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COMPARATIVE ANALYSIS OF SPECIES AND FACIES: A STUDY OF TWO LATE PLEISTOCENE FOSSIL CORAL REEFS, SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

At least fifteen fossil coral reef localities that formed during oxygen isotope substage 5e (approximately 135-119 ka) exist on San Salvador Island, The Bahamas, of which only three have been intensively studied until recently: Cockburn Town fossil reef, Grotto Beach fossil reef, and Sue Point fossil reef. Two unstudied reefs at Reckley Hill Pond and Holiday Tract were investigated by the author to determine their physical and biologic characteristics using direct observation and transect sampling methods. The Reckley Hill Pond fossil reef outcrop is limited in exposure and species composition relative to the Grotto Beach and Sue Point fossil reefs. A single coral species, *Montastraea annularis* was found in the exposed outcrop. In contrast, Holiday Tract fossil reef is a much larger and more diverse fossil reef consisting of *in situ* and boulder rubble components, both of which were determined to be related constituents of the same patch reef. This reef is dominated by *Porites porites* with lesser numbers of *Agaricia agaricites* and *Diploria strigosa*. Beach progradation associated with marine regression at the end of the oxygen isotope substage 5e sea level highstand likely buried both reefs. When compared to modern analogues as well as two previously studied fossil reef sites at Grotto Beach and Sue Point, evidence suggests that the Reckley Hill Pond and Holiday Tract fossil reefs are considered patch reefs bearing similar physical and biologic characteristics. The depositional model of The Bahamas developed by Carew and Mylroie (1995) suggests the Reckley Hill Pond and Holiday Tract fossil reefs are roughly the same age, and formed during the oxygen isotope substage 5e highstand. The presence of a terra-rossa paleosol on these reefs (including the boulders at Holiday Tract) indicates a long-term period of exposure during the lowstand of sea level between substage 5e and present, as sea level during that interval failed to reach levels high enough to completely erode or bury these deposits.

INTRODUCTION

Of at least fifteen known fossil coral reef localities that exist on San Salvador Island, The Bahamas, only three have been intensely studied. The Cockburn Town, Grotto Beach, and Sue Point localities have each been interpreted as having originated during oxygen isotope substage 5e roughly 132-119 ka (Chen et al., 1991; Curran & White, 1984; Hattin & Warren, 1989; White, 1989). Cockburn Town fossil reef is dominated by *Acropora palmata* and *A. cervicornis*, with lesser amounts of *Diploria, Montastraea, and Porites* species and is believed to be a bank-barrier reef with distinctive ecological zones in a well-defined shallowing upward sequence (Curran & White, 1984). In contrast, Grotto Beach fossil reef is inferred to be a patch reef characterized by small aggregates of a few coral species, in this case, *Diploria*, *Montastraea,* and *Porites* (Hattin & Warren, 1989). Sue Point fossil reef is also believed to be a patch reef, sharing the majority of its faunal composition with Grotto Beach (White, 1989)

Of the remaining fossil reefs, very little is known as their location and exposure has prevented the depth of study afforded by the Cockburn Town, Grotto Beach, and Sue Point localities. My research focuses on two of these reefs, Holiday Tract and Reckley Hill Pond (Fig. 1), to characterize their localities for the first time based on physical and biologic assessments, and compares them to modern and ancient equivalents on the island. Holiday Tract fossil reef is located on San Salvador's eastern shore midway between Almgreen Cay and The Bluff (Figs. 1 and 2). It is characterized by a continuous 275 m fossil reef outcrop within the intertidal zone of the present day shoreline, and a near continuous line of boulder rubble just under the modern dune ridge paralleling the outcrop between 0.5 and 7 m to the west. Both the reef outcrop and boulder line run in a north-northeast to south-southwest orientation. In contrast, Reckley Hill Pond fossil reef is located on the northeastern end of the island just behind the Gerace Research Center (formerly known as the Bahamian Field Station) about 0.5 km inland to the south (Fig. 3). The main exposure point of this reef outcrop runs 4.8 m on a wooded trail just south of Reckley Hill Pond and is 1.1 m across at its widest point. Some coral specimens are also found on less than a dozen loose rocks scattered no more than 4 m off the main trail to the west. The main outcrop is eroded and worn to ground level, below ground level in some places.

