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

Robert F. Dill
Caribbean Marine Research Center

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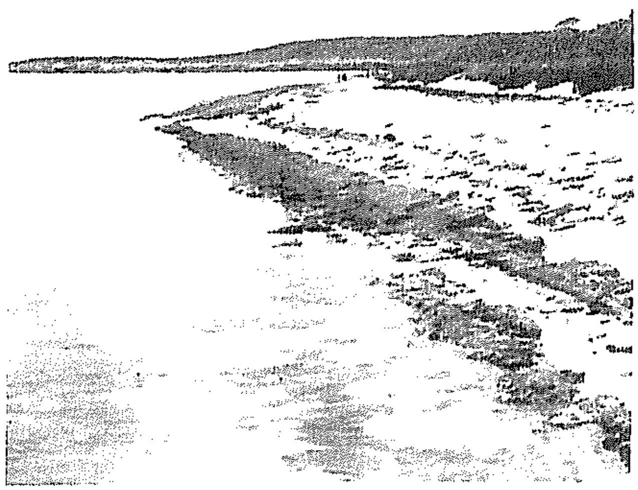

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H. Allen Curran
Department of Geology
Smith College
Northampton, Massachusetts 01063

and

Robert F. Dill
Caribbean Marine Research Center
Lee Stocking Island, Bahamas

Bahamian Field Station
San Salvador, Bahamas

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H. Allen Curran
Department of Geology
Smith College
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Robert F. Dill
Caribbean Marine Research Center
Lee Stocking Island, Bahamas

ABSTRACT

Rock exposures in a submarine cave on Norman's Pond Cay, near the southern end of the Exuma Cays, reveal a continuous stratigraphic section to a depth of -90 ft. Four units are recognized, progressing from the surface of the island into the subsurface. Unit 1 is a carbonate eolianite that caps the northern end of the island. It is overlain by a caliche/paleosol surface and is of presumed late Pleistocene age, having formed in a coastal dune environment. Unit 2 lies at and just above sea level and is of marine origin, consisting of shelly calcarenite with chunks of patch reef corals, not in growth position. It presumably was deposited in Sangamon time during the oxygen isotope stage 5e sea-level highstand. Unit 3 is a carbonate eolianite that extends to -30 ft., where it terminates in sharp contact with the underlying unit. This eolianite contains distinctive palm frond molds, cluster burrows, and *Cerion* sp. shells. Probably it was formed during transgression in early Sangamon time. Unit 4 is a massive, shelly calcarenite of subtidal origin and containing large callianassid burrow systems. This unit extends to at least -90 ft. and represents a prolonged sea-level highstand, probably during oxygen isotope stage 7 (~190 to 240 ka). Speleothems in the cave formed during Pleistocene sea-level lowstands. They have potential for age-dating and could supply geochronology for a significant amount of late Quaternary history.

INTRODUCTION

The walls of a large and deep submarine cave on Norman's Pond Cay of the Exuma Cays (Fig. 1) present a unique view of the subsurface stratigraphy of a Bahamian island. The cave has its entrance at sea level, and it extends inland for more than 350 ft. and to a depth of greater than -200 ft. It was mapped (Fig. 2) by Dick Wilkins in the mid - 1980's, with support from the staff of the Caribbean Marine Research Center (CMRC) on Lee Stocking Island. We have investigated the cave through a series of scuba dives conducted in January, 1989 and 1990, and November, 1990.

The purpose of this paper is to present a geological reconnaissance view of the cave and the stratigraphy of its walls and their trace fossils, body fossils, and physical sedimentary structures. A preliminary report on the cave stratigraphy was given by Curran and Dill (1990). This paper expands that report. A short video program made from within the cave also is available from the senior author.

The cave is completely submerged in seawater and all work within must be accomplished by scuba diving. This difficulty is compounded by the cave's large and dark interior, great depth, and silt on wall ledges and the cave bottom that is easily disturbed. Consequently, the cave's secrets are not easily revealed. After well over fifteen dives in the cave, some to depths of as much as -150 ft., we still are in the reconnaissance stage of exploration, with much detailed work yet to be done.

