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PRELIMINARY INVESTIGATIONS OF 13 FOSSIL REEFS ON SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

The purpose of this study is to conduct field studies of fossil reefs on the San Salvador Island in order to determine the paleontological and geological background of these reefs with particular emphasis on preservation. There are fifteen known subaerial fossil reef localities on San Salvador Island, Bahamas which are located on or close to the current shoreline. They are part of the Cockburn Town Member of the Grotto Beach Formation and represent the oxygen isotope substage 5e (~131 to 119 ka) sea-level highstand (when sea level was up to +6m above modern). The reefs range from an *in situ* bank/barrier reef to a series of small patch reefs. The most extensive fossil reefs encompass the western (leeward) side of San Salvador Island, while small reefs and reef rubble comprise the eastern (windward) side reefs.

The coastal Cockburn Town (west), Sue Point (northwest), Devils Point (west), Crab Cay (east), and Holiday Tract (southeast) fossil reefs are the most extensive reefs on the island. They consist of *in situ*, overturned, and fragmented fossil corals entombed in a fine calcarenite, with an overlying, subtidal and/or beach package, and commonly an eolianite. This sequence is usually topped by a terra rossa paleosol. North Storrs Lake reef is an *in situ* fossil patch reef 350m inland of the eastern coast and consists of breccia, *in situ* and overturned coral fossils in calcarenite, subtidal molluscan fossils, and a terra rossa paleosol with a caliche/calcrete crust. Pigeon Creek reef is a poorly-preserved *Montastrea sp.*-dominated reef in a tidal creek, with *in situ* and rotated fossil corals, subtidal calcarenite with abundant mollusks, breccia containing corals and mollusks, and a terra rossa paleosol. The southwestern coastal Grotto Beach reef and northern inland Mosquito reef are Porities sp. dominated, patch reefs with *Neogoniolithon* contained within a subtidal calcarenite, beach facies, and an eolianite. The south coast Gulf reef is a disarticulated, *Acropora* sp.-dominated outcrop that includes coral fossils entombed in a fine calcarenite, a protosol, a regressive eolinite, vegemorphs, and a caliche/calcrete crust capping the cliff. Storr's Lake Narrows and Salt Pond, on the east coast; Reckley Hill Pond on the north coast interior; and Quarry Point on the southwest coast are coral rubble sites, containing rotated corals within fine calcarenites. The fossil reefs of San Salvador Island mark a period of carbonate deposition that may have helped control overall island development.

INTRODUCTION

The Quaternary evolution of the San Salvador Island landscape has been largely controlled by glacioeustatic sea-level fluctuations that affected both the deposition and alteration of carbonate sediments. Coral reefs have been instrumental in the deposition phase. During the last interglacial (oxygen isotope 5e, ~125ka), sea level rose to +6m above present thereby submerging most of the platform. Corals then grew on the newly submerged platform forming, in some circumstances, extensive reefs. As sea-level dropped, the coral reefs were either buried or disarticulated and destroyed.

Today, the fossil coral reefs can be found in the Cockburn Town Member of the Grotto Beach Formation. We have conducted field studies on 13 reefs on the island in order to determine the paleontological and geological background of these reefs with particular emphasis on preservation. There are at least 15 known fossil reefs on the island, but only four of which have been researched (Cockburn Town, Sue Point, Grotto Beach, and Mosquito) (Curran and White, 1984; Vierma et al., 1984; White, 1989; and Hattin, 1989). The known fossil reef locations are on the current island perimeter (Figure 1). Of these reefs, those with the most complexity and diversity are located on the west and northwest sides. The reefs range from an *in situ* bank/barrier reef to patch reefs and reef rubble with the primary coral being *Montastraea.*

The earliest studies of the fossil reefs on the island were conducted by Curran and White (1984) on the Cockburn Town fossil reef, Vierma et al. (1984) on Mosquito fossil reef, White (1989) on Sue Point fossil reef, and Hattin (1989) on the Grotto Beach fossil reef. Of these four, the most extensive work has been done on the Cockburn Town and Sue Point reefs because of their exceptional preservation and accessibility. Beyond these taxonomic studies, the fossil reefs on the island have also used to identify the last interglacial highstand (oxygen isotope substage 5e) using U/Th age dating (Carew and Mylroie, 1987; Chen et al, 1991; White et al., 1996).

