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Geology of Cat Island, Bahamas: A Field Trip Guide

John E. Mylroie
Mississippi State University

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

Deborah Freile
New Jersey City University

James L. Carew
College of Charleston

Neil E. Sealey
Media Enterprises, Ltd.

See next page for additional authors

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Authors

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13th Symposium on the Geology of the Bahamas
and Other Carbonate Regions

Gerace Research Center
San Salvador, Bahamas
2006

COVER PHOTO: The Hermitage on Mt Alvernia (Comer Hill), Cat Island, Bahamas. This eolianite ridge is the highest point in The Bahamas at 206 feet (63 m). The crest of the ridge is oolitic with some identifiable biolclasts. The story behind the building of the Hermitage is an interesting piece of Bahamian lore, and is discussed in the Stop 1 section of the field guide. Photo by John Mylroie.

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John E. Mylroie
Dept. of Geosciences
Mississippi State Univ.
Mississippi State, MS 39762

H. Allen Curran
Dept. of Geology
Smith College
Northampton, MA 01063

Deborah Freile
Dept. of Geoscience
New Jersey City Univ.
Jersey City, NJ 07305

James L. Carew
Dept. of Geology
College of Charleston
Charleston, SC 29424

Neil E. Sealey
Media Enterprises Ltd.
P.O. Box N-9240
Nassau, Bahamas

Vincent J. Voegeli
Gerace Research Center
San Salvador, Bahamas

The College of The Bahamas
Gerace Research Center
San Salvador, Bahamas

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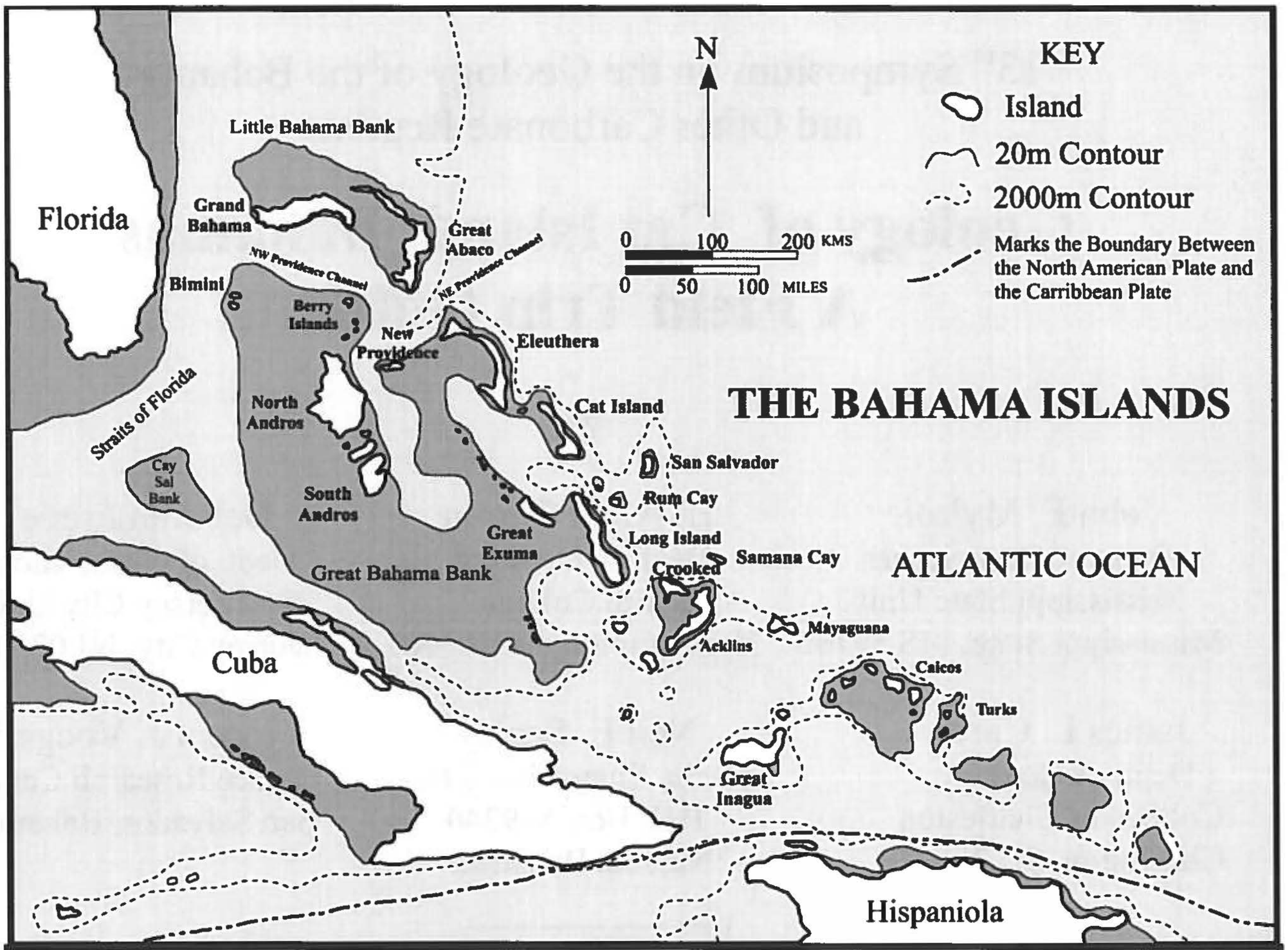


Figure 1. Index map for the Bahamian Archipelago, showing the locations of Cat Island and San Salvador Island (from Walker, 2006).

INTRODUCTION

The purpose of this field guide is to describe and illustrate some of the unique and interesting geological sites on Cat Island, Bahamas. Cat Island is one of the Bahamian "Family Islands" or "Out Islands," and it has a population of 1,634 inhabitants (Government of the Bahamas, 2000). The center of the island lies approximately 200 km east-southeast of Nassau, the capital city of the Bahamas, located on New Providence Island (Figure 1). Life on Cat Island is tranquil and community oriented. Cat Island was for centuries called "San Salvador" in belief that it was the first landing place of Christopher Columbus in the New World in 1492, but in 1926 the Very Reverend Chrysostom Schreiner succeeded in having the Bahamian Legislature bestow the honor on what was then Watling's Island (Albury, 1975). Cat Island supposedly obtained its name from the pirate, Arthur Catt (Popov and Popov, 1988), but others say it may be because of a horde of cats encountered by the English in the 1600's (Geographia, 2006). The island is recognized (Dupuch, 1989) as being one of the places where Obeah, native witchcraft or voodoo, is still practiced. The most famous alumnus of Cat Island is Sidney Poitier, an academy award-winning actor for "Lilies of the Field" in 1963. Monsignor John Hawes also left his imprint on the island in the first half of the 20th century (see more below).

At the beginning of the twentieth century Cat Island was one of the most populous Out Islands, 5000+ people in 1911. Only Eleuthera and Andros had more inhabitants (Government of the Bahamas, 2000), but flight from the island to New Providence and lack of major development has led to its present state of neglect and abandonment of properties. All the settlements visited during the field trip will exhibit abandoned houses, with Old Bight being the most extreme example.

Similar to Eleuthera Island to the north, and Long Island to the south, Cat Island is a narrow but elongate island, 80 km in length trending NNW to SSE (Figures 1 and 2) along the eastern margin of the Great Bahama Bank. It rests between the North Atlantic Ocean to the east and Exuma Sound to the west. The mid to late Quaternary all-carbonate geology of Cat Island is varied and spectacular, including the highest elevation in the Bahamas at 63 m. We hope that this field guide and trip will pique interest in the geology of Cat Island and serve as a catalyst for future geologic investigations over the greater extent of the island.

Many of the sites we will visit are on private or restricted lands and special permission is necessary for entry to some of these areas. For these reasons, it may not be possible for someone who is using a copy of this field guide at a later date to follow precisely in our footsteps. Last-minute changes owing to weather conditions or time constraints may result in our field trip taking alternate routes and visiting a slightly different selection of sites than presented in the text. We are guests on Cat Island, and all field trip participants are urged to treat the areas we visit with the utmost respect. It is illegal to undertake scientific research in the Bahamas without a government research permit.

PLEASE DO NOT MAKE SAMPLE COLLECTIONS AT ANY STOP WITHOUT ASKING THE FIELD TRIP LEADERS IN ADVANCE. WE REQUEST THE SAME RESPECT FOR PRESERVATION OF THESE GEOLOGIC SITES FROM ALL SUBSEQUENT USERS OF THIS GUIDEBOOK.

A section of the geology of the Bahamas, and a section on island karst processes, have been included in this field guide for those field trip participants who are unfamiliar with the Bahamas. Those sections follow immediately.

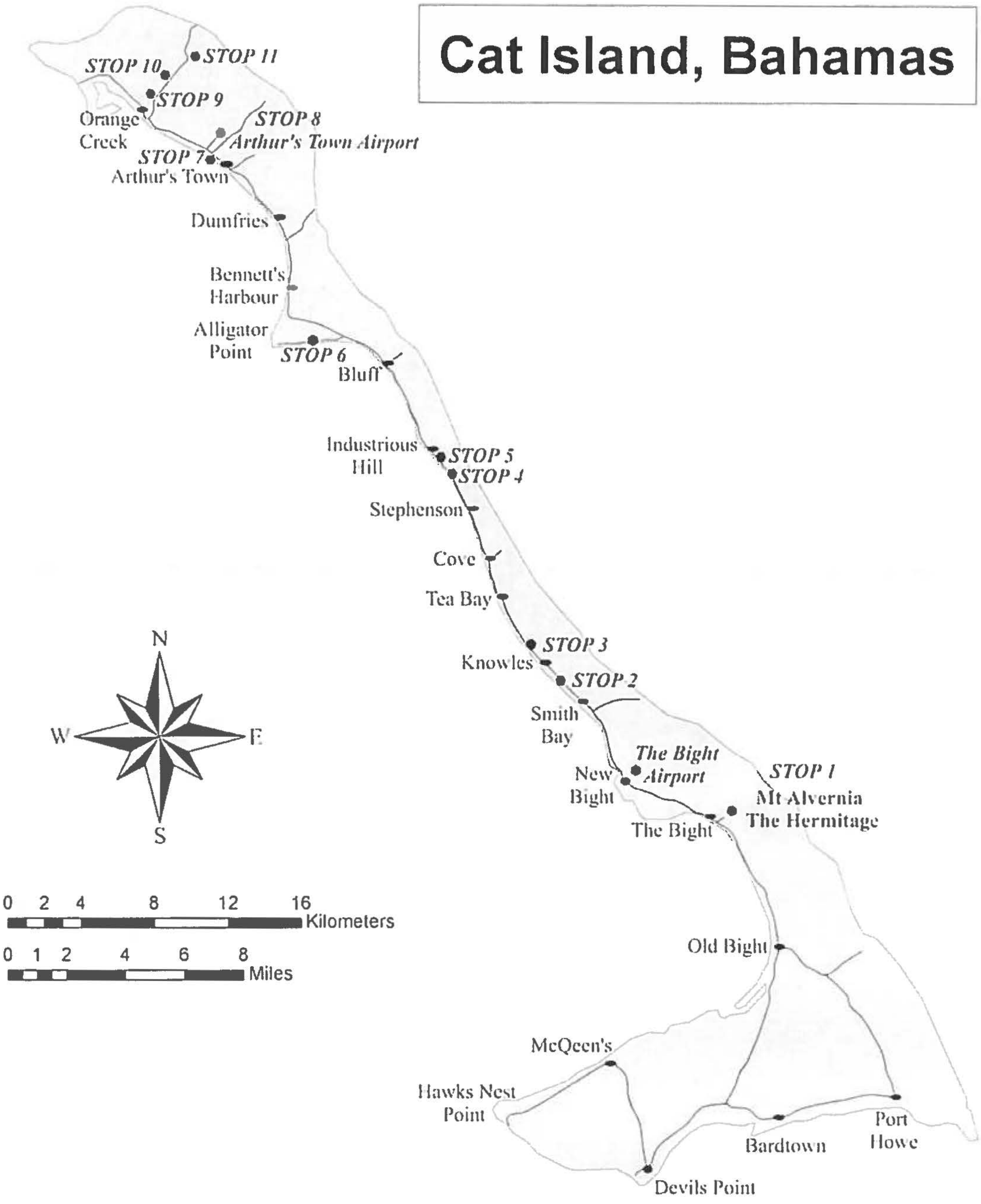


Figure 2. Map of Cat Island, Bahamas, showing field trip stops and major landmarks.

For all of you “old hands”, you can skip these sections and proceed directly to the field trip stop descriptions, to see what we turned up during our reconnaissance trip in February of this year. The official name for the country we are in is “The Bahamas”, but “Bahamas” will be used in this field guide, as experience has taught us readers get confused when “The” is used; they assume a new sentence has begun.

REGIONAL SETTING

The Bahama Islands comprise a 1,000 km long portion of a NW-SE trending archipelago that extends from Little Bahama Bank off the coast of Florida to Great Inagua Island, just off the coast of Cuba (Figure 1). The archipelago extends farther southeast as the Turks and Caicos Islands, a separate political entity, and terminates with Silver Bank and Navidad Bank. The northwestern Bahama islands are isolated landmasses that project above sea level from two large carbonate platforms, Little Bahama Bank and Great Bahama Bank. To the southeast, beginning in the area of San Salvador Island, the Bahamas comprise small isolated platforms capped by islands that cover a significant portion of the available platform area. The Bahamian platforms have been sites of carbonate deposition since at least Cretaceous time, resulting in a minimum sedimentary cover thickness of 5.4 km (Meyerhoff and Hatten, 1974) and perhaps as much as 10 km (Uchupi et al., 1971). The large platforms to the northwest are dissected by deep channels and troughs (Figure 1), whereas the isolated platforms of the southeastern Bahamas largely are surrounded by deep water. Water depths on the platforms are generally less than 10 meters.

The origin of the Bahama platforms has been the subject of much debate, from which two main theories have evolved. Mullins and Lynts (1977) proposed a "graben" hypothesis, which explains the current configuration of the Bahama Archipelago as the result of plate tectonic motion that produced the opening of the Atlantic Ocean in the Mesozoic. The pattern of banks, troughs and basins is explained as resulting from an initial horst and graben pattern consistent with continental rifting. The competing theory is the "megabank" hypothesis (Meyerhoff and Hatten, 1974; Sheridan et al., 1981; Ladd and Sheridan, 1987), which holds that the modern Bahamas are a segmented remnant of a much larger and continuous Mesozoic carbonate platform. Recent work by Eberli and Ginsberg (1987), Mullins and Hine (1989; 1990), Melim and Masaferro (1997), and Manfrino and Ginsberg (2001) has demonstrated that the Bahama banks are undergoing both depositional progradation and erosional segmentation.

The geologic literature on the Bahamas is extensive, but the bulk of that literature deals with the carbonate banks and related deep-water environments. With the exception of San Salvador, comparatively little work has been done on the subaerial geology of other Bahamian islands. The first modern geologic map of a Bahamian island was not published until Titus' work on San Salvador in 1980 (Titus, 1980). Hutto and Carew (1984) on San Salvador, Garrett and Gould (1984) on New Providence, Carew and Mylroie (1985) on San Salvador, Wilbur (1987; 1991) on Little San Salvador and West Plana Cay, Carew and Mylroie (1989a) on South Andros, and Kindler (1995) on Lee Stocking Island, represent some of the initial attempts to provide geologic descriptions of whole islands. A thorough overview of Bahamian island geology can be found in Curran and White (1995).

SUBAERIAL GEOLOGY OF THE BAHAMAS

The exposed rocks of The Bahamas are all mid to late Quaternary carbonates, dominated by eolianites and subtidal facies at low elevations and solely by eolianites at elevations above 8 m. Paleosols can occur at all elevations. The glacio-eustatic sea-level changes during Quaternary time alternately have flooded and exposed the Bahamian platforms, subjecting them to cycles of carbonate deposition and dissolution, respectively. Significant carbonate deposition has occurred in the past only when the platforms are flooded, as is increasingly the case today.

The carbonate sequences of the Bahamas can be viewed as individual packages deposited on each sea level highstand, separated by erosional unconformities (usually marked by paleosols) produced by each sea-level lowstand (Carew and Mylroie, 1995a; 1997). Each depositional package consists of three parts: a transgressive phase, a stillstand phase, and a regressive phase. These phases each contain a subtidal, intertidal, and eolianite component. Holocene sea level is sufficiently high so that the only marine deposits exposed on land today are those associated with the high stillstand phase of oxygen isotope substage 5e (OIS 5e), about 131,000 to 119,000 years ago (Chen et al., 1991). At its maximum, sea level was about 6 m higher than at present. The transgressive and regressive marine deposits of substage 5e are below modern sea level, and the stillstand subtidal deposits of sea-level highstands prior to those of substage 5e also are not visible. Given isostatic subsidence rates of 1-2 m per 100,000 years (Mullins and Lynts, 1977; Carew and Mylroie, 1995b), earlier highstands were either not high enough, as for stage 7, or if high enough, occurred too long ago, as for stage 9 and earlier, to have those subtidal deposits expressed above modern sea level. In contrast, eolianites form topographic highs that extend well above past and modern sea levels, so eolianites from numerous highstands, from the mid Pleistocene to the Holocene, are widely exposed on Bahamian islands.

During transgression, carbonate sediments are deposited when bank tops flood, and beach sediments are continually remobilized by the bulldozing action of the advancing sea. Large dunes are formed, which may be subsequently attacked by wave action as sea level continues to rise. Only the largest or most favorably positioned transgressive eolianites survive the rise of sea level to a maximum. During the stillstand of a sea-level high, subtidal and intertidal facies are deposited, but as the system reaches equilibrium, eolianite production is apparently less than during transgression. This decrease in eolianite production may be a response to reefs growing to wave base, and lagoons becoming more quiescent, such that sand supply to the beaches is reduced. During regression, stillstand subtidal lagoon deposits are reworked by wave base and beach processes, and substantial eolianite packages can be formed. These regressive eolianites are abandoned by falling sea level. As sea level moves off the platform, erosional forces take over and soils are produced that will eventually be preserved as paleosols. It is important to recognize that during the Quaternary, the Bahamas have been in a sea-level lowstand condition as a result of glacio-eustasy for about 85 to 90% of the time. The Quaternary carbonate units seen exposed in the Bahamas today represent deposition during that small fraction of the time when sea levels were high enough to flood the banks and turn on the carbonate sediment factory.

In the Bahamas, the most complete sequence of deposits representing a transgression, stillstand, and regression cycle is the depositional package formed during the OIS 5e event. Older packages are incomplete, for the reasons given earlier, and the Holocene package does not, as yet, contain a true regressive phase (although it does contain progradational regressive deposits). A general model for the development of the stratigraphy of Bahamian islands was first proposed by Carew and Mylroie in 1985. This model was developed using San Salvador Island as the specific example, but it has been successfully transported to other islands by Carew and Mylroie (1989b) and by other workers (Wilbur, 1987, 1991; Kindler, 1995). The model has been modified with the accumulation of new data (Carew and Mylroie, 1989b; 1991; 1995a; 1997). A stratigraphy developed from this model is presented in Figure 3, and it is the basis for the stratigraphic assignments and descriptions given in this field guide. This stratigraphy is based on field relationships, and does not require the use of geochronological tools, although it subsequently has been substantiated by a number of geochronologic methods (Carew and Mylroie, 1987). A spirited debate developed in the 1990s about Bahamian stratigraphy (see Carew and Mylroie, 1997, and references therein) centered on the reliability of amino acid racemization (AAR) analyses for making stratigraphic subdivisions in the absence of evidence provided by field relationships.

The eolianite packages older than OIS 5e were initially lumped together as the Owl's Hole Formation, although it was recognized at the time that this unit probably contained eolianites from a number of pre-substage 5e sea-level events (Carew and Mylroie, 1985). AAR data were subsequently used to subdivide the Owl's Hole into multiple units on San Salvador Island (Hearty and Kindler, 1993). While AAR data were considered controversial, it was later established on Eleuthera Island that subdivisions of the Owl's Hole could be demonstrated in the field (Kindler and Hearty, 1995; Panuska et al., 2002). Paleomagnetic analysis of the secular variation in paleosols also indicated that the Owl's Hole could be subdivided (Figure 3) into at least an upper and lower unit on San Salvador Island (Panuska et al., 1999). The eolianites of the Owl's Hole Formation are predominantly bioclastic, and ooids are extremely rare. The Owl's Hole Formation is usually recognized in the field by its relationship to overlying deposits. Efforts to subdivide units in the Bahamas by petrologic methods have been attempted (e.g. Kindler and Hearty, 1996; 1997), but demonstrated petrologic variability among single Pleistocene units, as well as in Holocene units, indicates that this technique is not reliable (e.g. Sparkman et al., 2001). Stop 6 on this field trip will provide a cautionary tale.

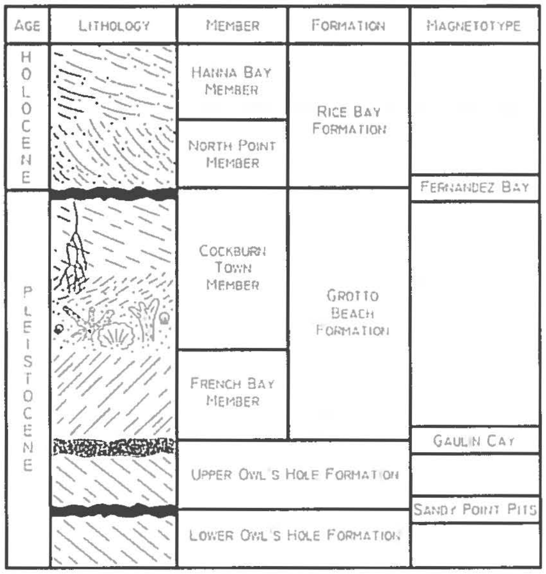


Figure 3. Stratigraphy of the Bahamas.

