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PLEISTOCENE MOLLUSCAN ASSEMBLAGES ON SAN SALVADOR ISLAND, BAHAMAS: PRELIMINARY INVESTIGATIONS AND INTERPRETATIONS

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ABSTRACT

Sea level high stands in the late Pleistocene flooded much of San Salvador Island. The extensive series of lakes and lagoons formed under these conditions produced numerous deposits rich in fossil molluscs at elevations up to 2 m above present sea level. These deposits may help to define the extent and environment of inland water bodies on the island at different times in the late Pleistocene. Eighty samples were collected from 11 different exposures of molluscan-rich rocks on San Salvador. Four different assemblages have been identified, each assemblage characteristic of a different depositional environment. These environments are marine, lagoon (including tidal creek), lacustrine, and lake/lagoon transitional environments.

INTRODUCTION

Sea level rises in the late Pleistocene (Oxygen isotope stages 5e, c, a, and perhaps 3 of Shackleton and Opdyke, 1973) resulted in the formation of fossiliferous marine, lagoon, and lake deposits above current sea level on San Salvador Island, Bahamas (Carew and Mylroie, 1985). Such deposits are also known from several other Bahamian islands (Garret and Gould, 1984; Mitchell, 1984a, 1987b., Carew and Mylroie, 1989; Wilber, 1987; White and Curran, 1987). The faunal assemblages associated with each of the deposits are often unique, thus making the deposits easily distinguishable from one another. This study was originally undertaken to examine "lake facies" deposits on San Salvador Island. Many molluscan-rich deposits had been found in the interior of San Salvador and informally referred to as "lake facies" by many workers. Titus (1983, 1984, 1987) was the first to formalize a theory on the deposition of the fossiliferous rocks. The lake facies was supposed to have been deposited in a large lake, Lake Cockburn, that formed from the coalescing of smaller lakes due to a +2 m sea level rise around 49,000 ybp (oxygen isotope stage 3) (Titus, 1983, 1984, 1987). Closer inspection of such deposits has revealed that the majority of the fossiliferous exposures do not in fact represent remnants of a more extensive system of lakes. Most of the deposits contain molluscan fossil assemblages more typical of a marine or restricted lagoon environment. Although a few lacustrine deposits do exist, it is questionable as to whether they all could have formed during a stage 3 sea level rise. It should be noted that the concept of a sea level rise above current elevation during stage 3 is a subject of debate (Mylroie and Carew, 1988).

This study is a first step in a more detailed analysis (Hagey,in prep.) of the Pleistocene mollusc-rich deposits in the interior of San Salvador. Molluscs associated with each of eleven sampling localities have been identified in an attempt to determine the nature of the water bodies at the time of deposition. Knowledge of water body types and extent may be of use in determining the event(s) which formed the deposits as well as the relative timing of the event(s). Better understanding of these deposits is important to the widely used Bahamian stratigraphy of Carew and Mylroie (1985).

BACKGROUND

Inland Water Bodies

To discuss the nature of Pleistocene inland water bodies, and their relation to the Holocene, a consistent terminology is needed. The Glossary of Geology (Bates and Jackson, 1987) definitions of lake and lagoon have been modified somewhat to fit the current usage in literature on the Bahamas. These steps are taken so the terms are unambiguous to the general reader as well as to the specialist in Bahamian geology.

Lake

A lake is an inland body of standing water occupying a topographic low. Depth of water does not allow for subaerial vegetation to take root completely across the expanse of water (Bates and Jackson, 1987). The water may be fresh, brackish, marine-equivalent, or hypersaline. A lake does not have a direct surface connection to the sea. Sea water may enter a lake, however, by way of porous bedrock, karst conduits, and/or storm flooding. The lakes on San Salvador Island have salinities ranging from brackish to hypersaline. Ponds are usually differentiated from lakes only on the basis of their smaller size (Bates and Jackson, 1987). Blue holes are similar to ponds in their surface expression, but are deep relative to their width (d/w > 1). They often connect to submerged cave systems. On San Salvador Island there are no true blue holes (Mylroie, personal communication). Instead, there are numerous ponds which contain blue holes. Blue holes opening into lagoons or the open ocean are called marine blue holes.

Lagoon

Bates and Jackson (1987, p. 365) define a lagoon as "a shallow stretch of seawater... near or communicating with the sea and partly or completely separated from it by a low, narrow, elongate strip of land, such as a reef, barrier island, sand bank, or spit...". Slight modification of this general definition is required for the purpose of this study. The term lagoon will only refer to a shallow body of water with a direct surface connection to the ocean. From this, two types of lagoons are discernable: 1) those with open marine interaction; and 2) those with limited marine interaction. The degree of connectivity to the ocean controls the mechanical energy and water chemistry of the lagoon. An open lagoon, or a lagoon with several active tidal inlets, will have conditions similar to the ocean.

Tidal Creek

A lagoon with limited surface connectivity to the ocean, for example one tidal inlet or several narrow inlets, will have marine conditions only in the vicinity of the tidal inlet. Water chemistry and mechanical energy will be influenced by other controlling factors. Salinity, for example, is dependent on the amount of fresh water input (i.e., a high net input of fresh water may result in brackish conditions, whereas a low net input may result in hypersaline conditions). On San Salvador, Pigeon Creek is a lagoon almost entirely enclosed by dune ridges where marine influence is limited to a single tidal inlet. Therefore, Pigeon Creek is marine in nature near the tidal inlet becoming increasingly saline further inland.

The term "creek" (as in Pigeon Creek) needs clarification. In this usage, creek does not imply fresh water or a net outflow from the island (although either may exist, as on Andros Island). In the British usage, a creek is a lagoon with a tidal inlet (Bates and Jackson, 1987). The Bahamas are a former British colony, and because of this many bodies of water that would be called lagoons in the American usage are called creeks.

Related Studies

Pleistocene deposits rich in fossil molluscan fauna have a patchy distribution in both the coastal regions and the interior of San Salvador Island. They have been noted in works by Titus (1983, 1984, 1987), Florentino and Bain (1984), Vierma and others (1984), White and others (1984), Bain (1985, 1989, 1990), Curran and White (1985), Teeter (1985), Sims (1987), Hagey (1988), and Edwards and others (1990). To date, however, there has been no single study completed involving many different deposits from a variety of different environments, in which characteristic assemblages for the deposits are compared, and interpretations made of timing and environments of deposition.

