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Front Cover: Close-up view of a patch-reef coral head in Grahams Harbor, north of Dump Reef. As shown here, Caribbean shallow-water reefs have declined since the mid-1980s and are now largely overgrown by fleshy green macroalgae and a variety of encrusting organisms. See Curran et al., "Shallow-water reefs in transition," this volume, p. 13. Photograph by Ron Lewis.

Back Cover: Dr. A. Conrad Neumann, University of North Carolina, Chapel Hill, NC, Keynote Speaker for the 11th Symposium and author of "Cement loading: A carbonate retrospective," this volume, p. xii. Photograph by Mark Boardman.

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DEPOSITIONAL HISTORY OF A COASTAL EVAPORITE SALINA SALT POND, SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

Salt Pond is a coastal salina on the eastern shore of San Salvador Island, Bahamas. The salina is unusual among San Salvador's many lakes in that it undergoes a period of desiccation on a regular basis. Measured salinities range from 20 to 356 ppt., and evaporite deposits have been observed forming in its basin. Historical records of salinity, rainfall, and lake level demonstrate that these variables are highly correlated.

The following six facies were identified: evaporites and silty flocculates, carbonate mud, carbonate sand, laminated cyanobacterial zones, peat, and basal sand and silt. The depositional history as interpreted from the sedimentary facies indicates a succession from a marine subtidal environment to a fresh water condition, followed by periods of saline intrusion and increasing salinity. Several marked zones of sediment representing storm washover events are also present.

Currently, carbonate sediments in the pond are undergoing dolomitization. X-ray diffraction analysis of the sediment from one core in the salina has detected dolomite at a depth of approximately 32 cm. Porewater chemical analyses demonstrate that the sediment in the salina is within the dolomite stability field.

INTRODUCTION

The purpose of this study is to describe the coastal salina, Salt Pond, on the eastern side of San Salvador Island, Bahamas and to reconstruct its depositional history. San Salvador is an isolated stable carbonate platform located on the eastern margin of the Bahamian Island chain. San Salvador's climate is semi-arid, with evaporation exceeding precipitation. The average precipitation over a 72-year period for San Salvador is 102 cm per year. However, annual variation in precipitation is extreme, ranging from 195 cm/year to 47 cm/year (Foos, 1994).

