PROCEEDINGS OF THE 12TH SYMPOSIUM ON THE GEOLOGY OF THE BAHAMAS AND OTHER CARBONATE REGIONS

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Edited by
R. Laurence Davis and Douglas W. Gamble

Production Editor:
Douglas W. Gamble

Gerace Research Center
San Salvador, Bahamas
2006

Front Cover: Crinoids in waters of San Salvador, Bahamas. Photograph by Sandy Voegeli, 2003.

Back Cover: Dr. H. Leonard Vacher, University of South Florida, Keynote Speaker for the 12th Symposium and author of "Keynote Address – Plato, Archimedes, Ghyben Herzberg, and Mylroie", this volume , p. ix. Photograph by Don Seale.

Wallace Press, Concord, NH.

ISBN 0-935909-77-X

GEOMORPHOLOGICAL AND HYDROLOGICAL CONTROLS OF FRESH WATER WETLANDS ON SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

The interior of San Salvador Island is dominated by large, shallow inland lakes bounded by lithified carbonate dunes. The island has a tropical savanna climate with a winter dry season. The water budget is negative, and when combined with the island's low elevation and extensive karst, creates conditions that favor saline to hypersaline water chemistry in the lakes. However, careful exploration of the island's interior has shown that, despite these conditions, there are many freshwater wetlands. The purpose of this study is to account for their presence and to determine how they fit into the islands hydrologic regime.

Seven wetlands ranging from fresh to slightly brackish were examined during four trips between 2002 and 2004. Trips occurred at the beginning of the year's dry season and again near its end. Rock thin sections, water chemistry, and water level data were collected at each site. GPS points were collected to create basin morphologies for most of the study sites. The wetlands themselves are located in shallow depressions. Short time interval data logging of water levels in the wetlands did not show a clear tidal signal. During the dry season, water levels declined and dissolved solid concentrations increased. This suggests that the wetland system is evaporation dominated and are the wetland areas were at least partially underlain by micritic paleosols.

We hypothesize that the geology and geomorphology of the areas surrounding the freshwater wetlands work like a natural "catch" basin. Rainwater first infiltrates the thin soil layer, and is then transported by interflow along the impervious paleosol. The water then pools in the lowest areas, perched on the paleosols, and evaporation during the dry season.

INTRODUCTION

The Bahamian Archipelago includes roughly 700 islands and stretches from off the coast of Florida for over 850 km in a southeast direction. While most of the islands are small, many are large enough to contain inland bodies of water, often in the form of lakes located between the inter-dune swales. A study on the hydrology of San Salvador Island by Davis and Johnson (1989) emphasized the presence of an overall negative water budget, causing most of the water bodies to range from brackish to saline. Despite the negative water budgets, San Salvador does have a few fresh water wetlands. Previous studies have focused on the lakes and ponds which range from brackish to hypersaline, leaving the genesis and hydrology of the freshwater wetlands largely unknown. The goal of this research was to formulate and test hypotheses about the origin and hydrology of these freshwater wetlands.

BACKGROUND

Climatic Conditions

The Bahamian Islands, including San Salvador, are considered to have a tropical savanna climate (Shaklee, 1996), with temperatures remaining on average above 18°C year round and a dry season during the winter months. The island has an overall negative water budget where evaporation exceeds precipitation (Davis and Johnson, 1989). The negative water budget creates conditions causing the inland lakes to range from saline to hyper-saline.

Geology

The following overview of San Salvador geology is based on papers by Carew and Mylroie (1995, 1997). The bedrock on San Salvador Island consists of young carbonates deposited primarily during interglacial highstands in the form of eolionite dune formations, shallow marine deposits, and inland lake and lagoon deposits. The rocks have been divided into three formations (Figure 1), the Owls Hole Formation (Pleistocene), the Grotto Beach Formation (Pleistocene), and the Rice Bay Formation (Holocene). The Owl's Hole Formation is the oldest formation on the island and consists of eolionite limestones capped by a micritic terra-rosa paleosol. The Grotto Beach Formation overlies the Owl's Hole Formation and consists of eolionites and beach facies to subtidal marine limestones. This formation is also capped in areas by a terra-rosa paleosol. The Rice Bay Formation overlies the Grotto Beach Formation and consists of eolionites and beach facies. According to Carew and Mylroie (1995), landforms with elevations above seven meters are all eolian in origin while land forms below seven meters in elevation are a mixture of marine, lacustrine, and terrestrial limestones.

