PROCEEDINGS

OF THE FOURTH SYMPOSIUM

ON THE GEOLOGY OF THE BAHAMAS

Editor

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Production Editor

Donald T. Gerace

Sponsored by the Bahamian Field Station

June 17 - 22, 1988

ISBN 0-935909-31-1

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

THE GEOLOGY OF EASTERN SOUTH ANDROS ISLAND, BAHAMAS: A PRELIMINARY REPORT

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ABSTRACT

Field investigation and preliminary laboratory study of rocks exposed along the eastern margin of South Andros Island, Bahamas has revealed the following. There are essentially no lithified Holocene rocks, in contrast to many other Bahamian islands (e.g. San Salvador, New Providence, Eleuthera, Great Inagua). All surficial rocks appear related to only one high stand of sea level, most likely that of the Sangamon (Oxygen isotope stage 5). The oldest rocks are eolian calcarenites exposed on an offshore cay just north of Mars Bay, where truncated eolianites are encrusted by fossil corals and both are capped by a paleosol. There are few fossil coral localities, but extrapolation between sites suggests an eastern string of patch to bank-margin coral reefs that now outcrop as much as 2 m above sea level.

The majority of the island below 5-6 m elevation consists of ooid shoals and lagoonal deposits, that are sometimes capped by Pleistocene eolianites. The more significant Pleistocene ridges trend approximately parallel to the shore, but lie 100 to 1000 meters or more inland. At all localities the rocks are covered with a paleosol or its remnants. No underlying paleosols were observed.

All rocks are solutionally altered on a scale from small pits, to banana holes, to blue holes. The majority of blue holes are developed along a sub-parallel to bank-margin fracture zone that has the physical appearance of a graben. It is suggested that progradational collapse upward from a deep cavern system developed along that trend provides a plausible origin for those blue holes. The original fracturing may be the result of bank margin subsidence, or original Mesozoic tectonics. There are also numerous small branching dry caves that were developed along the margins of a freshwater lens perched on a past higher sea level that may or may not be coincident with the highstand discussed above.

INTRODUCTION

This study was undertaken as part of the British-organized Andros '87 Project. The Project was a multidisciplinary scientific investigation of the geology, geochemistry, and biology of the blue holes of South Andros Island, Bahamas (Palmer, 1988). The field work for our part of the project was conducted in July 1987.

We were invited to be a part of the Project for the purpose of establishing the stratigraphic, sedimentologic, and structural setting of the blue holes. Additionally, we were to determine whether the stratigraphic model established on San Salvador Island (Carew & Mylroie, 1985) (Fig. 1) could be used successfully on South Andros.

METHODS

Field investigation and outcrop sampling was conducted by walking all available coastal outcrops along the east coast of South Andros Island from Driggs Hill to Mars Bay (see Fig. 2). Use of a zodiac boat permitted us to visit and investigate exposed rock on all the offshore cays from Goulding Cay to High Cay (see Fig. 2). We also investigated all quarries and pits, road cuts, and some blue holes (down-blue hole geology was directed by Dr. Peter Smart of the University of Bristol). We studied the rocky exposures inland along the banks of Deep and Little Creeks (see Fig. 2), and hiked inland to investigate all inland paleo-dune ridges in eastern South Andros. Finally all macroscopic (enterable) subaerial caves were investigated and where possible, mapped.

Eighty-eight samples were taken for further laboratory investigation. To this date slab descriptions and some thin section analyses have been completed. Further thin-section study, U/Th dating of some *in situ* fossil corals, and S.E.M. investigations are still to be done.

