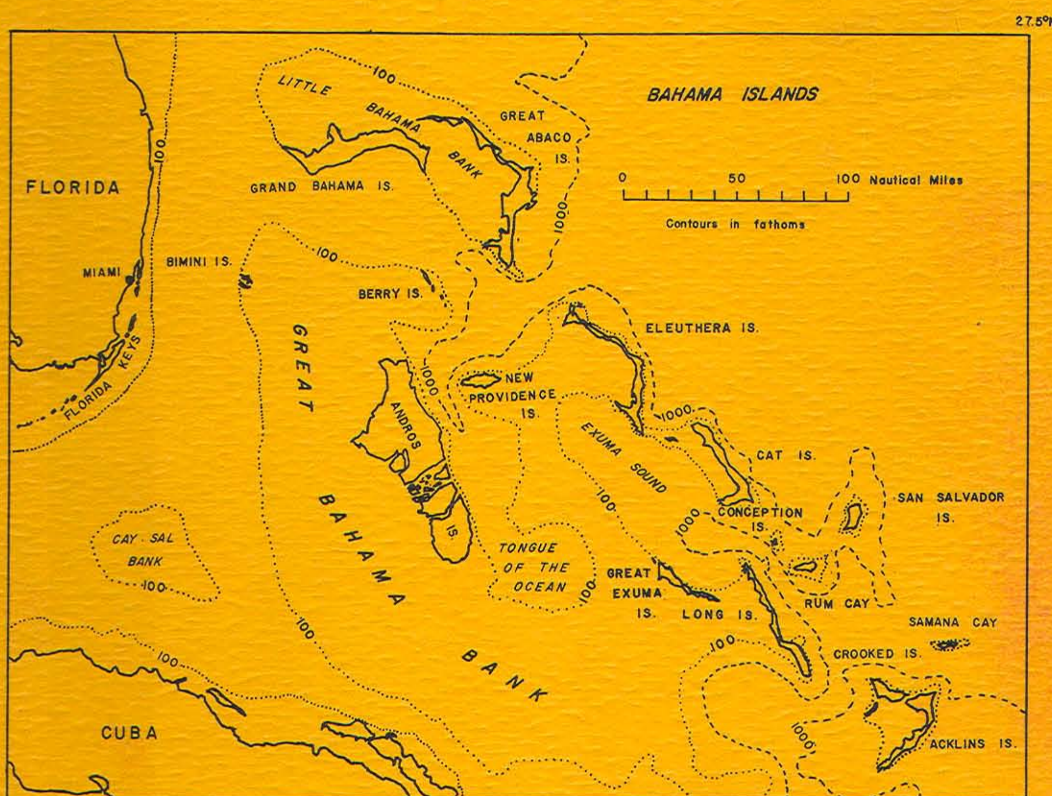
PROCEEDINGS OF THE FIRST SYMPOSIUM ON THE GEOLOGY OF THE BAHAMAS

MARCH 23--25, 1982



CCFL Field Station
San Salvador, Bahamas

College Center of the Finger Lakes
Bahamas Field Station
San Salvador, Bahamas

HOLOCENE LITHIFICATION OF CARBONATE SEDIMENTS, SAN SALVADOR ISLAND, BAHAMAS

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San Salvador Island is one of the world's finest natural laboratories for observation and study of lithification processes in Holocene carbonate sediments. Examples of ongoing subtidal, beach, lagoon, and dune lithification are evident at many island localities, and offer a wealth of opportunities for research. This note includes a summary of lithification phenomena, most of which were examined during the March, 1982, field conference, and is intended as a guide for future visitors as well as for instructors who offer courses concerned with the generation, transport, deposition and lithification of the island's carbonate sediments. Pristine quality of the modern environments, small size of the island, and easy access to the described sites combine to make San Salvador an ideal place for researching the origin and stratigraphic significance of carbonate bodies that have undergone lithification in recent times. All place names used in this summary are shown on the index map.

Beachrock

Holocene beachrock is a major feature in the shoreline environments of San Salvador. Conspicuous examples include those at CCFL Beach, the south shore of Rice Bay, the beach area lying directly to the northeast of Rocky Point, and the shore of Fernandez Bay. At CCFL Beach the rock is developed along a 490 m stretch of shoreline that extends eastward from the CCFL launching ramps (Fig. 1). The rock is well cemented, and is mostly colored yellow or black according to position within the intertidal zone. Rock hardness and coloration, which is caused by growths of algae (Stephenson and Stephenson, 1951), is suggestive of considerable antiquity. However, cemented into the rock are such modern artifacts as bolts, drive chains, carbonated-beverage bottles, fragments of milk glass, and even a well-preserved cast iron cannonball (Fig. 2). At the inner (landward) edge of the beachrock exposure are scattered, loose slabs of clean, loosely cemented carbonate sand that lie partially buried in similarly textured, noncemented foreshore sand. Collectively, the foregoing observations suggest that the CCFL beachrock has been cemented in very recent times and is continuing at present.