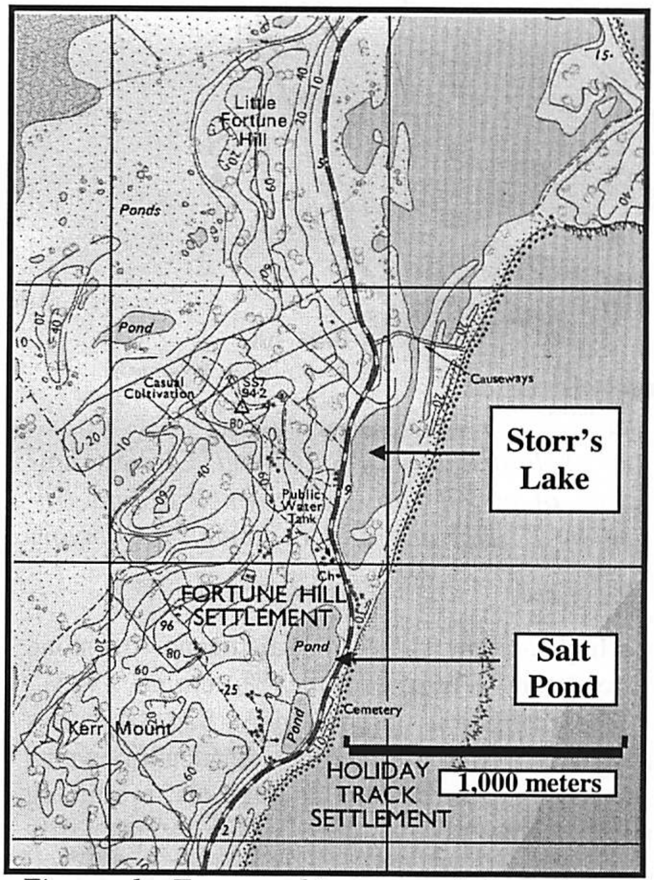

Figure 1. Topographic map of San Salvador, showing the location of Salt Pond

Salt Pond, located on the eastern side of the island (Figure 1), is one of many hypersaline lakes found on San Salvador (Teeter, et al., 1987). The salina's basin is separated from the Atlantic Ocean by a narrow, flat-topped ridge of Pleistocene-age bedrock, followed by a vegetation-stabilized dune ridg and a relatively steep carbonate sand beach. The bedrock ridge separates the salina from Storr's Lake to the north (Figure 1), an isolated former tidal creek (Corwin, 1985; Zabielski and Neumann, 1990). The Salt Pond basin is separated from the Granny Lake basin to the west

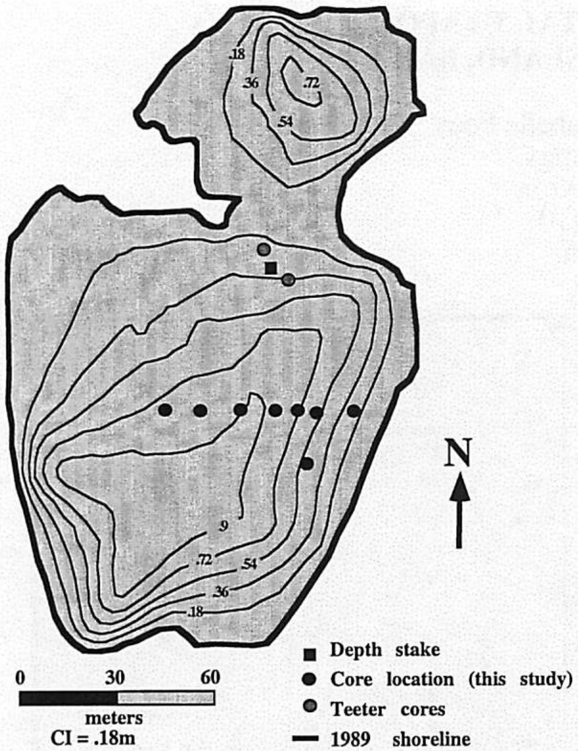

Figure 2. Bathymetry of Salt Pond. Circles show location of piston cores. (Bathymetric data collected by K. Hartong and D. Lauck in January 1983)

by a high arcuate ridge of Pleistocene limestone that represents a lithified dune (Florentino, 1985).

Salt Pond is unique among San Salvador's many lakes in that it undergoes desiccation events at what appear to be regular intervals, producing thick deposits of evaporite minerals, primarily halite and gypsum. These salt crusts are ephemeral and last generally until the next wet season, when an influx of lower salinity water of marine, ground, or meteoric origin dissolves the halite and returns it to solution.

Present conditions in Salt Pond were investigated by field observations of the present shoreline and facies distribution. In addition, available salinity and bathymetric data was compiled. A bathymetric map shows that the salina is divided into two basins: a smaller, more constricted basin at the north and a wider and longer basin to the south (Figure 2). Eight piston cores were taken in December 1992 in the southern basin and were analyzed to investigate the depositional history of Salt Pond. Six of the cores were collected along an east-west transect at 10 m intervals. Core numbers represent distance from the December 1992 shoreline. The cores were described, their mineralogy was determined by XRD, and the diagenetic conditions were determined through pore-water analyses of Mg and Ca.

RECENT SALINITY HISTORY

Semi-annual salinity measurements were conducted at Salt Pond between 1985 and 1994, and water level was determined relative to a stationary depth stake between 1987 and 1993 by J. Teeter (personal communication). Additional salinity data was collected by K. Trubee (7/01, 5/02) and the authors (1/93, 6/02). Salinity varied significantly, ranging from a low of 20$^{o}/_{oo}$ in June 2002 to a high of 356$^{o}/_{oo}$ in July 1992 (Figure 3). Measured water level in the lake has fluctuated by up to 57 cm in recent years. Generally, the water levels in the lake were higher in December than in June/July.

