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STROMATOLITES FROM THE PROTEROZOIC ANIMIKIE AND SIBLEY GROUPS, ONTARIO

(Report, 9 figures and 22 plates)

H. J. Hofmann

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ABSTRACT

Stromatolites from the Aphebian Animikie Group and the Helikian Sibley Group northwest of Lake Superior are described and illustrated.

The Animikie forms are present at 2 chert horizons in the Gunflint Formation (one at the base and one near the middle), and in the correlative Biwabik Formation. They comprise lamellar, columnar-lamellar, columnar, nodular, and oncolitic forms, which are grouped into 7 arbitrary categories, Forms A to G. These structures appear to be part of a spectrum of related forms which grew under different relative rates of accumulation of stromatolite laminae and sand-sized clastic material. The basic form (Form A) which is composed of closely spaced, linked hemispheroids (LLH-C) with tabular attitude and a high degree of inheritance of successive laminae, is referable to Stratifera Korolyuk in the orthodox binomial stromatolite classification. The other forms exhibit more or less consistent variations in shape, size, spacing, linkage, overall attitude, and inheritance of laminae, and have characteristics attributable to the following groups with which they are compared, but not identified: Irregularia Korolyuk, Kussiella Krylov, Tungussia Semikhatov, Gymnosolen Steinmann, Archaeozoon Matthew, Cryptozoon Hall, and Colleniella Korolyuk. The oncolite is Osagia Twenhofel.

Three types of microstructure were observed: simple distinct, simple diffuse, and pillared. The now well known Gunflint microfossils are derived predominantly from stromatolites with the simple diffuse microstructure.

The Sibley stromatolites which occur in dolomite beds at least 90 m (300 feet) above the base of the unit, are identifiable as Conophyton, cf. C. garganicus Korolyuk (emend.). Their Helikian age is in agreement with the stratigraphic scheme for the Riphean conophytons.

STROMATOLITES FROM THE PROTEROZOIC ANIMIKIE AND SIBLEY GROUPS, ONTARIO

INTRODUCTION

Proterozoic sedimentary sequences abound in the area of the Canadian Shield and bordering geosynclines. Most of these have now been dated directly or indirectly by radiometric methods, and placed into a time-stratigraphic framework (Stockwell, 1964, p. 12). With increasing interest in Precambrian paleontology, these Proterozoic rocks are being subjected to closer scrutiny than ever before, not only for the evidence of the presence of biologic and biosedimentary structures, but also for the biologic, geochemical, paleoecologic, geochronologic, and quantitative significance of this evidence.

Over the last decade apparently successful attempts have been made by Soviet geologists in developing a biostratigraphic zonation for most of the Proterozoic on the basis of characteristic assemblages of forms of stromatolites, including oncolites, and katagraphs (Keller, 1966; Komar and Semikhatov, 1968). This scheme has not yet been critically evaluated through similar studies in North America, and it is only now being followed up.

The present paper summarizes the results of observations made on stromatolites from two of the Proterozoic sequences of the Canadian Shield, the Aphebian Animikie Group, and the Helikian Sibley Group, in the Thunder Bay district of northwestern Ontario. It exposes some of the difficulties of comparing forms from the Animikie with those of the present Russian classification, but also shows the usefulness of this classification when applied to the Sibley stromatolites.

ACKNOWLEDGMENTS

I am indebted to Drs. A.M. Goodwin and W.W. Moorhouse for information and discussion on Animikie stratigraphy and good stromatolite localities. Dr. Goodwin and Dr. J.A. Donaldson reviewed the manuscript. Mr. J.M. Franklin conducted me to the main localities of the Sibley stromatolites and provided a log of a drill core taken west of Disraeli Lake. Mr. S.J. d'Appolonia assisted me in the field, office and the laboratory. The majority of the photographs were taken by Mr. F.J. Cooke of the Photographic Section, Geological Survey of Canada.

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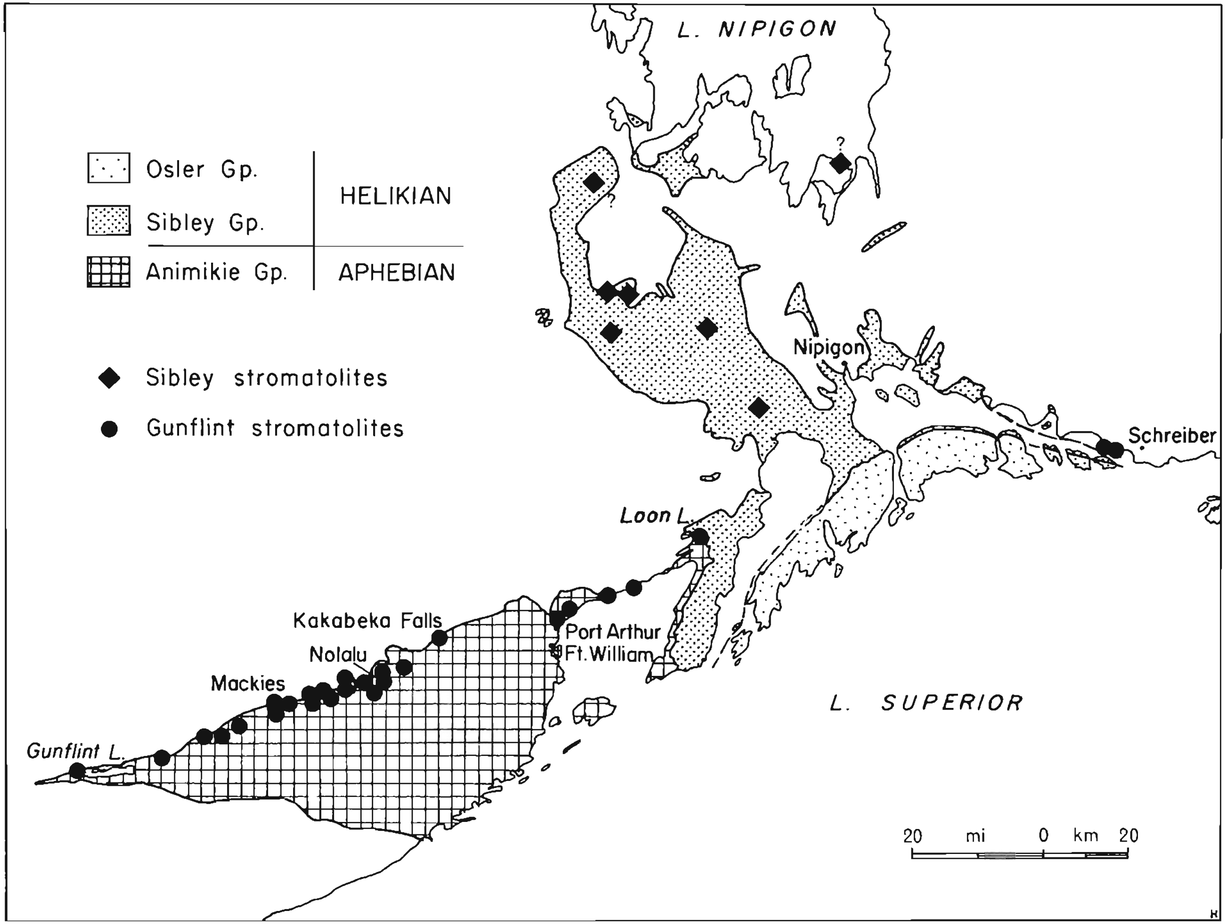


Figure 1. Map of the distribution of Proterozoic rocks and stromatolites NW of Lake Superior.

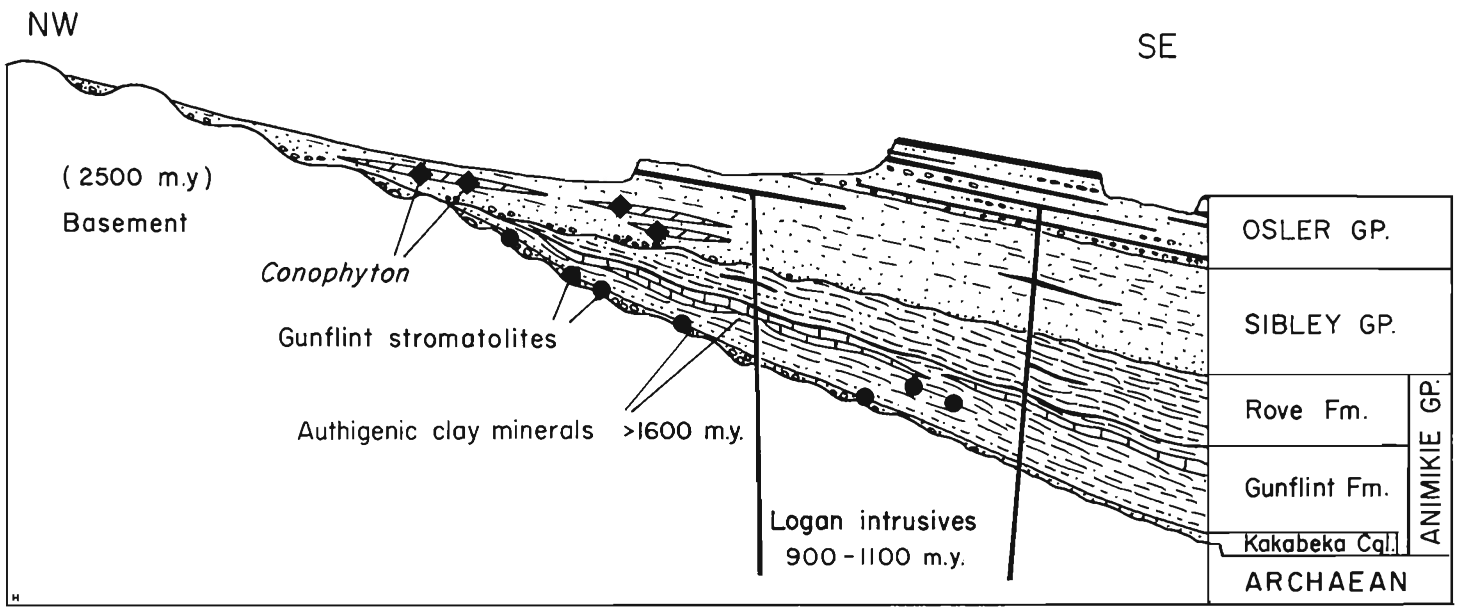


Figure 2. Schematic cross section from Lake Nipigon (NW) to Lake Superior (SE), showing stratigraphic relationships of the stromatolitic units.

GENERAL SETTING

The geographic and stratigraphic setting of the Animikie and Sibley rocks is summarized in Figures 1 and 2, which are based on detailed information provided by Wilson (1910), Tanton (1926, 1931), Gill (1926, 1927), Goodwin (1956, 1960), Moorhouse (1960), Pye and Fenwick (1965), and Pye (1968).

The Animikie Group occupies a large outcrop area wedged between a straight line connecting Gunflint Lake and Loon Lake, and the northwest shore of Lake Superior, and is found in small patches of outcrop west of Schreiber. It unconformably overlies an Archean basement of igneous and metamorphic rocks yielding K-Ar mineral ages of the order of 2, 500 m. y. (Stockwell, 1964, p. 5, Fig. 1). In most areas the basal unit is a thin conglomerate (Kakabeka member), generally less than 3 feet (1 m) thick, but locally reaching a thickness of 10 feet (3 m). This is followed by a variety of rock types, including ferruginous and stromatolitic chert, taconite, black pelite, greywacke, tuffite, carbonate, and small lava flows, which are grouped as the 250-to-500-foot (80-170 m) thick Gunflint Formation. Conformably above is the Rove Formation, a 300-to-2, 000-foot (90-600 m) thick unit of predominantly black pelites, black pelites with gigantic concretions, and sole-marked fine and coarse psammites. The age of deposition of the Gunflint, based on K-Ar and Rb-Sr analyses of authigenic and unmetamorphosed clays as well as whole rock samples, has been found to be of the order of 1, 600-1, 900 m. y. (Hurley et al., 1962; Kovach and Faure, 1967).

Outcrops of the Sibley Group are essentially confined to the area between Lake Nipigon and Lake Superior. The Sibley rests unconformably on the Animikie, or, where this is absent, directly on the Archean. It comprises at least 300-600 feet (90-180 m) of conglomerate, brick red mudstone and sandstone, white sandstone, and pink and grey stromatolitic dolomite.

The Animikie and Sibley rocks are intruded by extensive concordant and discordant sheets of Keweenawan diabase (Logan intrusions), which yield K-Ar ages on biotite and whole-rock samples in the range of 900-1, 100 m. y. (GSC samples 61-138, 64-101, and 64-113; see: Lowdon et al., 1963, p. 80; and Wanless et al., 1966, pp. 66, 71).

Disconformably above the Sibley is the Osler Group, a succession of Keweenawan lava flows, conglomerate, crossbedded sandstone and mudstone, with an estimated thickness of 6, 000-10, 000 feet (1, 800-3, 000 m). Rocks younger than the Osler have not been reported.

All the stratigraphic units have a gentle regional dip (less than 15°) to the southeast. The Gunflint and Rove thicken southwestward into the correlative Biwabik and Virginia Formations (Grout and Schwartz, 1933, p. 15; White, 1954, p. 27, Pl. 1; Moorhouse, 1960, p. 34). Reliable information on thickness trends in the Sibley and Osler is not yet available.