The CCFL beachrock dips seaward at an angle corresponding to seaward slope of the present foreshore surface. At normal high tide the landward edge of the main beachrock exposure lies a meter or two offshore, and the topographically highest part of the rock is barely awash. Apparently, beachrock lithification has occurred in a progressively landward direction, and the backwash of storm waves has eroded the landward edges of beachrock beds so as to form low, landward-facing scarps.

The beachrock grains are predominantly lithoclasts, with conspicuous numbers of grains derived from algae, foraminifers and mollusks. Isopachous cement, consisting of needle-like crystals presumed to be aragonite, fills only partially the interstices of this highly porous rock.

Fig. 1:
Exposure of Holocene beachrock at CCFL Beach. Loose blocks of beachrock on landward side of exposure could become incorporated into any new beachrock that may form here.

Fig. 2:
Exposure of Holocene beachrock at CCFL Beach, showing cannonball that was almost completely enclosed by well-lithified rock before excavation.

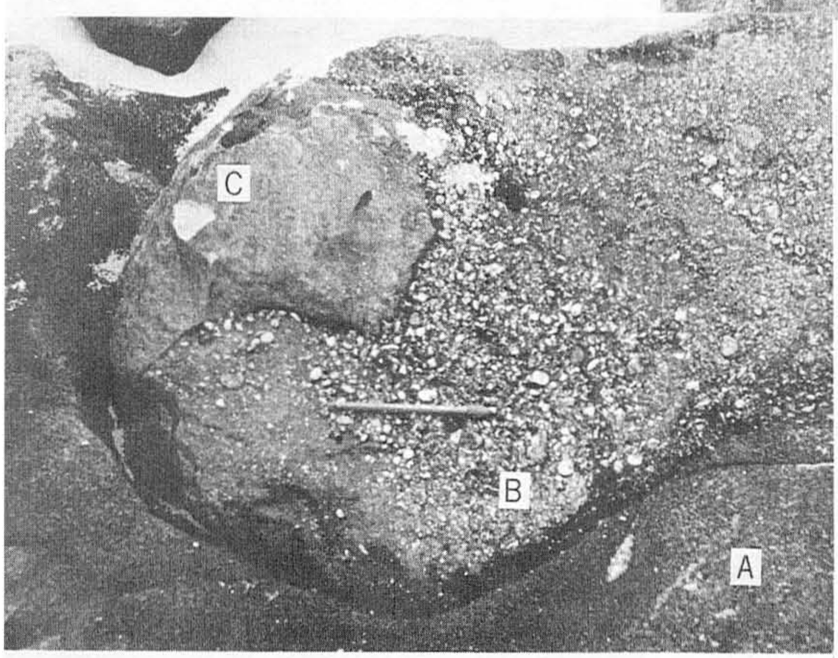

Fig. 3:
Exposure of Holocene beachrock on beach shortly to the northeast of Rocky Point. Note beachrock cobble (C) enclosed in beachrock boulder (B) that is, in turn, incorporated within the latest generation of beachrock (A).

The landward edge of CCFL beach, adjacent to the main body of beachrock, is marked by a low cliff held up by a hole-riddled, thinly bedded, gently seaward-dipping limestone that lies within the gray zone of Stephenson and Stephenson (1951), and consists of sand-sized carbonate grains. The top of this cliff lies between one and two meters above the level of normal high tides, and would seem to belong to an elevated, Pleistocene beach facies.

Interpretation of this holey, cliff-forming limestone is clarified by comparison with a similar cliff that faces the beach extending northeastward from Rocky Point. At this locality, the high-energy beach is associated with an impressive development of beachrock. The beachrock slopes seaward at an angle of approximately 6 to 10 degrees--the same as for unconsolidated sands on the adjoining foreshore. This beachrock is remarkable for its content of boulders, which reach maximum lengths in excess of one meter and were derived from earlier-formed beachrock (Fig. 3). The entire complex comprises evidence of repeated beachrock development and disruption by storms. Here, as at CCFL Beach, the beach is bordered landward by a low coastal cliff that comprises a 2 meter thickness of hole-riddled, thinly bedded, seawardly dipping limestone. As at CCFL Beach, the limestone consists of sand-sized carbonate grains. Here, however, the limestone cliff is discontinuous, and the intervals between limestone exposures are filled with mostly loose carbonate sand that is thinly laminated, with seaward dip at an angle corresponding to that of the adjacent limestone (Fig. 4).