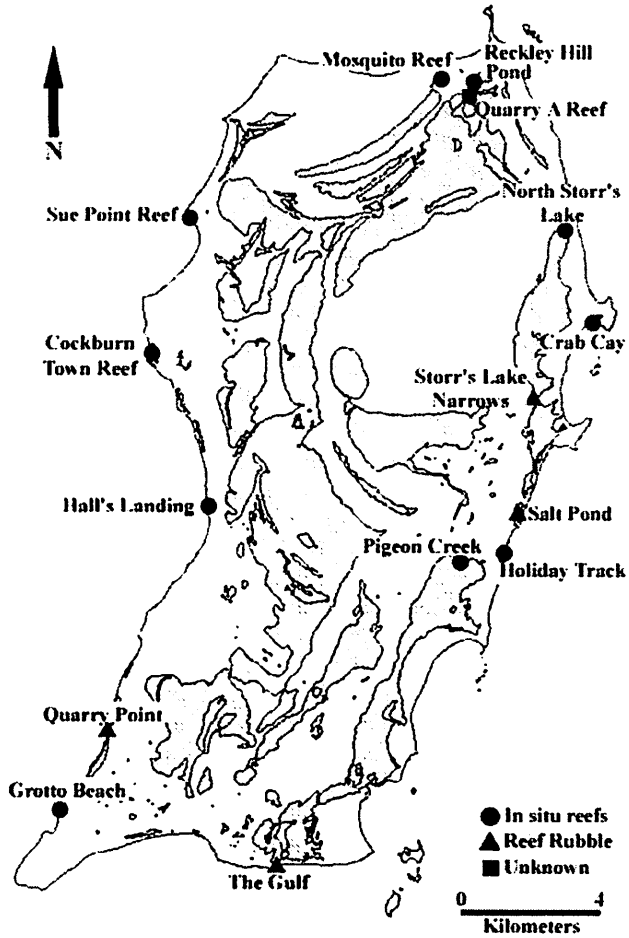

Figure 1. San Salvador Island with known fossil reef localities (map from Robinson and Davis, 1999).

METHODS

Measuring and sampling of 13 fossil reefs was conducted during three trips to San Salvador Island. The first trip included the reefs at Crab Cay, Salt Pond, Storr's Lake Narrows, and Reckley Hill Pond; the second Pigeon Creek, The Gulf, North Storr's Lake, and Grotto Beach; and the third trip Cockburn Town, Sue Point, Hall's Landing, Mosquito Marsh, and Quarry Point. Fossil corals had been reported from Quarry A (Carew and Mylroie, 1987), but the site has been altered by further quarrying and the corals could not be located for this study. The reefs were divided into categories, depending on the size and type of reef, during each trip in order to use consistent field techniques. The reefs with supplemental maps (Grotto Beach, Cockburn Town, Sue Point, and Mosquito Marsh reefs) were measured and the geology and paleontology of the areas were compared with the published maps and were photographed accordingly.

At Salt Pond, Storr's Lake Narrows, Reckley Hill Pond, the Gulf, and Quarry Point; transects across the reefs were created and the general geology along each transect was recorded. These transects were each set up to obtain the best information from the available exposed outcrop, and as such are somewhat arbitrary and are independent of each other. The location and