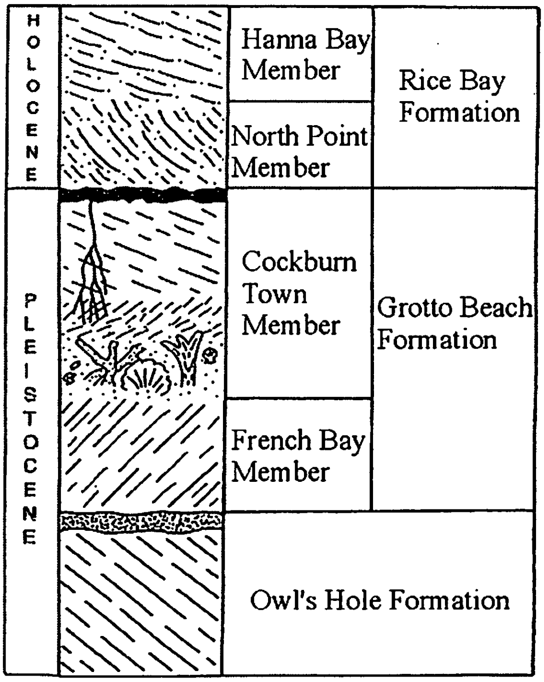

Figure 1. Bahamian Stratigraphic Column. (After Carew and Mylroie 1997).

The formation of the paleosols that cap the Pleistocene formations has been discussed by Boardman, et al. (1995). They described the different paleosols as either laminated crusts, homogenous crusts, or breccia-conglomerate paleosols. The laminated crusts are the most common form on San Salvador. The paleosols contain a fraction of insoluble residues which are made up of both organic and inorganic materials. The soils were micritized rapidly to form a hard crust on the landscape. Mylroie et al. (1995) suggested that the impervious micritized paleosols can prevent water infiltration on the land surface. This would result in diversion of rainwater overland with infiltration concentrating in areas where the paleosols are absent or breached. For the purpose of this study, that idea is extended to include water diversion over the micritic crusts and protosols as well as the paleosols of San Salvador.

Hydrology

Most modern groundwater textbooks (e.g. Dingman, 1994) present the Ghyben-Herzberg model as an explanation of the relationship between the depth to salt water and the height of the water table on islands or near coastlines. This model indicates that the salt-fresh water interface should extend below sea level to a depth of 40 times the height of the water table above sea level. Davis and Johnson (1989) examined groundwater lenses on San Salvador which range from fresh to brackish and float on saline groundwater.

The low-lying topography on San Salvador plays an important role in freshwater lens thickness and surface water body morphology. The island is dominated by a series of inland lakes. These lakes range in shape from circular blue holes to elongate crescent-shaped lakes formed in the topographic lows between the eolionite ridges (Teeter, 1995). Since the lake bottoms are below sea level, the water in the lakes is at sea level and ranges in salinity from brackish to hypersaline. The negative water budget causes evaporation from the surface zone of the lakes and ponds which causes an up-welling of the saline waters (Davis and Johnson, 1989). This causes the lakes and ponds to range from saline to hypersaline and forces the fresh groundwater lenses to be discontinuous and located under the eolionite dune ridges (Davis and Johnson 1989) (Figure 2). Despite this model, which suggests that freshwater wetlands should be rare or non-existent on San Salvador, there are still a number of these wetlands on the island.

Terrestrial Ecology

The plant communities on San Salvador were identified by Smith (1993). He classified the freshwater wetland communities into two subcategories, the Palmetto Flats and *Typha* marshland. Other wetlands communities were classified by Smith as the Sinkhole Subcommunity of the Blacklands Community and the Whitelands Community. Typical vegetation for all freshwater wetland types includes the Sabal Palms (*Sabal palmettos*), Cattails (*Typha domingensis*), freshwater sawgrass (*Cladium jamaicensis*), rush (*Dichromena colorata* and *Eleocharis cellulosa*), pennyworts (*Centella asiatica*), marsh lippia (*Phyla stoechadifolia*) and Ludwigia (*Ludwigia octovalvis*).

