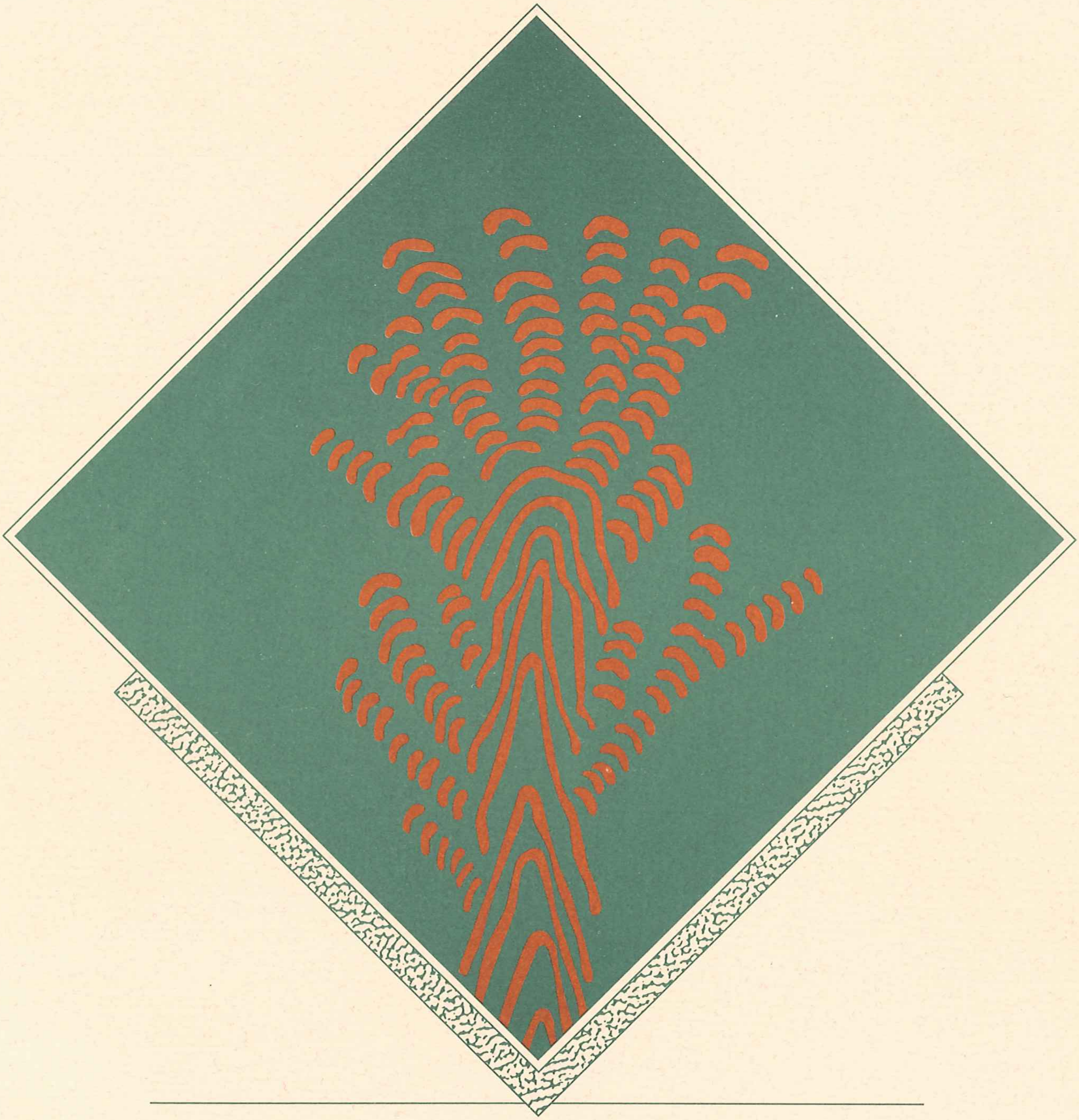

STROMATOLITE

NEWSLETTER

NUMBER 14 1989 • JOHN M KENNARD • ROBERT V BURNE

STROMATOLITE NEWSLETTER
NUMBER 14
1989

Edited by

John M. Kennard and Robert V. Burne

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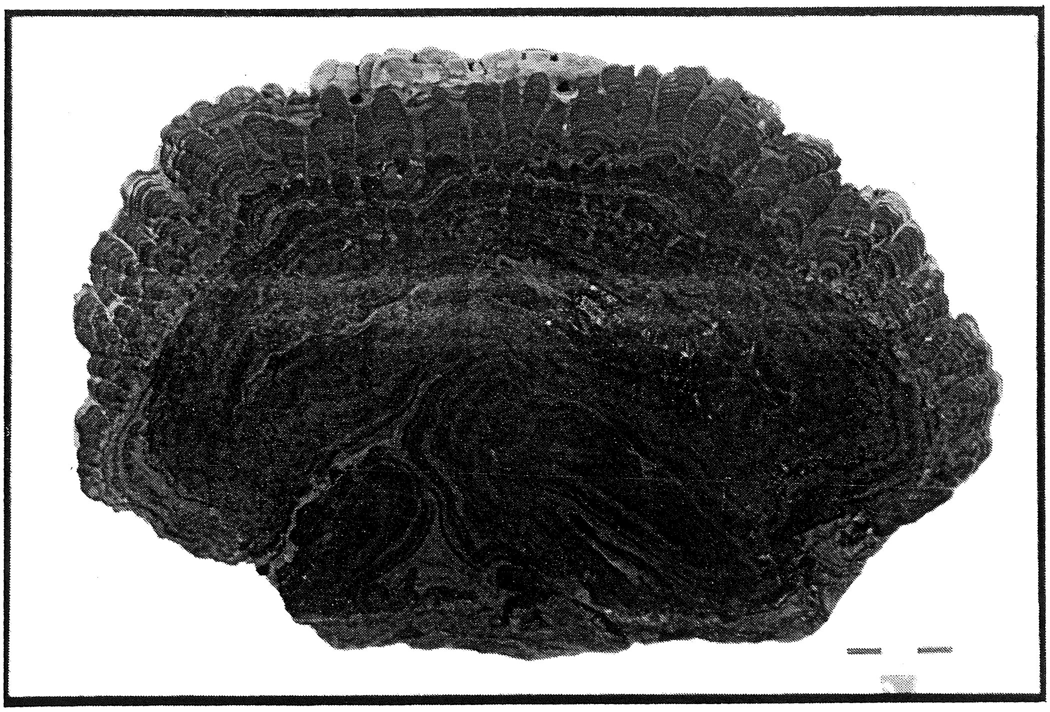

FRONTISPIECE

Lacustrine stromatolite from the Lauterecken Strata, Kusel Group, Lower Rotliegend, Saar-Nahe Basin, southwest Germany. See report by Axel Höhn (page 36). Photograph by courtesy of Axel Höhn.

Editors' Comments

It is now several years since the previous issue of the Newsletter was produced. During this period there has has been a resurgence in stromotolite research and initiatives have been undertaken to bring specialists from diverse backgrounds to focus their attention on structures built by past and extant benthic micrbial communities. The new format and scope of this issue of the Newsletter is largely a reflection of this renewed interest and activity.

Perhaps the most significant recent initiative has been the establishment and prosperity of IGCP Project 261 "**Stromatolite**". An overview of this Project heads this issue of the Newsletter, and a magnificent contribution to that Project by Kathleen Grey - a draft copy of a **Handbook for the Study of Stromatolites and Associated Structures** - concludes this issue. In addition to the more traditional areas of interest such as the depositional setting, morphogenesis and the biostratigraphic application of stromatolites and their preserved microbiota, several new endeavours are reported in this issue, including: the application of lacustrine and fluvial stromatolites to palaeohydrology and palaeoclimatology (reports by Casanova, Höhn, Freytet, and Mohanti and Das), increasing use of isotopic data to determine depositional and diagenetic histories of stromatolitic sequences (reports by Casanova, Fairchild, Höhn, Southgate, and Tewari), the study of siliciclastic stromatolites (report by Witkowski), and the analysis of thrombolites (reports by Aitken and Narbonne, Armella, Kennard, Pratt, and Moore).

We would like to thank all who contributed reports to this Newsletter. Your continued contribution, both scientific and financial, will ensure the success of the Newsletter as an international forum for news exchange between palaeontologists, sedimentologists, microbiologists and geochemists.

Finally, on behalf of all stromatophiles, we would like to thank Claude Monty for his considerable efforts over several years to compile, edit and produce earlier issues of the Newsletter. We look forward to his latest contribution to stromatolite studies: a second volume of Phanerozoic Stromatolites to be published soon.

John M. Kennard
Robert V. Burne

MICROBIALITES THROUGH SPACE AND TIME: A PERSPECTIVE OF IGCP PROJECT 261 - "STROMATOLITES"

"The project should be pursued with vigour and enthusiasm" Dhiraj Bannerjee

Until fifteen years ago the study of stromatolites and microbial sedimentation had proceeded in different countries according to different national traditions and employing a variety of often mutually exclusive procedures. No one country contained the full range of stromatolite bearing lithologies, modern stromatolite forming environments, or workers skilled in all the necessary disciplines. Not least of the problems was that of understanding exactly what was meant by the term "Stromatolite". However, following initiatives of Prof. Rankama and Prof. Glaessner, and spurred partly by the increasing global interest in the Proterozoic, a significant breakthrough came with the compilation of a comprehensive set of papers in the book "Stromatolites", edited by Malcolm Walter and published by Elsevier in 1976. Surprisingly, following this publication the impetus of stromatolite research slowed. It was as if the highly individualistic approaches of many of the key workers, the broad range of disciplines involved, and the wide dispersion of field localities produced an atmosphere of disarray rather than integration. Despite the support for the Stromatolite Newsletter, and the important initiatives of projects such as PPRG and IGCP 157, the views of workers and their methodologies did not converge to produce a common approach to the problem.

It was against this background that, in 1985, Ian Fairchild and Janine Bertrand-Sarfati suggested that an IGCP Project be mounted to focus international stromatolite research. The creation of the Project was reported in the last Stromatolite Newsletter under the heading "Stromatolites on the Move!". The emphasis would be on international co-operation in the pursuit of nine aims which comprehensively spanned the breadth of stromatolite studies (Monty, 1986). The Project attempted to reach all countries and to involve researchers at all levels, with the dissemination of ideas from highly funded "trans-Atlantic" research schools to scientists in less developed countries an important priority. Thus, in 1988 the Project had 200 corresponding members scattered through 34 countries. The initial aim of this international communication network was to synthesis the state of knowledge, to promote exchange of ideas, and to facilitate the visits of scientists from countries with only limited exposures of stromatolites to key localities such as the definitive exposures described by Kalkowsky in Germany, the magnificent modern occurences at Shark Bay, Australia, and Lee Stocking Island, Bahamas, and the perfectly preserved and exposed Proterozoic forms in the vicinity of Atar, Mauritania.

It is now appropriate, after two successful years, to move from the stage of sharing and synthesising existing knowledge to the task of identifying new areas for research so as to fill the many gaps in our understanding of microbialites. We need to review and perhaps revise our Project's objectives in the areas of taxonomy, biostratigraphy, and ecological associations of stromatolites and other microbialites, and to ensure that techniques of modern ecological and sedimentological analysis are applied in an equivalent way in all countries.

"Stromatolites undoubtedly have stratigraphic significance"

Zhu Shixing, Xu Chaolei & Gao Jianping

One of the first steps towards standardising terminology and descriptive methods, or at least achieving a mutual understanding of the variety methods used, is the compilation of the **Handbook for the Study of Stromatolites and Associated Structures**, the initial draft of the first part of which is included in this volume for your review and comment. Kathleen Grey has undertaken the outstanding task of bringing this together. The Project Field Workshop held in Mauritania (Bertrand-Sarfati and Moussine-Pouchkine, 1988) provided a venue for a group of eminent stromatophiles from varied backgrounds to discuss the ideas and approaches to be incorporated in the Handbook and to try to apply these methods in the field in an area of outstanding exposure, preservation and stratigraphic and environmental diversity. One of the problems discussed in Atar was the need to provide some form of treatise to standardise the use of stromatolite nomenclature. An exhaustive treatise covering all named stromatolites is, sadly, beyond the resources of the Project. However standardisation of approach is urgently required. The continued coining of names unsupported by adequate type-descriptions will only further confuse the situation. The proposal, then, is to compile a mini-treatise to cover the "top twenty" or so most frequently encountered stromatolite taxa. Your ideas as to the list of which stromatolites should be included in this work are welcomed.

Another objective of the Project is to compile and compare, on a world-wide basis, columns of the biostratigraphical and environmental succesion in all Precambrian stromatolite-bearing basins to assess the possibility of intra-basinal, inter-basinal, and inter-regional correlation. The framework for this comparison has now been established by the IUGS Subcommission on Precambrian Stratigraphy, chaired by Ken Plumb, which has assessed existing Precambrian subdivisions and has proposed a geochronologically constrained subdivision of the Precambrian that is applicable on a world-wide basis (Fig. 1). This proposal is expected to be ratified by a postal vote of the IUGS Commission on Stratigraphy in the near future. A special working group is considering the Terminal Precambrian System (refered to, for the time being, as "Neoproterozoic III"), and there is great potential for liason between our Project and the working group, which is chaired by Prof. Andy Knoll.

Other areas of interest are the increasing awareness of the significance of thrombolites in Cambrian and Ordovician successions, and the correlation between the stratigraphic ranges of stromatolites and those of planktic microbes through the Proterozoic.

"Stromatolites are a traditional mystery" Kerry Kelts

In the introductory statements to the 1976 "Stromatolite" volume, Malcolm Walter observed that ... "The only unifying feature of stromatolites is their genesis". This concept led to the introduction of the term "Microbialite" (Burne and Moore, 1987) to refer to <u>all</u> organo-sedimentary structures formed by the interaction between a benthic microbial community and its environment, whether they be the well-laminated stromatolites of the Proterozoic, the thrombolites of the Cambrian-Ordovician, the more obscure Palaeozoic mud-mounds, or even the non-skeletal material so commonly associated with skeletal reef frame. In order to progress with our understanding of the significance of these structures and especially to understand the record of the the first three billion years of life on Earth, it is necessary to see beyond them to the ecosystem in which they were formed, and to assess the biological and environmental controls on that ecosystem. There are a great variety of possibilities, ranging from the simplicity of an axenic culture to the complexity of a modern coral-reef in which benthic microbes play an important but relatively minor role. In between these extremes are the ecosystems in which microbialites dominate.

One limitation to this approach has been the scarcity of modern examples of microbially-dominated ecosystems that are comparable with ancient examples. However, a number of diverse ecosystems have been recently discovered in localities such as Exuma, Bahamas, Lake Clifton, and Shark Bay, Western Australia, in which lithified microbialites are forming. We now have a range of modern occurrences available for study ranging from unlithified mats to morphologically complex lithified structures. The principles of uniformitarianism may be applied, for although the present highly evolved ecosystems are very different from their Proterozoic counterparts, the physical and biological processes operating within them have remained the same. We

COMPARATIVE PRECAMBRIAN SUBDIVISIONS

AGE (Ma)	500 – 1000 – 1500 – 2000 – 2500 – 3000	
IUGS (Subcommission on Precambrian Stratigraphy) – EON	(CAMBRIAN) / PROTEROZOIC / —2500— / ARCHAEAN	Preliminary recommendations from Eighth Meeting, SPS, September, 1988 (Plumb & Flint, *Precambrian Res.*, in prep.). Modifies recommendations of Plumb & James 1986. *Precambrian Res.*, 32: 65-92. Must still be confirmed by postal ballot of all SCS Members, and then formalised by IUGS. Acceptance of Period subdivisions not certain at this stage. May be reviewed or deferred.
IUGS – ERA	"Neoproterozoic III" / NEOPROTEROZOIC / —1000— / MESO-PROTEROZOIC / —1600— / PALAEO-PROTEROZOIC / —2500— / ARCHAEAN	
IUGS – PERIOD	—650— / Cryogenian / —850— / Tonian / Stenian / —1200— / Ectasian / —1400— / Calymmian / Statherian / —1800— / Orosirian / —2050— / Rhyacian / —2300— / Siderian	
AUSTRALIA – "OLD" (*Dunn et al., 1966*)	PROTEROZOIC: ADELAIDEAN / —1400— / CARPENTAR-IAN / —1800— / EARLY PROTEROZ. (*Nullaginian*) / —2300— / ARCHAEAN	Dunn, Plumb, & Roberts, 1966. *J. Geol. Soc. Aust.*, 13: 593-608. Plumb, 1985. *Precambrian Res.*, 29: 303-329. Many published maps still use the Dunn et al. scheme, although the age ranges of the reference sections are now quite different. Plumb recommends restricting terms to local tectonostratigraphic groupings; not as a formal time scale. No units yet defined to fill time gaps in colum * above).
AUSTRALIA – PRESENT STATUS (*Plumb, 1985*)	PROTEROZOIC: ADELAIDEAN / —870— / * / —1400— / CARPENTAR-IAN / —1800— / * / —2400— / —2500— ARCHAEAN: NULLAGINIAN / —2800—	
NORTH AMERICA	PROTEROZOIC: (Z) Late Proterozoic / —900— / Middle Proterozoic (Y) / —1600— / Early Proterozoic (X) / —2500— / ARCHAEAN (W)	Decade of North American Geology Series. *Spec. Publs Geol. Soc Am.* Throughout USA, Canada & Mexico. W, X, Y, Z: old USGS terms for same units.
CANADA	PROTEROZOIC: Hadrynian: Neohad / —700— / Paleohad / —1000— / Helikian: Neohel / —1400— / Paleohel / —1750— / Aphebian: Neoaph / —1860— / Meso-apheb. / —2250— / Paleoaph / —2500— / ARCHAEAN	Okulitch, 1988. *Geol. Surv. Can. Pap.*, 87-23. Okulitch also incorporates the adjacent DNAG 3-fold subdivision of the Proterozoic, as an alternative.
CHINA	PROTEROZOIC: Sinian Sys. / —800— / Qingbaikou / —1000— / Jixian System / —1600— / Changcheng Sys. / 1850 / Lower Proterozoic / —2500— / ARCHAEAN	Sun & Lu, 1985. *Precambrian Res.*, 28: 137-162. Wide opinion that base Changcheng is now 1850 Ma (cf. Sun & Lu). Changcheng-Jixian boundary usually 1400 Ma; prefer Sun & Lu .
U.S.S.R.	Vendian / 680 / RIPHEAN: Kudash / —700— / Upper / —1050— / Middle / —1350— / Lower / —1650— / LOWER PROTEROZOIC / —2600— / ARCHAEAN	Keller, 1979. *Geol. Mag.*, 116: 419-504.
STH AFRICA	PROTEROZOIC: Namibian / —900— / Mogolian / —2050— / Vaalian / —2500— / ARCHAEAN: Randian / —3000— / Swazian	Decision by South African Commitee for Stratigraphy, August, 1988 (unpublished). Modifies SACS, 1980. *Handb. Geol. Surv. S.Afr.*

Compiled by K.A. Plumb, Bureau of Mineral Resources, November, 1988.

Figure 1. New sub-division of the Precambrian proposed by IUGS Subcommission on Precambrian Stratigraphy, along with existing sub-divisions.

can now begin to unravel the problems such as; changing microbialite diversity with time; mechanisms and controls on the lithification of microbialites and the information this preserves on the changing nature of the marine environment through time; the factors that limit microbialite growth; and the genetic controls on microstructure and external morphology.

The prospect of anthropogenically induced climate change is encouraging geoscientists to examine the consequences of a reduction of biodiversity on Earth. This is prompting a review of the geological record to discover; the attributes of forms which undergo extinction and those which survive; the nature of refuges in which life persists; the return of a system to pre-event levels of biomass diversity and system complexity; and so-called diversity anomalies, in which the same environments are occupied by different life-forms (IUGS-UNESCO, 1989). The study of the geological history of microbial ecosystems has a great deal to offer in all of these areas, and by encouraging this work the Project will be playing a part in ensuring the continued well-being of the human race on planet Earth.

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Robert V. Burne
Project Leader, IGCP 261 (1987 - 1989)

REPORT OF MEETINGS, EVENTS, NEW BOOKS

A New Lease of Life for Stromatolites and Stromatophiles

As former editor of the Stromatolite Newsletters for several years, I am particularly happy to see that it has finally been possible to edit them in a more professional manner, thanks to the collaboration and assistance of the Bureau of Mineral Resources. The moderate dues will help cover the cost of production and ensure the high quality and scientific value of our Newsletter, the more that it is sponsored by the IGCP 261 (hence by the IUGS), a project that was born during the Canberra IAS meeting in 1986. This development was essential as it was no longer possible, as far as I was concerned, to drain my research budget to pay a secretary and to cover reproduction, binding and mailing of the Newsletter and related mail. Although the costs were high, I do not regret it at all as it was for the sake of Stromatophiles. Now, with the collaboration of all of us and our new Editors, the Stromatolite Newsletter enters into its golden age to become a true publication. Also, with the creation of IGCP project 261 presently led by Bob Burne, the study of stromatolites has gained real status as a recognized scientific discipline with well defined objectives. This is extremely stimulating; it should definitely lead to breakthroughs in the understanding of the nature, the working and the history of these microbial ecosystems as well as of their environmental and stratigraphical significance.

So, on behalf of all my past correspondants, I would like to congratulate our Australian collegues as well as those who have already organized fascinating field trips since the creation of IGCP project 261.

Upon closing this note, I have a deep thought for those early geologists whose writings opened my eyes to stromatolites at the beginning of my career; I mean Kalkowsky, Maslov and others...

C.L.V. Monty

Thethys IGCP Stromatolite Working Group

An IGCP local group, comprising France, Italy, and Spain, is constituted and had its first meeting in Marseille during the meeting on Biosedimentation in October 1988, and a one-day field trip to see the Tertiary lacustrine stromatolites in down-town Marseille. We plan to organize a three-day field trip in Limagne, probably in September 1989, also to see Tertiary lacustrine stromatolites.

Janine Sarfati

Indian IGCP Stromatolite Working Group

The first meeting of the National Working Group of IGCP Project 261 in India was held at the Geological Survey of India headquarters, Calcutta, on 3rd May 1988. A second meeting was held on 1st October 1988 in Wadia Institute of Himalayan Geology after the Indo-Soviet Symposium on Stromatolites. It was emphasised by me in the Working Group that work on the standardization of classification and Linnean nomenclature of Indian (Himalayan and Peninsular) stromatolites for their use in inter-continental correlation should be undertaken. The following recommendations of the Taxonomy Special Interest Group (TSIG) given in discussion paper 1 (Principles of stromatolite taxonomy by K. Grey and M.A. Semikhatov) and discussion paper 2 (classification using Linnean Taxonomy by K. Grey and M.A. Semikhatov) may be followed. I prepared a complete list of group genera and form species of stromatolite and microbiota occurrences in India. A bibliography on "Stromatolite and Microbiota Research in India" (1938-88) was compiled and published by me as one of the IGCP-261 activities.

It was also felt that an "Indian Stromatolite Newsletter" may also be published for better interaction amongst Indian stromatophiles.

Vinod C. Tewari

Indo-Soviet Symposium

An Indo-Soviet Symposium on "Stromatolites and Stromatolitic Deposits" was organised by the Wadia Institute of Himalayan Geology (WIHG), Dehra Dun, from 30 September to 1 October 1988. This symposium was sponsored by the Indian National Science Academy (INSA), New Delhi, and supported by the Department of Science and Technology (DST), Council of Scientific and Industrial Research (CSIR), and Oil and Natural Gas Commission (ONGC), Dehra Dun. This symposium was organised under the aegis of the Indo-Soviet Science and Technology Co-operation Programme between the Academy of Sciences, USSR, and the Department of Science and Technology, Govt. of India.

The following 5 topics were included in the scientific programme, and 35 papers (9 Soviet and 26 Indian) on these topics were presented by participants:

1. Use of stromatolites and fossil algae in biostratigraphic subdivision in India and USSR (based on modern classification, terminology and systematics).
2. Facies of stromatolite formation, palaeoecology, environment of deposition of stromatolitic sediments, and palaeogeographic reconstruction.
3. Role of microbial communities in biomineralisation and formation of economic mineral deposits.
4. Stromatolite-forming microbiota, their systematics and role.
5. Isotope and organic geochemistry of stromatolites and microbiota.

Two post symposium excursions were organized: (i) to the nearby Lower Cambrian (Tommotian) stromatolite (Tewari, 1984) locality at Pyrites Phosphate and Chemicals Ltd., Durmala Mine, Mussoorie syncline, and (ii) to the Proterozoic stromatolite localities in Udaipur and Chittorgarh, Rajasthan. These stromatolite assemblages were compared with Proterozoic and Lower Cambrian sequences of the Karelia and Siberian platforms, USSR.

Vinod C. Tewari

Phanerozoic Stromatolites II

A second volume of Phanerozoic Stromatolites, edited by Claude Monty, is to be published by Springer-Verlag. It contains the following papers:

Introduction : C.L.V. MONTY

MONTY C.L.V. : Lower Paleozoic stromatolites and microbial accretions, a review.

KENNARD J.M. : Thrombolites and stromatolites within shale-carbonate cycles, Middle-Late Cambrian Shannon Formation, Amadeus Basin, Central Australia.

FRIEDMAN G. : Domed stromatolites from Saratoga, New York, U.S.A.

STINCHCOMB B.L. : Cambro-Ordovician stromatolite reefs and associated molluscan assemblages - Ozark uplift - U.S.A.

MITCHELL R.W. : Freshwater stromatolites : ancient and modern.

YUE LEI : Studies of deposits of algae-coated grains, Central New South Wales, Australia.

MORTENSEN P.S. : Upper Silurian algae from the M'Clintock Basin, Arctic Canada.

MONTY C.L.V. : Devonian cavity-dwelling stromatolites.

PARNELL : A Paleozoic hot spring stromatolite deposit : the East Kirkton Limestone, Scotland.

CHAFETZ H.S., RUSH P.F. and SCHODERBEK D. : Occult aragonitic fabrics and structures within the black stromatolites of the Pennsylvanian Panther Seep Formation, San Andres Moutains, New Mexico, U.S.A.

GASIEWICZ A. : The platy dolomite (Upper Permian) peritidal stromatolitic lithofacies related to environmental changes.

CWIZEWICZ, PIEKARSKA and SZULC : The lower Permian freshwater stromatolites of the Krakow Upland, S. Poland.

PONCET J. : Permian (Autunian) oncolites from the basin of Carentan, Northwestern France.

TUCKER M.E. & LESLIE A.B. : Triassic (Keuper) lacustrine stromatolites from South Wales, U.K.

PIERKASKA & GRASIOROWSKI : Cryptalgal structures in Wozniki Limestones, Triassic/Jurassic boundary, playa lake deposits, Southern Poland.

VERA J.A. & ALGARRA A.M. : Mesozoic stratigraphic breaks and pelagic stromatolites in the Betic Cordillera, Southern Spain.

ALGARRA A.M. & VERA J.A. : Mesozoic pelagic phosphate stromatolites from the Penibetic (Betic Cordillera, Southern Spain).

BALLARINI L., MASSARI F., NARDI S. & SCUDELER BACCELLE : Amino-acids in the pelagic stromatolites of the Rosso Ammonitico Veronese Formation (Middle-Upper Jurassic, Southern Alps, Italy).

DROMART G., GAILLARD C. & JANSA L.F. : Deep-marine microbial structures in Upper Jurassic of Western Tethys.

GASIEWICZ A. : The Albian (Lower Cretaceous) fungal silica-iron stromatolites from N.E. margin of the Holy Cross Mts (S.E. Poland).

BERTRAND-SARFATI J., FREYTET P. & PLAZIAT J.C. : Microstructures and biogenic remains in non marine stromatolites (Tertiary, France). Comparison with some Precambrian microstructures.

LINDQVIST J. : Oncolites from a Miocene lake shore Manuherikia Group, South Island, New Zealand.

GERDES G. : Peritidal stromatolites: a synopsis.

WHARTON A. : Microbial mats and modern stromatolites in perennially ice-covered Antarctic Lakes.

MONTY C.L.V. : Bahamian microbial carbonate flakes.

DAVAUD E., STRASSER A. & JEDOUI Y. : Stromatolite and serpulid bioherms in a Holocene restricted lagoon (Sebkha El Melah, Southeastern Tunisia).

CASANOVA J. : Stromatolites from the East African rift : a synopsis.

WINSBOROUGH B. : Freshwater oncolites, coated pebbles, bioherms and microbial crusts from a spring-fed Lake in Northeastern Mexico.

MOORE L., & BURNE B. : The modern thrombolitic microbialites of Lake Clifton, W. Australia.

SZULC J. & SMYCK B. : Bacterially controlled calcification of the freshwater Schizothrix stromatolite : an example from Pieniny Mts, Southern Poland.

JONES B. : Micro-organisms and their role in carbonate diagenesis : examples from the karst terrains of the Cayman Islands, British West Indies.

C.L.V. Monty

New Journal: Carbonates and Evaporites

Recent papers of interest to stromatophiles in this journal include: "Thrombolites of the lower Devonian Manlius Formation of Central New York State"; "Gypsum carbonate laminites in a Recent sabkha, Kuwait"; and "Diagenesis of sabkha-related sulphate nodules in the Early Proterozoic Gordon Lake Formation, Canada".

Gerald M. Friedman

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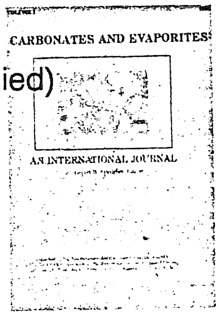
CARBONATES AND EVAPORITES



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RENTAL USE OF MAILING LIST: Yes

THIS JOURNAL IS ABSTRACTED AND/OR INDEXED IN: GeoRef, Sedimentology, Geographical Abstract

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Friends of the Algae Newsletter

Stromatophiles are reminded of our sister newsletter Friends of the Algae which deals mainly with fossil algae (eukaryotes) that do not form stromatolites. This newsletter thus complements our own newsletter, and you are encouraged to forward contributions to the editors H.M.C. Danielli, Texaco EPTD, PO Box 770070, Houston, Texas 77215-0070, U.S.A., and J.M. Cys, 3533 Stadium Drive, Fort Worth, Texas 76109, U.S.A. They would welcome thesis abstracts, short research articles, book reviews, resumes from phycophiles looking for research or industrial positions, and other phycophile news.

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Precambrian thrombolites from the Mackenzie Mountains, Northwestern Canada

[Abstract: submitted to PALAIOS, February, 1989]

This report documents the occurrence of thrombolites in the Ediacaran/Vendian Blueflower Formation and the Upper Riphaean Little Dal Group. These occurrences are significant biostratigraphically in the light of published opinions to the effect that thrombolites first appear near the Precambrian-Cambrian boundary. Furthermore, they are significant with respect to models of the evolution of organic communities across the Precambrian-Cambrian boundary, and demonstrate conclusively that thrombolites are not simply burrowed/bored algal stromatolites.

Claudia Armella
Museo Argentino de Ciencias Naturales "Bernardino Rivadavia"
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Argentina

Mesostructure, megastructure and paleoenvironmental meaning of Cambro-Ordovician thrombolites from Argentina

The La Flecha Formation (Cambrian-Ordovician boundary) from the Argentinian Precordillera has a biocyclic organosedimentary pattern. Associations of biocyclic sedimentary and algal structures have been analysed. They suggest sea level fluctuations. An ideal biocycle has been characterised and a summary of Argentinian thrombolite paleoenvironments has been reported.

Introduction: This report analyses La Flecha Formation thrombolites as the main element which characterizes the Cambrian-Ordovician boundary from San Juan

Precordillera Basin, Argentina (Fig. I). These thrombolites are related to stromatolites and form transgressive biocycles. In spite of the fact that this sequence does not contain any fauna, the age is supposed to be Upper Cambrian and Tremadocian, as Bordonaro (1983) found Middle Upper Cambrian trilobites (*Bollaspidella* Zone) and Lower Arenigian conodontes (*Oepicodus evae*) overlying and underlying.

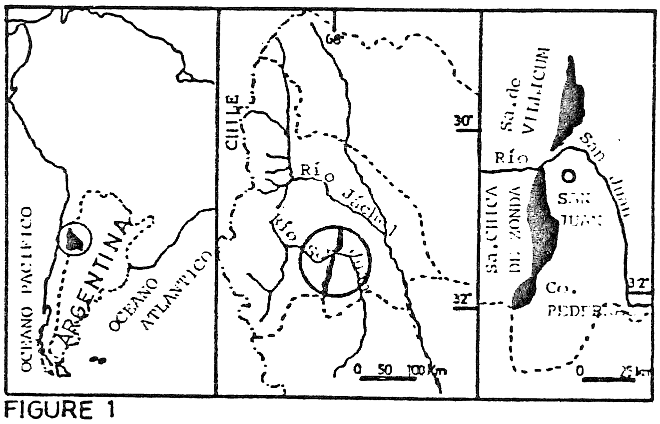


FIGURE 1

I propose a morphological classification of these thrombolite meso- and magastructures, and suggest the paleoenvironment in which they formed.

Mesostructure: The pattern and the gowth vector of the clots may be determined by the following mesostructures.

1. Tromboloide: poorly defined thrombolitic net.
2. Encephalic: uniform net with synusoidal clots similar to a brain (Baldis and others, 1981).
3. Vertical.
4. Batridermic: (latin: *batrachium,* toad; *dermis*, skin) low density of clots related to *Renalcis* colonies.
5. Radial.
6. Encephaloestromatolitic: thin and well defined beds of encephalic thrombolites.
7. Arborescent: concentric dendritic clots like a cabbage.
8. Lanceolated: with a middle main vector and many divergent growing lines from the former one.

Megastructure: The types of megastructures observed in outcrops are shown in Figure 2.

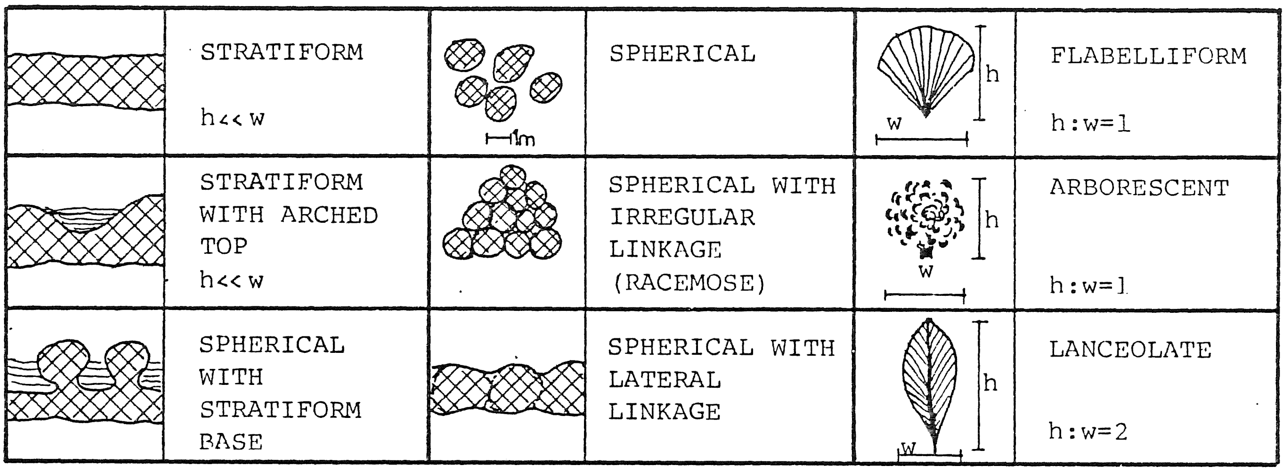
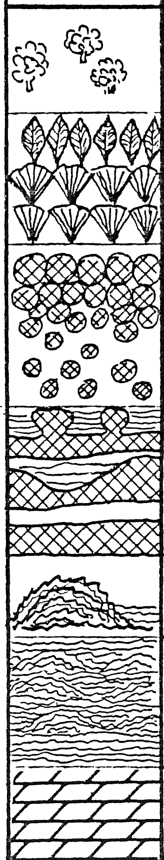


FIGURE 2: Megastructures of thrombolites
encephalic mesostructure; interthrombolitic channels; h:high; w:wide

Theoretical Biocycle: The La Flecha Formation gives an excellant example of cyclic biosedimentation. Biocycles begin with stromatolites at the base and pass to well developed thrombolites at the top. Their characteristics are summarized in Table 1.



THEORICAL BIOCYCLE	FACIES	BIOSTROMAL KIND	CHARACTERISTICS	ENERGY	ENVIRONMENT
	ARBORESCENT THROMBOLITES	No	Scattered forms into a micritic sustratum	Low	Subtidal
	FLABELLIFORM AND LANCEOLATE THROMBOLITES	They usually form density colonies	Banded interthrombolitic channels	Low	Shallow subtidal
	SPHERICAL THROMBOLITES	They usually form density accumulation	Moving forms coming from the strangling effect of the underlying accumulations	High	Intertidal-Subtidal
	STRATIFORM THROMBOLITES	Low restricted forms	Increased of synoptic relief seaward. Channels .	Moderate	Subtidal Intertidal
	COMPOUND STROMATOLITES		Synoptic relief upper 0.50m	Moderate	Protected intertidal
	PLANAR AND LOW SYNOPTIC RELIEF STROMATOLITES		*Stratifera*, *Collenia*. Fenestral fabric Storm layers	Low	Peritidal and shallow intertidal
	DOLOMITIC MUDSTONE		Fenestral fabric. Mudcracs. Storm layers	Low	Peritidal

TABLE:I

Conclusions: The depositional model for the Cambrian-Ordovician basin in the Argentina Precordillera suggests wide and partially restricted tidal shelf with a general transgressive behavior in all the sequence. The type of megastructure and the density of the colonies are the main factors which have controlled the degree of restriction of the basin.

This report benefitted substantially from the critical reading of Dra. Liliana Castro.

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I see that my last contribution to the Stromatolite Newsletter was back in 1983. Work continues on stromatolites of all ages and on Proterozoic and Archean microfossils. Some things never change!

Current projects are: 1) Late Proterozoic through Early Ordovician stromatolites. My graduate student, Karen Griffin, will be researching various aspects of this research for her thesis. 2) Nonmarine stromatolites from Cenozoic deposits of California and Nevada. Julie Rich, another graduate student of mine, will study these for her thesis project. 3) Recent giant subtidal columnar stromatolites from Lee Stocking Island, Bahamas. Robert Riding (Cardiff), Karen Griffin, Barbara Winsborough (Austin), Robert Dill (San Diego) and I are finishing a paper on the role of the eukaryotes in the construction of these stromatolites. 4) More on the paleobiology of Gunflint stromatolites. 5) The paleobiological significance of Early Archean stromatolites.

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In the several years since my last contribution, the Baas Becking Geobiological Laboratory has been reviewed, and subsequently terminated; I was transferred from CSIRO to the BMR; the BMR has been reviewed and the recommendations of that review are now being implemented. I am currently involved in the BMR Fossil Fuels Program as a member of a project investigating "controls on source bed occurrence and composition". This involves collaboration with Roger Summons, Chris Boreham, Zarko Roksandic and Trevor Powell on the microbial contribution to, and modification of, hydrocarbon-prone organic matter in sedimentary environments. My work also encompasses the application of microbial ecology to paleoenvironmental interpretation and "The Great Biomarker Hunt" i.e. ascertaining the specific (microbial) source(s) of various biomarker molecules present in modern and ancient sediments. To this end, much of my time since joining the BMR has been spent setting up a functional microbiology laboratory.

I have been trying to overcome the backlog of unwritten/unpublished manuscripts that accumulated during my transfer to BMR. Some headway has been made (see below) but there are others still to come, including some studies on the physiological ecology of the mat-forming cyanobacterium *Entophysalis* major, photoheterotrophic activity in a variety of microbial mats, and collaborative work on the subtidal diatom mats of Hamelin Pool with Jacob John (Curtin University), Elisa D'Amelio (NASA-Ames) and Bev Pierson (University of Puget Sound). Allan Pentecost (King's College, London) was awarded a Royal Society Travelling Fellowship which enabled him to spend several weeks in Canberra where we investigated cyanobacterial sheaths and carbonate precipitation. I had the good fortune to participate in Bill Schopf's PPRG-P operation which included support to carry out experimental fieldwork in Mexican salinas (also courtesy of cooperation from Dave Des Marais, NASA-Ames) and in New Zealand geothermal areas, making an interesting change from our normal Australian habitats such as Shark Bay.

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Work on modern microbialites has been undertaken in Hamelin Pool, Shark Bay, Western Australia (in association with colleagues from the former Baas Becking Laboratory) and in a variety of lakes in coastal regions of South Australia and Western Australia (in association with Linda Moore, University of Western Australia).