	Paleosol	Deposit*	Karst	Coralstone	Dominate Coral	Size	Current Location ⌖	Preserv-ation
Cockburn Town	terra rossa	s, b, e	Past	*In itu*	*Acropora* sp.✧	650m ✧	OS	Excellent
Crab Cay	terra rossa	s, b, e	Past	*In situ*	*Montastraea* sp.	165m	OS	Excellent
Grotto Beach	N/P	s, b, e	Recent	*In situ*	*Porites* sp.	18m	OS	Good
Hall's Landing	terra rossa	s, b	Past	*In situ*	*Montastraea* sp.	242m	OS	Fair
Holiday Track♦	terra rossa	s, b	Recent	*In situ*	*Agaricia* sp.	276m	OS	Good
Mosquito Reef	N/P	s, b, e	Recent	*In situ*	*Porites* sp. ☙	41m☙	WL	Good
North Storr's Lake	terra rossa	s	Recent	*In situ*	*Montastraea* sp.	107m	OS	Excellent
Pigeon Creek	terra rossa	s	Recent	*In situ*	*Montastraea* sp.	166m	TC	Fair
Quarry Point	terra rossa	s, b	Past	Rubblestone	*Montastraea* sp.	167m	OS	Poor
Reckley Hill Pond Reef	terra rossa	s, b, e	None	Rubblestone	*Diploria* sp.	8m	LS	Fair
Salt Pond	terra rossa	s	Recent	Rubblestone	*Diploria* sp.	127m	LS	Fair
Storr's Lake Narrows	N/P	s	Recent	Rubblestone	*Diploria* sp.	20m	LS	Fair
Sue Point	terra rossa	s, b, e	Past	*In situ*	*Montastraea* sp.	243m ❖	OS	Excellent
The Gulf	protosol	e	Past	Rubblestone	*Acropora* sp.	27m	OS	Poor

*Table 1. Information gathered about each reef studied. *N/P-not present, s-subtidal, b-beach, e-eolianite; ⌖OS-ocean shoreline, WL-wetland, LS-lake shoreline, TC-tidal creek shoreline; ♦McGee, 2006; ☙Vierma et al. 1984; ❖White, 1989; ✧White et al., 1984*

position of individual fossil corals were then plotted and photographed as well as identified using *A Field Guide to Coral Reefs: Caribbean and Florida* (Kaplan, 1982) and *The Audubon Society Field Guide to North American Seashore Creatures* (Meinkoth, 1981). They were later confirmed using the *Neogene Marine Biota of Tropical America Database.* Samples were collected that were *in situ* or near *in situ* position for later analysis.The more extensive reefs at Crab Cay, Pigeon Creek, North Storr's Lake, and Hall's

Landing were also observed through multiple sampling transects. However, due to the size of the reef complex, the corals were plotted based on primary coral species in a particular transect and the secondary and unique species were recorded to measure for diversity. Each transect was photographed and samples were removed from *in situ* position.