Overlying the Owl's Hole Formation, and separated from it by a paleosol or other erosion surface, is the Grotto Beach Formation. This formation was deposited during OIS 5e, and it consists of two members. The older French Bay Member is a transgressive eolianite (Carew and Mylroie, 1985; 1997). In some places, transgressive eolianites are marked by an erosional platform on which later stillstand fossil corals are found (Halley et al., 1991; Carew and Mylroie, 1995a). The Cockburn Town Member is a complex array of stillstand subtidal and intertidal facies overlain by regressive eolianites. In earlier versions of the Carew and Mylroie stratigraphic model (Carew and Mylroie, 1985; 1989b), the Grotto Beach Formation also contained the Dixon Hill Member, thought to represent an eolianite deposited during oxygen isotope substage 5a about 85,000 years ago. This member, based solely on amino acid racemization data, proved incorrect (Mirecki et al., 1993), and it was subsequently eliminated from the stratigraphy (Carew and Mylroie, 1995a; 1997). During Grotto Beach time, ooids were produced in great numbers, and the vast majority of eolianites in the Grotto Beach Formation are either oolitic or contain appreciable ooids.

Another debate concerning Bahamian geology involved the existence of OIS 5a eolianites (see Carew and Mylroie, 1997; Kindler and Hearty, 1997 and references therein). As noted above, AAR data were used to create a substage 5a eolian unit in 1985 (Carew and Mylroie, 1985), but that unit was dropped when field work demonstrated that the unit in question was older than substage 5e (Carew and Mylroie, 1997), and laboratory tests indicated use of the land snail Cerion for AAR work was extremely unreliable (Mirecki et al., 1993). However, use of whole rock AAR analysis was argued to avoid this problem and was used to identify substage 5a eolianites on a number of Bahamian islands (Kindler and Hearty, 1997 and references therein). No field evidence has been established to demonstrate, one way or the other, that substage 5a units exist in the Bahamas. However, AAR data have been used to identify substage 5a eolian units on Bermuda (Vacher and Hearty, 1989).

Overlying the Grotto Beach Formation and separated from it by a paleosol or other erosion surface are the rocks of the Rice Bay Formation, deposited during Holocene time. The Rice Bay Formation also is divided into two members, based on their depositional history relative to Holocene sea level. The North Point Member consists entirely of eolianites, whose foreset beds can be followed at least 2 m below modern sea level in some places. Whole rock carbon-14 measurements from the North Point Member indicate ages centered around 5,000 yBP (Carew and Mylroie, 1987). Laterally adjacent, but rarely in an overlying position, is the younger Hanna Bay Member (see Curran, et al., 2004 for an example of the Hanna Bay Member overlying the North Point Member). This unit consists of intertidal facies and eolianites deposited in equilibrium with modern sea level. The eolianites have a radiocarbon age centered around 3,000 yBP, but some beach rock has ages as young as 400 yBP (Carew and Mylroie, 1987). While weakly developed ooids have been reported from the early stages of North Point Member deposition (Carney and Boardman, 1991), the Rice Bay Formation exposures on San Salvador are predominantly peloidal and bioclastic. Cat Island has introduced new insights into the ooid question, as will be seen later. North Point Member rocks around the Bahamas are now being attacked by wave erosion. Sea caves, talus, and coral communities on wave-cut eolianite benches of the North Point Member exist, as mentioned earlier for the rock record of the transgressive French Bay Member of the Grotto Beach Formation.

FRESHWATER LENS HYDROLOGY AND KARST PROCESSES

In any essentially homogeneous body of rock like that of the carbonates forming the Bahamian islands, the freshwater lens floats on underlying, denser seawater that permeates the subsurface. The model for the ideal behavior of such water masses is the Ghyben-Herzberg-Dupuit model. In reality, variations in rock permeability and other factors result in distortion of the ideal lens shape in the Bahamas (e.g. Vacher and Bengtsson, 1989). Nonetheless, the Ghyben-Herzberg-Dupuit model serves as a useful first approximation of the relationship between the freshwater and underlying marine groundwater in an island.

During past higher stands of the sea, the fresh groundwater lens in each island was as high or higher than it is today. Beneath the surface of those past freshwater lenses, within the limestone rock of the islands, caves were produced by dissolution. Each time sea level fell, the caves became abandoned and dry. Under today's climatic conditions the Earth is warm and sea level is relatively high, but not quite as high as at some times in the past. We can therefore enter dry caves today throughout the Bahamas. In contrast, the blue holes of the Bahamas lead into caves that are flooded by seawater. These blue holes represent the cumulative dissolution and collapse that has occurred during many sea-level fluctuations. The complexity of cave passages found in blue holes is the result of overprinting of repeated marine, freshwater, and subaerial conditions throughout Quaternary time. Conversely, the presently dry caves of the Bahamas formed during the relatively short time periods of the late Pleistocene when sea level was higher than at present. Bahamian caves that formed above modern sea-level elevation prior to OIS 5e time today lie below modern sea level owing to isostatic subsidence of the platforms (Carew and Mylroie, 1995b); however some data can be marshaled that call this interpretation into question (Lascu, 2005). Taking isostatic subsidence into account, sea level was high enough to produce the observed subaerial caves for a maximum of about 12,000 years of the OIS 5e time period. In addition, during that sea-level highstand, only the eolian ridges and a few beach and shoal deposits stood above sea level, and island size in the Bahamas was dramatically reduced compared to that of today's islands. As a consequence, freshwater lens volumes and discharges were comparably reduced. An end result of this scenario is recognition that dry Bahamian caves seen today represent development during a very short time period within small freshwater lenses and with minimal overprinting by later events. Any model that attempts to explain development of these dissolutional caves must operate under these tight constraints of time and space.

The largest of these caves develop by mixing dissolution at the distal margin of the fresh water lens, under the flank of the enclosing landmass, so they are called *flank margin caves* (Mylroie and Carew, 1990). Abundant, but smaller caves develop at the top of the lens, away from the lens margin. In the Bahamas, they commonly develop in the broad, low-elevation regions that make up significant parts of these islands. As a result, their roofs are prone to collapse, and they are common features. Once collapsed, they collect soil and vegetative debris, as well as water and are favored for the growing of specialty crops, such as bananas, which is how their name, *banana hole*, was derived. We will see a classic flank margin cave at Stop 5, and a very problematic cave at Stop 1 that could be a banana hole (Harris, et al., 1995). The cave at Stop 11 (an alternate stop that time limitations will prevent us from visiting) is also a flank margin cave. Banana holes will be common and easily seen in the towns along the road near the airport at The Bight (Figure 2). Figure 4 is an idealized representation of the major karst features found in the Bahamas, excepting blue holes.

The Bahamas were the starting point for the development of what has become the Carbonate Island Karst Model (Jenson et al., 2006) or CIKM. The salient points of this model are shown in Table 1. The key aspects are that cave and karst development in

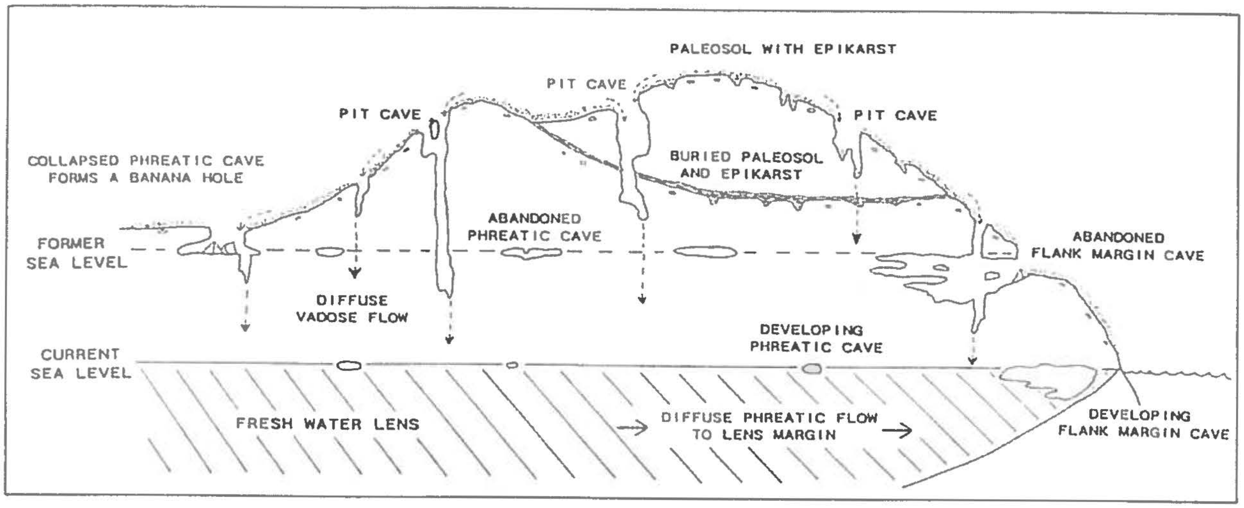


Figure 4. Cave and karst features commonly found on Bahamian islands.

carbonate islands is very different from that found in carbonate rocks of continental interiors, where most such research has been done. Basically, karst development under the CIKM is controlled by the youthful age of the rock involved (almost always Cenozoic, commonly Quaternary), the dissolutional aggressivity provided by mixing of freshwater and seawater, and the change in sea level created by glacio-eustasy and tectonics. Island configuration, especially as regards carbonate and non-carbonate rocks is also crucial. This last item has little meaning in The Bahamas, as these islands are 100% carbonates.

The youthfulness of Bahamian carbonate rocks creates different water-flow dynamics than are found in the dense, diagenetically-mature carbonates of continental interiors. The Bahamas exemplify what has been described as *eogenetic karst*, defined by Vacher and Mylroie (2002, p. 183) as "the land surface evolving on, and the pore system developing in, rocks undergoing eogenetic, meteoric diagenesis." The term "eogenetic" was taken from Choquette and Pray (1970, p. 215) who defined the three time-porosity stages of carbonate rock evolution: "the time of early burial as *eogenetic*, the time of deeper burial as

Table 1. Carbonate Island Karst Model

***Common attributes* that distinguish *island karst* from karst of interior settings**	***Distinct geomorphic types* that distinguish carbonate islands from one another**
The karst is *eogenetic*.	*Simple Carbonate Islands:* Non-carbonate rocks remain below the zone of fresh-water influence, and recharge is exclusively autogenic. (Fig. 1a)
Dissolution is enhanced at the surface, bottom, and margin of the freshwater lens by mixing of waters and trapping of organic materials at these boundaries.	*Carbonate Cover Islands:* Non-carbonate basement rocks deflect percolating water and partition the fresh-water lens. (Fig. 1b)
Glacio-eustatic sea-level fluctuations impose dissolutional and diagenetic imprints reflecting the vertical migration of the lens.	*Composite Islands:* Non-carbonate basement exposed at the surface, and allogenic recharge is delivered to insurgences on the contacts. (Fig. 1c)
Tectonic uplift and subsidence overprints the glacio-eustatic imprints with additional dissolutional and diagenetic imprints, as well as structural modifications	*Complex Islands:* Interfingering of carbonate/non-carbonate facies and faulting combine to produce complex aquifer features. (Fig. 1d)

mesogenetic, and the late stage associated with long-buried carbonates as *telogenetic*." Eogenetic carbonate rocks have not been extensively compacted or cemented and retain much of their primary depositional porosity. Most carbonate islands, and almost all carbonate islands found in tropical or subtropical locations, are made up of eogenetic limestones (Late Cenozoic) that were deposited proximal to the setting in which they presently occur. The term eogenetic karren has been applied to the unique etching and dissolution of surface carbonates on carbonate islands and coasts (Taborosi et al., 2004), which encompasses interior forms as well as the traditional coastal "phytokarst" of Folk, et al. (1973). Taborosi et al. (2004) also review the various terms and mechanisms proposed over the years to describe and explain such karren, providing updated interpretations. Island karst has been defined as that which forms under the constraints of the CIKM, whereas karst that develops in the interior of islands, removed from CIKM controls, is karst on islands (Vacher and Mylroie, 2002). For example, the caves and karst found in the Bahamas is island karst, but the cockpit karst of Jamaica, or the Mogote karst of Cuba and Puerto Rico, is karst on islands, as it differs little from what would be found in a tropical, continental interior karst.

A famous karst feature of the Bahamas is the blue hole. The term "blue hole" has been used in a variety of ways. A complete review of the history of blue hole studies, and the various uses of the term, can be found in Mylroie, et al. (1995). A different approach to defining and describing blue holes can be found in Schwabe and Carew (2006). Blue holes are defined here as: "subsurface voids that are developed in carbonate banks and islands; are open to the earth's surface; contain tidally-influenced waters of fresh, marine, or mixed chemistry; extend below sea level for a majority of their depth; and may provide access to submerged cave passages." (Mylroie, et al. 1995, p. 225). Blue holes are found in two settings: "ocean holes open directly into the present marine environment and contain marine water, usually with tidal flow; inland blue holes are isolated by present topography from marine conditions, and open directly onto the land surface or into an isolated pond or lake, and contain tidally-influenced water of a variety of chemistries from fresh to marine" (Mylroie et al., 1995, p. 225). The most common alternative use of the term "blue hole" is to describe large and deep karst springs in continental interiors (Mylroie et al., 1995).

In the northwestern Bahamas, blue holes with depths in the 100-125 m range are common, and it was thought that their depth was limited by the position of the lowest glacial sea-level lowstand, which was about 125 m below present sea level. However, exploratory wells commonly intersect voids below that depth (e.g. depths of 21 to 4082 m; the deepest of these voids was large enough to accept 2,430 m of broken drill pipe [Meyerhoff and Hatten, 1974]). Dean's Blue Hole on Long Island is known to be over 200 m deep, ending in a vast chamber (Wilson, 1994). Blue holes commonly lead into major horizontal cave systems, such as Lucayan Caverns on Grand Bahama Island, and Conch Blue Hole on North Andros Island. This field trip has alternate sites (Stops 9 and 10) that demonstrate two very different types of blue holes, but time limitations will likely prevent visitation. Blue holes are common on the island. The most complete study of blue holes to date on Cat Island is that by Palmer et al. (1986).

GEOLOGY OF CAT ISLAND

The geology of Cat Island is almost unknown, because little work has been done here. The work of Lind (1969), one of the rare papers on

Cat Island geology, presented a broad overview of the coastal landforms of the Bahamas.. Field work in January of 1985 was conducted to do a preliminary assessment of the cave resources of the island (Palmer, 1986; Palmer et al., 1986). The field trip presented here, based on four days of work conducted by six geologists authoring this field guide, represents a step forward for Cat Island geology. As this group barely scratched the surface, the potential for significant geological discoveries remains.

The stratigraphy seen on Cat Island appears to follow the general pattern of other Bahamian Islands that have received more study. This field guide is the first published use of a Bahamian geologic model on Cat Island. The Rice Bay Formation is abundantly present along the west coast of the island. These rocks fall primarily into the Hanna Bay Member (Stops 2 and 6), but outcrops of the North Point Member are also present (lunch stop and possibly Stop 6 as well). The Rice Bay Formation/Grotto Beach Formation contact will be visible at Stop 2. Cockburn Town Member rocks of the Grotto Beach Formation will be seen at Stop 4, however it is indeterminate at this time if the underlying eolianites present here are French Bay Member rocks of the Grotto Beach Formation, or Owl's Hole Formation rocks. Stop 1 will display a very unusual karst feature, and Stop 5 will visit a flank margin cave. Stop 3 will investigate the problems of sea walls and coastal erosion. Stop 6 will explore the Holocene deposits of Alligator Point. Stop 7 will investigate cementation in the present-day beach environment, and Stop 8 will present a problematic subtidal/intertidal outcrop. Stops 9, 10, and 11 are included with the optimistic hope that time may be available to visit those locations (most likely not). A brief half-day field trip simply cannot cover the geology of the entire island, but we think that the stops selected for this trip do offer a representative overview of the Quaternary geology of Cat Island. Furthermore, we hope that these stops will spur comment and discussion and will demonstrate how the stratigraphic model presented earlier can be applied to Cat Island.

Areas that we visited in February, but were not logistically feasible for a half-day field trip, contain more information. At numerous locations along the east coast of Cat Island, fossil corals, molluscs and other subtidal deposits are common (Figure 5). The fossils are above modern sea level, and terra rossa paleosol covers many of these outcrops, indicating the rocks are Cockburn Town Member of the Grotto Beach Formation. In a road cut on the highway from The Bight to Port Howe (Figure 2), trending bottom to top, an eolianite-paleosol-eolianite-paleosol sequence can be seen (Figure 6). The lower eolianite also contains a calcarenite protosol. Such a sequence indicates that the lower unit must be Owl's Hole Formation. The upper eolianite, as it is beneath a terra rossa paleosol, must be Pleistocene in age. Without a measurement that can accurately identify the top unit, it could be Grotto Beach Formation or an upper unit of the Owl's Hole Formation. In any event, the sequence is the clearest proof yet that Owl's Hole rocks are present on Cat Island.

FIELD TRIP

As vehicle odometers are in miles, and the local topographic maps are in feet for elevations, those units are used in this field guide, with metric equivalents where necessary, for distances and elevations. For standard scientific values (such as sea level elevations and depths), metric units alone will be used. The topographic maps have a 1 km grid and dual scale bars.

The field trip begins at The Bight airport (TBI) in southern Cat Island, at 24°18' 47.4", 75 ° 27'31.0". From the airport, head south 3.4 miles on the main island highway into New

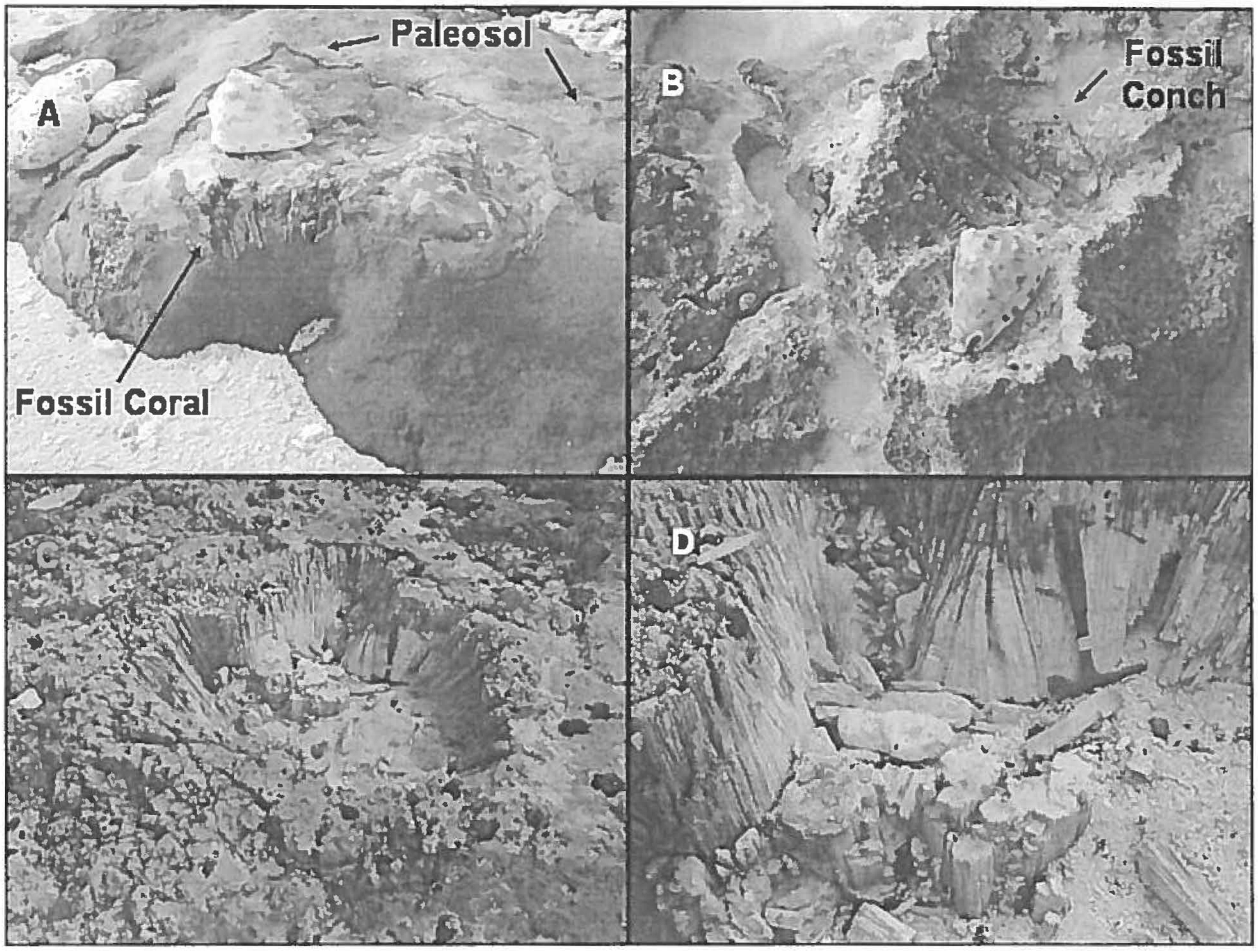


Figure 5. Outcrops of subtidal facies on the east side of Cat Island. A) Fossil coral covered by paleosol. Modern helmet conch is 12 cm long for scale. B) Fossil conch, *Strombus gigas*, and fossil coral fragments. Modern helmet conch is 12 cm long for scale. C) Large fossilized Monastrea coral head. Rock hammer for scale. D) Close up of Figure 5C, showing columnar nature of the fossil coral. Rock hammer for scale.

Bight Settlement, turning left (east) on the road marked to the Hermitage. After 0.6 miles, park in the Hermitage parking lot (24°17'36.1", 75°24'35.0") at the base of a high hill, Comer Hill, now called Mount Alvernia. This is Stop 1.

STOP 1 - MT ALVERNIA.