VARIATION OF *CERION* POPULATIONS ON SAN SALVADOR

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Cerion is a genus of West Indian pulmonate land snail, the sole genus of the family Cerionidae. The genus has been divided into more than 600 named entities, but the number of valid species is unknown (Mayr and Rosen, 1956). The profusion of named species has resulted from the high degree of variation present at the species level. Investigations concerning the causes of variation in *Cerion* populations were conducted by the author during 1979 and 1980 at the CCFL Bahamian Field Station on the island of San Salvador in the Bahamas.

San Salvador supports many local populations of *Cerion.* (Fig. 1) Data on shell structure in thirty populations has been collected and statistically analyzed, demonstrating that variation between the local populations is significant. Two factors, predation and sandblasting, were observed which may help to explain population variability in *Cerion.*

Land crabs are known to prey upon *Cerion* (Woodruff, 1978). Predation of *Cerion* populations by the land crab *Cardisoma* is intense on San Salvador and is thought to be an important selective force resulting in variation between individual populations. The jagged holes on opposing side of *Cerion* shells appear to be the result of damage by land crabs. It is thought that the snail is gripped by one claw of the land

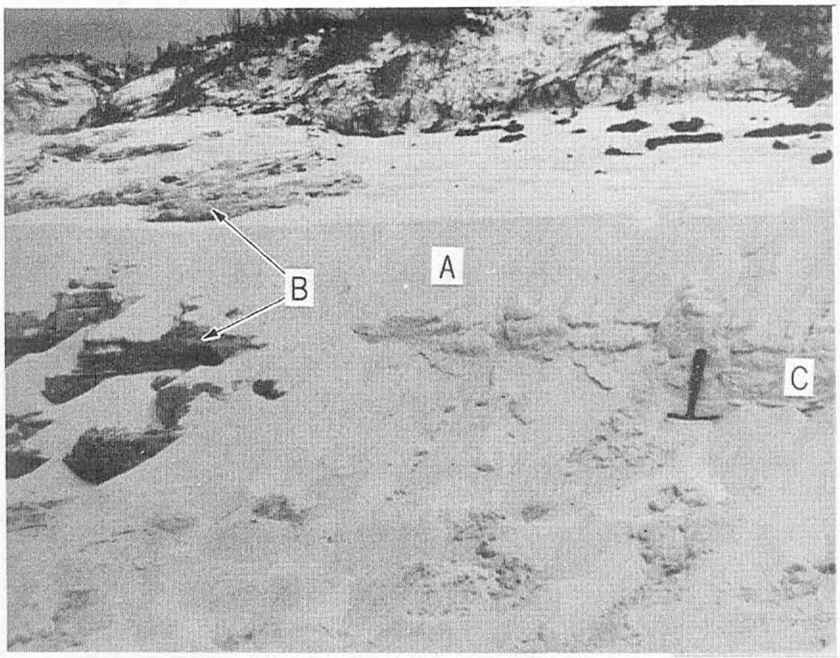

Fig. 4:
Same locality as Fig. 3, showing storm-beach deposits. A, High-level beach sands formed by deposition during fairly recent storm(s). B, Lithified, high-level beach sands deposited by more ancient Holocene storm(s) and now cemented into cliff-forming limestone. Note accordance of uppermost surfaces of limestone and recent sand. Note also that the most recent storm-beach sands show initial stages of cementation (C).