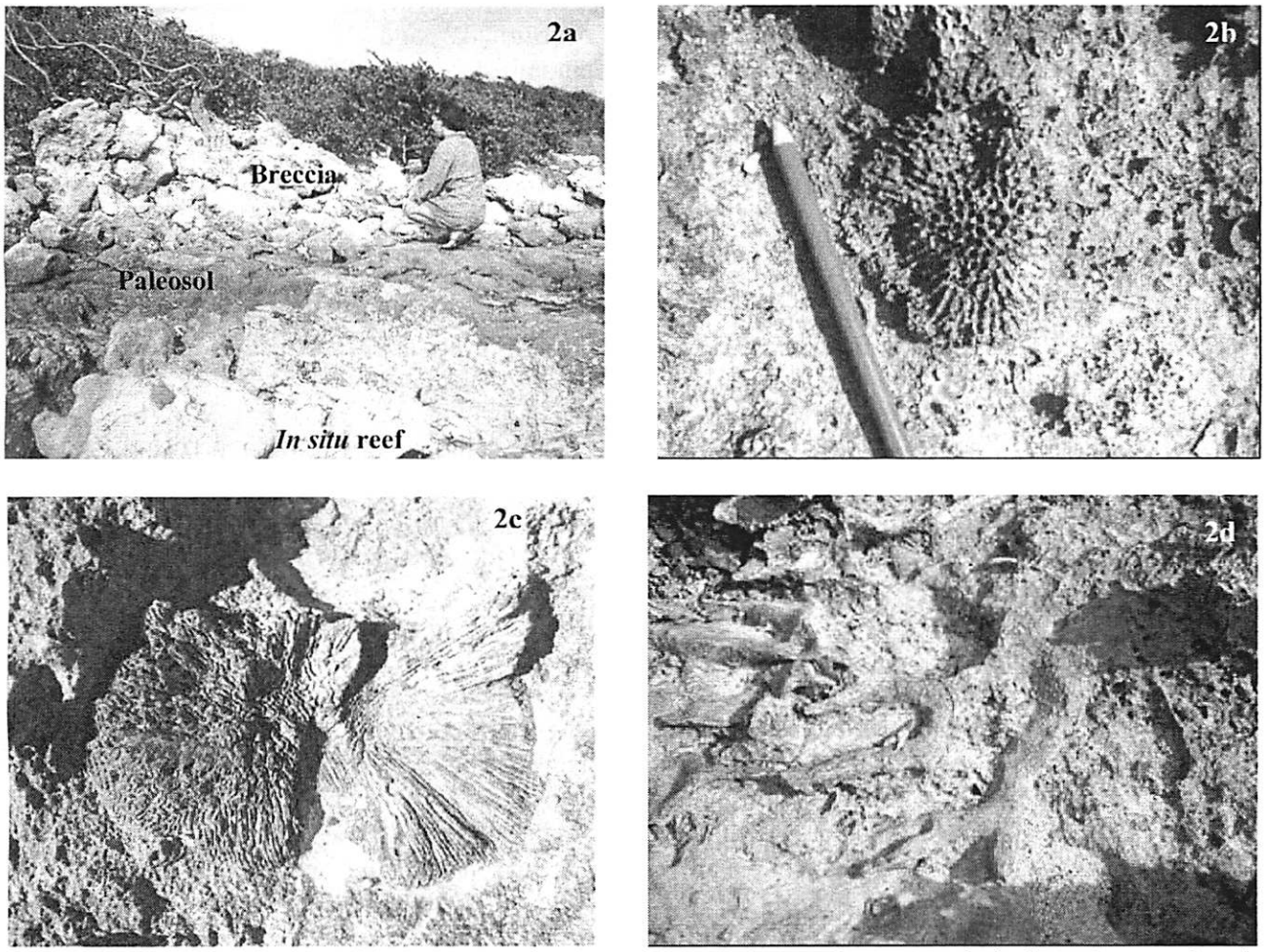

Figure 2. a. Vertical view of deposits over in situ *reef at Crab Cay, b.* M. annularis *from Pigeon Creek, c.* D. strigosa *from Hall's Landing, d.* A. palmata *from Crab Cay*

Skeletal samples of *Montastraea annularis* and *Diploria strigosa* from Crab Cay, Storr's Lake Narrows, and Salt Pond were thin sectioned and impregnated with epoxy in order to study the preservation and degree of alteration in the corals. Samples from the same corals were also analyzed by X-ray diffractometry so as to establish the degree of diagenetic alteration.

RESULTS AND DISCUSSION

The fossil reefs on San Salvador Island (Figure 1) include: 1 *in situ* bank/barrier reef (Cockburn Town reef), 8 *in situ* patch reefs (Crab Cay, Grotto Beach, Hall's Landing, Holiday Track Mosquito reef, North Storr's Lake, Pigeon Creek, and Sue Point) and 4 reef rubble localities (Quarry Point, Salt Pond, Storr's Lake Narrows, and The Gulf). A summary of the taxonomic analysis completed for this study are listed in Table 1 and a summary of each type of fossil reef is discussed below.subtidal and beach deposits to eolianites (Curran and White, 1984).

Bank/Barrier Reef

The Cockburn Town fossil reef is the only known fossilized bank/barrier reef on San Salvador Island. It is located on the western (leeward) side of the island extending 650m along the shore at Cockburn Town. The reef

complex is dominated by *Acropora palmata* and *A. cervicornis*, with lesser amounts of *Diploria* sp., *Montastraea* sp., and *Porites* sp. It has distinct ecological zones in addition to a well-defined shallowing upward sequence grading from *in situ* fossil corals through to shallow During the last interglacial, the Cockburn Town reef flourished. The reef records evidence of a sea level adjustment in substage 5e (White et al., 1996). As subsequent regression occurred, the reef quickly became buried by the prograding shoreline, or by a major storm event (Carew and Mylroie, 1995a). This changing environment allowed subtidal, beach and, later, eolian calcarenites to accumulate on the reef.