Titus (1983, 1984, 1987) and Teeter (1985) mention lacustrine deposits and the probability of more extensive lakes on San Salvador in the Pleistocene. Edwards and others (1990) point out a possible lagoonal deposit in the northeast corner of San Salvador. Molluscs in Quarry A are mentioned by Bain (1985, 1989) and have been studied in some detail by Hagey (1988). Florentino and Bain (1984) found Pleistocene deposits with a marine molluscan fauna around Granny Lake. Molluscs in Quarry E are mentioned by Teeter (1985), Teeter and Thalman (1984), and Thalman (1983) and studied in some detail by Hagey (1988). Molluscs in the Cockburn Town Fossil Reef complex have been discussed by White and others (1984) and Curran and White (1985) and studied by Hagey (1988). White (1989) also reports molluscs in the Sue Point fossil reef complex. Vierma and others (1984) report molluscs associated with a fossil reef deposit in the interior of northern San Salvador. Sims (1987) reports mollusc-rich deposits in the southern portion of San Salvador, and Hebert (1990) finds them in the northern interior. Various workers have noted and/or studied Pleistocene mollusc-containing deposits from other Bahamian islands: Rum Cay (Mitchell, 1987b), Great Exuma (Mitchell, 1984a), New Providence (Garret and Gould, 1984), South Andros (Carew and Mylroie, 1989), West Plana Cay (Wilber, 1987), and Great Inagua (White and Curran, 1987).

It is often useful to look at the present and earlier Holocene lake, lagoon, and marine environments to make interpretations about similar Pleistocene environments. The modern lakes and ponds on San Salvador have been well studied with respect to sedimentology, water chemistry, microfauna, and macrofauna (Bowman and Teeter, 1982; Sanger and Teeter, 1982; Teeter, 1983, 1989; Crotty and Teeter, 1984; Kwolek, 1984; Pacheco and Forades, 1987; Teeter and others, 1987; Davis and Johnson, 1989; Edwards and others, 1990; Teeter and Quick, 1990; Winter, 1990; Edwards and Fregeau, in review). Pigeon Creek, San Salvador's only tidal creek, has been studied in detail by Teeter and Thalman (1984), Teeter (1985), Mitchell (1987a), and Slone and others (1990). Open (non-tidal creek) lagoons on San Salvador have been studied by Andersen and Boardman (1989), Colby and Boardman (1989), and Pace and others (1989). Similar water bodies on other Bahamian islands are included in recent works by Mitchell (1984, 1985, 1987b), Wilber (1987), Mitchell and others (1989), and Mitchell and Sigler (1989).

It is important to keep in mind that a lake or a tidal creek is not necessarily a static feature even if sea level is at a constant level. Tidal creek inlets can become closed due to spit, bar, beach, and/or dune deposition. These deposits can in turn be breached to allow for the opening of an inlet. Transitions between these two types of water bodies were shown to have occurred in the Holocene of the Bahamas. Such transitions apparently happened in the Pleistocene as well (Mitchell, 1987b). In the Holocene, these transitions are mainly restricted to the coastal areas. With higher sea levels in the Pleistocene transitions could well have occurred in the more central regions of the present day islands. Geomorphic changes of San Salvador's coastline resulting in transitions between lakes and lagoons are dicussed by Thalman (1983), Teeter and Thalman (1984), Teeter (1985b), Mitchell and Keegan (1987), Winter (1987), and Zabielski and Neumann (1990). Recognition of these changes is based on geomorphic, sedimentologic, archeologic, and/or paleontologic evidence. Evidence of similar events on other Bahamian islands is included in works by Garret and Gould (1984), Mitchell (1987b), Mitchell and Keegan (1987), Wilbur (1987), and Mitchell and others (1989).

METHODS

Eighty rock samples were taken from eleven locations on San Salvador from June, 1987, to June, 1990. The locations, Miller Pond, Base Ponds, Quarry A, Beach Cave, Quarry E, Stouts Lake, Watlings Blue Hole, Titus Pond, Church Site, Cockburn Town Fossil Reef, and North Victoria Hill are shown in Figure 1. Several considerations were taken into account when sampling a particular location: 1) samples were preferentially chosen where shell material was abundant; 2) whole shells were preferred to broken shelly material for ease of identification; 3) good preservation was also important for identification purposes; 4) it was attempted to chose samples representative of the entire exposure; and 5) in/situ exposures, where present, were sampled preferentially over float; some locations, however, contained only float. In several cases, rocks with little or no shell material were collected for petrographic comparison with fossil-rich rocks found in the same location (Hagey, in prep.). In the laboratory the fossil molluscs in each sample were identified and approximate relative abundances were noted. Molluscan assemblages characteristic of different possible depositional environments were then established.

In conjunction with the fossil collecting, samples were collected for paleomagnetic analysis at four sites that had a paleosol overlying the fossil material: Miller Pond, Beach Cave, Quarry E, and Stouts Lake. The sampling was conducted by Bruce C. Panuska of Mississippi State University as part of an on-going research program on geochronology (see Panuska and others, this volume).

SAMPLE LOCATIONS

Miller Pond is a small hypersaline pond

located approximately 0.5 km WSW of the Bahamian Field Station (Figure 1). It is bordered to the west, north, and east by Pleistocene dune ridges up to 25 m high. To the south of Miller Pond, across a narrow low land area, is North Little Lake. Twenty-seven samples of fossiliferous bedrock were taken from the north shore of North Little Lake, across the strip of land between North Little Lake and Miller Pond, and around the perimeter of Miller Pond. For a detailed sampling map see Hagey (in/prep.).

