ATOLL RESEARCH BULLETIN

NO. 232

A SALINE LAGOON ON CAYO SAL, WESTERN VENEZUELA

by Malcolm P. Weiss

Issued by
THE SMITHSONIAN INSTITUTION
Washington, D. C., U.S.A.

September 1979

A SALINE LAGOON ON CAYO SAL, WESTERN VENEZUELA

By Malcolm P. Weiss [1/]

INTRODUCTION

Cayo Sal, the largest of a group of small coralgal (i.e., a framework of corals and coralline algae) keys off Chichiriviche, Estado Falcón, contains an enclosed hypersaline lagoon, La Salina (Figs. 1, 2). Although atoll-like in plan view, Cayo Sal rests on the shallow (<20 m) continental shelf and is not an atoll in the fullest sense (Bryan, 1953a, 1953b). During field investigation of the keys, marine sediments, and pollution by unbridled coastal development (Weiss *et al.*, in press; Weiss and Goddard, 1977), some shallow cores were taken in La Salina. This report results from the the study of those cores and the geology of Cayo Sal.

Gypsum is formed and preserved in La Salina, and halite is generated seasonally. Peat buried beneath the lagoon sediments suggests that sea level has risen about 1.5 m in the last 2700 years. Conditions of hypersalinity and the consequent sediments are in some respects similar to those in a lagoon on Gran Roque, an island in the Los Roques group (Sonnenfeld, 1973), as will be seen. The sedimentary record and morphology of Cayo Sal suggest that both were disrupted by hurricane or tsunami about 500 years ago.

CAYO SAL

Cayo Sal is an islet (10°56.7' N. Lat.; 68°15.6' W. Long.), in the form of a completely closed curve, resting on a growing coralgal reef platform, and surrounding an entirely enclosed lagoon, La Salina (Fig. 2). The reef platform, i.e., that part less than 2 m deep, extends 1.8 km in an east-west direction, 1.13 km north-south, and has an area of 0.94 km^2. The area enclosed by the seashore of Cayo Sal, including both land and lagoon, is 0.63 km^2, with maximum east-west extent of 1.25 km and north-south extent of 0.83 km. These values do not vary significantly with tide stage because the tidal range is less than 0.5 m.

The area of La Salina varies seasonally (Fig. 2). Apparent extremes recorded in aerial photographs (Fig. 3) compare closely with traces of strandlines on the ground, and show the surface area of La Salina ranges between 0.33 and 0.37 km^2. These values are for recent dry-and-wet seasonal extremes and for annual differences of the last quarter-century, the period of adequate records.

Cayo Sal is formed largely of skeletal carbonate sand. Windblown sand and silt, and mud brought by occasional floods of stream water over the nearshore waters provide only traces of terrigenous

---

[1/] Department of Geology, Northern Illinois University, DeKalb, Illinois, 60115 (Manuscript received April, 1976; revised Dec., 1976--Eds.)

material to the key. The island apparently began as a patch reef growing on a high spot of the drowned alluvial plain of the Tocuyo River (Weiss *et al.*, in press).

The major elements of the coral community are typical for the Caribbean: *Acropora palmata* (Lamarck) in the surf zone is buttressed by *Montastrea annularis* (Ellis and Solander) and species of *Diploria* below, and *Acropora cervicornis* (Lamarck) occurs in protected nooks, at the lee ends of the reef and along the break in slope of the sediment apron on the southwest side. Species of *Porites* also occur, especially in El Huequito, and also with *Siderastrea* in the *Thalassia-Halimeda* community on the shallow apron of skeletal mud and sand west of the island. The inner part of the reef flat is mostly barren of corals and calcareous green algae, but paved by crusts of coralline algae or littered with algae-encrusted skeletal debris. A more widespread coral community is developed in El Huequito (Fig. 2), and most of the remainder of that bay floor is of skeletal sand and rubble.

The reef platform is not much larger than the island, except for the wide flat at the northeast corner. The morphology of the area, both in plan and in profile, suggests that El Huequito (Fig. 2) could have been formed if sediments of the former northeast corner of the island were moved southwestward by storm(s), filling that corner of La Salina, while exposing older reef-flat material to renewed colonization by corals. The low sandy barrier between La Salina and El Huequito has just a few small trees and little scrub, which seem to be migrating from the ends of the barrier. Even so, such an event cannot have been recent, if it indeed occurred; local people have no knowledge or stories of such an event and the floor of El Huequito, although shallow, has a large community of *Acropora palmata, Porites furcata* Lamarck, and *Diploria sp.* Their sizes suggest several decades of growth, based on an assumed rate of about 5 cm/yr for *A. palmata.*

The land is asymmetrical in profile at most sections, with highest elevations closer to the sea than to the lagoon. It is made mostly of skeletal sand but locally of coral chunks--up to 1.3 m long (Fig. 2). Most is stabilized by scrub growth, including sea grape and red mangrove. It has changed little in the quarter-century for which maps and air photos are available, except for some recent grading and introduction of palm trees on the inhabited western end and southwestern side (Weiss and Goddard, 1977). Accumulation of skeletal debris tends to enlarge the island by addition to its margin, but some is thrown across the island and spread into La Salina as splays of skeletal debris.

LA SALINA

A wet-season stage is shown in Figure 3A, and a dry season stage in Figure 3B. In September, 1972, the lagoon was indistinguishable from that pictured in 3B.

Bathymetry

Neither precise nor numerous depth measurements are available.

The deepest part is northeast of the center, where it was about 0.5 m deep during relatively high water in mid-November, 1972. Depth at the same place during maximum flooding (highest shore features) in recent years must have been of the order of 1 m. The bottom slopes gently from all shores into the shallow basin. The soft, slimy bottom makes "depth" an uncertain measurement; a smelly, red and black organic slime covers the bottom especially in the NE and NW quadrants. The area between high-water and low-water marks (Fig. 2) is a sort of "littoral zone." It is 60-100 m wide in the SSE quadrant and only 15-20 m wide in the NE quadrant.

When the water in La Salina is low, two small ponds become separated from the major body of water near its northwest corner (Fig. 2). The smaller of these is a low place in a sinuous channel a few meters wide that extends from La Salina almost to the sea. Although the channel held a few puddles and soggy spots in November of 1972, it is overgrown with brush and closed by the low berm at the beach. It clearly has not functioned as a water conduit for some years, but may again before long, however, for the small bay just to the north is undergoing vigorous erosion. The shore there was formerly protected by a line of beachrock (Fig. 2), but it has been breached and waves are rapidly removing the unconsolidated sand of that part of the island and sweeping it westward past the northwest point of the island. These little ponds contained brackish water during three separate visits. They are somewhat protected by vegetation from wind and sun, and thus can and do stand slightly higher than La Salina and up to 0.3 m above sea level, depending upon the tides.

Some parts of the lagoon bottom are highly reflective when the water is low (Fig. 3B). October, 1969, aerial photos show areas of the bottom that are reflective. These patches are mostly skeletal sand, and they include most of the "littoral zone" and irregular splays that reach from the east side nearly to the middle of the lagoon. Proximal parts of two such splays form wide "tongues" in the "littoral" zone in the southeast quadrant of La Salina (Fig. 2).

Hydrography

The level of La Salina was observed in September and measured once each in October, November, and December of 1972, thus covering the tail of the dry season and most of the wet season (Weiss *et al.*, in press). The level ranged from 24 cm above to 31 cm below the sea surface at the times of measurement (made at different stages of the tide). The difference between the observed extreme levels of the lagoon itself is 41 cm, significantly larger than the local tidal range of 25-30 cm. Differences would surely be somewhat greater if the lowest levels of the salt-forming dry seasons could be compared with these data. The changes of level each year arise from the fact that the ratio of precipitation to evaporation is strongly skewed in time. Records are fairly complete for the immediate region back to the mid-1950's (Table 1), about the same period for which maps exist. They show that nearly half of the annual precipitation occurs in the months of October-December, on the average, and similarly, that about 60 percent occurs from September through January.

Evaporation data are available from a station 50 km farther southeast and show a rather uniform rate through each month of the year (Table 1). Data assembled by Lahey (1958) suggest that evaporation is more uniform regionally than is precipitation. At Cayo Sal the evaporation/precipitation ratio is very high during a dry season from later winter to early fall, and low during the late fall and winter. Using mean values for the months of the year (Weiss *et al.,* in press), evaporation for October-December is 40% of rainfall, and 115% for the other nine months of the year.

Fluctuation of the level of La Salina would be greater than it is if precipitation and evaporation were the only inputs and outputs from the lagoon. Because the island is formed of unconsolidated skeletal sand and gravelly sand, percolation to or from the sea occurs readily, depending upon the relative level of La Salina and stage of the tide. This percolation, although widespread, is slow and diffuse where the subaerial material is widest. The narrow barrier of skeletal sand between El Huequito and La Salina (Fig. 2), however, has a number of seeps on the southwest side; sea water bleeds slowly from these when the tide is higher than La Salina and runs in rills down the slope into the warmer water of the lagoon. The seeps support slimy red mats, probably soft algae similar to those on the nearby bottom of La Salina. No evidence of reverse flow from La Salina to the sea was observed, but surf would obscure any outlets on the seaward side. Extreme levels of flooding or drying of the lagoon are thus moderated by phreatic connection with the sea.

During periods between abundant and deficient precipitation the level of the lagoon must be in nearly hydrostatic equilibrium with the sea, and therefore gains or loses little salt from or to it. During the wet months, the lagoon will stand high, have a lesser salinity than at other times of the year, and produce a net seaward flow of groundwater. During the much longer dry season the lagoon will stand low and gain water of normal salinity by percolation; persistent evaporation will raise the salinity in La Salina to levels that percipitate halite and gypsum. The occurrence of halite is seasonal and requires salinity ≥ 270 °/oo. Gypsum persists and becomes part of the sedimentary fill of the lagoon. Local people gather salt each season for commercial purposes, and say that fall rains "spoil the salt."