METHODS

At Reckley Hill Pond fossil reef, one main transect was measured extending 4.8 m along the length of the exposed outcrop. Data were collected at points every 1.2 m along the transect with a 0.5 m range on either side. An overall physical description of the interval was recorded along with a census of coral fossils at each point. Photographs were taken of each interval to document species and matrix. Coral identification was performed using an online dichotomous key published by the University of Iowa's Neogene Marine Biota of Tropical America database, and supplemented with identification books published by Colin (1988) and Humann (2001).

At Holiday Tract fossil reef, four 20 m transects were measured within the rubble component, with two transects in each of two major rubble areas that were characterized by more concentrated aggregates of boulders (Figure 4). Area 1 (Transects 1 and 2) was 49.6 m long and 12.8 m across at its widest point. Transects 1 and 2 paralleled one another with a 3 m distance between. Area 2 (Transects 3 and 4) was 44.6 m long and 18.1 m across at its widest, although it averaged a width of no more than 7 m. This narrowness made it necessary to orient transects 3 and 4 in a linear rather than parallel arrangement.

Figure 1. San Salvador Island featuring Reckley Hill Pond fossil reef (1) and Holiday Tract fossil reef (2). (After Robinson and Davis, 1999).

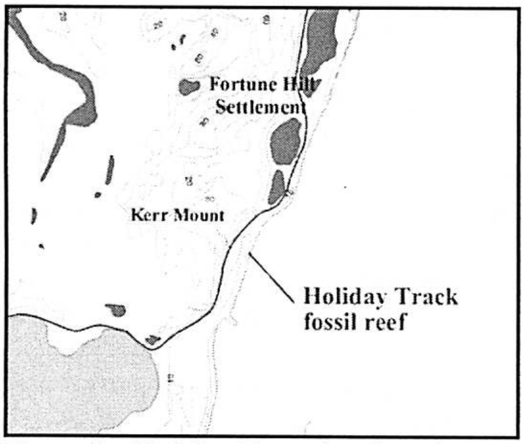

Figure 2. Holiday Tract fossil reef site. (After Robinson and Davis, 1999)

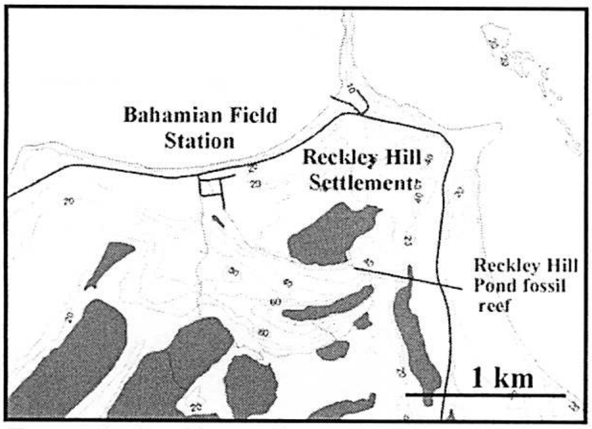

Figure 3. Reckley Hill Pond fossil reef site. (After Robinson and 1999)

Because the rubble component of the reef site is a continuous but scattered fossil assembly, I decided that continuity between the transect orientations between Areas 1 and 2 was not as crucial as data extrapolation coming from the area. Data collection took place along the complete length of each transect using a belt transect sampling technique with a 0.5 m range on either side. Data were recorded and species were identified in the same manner used at Reckley Hill Pond fossil reef.