Studies in Shark Bay are shedding new light on this classic stromatolite occurrence and will hopefully correct some of the misconceptions that have arisen from earlier descriptions. The most important of these is the oft-quoted suggestion that lithified stromatolites of Hamelin Pool are dominantly the product of the intertidal environment. Around the coast of Hamelin Pool, subtidal stromatolites occur ubiquitously in the shallow (1-3 m) inshore zone of the sub-littoral platform. They exhibit considerable morphological variation, ranging from isolated club-shaped forms sculpted by migrating ooid shoals near Flagpole landing, through complex reef-like structures at Carbla Point, some sproating columns, to large elongate loaf-shaped structures in deeper water north of Carbla. The species diversity of the ecosystem associated with the stromatolites appears to decrease towards the southern end of the pool, perhaps because of increasing salinity, but remains relatively high. It includes a diatom-rich benthic algal community (BMC), bivalves, shrimp, fish, macro-algae and sea-snakes. Falling sea-level over the past 6000 years has left former subtidal stromatolites stranded in the intertidal zone, where they are either colonised by intertidal BMC, such as *Entophysalis* dominated pustular mat, or are subjected to dissolution. Studies of the internal structures of the Hamelin Pool stromatolites are being undertaken, using slabbed and polished plastic impregnated specimens.

Studies of South Australian lakes are being finalised, with the relationships between groundwater/lakewater interactions and microbial calcification being examined. In Lake Fellmongery spherulitic monohydrocalcite microbialites occur, while in Sleaford Mere aragonitic microbialites have developed both tufa-like and digitate columnar internal structures. Lake Inneston harbours gypsum microbialites.

In Western Australia the perfectly laminated hemispherical microbialites of Pink Lake, near Esperance, are associated with a coccoid-dominated BMC, and provide an analogue for the formation of the well-known sub-fossil stromatolites of Marion Lake, South Australia, as well as for the Proterozoic form *Stratifera undulata*. The tepee structures of Lake Preston, described by L.S. Moore elsewhere in this volume, continue across the permanently submerged margins of the lake, where delicate coral-like branching microbialites grow vertically 10-15 cm from the tepee crests.

Examination of these localities has generated aview of microbialites as the products of a complex ecosystem based on the activities of a BMC, but also involving higher organisms to varying degrees. this counters the view that modern microbialites can only survive in biological deserts generated by extreme conditions such as hypersalinity, prolonged exposure or high temperatures. Lake Clifton (hyposaline) and Hamelin Pool (hypersaline) have conditions which permit large species diversity, while still excluding the development of organisms that would limit the occurrence of BMC because of grazing pressure or competition. The microbialites are like coral-reefs in that they form rigid structures in oligotrophic waters and are capable of generating their own sedimentary environments. Radiocarbon dating of both the thrombolitic structures in Lake Clifton and the stromatolitic structures of Hamelin Pool indicate that they have growth rates that are an order of magnitude less than growth rates of scleractinian corals. This suggests that the absence of calcareous microbialites from modern coral-reefs, and from analogous skeletal structures throughout the Phanerozoic, may be due to competitive exclusion rather than grazing pressure.

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As many things happened during the past two years, it seems easier to report on my work geographically.

Intertropical Africa - A non-negligible part of Quaternary limestones in Intertropical Africa results from microbial mineralisations. Stromatolites have colonized a wide range of environments corresponding to different hydroclimatic situations: travertines in fluviatile environment, oncolites in flood plains, encrustations in sebkha areas and shorelines of deep, fresh water lakes. The stromatolite morphologies represent a complete catalog of microbial carbonates: oncolites, chemneys, pool-rim dams, bioherms, planar or cylindrical encrustations. The building organisms may be either pure bacterial colonies (hydrothermal and lacustrine), cyanophyte associations (fluviatile and lacustrine) or complex microbial biocoenoses. I tried to synthesize the state of knowledge in two papers to be published by Pergamon and Springer, respectively.

Rift Suguta (Kenya) - The Suguta rift is the most arid area of Kenya. It is characterized by a strongly negative hydrological budget. Pleistocene high lake levels are indicated by the presence of stromatolites, up to one meter thick. They consist exclusively of calcite of bacterial origin, which is peculiar in East Africa where lacustrine stromatolites are commonly of algal origin. The encrustations cover hard substrates, including bedrock surfaces as well as some vegetal remains. They show a variety of growth forms from large flattened oncolites, tabular crusts to hemispheric bioherms.

Lake Tanganyika (Burundi) - Lake Tanganyika is the largest lake (32 OOO km^2, maximum depth 1470 m) in the western branch of the East African Rift System. Stromatolites occur between 6 and $\geq$ 50 metres deep; they are associated with lower lake levels dated from $\approx$ 3500 to $\approx$ l400 yrs B.P.. The encrustations consist of low Mg-calcite and their thickness varies according to the depth and the stability of paleolake Tanganyika. No living encrusting microbial community has been observed.

Sebkha Chemchane (Mauritania) - Paleohydrology and paleoecology in the Sebkha of Chemchane region is reconstructed from the comparative analyses of mineralogy, stable isotope ratios of bulk carbonates, and palynology from sediment cores. The section spans from 13500 yrs B.P. to the mid Holocene. Maximum lake extension is recorded in a girdle of stromatolite carbonates dated from 8300 to 6500 yrs B.P.. This high lake level corresponds to the regional development of Sahalo-Sudanian vegetation.

Marseille Graben (France) - Continental sedimentation in the "Marseille Rift" during the Oligocene allowed the development of stromatolites in fluvial and lacustrine environments. Biosedimentological and isotopic analyses of these carbonates have been used to document the sedimentary and hydroclimatic history of the graben. Stampian bioherms developed in a shallow lake under tropical climatic conditions. A partial sub-aerial diagenesis of the stromatolites due to *Microcodium* activity is often observed. At the "Oligocene terminal" stromatolites formed again. They are interbedded with clastic flood deposits related to anastomosed river systems.

Altiplano (Bolivia) - The study of Quaternary paleohydrology and paleoclimatology of the Bolivian Altiplano from lacustrine stromatolites is conducted by a graduate student, B. Rondeau, who will defend his Master's thesis next summer.

Kelly Lake (British Columbia) - Less than twenty modern stromatolite-bearing fresh water lakes have been surveyed, mainly in the temperate zone of the northern hemisphere. Only a handful of these have a reasonably complete description including parameters of microbiology, mineralogy and water chemistry, as well as the macroscopic and microscopic description of the stromatolites. Kelly Lake is a new project we (coll. R. Renaut & B. Owen) started recently to partly fill this gap.

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The study of extant microbial communities has enabled us to know about their role in carbonate precipitation and accretion of stromatolites. Unfortunately, we do not have their phosphate precipitating counterparts. From the study of Holocene phosphorite we could know that microorganisms bodily contribute (through diagenetic degradation) towards enhancing the phosphorous content of the ambient water, which eventually leads to inorganic precipitation of phosphorite. It is now widely believed that most ancient non-stromatolitic phosphorites are derived from such a process involving the indirect participation of microorganisms.

Occurrences of exclusively stromatolitic phosphorite in the early Proterozoic Aravalli carbonate sequence of India makes us believe that stromatolite-building microorganisms (especially cyanobacteria) did play a prominent role in phosphorite formation in the Precambrian eon, in more or less a similar manner to their extant carbonate counterparts. A significant proportion of stromatolitic phosphorite within most of the late Proterozoic phosphorite deposits of the world supports this assumption (Table 1).

The diminishing amount of stromatolitic phosphorite within most Cambrian to late Cretaceous - Eocene phosphorite deposits of the world suggests that cyanobacterial communities could not excercise their full influence on younger phosphogenic systems, possibly due to the appearance of higher life. As a result, the dominantly biogenic phosphogenic system of the Precambrian eon was replaced by a prominent abiogenic phosphogenic system during the Phanerozoic eon.

TABLE 1. PHOSPHATE BEARING STROMATOLITES AND THEIR POTENTIALITIES

AGE	LOCATION	FORMATION	% P_2O_5	RESERVES (M.T.)	SPECIFIC ATTRIBUTES
Lower Eocene-U. Cretaceous	Tatric Abian Poland	High Tatric Albian limestone	-	-	Small amount of phosphate occurs as microstromatolites.
	Nahal Ashash area (Negev), Isreal	Mishash Fm.	-	-	Stromatolites contribute significant amount of phosporous.
Cambrian	Birmania, India	Birmania Fm.	5-10	4.34	Stromatolites form part of phosporite horizon.
	Mussoorie, India	Tal Fm	15-35	29.32	" "
	Georgina Basin, Australia	-	-	-	Stromatolitic phosphate forms thin bands within main phosphorite horizon.
	Karatau Basin, USSR	-	-	-	Stromatolites main receptacle of phosphate.
	Khubsugul, USSR	-	-	-	" "
Late Proterozoic	Pithoragarh, India	Gangolihat dolomites	5-12	-	Stromatolites form small amount of low grade phosphorite.
	Hirapur, India	Bijawar group	-	-	" "
	Cumbum, India	Cumbum Fm.	20-30	-	" "
	Durg district, India	Nandini lst.	5-17	-	" "
	Baitadi and Bajang, Nepal	Limestone	-	-	" "
	Yangzi region, China	Doushantuo	25-35	-	Stromatolites form significant amount of phosphorous.
	Alborz, Soltanieb-Iran ranges & other places	-	-	-	Contribute nearly 80% of allochem phosphate.
	Gornaya Shoriya, USSR	Belka Fm.	-	-	Stromatolites main receptacle of phosphate.
Early Proterozoic	Udaipur, India	Aravalli supergroup	15-35	80	Stromatolites sole repository of phosphate.
	Sallopat, India	" "	15-30	6.5	" "
	Gandhra, India	" "	10-20	-	" "
	Jhabua, India	" "	14-29	7.7	" "

In light of the above, it is suggested that phosphorite the world over be examined afresh in order to trace the crucial relationship between evolving life and phosphogenic systems.

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I am interested in applying diagenetic relationships I have observed in modern Bahamian, high-relief, hardened columnar stromatolites to certain ancient stromatolitic/thrombolitic sequences. The stromatolites I am working with are those associated with active oolitic tidal bars in the Schooner Cays ooid shoal complex on Eleuthera Bank, northern Bahamas. I first described these stromatolites in a 1983 Science article.

I am soliciting ancient examples, of any age, of apparent micritic stromatolites or thrombolites which are intimately associated with active grainstones of either oolitic or skeletal composition. I have observed interesting styles of early marine diagenetic alteration in my Bahamian examples which might offer an alternative explanation for the coexistence of some micritic stromatolites or thrombolites with high-energy active grainstones. From a depositional standpoint, such a relationship is anomalous based on my observations of modern columnar stromatolites in the Bahamas and Hamelin Pool.

I would be interested in receiving small samples of stromatolites/thrombolites and host grainstones from pertinent ancient sequences where this relationship exists. I plan to test my ideas on your samples using new microscopic techniques I have developed and will keep you abreast of my findings. Thanks for considering my request.

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A Preliminary Study of the Cambrian in Northern China

Except for a recent report about stromatolites in the Cambrian from Xinjian, Cambrian stromatolites have rarely been studied. Generally speaking, people have the impression that stromatolites are not well developed and are uncommon in the Cambrian. However, on the basis of our work, stromatolites are widespread and abundant in some formations or members in some areas. They are mainly distributed in the following areas: the middle-southern part of the Taihang Mountains and the eastern part of Yanshan, Hebei province; Xishan, Beijing; Taizhihe River Valley, Liaoning province; the southeast Shanxi and the Zhongtiashan region of Shanxi province; the north of Henan province; Changqing, Shandon province; and the Xuzhou and Jiawang regions of Jiangsu province.

As far as the authors know, five formations in the three series of the Cambrian contain rich stromatolites, and three formations (Mantou, Maozhuang and Xuzhuang Formations) lack stromatolites. The stromatolites are mainly in seven horizons and are assigned to ten genera and six species, including two new genera, three new species and one conformis species: *Stratifera pseudocolonnella, S.* sp., *Gruneria sinensis, G.* cf. *biwabikia, Yiaoshanella yiaoshanensis* (gen. et sp. nov), *Acaciella sinensis* (sp. nov), *Colonnella* sp., *Tangwangzhaella Du* (gen. nov), and *Microstylus leizhuangensis* (sp. nov). Some other types have not yet been identified. In addition, there are oncolites (*Radosus crustosus*).

The general characteristics of the Cambrian stromatolites in northern China are large individuals, simple shapes and few types. They are represented essentially by stratified, columnar, branch-columnar, curve-columnar and spherical stromatolites, most of which contain numerous organisms and are furnished with obvious biological structure. Some also contain traces of biological disturbance and co-exist with trilobites. Stromatolites of the Cambrian mostly exist in limestone reefs and ferruginous limestone. By inference, their environment of formation is normal, open shallow sea and clear water basin (subtidal zone). Some of them are directly formed on windstorm deposits; that is, a turbulent, high energy depositional environment.

In general, stromatolites of the Cambrian are similar in appearance and characteristics to those of the terminal Precambrian (Sinian system). However, Cambrian stromatolites are much less abundant, less diverse, large in individual size and simple in shape (mainly stratiform and columnar forms), and some contain rich organisms [metazoans]. Furthermore, the Cambrian lacks silicious and phosphatic stromatolites as well as *Boxonta, Linella* and *Potomia*. Up to now, *Conophyton* has not been discovered in the Cambrian. However some new genera and species of micro-columnar and large-columnar stromatolites have been found in the Cambrian. In short, Cambrian stromatolites in northern China have some inherit resemblances as well as differences [to Precambrian stromatolites].

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Work on several Proterozoic stromatolitic formations is in progress aimed to assess the origin of the carbonate in stromatolites. In part this is a continuation of completed studies on palaeoenvironments.

Glacio-lacustrine stromatolites from the Vendian of northeast Spitsbergen are both calcitic (relatively freshwater) and dolomitic (highly evaporated). Fairchild and Spiro (1987) published data on the former. The dolomitic varieties are extremely enriched in ^{18}O with $\delta^{18}O$ values up to $+10_{PDB}$ (paper in press in Geological Magazine) and form part of a $\delta^{13}C$ - $\delta^{18}O$ trend that is now being recognized in many lacustrine carbonate successions. No vital effects on geochemistry are apparent.

Studies on stromatolites from East Greenland have demonstrated a great lateral persistence of ?latest Riphean biostromes (Herrington and Fairchild, 1989). Vendian "lagoonal" stromatolites lie near the top of a major shallowing-upwards hemicycle, show probable depth related morphological trends (Fairchild and Herrington, 1988) and formed in an identical environment to stromatolites from the Vendian of western Scotland (Fairchild, 1989). Petrographic and geochemical studies point towards a detrital origin for the bulk of even the muddy carbonate; subordinate apparently *in situ* precipitated carbonate is chemically indistinguishable.

Collaborative work with J. Bertrand-Sarfati and J.D. Marshall on Upper Riphean Mauritanian stromatolites has revealed a major stratigraphic $\delta^{13}C$ isotope anomaly which reflects a major switchover from Mg-calcite to aragonite formation in stromatolites and associated sediments. The two minerals were stabilized at different stages in diagenesis from different fluids, leading to the isotopic shift. There is no difference in chemistry between stromatolitic micrite and marine cement.

Collaborative work with A. Knoll, K. Swett and J.D. Marshall on Late Riphean tidal flat dolomitic stromatolites (with classic silicified cyanobacterial microbiotas) from northeast Spitsbergen is also aimed at clarifying the microbial contribution to the chemical and petrographic attributes of the stromatolites.

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During 1988, I studied stromatolites of small rivers in various areas in France, including the Seine River between Paris and Rouen. In all cases, there occurs a more or less important amount of algal constructions, oncolites, encrusted shells and branches, and also encrustments of the river floor. Optical and electron microscopic studies certify the great importance of algae in these constructions (*Rivularia* and *Phormidium*).

Some publications are in preparation, particularly for a meeting about "Quaternary travertines and tufas of the Seine and Somme Rivers drainage basins, and adjacent areas" (Rouen, November 14, 1989). The main topics of the meeting are: carbonate edifices; building organisms; relative chronology and paleoclimatology; datations; tufas and neotectonics. Organizer is F. Lecolle, 20 rue Baudet, 78840 Fréneuse, France.

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Spectacular domed microbial mats (cabbage heads) and oolitic limestone at Lester Park near Saratoga, New York [Northeastern Geology, 1988, 10, 8-12]

This is the site of one of the finest examples of domed stromatolites to be seen anywhere in ancient rocks. These structures, which are part of the Hoyt limestone of late Cambrian (Trempeleauan) age, were described by James Hall as early as 1847. An earlier study at this site drew attention to the first discovery of ooids in North America (Steele, 1825).

Stromatolites are laminated, lithified deposits formed by cyanobacteria, and consist of alternating layers of calcite and dolomite. On the east side of the road in Lester Park a glaciated surface exposes horizontal sections of the cabbage-shaped heads composed of vertically stacked, hemispherical stromatolites. The algal heads are discrete club-shaped or columnar structures built of hemispheroidal stromatolites expanding upward from a base. The heads, many of them compound, are circular in horizontal section, and range in diameter from a few centimeters to a meter. The size of the larger heads suggests that they formed in highly turbulent waters. Between the heads are skeletal fragments of trilobites, brachiopods, and pelecypods.

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Stromatolite Handbook

I have been busy collating information for the handbook on stromatolite descriptions to be produced by IGCP 261. A preliminary draft was presented at the Mauritanian meeting, and a second draft incorporating changes suggested by meeting participants is presented in this volume. I have been promised sections on special topics by other authors. I encourage comments on this second draft from all stromatophiles, and hope that the Washington IGC in July will provide a good forum for open and constructive comment. The emphasis of this part of the handbook is on how to describe stromatolites. This is in response to discussions by IGCP participants who stressed the need to standardise descriptive methods - the more controversial issues of whether to call them stromatolites or microbialites, or the value of binomial taxonomy, are only briefly considered, and are felt to be mainly a matter of author's preference.

Stromatolite Projects

The highlight of 1987 was the visit of Misha Semikhatov and Andy Knoll for a field trip to the western Bangemall Basin. This gave Misha and I a valuable opportunity to compare working methods and discuss ways of rationalizing stromatolite descriptions as part of the IGCP 261 Special Interest Group in Taxonomy. The short trip allowed us to examine the basal Bangemall Group and assess the potential of stromatolites for more detailed correlation than has previously been possible (see below). Andy Knoll collected an extensive suite of black cherts for microfossil studies. Misha and I examined the extensive stromatolite collection of the Geological Survey of WA during his visit. With few exceptions (eg. *Pilbaria perplexa*), WA forms have little in common with Russian forms, suggesting marked provinciality.

This provinciality was further emphasized by the stromatolites examined during the Mauritania meeting in December 1988. Although the sequence around Atar is approximately the same age as sequences in Western Australia, the stromatolite forms show little similarity.

Although inter-continental correlations may still not be practical, stromatolites continue to be extremely useful for correlations within Western Australia. In recent years they have been used to help distinguish between the 1.8 Ga Glengarry Group and the 1.7 Ga Earaheedy group in the Glengarry Sub-basin, and my main work in 1989 will be to describe the forms collected in the last few years. After that I will begin writing up the extensive collection of late Proterozoic stromatolites from the Bangemall Group and overlying sequences.

Recent Advances in Western Australian Biostratigraphy

The state's stratigraphy has recently undergone substantial changes as a result of mapping carried out by the Geological Survey of Western Australia. The new stratigraphic interpretations are summarized in the recently issued 1:1 000 000 Geological State Map. From a biostratigraphic viewpoint, the new stratigraphy resolves some previously anomalous stromatolite occurrences. For example, *Acaciella* cf. *A. australica* from the Skates Hills Formation, supposedly about 1.1 Ga, has closer affinities with a 0.8 to 0.9 Ga Bitter Springs form, an interpretation in keeping with the latest stratigraphic evidence.

The oldest part of the Bangemall sequence, containing *Conophyton garganicum austraiis, Collonella* and *Paniscollenia* new forms, is now thought to be between 1.6 and 1.4 Ga from isotopic Pb/Pb dating. This includes the Irregully Formation and its equivalents. The former upper Irregully Formation and Top Camp Dolomite are now separated from the underlying sequence by a disconformity, and have been re-defined as the Gooragoora Sandstone and Cheyne Springs Formation. The Cheyne Springs Formation contains *Baicalia capricornia* and *Conophyton* new form. *B. capricornia* also occurs in the Uaroo Group, indicating a correlation with this part of the Bangemall Group.

Stromatolites in the overlying Bangemall Group still need re-assessment. Another form of *Conophyton* occurs in the Backdoor Formation in the only part of the sequence now thought to be about 1.1 Ga, and is similar to a Manganese Group *Conophyton*. The Manganese Group is thought to correlate with this upper part of the Bangemall Group proper.

The Yeneena Group and Waltha Woora Formations can be correlated with each other using stromatolites, and unconformably overlie the Manganese Group. The Yeneena

Group seems to be about 0.8 to 0.9 Ga from some preliminary dating and it is apparently unconformably overlain by the newly-defined Savory Group, which incorporates sandstone units previously assigned to the Bangemall Group in the eastern Bangemall Basin. This sequence contains late Proterozoic glacials and is therefore about 0.75 Ga or younger. The lower part of this sequence contains the Skates Hills Formation with the no-longer anomalously occurring *Acaciella* cf. *A. australica*.

A considerable amount of work remains to be done. Some of the stratigraphic relationships require further delineation, but the broad picture which is emerging is strongly supported by the stromatolite evidence. Detailed description of the stromatolites will be part of my programme for the next few years.

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Current Research:

l. Stromatolitic microbiota from Middle Proterozoic Bylot Supergroup, Baffin Island (with G.D. Jackson).

2. Morphometric studies of stromatolites and trace fossils, using an image analyzer, are continuing. Ph.D. student Lawrence Bernstein is using this method to characterize the biosedimentary structures of the Lower Ordovician Beekmantown Group of the Ottawa - St. Lawrence valleys (Quebec and Ontario).

3. A tentative classification of stromatolites based on size is being evaluated (see table next page).

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SIZE CLASSIFICATION OF STROMATOLITES
H.J. Hofmann

WIDTH (m)	SCHEME A	SCHEME B	EXAMPLES	REMARKS
	kilometric			
10^3		GIGASTROMATOLITES		
	hectometric		Biostromes	
	decametric	MEGASTROMATOLITES		
	metric		Bioherms	
10^0				
	decimetric	MACROSTROMATOLITES		◊ H
	centimetric	MESOSTROMATOLITES	*Gymnosolen*	
	millimetric	MINISTROMATOLITES	*Pseudogymnosolen*	◊ S
10^{-3}				
	submillimetric	MICROSTROMATOLITES	*Frutexites*	
10^{-6}				◊ R

Letters in the remarks column of the table refer to limits imposed on the study of stromatolites: H = upper size limit for handling of specimens; S = lower size limit for sawing of specimens; R = lower limit of resolution of optical microscope)

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Stable isotopes of lacustrine stromatolites from the Permo-Carboniferous Saar-Nahe Basin (SW-Germany): Preliminary Results

The stromatolites of the Saar-Nahe Basin are the best developed microbialites within the Permo-Carboniferous intermontane basins of Europe (Schäfer and Staff, 1978). They comprise both domical and tabular forms (see frontispiece). In the frequently occuring lacustrine deposits, stromatolites are very abundant. They occupy near shore zones and swells of some lakes in the Rotliegend strata of the Saar-Nahe Basin.

In the uppermost Carboniferous lake system and in some Rotliegend lake systems, stromatolites directly overlie thin coal seams. In other Rotliegend lake systems, they alternate with bituminous black shales which are typical of pelagic zones of hydrologically open lakes in the Kusel and Lebach Groups (Fig. 1). The stromatolites of the younger Nahe Group are interbedded with reddish mudstones, indicating a development towards hydrologically closed lakes (playas) during the Rotliegend (Stapf, 1982). The measurement of stable isotope ratios in naturally occuring materials has become a valuable source of information on the origin and paleoenvironmental history of those materials (Schidlowski, 1988). The present investigation gives, for the first time, results of carbon and oxygen isotope distributions in lacustrine stromatolites from a 3.5 km thick sequence from Upper-Carboniferous to Upper-Rotliegend (Höhn and others, 1989).

The mineralogical composition of the stromatolite samples shows a domination of either calcites or dolomites. The coexistence of both minerals in significant quantities is extremely rare. Detrital quartz is present in varying amounts (two samples contain volcanogenic SiO_2, Fig. 1). The initially deposited carbonate phases in the stromatolites were Mg-calcites. Depending on the local sedimentary environment (in terms of different permeability and porosity), some of the calcites were subsequently converted to dolomites due to very early diagenetic processes.

The carbon isotope data show different compositions of calcites (mean $\delta^{13}C_{carb.}$ = +1.13% PDB) and dolomites (mean $\delta^{13}C_{carb.}$ = -3.5% PDB). The positive $\delta^{13}C$ values of the calcites coincide with the field of normal marine limestones (Keith and Weber, 1964). Consequently, these data are no longer considered to be useful as a reference (this topic was also discussed during the EUG-V meeting in Strasbourg, March 1989). The water of the Rotliegend lakes could have changed its composition due to increased productivity. Planktonic algae as well as macrophytes, selectively extract ^{12}C for their tissues. Consequently a continous depletion of ^{12}C from the lake water may have occurred leaving the residual carbon pool enriched in ^{13}C. Another possible explanation could be an input of additional ^{13}C enriched CO_2 to the lake water through volcanic springs because of volcanic activities in the vicinity of some stromatolite sites during the Rotliegend. However, a comparison with isotope data from lacustrine and hydrothermal stromatolites from the African Rift Valley lakes (Casanova and Hillaire-Marcel, 1987) seems to rule out this possibility.

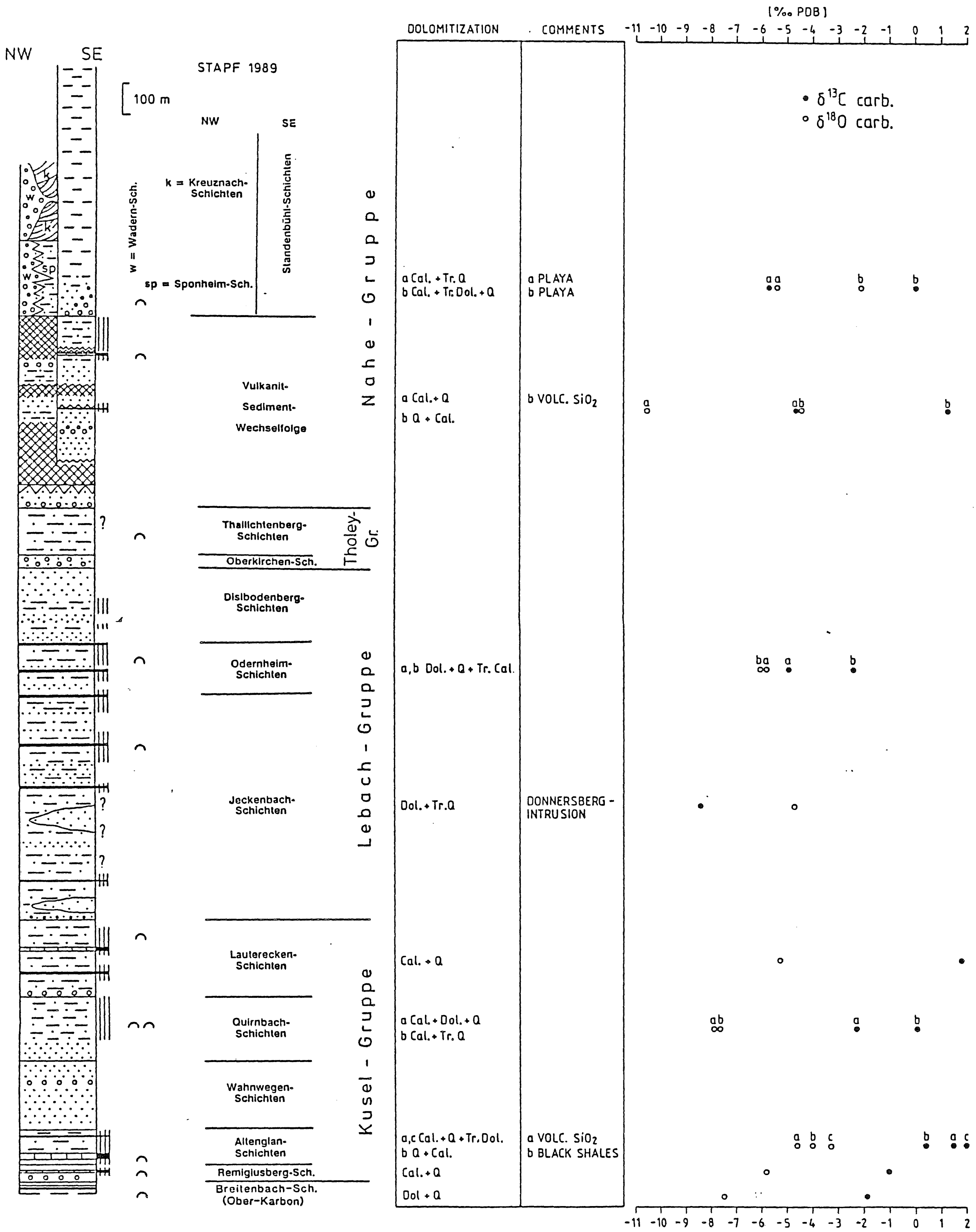

Fig. 1. Stratigraphic section from the Upper-Carboniferous to Upper-Rotliegend with isotope data. Semi-circles mark stromatolite occurrences and sample sites. Vertical signature points to massive limestone units.

The $\delta^{13}C_{org.}$ values of all samples scatter around -25% PDB throughout the profile (organic carbon content between 0.2 and 0.6%). Therefore the stromatolite-building microorganisms do not reflect environmental changes from freshwater to playa conditions with regard to isotope data of the organic matter.

Participants in this investigation are M. Schidlowski (Max-Planck-Institut für Chemie, Mainz) and K. Stapf (Institut für Geologie, Universität Mainz). Our future work will concentrate on selected parts of the Permo-Carboniferous profile, including non-stromatolitic material (black shales etc.). Furthermore, it is planned to extend the isotope analyses to younger stromatolitic strata from the Zechstein and Buntsandstein in cooperation with J. Paul (Universität Göttingen), including the samples from the Kalkowsky Locality displayed in the fourth circular of IGCP Project 261.

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Miocene Tidal Flat Stromatolites, Dam Formation, Saudi Arabia

Stromatolites occur in the lower part of the Miocene Dam Formation of Saudi Arabia, which consists of three upward-deepening cycles in the Al Lidam area. Stromatolites are present at the top of the third cycle. A typical upward-deepening cycle begins with supratidal gypsiferous claystones grading upward into intertidal sandstones and shallow subtidal to lower intertidal limestones and thin-bedded oolitic grainstones. Symmetrical, flat-topped ripple marks and low-angle planar cross-bedding, showing a bimodal pattern, are common in the oolitic grainstones. Stromatolites occur on top of the oolitic grainstones and form a 50-80 cm thick unit at the top of the third cycle. Stromatolites occur as closely spaced, discrete columnar structures which range from 2 to 5 cm in cross section and from 3 to nearly 20 cm in height. The columns comprise fine laminae with well-developed fenestral fabric. Oolitic grainstones containing abundant stromatolitic intraclasts, derived from the columns, overlie and fill areas between stromatolitic columns.

The lithologic characteristics and faunal content of the oolitic grainstones indicate that these strata were deposited in a shallow subtidal to lower intertidal environment. The discrete columnar shapes and fenestral fabric of the stromatolites, and their association with oolitic grainstones, indicate that these forms grew in the same environment in which oolitic grainstones were formed.

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My research and that of some of my students has dealt with late Paleozoic Ostracoda associated with low-relief, tabular, algal stromatolites. In a study of Lower Permian rocks of the Midcontinent of North America, we have extracted ostracodes from stromatolitic limestone by crushing. Fortunately, most of the ostracodes are smooth and pop out of the limestone with little difficulty. We are of the opinion, which we unfortunately cannot substantiate scientifically, that some of the ostracodes, especially *Paraparchites humerosus* are responsible for much of the damage the stromatolites have received and, perhaps, have produced much of the relief on them as well.

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Cambro-Ordovician Thrombolites, western Newfoundland

Most of my effort over the last few years has gone towards completing my PhD thesis "The structure and origin of Cambro-Ordovician Thrombolites, western Newfoundland", Memorial University, Canada. Preliminary results of this study were presented by Kennard and James (1986a,b). A major aspect of this study was the development of an integrated scheme to systematically analyse the structure and interpret the origin of thrombolites. This scheme utilizes a three-tiered analysis of microbial buildups: 1) megastructure, the overall bed form, 2) mesostructure, the internal fabric, and 3) micro-structure, the microscopic fabric. This scheme has proved equally applicable to Cambrian and Ordovician thrombolites, stromatolites, *Epiphyton-Renalcis-Girvanella* "microfossil" boundstones, and mixed microbial-metazoan buildups in western

Newfoundland, elsewhere in North America and central Australia, and highlights differences between these types of buildups.

It has proved useful to introduce a new term "**thromboid**" to refer to the mesoscopic, millimetric to centimetric-sized clots (cryptalgal clots *sensu* Aitken, 1967; mesoclots *sensu* Kennard and James, 1986a) that construct the structural framework of thrombolites. This term was chosen to emphasize and facilitate comparisons between thrombolites and stromatolites; thus thrombolites are composed of thromboids and interframework sediment, whereas stromatolites are composed of stromatoids (superimposed laminae; Kalkowsky, 1908) with or without interframework sediment. Thromboids display a wide variety of shapes and arrangements (Fig. 1).

Microstructural analysis (Fig. 2) indicates that Cambro-Ordovician thrombolites were most commonly constructed by relatively complex coccoid or coccoid-dominated microbial communities, and that the dominant process involved in their formation was *in situ* calcification of the microbial community. This calcified community formed a rigid framework between which autochthonous and allochthonous sediment accumulated. In contrast, co-occurring stromatolites were most commonly constructed by internally well differentiated filamentous or filament-dominated communities, and the dominant process involved in their formation was mechanical trapping and binding of detritus, either alone or in combination with *in situ* calcification of the microbial community. Thrombolites are commonly associated with a diverse and abundant metazoan fauna, whereas metazoans are rarely associated with stromatolites.

Thrombolites and stromatolites within shale-carbonate cycles, central Australia

Thrombolites and stromatolites are widespread within shallowing-upward carbonate cycles in the Middle-Late Cambrian Shannon Formation in the Amadeus Basin, central Australia. Stromatolite-dominated intertidal cycles in the lower part of the formation, and thick subtidal based thrombolite-dominated cycles in the upper portion of the formation, record ecologic successions of benthic microbial communities in response to sea-level and\or climatic fluctuations and shoaling sedimentation. Distinct microbial communities colonized successive environments differentiated by water depth, tubulence, frequency of exposure, abundance of metazoans, salinity and supply of detrital sediment. Systematic analysis of the mega-, meso- and micro-structure of these microbialites enables an evaluation of the relative biological and environmental contributions to their morphogenesis: megastructure is primarily controlled by environmental factors;

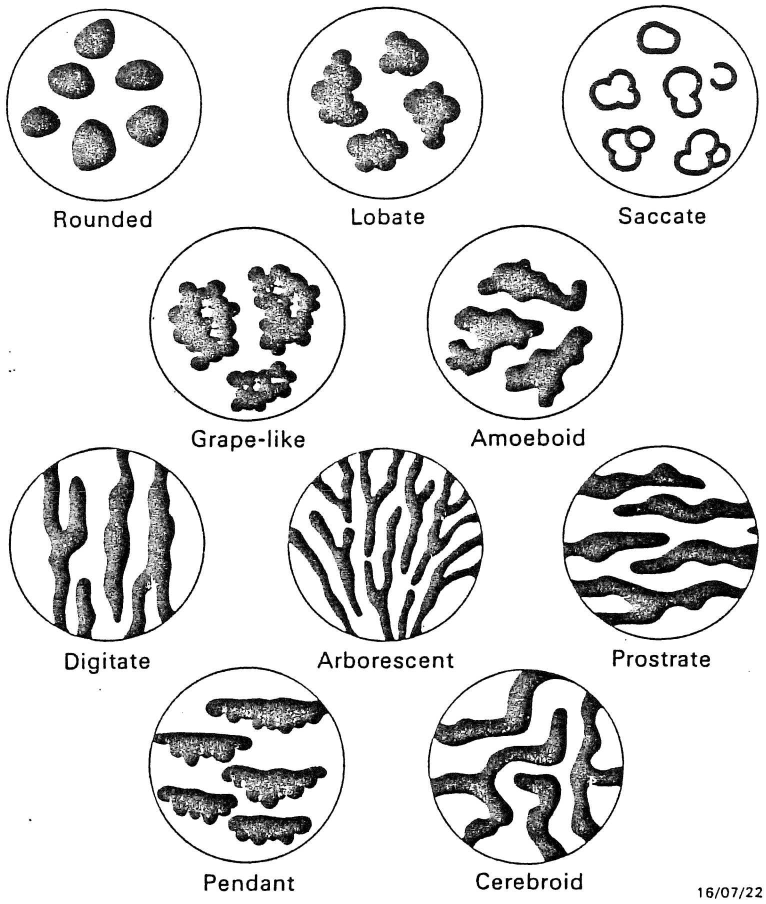

Figure 1. Schematic illustration of thromboids

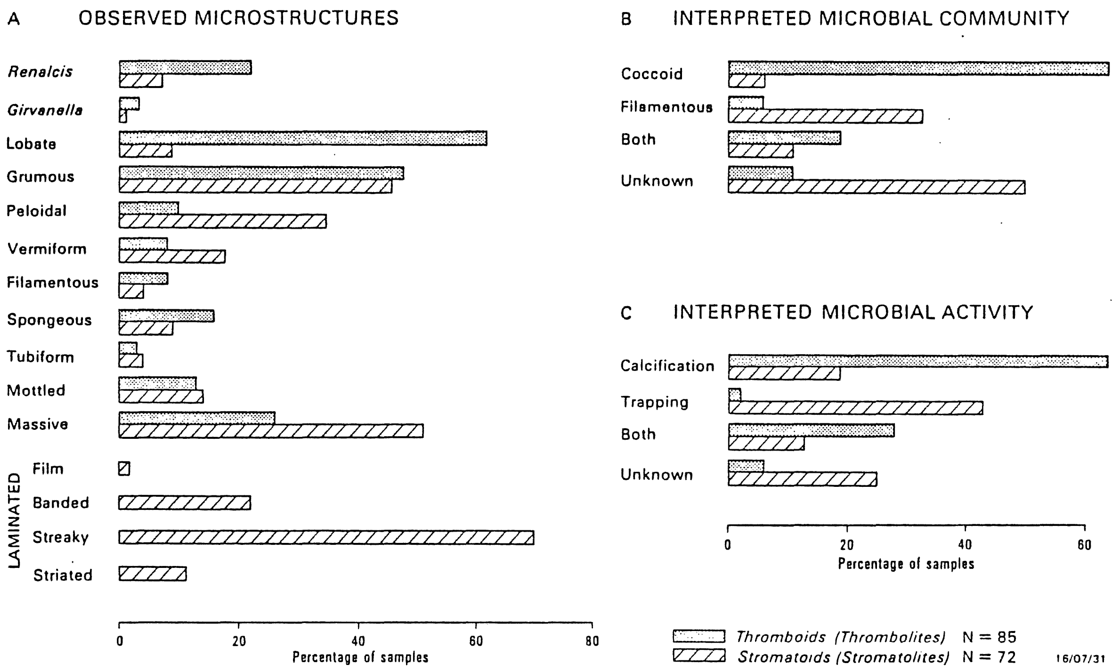

Figure 2. Comparative analysis of (A) observed microstructure, (B) interpreted microbial community, and (C) interpreted microbial activity of thromboids (thrombolites) and stromatoids (stromatolites).

mesostructure is controlled by a complex interaction of biological and environmental factors; microstructure is controlled by the microbial community and commonly provides evidence of the internal organization and composition (filamentous or coccoid) of that community.

Based on estimates of the absolute age of the Shannon Formation and the number of cycles measured at five sections, the period of the shale-carbonate cycles is estimated to be 45000 - 130000 years. That is, within the Milankovitch band. Fourier spectral analysis, however, does not provide conclusive evidence of a spectrum of Milankovitch signatures.

In collaboration with David Des Marais (NASA, Ames Research Centre, California) the carbon and oxygen isotopic signature of the thrombolite\stromatolite cycles is being studied to evaluate the relative importance of biological versus environmental isotopic fractionation.

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In collaboration with Prof. G. Müller of the Institute für Sedimentforschung, Heidelberg University, West Germany, I proposed a model for the genesis of Middle Riphean Gangolihat phosphatic stromatolites of the Lesser Kumaon Himalaya, Uttar Pradesh. The phosphate, in the form of carbonate fluorapatite, is exclusively associated with stromatolite-bearing horizons. The apatite characteristically occurs as an envelope around columnar stromatolites as well as stromatolite laminae, and as intraclasts within intercolumnar spaces of stromatolites.