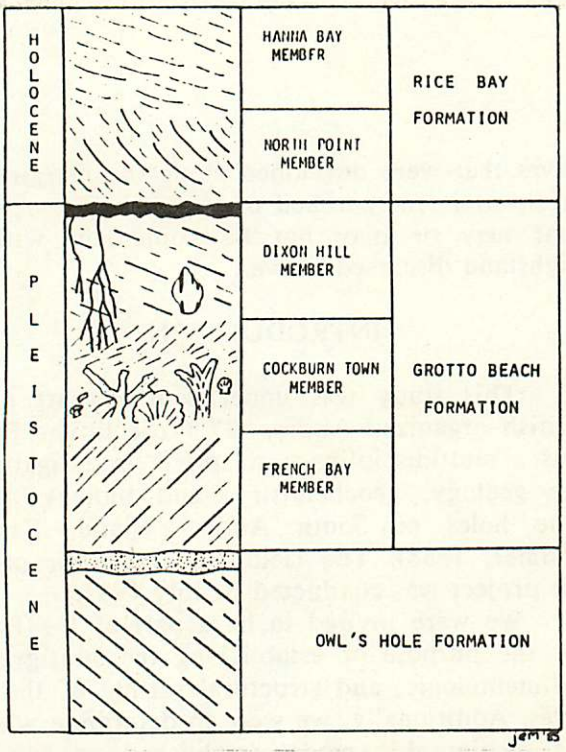

Fig. 1. Stratigraphic column for the Late Quaternary of the Bahamas. This stratigraphy was developed on San Salvador and has been successfully applied to the geology on New Providence, Great Inagua and Little San Salvador islands.

HOLOCENE

Unlike many other Bahamian islands (e.g. San Salvador, New Providence, Eleuthera, Great Inagua), there are essentially no lithified Holocene deposits, with the exception of a few scattered, weakly cemented back-beach deposits at a coastal location just N of Deep Creek. There are unlithified Holocene sediments comprising beach and back-beach, shallow subtidal lagoon, offshore shoal, creek channel, and lowland mangrove marsh and grass flat facies.

The offshore shoal that parallels much of the southern half of South Andros is composed primarily of 0.5-1mm diameter ooids. The lagoon that lies behind this shoal contains a variable mixture of ooids, bioclastic fragments, forams, peloids and aggregate grains with variable amounts of micrite. The beaches comprise a variety of calcarenites that show diminished ooid content with distance from the shoal. The creek channels, marsh, and grass flats that occupy much of the low-lying interior of this primarily flat island were not investigated.

PLEISTOCENE

Offshore Cays

The outcrops found on the offshore cays comprise subtidal ooid shoal deposits, and *in situ* reef corals and associated facies. There are a few larger cays (e.g. High Cay) that have outcrops of dune facies that extend to about 15 m above present sea level. The *in situ* corals extend upward to approximately 2 m above present sea level.

For much of the relatively flat low-lying cays it is not possible, in the field, to determine whether steeply dipping (25^{o}-30^{o}) cross beds are part of a shoal or are truncated eolian dune. Because there are relatively coarse shell hash and whole shell layers, and herring-bone cross bedded horizons associated with these steeply dipping beds in a moderate, but widespread number of locations on these cays, we believe that most of these deposits were part of a series of shoals that occupied this area during the Pleistocene. In a few locations there were subaerial eolian accumulations that formed islands along the eastern margin of South Andros during a time of past sea level higher than present. There is a paleosol/calcrete or its remnants that caps all outcrops.

Coastal Outcrops

Most of the coastal outcrops are low lying (0-2 m above sea level). These exhibit textures and compositions assignable to subtidal, shoal, beach, or reef. In a few notable localities (e.g. The Bluff) there are coastal cliffs that reveal subtidal facies low in the section, that grade upward into beach and then back-beach dune facies that extend up to 10 m above present sea level.

Outcrops along The Bluff settlement are particularly well developed and exposed. At the northern end of the cliffs there are sea caves along the coast that provide a window carved into the interior of a well developed coral reef complex comprising numerous taxa, conspicuous among which are *Acropora cervicornis*, *Montastrea annularis* and *Diploria* sp. Along the cliffs lateral to these reef deposits the rocks comprise a variety of subtidal deposits including ooid shoals and mixed bioclastic ooid subtidal sands. These subtidal facies extend to approximately 5 m above sea level where they grade upward into beach facies. These facies then pass upward into back--beach dune facies that extend inland to eolian ridges up to 20 m above sea level. The outcrops are capped by a paleosol/calcrete or its remnants.

Pits and Quarries

Depending on the elevation of, and depth to which pits and quarries penetrate, a variety of sedimentary facies are exposed. All exposures within a few meters of sea level are assignable to subtidal facies. A few exposures at higher elevations reveal beach and dune facies.

A particularly noteworthy exposure was seen at Driggs Hill where bulldozer excavation of a new harbor was underway. Excavation behind coffer dams below sea level revealed a complex subtidal facies mosaic composed of patches of reef corals surrounded and entombed by subtidal sands. These deposits extended upward to several meters above present sea level. At the present time all of this outcrop below sea level should be flooded by sea water. A paleosol/calcrete or its remnants caps all natural exposures.

