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MODERN STROMATOLITES AND ASSOCIATED MATS: SAN SALVADOR, BAHAMAS

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ABSTRACT

Stromatolitic growths of Mg-calcite are forming subtidally in several hypersaline lagoons on San Salvador, Bahamas. A study in Storrs Lake reveals that they range from locally thickened laminated crusts to club-shaped heads over 1 m in diameter and up to 1 m tall in water depths up to 2 m deep. The surface of the sediment and the heads is everywhere draped by a dark green, cohesive, microbial mat. Heads in water depth less than 1 m are larger, have a deeply pitted top, and protrude 10 cm or more above the sediment surface, while those in deeper water protrude only a centimeter or more above the mat level and have a smooth, crenulate surface. The exterior of the heads is densely cemented while the interiors often crumble into loose stacks of millimeter thick laminae and thicker intervals of thrombolitic, non-layered growth. The top exterior few centimeters of all sampled heads exhibit a more massive structure while walls, bases and inner portions can be finely laminated. The enclosing muddy sediment is composed of carbonate, gypsum and organic matter. Measured salinities range from 60 to over 100 parts per thousand and may vary throughout the seasons. The ubiquitous microbial mat is made up of filamentous and unicellar cyanobacteria as well as anaerobic photosynthetic bacteria. Gradients of oxygen were measured by microelectrodes to be over 4 times atmospheric concentration during daylight in the upper 5 mm below which anoxic conditions abruptly set in. Corresponding pH in the high oxygen zone went over 9 and fell to close to 7 in the anoxic zone beneath. SEM photos reveal euhedral crystal faces of apparently freshly precipitated Mg-calcite on the small hard nodes that form along the mat/head contact. Commonly, however the surfaces reveal evidence of episodes of dissolution indicating a complex alteration of deposition and dissolution on and within the calcified heads. It appears at present that these calcified heads undergo both thrombolitic and stromatolitic intervals, and that they accrete by chemical precipitation at the mat/head contact as well as internal cementation. Foreign material incorporated into the stromatolites indicates some accretion by trapping but it appears to be a very secondary process.

INTRODUCTION

The major macroscopic evidence that life existed on earth as early as 3.5 billion years ago is in the form of fossil stromatolites, "organo-sedimentary structures produced by the sediment trapping, binding, and/or precipitation as a result of the growth and metabolic activity of micro-organisms, principally cyanophytes" (Awramik and Margulis, 1976). These ancient bulbous upgrowths exhibit a wide variety of sizes and shapes. They are often finely or coarsely laminated (i.e., Garrett, 1970), but can also be massive with a clotted microfabric yielding a form for which Aitken (1967) reserves the term, "thrombolite." Pre-Cambrian and early Phanerozoic forms are very fine-grained carbonate, sometimes cherty, and are usually associated with marine facies ranging from hypersaline bays to open shelves (Griffin and

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A complex peripheral terminology has grown associated with stromatolites and thrombolites in an attempt to clarify description, elucidate origin or point out process. Typical is a recent review by Burne and Moore (1987) which suggests a series of terms centering upon "microbialite." The result is a good review of the complexities of the associated phenomena and a scheme of terms that mirrors the complexity rather then reducing it. "Lithoherm," for instance is proposed in relation to some stromatolitic forms well beyond its original definition as a "subphotic" feature (Neumann, et al., 1977).

Awramik, this vol.). It is often not clear if the ancient forms were mostly precipitated or if they accumulated by trapping and subsequent cementation of particles from the water column. Questions of the calcification of these earliest macrofossils, the organisms responsible and the associated ecological conditions are of great interest to the evolution of life and the conditions on earth under which life pioneered.

Mats of blue-green algae (now "cyanobacteria") were suspected as the causative agent for stromatolites, and many studies of living mat communities ensued. Living mats, however, are commonly soft and rarely build up into layered carbonate accumulations of the proportions, complexity and abundance of ancient stromatolites. Rarely, they are calcified such as some *Scytonema* mats at Andros, Bahamas (Monty, 1967). Commonly, however, they are soft and composed of a single, organic mat that rapidly recycles, usually due to grazing by higher organisms (Garrett, 1970), or by physical destruction (Neumann, et al, 1970).

The ancient stromatolites remained mute on the subject of their exact origin, or of the environmental parameters responsible for their existence, distribution or form, until the early 1960's when lithified stromatolitic growths of the size, shape and internal structure very similar to ancient forms were discovered in hypersaline Shark Bay on the remote west coast of Australia (Logan, 1961). Although recent work has shown that they are complex and enigmatic, the inference was then that they were modern forms in the process of formation, and thus a living analog for the ancient. Since then there have been other modern, currently accreting, lithified, stromatolitic bodies found in settings ranging from high energy to low energy supratidal to subtidal marine, as well as fresh, brackish and hypersaline water chemistries (i.e. Logan, 1961; Eggleston and Dean, 1976; Halley, 1976; Osborne, et al, 1982; Dill, et al, 1986; Cohen and Thouin, 1987; Braithwaite, et al, 1989). These include precipitated ("skeletal") forms as well as those created mostly by trapping and binding of sediment (i.e., the Shark Bay forms as well as the recently described Exuma examples of Dill, et al, 1988). The mineralogy of the precipitated forms is usually aragonite or low-Mg calcite. They can be layered (stromatolitic) or massive (thrombolitic). McNeese (1988) and Griffin (1988) have recently tabulated the properties of recent stromatolites. The few generalizations that do emerge are that the modern fresh water forms are usually fine grained, and thus possibly precipitated, while the marine forms are composed mostly of trapped and subsequently cemented sediment (Griffin and Awramik, this volume). As we might have suspected, there is no single analog to a 3.5 billion year past. Good modern candidates for the fine-grained, laminated, Pre-Cambrian and early Paleozoic precursors are still needed. The fine-grained, laminated stromatolites forming in Storrs Lake may help provide them.

The occurrence of stromatolites in Storrs Lake, San Salvador Island, Bahamas (Fig. 1) has been known for several years (J. Teeter, pers. comm.) and was first reported by Hattin (1982). Mann and Hoffman (1984) described soft, flat, algal structures at the nearshore periphery which were uncalcified and unlaminated. Cowin (1985) mentioned stromatolitic layers when he described the ostracode stratigraphy of the lake. The occurrence of large calcified heads offshore was reported to us by J. Teeter and D. Gerace (1985, pers. comm.) The occurrence and distribution of Storrs Lake stromatolites have recently been described by Mann and Nelson (in press). Pentecost (this vol.) describes small, bulbous, radially calcified heads in the shallow, nearshore periphery of Storrs Lake and associates them with *Scytonema* growth. It wasn't until 1987 when we waded out into waist-deep water, loosened a one-meter-large specimen from its crust-like base beneath the organic mud with a crowbar, and wrestled the calcified mass ashore that we realized that here indeed were large, layered, fine-grained, mushroom-shaped stromatolites that appeared to be good candidates for Pre-Cambrian and early Phanerozoic counterparts.

McNeese (1988) described the calcified elements of the crusts, bulbous upgrowths and stromatolitic heads of Storr's Lake as part of a Master of Science thesis. Work is continuing on the Holocene history of lake deposition, the isotopic geochemistry of the hypersaline system as well as the production, metabolism and calcification of the cyanobacteria associated with the stromatolite and crust formation. Reported here are the occurrence and description of the stromatolitic structures found within the lake and some properties of the cyanobacterial mats associated with them.

STORRS LAKE

Late Holocene sea level rise resulted in the interior flooding of an enclosed, karstified, Pleis-