Reckley Hill Pond and Holiday Tract were sampled differently to accommodate the physical differences in the two reefs. Reckley Hill Pond fossil reef is substantially smaller in size than Holiday Tract, and is comprised of a single, narrow, linear outcrop exposure (Figure 5). In contrast, Holiday Tract fossil reef is composed of a continuous line of boulder rubble paralleling a continuous adjacent *in situ* reef outcrop, both 275 m in length (Figure 6). Although it remains in its original position, the *in situ* component of the locality would theoretically yield more reliable biologic data, its position in the intertidal zone limits its exposure. Even at low tide, portions of the fossil reef are still submerged, impeding surveying. Its position in the intertidal zone also has contributed to extensive erosion of the reef facies and has allowed for the deposition of tar washed onto the outcrop (Figure 7). These two factors greatly limit the ability to assess species compositions and matrix and required that all such measurements be completed on the reef rubble component of the reef. Although the reef rubble is not *in situ*, the presence of paleosol in its matrix as well as that of the reef outcrop component, identify them a part of the Grotto Beach Formation, as defined by Carew and Mylroie (1995). Their proximity (between 1 and 3 m apart) and parallel positioning suggests that the boulders were derived from an outcrop that was seaward of the current intertidal one.

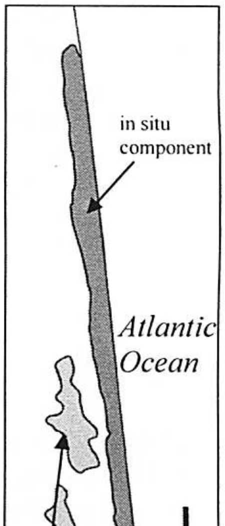

Figure 4. Holiday Tract fossil reef components.

Figure 5. Reckley Hill outcrop (within outline) just above leaf litter along trail.

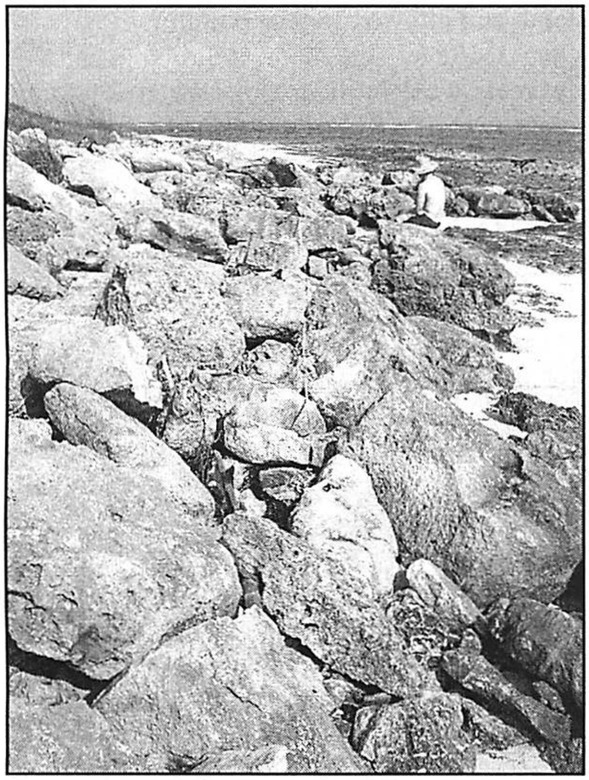

Figure 6. Holiday Tract boulder rubble component.

Although invertebrate trace and body fossils were noted when found, only coral species appearing to be *in situ* were counted and measured as part of the biologic assessment. Unlike corals, mobile invertebrate species such as bivalves and gastropods, are likely to become cemented into a previously fossilized reef outcrop andcan appear similar to ancient shells. Because this phenomenon can dramatically impact the characterization of the reef, other than corals, only sure instances of ancient fossils were recorded, but not quantified.

