PROCEEDINGS
OF THE FOURTH SYMPOSIUM
ON THE GEOLOGY OF THE BAHAMAS

Editor

John E. Mylroie

Production Editor

Donald T. Gerace

Sponsored by the Bahamian Field Station

June 17 - 22, 1988

ISBN 0-935909-31-1

Printed by Don Heuer in the U.S.A.

GIANT BAHAMIAN STROMATOLITES: A MODERN ANALOG FOR WHAT?

K. M. Griffin
S. M. Awramik
Department of Geological Sciences
Preston Cloud Research Laboratory
University of California
Santa Barbara, California 93106

ABSTRACT

With the discovery of giant subtidal stromatolites in ooid shoals of the Bahamas, a new set of environmental and biological factors important for the interpretations of stromatolites became apparent. The entirely subtidal nature of the Bahamian stromatolites along with their coarse-grained sediment, laminated and somewhat disrupted internal structure, construction by an eukaryote-prokaryote community, impressive size and variable shape along with similar subtidal stromatolites from Shark Bay, Western Australia further underscores the importance of the subtidal stromatolites for the understanding of the ancient stromatolite record. When this information is coupled with other sites where stromatolites are forming (Awramik, 1984), it becomes clear that a great variety of environmental and biological factors operate during the formation of stromatolites. Before new information on Bahamian stromatolites can be used for generalizations on fossil stromatolites, one fundamental question must be addressed: To what extent are modern marine subtidal stromatolites analogs for their ancient counterparts?

Pre-Phanerozoic stromatolites are very different from the Bahamian stromatolites. These ancient stromatolites are primarily composed of fine-grained sediment (<50 um) and often have well-defined, undisrupted laminae. Ancient stromatolites also have a greater diversity of forms than is seen in modern marine stromatolites and in many cases the forms are within definable limits of variability and hence are amenable to crude taxonomic treatment. PrePhanerozoic stromatolites were much more widespread, occupying a greater variety of environments and were not restricted by metazoans as many modern examples commonly are.

In the search for ancient counterparts to the Bahamian stromatolites. Phanerozoic stromatolites are in many ways better analogs. Paleozoic stromatolites, in particular Cambrian and Ordovician stromatolites and thrombolites are the best counterparts since they commonly have laminated to unlaminated internal fabrics, similar shapes and often occur in current swept, subtidal environments reminiscent of the Bahamian stromatolites. Most of these early Phanerozoic stromatolites, however, differ from the modern counterparts because of their micritic composition.

Therefore, the giant Bahamian stromatolites, as well as the subtidal stromatolites from Shark Bay, remain modern analogs in search of an ancient counterpart. However, by studying the processes of stromatolite formation in the Bahamian examples, and by acknowledging the similarities and differences between modern and ancient stromatolites, a better understanding of the processes important in stromatolite formation will be achieved.

INTRODUCTION

This paper is a preliminary report on some of the fundamental similarities and differences of modern and ancient marine stromatolites. It is an outgrowth of a series of discussions, reference searches, field work, hand sample and thin-section analyses of pre-Phanerozoic, Cambrian and modern stromatolites. In particular, stromatolites from the Upper Cambrian Nopah Formation in eastern California, and the modern stromatolites from Shark Bay, Western Australia and Lee Stocking Island, Bahamas were studied in great detail. The main goal is to illustrate that modern marine stromatolites are an important key to a better understanding of early Paleozoic stromatolites; however, they are not directly analogous structures. The modern stromatolites are compared to two groups of ancient stromatolites: 1)Proterozoic stromatolites and, 2) Phanerozoic stromatolites and thrombolites from the Cambrian and

	Modern calcified marine stromatolites	**Pre-Phanerozoic stromatolites**	**M. Cambrian to E. Ordovician stromatolites and thrombolites**
Environmental Occurrence	-Hypersaline bay -Ooid shoals	-Intertidal, supratidal -Subtidal platforms -Lagoonal -Reefal -Lakes, hotsprings * generally very widespread	-Patch reefs associated with active peloid and ooid shoals -Lagoonal areas in the lee of active ooid shoals -Hypersaline bay -Marginal reefs of a rimmed shelf
External Morphology	-Columns -Mounds -Irregular shaped	-Columns -Branching columns -Coniform -Mounds -Irregular shaped	-Columns -Mounds -Irregular shaped
Internal Structure	-Laminated -Unlaminated	-Well to irregularly laminated	-Laminated -Clotted (unlaminated)
Composition	-Medium-grained ooid and peloidal sand	-Very fine-grained carbonate and rare chert	-Very fine-grained carbonate and very rare chert

Fig. 1. A chart comparing several characteristics of modern, pre-Phanerozoic and early Paleozoic stromatolites.