Leave the vehicles and take the trail that starts under the arch (Figure 7). The trail rises steeply up the hill, past numerous carvings and sculptures depicting the 14 Stations of the Cross (Figure 8). A trail up a gentler slope can be taken to the left that loops around to the rear of the buildings on the hill crest. The steep trail will end by passing though a second arch and into the grounds of the Hermitage (Cover Photo and Figure 9). The following history is encapsulated from Anson (1957), Evans (1984), and Taylor (2000).

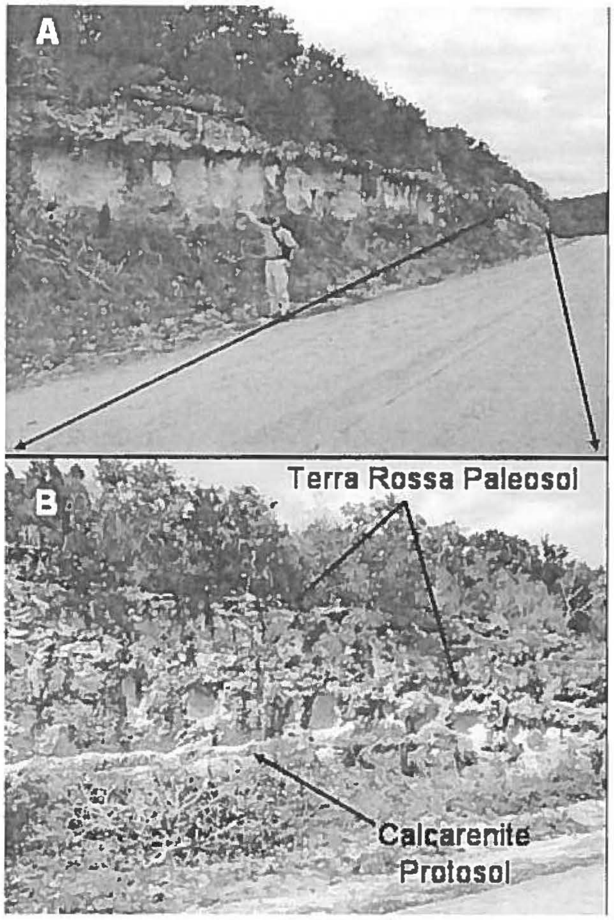


Figure 6. Road cut north of Port Howe. A) Overview of road cut. B) Close up of the north end of the road cut, showing, from bottom to top: eolianite, calcarenite protosol, eolianite, terra rossa paleosol, eolianite, terra rossa paleosol. The sequence indicates, that at the most conservative, the lower eolianite-calcarenite protosol-eolianite portion of the sequence is Owl's Hole Formation.

Monsignor John Hawes, Father Jerome, the Hermit of Cat Island, and his Hermitage.

John Hawes (1876-1956) was an Anglican priest who came to the Bahamas in 1909, and after a brief stay converted to Roman Catholicism. He spent most of the next 40 years in Western Australia but then returned to the Bahamas in 1939, where he stayed until his death. During this latter period he increasingly sought the Franciscan life of penury and solitude, and to this end built the Hermitage, which was his final home.

Throughout his life Hawes was in demand as a church architect, a calling for which he was both professionally trained and temperamentally suited. His talents included every aspect of construction from mixing mortar to carving figures and painting altars. One of his first buildings was the Anglican church of St. Paul's in Clarence Town, Long Island, which town was later to be the site for his Roman Catholic church of St Peter and St Paul (in 1946). Today these two churches dominate the Long Island skyline.

Hawes settled on Cat Island and quickly identified Mount Coma (Comer Hill on the topographic map), which he renamed Mt Alvernia, as the site for his hermitage. Work started in 1940 and was essentially finished a year later. All the detail are Hawes', including the 14 Stations of the Cross (Figures 7 and 8), which were handcrafted by Hawes himself.

Hawes built churches, chapels or residences at Freetown, Port Howe, Bain Town, and Old Bight on Cat Island; and at Mortimer's, Dunmore, and Clarence Town on Long Island. There were many other buildings including a church on Bimini and much of St Augustine's Abbey and School in Nassau.

The Hermitage

Mount Alvernia is the highest hill in the Bahamas at 206 feet (63 m), and provides striking views across the island. It is also remarkable in having a large cave at about 180 feet (55 m) above msl, which Hawes used to sleep in while he built the Hermitage (Figure 10 and 11). He named the cave St Francis' Grotto, erected an altar in it, and said mass there. A smaller cave some 20 feet long (6 m)

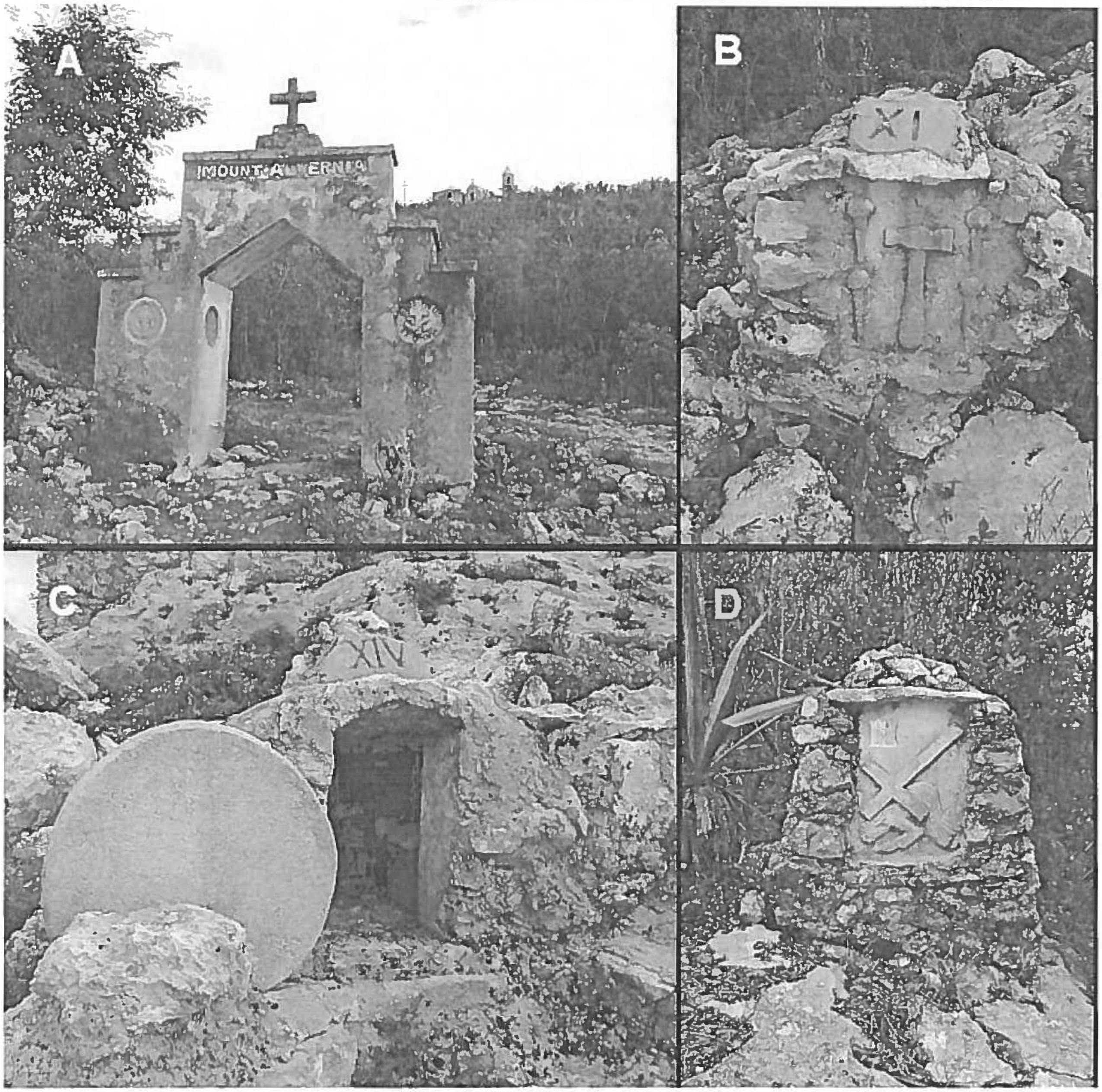


Figure 7. Selected features on the trail to the Hermitage. A) Arch at the beginning of the trail. B) Position 11 (XI). C) Position 14 (XIV), the tomb. D) Position 3 (III).

near the top of the path to the Hermitage was chosen as his burial cave (Figures 9C and 12). A benchmark (Figure 9B) marks the high point.

For Hawes the construction of the steps up the hill and the placing and design of the fourteen Stations of the Cross were an integral part of the construction of the Hermitage. The buildings of the Hermitage form a tight complex at the summit of the hill (Cover Photo and Figure 8), with a separate original kitchen located to the east which is still intact. He also built a sundial, which was stolen, but luckily recovered and replaced where it stands today. Unfortunately it

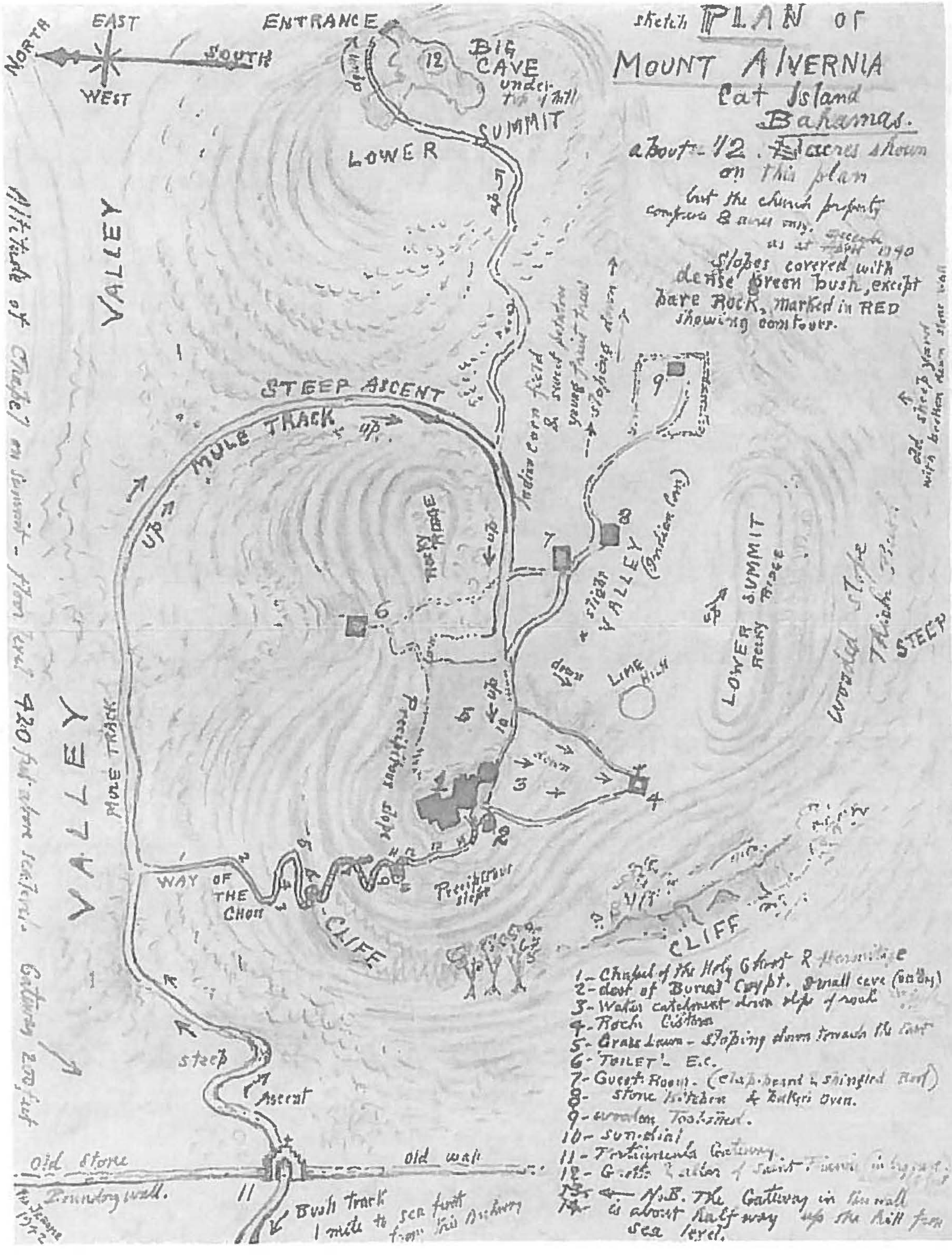


Figure 8. Map of Mt Alvernia by John Hawes. Note the “Way of the Cross” trail, the “Mule Track” swinging around to the north, then east and south into the Hermitage. The “Burial Crypt” is numbered “2”, and the “Big Cave” is numbered “12”. Reproduced from Taylor (2000).

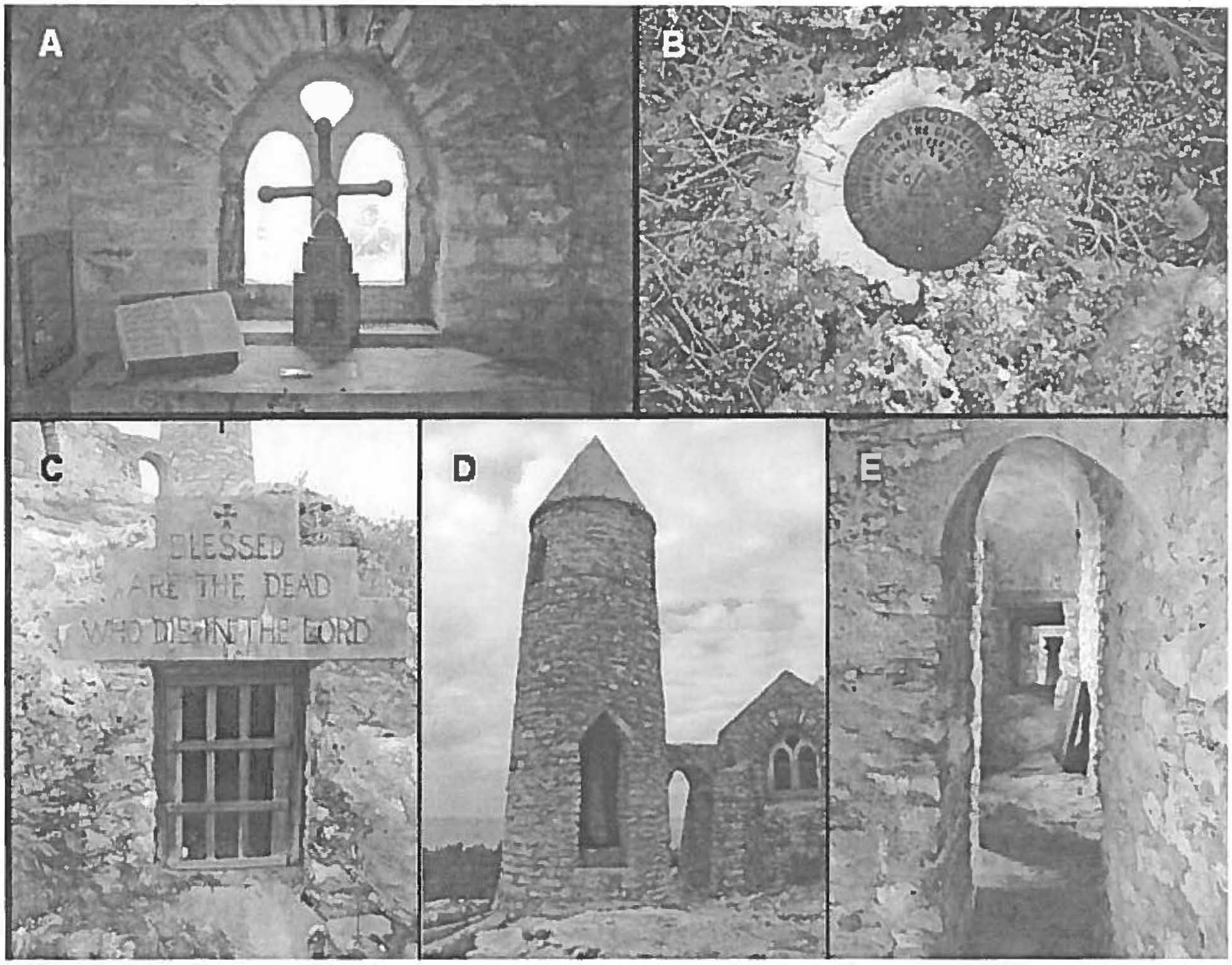


Figure 9. Features of the Hermitage. A) The chapel. B) The benchmark at the 206 foot elevation. C) The burial cave of Father Jerome (John Hawes), which may be a natural cave. D) The bell tower. E) Inner passage connecting the cell to the sanctuary.

was placed the wrong way round when being reattached.

The buildings of the Hermitage comprise from the south going north:

- The Angelus Tower
- The Church of the Holy Spirit, or Oratory

The Hermitage proper, including the

- Cell (bedroom),
- Kitchen,
- Cloister,
- And Guest Cell, the most northern building.

An important feature of the buildings reflects Hawes' long fight against leaks and termites, which is the avoidance of lumber in construction as much as possible. To this end many of his roofs are arches or domes made of concrete, and consequently heavily buttressed. Visitors will realize that Hawes abhorred unnecessary adornment and he frequently stated how he sought a simple and economical style. Architecturally his structures were more or less Gothic, but as Hawes wrote :

"'*Stylemongering' is to be shunned, and the architecture should be reminiscent without pedantry, and varied without being freakish.*"

"To fulfill its purpose a church must be devotional, he cared not what or how debased the style might be, as long as it had an interior that would be an aid to people to pray." (quoted in Taylor 2000).

The other feature is the deceptively small scale of the buildings. Hawes was building a miniature monastery for his reclusive lifestyle, and scaled everything down to the minimum size necessary for his acetic life. He recorded many times how he suffered from cold and drafts in his cell (bedroom).

In 1956 his body was shipped to Cat Island and buried in his cave as he requested (Figures 9C and 12), without a coffin and in his grey Franciscan habit. He body lies at the end of the burial cave approximately under the oratory.

The Geology of Mount Alvernia

Mount Alvernia has two important geological implications. First, it is the highest point in the Bahamas at 206 feet (63 m, Figure 9B). It has been claimed in some advertising brochures that Long Island has the highest point, but examination of maps shows that the highest point on Long Island does not reach above 185 feet. The hill immediately behind Mount Alvernia also shows a 200 foot contour line, as does Aaron Hill, 1.3 miles (2 km) to the southeast. At least two other ridges in the area show a 175 foot contour, and at the far north of the island, hills reach over 160 feet (49 m). So Mount Alvernia, while the highest point, is surrounded by elevations uncommonly high for

Figure 10. Drawing of the "Big Cave" of Figure 8, labeled here as "St Francis Grotto". Compare to the images in Figure 11; the salient phreatic morphology of the cave is faithfully reproduced. Also note the crab, rat and lizard depictions, common inhabitants of Bahamian caves. Reproduced from Taylor (2000).