Measurements of some of the water properties were made by Sr. Pablo Almeida between 1000 and 1100 hours local time on December 19, 1972, in the midst of that rainy season; the level of La Salina was 0.3 m below the sea at that time. Water temperature ranged from 29.1°C. close to the edge of the lagoon to 29.8°C. in the body of the lagoon. This compares with 27.9°C. in the nearby open sea at the same time. Salinity ranged from 161.9 to 165.7 °/oo in La Salina (Fig. 2) but was 36.6 °/oo at one meter depth in the open sea windward of Cayo Sal. The lowest lagoon value was from warm water toward the windward shore (Fig. 2, Sta. 3). Stations in mid-lagoon or toward the leeward side showed values of 164.5 °/oo or more. These facts and rafts or floes of salt crystals seen floating in the leeward sector of La Salina in September suggest a slow movement of surface water to leeward; salt crystals may be induced on the lagoon bottom by a compensatory underflow to windward, rather like that reported from Los Roques by Hudec and Sonnenfeld (1974).

SEDIMENTS

Mud is rather more abundant than sand on the lagoon floor today, except close to the shore and in the skeletal-sand splays. Autochthonous substances are, in decreasing abundance, gypsum (Fig. 4), mollusc shells (mostly snails) and debris (Fig. 5), and cemented carbonate crusts (Fig. 6). Halite is conspicuous, but only during the dry season. The microflora of the water and the soft red algae locally on the bottom do not contribute significantly to the sediments. The allochthonous substances are mostly skeletal particles thrown over the island by storm waves (Fig. 7); as sand and mud sizes prevail over minor skeletal gravel it is probable that most of the contribution comes from the island itself or the beaches, rather than directly from the reef. Peat, plant shreds and minute unidentified capsules, probably of plant origin (see appendix) come from the key; only the peat is significant (Fig. 8). Carbonate peloids (small ovoidal pellets of carbonate mud, but not known to be fecal in origin) are common, and probably are both autochthonous and allochthonous. Traces of siliceous sand and mud occur, and are believed to be wind-borne.

Halite. Although halite is a negligible constituent of the lagoon sediments, it is formed in abundance each dry season. During a traverse in September, 1972, the late part of the dry season, a great deal of salt was observed. Salt rafts, formed of small crystals aggregated into sheets a few millimeters thick and up to several square meters in area, lay cracked, overthrust and jumbled against the lee shore. Others were seen in open water, where they form and then sail to leeward. A few piles of salt sagged on the lagoon shore, remnants of salt-gathering earlier that season. Hopper crystals (hollow, square pyramids, stepped both inside and out) were widespread on the lagoon floor. Their abundance and coverage change with the season; hopper crystals covered the bottom to within about 50 m of the shore in mid-October, but were gone a month later. Hoppers were as large as 3 cm on an edge of the square base of the hollow pyramid, but most were smaller. Hypersaline pore water filled the upper few centimeters of lagoon sediments, based on the amount of NaCl in dried samples. This is an appropriate condition for the late stage of the dessicating season, but probably changes through the seasons. For convenience, and to avoid the complication of different porosities in the samples, the ratios of mineral fractions are reported herein on an NaCl-free basis.

Gypsum. The principal evaporite mineral other than halite is gypsum. The amount in the sediments ranges from 0-70 per cent, and its abundance is inversely proportional to that of total carbonates. This relative abundance is also expressed areally, for gypsum is scarce or absent close to shore where skeletal material is abundant and where rainfall and runoff reduce the salinity of the marginal shallows. Most of the gypsum occurs as small, loose crystals--"seed gypsum"--in the fine sand to silt size-range and poorly sorted. Some crystals of granule size also occur. Where gypsum is abundant the beds have a granular, sandy look (Fig. 4). Stubby prisms and polyhedral discoids, like the smaller ones illustrated by Illing *et al.* (1965, figs. 5a, 5b, respectively), are the common crystal forms; blades are less numerous. The deposits and crystals are like those beneath Lake Marion, near Cape Spencer of the Yorke Peninsula, South Australia.

The abundance discoids are similar in form and crystallography to the much larger ones described by Merritt (1935, fig. 1), are milky or frosty looking, and most have convexly curved crystal faces. These qualities duplicate those of similar crystals of a variety of sizes, all reported from hypersaline environments (Masson, 1955; Eardley and Stringham, 1952; Shearman, 1966; p. 210; Illing *et al.*, 1965; Dunham, 1972, figs. III-64 and III-67). The curved faces of the crystals in La Salina confirm the suggestion of Deicha (1946) that NaCl concentration "poisons" the gypsum crystals and distorts their crystallography. Cody (1976, fig. 7) has produced similar crystals experimentally in saline gels, although he ascribes most of the discoidal grains to corrosion *in situ*. The countless individual euhedral-to-subhedral crystals in La Salina must have grown, rather than be the corroded remnants of larger grains.

Many discoid crystals have ragged edges and are pierced with grooves or cavities. The holes may be imperfections or may have held particles of other minerals, for calcite, dolomite and traces of halite are still enclosed in some gypsum grains. Colored zones and inclusions, probably organic stains or particles, are seen in transmitted light.

The second most abundant type of gypsum crystal in La Salina sediments is stubby prisms with 4-6 faces and blunt terminations. These are limpid and have flat, clear faces; if very short they look like little cut jewels. Cody (1976, fig. 4) grew some of this type, but most of his prisms were much more elongated. Analogous crystals of larger size occur in wet parts of Qatar sabkhas (Illing *et al.*, 1965, p. 95, fig. 5a). They report (p. 95) "...white, fine, sugary gypsum..." associated with halite in dry parts of sabkhas; the crystal form is not given. Similar porous layers of masses of prismatic and discoidal gypsum crystals formed on the floor of La Salina from time to time in the Holocene. Apparently the prismatic type contains no halite or carbonate impurities. It's possible that the clear prismatic crystals form when halite is not crystallizing, and that the cloudy discoid crystals with inclusions and curved faces form during the dry season, and perhaps after burial as well.

Although the great bulk of the gypsum is unconsolidated, small masses of intergrown crystals do occur (Fig. 6A, 6F) and some is cemented into the carbonate grapestone and crusts (Fig. 6B). The patchy clumps of gypsum seen on inter- and supratidal flats (sabkhas) bordering the Persian Gulf (Illing *et al.*, 1965, fig. 6c) were not observed at La Salina, nor even the cementing of carbonate laminae by gypsum, as on Bonaire (Lucia, 1968, fig. 10c). Dense pavements of elongate prismatic gypsum crystals, 20-30 cm long and packed with their lengths arranged vertically, do not occur. Such pavements are conspicuous in the younger deposits of the sulfate lakes near Cape Spencer, South Australia, where part of the CaO came from ground water drainage (C. von der Borch, personal communication, 1975), and the NaCl salinity must thereby have been lower than it is in La Salina.

Molluscs. The significant autochthonous biogenic mineral particles are whole or broken shells of small snails. Shells of dead cerithids litter the shore by the thousands at the end of the dry season. They contribute to sediment near the shore, but less so in mid-lagoon (Table 2). These molluscs are seasonal--*i.e.*, they flourish when salinity is suitable for them. A number of other species and a few clams are contained in the stratigraphic record (Table 2, Fig. 5), but only a few occur in the youngest layers of each core. Fossils other than molluscs occur in only trivial volumes, see below.

Carbonate-cemented Crusts. Away from the organic slime in the northern part of the lagoon, the bottom is of rather firmly packed granular material--skeletal and gypsum grains and peloids. Small masses of grapestone are common, but thin, brittle plates and chips (1-3 cm dia.) enclosing many grains are more conspicuous (Fig. 6B-E). Although traces of organic matter are entrapped in these bits of crust, very few samples have textures suggestive of algal laminites, or more than two superposed laminae, so they are not stromatolites. The crusts are porous to dense, no more than a few millimeters thick, and break easily. Some are pierced with small holes. The crusts appear related to the lacy carbonate crusts reported by Lucia (1968) from the Pekelmeer on Bonaire, but those are subaerial, more persistent, more porous, and much thicker. The grains cemented into these thin crusts may be any of the autochthonous carbonates (Mg-calcite, aragonite, dolomite), the allochthonous carbonates (Mg-calcite, aragonite), gypsum, or pieces of older crust or grapestone of these same kinds. Two types (A and B) are recognized by macroscopic characters.

A) Fresh-looking, pale yellowish gray, porous, easily broken crusts (Fig. 6C) occur on the lagoon floor at all sites sampled. Enclosed in them are grains of older carbonates (peloids, and some coated peloids and fossils--Fig. 6G, 6H), lithic grains of old crust (Fig. 6I), gypsum crystals and clusters (Fig. 6F), and pisoliths (Fig. 6J). Ostracodes and small forams are common; snails are few because most are larger than the thickness of the crusts. A few quartz grains (Fig. 6I) and rare collophane occur too. X-ray analysis of fresh material shows it to be mostly aragonite and Mg-calcite in ratios of 5/1 to 2/1. Thin sections show microspar lining or filling intergranular pores and holes in fossils, and cementing grains at points of contact (Fig. 6F-J). These bits of crust are sedimentary grains of both aragonite and Mg-calcite, partially lithified by a contemporaneous micritic Mg-calcite and some aragonite druse.

B) Dull, gray to dark gray, generally denser, sometimes etched chips of crust, otherwise similar to (A), are taken to be older examples of that same sort (Fig. 6D, 6E). These dark chips occur scattered throughout the cores; the few on the lagoon floor probably have been displaced from older layers and redeposited. The older aggregates are mineralogically more heterogeneous than the fresh ones, for all X-rayed contain some dolomite. Aragonite is less abundant than in the "fresher" crusts, and one from Unit 3K is of dolomite with only traces of aragonite and Mg-calcite. A sample from Unit 3D is obscurely laminated and composed of weakly dolomitized skeletal sand of Mg-calcite. "Dolomites" contain 40-48 mol percent $MgCO_3$, and are thus protodolomite (i.e., poorly crystallized, Mg-deficient dolomite).