Ordovician. The stromatolite groups are compared in terms of their environmental occurrence, external morphology, internal structure and composition (see Fig. 1).

The following definitions of the words stromatolite and thrombolite are used throughout this paper. According to Awramik and Margulis' definition, a stromatolite is an "organosedimentary structure produced by sediment trapping, binding and/or precipitation as a result of the growth and metabolic activity of microorganisms, principally cyanophytes" (in Walter, 1976, pg. 1). Aitken (1967) introduced and defined the term thrombolite as a cryptalgal structure related to stromatolites but lacking lamination and characterized by a macroscopic clotted fabric.

As stated in the first paragraph, this is only a preliminary report. The data are presented in a generalized format and future work will help to refine and test some of the broad generalizations made. Basically, we believe that by making the comparison outlined in this paper and by asking the question, "to what extent are modern stromatolites <u>different</u> from ancient stromatolites?", a better understanding of ancient stromatolites will be achieved.

PRE-PHANEROZOIC STROMATOLITES

Pre-Phanerozoic stromatolites are known to have formed under a wide variety of environmental conditions. In the marine realm, intertidal (Truswell and Eriksson, 1974), subtidal platform (Bertrand-Sarfati and Moussine-Pouchkine, 1988), deep water (Hoffman, 1974), lagoonal (Walter, et al., 1988), reefal (Hoffman, 1974), as well as supratidal environments (Grotzinger, 1986) had stromatolites. Non-marine stromatolites, although less well known and apparently less common, occurred in ephemeral lakes (Hoffman, 1976) and even in thermal springs (Walter, 1972). This is not unlike their environmental distribution today; however, subtidal marine stromatolites were most dominant in the Proterozoic.

The external morphology of pre-Phanerozoic stromatolites is extremely varied. Many of the stromatolite forms, in particular those with columnar and columnar-branching morphology, are within definable limits of variability and have therefore been assigned latinized names using an artificial binomial nomenclature. Even if the binomial nomenclature of stromatolitic forms is not widely accepted as comparable to the nomenclature of animals and plants, these "taxonomic" names are useful in discussions on the diversity in pre-Phanerozoic stromatolites. An early study on the "taxonomic" diversity of pre-Phanerozoic and early Phanerozoic stromatolites (Awramik, 1971) showed the diversity of columnar pre-Phanerozoic stromatolite "taxa" to be much higher than Phanerozoic stromatolite diversity.

The internal structure and composition of most pre-Phanerozoic stromatolites is that of well-defined thin laminae (roughly 100 um thick) composed of fine-grained (<50 um) carbonate at times replaced silica. These well- defined thin laminae of pre-Phanerozoic stromatolites differ from most early Phanerozoic and modern stromatolites.

CAMBRIAN AND ORDOVICIAN STROMATOLITES AND THROMBOLITES

As with pre-Phanerozoic stromatolites, Cambrian and Ordovician stromatolites and thrombolites are known to have formed under a variety of environmental conditions. They are often described as having formed in high energy environments such as patch reefs associated with active peloid and ooid shoals (Kennard, 1981; Moshier, 1986; Rees, 1986; and Griffin, 1988), and as marginal reefs on a rimmed shelf (Demicco, 1985). Thrombolites and stromatolites have also been described as forming in intertidal to very shallow subtidal waters (Sepkoski, 1977) and in the lagoonal areas behind active ooid shoals (Owen, 1973). Generally these Upper Cambrian and Lower Ordovician microbial structures were very widespread in terms of their paleoenvironmental and geographic distribution much like the pre--Phanerozoic stromatolites, however, at reduced numbers of occurrences.

The external morphology of early Paleozoic stromatolites and thrombolites does not show the diversity of form seen in pre-Phanerozoic stromatolites. Proterozoic stromatolites range in shape from domical to columnar, with columnar-branching and conical stromatolites being abundant and distinctive. The Cambrian and Ordovician stromatolite forms range from domical, to columns with minor branching. The branching, however, is not as pronounced or elaborate as found in Proterozoic stromatolites. The thrombolites are also columnar to mound-shaped in external form with no apparent branching. There are also numerous thrombolite forms which are extremely irregular and highly variable in shape. They range from small loaf-shaped lumps to large elongated Omega shaped structures in plan view, that preclude a generalized description.