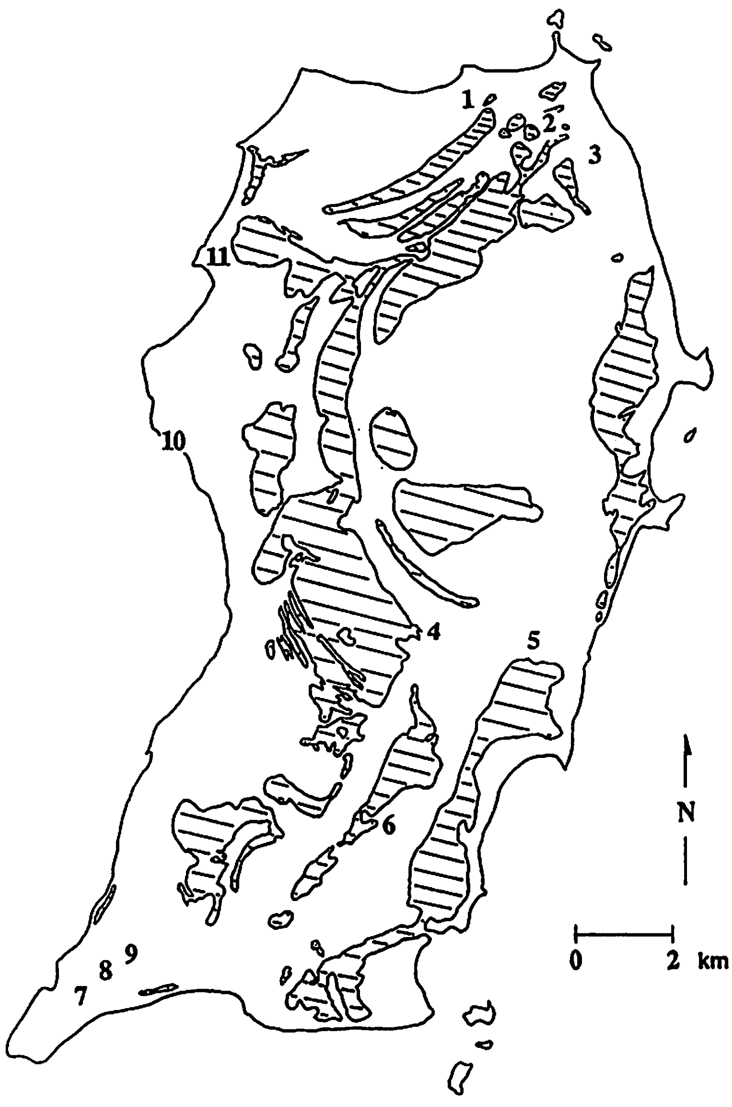

Fig. 1. Sampling locations on San Salvador Island. 1: Miller Pond; 2: Base Ponds. 3: Quarry A; 4: Beach Cave; 5: Quarry E; 6: Stouts Lake; 7: Watlings Blue Hole; 8: Titus Pond; 9: Church Site; 10: Cockburn Town Fossil Reef; 11: North Victoria Hill.

"Base Ponds" refers to a complex of small, tidally influenced ponds of marine-equivalent salinity located to the southeast of the Bahamian Field Station (Figure 1). Twelve samples were taken from Pleistocene bedrock exposures in the vicinity of No Name, Pain, Moon Rock, and Oyster Ponds, as well as in several locations between ponds. A paleosol covers some of the fossiliferous deposits. For a more detailed description of this area and a map of sampling locations see Edwards and others (1990) and Hagey (in prep.).

Quarry A is located on the west side of the road in the settlement of United Estates in the northeastern corner of San Salvador (Figure 1). The quarry contains Pleistocene deposits from several different near shore depositional environments (see Bain, 1985, 1989). One sample each was collected from fossiliferous beach and subtidal deposits in the west-central portion of the quarry.

The Beach Cave site is a location on the eastern shore of Great Lake, lakeward of Beach Cave (Figure 1). This part of Great Lake is characterized by a mangrove forest which covers an eastward projecting arm of the lake. Prominent Pleistocene dune ridges (up to 40 m in elevation) border this part of the lake to the north, east, and south. To the west is the main body of Great Lake. Three samples were collected from the northern shore of this mangrove covered arm.

Quarry E (North Pigeon Creek Quarry) is located in the southeastern portion of San Salvador between the road and the north arm of Pigeon Creek (Figure 1). Thalman (1983) and Thalman and Teeter (1983) describe the Pleistocene depositional environments (tidal delta and *Thalassia* beds) exposed in the quarry walls. Six samples were collected: Four from the eastern wall (equivalent to the lower pro-delta unit) and two samples of fossil-rich float from the southwestern quarry floor.

Five samples were collected from Stouts Lake, a narrow, roughly linear, northeast-southwest trending hypersaline lake in south-central San Salvador (Figure 1). Four of the samples are from an isthmus, located about midway down the eastern side of the lake. A fifth sample was collected by James W. Teeter approximately 0.5 km north of the isthmus. The isthmus is made up largely of patchy, discontinuous fossiliferous bedrock. This type of bedrock does not appear to extend all the way to the