Roadcuts

There is one major N-S road that is close to and parallels the eastern shoreline. There are also other minor N-S roads, and a few short and two long E-W roadway/tracks (e.g. Blister Rock Road). Road cuts on the N-S roads bisect a variety of facies depending on road elevation. Exposures representing subtidal, shoal, beach, and dune facies can be seen. At The Bluff settlement the N-S road splits the outcrops described earlier, within the beach to back-beach facies.

East-west roads penetrate into the interior of the island. They mostly reveal only exposures of eolian dune facies, but they do show that the N-S elongate eolian ridges are primarily oolitic.

Only the E-W road to Black Point settlement (just N of Deep Creek) penetrates facies other than eolian. Along that road can be found a sequence of outcrops beginning at its eastern end with subtidal facies, and progressing along the road and upsection to an oolitic eolian ridge outcrop at its western termination. All outcrops are capped by a paleosol/calcrete or its remnants.

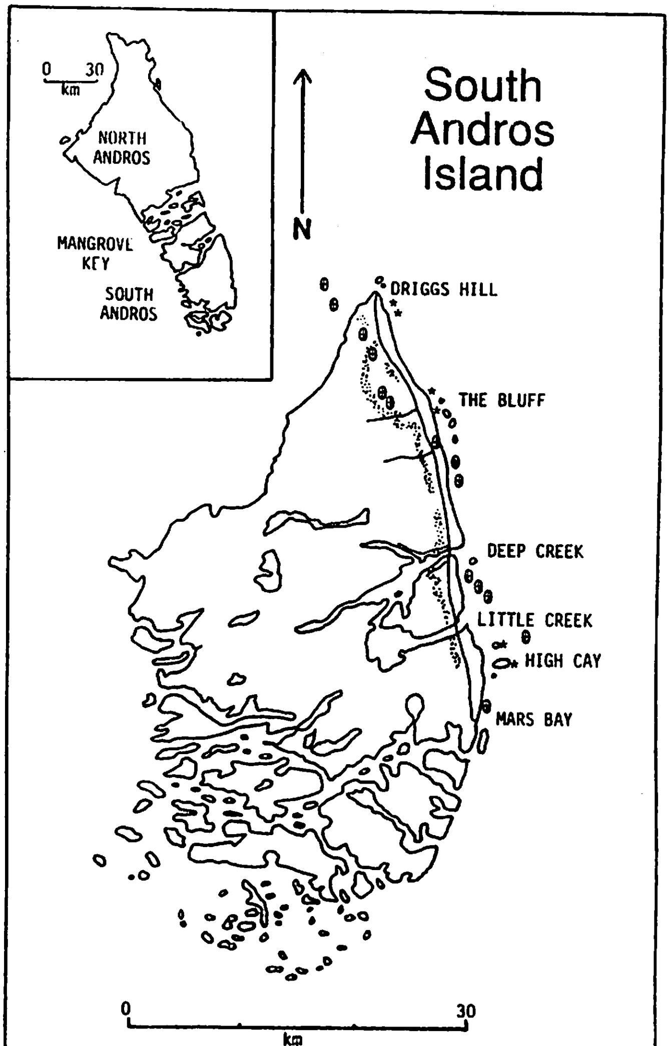

Fig. 2. Map of South Andros Island, Bahamas, showing major landmarks, fossil reefs, dune tracts and roads. The low-lying, western part of the island was not examined.