The internal structure of Cambrian and Ordovician stromatolites ranges from coarse to irregularly laminated and the thrombolites have the diagnostic clotted, non-laminated fabric. In contrast to pre-Phanerozoic stromatolites which have well defined, thin laminae, the Upper Cambrian Nopah Formation stromatolites have a mixture of laminae that are generally >1mm thick with some that are not well defined or laminated. Preservation of the clotted thrombolitic internal structure is extremely variable in the Nopah Formation in part due to extensive dolomite recrystallization. Better preservation occurs in the Upper Cambrian of west Texas, in the San Saba Member of the Wilberns Formation where feeding-burrow traces can be observed which disrupt the laminar microstructure (Ruppel and Kerans, 1987). No burrowed laminae were observed in the Nopah Formation stromatolites.

Many Cambrian and Ordovician stromatolites and thrombolites are composed of micrite. In both the Nopah and the Wilberns stromatolites up to 85% of the structures is micrite in contrast to the coarse grainstones and packstones of the adjacent channel-fill sediments. Upper Cambrian stromatolites examined from the Hoyt Limestone, New York, have a significant component of ooids and peloids.

MODERN MARINE CALCIFIED STROMATOLITES

In contrast to the ancient stromatolite examples, large modern subtidal stromatolites presently are known from only three locations. Dill et al (1986) described the giant subtidal marine stromatolites in an active ooid shoal of the Exuma Keys. Similar stromatolites have been described by Dravis (1983) from Eleuthera in the Bahamas. The classic locality of modern marine stromatolites is the hypersaline marine inlet, Hamelin Pool, of Shark Bay in Western Australia (Playford and Cockbain, 1976). Although it is probable that more sites will be found in the future, it is safe to conclude that modern subtidal stromatolites are rare in today's oceans compared to the early Paleozoic and older times.

The external morphology of the modern stromatolites include columns, mounds and irregular "arabesque-shaped" structures (Playford and Cockbain, 1976; Dill, et al., 1986). The overall mound-shaped morphology is often elongated parallel to and over-steepened toward the current direction. Similar over steepened shapes can be found in the ancient record.

The internal structure and composition of the stromatolites from Lee Stocking Island and Shark Bay are similar. Greater than 80% of the stromatolite sediment is 0.25mm in diameter at Lee Stocking Island. The large stromatolites studied thus far are composed of small laminated columns up to 3cm wide, that are often enveloped by single laminae that cover the entire stromatolite. The laminae in certain areas of the stromatolite are disrupted by boring clams, sponges and various other escavating organisms.

The overall internal structure of these modern stromatolites is more similar to early Phanerozoic forms primarily based on their similarity of disrupted internal fabrics as exemplified by the Wilberns Formation stromatolites (Ruppel and Kerans, 1987). One important difference, however, is that some early Phanerozoic stromatolites are composed of micrite and others coarse ooid and peloid sand whereas all the presently known large modern subtidal stromatolites are composed of coarse-grained ooid sands.

DISCUSSION

The stromatolites of ooid shoals in the Bahamas and those in Shark Bay, Western Australia, are modern stromatolites that differ from pre-Phanerozoic and early Phanerozoic stromatolites in the following ways:

1. The modern stromatolites are more restricted in their environmental occurrence than the ancient stromatolites. This restriction is probably due to the destructive effects of grazing and burrowing organisms (Garrett, 1970; Awramik, 1971) that inhabit shallow water marine environments and/or the competitive exclusion by reef-building and skeleton-forming organisms that have diversified since the early Phanerozoic (Monty, 1973). The near total exclusion of modern marine stromatolites from shallow environments is not surprising when viewed from an evolutionary perspective. Dramatic changes in the ecology of shallow marine communities has occurred since the early Phanerozoic due to the diversification of marine invertebrates though time (Bambach, 1983, 1985; Sepkoski, 1982; and Sepkoski and Miller, 1985).

2. An external morphologic similarity exists between modern and early Phanerozoic stromatolites as well as with some pre-Phanerozoic stromatolites. What this actually means about the biological or environmental similarities among the stromatolite groups is not understood. The debate on whether stromatolite external morphology reflects primarily environmental or biological differences is still unresolved (see Golubic, in press; for a recent review of the subject) and no doubt both factors play significant roles. Insight into the answers to many of the questions could be resolved through careful study of the Lee Stocking Island stromatolites. By documenting: 1) the microbiology, 2) the growth and cementation rate of the living stromatolites, 3) the degree of encrustation, 4) the physical and biological erosion, 5) the sediments deposited, and 6) the environmental setting, some important parameters that influence stromatolite morphogenesis may be resolved.