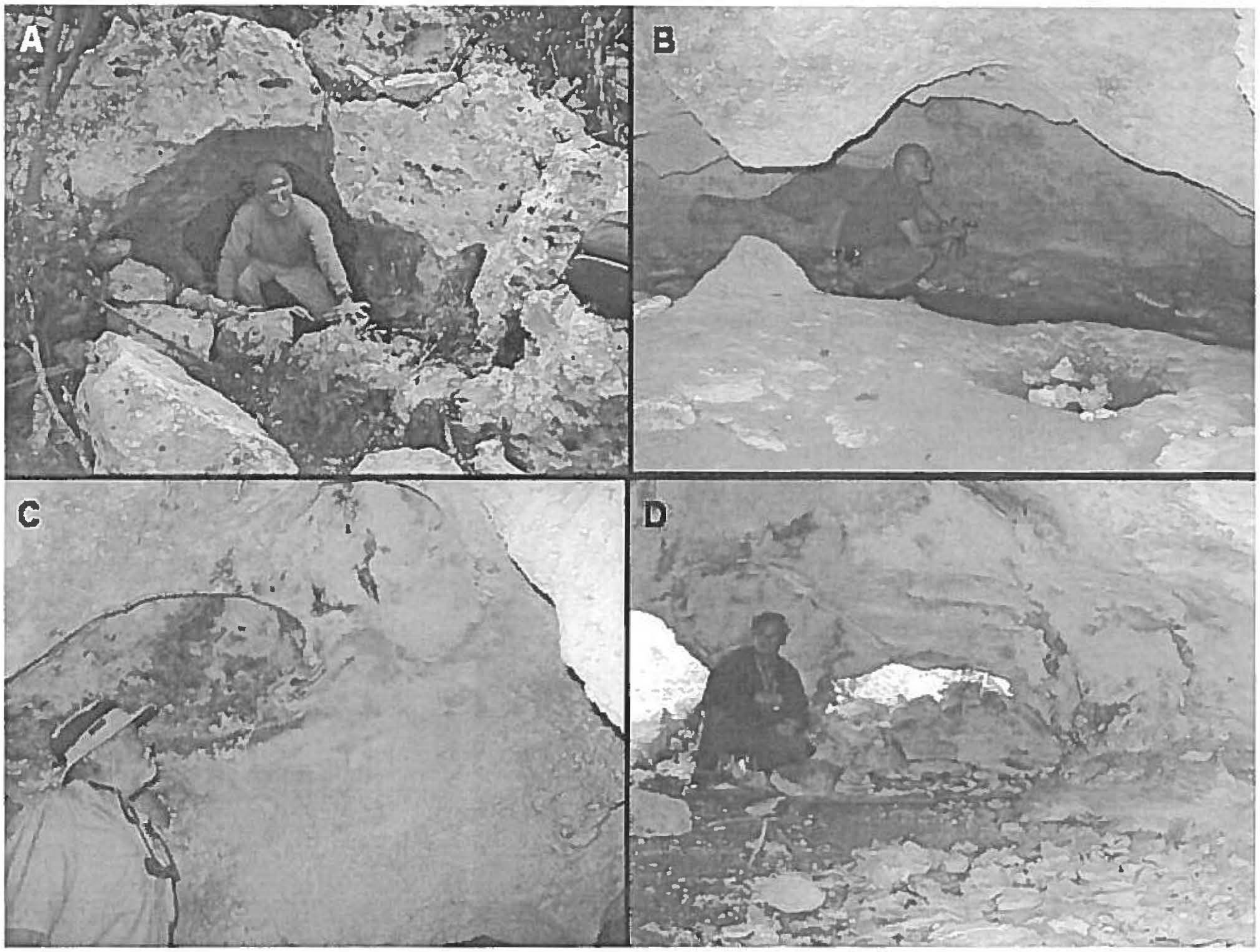
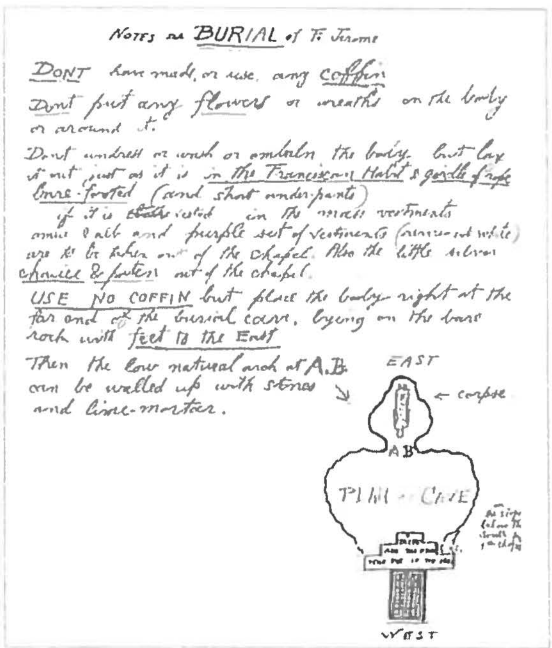


Figure 11. Cave on the eastern side of Mt Alvernia. A) Main entrance to the cave. B) Curvilinear walls, ceiling and floor, indicative of phreatic dissolution. C) Bell holes in cave ceiling, another possible indicator of phreatic dissolution. D) Looking towards the entrance, which was created by erosional retreat of the hillside.

the Bahamas as a whole. The ability of wind to pile carbonate sands over 200 feet (60 m) in elevation is itself noteworthy. What is not known at this location is if the hill represents a single depositional event, or a series of eolian on-lapping events from separate sea-level highstands. Such on-lapping can be seen on San Salvador (Sparkman et al., 2001) or Eleuthera (Panuska, et al., 2002). A cursory examination of the hillslope on the west side of Mount Alvernia did not reveal any obvious terra rossa paleosols that would indicate multiple episodes of eolian deposition over several sea-level highstands, but paleosols are notoriously difficult to recognize on weathered, unbreached surfaces.

The second major geologic feature is the caves. The first cave, the Burial Cave, is encountered at the top of the climb, before and to the right (south) of the archway into the Hermitage courtyard. It has a wooden grate across the low entrance (Figures 9C and 12). What can be seen of the cave's interior indicates that it has a phreatic dissolutional pattern, but the walls are highly weathered. The entrance is too small to have allowed excavation of the interior by eolian and related processes, such as tafoni caves as discussed for the Bahamas by Walker (2006). The historical record would indicate that the cave is natural, but there exists the possibility that it was artificially excavated. The wall blocking the innermost chamber can be discerned through the gate. The inability to enter the cave and observe all the cave features closely limits what can be speculated about the cave's origin. A small dissolution pocket exists above the cave. But there is more to the story.



Notes on BURIAL of F. Jerome

DONT have made, or use, any coffin

Dont put any flowers or wreaths on the body or around it.

Dont undress or wash or embalm the body. but lay it out just as it is in the Franciscan Habit & girdle of rope bare-footed (and short under-pants)

if it is [illegible] vested in the mass vestments [illegible] alb and purple set of vestments (amice and white) are to be taken out of the chapel. Also the little silver chalice & paten out of the chapel.

USE NO COFFIN but place the body right at the far end of the burial cave, lying on the bare rock with feet to the East

Then the low natural arch at A.B. can be walled up with stones and lime-mortar.

Figure 12. Map of the Burial Cave, with instructions by Father Jerome on how his body should be interred. The term "natural arch" suggests that this cave, as with the "Big Cave", is a product of phreatic dissolution. Reproduced from Taylor (2000).

From the Hermitage courtyard, a trail leads east across a low saddle and around the north side of the adjoining 200-foot high hill (figure 8). The trail ends at the cave entrance for Big Cave (Figure 8), also called St. Francis Grotto (Figure 10), not far below the crest of this second hill. The entrance faces east (Figure 11A) and leads into a small but somewhat spacious cave. The cave, as noted earlier, was used by Father Jerome prior to completion of the Hermitage (Figure 10). This cave demonstrates all the features commonly associated with phreatic (sub-watertable) processes: bell holes in the ceiling, wall pockets, bedrock spans and pillars, and curvilinear walls (Figure 11B and 11C). Elsewhere in the Bahamas, such caves are only found within 6 to 7 m of current sea level, as they are believed to have formed in the fresh-water lens elevated by the OIS 5e sea-level highstand (Carew and Mylroie 1995b). These phreatic dissolutional caves, flank margin caves and banana holes, are common on almost all Bahamian islands, but not above 6 to 7 m elevation. While the Burial Cave is problematic and argumentative concerning its origin, the larger, and enterable, Big Cave clearly indicates phreatic development at an elevation of approximately 180 feet (55 m). Assuming tectonic stability, to place the fresh-water lens at this height would require a Quaternary sea-level rise not recorded in the Bahamas or anywhere in the world. As with the Burial Cave, the relatively small entrance and the phreatic indicators of Big Cave rule out a pseudokarst origin, such as a tafoni cave or a sea cave. There remain some possible explanations.

First, the cave could be a result of vadose activity, similar to pit caves found throughout the Bahamas. To do so requires a massive reinterpretation by many karst geologists of the diagnostic features currently associated with phreatic dissolution. A second alternative explanation is that the cave is the result of dissolution within a fresh-water body perched on a dense, micritic terra rossa paleosol. Such an interpretation requires that the Mount Alvernia dune be a composite dune, that is, one formed by multiple sea-level highstand depositional events, separated by long sea-level lowstand events during which paleosols formed. The paleosol would need to have formed with a basin-like configuration, so as to retain water after a second eolianite was deposited over the basin. This perched water table would have been able to dissolve banana hole caves, primarily by the mixing of descending vadose water and the phreatic water of the water table. Oxidation of organics could also have assisted this dissolution. As with observations on the west side of Mount Alvernia, a cursory inspection of the land area around the cave did not locate an obvious paleosol, so the veracity of the "banana hole" interpretation is not established. Two rock samples, taken on the surface from just south of the cave entrance, are primarily oolitic, with identifiable bioclasts. To paraphrase a reviewer of an early paper that Jim Carew and John Mylroie once submitted, "if true, these data are a veritable anvil on the railroad tracks of island karst progress".

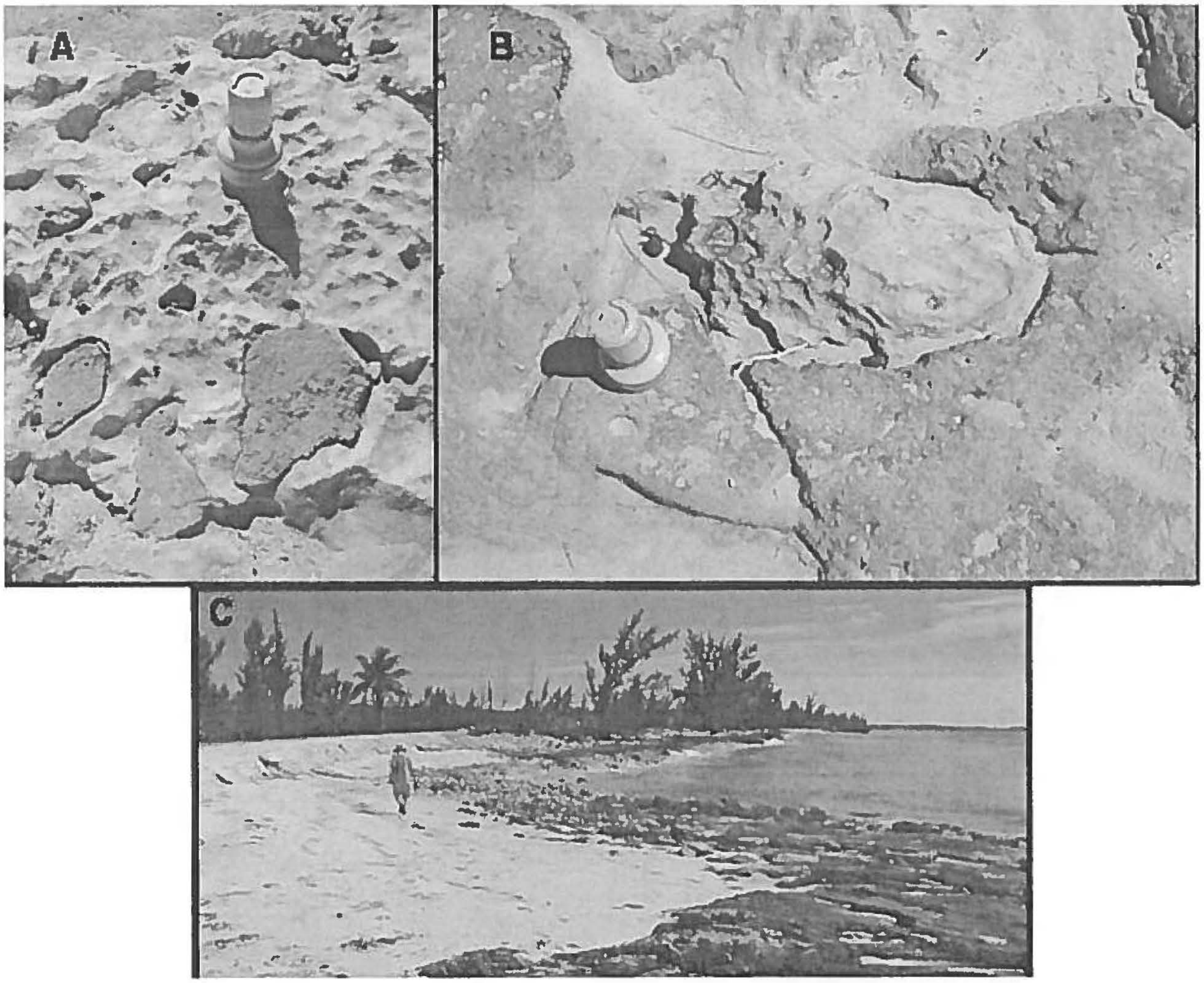


Figure 13. Holocene/Pleistocene contact. A) Holocene Hanna Bay Member beach sands resting in pockets on the terra rossa paleosol covering the underlying Pleistocene Cockburn Town Member calcarenite. Flashlight is 12 cm long for scale. B) Same stratigraphy and scale as in (B), but with the paleosol protruding up through the Holocene cover. C) Overview, looking south past the person, of the outcrops shown in (A) and (B).

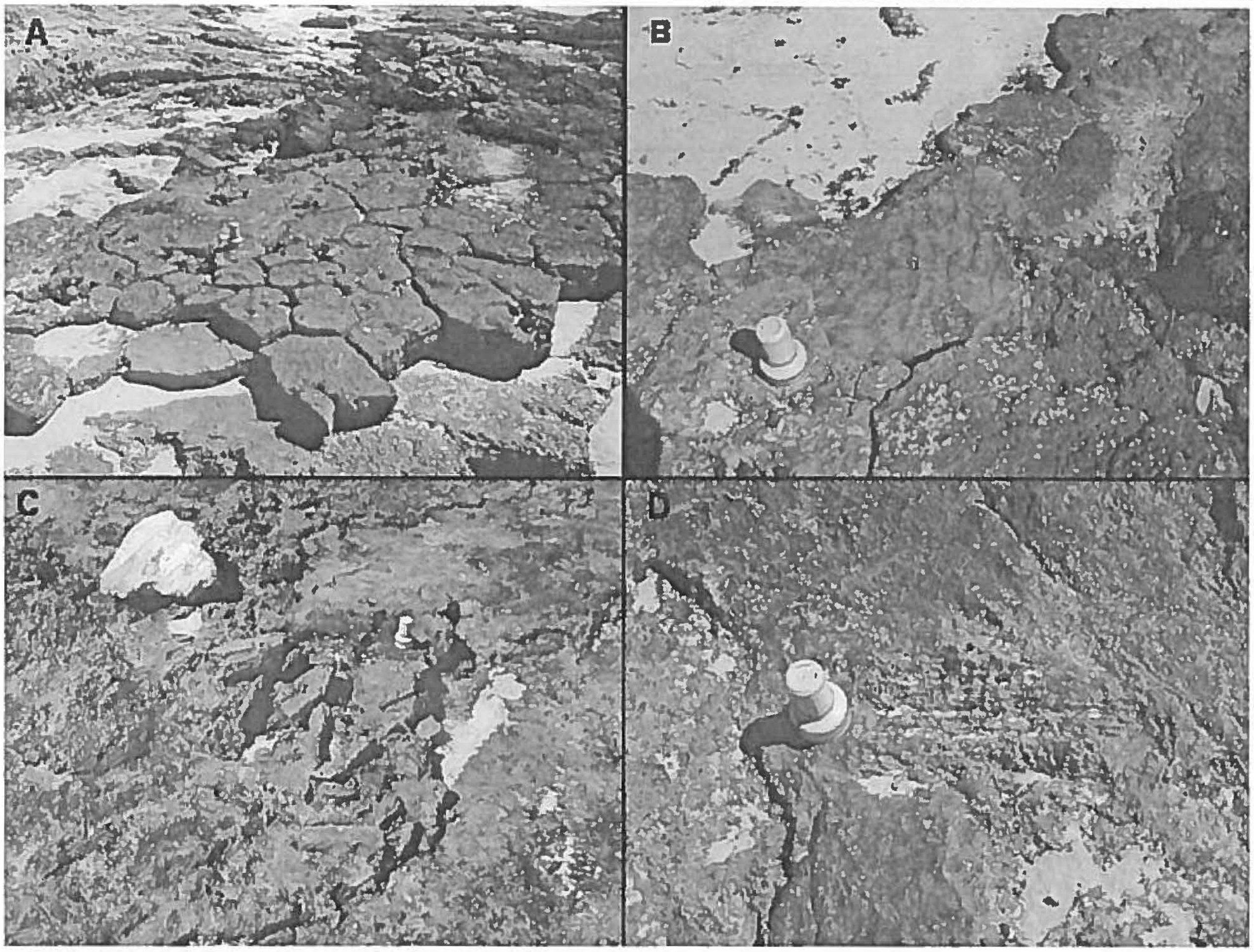


Figure 14. Features of the Hanna Bay at Stop 2. Site is at the location of the photographer in Figure 13C. A) Polygonal cracking. Flashlight 12 cm long for scale. B) Ripple marks on a bedding plane. C) Beach breccia facies, expressed in relief. D) Beach breccia facies, worn smooth with surrounding calcarenite.

Enjoy the view from the top of Mount Alvernia one last time, and then descend to the vehicles and depart for the next stop. From the Hermitage parking lot, drive west to the main highway, and turn right to continue north on the main highway, passing the airport after 4 miles (as measured from the Hermitage parking lot). Continue another 4.2 miles north to where there are low outcrops on the coast to the west, about 30 ft (10 m) from the road. A small beach 100 ft (30 m) long separates two outcrops. This is Stop 2, a total of 12.2 miles from the start of the trip at the airport, at 24°21’33.4”, 75°29’51.5”. Pull over off the road to the west and exit the vehicle carefully, remembering that the traffic will be going north in the west lane, south in the east lane, British style.

STOP 2 – HOLOCENE/PLEISTOCENE BOUNDARY.

Walk slightly downslope westward to the coastal outcrops. At this locality (Figure 13C), the Holocene Hanna Bay Member of the Rice Bay formation intertidal rocks overlie undifferentiated Pleistocene carbonates, with a terra rossa paleosol in between, indicating the Holocene/Pleistocene contact. The Pleistocene rocks and overlying paleosol have some undulating relief, such that in places they stick up through the Hanna Bay cover, and in other places the Hanna Bay rocks exist only in low spots in the paleosol surface (Figure 13A and 13B). While the Pleistocene rocks are undifferentiated, their low bedding angle and grain content indicate they are likely to be intertidal sands, from OIS 5e, and therefore part of the Cockburn Town Member of the Grotto Beach Formation. The superposition of Holocene Hanna Bay intertidal rocks over the Late Pleistocene intertidal rocks is a good demonstration of difficulty in mapping the stratigraphy in the Bahamas. Coastal processes commonly strip the paleosol cover off of Pleistocene intertidal rocks in the Bahamas, and can leave the rocks of Pleistocene age looking remarkably like Holocene intertidal rocks. In this locality, the cover of Holocene rocks helped preserve the paleosol, making identification of the lower unit as Pleistocene very simple. Crossing the beach to the north, the outcrop there is entirely Hanna Bay Member, grading from intertidal to supratidal to back beach eolian deposits, with wind-ripple marks, polygonal jointing, beach breccia blocks, and other features (Figure 14).

Return to the vehicle and continue north. From this locality and for the next ~3.5 miles, a variety of localities show emplacement of a

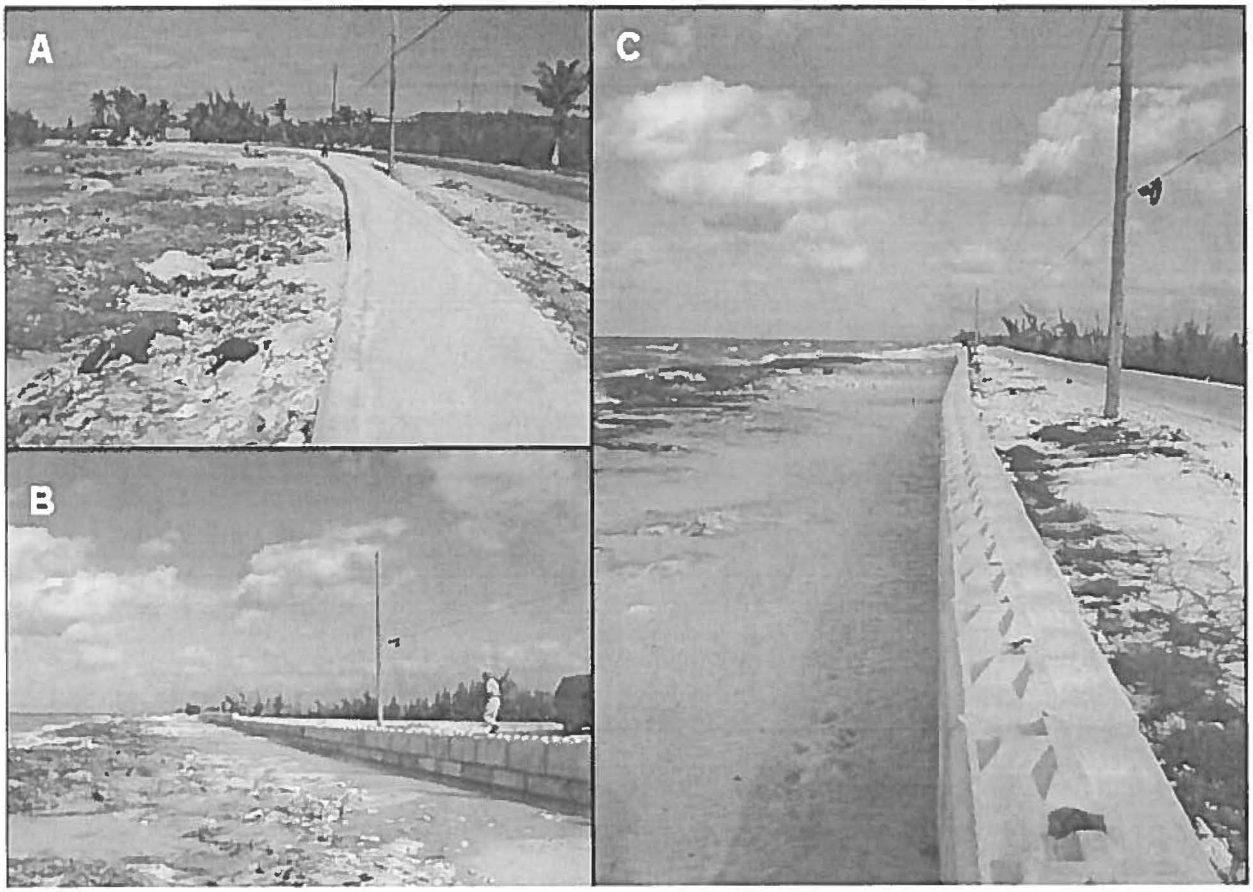


Figure 15. Sea walls on the west side of Cat Island. A) The sea wall separates the coastal rocks and sands from the road on the left (west); to the right (east) are brackish lagoons and marshes. B and C) Sand is being scoured from the beach by wave energy reflected from the sea wall and wall undermining can be expected. Looking north.

Figure 16. Sea wall damage, west side of Cat Island. A) Wall-end failure caused by wave energy wrapping around the end of the sea wall. B) Attempt to protect the wall end with a concrete patch, which has failed. C) Undermining and failure of the sea wall. D) Patching of the highway surface, February, 2006, where waves had overtopped the sea wall.

new sea wall. This sea wall already shows many erosional and other problems. At 1.5 miles north from Stop 2 is a major wall collapse. At 0.3 miles further an unusual building made of conch shells embedded in concrete is present. Behind this structure, the coastal rock may show a contact between the Grotto Beach Formation and the Owl's Hole Formation, but the field trip organizers found the site equivocal. Continue on another 1.6 miles (15.6 miles from the start) to the next stop, Stop 3, at 24°23'59.5", 75°31'38.2".