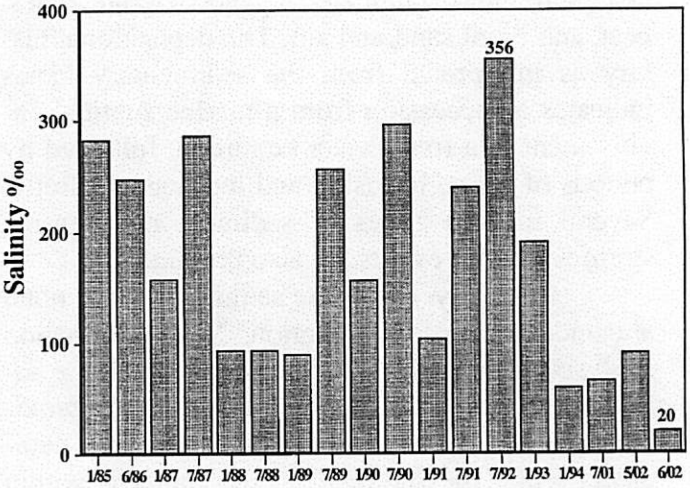

Figure 3. Historic salinity data for Salt Pond.

Lake level is inversely correlated with salinity (Figure 4). Rainfall during the six months prior to each salinity measurement was compiled. A comparison of salinity to precipitation during the previous six months also indicates an inverse relationship (Figure 5). These relationships demonstrate the high degree to which the salina system is dependent on precipitation. Years with low precipitation lead to low water level and high salinity, and years with high precipitation lead to high water level and low salinity conditions.

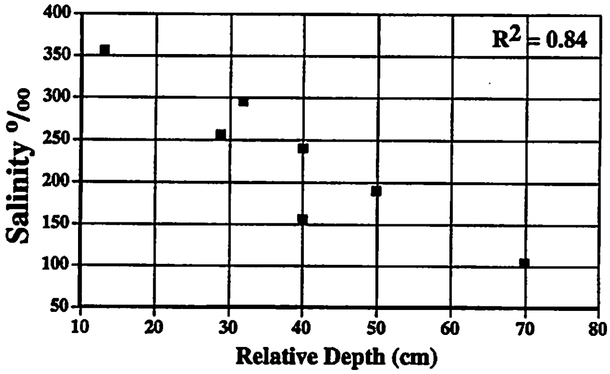

Figure 4. Graph showing the salinity vs. relative depth for Salt Pond

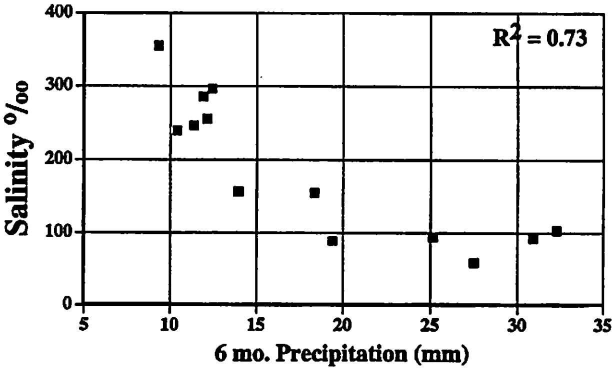

Figure 5. Graph showing salinity vs. precipitation during the previous 6 months for Salt Pond.

During July 1992, a period of low water level and high salinity, significant deposits of evaporite minerals formed a thick crust over the lake surface. This crust was ephemeral: it broke up and redissolved with the coming of the next wet period.

FACIES DESCRIPTIONS

There are six depositional facies represented by the sediment profile of Salt Pond: (1) evaporite and flocculated mud, (2) carbonate sand, (3) carbonate mud, (4) laminated zones, (5) peat, and (6) gray basal sand and silt (Figures 6 and 7).