3. The internal structure of modern stromatolites is superficially more similar to early Phanerozoic stromatolites than to those from the pre-Phanerozoic. This similarity lies in the coarse often disrupted laminae and in the unlaminated areas of modern and Phanerozoic stromatolites. The voids or fenestrae in the modern Bahamian stromatolites are interpreted to be caused by the degradation of organic matter (Dill et al., 1986). Other unlaminated regions are due to escavation by metazoans and sponges which is reminiscent of the Upper Cambrian Wilberns Formation where extensive feeding-burrow traces disrupted the laminar microstructure.

4. The internal sedimentological composition of the modern stromatolites is very different from pre-Phanerozoic examples and also from many of the early Phanerozoic stromatolites and thrombolites. The coarse grained nature of the modern stromatolites may reflect a fundamental difference in the sediment available and in the microbial community responsible for the accretion of the the stromatolites (Awramik and Riding, 1988). Awramik and Riding (1988) postulated that the modern stromatolites are able to accrete coarse-grained sediment because the organisms that are trapping the sediment are larger; modern stromatolites have a greater component of eukaryotic algae which are larger than the prokaryote-dominated communities of the

pre-Phanerozoic and therefore modern stromatolite communities can trap a larger size class of sediment.

In summary, this comparison between modern and ancient stromatolites demonstrates that modern marine stromatolites are not perfect analogs for their ancient counterparts. Some of the differences are due to the evolution and diversification of grazing and burrowing metazoans (Garrett, 1970; Awramik, 1971) into shallow marine communities where pre-Phanerozoic stromatolites and early Phanerozoic stromatolites and thrombolites flourished. Preliminary investigations on the differences between the internal structure and composition of modern and pre-Phanerozoic stromatolites and some early Phanerozoic stromatolites indicate a sedimentological difference and hence a possible difference in the microbial communities responsible for their construction (Awramik and Riding, 1988). Other similarities and differences between modern and ancient stromatolites such as external morphology remain unresolved. Continued research on the modern marine stromatolites from the Bahamas and Shark Bay, Western Australia may lead to a better understanding of the physical and biological processes important in stromatolite accretion which will undoubtedly bring insight to fundamental questions such as stromatolite morphogenesis. Also continued work on modern lake stromatolites such as those found on San Salvador Island, (see the paper by Neumann et al., this volume) will add to a better understanding of modern and ancient stromatolites.

CONCLUSIONS

Unlike pre-Phanerozoic or early Phanerozoic stromatolites and thrombolites, modern calcified marine stromatolites are rare in today's oceans and are restricted in their environmental occurrence.

Modern marine stromatolites have external morphologies similar to Phanerozoic stromatolites from Cambrian to Ordovician time and do not show the morphological complexity of pre-Phanerozoic stromatolites.

The internal structure of modern calcified stromatolites is coarsely laminated to unlaminated which is similar to Cambrian to Ordovician stromatolites' internal structure but differs from the pre-Phanerozoic stromatolites which lack disrupted to clotted internal fabrics.

Modern calcified marine stromatolites are composed of coarse-grained sand, dominantly ooid sand, whereas most pre-Phanerozoic and early Phanerozoic stromatolites are composed dominantly of fine-grained material.

REFERENCES CITED

Aitken, J.D. 1967, Classification and environmental significance of cryptalgal limestones and dolomites with illustrations from the Cambrian and Ordovician of Southwestern Alberta: Journal of Sedimentary Petrology, v. 37, n. 4, p. 1163-1178.

Awramik, S.M., 1971, Precambrian columnar stromatolite diversity: Reflection of metazoan appearance: Science, v. 174, p. 825-827.

Awramik, S.M., 1984, Ancient stromatolites and microbial mats, in Cohen, Y., Castenholtz R.W., and Halvorson, H.O., ed., Microbial Mats, Stromatolites: Alan Liss, Inc., New York, pg. 1-22.

Awramik, S.M., and Riding, R., 1988, Role of algal eukaryotes in subtidal columnar stromatolite formation: Proceedings of the National Academy of Science USA, v. 85, pg. 1327- 1329.

Bambach, R.K., 1983, Ecospace utilization and guilds in marine communities through the Phanerozoic, in Tevesz, M.J.S., and McCall, P.M., eds., Biotic Interactions in Recent and Fossil Benthic Communities: Plenum, New York, pg. 719- 746.

Bambach, R.K., 1985, Diversity and adaptive variety: The ecology of diversification in marine faunas through the Phanerozoic, in Valentine, J.W., ed., Phanerozoic Diversity Patterns: Profiles in Macroevolution: Princeton University Press, Princeton, New Jersey, pg. 191-254.