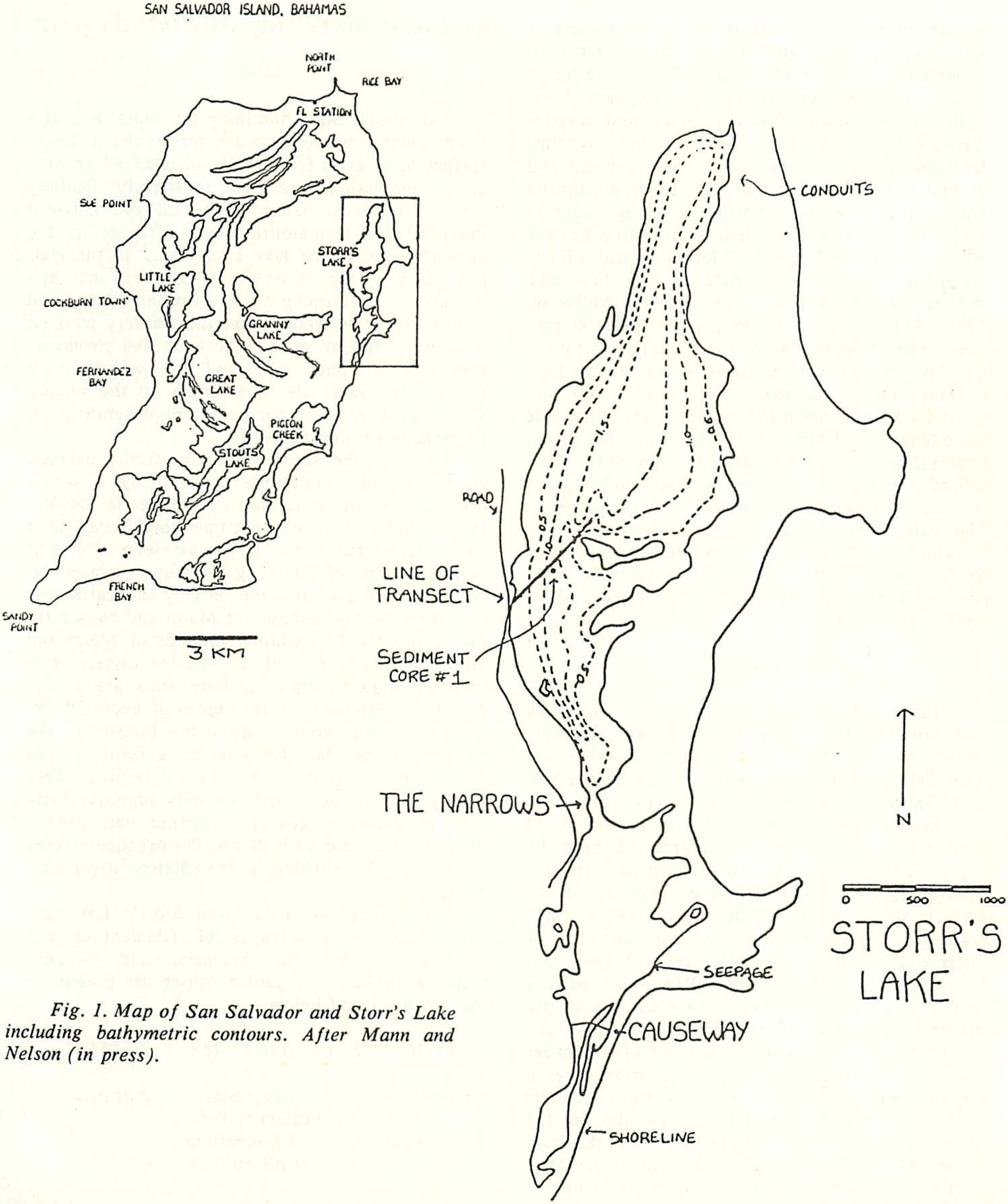


Fig. 1. Map of San Salvador and Storr's Lake including bathymetric contours. After Mann and Nelson (in press).

tocene, interdune depression on the east coast of San Salvador Island and created Storrs Lake (Fig. 2) which is now 7.3 km long, 1.4 km wide and 1 to 2 m deep. Mangroves rim the periphery. Conduits in the eastern bedrock ridge and seepage through Holocene sand afford limited exchange with the ocean. Evaporation exceeds rainfall and ground water influx so that the observed salinities within the lake are elevated. Average rainfall varies from lows of less than 2" in March to over 10" in October (Bahamas Meteorological office, compiled data). Limited data suggest that lake salinity varies inversely with rainfall (McNeese, 1988). March-April maximums of over 100 ppt. have been recorded. West season minimum salinities have not been determined. A six month, Dec. to May, record fluctuates from 70 to 100 ppt. around a 85 ppt. mean (McNeese, 1988). Ostracode assemblages indicate that the lake has been hypersaline since its formation with only local, sporadic incursions of open marine conditions in the area called, "The Narrows" (Corwin, 1985). The water color in the lake varies from brown to brownish green and has been reported by locals to "go white" on occasions (D. Gerace, pers. comm.). Turbidity measured by secchi disc in Dec. 1987 was only 46 cm.

SEDIMENTS

Lake floor sediments are up to 2 m thick and are covered by a thick, tough, leathery, microbial mat which becomes less cohesive and more flocculent as water depth increases to 1.5 to 2 m. The upper 10 cm. of mat-bound sediment is an organic-rich carbonate which is 44 to 74 percent organic matter as determined both by digestion of organics and dissolution of carbonate (McNeese, 1988). The carbonate fraction of the surface sediment is mostly very fine to fine-grained, sand-sized, sub-spherical particles of micritic Mg-calcite averaging 10 mole per cent Mg (McNeese, 1988). The XRD peaks of the sediment Mg-calcite from individual layers are sharper than those of the calcified heads, suggesting that the heads are composed of a broader spectrum of Mg-calcite phases deposited over a greater time span. There are only trace amounts of forams and disarticulated ostracodes in the surface sediment. The inference is that the bulk of the mat-bound, disseminated, sedimentary Mg-calcite is nondetrital and precipitated somehow within or beneath the cyanobacterial mat.

MICROBIAL MATS AND ASSOCIATED CRUSTS

Mats

Microbial mats dominate the biota of Storrs Lake. Their consistency characterizes the sediment surface and varies from thick, uncalcified gelatinous accumulations nearshore to cohesive leathery mats with disseminated calcite on and between the lithified, stromatolitic heads offshore. In the deepest parts of the lake at 1.5 to 2 m the mats lose their strong cohesiveness and are not apparent by macroscopic observation. Mann and Nelson (in press) report that the leathery mats on the soft sediment surface between the stromatolites can at times withstand the weight of a person. The mats are dark green on the surface with a pink zone of anaerobic, photosynthesizing bacteria a few mm beneath.

Nearest the shore is a periodically exposed gelatinous mat sometimes covered by a white, organic crust of desiccated cyanobacteria. Beyond this the subaqueous mat becomes thick, coagulated and characterized by large diameter (20 cm) hemispheroids of clear, gelatinous, extracellular ectoplasm. These are the largely noncalcareous "thrombolitic pie mounds" of Mann and Nelson (in press) and the *Phormidium* mounds of Mann and Hoffman (1984) as well. Except for disseminated carbonate grains, these inshore mats are uncalcified and extend to water depths of about 30 cm. The gelatinous mounds are often buoyed to the surface during the afternoon as a result of gas accumulation within them. The gas is presumably mostly but not necessarily entirely photosynthetically produced oxygen. The organic mats quickly become anaerobic with depth. Disturbance effuses hydrogen sulfide which is immediately obvious by smell.

All described mats from Storr's Lake are very complex assemblages of filamentous and coccoid cyanobacteria, bacteria, and diatoms. Some of the micro-organism which are present in the mat are listed below:

CYANOBACTERIA	*BACTERIA*	*DIATOM*
Phormidium	*Beggiatoa* (colorless sulfur)	*Navicula*
Microcoleus	*Chromatium* (purple sulfur)	
Calothrix		
Spirulina		
Scytonema		