STOP 3 – SEA WALL.

The Sea Walls of Cat Island

There are a number of sea walls along the central part of the west coast of Cat Island, mostly along a three-mile stretch of coast between Tea Bay and Smith's Bay settlements (Figure 2). There is also a new sea wall in Arthur's Town at Stop 7, but the following account excludes this structure as it serves a different purpose from the other walls.

These walls were constructed following Hurricane Floyd in 1999, but were impacted soon after completion by Hurricane Michelle in 2001. In 2006 the government announced a $1m Inter-American Development Bank (IDB) funded sea-wall repair project. The field visit draws attention to the need for walls in these circumstances; the alternatives to walls; the limitations of the walls; and the failure of the walls in part.

Location

The particular nature of the shoreline where walls have been built is not essentially different from much of the coast anywhere along the central west side of Cat Island. However, the field trip will provide an opportunity to examine this suggestion. What is evident is that the walls protect settlements and related infrastructure, most notably roads (Figure 15), and it may be questioned as to whether efforts should be made to continually build expensive walls when alternative solutions exist in many areas, such as the relocation of the road away from the immediate shoreline. In some areas natural beach and dune development may resume if this was done, in other areas limited erosion of the rocky shore would continue, but in either case further intervention would be unnecessary.

A number of locations occur where deposition has led to brackish lagoons being created behind a beach and dune system, and the settlement and road have occupied the space between beach and pond (Figure 15). The infrastructure then led to erosion of the natural dune leading to absolute sand loss from the beach/dune system during storm conditions (Figure 15B and 15C). Ultimately this has led to the decision to build sea walls to protect the road. As these are not densely settled urban areas there is a case for relocating the roads behind the lagoons, or simply further inland, away from the shore. (Observers can judge for themselves to what extent this is possible, depending on exactly where stops are made during the field trip.)

Wall construction

The nature of the walls will be seen to be fairly uniform, basically a low structure buttressing the road but allowing water to drain back into the sea (Figure 15). There are surface and buried outflow channels to facilitate this, and the walls are solid concrete so that they do not get easily undermined or penetrated. This seems to be a standard design adopted for IDB-funded structures in this region. Nevertheless the refraction of waves from the face of the vertical walls is such that scouring is created and the beach in front of the wall becomes stripped down in some areas, creating conditions for wall failure (Figure 15B and 15C).

In particular sea walls are noted for the their vulnerability to erosion at their ends ('wall-end failure'). A poorly designed wall will allow waves to refract around the wall-end and cause undermining from behind (Figure 16A and 16B). This is usually anticipated by a number of techniques such as curving the wall-ends back to the shore, or extending the walls well into the naturally protected areas. In the case of Cat Island none of the walls have been professionally ended, and it appears that a secondary contractor has tried to finish the ends with a fill-and–cover system (Figure 16B). Without exception these ends are all damaged and failing, and in the worst case at Knowles the sea has rounded the wall and the entire structure has started to collapse (Figure 16 C). Wall and road repairs are ongoing (Figure 16D).

Conclusion

Participants may like to carry their observations over to San Salvador where a similar wall has been constructed along Fernandez Bay, also on the west side of the island. Much of the professional literature today advocates 'soft' as opposed to 'hard' solutions for coastal protection. Preserving beach/dune systems, or rebuilding them, are well recorded for Britain, the Netherlands, and the east coast of the US, with the most pertinent examples from Florida which experiences similar tides and weather patterns to the Bahamas. The present spate of wall building in the Bahamas seems to suggest that coastal restoration is not the prime focus, but rather quick fixes to the shoreline infrastructure dominate the decision-making.

Re-board the vehicle and drive north for 4.0 miles, to Stop 4 at telephone pole number 469, just north of a small point called Ben Bluff at 24°27'12.9", 75°32'58.1", 19.6 miles from the start.

STOP 4 – COCKBURN TOWN SUBTIDAL FACIES.

From the road, follow a small bush trail a few meters past the telephone pole and to the coastal rocks, heading first west to the open rocky area, then south onto a low bench in the eolianite ridge that makes up Ben Bluff (Figure 17). These rocky outcrops consist mostly of Pleistocene eolian calcarenites that are capped by a well-developed terra rossa paleosol. This paleosol is very complex and some patches are clast-rich. In a few locations, mostly to the left (south) and seaward (west) of the trail end, there are exposures of deposits containing fossil corals, calcarenite with molluscan shells, and *in situ* clumps of coralline red algae (*Neogoniolithon*), all capped by a terra rossa paleosol (Figure 18). The presence of the *in situ Neogoniolithon* provides unequivocal evidence that these deposits are subtidal in origin, and not a deposit washed onto the shore by waves in either Pleistocene or Holocene time, and subsequently lithified.

Because of the limited exposure and the complexity of the paleosol(s), it is difficult to determine the stratigraphic relationships between the subtidal deposits, eolianites, and paleosol(s). There are two possibilities. Either the subtidal deposits lie atop a terra rossa paleosol that caps the eolian calcarenites, and the subtidal deposits themselves are capped by a second terra rossa paleosol; or, the eolianites and subtidal deposits are capped by the same paleosol. Throughout the Bahamas, Pleistocene subtidal deposits are assigned to the Cockburn Town Member of the Grotto Beach Formation, and no Pleistocene subtidal deposits in the Bahamas have been unequivocally dated to any time other than OIS substage 5e (c.a. 131 ka-119 ka, Chen et al., 1991; Carew and Mylroie, 1995b). So, if the eolianites at this location are capped by a terra rossa paleosol that lies beneath the subtidal *Neogoniolithon*-bearing rocks of the Grotto

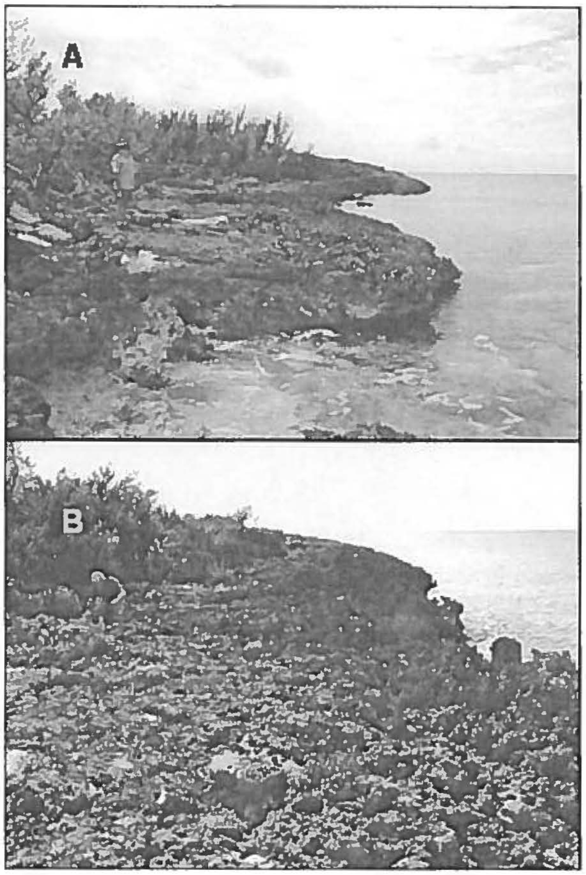


Figure 17. Two views (A and B) of the eolianite bench at Stop 4, which was notched on a previous sea-level highstand, with corals growing on that subtidal bench during OIS 5e.

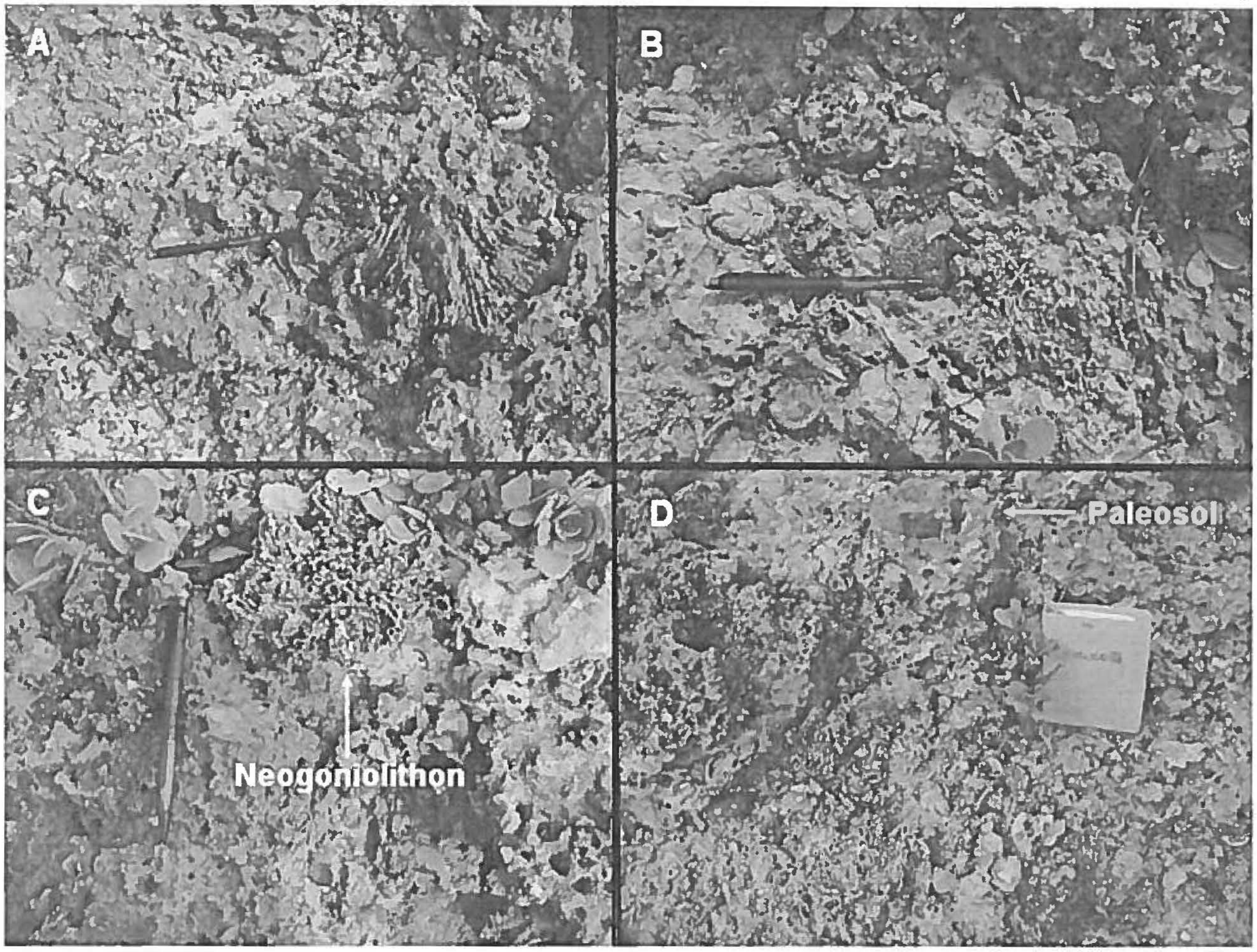


Figure 18. OIS 5e subtidal fossils at Stop 4. A) Coral head to the right of the pencil, which is 15 cm long. B) Complex mixture of mollusks, corals, and *Neogoniolithon.* C) Well preserved *Neogoniolithon.* D) Terra rossa paleosol providing a resistant cap, creating a residual pillar, and overlying a mixture of mollusks, corals, and *Neogoniolithon.* Notebook is18 cm high for scale.

Beach Formation, then they must represent material deposited during an earlier glacio-eustatic highstand of sea level (e.g., OIS Stage 7, 9, or 11). As such they would be assigned to the Owl's Hole Formation. On the other hand, if the subtidal deposits and the eolianites are capped by the same paleosol; then the eolianites must be transgressive-phase eolianites of the French Bay Member of the Grotto Beach Formation that were subsequently notched by coastal erosion associated with continued rise of sea level to its acme during the stillstand. Then the *Neogoniolithon*-bearing subtidal deposits represent the Cockburn Town Member of the Grotto Beach Formation, and were deposited during the stillstand of sea level associated with OIS 5e. *Neogoniolithon* is not commonly found in outcrops in the Bahamas, but it is very prevalent here. The fossil reef at Grotto Beach on San Salvador Island is another example where *Neogoniolithon* is found.

Continuing southwest for several hundred meters to the western-most point of Ben Bluff, some flank margin caves, breached by wave action, can be located (Figure 19). One of the caves shows interesting dissolutional surfaces showing the cusps, curvilinear surfaces, and ceiling pockets associated with phreatic dissolution (Figure 19C and 19D).

Re-board the vehicles and continue north on the main highway for 0.6 miles (20.2 miles total) to Stop 5, at 24°27'40.4", 75°33'11.8", just south of the town of Industrious Hill, at an obvious cave entrance marked with a sign that says "Bat Cave".

STOP 5 – BAT CAVE.

Bat Cave (known as Industrious Hill Cave in Palmer et al., 1986) is a characteristic flank margin cave (Figure 20). The term "flank margin" comes from the development of a cave in the distal margin of a fresh-water lens, under the flank of the enclosing landmass. In this case, as with all other flank margin caves in the Bahamas (Mount Alvernia not withstanding), the cave formed during the OIS 5e sea-level highstand, when the ocean would have made the eolianite hill containing the cave into a small island. The fresh-water lens in that island, by mixing dissolution, was able to

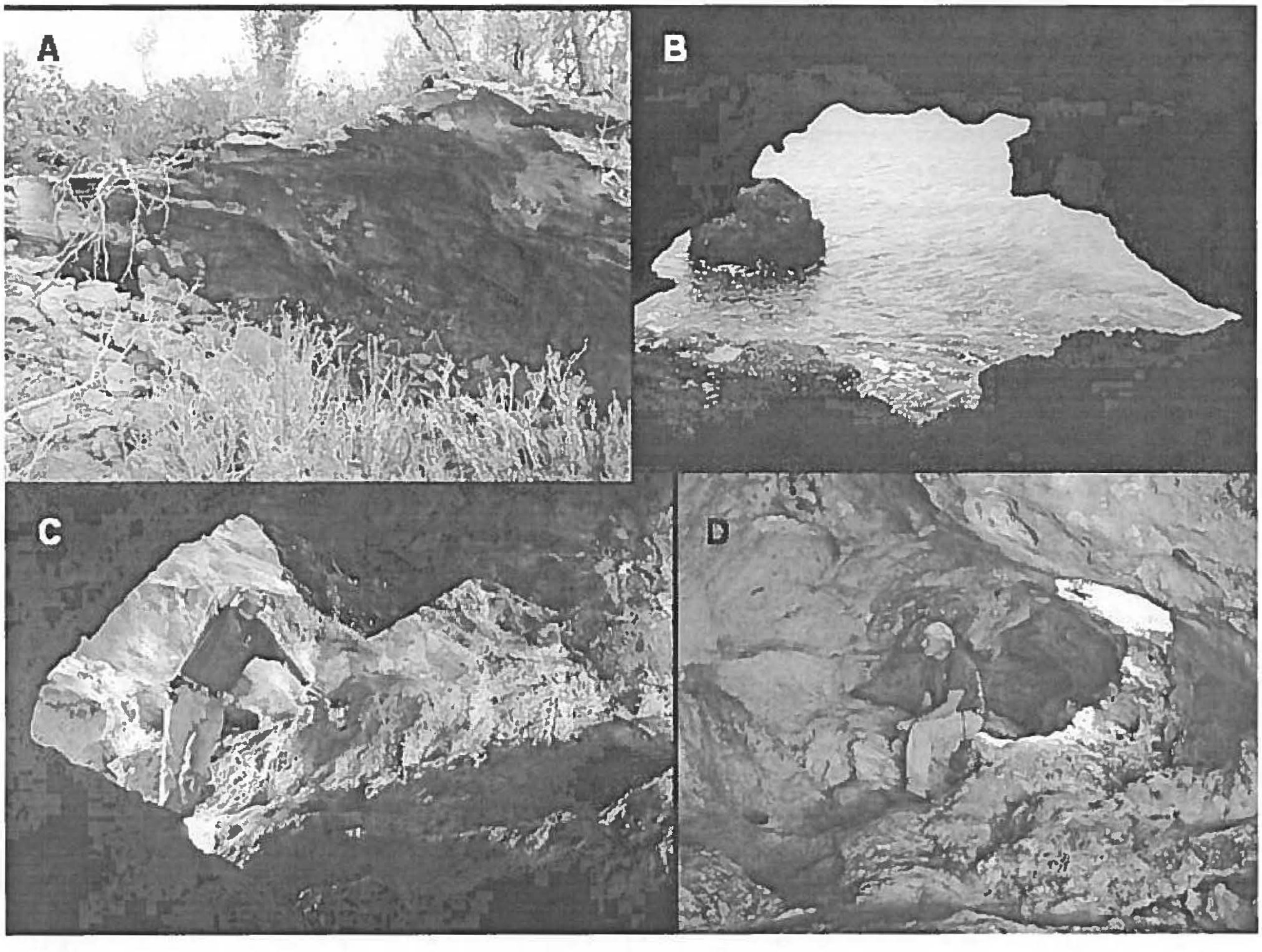


Figure 19. Caves at Stop 4, west of the fossil coral outcrop. A) Partially-collapsed flank margin cave, as a result of coastal erosion. B) An almost completely intact flank margin cave, breached by wave erosion. C) and D) Interior of the cave in (B), showing phreatic dissolutional surfaces.

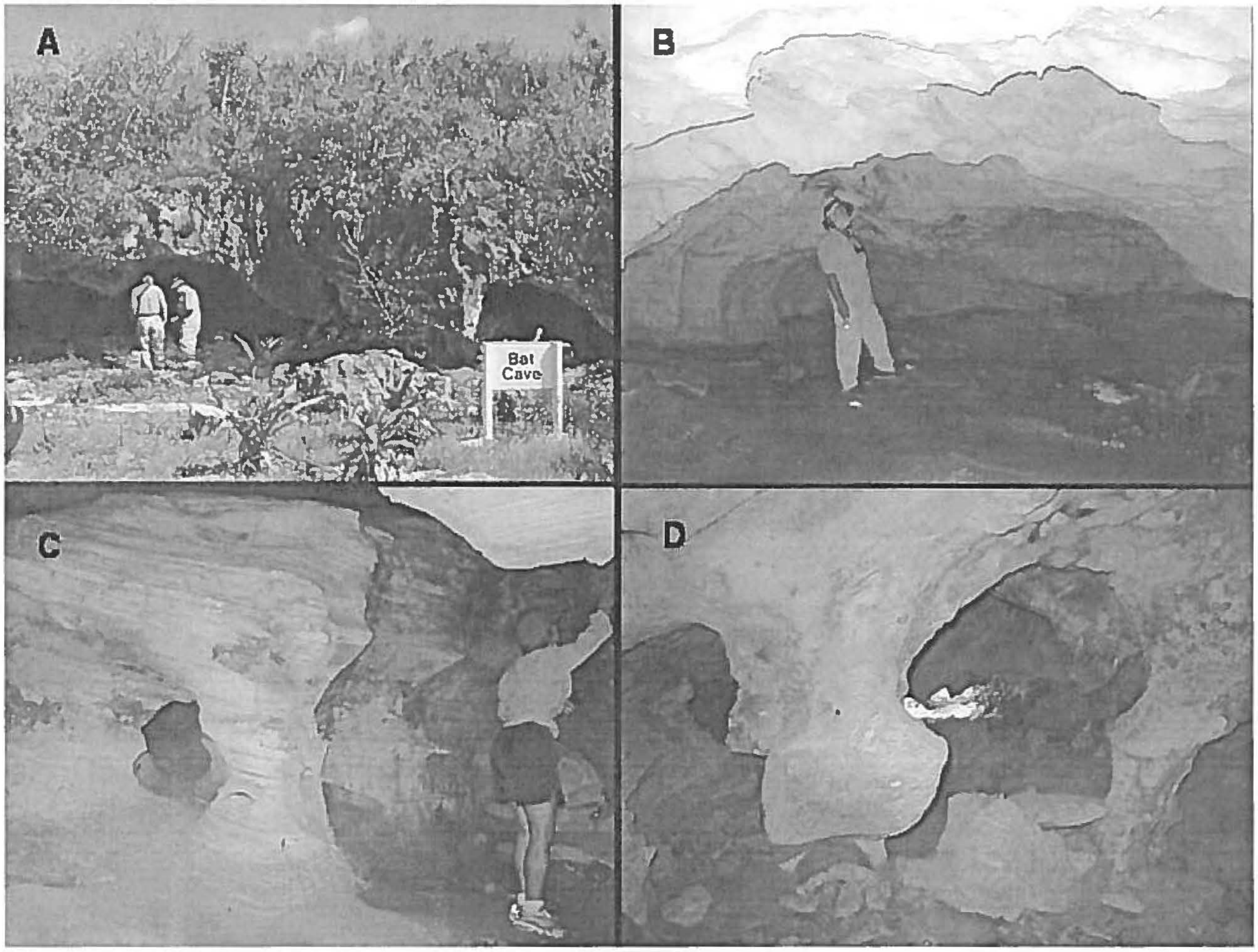


Figure 20. Bat Cave (aka Industrious Hill Cave). A) Entrance of the cave caused by erosional retreat of the edge of the hill. B) Main chamber of Bat Cave, showing excellent phreatic dissolutional surfaces. C) and D) Complex dissolutional wall sculpture, common in caves formed by mixing dissolution. Note dip of eolianite beds.

dissolve out the cave. Entering the cave, one can see that the entrances were produced by hillslope retreat, which breached the cave to the outside (figure 20A). The cave consists of a large main chamber (Figure 20B), with a series of passages radiating off in various directions (Figure 20C and 20D), which is consistent for flank margin caves in the Bahamas, and elsewhere (Isla de Mona, Puerto Rico [Frank et al., 1998]; Mariana Islands, [Jenson et al, 2006], etc.). The cave was not a conduit, but a mixing chamber. It did not experience turbulent flow, and none of the typical flow markings found in continental stream caves are present. The cave has some bats today, and contains some bat guano. Many Bahamian caves were mined for their bat guano during the mid-1800s, and as a result, archeological and other cultural material has long since been removed, but more of the cave, especially the floor morphology, can be seen. The cave walls, roof and floor reveal dissolutional sculpture that is associated with phreatic dissolution (Figure 20B, 20C and 20D). This morphology is consistent, however, with what was seen in the problematic Mount Alvernia caves earlier.