Evaporites and Flocculated Mud

This facies consists of a dark colored, flocculated, silty suspension, rich in organic content, with light colored evaporite layers composed of halite and gypsum mush and single gypsum rosettes. The evaporite and silty flocculation facies blankets the interior of the salina and thickens at its center. This facies is consistent with hypersaline conditions observed in several other lakes on San Salvador Island.

Carbonate Sand

This facies is comprised of light-colored fine to medium grained bioclastic sands. Some pink and dark brown grains are scattered in this material. Particularly at the salina margin, these materials show some hardground formation and algal lamination. *Anamolacardia* and *Cerithidia* shells are associated with this facies. The carbonate sand facies is present in the salina in a seaward thickening wedge, consistent with a washover fan deposit. Analysis of beach sand and sand from the cores by XRD indicated that the two are similar in composition, being mainly aragonitic. Several of these sand layers are distinct over the width of the salina. Further support for this interpretation is the presence of marine foraminifera in the sandy layers.

Carbonate Mud

This facies consists of gray to brown-gray silty carbonate mud. It comprises the bulk of the cores and displays subtle color variations from gray to gray-brown with increasing depth. The sediment is poorly sorted and displays no bedding. Numerous scattered tan medium-sized bioclastic sand grains are present in this facies. Many *Cerithidia* and some *Anomalocardia* are also present. The carbonate mud layers are thickest at the center of the salina and are probably representative of less hypersaline conditions.

Laminated Zone

This facies consists of dark brown, olive green, white, pink, and tan laminae of soft organic