It is envisaged that the columnar stromatolites grew in a lagoon. The rate of sedimentation was very very slow and there was almost no supply of terrigenous material. Subsequently, intercolumnar spaces were filled with sediments rich in organic matter. This resulted in the development of two distinct microenvironments; one above the sediment/water interface, and the other below the sediment/water interface. The organic matter in the sediment was attacked by bacteria and in this way phosphorous was released. Except near the sediment/water interface where phosphorous was lost to the normal marine water, the liberated phosphorous made the pore water relatively richer in phosphorous content. The two microenvironments supported two distinct microbial conmunities. One microbial community flourished above the sediment/water interface and was responsible for the normal growth of the columnar stromatolites,

while another microbial community developed below the sediment/water interface and was dominated by sessile bacteria. This latter community attacked the stromatolite surfaces, including oncolites and stromatolitic intraclasts, because food was available for the microbial community on these surfaces. This microenvironment was oxygen deficient where sessile bacteria flourished by utilising the available phosphorous in the ambient environment either by directly secreting calcium phosphate around its cells or by forming encrustations around those surfaces where food was available. Thus carbonate fluorapatite was formed by an early diagenetic process by the participation of the sessile bacteria.
A similar origin can be suggested for the Middle Riphean phosphatic stromatolites of the Tirohan limestone (Lower Vindhyan) of Central India.

One of my students, Miss Purnima Srivastava, is working on the Deoban microbiota (Riphean) of Garhwal Lesser Himalaya, Uttar Pradesh. This work is based on petrographic thin section study of black bedded chert which has yielded a diverse and well preserved microfossil assemblage comprising both filamentous and coccoid forms. However, filamentous forms dominate the assemblage. 23 species of coccoid forms belonging to 19 genera have been identified. Of these, *Myxococcoides minor, Glenobotrydion aenigmatis, Eosynechococcus isolatus, Melasmatosphaera media* and *Huroniospora psilata* are the most dominant coccoid forms, and they constitute about 50% of the coccoid population. In the case of filamentous forms, 15 species belonging to 12 genera have been identified. *Biocatenoides, Gunflintia* and *Eomycetopsis* constitute about 50% of the assemblage of microfossils. At least two generations of filamentous forms could be recorded in the present assemblage.

Recently, work on a new Project entitled "Stromatolite Biostratigraphy of the Vindhyan Supergroup" has started. The project has been sanctioned by the Department of Science and Technology, New Delhi.

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Research is in progress on recently discovered stratified microbial communities in laminated intertidal sediments north of Estero El Puente, near San Carlos, Baja California Sur, Mexico.

The sediments range in thickness from 0.5 to 30 cm and are found in and along meandering, mangrove-lined, tidal channels. Extensive areas (metres square) of desiccation polygons are found in a number of pond-like, isolated channel meanders. Microscopic observations in the field and spectrophotometric analysis of acetone-extracted pigments have identified the pricipal microbial constituents of the various morphotypes of microbial mats found at Estero El Puente. Typically *Microcoleus, Lyngbya* and *Oscillatoria* mats cover extensive areas, though other cyanobacteria such as *Anabaena* and *Spirulina* as well as many diatoms are evident. The reddish layers of the microbial mats contain *Rivularia-Calothrix*-like organisms as well as phototrophic bacteria such as *Chromatium* and *Chloroflexus*.

The San Carlos site, part of the Sub-Provincia, La Purisima-Iray, lies in a thick Cenozoic sequence dating from the Paleocene to the present. Facies include marine terrace, beach ridge and lacustrine deposits. The Estero El Puente region is dominated by swale topography with extensive beach ridges parallel to the coast. The height of the ridges declines from east to west; that is, towards the sea. The troughs between many of the beach ridges also contain stratified microbial communities, some up to 10 km from the ocean. The beach ridges are believed to be associated with the tectonic uplift of the Baja California Peninsula. The contemporaneous marine transgression created hypersaline coastal lagoons through capillary evaporation and infiltration. The limited relief along the coast of Puerto San Carlos BCS has led to the formation of meandering, mangrove-lined, tidal channels containing laminated microbial mats.

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I have studied stromatolites from the calcareous facies of the Chutiya Formation, Semri Group (Middle Proterozoic), and Sirbu Shale Formation, Lower Bhander Group (Late Proterozoic). The Chutiya Formation stromatolite is morphologically alike *Newlandia* Walcott, indicating barrier coastline deposition. A new form of *Tungussia* was identified from the Sirbw Shale; it is highly branched and has bridge connections indicating shallow, agitated water conditions. Stromatolites of Vendian age have been collected from the Bulywan Limestome Formatiom, Vindhyan, exposed around Lakheri Rajasthan. This bed is overlain by the Dholpur Shale Formation which contains Ediacaran fauna (*Cyclomedusa, Ediacara, Medusinites, Dickinsonia*). This is the first report of Ediacaran fauna from the Precambrian of India.

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Microbial constituents in Quaternary travertine deposits in parts of Orissa Sate, India (M.M., S.D.)

Travertine deposits of Quaternary age occur at several places in Phulbani and Puri districts, Orissa State, India (Fig. 1A). The deposits occur along or close to stream courses presently (or formerly) flowing in a hilly Pre-Cambrian terrain of crystalline rocks like gneisses, granulites etc. They are generally found at [sites of] steep gradient along the stream course such as rapids, water falls or where boulders protrude above water level. These sites are principally the loci of vigorous agitation and provide a niche for algae and mosses which positively influence carbonate precipitation and encrustation processes. The deposits are generally massive, lenticular or somewhat irregular. They measure 5-120 m in their longest extension and are 2-30 m thick. The deposits are varyingly covered by living bryophytes (principally mosses) and pteridophytes. Watery substrate is rich in blue-green algae. Laminated algal crusts occur conspicuously as an organic constituent in the travertine, being associated at places with carbonate encrusted moss-rich deposits. They form stratified deposits, may show slight arching and contortion, drape over moss-rich pockets as hemispherical bulgings and may show swirly horizontal to subvertical stratifications. There may be other orientations with laminae paralleling the substrate. The laminae locally appear spongy with alternation of zones of light brownish and deeper yellowish brown colour 5 mm and 2 mm thick, respectively. At places the crusts are relatively more compact with wrinkle marks on the surface, laminae are 1.0-1.5 mm thick with alternating thin, darker, undulating laminae. Laminae thickness varies within a deposit. Microscopic examination shows the presence of bushy, thin filaments in calcite spar. These may be densely packed or loose with pore spaces between the filaments. The bushy filaments appear to radiate out roughly perpendicular to the laminae. The filaments may be broken and loosely dispersed in the rock. The cyanophyte with unbranched, thin cylindrical form, apparently with elongate cells, probably belongs to the genus *Phormidium*. These bushy layers merge into relatively darker yellowish brown laminae in which there are short, curved or slightly larger wavy algal strands which may belong to the genus *Schizothrix*. Love and Chafetz (1988) documented similar observations. There are darker micritic to microsparry patches associated with the wavy algal strands. Neomorphism has varyingly affected carbonate grains. At places there are small clots which may show a beaded pattern. Voids are also present. Phosphate and nitrogen concentration and light may control the growth and periodicity of the algal-rich layers. Diffuse to spherical clumps, probably bacteria, occur in the travertine carbonates. They appear darkish, opaque to brownish in thin sections, range from 10 μm to less than 100 μm in diameter, and are surrounded by calcite crystals. Surficially, the bacterial mat appears whitish. Bacterial precipitation of calcite around gas bubbles has locally formed "foam rock" (Chafetz and Folk, 1984). Bacterial shrubs looking like tiny cauliflower-shaped heads occur in gentle depressions in the deposit. Size varies from less than a millimetre to about 1 cm. The inorganic travertines associated with organically constructed portions include spelean-like deposits. The organic and inorganic constituents reflect the wide range of micro-environments present in a travertine facies. The organic ecosystem is governed by a chemically dynamic equilibrium system in which the amount of dissolved carbon dioxide is a critical factor. Equilibrium may be altered biogenically by photo-synthesis, raising pH and leading to carbonate precipitation and encrustation processes.

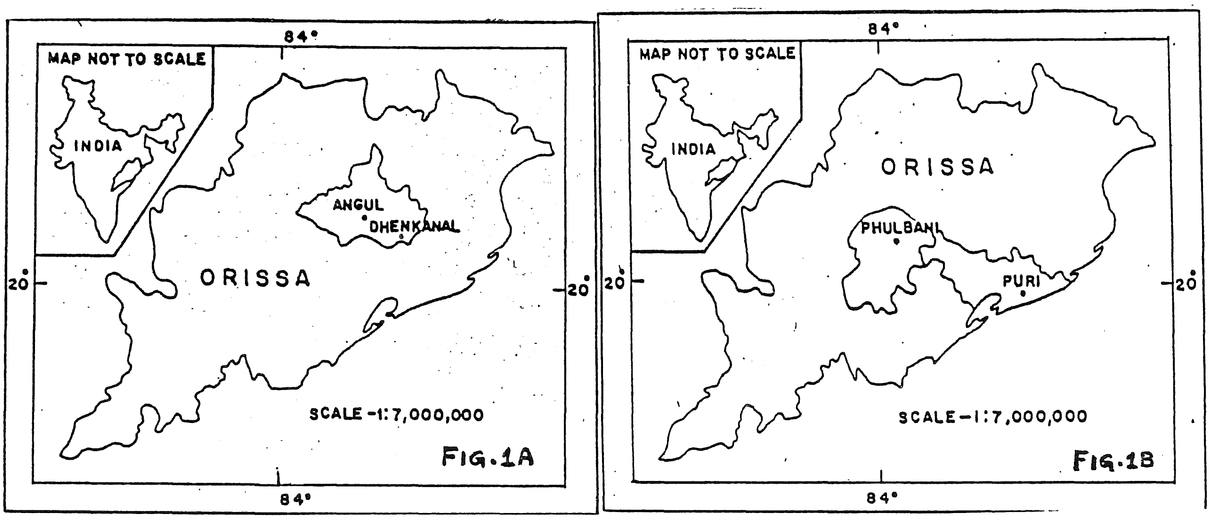

Figure 1. Maps of Orissa: (A) Puri and Phulbani districts, and (B) Dhenkanal district.

Laminated microbial carbonate crusts in ancient probable lake margin environment of the Talchir Gondwana Basin (Upper Carboniferous), Orissa State, India (M.M.)

Pandya (1987) reported some unusual structures in Member C of the Bedasar Formation (Pandya, 1984) of the Talchir Group near Bedasar village, about 8 km northwest of Angul town, Dhenkanal district (Fig. 1B), and ascribed an algal origin to them. The structures occur in a sequence of shales with nodular limestones 15-20 m thick. Pandya interpreted the Talchir Group of sediments to have formed in a lake delta with development of various facies such as distributary channels, subaquous delta platform, delta slope and pro-delta facies. The present observations are based on a newly located zone of microbial carbonate crusts, about 5 km east of the locality mentioned by Pandya (1987), by the side of the Nandira Jhor stream. The observations and remarks given, add further information to the understanding of these structures. The carbonate crusts occur in dark shales of about 10 m thickness as crudely very thin-bedded to thinly laminated, roundish to ovoid and discoidal bodies having a darkish grey to slightly brownish colour. They measure up to about 35 cm in diameter and 10 cm in height. Smaller elliptical to flattish discoidal forms also occur. At the contact with the overlying sandy beds, pockets of darkish carbonates occur and show some raised, thread-like, alignments. Along strike, in a zone about 0.5 km long and 20 m wide, at least 10 such ovoid carbonate bodies were observed. The central portion of the upper surface of the bodies is hard, slightly elevated and wrinkled, thinly laminated and is pitted in appearance, the pits being 1-2 cm in diameter and up to 1 cm deep. There are ridges and furrows as well. Around this central portion, occupying about 15 cm or slightly more in extension, the material is relatively softer and there are uneven ridges and depressions with irregular wrinkled laminations conforming to the outline of the bodies. A peeling off of material is seen. Dense, flattish, very thinly laminated bundle-like aggregates of irregular form, varying in width within 1 cm, traverse the surface. Longitudinal sections show dense carbonates of a slightly darker colour with very crude bedding and layers of fibrous calcite 0.1 to 2 cm high lying perpendicular to the very thin bedding or laminae. Fibrous calcite layers at places appear to be stacked one above the other. In extreme cases, the fibrous calcite forms conical bundles and the conical tips of the opposite bundles meet in cone-in-cone fashion. The sides of the cones show transverse ridges. Dark clayey laminae are also associated. Microscopic study reveals crowded filaments, often indistinct with an apparent vertical orientation, and interspersed undulating strands of greenish to yellowish brown colour which may be algal. Due to neomorphism, microspar and pseudospar have been formed. Pseudospar may range up to 100 μm in size. Fibrous calcite occurs in bundles showing conical tips. Layers of yellowish strands are ruptured and torn apart by fibrous calcite by force of the growing crystals. Within masses of fibrous calcite, relics of yellowish patches remain. Pseudospar and fibrous calcite are fractured indicating growth in a stress field. Field occurrence, morphology and micro-constitution suggest that cyanobacteria probably played a dominant role in forming the carbonate crusts and shaping them as discrete, ovoid buildups along the Lower Gondwana lake margin of the Talchir Basin (Fig. 2). In nutrient-rich lakes, biogenic carbonate precipitation by both planktonic and benthonic blue-green algae is prevalent. Precipitated carbonate sediments, along with surrounding siliciclastic clays and sands, might have been trapped and bound within the algal thalli. Crystallisation may have also occurred within the algal thalli in a microenvironment partially isolated from the ambient water. Organic and inorganic colloidal and fibrous systems could influence crystallisation process. The disposition of fibrous calcite layers in the carbonate crusts suggests that their formation may have been controlled by algal thalli and its microenvironment. Specific biological properties and environmental influences need to be considered while evaluating encrustation processes. Organisms may initiate crystal nucleation and facilitate specific orientation of crystals. The ridges and furrows and peeling off of materials in the crust may be due to the cumulative result of several crustal cycles during which crustal growth and dissolution might have occurred. The crust may be growing due to prolific algal growth and carbonate deposition from a buffered carbonate saturated environment, whereas at the base, buried algal filaments

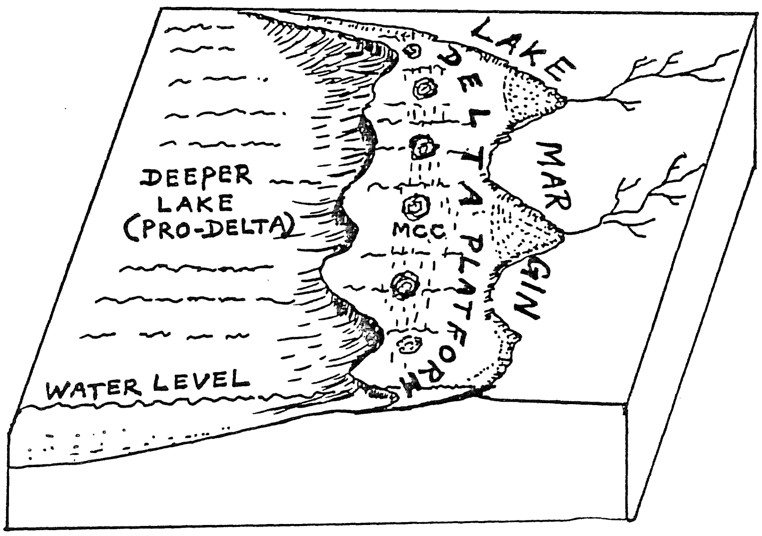

Figure 2. Schematic environmental model of lacustrine microbial carbonate crust (MCC).

might be undergoing bacterial decomposition and carbonate is dissolved due to the resultant accumulation of carbon dioxide (Golubic, 1973). The dissolution may be stopping and recolonisation by cyanobacteria may be starting a fresh cycle of crust formation. The bodies of lacustrine cyanobacterial crust may have the palaeogeographic significance of lacustrine shoreline marker.

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Studies on the microbial carbonates of Lake Clifton (Western Australia) continued throughout 1987 and 1988. These structures, formerly referred to as stromatolites, are more correctly termed thrombolitic microbialites as they are characterised by a clotted internal structure rather than fine planar laminae (Burne and Moore, 1987). The internal framework is calcified, composed of mineralised aggregates of *Scytonema* filaments. The framework is irregular, made up of mesoclots of aragonite with fenestrae in which unconsolidated sediments, including gastropod and ostracod shells and detrital pellets accumulate. The outer fenestrae are inhabited by large populations of isopods, amphipods, trichopteran larvae and small fish.

Gross external morphology varies between localities, being controlled by a range of environmental parameters including water depth, exposure time, sedimentation rates and erosion due to wave and current action. The dominant microbial components and the internal framework, however, remain fairly consistent with only slight variations evident in terms of the amount of cavity infilling, thickness of cavity linings, and the density of mesoclots. The internal structures and the textures are under microbial control.

In addition to the morphological types of thrombolites already described (Moore *et al.,*1983; Moore, 1987; and Burne and Moore, 1987), large columnar structures over 1.2 m high have been located in a channel towards the southern end of the lake. The channel has a maximum depth of 3 m but is less than 300 m wide. As a consequence a strong wind-blown current is present for much of the time. This has eroded away sediments from the sides and base of the channel exposing *Katelysia* shells. These shells are remnants of the marine phase of the lakeland formation and have become a substrate for microbialite formation. Tiny microbialites from 1-5 cm in diameter and generally 3-4 cm high have been found forming on the shells. This is the first record of such structures growing attached to a hard substrate in this lake, since all previously recorded formations were found growing in soft, unconsolidated sediments.

The major process of formation of the Lake Clifton thrombolites appears to be the precipitation of a mineral phase in a manner and environment determined by the character of the benthic microbial community, i.e. biologically influenced, non-skeletal calcification. The Lake Clifton thrombolites are comparable with the Cambrian thrombolites described by Kennard and James (1986), although the major constructive microorganism in Lake Clifton is filamentous not coccoid. They also exhibit many internal and external similarities to the 'algal limestones' or tufa described by Brown (1964), Francis (1984) and Boscence (per. comm.) in the basal Purbeck facies of Lulworth Cove, Dorset, U.K.

Collaborative studies are continuing with Kathleen Grey of the Geological Survey of Western Australia and Bob Burne of the Bureau of Mineral Resources, Canberra. Dr Burne and myself recently investigated an occurrence of 'algal biscuits' in the Scott River area in the lower south-west of Western Australia. These structures, discovered by John Koeyers, bear a striking resemblance to the 'algal biscuits' described by Sir Douglas Mawson in 1929, from South Australia. They are composed of calcite and exhibit concentric laminations. They are flat structures ranging from a few millimeters to 13 cm in diameter. A variety of cyanobacteria have been found associated, but their involvement in the genesis of the structures is not clear at this stage.

Large tepee structures have been discovered along the margins of Lake Preston, south-west of Lake Clifton, Western Australia. Lake Preston is a hypersaline lake; salinity ranged from 42 g L^{-1} to 78 gL^{-1} in 1984. The tepees are present in the indurated platform that covers much of the eastern foreshore. The underside of the tepee plates is coated in a blackish substance composed for the most part of manganese. Further investigations are being carried out on these formations to determine whether microorganisms are involved in the process of formation. Studies of thin sections and chemical data from a number South Australian Lakes, the tufa deposits from Augusta and stromatolites from Pink Lake , Western Australia are continuing.

During 1988, stable isotope and hydrogeochemical studies were undertaken in association with Dr J Turner of the Division of Water Resources, CSIRO. These data provide three separate lines of evidence for the intrusion of fresh alkaline groundwaters along the eastern shore of Lake Clifton and highlight the close groundwater-lakewater relationship. The thrombolites are intimately associated with the region of groundwater influx, and a ^{13}C isotopic study of the inorganic carbon that constitutes these structures demonstrated that carbonate deposition is being mediated by biological rather than inorganic processes.

Over the past three years, there has been a noticable increase in the growth of the green alga, *Cladophora*. Parts of the microbialite reef formation at the northern end of the lake appear to be the worst effected at this stage. The green alga is coating the structures which could prove deleterious to the continued growth of these microbial carbonates as they rely on the photosynthetic processes of the cyanobacteria for their genesis. Increased land use and development along the eastern shore may result in nutrient enrichment through groundwater resurgence. This increase in the growth of *Cladophora* has led to a preliminary study of the current nutrient status of the lake water and the groundwater. Initial results indicate a ten-fold increase in total phosphorus compared to base-line data collected in 1979. It is not yet clear whether the increased nutrient load is entering the lake exclusively through groundwater or whether it is a combination of this and elevated surface runoff produced by extensive clearing near the eastern shoreline.

Collaborative scanning electron microscopic studies have been undertaken with Dr Alain Couté of the Muséum National d'Histoire Naturelle, Laboratoire de Cryptogamie, Paris, to describe the major constructive microorganisms of the Lake Clifton thrombolites to species level and to elucidate various aspects of cyanobacterial physiology. A more diverse fauna is now known to be associated with the Lake Clifton thrombolites than was initially recorded. In addition to a variety of crustaceans, polychaetes and nematodes, recent sampling has yielded sea anenomes and bryozoans from the thrombolites. A third genus of teleost (*Favanogobius*) has also been recorded. It is becoming increasingly obvious that the thrombolites are an important ecological component of the lake environment and their role can in several ways be considered analogous to coral reefs in open marine systems.

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Stromatolites of the Sierras Bayas Group, Upper Proterozoic of Olavarría, Sierras Septentrionales, Argentina

The Sierras Bayas Group is the oldest non-metamorphosed sedimentary sequence known in Argentina. It outcrops close to Olavarría in the Sierras Septentrionales of the Buenos Aires province, in the central eastern part of Argentina (Fig. 1). This group is divided into three formations: Villa Mónica Formation, Cerro Largo Formation and Loma Negra Formation. The Villa Mónica Formation is formed by siliclastic rocks in the lower part and dolomites in the upper part. The latter are 35 m thick, consist of three informal members (lower, middle and upper) and are mainly composed of stromatolites which show a wide diversity in morphology. These stromatolites have recently been studied in detail by Poiré (1987). An outline of that work is presented here.

The stromatolites of the Villa Mónica Formation have been studied on four different scales: megascale, mesoscale, small scale and microscale. The megascale shows that the lower and upper members are mainly composed of 0.5 - 1 m thick domal biostromes and 0.05 - 0.30m thick interbiostromal green shales. A few bioherms are present in the top of the unit. In the middle member they are absent, with only one level of *Cryptozoon fm*. In the mesoscale, two kinds of patterns have been distinguished dependent on the vertical and lateral arrangement of the stromatolites inside the biostromes. In one case, when the stromatolites do not present any variation along the bed, these bioconstructions have been named "monostromatolite layers". In the other case, "stromatolite cycles" are defined when there are changes in stromatolite morphology (cf. Serebryakov, 1976). Thus, three "monostromatolite layers" (Fig. 2, I-III) and six "stromatolite cycles" (Fig. 2, IV-IX) have been identified. The small scale has been used to look at the gross morphology and to classify stromatolites (Groups) and the microscale for the microstructure (forms).

Monostromatolite layers and their stromatolites are as follows:

I Flat laminated stratiform stromatolites (*Stratifera* fm.).

II Gently folded laminated stratiform stromatolites (*Gongylina* fm.).

III Globoidal laminated bulbous stromatolites (*Cryptozoon* fm.).

Figure 1.- Location map.

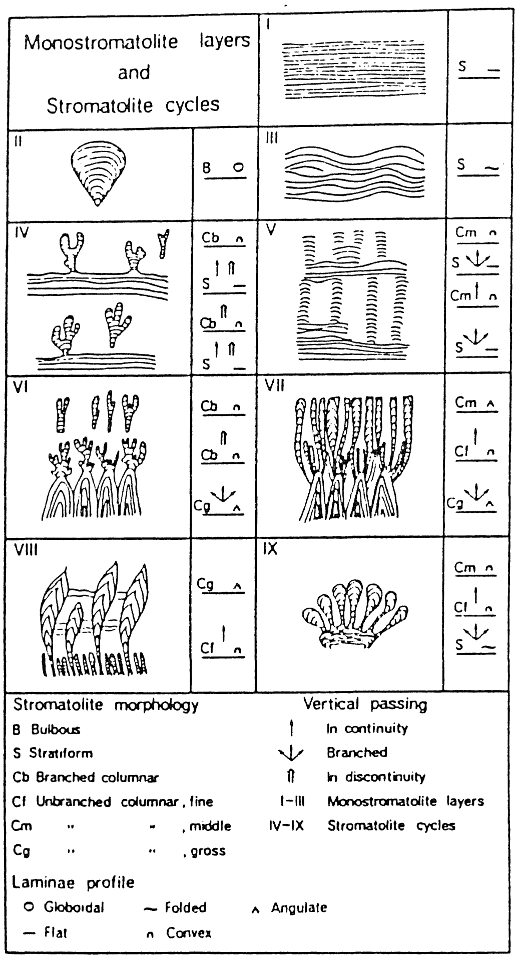

Figure 2.- Monostromatolite layers and stromatolite cycles of Olavarría.

Stromatolite cycles and their stromatolites are as follows:

IV Planar laminated stratiform stromatolites passing upwards (in continuity or in discontinuity) to convex laminated digitate columnar stromatolites (*Kotuikania* fm., *Katavia* fm. and *Stratifera* fm.).

V Gently folded laminated stratiform stromatolites grading upwards to convex laminated columnar stromatolites (*Kussiella* fm.).

VI Wide conical laminated columwar stromatolites with smaller columnar branching stromatolites in their apex. They pass upwards in discontinuity to different kinds of convex laminated columnar stromatolites (*Conophyton* fm., *Inzeria* fm., *Minjaria* fm., *Parmites* fm., *Parmites* cf. *concrescens, Gymnosolem* fm., *Jurusonia* cf. *nisvensis*).

VII Wide conical laminated columnar stromatolites with convex laminated smaller cylindrical columns branching from their apex. The growth of some columns in the last third of the biostrome suddenly stops, whereas others still continue to grow and widen upwards forming middle-sized conical laminated columns (*Conophyton ?ressotti* and *Jacutophytom* fm.).

VIII Convex laminated cylindrical unbranched columnar stromatolites. Some of them suddenly stop their growth while others develop wide conical laminated falcated columns (Colonella fm. and *Conophyton* fm.).

IX Wavy laminated gently domed stratiform stromatolites grading upwards to very close spaced convex laminated unbranched columns, which as a whole, show a dendroid stromatolite form.

Sedimentologically, each stromatolite cycle records changes in the hydrodynamic conditions during its growth, due to sea level fluctuations. Almost all of them (eg. VI, VII) are interpreted as shallowing-upward sequence (cf. James, 1984), while others (VIII) are interpreted as originating by deepening processes whenever the *Conophyton* Group is deeper than columnar stromatolites (cf. Donaldson, 1976).

The lower member shows both [shallowing and deepening trends] in each biostrome and in general, a shallowing-upward trend from high subtidal to low-middle intertidal zone. In contrast, the middle member is probably subtidal as indicated by the presence of isolated *Cryptozoon* (cf. Playford and Cockbain, 1976). The upper member again shows a shallowing-upward trend even more strongly than the lower member. The depositional environments probably ranged from high subtidal in the base (mainly *Cryptozoon* fm. and *Conophyton* fm.) to high intertidal in the top (domed bioherms, fenestral fabric, desiccation cracks and evaporite molds) covered by red shale with evidence of subaerial exposure.

An 800-900 Ma age for the stromatolitic assemblage of Olavarría is suggested (cf. Semikhatov, 1986). This Late Proterozoic age is also supported both by Cingolani (pers. comn.) who recorded a Rb/Sr 795 ± 28 Ma age for diagenetic clay minerals in interbiostromal green shales of the Villa Mónica Formation, and by a Rb/Sr age of 769 ± 12 Ma for the overlying Cerro Largo Formation (Bonhomme and Cingolani, 1980).

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Work on microbial structures continues to be focused mostly on Phanerozoic thrombolites and problematical microfossils, in both shallow- and deep-water settings. Participation in the IGCP Project 261 field workshop to Mauritania provided important experience with well-preserved pre-Cambrian stromatolites and strengthened my perception of (1) the "evolutionary" connection between deep-water *Conophyton* bioherms and Paleozoic mud-mounds, and (2) differences in reef characteristics as a function of depth. A large number of studies and manuscripts are in progress, including; Cambrian deep-water reefs and their place in the development of mud-mound fabrics; middle Cambrian thrombolite mounds from the Canadian Rocky Mountains (with Jim Aitken); Jurassic mud-mounds from offshore Nova Scotia (with Lubosh Jansa); Lower Cretaceous thrombolite mounds from Oman; and petrography of stromatolites from the middle Proterozoic Belt Group, southern Canadian Rocky

Mountains. Joint projects on mud-mounds with Isabel Zamarreno, Alexis Moussine-Pouchkine and Claude Monty are in the planning stage.

Readers should be aware of a proposed day-long session on mud-mounds planned for the 1990 meeting of the International Association of Sedimentologists in Nottingham. A special publication of the I.A.S. is planned to include review papers, original contributions as well as case studies dealing with mud-mounds.

Another volume of interest to most stromatophiles is Memoir 13 of the Canadian Society of Petroleum Geologists, a massive and yet inexpensive tome presenting over IOO case histories of Canadian reefs, many of which describe microbial structures.

Recent publications

Pratt, B.R., 1988a. The only known Precambrian reef in the Canadian Appalachians: Proterozoic stromatolites at Saint John, New Brunswick. In Geldsetzer H.H.J., and others (Eds.), Reefs, Canada and Adjacent Areas. Canadian Society of Petroleum Geologists, Memoir 13, 110-112.

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Pratt, B.R., and Smewing, J.D., 1989 (in press). Jurassic and Lower Cretaceous platform margin evolution, central Oman Mountains. In Robertson A.H.F., and Searle, M.P. (eds.), Geology and tectonics of the Oman Mountains and adjoining areas. Geological Society of London, Special Publication. [microbial-coral-stromatoporoid reefs comprise part of the facies spectrum]

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Present work is concentrated in the Nainital synform of the Krol-belt of Lesser Himalaya which comprises a sequence of Late Proterozoic to Early Cambrian age. The upper part of the Krol sequence of Nainital shows sporadic development of stunted columnar stromatolites, mainly *Columnocollenia* type. These stromatolitic dolomites of upper Krol unit contain an assemblage of *Renalcis* sp., *Epiphyton* sp. and *Solenopora* sp., suggesting an Early Palaeozoic age for these rocks. In the basal part of these dolomites, a zone of phosphatic rocks yielded Early Cambrian (Tommotian) shelly microfauna (*Olivooides* sp., *Hertzina* sp. *Lapworthella* sp., *Cambrotubulus* sp. and *Colooloides* sp). Below this in the middle part of the Krol Formation, a black chert yielded a Late Proterozoic microbiota containing *Caudiculophycus* sp.. Further down in the sequence in the Infra-Krol rocks, black chert nodules in carbonaceous shales yielded a Proterozoic microbiota assemblage comprising *Gunflintia minuta, Eomycetopsis robusta, Eosphaera* sp., *Palaeoanacystisverlgaris* and *Huroniospora* sp.

The following papers were presented at the Indo-Soviet Symposium on Stromatolites and Stromatolitic Rocks held at Dehradun, India, 30 September - 1 October, 1988:
1. Raha, P.K., Das, D.P., & Moitra, A.K. Fossil algae from the Krol Formation of Nainital synform, U.P. Himalaya, India, and their age significance. Abst., 21.
2. Raha, P.K., & Das, D.P. Correlation of Upper Proterozoic basins of India and its palaeogeographic significance. Apst., 41.
3. Raha, P.K., & Moitra, A.K. Biostratigraphic significance of Proterozoic microbiota from stromatolitic black chert of Jammu Limestone, Udhampur District, J. & K. State, India.

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Das, D.P., Raha, P.K., and Acharyya, S.K., 1987. Tommotian shelly microfauna from basal part of Upper Krol unit of Nainital synform, U.P. Himalaya, India. Indian Minerals, 41(4), 49-59.

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A sedimentation model of very large, flat, cratonic areas has been interpreted in Western Africa. It represents an extremely flat ramp where sedimentation is dominated by two processes: 1) rising sea level covers the area with a blanket of water and widespread columnar stromatolite biostromes are built, and 2) during a stable phase between sea-level rises, storm- and wave-dominated settings occur in which a mosaic of facies are deposited. No tidal influence can be recognized in these sedimentation areas (Bertrand-Sarfati & Moussine-Pouchkine, 1988; Bertrand-Sarfati and others, 1989).

The field trip organized by myself and Alexis Moussine-Pouchkine to Mauritania was centred on both stromatolites and sedimentation. Twelve specialists from diverse backgrounds (Stan Awramik, Bob Burne, Joel Casanova, Ian Fairchild, Kath Grey, Hans Hofmann, M. Julivert, Josef Paul, Brian Pratt and Isabell Zamarreno) spent 12 days in the field and all agreed that the outcrops were excellant and stromatolites magnificent (see notices, this volume). A meeting was held in Nouakchott before the field trip. Some field guides are still available.

In the near-future I plan to go to western Algerian Sahara (some 1000 km from Mauritania) to do further work, in collaboration with the Algerian Geological Survey (ONIG), on the sedimentation of cratonic areas. There it will be possible to study the borders of the cratonic area, and therefore to extend the interpretation of the sedimentation mechanisms.

During the Cardiff Fossil Algae Symposium meeting in 1988, Allan Pentecost was interested by the comparison of some Precambrian stromatolite microstructures (in tussocks) with freshwater stromatolites built by *Rivularia* and *Homeothrix*. I will give a talk on this in EUG Strasburg in March and we will publish the results soon.

I am also involved in a sedimentological study of an Upper Proterozoic carbonate group in central Africa. The proposed sedimentation model, based on the sedimentological features of the "Schisto-calcaire" in the Niari region, is that of a platform-to-carbonate-ramp comparable to the Persian Gulf setting (Bertrand-Sarfati and Milandou, 1987). Five prograding facies belts are recognized. Shales and ribbon limestones occur in the deeper ramp, and giant stromatolites and carbonates deposited in depressions of the stromatolite surface occur in the upper part of the ramp. These carbonates are buried by prograding oolite and sand shoals. The uppermost oolite layers display features of subaerial exposure. Protected by the shoal, the inner platform comprises lagoonal-to-sabkha sediments, essentially cyclic carbonates with stromatolites (Bertrand-Sarfati and Vicat, 1987) and tidal sediments, periodically emergent and displaying a cortege of diagenetic alterations due to evaporite growth and diagenesis.

The giant stromatolites represent a huge buildup. It has been recognized in three areas, spaced 40 km from east to west and 20 km from north to south. Stromatolites are complex anastomosing bioherms, with very low relief (less than 1 m) and reaching 100 m in length. They look like superimposed pillows with central low depressions filled with sediment deposited from suspension (very moderate energy). They have outer enveloping laminae and flat laminae, and when the buildups are superimposed they can reach 7-15 m high. They are deposited in moderate energy environments in the higher, basinward, part of the ramp; that is in the subtidal zone (Bertrand-Sarfati and Milandou, in press).

In the near future I will continue to work on the Congo sedimentation, especially the definition of diagenetic-evaporitic facies. A thesis will be defended by M. Milandou. In the more distant future, I hope to return to eastern Algerian Sahara to do more work on the Carboniferous stromatolites that I reported in 1978. I also have plans with Tom Fairchild to work on the Proterozoic stromatolites of Brazil.

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Stable Isotope Characterization of Carbonate Rocks (particularly stromatolites) in the Loves Creek Member of the Bitter Springs Formation, Australia

Collaborative work with Dr D. Des Marais (NASA) on stromatolites in the Loves Creek Member of the Bitter Springs Formation is centred upon the stable isotope characterization of 1) the various stromatolite form-taxon recognised by Walter (1972), and 2) the marine and lacustrine portions of the sequence (Southgate, 1986, 1989). Preliminary sampling of shallowing-upward cycles in the marine portions of the sequence indicates $\delta^{13}C$ values between -2 and -4 PDB and $\delta^{18}O$ values between -8 and -6 PDB. This contrasts with the lacustrine portions of the sequence where $\delta^{13}C$ values range between +3 and +5 and $\delta^{18}O$ values lie between -1O and -2. A field trip is scheduled for September 1989 and during this trip it is planned to sample limestones and dolostones in marine stromatolite cycles and lacustrine sequences at Ross River, Jay Creek, Ellery Creek and Katapata Gap. These surface samples will be complimented by material from the Alice Springs BMR 27 and 28 boreholes drilled at Corroborree Rock and Ross River, respectively.

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My research project on the Late Precambrian - Lower Cambrian stromatolites and microbiota from the Lesser Himalaya is continued after coming back from USSR in 1987. I visited USSR (1986-87) under an Indo-Soviet Scientific Exchange Programme and got an opportunity to work and discuss with Soviet specialists on stromatolites. The stromatolites from type sections of Riphean, Vendian and Lower Cambrian of the Russian platform, Siberian platform and Central Asia were studied and compared with the Indian Late Precambrian - Lower Cambrian sequence. The stromatolite collections of Drs. M.A. Semikhatov, (Mrs.) M.E. Raaben, V.A. Komar, I.N. Krylov (all of Geological Institute, GIN, Academy of Sciences, Moscow), Drs. (Mrs.) I.K. Koroljuk, I.G. Shapovalova and A.D. Sidorov (all of Institute Geologii Irazrabotki Govyuchikh Iskopaemikh, Fersmana, IGRGI, Moscow) and Drs. V.Yu. Shenfil and V. Khomentovski (Institute of Geology and Geophysics, Novosibirsk) were seen. The Palaeontological Institute (PIN), Moscow, and Institute of Geology and Geochronology, Leningrad, were also visited, and I interacted with specialists working on Precambrian and Cambrian palaeobiology (A.Yu. Rozanov), evolution of microbiota/acritarchs (V.N. Sergeev), metazoans/Ediacara fauna (Misha Fedonkin), *Vendotaenia* flora (Marine Gnilovskaya), cribicyathids (Tanya Sayutina), archaeocyathids (I.T. Zhuravleva) and earliest skeletal microfossils (V.V. Missarzhevskii and Nadezhda Esakova).

The biostratigraphic usefulness of the stromatolite taxa in the Precambrian and Lower Cambrian carbonates and phosphorites of the Lesser Himalaya has been assessed with special reference to the Precambrian-Cambrian boundary. The distribution of stromatolite taxa in time and space across the Precambrian-Cambrian boundary suggests that only Lower Riphean to Lower Cambrian taxa are found in the Lesser

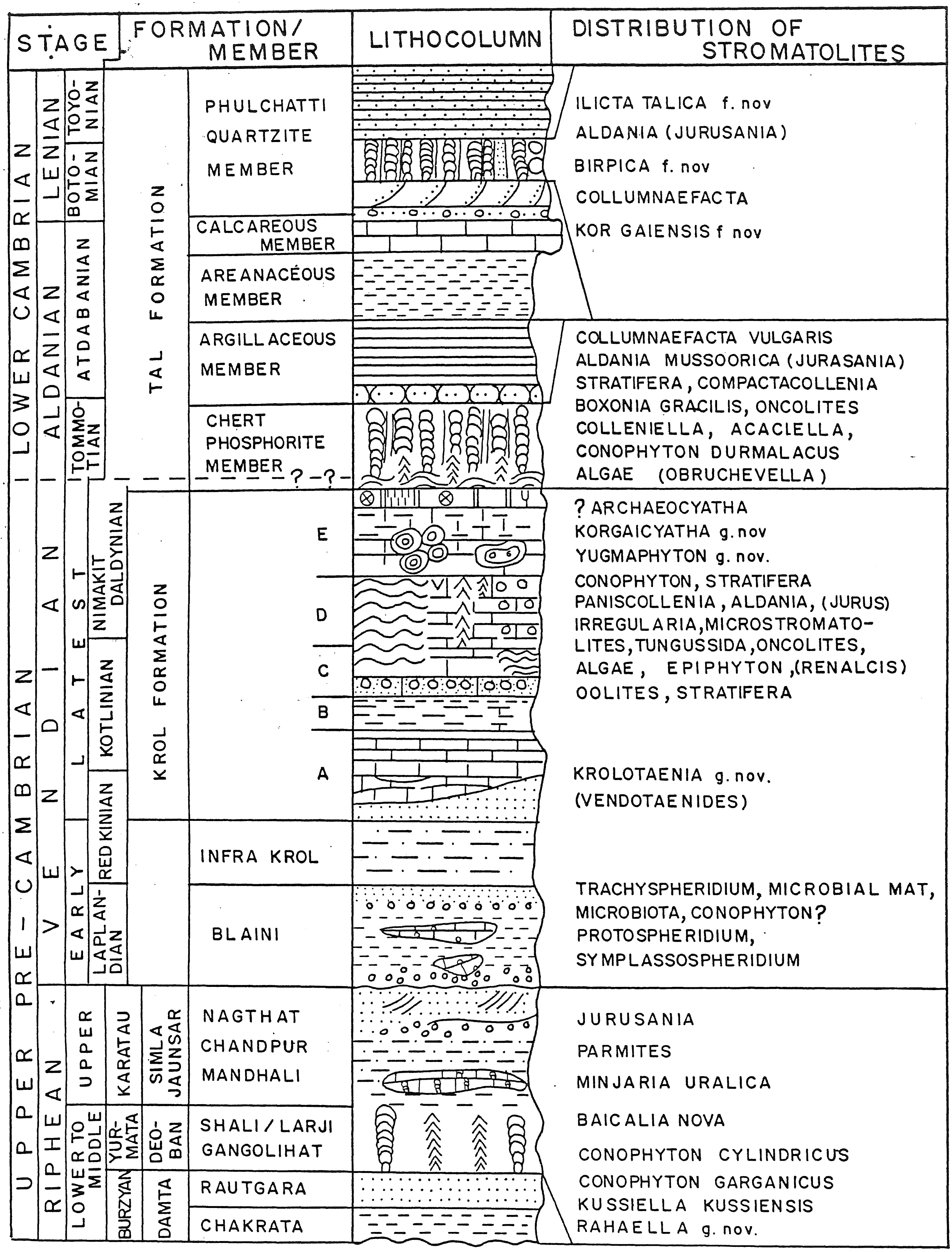

Figure 1. Distribution of stromatolites in the Precambrian and Lower Cambrian of Lesser Himalaya, India (modified after Tewari, 1984).