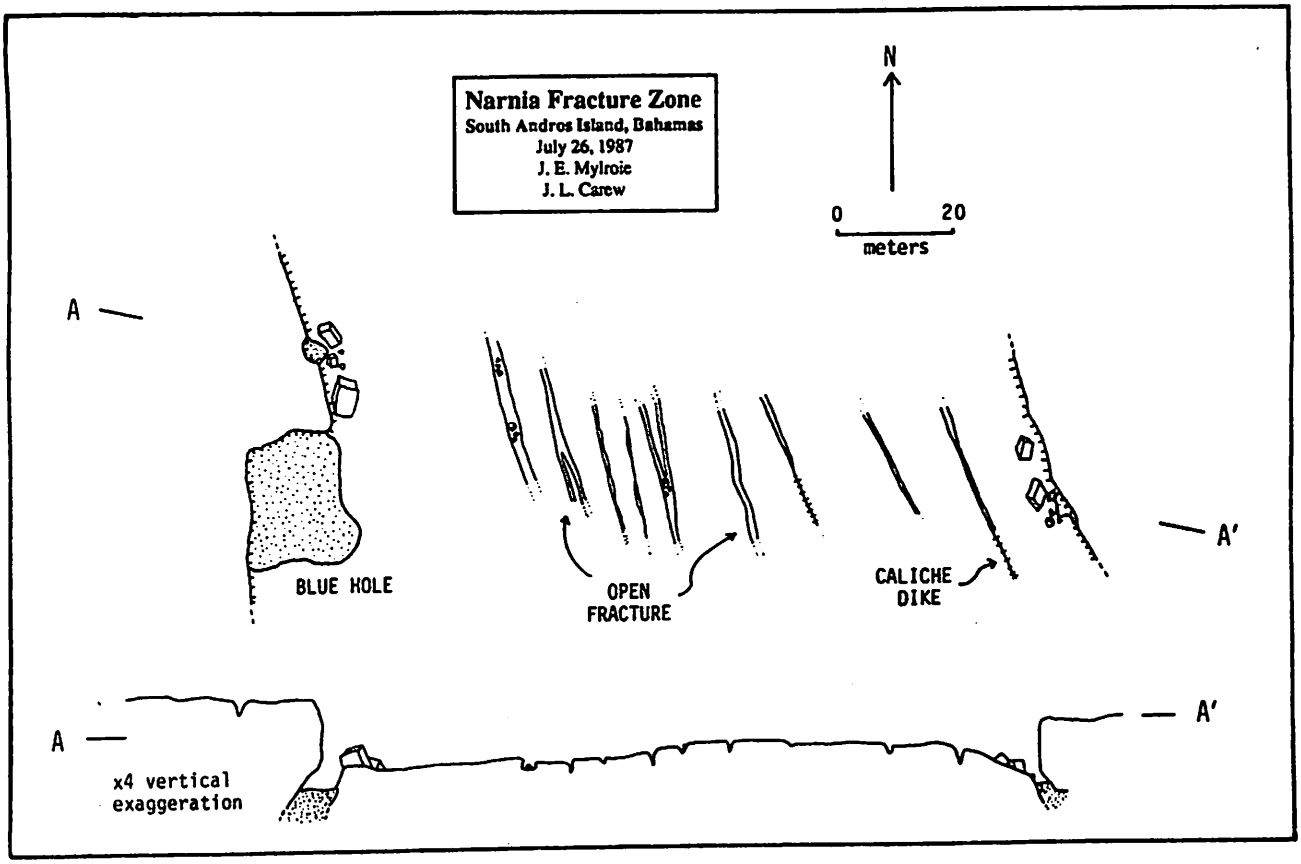

Fig. 3. Map and cross section view of the Narnia Fracture Zone, located halfway between the Bluff and Deep Creek (see Fig. 2). This graben-like feature is one of many along a zone that is sub-parallel to the Tongue of the Ocean to the east.

Creeks

Utilizing an inflatable boat and short inland treks at appropriate and accessible locations we investigated the margins of the channels of Deep Creek and Little Creek (see Fig. 2). Those water-ways provided another avenue for exploration westward into the island's interior. We proceeded westward as far as was possible or practical. In each case outcrops seen near the eastern end revealed subtidal oolitic and oolitic-bioclastic facies. In some cases demonstrable subtidal shoal facies extend to 5 m - 6 m above present sea level.

At more westerly locations the creeks sequentially truncate the interior N-S dune ridges. At some locations subtidal deposits crop out from the water level to several meters above it, and then beach through dune facies are developed sequentially up the outcrop to a dune ridge crest 12-15 m above water level. The dune facies are oolitic. Outcrops are all capped by a paleosol/ calcrete or its remnants. Most of the island's interior is a flat lowland plain covered by marsh, swamp, algal and grass flats with "islets" of rocky bedrock sprinkled in. We did not investigate those areas.

Fracture Zones

Behind the Batelco offices south of The Bluff settlement the Bahamians had cleared a large area by slash and burn. The cleared area exposed part of the fracture zone that trends subparallel to the coast, and along which the blue holes are developed, in this case Narnia Blue Hole. The cleared area provided a relatively long line-of-site view of the fracture zone which is usually buried in vegetation and very difficult to see. Figure 3 depicts this portion of the graben -like fracture zone. The cliffs on this "graben" margin reveal predominantly oolitic subtidal and shoal facies. Detailed sampling was done in this area, but the samples have not yet been analyzed. Narnia Blue Hole is found along the western margin of this fracture zone.

The fracture zones along the eastern margin of South Andros pose an interesting geologic problem. The fractures appear tectonic in origin, but occur in an area (the Bahamas platform) noted for its tectonic stability (Mullins and Lynts, 1977). The fractures are oriented subparallel to the trend of the eastern margin of the Andros portion of the platform, and therefore nearly parallel to the orientation of Tongue of the Ocean (TOTO).