Several samples of calcite from both fresh and old crusts and grapestone were measured for Mg content by the method of Neumann (1965). The mode mol percent of $MgCO_3$ ranges from 5.4 to 7.6, but only one is over 5.8.

These aggregates are petrographically very like crusts of the Pekelmeer (Lucia, 1968, figs. 17, 18) except that "pisoliths" (Fig. 6J) are smaller (*ca.* 0.5 mm) in La Salina. Multiple stages of irregular growth prevail in these also, and some have double nuclei. Except for size they seem homologous with those of Bonaire, are only locally abundant and nowhere dominant. To call them oölites because of their size would mislead the reader. Cemented peloidal aggregates (older crust) are reworked and redeposited (Fig. 6I). The mineralogy and textures compare closely with the diagenetic features of the "hypersaline field" of the Shark Bay sublittoral (Logan, 1974). Hypersaline water sinks through a mesh of mostly carbonate grains there and at La Salina. Hudec and Sonnenfeld (1974) credit efficient absorption of incident solar energy for elevated temperatures (> 40°C.) in another hypersaline lagoon and believe the heat enhances the diagenesis therein. A similar effect may occur seasonally in La Salina. One particularly dense, smooth, ivory-colored, presumably young, sample from the top unit of Core 6 (Fig. 9) is aragonite, with minor, subequal amounts of Mg-calcite and protodolomite; it is homogeneous and the minor constituents are not distinct.

In summary, fresh or reworked grains of aragonite and Mg-calcite accumulate and may be cemented by the same minerals; with time the aragonite inverts or is replaced, and dolomitization may occur. Dolomitized material is not uniformly associated with gypsum, but most units that contain some protodolomite contain some gypsum.

Organic Materials. Traces ($\leq$ 2%) of impalpable brownish-black macerated tissue is mixed with fine clay in some units, especially those close to the peats or to the present lagoon floor. The unidentified plant capsules (see appendix), peaty clumps and a few chips of wood (probably mangrove) make up 1-12% of some units (Fig. 5). The large organic fraction in unit 6A (Fig. 9) is of algae with perhaps some additions from the nearby habitations.

Layers of compact peat occur at the bottom of Core 3 and within Core 4 (Fig. 8, 9). The thickness of gravelly skeletal sand stopped the corer at other sites. Because both peats are quite similar, only Core 3-Bed L was analyzed, by R.H. Tschudy, and filed as U.S.G.S. paleobotanical locality D5038. According to Dr. Tschudy, the peat is decomposed organic matter containing many fungal hyphae, some rootlets, and the algae *Tetraporina* sp. and *Pediastrum (?)*. Pollen is not abundant, but those of *Rhizophora* (probably *R. mangle*), Chenopods and Myrtaceae occur; spores of several ferns also occur. Calcareous fossils that may have occurred were destroyed by the acidity of the peat, but no siliceous fossils occur either. Microforaminifera and dinoflagellate cysts indicate a marine influence, as do the algae, according to Tschudy, and the presence of so few pollen types suggests little diversity of vegetation in a community dominated by mangroves. This is the case for modern red mangrove communities in this region, and the ancient community is considered to have been dominated similarly by red mangrove. Like deposits of similar age have been described from Columbia by Cohen and Wiedemann (1973).

Allochthonous Skeletal Carbonates. Most of the lagoon sediment is muddy skeletal sand and gravel (Fig. 5, 7, 8); except for the grapestone and patchy crusts discussed above it is not consolidated. The particles are the debris of the reef flats, ocean beaches and the island itself: gravel is mostly of *Porites* and clam shells; sand is mostly *Halimeda* and snail fragments, ostracodes, peloids, and coated grains; mud is largely algal, plus micrite bored from coarser fragments. Quite recent aprons of this material lie along the southwestern shore of La Salina, north of Sites 1 and 2, and exemplify the main mode of lagoon filling.

These materials are Mg-calcite and aragonite. Although the skeletal sand is friable, some weakly cemented grapestone clumps occur. The grapestone is dolomitized to various degrees in the older beds; mol percentage of $MgCO_3$ ranges from 40-44%.

Siliceous Materials. Terrigenous minerals are the smallest inorganic fractions of all the samples, ≤ 1 percent in most samples, and as high as 4 percent in a very few (NaCl-free basis). Most of these grains are rounded and subrounded fine quartz sand (Fig. 6H); a few rock fragments also occur. Clays occur in trivial amounts so were not analyzed. They are surely of the same species found on the sea bottom nearby (Weiss *et al.*, in press): mostly chlorite and kaolinite, with some illite and traces of pyrophyllite.

The coarser materials and some clays are eolian; clay is also brought by the occasional spread of muddy fresh water over the coastal waters, following severe inland storms.

Fossils. Major skeletal fractions such as *Porites* and *Halimeda* have already been mentioned. These, along with minor amounts of echinoid spines, serpulid tubes and crustose coralline algae, reflect the prevailing reef-flat and grass-bed communities around the island. Grains of these types occur throughout most cores, but are scarce to absent in the highly gypsiferous beds (Fig. 9). Ostracodes are abundant in the modern sediment and calcareous older layers, but are less numerous in the gypsiferous layers. Foraminifera occur in all cores and most beds, but are much less numerous than the ostracodes, particularly in the gypsum sands; the forams may well have lived in the lagoon (Murray, 1970). Fragments of bone and crustaceans are trivial. Pulmonate snails occur only in the older layers at two sites (Table 2).

The rather numerous molluscs were identified, and their occurrence is given in Table 2. Of the many types found in the cores, only 5 occur in the youngest stratigraphic units (Table 2). All identifiable genera are typical of Late Cenozoic and Holocene brackish or shallow marine environments (Weisbord, 1962). Their diminishing abundance with time points to a progressive "poisoning" of the lagoon by increased salinity, just as does the development of gypsum.

STRATIGRAPHY

The cores on which this study is based were obtained with a driven steel pipe of 6.5 cm ID. Measurements of penetration depth and length of "rise" of core into the pipe were made each time before the core and barrel were withdrawn. All cores were compressed considerably, to as little as 50-60 percent of depth of penetration. The unit-thicknesses illustrated (Fig. 9) are all "restored," *i.e.,* increased from their recovered length by the factor necessary to expand the total length of core recovered to the actual depth of penetration. The amounts of linear compaction are compatible with experimental ranges given by Emery and Hülsemann (1964). Although they report that compaction is of uniform magnitude throughout the lengths of short cores, the different facies and textures of La Salina cores may not have compacted uniformly. Core lengths illustrated and discussed here are believed to be real; the thicknesses of several units in each core may have been distorted mutually by this extrapolation process, but none are thick enough to vitiate the geological conclusions.

The sedimentary record in La Salina is rather disorderly because thin, local fan-shaped wedges of skeletal-peloidal sandy mud have invaded the margins of the lagoon from time to time. These become markedly finer in texture towards the lagoon, from muddy gravel to mud or sand, in short distances from the edge of the lagoon. Their breadth is small with respect to the spacing between cores, which hinders correlations. Facies in mid-lagoon may also be of small extent; *e.g.,* Core 5B contains a unit of skeletal debris with peat (5B-C) which is only just recognizable in Core 5A, only 30 meters farther north (Fig. 2, 9). The peat in Core 4 lies 37 cm below the floor of the lagoon, whereas that in Core 3 is 123 cm deep; they have radiocarbon ages of 2980 and 2690 years, respectively (Fig. 9). Part of the section of Core 4 is believed to be overturned, as explained below.

Radiocarbon dates have been obtained from certain of the units. Most confidence is placed in those from the peat layers (3L and 4C) because (1) the peats are relatively thin, and (2) ages of carbonate units are doubtless the medians of broad spectra of maximum ages of grains. Given the patchy deposition of skeletal material, absolute ages might be the best correlation tool; sedimentation rates, however, were erratic in both space and time so that no correlative ties are suggested in Figure 9.

Ages of dated units are posted in Figure 9, and considered to be the age of the mid-point of each unit. Measurements, made by Dennis Coleman of the Illinois Geological Survey, are as follows:

Unit	Radiocarbon Years B.P.	B.C. Years	A.D.
2C	3170 ± 75	1220	
2E	3770 ± 100	1820	
3L	2690 ± 75	740	
4B part A	440 ± 75		1510
part B	540 ± 75		1410
4C	2980 ± 120	1030	
4D	767 ± 75		1183
5A-B	950 ± 75		1000
5A-C	2820 ± 75	870	

Approximate average rates of sedimentation can be computed from the ages and stratigraphic intervals between the mid-points of dated units. For older intervals, the rate from Unit 2E to 2C is 0.09 cm/yr near the lagoon margin and 0.02 cm/yr from 5A-D to 5A-B in mid-lagoon. For younger intervals (up to the lagoon floor) the rate is 0.02 cm/yr for both Units 2C and 5A-B. The average rate from 3L to the surface is 0.05 cm/yr, but the interval is so thick the value is unreliable. The rate from 4B to the surface is the same, but the abnormal history of Unit 4B (see below) requires this value be ignored.

Normal Succession. The stratic succession in La Salina records a history of lagoonal sedimentation, but one with a marked change from normal marine to hypersaline conditions. Peat and skeletal-peloidal carbonates are the older sediments, the carbonates having been brought mostly from the island and seaward beaches by storms. The main body of sediment, continuing to the present day, is of carbonates with gypsum. The gypsum, together with modern-day seasonal halite, records the deterioration of circulation and onset of hypersaline conditions. This began about 2700 years B.P., and terminated the accumulation of red mangrove peat 3L.