THE GEOLOGIC SETTING

The entrance to the cave is located near the northwest tip of Norman's Pond Cay (Fig. 1), about 3 km by boat from the CMRC pier. Here a large, rectangular-shaped seawater pool (about 3 x 6 m, long axis leading into the cave) lies just inland of the high-tide line on the rocky shore of a small bay. This bay is on the southwest flank of the prominent bedrock ridge of carbonate eolianite that dominates the topography of the northern end of the island. The cave entrance is at the back of the pool, beneath a rock ledge, and it is essentially continually submerged. There are several small conduits that run underground from the pool to the sea, and the pool does have a modest tidal range (about 0.5 to 0.75 m). We have observed no strong tidal or other currents within the cave proper.

Two roughly parallel master joints striking N 50° W emerge from the sea floor to bound the long sides of the cave pool and extend into the cave, seemingly controlling the direction and form of the cave walls. A prominent, well calichified joint (caliche dike of White and others, 1984) lies in parallel position just to the south of the cave pool. At least the upper part of the cave (to -100 ft.) appears to have formed principally by stoping and collapse along the parallel master joints. The lower part of the cave (Fig. 2) also has a narrow, straight form and seems to be controlled by these same joints. The N 50° W strike of these joints is generally parallel with the platform shelf margin along Exuma Sound (see Fig. 1).