HYPOTHESIS

This study attempts to determine how freshwater wetlands exist in the geologic and hydrologic regime of San Salvador. Two conceptual models were explored, the first being a breach of the freshwater lens and the second a perched wetland basin. If the wetlands are intersecting the freshwater lens, we would expect the bottom of the wetlands to be at or below sea level, the water to be brackish or saline, as the rest of the water bodies on the island, and there could be a muted a tidal signal. In this conceptual model the freshwater from the lens would seep out into the wetlands, keeping the land wet with fresh water. If the wetlands are perched systems, the basins would likely be at or above sea level, there would not a tidal signal, and there would be an impermeable layer preventing the saline groundwater from upwelling to the surface during the dry season. Any of the wetland areas may also be influenced by the presence of an underlying micritized paleosol creating a relatively impervious layer which would divert rainwater to the lowest spots in the wetland. The wetlands on the island may be influenced by both conceptual models and

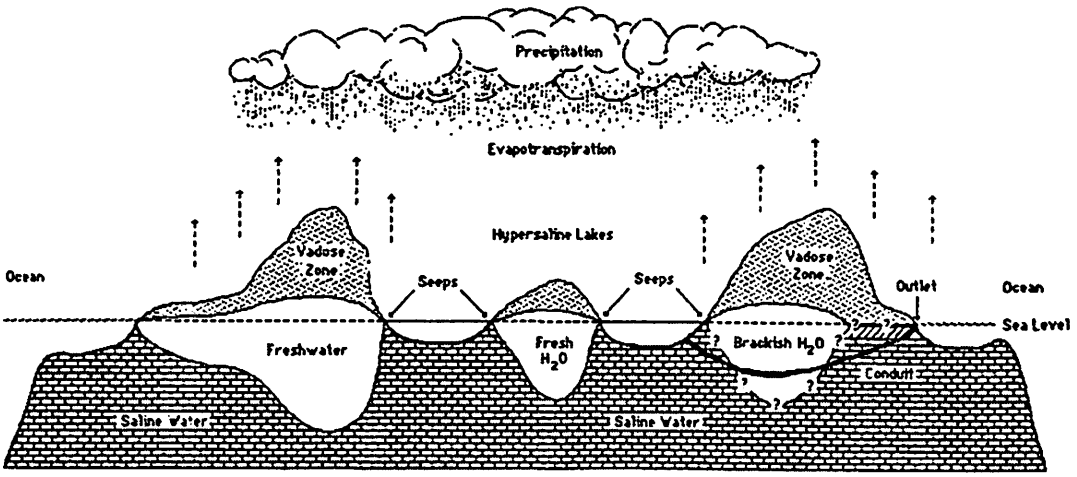

Figure 2: Freshwater lens dissection (Davis and Johnson, 1989)

Site	Wetland Name	Size (Ha)	Community Type	Wet
1	Jake Jones	3.5	Whitelands	Year Round
2	North Victoria Hill	9	Palmetto Flat	Year Round
3	Airport	7	Typha Marsh	Year Round
4	Interior	70	Sinkhole	Seasonal
5	Allen Settlement	< ½	Sinkhole	Seasonal
5	Quarry	< 1	Anthropogenic	Year Round
5	Southern Palmetto Flat	2	Palmetto Flat	Year Round

Table 1. Study site comparison.

may exhibit characteristic from both models.

STUDY SITES

Seven freshwater wetlands were chosen from around San Salvador Island to test these two hypotheses. The general locations for each study site are numbered and located on the map of San Salvador (Figure 3). Details outlining the study sites are compared in Table 1 which is followed by a brief description for each wetland.

The Jake Jones Road wetland site, marked by number 1 on Figure 3, is located on either side of the Jake Jones road and covers about three and a half hectares. The area contains thick vegetation consisting primarily of dense stands of Sabal palms with a thick organic layer covering the ground surface. There is a small pool of water on the east side of the Jake Jones road which remains wet year round. This area resembles Smith's (1993) description of a Whitelands Community.