Re-board the vehicle, and continue north on the main highway. After 5.4 miles, the turn-off to Stop 6 is passed as the road to the Pigeon Cay Resort. Continue north 4.5 miles to Bennett's Harbor, drive through town and continue another 0.9 miles to Sammy T's, a resort at 32.6 miles from the start at the airport.

LUNCH

Stop at Sammy T's for lunch. If time allows, walk west and south along the coast for a few hundred meters. The rocky peninsula here (Figure 21) is Holocene Rice Bay Formation, as can be determined from the lack of a paleosol. The bedding indicates the rock is an eolianite. The dip of the foreset beds below modern sea level identifies the unit as the North Point Member (Figure 21C). Also at this location the invasive *Casuarina* sp will be seen at several points along the beach (Figure 21B and 21D), both north and south of Sammy T's boardwalk. It is claimed (Sealey 2006) that *Casuarina* groves facilitate beach erosion by killing the vegetation beneath their foliage, and so exposing the sand beneath to erosion and loss during stormy conditions. The *Casuarina* stand at this location exhibits this phenomenon, and it

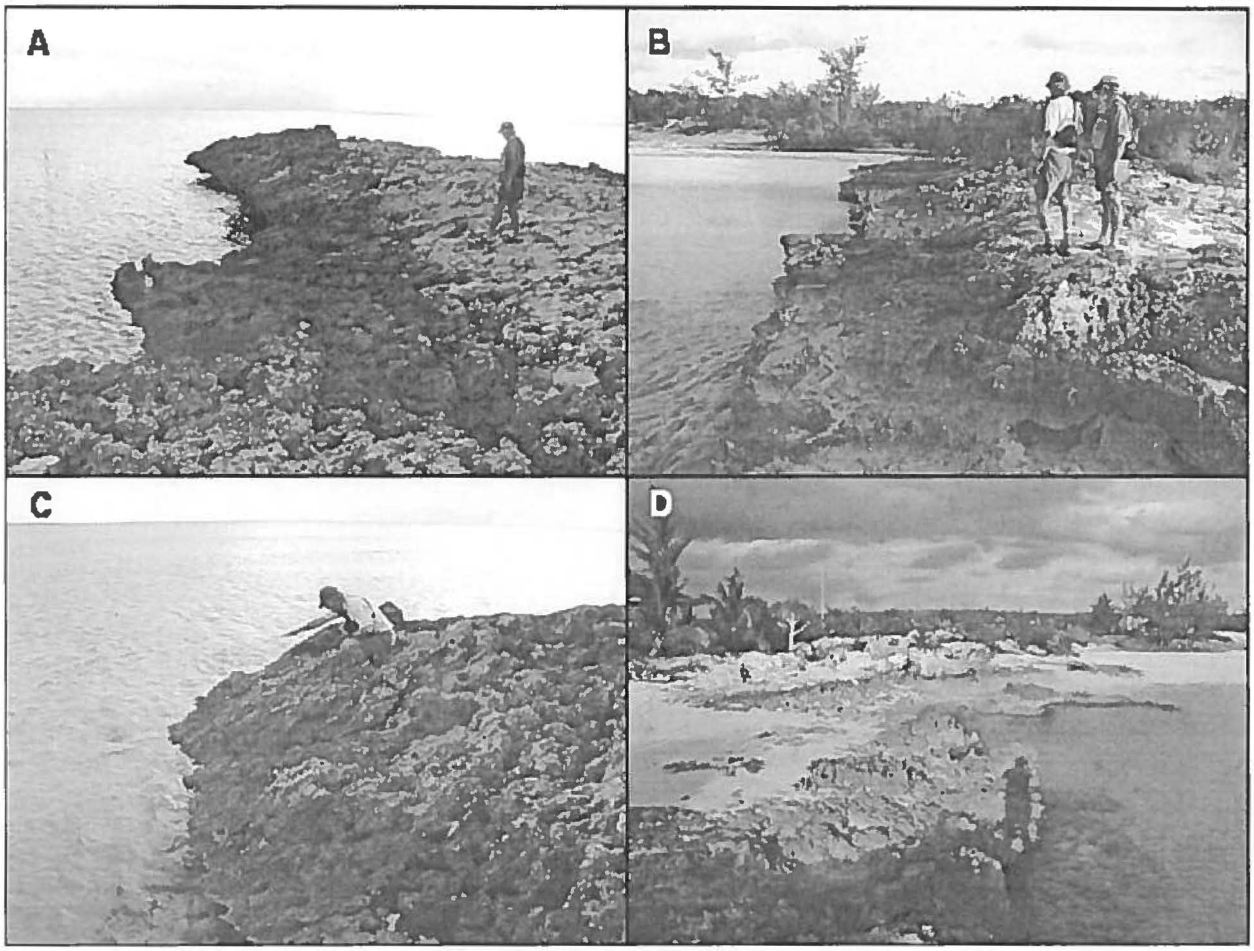


Figure 21. Outcrop of North Point Member rocks at the lunch stop. A) Long, linear eolianite ridge, which lacks a covering paleosol, indicating Holocene age Rice Bay Formation. B) Notching of eolian beds by wave action. C) Eolian beds dip below sea level indicating North Point Member rocks. D) Holocene benching and truncation of the eolianite beds; this may have occurred at Stop 4 during OIS 5e. Note the *Casuarina* visible on the beach in B and D.

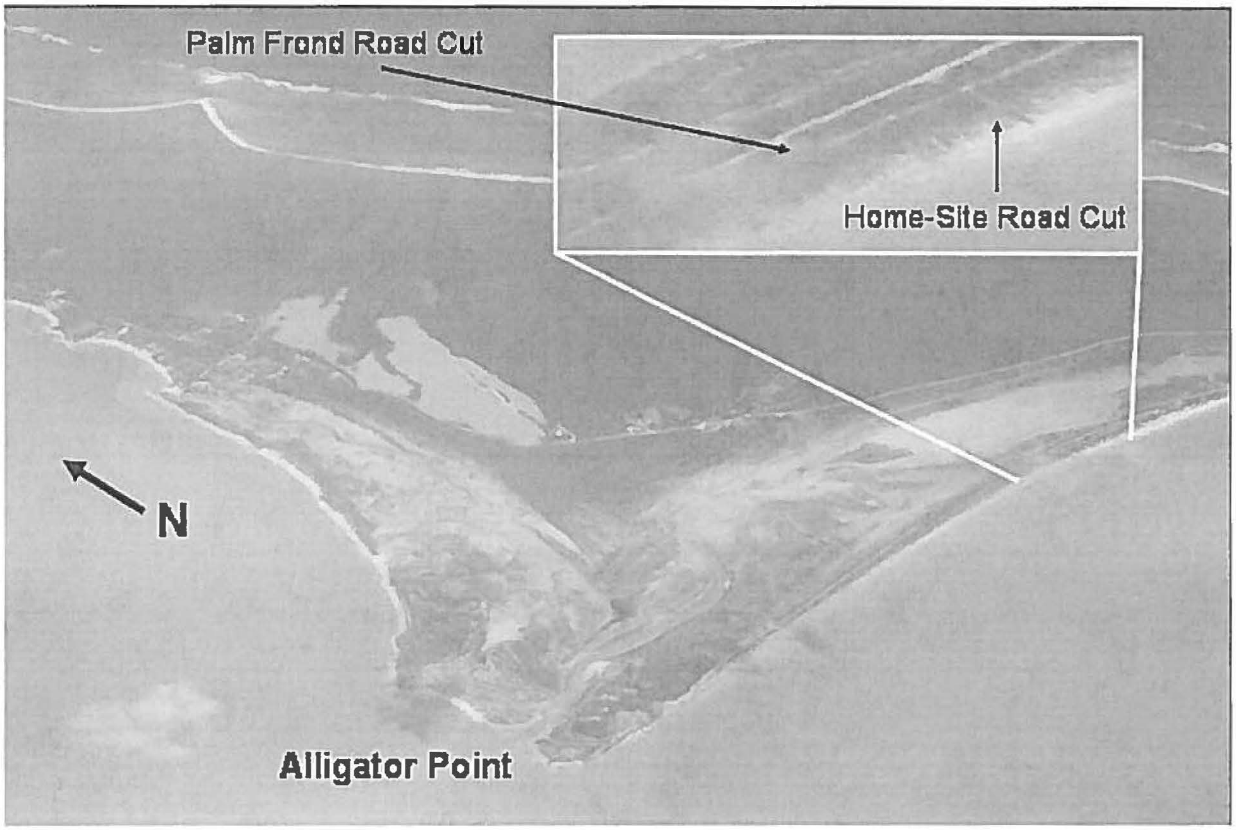


Figure 22. Aerial photo of the Alligator Point area, taken in February, 2006, showing the major features of Stop 6.

is likely that if not removed severe beach erosion and amenity loss will result whenever storm waves are generated on this shoreline. Native dune-building vegetation can be seen in areas adjacent to *Casuarina* locations for comparison.

After lunch, retrace south 5.4 miles and turn right (west) onto the Pigeon Cay Resort road, bear right after 0.2 miles passing the resort (24°31'37.4", 75°35'45.3"), and continue north. After 0.8 miles, bear left (west or seaward) at the fork in the road, and continue another 0.6 miles, stopping at a road cut up a side road to the left (west) at 24°31'54.3" 75°37'07.9" (27.2 miles from the start if the drive to Sammy T's is neglected, add 10.8 miles for the lunch stop). Exit the vehicle and go uphill to the road cut. This is Stop 6.

STOP 6 – ALLIGATOR POINT.

In his pioneering study of the Holocene coastal landforms of Cat Island, Lind (1969) described Alligator Point and the similar but smaller Orange Creek Point, at the northwest corner of the island, as cuspate barrier spits. Alligator Point is a large and complex geomorphic feature consisting of a broad, terraced northern ridge complex and a narrow, steep-sided southern ridge separated by a branching tidal channel that opens into Exuma Sound at the tip of the point (Figure 22).

The geology of this stop begins at an outcrop generated by excavation for an access road to new home sites being developed along part of the southern barrier dune ridge (Figure 22 inset). The outcrop cuts the long axis of a fossil dune and reveals a section of well-bedded

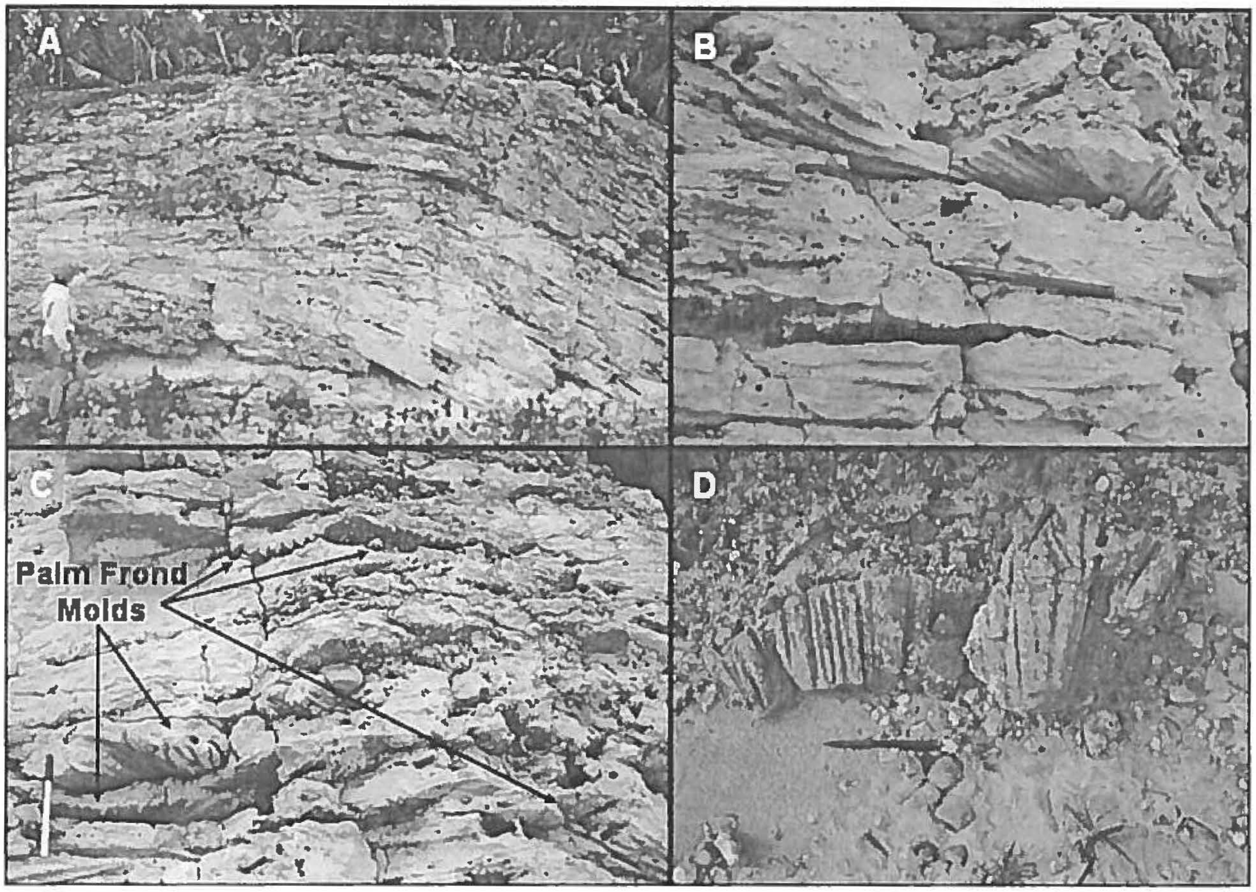


Figure 23. First part of Stop 6, road cut in eolianite above 10 m elevation. A) View of the road cut. B) and C) Palm frond molds expressed in the wall of the road cut. Pen and pencil each 15 cm long for scale. D) Loose blocks from bulldozing of the road, showing clear palm frond molds.

carbonate eolianite up to 12 feet (4 m) in thickness (Figure 23A). There is no calichified paleosol at the top of the dune ridge, confirming a Holocene age for these beds. Following the Carew and Mylroie (1995a, 1997) stratigraphy, they can be assigned to the Rice Bay Formation.

This dune displays classic rollover structure, with the windward beds dipping gently southward (~10°) and the leeward beds dipping steeply (~30°) northward. Note that the crest of this dune lies a good 6 ft (2 m) above the dune cut. Lind (1969) reported dune crests along this ridge to be about 65 ft (20 m) above sea level, rivaling the maximum heights of Holocene dunes at Devil's Point and Greenwood at the southern end of Cat Island.

A close look at the stratification of these beds will reveal the distinctive fine/coarse-grained couplets that characterize Bahamian eolianites (White and Curran, 1988). Even more notable here is the presence of numerous coarsely crenulated surfaces along bedding planes (Figure 23B, 23C and 23D). These structures are interpreted as the molds of palm fronds, formed by the burial of fronds in drifting dune sands. Similar structures have been found in Holocene eolianites on Lee Stocking Island of the Exuma Cays (White and Curran, 1993), as well as in late Pleistocene eolianites from several other localities in the Bahamas and on Bermuda. This outcrop reveals the greatest concentration of fossil palm frond molds observed to date in the Bahamas! Note that silver thatch palms (*Coccothrinax argentata*) are the most common trees growing on the surface overlying this outcrop and elsewhere on Alligator Point. Silver thatch fronds are the likely modern analogue for the fossil frond molds found here.

These eolianite beds have a very well-sorted texture and are composed dominantly of very fine to fine, mostly spherical, aragonitic ooids, with minor peloids and skeletal grains. Ooids average 200 microns in diameter with most being thinly coated with micritic peloidal nuclei (Figure 24A). The ooid sands presumably originated on the leeward Exuma Sound shelf of Cat Island and were moved inland by wave and wind transport.

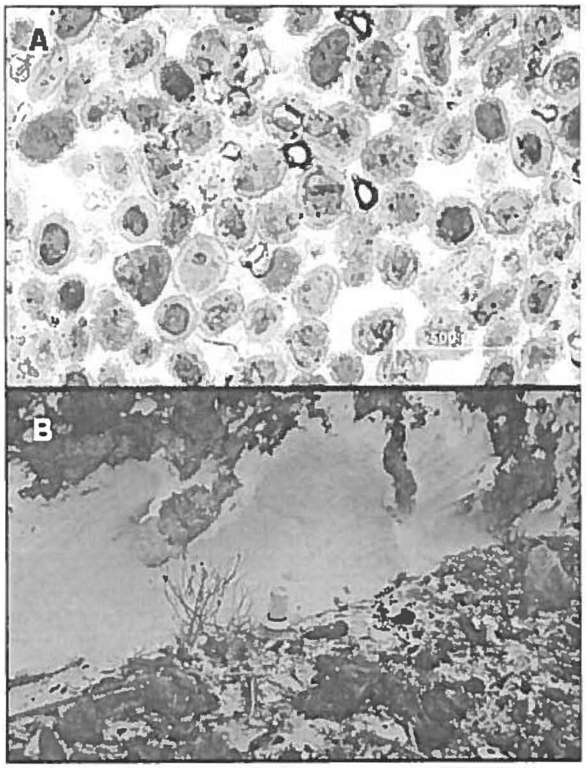


Figure 24. A) Photomicrograph of a thin section from the Stop 6 eolianites, showing dominance of thinly-coated ooids. B) Small tafoni cave in a road cut leading to the coast at Stop 6. Wind erosion, assisted by sea-salt crystal wedging, forms these hollows quickly, as the road cut is less than 20 years old. Flashlight 12 cm high for scale.

Now follow the new development access road east for about 450 ft (140 m) to a home-site road and excavation area offering a clear path down to the beach. Here two low cuts into the underlying eoliante beds reveal several moderately well developed cluster burrows, as described by Curran and White (2001 and earlier publications) from Holocene eolianites on San Salvador and elsewhere. These large and complex burrows were interpreted by Curran and White (2001) as the brooding structures of digger wasps (Family Sphecidae). Also present are modern root traces in various orientations, miscellaneous burrows made by modern insects, and several small taphoni caves (Figure 24B).

Continue with care down the steep slope toward the beach. This fairly well-lithified, south-ward-facing slope represents the windward flank of the dune-ridge complex. Note the presence of small- to moderate-sized fossil dunelets on this surface (Figure 25A and 25B). Large, smooth areas on the slope are characterized by a well-formed polygonal fracture pattern (Figure 25C and 25D), likely developed owing to the homogenous nature of the underlying oolitic eolianite. Note the similarity to the polygons seen at Stop 2 (Figure 14A).

With approach to the beach and the water's edge, the dip of the eolianite beds levels to near horizontal, and the beds cropping out along the beach are interpreted as having been deposited in a beach backshore zone (Figure 25A and Figure 26). The asymptotic relationship of these beds to modern sea level indicates that they can be assigned to the Hanna Bay Member of the Rice Bay Formation following the stratigraphic criteria of Carew and Mylroie (1995a, 1997).