Red mangrove will grow in waters ranging from normally saline to fresh, but establishment of seedlings is favored by initial salinity approaching that of normal sea water (Stern and Voigt, 1959). Although no work has been done on the tolerance levels of mature plants, hypersaline environments appear to be unfavorable. Red mangrove cannot pioneer or expand under hypersaline conditions, however, for seedlings are deterred by salinities 140% of normal, *i.e.,* about 50°/₀₀ (Bowman, 1917, pp. 631, 671). Thus, the mangrove community must have deteriorated even before conditions had become suitable for the accumulation of gypsum.

A tenuous link to the sea has existed at the northwest corner of

La Salina in more recent times, through the small pond (Fig. 2) and channel described earlier. It is possible that this was the site of the 2700-year-old connection to the sea. Gypsum is sparse in Core 6, the nearest sample site, and the acid-resistant residues contain more quartz sand and silt than other cores. The amount of quartz increases upward, to about 4 percent of the salt-free solids. Eolian transport may have brought some, but the muddy fresh water that overspreads coastal waters and surrounds the keys several times each year (Weiss *et al.*, in press) could have brought fine clastics from the mainland by intermittent flooding of this channel. The increase of quartz upward in Core 6 is, by this hypothesis, compatible with rising sea level postulated for the last 2500-3000 years. The amount of quartz is less than that in modern bottom sediments near Cayo Sal, and it comes largely from such lenses of muddy flood water (Weiss *et al.*, in press).

Overturned Succession. The age relations in Core 4 are anomalous, for an old peat lies on apparently much younger carbonate sediment. Peat 4C has two sharp contacts, is of age similar to peat 3L, and lies 86 cm higher (top-to-top) than Unit 3L. Peat 4C is "too high"--at a stratic level too young for its age of 2980 years (Fig. 9). However uncertain the dates on carbonate units may be, the dates of peats are good. Because of its anomalous stratic position, Unit 4C is shown bounded by unconformities (Fig. 9).

The abnormal form of the northeastern quadrant of Cayo Sal reef platform was touched on earlier. El Huequito (Fig. 2) has the shape of a segment of a circle centered at the northeast corner of the reef platform. It is separated from La Salina by a narrow, low berm of skeletal sand that is lower and quite different from the coral cobble material to the west and east of it (Fig. 2). That berm is poorly vegetated, especially by comparison to other parts of the island, and its height and profile suggest it was formed by the surf in the bay, as though an open gap may have been closed progressively by surf and by growth of low sand spits from both sides of the bay.

One hypothesis to explain the topographic and geographic aspects of El Huequito, and the stratic and chronic aspects of Core 4, is that La Salina once included the area of El Huequito, and that catastrophic destruction of the northeast corner of Cayo Sal made several changes in quick succession:

i) displaced the unconsolidated material of the northeast corner of the island without displacing much of the coarse coralgal rubble to right and left (Fig. 2)(if it was indeed already there);

ii) tore up an old mat of peat from below the lagoon floor, rafted it southwestward and redeposited it as Unit 4C. (About 5% of Unit 5B-C and basal 5B-B is shreds and clots of peat, possibly part of this same redeposited mat of peat.);

iii) spread mineral debris from lagoonal and supratidal deposits over the floor of El Huequito and part of La Salina (?Units 4A, 4B?);

iv) and left El Huequito open to the sea and exposed to colonization by corals.

Considerable relocation of fine materials must also have occurred throughout the lagoon, but these cannot now be distinguished with confidence. The hypersaline condition of La Salina was moderated until separation of El Huequito from La Salina once again established hypersalinity in the lagoon.

The event must have occurred after 770 B.P. and before 500 B.P. Unit 4D is thick (Fig. 9) and the upper part is certainly much younger than 770 years, but by how much cannot be even guessed (it may even include some carbonate redeposited along with the peat). In historic terms this occurred between 1180 and 1450 A.D., probably closer to the later date.

Subsequent to this supposed event, corals became established in El Huequito, and surf filled the breach into the lagoon by building a sandy beach and berm along the southwest margin of the bay, perhaps where the storm-laid debris was heaped highest. Plant succession is still in early stages on this berm.

Such a catastrophic event ought to have left other evidences of its occurrence. Damage *has* occurred on the northeast quadrants of neighboring islands (Weiss *et al.*, in press), but no means of estimating dates is at hand. The northeast quadrant of the reef edge of Cayo Peraza (Fig. 1) was broken sometime before 1950, the date of earliest air photos. This allowed heavier surf to reach the island and displace loose sand from behind protective rims of beachrock (themselves having radiocarbon ages of zero years). The reef flat on the northeast quadrant of Cayo de Los Muertos (Fig. 1) is littered with *Acropora palmata* displaced from the reef front. The platform north of Cayo Borracho (Fig. 1) has larger areas of coral rubble than of living coral, despite being a favorable site with regard to depth, clarity, and circulation. Each of these examples seems "modern" in aspect, for debris thrown onto a reef flat probably cannot endure boring and solution more than a few decades. These additional examples do little more than show that spectacularly destructive waves have struck this coast from the northeast. It remains to consider their sources and frequency.

HURRICANES AND TSUNAMIS

Destructive waves from hurricane or seismic events--or surges associated with either--might do the job, but neither sort of catastrophe is common in the southern Caribbean. Further, historical records of natural events are almost non-existent for this part of rural Venezuela.

Hurricanes

Hurricanes are not known to originate in the central part of the Caribbean--*i.e.*, between Colombia-Venezuela and Jamaica-Hispaniola (Dunn, 1956). Further, only four (1802, 1877, 1892, 1933) have passed along or across Venezuela's Caribbean coast in nearly 500 years

(Tannehill, 1950). Those spawned in the major source area (off Martinique-Barbados-Trinidad) cross the Caribbean on a westward track, but almost without exception they twist slowly to the right (Garriott, 1900; Fassig, 1913; Mitchell, 1924; Dunn and Miller, 1964) so as to swing away from Venezuela and Colombia. This fact, plus the concentration of wind power in the right front quadrant of each advancing storm, protects coastal Venezuela and the waters out to the Dutch A-B-C islands from all but those storms that are abnormally far to the south. Tropical storms of sub-hurricane intensity are less restricted (Colón, 1953), but also less damaging; their incidence and tracks are less thoroughly known, particularly in the pre-20th Century records.

Hurricane records of differing precision are available from 1493 to the present. It is clear that most of those originating near or passing through this part of the Caribbean Sea pass the meridian of Chichiriviche (68°15') at latitudes of 14° or more North (Tannehill, 1950; Dunn and Miller, 1964), and that those abnormally far south for this longitude pass south of 13° North Latitude. Between the 13° parallel and the coast at Chichiriviche is a distance of about 230 kms. The frequency of those hurricanes known to have crossed the 68° meridian south of 13° N. Lat. is a reasonable guide to the frequency of major storms that may have damaged the coast of western Venezuela directly or created spectacular storm surges (Table 3). The hurricanes that passed closest to Venezuela are starred in Table 3. According to the National Hurricane Center, storms this far south are *usually* not as intense as elsewhere, although these very rare events *may* also have been abnormally violent (P. J. Hebert, personal communication, 1976). Major damage to the coast of western Venezuela might thus be expected to have occurred as a result of hurricanes once every 100 years.

Tsunamis

Tsunamis or seiches are on record back to 1530 A.D. (Berninghausen, 1969), but only five are known to have damaged Venezuela. Three (1530, 1853, 1929) severely damaged Cumaná, on the north coast of Venezuela 440 km ESE of Chichiriviche. Damaging waves not known to have been associated with earthquakes--probably storm surges according to Berninghausen (1969)--were recorded "from Venezuela" in 1543 and on the coast 160 km west of Chichiriviche in 1955. None of these occurrences suggests itself as the cause of damage to Cayo Sal, but they illustrate destructive waves that occasionally strike the Venezuelan coast, and none coincided with any of the hurricanes listed in Table 3.

The average rate of destructive wave attack in this area since 1493, whether from hurricanes or tsunamis, is two per century. Even so, no historical incident can be correlated with the formation of El Huequito and the abnormal stratigraphy of Core 4 in La Salina. Not only was that pre-Columbian (if the radiocarbon dates on carbonates can be trusted), but records of catastrophic events of this sort that affected the more rural parts of that long coastline, especially in older times, are poor. Chichiriviche, for example, had no highway access until the early 1960's.

GEOLOGIC HISTORY

The old peat in Core 3 (Unit 3L) lies 123 cm below the floor of the lagoon and is 17 cm thick; it broke clean at the bottom of the core, so the in-place peat must be thicker than the 17 cm recovered. The top of the peat is 1.49 m below "local" mean sea level (the median position between high and low water, according to observations and local sources). No tide gauges exist near here; the closest is a La Guaira, 160 km to the east.

The depth of the lagoon 2500-3000 years ago cannot be known, but its bottom at Core 3 (Fig. 2) cannot have been higher than 1.49 m below present mean sea level. At that time the lagoon must have been either (a) of fresh to brackish water and slightly supratidal, or (b) connected by a channel(s) to the sea and intertidal. Separation of the lagoon from the sea now is only by the wave-built carbonate-sand island, a common condition for shallow coral banks, so cause "b" seems more likely. The present lagoon is intertidal-to-supratidal, permanently hypersaline, and connected regularly to the sea only by the shallow phreatic zone under the island. The change from either "a" or "b" to the present configuration requires that a relative rise of sea level, of about 1.5 m, have occurred in the last 2600-2700 radiocarbon years. Free connection to the sea must have been closed off during this time, possibly by shore processes of the rising sea--the remobilization of stable sediment and closing of channel(s) by longshore transport.