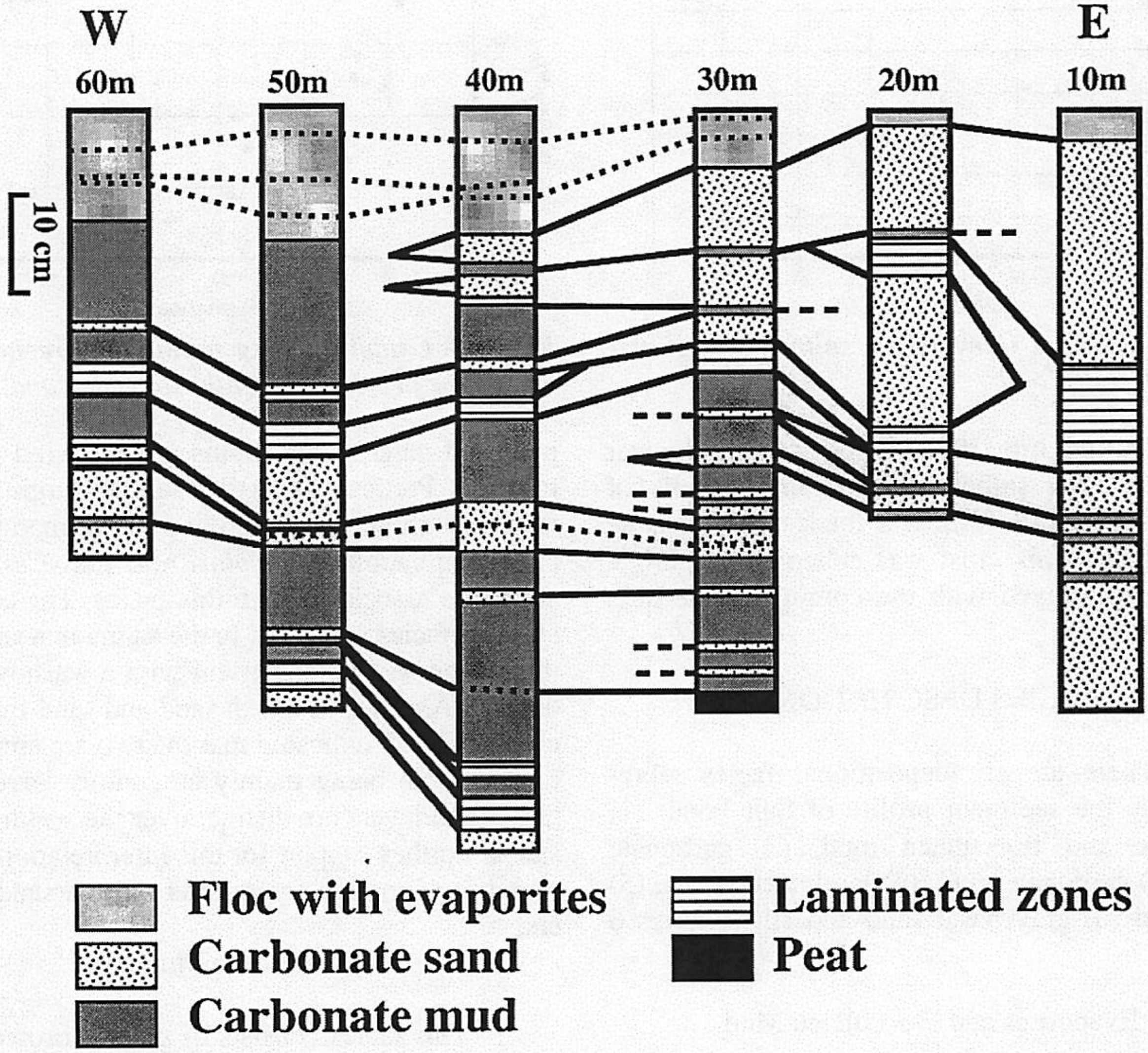

Figure 6. Correlation of sediment facies for cores collected from Salt Pond. Core numbers represent distance from the December 1992 shoreline.

material. These zones are present in the lower and upper areas of the deeper cores and are characterized by fine-grained sediment and algal layers. Thin layers of sand occur as partings in this facies. These zones are laterally traceable and probably represent similar conditions to those that exist on the present salina margin.

Peat

A dark brown to black friable peat formed the lower terminus of the 30-meter core (Figure 6). This peat layer is thin, approximately 1.5 cm in thickness, and was not observed in any of the other cores. The peat facies represents a freshwater stage of the pond.

Gray Basal Sand and Silt

This facies consists of fine- to coarse-grained sand and silt. It forms the basal layer of the 40- meter core. Many *Anamolacardia* shells of varying size are associated with this facies. The basal sand and silt facies, observed in the central portion of the salina, may represent the oldest unconsolidated material in the pond.