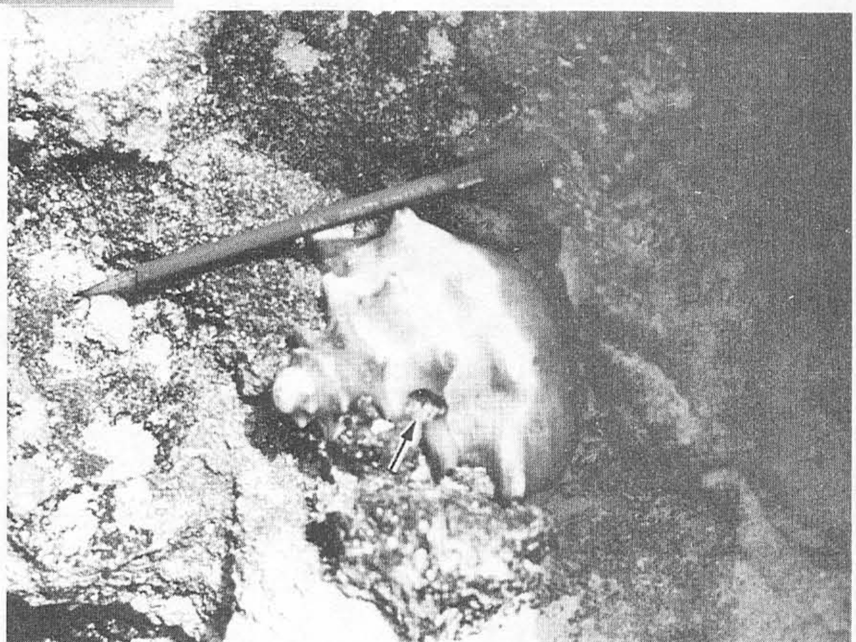

Fig. 5:
Culturally modified conch in cliff-forming, storm-beach limestone at Barker's Point. Presence of such conchs attests youthful age of this rock, which has been dated as 80 years B.P. by the radiocarbon method. Hole (arrow) in conch is man made.

Fig. 6:
Eolianite exposure at coastal reentrant 0.6 km north of East Beach access road from United Estates. Rock in lower part of exposure is better cemented than that above. At higher levels, rock crumbles readily to form loose sand (arrow).

youthful age of the rock, which yields a radiocarbon age of 80 year B.P. (Stipp, 1981). This rock apparently originated by lithification of a gravelly storm-beach sand in near-recent time.

Beachrock, whether formed in the fair weather foreshore or by lithification of higher-level, storm-beach sands, poses numerous problems. What triggers the lithification process? Why are some beaches characterized by extensive beachrock development and others are not? Is the cement derived primarily from evaporation of seawater? To what extent is percolating rainwater a factor? Is there a relationship between occurrences of beachrock and the flow of groundwater towards the sea? Does lithification occur sporadically, or is the lithification process essentially continuous? How far seaward do the blankets of beachrock extend? Has beachrock formation proceeded in a gradually shoreward direction during the post-Wisconsinan rise of sea level? These and related questions are the grist for much future research on San Salvador beachrock deposits.

Dunes

The efficacy of salt spray as a factor in Holocene lithification of coastal sands is illustrated very well in the coastal cliff situated near the north end of East Beach, approximately 0.6 kilometer north of the beach access road leading eastward from United Estates. Here, the lower-most eolian carbonate sands that are exposed in a coastal promontory are much better cemented than eolian sands lying in the same stratigraphic position in an adjacent coastal reentrant (Fig. 6). Furthermore, partially lithified dune sands extend farther up the coastal cliff at the promontory than in the coastal reentrant. These differences in degree of eolianite lithification are apparently related to differences in degree of sediment wetting by salt spray, rocks of the promontory being wetted more often and more thoroughly than sands of the coastal reentrant. Support for the salt-spray cementation mechanism is evident in the distance into the cliff that sands have been cemented. In the coastal reentrant, cementation is largely surficial, i.e., extending only a few centimeters into the cliff. This crust can be dislodged readily with a shovel so as to expose mostly noncemented sands within. At the top of the dune ridge the eolian sands are vegetated, but are nonlithified. At this distance above the beach (approximately 10 m) salt spray has little or no effect on lithification. At North Point the dune sands are generally well cemented, which may be owing largely to exposure of the peninsula to salt spray.

The hypothesis of coastal dune-sand lithification by evaporation of salt spray needs testing. Does percolation of rain water play a significant role in cementation? What is the nature of the cement? Are the weakly cemented crusts on dunes now lying at inland locations, such as between the north end of Pigeon Creek and the present east coast, relict crusts or are they forming today? These and other questions regarding lithification of dune deposits are worthy of investigation.

Storm Gravel

At the westernmost edge of French Bay Beach, west of Government Dock, cliff-forming, Pleistocene eolianite is overlain locally by a well-cemented veneer of cobble and boulder conglomerate (Fig. 7). The eolianite is mantled by a hard, brittle crust of caliche, and contact between the conglomerate and the crusted eolianite is sharp. The conglomerate has been interpreted as a talus deposit that resulted from downslope movement of bedrock fragments derived from erosion of a karstic terrain (Mylorie, oral comm., 1982). However, limestone cobbles and boulders in karst terrains are normally solution sculptured into a wide range of commonly bizarre shapes. In this conglomerate limestone clasts range generally from angular to rounded shapes of the sort that might result from erosion and transport in a high-energy environment.