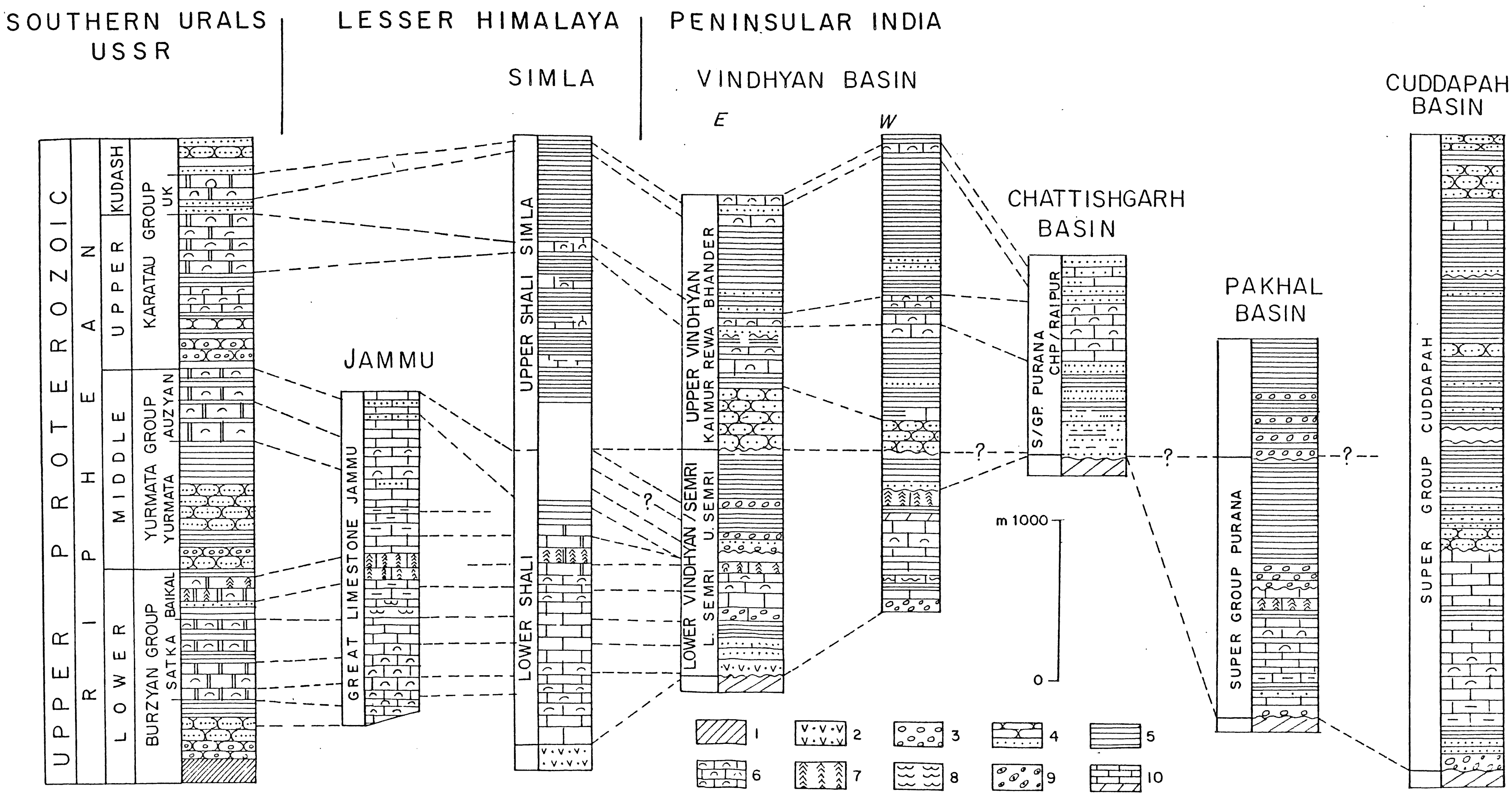

Figure 2. Correlation of Upper Proterozoic sequences of Southern Urals, Lesser Himalaya and Peninsular India.

Himalaya. Early Precambrian (pre Riphean) stromatolites have not been recorded so far. Late Precambrian (Riphean) stromatolite taxa are widely distributed in the carbonates of the Inner Lesser Himalaya. The latest Precambrian (Vendian) stromatolite taxa are found in the Upper Krol Formation. The Precambrian-Cambrian boundary and the Lower Cambrian (Tommotian and Late Lenian/Toyonian) taxa are restricted to the Tal Formation, which is the youngest stratigraphic litho-unit in the revised time stratigraphy of the Lesser Himalya (Tewari, 1984a, 1984b, 1987, 1988). The Precambrian and Lower Cambrian succession of the Lesser Himalaya has been subdivided on the basis of the stromatolite assemblages (Fig. 1) and the Precambrian-Cambrian boundary has been established in the Chert Phosphorite Member of the Lower Tal Formation (Tewari, 1988).

A comparative study of Lower Riphean to Lower Cambrian stromatolite taxa from the Siberian platform USSR and the Lesser Himalaya show remarkable similarity. The Upper Precambrian and Lower Cambrian sequences of Eurasia and Lesser Himalaya and Upper Precambrian successions of Peninsular India are correlatable (Fig. 2).

National Collaborative Programmes

1. The collaborative research on "Proterozoic micro-biota from Lesser Himalaya" with Dr. Manoj Shukla of Birbal Sahni Institute of Palaeobotany (BSIP) Lucknow is in progress. A very rich assemblage of three-dimensionally preserved microbiota is recorded in petrographic thin sections of the Deoban black cherts. A detailed paper on taxonomy, global comparision, affinity and palaeoecology has been published in Palaeobotanist (Shukla, Tewari and Yadav, 1987). Recently, vase-shaped microfossils (VSMS) and other forms of uncertain animal affinity have been recorded from the Deoban Dolomite. The C and O isotopic ratios of the Deoban dolomites indicate enrichment of C and depletion of O, signifying high organic activity which is also supported by the abundance of planktons and acritarchs. A paper entitled "Palaeobiology of the Late Proterozoic Deoban Limestone from Lesser Himalaya, India" will be presented at the Sixth International Society for the Study of the Origin of Life, and the Ninth International Conference on the Origin of Life (Prague, Czechoslovakia, July 3-8, 1989).

2. The stable isotope geochemistry of the Precambrian-Cambrian stromatolitic carbonates of the Lesser Himalaya (Deoban-Blaini-Krol-Tal succession) has been initiated under a collaborative programme with the National Geophysical Research Institute (NGRI), Hydrabad. The research project "Biosedimentological and stable

isotope studies of Late Proterozoic - Early Cambrian stromatolitic carbonates of the Lesser Himalaya" has been initiated with Dr. B. Kumar of NGRI.

Carbon and oxygen isotopic studies of stromatolitic carbonates from the Krol and Tal litho-units of the Korgai syncline show that $\delta^{13}C$ values of carbonates lie in the range -6.2 to +6% (PDB) and the corresponding $\delta^{18}O$ values range between +18.4 to +28.9% (SMOW). A positive shift of about 6% relative to carbon isotope mean for marine sedimentary carbonate carbon ($\delta^{13}C$ = Zero permil vs PDB) synchronous with positive shifts for Krol C and Krol D litho-units suggest pronounced increases in organic carbon flux and oxygen level of the depositional environment. The positive carbon and oxygen isotope displacements for Krol C and Krol D carbonates, followed by ^{13}C and ^{18}O depletion and decrease in carbonate sedimentation towards the Tal sedimentary sequence, support earlier investigations (Tewar, 1984) and indicate that the Precambrian-Cambrian boundary may possibly lie near the Krol-Tal contact.

Isotope age patterns of Precambrian/Cambrian carbon and sulphur-bearing sediments show that early Precambrian sediments have crustal like ^{13}C : ^{12}C ratios and near mantle like ^{18}O : ^{16}O and ^{34}S : ^{32}S ratios, followed by a gradual change towards crustal like oxygen and sulphur isotope ratios up to Late Precambrian time and a sharp change in $\delta^{13}C$, $\delta^{18}O$ and $\delta^{34}S$ signatures at the Precambrian/Cambrian boundary. These isotopic trends for carbon and oxygen are consistent with recently obtained isotope age curves of Precambrian/Cambrian carbonates from Peninsular and Himalayan regions of India, Aldan section of Siberia, Anti Atlas section of Morocco and from China, and are shown to mark global phenomenon in the history and development of early Earth. The evaluation of the earlier reported data from several Precambrian deposits of the World along with our data show that (i) Earth's early atmosphere-ocean system was buffered by the mantle, (ii) positive $\delta^{13}C$ shift for carbonate carbon in middle and Late Precambrian times are followed by a negative shift at the Precambrian/Cambrian boundary, the former indicating blooms in organic productivity and the latter biomass extinction, (iii) $\delta^{18}O$ content of carbonates from Precambrian to Cambrian times changed due to varying rates of photosynthesis, and (iv) oceans at the end of Precambrian time were anoxic, acidified and stratified.

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Studies of Stromatolite Columnar Heliotropism.

Research is continuing under a grant from the National Science Foundation (USA) to investigate the use of heliotropic stromatolites as recorders of tectonic activity and ancient Earth-Sun-Moon dynamics. An initial task is to catalog potentially useful stromatolites and their locations on each continent over the full range of stromatolite ages. A catalog is planned as a continuing list of useful stromatolites (and/or algae growth fossils) and their sites. Data will be obtained from existing literature and from knowledgeable researchers.

The existence of stromatolite columnar heliotropism is and has been a debated topic. There is now solid evidence of living heliotropic algal growths occurring in widely separated locations. Further there are several published articles of suspected (probable) heliotropism in fossil stromatolites. The first such publications were those by Nordeng (1959, 1963) and Vologdin (1961, 1963) who each suggested use of fossil stromatolitic columns inclined to local strata as indicators of the latitude at which the stromatolites formed - if heliotropic. Their contributions were not well received, probably due to the then current belief that stromatolite columns, if and when inclined, were influenced solely by the direction of water flow. Later, Vanyo and Awramik (1982) published an independent but similar suggestion upon observing a sinusoidal pattern in a columnar stromatolite. Supporting evidence within the stromatolite sample corroborated their tentative conclusion of heliotropism. For example, the inclination angle of the sinusoidal wave matched closely the present inclination of the Earth's spin axis; the sinusoidal plane nearly aligned with the preserved paleomagnetic field direction; and laminae/wavelength agreed closely with other estimates of days/year at that Earth age. This research was continued in Vanyo and Awramik (1985).

The existence and location of currently forming stromatolitic-like growths are reported in Awramik and Vanyo (1986; stromatolitic columns in Shark Bay, Australia) and in

Vanyo, Hutchinson and Awramik (1986; a variety of algal growths, some stromatolitic in form, at Yellowstone National Park, USA). The Yellowstone growths in particular have been re-examined on several additional occasions; they are the subject of continuing research, and may be examined by contacting R. Hutchinson, Research Geologist, Yellowstone National Park, Wyoming.

Stromatolites most appropriate for this research appear to possess the following qualities: l) clean parallel columns with little or no "branching", 2) small diameter to height ratio, or even better, small diameter to annual growth rate ratio, 3) adjacent (local) strata defining horizontal during stromatolite growth, 4) local strata orientable to continental land mass, 5) accurate age estimate of stromatolitic layer, 6) well preserved laminae, 7) preserved paleomagnetic field, and 8) columns/cones inclined to local strata and/or a columnar sinusoidal pattern.

Items I to 5 would place the stromatolite and its site in the catalog as a "useful" site for further studies and possible extraction of oriented specimens. Items 6 and 7 are desirable but not necessary for all studies, and item 8 would give a high priority to selection of that site for studies. Preservation of microfossils and other information do not appear to be necessary ingredients for this research. Details on the use of heliotropic stromatolites to deduce tectonic histories and ancient Earth-Sun-Moon dynamics are included in the references listed below.

All persons interested in the subject of stromatolites and their use as indicators of past events are encouraged to write to the author. All contributions to the catalog will be acknowledged, and all contributors will receive copies of the catalog on a periodic basis.

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I will leave the Bureau of Mineral Resources in July this year to (get married) and start a new career as an independant research scientist and consultant in Sydney. I am considering several research projects to further my work on the geology of the Proterozoic. I hope to be able to establish collaborative projects with some of my academic colleagues. I want to follow up the work of my student Zang Wenlong on the acritarchs of the Pertatataka Formation, and my own research on the trace fossils of the Arumbera Sandstone, central Australia. Zang discovered an extraordinarily abundant and diverse assemblage. Preliminary work by Roger Summons of BMR on biomarkers from the Pertatataka also needs to be followed up and linked with the taxonomy and sedimentology. For the Arumbera, I will add to the taxonomy (now in press) the palaeoecology of the trace-makers, and more detailed stratigraphy at one or two key sections. In addition, I want to help to bring to a fruitful conclusion a joint study of the Roper Group that I started some time ago with Roger Summons and Andy Knoll. I will also look for opportunities for research on stromatolites; I hope to write up more of the research I did in Shark Bay.

I plan to consult in the fields of environmental geology (drawing on my experience in Holocene sedimentary environments and, over the last few years, in hydrology) and Precambrian sedimentary geology (including sedimentary mineral deposits and petroleum).

From mid July my mailing address will be PO Box 258, Northbridge, NSW 2063, Australia, and my telephone number will be 02-9587554.

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In a comprehensive study of algal fossils in the Precambrian from the Kangdian Area, Sichuan-Yunnan, SW China, stromatolite data from the Presinian Hekou, Kunyang and Dongchuan Groups (1600 to 850 Ma) suggest some interesting conlusions:

1. The biostratigraphic application of stromatolites is available only when their environment of formation has been clearly investigated. Stromatolites used as [biostratigraphic] fossils must be those formed in a stable environment which had limited influence on their growth, and in which biological control was a decisive factor of their formation. It is evident that the available stromatolites for biostratigraphy are only those that formed in a stable subtidal, mostly lower-subtidal, environment. Upper intertidal stromatolites with distinct columnar shape, which sometimes have the same appearance as those in lower-subtidal environments, grew in high energy conditions and are not available [suitable] for biostratigraphic study.
2. The morphology of stromatolite column[s] or cluster[s] and changes of stromatolite-bed or reef are useful for local basin analysis and paleoenvironmental study.
3. The oxygen isotope values of the Precambrian stromatolites show a decreasing trend with increasing age which is [and provides] a good reference for discussion of the stratigraphic sequence where they were obtained. Furthermore, oxygen isotopes also show an increasing trend with decreasing depth of the studied basin, providing an environmental indicator.
4. Acritarchs from the studied Precambrian strata in the same area also indicate a distinct trend of increasing envelope diameter with increasing age, and decreasing diameter with increasing depth of the local basin where they were.

This data demonstrates again the usefulness of biostratigraphic and environmental analysis of Precambrian stromatolites, stromatolitic oxygen isotopes and acritarchs.

Publications

Wang Fuxing, 1987. A briefing on Precambrian stromatolites and microfossils from South-West China. Precambrian Geology No. 3. International Symposium on Late Precambrian Geology. Geological Publishing House, Beijing, 479-494.

Wang Fuxing, 1988. Assemblages and application of Presinian stromatolites from the Kangdian Area. Bull. Chengdu Inst. Geol. Min. Res., No. 9, 1-16.

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Efforts are concentrated on coralline sponge (chaetetid) occurrences in the Carboniferous. Stromatolites are associated with some of these coralline sponge reef mounds. Summary paper on temporal changes in Carboniferous reef mound communities is published in PALAIOS Ancient Reef Ecosystem theme issue (PALAIOS, 1988, 3, 152-169), and role of stromatolites is commented on in that paper.

I very much enjoy the STROMATOLITE NEWSLETTER and find it an excellant way to help me "keep up".

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After five years of studies (1984-1988) I completed my PhD thesis, entitled "Fossilization processes of microbial mat in the clastic sediments of the Puck Bay". The subject of the study was modern microbial mat, Holocene microbial, laminated, siliciclastic deposits, and lower Jurassic fine-grained laminated sandstones from Central Poland. The aim of the study was to determine the genetic relationships between modern microbial mat and clastic laminated deposits. In order to achieve this a research programme was devised, which included:

1. Characteristics of inorganic fraction; i.e. granulometric analysis and mineral composition.

2. Species composition of microorganisms occurring in modern mat and Holocene laminated deposits, including paleoecological analysis.
3. Comparison of modern microbial mat and Holocene laminated deposits with the Jurassic laminated sandstones.

The modern microbial mat of clastic sediments of brackish water from the Puck Bay area (Southern Baltic Sea) possesses all of the features typical of its counterparts from carbonate sediments. It differs in species composition of mat-forming microorganisms and in the mechanism of laminar structure formation, which in the studied area is episodic. The process of mat development in the Puck Bay indicates cyclic changes in the course of the vegetation season. In spring and early summer the main mat-forming microorganisms (cyanobacteria, green algae and diatoms) are evenly distributed. The cyanobacteria are mostly represented by coccoid genera: *Microcystis, Merismopedia* and *Aphanothece*. The organic matter content is less than 10%. The mat forms a thin cover of the bottom and can be destroyed by wave action. The investigated mat attains its maximum development during the summer bloom of cyanobacteria (August/September). At that time the mat community is strongly dominated by filamentous cyanobacteria: *Oscillatoria, Lyngbya* and *Phormidium*. Organic matter content approximates 50%. The mat forms a thick, coherent cover of the Puck Bay coastal shallows. Besides microorganisms and microphyte detritus, there also occur significant amounts of degradation products; i.e. amorphous organic

matter and hydrogen sulfide. The coherence of the mat structure, the elimination of macro- and meio-fauna, and burial of the mat are the main factors promoting its fossilization.

In the subfossil siliciclastic, microbial, laminated deposits the presence of rich microbiota has been stated [observed]. Besides cyanobacteria (both coccoid and filamentous), coccoid and filamentous green algae and diatoms were also found. Of these only diatoms are of paleoenvironmental significance. Comparison of the modern mat and the subfossil microbiotas indicates that during the summer cyanobacterial bloom, the studied mat posesses its highest preservation potential. Hydrocarbons extracted from the investigated deposits indicate compounds directly contributed from microorganisms (short chain n-alkanes, even n-alkanes, 7-metyloheptadecan, hopanoids), and components originating from post-burial bacterial processes (sterenes). Composition of the hydrocarbon fraction shows the autochthonous origin and the early stage of diagenesis of the deposited organic matter.

Preliminary results of the studies of the lower Jurassic laminated sandstones showed the presence of cyanobacteria-like microfossils, both cocoid and filamentous. Since the clastic deposits of microbial origin do not possess such evident structural features as their counterparts from carbonate sediments, some attributes which might be useful for further studies of clastic laminated deposits are proposed:

1. The mutual relationships between mineral detritus and organic matter (in order to exclude the higher plant detritus.
2. Microfossils occurring in the deposits.
3. Hydrocarbon fraction composition (if of autochthonous origin).

It has to be emphasized that the results presented here shed a more optimistic light on the problem of the preservation potential of microbial mats from clastic sediments, which for a long time has been thought to be negligible. They also encourage us to undertake more detailed studies of organic matter laminated sandstones.

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In recent years, microfossils including empty tube-like filaments and coccoid cells have been obtained from siliceous stratiform stromatolites of the Upper Proterozoic Niyan Formation at Qingtongshan in Suxian district. There are many well preserved coccoid microfossils in the Niyan microbiota. According to their morphological features, they may be attributed to *Gloeodiniopsis* Schopf, 1968; *Caryosphaeroides* Schopf, 1968; *Eozygion* Schopf & Blacic, 1971; *Bigeminococcus* Schopf & Blacic, 1971; *Eotetrahedrion* Schopf & Blacic, 1971; *Protosphaeridium* Timofeev, 1960; and others. According to the criteria proposed by Oehler and others (1976) for distinguishing both cross tetrads and tetrahedral tetrads, ... [text missing]. In Three-dimensional mapping of spheroid positions, by measuring actual distances between constituent spheroids in the same tetrad, the spatial arrangement of some tetrads has been reconstructed as *Eotetrahedrion princeps* Schopf & Blacic by Knoll and Golubic, 1979. On this basis we can conclude that the tetrahedal tetrads were produced by cell shifting as a result of normal diagenetic processes of degradation and compaction.

HANDBOOK FOR THE STUDY OF STROMATOLITES
AND ASSOCIATED STRUCTURES

(Second Draft)

by

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A second draft of the stromatolite handbook is included in this issue of the Stromatolite Newsletter for you to comment on. It is intended as a *guide* to help in the exchange of information, and as an attempt to standardize terminology, so the emphasis is on how to describe the structures, rather than on how to classify them. There are still many aspects to be tidied up, but at this stage some feedback is required.

The final version of the handbook should include chapters on describing Phanerozoic and Recent stromatolites, and a section on Thrombolites. A chapter on classification is partially written and will be circulated for comment at a later stage. Are there any other major sections which should be included? If so, who should write them? Have any of your favourite terms or methods been omitted? The glossary has been compiled mainly from the English literature and should probably include terms in use in other languages. For example, many morphological terms were derived from Russian authors, and their contribution should be acknowledged. Any help with compiling these data would be greatly appreciated.

This draft requires comment and input from *you*. Please send your criticisms, comments, notes on glaring omissions etc. to Kath Grey at the above address. Short contributions will be acknowledged as "written communications"; longer submissions will be authored by the contributor.

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CHAPTER THREE - TERMINOLOGY FOR FOSSIL MICROBIALITES

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CHAPTER ONE

INTRODUCTION

PREAMBLE

This handbook was prepared as a result of discussions held at a meeting of **IGCP Working Group 261 - Stromatolites** during the 4th International Symposium on Fossil Algae in Cardiff, in August 1988. Participants represented a wide range of interests in the field of stromatolite studies. Nearly all felt the need for some type of handbook which would rationalize stromatolite description.

There are still many problems requiring solution in stromatolite studies. Not least is the difficulty of morphological description and classification, stemming from the fact that we are dealing with ecosystems, rather than individual species. Stromatolite taxonomists justify the use of Linnean nomenclature on practical grounds, and point to the successful development of stromatolite biostratigraphy in USSR, China and Australia (Grey and Semikhatov, 1988a and b). However, other workers find it difficult to accept the use of binomial nomenclature, and some lack the biological training necessary to apply names correctly. Even among those who purport to follow the recommendations of the International Code of Botanical Nomenclature - ICBN - (Lanjouw, 1966), there is little consistency. Many taxa have inadequate diagnoses, and different workers give different weight to significant characteristics.

The result of these problems is a growing lack of communication between workers. From IGCP 261 discussions, it soon became obvious that all workers would benefit from the adoption of a standard descriptive method, with a well- defined and readily applicable terminology. It was also apparent that the standard description should be independent of formal nomenclature, but at the same time be sufficiently flexible to cater for both those who wish to formally name taxa and for those who do not.

This handbook is an attempt to rationalize and standardize stromatolite terminology. Much of the information is already published, but is scattered through the literature (Raaben, 1969a, b; Hofmann, 1969; Bertrand- Sarfati, 1976; Walter, 1972, 1976; Preiss, 1972, 1976; Komar and others, 1965; Krylov, 1976). Terminology adopted is that most commonly used and readily applied (alternatives are listed in the glossary). The aim is to allow any worker to be able to visualize the salient features of a stromatolite described by another worker, regardless of whether the description was originally for stratigraphic, sedimentological or microbiological purposes.

Descriptive formats and terminology will probably require modification once they have been tested by practical application, and therefore this handbook should be considered as an interim measure, rather than as a definitive publication.

GENERAL PRINCIPLES OF DESCRIPTION

Stromatolite workers still need to understand much more about stromatolite growth and development before they can decide which features are most relevant in description. The greatest need at present is for mutually comprehensible descriptions. This initially means describing all observable features in a standard format which will facilitate comparison. The suggested format for description given in this handbook can be followed by any worker and should be as complete as possible. If no data are available (for example, where a description is based on field studies only and therefore does not include microstructure, or where there is only a single column on which to base a description) these limitations should be made clear in the description.

PHILOSOPHY OF NAMING STROMATOLITES

Attitudes towards stromatolite classification have not changed greatly since Krylov (1976) identified three groups of stromatolite workers, each with a different approach to stromatolite classification

1. Those who think stromatolite morphology (and microstructure) is accidental and has no regular relation to the composition of the stromatolite-forming microbiota;

2. Those who consider the shape of the stromatolite to be regularly associated with their formative conditions (ie. different microbial mats will produce similar morphologies under similar environmental conditions, and identical microbial mats will form different morphologies under different environmental conditions);

3. Those who assume that biological control is a major factor in determining stromatolite morphology.

Each of these philosophies has resulted in different systems of classification, but the problems confronting stromatolite workers have changed little over the years (Johnson, 1966; Logan and others, 1964; Krylov, 1976). Each generation of workers has proposed a solution, but none has been entirely satisfactory, or been widely adopted. The difficulties of applying Linnean nomenclature have been discussed at length, rejected by some, and favoured by others. On the other hand few workers find that informal classifications facilitate comparisons. The descriptive formulae proposed by Logan and others (1964) are useful for describing fairly simple geometric patterns found in modern stromatolites, but become cumbersome when applied to the highly polymorphic and more complexly branching forms found in the Proterozoic, and are inapplicable to some Phanerozoic stromatolites, particularly those with thrombolitic fabrics.

There are, however, several drawbacks to using 'non-Linnean' binomials. Because there are no strict guidelines for applying the names, nomenclatural stability is not enforced; there are no rules of priority; there is no system of 'type specimens' to act as a reference to the typical morphology; and there is a possibility that the names will be confused with names which have genuine taxonomic status by geologists unfamiliar with the peculiarities of stromatolite nomenclature.

Although methods for naming stromatolites are discussed later in this handbook (Chapter 4, in preparation), the actual method adopted is left to the discretion of individual authors. Authors may choose to adopt Linnean taxonomy with all its ramifications; or they may decide not to apply names at all. Either way some method of cataloguing different morphological types must be applied.

To allow comparisons between the types of description, a system of "informal" classification is recommended which parallels the "formal" one. The use of informal nomenclature provides a simple system for those workers who feel it is inappropriate (or who do not wish) to name stromatolites.

USING FORMAL NOMENCLATURE

Many authors (for example: Maslov, 1960; Semikhatov, 1962; Krylov, 1963, 1976; Sarfati, 1972; Walter, 1972; Preiss, 1972; Grey, 1984) have found that adoption of the Linnean system is the only satisfactory method which can be applied in biostratigraphy. These authors have accepted that the ICBN provides the most appropriate method for naming the structures.

To indicate the heterogeneity of stromatolite structures, workers who adopt the Code often prefer to use the terms "group" and "form" as replacements for "genus" and "species" respectively. It may be more useful to use "morphogenus" and "morphospecies" (see Chapter 4). In all other respects formal stromatolite names must conform to the ICBN. This is because the stability of nomenclature is of paramount importance. Biostratigraphic palaeontologists must observe the rules, because names which do not conform to the Code are invalid. Stromatolite nomenclature provides many examples of the chaos which ensues when workers do not apply the Code rigorously. It is therefore strongly recommended that if a worker wishes to name stromatolites, the names should comply with the rules of the ICBN.

Before adopting formal names for morphological variants, each author should determine his/her philosophy with regard to Linnean nomenclature, and its application to structures built by microbial communities. Most workers acknowledge that stomatolites are not species in the accepted biological sense. However, binomial nomenclature provides a practical scheme of classification which enables rapid identification and mutual understanding (Grey and Semikhatov, 1988a and b).

The current ICBN (Lanjouw, 1966) does not have any special provisions for dealing with compound structures, although the problems associated with groups such as lichens are under consideration. Meanwhile, several problematic fossil groups are left in limbo. Such problematic structures can be accommodated within the framework of the ICBN by treating them as temporary measures to be used until such time as the individual components can be recognised - see Chapter 4 for more detailed discussion.

Problems of stromatolite nomenclature are unlikely to be resolved in the near future. For many workers interested in the practical applications of stromatolite biostratigraphy, the utility of binomial nomenclature outweighs philosophical reservations about applying names strictly within the guidelines of the Code. For those who have the training, confidence and inclination to use a formal biological system, binomial nomenclature provides the most effective means of communicating concepts of morphological similarities and differences.

USING "NON-FORMAL" NOMENCLATURE

It is clear from many publications and discussions that a percentage of workers will never wish to use binomial nomenclature. Nevertheless, they need to describe stromatolites in a manner which allows comparisons to be made. For those who still have reservations about formal nomenclature, a system of **open nomenclature** is suggested. In this method, each described form is designated by a term such as "Stromatolite form 1", "Stromatolite form 2" etc, followed by the author's name and date.

Each stromatolite should then be described in detail, using descriptive methods that parallel those used for formal taxonomy. Most importantly, the form should be adequately illustrated. Where possible, one specimen should be nominated to typify the concept of the morphology. This will reduce confusion should the informal category be incorporated in a formal taxon at a future date.

Open nomenclature allows non-taxonomic descriptions to be compared readily with taxonomic ones, and reduces problems arising from lack of familiarity with the taxonomic literature. As well as providing 'non-taxonomists' with a system for describing stromatolites, open nomenclature can also be used in taxonomic studies. It is invaluable when adopted for stromatolites which cannot confidently be assigned to named taxa, perhaps because of poor preservation, inadequate or unrepresentative sampling, or dissimilarity to previously described taxa.

By providing a detailed, standardised description and adopting open nomenclature, authors will facilitate future taxonomic assignment. The original description can be readily cited in synonymy. Open nomenclature provides both taxonomist and non-taxonomist with a "half-way stage" to formal nomenclature.

CHAPTER 2

METHODOLOGY FOR FOSSIL STROMATOLITES

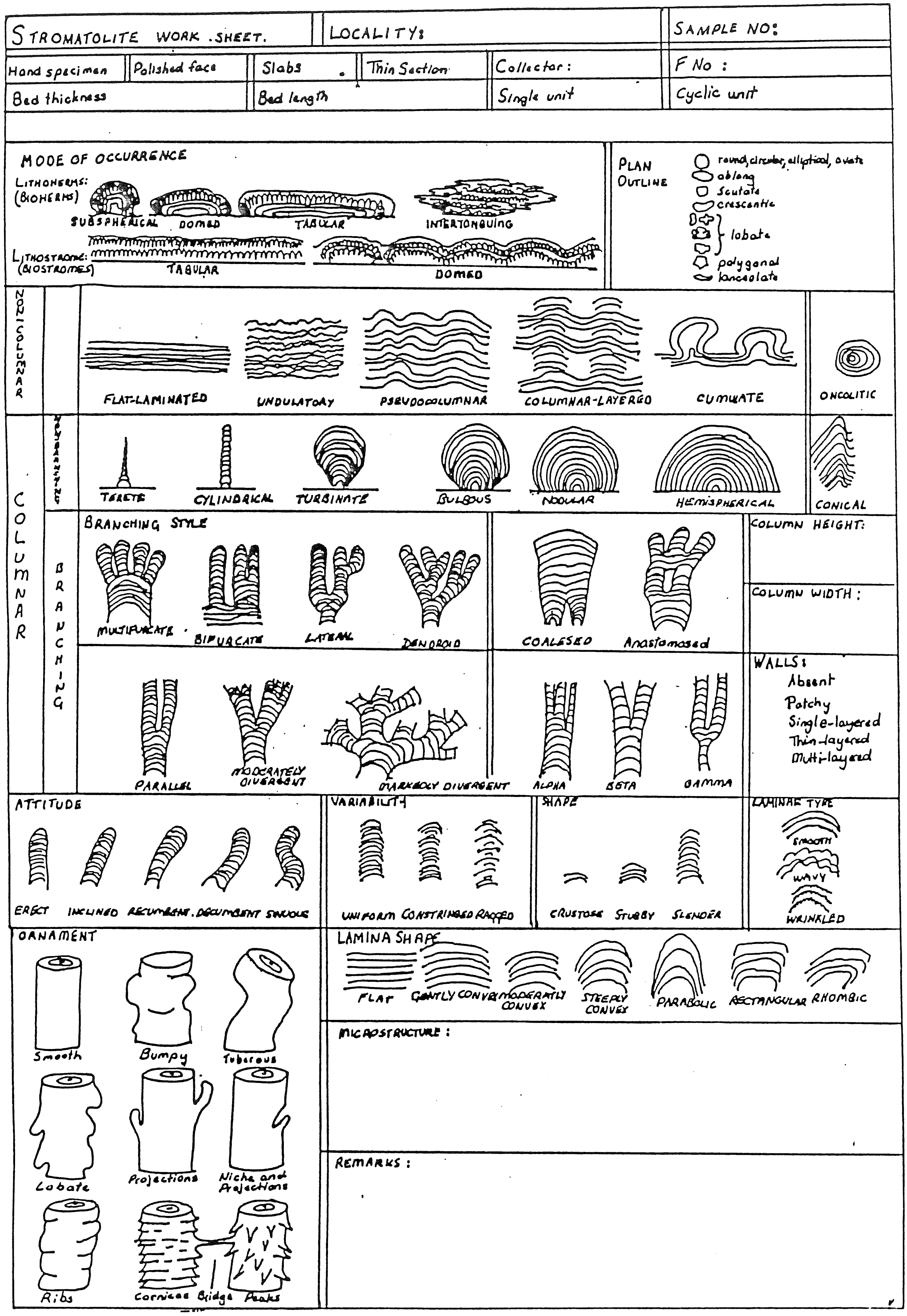
This catalogue is a compilation of procedures which can be readily applied by most workers. Although the term "stromatolite" is used throughout this section, many of the methods can be applied to the study of microbialites (Burne and Moore, 1987) in general. As many techniques as possible are described here, although not all need be used. However, methods which may be too elaborate for general use, could be significant for resolving specific problems of identification. At this stage in stromatolite studies descriptions of basic features need to be as comprehensive as possible, and to reflect detailed, systematic observations.

Not everyone has access to sophisticated techniques, such as computer analysis, and for some workers even obtaining sufficient thin sections or serial slabs can be a problem. However, such shortcomings do not excuse inadequately prepared descriptions. Stromatolite descriptions must be based on a combination of field and laboratory observations. Techniques described by several authors are collected together in this guidebook to form a single reference manual. Philosophical arguments and the rationale behind the various methods are not discussed here; for these, workers should consult the original authors.

Recording observations in both the field and laboratory can be done quickly by the use of a work sheet (Fig. 1). This example is based on illustrations given by Walter (1972) and Preiss (1972, 1976). Such a sheet provides a ready reference to the main features to be observed, and provides a check list of salient features for a later stage of description. The outline sheet should be supplemented by more detailed field and laboratory notes.

1. FIELD OBSERVATIONS

Stromatolites vary enormously in size (Hofmann and Jackson, 1987), and this feature is often significant in taxonomic description (Fig. 2). Characteristics such as lithoherm size, shape and spacing may also be diagnostic. For these reasons, field observations need to be as complete as possible. Obviously the quality of field observations will depend on the quality of the outcrop, but workers should try to follow the check list devised by Preiss (1976) and given below with some minor modifications.



1. Suggested work sheet for stromatolite field studies (based on Preiss, 1972, 1976; Walter, 1972)

SIZE CLASSIFICATION OF STROMATOLITES

WIDTH (m)	SCHEME A	SCHEME B	EXAMPLES
	kilometric		
10^{3}		GIGASTROMATOLITES	
	hectometric		Biostromes
	decametric	MEGASTROMATOLITES	
	metric		Bioherms
10^{0}			
	decimetric	MACROSTROMATOLITES	
	centimetric	MESOSTROMATOLITES	*Gymnosolen*
	millimetric	MINISTROMATOLITES	*Pseudogymnosolen*
10^{-3}			
	submillimetric	MICROSTROMATOLITES	*Frutexites*
10^{-6}			

2. Size classification of stromatolites (based on H.J. Hofmann, 1986).

1.1 Macrostructure - nature of stromatolite beds

(a) What is the thickness of the stromatolite bed?

(b) Is it composed of a single cycle of stromatolite morphologies and associated sediments, or of several superimposed cyclical units?

(c) What is the lateral extent of the bed and its constituent units?

(d) What is the shape of the bed and its constituent units, and what are the relationships of these to the surrounding rock types? Is it extensive or patchy in occurrence?

(e) What are the lithologies of the stromatolites and surrounding sediments? What is the state of preservation?

(f) What is the shape and relief of successive growth surfaces of the stromatolites? (The "synoptic profile" of Hofmann, 1969a).

(g) What is the mode of occurrence:- lithoherm (tabular, domed, subspherical or intertonguing), or biostrome (tabular or domed)? Is there any indication of consistent elongation or inclination? If so record the relevant direction of the axes for as many lithoherms as possible.

1.2 Mesostructure - intermediate-scale structures

(a) What is the nature of the constituents of the stromatolitic beds? Any of the following may be present, in any combination: stratiform stromatolites (flat- laminated, laterally linked, undulatory and pseudocolumnar); columns and cumuli (cumulate stromatolites).

(b) What are the vertical and lateral relationships of these constituents to one another?

(c) If columns are present, are they branched? If so, note the style and frequency of branching: parallel branching (alpha-parallel, beta-parallel, gamma- parallel) slightly divergent branching, markedly divergent branching.

(d) What is the shape of the columns in longitudinal sections, eg. regular, subcylindrical, tuberous, gnarled, straight, curved.

(e) What is their shape in transverse section, e.g. round oval, rounded-polygonal, lobate, or elongated.

(f) What are the relative orientations of the columns to one another?

(g) What is the nature of the sediment in the interspaces between columns?

(h) What is the nature of the laminae (if any) in the interspace margins?

1.3 Microstructure - fabric, lamination and texture

Most of these features can only be examined in detail after laboratory preparation. Nevertheless, some preliminary observations can be made in the field, and the recognition of various types of microstructure forms the basis for the selection of samples suitable for laboratory preparation and more detailed study.

(a) Are laminae present (stromatolite) or absent (thrombolite)?

(b) If laminae are not present describe the fabric using the terminology for thrombolites (Chapter 3 - 7).

(c) If laminae are present describe the fabric using the terminology for stromatolites (Chapter 3 - 6.)

(d) What is the nature of the column margins, e.g. smooth, bumpy, ragged, or with large overhangs?

(e) Are the margins formed by laminae bending over and enveloping the lateral surface to form a wall? If so is the wall continuous or patchy? Is it formed by only a few laminae or is it multilaminate?

(f) What is the shape of the laminae in the columns e.g. conical (this can only be seen in axial section), gently to steeply convex, rectangular, rhombic, smooth, wavy or wrinkled?

(g) Are there any lateral or vertical changes in any of these features when traced throughout the lithoherm or lithostrome, especially for instance, at lithoherm margins?

2. FIELD PHOTOGRAPHY

Many of the features described above can best be recorded by photography. Photographs are particularly valuable for supplementing data where there are collecting problems because of large column sizes. Stromatolites in rock faces can be particularly difficult subjects and a few hints are given here to improve the standard of photography.

Pay special attention to lighting. Obviously this is difficult to control, but some problems can be eliminated. Try to clear away any vegetation which may cast shadows, and remove loose rubble which could confuse details. It may be possible to photograph the outcrop at different times of day to allow different lighting angles to enhance certain features. If the sunlight is too bright, an umbrella or other means of shading may improve matters. A flash may help where lighting is poor, or you may use a flashcard - a sheet of white card positioned to reflect light onto the rock surface. Take photographs before sampling.

Outcrops which are lichen-covered, or otherwise difficult to see, can sometimes be improved by the judicious use of a scrubbing brush or acid. If the contrast is still insufficient for photography, it may be necessary to outline the columns with a water-soluble felt-tipped marking pen (e.g. Walter, 1972, Pl 21, fig. 3).

Use a scale in photographs, preferably one marked in centimetres, although standard-sized objects such as lens caps and hammers can be substituted. However, if you use non-standard objects, such as coins, note the dimensions in the figure caption. Photo-montage of juxtaposed photographs can be used to show elongated structures such as lithostromes.

3. SAMPLING

This is one of the most important aspects of studying a stromatolite. Ideally it is best to take several samples from each locality to show the range of variation. Samples from the centre and margins of a stromatolitic outcrop, and from various parts of a lithoherm, may vary considerably. An ideal sample should include several columns so that branching style and relationships between columns can be examined.

Unfortunately, it is rarely possible to collect ideal samples. Usually there are constraints on sampling resulting from the large bulk of material required. In such cases the samples should be carefully chosen to be as representative as possible. Where columns are too large to be sampled in a group, it may be necessary to collect smaller samples from each column, for example, specimens from the column centre and column margins can be used to determine the extent of variability. Such an approach is often necessary for the larger forms of Conophyton, where it is very important to collect representative portions of the axial zone. It is also preferable to collect samples from as many localities as possible.