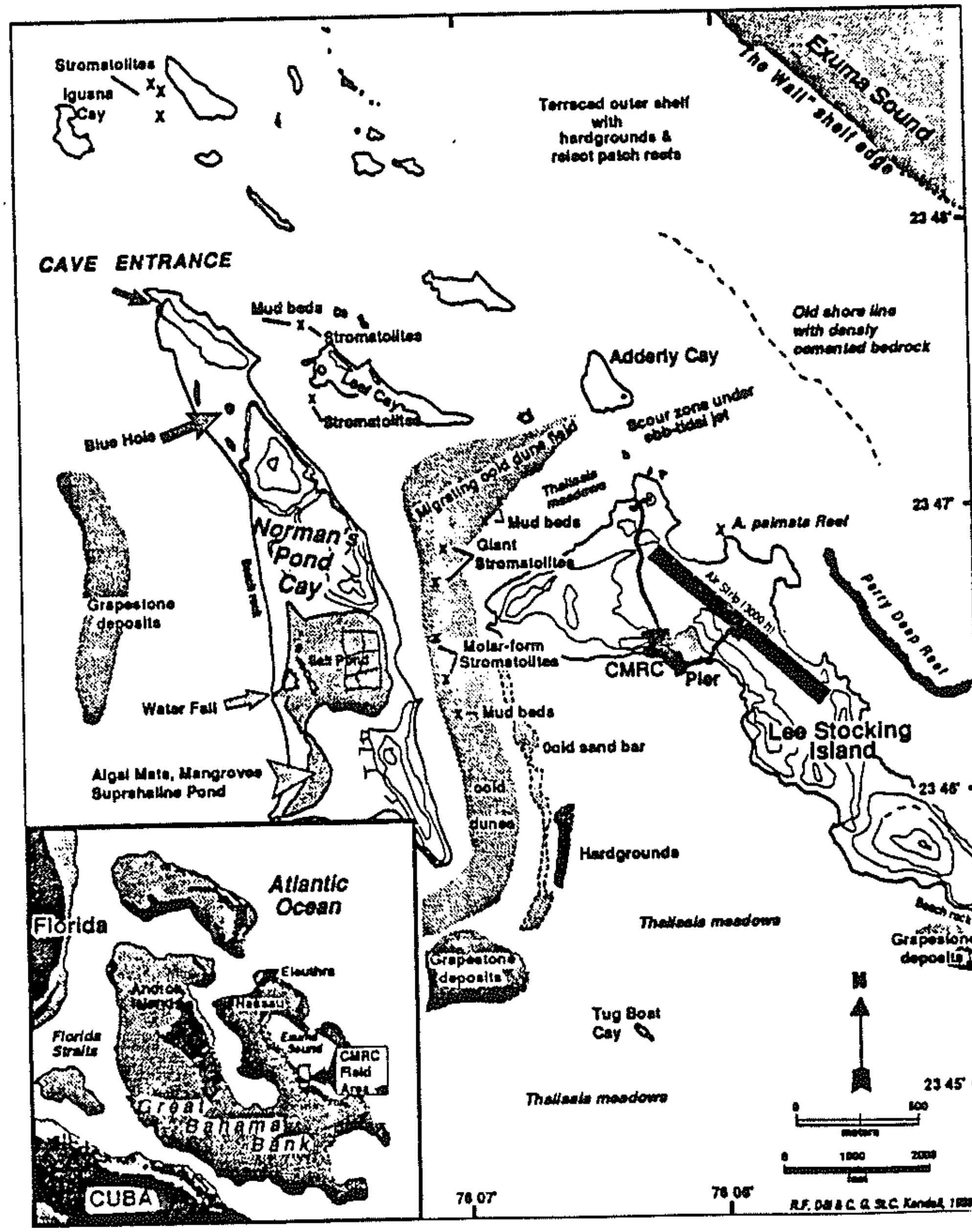

Fig. 1. Index map showing the location of the cave on Norman's Pond Cay, Exuma Cays, Bahamas. Inset map shows the location of the study area within the Bahama Archipelago.

Possibly these joints formed during times of lowered sea level with the settling or shifting of large blocks along this margin. This theory needs to be tested by further structural investigation on a regional basis. In its upper chamber, the cave walls are sufficiently fresh so that major unit contacts, trace and shelly fossils, and physical sedimentary structures can be observed.

Steeply seaward dipping (30° NW) carbonate eolianites crop out along the coast on either side of the cave entrance. These eolianites are capped by a well-developed caliche/paleosol surface and, by analogy with other, similar eolianites in the Bahamas that lie below paleosols (Carew and Mylroie, 1985), are presumed to be of late Pleistocene age. The terrestrial part of the stratigraphic sequence here is that of a shallowing-upward carbonate facies sequence, similar to that described on San Salvador Island by White and others (1984).

THE STRATIGRAPHIC SECTION

The relatively clean walls of the upper part of the cave and the rock outcrops at the cave entrance and nearby vicinity permit the recognition of four distinct facies or rock units in the cave stratigraphic sequence. This sequence is summarized in Figure 3, and each unit is described briefly below.