Independent evidence of a rise of this magnitude is to be found on the mainland just a few kilometers away. Two drowned terraces occur in the Golfete de Guare, near Chichiriviche (Weiss, 1973). The Golfete is an abandoned sinuous channel of the Tocuyo River, the master stream of the alluvial lowland of eastern Falcôn State. Near the mouth of the Golfete the edge of the deeper and older terrace is 5.2 m below modern sea level, and suggests that sea level had been rising intermittently even prior to 2700 years ago. The younger terrace edge is 1.8 m deep, and of the right order to correlate in vertical extent with the evidence from the sediments of La Salina.

Evidence for comparable rise or Late Holocene sea level comes also from other areas. Wiedemann (1973) found a red mangrove peat 2430 radiocarbon years old buried beneath sediments of a large coastal lagoon in Colombia. His site "a" (Wiedemann, 1973, fig. 5, table 1) is close to the coast, and records a relative rise of sea level of about 2 m in 2300 years. This is a change of the same order of magnitude as that recorded here from Venezuela, but the sites are 460 km apart and the coincidence cannot support a claim of eustatic change alone.

Scholl *et al.* (1969) recently revised the eustatic rise curve for Florida; the rise there has been almost exactly 1 m in the same period of 2700 radiocarbon years. Peats from a wider geographic range, including Bermuda and Louisiana, were the basis for a steady eustatic rate developed by Redfield (1967) for the last 4000 years. Over 2700 years, that rate gives a value of 2 m. Clearly, the relative rise of sea level at Chichiriviche has been at least partly eustatic in nature.

The similarity of the vertical intervals cited from other studies, and the mostly low-lying Late Tertiary terrain of this part of the Venezuelan coast strongly suggest that the rise has been mostly or wholly eustatic.

CONCLUSION

La Salina had normal or brackish salinity 2700-2900 radiocarbon years ago, and accumulated red mangrove peat. Sea level was 1.5-1.8 m lower than at present. About 2600-2700 years ago the connection from the lagoon to the sea was interrupted as shore processes of the rising sea disturbed old beach and island deposits, and longshore transport made a new configuration of the supratidal sediment. The lagoon became, and remains, hypersaline; abundant gypsum crystallized and is preserved in the sedimentary fill. Halite forms and redissolves seasonally, so is not part of the geologic record. Sea-level rises of this magnitude and rate are attested to by drowned terraces on the nearby mainland and by buried peats in Colombia. Similarity of this rise to the eustatic values for the western Atlantic and Gulf of Mexico suggests that it is itself mostly eustatic in nature.

Between 1180 and 1450 A.D., probably closer to the latter, a tsunami or severe storm surge struck the northeast quadrant of the island, turning part of the old lagoon into a bay. At the same time a buried peat was reexposed and resedimented at an anomalous (higher) elevation, within carbonate sediments younger than itself. The salinity of the lagoon became normal, temporarily, until closure of the gap cut off circulation once more. The incomplete plant succession on the part of the island between the bay and lagoon suggests that that deposit is young, or has been unstable since becoming subaerial. Coral growth in the bay is recent. Both facts point to a catastrophe in historic times, but none is recorded in the archives of Venezuelan coastal disasters. An event in the early 15th Century is therefore a best estimate of the occurrence.

Acknowledgements. Srs. D.A. Goddard, G. Gonzales, and X. Picard joined in the coring. D.D. Coleman made the radiocarbon age determinations, and I am grateful not only to him but to the Illinois State Geological Survey for this courtesy. R.H. Tschudy, of the U.S. Geological Survey, analyzed the peat from Core 3. I.E. Odom and B. Terrell assisted with X-ray diffraction runs. J. Gibson-Smith identified the snails and other fossils. The assistance of all these persons is very much appreciated. The Venezuelan Ministerio de Minas e Hidrocarburos supported the field work; Northern Illinois University supported the laboratory work. The clarity of the text was much improved by suggestions from F.R. Fosberg, S.H. Frost, L.C. Gerhard and Ian Macintyre. For this I give them thanks but none of the responsibility.

REFERENCES

Berninghausen, W. H. 1968. Tsunamis and seismic seiches reported from the western North and South Atlantic and the coastal waters of northwestern Europe. Naval Oceanographic Office Inf. Rpt. No. 68-85, Washington, D.C. iii + 48 p.

Bowman, H. H. M. 1917. Ecology and physiology of the red mangrove. Proc. Am. Phil. Soc. 56:589-672.

Bryan, E. H., Jr. 1953a. Introduction to the geography of atolls. Chap. 1 in Atoll Res. Bull. 17.

________. 1953b. Check list of atolls. Atoll Res. Bull. 19.

Cody, R. D. 1976. Growth and early diagenetic changes in artificial gypsum crystals grown within bentonite muds and gels. Bull. Geol. Soc. Am. 87:1163-1168.

Cohen, A. D. and Wiedemann, H. U. 1973. Distribution and depositional history of some pre-lagoonal Holocene sediment in the Ciénaga Grande de Santa Marta, Colombia. Mitt. Inst. Colombo-Alemán de Invest. Cient. 7:139-154.

Colón, J. A. 1953. A study of hurricane tracks for forecasting purposes. Monthly Weather Rev. 81:53-66.

Deicha, G. 1946. Remarque sur la gènese des faces courbes de cristaux. Bull. Soc. française Min. 69:47.

Dunham, R. J. 1972. Capitan Reef, New Mexico and Texas: facts and questions to aid interpretation and group discussion. Soc. Econ. Paleontologists and Mineralogists, Permian Basin Section, Publ. 72-14. Midland, Texas. xiii + 294 p.

Dunn, G. E. 1956. Areas of hurricane development. Monthly Weather Rev. 84:47-51.

________ and Miller, B. I. 1964. Atlantic hurricanes (rev. ed.). Baton Rouge: Louisiana State University Press. 377 p.

Eardley, A. J. and Stringham, B. 1952. Selenite crystals in the clays of Great Salt Lake. Jour. Sedimentary Petrology 22:234-238.

Emery, K. O. and Hülsemann, J. 1964. Shortening of sediment cores collected in open barrel gravity corers. Sedimentology 3:144-154.

Fassig, O. L. 1913. Hurricanes of the West Indies. U.S. Weather Bureau Bull. X, Washington, D.C. 28 p.

Friedman, G. M. 1973. Petrographic data and comments on the depositional environment of the Miocene sulfates and dolomites at Sites 124, 132, and 134, western Mediterranean Sea. Pp. 695-708 in

Ryan, W. B. F., Hsü, K. J., *et al.* Initial Reports of the Deep Sea Drilling Project, v. XIII, pt. 2, Washington, D.C. (U.S. Gov't. Printing Office) ix + 517-1447.

Garriott, E. B. 1900. West Indian hurricanes. U.S. Weather Bureau Bull. H, Washington, D.C. 69 p.

Hudec, P. P. and Sonnenfeld, P. 1974. Hot brines on Los Roques, Venezuela. Science 185:440-442.

Illing, L. V., Wells, A. J. and Taylor, J. C. M. 1965. Penecontemporary dolomite in the Persian Gulf. Soc. Econ. Paleontologists and Mineralogists Spec. Publ. No. 13:89-111.

Lahey, J. F. 1958. On the origin of the dry climate in northeastern South America and the southern Caribbean. Madison: University of Wisconsin Meteorology Dept. Sci. Report no. 10. 235 p.

Logan, B. W. 1974. Inventory of diagenesis in Holocene-Recent carbonate sediments, Shark Bay, Western Australia. Am. Assoc. Pet. Geol. Mem. 22, p. 195-249.

Lucia, F. J. 1968. Recent sediments and diagenesis of south Bonaire, Netherlands Antilles. Jour. Sedimentary Petrology 38:845-858.

Masson, P. H. 1955. An occurrence of gypsum in southwest Texas. Jour. Sedimentary Petrology 25:72-77.

Merritt, C. A. 1935. Gypsum crystals from Alfalfa County, Oklahoma. Am. Mineralogist 20:674.

Mitchell, C. L. 1924. West Indian hurricanes and other tropical cyclones of the North Atlantic Ocean. Monthly Weather Rev. Suppl. 24, Washington, D.C. 47 p.

Murray, J. W. 1970. The foraminifera of the hypersaline Abu Dhabi lagoon, Persian Gulf. Lethaia 3:51-68.

Neumann, A. C. 1965. Processes of Recent carbonate sedimentation in Harrington Sound, Bermuda. Bull. Mar. Sci. 15:987-1035.

Redfield, A. C. 1967. Postglacial change in sea level in the western North Atlantic Ocean. Science 157:687-692.

Redfield, W. C. 1846. On three several hurricanes of the Atlantic and their relations to northers of Mexico and Central America, with notices of other storms. New Haven, Connecticut. 118 p.

Scholl, D. W., Craighead, F. C. and Stuiver, M. 1969. Florida submergence curve revised: its relation to coastal sedimentation rates. Science 163:562-564.

Shearman, D. J. 1966. Origin of marine evaporites by diagenesis. Bull. Inst. Min. & Metal. 75:208-215.

Sonnenfeld, P. 1973. Recent lagoonal carbonates in the Venezuelan Antilles. Caracas: II Congr. Latinamericano de Geol. 11 p.

________ and Hudec, P. P. 1975. Heliothermal constraints on sedimentation in a Venezuelan lagoon (abstr.). Geol. Soc. Am. Abstracts with Programs: v. 7, no. 6:861-862.

Stern, W. L. and Voigt, G. K. 1959. Effect of salt concentration on growth of red mangrove in culture. Bot. Gazette 121:36-39.

Tannehill, I. R. 1950. Hurricanes (7th ed.). Princeton: Princeton University Press. 304 p.

Weisbord, N. E. 1962. Late Cenozoic gastropods from northern Venezuela. Bulls. Am. Paleontology, v. 42, no. 193. 672 p.