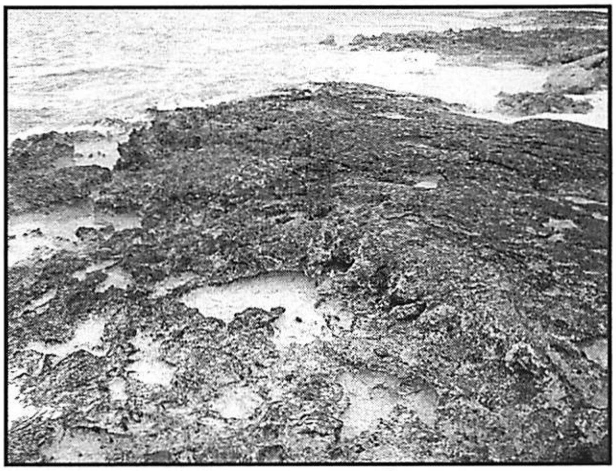

Figure 7. Holiday Tract: tar deposition on in situ component in intertidal zone of outcrop.

RESULTS AND DISCUSSION

Reckley Hill Pond

Excavation in the sediment along the linear portion of the outcrop revealed unexposed outcrop just 3 to 5 cm below the surface. Four similar excavations up to 10 cm deep were dug a maximum of 3 m to the west of the outcrop; however, they revealed no underlying outcrop or fossils. Excavations of this type were not carried out east of the main exposure due to thick vegetation. The fossil reef is therefore at least 4.8 m by 1.2 m. A possible interpretation would be that only the higher elevation areas of the reef are exposed, with lower-lying areas buried in sediment.

Numerous coral fossils can be found throughout the outcrop, as well as on loose carbonate rocks less than 3 m west of the main trail. Corallites were between 3 and 4 mm in diameter, had 12 septa, and formed plocoid colonies. All fossil corals found at this location were of the same species, *Montastraea annularis* (Figures 8 and 9). Recording specific numbers of individuals was not possible due to weathering of the outcrop, likely caused by foot traffic on the trail.

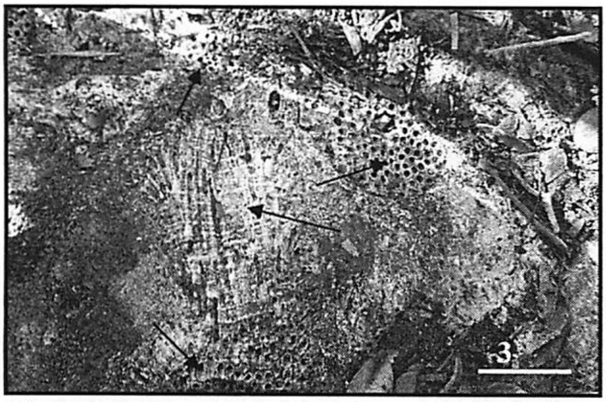

Figure 8. Outcrop with M. annularis (indicated by arrows).

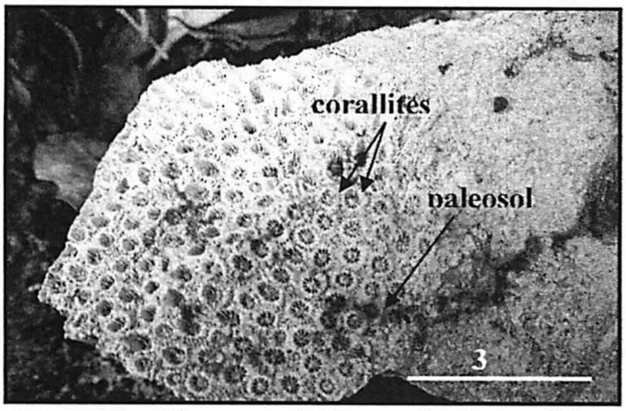

Figure 9. Close-up of M. annularis corallites and paleosol on rock fragment.