SPECIES	COCKBURN TOWN	QUARRY E	QUARRY A	BASE PONDS	CHURCH SITE 2	STOUTS LAKE	BEACH CAVE	TITUS POND	NORTH VICTORIA	MILLER POND	WATLINGS BLUE	CHURCH SITE 1
Barbatia cancellaria (B)	A	C	A						R			
Chione cancellata (B)	A	A	C	C	C	C	C	A	C	R	R	
Linga pensylvanica (B)	A	R	C								R	
Acar domingensis (B)	C	R	C	R								
Americardia media (B)	C	A	C	C	R	C		C	C			R
Arca imbricata (B)	C	R	R	R								
Bulla occidentalis (G)	C	C	C	C	C	A	A	C			R	
Cerithium eburneum (G)	C	C	C	C	C	C	R	C				
Cerithium litteratum (G)	C	C		C	C	A			R			
Chama sinuosa (B)	C											
Chione pygmaea (B)	C	R	C									
Columbella mercatoria (G)	C	C	A									
Cyphoma gibbosum (G)	C											
Laevicardium laevigatum (B)	C	R	R									
Lima scabra (B)	C	R										
Olivella nivea (G)	C	C	A			R						
Phyllonotus pomum (G)	C	R			R							
Polinices lacteus (G)	C	R	C	R	R				R			
Astraea phoebia (G)	R											
Astraea tecta americana (G)	R		R									
Barbatia candida (B)	R											
Brachiodontus modiolus (B)	R								R			
Callistoma jujubinum (G)	R											
Chlamys arnata (B)	R											
Cittarium pica (G)	R											
Codakia orbicularis (B)	R		R	A	R	C	R			R		
Conus jaspideus (G)	R	R	R									
Cypraea cinera (G)	R											
Dendrostrea frons (B)	R											
Diodora listeri (G)	R	R	C									
Divaricella quadrisulcata (B)	R		R		C				R			
Fasciolaria tulipa (G)	R											
Fissurella barbadensis (G)	R	R	R									
Glycymeris pectinata (B)	R	R		R								
Glycymeris undata (B)	R											
Hemitoma emarginata (G)	R		R									
Hipponix antiquatas (G)	R	R	C									
Latirus angulatas (G)	R		R									
Lima lima (B)	R	R										
Modiolus americanus (B)	R			R					R			
Modulus modulus (G)	R	R	C	R	R	R						
Nassarius albus (G)	R	R	A	R	R	R	R		R			
Nerita peloronta (G)	R	R	R									
Pseudochama radians (B)	R	R										
Pyramidella dolabrata (G)	R				R							
Spondylus americanus (B)	R											
Strigilla mirabilis (B)	R		R									
Strombus gigas (G)	R				R							
Tegula fasciata (G)	R	R		C								
Tegula lividomaculata (G)	R											
Tellina listeri (B)	R			R	R			R	R			
Tellina radiata (B)	R	R	R	R								
Terebra glossema (G)	R											
Trivia pediculus (G)	R	R										
Trivia quadripunctata (G)	R	R	R									
Anodonta alba (B)		R								R		
Cadus maculosa (G)		R										
Cerion glans (G)		R								R		
Chione paphia (B)		R		R	C			C				
Codakia orbiculata (B)		R		A		R			C			
Littorina nebulosa (G)		R	R							•		
Lucapina suffusa (G)		R										
Tectarius muricatas (G)		R										
Tellina sp. (B)		R			R	R			R			
Acmaea leucopleura (G)			C									
Diodora minuta (G)			C									
Anadara brasiliana (B)				R								
Anadara notabilis (B)				C								
Antigona listeri (B)				R								
Cerithium algicola (G)				R								
Cymatium labiosum (G)				R								
Melampus monile (G)				R								
Pinctada imbricata (B)				R								
Trachycardium muricatum (B)				R								
Dosinia discus (B)					R		R					
Tellina tampaensis (B)							R					
Bulla sp. (G)									R	R	R	
Codakia costata (G)									C			
Isognomon radiata (B)									R			
Lithophaga sp. (B)									R			
Modiolus sp. (B)									R			
Tornatina canaliculata (G)									R			
Anomalocardia auberiana (B)		C		C	R	C	C		C	A	C	A
Batillaria minima (G)	R	A	C			C	R		A	C	R	R
Cerithidea costata (G)		R		R	R	R			R	C	R	R
Cerithium lutosum (G)		A		R		C			A	A	C	R
Marginella apicina (G)										R	C	C
Polymesoda maritima (B)		R				R	R		R	C	A	R

Table 1. Molluscan fauna present at the eleven sampling sites shown in Figure 1. Approximate relative abundances are designated by "A" (abundant), "C" (common), and "R" (rare). "(B)" and "(G)" indicate bivalve and gastropod, respectively. Note: Church Site contains two distinctly different mollusc-rich deposits - Church Site 1 and Church Site 2.

mangrove island to the west. A 25 m high Pleistocene dune ridge borders this section of the Stouts Lake shoreline to the east. Immediately to the west is the lake itself, and then another 20-30 m high ridge on the western margin of the lake.

Watlings Blue Hole is located in the southwestrn corner of San Salvador (Figure 1). It sits in a relatively flat low-lying area that extends to the northwest. To the southeast is a 25 m high Pleistocene dune ridge. A wall surrounding the water body is made up in part by blocks of rock rich in fossil molluscs. An in-place exposure in the immediate vicinity has not been found to date. Five samples of the float were collected, however, for comparison with other fossiliferous deposits on the island. Two samples of very sparsely fossiliferous in-place bedrock were collected from the eastern side of Watlings Blue Hole. The shell material is either extensively broken up or weathered, making it unidentifiable. These samples were obtained for thin section analysis, as a comparison with the well-preserved, fossiliferous wall-rock float (Hagey, in prep.).

A small unnamed pond in the southwest portion of San Salvador is referred to in this study as "Titus Pond" (Figure 1). Titus Pond is located approximately 1 km ENE of Watlings Blue Hole. A 20 m high dune ridge lies to the south of the pond. A relatively flat, broken up, and weathered bedrock exposure extends several tens of meters outward from the north side of the pond. In places the bedrock is rather fossiliferous. A single sample was taken from a fossil-rich portion of the exposure approximately 5 m north of the pond.

Church Site is located approximately 0.5 km NNE of Titus Pond in southwestern San Salvador (Figure 1). The site contains a shallow quarry that is thought to have been originally intended as the basement for a church that was never built (Titus, personal communication). The actual quarry is a few hundred meters southeast of the site indicated on the Columbus Landings master plan. Four samples were collected of fossil-rich float rock. Two samples are from the southern portion of the quarry, one is from the northern portion. The fourth sample is from an area approximately 50 m northwest of the quarry. Although none of the samples were found in place, an in place exposure of fossiliferous rock covered by a paleosol is present approximately 15 m northwest of the quarry. This deposit was cored to a depth of 34 cm by Sims (1987). A large loose block with a paleosol crust indicating the probable up direction was also found.

The Cockburn Town Reef, described in detail by Curran and White (1985) and White, Kurkjy, and Curran (1984) is located on the, west coast of San Salvador (Figure 1). Three samples representing coral rubble, beach, and intertidal depositional environments are included in this study. For a map showing locations of samples, see Hagey (1988).

North Victoria Hill refers to a site south of the settlement of the same name in the northwest portion of San Salvador (Figure 1). This site is located about 300 m due east of the access trail cut to the Sue Point Fossil Reef. Eight samples were taken from a low-lying area that extends eastward from a 7 m high dune ridge. Approximately 400 m to the east is Northwest Arm Lake. Blocks of sparsely fossiliferous bedrock are found imbedded in the soil of an abandoned agricultural field.

RESULTS

Table 1 shows the fossil mollusc species found to be present at each of the eleven sampling sites. (Note: Church Site contains two distinctly different assemblages which are designated by Church Site 1 and Church Site 2.) Visual (non-quantitative) analysis of the abundances of these species is designated by the letters A (abundant), C (common), and R (rare). As this is based on analysis of hand samples, it may not reflect the true relationships of species over an entire outcrop. At all locations except Titus Pond, numerous samples were taken in order to get a better representation of the species present over the entire exposure. For a detailed breakdown of the species found in the numerous samples from each site see Hagey (in/prep.).