Determining cause and effect is difficult based on the available data. Arguments could be made to suggest that the fractures represent a surficial expression of the crustal fractures thought by some (Mullins and Lynts, 1977) to be the source of an original horst and graben topography of the Bahamas region, that is expressed today as linear platforms with co-linear embayments. Alternatively, the proximity of the depths of TOTO to the platform margin may result in gravity sliding of the platform towards TOTO, with subsequent fracturing parallel to TOTO. The fracturing could: (1) result from gravity sliding active today; (2) result from faulting only active during Pleistocene sea level low stands when 100+ m of bouyant seawater support to the platform margin would be lost; or (3) result from faulting that has been inactive since some much earlier time.

Yet another prospect is that the grabens and associated fractures represent stoping structures from large solution conduits at depth. This idea requires a mechanism for the development of very large solutional voids subparallel to the bank margin. A possible reason can be found in the interaction between outward discharging freshwater and inward encroaching marine waters. That mixing produces a very solutionally aggressive groundwater that has been well documented (Back and others, 1986; Mylroie, 1988; Whitaker and others, 1988; Smart and others, 1988). Those conditions would place a zone of high solutional agressivity inward from the platform margin, but parallel to it. As the fractures penetrate rocks as young as 125,000 years old, regardless of their origin the final surficial expression of these features is relatively recent.

A polygenetic origin for the fractures is also possible. Given a fracture pattern either inherited from basement tectonics, or developed from gravity sliding towards TOTO, this fracture system could be expected to become a preferred flow path for groundwater in the island, causing a preferred site for solution at depth which is subsequently expressed at the surface as a graben fracture system. Study of the subsurface geology of the fascinating hydrological/structural aspects of the blue holes was conducted under the direction of Dr. Peter Smart of the University of Bristol, and preliminary results have been reported (Smart and others, 1988; Whitaker and others, 1988).

Caves

South Andros Island has a number of caves that are currently subaerial. These caves developed by solution at a past higher sea level (assuming platform tectonic stability) when the freshwater lens stood at a higher elevation than today. The caves conform to the pattern of the flank margin model of cave development (Mylroie, 1988). They consist of simple phreatic chambers with radiating tubes that developed in the zone of mixing between the discharging freshwater and landward encroaching marine waters. A map of South Deep Creek Cave, a typical flank margin cave, shows the main features of this type of cave development (see Fig. 4). The cave has a large central chamber that occurs on the margin of a dune, and which has been breached by recent surface erosion. A single phreatic tube leads inward into the dune mass, and ends abruptly. Caves of this type are common all over the Bahamas (Mylroie, 1988).

A different type of cave development is shown in figure 5. Ratbat Cave is a feature produced by stoping upward from a large void (assumed to be solutional) at depth. Instead of producing a graben feature as is common on South Andros, the fracture zone passed beneath an eolian ridge which had sufficient mechanical strength to bridge the void produced by collapse. On either side of this dune ridge, the fracture can be recognized by a series of linear blue holes. The plan and cross section of Ratbat Cave show that the cave has regions of deep water and dry areas of collapsed rock. This type of cave development is unusual in the Bahama islands, but is common on Bermuda (Mylroie, 1984).

SUMMARY AND CONCLUSIONS

All of the rocks exposed on South Andros Island appear to have been deposited during only one high stand of sea level about 5 to 6 m above present. It seems most reasonable that these rocks were deposited during the late rise, still-stand, and early fall of the high stand associated with oxygen isotope substage 5e (Sangamonian; circa 125,000 years ago) (Shackleton & Opdyke,