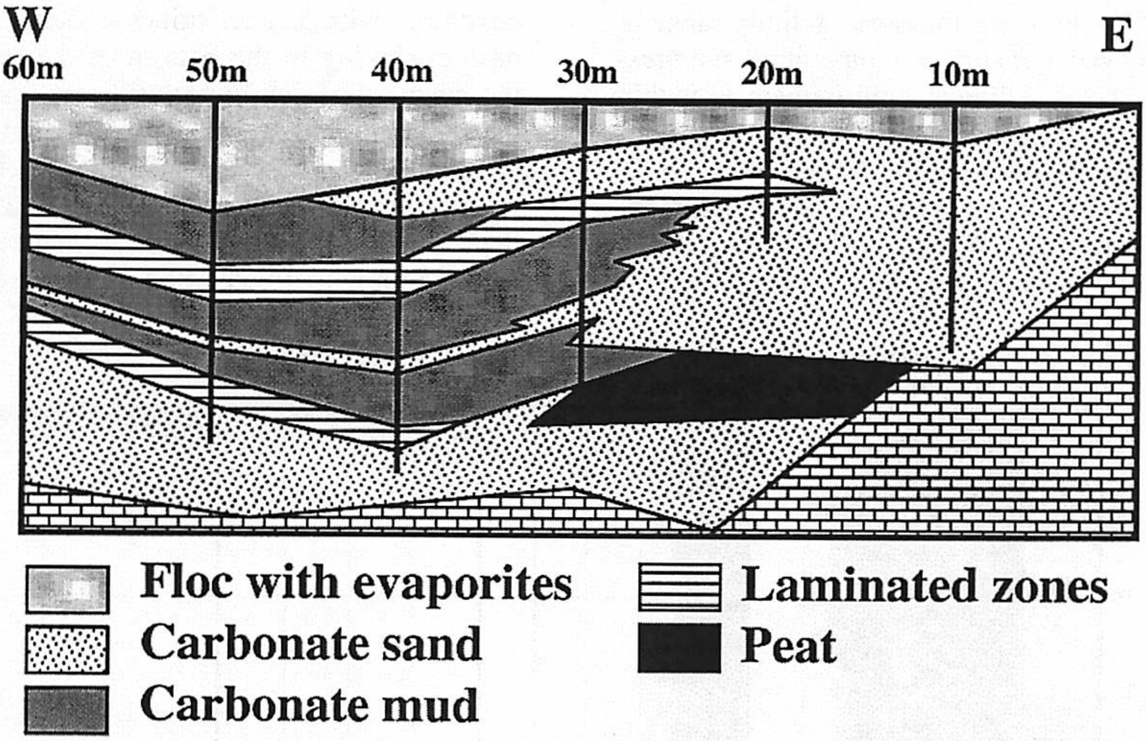

Figure 7. General representation of sediment facies in Salt Pond. Core numbers represent distance from the December 1992 shoreline.

MINERALOGY

Sediment from the 30 meter core was sampled every 1 cm and the mineralogy was determined by X-ray diffraction. The normalized relative intensities were multiplied by a weight factor (aragonite-5, calcite-1, dolomite-0.9, gypsum-1) to approximate relative abundances. Four minerals were identified: calcite ($CaCO_3$), aragonite ($CaCO_3$), gypsum ($CaSO_4 \cdot 2H_2O$), and dolomite ($Ca,Mg(CO_3)_2$). The mineralogy of the core is dominated by aragonite, which occurs throughout the core with the exception of the top few centimeters (Figure 8). The concentration of low-magnesium calcites inversely related to the aragonite concentration. Gypsum is restricted to the top few centimeters of the core. Dolomite occurs in the top few centimeters and in a few discrete zones in the upper half and bottom half (below 30 cm) of the core. In the upper portion of the core, dolomite coincides with zones of small fragmented crusts that appear to have been reworked into the sediment. Proto-dolomitization has been associated with hardgrounds on San Salvador, mainly from algal action (Pentecost, 1989). This additional evidence of dolomitization with depth confirms Furman et al.'s (1993) detection of the mineral in the salina sediments.

The molar Mg/Ca ratio in pore water ranged from 2 to 15 (Figure 9). The pore water data indicates a depletion of magnesium relative to calcium below 31 to 35 cm. The X-ray data points to a mineralogical change at this approximate depth, coincident with the first dolomite peaks. The chemical reaction that characterizes the dolomitization reaction has been determined to be

$$2\ Ca\,CO_3 + Mg^{2+} = CaMg(CO_3)_2 + Ca^{2+}$$

This reaction involves the partial replacement of calcium by magnesium and results in both a depleted magnesium concentration and an elevated calcium concentration. Thus, the porewater analysis indicates that dolomitization is occurring in the sediments, lowering the concentrations of magnesium as that ion is taken into the proto-dolomite structure.

In light of the measured salinity range in the salina water at surface temperature and pressure, the pond sediment environment is within the field of thermodynamic stability for dolomite (Folk, 1974). A reflux model of dolomitization best fits the site characteristics and geography (Tucker and Wright, 1990; Davis, 1983). The following model is proposed: (1) saline waters in the salina are subject to solar heating and evaporation, (2) the salina's water periodically reached a halite and gypsum precipitation condition, with heavier brines enriched in magnesium sinking to the bottom of the salina, (3) the magnesium rich brine infiltrates deeper into the sediment and at 31-38 cm, dolomite begins to form by step-wise replacement of calcium by magnesium (Furman et al.'s (1993), leading to a depletion in the brine relative to magnesium by enriching it with 'freed' calcium. Based on pore