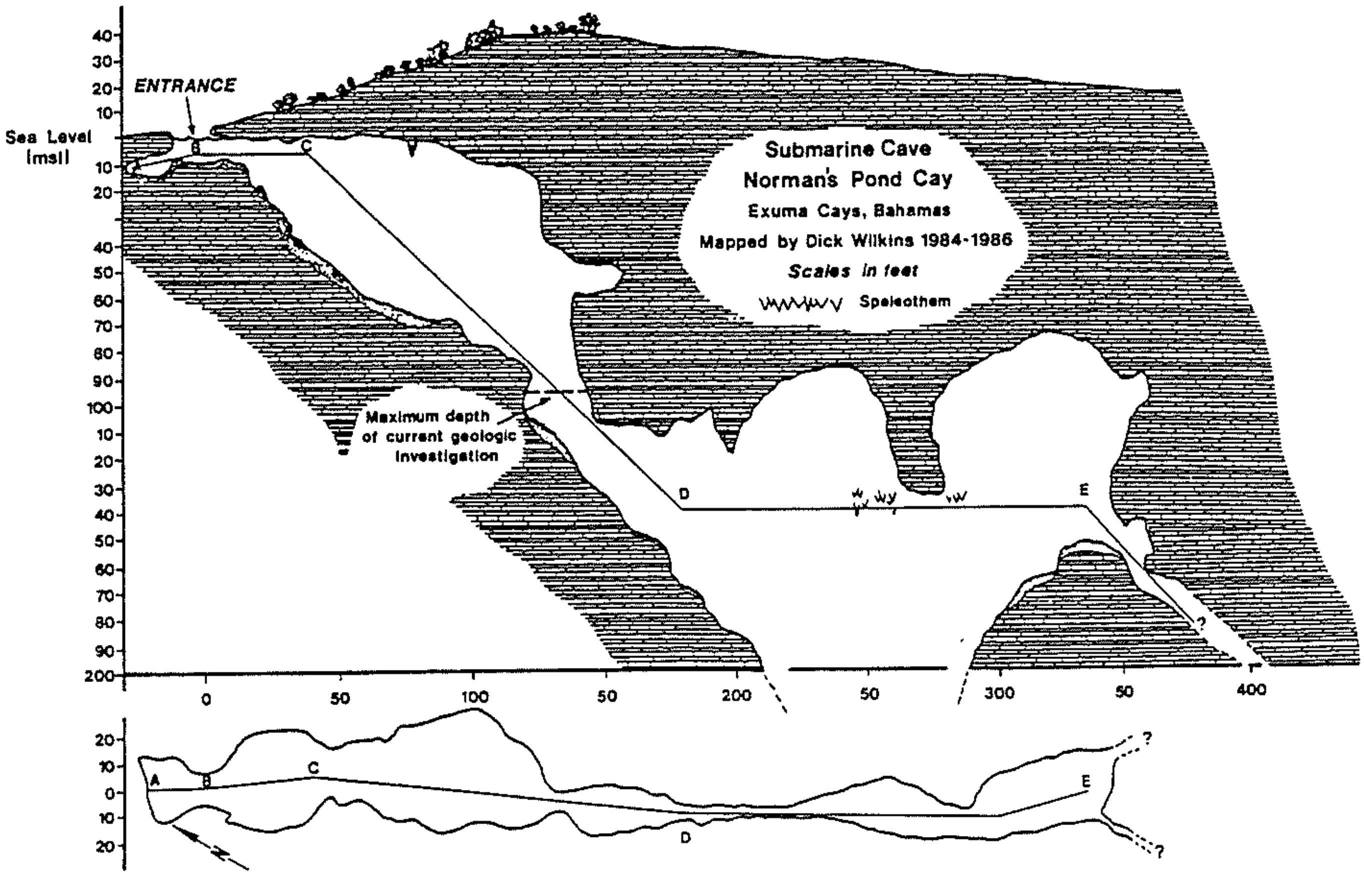

Fig. 2. Cross-sectional and plan view maps of the Norman's Pond Cay submarine cave. This map modified from the original made by Dick Wilkins.

Depths are given in feet as recorded from scuba depth gauges. As one goes deeper in the cave, the walls become progressively more obscured, first by a slimy, rusty-brown iron oxide flocculate that begins to become very noticeable in the -30 to -40 ft. depth range. This flocculate likely is similar to that reported by Li and others (1989) from speleothems in the Lucayan Caverns on Grand Bahama Island. Flowstone, although present at shallower depths, really begins to become pervasive and to obscure the cave walls at about -60 ft. By -85 ft. flowstone, stalactites, and stalagmites largely cover the walls.

Unit 1: > + 3 ft. above MLT (mean low tide) -- steeply dipping calcarenites or carbonate eolianites deposited in a coastal dune environment. Rhizomorphs are common in the outcrops near the cave entrance, and this eolianite is capped by a caliche/paleosol surface.

Unit 2: MLT to +3 ft. -- shelly calcarenite of variable texture and thickness. Chunks of corals, including *Acropora cervicornis*, *Diploria clivosa*, *D. strigosa*, and *Montastrea annularis*, are in this bed and can be found in the rock of the cave pool and in the low area surrounding the cave entrance. These beds also contain locally abundant arcoid bivalve shells and small shells and shell fragments of other marine bivalves and gastropods.

Unit 3: MLT to -30 ft. -- carbonate eolianite beds, steeply dipping, in variable directions, but with a predominant dip trend from the NE (left wall as one swims into the cave) to the SW (right) wall of the cave. Palm frond molds are present on the left wall near the cave entrance at about -7 to -10 ft. Cluster burrows are common on the left wall in the mid reach of the cave at about -20 ft. Shells of *Cerion* sp. and another land snail can be found sparcely dissiminated throughout this unit.