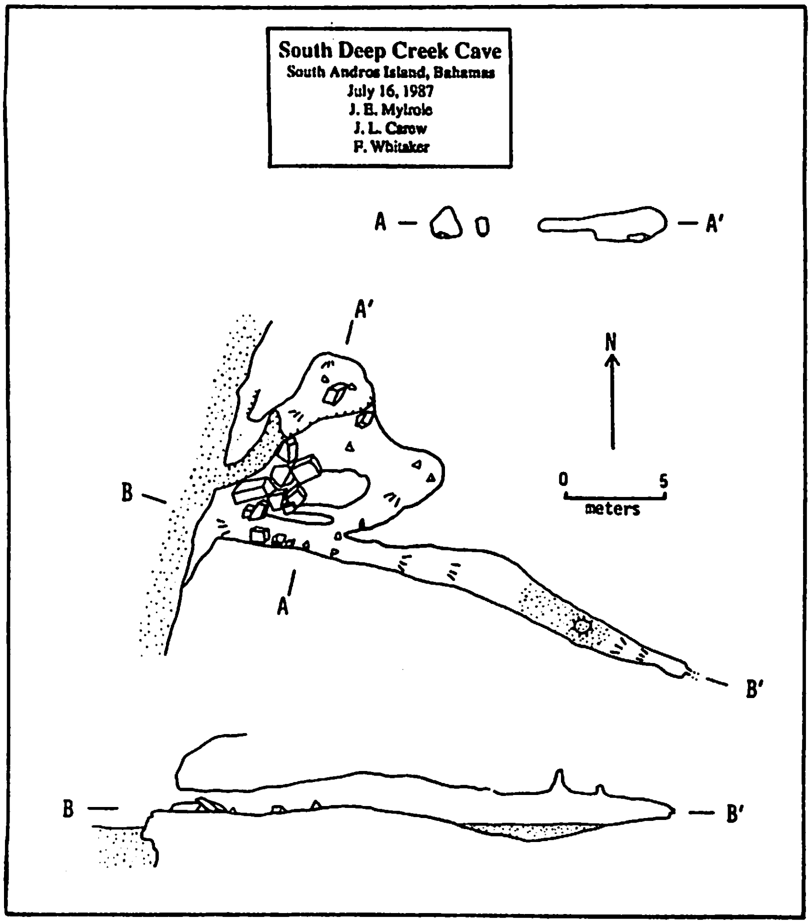

Fig. 4. Map and cross section of South Deep Creek Cave. This cave developed by solution along the margin of a freshwater lens where it mixed with sea water during a past sea level higher than at present. The rocks in which the cave is developed are believed to be 125,000 years old (oxygen isotope stage 5e). This requires that the cave developed on the regression of that sea level high, or during some later sea level high-stand that reached above current sea level. The cave is located on the south bank of Deep Creek where it cuts through the dune ridge system.

1973). All of these rocks can be assigned to the Grotto Beach Formation as defined on San Salvador (see Fig. 1), where U/Th and amino acid analyses yield ages of around 125,000 years (Carew & Mylroie, 1985, 1987). Like the Grotto Beach Formation on San Salvador the eolian facies are predominantly oolitic.

Only one paleosol is exposed on South Andros, and it is found to cap depositional as well as truncated bedding surfaces of Pleistocene rocks. The paleosol varies from a relatively thin brownish layered calcrete to better expressed paleosol and solution-filling remnants. As the rocks covered by the paleosol are believed to be Grotto Beach Formation, the paleosol represents the Pleistocene-Holocene transition, as shown on San Salvador (Carew and Mylroie, 1985).

The demonstrably oldest rocks seen on South Andros consist of an eolian ridge on High Cay (see Fig. 2) that was truncated to form a flat platform. On its eastern margin, fossil corals can be seen encrusted on this truncation surface, and both the dune and the corals are partially covered by a paleosol (Fig. 6). We suggest that this outcrop can be interpreted as follows. During the transgression of sea level associated with oxygen isotope substage 5e, oolitic dune ridges were built, among them High Cay. Continued rise in sea level truncated part of High Cay and then inundated the truncation platform on which the corals later grew. After sea level fell the paleosol developed on all exposed surfaces. The lack of a paleosol below the coral argues against an earlier origin (oxygen isotope stage 7) for the dune.

There are only a few fossil coral reef outcrops, but extrapolation among sites suggests the existence of a string of patch to bank-margin reefs developed along the eastern margin of South Andros during the Sangamon. Some of these now outcrop 2-3 m above sea level.

The bulk of the island below 5 to 6 m elevation comprises a suite of subtidal deposits consisting of ooid shoal and shallow lagoon deposits. In a few places these subtidal deposits can be seen to grade upward into beach and dune deposits.