A reasonable analog of the French Bay conglomerate can be studied on the north shore of San Salvador, exactly 1.1 km west (by way of Queen's Highway) from the turnoff to Dump Point. Here, Pleistocene (?) limestone, coated with a reddish brown crust, is exposed in the intertidal zone and disappears landward beneath a recent storm gravel consisting of subangular to well rounded, mostly cobble-sized limestone clasts. These clasts are composed of lime grainstone and are light colored, i.e., they have been deposited recently and have not yet become discolored by weathering or algal infestation. A few of these modern clasts are scattered across the landward side of the crusted bedrock exposure, and are cemented firmly to the crust (Fig. 8). If the entire mass of storm-gravel clasts was to become cemented together, and to the underlying bedrock, a limestone-cobble conglomerate would result. Such a conglomerate body would have

Fig. 7:
Poorly sorted, pebbly cobbly boulder conglomerate near east end of low coastal cliff at French Bay. Note well rounded clasts near man's hand (arrow).

Fig. 8:
Cobbles of gravel generated by recent storms at inner edge of beach, 1.1 km west of turnoff leading to Dump Point. Clasts are cemented firmly to underlying caliche-like crust on Pleistocene bedrock.

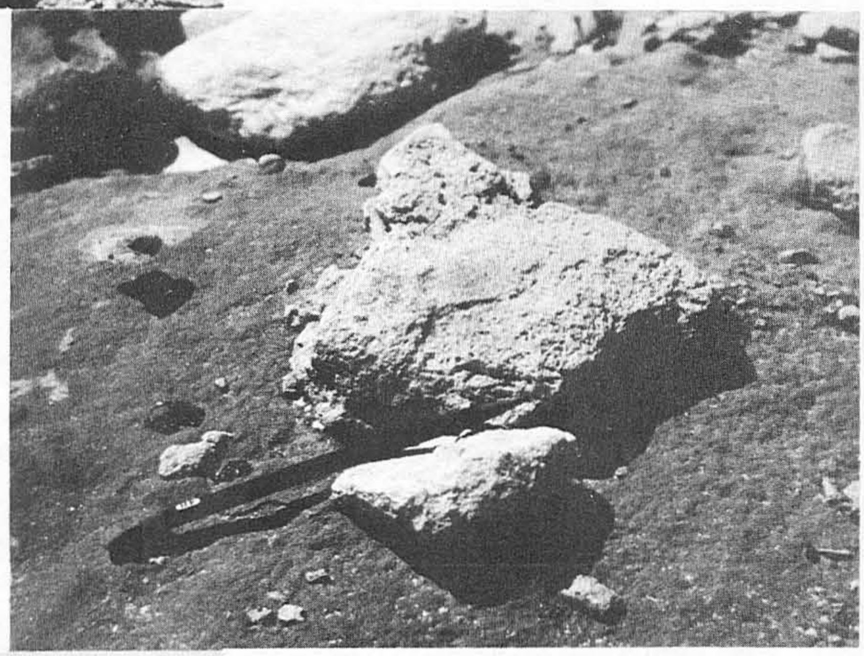

Fig. 9:
Thinly bedded limestone slab from shortly beneath sediment-water interface in southwest end of Pigeon Creek lagoon.

an appearance that is essentially identical to that at French Bay, and would have an identical stratigraphic relationship to the underlying crusted limestone.

Several questions attend interpretation of the French Bay conglomerate. At what time in history was the gravel deposited? Is the elevation above present sea level compatable with water levels suggested by upper surfaces of the Grotto Beach or Cockburntown (Sangamonian) reefs? Were the clasts derived from eolianite (suggesting downslope transport) or subtidal and beach facies (suggesting marine erosion and wave transport)? What is the nature of the cementing substance? Are clast shapes compatable with the talus or with the storm-gravel hypothesis?

Lagoonal Limestone

The southwestern end of Pigeon Creek, where the lagoon is approached most closely by the Columbus Landings paved road, comprises large open expanses of shallow water, less than 1 meter deep, that are fringed and dotted with dense growths of red mangrove. At this locality lagoonal sediment consists of poorly sorted carbonate sand that is admixed with carbonate mud and clear gelatinous material. The coarser carbonate particles include several genera of foraminifera, ostracodes, small high-spired gastropods, and minute thin-shelled bivalves. The most obvious skeletal constituent is peneroplid forams, which reach a maximum diameter of several millimeters and produce in the sediment a characteristic white-speckled appearance. Shortly beneath this surficial material the sediment has been cemented so as to form an extensive sheet of crumbly limestone that is distinctly bedded and reaches maximum thickness of 3 to 4 cm (Fig. 9). The rock is a poorly sorted grainstone, with grains mostly in the fine- to very-coarse sand range. Most of the grains are micritic peloids and may be largely fecal pellets and/or altered ooliths. Skeletal grains were derived mainly from forams and molluscs, and many have a micritic envelope. The cement comprises an isopachous fringe of minute, needle-like crystals of the aragonite habit, but cementation is weak and the rock is highly porous. Although most grains have been bleached to a nearly white color, some of the ostracod valves retain a dark coloration, suggesting that lithification has occurred recently and that there has been no subaerial exposure of the sediment. Lithification only of the near surface sediment also suggests that cementation is a recent phenomenon.