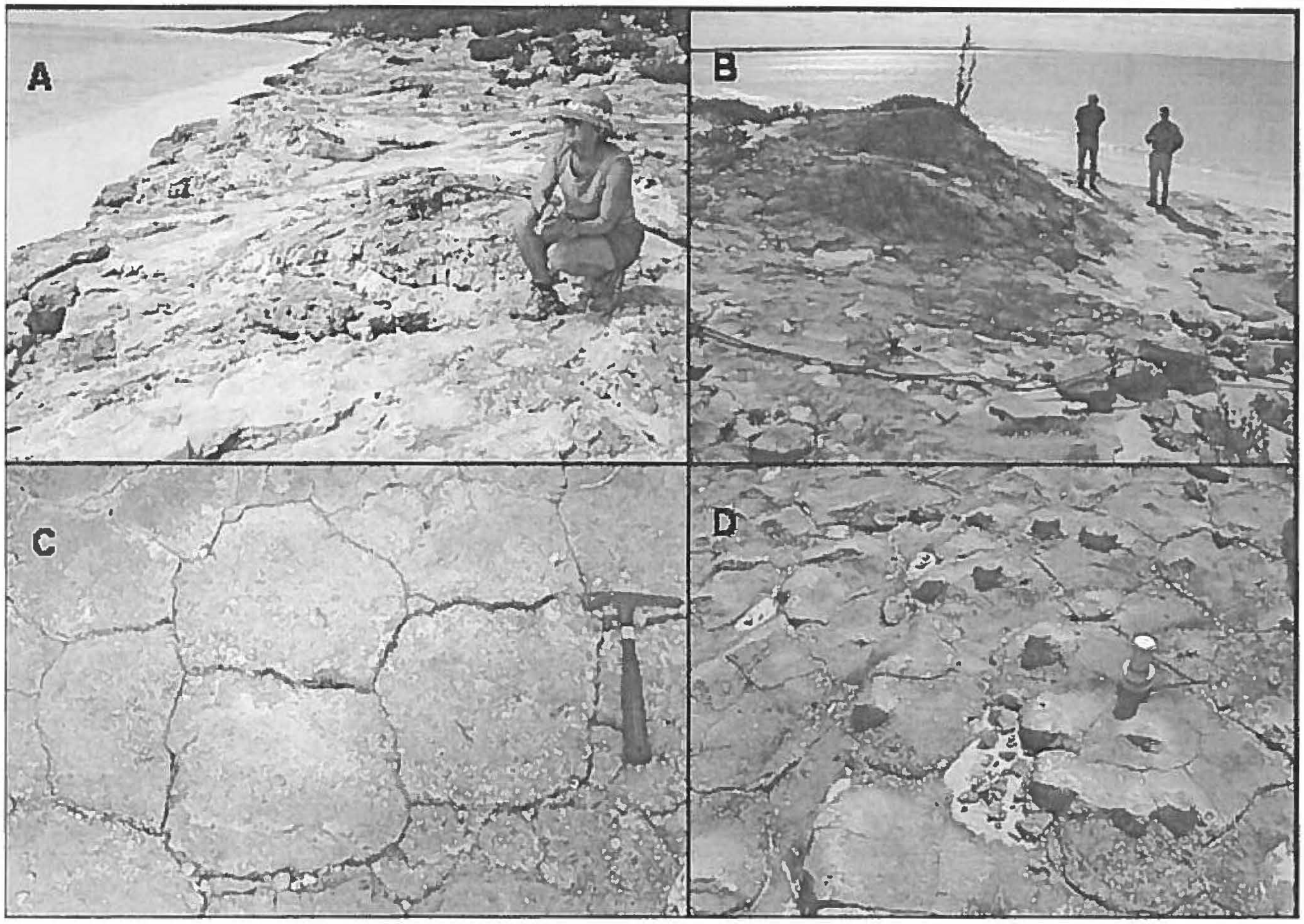


Figure 25. Coastal outcrops at Stop 6. A) and B) Hummocky small dunes within the main dune trend. Note in (A) how the beds are asymptotic to sea level. C) and D), Polygonal jointing, as also seen at Stop 2 (Figure 14A). In (D), micritization along a bedding plane creating a slightly resistant surface, producing miniature buttes. Flashlight 12 cm high for scale.

Beds cropping out along the back of the modern beach and exposed in vertical section by coastal erosion contain molluscan fossils, including whole valves of clams and occasional large queen conch shells (*Strombus gigas*). Also present in these backshore beds are some fossil ghost crab burrows (*Psilonichnus upsilon*, tracemaker organism = *Ocypode quadrata*). This trace fossil is commonly found in Holocene backshore beds throughout the Bahamas (Curran, 1997). These outcrops along the beach show that the backshore beds transition upward directly into dunal beds. Trace fossils are present in these beds, including several good examples of stellate burrows, also, as noted earlier, large and complex burrows interpreted by Curran and White (2001) as insect brooding structures, in this case formed by sweat bees (Family Halictidae). Back-beach breccia blocks (Figure 26B and 26C) are found here, as at Stop 2 (Figure 14C 7 14D).

Lind (1969, p. 106) postulated that the larger dunes of the ridge crest (Figure 22 and Figure 23A) were "relatively old" owing to their more thorough cementation, and he indicated that eolianite beds dip into the surf at the western end of the southern barrier of the point (Lind,

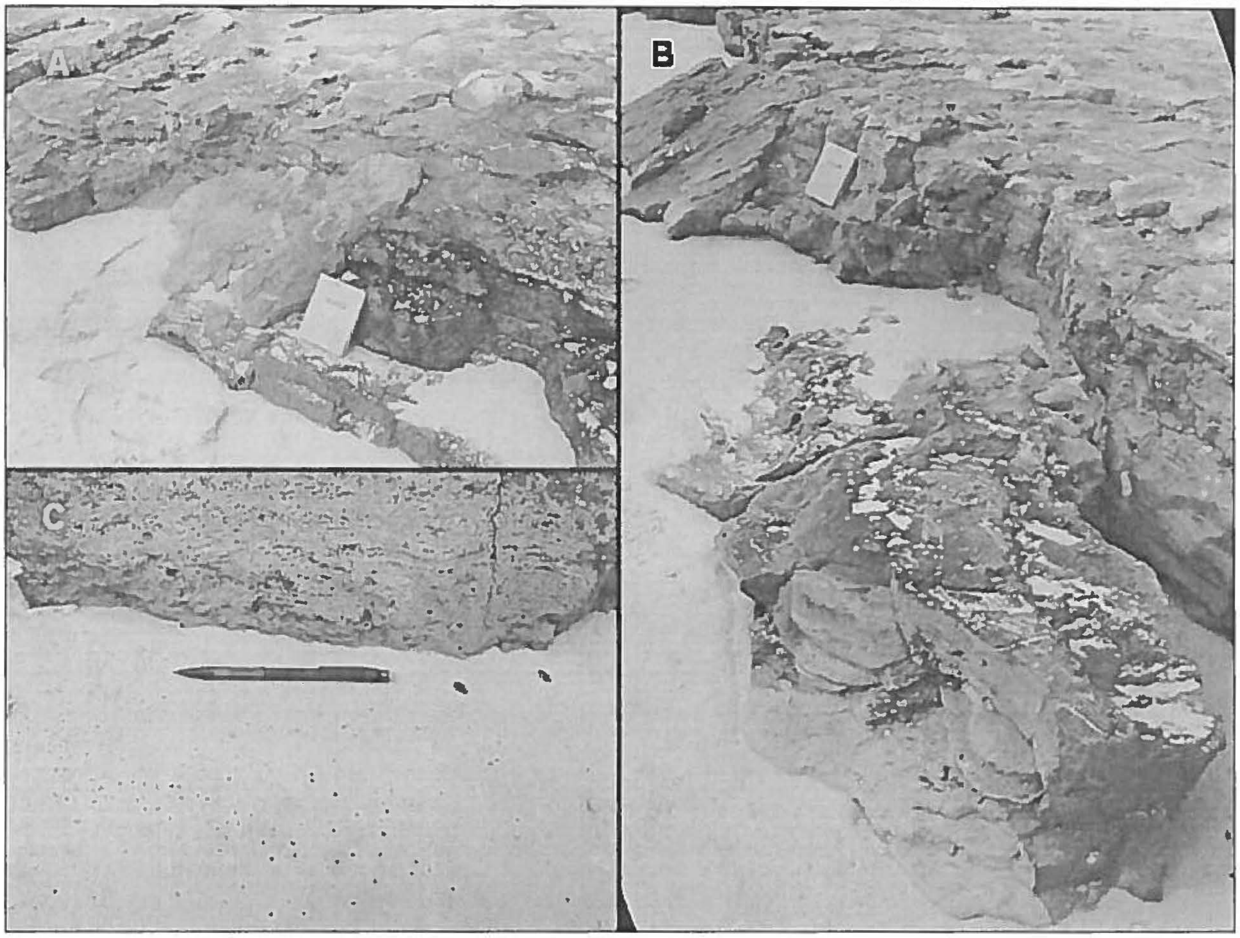


Figure 26. Rock/beach interactions at Stop 6. A) Lithified beach breccia block. B) New beach breccia block in the process of formation. C) Fenestral porosity in both the loose sands and in the adjacent Hanna Bay Member beach rock.

1969, Fig. 61). If so, these beds would be assigned to the North Point Member of the Rice Bay Formation, again following the Carew and Mylroie stratigraphy (1995a, 1997). These important details could not be addressed during the geologic reconnaissance in preparation for this field trip owing to time constraints. Alligator Point is a large feature with interesting Holocene geology, and it merits further geologic investigation in the future.

Re-board the vehicles, and drive back past the Pigeon Cay Resort to the main road, and continue north, past Sammy T's. After a further 0.9 miles, pass through the town of Dumfries, and 1.8 miles later enter Arthur's Town. Passing through town for 0.8 miles, turn left (west) up a road up to a massive sea wall, at Stop 7 (36.1 miles from the start at the airport if the back and forth from Sammy T's and Stop 6 is subtracted).

STOP 7 – MODERN BEACH ROCK.

Here, young Holocene beach rock can be seen partially entombing the transmission and back axle of a car (Figure 27A, 27B and 27C). The transmission and axle appear *in situ*, that is, in the position they held when the car was intact. This site indicates the rapidity with which carbonate sediments can lithify in this environment. The beach rock here also shows

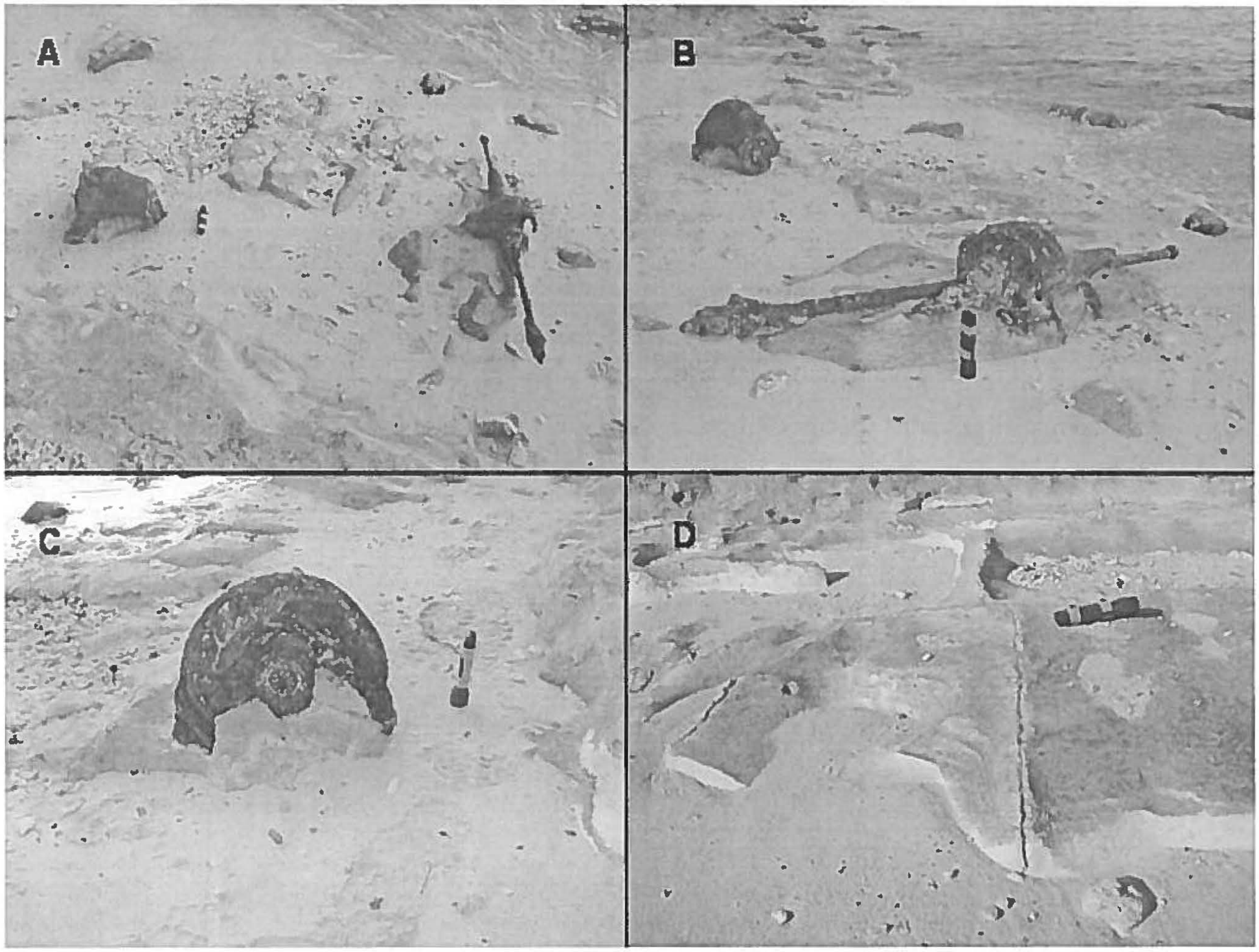


Figure 27. Modern beach lithification at Stop 7. A), B) and C) Transmission and rear axle of a car, cemented in place as an example of the rapidity of carbonate lithification. D) Joints in modern beach rock expressing as resistant features as a result of cementation by water flowing through them. Flashlight is 15 cm long for scale.

inversion of topography, where joints have become micritized and so resist erosion and stand above the surrounding beach rock as linear ridges (Figure 27D). This beach rock represents the young boundary of the Holocene Hanna Bay Member of the Rice Bay Formation, as the rock is at most a few decades old. Adult refreshments are available at this spot.

Re-board the vehicle, and drive east to the main road and go north 0.2 miles, turning right (east) onto the Arthur's Town Airport Road (this point is 36.3 miles from the start, excepting the lunch and Stop 6 driving). After 0.3 miles, as the road comes to the airport terminal, notice the rocks to the north in the road cut. This is Stop 8, 36.6 miles from the start by direct routing.

STOP 8 – COCKBURN TOWN FACIES.

This road cut displays some complex bedforms that appear to be herringbone cross bedding mixed with a breccia block facies (Figure 28). The appearance of subtidal facies above

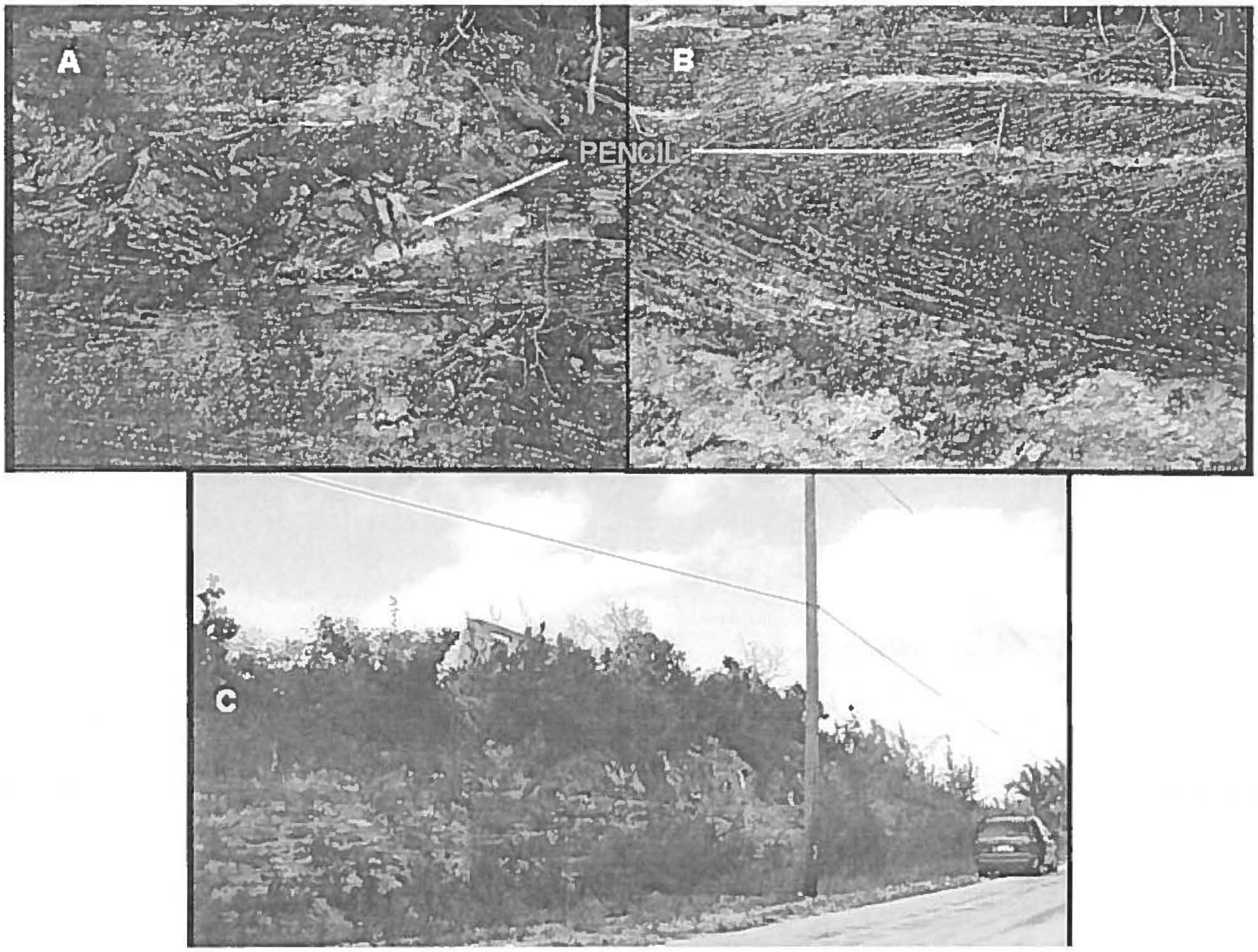


Figure 28. Outcrop in the road cut at Arthur's Town Airport, Stop 8. A) Beach breccia facies. Pencil 15 cm long for scale. B) Herringbone cross bedding, a subtidal indicator. C) Overview of the outcrop, looking east.

modern sea level identifies the unit as the Cockburn Town Member of the Grotto Beach Formation. However, the outcrop has peculiarities that generated some debate and confusion amongst the reconnaissance team in February 2006. The field trip attendees are invited to lend their expertise to the discussion.

Walk 0.1 miles to the airport terminal to complete the field trip.

ACCESSORY FIELD TRIP STOPS

If time allows, or on a later visit, further field trip stops are available. From mile point 36.3, the turn-off to the east to the airport, continue north 2.2 miles and turn right (east) onto Dickie Road. After 0.3 miles, pull over in front of a circular pool of water on the north side of the road. This is Stop 9.

STOP 9 – LITTLE FOUNTAIN BLUE HOLE.

The water body is Little Fountain Blue Hole (Figure 29A). The rock ledge at the north side is ultra white because local people commonly use the fresh/brackish water of the blue hole to do their laundry, and they use bleach as part of the cleaning process on the ledge. Palmer et al. (1986) reported the blue hole to be fresh water to a depth of 7 m, where an indistinct halocline separates H_2S-containing brackish water continuing down to a maximum depth of 15 m. Optical refractometer measurements in February 2006 indicated the surface water was brackish. The bottom slopes from north to south. The bedrock rim is a common feature of blue holes in the Bahamas.

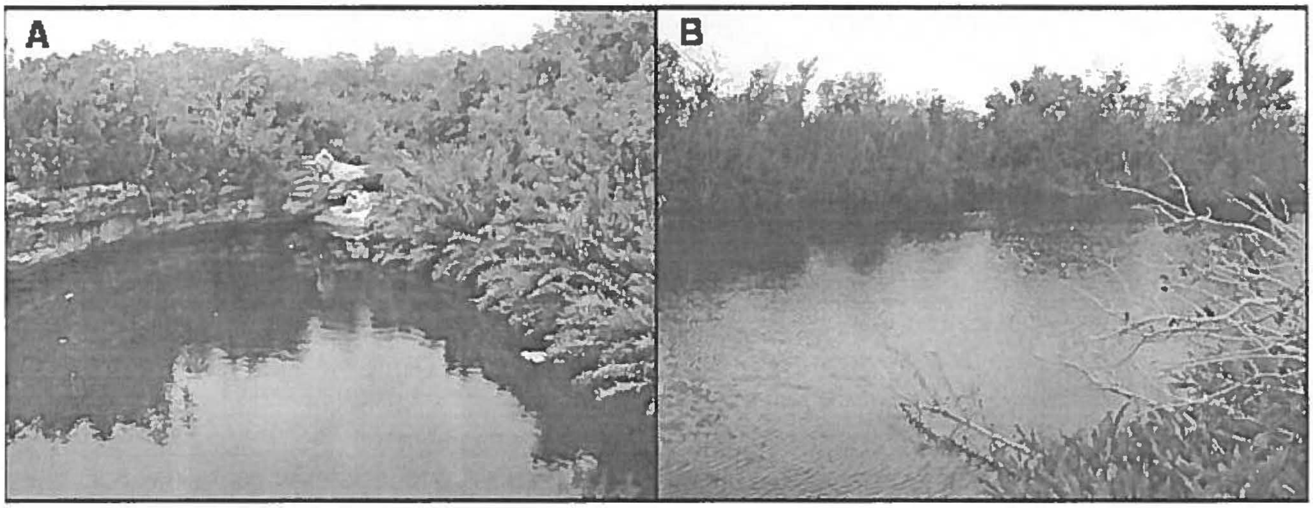


Figure 29. Stops 9 and 10 on Dickie Road. A) Little Fountain blue hole, deepest part is below the photgrapher. View is to the north. B) Big Fountain blue hole. Deepest part is to the right (east).

Re-board the vehicle, and continue east on Dickie Road a further 0.8 miles and pull off to the left (north) where a large pool of water exists. This is Stop 10.

STOP 10 – BIG FOUNTAIN BLUE HOLE.

The large water body is Big Fountain Blue Hole (Figure 29B). Palmer et al. (1986) reported that despite being over 1500 m from the coast, the fresh-water lens is thin here, and a marked halocline is reached at a depth of 3 m. Crossing this halocline resulted in a temperature jump from 22.2 °C to 25.5 °C at the time of the investigation (Palmer et al.,1986), with evidence of H_2S. The maximum depth is 33 m at the southeast corner of the blue hole. From this deep point a cave passage trends east and then north, with abundant vadose speleothems (stalagmites and stalactites drowned by the Holocene sea-level rise). The passage opens into a very large and deep chamber, named by Palmer et al. (1986) "The Well at the End of the World", which descended to a depth of 63 m. Cave life was abundant, and a bacterial mat area was noticed at 20 m depth, associated with a "sulphurous zone" (Palmer et al., 1986, p. 75).

Re-board the vehicle and continue east on Dickie Road for 0.5 miles, stopping where a sign indicates a cave to the right (south). This is Stop 11.

STOP 11 – GRIFFIN CAVE.