Published data on paleocurrent directions in the Rove (Morey, 1967), and personal observations on a small number of sole marks in the Gunflint, indicate southeasterly transport during deposition of the Animikie sediments, whereas sediment dispersal during Sibley and Osler sedimentation was to the southwest (Hamblin, 1965, p. 953).

ANIMIKIE STROMATOLITES

General

Nearly a century has passed since Robert Bell of the Geological Survey of Canada reported "small coral-like siliceous concretions and vertical cylinders of chalcedony, transverse sections of which show fine concentric rings resembling agate" from an area just west of Fort William (Bell, 1870, p. 324). He was referring to structures now called stromatolites, in rocks presently identified as part of the Gunflint Formation. However, it was not until the mid-1920's that more information on their geographic and stratigraphic distribution within the Gunflint of Ontario was obtained through the studies of Tanton (1926, 1931), and Gill (1926). Illustrations of these forms and detail maps of their occurrences were published by Moore (1925), Gill (1927), Goodwin (1956, 1960), Moorhouse (1960), Moorhouse and Beales (1962), and Cloud (1965), but their systematic study had not been attempted. They are now known to be confined to two definite horizons within the formation, namely one at the base, and one near the middle of the Gunflint (Moorhouse, 1960, pp. 11, 34; Goodwin, 1960, pp. 46, 48). Northeast of Kakabeka Falls the structures are found sporadically only at the base of the formation. The information on the distribution of Gunflint stromatolites is summarized in Figures 1 and 2.

Stromatolites also occur at two similar horizons in the correlative Biwabik Formation of Minnesota (Gruner, 1924, section in pocket; White, 1954, Pl. 1). These were mentioned and illustrated by Leith (1903, Pl. XII A), who, however, ascribed a deformational origin to them. Following the results of C. D. Walcott's studies on Precambrian stromatolites and their interpretation as algal structures, Grout and Broderick (1919a, b) considered a similar algal origin for those from the Biwabik. Grout and Broderick also observed that each of the two horizons is characterized by a distinct morphologic type of stromatolite; the basal horizon with a form which they named Collenia (?) biwabikensis, and the upper horizon with one which they named Collenia(?) ferrata (Grout and Broderick, 1919a). The importance of this observation has subsequently been questioned (Moorhouse and Beales, 1962, p. 102).

The Gunflint stromatolites distinguish themselves from most other reported Canadian Precambrian stromatolites in several important ways. The most obvious is their occurrence in bedded black, red and green cherts, rather than in limestone or dolomite. A second important difference is their comparatively small size, and the extreme fineness of their laminae which are much more delicate than those of carbonate stromatolites. Thirdly, there is an intimate association with siliceous spheroids (oölites and oncolites) and detrital quartz and iron minerals. Lastly, those stromatolites that are in black chert have preserved a prolific fossil microflora (Barghoorn and Tyler, 1965; Cloud, 1965).

Samples for the present study were obtained from both the lower and upper levels, at localities between Gunflint Lake in the southwest and Schreiber in the northeast. In mode of occurrence the stromatolites from the two Gunflint horizons differ somewhat from each other. Those in the lower one are preferentially developed along the Archean-Proterozoic unconformity as decimeter – to meter-sized biohermal mounds containing millimeter – to centimeter-sized branching columnar (the SH type of Logan, Rezak, and Ginsburg, 1964) and columnar-lamellar structures (the LLH type of Logan, Rezak, and Ginsburg, 1964). These domal masses either encrust the basement directly, or encrust boulders and pebbles of the basal conglomerate member of the Gunflint Formation (Fig. 3; Pl. 11, Fig. 2; Pl. 13, Fig. 2; see also Goodwin, 1960, pp. 49, 50; and Cloud, 1965, Fig. 1). Those in the upper horizon, and also some in the lower horizon, developed as more openly spaced, individual branching columnar-lamellar as well as domal forms on an unconsolidated, arenitic substrate.

Classification

The Gunflint stromatolites pose a problem in classification. The structures are so variable in their morphology that the whole spectrum from single columns to complex mounds containing several geometric forms is represented. The form variety is certainly much greater than only the 2 "species", which Grout and Broderick (1919a) described from the Biwabik. Yet, there are particular forms which are more common than others, and these are here singled out and discussed.

The classification of stromatolites itself is still in the process of constant revision. Over the years, more than a dozen schemes have been proposed, and not one has found favour with everyone. Nor is there a prospect that this will correct itself in the near future. Still unresolved are opposing opinions as to whether stromatolite morphology represents particular environmental conditions (a view held in North America), or biologic and geochronologic factors (a view held in the Soviet Union). During the last decade Russian geologists have claimed success in subdividing the later part of the Proterozoic (Riphean-Vendian) on the basis of empirically determined distributions and ranges of stromatolite forms (and katagraphs), supplemented by radiometric age determinations. Their stromatolite classification utilizes a binomial nomenclature and considers such features as the type of structure

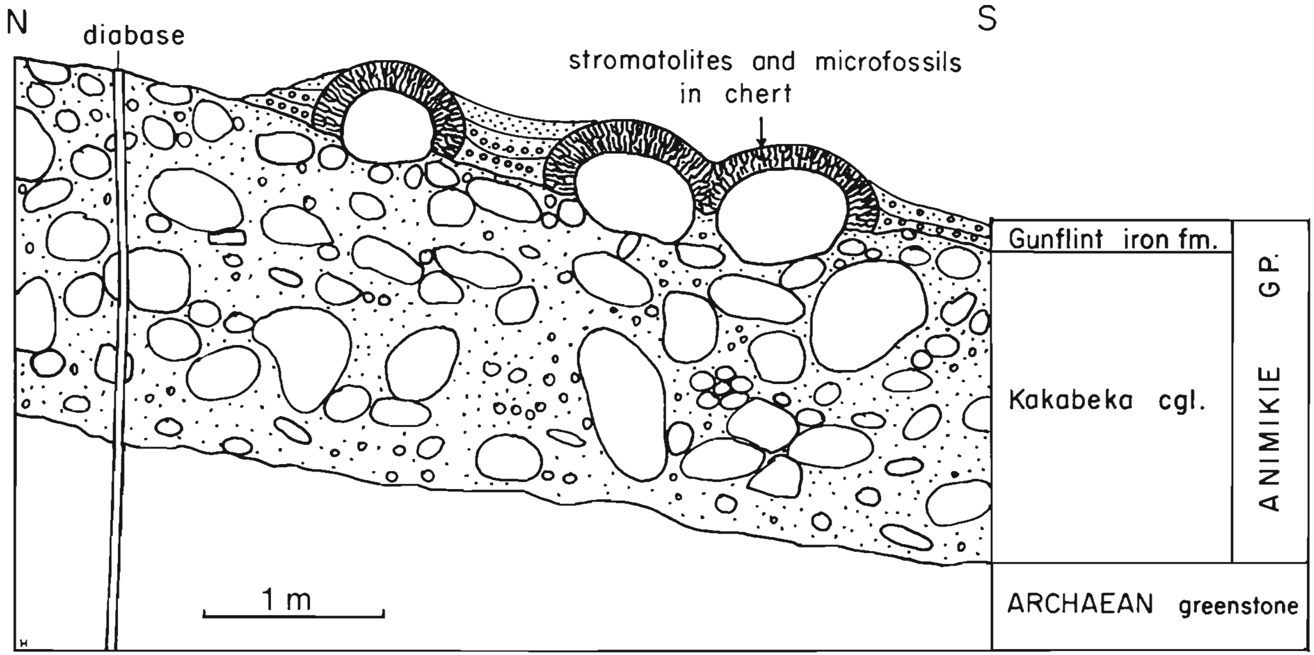


Figure 3. Vertical section illustrating the occurrence of stromatolite (Form F) bioherms as encrustations on boulders, at the beach locality 6.4 km W of Schreiber, Ontario (G.S.C locality 78417).

(columnar, nodular, lamellar), the pattern of the branching, the character of the lateral surface of the columns, and the microstructure of the laminae (Korolyuk, 1960; Krylov, 1963; Komar, 1966). Similar extensive studies to corroborate the Russian findings are not yet available for North America.

An attempt made to utilize the Russian scheme for the Animikie stromatolites has met with some difficulties. The first is that this scheme was developed primarily for columnar Riphean forms in carbonates; those in the Gunflint are pre-Riphean (Aphebian) and occur in chert. The greatest number of groups (form genera) in the Riphean is in the category of columnar (SH) stromatolites. In contrast, most of the Gunflint specimens are of the lamellar and columnar-lamellar (LLH) types. Yet, except for the continuous nature of the laminae, the columns themselves are morphologically hardly distinguishable from certain Riphean columnar forms. Another difficulty is the ambiguity which arises from the fact that gradational types exist, and that a particular structure could be assigned to more than one named form; examples of this are illustrated in this paper.

In view of these circumstances it was deemed necessary to use an informal scheme of reference for the present, and to assign the Gunflint stromatolites on provisional basis to arbitrary categories A to G (Fig. 4). Each is described and illustrated, and its affinities with forms in both the Russian and the Logan-Rezak-Ginsburg classifications are noted.

The stromatolites are here viewed as three-dimensional geometric bodies which grew as a result of the stacking of an essentially two-dimensional form, the lamina. Different growth forms are generated by certain changes in size, shape, or position of successive laminae. The geometric properties of the laminae thus provide a basis for analysis of the structures. To facilitate discussion, most of these properties are defined in Figure 5 and subsequently discussed.

Components: Stromatolites are characteristically laminated. The ideal fundamental lamina is a few microns thick and is made up of alternating light and dark lamellae. However, in fossil specimens the dark lamellae may not always have accumulated, or may have become obliterated during diagenesis, so that only a few survived to appear in the thin section as a lamination. This factor may result in overestimating the thicknesses of the fundamental laminae.

Shape: This refers to individual curvatures observed on a mesoscopic (hand specimen) scale. The laminae have various configurations, but form essentially convex-up hemispheroids which range from flat to globoidal with oblate and prolate varieties. The shape is best determined by serial sectioning, although 3 mutually perpendicular sections, including the longitudinal and transverse, suffice to give an indication of morphology. If the structure is not uniform, additional terms can be used to describe the shape, e.g., lobate, vermiculate, polygonal.

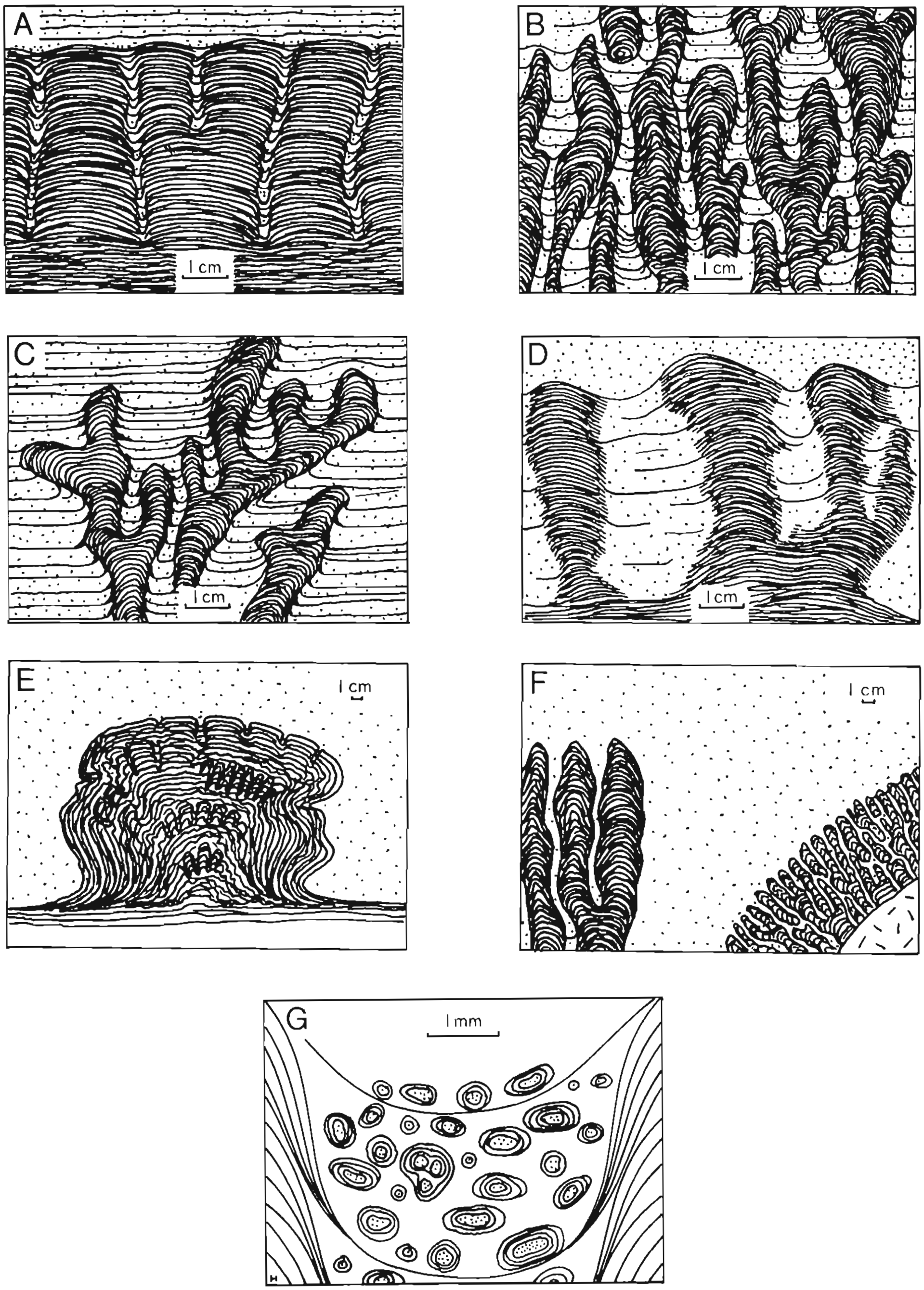


Figure 4. Pictorial summary of main types of Animikie stromatolites.