At about -30 ft. there is a prominent zone of thin-bedded eolianite in sharp contact with the underlying unit. These thin beds are steeply dipping above the contact but commonly are near horizontal along the contact. This sharp contact can be traced virtually continuously around the walls of the cave upper chamber.

Unit 4: -30 to -90 ft. and possibly deeper -- massive shelly calcarenite beds. Small marine bivalve and gastropod shells and shell fragments, commonly preserved as molds, are found throughout the unit. Large callianassid burrow systems (*Ophiomorpha* sp.) are prominent on the right wall between -35 to -60 ft. Below about -50 ft. the texture of the rock is highly bioturbated.

We have not found a bottom contact for this unit. In November, 1990, we made several deep dives (deepest -150 ft.) to collect speleothem samples and did not see a contact. But, as stated earlier, the walls at these deeper depths become increasingly covered by flowstone. Beginning at about -70 ft., the grains of the wall rock show marked effects of dissolution and diagenesis.

INTERPRETATION OF THE UNITS, WITH ICHNOLOGIC DISCUSSION

The steeply seaward dipping carbonate eolianites (Unit 1) overlain by a caliche/paleosol surface at the top of the cave stratigraphic section are very much like other, similar eolianites that cap islands throughout the Bahamas. Their stratigraphic position above a coral-bearing marine layer and below a calichified surface indicates a late Pleistocene age. Based on this stratigraphic position, these beds probably correlate with the upper part of the Cockburn Town Member of the Grotto Beach Formation on San Salvador Island (Carew and Mylroie, 1985). If this is correct, then these eolianites are regressive and part of a shallowing-upward carbonate sequence, similar to that described by White and others (1984) for the eolianites overlying the Cockburn Town fossil coral reef on San Salvador.

An alternate interpretation would be that these eolianites are younger and not directly related to a shallowing-upward cycle from the underlying marine beds. In this case, they could be correlated with the Dixon Hill Member of the Grotto Beach Formation on San Salvador (Carew and Mylroie, 1985). As such, they would be transgressive and with an age of ~85 ka.

Given the fact that marine beds directly underlie this eolianite, we favor the former interpretation. However, exposure is limited in the cave entrance area and the northern end of Norman's Pond Cay has not yet been geologically explored. New information may be forthcoming from the field area that would modify this interpretation.

The fossil coral-bearing, shelly calcarenites (Unit 2) of marine origin correlate on Norman's Pond Cay with an *Acropora cervicornis* fossil coral patch reef located around a blue hole a short distance to the south of the cave entrance (Fig. 1). Other, similar patch reefs crop out along the southern coast of Norman's Pond Cay and elsewhere in the southern Exuma islands (Halley and others, 1991).

These coral-bearing marine beds undoubtedly correlate with the reefal part of the Cockburn Town Member on San Salvador (Carew and Mylroie, 1985). As such they represent the Sangamon sea-level highstand (oxygen isotope stage 5e) at ~126-123 ka (Chen and others, 1991) or a slightly younger age (~119-117 ka) as reported by Halley and others (1991). The lowermost eolianite beds (Unit 3) are likely to correlate with the French Bay Member of the Grotto Beach Formation on San Salvador (Carew and Mylroie, 1985), on the basis of similar stratigraphic position. In this interpretation, these eolianites would be transgressive and record conditions of rising sea level in early Sangamon time.

Within the cave, these eolianites contain some distinctive, large (to about 45 cm length) ridge and groove structures with a fan - shaped form (Fig. 3).