The origin of this limestone is a problem in need of detailed study. Waters of the lagoon are easily warmed by solar radiation, and salinity reaches a maximum of 42 o/oo (Mitchell, oral comm., 1982). These factors suggest that the lagoonal waters may at times be supersaturated with calcium carbonate. High initial porosity would facilitate the flow of carbonate-saturated water through the original sediment by tidal pumping. Such pumping could affect only the upper few centimeters of sediment, with development of cement crystals gradually reducing permeability. Persian Gulf marine cementation described by Shinn (1969) is a reasonably good analog, but many questions remain. How extensive is this limestone? Are there places where cementation has affected any of the more deeply buried sediments? When did cementation occur? Is cementation still in progress? Under what conditions of temperature, salinity or tidal action did the lithification occur? Do these limestones have an origin in common with those of hypersaline Storr's Lake (Teeter, oral comm., 1982).

Stromatolites

Algal mats are a common phenomenon in lacustrine environments of San Salvador, and are especially evident at times of low water levels. For example, a thick, rubbery algal mat caps organic-rich carbonate sediments in a lake that lies directly adjacent to Queen's Highway at Rocky Point. During dry spells the algal mat is exposed to air and becomes disrupted by polygonal patterns of dessication cracks that are readily seen from the paved road.

Algal mats are developed extensively along the western shore of Storr's Lake. During low-water stands many of the mats are exposed to the atmosphere and shrivel so as to form lumpy or mammilated surfaces. Most of the underlying sediment is unconsolidated, and laminations are at best poorly developed. However, at the northernmost place where Queen's Highway approaches the lake closely, algal mats are associated with true stromatolites (Fig. 10). These structures comprise crudely laminated, fine sand- to fine gravel-sized carbonate grains that are bound together to form crumbly limestone knobs that are as much as 15 to 20 cm in diameter and 12 to 15 cm tall (Fig. 11). These are true columnar stromatolites--perhaps the finest examples yet discovered in the Caribbean/Bahamas region. The

Fig. 10:
West Side of Storr's Lake, showing emergent crests of columnar stromatolites that are encrusted by living alga mats.

