *upsilon* and the ghost crab, *Ocypode* *quadrata*, has been well established. Because *O. quadrata* is known to confine its burrow principally to the upper foreshore-backshore zone on modern Bahamian beaches, the occurrence of *P. upsilon* in Holocene and Pleistocene calcarenites of the Bahamas and geologically similar areas is a strong indicator of backshore deposits. As such, the trace fossil has particular significance for the determination of past sea level positions.

2. *Skolithos* *linearis* burrows are common in the proto-dunes and dunal deposits of the upper part of the Hanna Bay Member. This occurrence represents an environmental range extension for this near ubiquitous trace fossil. Obviously the occurrence of *S. linearis* is not *per se* diagnostic of an eolian environment, but its presence in ancient carbonates should not be used to exclude the possibility of eolian deposition.

3. The large cluster burrow trace fossils found in the North Point Member are unique and quite unlike any other described trace fossil. They are believed to have formed by the hatchlings of an invertebrate, very possibly a species of digger wasp, as the matured hatchlings migrated to the surface. These trace fossils are confined to the dune environment, and they may well prove to be diagnostic of eolian sedimentation.

4. The small, irregular burrows that extend laterally and to some extent vertically through the sediment of the North Point Member eolianites probably are not sufficiently distinct morphologically to be regarded as unique to the dunal environment. However, in the study area, these trace fossils showed a pattern of restricted occurrence in sandflow and grainfall strata of the protected, lee-side of dunes, and their presence may aid in reconstructing ancient dunes.

5. Plant trace fossils and root molds that occur along eolianite bedding planes can have distinctive forms that may be related to modern plant analogs.

With further study, these trace fossils and mold forms may prove useful in defining subzones within the proto-dune/dune environment.

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