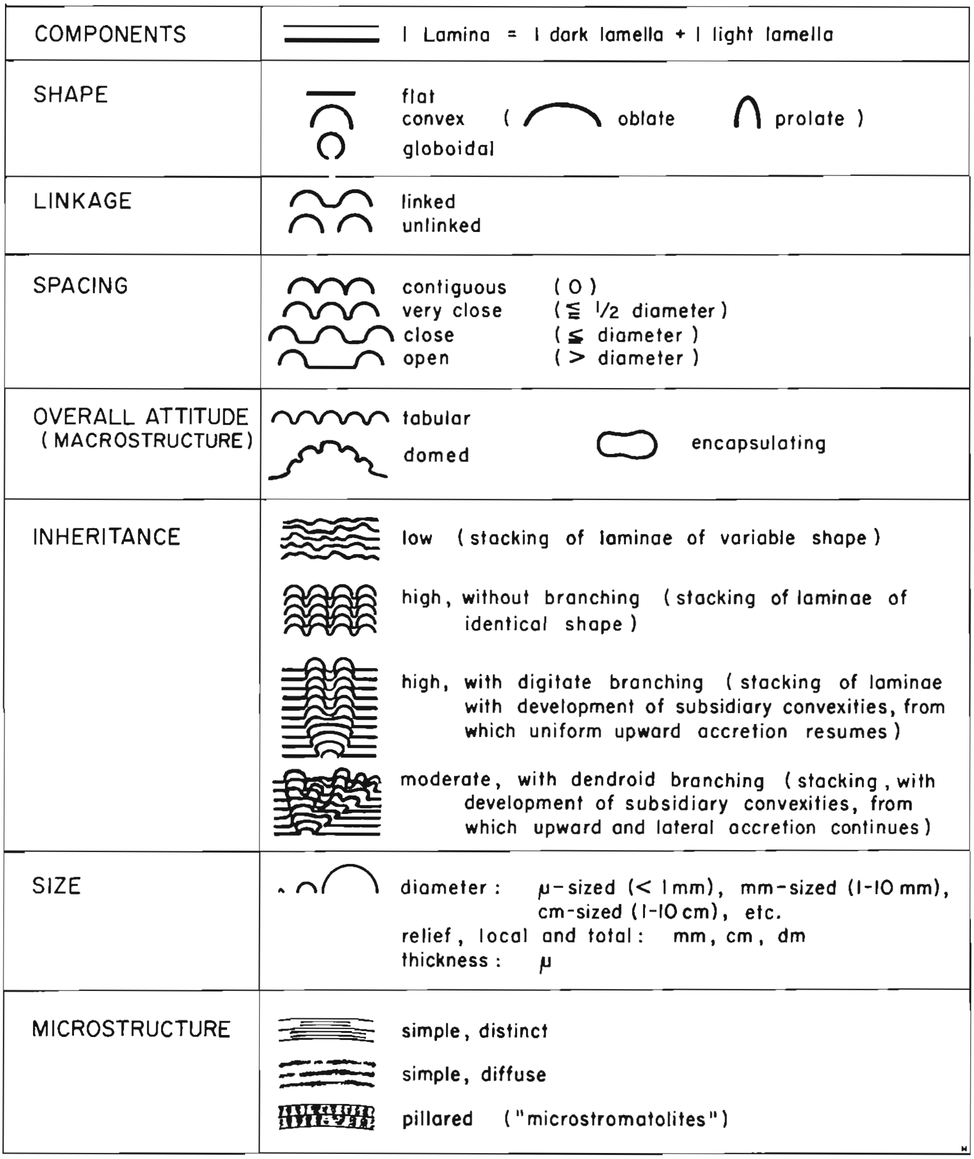


Figure 5. Terminology for properties of laminae of Animikie stromatolites.

Linkage: The individual hemispheroids may be linked or unlinked, depending on whether or not the laminae are demonstrably continuous across the inter-mound area. This property is best seen in vertical sections.

Spacing: The hemispheroids may be contiguous, or be closely or openly spaced. This is best determined statistically from transverse (horizontal) sections, because random vertical sections will show an apparent spacing which is larger than the actual spacing.

Overall structure (macrostructure): In relation to adjoining ones, the hemispheroids may themselves be arranged in a tabular, domed, or encapsulating fashion. If they are linked, as most of the Gunflint forms are, the laminae assume a corrugated expression.

Inheritance: A feature of paramount importance in stromatolite classification is the type of stacking, because it produces the 3-dimensional form (gross morphology) of the final stromatolite. The degree of inheritance from one lamina to the next ranges from low to high, but can vary within a column, and from one column to the adjoining one. The type of growth may be with and without branching, depending on whether or not subsidiary convexities develop. It may also involve a reduction of convexities, producing coalescence, or fusion, of 2 or more columns.

Size: The absolute size of the hemispheroids is determined by statistical treatment of measurements of diameter, relief, and thickness. It is necessary, for non-tabular assemblages, to distinguish between local and total diameters and reliefs. Structures are said to be mm-sized if the diameters are 1-10 mm, cm-sized if 1-10 cm, and so on. The actual height of the final stromatolite structure is something quite distinct from the relief of the individual laminae, and depends primarily on the duration of the conditions allowing accretion of the individual superimposed laminae. For linked structures, the height of the columns is generally much greater than the relief, whereas in unlinked columns the height may sometimes equal the relief of the terminal lamina.

Microstructure: The microstructure is determined in thin sections under the microscope. In the Animikie forms 3 main types are distinguished. The first (Pls. 5-6) is one with simple and distinct dark lamellae, usually composed of iron minerals, chiefly hematite, but sometimes, as in some oncolites, by organic matter. These lamellae are spaced from 2 to 100 microns apart. However, where the lamellae are well preserved, as in some pockets (Pl. 6, Figs. 1-2), it can be seen that a single lamina is of the order of 2 to 4 microns in thickness, and that the dark and light lamellae are approximately of equal thickness. In other parts of the section the spacing of the dark lamellae is much greater due to non-deposition or diagenetic obliteration. It is thus important to be careful in assessing the thickness of the fundamental lamina. In thin sections of stromatolites with this type of microstructure no microfossils were identified.

The second type of microstructure is also a simple one, but instead of distinct lamellae, there is only a pervasive, diffuse pattern of darker and lighter laminations within even-textured chert (Pl. 6, Figs. 3-4, Pls. 10, 13). These laminations may not necessarily be preserved fundamental laminae in the sense as defined in Figure 5. The darker laminations are regions of more concentrated organic matter, including structurally preserved microfossils (the Gunflint flora described by Barghoorn and Tyler, 1965, and others). The filamentous microscopic entities (Gunflintia, Animikiea) are arranged in all directions, only sometimes showing a preferred orientation parallel to the lamination. It is evident that rhythmic development of a 2 to 4 micron lamina has not occurred. The structures seem to have been built up with thicker layers and in a more continuous fashion, without compression of the filaments, sometimes with more, sometimes with less organic matter. The darker and lighter laminations are of variable thickness, and may be up to several hundred microns thick.

A third type of microstructure is more complex than the other two. In this type, 10-50 micron-wide pillars of dark material (iron minerals, organic matter) and of variable height, are disposed approximately perpendicular to, and between, dark laminations (Pl. 8, Fig. 1). These occur in some of the stromatolites of Forms A, D and E. Where well preserved, they show convex, 2-micron thick laminae, arranged in a columnar, locally branching pattern (Pl. 8, Figs. 2-3). These columns are here referred to as 'microstromatolites'.

With the information outlined in the preceding paragraphs, the properties of the Animikie stromatolites can be summarized in tabular form for easy comparison as follows (Table 1). Characteristics of particular interest are underlined.

Form A

Plate 1

Gnarled and contorted bedding, Leith 1903, U.S. Geol. Surv., Monog. v. 43, p. 120, Pl. XII A. Collenia(?) biwabikensis, Grout and Broderick 1919, Amer. J. Sci., v. 48, p. 205, Fig. 1.
Algal structures, Moore 1925, Trans. Roy. Soc. Can., v. 19, sec. 4, Pl. 3.
Stromatolites, Moorhouse and Beales, 1962, Trans. Roy. Soc. Can., v. 56, ser. 3, sec. 3, p. 99, Fig. 1b.

This form is composed of millimeter- to decimeter-sized, linked, oblate hemispheroids, with very close spacing and a high to moderate degree of inheritance, appearing as erect, sometimes branching columns. The overall structure of the laminae is tabular, but it is slightly domed where developed above moundlike structures. Narrow concave pockets or furrows between the convexities contain collections of sand-sized granules and

spheroids (including oncolites of Form G, Osagia Twenhofel). The microstructure of the laminae is generally simple (distinct as well as diffuse), and in some sections also pillared.

Form A occurs in both horizons of the Gunflint Formation. It is also reported from the lower horizon of the Biwabik Formation in Minnesota, where the name Collenia(?) biwabikensis was applied to it by Grout and Broderick (1919a). However, assignment to the group (form genus) Collenia Walcott is not advisable, inasmuch as the type species, Collenia undosa Walcott, has a strongly domed lamination and a nodular, rather than tabular aspect. Form A is more readily identified with Stratifera Korolyuk. The Animikie structures are therefore appropriately referred to as Stratifera biwabikensis (Grout and Broderick 1919).

Form B

Plate 2; part of Plate 3

Collenia(?) ferrata, Grout and Broderick 1919a, Amer. J. Sci., v. 48, p. 205, Figs. 2-4; 1919b, Minn. Geol. Surv., Bull. 10, p. 21, Pl. VIIA-C.

Gymnosolen-type stromatolite, Moorhouse and Beales, 1962, Trans. Roy. Soc. Can., v. 56, ser. 3, sec. 3, p. 101, Fig. 1e.

Form B comprises millimetre- to centimetre-sized, linked convex hemispheroids with close to very close spacing and a high degree of inheritance. The hemispheroids are arranged in a tabular manner and are stacked to form subparallel, erect to slightly inclined, subequal columns with digitate branching. The intercolumnar regions are filled with accumulations of sand-sized granules and spheroids, and are somewhat more spacious than those in Form A. The laminations are fairly uniform within the columns, but at the margins they are bunched at intervals and give the column a frayed appearance. The microstructure of the lamellae is simple and distinct.

This type of stromatolite occurs at both horizons in the Gunflint, and in the upper horizon of the Biwabik Formation, where it was named Collenia(?) ferrata by Grout and Broderick (1919a). As with Form A, assignment to Collenia Walcott is not proper. The branching and columnar aspect is hardly distinguishable from Gymnosolen Steinmann; it differs from it only in the continuous (linked) nature of the laminae and the frayed lateral margins. In Gymnosolen the laminae are more prolate and not linked, with the result that the margins are smooth. On the other hand, the linked nature is that of the lamellar stromatolite Stratifera Korolyuk. It thus does not seem possible to satisfactorily accommodate Form B within the present Russian classifications.