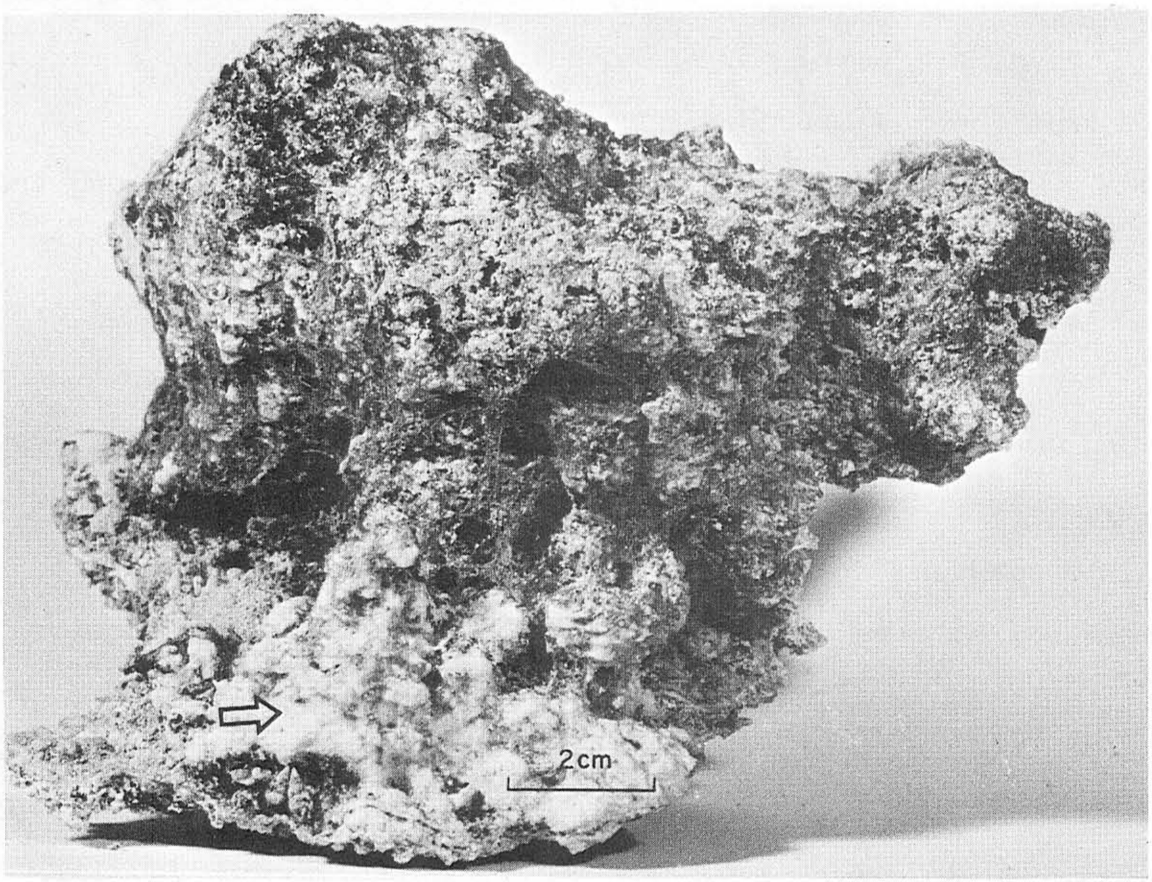

Fig. 11:
Side view of modern stromatolite from west side of Storr's Lake, showing irregularly columnar shape. Arrow indicates crust composed of nearly white, well-cemented, very fine-grained calcitic limestone mentioned in text. Photo by George R. Ringer.

stromatolites are capped by a gelatinous algal mat, at least part of which comprises thread-like filaments resembling Lyngbya. Associated with the stromatolite illustrated in Figure 11 is a nearly white, very well cemented carbonate crust, which extends beneath the stromatolite and apparently formed a base on which the structure was constructed. The crust is exposed locally along the side of the stromatolite (see arrow on Figure 11) and there forms a mammilated, moundlike satellite structure. This very fine grained carbonate consists wholly of calcite and may be of algal origin.

Regarding origin of these stromatolites several questions arise:

1. What factors are involved in development of the columnar shape? Did these stromatolites originate by convolution of an algal mat during a period of dessication? If not, how was sediment added to upper portions of the structures?
2. What is the time frame within which such stromatolites form?
3. Why is the occurrence of these stromatolites so restricted?
4. Which forms of algae are involved in the stromatolite-forming algal mats?
5. Under what conditions and by what mechanism did the hard, fine-grained limestone form?

The stromatolitic structures at Storr's Lake pose some interesting questions and furnish an excellent subject for future research.

Cliff Blocks

Along the coastal cliff north of Grotto Beach reef blocks of laminated limestone belonging to the beach lithofacies of the Grotto Beach Limestone manifest various stages of incorporation into the local bedrock. The beach lithofacies has been subjected repeatedly to the agencies of coastal erosion, and at various times large blocks have been dislodged (Figs. 12, 13). Some of

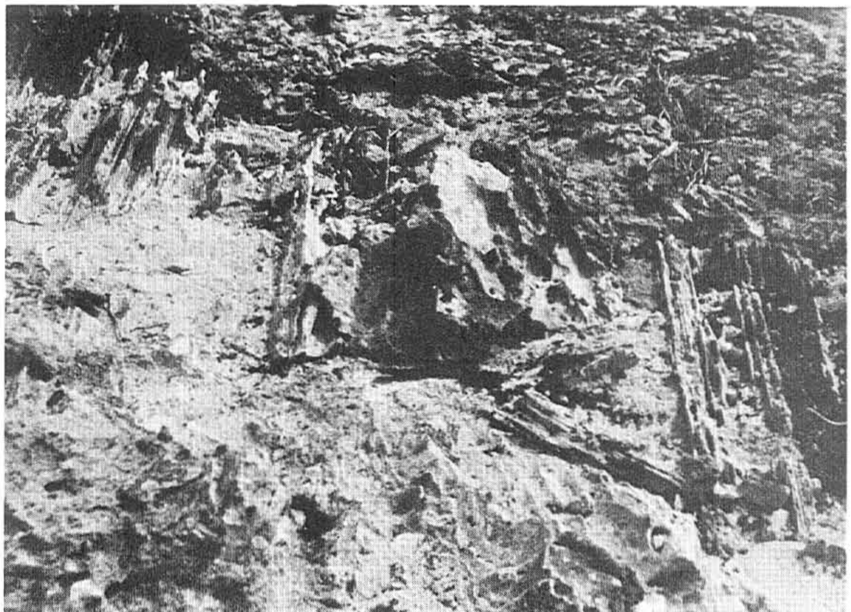

Fig. 12:
Displaced boulders of beach-rock incorporated into lower shoreface lithofacies of Grotto Beach Lime-stone on landward side of largest Pleistocene reef at the Grotto Beach locality.