DISCUSSION

While all of the species of molluscs in Table 1 may be found in marine or restricted marine environments, the nature of the assemblages are diagnostic of a variety of habitats. Depositional environments with the most efficient connection to the open ocean (reef, subtidal, intertidal, open lagoon, and beach) typically have high diversity assemblages. More restricted lagoons and tidal creeks have lower diversity assemblages. In the case of a tidal creek-lake transitional environment, an assemblage is expected to contain a mixture of typically marine fauna and typically lacustrine fauna.

Typical molluscs found in the present day lakes and ponds of San Salvador Island (Edwards and others, 1990; Edwards and Fregeau, in review) are used to define Pleistocene deposits thought to have formed in lake environments. The characteristic species include: *Anomalocardia auberiana* and *Polymesoda maritima* (bivalves), and *Batillaria minima, Cerithidea costata* and *Cerithium lutosum* (gastropods). There are modern exceptions, however, as noted in Edwards and others (1990) and in Edwards and Fregeau (in review). Several small water bodies in the interior of San Salvador contain anomalous assemblages of molluscs. The anomalous fauna (i.e., *Barbatia cancellaria, Codakia orbiculata*, and several species of oysters) are usually associated with marine environments. The ponds these species inhabit are connected to the ocean by karst conduits and therefore maintain salinities equivalent to normal marine. There are several possibilities as to how the marine fauna got into the ponds (see Edwards and others, 1990).

The most diverse assemblages of molluscs are found at three outcrops representing shallow and/or coastal marine environments: Cockburn Town fossil reef (55 species), Quarry E (40 species), and Quarry A (32 species) (Table 1). All three locations are interpreted to have experienced direct communication with the open ocean in the late Pleistocene. Fossil corals in the Cockburn Town reef have been dated by U/Th methods using mass spectrometry at approximately 131,000 - 119,000 ybp (Curran and others, 1989). Fossil corals from Quarry A have been U/Th dated using alpha counts at approximately 140,000 ($\pm$ 9,000) ybp (Carew and Mylroie, 1987). The assemblages of molluscs from these sites serve well as a "typically marine" comparison for all the other assemblages of molluscs found in the interior regions of San Salvador.

The more inland the deposits, the more the diversity drops off. This tends to imply more restricted or entirely restricted conditions during deposition such as would be expected in a lake, lagoon or tidal creek. The Base Ponds, Beach Cave, Stouts Lake, Titus Pond, and Church Site 2 probably record a more restricted lagoon/tidal creek environment. They all contain mainly marine faunal assemblages of low diversity (in comparison with the known marine depositional environments) (Table 1). Miller Pond, Watlings Blue Hole, and Church Site 1 almost exclusively contain molluscs typical of lake environments (Table 1). Samples collected at North Victoria Hill are interpreted to record transitional stages of a flooding event (between lake and lagoon) or perhaps fluctuating periods of more and less restricted conditions. This type of environment appears to explain the mixed assemblage of more typically lacustrine fauna with more typically marine fauna (Table 1).

Fig. 2. San Salvador Island at a +6 m sea level highstand. Note: There are no isolated inland lakes. Stippled areas indicate land. (After Mylroie and Carew, 1990)

Existing topographic structures of Pleistocene age on San Salvador Island indicate that a +6m rise in sea level, equivalent to oxygen isotope substage 5e (Shackleton and Opdyke, 1973), produces no isolated inland lakes. Instead, a series of lagoons is produced with varying degrees of connectivity to the open ocean (Figure 2) (Mylroie and Carew, 1990; Vacher and Mylroie, this volume). Some of the inlets may have been closed, however, allowing for lakes to exist, and then later opened again. There is no way to be sure that either or both of these events took place. Therefore, if the lake deposits in question were formed in a lacustrine environment, the water bodies most likely were formed during the transgressive or regressive phase of the sea level highstand, when the platform was less completely flooded. Or, as Titus (1983, 1984, 1987) has suggested, lake conditions may have existed during a lower sea level rise at a different time than substage 5e (Figure 3). In an idealistic model, it would be possible that the deposits could record the transition from initial transgression (lakes and more restricted lagoons) to highstand (open marine and lagoons) to regression (lakes and more restricted lagoons). The rate of sea level change and the duration of any given level would have influenced deposition. Alternatively, during the highstand, the formation or breaching of barriers could alter the inland water body environment, causing a change in the type of mollusc accumulation.

Samples from Watlings Blue Hole and Church Site 1 contain typical lacustrine molluscan assemblages and, therefore, most likely do imply that at a time in the late Pleistocene inland lakes were more extensive than at present. Both of these localities also contain separate (from the lacustrine) typical marine molluscan assemblages (not mixed, as at North Victoria Hill). While no in/situ exposures have been found around Watlings Blue Hole, examination of the area surrounding Church Site did result in an in/situ exposure of the lacustrine facies (covered by paleosol). Close inspection of a large block of float revealed that some of the lacustrine facies is overlain by the marine facies, which is in turn covered by a paleosol. This sequence of lake-marine-paleosol shows that at least some of the lacustrine facies was in place before the marine unit was deposited. The lacustrine facies, therefore, had to have been deposited during the transgressive stage of a sea level highstand event, or before breaching of a