The North Victoria Hill wetland, marked by number 2 on Figure 3, is also called Granny Pond by the locals. This wetland consists of almost nine hectares of Palmetto Flats and is located downhill from the old Air Force Building south of the North Victoria Hill Settlement. This wetland contains a pond in the northwestern corner. This is the only wetland in the study which was slightly brackish.

The Airport wetland, number 3 on Figure 3, consists of two sections divided by the road to the Club Med facility and has a combined area of about seven hectares There is a small pond in the southeast corner of the wetland to the west of the Club Med road.

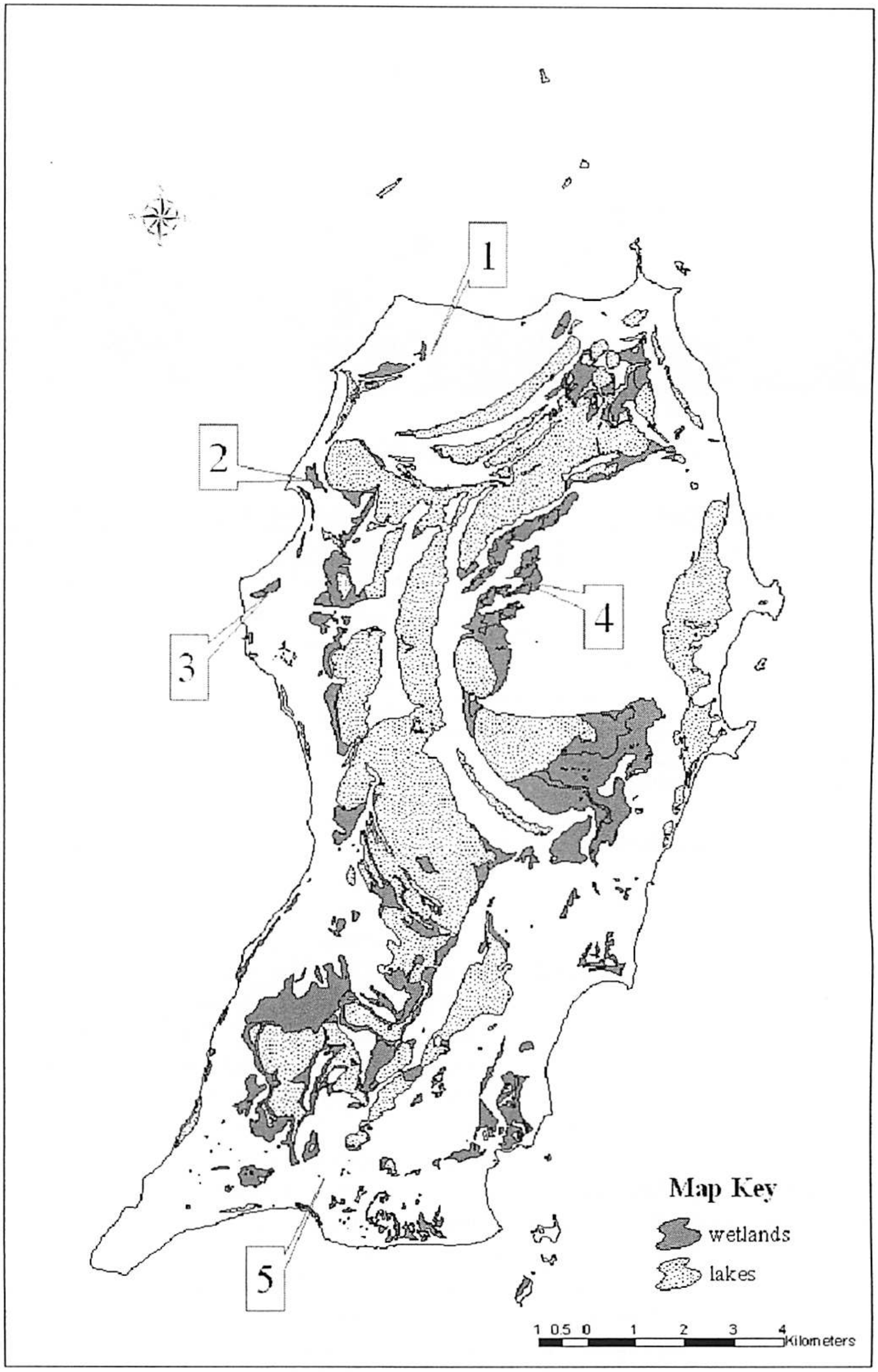

Figure 3. Freshwater wetland study sites, San Salvador Island, Bahamas. (After: Robinson and Davis 1999)

This is the wetland classified as a *Typha* marshland.