The following hints for sampling are based on those given by Preiss (1976, p. 9):

(1) Samples should be selected such that they fit readily into the vice of a slabbing saw, e.g. roughly 25 cm cubes in the case of a 61 cm diameter saw, but longer specimens (to about 50 cm) can be accommodated sideways.

(2) They should show on at least one surface a clear cross-section of several columns.

(3) Different samples should be selected to be representative of the whole outcrop, including samples from the centre and margins of lithoherms, and from the base to the top of the bed to illustrate vertical changes.

(4) Single samples should be selected which illustrate vertical changes from one morphology to another (e.g. flat-laminated to columnar) or changes in style of branching.

(5) In the case of stromatolite columns too large to be handled physically, careful field observations, preferably in different orientations, will be needed to show branching style, column

shape, lamina shape and margin structure. Specimens can then be collected to show portions of columns, e.g. marginal parts for reconstruction to show margin structure.

4. LABORATORY EXAMINATION

Field studies need to be supplemented by detailed laboratory examination. For this part of the study it is important that samples are carefully numbered in the field, and that their orientation and relative positions are noted where possible. Special attention must be paid to the numbering of offcuts and serial slabs. The most convenient method is to use one number for each block collected, and to label each consecutive face of a serial slab alphabetically.

4.1 Cleaning

Simple cleaning of the blocks can often reveal features previously obscured in the field. Particles of soil, and endolithic organisms should be removed. This can often be done by scrubbing with a nylon or wire brush, and the use of detergent if necessary. Dilute hydrochloric acid may cleanse particularly difficult surfaces. It may be worthwhile to photograph clean surfaces at this stage.

4.2 Cutting

Although important details can be determined from weathered surfaces, it is usually necessary to cut the sample to examine column shape, spacing and branching. Serial slabbing techniques and graphic reconstructions are particularly appropriate for determining three-dimensional characteristics. Hints on choosing and preparing samples are given by Hofmann (1976, p. 16), and he recommends that samples selected for cutting should show good cross-sections of columns, and preferably include at least two or three columns. Ideal samples cannot always be obtained, particularly where columns are large, and in such cases it is best to sample a range of morphological variants. The collector should also bear in mind the restrictions on sample size imposed by handling and transporting a specimen, and in particular the maximum dimensions determined by the diameter of the saw blade.

Ideally specimens should be cut into right angled blocks to obtain three-dimensional views in known orientation. It is often useful to make an initial vertical cut across one end of the specimen to check on preservation and orientation before undertaking serial slabbing. Columns should be aligned as closely to the vertical as possible. Horizontal cuts may also be made at either the top or bottom of the specimen. Such cuts provide a planar surface which can be used to examine plan views of columns and to act as a reference surface for serial reconstruction.

A horizontal surface facilitates cutting and reduces orientation problems during sawing, but if the sample has an irregular shape, too much column detail may be cut off. In such cases a horizontal reference line can be drawn around the specimen. The reference line can then be marked across the cut face, and used as the base line for reconstruction.

Cutting irregular samples is often difficult and special attention must be paid to orientation in the saw. It is sometimes possible to use wedges to hold the sample in the correct orientation. Difficult samples can first be set in correct orientation in a cardboard box filled with plaster of paris. This provides a suitable planar surface, and the saw cuts are made through the cardboard plaster and specimen. Although this technique makes cutting easier, remember that the plaster will conceal features on weathered surfaces.

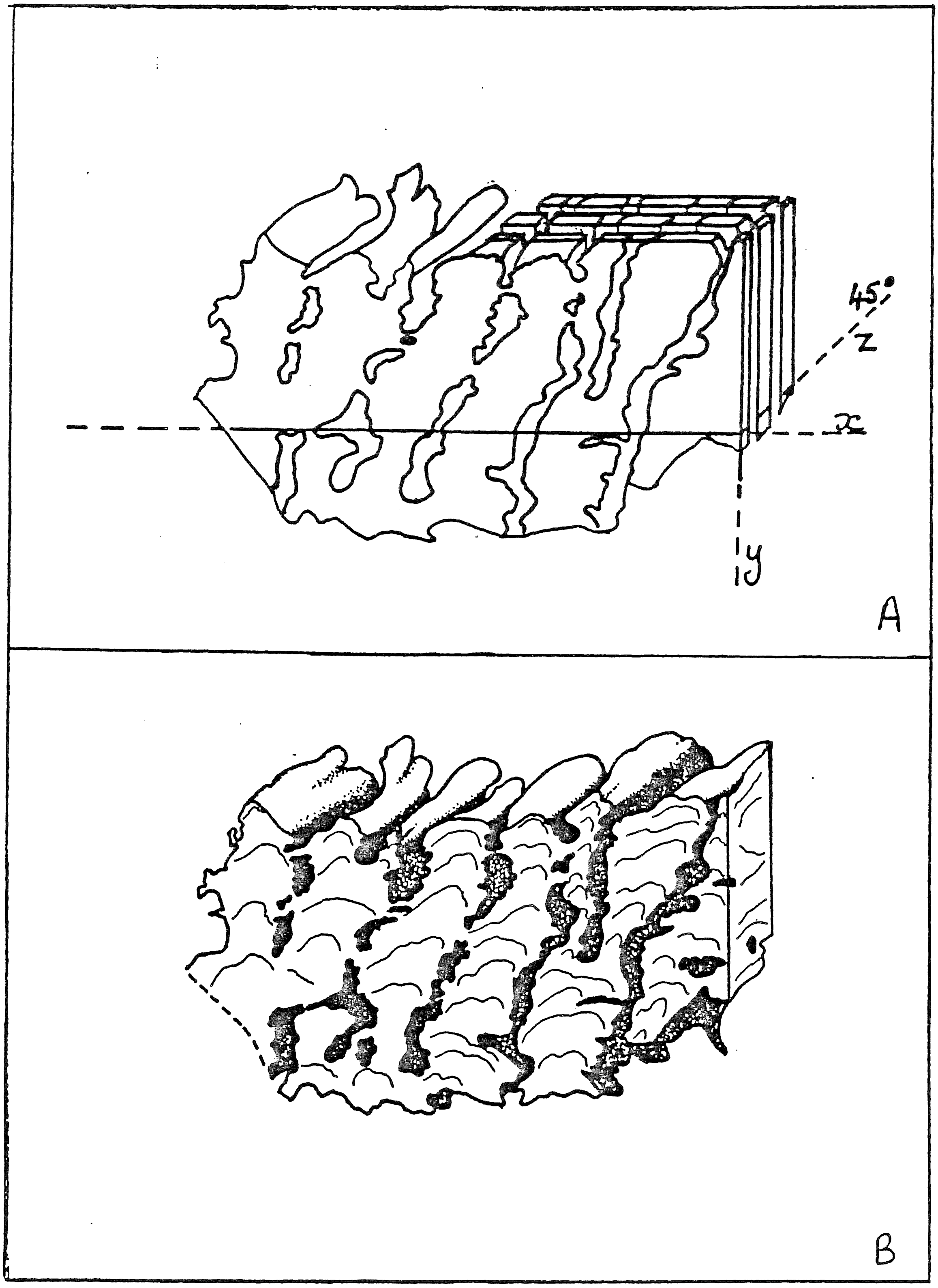
Sometimes examination of a single vertical face may suffice for identification, especially in the case of a well-known taxon. Hofmann (1977, p. 193) pointed out that examination of extensive longitudinal and transverse sections in outcrop can serve the same fuction as serial slabbing, and morphometric analysis can be used to represent the data through statistical parameters (see section 4.3). However, it is still useful to provide at least one or two three-dimensional reconstructions, particularly of new taxa. For this serial slabbing is necessary (see section 4.3).

4.3 Serial slabbing

Serial slabbing is a technique designed by Krylov (1963) to allow three-dimensional "graphic reconstruction" of stromatolite columns. Krylov used serial longitudinal sections, and this method has been the most widely adopted. However, Raaben (1969b) used serial transverse sections, and Horodyski (1976, fig. 3) made three-dimensional models from cardboard templates. The method, with some modifications, has been described in detail by Walter (1972, p. 6 - 8), Preiss (1976, p. 9 - 11) and Hofmann (1976, pp. 16).

A large diameter diamond-tipped automatic saw (usually about 61 cm) with an adjustable clamp or vice is used. Rocks should be positioned in the vice in such a way that regularly-spaced serial cuts can be made parallel to the columns. It may be necessary to reposition a large block several times during cutting. The number of slabs and their thickness is determined by the column diameters. Ideally each column should be present on four successive faces. Very thin slabs (4 - 5 mm thick) can be cut from large blocks without breaking if a piece of foam plastic or rubber is placed in the receptacle underneath the slices being sawed off (Hofmann, 1976).

The thickness of material lost in the saw cut and grinding should be estimated (usually about 2 mm). Hofmann (1976) suggests that the finished thickness of the slices should be equal to, or multiples (2, 3, 4) of the missing thicknesses. While this is preferable because it makes graphical reconstruction easier, it is not always possible. Provided the thickness of the saw cut is known and the thickness of the slab can be measured, acceptable reconstructions can still be drawn (Fig. 3). Each cut provides two sections, which are smooth ground (see section 4.4), and then traced on transparent overlays by the method described below (see section 4.8).



3. Method for serial slabbing of irregularly shaped blocks, A) partially reconstructed diagram showing position of slabs and reference lines, B) completed three-dimensional reconstruction

4.4 Polishing and alternatives

Details of laminae and wall structure are best observed on cut faces, but it is usually necessary to polish or otherwise treat the surfaces to enhance contrast (Bouma, 1969, pp. 133). Initial grinding is usually carried out on an automatic lap using progressively finer grades of abrasive powder - generally carborundum (starting from around grade 180 up to around grade 600). Polishing is carried out with finer grade powders (from around grade 600 carborundum powder up to grade 1200 carborundum paper). The finishing stages must be done by hand. The surface is polished using tin oxide paste - or similar compound - and a soft cloth or piece of carpet. Alternative methods are discussed by Bouma (1969, p. 133).

Polishing is time-consuming, but usually produces the best results. It is often required for photographic or display purposes. Select the best faces for polishing, and use a quicker technique for other faces. An alternative to high-gloss polishing is to "smooth-grind" the surface (using carborundum powder up to about grade 600). Further work is then carried out on a wet surface, with/or without a transparent overlay (see section 4.7). For photographic purposes, particularly in the case of low contrast specimens, the surface can be coated with oil (cooking oil is adequate and cheap).

Alternatively the surface can be coated with a variety of wax or similar finishes (Bouma, 1969, p. 133), or sprayed with a gloss-finish enamel spray or lacquer. This operation should be carried out under a ventilation hood. Results are variable - the lacquer may soak into porous samples; often it is difficult to obtain an even distribution of the spray. In many cases, details of structure can be observed by preparing transparent peels or glass-mounted sections (see sections 4.5 and 4.6).

4.5 Thick and thin sections

Samples for sectioning require careful selection to show representative portions of the stromatolite, and good preservation of microstructure. Sections are usually larger and thicker than conventional petrological sections, but are prepared by the same techniques. The size of the section depends on the features to be examined, but sections 105 by 65 mm can often accommodate some of the more important features such as column margins, laminar details, and interspace features.

Normal petrological thin sections are commonly 30 um thick. This is usually too thin for features of structure and texture to be observed. A thickness of between 40 and 60 um (Bouma, 1969, p. 132; Preiss, 1976) is required, and the simplest method is to grind the section to about 60 um - this can be done on an automatic grinder - and then by hand grinding and inspecting at frequent intervals until optimum thickness is obtained. Detailed methods for preparing "thick" sections are given by Bouma (1969, p. 134).

Examination of specimens should be carried out at several levels (Preiss, 1976, p. 10 -11), and should include inspection for microfossils. Studies of petrological sections can be aided by the use of staining techniques (Friedman, 1959; Bouma, 1969, pp. 251, Warne, 1962). Conventional petrological studies on standard thin sections can also used to determine the mineralogy.

4.6 Acetate peels

A variety of techniques for preparing peels have been described (Bouma, 1969, pp. 63; Stewart and Taylor, 1965; Davies and Till, 1968; Price, 1975). The techniques applied are determined by factors such as lithology and preservation. Methods of preparing large-sized lacquer, polyester or epoxy resin peels from weathered surfaces in the field (Bouma, 1969, pp. 2) do not seem to have been attempted by stromatolite workers, but may be worth consideration.

The most common method of preparing peels of stromatolitic carbonates is the "acetate sheet" method (Bouma, 1969, pp. 66; Preiss, 1976). Acetate peels can be prepared rapidly with a little practice. They can cover large surfaces, and are cheaper and easier to handle and store than thin sections. The simplest method is as follows:

(a) Smooth grind carbonate rocks and slabs selected for acetate peel preparation.

(b) Lightly etch the prepared surface with 10% or less hydrochloric acid - usually for between 10 and 30 seconds. (Silicified specimens can be etched with hydrofluoric acid (Price, 1975), but this is not recommended because the acid is extremely dangerous).

(c) Gently wash the surface with water and then air-dry the surface. This can be speeded up by using a jet of compressed air or with heat lamps. Be careful not to damage the etched surface.

(d) Place the selected surface at a gently-inclined position - use a bed of sand if necessary - and wet with acetone. (A preliminary wetting and drying with acetone will ensure that any traces of water are removed and will improve the quality of the final peel.) Enough acetone should be used to form a thin film on the surface.

(e) Slowly lower a thin acetate sheet (preferably 0.2 mm thick) onto the wet surface. Start at the lower edge, and curve the sheet gently to make contact with the surface. Carefully press out any air bubbles, preferably using a roller because fingers can leave imprints.

(f) Allow the peel to dry (this can take from 5 to 30 minutes). Test that the peel is ready by lifting an edge - the peel should pull away freely. Pull the peel away steadily, trim the edges, allow to dry, and press flat if necessary.

Two or three peels can be prepared in this way before it becomes necessary to regrind and re-etch the surface. Peels which stick need to be removed with acetone and a razor blade. The surface must then be reprepared. A variety of carbonate staining techniques may be used to enhance details of features (Bouma, 1969, pp. 251; Warne, 1962). Alizarin red is a particularly useful stain for this purpose. Peels can be stored in a loose-leaf file inside plastic sample bags, or in a document-display folder. Alternatively they can be made into glass slides (Stewart and Taylor, 1965; Bouma, 1969, p. 68).

A simple technique, known as the "streak print" method (Morris and Ewers, 1978) can be used for making peels - especially of siltstone or shale lithologies. This method uses transparent self-adhesive tape (sellotape or scotch tape), which is pressed smoothly onto the rock surface, and then peeled off and mounted on a backing. This is usually of white paper, although a darker sheet can be used to show up light-cloured minerals, or transparent plastic can be substituted.

For stromatolite samples, the surface to be replicated is covered with parallel strips of tape. These are then removed and stuck on the backing surface in the same relative positions. This method works well with shaley or silty carbonates, but is only effective on surfaces which have not been highly polished. Staining is also possible with the "streak-print" technique (Morris and Ewers, 1978, p. 564), but its applications for the preparation of streak prints from carbonate samples requires further investigation.

4.7 Line drawings

Simple line drawings of cut surfaces provide valuable information about column outlines, margin structures and laminar profiles. These features show up clearly on highly polished or varnished faces, but such preparation is time consuming. The simplest technique is to smooth-grind the cut surface (using carborundum powder up to grade 600), wet the cut surface to increase the contrast of the various features, and position a sheet of transparent drafting film (of the type used for air-photo overlays) on the wet surface. Details of laminae etc. show up clearly through the film and can be traced directly using indelible ink.

Where specimens are poorly preserved, the relevant details can first be picked out by the use of pencil lines drawn directly on to the rock surface. Contrast can also be improved by etching or staining.

An alternative method is to photograph the specimen; draw in the the required lines directly on the photograph with indian ink; then to bleach the photograph chemically (Isham, 1965, p. 464).

4.8 Three-dimensional graphical reconstruction

The procedure for constructing a three-dimensional diagram from serial slabs was pioneered by Krylov (1963) and subsequently described by Walter (1972), Preiss (1976) and Hofmann (1976). Stages in the preparation (Fig. 3) are illustrated by Walter (1972, fig. 2), Preiss (1976, fig. 3) and Hofmann (1976, fig. 1).

The method summarized below combines the methods described by these authors.

(a) Fasten a large sheet of millimeter graph paper to the drafting surface to act as the control grid.

(b) Tape a large work sheet of transparent drafting film on top of the graph paper to form the work sheet. The original tracings are inserted between the work sheet and the control grid. Reconstructions are made on block diagrams corrected for perspective by tracing outlines of columns from successive tracings usually offset at an angle of 45°. It is best to work in pencil, so that only relevant lines are inked in on the final diagram.

(c) Select a position for the point of origin for the block diagram. This coincides with the intersection of the base reference line (x axis) and the vertical reference line (y axis). This point can be on either the left or right side of the diagram as determined by the details on the tracings. Draw the x^1 and y^1 reference lines on the work sheet.

(d) Construct a line at a 45° angle from the point of origin. (This is usually drawn in the upper right quadrant to provide a dextral view, but sinistral views can also be constructed). This is the lateral reference line (the z axis). The point of origin of successive tracings are located along this line.

(e) Insert the first tracing between the control grid and the work sheet so that the x and y axes on both the tracing and work sheets coincide. Trace the outline of the columns onto the work sheet.

(f) For greater accuracy in column reconstruction follow the contour method devised by Hofmann (1976). To do this mark those points on the column margin which intersect grid lines. The spacing of the grid should be regular, but will need to be selected according to the size of the columns to be reconstructed. Remove Tracing (1).

(g) Determine the actual thickness separating Tracing (1) from Tracing (2) and calculate the displacement distance corrected for perspective - i.e. the thickness multiplied by cosine 45° or t x 0.7. Mark the calculated value on the z axis. Construct reference lines x^2 and y^2 from this point. These are the new base lines for Tracing 2.

(h) Because facing slabs present mirror images, every second tracing must be reversed for the reconstruction. Insert the reversed Tracing (2) so that the reference lines coincide with the x^2 and y^2 axes.

(i) Imagine that the outline of Tracing (1) is opaque. Trace the "visible" outline of columns from Tracing (2). Again mark all points where outlines intersect grid lines. Hofmann (1976, p. 19) points out that the "procedure is considerably simplified if the serial sections are cut and ground so as to be an even number of millimetres apart (4, 6 mm, etc.): This is because the distance between successive horizontal reference lines in the projection chosen is equal to 1/2 the true distance as measured on the original sample (cos 45° x cos 45°) allowing the horizontal reticle lines to be used directly as guides. Thus, if the sections are 4mm apart in reality, the horizontal x reference line of the second tracing lies along the grid lines 2 mm above the first, but shifted 45° to one side. This is equivalent to moving the reference points 4x cos 45° = 2.8 mm along the projection's oblique" [z] "coordinate."

If Hofmann's suggestion of using even, regular spacing of faces has not been adopted, the contour intersection can still be marked by slipping a second sheet of graph paper, marked with x and y axes, under the work sheet. Position the sheet so that the axes coincide with x^2 and y^2, and use the same grid selected for Tracing (1) to mark off the intersections.

(j) Repeat the operation for all the tracings, remembering to offset each by the appropriate distance, and to reverse every second tracing.

(k) Join the points of equal elevation indicated by the column margin/grid intersections (if the reconstruction is a complex one it may be simpler to join the points together after adding each outline).

(l) Add any required intermediate profiles (Hofmann, 1976, p. 19). The use of supplemetary profiles should be recorded in the figure caption.

(m) Reposition Tracing (1) and trace the outlines of the laminae on the "cut face" of the columns. (This can be done earlier, but tends to clutter up the working diagram.)

(n) Make a clean copy of the drawing in ink. The completed diagram can either retain hypsometric contours, or be stippled or shaded (Isham, 1965, p. 461). Stippling requires practice to produce the correct degree of shading, and is subject to the idiosyncrasies of individual authors. It is often possible to identify the draftsman from the style of execution, leading to problems of subjectivity (Hofmann, 1976, p. 15). Nevertheless, well-executed stippled reconstructions sometimes provide the clearest image of the three- dimensional properties of stromatolite columns.

Depending on the state of preservation, ease of slabbing, and size of specimens (for example, very delicate columns are often difficult to depict accurately) it is not always possible to make accurate reconstructions. Walter (1972, p. 8) suggested the following reliability rating:

R1 - as accurate as the method allows with well preserved, distinct columns.

R2 - column margins are slightly altered or indistinct; the gross shape is as accurate as for R1 but the margin structure is a little inaccurate.

R3 - columns are very indistinct or altered; gross structures as reconstructed moderately inaccurate (e.g. may be more or less coalescing than shown, bridges may be missed or interspace laminae mistaken for bridges); reconstructions of the column-margin structure are very unreliable.

Sometimes an interpretative reconstruction, based partially on serial slabbing, but also on the observation of field relationships of the various components, can be used to illustrate three-dimensional growth relationships. This is particularly useful with very large or very small specimens, but it is important that such diagrams are not mistaken for accurate reconstructions. They should be included in a separate category:

R4 - highly interpretative; based on field observations of features, and perhaps using data from partial reconstruction.

4.9 Statistical parameters and morphometrics

Various statistical parameters can be used to characterize stromatolite morphologies (Komar and others, 1965a; Preiss 1972, 1973, 1976; Walter, 1972). Most of the parameters measured can be plotted as histograms or frequency diagrams, and statistical methods can be used for more detailed analysis.

Hofmann (1969) made a detailed analysis of the geometric attributes of morphological features. These initial studies were followed by a series of papers (Hofmann, 1976b, 1977, 1978; Zhang Yun and Hofmann, 1982) advocating a morphometric approach to stromatolite classification. To date these methods have not been widely adopted, but as computer technology becomes more widely available, this type of analysis should become more commonplace.

Parameters considered by various authors as suitable for statistical and morphometrical analysis, and of possible significance for classification, are listed below. The publications listed should be consulted for more detailed descriptions of the methods.

(a) Longitudinal profile (silhouette) (Hofmann, 1976b, 1977, 1978)

(b) Diameter variations of columns (Hofmann, 1976b)

(c) Plan outline (cross-section) (Hofmann, 1976b, 1977, 1978)

(d) Laminar profile (Hofmann, 1976b, 1977, 1978)

(e) Degree of lamina convexity (Preiss, 1976, Zhang Yun and Hofmann, 1982)

(f) Thicknesses of the laminae (Preiss, 1976)

(h) Ratio of laminae thickness in conical stromatolites (Komar and others, 1965a, Preiss, 1972, 1976; Walter, 1972; Hofmann, 1978, p. 581 - for a dissenting view)

(i) Coefficient of crestal zone thickening in conical stromatolites (Komar and others, 1965a, Preiss, 1972, 1976; Walter, 1972; Hofmann, 1978, p. 581 for a dissenting view)

(j) Microstructure (Hofmann, 1976b, 1977, 1978)

4.10 Photography

Photographs play a crucial role in disseminating information about stromatolite taxa, and need to be of high quality. Their production is a skill acquired through practice, and special care must also be taken in plate preparation (Palmer, 1965). Stromatolites can be very difficult subjects to photograph, and require attention to correct orientation, low-angle incident lighting, elimination of reflection from polished surfaces, and maximum contrast. Specimens should be photographed for the optimum resolution of details, and to obtain this a fairly flexible approach is needed.

Some useful hints are given by Rasetti (1965), Whittington, 1965, and Douglass (1965). Contrast can be enhanced by techniques such as wetting the surface, or using glycerine or cooking oil. Bouma (1969) describes various methods for the photography of peels (p. 75), and for polished surfaces and thin or thick sections (p. 134).

Because stromatolites are a polymorphic group, the use of only one or two photographs is seldom adequate to give a representative view of the range of variation of a taxon. One of the more objective approaches to stromatolite illustration is the 'zoom' technique adopted by Hofmann (1977, 1978) and followed by Grey (1984). Hofmann (1977, p. 177) shows the components which make up a stromatolite bed (modified slightly by Grey, 1984, p. 9). To convey an adequate impression of a taxon, it is necessary to illustrate each of these components. Thus Hofmann uses a series of photographs, at successively larger scales (see Hofmann, 1977, figs 11 and 12), and wherever possible, each photograph is an enlargement of part of the previous one. A rectangle is used to pinpoint the area of enlargement, and in this way, a comprehensive picture of the nature of the components can be built up.

The first photograph of the series generally illustrates features observable in outcrop, such as the shape of the lithoherm, the shape of the fascicle (see Grey, 1984, p. 4), the spatial relationships of the columns, and the branching pattern. These photographs are often taken in the field, but can be of polished slabs for smaller specimens. Polished slabs and large peels can be used for general views of longitudinal sections, emphasising features such as column shape, branching and laminar profiles. A close up of an individual column shows the overall features of the laminae, and details of margin structures, ornament and/or bridging.

Finer details of laminar shapes and structure, together with an overall impression of the microstructure can best be obtained from a peel or thin section. It is usually necessary to use low power photomicrography for this phase of illustration; followed by a high power illustration of the microstructure.

Bar scales on the actual photographs are preferable to plate captions such as "magnification X2", because illustrations can sometimes be reduced during publication. All photographs should have a scale. It is often simplest to place a temporary scale adjacent to the specimen, in an area which will not appear on the final photograph. The temporary scale can then be cut off and a properly drafted bar scale added to the final photograph. This allows greater flexibility when enhancing the contrast of the specimen.

4.11 Preparing descriptions

Communication between stromatolite workers is enhanced by the use of standardized descriptive formats. Workers are often confronted by descriptions in a foreign language. Deciphering the relevant parts becomes easier when the systematc section conforms to a standard layout. Stromatolite descriptions play only a minor role in many papers, but the information presented may prove to be significant for another worker interested in taxonomy. It is, therefore, strongly recommended that any author who plans to include stromatolite descriptions in a paper should place these descriptions in a "Systematic descriptions" section at the end of the manuscript, just before the references.

The stromatolites which have been recognized should be divided into morphological variants. Each kind should be either distinguished by the use of open nomenclature, e.g. "Stromatolite form 1", or be given a formal binomial determination, according to the author's preference. The description of the designated taxa should be as comprehensive as possible, and illustrations are vital.

Formal descriptions should consist of a correctly constituted latinized binomial, a synonomy as appropriate, a diagnosis for a new taxon, a detailed description, and relevant stratigraphical and geographical data. A suggested format for such a description is given in the following section. Chapter 3 deals in more detail with aspects of terminology.

4.12 Suggested layout for descriptions

[Morphogeneric description]

[Name of morphogenus] new morphogenus

[Synonomy] :quote all previous identifications as necessary

Type form: [name of type form + author] or [name of new type form + new morphospecies]

Derivation of Name: explain the origin of the name, e.g. after a place or morphological characteristic.

Diagnosis: either give a brief list of main distinguishing features if describing a new taxon, or quote a reference to a previous author if necessary. If describing a new morphogenus which is monospecific the diagnosis can be stated to be "as for new morphospecies".

Content: list all contained morphospecies with authors and dates.

Remarks: make any comments here concerning the circumscription of the morphogenus e.g. "Several morphospecies previously assigned to this taxon are now considered to be a separate morphogenus because they are characterized by the development of niches, and have a distinctive microstructure".

Distribution: list previously recorded stratigraphic and geographic occurrences of the morphogenus e.g. "Widespread in the late Proterozoic of USSR and Australia" or "Known only from the Duck Creek Dolomite, Wyloo Group, in the Capricorn Orogen of Western Australia ([Author, Date])".

[Morphospecific description]

[morphospecific name] new morphospecies
or

Stromatolite form [No]

(Plate 1, figs 3 - 5)

[Synonomy]
[Date] Stromatolite mgen. and msp. indet. [Author's name] p. 1, Pl. 1, fig. 1

Material: list the catalogue numbers of the specimens used to define the morphospecies and their locality details - holotype first, then paratypes and other material. If using a previously described species, give details of holotype. Document where the new material is housed if this has not been dealt with earlier.

Derivation of name: [explain the origin of the name e.g. after a place or morphological characteristic, etc.]

Diagnosis: list the main diagnostic features (including those which distinguish this morphospecies from others with the same general characteristics).

Description: this is the main description of the morphospecies and should include all of the characteristics. Follow the layout, suggestions, subheadings and terminology detailed in Chapter 3.

Remarks: comment on features such as reassignment; previous references to the form, or associations with other forms.

Comparisons: this section provides vital information for workers using use your descriptions and illustrations. Explain how the morphospecies differs from others in the same morphogenus. Comment on other morphospecies which may have some characteristics in common. Remember that field geologists without a taxonomic background may use your identification, so emphasize the features which distinguish this taxon from others occurring in the same sequence.

Distribution and Age: give general geographic and stratigraphic distributions, together with relevant radiometric or other dating. If the morphospecies has been previously described, list occurrences and appropriate references.

Illustrations: these are vital and should be of the highest quality attainable. Use both line drawings and photographs (see section 4.10).

CHAPTER 3

TERMINOLOGY FOR FOSSIL MICROBIALITES

INTRODUCTION

This chapter includes features common to both stromatolites and thrombolites, so the general descriptive term microbialite (Burne and Moore, 1987) is used, except where the decription deals specifically with laminated structures (i.e stromatolites) or with non-laminated structures (i.e thrombolites) in the sense of Burne and Moore (1987). The chapter deals in detail with the terminology used to describe various microbialite characteristics (Fig. 1). The discussion of the terms follows a general layout suitable for morphological descriptions, and it is recommended that authors make use of the suggested subheadings within such descriptions. The main aspects to be considered are:

1. Nature of the outcrop
2. Bed
3. Mode of occurrence
4. Branching habit
5. Column shape
6. Margin structure
7. Nature of the laminae
8. Texture (Microstructure)
9. Interspace filling
10. Secondary alteration

1. THE OUTCROP

The type of observations to be made at the outcrop have already been described in Chapter 2 (section 1.1). A few further hints are given here, and some general headings are suggested.

1.1 Location

Microbialite localities are best given in latitude and longitude, and should be accompanied by a map showing general locations for the area under consideration. For remote localities it is advisable to include access data. If several locations are being discussed, it may be simplest to give each locality a code number, mark it on the map, and then group all locality data in an Appendix (Grey, 1984). This avoids cluttering the text with repetitive information.

Stratigraphic information is also important. Usually the stratigraphic sequence will be described at the beginning of the paper, and it should be enough to name the formation and group in which the taxon occurs. If the microbialite occurs at more than one locality, include a discussion of any variation in morphology between localities.

1.2 Areal extent

The reader should be given a clear idea of the lateral and vertical extent of the outcrop.

1.3 General details of preservation and exposure

This should include information on lithology, weathering, diagenetic and other secondary alterations affecting the outcrop, and any additional factors which may influence preservation.

1.4 Lateral and vertical variations of microbialites

Any significant variations should be recorded, and if the variants are considered sufficiently distinctive to belong to different taxa, the relationships between them should be discussed here. Comment on whether the relationships are transitional, abrupt, or part of a "bioherm series" (Walter and others, 1988) - see Chapter 4. Is there any evidence of cyclic development?

If microbialites show "recurring, consistent associations of different stromatolites within bioherms and biostromes" you may decide to use the bioherm series nomenclature of Walter and others (1988). Where several taxa are grouped into a bioherm series, the name for the series is distinguished by being entirely capitalized e.g BALBIRINA PRIMA, and a description of the bioherm series precedes descriptions of its component taxa.

2. THE BED

If several microbialite horizons are present, it may be necessary to describe them separately. Where there is little variation from horizon to horizon, a more generalized description may be given.

2.1 Thickness

Is the microbialite horizon of uniform thickness or is it a series of lenses?

2.2 Lithology

What is the lithology of the microbialite? Does this contrast with the rest of the unit in which it occurs e.g. carbonate lithoherms in a calcareous siltstone and shale horizon (Bertrand-Sarfati, 1972, figs 2 and 9; Bertrand- Sarfati and Moussine-Pouchkine, 1985, fig. 4)?

2.3 Nature of upper and lower boundaries

Are the boundaries of the microbialite-containing bed well-defined or transitional into overlying or underlying sediments? Is there evidence of erosion or unconformity? Does the base of the bed coincide with the base of the microbialite horizon? Do microbialites begin with stratiform laminae, or do columns develop independently? If the microbial lithoherm differs from the containing bed, what is the nature of the boundary between the two?

3. MODE OF OCCURRENCE

This section covers the gross morphology of the microbialite mass within the bed - the reef, carbonate buildup, or the microbial lithoherm of Burne and Moore (1987). Does the microbialite occur in microbial lithoherms (bioherms) or lithostromes (biostromes), and/or as separate fascicles (Grey, 1984), and/or as individual columns or oncolites (Fig. 4)? What is the nature of the microbial lithoherm? Does it have a unified base which divides upwards into fascicles or columns? Is it complex, consisting of several anastomosing and dividing layers?

3.1 Mode and Shape

Is the microbialite mass a lithoherm or lithostrome (Fig. 5)? Walter (1972) defined a lithostrome (biostrome) as having a length one hundred times its height. These values are somewhat arbitrary, but provide a reasonable guide. Where the structure is inadequately exposed, it may be difficult to determine the three- dimensional nature of that part of the carbonate mass containing microbialites. In such cases the term "microbialite buildup" (after Heckel, 1974, p. 92) can be used.

3.1.1 Lithoherms (Bioherms)

Lithoherms sometimes have quite distinctive shapes (Fig. 5A), and these should be described, and dimensions and orientations given where possible. Lithoherms can be:

a) subspherical
b) domed
c) tabular
d) intertonguing

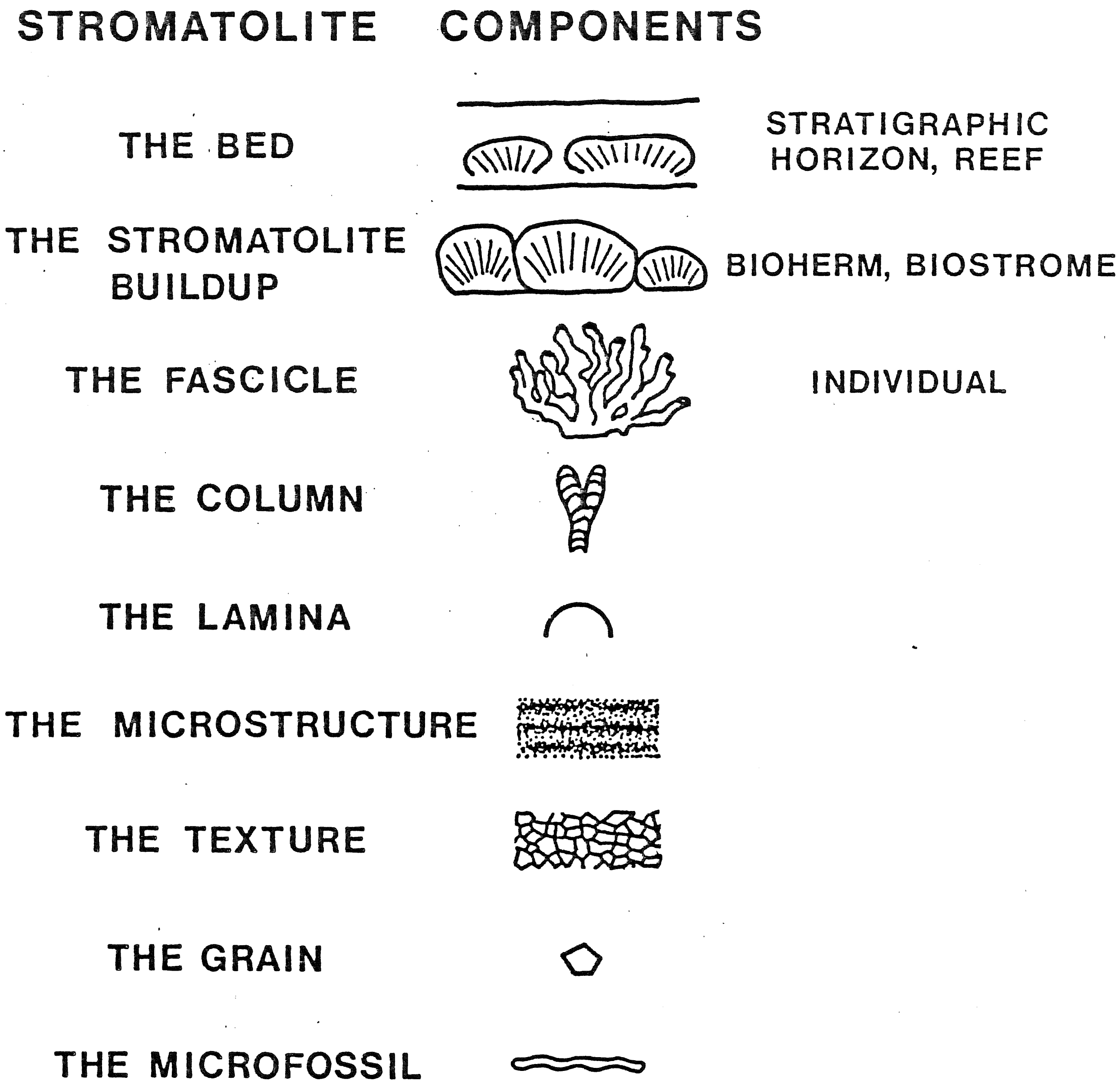
3.1.2 Lithostromes (biostromes)

Lithostromes can also show variation in shape (Fig. 5B), and sometimes a lithostrome is formed by a series of laterally-linked lithoherms. Lithostromes can be:

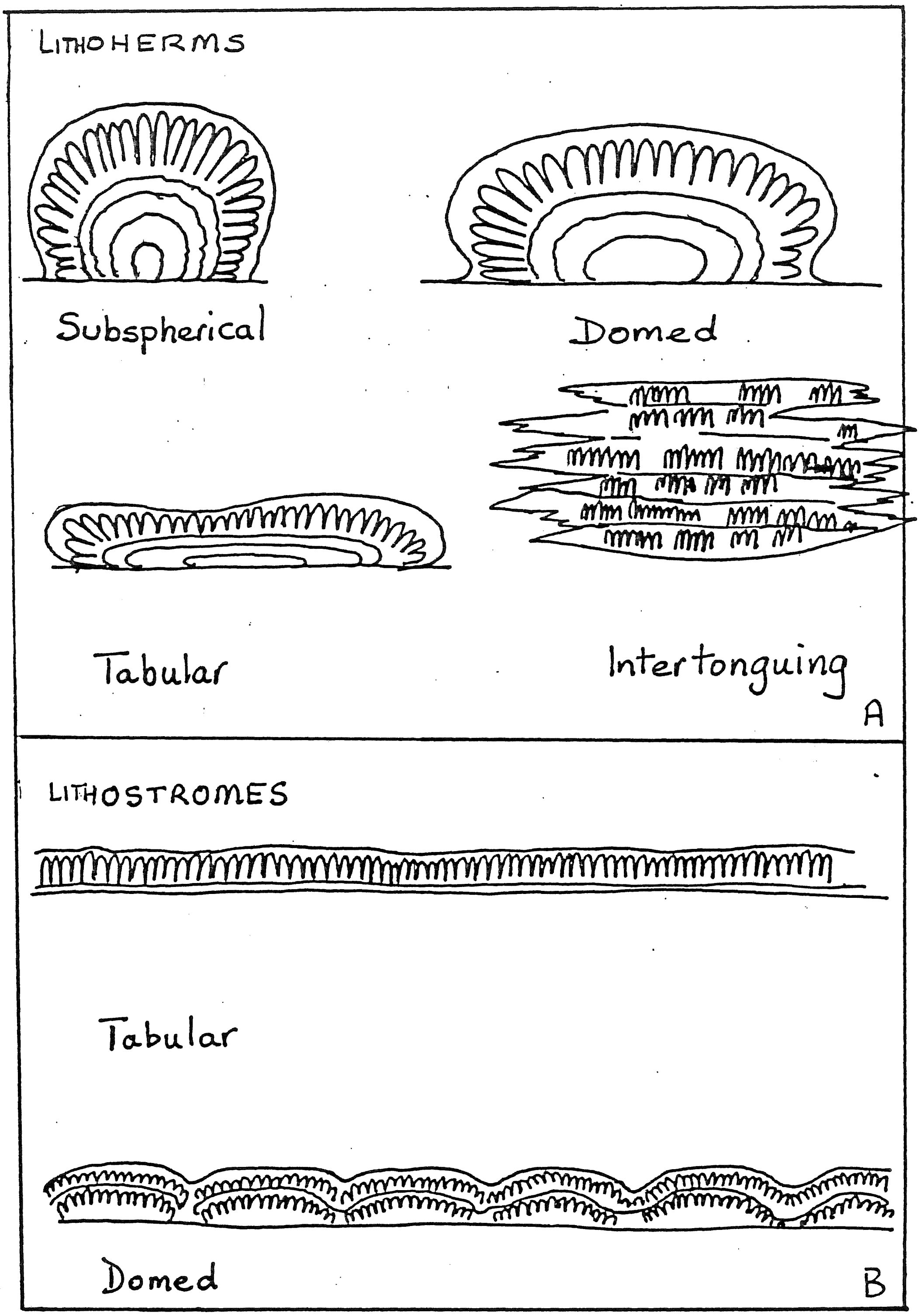
a) tabular
b) domed

3.2 Constituents of Lithoherms

Is it necessary to describe the lithoherms in terms of "Bioherm Series" (Walter and others, 1988). Consider the range of morphological variation which occurs in both gross morphology and microstructure. The description of a bioherm series should form the first level of the description, and should include a list of all the component taxa. Each taxon should then be described following the standard methods for the description of taxa as outlined here. Lithoherms which are not to be described as bioherm series may still be composed of recognisable units - e.g the "fascicle" of Grey (1984, p. 4). Note the shape and relationships of fascicles within the bioherm.