The entrance to Griffin Cave (Palmer et al., 1986) is an obvious opening in a small cliff that faces northeast, just a few meters south from the road. A scree slope leads into a chamber that contains a man-made wall, finished to the outside, but rough stone on the inside (Figure 30A). Locals say that slaves housed here during the plantation period in the early 1800s built the wall. A choice of two passages lead onward, the right or west passage being the easier to negotiate (Figure 30C). Both lead to a complex of large chambers with many side passages, and many bats (Figure 30B and 30D). The cave pattern and dissolutional sculpture indicate that it is a flank margin cave. The southern passage, from the entrance chamber to the back chambers, is unusual in having a cross section similar to that found in continental caves, where phreatic tubes have had vadose canyons later incised into their floor (Figure 30C). To be a vadose canyon, turbulent, conduit flow would need to have occurred, which is very unlikely. The "canyon" shape may represent a dissolutional artifact. Such passage shapes are very rare in the Bahamas, and are known from only a few caves, such as 8-Mile Cave on Abaco (Walker, 2006) and Chinese Fire Drill Cave on San Salvador (Mylroie, 1983).

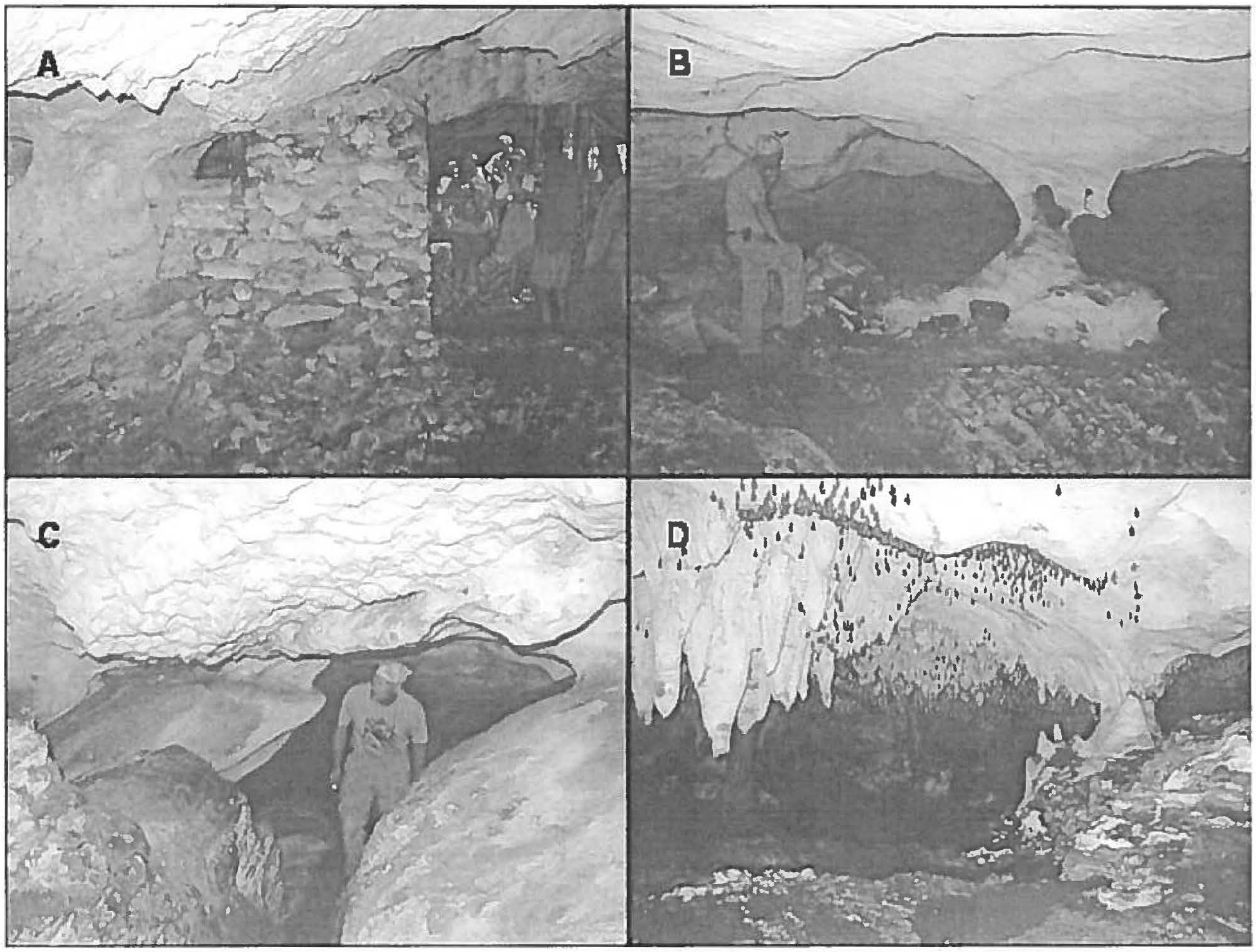


Figure 30. Griffin Cave, Stop 11 on Dickie Road. A) Entrance chamber with wall, looking out (northeast). B) Main inner chamber showing dissolutional sculpture and eolianite beds. C) Right hand passage from entrance chamber into the main chamber. D) Bats in a side area of the main chamber; floor to ceiling height is 2.5 m.

This ends the field trip. The reconnaissance work in February 2006 barely scratched the surface of the geological record of Cat Island. The potential for significant future work is outstanding.

ACKNOWLEDGMENTS

The field trip leaders are grateful to the staff and management of the Sammy T's for housing support, and Gilbert's Car Rental for transportation. Nick Cripps and John Cotton helped in locating remote field sites. Over its several decades of existence, The Gerace Research Center (formerly the Bahamian Field Station) has been instrumental in support of geological investigations throughout the Bahamas and of much of the research presented herein. The staff of the Gerace Research Center also provided full background logistical support for the field trip. Jane Curran provided patient field support, and Joan Mylroie assisted greatly with the manuscript production. The Bahamian government provided the research permits which allowed this field work to occur. The people of Cat Island and The Bahamas have been most gracious and helpful in assisting us in our field investigations. They have provided transportation, guided us to outcrops and caves, assisted with our surveys, granted permissions for access to private lands, and generally made us feel welcome. We extend our thanks to all.

REFERENCES CITED

Albury, P., 1975, The Story of the Bahamas. St. Martin's Press, Inc., New York, NY, 294 p.

Anson, P.F. 1957, The Hermit of Cat Island, The Life of Fra Jerome Hawes, P J Kennedy & Sons, New York, 296 p.

Carew, J. L., and Mylroie, J. E., 1985, Pleistocene and Holocene stratigraphy of San Salvador Island, Bahamas, with reference to marine and terrestrial lithofacies at French Bay, *in* Curran, H. A., ed., Guidebook for Geological Society of America, Orlando Annual Meeting Field Trip #2, Fort Lauderdale, FL, CCFL Bahamian Field Station, p. 11-61.

Carew, J. L., and Mylroie, J. E., 1987, A refined geochronology for San Salvador Island, Bahamas, *in* Curran, H. A., Ed., Proceedings of the Third Symposium on the Geology of the Bahamas, Fort Lauderdale, FL, CCFL Bahamian Field Station, p. 35-44.

Carew, J. L., and Mylroie, J. E., 1989a, The geology of eastern South Andros Island, Bahamas: A preliminary report, *in* Mylroie, J. E., Ed., Proceedings of the Fourth Symposium on the Geology of the Bahamas, Port Charlotte, Florida, Bahamian Field Station, p. 73-81.

Carew, J. L., and Mylroie, J. E., 1989b, Stratigraphy, depositional history, and karst of San Salvador Island, Bahamas, *in* Curran, H. A., Ed., 1989, Pleistocene and Holocene carbonate environments on San Salvador Island, Bahamas - Field trip guidebook T175, 28th International Geological Congress, American Geophysical Union, Washington, D.C., p. 7-15.

Carew, J. L., and Mylroie, J. E., 1991 [abstract], A stratigraphic model of the Bahama Islands: GSA Abstracts with Programs, v. 23, no. 1, p. 14.

Carew, J. L., and Mylroie, J. E., 1995a, A stratigraphic and depositional model for the Bahama Islands. *in* Curran, H. A. and White, B., eds., Geological Society of America Special Paper 300, Terrestrial and Shallow Marine

Geology of the Bahamas and Bermuda, p. 5-31.

Carew, J. L., and Mylroie, J. E., 1995b, Quaternary tectonic Stability of the Bahamian Archipelago: Evidence from fossil coral reefs and flank margin caves: Quaternary Science Reviews, v. 14, p. 144-153.

Carew, J. L. and Mylroie, J. E., 1997, Geology of the Bahamas. *in* Vacher, H. L., and Quinn, T. M., eds., Geology and hydrogeology of carbonate islands, Elsevier Science Publishers (948 p.), p. 91-139.

Carney, C., and Boardman, M. R., 1991 [abstract], Oolitic sediments in a modern carbonate lagoon, Graham's Harbor, San Salvador, Bahamas: GSA Abstracts with Programs, v. 23, n. 5, p. A225.

Chen, J.H., Curran, H.A., White, B. and Wasserburg, G.J., 1991, Precise chronology of the last intergalcial period: ^{234}U-^{230}Th data from fossil coral reefs in the Bahamas: Geological Society of America Bulletin, v. 103. P. 82-97.

Choquette, P.W., and Pray, L.C., 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates: American Assoc. Petroleum Geologists Bull., v. 54(2), p. 207-250.

Curran, H. A., and White, B., Eds., 1995, Geological Society of America Special Paper 300, Terrestrial and shallow marine geology of the Bahamas and Bermuda, 344 p.

Curran, H.A., and White, B., 2001, Ichnology of Holocene carbonate eolianites of the Bahamas, *in* Abegg, F.E., Harris, P.M., and Loope, D.B., eds., Modern and Ancient Carbonate Eolianites: Sedimentology, Sequence Stratigraphy, and Diagenesis: Tulsa, SEPM (Society for Sedimentary Geology) Special Publication No. 71, p. 47-56.

Dupuch, E., 1989, Bahamas Handbook and Businessman's Annual. Etienne Dupuch, Jr., Publications, Nassau Bahamas, 478 p.

Eberli, G. P., and Ginsberg, R. N., 1987, Segmentation and coalesence of Cenozoic carbonate platforms, northwestern Great Bahama Bank: Geology, v. 15, p. 75-79.

Evans, A.G., 1984, The Conscious Stone, A Biography of John C. Hawes, Polding Press, Melbourne, 300 p.

Folk, R. L., Roberts, H. H. and Moore, C. H., 1973. Black Phytokarst from Hell, Cayman Islands, British West Indies. Geol. Soc. of America Bull., 84: 2351-2360.

Frank, E. F., Mylroie, J., Troester, J., Alexander, E. C., and Carew, J. L., 1998, Karst development and speleologensis, Isla de Mona, Puerto Rico: Journal of Cave and Karst Studies, v. 60, no. 2, p. 73-83.

Garrett, P., and Gould, S. J., 1984, Geology of New Providence Island, Bahamas: Geol. Soc. Amer. Bulletin, v. 95, p. 209-220.

Geographia, 2006, http://www.geographia.com/bahamas/bsciin01.htm

Government of the Bahamas, 2000, Population Census and Growth Rates www.bahamas.gov.bs/bahamasweb2/home.nsf/

Halley, R. B., Muhs, D. R., Shinn, E. A., Dill, R. F., and Kindinger, J. L., 1991 [abstract], A +1.5-m reef terrace in the southern Exuma Islands, Bahamas: GSA Abstracts with Programs, v. 23, n. 1, p. 40.

Harris, J. G., Mylroie, J. E., and Carew, J. L., 1995, Banana holes: Unique karst features of the Bahamas: Carbonates and Evaporites, v. 10, no. 2, p. 215-224.

Hearty, P.J. and Kindler, P., 1993, New perspectives on Bahamian geology: San Salvador Island, Bahamas: Journal of Coastal Research, v. 9, p. 577-594.

Hearty, P.J. and Kindler, P., 1995, Sea-level highstand chronology from stable carbonate platforms (Bermuda and The Bahamas): Journal of Coastal Research, v. 11, p. 675-689.

Hutto, T., and Carew, J. L., 1984, Petrology of eolian calcarenites, San Salvador Island, Bahamas, *in* Teeter, J. W., ed., Proceedings of the Second Symposium on the Geology of the Bahamas, Fort Lauderdale, Florida, CCFL Bahamian Field Station, p. 197-207.

Jenson, J. W., Keel, T. M., Mylroie, J. R., Mylroie, J. E., Stafford, K. W., Taborosi, D., and Wexel, C., 2006, Karst of the Mariana Islands: The interaction of tectonics, glacioeustasy and fresh-water/sea-water mixing in island carbonates: Geological Society of America Special Paper 404, p. 129-138.

Kindler, P., 1995, New data on the Holocene stratigraphy of Lee Stocking Island (Bahamas) and its relation to sea-level history: *in* Curran, H.A., and White, B. eds., Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda: Boulder, Colorado, Geological Society of America Special Paper 300, p. 105-116.

Kindler, P. and Harty, P.J., 1995, Pre-Sangamonian eolianites in the Bahamas? New evidence from Eleuthera Island: Marine Geology, v. 128, p.73-86.

Kindler, P and Hearty, P.J., 1996, Carbonate petrography as an indicator of climate and sea-level changes: new data from Bahamian Quaternary units: Sedimentology, v. 43, p.381-399.

Kindler, P and Hearty, P.J., 1997, Geology of the Bahamas: Architecture of Bahamian Islands. *in* Vacher, H. L., and Quinn, T. M., eds., Geology and hydrogeology of carbonate islands, Elsevier Science Publishers (948 p.), p. 141-160.

Ladd, J. W., and Sheridan, R. E., 1987, Seismic stratigraphy of the Bahamas: American Association of Petroleum Geologists Bulletin, v. 71, p. 719-736.

Lascu, I., 2005, Speleogenesis of large flank margin caves of the Bahamas, MSc. Thesis. Department of Geosciences, Mississippi State University, Mississippi State, MS, 218 p.

Lind, A.O., 1969, Coastal Landforms of Cat Island, Bahamas: A Study of Accretionary Topography and Sea-Level Change: Department of Geography Research Paper No. 122, University of Chicago, Chicago, Illinois, 156 p.

Manfrino, C.M., and Ginsburg, R.N., 2001, Pliocene to Pleistocene Deposition History of the Upper Platform Margin, *in* Ginsburg, R.N., ed., Subsurface Geology of a Prograding Carbonate Platform Margin, Great Bahama Bank: Results of the Bahamas Drilling Project. Society for Sedimentary Geology Special Publication No. 70: Tulsa, Society for Sedimentary Geology, p. 17-39

Melim, L. A., and Masaferro, J. L., 1997, Geology of the Bahamas: Subsurface geology of the Bahama Banks. *in* Vacher, H. L., and Quinn, T. M., eds., Geology and hydrogeology of carbonate islands, Elsevier Science Publishers (948 p.), p. 161-182.

Meyerhoff, A. A., and Hatten, C. W., 1974, Bahamas salient of North America: Tectonic framework, stratigraphy, and petroleum potential: American Association of Petroleum Geologists Bulletin, v. 58, p. 1201-1239.

Mirecki, J. E., Carew, J. L., and Mylroie, J. E., 1993, Precision of amino acid enantiomeric data from fossiliferous Late Quaternary units, San Salvador Island, Bahamas. *in* White, B. ed., Proceedings of the 6th Symposium on the Geology of the Bahamas, Port Charlotte, Florida, Bahamian Field Station, p. 95-101.

Mullins, H.T., and Lynts, G.W., 1977, Origin of the Northwestern Bahama Platform: Review and Reinterpretation: Geological Society of America Bulletin, v. 88, p. 1447-1461.

Mullins, H. T., and Hine, A. C., 1989, Scalloped bank margins: Beginning of the end for carbonate platforms?: Geology, v. 17, p. 30-39.

Mullins, H. T., and Hine, A. C., 1990, Reply to comments by M. M. Ball: Geology v. 18, p.95-96.

Mylroie, J. E., 1983, Karst Geology and Pleistocene History of San Salvador Island, Bahamas: *in* Gerace, D. T., ed., Proceedings of the First Symposium on the Geology of San Salvador Island, March 22-25, 1982, CCFL, Ft Lauderdale, Florida, p. 6-11.

Mylroie, J. E. and Carew, J. L., 1990, The Flank Margin Model for Dissolution Cave Development in Carbonate Platforms: Earth Surface Processes and Landforms, v. 15, p. 413-424.

Mylroie, J. E., Carew, J. L., and Moore, A. I., 1995, Blue holes: Definition and genesis: Carbonates and Evaporites, v. 10, no. 2, p. 225-233.

Palmer, R. J., 1986, Preliminary studies of speleogenesis on Cat Island, Bahamas: Cave Science, v. 13, no. 2, p. 79-82.

Palmer, R. J., McHale, M., and Hartlebury, R., 1986, The caves and blue holes of Cat Island: Cave Science, v. 13, no. 2, p. 71-78.

Panuska, B. C., Mylroie, J. E., and Carew, J. L., 1999, Paleomagnetic evidence for three Pleistocene paleosols on San Salvador Island. *in* Curran, H. A. and Mylroie, J. E., eds., Proceedings of the Ninth Symposium on the Geology of the Bahamas and other carbonate regions, Bahamian Field Station, San Salvador Island, Bahamas, p. 93-100.

Panuska, B. C., Boardman, M. R., Carew, J. L., Mylroie, J. E., Sealey, N. E., and Voegeli, V., 2002, Eleuthera Island Field Trip Guide, 11th Symposium on the Geology of the Bahamas and Other Carbonate Regions. Gerace Research Center, San Salvador Island, Bahamas, 20 p.

Popov, D. and Popov, N, eds., 1988, Island Expedition, The Central and Southern Bahamas. Graphic Media, Miama, FL, 208 p.

Schwabe, S. J. and Carew, J. L., 2006, Blue Holes: An Inappropriate Moniker for Water-filled Caves in the Bahamas. *in* Davis, R. L., and Gamble, D. W., eds., Proceedings of the 12th Symposium on the Geology of the Bahamas and Other Carbonate Regions, Gerace Research Center, San Salvador, Bahamas, p.179-187.

Sealey, Neil, 2006: The Cycle Of Casuarina-Induced Beach Erosion – A Case Study From Andros, Bahamas. *in* Gamble, D. ed., Proceedings of the 12th Symposium on the Geology of the Bahamas and other Carbonate Regions, 2004, Gerace Research Center, San Salvador, p. 197-205

Sheridan, R. E., Crosby, J. T., Bryan, G. M., and Stoffa, P. L., 1981, Stratigraphy and structure of southern Blake Plateau, northern Florida Straits, and northern Bahama platform from multichannel seismic reflection data: American Association of Petroleum Geologists Bulletin, v. 65, p. 2571-2593.

Sparkman-Johnson, S. D., Carew, J. L., and Mylroie, J. E., 2001, The surficial geology of the Hard Bargain area, San Salvador Island, Bahamas. *in* Carney, C. K. and Greenstein, B. J., eds., of the Tenth Symposium on the Geology of the Bahamas and other carbonate regions, Gerace Research Center, San Salvador Island, Bahamas, p. 67-77.

Taborosi, D., Jenson, J.W. and Mylroie, J.E. 2004, Karren features in island karst: Guam, Mariana Islands: Zeitschrifft fur Geomorphologie. N.F. 48: 369-389.

Taylor, J. J., 2000, Between Devotion and Design, The Architecture of John Cyril Hawes, 1876-1956. University of Western Australia Press, 428 p.

Titus, R., 1980, Emergent Facies Patterns on San Salvador Island, Bahamas, *in* Gerace, D.T., ed., Field Guide to the Geology of San Salvador: Miami, CCFL Bahamian Field Station, p. 92-105.

Uchupi, E., Milliman, J. D., Luyendyk, B. P., Brown, C. O., and Emery, K. O., 1971, Structure and origin of the southeastern Bahamas: American Association of Petroleum Geologists Bulletin, v. 55, p. 687-704.

Vacher, H. L. and Hearty, P., 1989, History of Stage 5 sea level in Bermuda: review with new evidence of a brief rise to present sea level during substage 5A: Quaternary Science Reviews, v. 8, p. 159-168.

Vacher, H. L. and Bengtsson, T. O., 1989, Effect of hydraulic conductivity on the residence time of meteoric ground water in Bermudian- and Bahamian-type Islands, *in* Mylroie, J. E., Ed., 1989, Proceedings of the fourth symposium on the geology of the Bahamas, June 1988, Bahamian Field Station, San Salvador, Bahamas, p. 337-351.

Vacher, H. L., and Mylroie, J. E., 2002, Eogenetic karst from the perspective of an equivalent porous medium:

Carbonates and Evaporites: v. 17, no. 2, p. 182-196.

Walker, L. N., 2006, The caves, karst and geology of Abaco Island, Bahamas. MSc Thesis, Mississippi State University, 241 p.

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., Proceedings of the 6th Symposium on the Geology of the Bahamas: San Salvador, Bahamian Field Station, p. 23-34.

Wilbur, R. J., 1987, Geology of Little San Salvador Island and West Plana Cay: Preliminary findings and implications for Bahamian island stratigraphy, *in* Curran, H. A., ed., Proceedings of the Third Symposium on the Geology of the Bahamas, Fort Lauderdale, FL, CCFL Bahamian Field Station, p. 181-204.

Wilbur, R. J., 1991 [abstract], Morphostratigraphy and depositional facies of West Plana Cay and Little San Salvador, Bahamas: Carbonate island response to sea level change: GSA Abstracts with Programs, v. 23, n. 1, p. 149.

Wilson, W. L., 1994, Morphology and Hydrology of the Deepest Known Cave in the Bahamas: Dean's Blue Hole, Long Island, *in* Boardman, M. R., (ed.), Seventh Symposium on the Geology of the Bahamas. Bahamian Field Station, San Salvador Island, Bahamas, p. 21

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