Patch Reefs

There are eight known *in situ* fossil patch reefs on San Salvador Island. They are located in a variety of modern environments ranging from beach to inland lakes. These reefs can further be subdivided into distinct groups based on similarities in size, structure, species, and preservation and the distinct groups are described below.

Crab Cay, Hall's Landing, Holiday Track, and Sue Point. Crab Cay, Hall's Landing, Holiday Track, and Sue Point fossil reefs constitute the largest set of the patch reefs on the island. Each location consists of a series of patch reefs that are on a current shoreline. The western reefs include Sue Point and Hall's Landing and the eastern reefs include Crab Cay and Holiday Track. The fossil reefs have been identified as being in the Cockburn Town Member of the Grotto Beach Formation based on U/Th alpha count dates (Carew and Mylroie, 1987).

Crab Cay is located on the northeastern coast of San Salvador Island. Along the southern flank of the cay is a fossil reef outcrop that has been identified as being in the Cockburn Town Member of the Grotto Beach Formation based on U/Th alpha count dates *(Montastrea annularis* 135±8 ka) (Carew and Mylroie, 1987). The total length of the reef is 165m. The reef geology consists of *in situ*, overturned, and fragmented fossil corals entombed in an oolitic and bioclastic sediment with an overlying terra rossa paleosol and caliche/calcrete crust. Directly overlying the reef is a terra rossa paleosol. The reef forms the shore of Crab Cay at this location and has an unlithified back beach rubble facies composed of sand, re-worked fossil corals, and modern coral fragments overlying the paleosol. Carew and Mylroie (1987) obtained samples of *M. annularis* and *D. strigosa* from Crab Cay, Hall's Landing, Sue Point and Holiday Track and determined that the corals were 100% aragonite. However, recent samples of fossilized *M. annularis* and *D. strigosa* from Crab Cay were subjected to X-ray diffraction and thin section analysis. Both of these procedures indicate that the fossil composition is primarily aragonite (99%) with trace amounts of calcite (1%).

Hall's Landing is situated on Fernandez Bay approximately 3km south of Cockburn Town. The reef is a series of three patch reefs totaling 242m long running north to south. The geology of the area includes a thin subtidal package consisting of bioclastic sediment, followed by a lithified beach deposit with a terra rossa paleosol overlaying the reef. The reef itself is an *in situ Montastraea* sp. dominated reef with lesser amounts of *Diploria strigosa* and *Porities porities*. The position of the corals suggests distinct ecological zonation in the reef that is common in patch reefs found today around the island.

The fossil reef at Holiday Track is located on the eastern shoreline and runs for 275m north to south. The reef is dominated by *Agaricia agaricites* and *P. porites,* indicating that the corals exposed are the remnants of a shallow back reef zone. Located around the corals is a subtidal deposit with a molluscan fauna. Overtop the reef is a terra rossa paleosol covered by lithifed Holocene beach deposits (McGee, 2006). The Holiday Track reef was originally dated using U/Th by Carew and Mylroie (1987) and resulted in an age of 103±4 ka. This date is not within the substage 5e interglacial, but rather, substage 5c. The

geology, however, suggests that the reef is a 5e reef.

Sue Point fossil reef complex is located on the western shoreline, south of Victoria Hill Settlement. The reef complex is actually a set of two linear patch reefs dominated by *Diploria, Montastraea,* and *Porites* (Curran and White, 1984). The situations of the corals indicate the development and preservation of distinct ecological zones similar to those found at Crab Cay and Hall's Landing. Atop the reef are subtidal, beach, and eolianite deposits capped by a terra rossa paleosol.

Grotto Beach and Mosquito Reef. Grotto Beach fossil reef and Mosquito reef are small patch reefs capped with fossilized coralline red algae. The Grotto Beach fossil reef is located on the southwestern side of the island on the current ocean shoreline. Mosquito reef is located on the northeast side, about 350m south of the current ocean shoreline in a wetland environment. The reefs are *Porites* dominated with lesser amounts of *Diploria* and *Montastraea.* Overlaying the reefs, as previously mentioned, is coralline red algae (Grotto Beach, *Neogoniolithon strictum*; Mosquito reef, *Goniolithon*). These coralline algae can be found in modern subtidal zones and are often exposed during low tides (Hattin and Warren, 1989; Vierma et al., 1984).