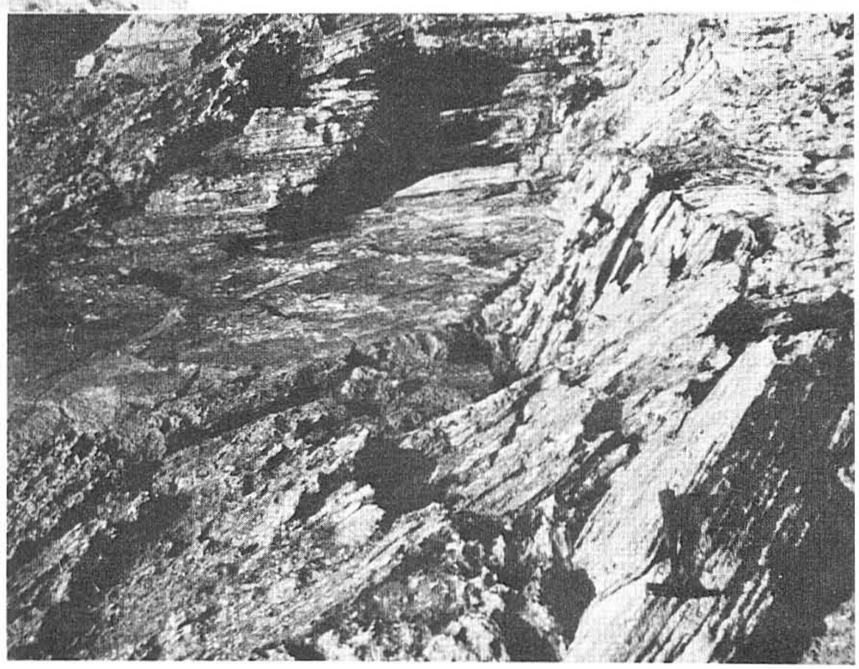

Fig. 13:
View along coastal cliff directly north of largest reef at Grotto Beach, showing blocks of beach lithofacies of Grotto Beach Lime-stone that have been dislodged by modern erosional processes. Some of these blocks are lying loosely on the cliff face whereas others have been cemented firmly to the subjacent Pleistocene bedrock.

the dislocation occurred during deposition of the Grotto Beach Limestone (Fig. 12), as manifest in large boulders of laminated limestone that are almost wholly enclosed in extensively bioturbated, littoral lime grainstones that are exposed landward of the fossil reef. Locally, this backreef lithofacies contains numerous, elongate, seawardly oriented rhizomorphs of beach morning glories that grew across prograded beach sands that buried the reef in Sagamonian time. Within this progradational carbonate sand body are blocks of limestone in which bedding planes lie at steep angles to the general stratification, and that may be chunks of beachrock that were ripped up by waves and incorporated into younger sediments that had buried or were burying the reef. Deposition of these blocks clearly occurred in Pleistocene time. However, a short distance north of the reef the coastal cliff is mantled locally by similar blocks of laminated limestone that have been dislodged in recent times. Some of these blocks lie loose along the cliff face whereas others are cemented firmly to Pleistocene bedrock. The latter appear much like the loose blocks, signifying that the lithification process has been active in recent times. Distinction between these recently cemented blocks and those of an early stage of dislodgement and cementation is not everywhere clear because the emplacement of some blocks clearly postdates deposition of the beach lithofacies but apparently predates recent coastal erosive and cementing processes. Apparently, blocks of Grotto Beach Limestone have been dislodged by coastal erosion at several times in the past, and such dislodgement is continuing at the present time. Evaporation of salt-water spray is suggested as the mechanism by which the most recently cemented blocks have been bound to the bedrock exposure.

Concluding Statement

Cementation of Holocene carbonate sediments is occurring at many places on San Salvador Island, and a wide variety of lithification processes are involved. Sites documented in the foregoing text are only a sample, most being included in the March, 1982 field conference. Interpretations set forth by the writer are largely untested, and remain to be verified or rejected on basis of further field and laboratory analysis. A wealth of research opportunities awaits the interested investigator.

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