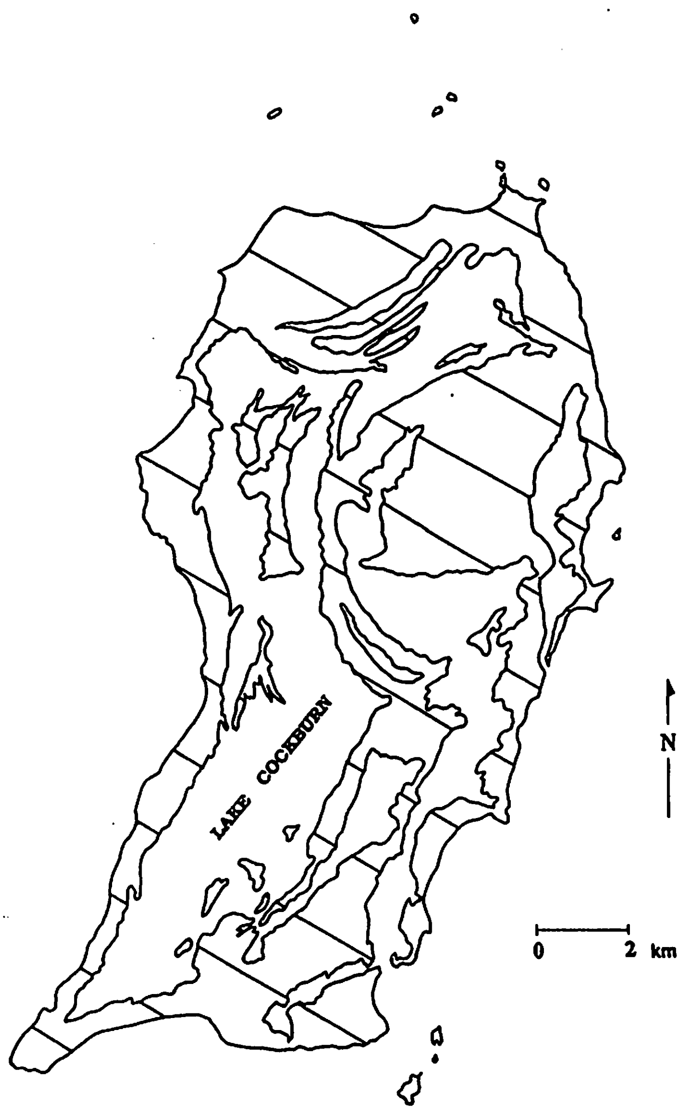

Fig. 3. Lake Cockburn: A large lake that could have possibly formed from the coalescing of smaller lakes due to a 2.5 m rise in sea level. Land is indicated by diagonal lines. (Redrafted from Titus, 1984)

restrictive barrier during the high stand. The lack of an intervening paleosol between the lake and the marine deposits precludes the lake deposits as relicts of an earlier highstand (Carew and Mylroie, 1989).

As mentioned previously, some of the more inland deposits contain rather low diversity marine faunal assemblages, suggesting restricted conditions. "Restrictedness" indicated by molluscan assemblages could possibly be used to determine timing of dune formation. For example, an assemblage that suggests more restricted conditions would seem to imply preexisting topography in order to create the restricted environment. Carew and Mylroie (1985) suggest that the large interior dunes of San Salvador Island formed on the oxygen isotope substage 5e transgression. The presence of "restricted" faunal assemblages appears to support this hypothesis. (See also Bain, 1990).

CONCLUSIONS

Four types of fossil assemblages have been defined, each representing a different environment of deposition: lake, lagoon, lake-lagoon transition, and marine. On San Salvador Island, deposits found at Miller Pond, Watlings Blue Hole, and Church Site 1 are thought to have formed in a lake environment, based on the molluscan fauna. The Base Ponds, Beach Cave, Stouts Lake, Titus Pond, and Church Site 2, containing low diversity marine assemblages of molluscs, are interpreted as representing former lagoon environments. North Victoria Hill contains a mixture of lacustrine and marine fauna and is therefore interpreted as having been a site of lake-lagoon (tidal creek) transition. Molluscs at the well-documented marine environments Cockburn Town fossil reef, Quarry A, and Quarry E indicate marine conditions as expected.

Church Site, containing two distinctly different assemblages, is the closest thing to the idealized model of a sea level highstand event being recognized using mollusc deposition. Here a lake deposit is overlain by a marine deposit. Either or both of the following may be true: 1) the lake deposits were formed on the transgression, followed by the marine deposits as the platform became increasingly flooded; or 2) both of the deposits were formed during the highstand of a sea level event, the marine deposits forming after breaching of barriers rather than continued sea level rise. The lack of an exposure surface between the two units precludes their deposition during separate sea level high stands. Further analysis of the deposits (especially those low diversity marine deposits found inland) may also help to refine interpretations of preexisting platform topography.

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REFERENCES CITED

Andersen, C.B. and Boardman, M.R., 1989, The depositional evolution of Snow Bay, San Salvador: in Mylroie, J.E., ed., Proceedings of the fourth symposium on the geology of the Bahamas: Port Charlotte, Florida, Bahamian Field Station, pp. 7-22.

Bain, R.J., 1985, Subtidal-beach-dune sequence, Quarry A: in Curran, H.A., ed., Pleistocene and Holocene carbonate environments on San Salvador Island, Bahamas-Guidebook for Geological Society of America, Orlando annual meeting field trip: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 63-72.

Bain, R.J., 1989, Pleistocene beach rock in a subtidal-beach-dune sequence, Quarry A: in Curran, H.A., ed., Pleistocene and Holocene carbonate environments on San Salvador Island, Bahamas, Field Trip Guidebook T 175, 28th International Geological Congress: Washington, D.C., American Geophysical Union, pp. 23-26.

Bain, R.J., 1990, Distribution of Pleistocene lithofacies in the interior of San Salvador Island, Bahamas, and possible genetic models: in Fifth symposium on the geology of the Bahamas, Abstracts and Programs, p. 7.

Bates, R.L. and Jackson, J.A., eds., 1987, The Glossary of Geology, Third Edition: Alexandria, Virginia, American Geological Institute, 788 p.

Bowman, P.A. and Teeter, J.W., 1982, The distribution of living and fossil foraminifera and their use in the interpretation of the post-Pleistocene history of Little Lake, San Salvador Island, Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian

Field Station, Occasional Papers, No. 1, 26 p.

Carew, J.L. and Mylroie, J.E., 1985, The Pleistocene and Holocene stratigraphy of San Salvador Island, Bahamas, with reference to marine and terrestrial lithofacies at French Bay: in Curran, H.A., ed., Pleistocene and Holocene carbonate environments on San Salvador Island, Bahamas-Guidebook for the Geological Society of America, Orlando annual meeting field trip: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 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: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 35-44.

Carew, J.L. and Mylroie, J.E., 1989, 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, pp. 73-81.

Colby, N.D. and Boardman, M.R., 1989, Depositional evolution of a windward, high-energy carbonate lagoon, San Salvador, Bahamas: in Mylroie, J.E., ed., Proceedings of the fourth symposium on the geology of the Bahamas: Port Charlotte, Florida, Bahamian Field Station, pp. 95-105.