Weiss, M. P. 1973. Carta batimétrica de Chichiriviche. Caracas: Ministerio de Minas e Hidrocarburos. Map + explanation.

________ and Goddard, D. A. 1977. Man's impact on coastal reefs--an example from Venezuela. Bull. Am. Assoc. Petroleum Geologists Studies in Geology, No. 4, pp. 111-124.

________, Goddard, D. A. and Picard, X. 1973. Reefs and associated deposits, Estado Falcón, Venezuela (abstr.). AAPG and SEPM Ann. Mtgs. Abstracts 1:97-98.

________. (In press). Marine geology of reefs and inner shelf, Chichiriviche, Estado Falcón, Venezuela. Marine Geology.

Wiedemann, H. U. 1973. Reconnaissance of the Ciénaga Grande de Santa Marta, Colombia: physical parameters and geological history. Mitt. Inst. Colombo-Alemán de Invest. Cient. 7:85-119.

Table 1. PRECIPITATION & EVAPORATION*

Precipitation (1954-1969)

	Annual Total in Millimeters	Percent of Annual in O, N, and D	Percent of Annual in Sept.-Jan.
Minimum Annual	560	20	35
Maximum Annual	1900	75	90
Mean Annual	1160	47	62

Evaporation (1950-1970)

	Minimum	Maximum	Mean
Monthly Averages (mm)	71 (Nov)	84 (Mar/Apr)	77.3
Annual Totals (mm)	-----	-----	927.0

---

*Condensed from Weiss *et al.* (in press).

Table 2. MOLLUSC OCCURRENCES

CORES	2					3				4				5A + 5B					6					Present in
FOSSILS / UNITS	A	B	C	D	E	A	J	K	L *	A	B	C *	D	A	B	C	D	E	A	B	C	D	E	top units
GASTOPODS																								
Arene (Marevalvata) sp.		o	o																					
Tricolia bella					o		●	●		o			o		o	●	+	o				o	+	X
Smaragdia viridis viridimaris			o																				o	
Rissoina cf. R. bryerea			o					o																
Zebina browniana							o	o					o		o	o	+	o			o	o	o	
Teinostoma (Idioraphe) sp.					o																			
Teinostoma (Pseudorotella) sp.					o																			
Caecum (Micranellum) regulare					o																			
Caecum (Meioceras) nitidum					o																			
Cerithium variable	●	o	+				o			o				o	o	o	o	●					+	X

CORES	2					3				4				5A + 5B					6					Present in
FOSSILS / UNITS	A	B	C	D	E	A	J	K	L *	A	B	C *	D	A	B	C	D	E	A	B	C	D	E	top units
Cerithium sp.	o	o				●	o	o		o	o		o		o		o		o			+	●	X
Bittium (Bittiolum) varium		o		o	o			o		o			o	o		o	o		o					X
Alaba incerta			o														o						o	
Alabina cerithidioides				o	+			o					o		+	o	●				o	●	●	
Cerithiopsis sp.																							o	
Balcis conoidea			o																				+	
Columbella mercatoria					o												o							
Anachis cf. A. obesa				o																				
Mitrella sp.								o										o					o	
Oliva (Minioliva) cf. perplexa			o	o	●												o	o					+	
Granula lavalleeana		o	o	o	o		o									o	●	o					+	
Bulla umbilicata					o																		o	
Haminoea aff. H. petiti				o	o																			
Turbonilla sp.					o								o				o				o	o		
Unidentified pulmonates				o	o																		o	

CORES	2					3	4				5A + 5B					6					Present in
FOSSILS / UNITS	A	B	C	D	E	A J K L *	A	B	C *	D	A	B	C	D	E	A	B	C	D	E	top units
PELECYPODS																					
Arcopsis adamsi			o								o									o	X
Brachiodontes sp.													o								
Codakia costata				o																o	
Gouldia cerina				o										o							
Number of groups represented	3	6	10	9	14	1 - - - - 6 7 -	5	2	-	8	4	7	8	16	9	3	1	4	8	24	5

o = 3 or fewer   ● = 4-5   + = more numerous   * Peat beds: no calcareous fossils; see text

Table 3. HURRICANE RECORD FOR

SOUTHERN CARIBBEAN SEA

1493-1801 - none known to have affected Venezuela (Garriott, 1900)

*1802 (Sept. 16) - Cumaná, Venezuela (10-11°N.; 64-65°W.)(Garriott, 1900)

1831 (June 23-27) - passed from Trinidad to north of Curaçao (Redfield, 1846)

Three other 19th-Century hurricanes crossed or came near to Trinidad, and may have had abnormally southerly courses like that of 1831. Their tracks subsequent to the dates and localities tabulated below are not known (Garriott, 1900), which suggests that they swept WNW across the open Caribbean.

Oct. 18, 1809 - Trinidad

Aug. 12, 1810 - Trinidad; Barbados

Oct. 10, 1847 - Tobago; Trinidad

*1877 (Sept. 21-Oct. 5) - storm apparently moved toward NW, and passed south of Curacao on the 23rd. (Garriott, 1900; Tannehill, 1950)

1886 (Aug. 16-28) - passed from Grenada and by Curaçao at about 13°N. (Fassig, 1913)

*1892 (Oct. 6-15) - passed from east of Tobago across Isla Margarita, passed about 30' (35 miles) north of Chichiriviche, and crossed the Paraguaná and Guajira peninsulas (Mitchell, 1924)

*1933 (June 27-July 6) - originated in the Atlantic, passed between Trinidad and the mainland of Venezuela, across the gulfs of Paria and Cariaco, and then across Bonaire and north of Curaçao. This is the only hurricane of record known to have passed south of Trinidad (Tannehill, 1950), although its track suggests that the Sept., 1877 storm may have had a similar course.

*Paths approached the mainland most closely, and are most likely to have affected the Chichiriviche area severely.

APPENDIX

"Seed"-like or "fruit"-like fossils, found in some of the mineral layers of the cores described above and referred to as "plant-capsules" on page 8, have been the subject of much interest, and as yet have not been identified, except to the extent that they seem to be of plant origin. They have been shown to neo-botanists and paleo-botanists, to entomologists, to bryozoologists, to malacologists. None of these would hazard a guess, except to suggest one of the other, totally different, groups of organisms.

I had no hesitation, at first glance at detached material, about calling them Ruppia maritima L. fruits, which would have been quite likely, considering the saline habitat. They were stalked, small asymmetrically ovoid beaked black objects. Closer examination of several dozens of specimens showed that this was not even a close possibility. The "fruits" were borne on a very slender branching "inflorescence", but mostly detached or on single capillary branches, occurred singly, in pairs, threes, and, in one example, decussately 4 together, united by their bases at two slightly different levels. The "fruits" are dehiscent dorsally by a trap-door-like arrangement, opening from below. The individual "fruits" are 1-2 mm long, somewhat laterally compressed, asymmetric, with a slender beak. On each side, just below the beak, is a thin spot, becoming an opening, giving the impression of two eyes. Well preserved examples are blackish, smooth. When somewhat weathered the surface is roughish and slightly brownish or purplish. All that were broken open were empty or had matrix inside. One already opened when found has a mass of small bodies that might be seeds or could be mineral grains.

We have as yet no clue to the identity of these fossils.

F. R. Fosberg

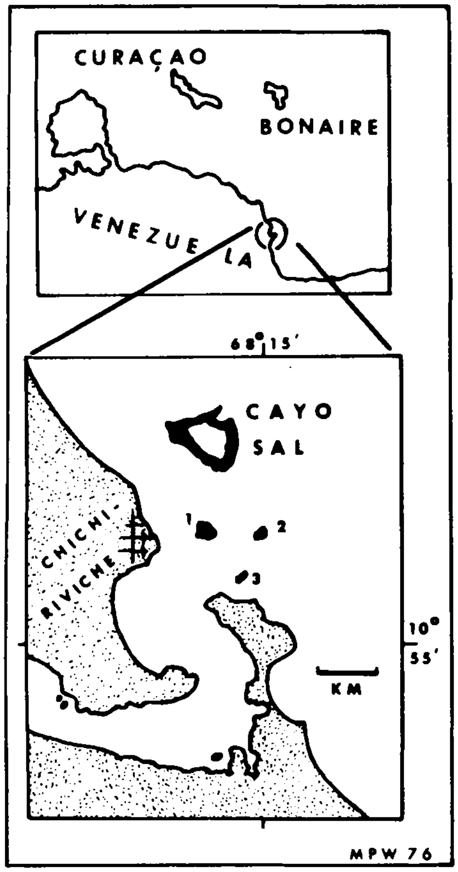

Fig. 1. Index Map. Cayo Sal is named; smaller cays are (1) Cayo de Los Muertos, (2) Cayo Peraza, (3) Cayo Pelón. Cayo Borracho (not shown) lies 3 km NNE of Cayo Sal.