Figure 2

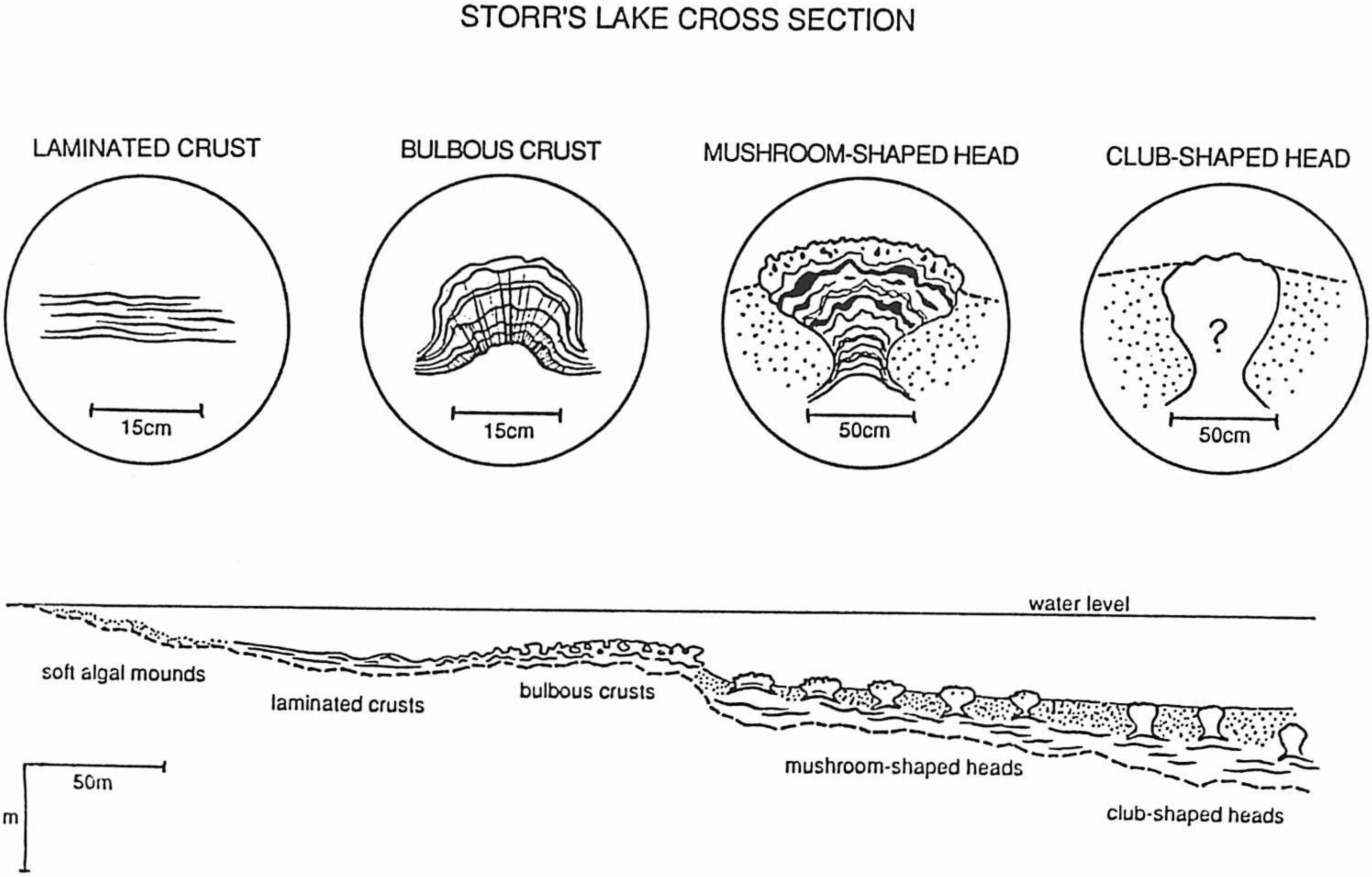


Figure 3

Crusts

Proceeding offshore, the onset of intensive calcification within and beneath the mats is obvious by the feel of the mats underfoot. Laminated, calcified crusts begin to appear within 50 m from shore in water depths that were about 20 cm at the time of observation in Dec., a particularly wet time. All depths are approximate and will vary with seasons. Mann and Nelson (in press) report seasonal variations of 16 cm in water level and infer that changes of up to 26 cm are possible. Near shore the crusts are horizontal, friable and foliate, but 150 to 200 m from shore in water depths of only 30 to 50 cm the laminated crusts begin to swell into locally mounded masses of 2 to 5 cm relief. These grow thicker and more calcified and coalesce into an anastomosing flattened surface of friable, bulbous crusts and heads. Head level stays at or near 10 cm water depth. An extensive terrace that can bear the weight of passers by is formed by the coalesced heads. This is the "hard calcareous table" of Mann and Nelson (in press). It is within this zone that low relief (10 cm), surficially blackened heads of radiating calcified elements occur. Pentecost (this vol.) has identified these radial calcified elements as those associated with the cyanobacterium, *Scytonema*. The surface mat here is also bright green with a deep pink zone a few millimeters beneath.

At about 250 m from shore along the study transect the terrace formed by the coalesced bulbous crusts and heads suddenly becomes more open and individual heads appear beyond a distinct drop off created by the sudden termination of the bulbous crust bench. Figure 3 is an offshore transect that depicts the distribution and general character of the calcified stromatolitic elements of the lake. Lakewide reconnaissance carried out in March 1989 confirms the general offshore distribution which characterizes the study transect.

Mat Chemistry

Oxygen microelectrode profiles were made on two of the inshore mats; (1) the innermost mat with the clear, ectoplasm hemispheroids, and (2) the next adjacent offshore mat which overlies the calcareous bulbous crusts that construct the inshore bench. A third, offshore mat was also profiled. This is the "leathery" mat that extends lakeward from the end of the bulbous crust shelf and is found on and between the calcified stromatolitic heads (Fig. 3).

Where the mat extends over the upper surface of the heads, it is broken only by centimeter-size, white, densely calcified nodes which grow upward as small pinnacles and ridges from the surface of the stromatolite head. Microelectrode profiles of dissolved oxygen made on the three mat types are shown in figure 4. Profiles made in the afternoon, when photosynthesis has been active for some time, show remarkably high oxygen concentrations in the upper 5 to 10 mm of the mats. The most extreme case is the four fold increase of oxygen above atmospheric concentration in the leathery mat. This is the same mat abutting and covering the offshore calcified heads. The oxygen concentration peaks at 400 percent of saturation at only 5 mm into the mat whereupon it rapidly goes to 0 and the mat becomes completely anaerobic. Post-respiration intervals reveal the reverse. They show no oxygen maxima, just a rapid decrease from saturation to anaerobiosis.

Daytime pH profiles were obtained by a standard combination electrode (Markson 985B) mounted on a micromanipulator which incrementally penetrated the mats (Fig. 5). "Stromatolite mat" refers to a mat in the "leathery mat" zone of the large heads that is actually on top of and covers the calcified stromatolitic head. The "leathery mat" is the cohesive mat between the heads. In both cases the pH rises to values over 9 coincident with the oxygen maxima at 5 mm depth in the mat.

The extreme oxygen maxima over such short mat intervals reveals high levels of photosynthetic activity with the subsequent uptake of comparable concentrations of CO_2. This loss of carbon dioxide produces high pH levels during the day and should achieve the reverse at night. The suggestion is that the intensely photosynthesizing mats create the potential to precipitate calcium carbonate in daylight and dissolve it at night. The crusts and heads then may only reflect a small net accumulation of an alternating process that fluxes large concentrations of calcium carbonate into and out of the system as a result of the photosynthetic process alone. This process may in turn be superimposed upon an overall seasonal effect, so that net accretion may be contained within seasonal brackets in water chemistry parameters. That statement must remain as vague as it is until the lake is "lived with" long enough to understand its seasonal chemistry and the response of the mats

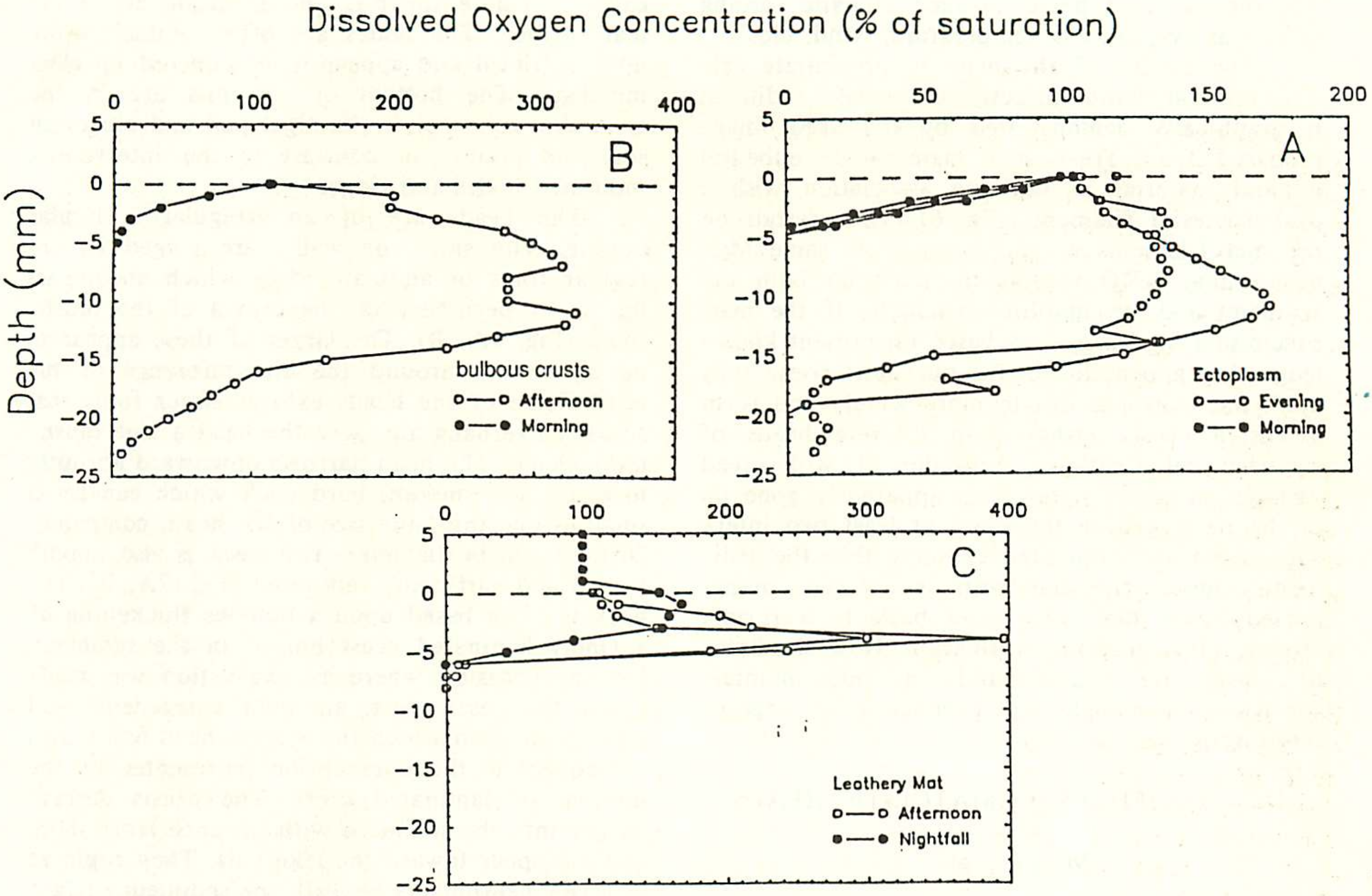


Fig. 4. Dissolved oxygen concentrations within three microbial communities at Storr's Lake, measured with oxygen microelectrodes. Diel variability in the oxygen concentration can be seen.