TABLE 1

Summary of Animikie Stromatolites

Form	Properties of laminae									Stromatolite affinities			GSC type numbers
	Shape	Linkage	Spacing	Overall attitude	Inheritance	Size			Microstructure	Classification of Logan, Rezak, and Ginsburg (1964)	Russian classifications (Korolyuk 1960, Krylov 1963, Komar 1966)		
						Diameter	Local relief	Total relief			Type	Group	
A	oblate	linked	very close	tabular to slightly domed	high to moderate	5 mm to 20 cm	mm to cm	mm to cm	simple and pillared	LLH-C	Lamellar; Columnar-lamellar	Stratifera Korolyuk	24534
B	convex	linked	close to very close	tabular	high, with digitate branching	3 mm to 2 cm	mm	mm	simple, distinct	LLH-C	Columnar-lamellar; actively branching	cf. Gymnosolen Steinmann cf. Stratifera Korolyuk	24535, 24536
C	convex to oblate	linked	very close to open	tabular to slightly domed	moderate, with dendroid branching	2 mm to 2 cm	mm	mm to cm	simple, distinct	LLH-C to LLH-S	Columnar-lamellar; actively branching	cf. Tungussia Semikhatov cf. Stratifera Korolyuk cf. Irregularia Korolyuk	24537, 24538, 24539, 24539a, 24540
D	oblate	partly linked	close	tabular	high, with and without branching	5 mm to 3 cm	mm	mm	simple and pillared	SH-V → LLH → SH-V ...	Columnar, Columnar-lamellar; branching	cf. Kussiella Krylov	24541, 24541a, b, 24542
E	variable; convex, oblate, prolate	linked	close	domed	variable low to high	2 mm to 8 cm (local)	mm	mm to dm	simple, diffuse and distinct; pillared	SH / LLH-C	Nodular	Total structure: cf. Cryptozoon Hall cf. Colleniella Korolyuk Individual parts of structure: cf. Stratifera Korolyuk cf. Irregularia Korolyuk	24381a, 24543, 24544, 24544a, 24545, 24546
F	convex, prolate	partly linked, unlinked	very close	tabular to domed	high, with digitate branching, and coalescence	2 mm to 3 cm (local)	mm to cm	mm to dm	simple, diffuse	SH	Columnar; actively branching, with walls	cf. Archaeozoon Matthew cf. Gymnosolen Steinmann	24547, 24547a, 24548, 24549, 24549a, 24550, 24550a,b,c, 24551 d 24551a
G	globoidal			encapsulating	high; concentric and overlapping	100μ to 5 mm			simple, distinct	SS	Oncolite	Osagia Twenhofel	24544, 24552, 24552a

Form C

Plates 3-5; Plate 6, Figures 1-2

Structures placed into this category are composed of millimeter-to centimeter-sized, linked, convex or oblate laminae with variable, very close to open spacing, and a moderate degree of inheritance. The laminae are tabular to slightly domed, and have a good development of secondary convexities, which has the result that the stacked laminae produce columns with profuse and divergent branches. The columns are mostly oblique to the bedding, but some are horizontal, and some even appear to have grown downward. In plan view the laminae appear subcircular, lobate, or vermiform. Because of the generally somewhat more open spacing, the laminae appear flat between the columns. As in Form B, the intercolumnar areas are replete with sand-sized granules and spheroids, the lateral margins are frayed, and the microstructure of the lamellae is simple and distinct.

Form C is found in both the lower and upper horizons. It is gradational with Form B, forming a more irregular type of end member with inclined, dendroid branches. In gross morphology it resembles Tungussia Semikhatov, but, like Form B, it is essentially a lamellar stromatolite, and thus has some of the characteristics of Stratifera Korolyuk and Irregularia Korolyuk.

Form D

Plates 7-8

Stromatolites grouped in Form D are built up of millimeter- to centimeter-sized, partly linked, oblate hemispheroids, with close spacing, a high degree of inheritance, and tabular disposition. Branching is seen in some specimens. The margins of the columns are jagged, and most of the laminae terminate at, or interfinger with, the coarse sand-sized intermound fill of terrigenous detritus and spheroids. A thin marginal zone of discoloration encloses the columns. The microstructure is more complex than in other forms in that, in addition to the light and dark layers, there are pillar-like bodies, like those already observed by Moorhouse and Beales (1962, Fig. 1c). In well preserved material (Pl. 8, Figs. 2-3) these are seen to be columnar, sometimes branching, 'microstromatolites'.

Type D stromatolites appear to be rare, and were observed only at the Winston Point locality (GSC locality 78418 - see Fig. 6) in a coarse sandstone within the basal 1 meter of the Gunflint. The gross morphology and the lateral termination of the laminae resemble those of Kussiella Krylov.

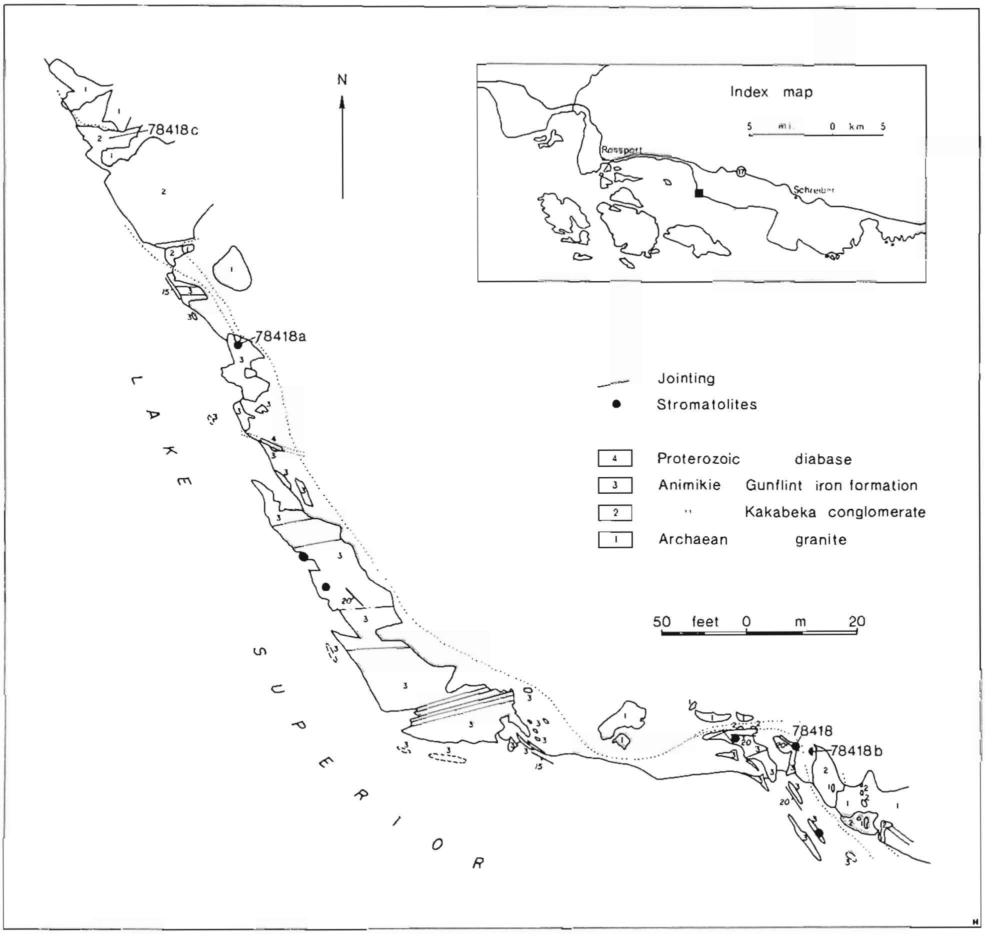


Figure 6. Geologic sketch map of Animikie rocks near Winston Point, showing exact position of stromatolite occurrences and numbered localities 78418, 78418a, 78418b, 78418c.

Form E

Plates 9-10; Plate 11, Figures 1, 3

Stromatolitic nodules and masses, Moorhouse and Beales, 1962, Trans. Roy. Soc. Can., v. 56, ser. 3, sec. 3, p. 101, Fig. 1f, (?) 1a.

Within the Gunflint there occur stromatolite mounds up to several metres across, which are built up of millimetre- to centimetre-sized, very closely spaced and domally linked, hemispheroids of variable shapes. The degree of inheritance is very variable, and the columns tend to be short, because the conditions favouring their growth were periodically disrupted. Form E is essentially a compound form, for within the larger nodular mass individual parts of the structures may have the geometric expression of the other forms of Animikie stromatolites. Sand-sized spheroids and granules occur along the laminae, and are common in the troughs of the corrugations. The microstructure is predominantly simple and may be distinct or diffuse. Some specimens have the pillar-like pattern.

In gross morphology the structures range from flattish domes to bulbous masses, and on this basis they may be referred to Colleniella Korolyuk or Cryptozoon Hall. In particular, the specimen illustrated in Plate 11, Figure 1 is very similar to Cryptozoon proliferum and C. undulatum from the Upper Cambrian of New York (see photographs in Goldring, 1938, pp. 34, 45 and 47). Individual parts of the structures resemble Forms A, B, and C, and would be indistinguishable from them in small fragments.

Form E is found in both horizons of the Gunflint Formation.

Form F

Plate 6, Figures 3-4; Plate 11, Figure 2; Plates 12-13

(?) Algal structures, Goodwin, 1960, Ont. Dept. Mines, Ann. Rept. v. 69, Pt. 7, Fig. p. 50.

Stromatolites, Barghoorn and Tyler, 1965, Science, v. 147, p. 565, Figs. 3, 4.
Stromatolites, Cloud, 1965, Science, v. 148, p. 29, Figs. 1, 2A-B.

Another form occurs in moundlike growths as well as in tabular attitude. The continuity of the laminae is lacking and the branching, columnar nature is very distinct. It is characterized by millimetre- to centimetre-sized, partly linked but mostly unlinked, very closely spaced, predominantly prolate hemispheroids with high local relief and complex cross sections. Inheritance is high, with digitate branching and coalescence of columns. The younger laminae enclose the older ones with comparatively little vertical change of diameter, resulting in closely spaced, smooth-walled columns that have pronounced microbathymetric relief. The spaces between the columns are subsequently filled with granules and spheroids comparable to those in the other Animikie stromatolites. The microstructure of the laminae is simple and diffuse, and microfossils are extremely abundant, particularly Gunflintia and Huroniospora.

Because of the close packing, non-lamellar nature, and branching-columnar habit, stromatolites of this type look like miniature editions of Archeaozoon Matthew, and are close to Gymnosolen Steinmann. They differ from these in that their horizontal cross sections tend to be much more irregular, varying from subcircular to lobate and vermiculate.

Form F was observed only in the basal horizon of the Gunflint, where it is developed as encrusting biohermal mounds on the Archean basement or on boulders of the basal Kakabeka conglomerate (Fig. 3). Specimens of a variety with large dimensions (diameters up to 3 cm and heights of at least 15 cm) were found in a large loose block at locality 78418b (see Fig. 6). The block cannot have come from very far, and is probably derived from the basal Gunflint beds below the lake just off shore. Relations to smaller forms within the same block are such as to suggest that the large variety grew on a flat substrate only centimeters away from the smaller variety which evidently was encrusting a boulder in or on the substrate.

Form G

Plates 10, 14-15

Among the spheroids found in association with the Gunflint stromatolites are micron- to millimetre-sized oncolites, formed of encapsulating globoidal laminae with simple, distinct microstructure. The laminae are rather variable in thickness and completeness, and are concentrically or overlappingly stacked around simple and composite nuclei of detrital grains.

Form G is widespread in the Gunflint, and commonly is seen in the pockets between stromatolite columns. The structures have a strong resemblance to those recently described and illustrated from the Aphebian Sokoman Iron-Formation of the central Labrador Trough (Dimroth, 1968).

An elaborate terminology for different forms (form species) of oncolites has been devised, and many 'species' have been named, and used for stratigraphic zonations in the Late Precambrian and Cambrian (e.g., Zhuravleva, 1964, p. 59). However, the validity of an oncolite stratigraphy has not been tested nor confirmed by workers in North America. Moreover, the evidence for the organic nature of some of the forms classed as oncolites (e.g., Radiosus Zhuravleva) is unconvincing. In the orthodox binomial taxonomy the Gunflint structures can be placed in the group Osagia Twenhofel.

The question may well be asked: why are these structures oncolites and not oolites? The criteria for distinguishing the two are somewhat equivocal. To demonstrate that the spheroids are oncolites, that is, that they resulted from processes associated with the life activities of algae (or bacteria) is difficult, if not impossible in most fossil specimens which lack identifiable organic microstructures. Oncolites are essentially small, unattached stromatolites, kept mobile by agitating currents. Their mode of formation is discussed by Logan, Rezak, and Ginsburg (1964, p. 81). Two of the distinguishing characteristics of oncolites are presumed to be the overlapping nature and the irregular thicknesses of the laminae. Also they tend to be less spherical than oolites. Spheroids in the Gunflint which exhibit these features are therefore here classed as oncolites.

Discussion

The data presented in the foregoing sections can now be discussed, and certain conclusions can be reached.

The environmental setting visualized for the Animikie stromatolites is one of shallow, agitated, silica-rich waters. Structures in the lower Gunflint horizon which encrust boulders and the basement probably formed in a shallow, littoral environment during the initial transgressive phase of a deepening Gunflint 'sea'. Exposure to wave action along beaches is indicated by the high degree of rounding and sorting of the associated sand-sized detrital material, which was kept in motion, and much of which was allowed to be transformed into coated spheroids (oolites-oncolites). Stromatolites in the second horizon near the middle of the Gunflint probably formed during a temporary return to shallow water conditions.