The Grotto Beach and Mosquito reefs show a similar shallowing upward sequence and deposition model as described in the last set of patch reefs. Subtidal, beach, and eolianite deposits are located on or near the reef complexes. In the case of Grotto Beach, the reef actually lies on top of an older eolianite (stage 7 or older). Atop the reef is subtidal, beach and substage 5e regressive eolianite deposits, with a capping paleosol. Subtidal and beach deposits overlay Mosquito reef; however, an eolinite is not directly connected to the reef complex, but there is an eolianite directly behind it (Hattin and Warren, 1989; Vierma et al., 1984).

North Storr's Lake and Pigeon Creek (Figure 3). North Storr's Lake and Pigeon Creek are located on the eastern side of the island. The reef at North Storr's Lake is located along the northern lake shoreline and runs 107m east to west. The geology of the area is within the Cockburn Town Member of the Grotto Beach Formation (Carew and Mylroie, 1995a) and consists of breccia, *in situ* and overturned coral fossils, subtidal molluscan fossils, a terra rossa paleosol, and a caliche/calcrete crust. The dominant *in situ* coral found throughout the reef is *Montastrea annularis.* The corals clearly show excellent preservation, for the delicate septa are still present and are comparable to living corals. This reef is the site of a karst feature that drains hypersaline water from Storr's Lake during tidal lows, but yields marine water during tidal highs. The karst feature is a series of holes and drains in the reef and associated rock. In several places, the karst action has dissolved away the center of coral heads, leaving a pit in the center of the coral. Pigeon Creek is a tidal creek that runs north to south along the southeastern periphery of San Salvador Island. It has direct access to marine water via a delta to the south. On the lobe at the northern shore of the creek is a fossil coral reef that is 166m long that has been identified as being in the Cockburn Town Member of the Grotto Beach Formation based on U/Th alpha count dates (*M. annularis* 146±10ka) (Carew and Mylroie, 1987). The geology of the area includes *in situ* and rotated fossil corals, subtidal deposits with abundant mollusks, breccia containing corals and mollusks, and a terra rossa paleosol. The rock and fossils in direct contact with the water have undergone dissolution creating karst-like terrain. The coral reef has such a high degree of dissolution that it is difficult to determine the abundance of the corals, though the dominant coral appears to be *Montastrea annularis.*

Depositional Model. All the fossilized patch reefs on San Salvador Island, as previously mentioned, occurred during the last interglacial (substage 5e). Given the data from these reefs, a general depositional model may be established. The reefs most likely flourished during the Pleistocene substage 5e still-stand ~125ka. During subsequent regression,