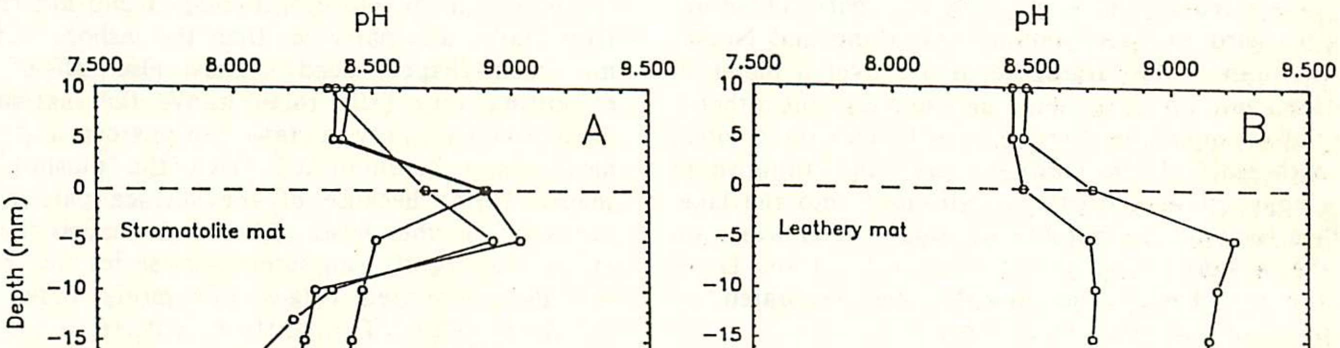


Fig. 5. Profiles of pH within the stromatolitic and leathery mat communities at Storr's Lake. Replicate profiles are plotted on the same axes.

and the calcified heads to such climatic forcing effects as evaporation, temperature, wind, etc.

The ability of the mats to precipitate calcitic mineral matter directly to the lake sediment is graphically demonstrated by the SEM image prepared from fresh mat material of euhedral mineral material in intimate association with a cyanobacterial filament (Fig. 6). The crystals on the mat filaments are apparently the same Mg-calcite that XRD reveals to make up both the sediment and stromatolite carbonate. If the mats precipitate Mg-calcite, as based on present knowledge they appear to do, the question arises, "why don't the mats precipitate more widely and form extensive crusts rather than discrete heads of localized calcification?" Episodes of widespread surficial crust formation has apparently gone on in the past because there are at least two intervals of buried, laminated crusts within the sediment column. The shallowest crust locally drapes buried heads that must date back to a former episode of stromatolite formation. How stromatolitic heads are initiated and why they maintain specific morphologies is a concern of ongoing interdisciplinary research.

THE CALCIFIED STROMATOLITIC HEADS

Morphology

Beginning in water depths of 60 to 80 cm discrete, lithified, stromatolitic heads are encountered along the study transect beyond the shelf of bulbous crust (Figs. 7A, B). The heads are spaced two to several meters apart. These are the "hard pinnacle mounds" of Mann and Nelson (in press). The largest heads are over a meter in diameter, up to a meter tall, and exhibit either a club or mushroom shape. Heads are found along both ends of the study transect and diminish in frequency with depth and distance into the lake. The belt of stromatolite development is wider on the western or landward side of the lake. There are two basic head morphologies separated by depth and distance from shore.

The inshore heads are larger, more spread out at the top and exhibit more relief above the sediment surface (about 10 cm) than the heads found in water deeper than one meter (Fig. 3). The inshore heads hereafter referred to as "mushroom-shaped heads," have flat tops indented by many pits 5 to 10 cm deep. The green leathery mat extends onto the head surface and covers the pits. Pinnacles (nodes) and sharp walls of dense calcite separate the pits and protrude above the mat surface. The nodes are often pinkish white upon retrieval and appear to be covered by clear mucilage. The bottom of the pits are in the anaerobic zone below the algal mat and are often soft and friable in contrast to the intervening indurated nodes and ridges.

The heads are of an irregularly circular outline. The sides, or walls, are ringed by irregular folds or annular ridges which encompass the lower periphery of the crown of the mushroom (Fig. 7A, B). The larger of these appear to be continuous around the circumference of the head. Some of the heads exhibit larger folds that actually overhang and give the head a true mushroom shape. The head narrows downward abruptly to a distinct, smooth, hard neck which can be as small as one third the size of the head, commonly 20 to 30 cm in diameter. This neck is also smooth walled and surficially indurated (Fig. 7A, B). The neck is often based upon a bulbous thickening of a finely laminated crust buried in the sediment. On one occasion where an excavation was made below the basal crust, an older antecedent head was found upon which the surface head had frown subsequent to the interruption represented by the interval of laminated crust. The crusts descent deeper into the sediment with distance from shore and disappear toward the lake axis. They begin at or a few centimeters beneath the sediment surface at the lakeward terminus of the bulbous crust terrace and descent to depths of 30 to 40 cm beneath the sediment surface.

The offshore heads, beginning at depths of 1.2 to 1.5 m are more club-shaped and are relatively taller and narrower than the inshore wider, mushroom-shaped heads. They also differ by exhibiting very little relief above the mat/sediment surface, only a few centimeters and are most easily distinguished from the mushroom-shaped forms because of the surface pattern of the top of the head. The club-shaped heads exhibit a tightly anastomosing series of low, rounded, indurated ridges and rarely show the elevated nodes. The surface pattern is more crenelated and reminiscent of a tightly convoluted brain (Fig. 8).

A cross section of one of the smaller, whole, mushroom-shaped heads was prepared by vacuum embedding the head in resin and sectioning it (Fig. 9). The internal structure is characterized by laminar horizontal and massive vertical elements which are cut by large voids. The voids appear to be empty (water filled) except for scant geopetal

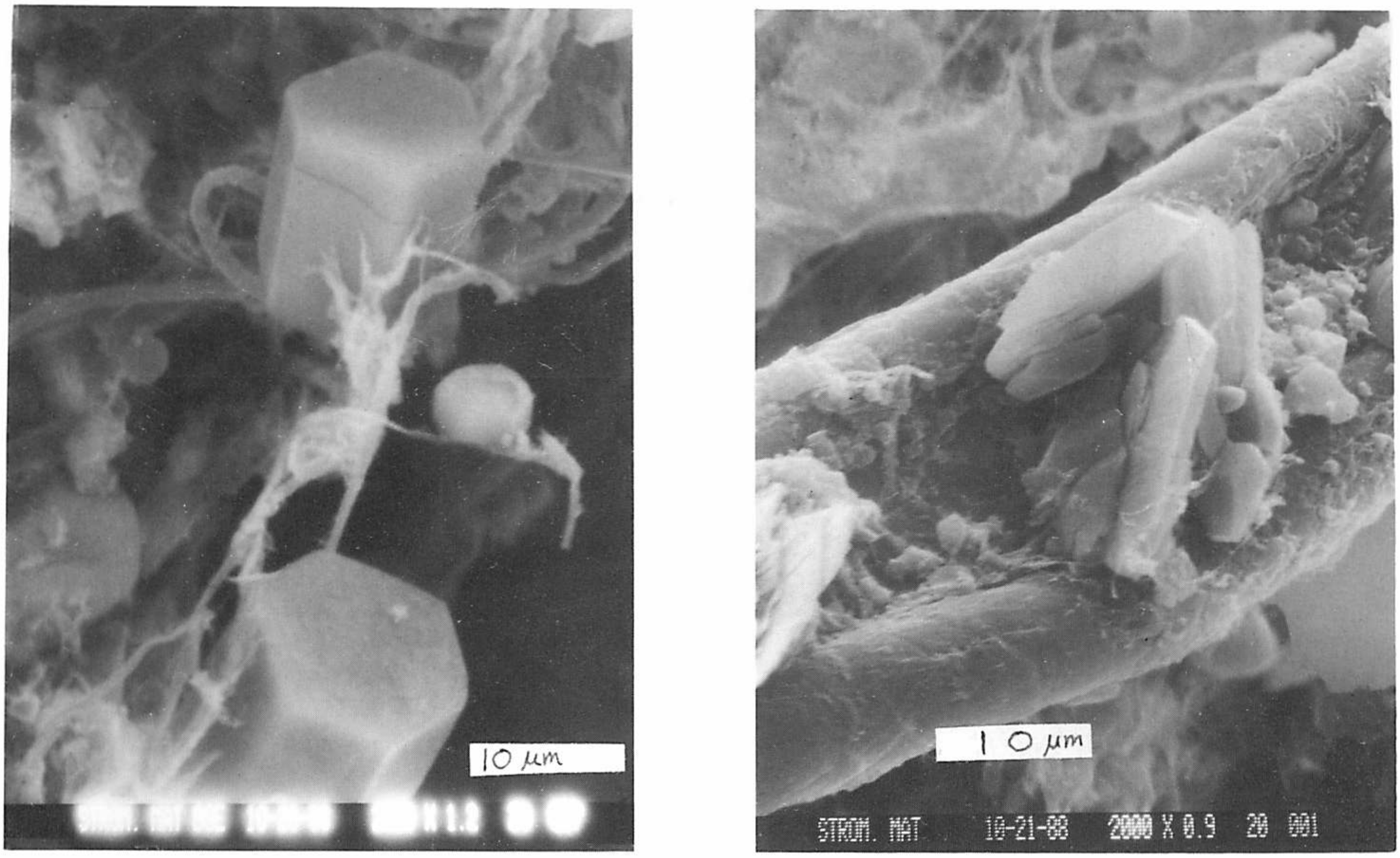


Fig. 6. Scanning electron micrographs of two examples of crystal formation in close association with cyanobacteria from a stromatolitic head.