Although the stromatolites with simple, diffuse lamination contain structurally and organically preserved microfossils, it is not yet clear which of these organisms, if any, are responsible for the formation of the stromatolites. The filaments of Gunflintia, and to a lesser extent Animikiea, are very abundant and would normally be likely contenders for this role; others, especially the spheres, were probably planktonic. However, in none of the many thin sections examined were these filamentous forms seen preserved in what could be regarded as bundles assembled in vertical or subvertical growth positions. They generally appear as a hash of short and long fragments with random attitudes, or with some preferred orientation parallel to the lamination, suggesting a final detrital accumulation also for these filaments. The even texture of the chert and the lack of a sharply defined lamination speak for a process of continuous accumulation of colloidal and organic material, in which periodically one constituent predominated over the other. The fact that the delicate cells of Huroniospora and other taxa are neither flattened by compaction, nor contiguous, nor bacterially degraded, indicates a history of relatively rapid accumulation and solidification of silica compared to the deposition of the biologic remains. It is thus not possible to

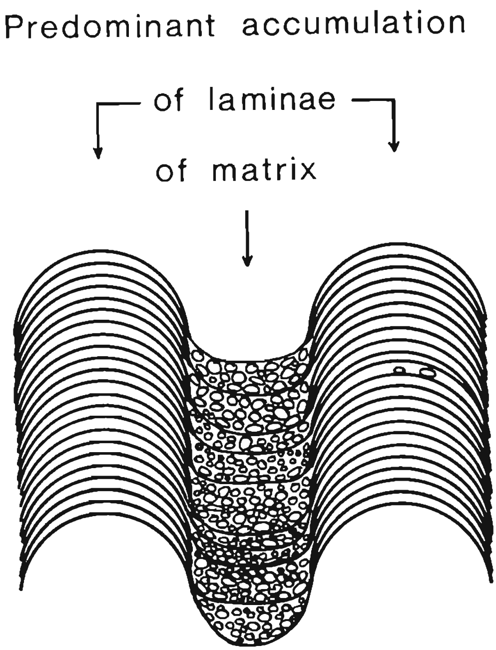


Figure 7. Formation of an Animikie stromatolite assemblage (schematic).

speak of well defined, dark organic lamellae and light, inorganic lamellae, but only of a pervasive lamination which is manifested because organic constituents periodically predominated during deposition.

In contrast, specimens with simple distinct lamination and those with pillared microstructure have laminae which are 2-4 microns thick and are devoid of structurally preserved microfossils. The rhythmic alternations are extremely fine, and their thickness is less than most of the Gunflint microfossils, except for the bacteria. This suggests the possibility that the structures are perhaps bacterial stromatolites, rather than algal stromatolites.

Let us now turn to the geometric aspects of the Animikie stromatolites. One of the overriding impressions gained from this study is that the properties of the laminae and the final gross morphology are variable over a wide range, with some forms predominant over others. Regardless of the ultimate cause of the formation of the laminae, be it algal, bacterial, or inorganic, any particular stromatolite assemblage from the Animikie can be considered as essentially composed of 2 material entities, the stromatolite _per se_, and the intervening matrix – the one presumably of organo-sedimentary origin, and the other of ultimate clastic origin (Fig. 7).

Even if one is not inclined to accept a biological role in their formation, one must admit that, under the action of waves or currents, at least 2 main mechanisms of accumulation have operated side by side to produce such a contrasting assemblage. These are (1) predominant stacking of laminae on the convexities; and (2) predominant but intermittent accumulation of rounded detrital grains in the adjoining concavities. The latter might be explained as a type of gravitational differentiation process, whereby the coarser granular material acquired maximum, stable equilibrium in the troughs. But inasmuch as granules and spheroids also are sometimes entrapped in the convexities, additional factors must play a role, e.g., the consistency of the laminar material, and hydrodynamic factors.

In view of the variable nature of the stromatolites it is desirable to determine whether a consistent relationship exists between Forms A to G on the basis of the two main types of accumulation mentioned above.

With reference to Figure 4, it seems likely that Form A is related to all the others. Form A could be transformed into Form B by steepening of the convexities, increasing the spacing, and increasing the amount of interhemispheroidal detritus. Form C could be obtained in the same manner as Form B, but with more irregular and laterally directed stacking of laminae. Form D differs from A in the wider spacing, the abundance of coarse clastic material between the columns, and the general discontinuity of the laminae across this coarse matrix, perhaps due to the high rate of accumulation or coarse grain size of the matrix. Form E is a compound form with domed laminae, individual parts of which are identical to Forms A, B, and C. It appears to have formed where sedimentation of coarse detrital material was very small for great lengths of time, thereby permitting the buildup to form with minimal interference or competition from matrix material, except in local pockets. In contrast, in Forms A to D the rate of laminar buildup only slightly exceeded that of matrix accumulation.

In Form F, as in Form E, the rate of deposition of granular material was very small for long intervals of time. The laminar stacking proceeded with pronounced prolate shapes, but with diffuse lamination, and resulted in columnar envelopes, and reduction, even elimination, of intercolumnar laminae. The preservation of the intercolumnar cavity, that is, the prevention of coalescence of the columns, may have been due to hydrodynamic factors or the milling action of well rounded grains, including oncolites.

Finally, the oncolites, constituting Form G, have laminae with centrifugal or multiradiate inheritance, developed in an encapsulating attitude, because of their mobility on the substrate under the influence of waves and currents.

One concludes that there is a genetic relationship between these arbitrarily defined forms, each of which reflects a particular local condition of accumulation. In this respect the relative rates of stacking of laminae and of concomitant matrix accumulation appear to be important in determining the lateral continuity, spacing, and perhaps overall configuration of the hemispheroids. Where growth was unrestricted, the stromatolite expanded (Form E). Where influx of matrix was abundant the development of laminae barely kept pace, and where its rate of accumulation exceeded that of the columns, as in the terminal stages of the specimen of Form D in Plate 7, Figure 1, the columns were buried. While biological factors may have been partly responsible for the development of the laminated structures, their influence over the morphology and the inheritance of the laminae cannot be determined directly.

SIBLEY STROMATOLITES

General

Stromatolites occur in porous, buff, pink and light grey dolomite beds within the area underlain by the Sibley Group (Figs. 1-2). The earliest reference to them appears to be that by Bell (1870, p. 342), who mentioned the occurrence of 'some indistinct forms resembling fossils' in limestone east of Cooke Point, on the south shore of Lake Nipigon. Wilson (1910, p. 68) later reported 'semi-translucent nodules which sometimes have the appearance of fossils' in dolomites within the valley of the Poshkokagan River, at the northwestern margin of the Sibley outcrop belt. Stromatolites were subsequently found north of the Thunder Cape map-area (Tanton, 1931, p. 56), but exact localities were not given, and the forms were considered to be of no value for purposes of age correlation. More recently, Roscoe (1967, p. 211) commented on the discovery of copper mineralization in stromatolitic units of the Sibley. These structures have never been described or illustrated.

Collections of stromatolites were made at several localities west of Nipigon (Fig. 8). Outcrops are generally poor, and no good section is exposed in the Disraeli Lake-Spruce River area. From drill records in the Disraeli Lake area (Phelps Dodge Corporation of Canada, Disraeli Lake Hole No. 2A; located about halfway between localities 79193 and 79195 in Fig. 8) it appears that the Sibley here has at least two major zones of stromatolitic dolomite, one exposed at surface, and another 10-foot (3 m) zone 240 feet (73 m) below the surface (J.M. Franklin, pers. comm., 1967).

Classification

Compared to the Gunflint forms, the specimens from the Sibley are much more readily placed in an orthodox stromatolite classification. All the forms in the present collections can be assigned to the group Conophyton

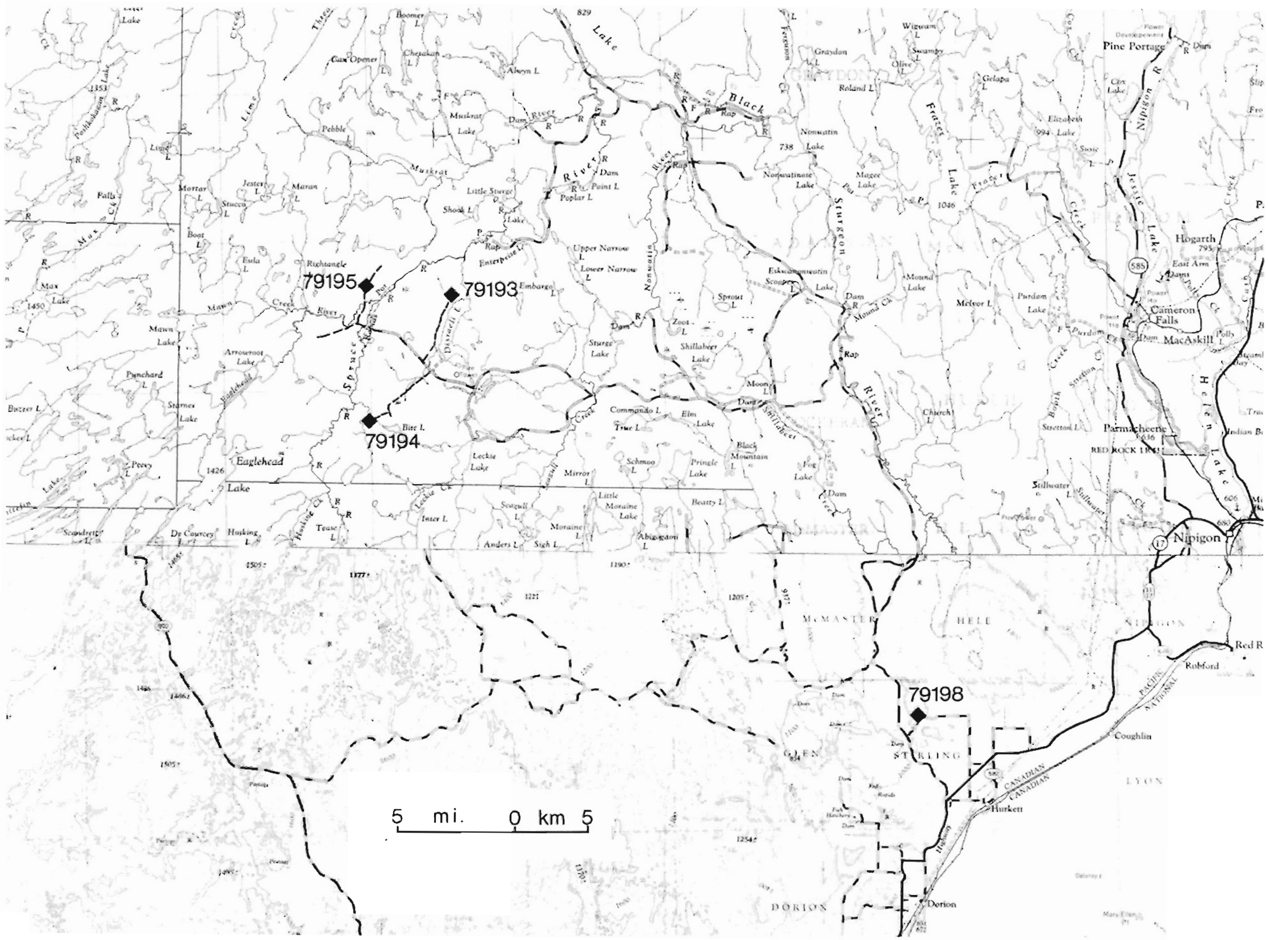


Figure 8. Map of the area west of Nipigon, showing access routes to stromatolites of the Sibley Group (G.S.C. localities 79193, 79194, 79195, and 79198).

Maslov (emend. Komar, Raaben, and Semikhatov, 1965). The structures are heavily dolomitized, and original microstructure of the laminae is not too well preserved.

Based on gross morphology, two main types of Conophyton are distinguishable: those with subcircular to elliptical plan outline (cross-section), and those with dentate to polygonal plan outline. The differences between them appear to be a function of the crowding of the columns.

The most comprehensive study of the group Conophyton is that of Komar, Raaben, and Semikhatov (1965). Not only do they provide a review of the literature on Conophyton up to 1965, and a thorough discussion of characteristic features, but they also, for the first time, established a basis for quantitative biometric studies which allowed them to recognize 7 distinct forms. Moreover, they discussed the stratigraphic significance and evolutionary trends. As emended by these authors, the diagnosis of the group Conophyton can be summarized as follows:

> Non-branching, columnar stromatolite. Columns without walls, subcylindrical, with straight axes, usually vertical to steeply inclined and always parallel to subparallel; lateral surface of columns smooth to ragged, some with mantle of distinct material; size of columns from several centimeters to several metres or more in diameter, and up to several tens of metres in height. Laminae conical to subconical, apex pointing upward, generally thickened in apical part to form an axial zone, but outside axial zone laminae are even; plan outlines are circular, oval, elliptical, lanceolate, polygonal, dentate; some with radial ribs. Microstructure of laminae characterized by light and dark lamellae with geometric regularity, light ones homogeneous, dark ones with varying internal structure.

As a basis for distinction of forms within the group Conophyton, Komar, Raaben, and Semikhatov (1965, p. 22) used the appearance of the microstructure. According to these authors, the microstructure is consistent within a single column, as well as in various specimens of the same form species from geographically widely separated regions. Their empirical studies, furthermore, apparently show particular forms to be stratigraphically restricted, and therefore of use in interbasinal correlation. The microstructure is determined from the appearance and relationship of the dark and light lamellae 'microlayers', that is, the shape and size of the dark lamellae with respect to the light ones. Three types and 7 subtypes were observed (Fig. 9).

The 7 forms are also differentiated quantitatively by biometric analysis, which includes measurements of the following characteristics:

MICROSTRUCTURES

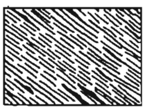
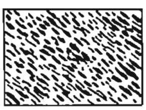
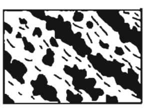
TYPE		Subtype	*Form*
RIBBONED		fragmentary - ribboned	*C. cylindricus*
		uniformly wavy-ribboned	*C. metula*
		non-uniformly ribboned	*C. circulus*
STRIATED		linearly striated	*C. garganicus*
		irregularly striated	*C. miloradoviči*
LUMPY		fragmentary - lumpy	*C. lituus*
		irregularly lumpy	*C. baculus*

Figure 9. Types and subtypes of microstructures of *Conophyton*, and corresponding from species, as established by Komar, Raaben, and Semikhatov (1965, p. 22) for specimens from the Riphean of the U.S.S.R.