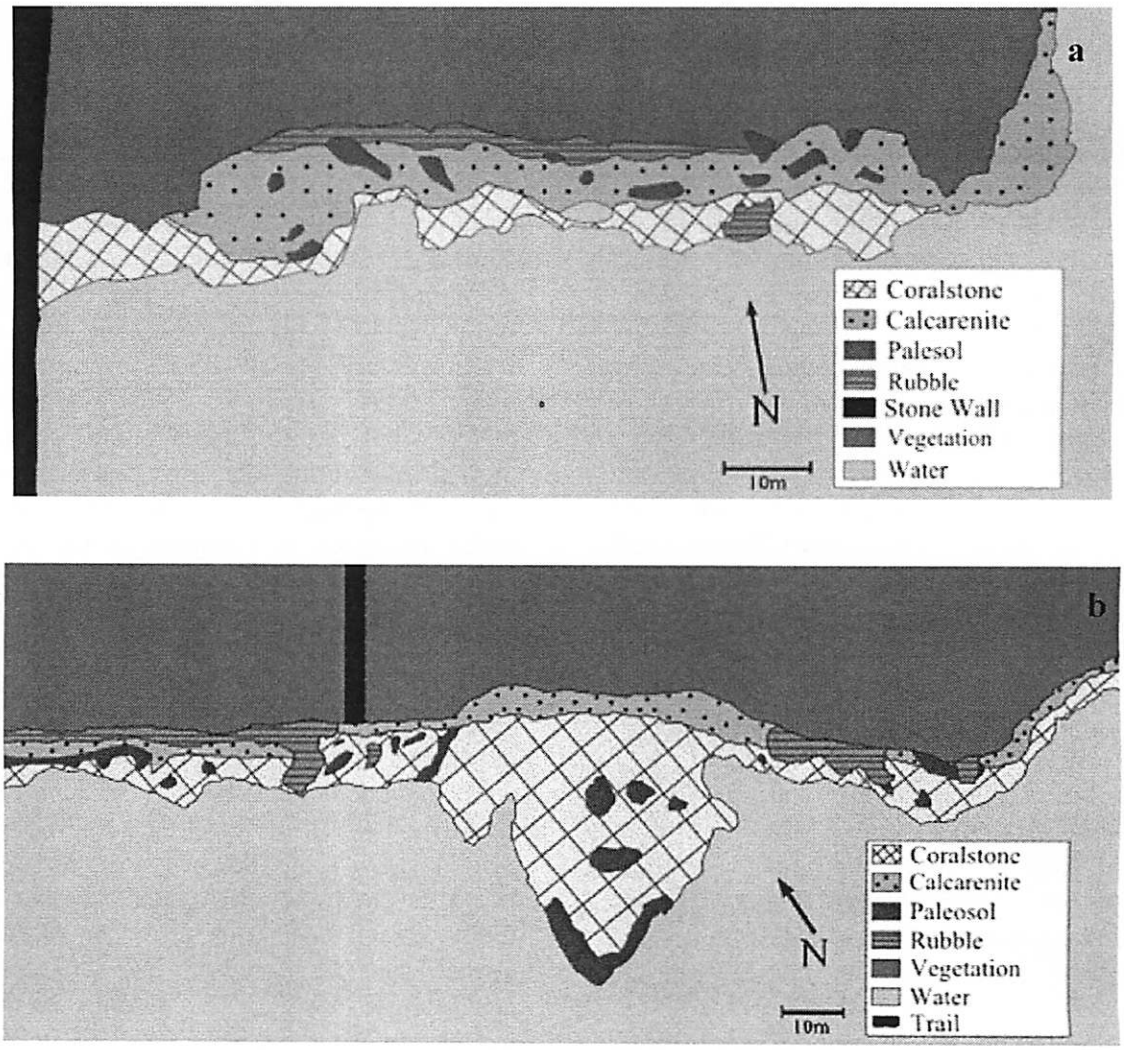

Figure 3. North Storr's Lake reef (a) and Pigeon Creek ree f(b) maps.

the reefs were partially buried by the prograding shoreline and associated beach and eolian deposits. Later lowstand phases further exposed the reef allowing for pedogenesis to occur that would later develop into a terra-rossa paleosol. Holocene transgression occurred, allowing further burial of the reefs in modern sands. Later erosion set the reefs in their current configuration.

Reef Rubble

Storr's Lake Narrows, Salt Pond, Reckley Hill Pond, and Quarry Point. Storr's Lake Narrows lie 640 m west of the current ocean shoreline on the shore of a hypersaline lake. The geology of the area has been identified as being in the Cockburn Town Member and consists of an oolitic and bioclastic breccia that ranges in size from 1 cm up to 1 m and fossil corals that range in size from 2 cm to 60 cm. Fossils were located on the western side of the Narrows within a small area, approximately 20m by 15 m, in breccia both in and on the lake's edge. A more extensive outcrop was reported prior to recent road widening (Carew and Mylroie, 1987). X-ray diffraction analysis indicates fossil composition to be primarily aragonite with trace amounts of calcite and low magnesium calcite. Thin section analysis confirms this by clearly showing original

aragonitic structure as well as micritization and calcite replacement.