4. Components of stromatolite-bearing beds
(After Grey, 1984; Hofmann, 1977)



5. Mode of occurrence - A) Lithoherms (Bioherms), B) Lithostromes (Biostromes)

3.2.1 Nature of Microbialite Constituents:

What are the shapes of the microbialites (Fig. 6) and what are their relationships within the bioherm or biostrome? They can be:

a) Stratiform [4.1.1]
b) Simple columnar [4.1.2]
c) Branching columnar [4.1.3]
d) Simple conical (does not include cylindrical columns with conical laminae) [4.1.4]
e) Linked conical (conical columns with abundant bridging) [4.1.5]
f) Branching conical (includes complex structures such as Jacutophyton [4.1.6]
f) Spheroidal (oncolites) [4.1.7]

3.2.2 Laminated or non-laminated

The term "microbialite" (Burne and Moore, 1987) was introduced to overcome the semantic problem of whether non-laminated structures - thrombolites - could be included within the term stromatolite, a term which implies that laminations are present. Studies of thrombolites (Aitken, 1967; Pratt and James, 1982; Kennard and James, 1986) have identified characteristic fabrics associated with non- laminated structures, mostly at the microstructure level. A parallel terminology can be used for mega- and mesostructural features (Pratt and James, 1982, p. 545), but a separate set of terminology must be applied to thrombolites once the fabric of the structure is considered. Determine whether the microbialites are:

a) laminated - i.e. stromatolites
b) non-laminated - i.e thrombolites

3.2.3 Linkage

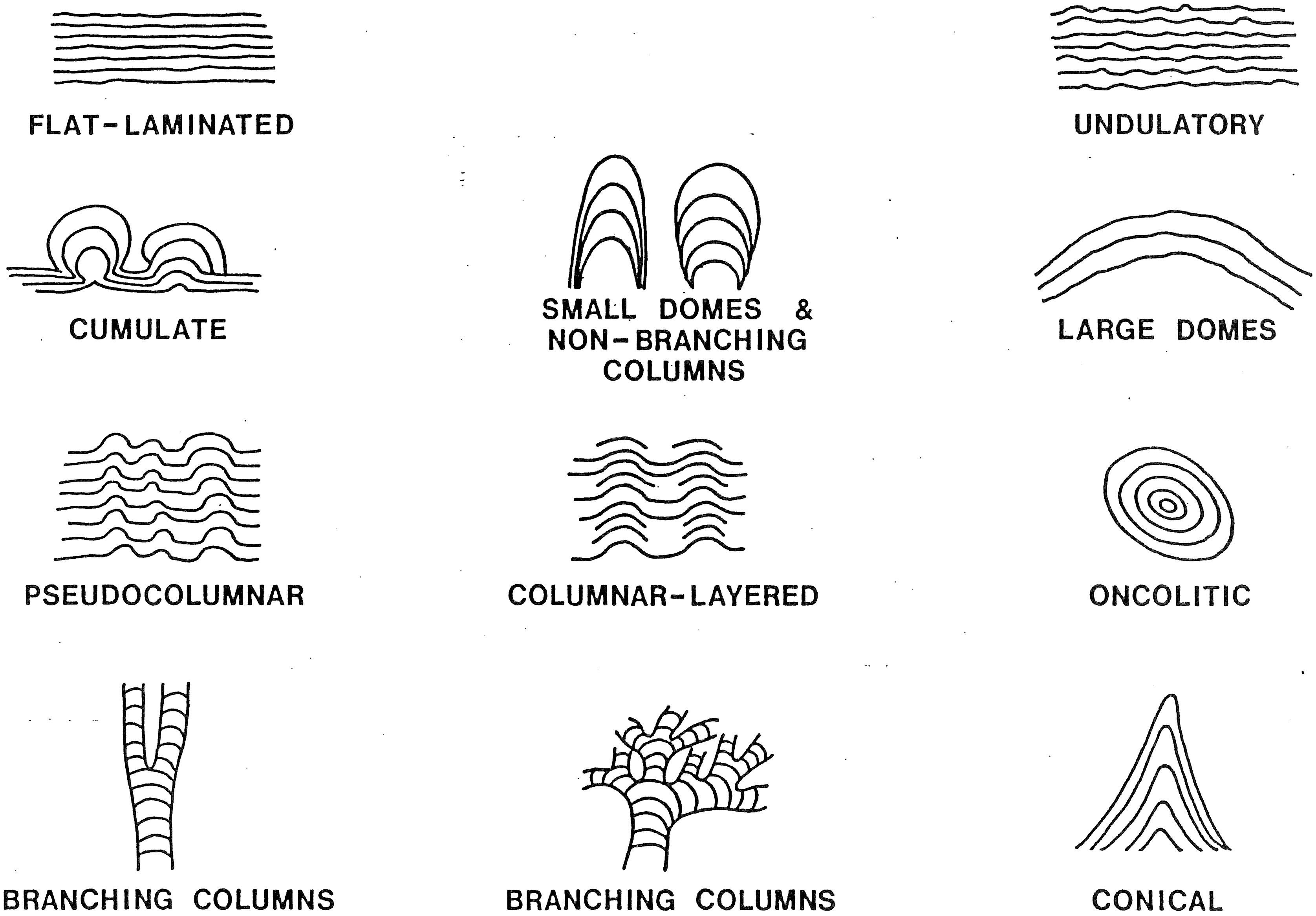
Linkage is the degree of connection between microbial lithoherms or fascicles (Fig. 7A). Are the lithoherms or fascicles:

a) linked
b) partly-linked
c) unlinked

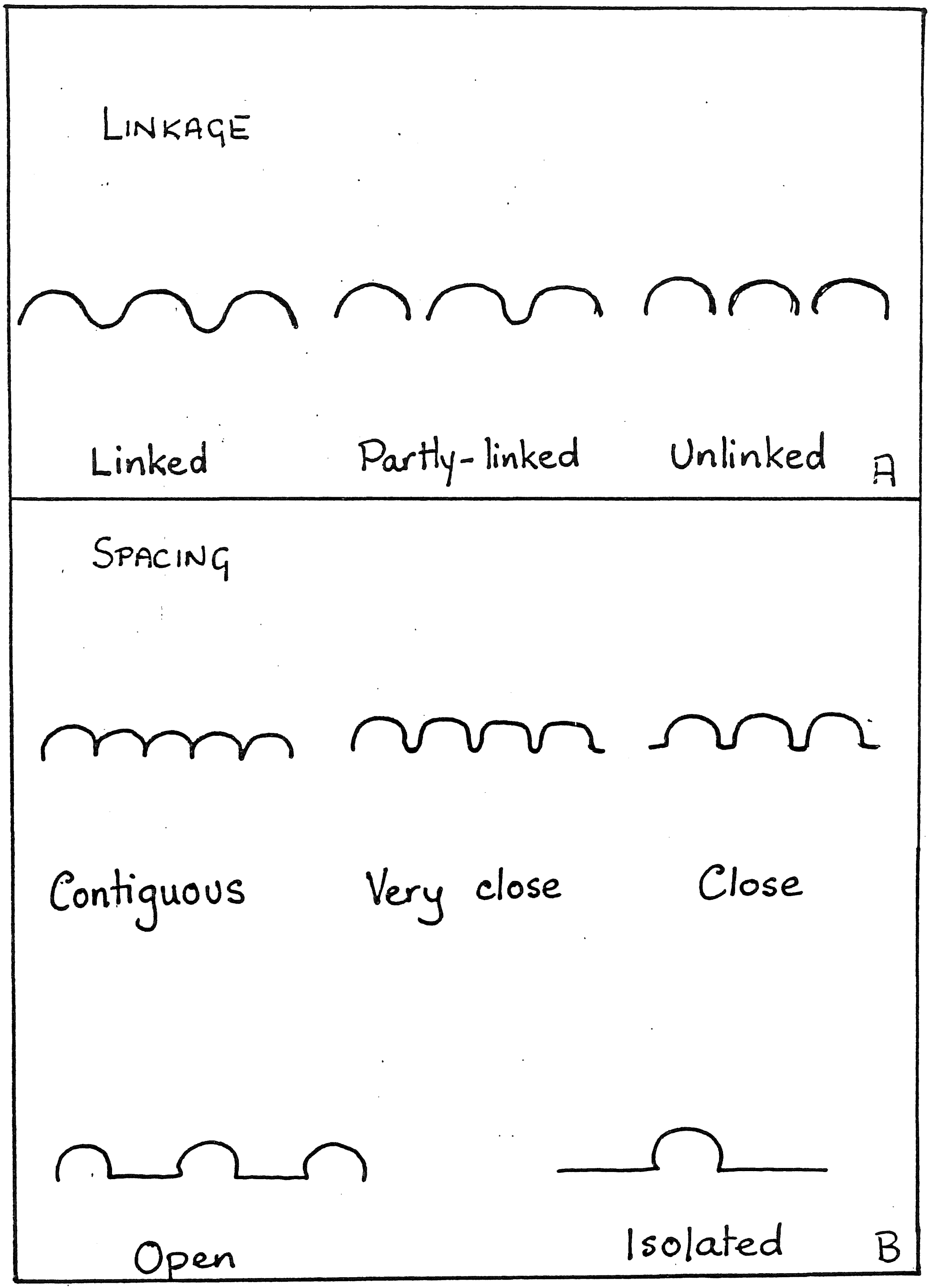
3.2.4 Spacing

Spacing between lithoherms and fascicles is an important feature (Fig. 7B). Sometimes lithoherms occur in clusters, or in an en echelon arrangement. Note any patterns carefully as they may be of significance in palaeoenvironmental interpretation. Are the lithoherms or fascicles:

a) contiguous
b) very closely spaced
c) closely spaced
d) openly spaced
e) isolated



6. Nature of microbialite constituents



7. Spacing of stromatolites - A) Linkage, B) Spacing (after Hofmann, 1969)

4. HABIT

4.1 Morphological Types

Hofmann (1969) gave a detailed account of geometrical parameters which control microbialite shape. A single fascicle can consist of several morphological types linked together by branching or overgrowth, e.g. a bushy, branching stromatolite may begin with a stratiform morphology and terminate with an encrusting layer of stratiform stromatolite. Although Hofmann's parameters provide a precise determination of shape, calculating them can be time consuming. The morphological type can often be determined by visual inspection and can be categorized by one of the following types:

4.1.1 Stratiform (Fig. 8)

a) flat-laminated
b) undulatory
c) pseudocolumnar
d) columnar-layered
e) cumulate

4.1.2 Simple Columnar (Fig. 9)

a) terete
b) cylindrical
c) turbinate
d) bulbous
e) nodular
f) hemispherical

4.1.3 Branching Columnar (Fig. 10)

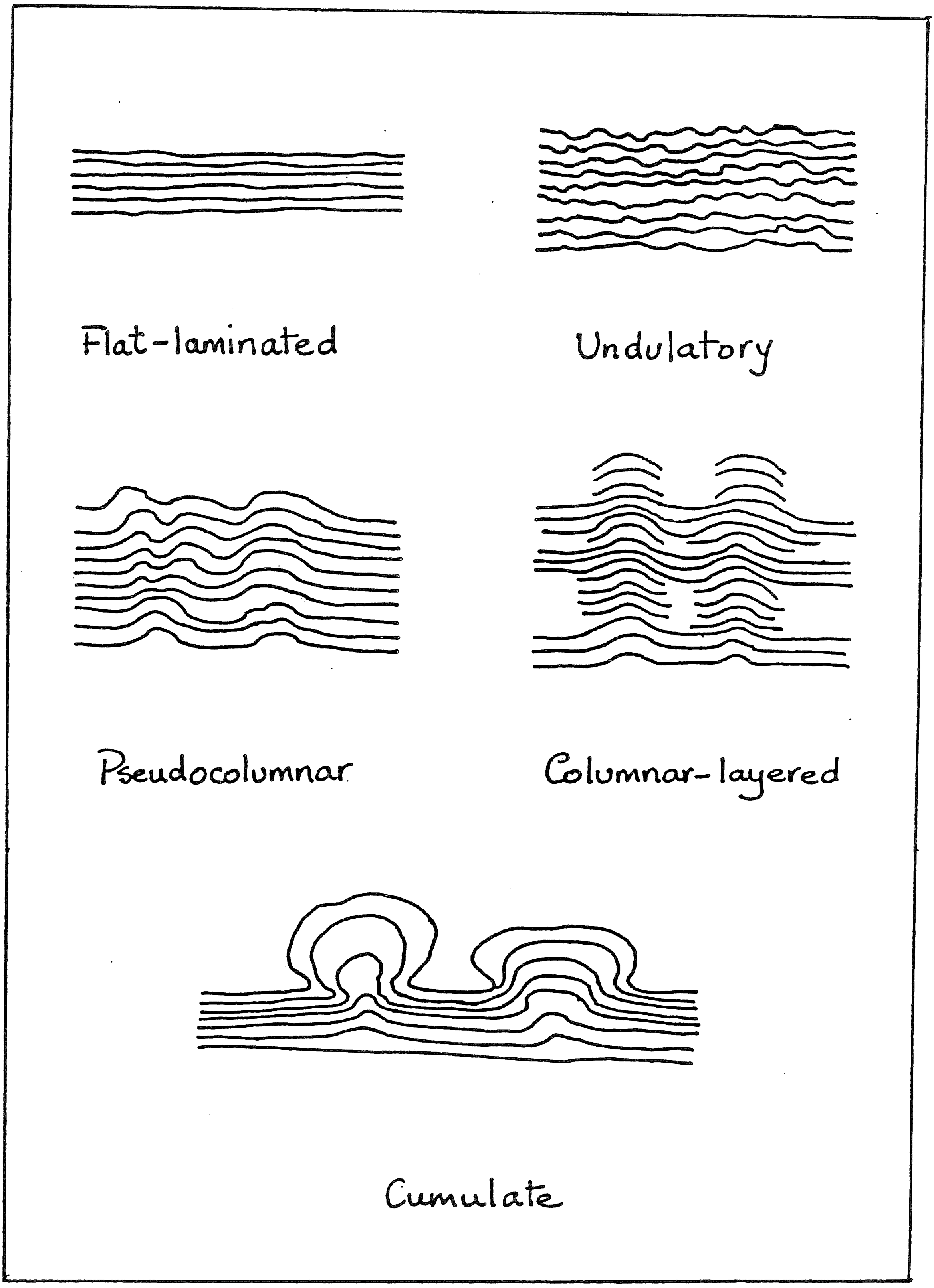
a) style

i) branching

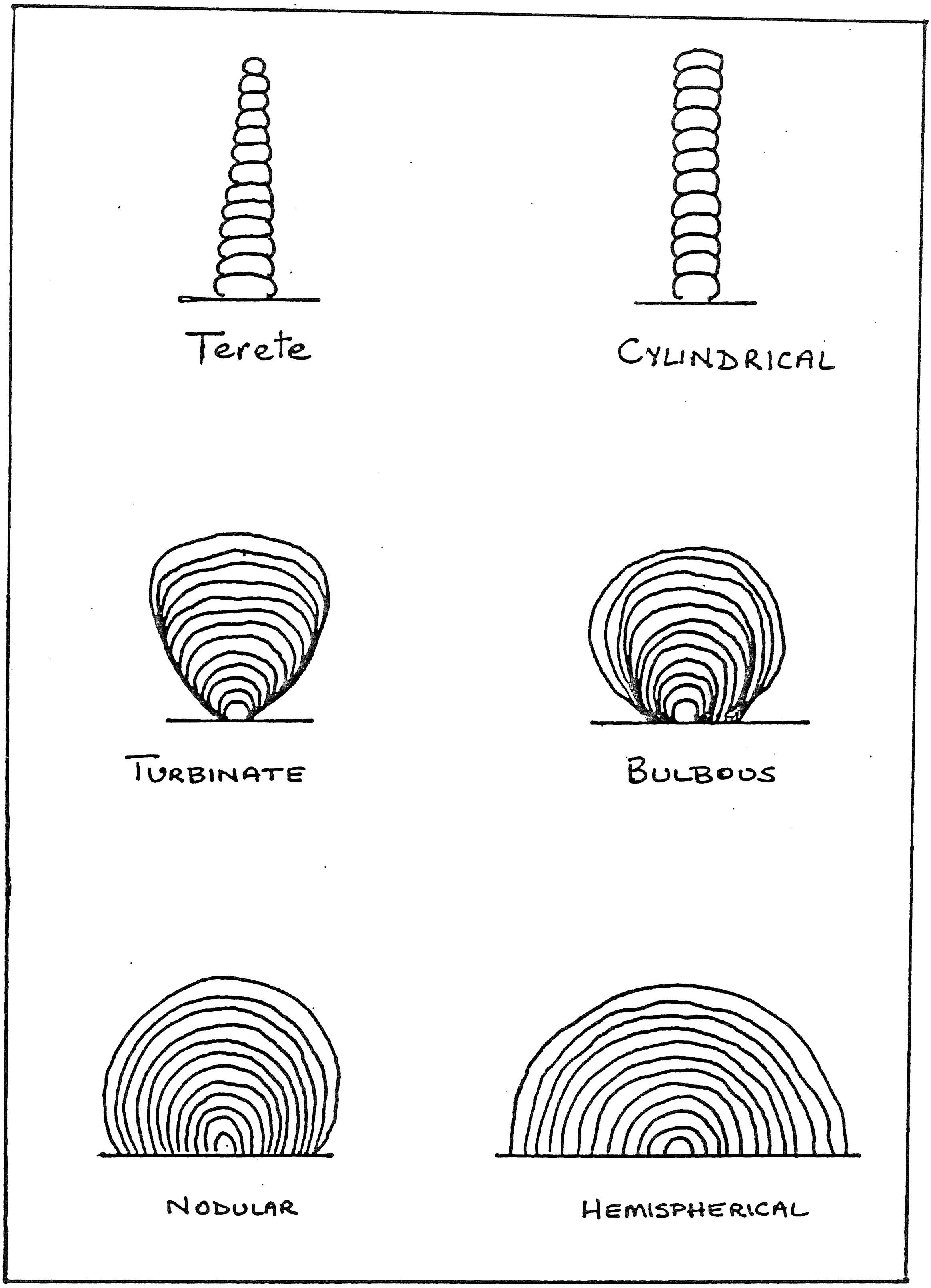
Branching style can be either **bifurcate**, where the column divides into two daughter columns; or **multifurcate**, where several daughter columns arise at the same horizon (Fig. 10A). Bifurcate branching can be either **dichotomous**, in which the daughter columns arise from the top of the parent column; or **lateral**, where the daughter column develops from the side of the parent column. Bifurcating daughter columns may form an **equal division** in which both are approximately the same width; or an **unequal division**, in which one is considerably larger than the other. Remember that equally divided columns may apparently have unequal widths if the plane of observation passes near the margin of one of the columns, but is near the middle of the other.

ii) convergence

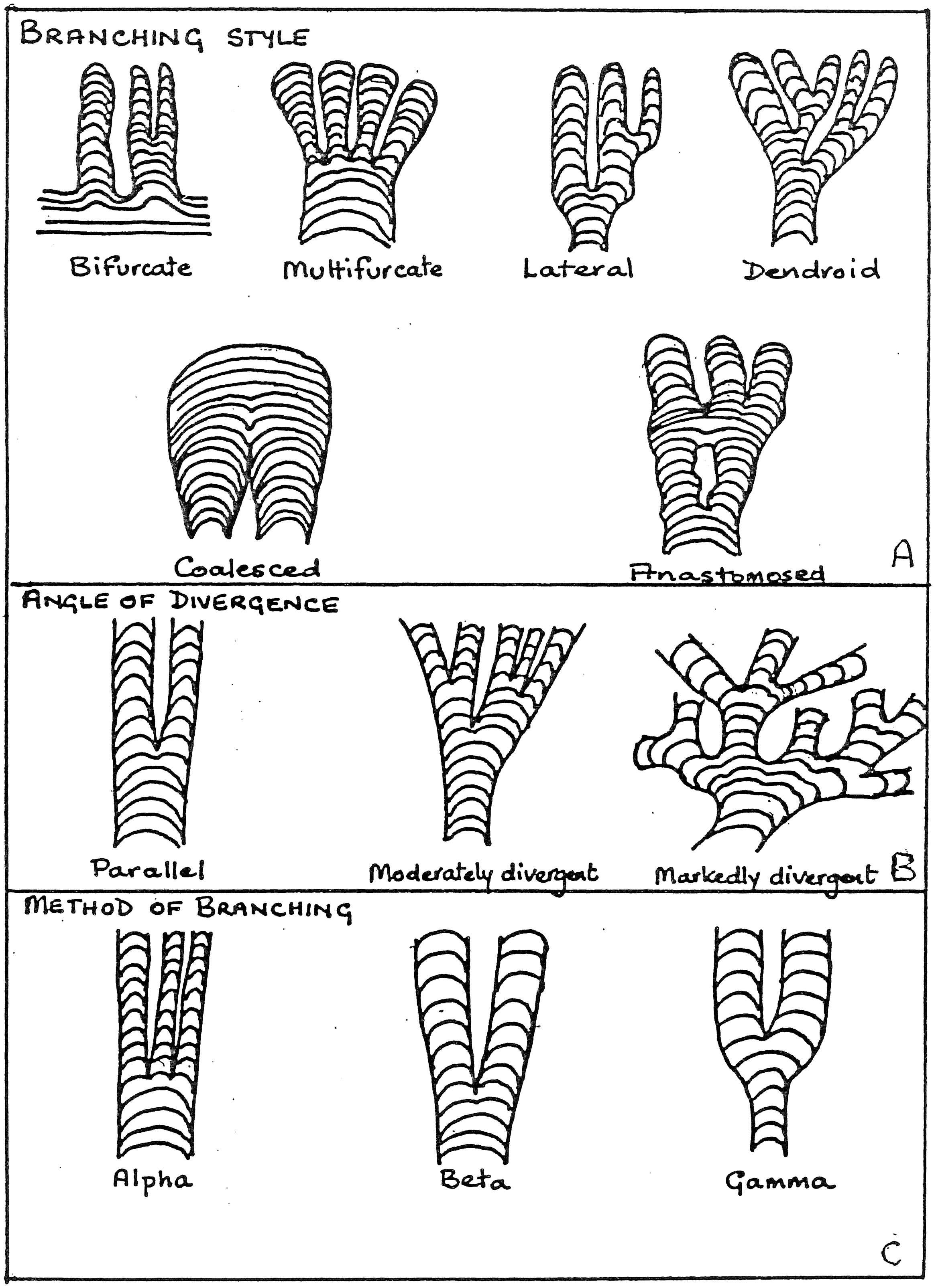
Some columns show a reconvergence after branching (Fig. 10A). This can be **coalescent**, in which two columns merge to form a larger column; or **anastomosed**, in which two columns are overgrown by a third larger column. The larger column may again subdivide, and the pattern be repeated several times. In practice it may not always be possible to make these distinctions.



8. Types of non-columnar stromatolite



9. Types of simple columnar stromatolite (after Hofmann, 1969)



10. Types of branching columnar stromatolites - A) Branching style, B) Angle of divergence C) Method of branching

b) Frequency of branching and spacing

Note the frequency of branching and its spacing along the column. Does branching occur at irregular intervals, or is the spacing consistent? Does branching occur in all adjacent columns at one particular horizon, or is it erratic? The shape created by the branching pattern can be further described by the use of terms such as arboriform, dendriform, fastigiate, bushy etc.

c) Angle of Divergence

What is the angle of divergence (Fig. 10B) of the daughter branches? This can be measured and given as a statistical parameter, or can be described as:

i) Parallel
ii) Moderately divergent
iii) Markedly divergent

d) Method of Branching

What is the method of branching, in particular, what happens to the column width in the area of branching (Fig. 10C)? Branching method can be of the following types:

i) Alpha - Branching in which the width of the individual remains constant.
ii) Beta - Branching in which the original column widens gradually before branching.
iii) Gamma - Branching in which the original column widens abruptly before branching.

4.1.4 Simple conical

The microbialites form simple, unlinked or rarely- linked cones (Fig. 11A). The commonest morphology is that typically assigned to the morphogenus Conophyton, consisting of conical laminae, a circular plan outline and a distinctive axial zone.

4.1.5 Linked conical

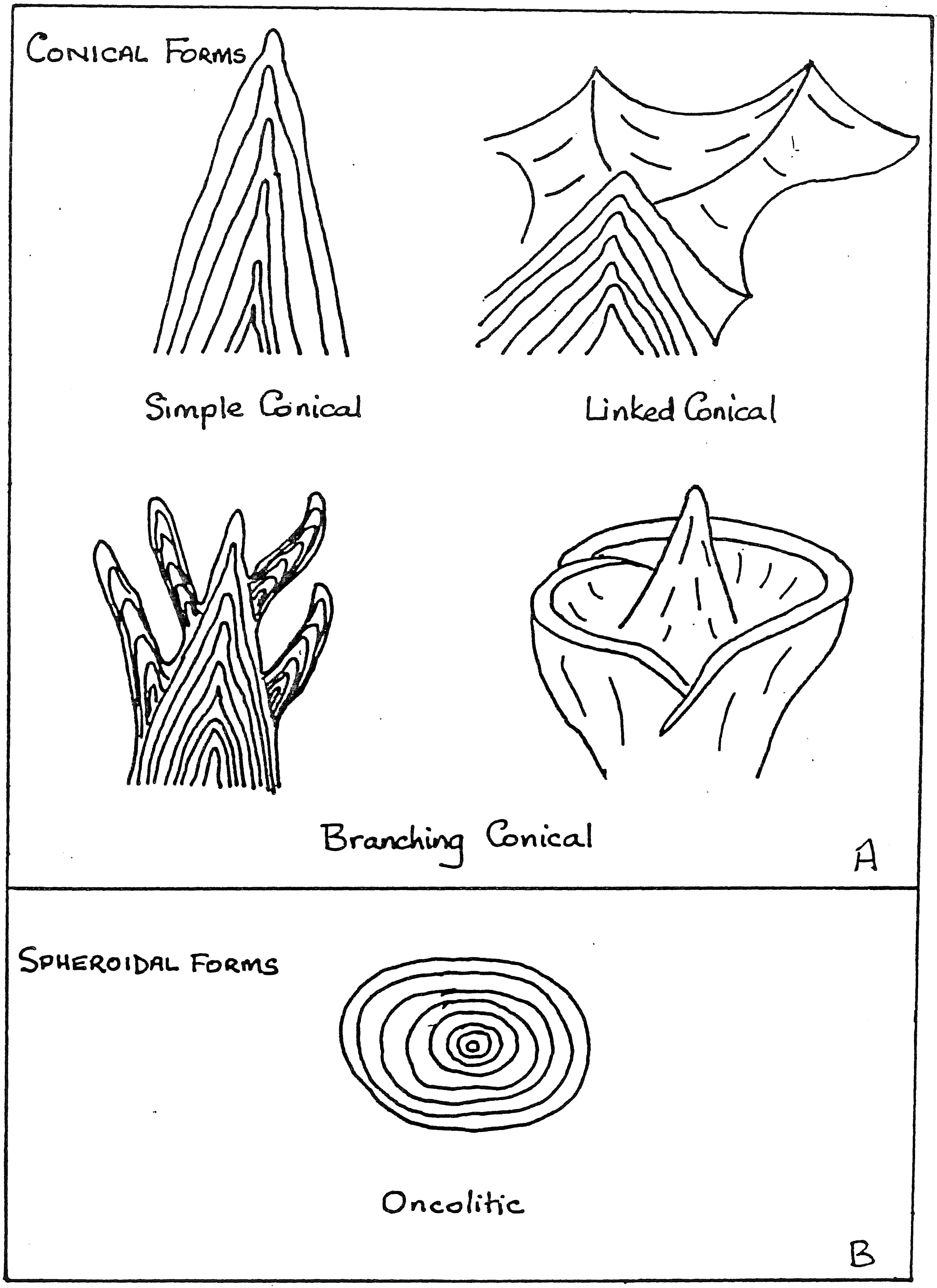
Although the microbialites form broadly conical structures, they may be ridged, and there is considerable linkage between the columns (Fig. 11A). Plan outlines are often eccentric, elongate ovoid or star-shaped.

4.1.6 Branching conical

Some conical stromatolites give rise to highly-complex structures (Fig. 11A) which consist of a central cone, surrounded by lateral branches (not necessarily with conical laminae) e.g. Jacutophyton ramosus Schapovalova 1979, or even to sheet-like rims which form petal-like appendages (e.g. Jacutophyton sahariensis Bertrand-Sarfati 1985 in Bertrand-Sarfati and Moussine-Pouchkine, 1985).

4.1.7 Spheroidal

This type of morphology includes the structures known as oncolites (Fig. 11B). They are completely detached from the



11. Types of conical and spheroidal stromatolites - A) Conical forms, B) Spheroidal forms

surrounding substrate, and are usually laminated, although non-laminated fabrics may also occur.

5. COLUMN SHAPE

5.1.5 Plan Outline

This is the horizontal cross-section of the microbialite i.e. the shape of the column when viewed in a plane at right angles to the direction of the growth vector (Fig. 12). Hofmann (1969) defined the following shapes:

a) Round: (circular, elliptical, ovate)
b) Oblong
c) Scutate (shaped like a shield)
d) Crescentic
e) Laxilobate (bilobate, multilobate), in which adjoining lobe margins are divergent.
f) Densilobate, in which adjoining lobe margins are parallel and very closely spaced.
g) Brevilobate, in which the lobes are very short and irregular).
h) Polygonal
i) Lanceolate

5.2 Vertical profile

The shape of a microbial column in profile is one of its most distinctive features (Fig. 13). Hofmann (1969) examined the various growth vectors that control the silhouette of columns, and used morphometric analysis (Hofmann, 1976, 1977, 1978) to determine the diagnostic significance of the features. Various aspects of the longitudinal profile should be recorded.

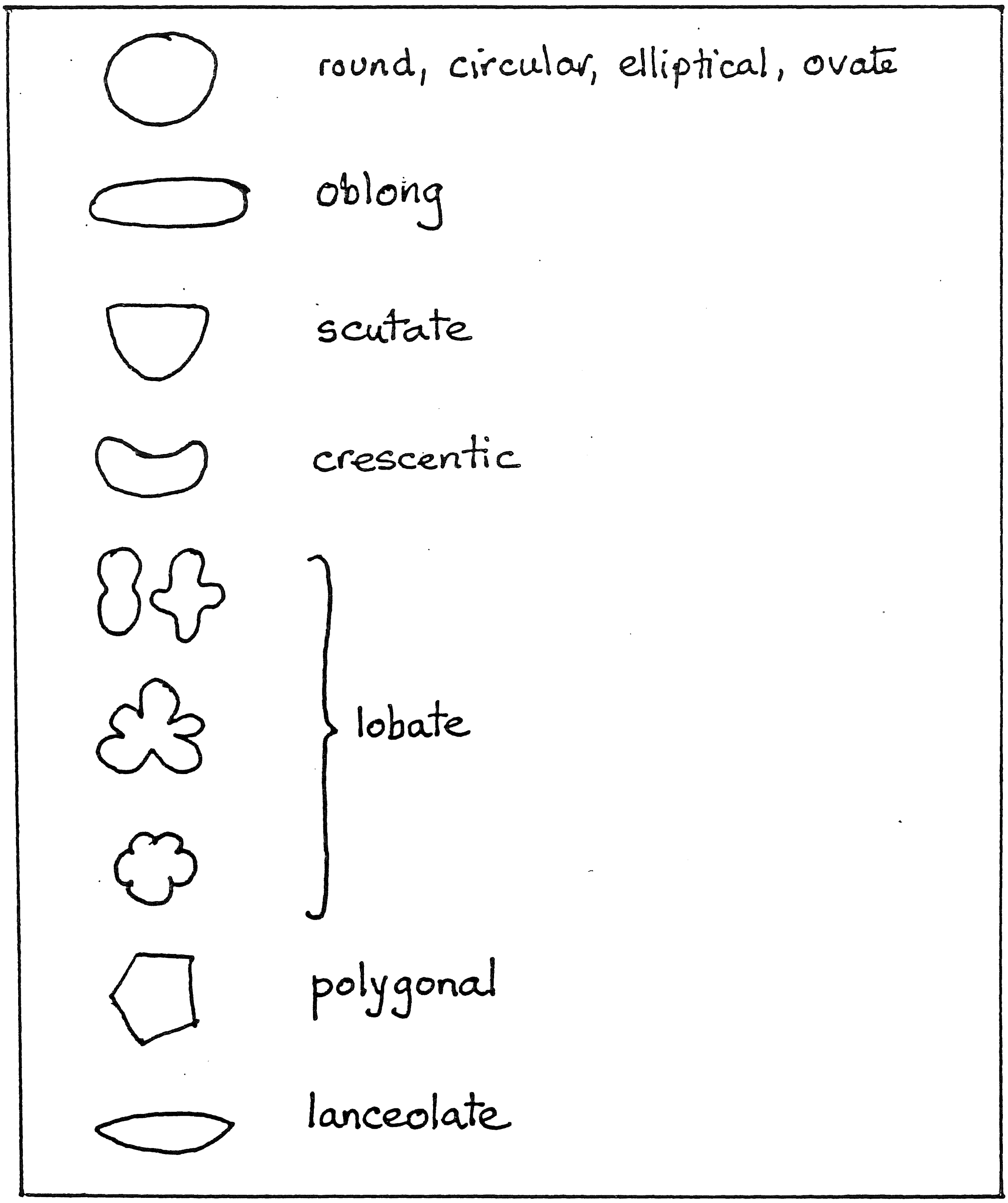
5.2.1 Column size

What is the average length (i.e vertical height) of the columns? What is their average diameter? It is usually best to quote a range of variation.

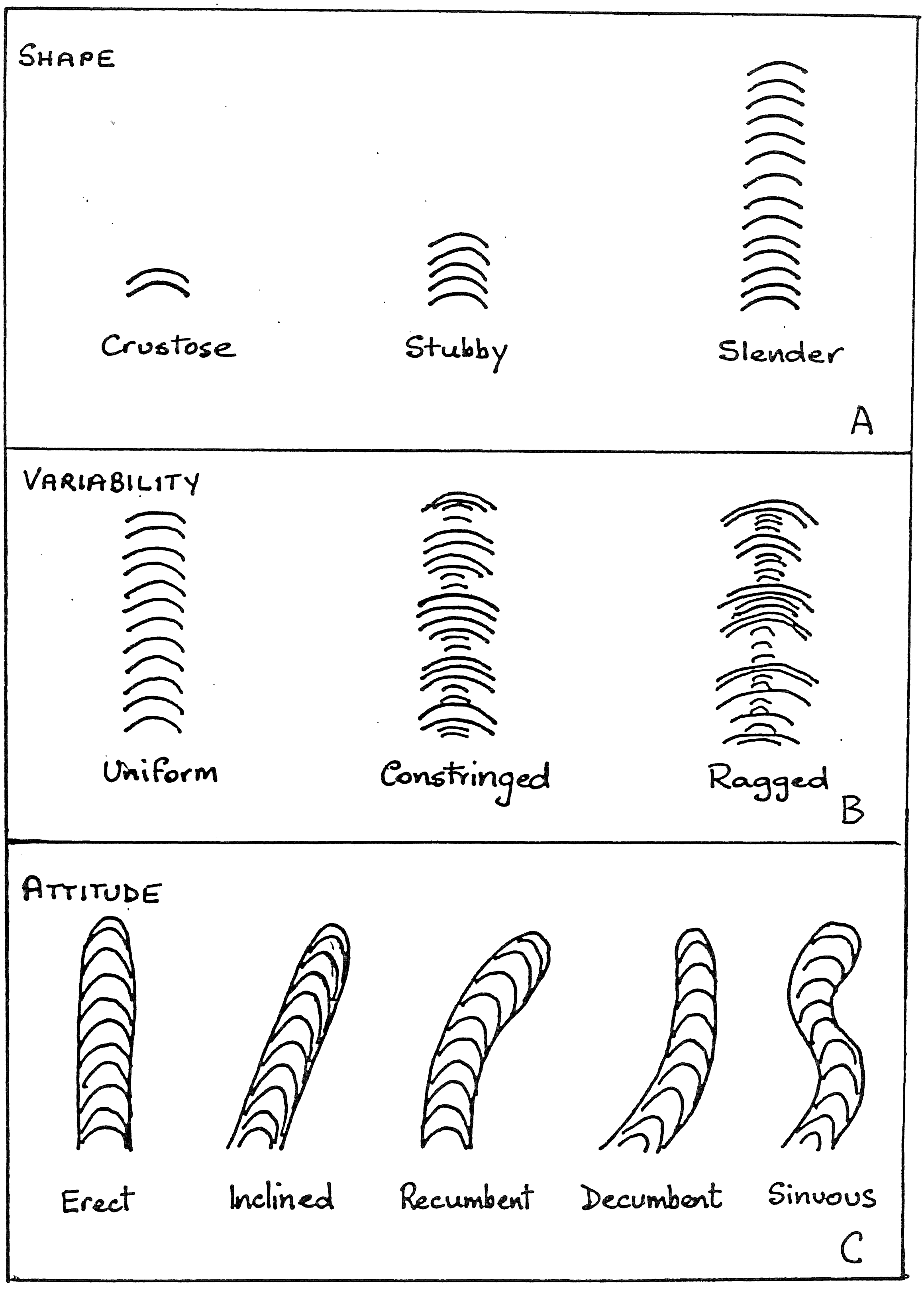
5.2.2 Elongation

What is the height to width ratio of the column? This is determined by the maintenance or duration of the upward growth vector, and, following Hofmann's (1969) terminology (Fig. 13A), can be described as:

a) Crustose ($H \ll 2r$)
b) Stubby ($H \sim 2r$)
c) Slender ($H \gg 2r$)



12. Plan outline of microbialites (after Hofmann, 1969)



13. Types of column - A) Shape, B) Variability C) Attitude (after Hofmann, 1969)

5.2.3 Variability of Growth

Does the diameter of the column remain constant, or does it vary (Fig. 13B)? Hofmann (1969) described the degrees of variability as:

a) Uniform - the diameter of the column is fairly constant in width.
b) Constringed - the diameter of the column is of variable width, but the changes occur slowly and fairly regularly.

c) Ragged - the diameter of the column is very variable, and variations occur rapidly and irregularly.

5.2.4 Attitude

What is the inclination of the column to the bedding plane, and is the column straight or curved? Hofmann (1969) recognized the following types (Fig. 13c):

a) Erect - straight and vertical
b) Inclined - straight but at an angle to the vertical
c) Recumbent - inclined with a convex curvature
d) Decumbent - inclined with a concave curvature
e) Sinuous - alternatively convex and concave
f) Centrifugal - growing outwards from a central point

6. FEATURES OF STROMATOLITES

6.1 MARGIN STRUCTURES

Margin structures are commonly formed by modification of the laminae, and are therefore features associated with stromatolites rather than with thrombolites.

6.1.1 Walls

A wall is formed by the downturning of laminae at column margins, and is a function of laminae shape and termination (Hofmann, 1969, p. 19). The significance of walls has not been satisfactorily determined, and synsedimentary erosion can sometimes remove evidence of a wall structure. Nevertheless, in some stromatolites the nature of the column margins is consistent, and appears to be a diagnostic characteristic.

Walls are described as **present**, **patchy** or **absent**, and this feature may vary along the length of columns when the characteristics of a fascicle are considered as a whole. Where walls are absent, laminae taper out with only slight downturning, and usually give the edge of the column a ragged appearance. Walls may be formed by only a few laminae, or may be **multilaminate**.

A wall may be **simple**, in which overlapping laminae are more or less parallel to each other along the sides of the column and gradually taper out; or **complex**, in which one or more laminae overlap the edges of several underlying laminae. In this case the overlapping laminae tend to terminate abruptly where they inturn against the column margin. Overlapped laminae tend to taper out. Some columns may have a precipitated outer coating, usually of sparry calcite or micrite, which is known a **selvage**.

6.1.2 Surface ornament

The nature of the outer wall determines the longitudinal profile or silhouette (Fig. 14). This is best observed in three-dimension reconstruction, but line- drawings, peels and thin sections can provide valuable clues. The terminology has been modified slightly from that given by Hofmann (1969) because the characteristics listed by him are difficult to determine. The ornament can be:

a) Smooth
b) Bumpy
c) Lobate
d) Rugate
e) Ragged
f) Projections (elongate protrusions from the column margins)
g) Niched (column margins have elongate hollows extending into the column body.

Combinations of several ornament types can occur - e.g. niches may be bordered by a projection. Three-dimensional reconstruction is particularly important for recognizing niches as hollows, rather than as spaces between branches.