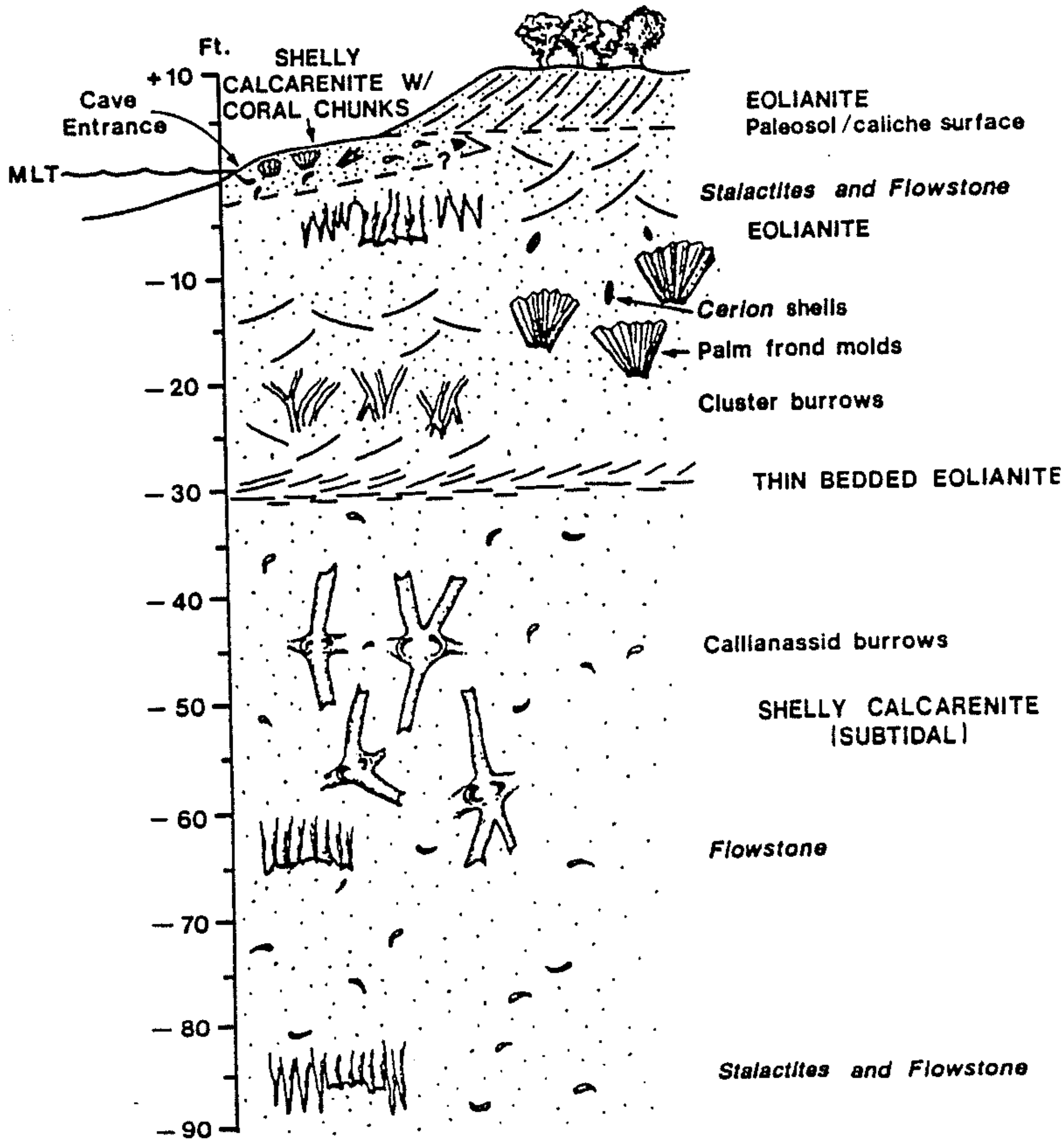

Fig. 3. Generalized stratigraphic column for the Norman's Pond Cay submarine cave. Flowstone becomes progressively more pervasive on the cave walls below - 60 ft. Details of the units and their contained structures are described in the text.

We interpret these structures to be palm frond molds, formed as dunal sand covered the accordian - like fronds of palms such as the silver thatch palm (*Coccothrinax argentata*). This palm is a dominant plant in the coastal coppice community and is very common in sandy terrestrial areas and on vegetated coastal sand dunes throughout the Bahamas. These Bahamian palm frond molds are very similar to the palm frond molds that occur commonly in the late Pleistocene Southampton Formation (carbonate eolianite) on Bermuda. In the Bahamas, other similar structures have been found by the senior author in Holocene eolianites on Lee Stocking Island and in eolianites on San Salvador (John Mylroie, pers. comm.).