M. annularis has a wide variety of morphotypes, believed to be depth-related (between 7 and 23 m), and is the predominant coral in shallow reef areas of the Caribbean and The Bahamas (Colin, 1988). Colonies are massive, ranging from 1 to 10 m in diameter, and often provide the foundation and underlying structural support for major reefs. Its encrusting appearance indicates a shallow to moderate reef, as this morphotype is most common at depths no more than 18 m, and flourishes at depths of 10 m or less (Colin, 1988).

Paleosol was present on the outcrop, particularly on the loose rocks bearing fossil coral. The underlying reef facies was stained a rust color as a result of high concentrations of iron oxides in the paleosol. The presence of paleosol on an exposed marine facies indicates the outcrop is part of the Cockburn Town Member of the Grotto Beach Formation and that it originated during oxygen isotope substage 5e (between 132 and 119 ka) (Chen et al., 1991; Carew & Mylroie, 1995). At that time, sea-level increased as much as 4 to 6 m above its present-day level, submerging the island until only its higher elevation eolian ridges were exposed. This substage 5e transgressive-phase (as well as any preceding transgressive-phases) was responsible for the erosion of previous reef facies on the island, and allowed for the building of new reefs. When sea-level fell in the regressive-phase, the new reefs were infilled with carbonate sediment, exposed, and eventually lithified. During sea-level lowstands, weathering and pedogenesis occurred. Atmospheric dust settled on exposed facies during this time, creating a soil that has been preserved as a paleosol. As there have been no interglacial phases since oxygen isotope stage 5 where sea level was above present sea-level, no later marine facies could have formed and been preserved above modern sea-level in the Bahamas. Hence, all fossil marine facies are restricted to the Grotto Beach Formation, and all subaerially exposed marine facies to its Cockburn Town Member.

Based on the dominant presence of *M. annularis*, it is likely this reef was a shallow patch reef. Exposure of the outcrop is not extensive, although overlying sediment and vegetation could, potentially, conceal its actual size. If the reef is truly singular in species and is roughly the size and shape that is visible, it would be classified as a patch reef. Numerous modern-day patch reefs can be found around San Salvador, including Sue Point on the west coast, and further south at Fernandez Bay and Grotto Beach. Fossil examples of patch reefs are also found at Sue Point and Grotto Beach. Species compositions in both these modern and ancient patch reefs largely consist of the reef-building *Montastraea* species, although they also commonly include *Porites*, and *Diploria* (Hattin and Warren, 1989; White, 1989).

Holiday Tract

Eighty-eight individual coral colonies were recorded along the four transects in the rubble component of Holiday Tract. The overall assemblage was comprised of twenty-five colonies of *Agaricia agaricities* (forma *agaricities*), nineteen colonies of *Porites porites* (forma *furcata,* also known as *Porites furcata*), seventeen colonies of *Montastraea cavernosa*, sixteen colonies of *Porites astreoides*, and eleven colonies of *Diploria strigosa* (Figure 10). *A. agaricites* and *P. porites* specimens were commonly positioned perpendicular to the substrate surface. *P. astreoides* was found in large encrustations on the boulders with exposed colony sizes ranging from 8 to 12 cm, the typical size for smaller colonies of this species. As these species are structurally resistant to wave energy and were rarely found juxtaposed onto one another, it is not likely they were broken and fossilized in a random assemblage. This suggests the reef was buried in sediment while in its growth position, fossilized, then subsequently fragmented into boulder rubble and deposited on shore.

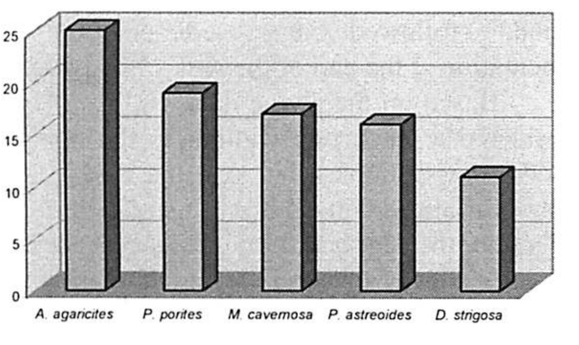

Figure 10. Coral species of rubble component, Holiday Tract.