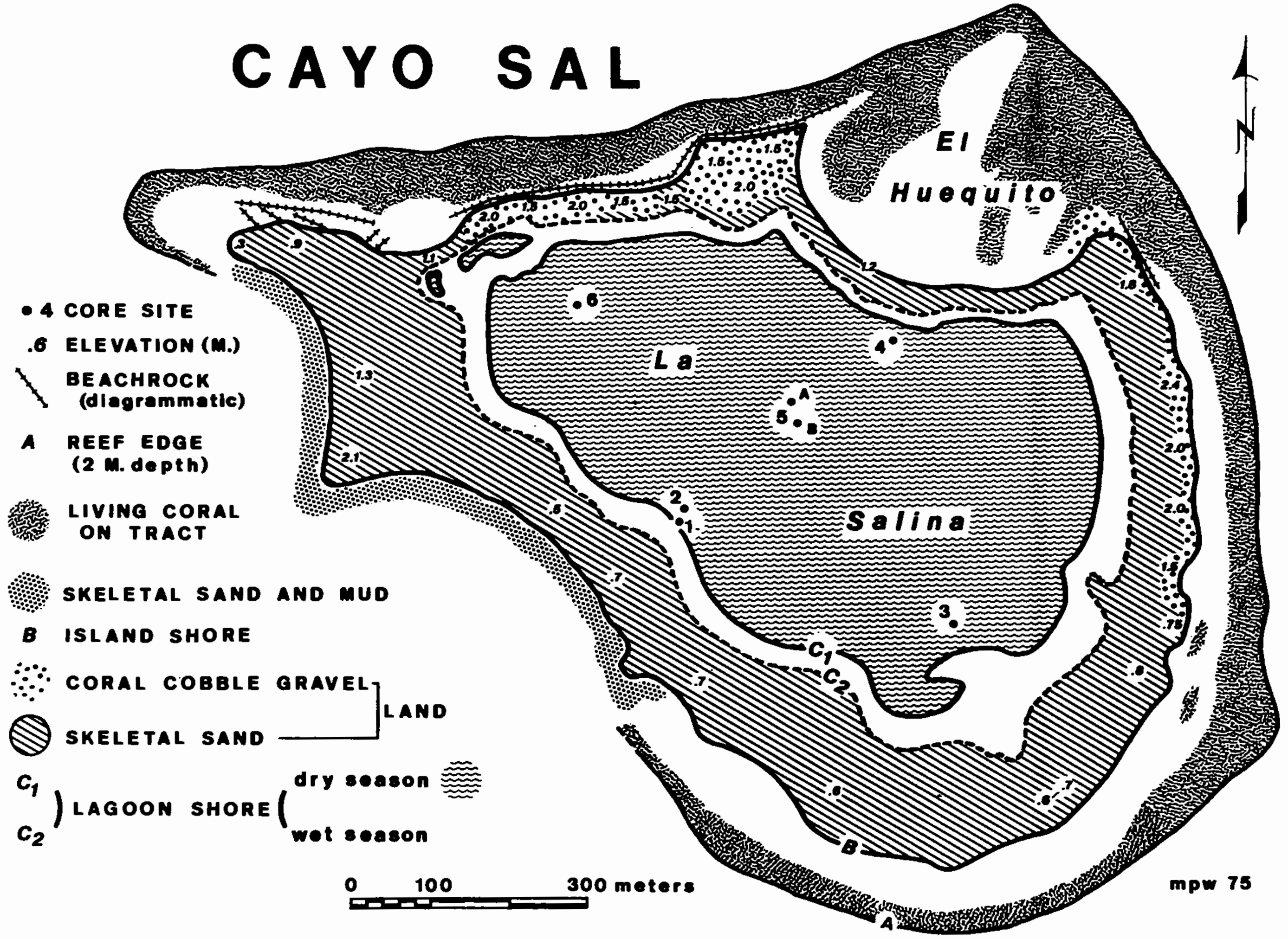

Fig. 2. Map of Cayo Sal, including island platform, reef tract, island, and lagoon (La Salina) with core locations. Compare with aerial photos in Figs. 3A and B.

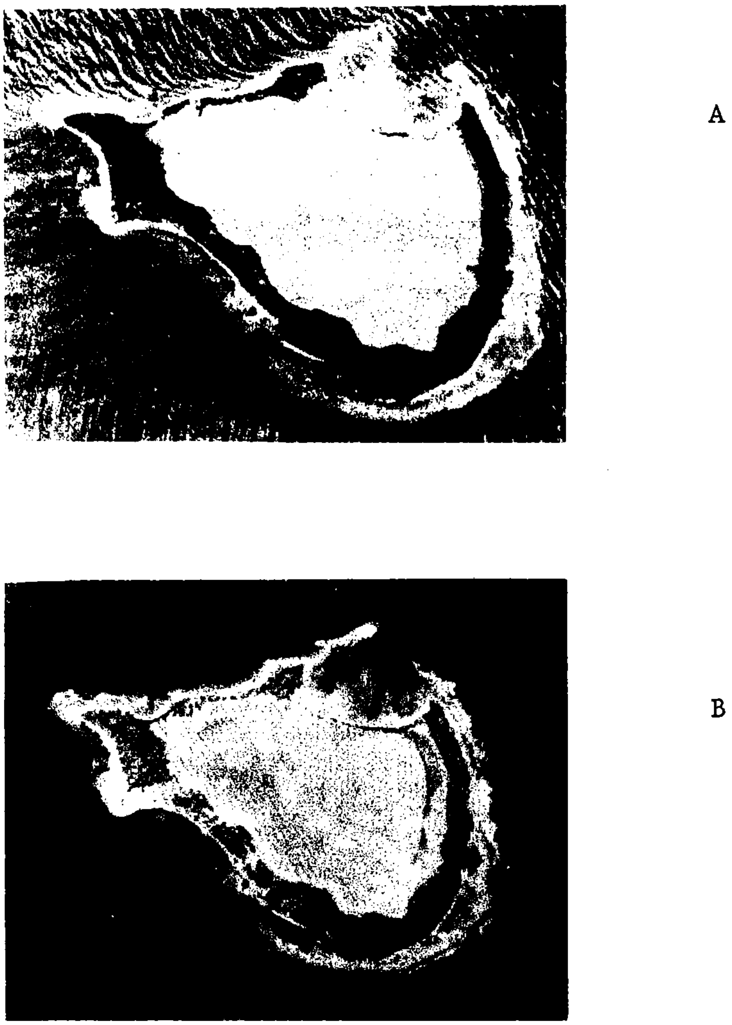

Fig. 3. A) Aerial photo of Cayo Sal taken during high stage of La Salina in winter of 1950-51. (Frame 241D, mission C-12, 1950-51)

B) Aerial photo of Cayo Sal taken during low stage of La Salina on May 6, 1965. (Frame 371, mission 020124, 1964-65)

(Published by authorization of Cartografía Nacional, M.O.P., Venezuela.)

Fig. 4. Gypsiferous units in Core 3, showing Beds G-J (cf. Fig. 8). H, I and J are more than half seed gypsum. Lighter laminae are highest in gypsum; darkest ones have conspicuous slime of clay and organic residues. Bar of 2 cm measures dry, compacted thickness.

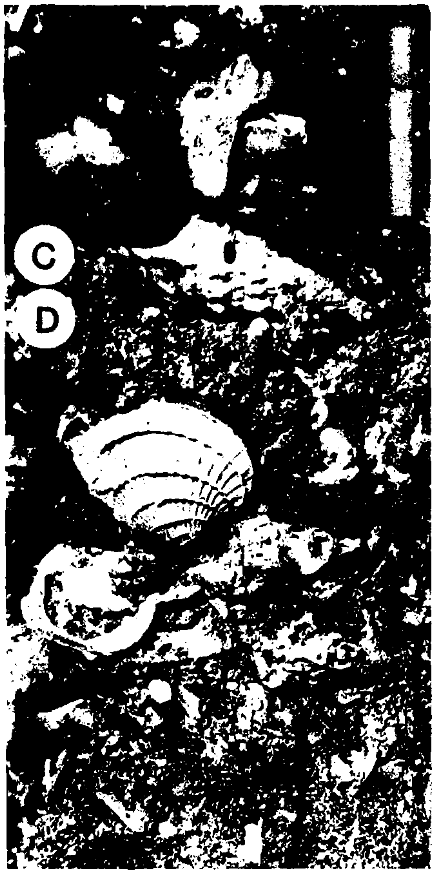

Fig. 5. Shells and scraps in older part of Core 5B. Bed C has skeletal sand and mud and a little peat that colors it conspicuously; the matrix of D is less well sorted and has less organic material (cf. Fig. 8). Bar of 2 cm measures dry, compacted thickness.

Figure 6 (facing)

A) Piece of gypsum crust, calcined and whitened during drying, from lagoon floor near Core 5B.

B) Crust of mixed gypsum and carbonate, from same sample as A.

C) Pale, "fresh" carbonate crust (Type A), from same sample as A.

D) Dark, "old" carbonate crust (Type B), from same sample as A, with intergrown gypsum rosette.

E) Darkened carbonate crust (Type B), from same sample as A.

F) Thin section of isolated gypsum rosette from same sample as A, cross-polarized light. Matrix is aragonite with some Mg-calcite and a trace of dolomite.

G-H) Two thin sections of peloidal-skeletal carbonate crusts from Core 2, Unit A, cross-polarized light. Crusts consist of aragonite, some Mg-calcite and a trace of dolomite, and are cemented by micrite and microspar, G) Peloids, with ostracodes and mollusc fragments, packed more tightly than in many grapestone and crust fragments. H) Peloids and skeletal grains, but more porous and with more conspicuous microspar.

I) Thin section of a druse-and-microspar cemented peloidal carbonate crust (Type A) containing older peloidal lithic grains (dark patches) as clasts, cross-polarized light. Bright spot against convex curve of larger lithic grain is quartz. Crust is of aragonite with some Mg-calcite; from Core 6, Unit A.

J) Thin section of pisolith of drusy aragonite with at least 5 generations of acicular druse, enclosed in porous fresh crust of cemented peloids, cross-polarized light. Crust is of aragonite with some Mg-calcite and a trace of dolomite; from lagoon floor near Core 5B.