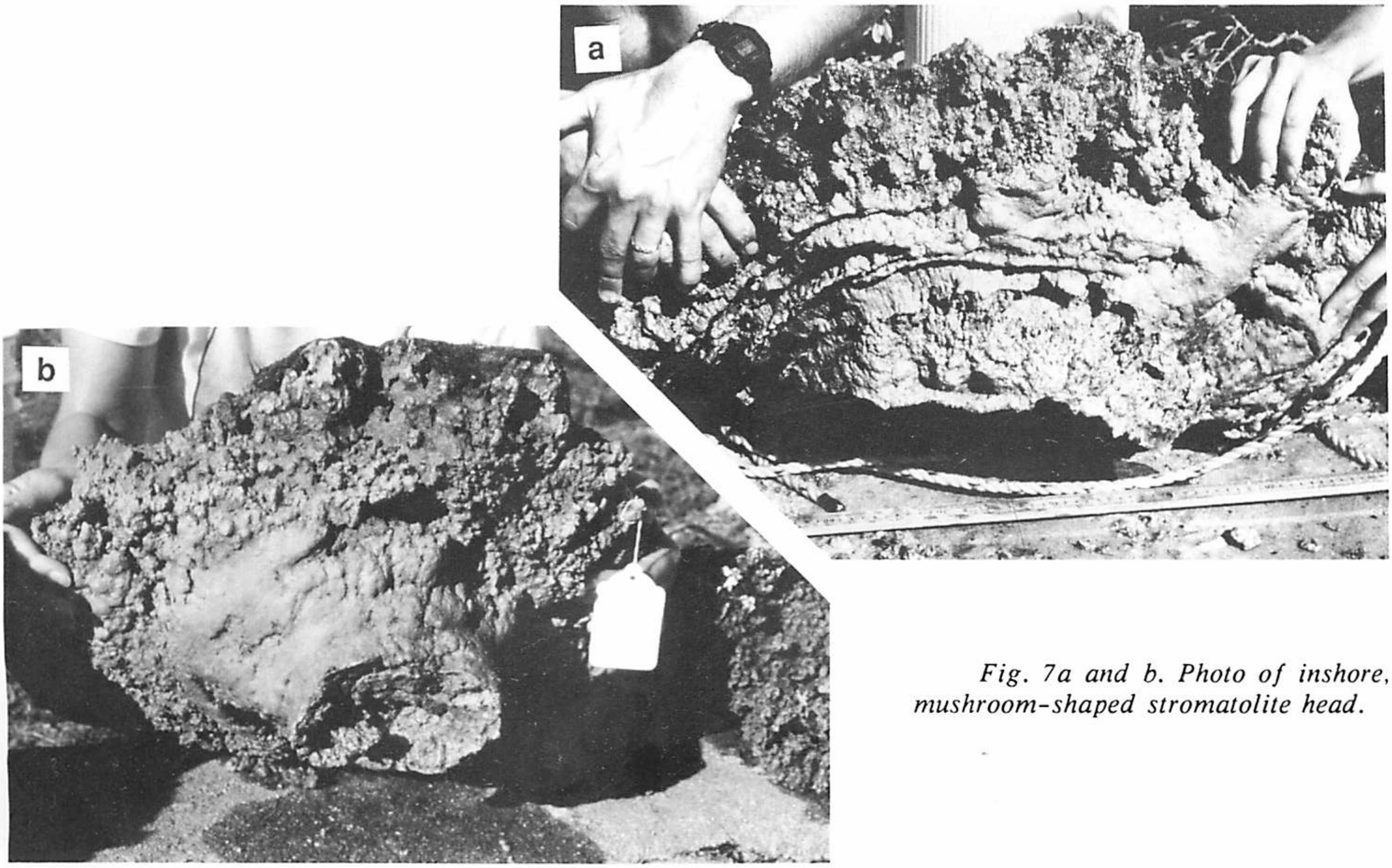


Fig. 7a and b. Photo of inshore, mushroom-shaped stromatolite head.

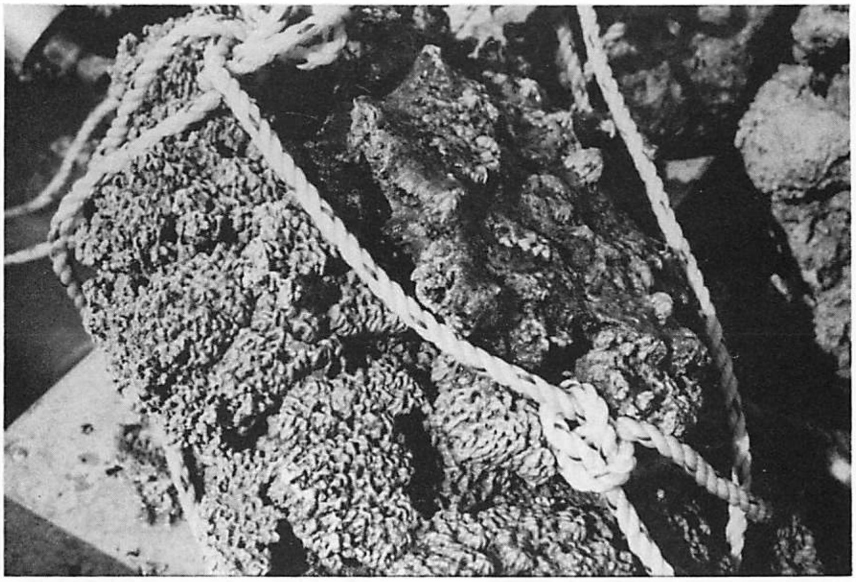


Fig. 8a. Surface pattern and overlying mat of offshore club-shaped stromatolite head.

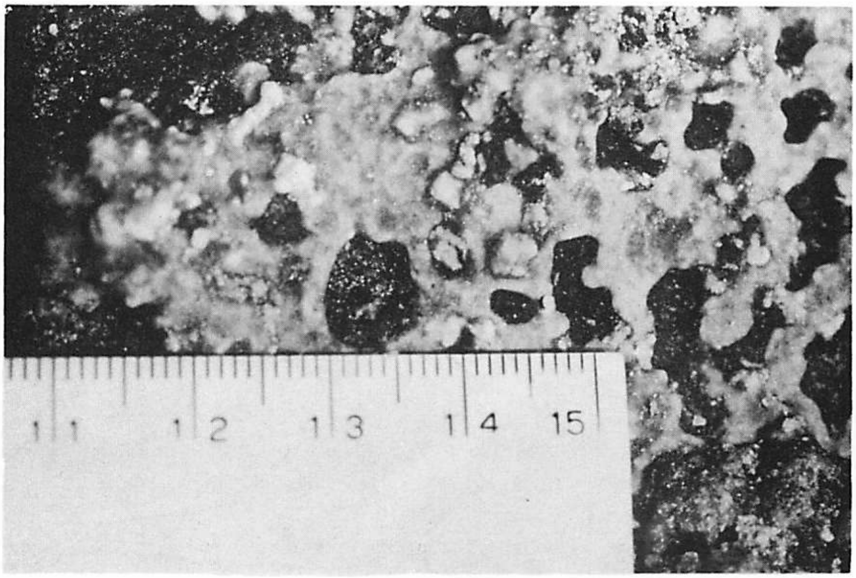


Fig. 8b. Detail of surface carbonate crust forming on top of club-shaped head and appearing to coalesce to form a thin lamina between the nodes on top of the mat. (1.25X)