Crotty, K.J. and Teeter, J.W., 1984, Post Pleistocene salinity variations in a blue hole, San Salvador Island, Bahamas, as interpreted from the ostracode fauna,: in Teeter, J.W., ed., Proceedings of the second symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 3- 16.

Curran, H.A. and White, B., 1984, Field guide to the Cockburn Town fossil reef, San Salvador Island, Bahamas: in Teeter, J.W., ed., Proceedings of the second symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 71-96.

Curran, H.A. and White, B., 1985, The Cockburn Town fossil coral reef: in Curran, H.A., ed., Pleistocene and Holocene carbonate environments on San Salvador Island, Bahamas-Guidebook for Geological Society of America, Orlando annual meeting field trip: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 95-120.

Curran, H.A., White, B., Chen, J.H. and Wasserburg, G.J., 1989, Comparative morphologic analysis and geochronology for the development and decline of two Pleistocene coral reefs, San Salvador and Great Inagua Islands, Bahamas: in Mylroie, J.E., ed., Proceedings of the fourth symposium on the geology of the Bahamas: Port Charlotte, Florida, Bahamian Field Station, pp. 107-117.

Davis, R.L. and Johnson, C.R., Jr., 1989, Karst hydrology of San Salvador: in Mylroie, J.E., ed., Proceedings of the fourth symposium on the geology of the Bahamas: Port Charlotte, Florida, Bahamian Field Station, pp. 118-135.

Edwards, D.C., Teeter, J.W. and Hagey, F.M., 1990, Geology and ecology of a complex of inland saline ponds, San Salvador Island, Fifth symposium on the geology of the Bahamas, Field Guide. Port Charlotte, Florida, Bahamian Field Station, pp. 35-45.

Edwards, D.C. and Fregeau, M.R., in review, Molluscan assemblages of two inland, tidal, brackish blue holes ("marine islands"), San Salvador Island, Bahamas: Veliger.

Florentino, E. and Bain, R.J., 1984, Environment of deposition of the Granny Lake oolite, San Salvador, Bahamas: in Teeter, J.W., ed., Proceedings of the second symposium on the geology of the Bahamas, Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 187- 196.

Garret, P. and Gould, S.J., 1984, Geology of New Providence Island, Bahamas: Geological Society of America Bulletin, v 95, pp. 209-220.

Hagey, F. M., 1988, The distribution of Pleistocene molluscan assemblages on San Salvador Island, Bahamas [unpublished B.A. Honors Thesis]: Williams College, 88 p.

Hagey, F.M., in prep., Analysis of Pleistocene inland lake and lagoon deposits on San Salvador Island, Bahamas, [M.S Thesis]: Mississippi State University.

Hebert, J.P., 1990, A lithofacies analysis of the northern portion of San Salvador Island, Bahamas: Fifth symposium on the geology of the Bahamas, Abstracts and Programs, pp 23-24.

Kwolek, J.M., 1984, Holocene deposition of a multi-layered carbonate sequence in Reckley Hill Settlement Pond, San Salvador Island, Bahamas: in Teeter, J.W., ed., Proceedings of the second symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 27-39.

Mitchell, S.W., 1984a, Geology of Great Exuma Island, second symposium on the geology of the Bahamas, field guide: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, 45 p.

Mitchell, S.W., 1984b, Late Holocene tidal creek-lake transitions, Long Island, Bahamas: in Teeter, J.W., ed., Addendum to Proceedings of the second symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 1-28.

Mitchell, S.W., 1985, Quaternary lacustrine and tidal creek microbiofacies of the Bahama Archipeligo and Florida Keys: Geological Society of America, Abstracts with Programs, v. 17, p.666

Mitchell, S.W., 1987a, Sedimentology of Pigeon Creek, San Salvador Island, Bahamas: in Curran, H.A., ed., Proceedings of the third symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 215-230.

Mitchell, S.W., 1987b, Surficial geology of Rum Cay, Bahama Islands: in Curran, H.A. ed., Proceedings of the third symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 231-241.

Mitchell, S.W., Baldwin, J.N., Buening, N. and Westell, B., 1989, Holocene depositional history of Conception Island, Bahamas: in Mylroie, J.E., ed., Proceedings of the fourth symposium on the geology of the Bahamas: Port Charlotte, Florida, Bahamian Field Station, pp. 209-220.

Mitchell, S.W. and Keegan, W.F., 1987, Reconstructinq the coastlines of the Bahama Islands in 1492: American Archeology, v. 6, n. 2, pp. 88-96

Mitchell, S.W. and Sigler, M.E., 1989, Twentieth century sedimentological development of Bonefish Pond, New Providence Island, Bahamas: in Mylroie, J.E., ed., Proceedings of the fourth symposium on the geology of the Bahamas: Port Charlotte, Florida, Bahamian Field Station, pp. 221 -234.

Mylroie, J.E. and Carew, J.L., 1988, Solution conduits as indicators of Late Quaternary sea level position: Quaternary Science Reviews, v. 7, pp. 55-64.

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, pp. 413-424.

Pace, W., Mylroie, J.E. and Carew, J.L., 1989, Sedimentology of a Holocene platform-margin carbonate lagoon: Blackwood Bay, San Salvador Island, Bahamas: in Mylroie, J.E., ed., Proceedings of the fourth symposium on the geology of the Bahamas: Port Charlotte, Florida, Bahamian Field Station, pp. 253-265.

Pacheco, P.J. and Foradas, J.G., 1987, Holocene environmental changes in the interior karst region of San Salvador, Bahamas: The Granny Lake pollen record: in Curran, H.A., ed., Proceedings of the third symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 115-122.

Panuska, B.C., Mylroie, J.E. and Carew, J.L., this volume, Paleomagnetic directions of paleosols on San Salvador: Prospects for stratigraphic correlation.

Sanger, D.B. and Teeter, J.W., 1982, The distribution of living and fossil ostracoda and their use in the interpretation of the post-Pleistocene history of Little Lake, San Salvador Island, Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, Occasional Papers, No. 1, 19 p.

Shackleton, N.J. and Opdyke, N.D., 1973, Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: Oxygen isotope temperatures and ice volumes on a 105 and 106 year scale: Quaternary Research, v. 3, pp. 39-55.