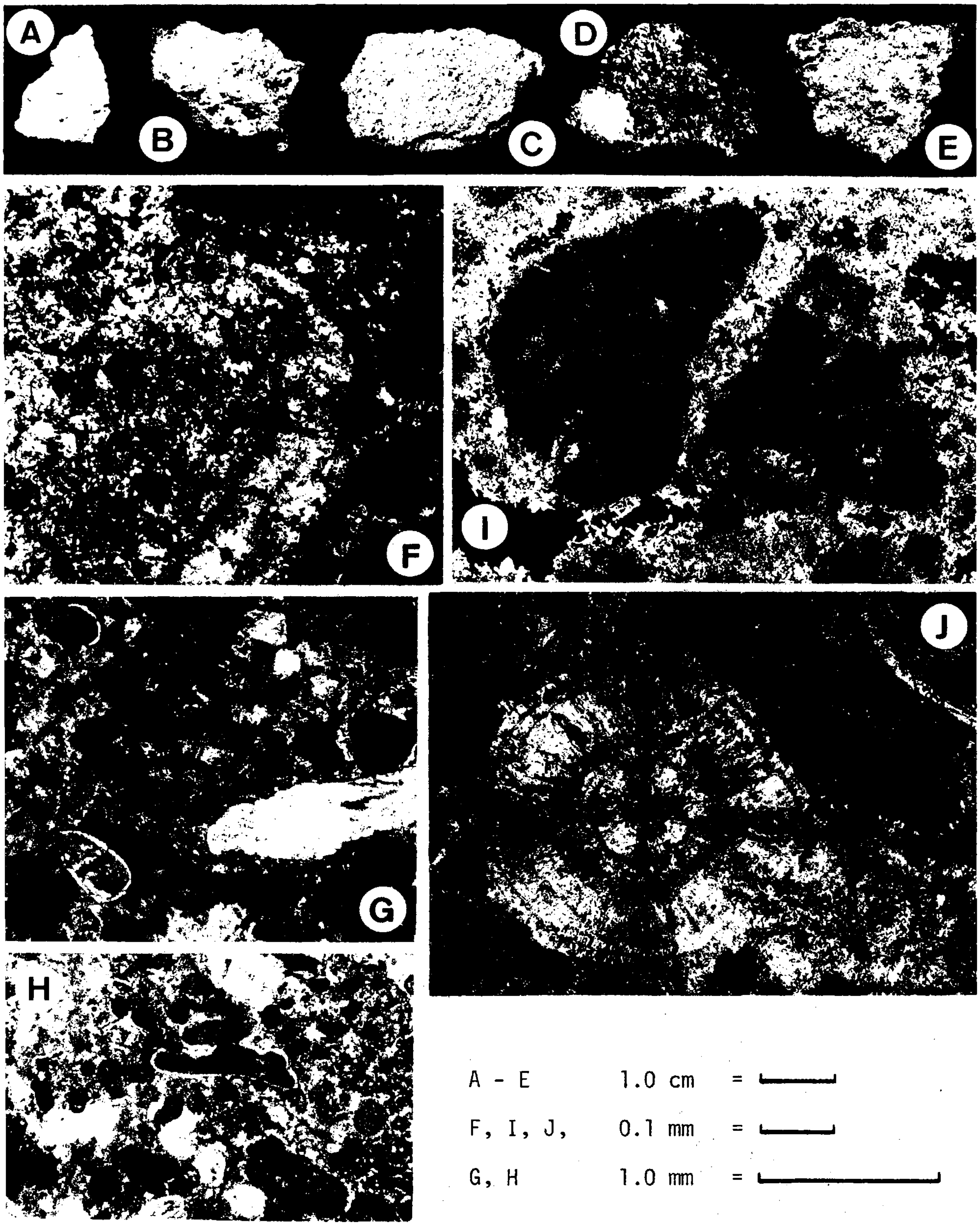

Fig. 6 - Cemented aggregates of gypsum and carbonate grains.

Fig. 7. Skeletal debris, mostly allochthonous, in Core 2. Bed C (above) has very little residue, but D has some peaty shreds and blebs (cf. Fig. 8). Bar of 2 cm measures dry, compacted thickness.

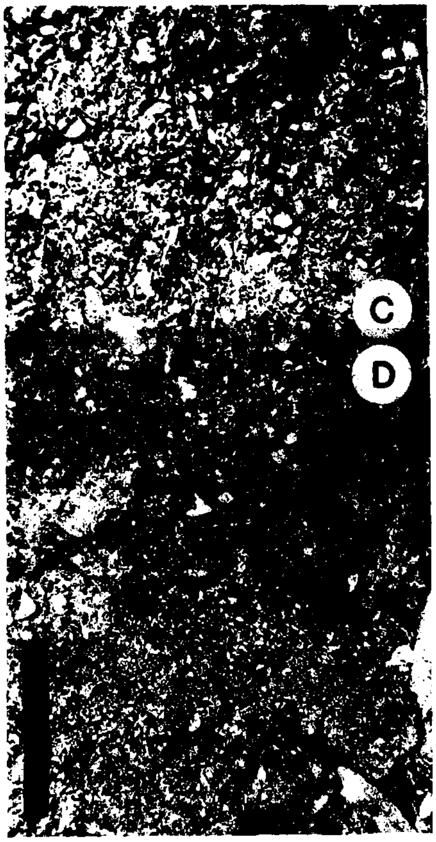

Fig 8. Beds K and L of Core 3 (cf. Fig. 9). Skeletal-peloidal debris with very little gypsum lies over a mangrove peat of 2690 ± 75 radiocarbon years that contains trivial amounts of mineral matter. Bar of 2 cm measures dry, compacted thickness.

Explanation for Figure 9 (facing)

CARBONATE is mostly skeletal and peloidal. GYPSUM is seed gypsum of sand and silt size. Organic material typcially exceeds quartz-plus-clay in acid-resistant RESIDUES. PEAT occurs as compact masses and as scattered shreds and blebs.

Three sedimentary structures are distinguished: SKELETAL--in which gross debris is conspicuous; MASSIVE--having a uniform, compact structure; LAMINATED--like massive but with color/textural bands such as gypsum and organic mud.

The textural ratios of the particles, grains and skeletal shards in the beds are given as MUD ≷ SAND-plus-granules.

Stratigraphic units are lettered from the lagoon floor down.

Radiocarbon dates refer to the units between the boundaries indicated.

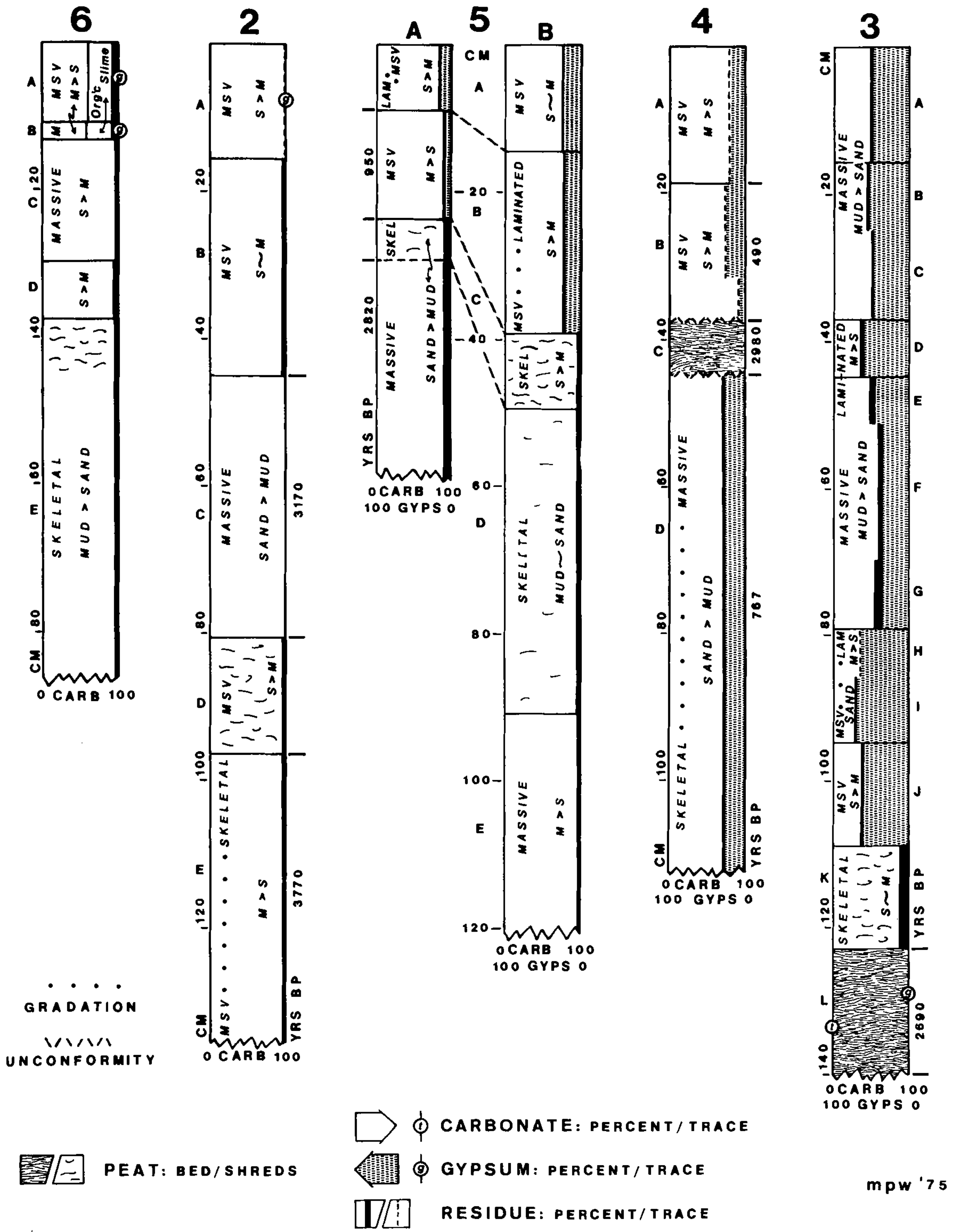

Fig. 9. Graphic logs of the cores arrayed with their tops (the lagoon floor) on a common line.

☆U.S. GOVERNMENT PRINTING OFFICE: 1979 297-875 1-3