Inspection of the invertebrate species on the rubble component revealed two individual clams, *Lithophaga (c.f.),* and a burrow cast from an unidentified organism, possibly a worm (Figures 11-12). These species were incorporated within the matrix of the boulders and in most cases, were covered with matrix themselves, dispelling any question of later deposition. A number of bivalves and gastropods were found as well; however, in most cases, determining their taphonomic history was not possible. Although some fossils were deeply embedded in the matrix of the outcrop and were interpreted as being the same age, some were embedded superficially, suggesting the possibility of later deposition. This is likely the case for *Cittarium pica*, a species of topshell abundant in the entire outcrop.

Of the species found in the rubble component, *A. agaricites* and *P. porites* were

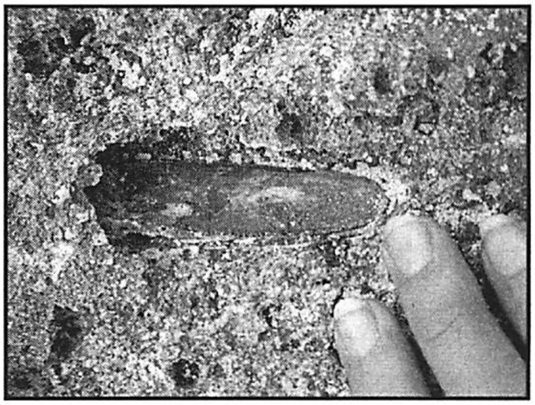

Figure 11. Lithophaga (c.f.), rubble component.

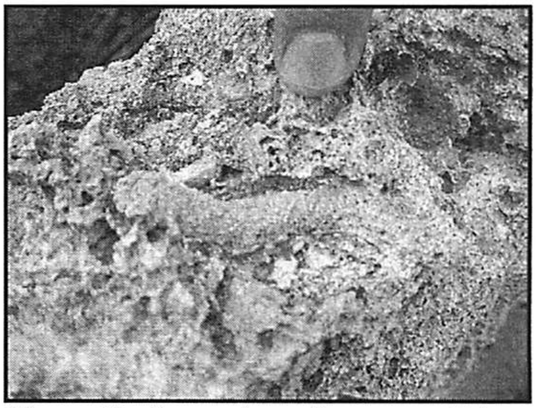

Figure 12. Invertebrate burrow, rubble component.

most commonly seen in the *in situ* component of the outcrop, typically in the upper intertidal zone. Although coated in a layer of tar, this layer was thin enough to serve as a cast of the fossil, revealing the shape of the colony and corallite underneath. A large colony of *D. strigosa*, 1.5 m across, was found in the lower intertidal zone of the *in situ* component. Based on the same criteria used to make this determination in the rubble component, these individuals also appeared to be in growth position.

Numerous modern tidal pools within the *in situ* component also contained many broken fragments of *Madracis mirabilis* (Figure 13). Commonly known as "Yellow Pencil Coral", the diameter of the branches of this species ranges from 0.5 to 1 cm, versus *P. porites*, whose branches range from 1.3 to 3.8 cm in diameter in the forma *furcata* (Humann, 2001). This difference in diameter accounts for the fragility of this species and its higher susceptibility to breakage compared to the stronger forma *furcata*, *A. agaricites*, and *D. strigosa*. With over fifty individuals documented, *Cittarium pica* was very common throughout the *in situ* reef, usually found in the tide pools or along spur and groove structures (Figure 14). As in the rubble component however, due to its superficial position on the outcrop, it is likely this species was deposited after reef fossilization. No other invertebrate species was found in the *in situ* component.