Sims, W.R., 1987, Facies analysis of carbonate rocks on the southern end of San Salvador Island, Bahamas [unpublished M.S. thesis]. The University of Akron, 135 p.

Slone, G.B., Boardman, M.R. and Cummins, R.H., 1990, Molluscan skeletal associations as a function of benthic cover and environmental stress: Pigeon Creek, San Salvador, Bahamas,: in Fifth symposium on the geology of the Bahamas, Abstracts and Programs, p. 18.

Teeter, J.W., 1983, The topographic, hydrologic, and sedimentologic setting of Little Lake, San Salvador Island, Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, Occasional Papers, No. 1, 7 p.

Teeter, J.W., 1985a, Holocene lacustrine depositional history: in Curran, H.A., ed., Pleistocene and Holocene carbonate environments on San Salvador Island, Bahamas - Guidebook for the Geological Society of America, Orlando annual meeting field trip: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 133-145.

Teeter, J.W., 1985b, Pigeon Creek Lagoon, a modern analogue of the Pleistocene Granny Lake Basin: in Curran, H.A., ed., Pleistocene and Holocene carbonate environments on San Salvador Island, Bahamas - Guidebook for the Geological Society of America, Orlando annual meeting field trip: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 147-160.

Teeter, J.W., 1989, Refinement and timing of salinity fluctuations in Watlings Blue Hole, San Salvador Island, Bahamas: in Mylroie, J.E., ed., Proceedings of the fourth symposium on the geology of the Bahamas: Port Charlotte, Florida, Bahamian Field Station, pp. 331-336.

Teeter, J.W. and Quick, T.J., 1990, Magnesium-salinity relation in the saline lake ostracode *Cyprideis americana*: Geology, v. 18, pp. 220-222.

Teeter, J.W. and Thalman, K.L., 1984, Field trip to Pigeon Creek: in Teeter, J.W., ed., Proceedings of the second symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 177-186.

Teeter, J.W., Beyke, R.J., Bray Jr., T.F., Brocculeri, T.F., Bruno, P.W., Dremann, J.J. and Kendall, R.L., 1987, Holocene depositional history of Salt Pond, San Salvador, Bahamas: in Curran, H.A., ed., Proceedings of the third symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 145-150.

Teeter, J.W., Beyke, R.J., Bray Jr., T.F., Dremann, J.J., Hooffstetter, L.J., Kendall, R.L., Schmidley, E.B. and Sims, W.R., 1987, Preliminary observations on the depositional history of Nixon's Blue Hole, Great Inagua, Bahamas: in Curran, H.A., ed., Proceedings of the third symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 151-154.

Thalman, K.L., 1983, A Pleistocene lagoon and its modern analogue, San Salvador, Bahamas [unpublished M.S. thesis]. The University of Akron, 166 p.

Titus, R., 1983, Quaternary stratigraphy of San Salvador, Bahamas: in Gerace, D.T., ed., Proceedings of the first symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 1-5.

Titus, R., 1984, Physical stratigraphy of San Salvador Island, Bahamas: in Teeter, J.W., ed., Proceedings of the second symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 187-196.

Titus, R., 1987, Geomorphology, stratigraphy, and the Quaternary history of San Salvador: in Curran, H.A., ed., Proceedings of the third symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 155-164.

Vacher, H.L. and Mylroie, J.E., this volume, Geomorphic evolution of topographic lows in Bermudian and Bahamian islands: Effect of Climate.

Vierma, L., Kwolek, J.M., Heidt, D.A., Hattin, D.E., Hasenmueller, W.A. and Feldman, H.R., 1984, Stratigraphic analysis of a newly discovered Pleistocene reef, San Salvador Island, Bahamas: The Compass, v. 62, #1, pp. 16-30.

White, B., 1989, Field guide to the Sue Point fossil coral reef, San Salvador Island, Bahamas: in Mylroie, J.E., ed., Proceedings of the fourth symposium on the geology of the Bahamas: Port Charlotte, Florida, Bahamian Field Station, pp. 353-365.

White, B. and Curran, H.A., 1987, Coral reef to eolianite transition in Pleistocene rocks of Great Inagua Island, Bahamas: in Curran, H.A., ed., Proceedings of the third symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 165-179.

White, B., Kurkjy, K.A. and Curran, H.A., 1984, A shallowing upward sequence in a Pleistocene coral reef and associated facies, San Salvador Island, Bahamas: in Teeter, J.W., ed., Proceedings of the second symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp 53-70.

Wilber, R.J., 1987, Geology of Little San Salvador and West Plana Cay: Preliminary findings with implications for Bahamian island stratigraphy: in Curran, H.A., ed., Proceedings of the third symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 181-204.

Winter, J., 1987, Speculations on prehistoric coastal topography of the Bahamas: in Teeter, J.W., ed., Proceedings of the second symposium on the geology of the Bahamas: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, pp. 205-213.

Winter, J., 1990, Recent geological finds on San Salvador: in Fifth symposium on the geology of the Bahamas, Abstracts and Programs, p. 28.

Zabielski, V.P. and Neumann, A.G., 1990, Some aspects of the depositional history of Storr's Lake, San Salvador Island, Bahamas: in Fifth symposium on the geology of the Bahamas, Abstracts and Programs, pp. 28-29.

Table 1. Molluscan fauna present at the eleven sampling sites shown in Figure 1. Approximate relative abundances are designated by "A" (abundant), "C" (common), and "R" (rare). "(B)" and "(G)" indicate bivalve and gastropod, respectively. Note: Church Site contains two distinctly different mollusc-rich deposits - Church Site 1 and Church Site 2.

Fig. 1. Sampling locations on San Salvador Island. 1: Miller Pond; 2: Base Ponds. 3: Quarry A; 4: Beach Cave; 5: Quarry E; 6: Stouts Lake; 7: Watlings Blue Hole; 8: Titus Pond; 9: Church Site; 10: Cockburn Town Fossil Reef; 11: North Victoria Hill.

Fig. 2. San Salvador Island at a +6 m sea level highstand. Note: There are no isolated inland lakes. Stippled areas indicate land. (After Mylroie and Carew, 1990)

Fig. 3. Lake Cockburn: A large lake that could have possibly formed from the coalescing of smaller lakes due to a 2.5 m rise in sea level. Land is indicated by diagonal lines. (Redrafted from Titus, 1984)