The larger N-S trending eolian ridges are developed subparallel to the bank margin (see Fig. 2). Their relationship to other facies usually cannot be observed. We interpret these as deposits formed during transgression to the acme of the Sangamonian high stand when most of the

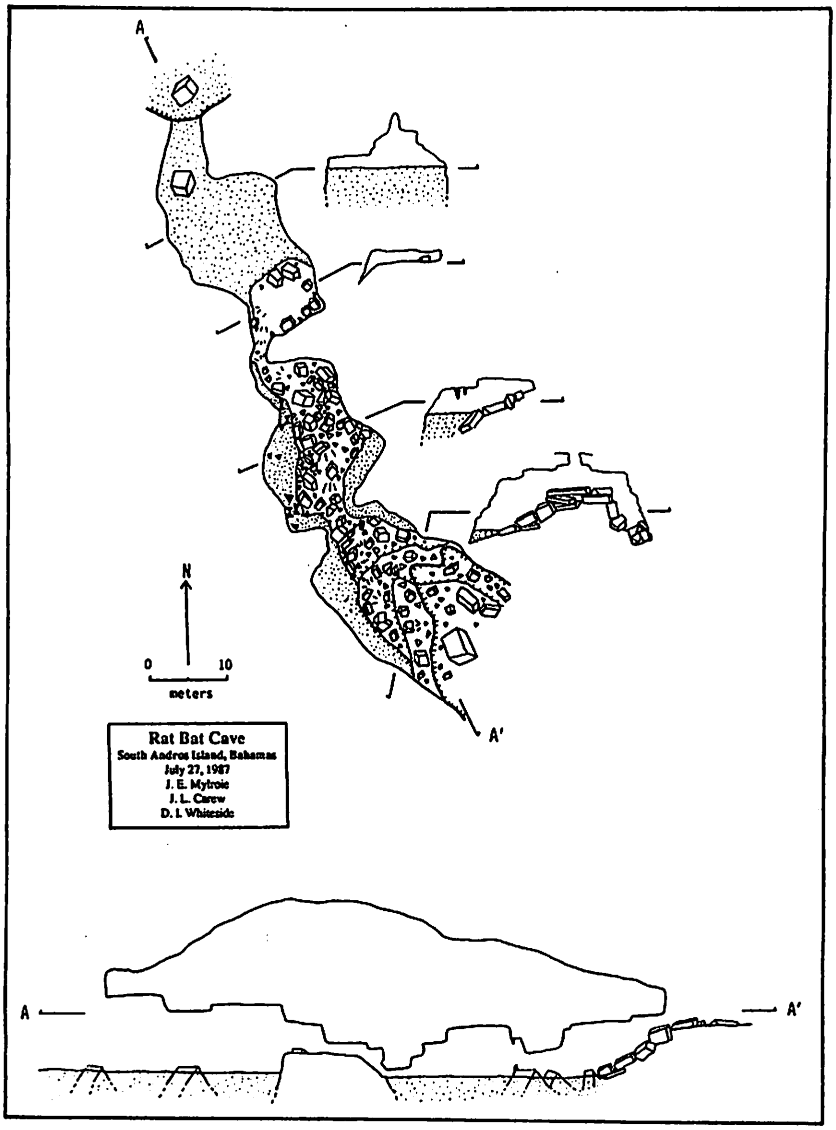

Fig. 5. Map and cross section of Ratbat Cave. This cave developed by upward collapse of a void at depth along a fracture zone. The cave exists where a dune ridge crosses the fracture zone. The dune ridge provided a roof to the fracture zone. This cave lies inland between The Bluff and Driggs Hill.

platform was flooded. These ridges may have been a series of cays at that time.

There are virtually no lithified Holocene rocks. This is in contrast to what is found on many other Bahamian islands (e.g. Great Inagua, Eleuthera, San Salvador, New Providence, etc.).

We note that our investigation of South Andros has yielded a geologic scenario that is remarkably similar to that found by Boardman & Bergstrand (1988) on North Andros.

The blue holes are primarily developed along a fracture system that lies sub-parallel to the eastern bank margin. The blue holes penetrate nearly 100 m down, and open to the surface through Pleistocene rocks assigned to the Grotto Beach Formation (circa 125,000 years old). The surface expression of the fracture zone is often graben-like.

The fractures are problematical as they occur in a supposedly tectonically stable area. Their development suggests a complex interaction between solutional process and perhaps gravity sliding of the platform edge into the Tongue of the Ocean.

The subaerial caves of South Andros fit models known from other carbonate islands. They are solution caves that developed during a higher sea level than exists at present. From their morphology and location, they fit the flank margin model of development (Mylroie, 1988). Additionally, there are stoping or collapse caves on South Andros. These were produced by upward progradation of a collapsing bedrock ceiling. These stoping caves are found associated with the graben-like fracture systems and their associated blue holes.