Using coral species as depth indicators can be difficult, as most corals occur over a range of depths. For example, *M. cavernosa* has a range of 2 to 91 m while *D. strigosa* ranges between 1 and 39 m (Humann, 2001). However variations in species form can be specific to a particular environment, usually based on light penetration and sediment suspension. *P. porites* forma *furcata* is most common in shallow back reef areas, as is the encrusting form of *P. astreoides*, and *A. agaricites* forma *agaricites* (Colin, 1988). Because both components of the Holiday Tract outcrop appear to be dominated by *P. porites* and *A. agaricites*, the outcrop was most likely part of the shallow back reef zone of a patch reef, with the rubble component being slightly deeper of the

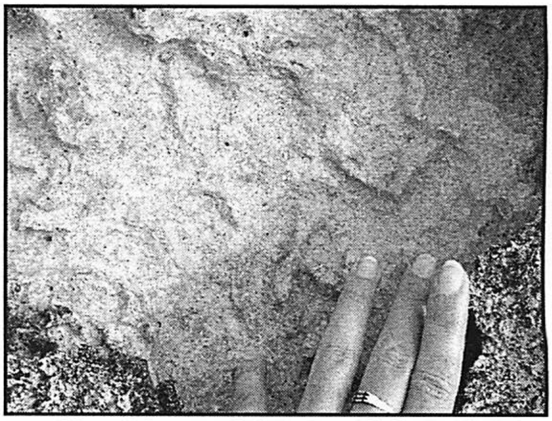

Figure 13. M. mirabilis in tidal pool, in situ component.

Figure 14. C. pica in tidal pool, in situ component.

two. The presence of *M. mirabilis* would seemingly contradict this, as it is a frail species typically found in deeper fore reef areas away from high wave energy (Colin, 1988). Its broken and deeply imbedded appearance however, suggests possible storm damage and deposition in the back reef framework during the reef's growth period, followed by sedimentation and cementation at the end of the reef's life cycle.

Based on the above data, Holiday Tract is considered a patch reef, similar to the numerous modern-day examples that skirt the island. Apart from variations in outcrop size, with one exception, the physical, biologic, and depositional characteristics of this reef closely mirror the fossil reefs found at Grotto Beach and Sue Point (Hattin and Warren, 1989; White, 1989). The sequence of the fossil reef at Holiday Tract is distinct from its fossil counterparts in that it does not demonstrate a clear shallowing-upward sequence of species and facies. Grotto Beach and Sue Point fossil reefs show a clear progression from subtidal marine to back-beach dune environments. In contrast, Holiday Tract appears to be a completely subtidal environment with only minor differences in species and facies between the *in situ* and rubble components.

A conceptual model was constructed detailing the sequence of origination and fossilization of the Holiday Tract outcrop (Fig. 15). During oxygen isotope substage 5e, sea-level reached a point allowing the growth of reef facies on eroded eolianites left behind from earlier interglacial periods. Though the back reef was dominated by sturdy shallow-water forms of coral, the deeper fore reef likely contained a number of more fragile species, namely *Madracis mirabilis*, which would periodically be broken during storms and washed into the back reef framework. Beach progradation washed sediment into the reef deposits, cementing and fossilizing any associated organisms. During the subsequent low-stand, when sea-level was approximately 125 m below present levels (Chen, et al., 1991), pedogenesis occurred atop the reef developing what would become a layer of paleosol. When sea level rose once more, approximately 6,000 years ago, wave energy and dissolution fractured the reef facies along its weakest points. Strong storms, such as hurricanes, deposited these fragments as boulder rubble onto the shore parallel to the higher back reef. This hypothesis is supported by the presence of paleosol on the *in situ* component of the reef, and more specifically by paleosol found on the rubble component. Because paleosol is found on the underside and on vertical faces of the boulders, these boulders could not now be in their original position, and therefore must have been disrupted and transported at a later time.