1) thickness of light (L_1) and dark (L_2) lamellae

2) ratio of thicknesses of dark and light lamellae for each pair of adjacent lamellae (L_2/L_1)

3) coefficient of thickening of the [light] lamellae

$$\left(\frac{\text{L in axial area}}{\text{L outside axial area}} \right)$$

4) angle at the top in the axial zone

$$\left(\frac{\alpha}{2} = \tan^{-1} \left[1/2 \; \frac{\text{diameter of axial zone}}{L_1 \text{ in axial area}} \right] \right)$$

5) diameter of the axial zone

Judging from the data presented by Komar, Raaben, and Semikhatov (1965 , Figs. 25-29), it would seem that items 3 and 4 in the above list are much less satisfactory for differentiating the forms than are the other items. In any case, the different forms are primarily identified by their respective diagnostic microstructure (Fig. 9).

Where laminar microstructure is preserved in the specimens from the Sibley Group, the closest resemblance is with the characteristics given for Conophyton garganicus Korolyuk (emend. Komar, Raaben, and Semikhatov, 1965, p. 42); the Sibley specimens are here referred to C., cf. C. garganicus.

Conophyton, cf. C. garganicus

Plates 16-22

The structures differ somewhat in morphology from one locality to the next; however, according to Komar, Raaben, and Semikhatov (1965, pp. 20, 22, 55), gross morphology and shape of laminae of Conophyton are not of diagnostic value. The pillars are vertical, parallel, cylindrical to prismatic, tightly to loosely packed, 2-10 cm in diameter (averaging about 6 cm), and are 50 cm or more high. Spacing between columns varies from 0 to 15 cm. Plan outlines are variably subcircular, elliptical, lanceolate, polygonal, and dentate. Apical angles of the stacked conical laminae lie between 30° and 80°, with most being between 40° and 60°. Axial zones are narrow, 1 to 2 mm across (Pl. 20, Fig. 2); radial ribs are present, and vary in number from 0 to 12 or more (Pl. 20, Fig. 1; Pl. 22). The dentate to polygonal outlines and the abundance of radial ribs are related to the packing, prevailing where spacing between columns is tight. Where spacing is more loosely developed the plan outlines are more rounded, and ribs tend to be reduced or absent. In sections where the outline is elliptical to lanceolate the major diameters exhibit a preferred alignment over a large area (Pl. 21).

The microstructure, where preserved, is linearly striated (Pl. 18, Fig. 3; Pl. 19), with the light lamellae 0.05 to 0.7 mm thick, and the dark ones 0.05 to 0.5 mm thick. Biometric study of specimens in the collection is difficult because of the high degree of recrystallization of most of the material, and only those from GSC locality 79193 were suitable for measuring lamellae thicknesses.

Measurements on specimens of the Sibley Conophyton are numerically somewhat different from those obtained with the Riphean specimens of C. garganicus. One is the generally smaller size; the Russian forms are reported to be 0.2 to 1.5 m across and up to 12 to 15 m high. Another is the greater range of thicknesses of both the light and dark lamellae, as compared to the Riphean forms, whose lamellae are generally less than 0.25 mm thick. A third difference is the width of the axial zones, whose range is given as 2.4 to 9.7 mm by Komar, Raaben, and Semikhatov (1965, p. 43); in the Sibley specimens they fall below this range even though of all the forms of Conophyton, C. garganicus has the thinnest axial zones (Komar, Raaben, and Semikhatov, 1965, Fig. 29). Yet another distinction is the larger number of radial ribs, reaching 12 or more, rather than only 4 or 6 as in the Riphean forms of Conophyton.

Discussion

Although the choice for the basis of classifying the forms (form species) may be debated, there can be no doubt that the presence of the group (form genus) Conophyton in the Sibley Group is established. In view of the apparent success of Soviet geologists in developing a stromatolite stratigraphy, including Conophyton, one is obliged to find out where the Sibley stromatolites would fit in their succession, and to test the validity of the scheme.

As shown in the descriptive section, the Sibley forms come closest to C. garganicus. In the Soviet Union C. garganicus was found to be essentially restricted to the Lower and Middle Riphean (Komar, Raaben, and Semikhatov, 1965, p. 59), which encompasses the time interval of about 1,600 m.y.-950 m.y. ago. The Sibley Group is dated as Helikian, which covers about the same interval. The new data obtained in the present study, therefore, are not in conflict with previously established ranges of this form, nor, for that matter, of C. cylindricus, C. metula, C. garganicus nordicus, and C. lituus.

According to the findings of Komar, Raaben, and Semikhatov (1965, p. 58), it appears that Conophyton is a genuine index fossil to the Precambrian, and that it is especially widely distributed and abundant in the Lower and Middle Riphean (Helikian). We may thus have in Conophyton a structure which not only characterizes the Proterozoic paleontologically, but is also readily identifiable.

CONCLUSION

Stromatolites are present in the Animikie and Sibley Groups. Those in the Animikie exhibit great variety in shape and are characterized by laminae which are predominantly continuous across a bioherm. Their spacing, size, inheritance, and other properties appear to have been influenced by local environmental factors, giving an indication of the different relative rates or amounts of accumulation of laminae and matrix. The shapes are gradational into one another, and their codification with respect to already named forms in an orthodox binomial classification was not possible except for the basic Form A (Stratifera; LLH-C) and the oncolite, Form G (Osagia; SS). New group and form names may have to be applied to accommodate the others. However, the possibility that the basis for the classification itself may have to be modified somewhat also exists. For example, the distinction between lamellar and columnar stromatolite types may actually be of minor importance, as this may depend only on the fact that in one case contemporaneous intermound sedimentation took place, whereas in the other it did not.

The samples studied, while providing extensive evidence of a diverse contemporary Aphebian microflora, have not afforded unequivocal evidence of the biological control over the buildup of the stromatolites themselves. A comparison of the Animikie stromatolites with those from other Aphebian assemblages with regard to correlation and zonation is not yet possible.

On the other hand, the Sibley stromatolites can be codified within the domain of a binomial classification. Their properties are close to those of Conophyton garganicus, and their Helikian age is in agreement with the biostratigraphic scheme developed for the Riphean conophytons.

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PLATES

The magnification of each photograph or group of photographs is indicated graphically, usually by a graduated 20 mm scale.

Stage co-ordinates are given with reference to GSC microscope No. 67-98, a Leitz ORTHOLUX microscope with biological stage. The slides are oriented with the catalogue number on the observer's right; the stage setting is 76 mm for all slides, regardless of size.

PLATE 1

Form A

Stratifera biwabikensis (Grout and Broderick)

Polished vertical section of a lamellar stromatolite (Stratifera) with a high degree of inheritance of closely spaced laminae, producing the columnar aspect. The columns are developed partly on a nodular growth form at the lower right, which can be assigned to Colleniella Korolyuk or Cryptozoon Hall.

The laminae are generally continuous across the slab, but some of them are broken at the concave portions, in the troughs of the laminar surfaces. The microstructure is of simple, alternating light and dark layers, supplemented in the light lamellae by minute pillar-like microstructures perpendicular to the lamination. The pockets between the columns are filled with spheroids and rounded detritus.

The specimen, preserved in brown chert, is from the basal 1 meter of the Gunflint Formation, at the N bank of the Whitefish River, 2.6 km (1.6 miles) WSW of Nolalu, Ontario.

GSC locality 78410. GSC type 24534. GSC photo 200907-E.

1

PLATE 2

Form B

Gymnosolen(?) ferrata (Grout and Broderick)

1. Polished vertical section of an assemblage of actively branching, subvertical columns with close spacing. Most of the laminae are continuous across the columns. Shaggy margins on the columns are produced where several of the laminae merge to form the connecting bridge between adjoining columns. The intercolumn pockets are filled with spheroids and granules. Note the type of branching in the columns at the right, which is indistinguishable from that found in Gymnosolen.

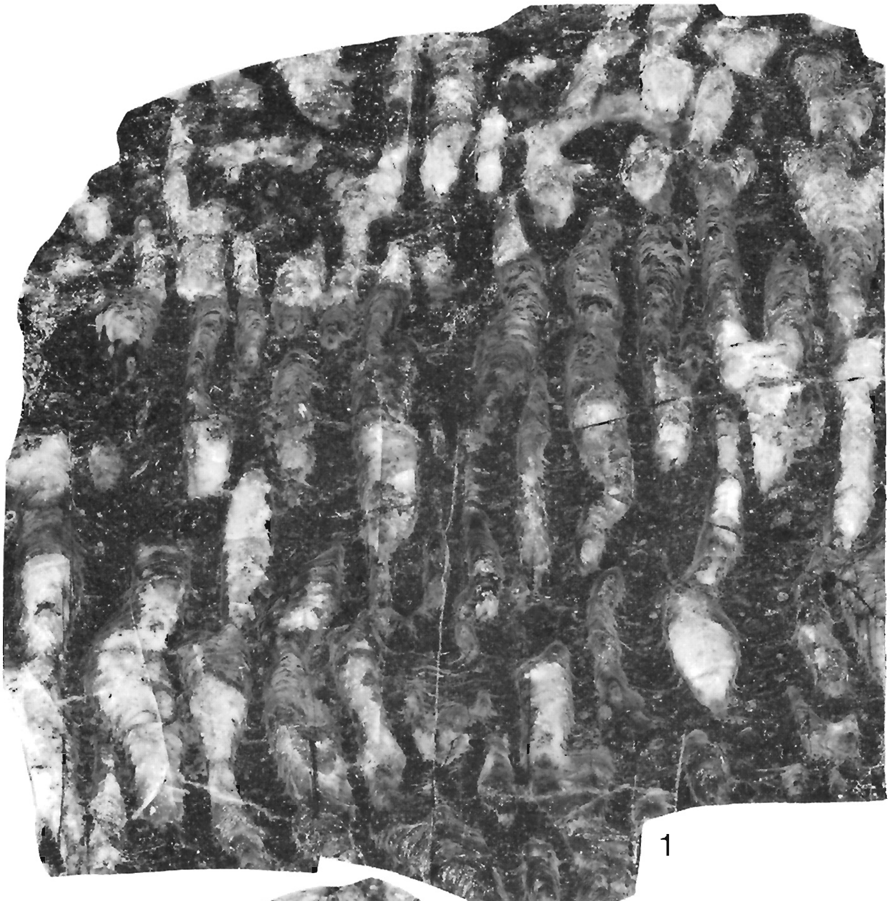
   The specimen, preserved in jasper, was collected loose from the roadside dump of the Mary Ellen Mine, 1.6 km (1 mile) W. of Biwabik, Minnesota. It is presumably derived from the upper stromatolite horizon near the middle of the Biwabik Formation. The structures can be identified with the form named Collenia(?) ferrata by Grout and Broderick (1919a).

   GSC type 24535. GSC photo 200744-C.

2. Polished horizontal section of Form B from the same locality as in Figure 1. Note the close spacing, the rounded to lobate cross-sections of the columns, and the confluence of some of the laminae.

   GSC type 24536. GSC photo 200744-F.

2



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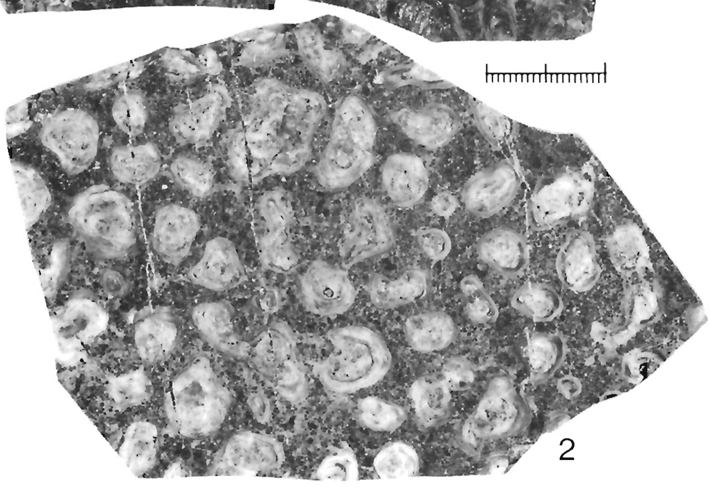

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PLATE 3

Form C

Polished vertical section of a mass of complex, branching columnar stromatolites in jasper. As in Form B, many of the laminae are continuous across a number of columns. The columns at the lower left of the photograph are more regular, subvertical, with the Gymnosolen-type branching. These can be referred to Form B. In the rest of the slab the columns are very irregular, with many bulges and recumbent to flat branches, and the pattern resembles that for Tungussia Semikhatov. This slab makes it obvious that Forms B and C can grade into each other.

In some places, as at right center, the laminae are sharply bent or reentrant, which suggests possible folding during a plastic, postdepositional stage, before lithification.

The slab is from the upper stromatolite horizon, near the middle of the Gunflint Formation, from an outcrop beside the jeep trail on the W. side of Mink Mountain, 7.3 km (4.6 miles) W. of Mackies, Ontario.

GSC locality 82436. GSC type 24537. GSC photo 200907-G.