Bertrand-Sarfati, J., and Moussine-Pouchkine, A., 1988, Is cratonic sedimentation consistent with available models: An example from the Upper Proterozoic of the West African craton: Sedimentary Geology, v. 58, pg. 255-276.

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, v. 234, p. 55-58.

Dravis, J.J., 1983, Hardened subtidal stromatolites, Bahamas: Science, v. 219, p. 385-386.

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

Golubic, S., Modern Stromatolites-A progress report, in Riding, R., ed., Fossil Algae, Second International Symposium, in press.

Griffin, K.M., 1988, Sedimentology and paleontology of thrombolites and stromatolites of the Upper Cambrian, Nopah Formation and their modern analog on Lee Stocking Island, Bahamas: Unpublished Master's Thesis, University of California, Santa Barbara, 147 pg.

Grotzinger, J.P., 1986, Evolution of Early Proterozoic passive-margin carbonate platform, Rocknest Formation, Wopmay Orogen, Northwest Territories, Canada: Journal of Sedimentary Petrology, v. 56, n. 6, pg. 831-847.

Hoffman, P.F., 1974, Shallow and deepwater stromatolites in Lower Proterozoic platform-to basin facies changes, Great Slave Lake, Canada: American Association of Petroleum Geologists, v. 58, pg. 856-867.

Hoffman, P.F., 1976, Environmental diversity of Middle Precambrian stromatolites: in Walter, M.R., ed., Stromatolites: Elsevier, Amsterdam, pg. 261-271.

Kennard, J.M., 1981, The Arrinthrunga Formation: Upper Cambrian epeiric carbonates in the Georgina Basin, central Australia: Bureau of Mineral Resources, Geology Geophysics Bulletin, n. 211, p. 1-61.

Moshier, S.O., 1986, Carbonate platform sedimentology, Upper Cambrian Richland Formation, Lebanon Valley, Pennsylvania: Journal Sedimentary Petrology, v. 56, n. 2, p. 204-216.

Monty, C.L.V., 1973, Precambrian background and Phanerozoic history of stromatolitic communities, an overview: Ann. Soc. Geol. Belgium, v. 96, pg. 585-624.

Owen, R.W., 1973, Red Sea algal sediments and the Hoyt Limestone of New York: A comparison of Recent and Cabrian algal deposition (Master's thesis): Rensselaer Polytechnic Institute, Troy, NY, 121 p.

Rees, M.N., 1986, A fault-controlled trough through a carbonate platform: The Middle Cambrian House Range embayment: Geological Society America Bulletin, v. 97, p. 1054-1069.

Ruppel, S.C., and Kerans, C., 1987, Paleozoic buildups and associated facies, Llano Uplift, central Texas: Society of Economic Paleontologists and Mineralogists, Midyear Meeting Field Trip Guidebook, Austin Geological Society Guidebook n. 10, 33 pg.

Playford, P.E., and Cockbain, A.E., 1976, Modern algal stromatolites at Hamelin Pool, a hypersaline barred basin in Shark Bay, Western Australia, in Walter, M.R., ed., Stromatolites: Elsevier, Amsterdam, pg. 389-411.

Sepkoski, J.J., 1975, Depositional environments and fossil assemblages on the Cambrian shelf: An example from the Dresbachian of the Northern Rocky Mountains: Geological Society of America, Abstracts with Programs, v. 7, n. 7, pg. 1264-1265.

Sepkoski, J.J., 1982, A compendium of fossil marine families: Contributions in Biology and Geology, Milwaukee Public Museum, v. 51, 25 pg.

Sepkoski, J.J., and Miller, A.I., 1985, Evolutionary faunas and the distribution of Paleozoic benthic communities in space and time, in Valentine, J.W., ed., Phanerozoic Diversity Patterns: Profiles in Macroevolution: Princeton University Press, Princeton, New Jersey, pg. 153-190.

Truswell, J.F., and Eriksson, K.A, 1974, Stromatolitic associations and their palaeo-environmental significance; a re-appraisal of a lower Proterozoic locality from the northern Cape Province, South Africa: Sedimentary Geology, v. 10, n. 1., pg. 1-23.

Walter, M.R., 1972, A hot-spring analog for the depositional environment of Precambrian Iron Formations of the Lake Superior Region:

Economic Geology, v. 67, pg. 965-980.

Walter, M.R., 1976, Stromatolites: Elsevier, New York, 790 pg.

Walter, M.R., Krylov, I.N., Muir, M.D., 1988, Stromatolites from Middles and Late Proterozoic sequences in the MacArthur and Georgina Basins and the Mount Isa Province, Australia: Alcheringa, v. 12, pg. 79-109.