Based on a sample taken from a species of *Diploria* from the outcrop, a question regarding which of the five substages in oxygen isotope stage 5 that Holiday Tract formed (Carew & Mylroie, 1987) has arisen. Using Uranium/ Thorium alpha count dating techniques, the sample age was determined to be 103 ± 4 ka, which could place it in oxygen isotope substage 5c (Carew & Mylroie, 1987). No other corals were dated from this site however, and samples of fossil corals throughout the island have yielded a range of dates falling closer to substage 5e, between 119,000 to 132,000 years (Chen et al., 1991; Carew & Mylroie, 1987). Combined with the relatively wide error range of U/Th alpha counts, further dating of samples at this locality is required before placing the formation of Holiday Tract fossil reef in substage 5c.

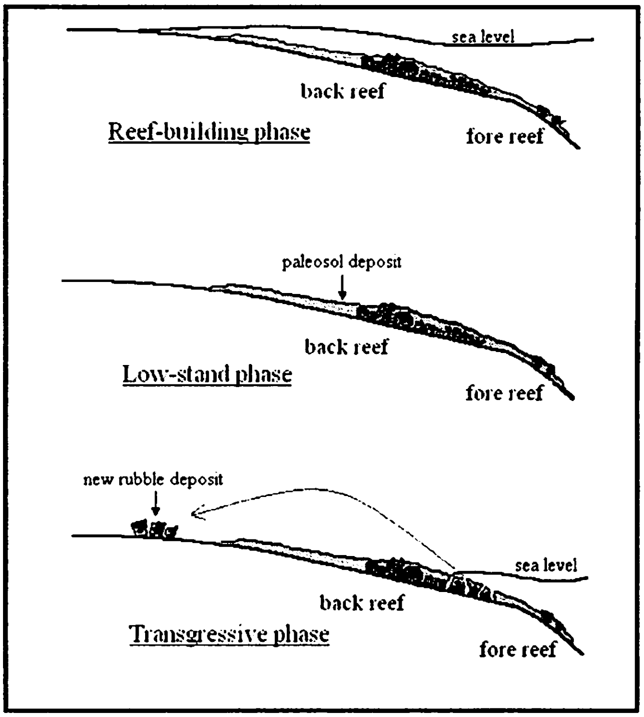

Figure 15. Conceptual model of the development of the Holiday Tract fossil reef.

CONCLUSIONS

Reckley Hill Pond fossil reef is likely a patch reef dominated by *M. annularis*, although further study is necessary to determine the extent of its size, shape, and species composition. The only known fossil reef sharing similar characteristics would be Mosquito Reef, a small, highly weathered fossil reef outcrop located south of the Gerace Research Center northwest of Reckley Hill Pond. Based on literature review and field sampling, Egerton (2003) showed that, it too, was limited in apparent exposure and species, and located adjacent to a wetland area. Further research must be done, however, before linking these reefs.

Holiday Tract fossil reef is a patch reef likely formed during oxygen-isotope substage 5e. It was subsequently fossilized by beach progradation when sea-level fell. It is dominated by *A. agaricites* and *P. porites*, with significant numbers of *P. astreoides*, *D. strigosa*, and *M. cavernosa*. Numerous invertebrates are present, although only the burrow of an unidentified species and *Lithophaga* (c.f.) body fossils are considered to have been part of the original reef.

Fossil and modern equivalents of Holiday Tract can be seen throughout San Salvador Island. Holiday Tract closely resembles Grotto Beach and Sue Point fossil reefs in coral compositions and shares a similar preservation history, fossilizing due to beach progradation at the end of an interglacial highstand. Although Holiday Tract does not appear to demonstrate a clear shallowing-upward sequence from submarine to back-beach dune facies, it is possible that a fore reef to back reef sequence is present but indistinguishable due to weathering and tar deposition. Modern reefs found at Grotto Beach, Sue Point, and Fernandez Bay share the same structural and biological characteristics as Holiday Tract as well with only slight variations in species composition. Recent studies by Egerton (2003) reveal that, based on size, location relative to the coastline, and preservation, although not in dominant coral species, a fossil reef at Hall's Landing just south of Cockburn Town also resembles Holiday Tract.

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