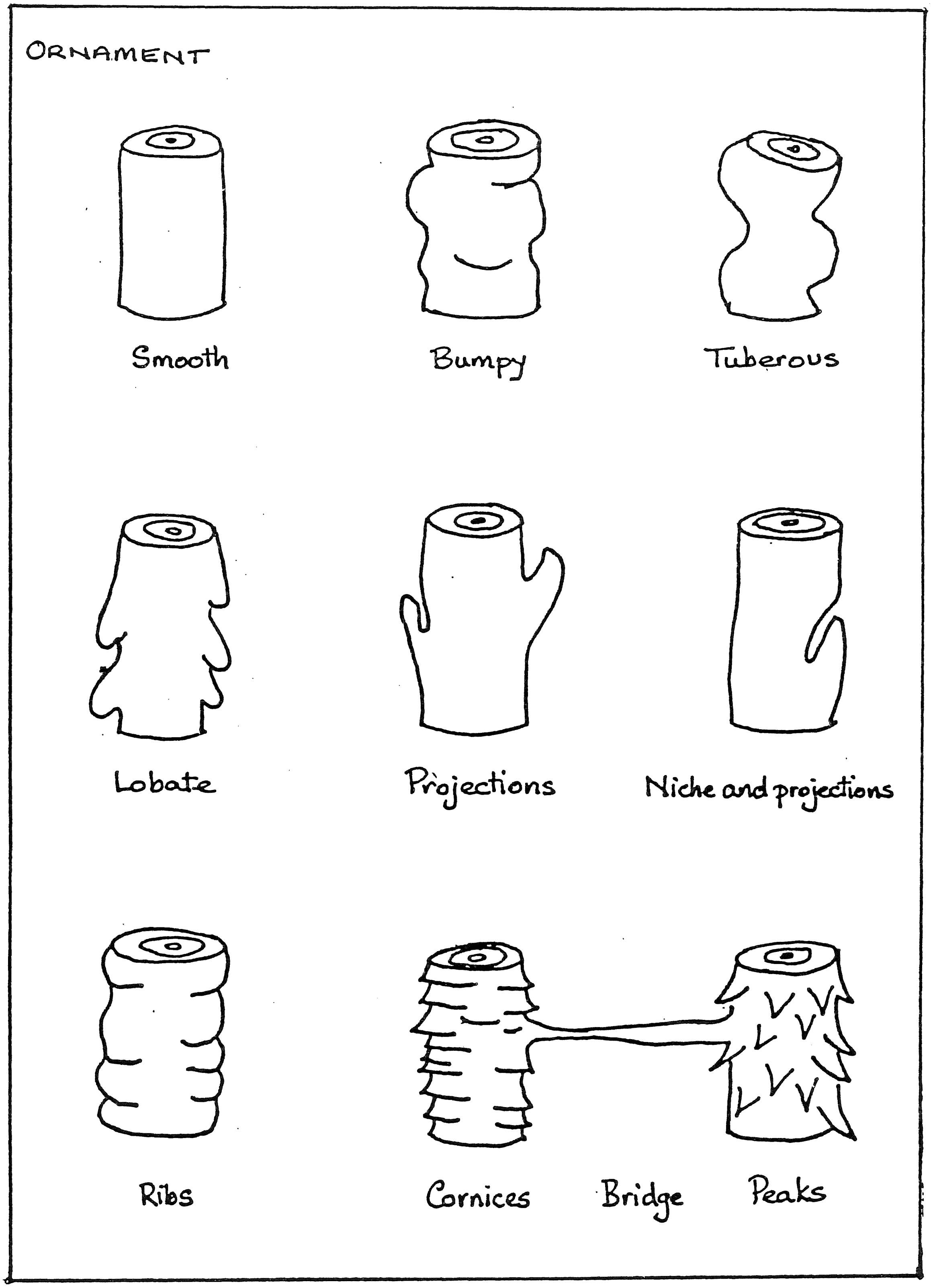
6.1.3 Linkage

Many columns show interconnections. These can be a faint trace of laminae - usually concave - developed across the interspaces; or the development of **bridges** (Fig. 14) - formed by several successive laminae connecting the columns. Bridging can be **slender** or **massive**, depending on the number of laminae involved.

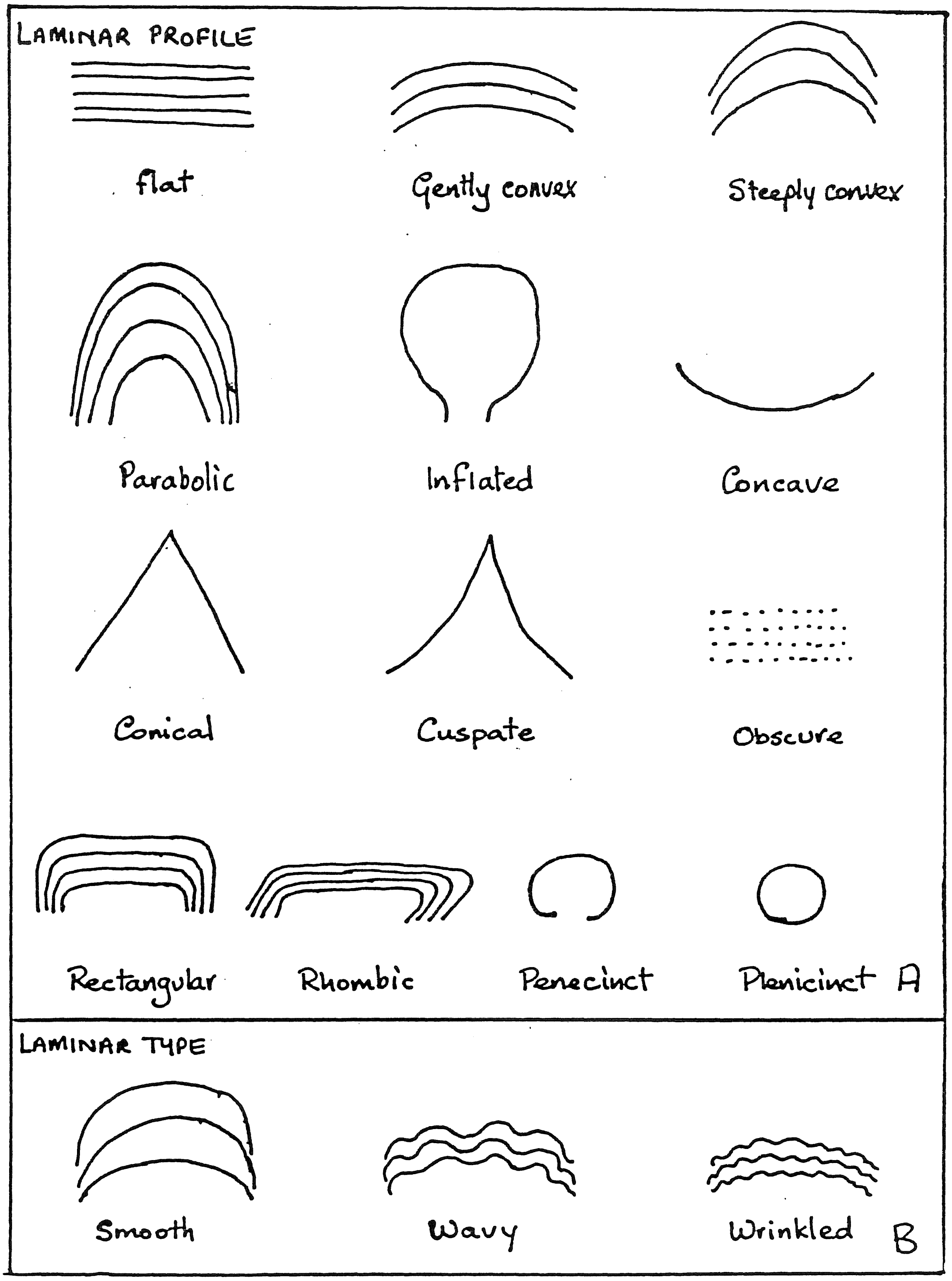
6.2 LAMINAE

The nature of the laminae is an extremely significant characteristic of laminated stromatolites (Fig. 15). The morphology and texture of the laminae are together referred to as the fabric (Bertrand-Sarfati and Walter, 1985). The fabric is the feature which provides the closest link with micoorganisms which built the stromatolite and which were involved in creating the shape and relief of the lamina.

The problems of recognizing overprinting caused by diagenesis has limited the understanding and use of microstructure as a diagnostic characteristic. However, there is increasing evidence that a particular mat type produces a



14. Types of column ornament



15. Types of laminae - A) Profile, B) Laminar type (after Hofmann, 1969)

particular type of microstructure, and that characteristic features of the mat are preserved even when diagenetic alteration has affected the stromatolite to a moderately high degree. Because of growing awareness of the specificity of fabrics, some workers now use microstructure and other lamina characteristics as diagnostic features at both morphogeneric and morphospecific level.

6.2.1 Lamina Profile

This is a very important characteristic in all laminated stromatolites. It can show considerable variation throughout the column or fascicle, but this variation is in itself diagnostic. The range of variation should be given, either from visual inspection, or from the use of morphometrics. Laminar profiles (Fig. 15A) can be of the following types (modified after Hofmann, 1969):

a) Flat
b) Gently Convex
c) Steeply Convex
d) Parabolic
e) Inflated
f) Concave
g) Conical
h) Cuspate
i) Obscure
j) Rectangular
k) Rhombic
l) Penecinct
m) Plenicinct

6.2.2 Lamina Type

Hofmann (1969) characterized laminae according to the order of curvature and the degree of eveness (Fig. 15B). Terms such as **even, corrugate, crenulate** and **dentate** can be used, but basically the nature of the laminae can be described as:

a) Smooth
b) Wavy
c) Wrinkled

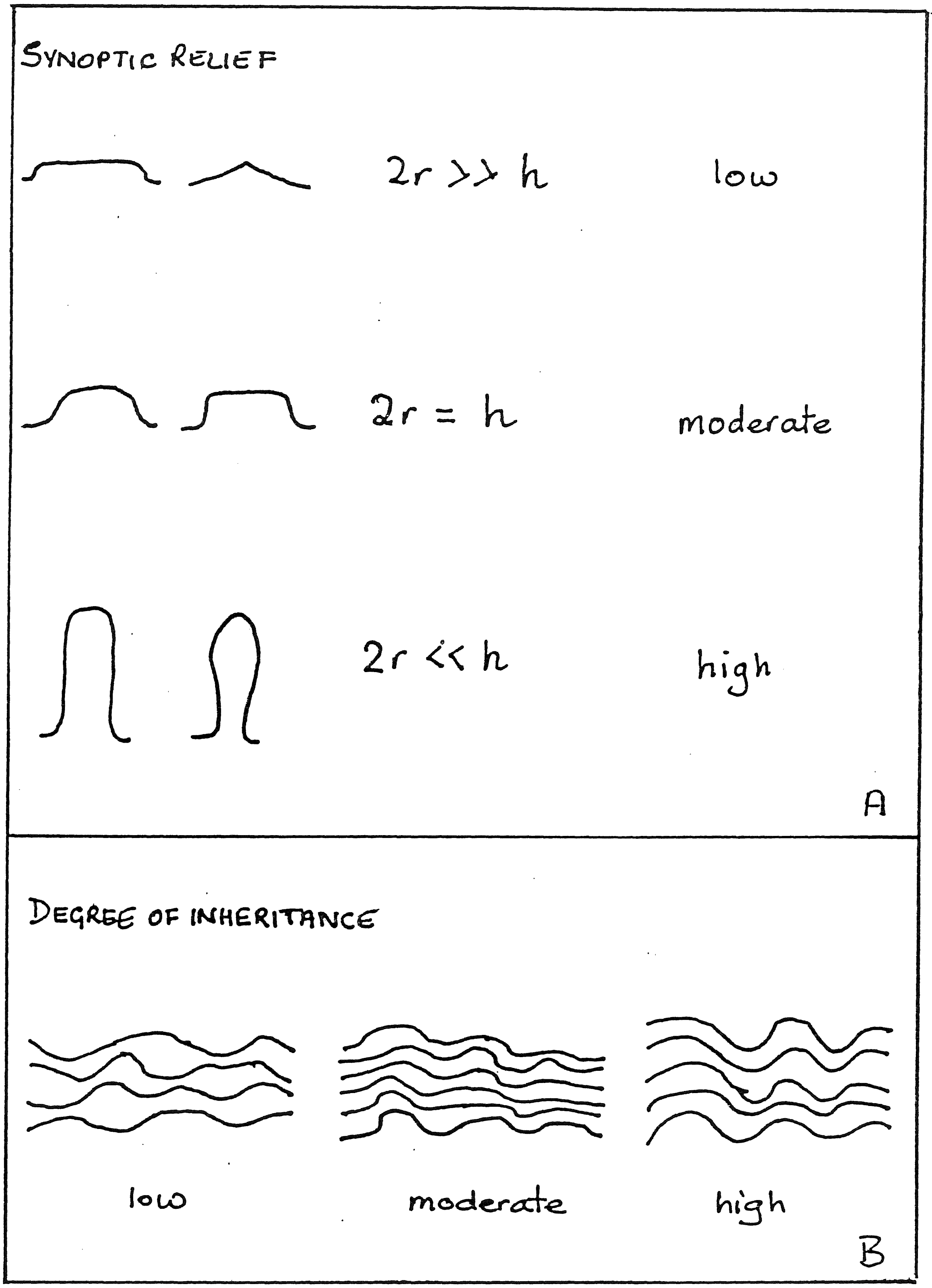
6.2.3 Synoptic Relief:

What is the nature of successive growth interfaces of the stromatolites (Fig. 16A)? Hofmann (1969, p. 9) characterized the synoptic relief as follows:

a) low - $2r \gg h$
b) moderate - $2r = h$
c) high - $2r \ll h$

6.2.5 Degree of Inheritance (serial development):

How closely do the shapes of successive laminae conform to preceeding laminar shapes (Fig. 16B)? Is the inheritance:



16. Superposition of laminae - A) Synoptic relief, B) Degree of inheritance (after Hofmann, 1969)

a) low - successive laminae rarely conform to the shape of the preceeding laminae. Laminae are frequently doubly convex, or may be offset in an alternating lensoid pattern.
b) moderate - some but not all laminae are conformable
c) high - most laminae are conformable

6.2.5 Lateral continuity

How continuous are the laminae across the column (Fig. 17) and how variable is their thickness? Is the lithology consistent across the column? A lamina can be:

a) Consistent - the lamination extends continuously from one side of the column to the other, the lithology is consistent, and there are only slight changes in thickness across the column.

b) Regularly variable in thickness - the lamination extends continuously from one side of the column to the other; the lithology is consistent; the thickness varies considerably, but regularly, across the column - usually tapering from a thick centre to thin margins.

c) Irregularly variable in thickness - the lamination extends continuously from one side of the column to the other; the lithology is consistent; the thickness varies considerably, but irregularly, across the column.

d) Lenticular - the lamination extends from one side of the column to the other, but forms a series of discontinuous but aligned lenses; the lithology within the lenses is consistent.

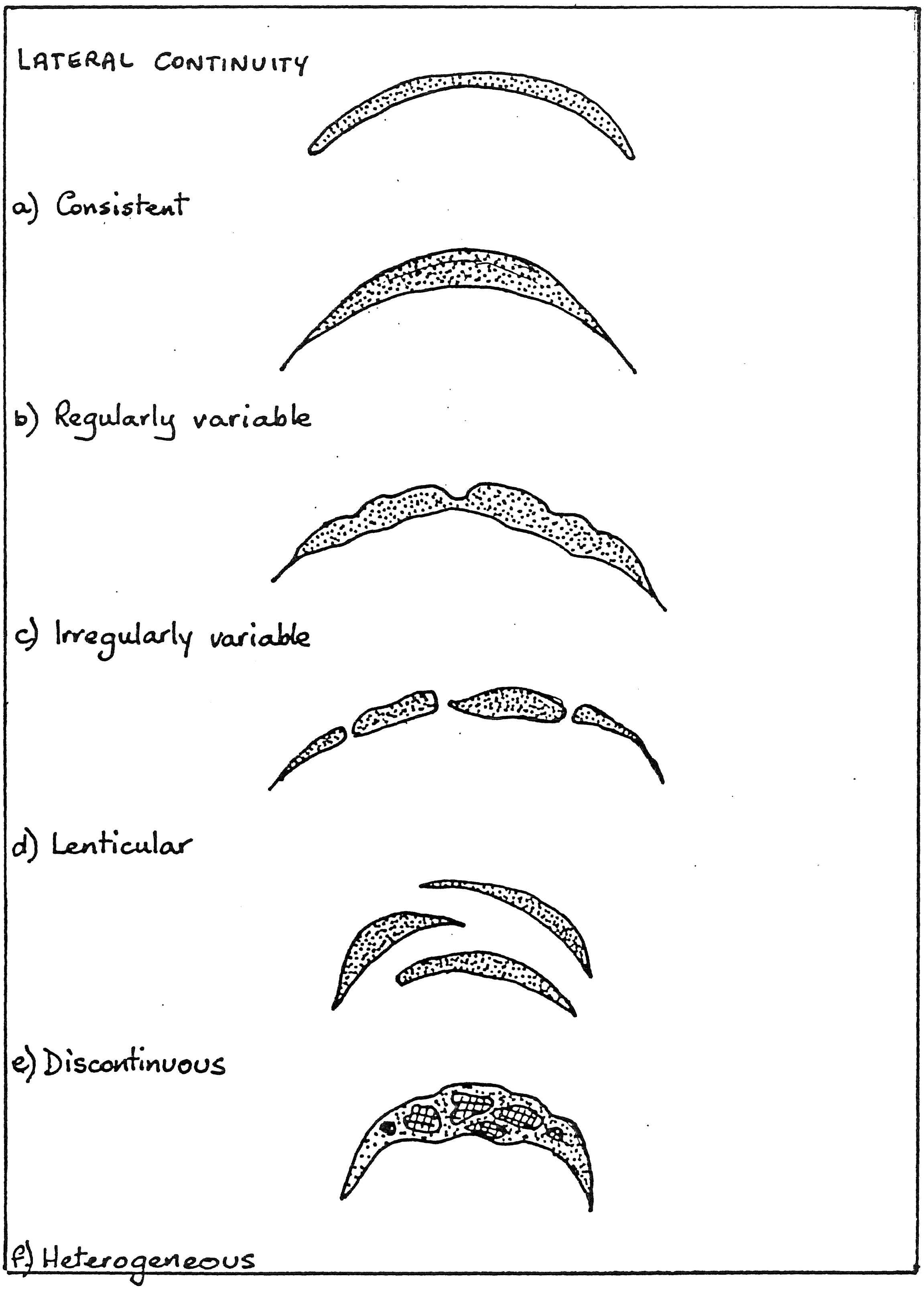
e) Discontinuous - the lamination does not extend from one side of the column to the other, but forms a series of discontinuous and offset lenses; the lithology within the lenses is consistent.

f) Heterogeneous - the lithology is different at the margins and in the centre of the column; the thickness can also be variable. The variation may result from either the nature of the original fabric, or from diagenesis.

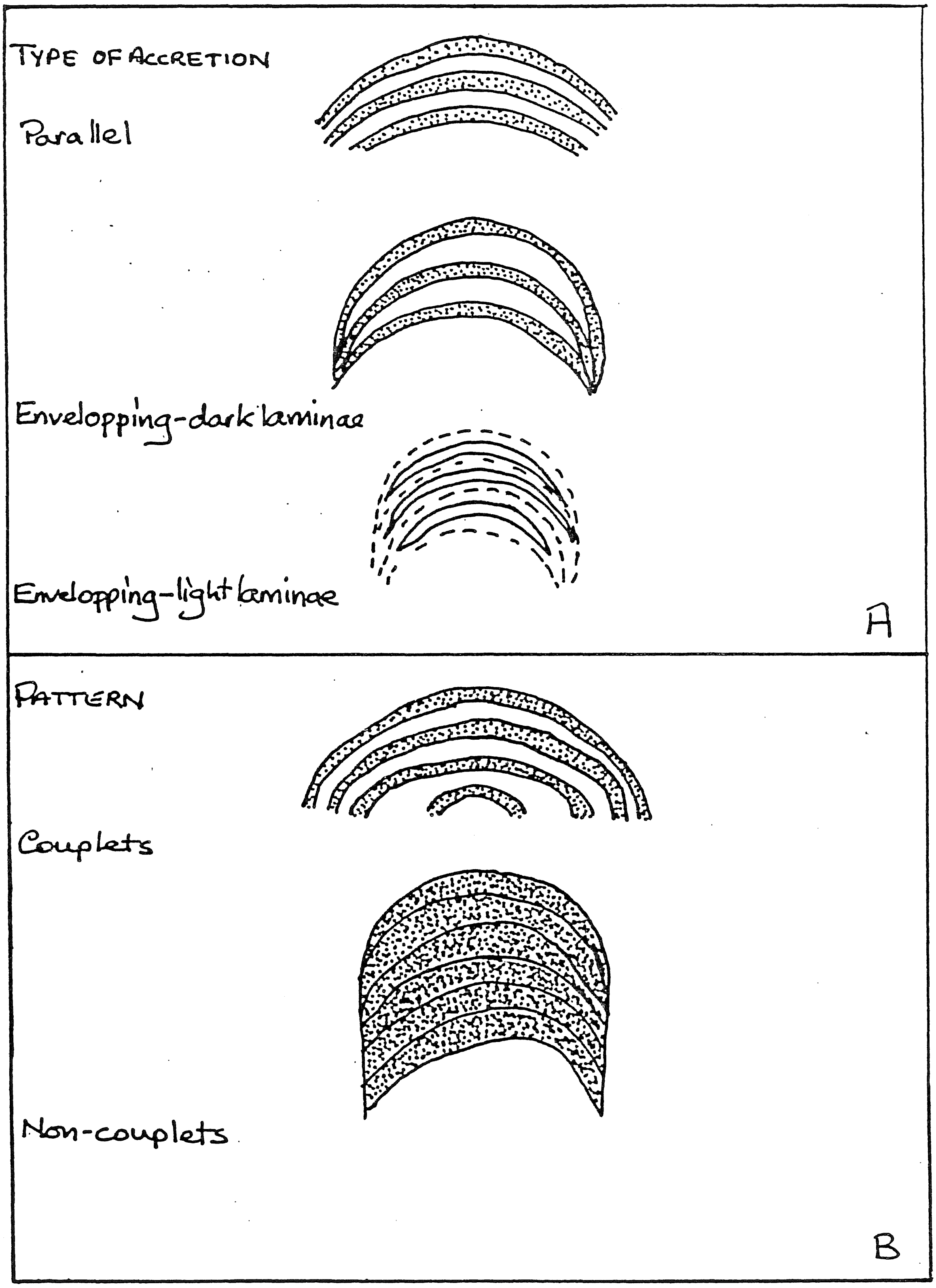
6.2.6 Type of accretion

How are the laminae stacked on top of each other (Fig. 18)? Can any patterns be recognized? Are the laminae **parallel** or do some laminae **overlap** the margins of others (Fig. 18A)? What types of laminae, and how many are involved in the formation of each pattern - do the dark laminae overlap the light ones, or do the light ones overlap? Do alternating laminae have very different fabrics?

A conventional view of stromatolite laminations is to regard them as pairs of alternating light and dark fabrics related to diurnal or seasonal changes. Although this pattern sometimes occurs, the model is much too simplistic (Monty,



17. Lateral continuity of laminae



18. Type and pattern of accretion - A) Type of accretion, B) Pattern

1976) and most sets of laminae reflect complex sedimentological, biological and diagenetic processes. Some stromatolites do have fairly uniform fabrics (Fig. 18B); in others the pattern may vary in different parts of the column, or different types of laminae may be intercalated. Descriptions of laminae should be based on the recognition of recurring patterns, and at the same time attempt to convey the range of variation which occurs.

The descriptive terminology which follows should not be regarded as consisting of mutually exclusive categories; in practice, many of the forms co-exist. The aim is to provide a set of useful terms which can be used to describe the associations.

Firstly, examine any overall pattern present in the laminae. Determine whether the laminae form **couplets** - i.e a simple alternation of light and dark laminae -, or **non- couplets** (Fig. 18B). Non-couplets can be described as having:

a) Even fabric - laminae all have the same fabric and boundaries probably represent micro- unconformities.

b) Void intercalated - in which either couplets or non- couplets are separated by a different type of lamination altogether, usually by an infill of sparite. This can be a result of the infill of an original void, or could be a product of diagenesis growing between laminae.

c) Composite fabric - laminae contain a mixture of fabric types; often these grade upwards

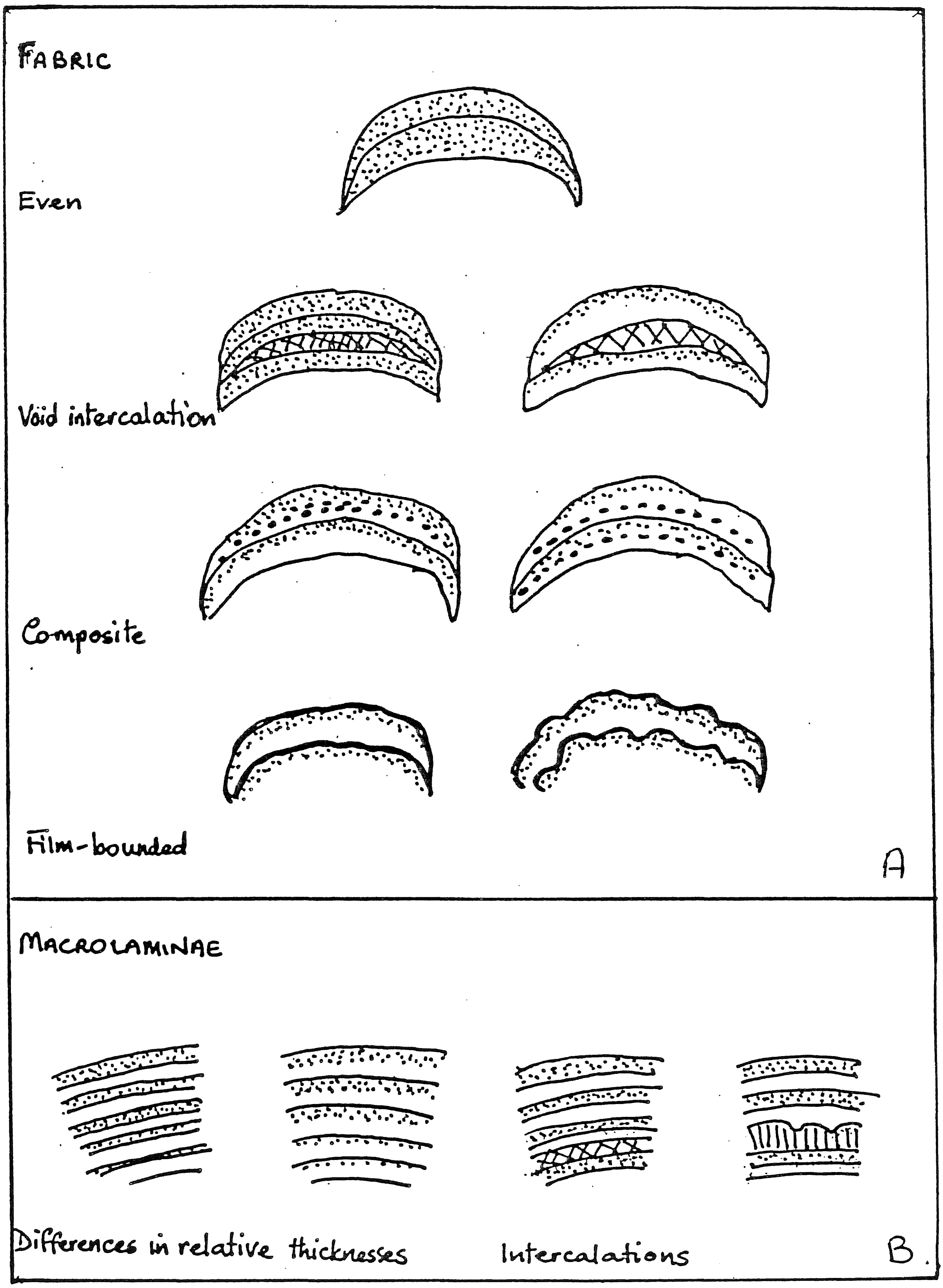
d) Film-bounded fabric - the uppermost limit of the laminae is a film; usually of dark material.

6.2.7 Macrolaminae

Can you distinguish any broad laminae made up of sets of finer laminae? A **macrolaminae** (Fig. 19) usually consists of a band formed by laminae of uniform thickness, juxtaposed against a second band containing laminae of a different thickness. The laminae forming the macrolaminae may be couplets or non-couplets. Macrolaminae can also be formed by the repeated occurrence of a lamina with a different fabric in a set of fairly uniform laminae e.g. void-filling laminae may occur at intervals and form boundaries to sets of light and dark laminae.

6.3 FABRIC AND MICROSTRUCTURE

Fabric "refers to internal spatial properties ....such as the development of a lamination", while microstructure "refers to the microscopic characteristics of the internal properties" (Monty, 1976). Although there have been studies of modern stromatolite fabrics, there has been no comprehensive review of



19. Fabric and macrolaminae

fossil fabric types. Forms listed here (in alphabetical order) are those recorded in the literature. There is no attempt to interpret their significance in terms of biogenetic and/or diagentic formation. Some fabrics are more diagenetically influenced than others. However, many still seem to reflect an original fabric even after considerable alteration. This suggests that fabric should be considered as an important factor in stromatolite classification.

The significance of the fabric lies in the fact that it is the record of the organisms which constructed the stromatolite. In modern microbial mats, the benthic mat community may consist of over 200 species living and dying together in a "stromatolite skyscraper" (Lynn Margulis, personal communication, 1987). It is still not clear to what extent the construction reflects the composition of the mat precursor. Nevertheless, several broad types of fabric can be recognized:

a) Banded: The laminae are very continuous and have abrupt, distinct, more or less parallel boundaries (Walter 1972, p. 12).
Examples:
- Baicalia burra Preiss 1972, Fig. 14c - evenly banded microstructure.
- Conophyton garganicum garganicum Korolyuk - distinctly banded microstructure (see Preiss 1973, Fig. 11e).
- Omachtenia utschurica Nuzhnov 1967 - broadly banded - (see Preiss 1974, Fig. 10c).
- Tungussia etina Preiss 1974, Fig. 11d - Wavy banded.

b) Catagraph-Bearing: Regular spheroids with a dark envelope in a clear calcite infilling in a microsparite matrix (Bertrand-Sarfati, 1976, p. 256).
Examples:
- Tifounkia ramificata Bertrand-Sarfati (see Bertrand-Sarfati, 1976, p. 257, Fig. 3b).
Other forms recorded by Bertrand-Sarfati (1976):
- Boxonia grumulosa Komar
- Boxonia lissa Komar
- Linella simica Krylov
- Boxonia inglica Semikhatov
- Linella ukka Krylov
- Baicalia rara Semikhatov

c) Film: Regularly banded, dark, thin (0.003mm) micritic films, alternating with clear sparite or microsparite (Bertrand-Sarfati, 1976, p. 253). The light laminae can be microbial, but the qualities of the film dominate the structure and control features such as coherence, thickness and straightness. Diagenesis may be responsible for the disruption or enlargement of films.
Examples:
- Conophyton ressoti var. jacqueti Bertrand-Sarfati - dark films in couplets (see Bertrand-Sarfati, 1976, p. 252, Fig. 1a).
- Baicalia mauritanica Bertrand-Sarfati - non-couplet, consists of groups of films, disrupted by diagenetic processes (see Bertrand-Sarfati, 1976, p. 252, Fig. 1b).
Bertrand-Sarfati (1976, p. 253) lists the following forms as

having film microstructure:-

- Baicalia lacera Semikhatov - films composed of fibres with sporadic clear layers containing peloids.
- Conophyton garganicum australe Walter 1972 - banded microstructure where the films are regular.
- Inzeria nyfrieslandica
- Tungussia indica
- Poludia polymorpha Raaben - "where the films of dark micrite occur within lamination of a more complex constitution.

d) Frutexites: a microstructure consisting of millimetre- sized, iron-rich shrubs, in which some trace of the original constructing organism remains (Playford et al, 1976, p. 554, Fig. 10b; Walter and Awramik, 1979).

e) Granular: Laminae poorly defined. Large grains are usually concentrated in dark layers. Preiss (1976) used this term to describe the microstructure in the central zone of Minjaria granulosa Preiss 1976). This form has granular microstructure which pinches out to thin, continuous laminae in the wall zone.

f) Grumelous: A mat composed of peloids (detrital or precipitated) and of narrow, sinuous patches which may be contorted and could be formed by disrupted filament casts. "Fine grained patches surrounded by coarser grains" (Walter 1972, p. 13.) - could be a modified form of vermiform.

g) Micritic-mat: "Basically the laminae are thick, darkish in colour and composed of micrite, their upper boundary may be straight, crinkled or scalloped. The laminae are formed ... of two different layers, the upper one (micritic) is darker than the lower one (microsparitic)." (Bertrand-Sarfati, 1976, p. 257, Fig. 3a). This type is fairly common in fossil stromatolites, but its origins are obscure with regard to microbial origin. This is because of an apparent convergence of mechanisms which result in the formation of the same microstructure.

The microstructure can occur in couplets or non-couplets, and consists of micritic laminae of variable thickness, and dark laminae which are even or composite. They can be composed of homogeneous micrite, be wavy or undulose, patchy or lenticular and be considerably modified by micro-erosion, or by secondary recrystallization.
Examples:

- Tungussia nodosa Semikhatov (see Bertrand-Sarfati, 1976, p. 257, fig. 3A).

Other forms recorded by Bertrand-Sarfati (1976) p. 256 (the first three also have banded microstructure)

- Jurusania burrensis Preiss
- Baicalia burra Preiss
- Acaciella augusta Preiss
- Jurusania nisvenis Krylov
- Jurusania cylindrica Krylov
- Baicalia capricornia Walter
- Inzeria intia Walter
- Gymnoslen ramsayi Steinman (has crinkled-mat fabric)

h) Pelletal: Laminae, which are well-defined, are formed from

pelloidal structures (Preiss, 1974).
Examples:
- Omachtenia utschurica Nuzhnov: pelletal microstructure. This form also has banded microstructure (see Preiss 1974, Fig. 10b).

i) Porostromate: "Porostromate microstructures are defined by the growth of loose or tangled, vertical, flabellate or flat-lying, striaght or sinuous calcified filaments or threads, or even of calcified unicells" (Monty, 1981).

j) Streaky: The laminae are moderately distinct and continuous; the darker are usually the most distinct and are set in a pale matrix into which they frequently grade vertically (Walter 1972, pp. 11 & 14). A subsidiary type is known as Irregular Streaky: Laminae are discontinuous and have jagged margins (Walter 1972, p. 12).
Examples:
- Acaciella augusta Preiss: regularly streaky microstructure (see Preiss 1972, p. 1, Fig. 11e).
- Gymnosolen cf. ramsayi: distinct streaky microstructure (see Preiss 1973, Fig. 12a).
- Inzeria conjuncta Preiss: distinctly streaky (see Preiss 1973, Fig. 14a).
- ?cf. Kulparia: streaky microstructure (see Preiss 1976, Fig. 46).

k) Striated: The laminae originally formed a chain of lenses (Walter 1972, pp. 12 & 14).

l) Tussocky: Irregular lamination defined by juxtaposition of separate hemispheric tussocks of different size (Bertrand-Sarfati, 1976, p. 253).
Examples:
- Tungussia globulosa Bertrand-Sarfati: filamentous tussocks. Tussocks commonly overgrown by a cement of pure sparite (Bertrand-Sarfati, 1976, p. 254, Fig. 2a). - Tungussia hemispherica Bertrand-Sarfati: tussocks commonly overgrown by a dark film (see Bertrand-Sarfati, 1976, p. 253).
- Serizia radians Bertrand-Sarfati: tussocks embedded in carbonate cement and detrital quartz (Bertrand-Sarfati, 1976, p. 253).
- Alternella hyperboreica Raaben: (intertwining films) in this case the tussocks seem to be without filaments and occur as flat pillows superimposed randomly. The dark films are moulded onto the surface of the pillows and seem to anastomose (Bertrand-Sarfati, 1972, p. 255).
- "Rivularia": Form tiny tussocks, encrusting various hard substances in streams, and have a microstructure of juxtaposed hemispheric tussocks (Bertrand-Sarfati, 1976, p. 255).
- Tarioufetia yilgarnia Preiss: tufted microstructure (Preiss 1976, Fig. 51).

m) Vermiform: Narrow, sinuous, pale coloured areas (usually of sparry carbonate) are surrounded by darker, usually fine- grained areas (usually carbonate) (Walter, 1972, p. 14; Bertrand-Sarfati, 1976, p. 255).
Examples:

- Madiganites mawsoni: vermiform structure (Bertrand- Sarfati, 1976, p. 254, Fig. 2b).

Also listed by Bertrand-Sarfati, p. 255:

- Acaciella angepena Preiss: more regularly laminated
- Boxonia gracilis Korolyuk: with granules more rounded
- Uricatella urica Korolyuk: with polygonal network
- Boxonia divertata Korolyuk: with a more variable network
- Minjaria procera Semikhatov: sporadically shows this structure.

7. FEATURES OF THROMBOLITES

(Section to be written)

8. INTERSPACE FILLING

A study of stromatolite interspaces provides valuable information on lithofacies relationships and palaeoecology. Note features such as the nature of the interspace filling (this can be done by standard carbonate petrological studies) and relationships between the interspace and column margin. Are the margins abrupt, or do they intergrade with the interspace sediments. Are there any laminae observable in the interspace areas; do they form bridges? Is the interspace sediment similar to that forming the laminae in the column. Is there evidence of erosion?

9. SECONDARY ALTERATION

This can be a separate study in itself, but for the purposes of stromatolite descriptions it is enough to comment on the extent of alteration observed. Is there evidence of diagenesis, recrystallization, secondary silicification? Are stylolites or veins present?

GLOSSARY

A.

ABIOTIC: "A term pertaining to substances or objects that are of nonbiologic origin; used especially in reference to organic matter produced via chemical reactions in the absence of living systems." (Schopf, 1983).

ABIOPHORIC: "Of stromatolites, lacking microfossils" (Walter, 1976).

ACCRETION VECTOR: "that growth vector which joins the mid- points (centres) of successive laminae, and whose strength at any one level is a measure of the surface area of the laminae at that level" (Hofmann, 1969, p. 17).

ACTIVE BRANCHING: a form of branching "in which the branches increase the width of the structure" (Hofmann, 1969). These features are not always easy to distinguish in practice, and Preiss (1972) and Walter (1972) preferred to use PARALLEL (alpha, beta and gamma), SLIGHTLY (MODERATELY) DIVERGENT and MARKEDLY DIVERGENT (q.v.).

AEGAGROPILE: "A lake ball consisting of radial, outgrowing, hair- like filaments formed by algae"...."cf. algal biscuit" (Bates and Jackson, 1980).

AEROBIC: An organism that respires using oxygen as the terminal e- acceptor for energy generation; may be obligately or facultatively dependant on oxygen;" (esp. a bacterium) that can live in the presence of free oxygen; also, said of its activities" (Bates and Jackson, 1980)

ALGAE: "Photosynthetic, eukaryotic, nonvascular (thallophytic) plants, unicellular or -multicellular, commonly aquatic; (Schopf, 1983). The obsolete term Blue-Green Algae described prokaryotic organisms now refered to as Cyanobacteria (Stanier, 1977;1982).

ALGAL: This adjective is no longer appropriate in situations where a microbial community including Cyanobacteria or other prokaryotic organisms is involved. The term "MICROBIAL" should be used in its place.

ALGAL (MICROBIAL) BALL: ALGAL (MICROBIAL) BISCUIT

ALGAL (MICROBIAL) BISCUIT: "Any of various hemispherical or disk-shaped calcareous masses, up to 20 cm in diameter, produced in freshwater as a result of precipitation by various blue green algae; e.g. a deposit of marl formed around a piece of algal material or other nucleus as a result of photosynthesis and found on the shallow bottoms of hard- water lakes of the temperate region" (Bates and Jackson, 1980). MICROBIAL BISCUIT is preferred unless the constructing organisms are true algae.

ALGAL LAMINATED SEDIMENTS: term used by Davies (1970) to describe flat microbial mats. MICROBIALLY LAMINATED SEDIMENTS is preferred (Burne and Moore, 1987).

ALGAL LIMESTONE:

1. term used by Johnson (1961) for stromatolite-bearing limestones.

2. A limestone composed largely of the remains of calcium- carbonate-producing algae, or one in which such algae serve to bind together the fragments of other calcium-carbonate- producing forms" (Bates and Jackson, 1980).

Should be used only for those limestones known to have been constructed by eukaryotic algae, and in particular by skeletal calcareous algae. True algae probably did not evolve until late in the Middle Precambrian and therefore the term should not be used for carbonates older than this. MICROBIAL LIMESTONE or MICROBIALITE should be substituted.

ANAEROBIC: An organism unable to use oxygen as the terminal e-acceptor for energy generation; may be aerotolerant (survive with O_2) or aerophobic (O_2 is toxic): "(esp. a bacterium) that can live in the absence of free oxygen; also said of its activities" (Bates and Jackson, 1980).

ANASTOMOSING BRANCHING: a term used for branching in which the columns exhibit both branching and fusion (Hofmann, 1969).

ANGULATE LAMINAR PROFILE: A laminae with a pointed crest and straight sides (see Hofmann, 1979, fig. 8).