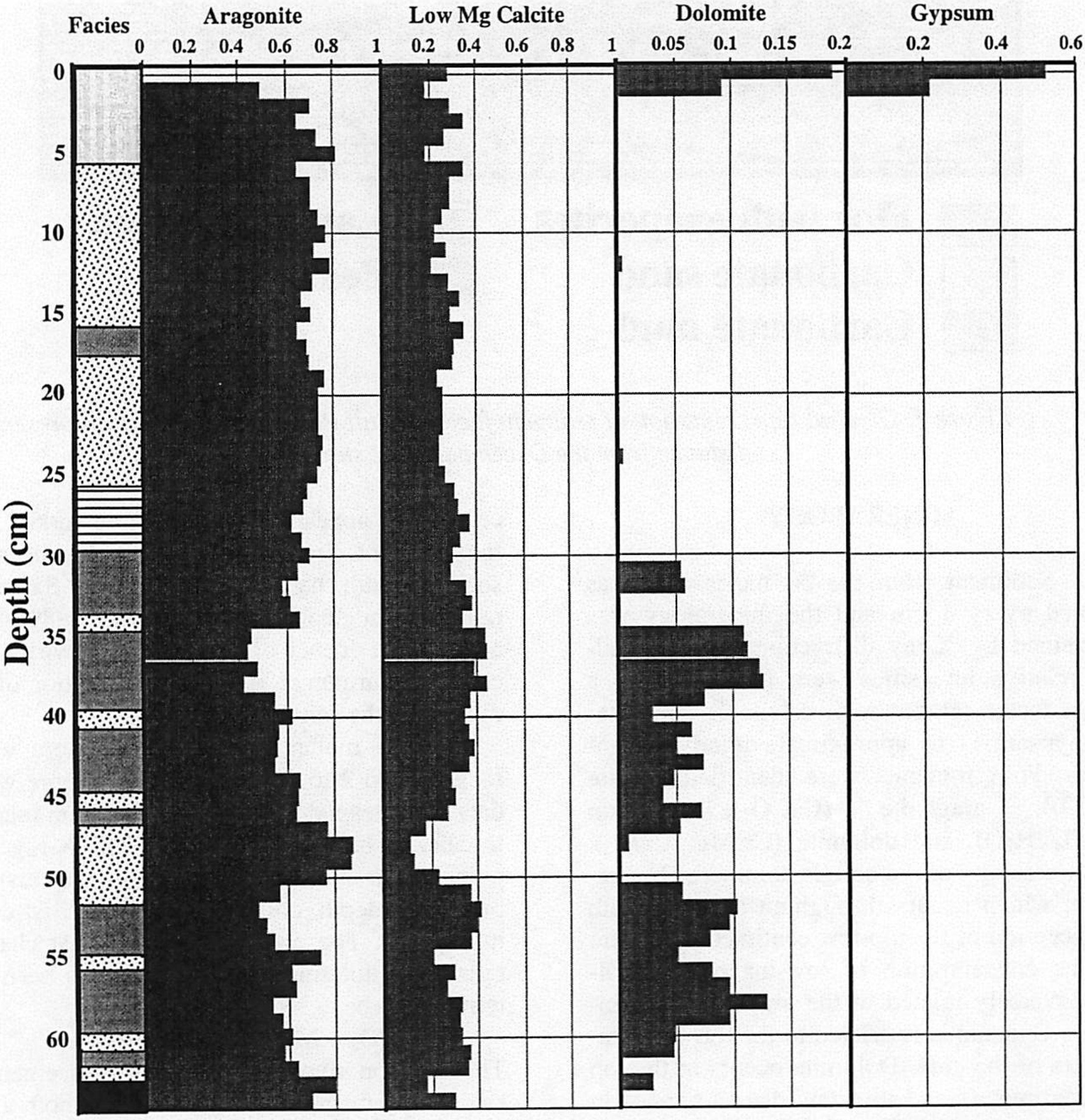

Figure 8. Relative XRD mineral intensities of samples from the 30-meter core (weight factors: aragonite-5, calcite-1, dolomite-0.9, gypsum-1).