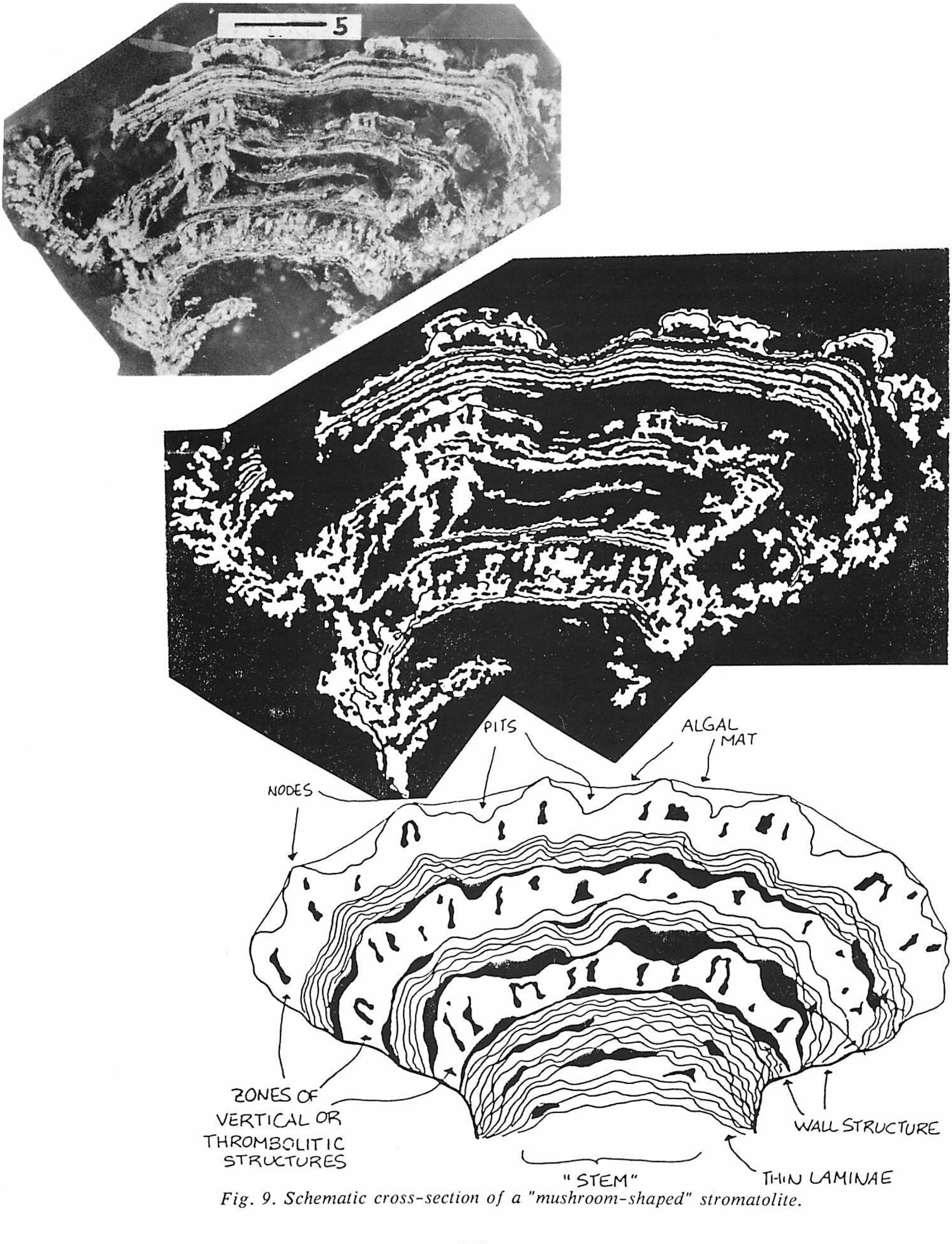


Fig. 9. Schematic cross-section of a "mushroom-shaped" stromatolite.

infill of internal organic and carbonate debris at the base. Repeating sequences of thin continuous laminae (0.5 to 2 mm thick) are broken only vertical, finger like, roughly radiating masses that are truncated below the present surface by a laminated interval. The nodes on the surface appear to be a new generation of re-established radial finger. The nodes and radial fingers appear to be macroscopically massive relative to the fine laminar crusts. They could be considered as "thrombolitic" elements within an overall stromatolitic structure except that microscopically they are made up of discontinuous laminar elements. Some intervals are dominated by these dense, irregularly radial, macroscopically massive, calcified structures while others are obviously, thinly laminated and friable. An interior wall on the right side appears to have been occluded by later lateral growth. The outwardly smooth walls of the neck and sides of the head are built up of thin (1 mm), discontinuous, crenelated laminae (Fig. 10B).

Mineralogy and Petrography

Mineralogical analysis of 31 samples of calcified components of the heads by XRD (walls, nodes, laminae) reveals a spectrum of Mg-calcites ranging from 12 to 17 mole percent. No aragonite or lo-Mg calcite was detected.

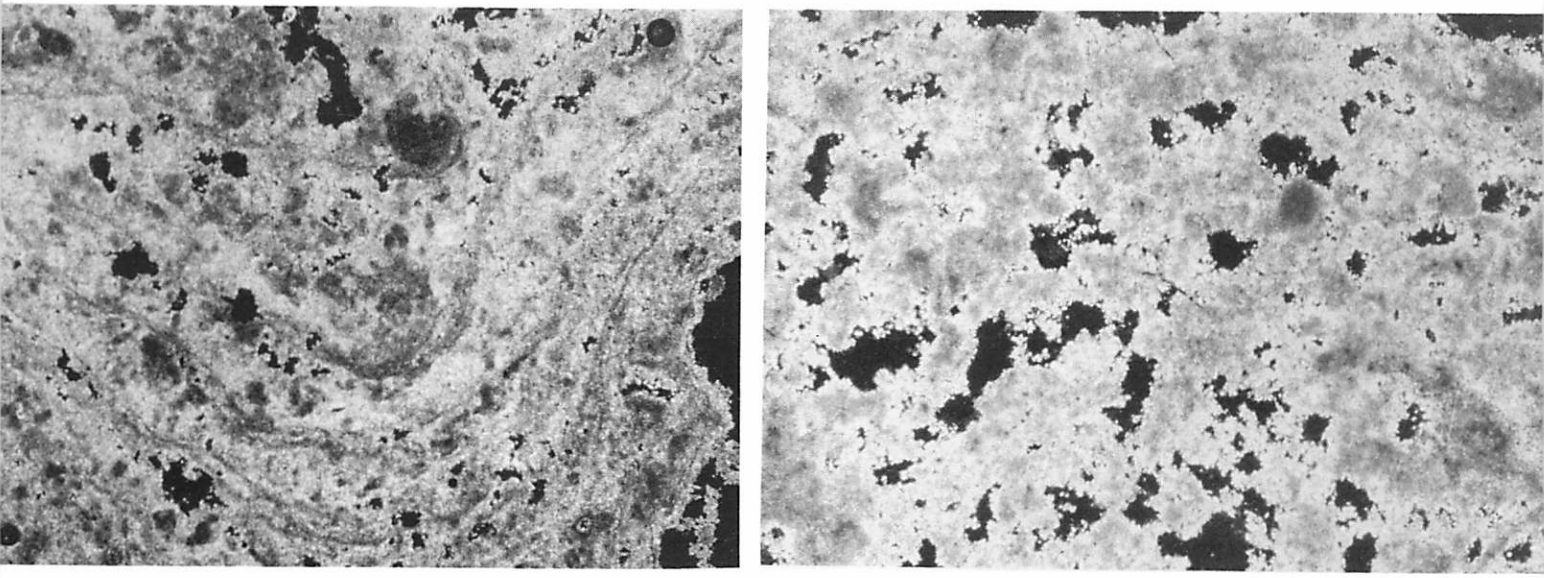
Petrographic analysis of embedded thin sections was performed on the various components of the lithified crusts and heads. The following forms of Mg-calcite were identified, and their frequency of occurrence estimated by 100 point counts (McNeese, 1988).

Spar/Microspar (5-20 microns)	
blunt needles or flattened spheres - crudely radiating, or random, "rice-shaped" needles	19%
Calcite microspar - lining and/or filling pore space	8%
bladed/platy crystal clusters - intergrown, variable, blunt-edged shapes	11%
rhombohedral crystals	trace
Micrite (<5 microns)	
peloidal-clusters and larger, indistinct, spherical masses	21%
clotted - dark colored, irregular patches	27%
Skeletal - includes foraminifera, ostracod, and gastropod	trace
Pore space	14%

The head interiors are characterized by a large amount of void space, almost no skeletal detrital components, and the bulk of the material is made up of several forms of micrite or microspar. Micrite occurs as clotted fabric, peloidal clusters and indistinct subcircular masses. Its color and opacity suggest that it is not only fine grained but also contains organic material, whereas the spar and microspar exhibit more clarity and crystalline form. The cloudy, dark micrite may be an early, rapid and original precipitate while the spar and microspar are remobilization products of multiphase dissolution and redeposition by internal crystal growth, i.e. cements. Dark cross cutting surfaces suggest organic concentrations at surfaces of dissolution akin to micro-disconformities.

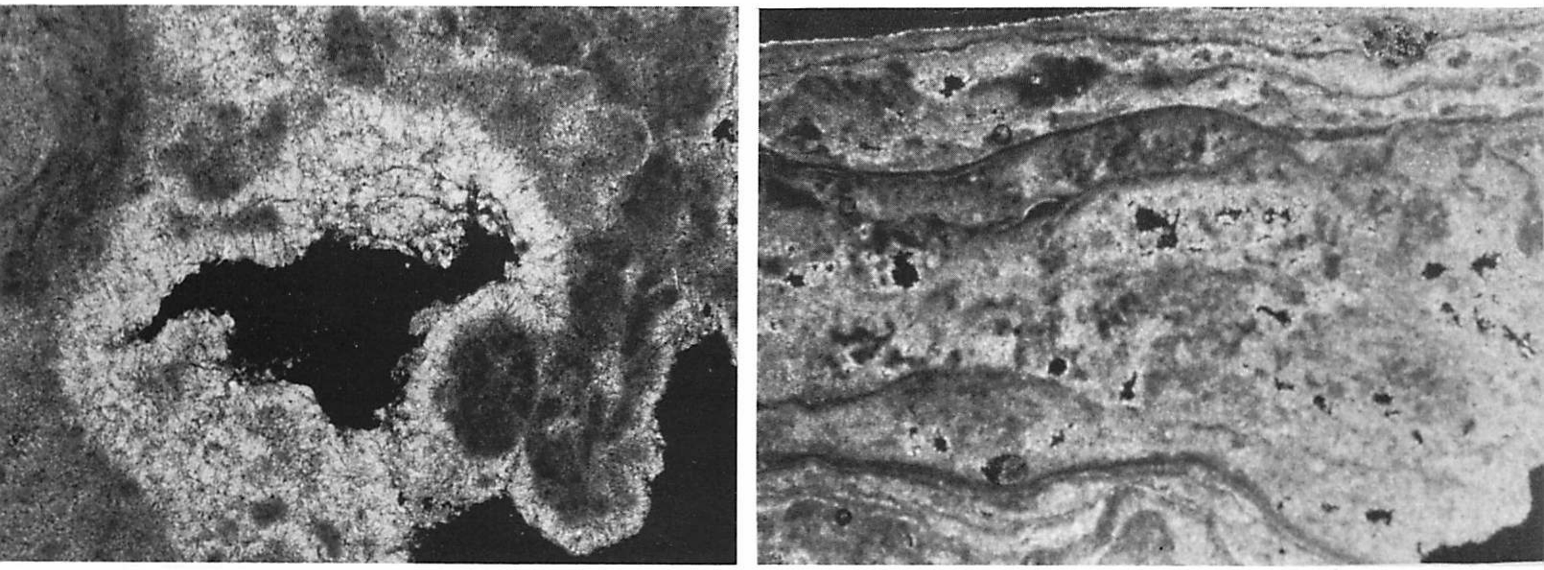
The thin sections and the micro-oxygen/pH profiles both suggest that photosynthetically driven, mat-mediated, micro-environments are subject to short intervals alternately favoring precipitation and then dissolution. This might provide an explanation of net accretion at the photosynthetically active, mat-covered stromatolite head, but it doesn't explain how the head-like forms are produced nor what modifications might follow in the anaerobic interior of the heads.