3

PLATE 4

Form C

Polished vertical section of another block with Form C, from the same locality as that in Plate 3. In this enlarged view the continuous nature of the laminae through the columns, and the concentration of the spheroids in inter-mound troughs are evident.

Of interest is also the vertical orientation of many of the large oblong clasts between the columns.

GSC locality 82436. GSC type 24538. GSC photo 200907-K.

4

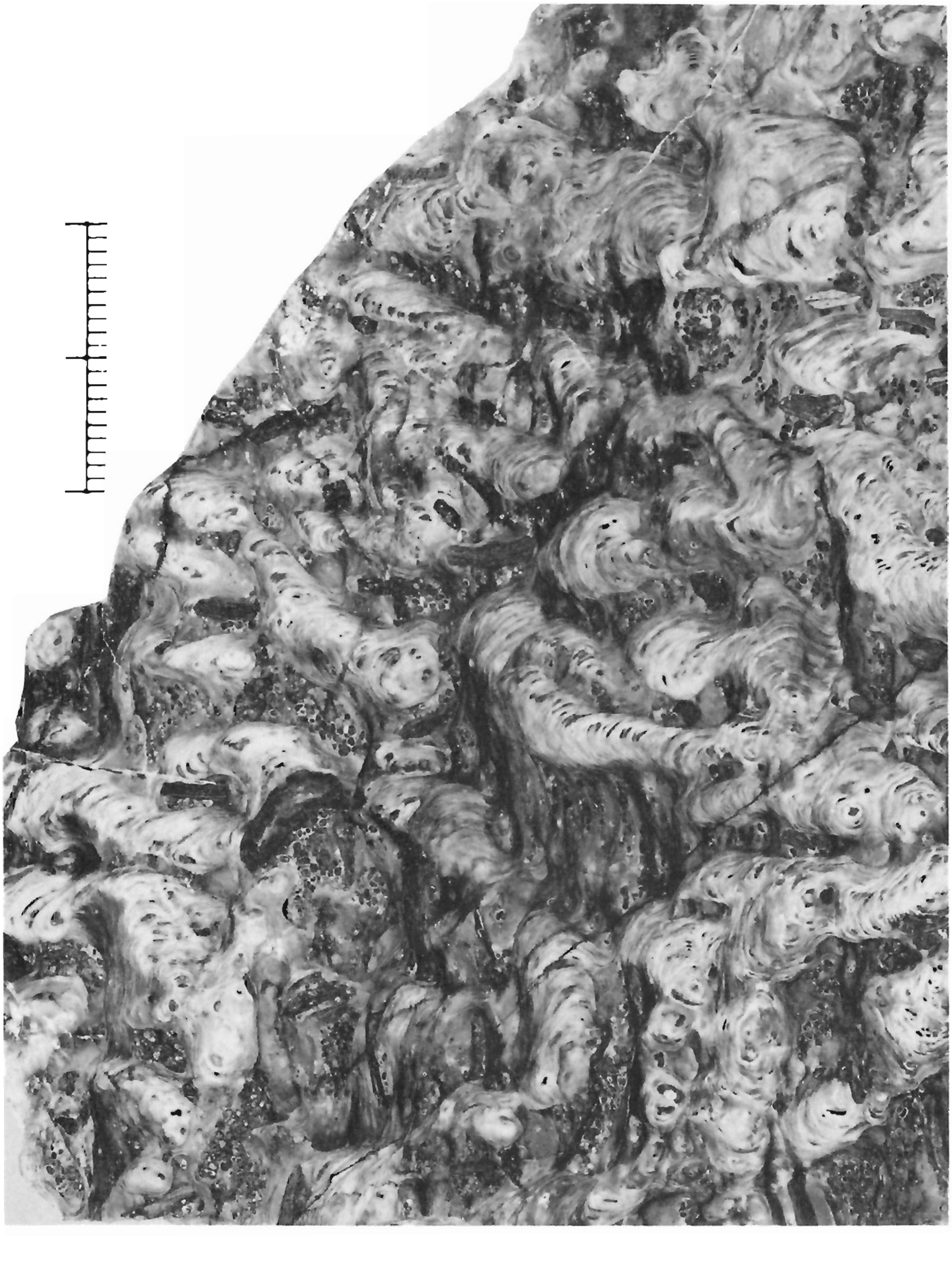

PLATE 5

Form C

1. Vertical thin section of Form C in plain, transmitted light. The photograph shows the simple, distinct, and continuous nature of the light and dark lamellae, and the accumulation of spheroids and detrital particles in the areas between the columns. The dark lamellae are outlined by hematite and present a somewhat knotty appearance in a patch where many of the 2-4μ laminae are preserved.

   The specimen is from the same locality as that in Plate 3.

   GSC locality 82436. GSC type 24539. GSC photo 200907-I.

2. Horizontal thin section of Form C in plain, transmitted light, illustrating the rounded, lobate, and vermiculate nature of the cross-section. The structure at right shows that the branching not only takes place in an upward direction, but also laterally. The section cuts obliquely across an inclined column at the centre. The oolites-oncolites and the detritus are concentrated in the troughs.

   The specimen is from the same locality as that in Plate 3.

   GSC locality 82436. GSC type 24540. GSC photo 200907-H.

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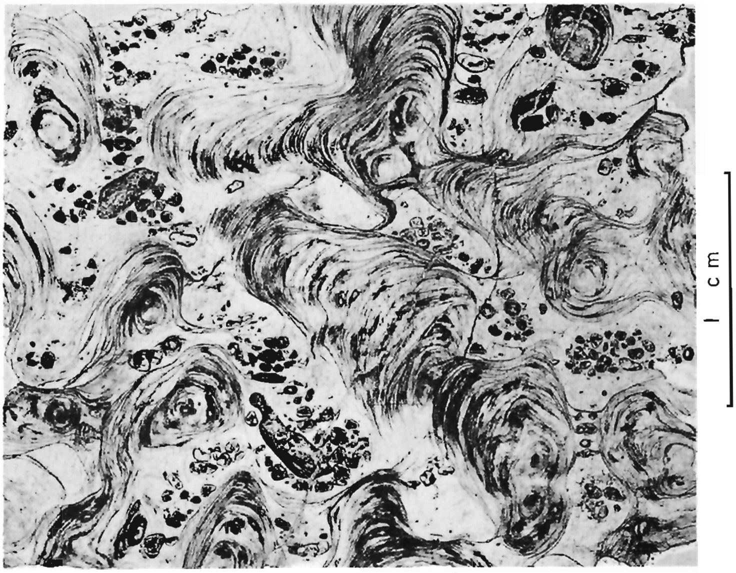

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PLATE 6

Two varieties of simple microstructure; Forms C and F

1. Vertical thin section of simple, distinct microstructure of Form C, in plain, transmitted light. The photograph is an enlarged view of a portion of the upper left column in Plate 5, Figure 1, and shows several of the patches where dark lamellae predominate over the light ones. Stage co-ordinates 101.6/31.0.

   GSC locality 82436. GSC type 24539. GSC photo 200931-H.

2. Vertical thin section in plain, transmitted light showing the distinct 2-4 micron laminae under high magnification. The view is from the same general area as in Figure 1. The dark lamellae are of limonite and hematite, and the light ones of chalcedony. Stage co-ordinates 95.7/29.2.

   GSC locality 82436. GSC type 24539. GSC photo 200931-I.

3. Thin section of simple, diffuse microstructure in Form F, in plain, transmitted light. The dark lamination is due to concentrations of organic matter, including structurally preserved microfossils, which are illustrated in Figure 4 to the right. An oncolite (Form G, Osagia Twenhofel) is embedded at the right. Compare this microstructure with the simple distinct type in Figure 1 above. Stage co-ordinates 100.5/36.3.

   GSC locality 78418b. GSC type 24551. GSC photo 200931-J.

4. A portion of a dark lamination of Figure 3 under high magnification, illustrating the absence of the 2-4 micron laminae and the presence of a hash of microfossils, chiefly the spheroids Huroniospora and the filaments Gunflintia. Stage co-ordinates 97.7/40.6.

   GSC locality 78418b. GSC type 24551. GSC photo 200931-K.

6

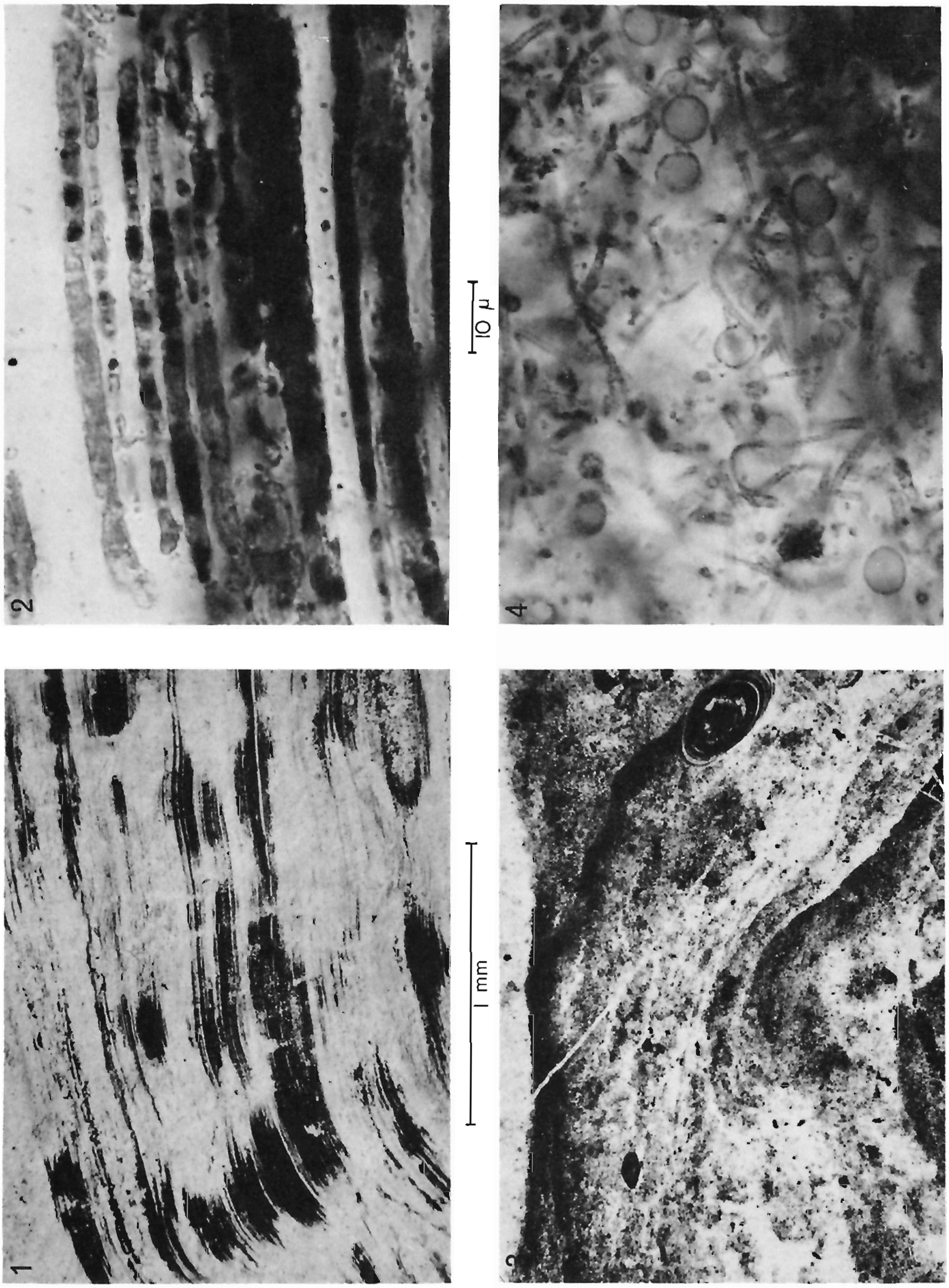


PLATE 7

Form D

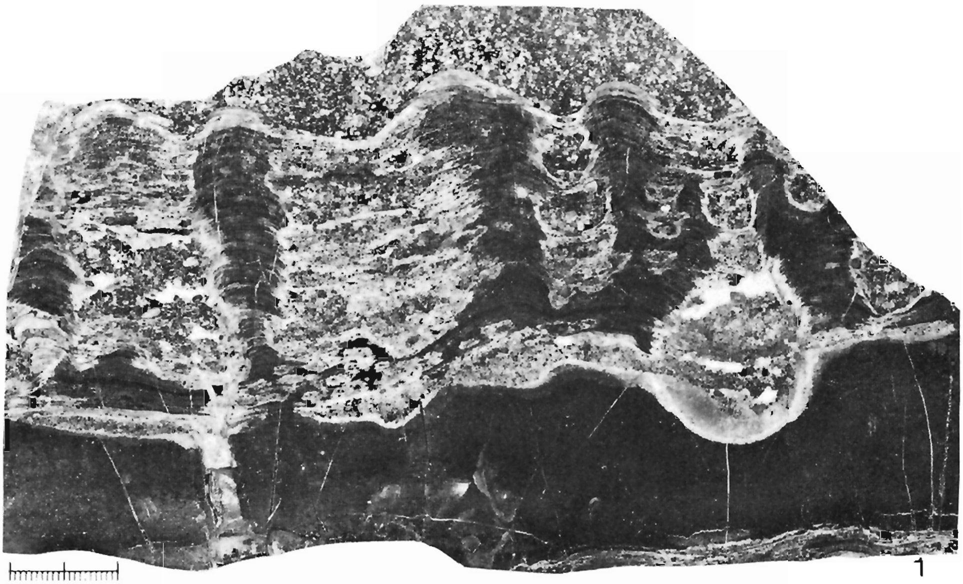
1. Vertical section of columnar stromatolites of Form D. They are preserved in black chert rich in organic compounds, but are peripherally discoloured. The laminae are generally oblate and are bent sharply downward at the margins, where most of them terminate; only a few pass across the intermound areas, which are filled with quartz and silicate detritus. The final microtopographic profile on the structures is emphasized by the textural contrast of the stromatolitic and nonstromatolite lithologies. For illustrations of the microstructure see Plate 8.