Salt Pond consists of two saline ponds divided by a natural bench consisting of calcarenite identified as being within the Cockburn Town Member. The geology consists of an oolitic and bioclastic breccia, marine corals and mollusks, and an overlying terra rossa paleosol. The fossils are located along the northern shore of the lake and on the bench, within the calcarenite and breccia. The terra rossa paleosol occurs most extensively along the northern shore; however, remnants can be seen at the bridge. Salt Pond is the site of a reef rubble pile as demonstrated by the breccia and the broken fragments of fossils that are lithified in a calcarenite covered by a terra rossa paleosol.

Reckley Hill Pond reef is located approximately 500m south of Grahams Harbor and southeast of the Gerace Research Center. It is located on a wooded trail that runs from the GRC, around Reckley Hill Pond. There is a thick cover of detrital material from the surrounding vegetation and, therefore, the exposure is limited. The area exposed in December 2003 ran 8m parallel to the trail and 2m at its widest spot. The exposed corals included overturned *Montastraea annularis* and *Diploria strigosa*. The geology of the area shows a terra rossa paleosol overlaying some corals and eolianite further south of the reef. Corals with a terra rossa paleosol cover is a characteristic feature in the Cockburn Town Member of the Grotto Beach Formation; therefore, the reef is also classified being in that Member in the absence of U/Th dates.

Quarry Point is located on the eastern shoreline approximately 2.5km north of Grotto Beach. The geology of the area has been classified as being in the Cockburn Town Member of the Grotto Beach Formation (*A. palmata* 145±12 ka) (Carew and Mylroie, 1987). The outcrop is an area of exposed beach rock and loose beach sand with corals uncovered intermittently. The primary coral found was *Montastraea annularis* with lesser amounts of *Diploria strigosa*. There seemed to be no *in situ* structure and the corals were found in overturned positions.

Storr's Lake Narrows, Salt Pond, Reckley Hill Pond, and Quarry Point are coral rubble sites. The reefs may have flourished during the Pleistocene 5e still-stand and were possibly destroyed by a storm event or from the post-5e drop in sea level. There is little evidence for the corals to have been transported a great distance because they still retain clear edges and show little to no rounding and are therefore assumed to be near the original reef locations. The remaining corals were then buried in sands, lithified, and later erosion exposed them.

The Gulf. The Gulf is a cliff approximately 7.5m high and 100m wide located on the southern shoreline west of Sandy Hook. The geology of the area is within the Cockburn Town Member of the Grotto Beach Formation based on U/Th alpha count dates (*Diploria* sp. 115±7ka) (Carew and Mylroie, 1995a). The outcrop includes coral fossils entombed in a fine sediment forming a basal platform, a protosol, a regressive eolinite with foreset beds that dip about 30° to the west, vegemorphs that extend through the eolinite, caliche/calcrete crust that caps the cliff, and storm tossed blocks containing entombed fossil corals and loose modern corals located at both the base of the cliff and at the top. The fossil corals at the base are primarily overturned *Acropora* sp. located on the basal platform. The fossil reef is subjected to nearly continuous wave erosion and is only exposed during low tides.

The *Acropora* sp. at the Gulf indicates that the reef developed in a high-energy environment during the substage 5e still-stand. During the subsequent regression, falling wavebase disarticulated the reef. The migrating shoreline buried the remaining coral underneath a regressive eolinite package. The Gulf is located only 100 m from the platform edge.

CONCLUSIONS

The fossilized coral reefs on San Salvador Island represent a time of prime reef

development. The sea level high-stand during the late Pleistocene (substage 5e) covered large portions of the San Salvador Island platform to +6m above modern day sea level and created an environment for carbonate reef growth and development. These reefs subsequently were buried, became fossilized, and subaerially exposed due to later erosion. The ruggedness and remoteness of the island interior, coupled with the paucity of good outcrops, make it feasible that other large and well-developed fossil reefs potentially exist there. However, the 15 known fossil reef localities are on the current island perimeter, suggesting San Salvador Island was an atoll-like bank during the last interglacial. The known reefs with the most complexity and diversity are located on the west and northwest sides, perhaps indicating development and also preferential preservation in the lee of the southeast tradewinds.

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