Also present in these eolianite beds, on the left cave wall in the area around -20 ft. (Fig. 3), are well-developed cluster burrows, similar to those described by Curran and White (1987) and White and Curran (1988) from the Holocene North Point Member of the Rice Bay Formation on San Salvador. These distinctive burrows consist of clusters of unlined burrow shafts, about 0.8-1 cm in diameter, radiating upward from a central area of origin. The total length or height of such structures in the cave is about 0.5 to 0.75 m. Curran and White (1987) interpreted these burrows as having been formed by the hatchlings of a burrowing (digger) wasp species as they moved from their egg capsules to the dunal surface/air interface. Such burrows are another indicator of the coastal dune paleoenvironment.

The massive, shelly calcarenites (Unit 4) of subtidal origin that occur below -30 ft. represent a prolonged sea-level highstand. Again, by stratigrahic position, these beds probably formed during the highstand of oxygen isotope stage 7 (~190 -240 ka, Harmon and others, 1983). To date, we have not detected any major break in this unit to a depth of -90 ft.

Large callianassid burrows are prominent in this unit, particularly on the right wall of the cave between -40 and -50 ft. (Fig. 3). The burrows commonly are preserved in concave epirelief, and they are well lined. As such, they clearly can be assigned to the ichnogenus *Ophiomorpha*. These *Ophiomorpha* are characterized by long shaft sections (~30 cm) punctuated by multiple tunnel junctures. They are not like the irregular boxworks of shafts and tunnels of *Ophiomorpha* sp. reported by Curran (1984) from Pleistocene Cockburn Town fossil reef sequence beds.

The form of the cave *Ophiomorpha* systems is very similar to that of modern callianassid burrow system casts that the senior author has obtained from Grahams Harbour, a large, somewhat protected, coastal bay or lagoon on San Salvador Island. Based on this likeness of callianassid burrow forms, it seems probable that the marine sediments of Unit 4 were deposited in a coastal lagoon/bay environment similar to that of Grahams Harbour. Below -50 ft., the sediments of Unit 4 were very heavily bioturbated, probably by callianassid burrowing. This also suggests a protected, coastal lagoon paleoenvironment.

CONCLUSIONS

The stratigraphic column of the Norman's Pond Cay submarine cave can be used to interpret the glacioeustatic history of the Bahamas beyond that normally revealed by surface outcrops on the islands. Working conditions within the cave are difficult, and we still are at the reconnaissance level in its exploration. We do not yet have radiometric dates for materials from within the cave. Nonetheless, based in part on correlation by stratigraphic position and physical characteristics with the well-established stratigraphic column for San Salvador Island (Carew and Mylroie, 1985), the following conclusions can be drawn:

1. The uppermost eolianites of the cave formed during sea regression with the onset of Wisconsinan glaciation. These beds probably correlate with the upper part of the Cockburn Town Member of the Grotto Beach Formation on San Salvador. An alternate interpretation would be that these beds are younger and transgressive, correlating to the Dixon Hill Member with an age of ~85 ka (Carew and Mylroie, 1985).

2. The coral-bearing marine beds near the top of the cave sequence and the nearby *Acropora cervicornis* reef correlate with the reefal part of the Cockburn Town Member on San Salvador and represent the Sangamon sea-level highstand (oxygen isotope stage 5e) at ~126-123 ka (Chen and others, 1991) or a slightly younger age.

3. The lowermost eolianites probably correlate with the French Bay Member of the

Grotto Beach Formation on San Salvador and are transgressive. If this is the case these beds mark rising sea level of early Sangamon time.

4. The massive marine calcarenites that occur below -30 ft. represent a prolonged sea-level highstand, probably during oxygen isotope stage 7 (~190-240 ka).

5. Speleothem in the cave formed during Pleistocene sea-level lowstands. If radiometric ages can be obtained from these materials and combined with ages from the marine units, a fairly complete record of the late Pleistocene history of the Bahamas could be obtained from this cave.

6. The trace fossil burrows within the cave represent the first reported occurrence known to the authors of fossil burrows in submarine outcrops. These trace fossils are particularly useful in enabling a more refined interpretation of the depositional environment of the rocks in which they occur.

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