The flank margin solutional caves indicate that sea level had to be higher than at present on South Andros at a time after the deposition of the rock in which the caves are developed. As the

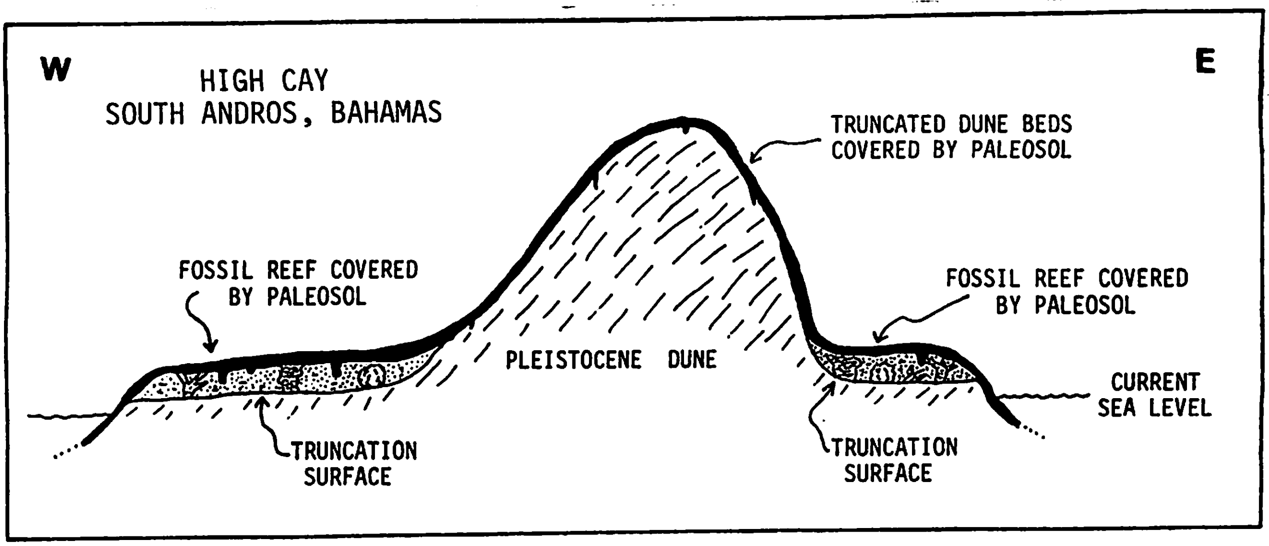

Fig. 6. Diagrammatic representation of the geology on High Cay. The truncation of the dune was followed by growth of coral at a higher sea level. All surfaces were subsequently modified by karst processes and paleosol development. The lack of a paleosol between the coral and the underlying dune suggests the dune was built on the Oxygen Isotope Stage 5e transgression, and subsequently notched by continued sea level rise. Coral then grew on the truncation surface. The truncation surface was formed by removal of some of the upper part of the dune by sea cliff retreat.

rock is believed to be 125,000 years old (oxygen isotope stage 5e), it implies that the caves developed in the dunes during the regression of the stage 5e highstand, or that a second high stand (oxygen isotope stage 5c, 5a or 3) produced the caves.

The surficial rocks of South Andros fit into the stratigraphy proposed by Carew and Mylroie (1985) for San Salvador Island (Fig. 1). Not all units exposed on San Salvador can be found exposed on South Andros. The Owl's Hole Formation and its associated paleosol were not observed on South Andros, in fact, no lower paleosol was seen. The Grotto Beach Formation is the dominant rock unit, and two members can be recognized. The French Bay Member can be seen on High Cay, as a transgressive dune cut and notched by the oxygen isotope Stage 5e highstand. The vast majority of South Andros is Cockburn Town Member subtidal and eolian carbonate facies. Cockburn Town Member facies rest on the truncated dune facies of the French Bay Member at High Cay. No Dixon Hill Member material (Stage 5a) was identifiable. The Holocene was remarkable for its paucity of lithified material, but what is present can only be generally categorized as Rice Bay Formation.

ACKNOWLEDGEMENTS

We thank the various individual and corporate sponsors of the Andros '87 Project, and the support of H.R.H. the Duke of Kent KG, for providing the funds and equipment necessary to undertake this international research expedition. Special thanks to: Ian Bishop for his whole hearted support and organization of this expedition, and his tireless good humor; Rob Palmer for leadership and drive to get the project off the ground; Neil Cave for companionship, entertainment and diving skill; and the Oxford Scientific and National Geographic film crew. A College of Charleston Faculty Research Grant provided additional funds for J. L. C. The Office of Research of Mississippi State University assisted J. E. M. Thanks to Joan Newell for word processing.

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