The surficial nodes in thin section (Fig. 10 A) are not massive but are thinly and discontinuously laminated with upwardly fining elements that also suggest rapid surficial precipitation followed by a slower, coarser, more crystalline infill and/or reorganization below. The outermost layers of the nodes are the thickest and least laminated peloidal and clotted micrite (Fig. 10 B, C). The nodes then appear to be sites of episodic accretion and perhaps dissolution as well. The smooth outer wall of the neck at the base of the stromatolite reveals crenulate, discontinuous laminae in thin section (Fig. 10 D). The downward



(a) Node with laminae.

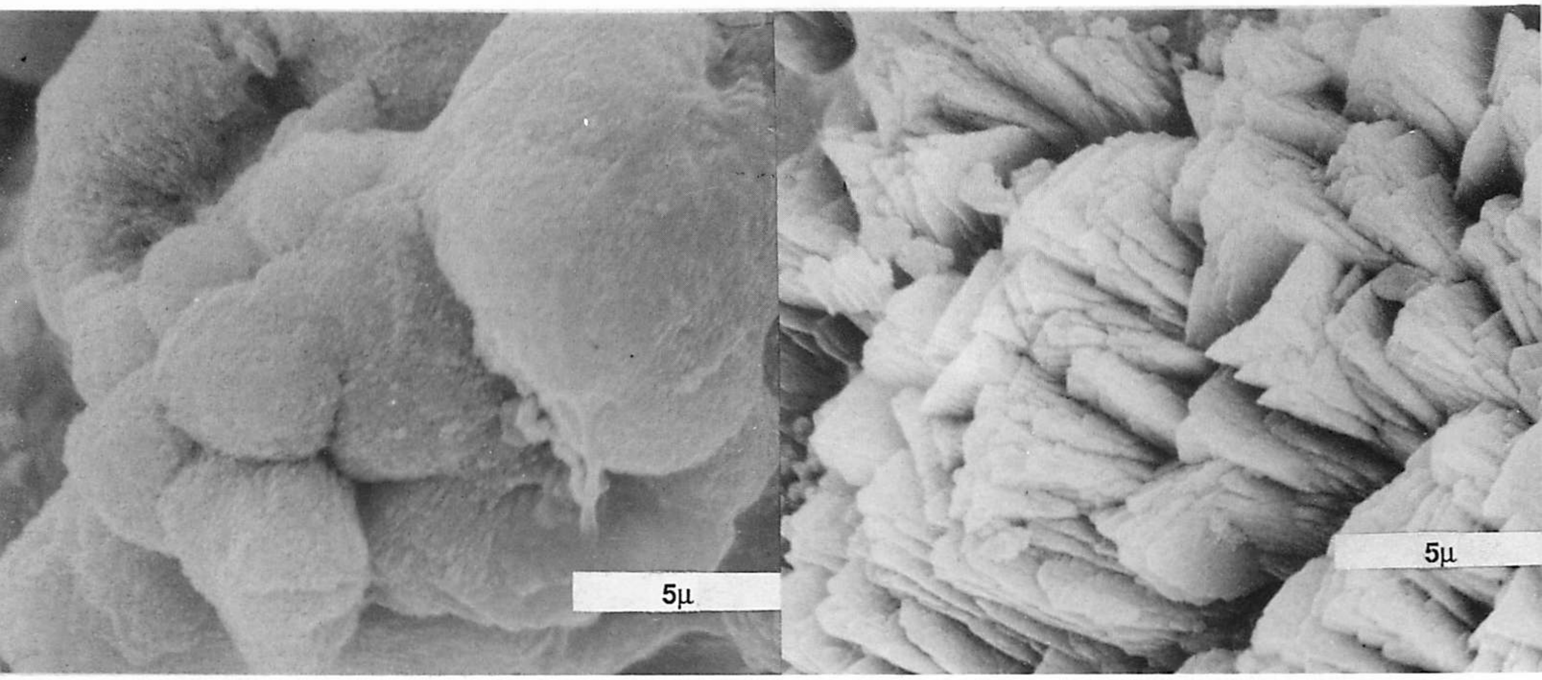
(b) Peloidal and clotted micrite rimmed with microspar.



(c) Microspar lined cavity in clotted and peloidal micrite.

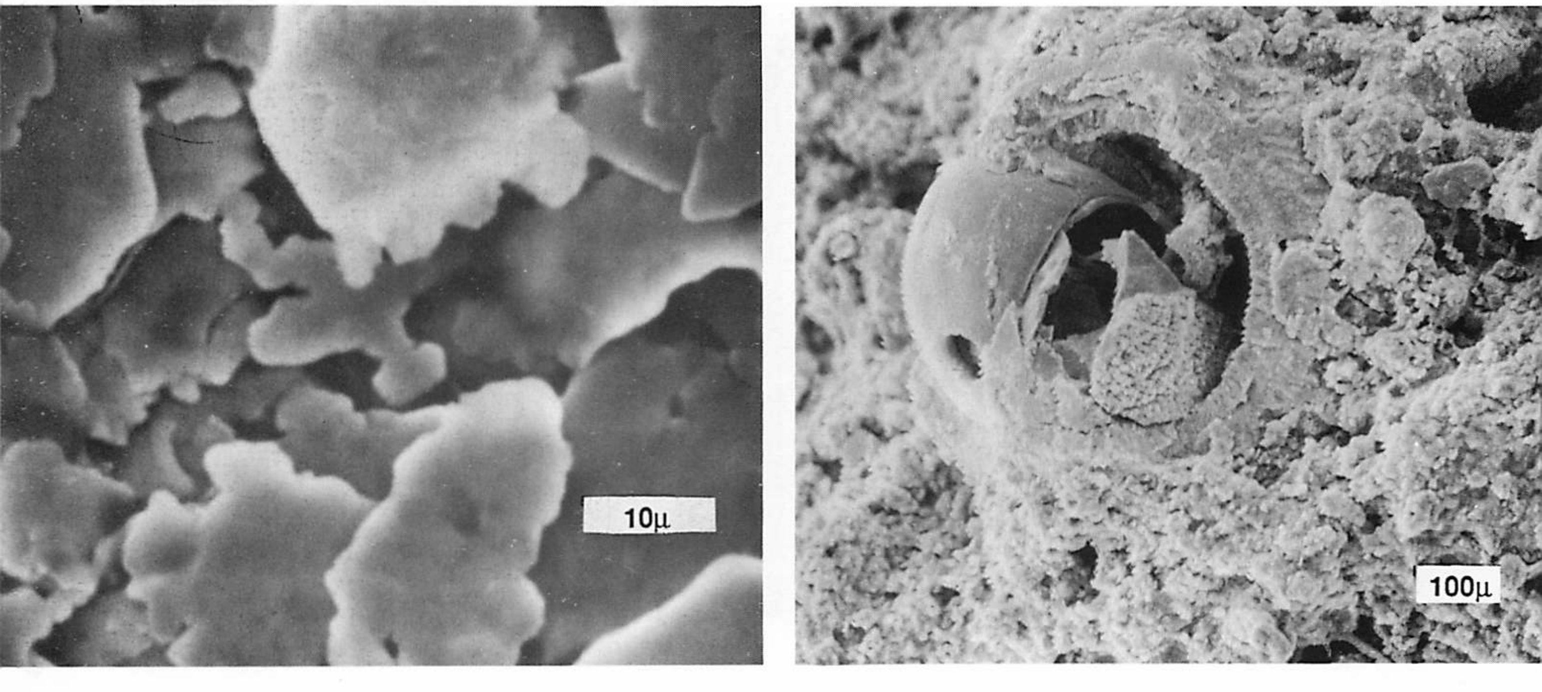
(d) Crenulated laminae on wall of stromatolitic neck.