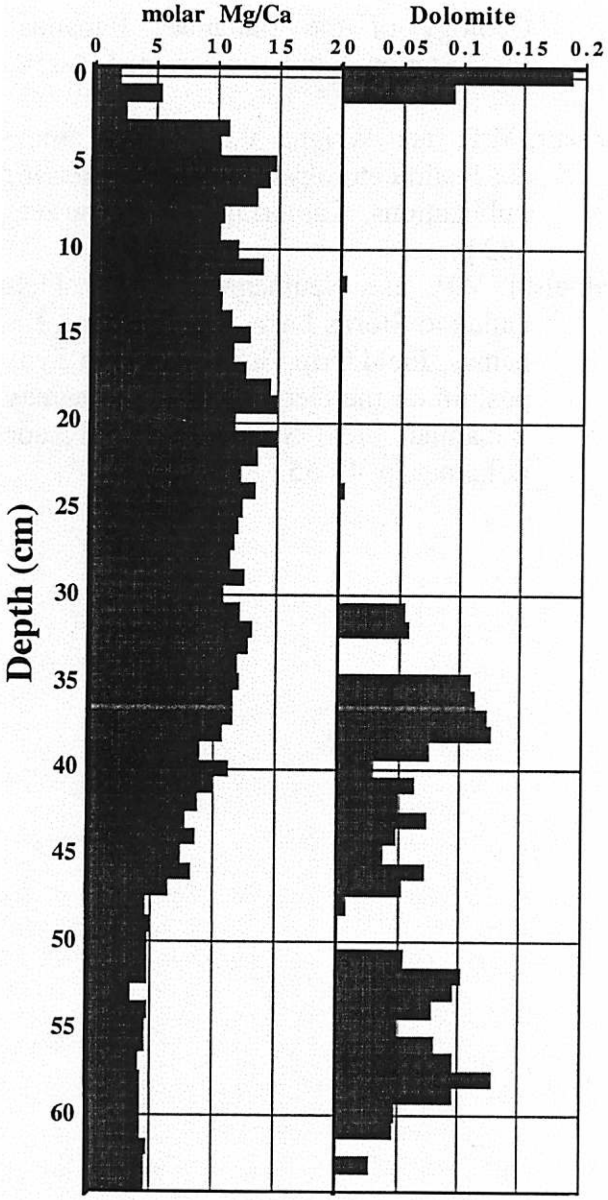

Figure 9. Molar Mg/Ca ratioof pore-water and relative XRD dolomite intensity of sediment samples from the 30-meter core.

water chemistry data alone, the formation of dolomite should be occurring throughout the entire section; however, kinetic interferences associated with the highly concentrated brines may be inhibiting the dolomitization process. These interferences may include the high ionic strength of seawater and brines, hydration of the Mg^{2+} ion, and the low activity of CO_3^{2-} (Tucker and Wright, 1990).

DEPOSITIONAL HISTORY

Based on the observations of the sediment and facies, the following depositional history for Salt Pond is proposed:

(1) Marine waters enter an interdunal swale, depositing the basal sand and silt.

(2) Restriction of circulation by a spit, bar, or other longshore transport results in hypersaline conditions (laminated zone). The spit or bar may have been be stabilized by woody vegetation, as evidenced by the peat layer.

(3) Inundation of the salina basin by an enlarged Storr's Lake drowns the laminated zone and deposits the carbonate mud facies.

(4) A period of increased storm activity leads to the deposition of a series of storm washover deposits, mainly carbonate sand, temporarily lowering salinity; however, the return of the carbonate mud facies indicates a return to higher salinity conditions.

(5) A return to hypersaline conditions is evidenced by the presence of a laminated zone above the carbonate mud. This period of hypersalinity is followed by another stormy period, with the deposition of another laterally extensive layer of carbonate sand.

(6) A final period of less hypersaline conditions following the deposition of the carbonate sand is evidenced in the uppermost portion of the carbonate mud facies.

(7) A gradual return to hypersaline conditions is shown by the topmost deposits of evaporites and flocculated mud.

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