The Interior wetlands, number 4 on Figure 3, are seasonal wetlands classified ecologically as the Sinkhole Subcommunity of the Blacklands. The wetlands consist of a series of shallow closed-contour depressions which are scattered over approximately 70 hectares of the interior between the east side of Six Pack Pond and the neighboring eolionite ridges.

The last three sites are in the area of number 5 on Figure 3. These are the Allen Settlement, Quarry Wetland and Southern Palmetto Flats. The Allen Settlement wetlands which are seasonal wetlands classified as the Sinkhole Subcommunity of the Blacklands. The area contains a chain of four shallow closed-contour depressions with a combined area of less than one half hectare. The site is located just off the west side of the main road between the Allen Settlement and the Belmont Church. The Quarry wetland is an actively developing plant community in a wetland created by quarry operations that intersected the groundwater. The wetland is located in an active quarry on the south end of the island and covers less than one hectare. The Southern Palmetto Flats is located about 100 meters west of the Quarry wetland. This wetland is erroneously classified on the topographic map as a mangrove swamp but actually resembles a Palmetto Flats community. The wetland covers two hectares and contains two ponds.

DATA COLLECTION

Several types of field data were collected in order to determine if the wetlands are above sea level, connected to the groundwater (seawater), perched above the groundwater, or underlain by an impervious paleosol. Data collected to make these determinations included water level changes over time using a pressure transducer water-level logger, water chemistry using digital titration methods on grab samples, and basin geomorphology. Rock samples were collected with a hammer and chisel and thin sections from these samples were analyzed for rock type. Fieldwork was accomplished during four visits to the island spanning two wet and dry season cycles between December 2002 and April 2004

RESULTS AND DISCUSSION

Water Level Fluctuations

The water-level logger did not show an obvious cyclic signal in any of the natural freshwater wetlands. Only the quarry wetland had a strong cyclic signal which we would expect since this wetland is the result of a breached freshwater lens from quarrying operations. The lack of a cyclic signal in the other wetlands does not prove that the wetlands are perched, but rather the connection may be so muted the signal does not register at the wetland surface. The long-term measurements observed a slow decline in water level over time.

Water Chemistry

All wetlands containing water during both seasons showed an increase in dissolved solids from the wet season to the dry season. The smaller wetlands dry out completely during the dry season and the larger wetlands dried completely only during an exceptionally dry year such as 2004. We used the Ca/Mg ratio as a signal of saline groundwater versus rainwater inputs into the freshwater wetland (Davis and Johnson, 1989). A high Ca/Mg ratio would indicate system inputs from fresh rainwater rather than saline groundwater which would increase the amount of Mg in the wetland. Only the North Victoria Hill showed a water chemistry with a very low Ca/Mg ratio during the dry season which indicates groundwater upwelling during this season. The same wetland had a high Ca/Mg ratio during the rainy season, indicating the inputs are from fresh rainwater.

Surface Geology

All of the study site wetlands, except the Jake Jones wetland, had a micritic crust on the surface. These crusts were often exposed at higher areas, and covered in low areas with up to about ten centimeters of muck. Thin sections showed evidence of paleosols such as red micritized clay and fossil root casts. The paleosols range from well developed in the largest wetland of North Victoria Hill to poorly developed in the smaller wetlands such as the sinkhole communities of the Interior wetland and Allen Settlement. Most of the thin sections showed evidence of diagenesis in a freshwater vadose environment as described in Estaban et al. (1983). This type of diagenesis is revealed in thin section by containing many different stages of diagenesis in the same sample including pockets grains and fabrics that are intact, dissolved, recalcified, and micritized. Rock samples from most of the wetlands exhibited multiple diagenetic stages. This would indicate periods of wetting and drying as would be found in a freshwater vadose environment. This process may be ongoing which would enhance the micritic crusts found in the wetlands. The micritic paleosols provide an impervious surface which promotes surface runoff and rainwater collection in the low-lying areas of the wetlands.