Fig. 10. Thin section view of stromatolite head. Scale; longitudinal field of view is: (a) 3.5mm (b) 3.5mm (c) 1.4mm (d) 3.5mm.



(a) Spherical clusters.

(b) Bladed crystals.



(c) "Jigsaw" fabric from laminae.

(d) Skeletal fragment, gastropod.

Fig. 11. SEM photos of stromatolite heads.

progression from peloidal and clotted micrite to microspar is even more distinct here than in the nodes on the head surface.

One limited but interesting observation provides a clue for one possible process of formation of the fine laminae seen in the heads. Figure 8B is a macroscopic view of the surface of a small mushroom-shaped head. Thin calcareous crusts are apparently overgrowing and coalescing on top of the algal mat that fills the larger pits. This will result in thin "ice-like" overgrowth that will join to form a continuous lamination which will abut the intervening nodes. Calcareous accretion then appears to occur both on and extending between the nodes and ridges of the stromatolite head surface.

Scanning Electron Microscopy

Some of the various forms of Mg-calcite observed by SEM are:

1. spherical clusters (Fig. 11 A),
2. stacks of sharp or blunt, bladed crystals (Fig. 11 B),
3. stacks of "jigsaw" crystals-irregularly shaped, individual flakes (Fig. 11 C), and
4. skeletal - gastropod, foraminifera (Fig. 11 D).

The preliminary interpretation of the SEM views is that the calcareous elements of the heads are dominated by a very patchy distribution of euhedral, sharp-bladed, crystal clusters as well as very finely crystalline spherical structures and also finely laminated plate-like structures. Partially dissolved counterparts of each of these fabrics are also common.

The SEM views supports the contention, drawn from both the microelectrode data and the thin sections, that the mineralized elements of the stromatolitic heads are Mg-calcite that appears to be undergoing alternate phases of fine-grained precipitation followed by phases of partial dissolution, and then subsequent regrowth of void-filling microspar cements. This is not at all incompatible with a system that is undergoing daily fluctuations due to photosynthetic processes. it does raise questions, however, of what limits or controls this mineral growth, and how fast is its net accumulation, and how is the characteristic mushroom- or club-shape achieved?

Radiocarbon Measurements

The radiocarbon values (from Beta Analytic, Coral Gables, FL) are given in Table 1. Radiocarbon measurements of the organic carbon as well as the carbonate (mineral) carbon contained in surface layers of a mushroom-shaped stromatolite (S3-4) both contained "modern" values and thus suggest recent mineralization. Values of nearly two thousand years, however, are obtained from the other three samples, one from the bulbous crusts closer to shore, one from a buried stromatolite encrusting fossil wood (mangrove?), and the third from the encrusted wood itself. Due to the "hardwater effect", radiocarbon measurements may tell more of the flux of ground water, and thus "dead" carbonate carbon, than of the true temporal age of the precipitated materials. The modern dates, on the other hand, indicate

Radiocarbon Measurements

The radiocarbon values (from Beta Analytic, Coral Cables, FL) are given below:

Lab. No.	Sample Description	C-14 Age	$\delta^{13}C$	^{13}C adj.age
Beta-26843	SSLM-1: Bulbous, Mg-calcite crust, ~100m from shore, 50 cm. water depth	1440±70BP	-1.7°/oo	1830±70BP
Beta-26844	SSLM-2: Wood (root) from SSLM-3	2360±70BP	-23.9°/oo	2380±70BP
Beta-26895	SSLM-3: Encrusting Mg-calcite stromatolite buried 30cm below sed. surface in club-shaped head zone, ~500m from shore in 1.2m depth	2310±70BP	-0.7°/oo	2710±70BP
Beta-28725 Beta-28726	S 3-4 surficial mat (organic) and underlying carbonate crust (inorganic) from upper surface of mushroom-shaped Stromatolite head 300 m from shore. Depth to top of head about 1 m.		-19.2°/oo -0.8°/oo	105.6±1%BP 107.7±1%BP (modern)

TABLE 1

that some precipitation is independent of the hard water effect. Either the flux of dead carbon into the lake is not constant and/or the formation of the stromatolites is episodic over periods of thousands of years. The fresh appearance of crystal *faces on* stromatolite surfaces refutes long periods of quiescence as does the intimate association of mat, head surface and calcified nodes. The isotope problem begs an answer and calls for a more rigorous program of sampling and measurements. Our exploratory values suggest a deeper complexity that may be due to wide seasonal variation, fractionation and/or recent diagenetic reorganization, or to yet unknown factors. It is apparent that the next chapter of our research should concentrate upon the isotopic character of the water, the organisms, the stromatolitic heads and crusts, as well as the sediments. Perhaps the cycling between these various pools will become assessable so that ages can be calculated.

At this point it is exciting to consider that we appear to have in Storrs Lake a calcifying microcosm of what may well have occurred over much of the earth over most of the geologic past. We have only scratched the surface and look forward to these curious stromatolites to shed more light on the dark past; a past they share with the earliest of living things.

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BIBLIOGRAPHY

Aitken, J.D., 1967, Classification and environmental significance of cryptalgal limestones and dolomites with illustrations from the Cambrian and Ordivician of southwestern Alberta: Jour. of Sed. Petrology, vol. 37, no. 4, p. 1163-1178.

Awramik, S.M., 1984, Ancient stromatolites and microbial mats: in Cohen, Castenholz, Halvorson (eds.) Microbial Mats: Stromatolites.

Braithwaite, C.J.R., Casanova, J., Frevert, T., and Whitton, B.A., 1989, Recent stromatolites in landlocked pools on Aldabra, western Indian Ocean: Palaeogr., Palaeocl., Palaeoecol., vol. 69, p. 145-165.

Burne, R.V., and Moore, L.S., 1987, Microbialites: organosedimentary deposits of benthic microbial communities. Palaios, vol. 2, p. 241-254.

Cohen, A.S. and Thouin, C., 1987, Nearshore carbonate deposits in Lake Tanganyika: Geology, vol. 15, p. 414-418.

Corwin, B.N., 1985, Paleoenvironments, using Holocene Ostracoda, in Storr's Lake, San Salvador, Bahamas: Masters Thesis, Dept. of Geology, University of Akron.

Dill, R.F., Shinn, E.A., Jones, A.T., Kelly, K., and Steinen, R.P., 1986, Giant subtidal stromatolites forming in normal salinity water: Nature, vol. 234, p. 55-58.

Eggleston, J.R. and Dean, W.E., 1976, Freshwater stromatolitic bioherms in Green Lake, New York: in Walter, M.R. (ed.) Stromatolites: Developments in Sedimentology: Elsevier, Amsterdam, Oxford, New York. p. 479-488.

Garrett, P., 1970, Phanerozoic stromatolites: Noncompetitive ecologic restriction by grazing and burrowing animals: Science, vol. 169, p. 171-173.

Griffin, Karen M., 1988, Sedimentology and Paleontology of Thrombolites and Stromatolites of the Upper Cambrian Nopal Formation and Their Modern Analog on Lee Stocking Island, Bahamas. University of California of Santa Barbara, Santa Barbara, CA, Unpublished M.S. thesis, 131 p.

Halley, R.B., 1976, Textural variations within Great Salt Lake algal mounds in Stromatolites: Developments in Sedimentology 20, M.R. Walter (ed.), Elsevier, Amsterdam, Oxford, New York, pp. 435-445.

Hattin, D.E., 1982, Holocene lithification of carbonate sediments San Salvador Island, Bahamas: Proc. First Symp. on Geology of Bahamas, San Salvador, Bahamas, Bahamian Field Station, p. 45-62.

Logan, B.W., 1961, Cryptozoan and associated stromatolites from the recent, Shark Bay, Western Australia: Jour. of Geol., vol. 69, p. 517-533.

Mann, C.J. and Hoffman, L.R., 1984, Algal mounds in Storr's Lake, San Salvador, Bahamas: Proc. 2nd Symp. on Geology of the Bahamas, CCFL Bahamian Field Station, p. 41-51.

Mann, C.J. and Nelson, W.M., (in press), Stromatolitic structures in Storr's Lakes, San Salvador Island, Bahama Islands: Palaios.

McNeese, L.R., 1988, Modern Stromatolites in Hypersaline Storrs Lake, San Salvador, Bahamas, unpublished Masters Thesis, Dept. of Geology, University of North Carolina, Chapel Hill, NC.

Monty, C.L.V., 1967, Distribution and structure of recent stromatolites algal mats, eastern Andros Island, Bahamas: Soc. Geol. Belgique Annales,v. 90, Bull. 3, p. B55-B100.

Neumann, A.C., C.D.Gebelein and T.P. Scoffin, 1970, The composition, structure and erodability of subtidal mats, Abaco, Bahamas: Jour. Sed. Petrol., 40, p. 274-297.

Neumann, A.C., J.W. Kofoed, and G.H. Keller, 1977, Lithoherms in the Straits of Florida. Geology, vol. 5, no. 1, p. 4-10.

Osborne, R.H., Licari, G.R. and Link, M.H., 1982, Modern lacustrine stromatolites, Walker Lake, Nevada: Sedimentary Geology, vol. 27.

Walter, M.R. (ed.), 1976, Stromatolites, Developments in Sedimentology 20, Elsevier, New York, 790 pp.