AUTOTROPH: "An organism that has the ability to use CO_2, present in the environment or generated from some other compound, as the sole source of cellular carbon." (Schopf, 1983).

AXIAL ZONE: term used in the study of conical stromatolites referring to a narrow cylinder in the centre of the column (Hofmann, 1969). The cylinder is usually formed from the successive development of tufts of filaments at the cone tip (Walter and others, 1976).

AXIS: "The centre line of a column" (Preiss, 1972; Walter, 1972).

B.

BACTERIA: "Prokaryotic organisms (including archaebacteria and prochlorophytes) other than cyanobacteria". (Schopf, 1983).

BANDED MICROSTRUCTURE: "One in which the laminae are very continuous and have abrupt, distinct more or less parallel boundaries" (Walter, 1972).

BENTHIC MICROBIAL COMMUNITY (BMC): a more or less complex benthic ecological association of microbes which may include fungi, photosynthetic prokaryotes, eukaryotic microalgae and chemoautotrophic and chemoheterotrophic microbes (Bauld, 1986).

BENTHOS: "Subaquaeous (usually marine) bottom-dwelling organisms." (Schopf, 1983).

BIOCOENOSE:"A community of organisms that live closely together and that form a natural ecologic unit." (Schopf, 1983).

BIOHERM:

A lens or mound-like buildup derived largely from the in situ production or activities of organisms, and which has a width to thickness ratio of less than or equal to thirty (Cumings 1932; Nelson et al. 1962).

2. "A circumscribed organo-sedimentary structure whose minimum width is less than or equal to one hundred times its maximum thickness, embedded in rocks of different lithology" (Preiss, 1972; Walter, 1972).

3. "A laterally extensive or broadly lenticular commonly "reef-like" rock mass built by and composed mainly of the remains of sedentery organisms." (Schopf, 1983).

The term was regarded by Burne and Moore (1987) as inappropriate for deposits of biologically influenced non skeletal cementation since in this case the build-up consists neither ot the remains of the sedentary organisms themselves, nor is it derived from the results of the in situ production or activities of the organism, since the microbes play an essentially "passive" role in the lithogenesis. They suggest term "MICROBIAL LITHOHERM" is more appropriate for non- skeletal structures.

Structures can be described as tabular, domed, subspherical or tonguing.

BIOPHORIC: "Of stromatolites, containing microfossils" (Walter, 1976).

BIOSTROME:

1. A stratiform or sheet-like buildup derived largely from the in situ production or activities of organisms, and which has a widthto thickness ratio of more than thirty (Cumings, 1932; Nelson et al., 1962)

2. "A stratiform organo-sedimentary structure whose minimum width is more than one hundred times its maximum thickness" (Preiss, 1972; Walter, 1972).

The term "MICROBIAL LITHOSTROME" has been proposed as more appropriate (Burne and Moore, 1987) for the products of non-skeletal sedimentation. (See also BIOHERM)

The structures can be tabular or domed. Preiss (1972) points out that "in practice it is rarely possible to see the three dimensional shape of the structure in outcrop. The distinction between bioherms and biostromes must ... be based on the dimensions visible in outcrop. If the outcrop is inadequate, the informal term "bed" is used". Because of this most geologists use a ratio of 1:30 rather than 1:100 to differentiate between BIOHERM and BIOSTROME.

BIOTA: "All of the organisms of a particular area or time." (Schopf, 1983).

BLUE-GREEN ALGAE: Obsolete term for CYANOBACTERIA (Stanier, 1977; 1982)

BMC: BENTHIC MICROBIAL COMMUNITY

BRANCHING: "The division of a column into new, discreet columns. Note: Columns become discrete when they are first separated by an interspace (Preiss, 1972; Walter, 1972).

Markedly divergent: Branching in which the axes of the new columns diverge at more than 45° (Walter, 1972).

Multiple: "Branching at approximately the same level into more than two new columns" (Walter, 1972).

Parallel: "Branching in which the axes of the new columns are parallel. Note: Most commonly, the axes of the new columns are also parallel to the axis of the original.

alpha-parallel: Branching in which the width of the individual remains constant.

beta-parallel: branching in which the original column widens gradually before branching.

gamma-parallel: branching in which the original column widens abruptly before branching."
(Walter, 1972).

BRIDGE: "Stromatolitic lamina or set of laminae linking adjacent columns" (Preiss, 1972; Walter, 1972).

BUILDUP: (Carbonate - ; Microbial -)" A circumscribed bed of (carbonate) rock which displays topographic relief above equivalent strata and differs in nature from typically thinner deposits of surrounding and underlying rocks".(Heckel, 1974).

BUMP: "Low, rounded protrusion on the side of a column" (Preiss, 1972; Walter, 1972).

C.

CATAGRAPHIA: "Microscopic carbonate problematica. Many are grapestones, botryoidal lumps, and other sedimentary structures" (Walter, 1972).

CENTRIFUGAL: term used by Hofmann (1969) to refer to the type of growth vector which produces a spheroidal stucture.

CHEMOTROPH: "An organism that uses inorganic or organic substances as energy sources (it is implied that these substances also provide reducing power for biosynthesis)." (Schopf, 1983).

CHEMOAUTOTROPH: "An autotroph that uses one or more inorganic compounds as the source of electrons (reducing power) and energy." (Schopf, 1983).

CHEMOHETEROTROPH: "An organism that uses organic compounds as the source of cellular carbon, reducing power, and energy." (Schopf, 1983).

CLOT: "A microscopic segregation of pigment" (Walter, 1972). See MICROCLOT, MESOCLOT & THROMBOID. See also Pratt and James (1982) Kennard and James (1986); Aitken (1967); Burne and Moore (1987) for a more detailed discussion of clotted fabrics associated with thrombolites.

COALESCING COLUMNS:

1. term used to describe column branching, in which the the columns are "inversely branched.... that is the stromatolite has root-like columns with laminae of small but increasing diameters, eventually growing together to [form] fewer columns with larger diameters" (Hofmann, 1969).

2. "Adjacent columns which join and continue growth as one column" (Preiss, 1972).

COCCOID CYANOBACTERIA: Unicellular cyanobacteria of spheroidal or ellipsoidal form.

COENOCYTIC: "A term pertaining to a filamentous organism that is tubular, lacking transverse walls to separate protoplasts into a series of cells; in eukaryotes (especially thallophytes) the term is used commonly in reference to a multinucleate cell." (Schopf, 1983).

COENOPLASE: A term coined by Twenhofel (1919, p. 342) to refer to the morphologically distinct growth form of a stromatolite (Hofmann, 1969, p. 3 and p. 5). The term is not commonly used. The terms "individual" (Walter, 1972) and "fascicle" (Grey, 1984) are used for somewhat similar concepts.

COLUMN: "Discrete stromatolitic structure with the dimension in the direction of growth usually greater than at least one of the transverse dimensions" (Preiss, 1972; Walter, 1972).

COLUMNAR-LAYERED STROMATOLITE: "A stromatolite in which short columnar and laterally linked (usually pseudocolumnar) portions alternate" (Preiss, 1972).

CONIATOLITE: A hard, sheetlike crust of aragonite found in supratidal saline environments in the Persian Gulf area (Purser and Loreau, 1973, p. 375).

CORNICE: "Peripheral overhanging portion of a lamina or set of laminae, elongated transversely to its column axis" (Preiss, 1972; Walter, 1972).

CONSTRINGED VARIABILITY (OF GROWTH VECTOR): term used to descibe the variability of a column diameter where the variation in the growth factor is relatively slow (Hofmann, 1969, p. 17 and fig. 10).

CONTIGUOUS COLUMNS: columns with margins touching each other. The spacing is zero (see Hofmann, 1969, fig. 9).

CORRUGATE LAMINAE: a form of crinkled lamination (see Hofmann, 1969, fig. 8).

CRENATE LAMINAE: a form of crinkled lamination (see Hofmann, 1969, fig. 8).

CREST: "The summit of an upward-convex lamina" (Preiss, 1972).

CRESTAL LINE: "Line joining the crests of successive laminae" (Preiss, 1972; Walter, 1972).

CRESTAL ZONE: "The environs of the crestal line" (Preiss, 1972; Walter, 1972). "In Conophyton, the crestal zone is specifically the zone of thickening and contortion of the laminae: the width of the crestal zone is the width of the crestal zone is the width of the thickened and/or contorted portions of laminae. Three types of crestal zones of Conophyton were distinguished by Komar et al. (1965)" (Preiss, 1972). A more detailed description is given by Walter (1972) and a possible method of formation is described by Walter and others (1976) - see also AXIAL ZONE.

CRINKLED LAMINATION: laminae which are not even (see Hofmann, 1969, fig. 8).

CRUSTOSE: term used to describe the type of column variability which produces a short, encrusting column in which H<<2r (Hofmann, 1969).

CRYPTALGAL: Rocks or rock structures formed "through the sediment- binding and/or carbonate-precipitating activities of non- skeletal algae" (Aitken, 1967, p. 1164) see comments under CRYPTALGAL SEDIMENTS, CRYPTOMICROBIAL, MICROBIAL and ALGAL.

CRYPTALGALAMINATE:

1. Carbonate rocks "displaying a distinctive form of discontinuous, more or less planar lamination believed to have resulted from the activities upon and within the sediments of successive mats or films of blue-green and green algae" (Aitken, 1967, p. 1164).

2. "Of stromatolites, those that have more or less planar laminae (synonym: stratiform)" (Walter, 1976). - see comments on CRYPTALGAL SEDIMENTS, CRYPTOMICROBIAL.

CRYPTALGAL SEDIMENTS:

"Rocks believed to have originated through the sediment- binding and/or carbonate precipitating activities of non- skeletal algae. .....(T)he influence of algae on the rock is more commonly inferred than observed (Aitken, 1967). Although this term has been widely adopted, we suggest it be abandoned in favour of the term MICROBIALITE since cyanobacteria are no longer regarded as algae and other microbial components are present alongside cyanobacteria in most microbial communities" Burne and Moore (1987). See also CRYPTOMICROBIALITE.

CRYPTIC MICROBIALITE: A microbialite having a CRYPTIC STRUCTURE (Burne and Moore, 1987). See also CRYPTOMICROBIALITE.

CRYPTIC STRUCTURE: A term used in the sense of Aitken (1967) and Kennard and James (1986) and restricted by Burne and Moore (1987) to describe microbialites which have an internal structure of a "vague, mottled or patchy texture attributed to microbial activity".

CRYPTOMICROBIAL: " "Cryptomicrobial" is a modification of Aitken's term 'cryptalgal' because in modern usage (see Bauld, 1981; Krumbein, 1983) algae are eucaryotic photosynthetic organisms, whereas sediment-forming microbial communities are commonly dominated by cyanobacteria (formerly called cyanophytes or "blue-green algae") which are procaryotic." (Kennard and James, 1986).

CUMULATE STROMATOLITE: "A rounded, protruding, non-columnar stromatolite" (Preiss, 1972; Walter, 1972).
CURVED: term used to describe the attitude of a column (Hofmann, 1969).

CUSPATE LAMINAR PROFILE: an angulate laminae in which the profile is concave on both sides of the crest (see Hofmann, 1969, fig. 8).

CYANOBACTERIA: "Prokaryotic, bacterium-like micro-organisms containing phycocyanin and/or phycoerythrin, chlorophyll a (but not chlorophyll b) and capable of oxygenic photosynthesis; numerous strains are also capable of anoxygenic photosynthesis; also referred to as blue- green algae, cyanophytes, and myxophytes " (Schopf, 1983).

CYANOPHYTE: CYANOBACTERIA, 'Blue-geen algae'.

D.

DECUMBENT: term referrring to the attitude of a column, in which the column is inclined with a concave curvature (Hofmann, 1969)

DENDROID: active branching in which the branches are sub- parallel (Hofmann, 1969). In this sense it is synonomous with MARKEDLY DIVERGENT BRANCHING. It is also used in a less specific sense to indicate multiple complex branching.

DENDRITIC INDIVIDUAL: "An individual composed of variously inclined divergently branched columns" (Walter, 1972).

DICHOTOMOUS BRANCHING: "Branching into two new columns" (Walter, 1972).

DIGITATE: active branching in which the branches are parallel (Hofmann, 1969). In this sense it is synonomous with LATERALLY DICHOTOMOUS BRANCHING.

DOMED: "With approximately constant radius of curvature" (Preiss, 1972; Walter, 1972).

E.

ENDOLITH: "Any of various micoorganisms growing within the pore spaces of a rock or lithified soil crust. " (Schopf, 1983).

ENDOLITHIC: "Of organisms, living within rock; specifically, boring microorganisms" (Walter, 1976).

ENVELOPE: WALL
ERECT: term used to describe the attitude of a column which is growing vertically (Hofmann, 1969).

EVEN LAMINAR PROFILE: smooth laminae without waves or wrinkles (see Hofmann, 1969, fig. 8).

EUCARYOTE: EUKARYOTE

EUKARYOTE:

1. "Nucleated protists and all higher organisms (i.e. including all algae but not cyanophytes)" (Walter, 1976).

2. "Unicellular or multicellular organisms (viz., protists, fungi, plants and animals) characterized by nucleus-, mitochondrion-, and (in plants and some protists) chloroplast-containing cells that are capable typically of mitotic cell division. "(Schopf, 1983).

F.

FASCICLE: Individual stromatolite "consisting of a group of columns which have a common point of origin, have developed by branching, and which have only minor variation in fabric throughout the structure" (Grey, 1984).

FILAMENTOUS CYANOBACTERIA: cyanobacteria having a filamentous growth form.

FIMBRIATE: term referring to column ornament characterized by having "fringes or lips hanging down" (Hofmann, 1969).

FLAT-LAMINATED STROMATOLITE: "Non-columnar stromatolite with flat continuous laminae" (Preiss, 1972).

FURCATE: passive branching in which "columns branch into smaller ones without increase in total width of the structure" (Hofmann, 1969). Synonymous with ALPHA PARALLEL BRANCHING.

G.

GENICULATE LAMINAR PROFILE: a laminae with a pointed crest which is convex on either side of the crest (see Hofmann, 1969, fig. 8).

GENTLY CONVEX LAMINA: "Ratio of height to width less than or equal to 0.5" (Preiss, 1972; Walter, 1972).

GLIDING:

1. "In procaryotes, slow movement not involving flagella" (Walter, 1976).

2. "A type of biologic locomotion, slow, smooth to jerky, not involving flagella, pseudopodia of similar structures, typical especially of the sheath-enclosed trichomes of filamentous prokaryotes. "(Schopf, 1983).

GLOBOIDAL LAMINAR PROFILE: A laminae which completely (penecinct), or almost completely (plenicinct), encloses a body, as in an oncolite (see Hofmann, 1969, fig. 8).

GNARLED COLUMN: "With large bumps" (Preiss, 1972; Walter, 1972).

GRUMELOUS: A type of microstructure composed of clots of diffuse peloids (detrital or precipitated) and of narrow sinuous patches which may be contorted. Commonly referred to as grumous (Walter, 1972) and synonymous with micro-clotted.

GRUMOUS: "Mineral texture in which fine-grained patches are surrounded by coarser grains" (Preiss, 1972; Walter, 1972) - "interpreted to have formed by partial recrystallization" (Preiss, 1972). -synonymous with micro-clotted.

H.

HELIOTROPISM: "Tropism (q.v.) in which the stimulus is sunlight" (Walter, 1976).

HETEROTROPH: "An organism that uses organic carbon compounds (defined for most purposes as compounds containing covalent C-H bonds) as sources of cellular carbon. "(Schopf, 1983).

HETEROTROPHISM: "In organisms, the requirement of a source of organic matter (food) from the environment" (Walter, 1976).

HOMEOSTASIS: "Maintenance of constancy of internal environment" (Walter, 1976).

HORIZONTAL: term referring to the attitude of growth of a column (Hofmann, 1969).

HYPIDIOTOPIC TEXTURE: "A texture intermediate between xenotopic and idiotopic" (Preiss, 1972; Walter, 1972).

I.

IDIOTOPIC TEXTURE: A texture in which the mineral grains are euhedral (Friedman,1965).

INCLINED: term referring to the attitude of growth of a column (Hofmann, 1969).

INDIVIDUAL:

1. "A single discrete stromatolite within which either the laminae are continuous or which comprises a group of columns arising from a single basal column" (Preiss, 1972).

2. "A group of columns arising from a single basal column or a discrete stomatolite within which the laminae are continuous" (Walter, 1972).

Grey (1984) criticised the term as being too ambiguous and substituted FASCICLE.

INFLEXED LAMINAR PROFILE: a laminar profile which is reflexed to form a crest; it can be ANGULATE, GENICULATE, or CUSPATE (see Hofmann, 1969, fig. 8).

INTERLOBATE TEXTURE: "A texture in which the intergrain boundaries are wrinkled" (Walter, 1972).

INTERSPACE: "The space between columns, usually filled with sediment" (Preiss, 1972; Walter, 1972).

L.

LAMINA: "The smallest unit of layering" (Preiss, 1972; Walter, 1972).

LANCEOLATE PLAN VIEW:

1. term used to describe the cross-section of some columns (see Hofmann, 1969, fig. 8).

2. "An elongate transverse section of a column, tapering at both ends" (Preiss, 1972).

LATERALLY-LINKED STROMATOLITE: "With wavy laminae continuous between crests" (Preiss, 1972; Walter, 1972).

LATERAL BRANCHING: branching in which one of the daughter columns develops on the side of the main column and usually has a smaller diameter than the main column.

LITHOHERM: "The term lithoherm was coined by Neumann et al. (1977) for deep-water rocky carbonate mounds formed by the sub-sea lithification of successive layers of trapped sediment and deposited skeletal debris. The term was proposed to signify a morphological expression of sub-sea lithification, and to emphasize the primary role of this chemical process in a biological buildup. Implicit in this was the need to distinguish lithoherms from buildups resulting from the skeletal deposition of carbonate. ....our use of the term lithoherm represents a slight modification of the original definition..... We.....[restrict] ... the terms bioherm and biostrome to deposits constructed largely of skeletal material (c.f. Krumbein, 1979) and [use] the terms microbial lithoherm and lithostrome for deposits in which the calcified framework is the product of biologically influenced, non-skeletal precipitation resulting form the effect of the BMC on the physiochemical microenvironment (Burne and Moore, 1987). The term replaces bioherm when used for microbial buildups.

LITHOSTROME: see discussion under LITHOHERM, BIOHERM and BIOSTROME

LOBATE PLAN VIEW: a column which develops lobes in cross- section; it can be described as laxilobate, bilobate, multilobate, densilobate or brevilobate (see Hofmann, 1969, fig. 8).

M.

MACROLAMINA: "A distinct set of laminae" (Preiss, 1972; Walter, 1972).

MANTLE: "a narrow peripheral zone of a non-laminated microfabric different from the laminated central portion of the stromatolite (Hofmann, 1969)". SELVAGE.

MESOCLOTS: Millimetre and centimetre-size individual clots within thrombolites (Kennard and James, 1986). Kennard (1989a, b) recommends that the term MESOCLOT be replaced by the term THROMBOID.

METAPHYTE: Eukaryotic, multicellular, usually megascopic plant, whether vascular or nonvascular (e.g. "seaweeds"). "(Schopf, 1983).

MICROBIAL: referring to microbes - a non-specific term useful for describing mixed assemblages of bacteria, algae and other microscopic organisms. Should be used instead of ALGAL unless referring specifically to eukaryotic assemblages (Kennard and James, 1986).

MICROBIAL BOUNDSTONES: Dunham (1962) introduced the term "Boundstone" and applied it to stromatolites. Rocks "formed principally by microbial trapping and binding of detritus" (Burne and Moore, 1987).

MICROBIAL BUILDUP: See BUILDUP and also Grey, (1984) and Burne and Moore (1987).

MICROBIAL FRAMESTONES: rocks "composed of a framework formed either as a result of biologically influenced calcification or (rarely) from microbial skeletal material (Skeletal Microbial Framestones)." (Burne and Moore, 1987).

MICROBIALITE: "Microbialites are organosedimentary deposits that have accreted as a result of a benthic microbial community trapping and binding detrital sediment and/or forming the locus of mineral precipitation" (Burne and Moore, 1987).

MICROBIAL LITHOHERM: see LITHOHERM .

MICROBIAL LITHOSTROME: a term introduced by Burne and Moore (1987) to replace BIOSTROME when used for carbonate buildups.

MICROBIAL MAT: A cohesive sheet formed by intertwining and cohesion between elements of a benthic microbial community and associated trapping and adhesion of sediment particles. The term is not synonymous with either BENTHIC MICROBIAL COMMUNITY or STROMATOLITE (Burne, 1989)

MICROBIAL TUFA: rock "formed when micoorganic material is incorporated during inorganic precipitation of carbonate" (Burne and Moore, 1987).

MICROBIOHERM: "Hand specimen-sized bioherm formed by the coalescing of individuals" (Walter, 1972).

MICROBIOTA: "A localized group of microscopic organisms that comprise a biocoenose, used especially in reference to communities of fossil micoorganisms that occur within a stromatolite or a particular stromatolitic horizon. "(Schopf, 1983).

MICROCLOT: see CLOT (Walter, 1972)

MICROFOSSIL: "A morphological fossil too small to be studied without the aid of a microscope (generally <0.2 mm), either the remains of a microscopic organism or of a larger organism (e.g., spores and pollen of higher plants)." (Schopf, 1983).

MICROPHYTOLITHS: "Oncolites and catagraphia" (Walter, 1972).

MICROSTRUCTURE: "The fine-scale structure of the stromatolite lamination, in particular the distinctness, continuity, thickness and composition of the laminae" (Preiss, 1972).

MICRO-UNCONFORMITY: "Surface of lamination discordance due to penecontemporaneous erosion within a stromatolite" (Preiss, 1972). 2. "Surface of lamination discontinuity within a stromatolite" (Walter, 1972).

N.

NAKED COLUMN: "Column without walls" (Walter, 1972).

NICHE: "A deep indentation on the side of a column" (Preiss, 1972; Walter, 1972).

O.

OBSCURE LAMINAR PROFILE: Where the laminae are nearly obliterated (see Hofmann, 1969, fig. 8).

ONCOLITE:

1. "Unattached stromatolite with encapsulating laminae" (Walter, 1972).

2. A microbialite having an ONCOLITIC STRUCTURE (Burne and Moore, 1987).

ONCOLITIC STRUCTURE: A term used in the sense of Pia (1927) and Peryt (1981) and adopted by Burne and Moore (1987) to describe microbialites with an internal structure which consists of concentric laminations.

ORGANIC: "A term pertaining or relating to a compound, structure, or a substance containing carbon, and usually hydrogen, oxygen and/or nitrogen, of the type characteristic of, but not limited to (e.g., non- biogenic organic matter), biologic systems." (Schopf, 1983).

P.

PALIMPSEST STROMATOLITIC MICROSTRUCTURE: Microstructure in a stromatolite sediment in which the distribution of kerogen, iron oxide, pyrite, or some other pigmenting material indicates the former distribuion of microbial remains" (Schopf, 1983).

PARABOLIC LAMINA: "A lamina whose axial longitudinal section approximates a parabola" (Preiss, 1972).

PASSIVE BRANCHING: branching "in which columns branch into smaller ones without increase in total width of structure" (passive, furcate). (Hofmann, 1969). Replaced by ALPHA PARALLEL BRANCHING (Walter, 1972).

PEAK: "Overhanging laminae or set of laminae with a small dimension transverse to the column" (Preiss, 1972; Walter, 1972).

PELLET: "Ovoid to sub-ovoid micritic carbonate grain of silt or sand size, lacking internal structure" (Preiss, 1972).

PELOID: A microcrystalline or cryptocrystalline allochemical grain of unspecified size or origin (McKee and Gutschicks, 1969; Bathurst 1975).

PENECINCT LAMINAR PROFILE: A laminae which completely encloses a body, as in an oncolite (see Hofmann, 1969, fig. 8).

PHOTIC ZONE: "That part of an aquaeous body where there is sufficient light penetration to support biological photosynthesis (of variable depth to about 200 m, but commonly about 50 m)" (Schopf, 1983).

PHOTOAUTOTROPH: "An organism that can use light as the energy source and CO_2 as the sole source of cellular carbon" (Schopf, 1983).

PHOTOHETEROTROPH: "An organism that can use light as the energy source and organic carbon compounds as sources of celluler carbon" (Schopf, 1983).

PHOTOHETEROTROPHISM: "Light-driven heterotrophism (q.v.)" (Walter, 1976).

PHOTOPHOBOTAXIS: "Phototaxis (q.v.) in which the organism reacts to a gradient in light intensity" (Walter, 1976).

PHOTOSYNTHESIS: "The conversion of CO_2 to organic cell materials, using light as a source of energy" (Walter, 1976).

PHOTOSYNTHETIC BACTERIA: Prokaryotic microorganisms capable of anoxygenic photosynthesis" (q.v.). Anoxyphotobacteria includes green and purple bacteria; some species(puple and green sulfur bacteria) use sulfur compounds as e^-donors for autiotrophic CO_2 incorporation. Oxyphotobacteria refers to oxygenic cyanobacteria, some of which are capable of facultative anoxygenic photosynthesis in a manner similar to the green and purple sulfur bacteria.

PHOTOTAXIS:

1. "Taxis (q.v.) in which the stimulus is light" (Walter, 1976).

2. "Locomotory movement of an organism (e.g., via gliding motility) in response to an environmental gradient of light, either toward a higher light concentration ("positive phototaxis") or away from a higher light concentration ("negative phototaxis")" (Schopf, 1983).

PHOTOPOTAXIS: "Phototaxis (q.v.) in which the organism detects the direction of the light source" (Walter, 1976).

PHOTOTROPH: "An organism that can use light as the energy source" (Schopf, 1983).

PHOTOTROPHISM: In organisms, the obtaining of energy from light" (Walter, 1976).

PHOTOTROPISM: "Tropism (q.v.) in which the stimulus is light" (Walter, 1976).

PIGMENT: "Colouring matter, organic or inorganic" (Preiss, 1972; Walter, 1972).

PLATY COLUMN: "A strongly transversely elongated column" (Preiss, 1972). 2. "A column in which one of the transverse dimensions is much larger than the other" (Walter, 1972).

PLENICINCT LAMINAR PROFILE: A laminae which almost completely encloses a body, as in an oncolite (see Hofmann, 1969, fig. 8).

POLYGONAL PLAN VIEW: term used to describe the cross-section of some columns (see Hofmann, 1969, fig. 8).

POROSTROMATA: A "family" defined by Pia (1927) of uncertain affinities, and referring to calcareous algae characterized by the presence of calcified tubules running parallel (Girvanella, Sphaerocodium) or perpendicular (Hedstromia, Orthonella, Mitcheldaenia, etc.) to the growth surface. The Porostromata comprise various algal colonies showing a preserved tubular microstructure and which are separated into genera and species of uncertain affinities (Monty, 1981). Pia's classification was reorganized by Monty (1981, p.2) and the term POROSTROMATE MICROSTRUCTURE was introduced by him.

POROSTROMATE MICROSTRUCTURE: "Porostromate microstructures are defined by the growth of loose or tangled, vertical, flabellate or flat-lying, straight or sinuous calcified filaments or threads, or even of calcified unicells" (Monty, 1981).

POTENTIAL STROMATOLITES: "Unconsolidated laminated systems, clearly related to the activity of microbial communities, often called "recent stromatolites" or "living stromatolites" are defined as "potential stromatolites" " (Krumbein, 1983).

PROCARYOTE: PROKARYOTE

PROJECTION: "Small columnar or conical outgrowth from the side of a column" (Preiss, 1972; Walter, 1972).

PROKARYOTE (Procaryote):

1. "Protist in which the genetic material is never separated from the cytoplasm by a nuclear membrane (specifically, bacteria and cyanophytes)" (Walter, 1976).

2. "Microorganisms (viz., bacteria, cyanobacteria, archaebacteria, and

prochlorophytes) characterized by cells that lack membrane-bound nuclei, mitochondria, chloroplasts, and similar organelles and that reproduce by non-meiotic division" (Schopf, 1983).

PSEUDOCOLUMNAR STROMATOLITE: "Laterally-linked stromatolite in which sucessive crests are superimposed forming column-like structures" (Preiss, 1972; Walter, 1972).

R.

RADIAL RIBS: Ornament typical of conical stromatolites forming ridges radiating from the apex of the cone, and often producing a star-shaped plan-section.

RAGGED VARIABILITY (OF GROWTH VECTOR): term used to descibe the variability of a column diameter where the variation in the growth factor is relatively rapid (Hofmann, 1969, p. 17 and fig. 10).

RAMIFYING: branching, usually of a complex nature.

RECTANGULAR LAMINA: "Lamina which in a longitudinal section of a column is flat topped with edges deflexed at about 90° (Preiss, 1972; Walter, 1972).

RECUMBENT: term used for attitude of columns in which the column is concavely curved (Hofmann, 1969).

REEF: A massive or layered, laterally restricted carbonate buildup which formed in situ, possessed topographic relief and was stabilised syndepositionally by organicgrowth and/or submarine cementation (Geldsetzer, James and Tebbutt, 1988). The term "ALGAL (i.e.Microbial) REEF" was used by Bradley (1929) to describe microbial buildups. Burne and Moore (1987) reject the use of the term reef for small scale structures because it "implies large scale structures, presenting a hazard to navigation and capable of developing independent sedimentary facies (Johnson, 1961; Cumings, 1932) or, in more modern usage, a sedimentary system within itself (James, 1983). The term is inappropriate for decimetre scale structures such as those figured by Bradley (1929). Such structures may however coalesce to form reefs (Logan, 1961; Playford and Cockbain, 1976; Moore et al., 1984) or, more correctly, microbial buildups (c.f. Heckel, 1974).

RHOMBIC LAMINA: "Lamina which in a longitudinal section of a column is flat topped with subparallel edges not perpendicular to the top" (Preiss, 1972; Walter, 1972).

RIB: "A low, rounded protrusion which is elongated transverely to the column on which it occurs" (Preiss, 1972; Walter, 1972).

RUGATE: a form of ornament in which the column is rhythmically constringed to produce concentric cornices (Hofmann, 1969).

S.

SCUTATE PLAN VIEW: shaped like a shield (see Hofmann, 1969, fig. 8).

SELVAGE: "Unlaminated coating on column margins" (Preiss, 1972; Walter, 1972). "Possible explanations for this include (a) micritization by algal boring; (b) inorganic precipitation of lime; (c) a thin algal film on column margins during growth. In some forms a selvage-like structure is probably the result of differential recrystallization of a wall" (Preiss, 1972). Synonomous with mantle.

SHEATH: "In prokaryotic microorganisms, extracellular, generally mucopolysaccharide, mucilagenous investments surrounding individual cells or colonies of cells; in filamentous prokaryotes, a cylindrical, hollow, mucilagenous organic tube that encompasses the cellular trichome" (Schopf, 1983).

SINTER: a form of tufa, commonly siliceous.

SINUOUS: term for the attitude of a column which is alternately concave and convex (Hofmann, 1969).

SKELETAL CALCIFICATION: "...a strictly directed biological process in which metabolism produces an organised mineralised structure with a pre-determined form. Although calcification in some cyanobacteria has been described as resembling skeletal formation (Golubic and Campbell, 1981) it is not a strictly directed biological process" (Burne and Moore, 1987).

SKELETAL STROMATOLITES: ..."stromatolites constructed by calcification of organisms which are not obligate calcifiers and which, when uncalcified, are still capable of constructing stromatolites" Riding (1977). Both Monty (1981) and Burne and Moore (1987) reject the term on the grounds that the calcified structures were not proper metabolised skeletons.

SLENDER: term describing the variability of growth of a column in which H >> 2r (Hofmann, 1969).

SMOOTH: term referring to a column lacking ornament or irregularities (Hofmann, 1969).

SPACING: a term referrring to the lateral relationships of synoptic hemispheroids. Spacing can be contiguous, very close, close, open, or isolated (see Hofmann, 1969, fig. 9).

SPHERULITIC MICROBIALITE: A microbialite having a SPHERULITIC STRUCTURE (Burne and Moore, 1987).

SPHERULITIC STRUCTURE: A term used in the sense of Taylor (1975) and adopted by Burne and Moore (1987) to describe microbialites with an internal structure consisting of spherular aggregates.

SPONGIOSTROMATA: A "family" defined by Pia (1927) of uncertain affinities, and referring to calcareous algal bodies showing no organic or "cellular" microstructures and comprising heads or nodules without any preserved organic microstructures; the stromatolites and the oncolites (Monty, 1981). Pia's classification was reorganized by Monty (1981, p.2) and the term SPONGIOSTROMATE MICROSTRUCTURE was introduced by him.

SPONGIOSTROMATE MICROSTRUCTURE: "microstructures which result from the individualization of micritic, spongious, fenestral, sparitic, pelloidal, detrital, etc. laminae or films, variously grouped and organized" (Monty, 1981, p. 2).

STEEPLY CONVEX LAMINA: "Ratio of height to width greater than 0.5" (Preiss, 1972; Walter, 1972).

STRAIGHT: term referring to the attitude of a column which is not curved (Hofmann, 1969).

STRATIFORM STROMATOLITE: "Non-columnar stromatolite with flat continuous lamellae (cryptalgalaminate sediment)" (Walter, 1972).

STREAKY MICROSTRUCTURE: "One in which the laminae are moderately distinct and continuous; the darker are usually the most distinct and they are set in a pale matrix into which they grade vertically" (Walter, 1972). - see Walter p. 11 - 12)

STRIATED MICROSTRUCTURE: "One in which the laminae originally formed as chains of lenses" (Walter, 1972).

STROMATOIDS: Term used by Kalkowsky (1908, p. 101, 104) for the individual laminated structures or superimposed laminae making up the rock type he called a "stromatolith". The term stromatoid has been used by Hofmann (1969a, 1973, 1976), Monty (1977), Krumbein (1983) and Paul (1987, 1988) and Kennard and James (1986).

Stromatoids are ..."the diagnostic components of stromatolites,"(Kennard and James, 1986; Burne and Moore, 1987).

STROMATOLITE: Originally "Stromatolith" (Kalkowsky, 1908, pp. 68 - 69), although Hofmann (1969, p. 3) points out that "stromatoid" (Kalkowsky, 1908, p. 101, 104) was actually the term used for the individual laminated structures making up the bioherm or biostrome. This point is controversial (see Monty, 1977; Krumbein, 1983; Paul, 1987,1988). However, the term "stromatolite is now firmly entrenched in the literature. Reviews and comments on the use of the term have been given by several authors (Hofmann, 1969; Monty, 1982) Krumbein, 1983; Buick and others, 1981; Burne and Moore, 1987) and are not repeated here, instead some of the better known definitions are quoted.

1. "Layered organo-sedimentary structure built by microscopic algae and bacteria" (Walter, 1972).
2. "An organosedimentary structure produced by sediment trapping, binding, and/or precipitiation as a result of the growth and metabolic activity of microorganisms, principally cyanophytes (blue-green algae)" (Walter, 1976, based on Awramik and Margulis, 1974).

3. "An accretionary organosedimentary structure, commonly laminated, megascopic, and calcareous, produced as a result of the growth and metabolic activities of (and usually due to the attendant trapping, binding, and/or precipitation of mineralic material by) benthonic, mat-building communities of mucilage-secreting microorganisms, principally filamentous photoautotrophic prokaryotes; broadly, a lithified or unlithified, commonly laminated, accretionary sedimentary structure produced by a microbial biocoenose" (Schopf, 1983).

4. "Stromatolites are laminated rocks, the origin of which can clearly be related to the activity of microbial communities, which by their morphology, physiology, and arrangement in space and time interact with the phsical and chemical environment to produce a laminated pattern which is retained in the final structure" (Krumbein, 1983).

5. see Burne and Moore (1987) for a discussion of the use of the term.

STROMATOLITH: The original term used by Kalkowsky for beds with distinct calcareous masses of fine, more or less flat, laminated structures in the Triassic Buntsandstein of northern Germany, and now replaced by the term STROMATOLITE (see Hofmann, 1969, p. 3).

STROMATOLITIC STRUCTURE: A term based on the usage of Kalkowsky (1908) and restricted by Burne and Moore, (1987) to microbialites having an internal structure of "fine, more or less planar lamination".

STROMATOLOID: "a term for structures that are morphologically similar to stromatolites, but are of uncertain origin" (Buick and others, 1981).

STUBBY: term used to describe the variability of growth in columns in which H approx. = 2r (Hofmann, 1969).

SYNOPTIC PROFILE: "..the morphologic aspect of a structure (e.g. a stromatolite column) at an instant of time during its formation" (Hofman, 1969a; Walter, 1976).

SYNOPTIC RELIEF: "... the relief of a structure (e.g. a stromatolite column) above its substrate at an instant of time during its formation" (Hofman, 1969a; Walter, 1976).

T.

TABULAR BIOHERM: "Bioherm with parallel upper and lower surfaces " (Walter, 1972).

TABULAR BIOSTROME: "Biostrome with parallel upper and lower surfaces" (Walter, 1972).

TAXIS: "Locomotory movement of an organism or cell in response to a directional stimulus, the direction of movement being oriented in relation to the stimulus" (Walter, 1976).

THROMBOID: Macroscopic clot within a thrombolite; the essential frame-building component of thrombolites (Kennard, 1989a, b). Equivalent to clot sensu Aitken (1967); thrombolite sensu Pratt and James (1982); and mesoclot sensu Kennard and James (1986).

THROMBOLITE:

1. "Cryptalgal structures related to stromatolites, but lacking lamination and characterised by a macroscopic clotted fabric" (Aitken, 1967).

2. "a thrombolite is a cryptalgal structure of variable shape, from prostrate to columnar, that may branch and anastomose, that lacks a distinctly laminated fabric, and that usually occurs in groups, imparting a macroscopically clotted appearance to the rock" (Pratt and James, 1982). In this sense equivalent to THROMBOID (q.v.)

3. "Thrombolites are characterized by a clotted mesoscopic fabric constructed by the penecontemporaneous growth and calcification of discrete colonies or growth forms of coccoid-dominated, internally poorly differentiated, microbial communities" (Kennard and James, 1986). Kennard and James recommended abandoning the revised definition given by (Pratt and James, 1982) and returning to that of Aitken (1967).

THROMBOLITIC STRUCTURE: A term based on the usage of Aitken (1967) and restricted by Burne and Moore, 1987) to describe microbialites which have an internal structure consisting of "a clotted texture".

TONGUING BIOHERM: "Bioherm whose margins intertongue with with the surrounding rock" (Walter, 1972).

TOPHUS: a form of tufa.

TRICHOME: "In filamentous prokaryotic microorganisms, the threadlike, usually many-celled strand that is encompassed commonly by a tubular sheath to form a filament" (Schopf, 1983).

TRAVERTINE: "..a form of 'freshwater' carbonate deposited by inorganic and organic processes from spring waters" (Chafetz and Folk, 1984) "a denser form of tufa" - Burne and Moore (1987).

TROPISM: "In an organism, response to a stimulus by growth curvature, the direction of curvature being determined by the direction from which the stimulus originates"(Walter, 1976).

TRUE BRANCHING: ACTIVE BRANCHING (Hofmann, 1969).

TUBERCULATE: Type of ornament consisting of small lobes (Hofmann, 1969).

TUBEROUS COLUMN: "Having prominent expansions and constrictions" (Preiss, 1972; Walter, 1972).

TUFA: "A chemical sedimentary rock composed of calcium carbonate, formed by evaporation as a thin, surficial, soft, spongy, cellular or porous, semifriable incrustation around the mouth of a hot or cold calcareous spring or seep, or along a stream carrying calcium carbonate in solution, and exceptionally as a thick, bulbous, concretionary or compact deposit in a lake or along its shore. It may also be precipitated by algae or bacteria." (Bates and Jackson, 1980).

U.

UMBELLATE: type of branching for columns that "at a certain level, pass into several considerably smaller, diverging branches (Hofmann, 1969).

UNDULATORY STROMATOLITE: "Laterally-linked stromatolite in which successive crests are not superimposed" (Preiss, 1972; Walter, 1972).

UNIFORM VARIABILITY (OF GROWTH VECTOR): term used to describe the variability of a column diameter where the variation in the growth factor is zero (Hofmann, 1969, p. 17 and fig. 10).

V.

VERMIFORM MICROSTRUCTURE: "One in which narrow, sinuous, pale- coloured areas (usually of sparry carbonate) are surrounded by darker, usually fine-grained areas (usually carbonate)" (Walter, 1972).

W.

WALL:

1. A structure which "contains the marginal, downwardly- directed, encrusting portions of laminae which are in contact with a matrix whose accumulation postdates that of the laminae with which it is in contact" (Hofmann, 1969).

2. "Structure at the margin of a column, formed by one or more laminae from within the column bending down and coating the column margin for at least a short distance" (Preiss, 1972; Walter, 1972).

WAVY LAMINA:

1. A form of crinkled laminae (see Hofmann, 1969, fig. 8).

2. A laminae "with flexures of wavelength greater than 2 mm (Preiss, 1972; Walter, 1972).

WRINKLED LAMINA: "With flexures of wavelength less than or equal to 2 mm" (Preiss, 1972; Walter, 1972).

X.

XENOTOPIC TEXTURE: Fabric in which the majority of the constituent grains are anhedral, i.e. are not bounded by crystal faces (Friedman, 1965).

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