CONCLUSIONS

Freshwater wetlands do exist on the island of San Salvador. Most of these wetlands owe their existence to underlying micritic crusts. Jake Jones is the only wetland not influenced by a micritic crust. In this wetland, the water collects in depressions where the thick soil layer and the dense canopy helps prevent evaporation of this water. The rest of the wetlands are influenced by a micritic crust which diverts rainwater overland and works as a natural catchment basin, collecting water and keeping it from infiltrating into the saline groundwater. For many of the wetlands this crust may also keep the saline groundwater from surface exposure and evaporation. These wetlands would be considered a perched system. The collected freshwater evaporated during the dry season leaving behind the dissolved solids. The larger the wetland basin, the more rainwater it can collect and the longer it will remain wet during the dry season. The major exception is the wetland at North Victoria Hill which is primarily perched, but also has a leak in the micritic crust which allows the saline groundwater to up well during extremely dry periods. For all the wetlands influenced by micritic crusts, the process of micritization may be presently occurring during the wetting and drying periods which increase the thickness and impermeability of the wetland basins enhancing the catchment basin effect.

ACKNOWLEDGMENTS

We would like to thank Dr. Donald T. Gerace, Chief Executive Officer, and Vincent Voegeli, Executive Director of the Gerace Research Center, San Salvador Bahamas for financial and logistical support. Assistance received from Jim Carew, Doug Gamble, Lee Kass, Bob Hunt, John Mylrioe, Mary Roden-Tice, and Tom Wolosz was greatly appreciated.

REFERENCES

Boardman, M. R., McCartney, R. F., and Eaton, M. R, 1995, Bahamian Paleosols:Origin, relation to paleoclimate, and stratigraphic significance, *in* Curran, H.A., and White, B., eds., Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda. Boulder, Colorado: Geological Society of America Special Paper 300. p 33-50.

Carew, J. L., and Mylrioe, J. E., 1995, Depositional model and stratigraphy for the Quaternary geology of the Bahama Islands, *in* Curran, H.A., and White, B., eds., Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda. Boulder, Colorado: Geological Society of America Special Paper 300. p 5-32.

Carew, J.L. Mylroie, J.E. 1997, Geology of the Bahamas, *in* Vacher, H.L. and Quinn, T.M., eds., Geology and Hydrogeology of Carbonate Islands. Developments in Sedimentology 54. Amsterdam, The Netherlands: Elsevier Science B.V.

Davis, R. Laurence, and Calvin, R. Johnson Jr. 1989. Karst Hydrology of San Salvador, *in* Mylroie, J.E., eds., Proceedings from the 4th Symposium on the Geology of the Bahamas. San Salvador Bahamas: Bahamian Field Station. p 118-135.

Dingman, S. L., 1994, Physical Hydrology. Macmillan College Publishing Company, New York, New York.

Estaban, M. and Klappa, C. F., 1983, Subaerial Exposure Environment, *in* Scholle, P.N., Bebert, D.G., Moore, C.H., eds., Carbonate Depositional Environments. Tulsa Oklahoma: The American Association of Petroleum Geologists.

Mylroie, J.E., and Carew, J.L. 1995. Karst Development on Carbonate Islands, *in* Budd,D.A., Saller, A.H., and Harris, P.M. , eds., Unconformities and Porosity in Carbonate Strata. American Association of Petroleum Geologists Memoir 63: p 55-76

Robinson, M.C. and Davis, R.L., 1999, San Salvador Island GIS Database. The University of New Haven and Bahamian Field Station.

Shaklee, R.V., 1996, Weather and Climate San Salvador Island, Bahamas. San Salvador Bahamas: Bahamian Field Station.

Smith, R.R., 1993, Field Guide to the Vegetation of San Salvador Island, The Bahamas. San Salvador Bahamas: Bahamian Field Station.

Teeter, J.W. Holocene Saline Lake History, San Salvador Island, Bahamas, *in* Curran, H.A., and White, B., eds., Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda. Boulder, Colorado: Geological Society of America Special Paper 300. p 117-124.