   The specimen is from the basal 1 metre of the Gunflint Formation at Winston Point, 9 km (5.5 miles) W. of Schreiber, Ontario (see Fig. 6 for exact location).

   GSC locality 78418. GSC type 24541. GSC photo 200744-B.

2. Horizontal section made from the same slab as that in Figure 1 above, showing the rounded cross-sections, close to open spacing, and the peripheral bleaching effects of the black columns. The section was taken at about 2/3 the height of the columns.

   GSC locality 78418. GSC type 24542. GSC photo 200744-H.



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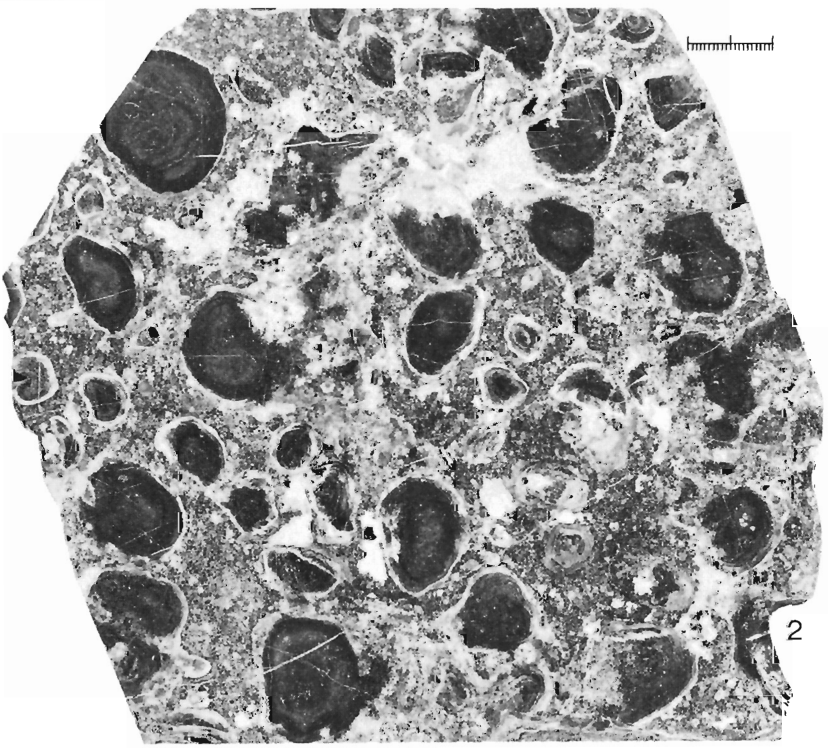


2

PLATE 8

Form D

1. Vertical thin section of Form D in plain, transmitted light. The specimen is from the same slab as that in Plate 7, and illustrates the microstructure of the laminae, the irregular lateral boundary, the peripheral bleaching effect, and the relation of the columns to the arenitic detritus. The pillared microstructure in the light lamellae is well developed in most parts of the columns. Oolites-oncolites are incorporated at the top of the column on the right. The black material is organic. This microstructure also occurs, in a somewhat modified form, in the specimen illustrated in Plate 1.

   GSC locality 78418. GSC type 24541a. GSC photo 200907-D.

2. Vertical thin section in plain, transmitted light. The photo shows an enlarged portion of the pillar-like structures visible in Figure 1. These are columnar 'microstromatolites', with microlamellae 2 to 5 microns in thickness. The photograph is of another thin section from the same slab as that in Plate 7. Stage co-ordinates 107.2/31.0.

   GSC locality 78418. GSC type 24541b. GSC photo 200906-B.

3. Vertical thin section, in plain, transmitted light. Another view in the same slide as adjoining Figure 2, showing branching in the columnar 'microstromatolite', and somewhat more distinct convex microlamellae. Stage co-ordinates 100.5/39.9.

   GSC locality 78418. GSC type 24541b. GSC photo 200906-D.

8

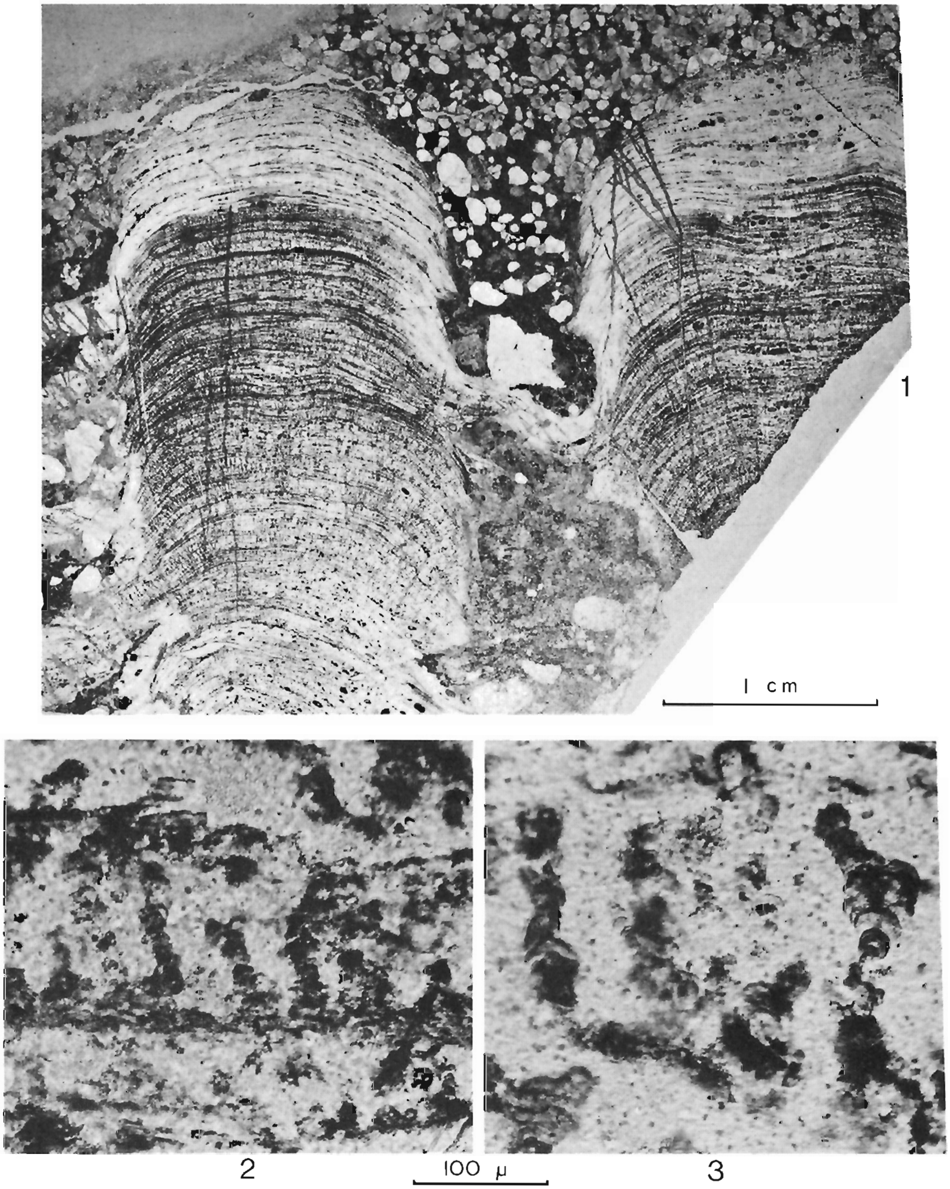


PLATE 9

Form E

Polished vertical section across a complex nodular stromatolite assemblage, from the basal 1 metre of the Gunflint Formation, at the N. bank of the Whitefish River, 2.6 km (1.6 miles) WSW. of Nolalu, Ontario. The structure is made up of domed, corrugated laminations and can be assigned to Cryptozoon Hall or Colleniella Korolyuk. The laminae have varying degrees of inheritance, and present different aspects in different parts of the structure. Near the centre they are very irregular, and that part of the bioherm could go under the name of Irregularia Korolyuk. This portion also resembles a 'crowded' Form C. In the outer portions, especially at top left, the pattern is very regular and is like that of Stratifera Korolyuk, and even approaches the configuration of Form B. The troughs of the corrugations are filled with spheroids and granules. As with the specimen illustrated in Plate 3, two forms of stromatolites seem to be gradational into each other. For illustration of the microstructure see Plate 10, Figure 1, and for a view of the weathered upper surface see Plate 10, Figure 3.

GSC locality 78410. GSC type 24543. GSC photo 200457-J.

9

PLATE 10

Forms E and G

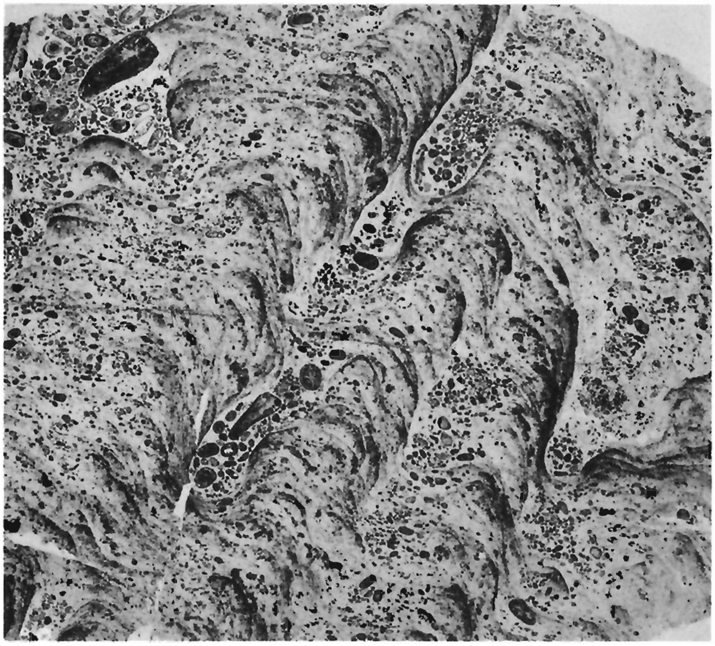
1. Vertical thin section, in plain, transmitted light, from the structure in Plate 9, illustrating the nature of the dark diffuse, organic laminations, their shape and continuity, and the pocket accumulations of Form G oncolites (Osagia Twenhofel). The oncolites are also abundant along the laminations in the columns, but are small compared to those in the pockets. The dark laminations are replete with microfossils.

   GSC locality 78410. GSC type 24544a. GSC photo 200743-D.

2. Subvertical thin section, in plain, transmitted light, from an encrusting reef-like mass of stromatolites in black chert. The view demonstrates an irregular, vermiculate nature of the columns. In some parts, as at top right and at centre right, the diffuse laminae are not continuous across the intercolumn pockets, and the pattern is transitional to that of Form F. The dark portions bear abundant microfossils.

   Westernmost occurrence of stromatolites at Winston Point, 9 km (5.5 miles) W. of Schreiber, Ontario. (See Fig. 6 for exact location.)

   GSC locality 78418a. GSC type 24381a. GSC photo 200743-F.



1 cm

1

2

PLATE 11

Form E

1. Polished vertical section across part of a complex nodular stromatolite assemblage resembling Cryptozoon Hall. The domed laminae are continuous throughout the structure, and locally show both low and high degrees of inheritance, forming Irregularia- and Stratifera-type patterns. The mound is preserved in grey, green, and black chert. Its size is indicated by the somewhat obscured 40-mm scale along the top margin.

   The specimen is from the lower part of the Gunflint in the road cut on the N. side of Highway 590, about 100 m W. of the intersection with Highways 11 and 17, 1.2 km WNW. of Kakabeka Falls, Ontario.

   GSC locality 78412. GSC type 24545. GSC photo 200447-B.

2. Vertical thin section, in plain, transmitted light, showing basal contact of a stromatolite bioherm with a greenstone boulder. The columns at the base have an aspect more characteristic of Form F than of Form E. The dark, diffuse lamellae are full of microfossils, particularly Huroniospora Barghoorn. Beach outcrop of basal Gunflint Formation, opposite small island in Lake Superior, 6.4 km (4 miles) W. of Schreiber, Ontario.

   GSC locality 78417. GSC type 24546. GSC photo 200450-C.

3. Weathered surface view of the top of the specimen illustrated in Plate 9, showing the lobate to vermiculate patterns of the uppermost columns, which approach the configuration of Form C.

   GSC locality 78410. GSC type 24543. GSC photo 200447-C.

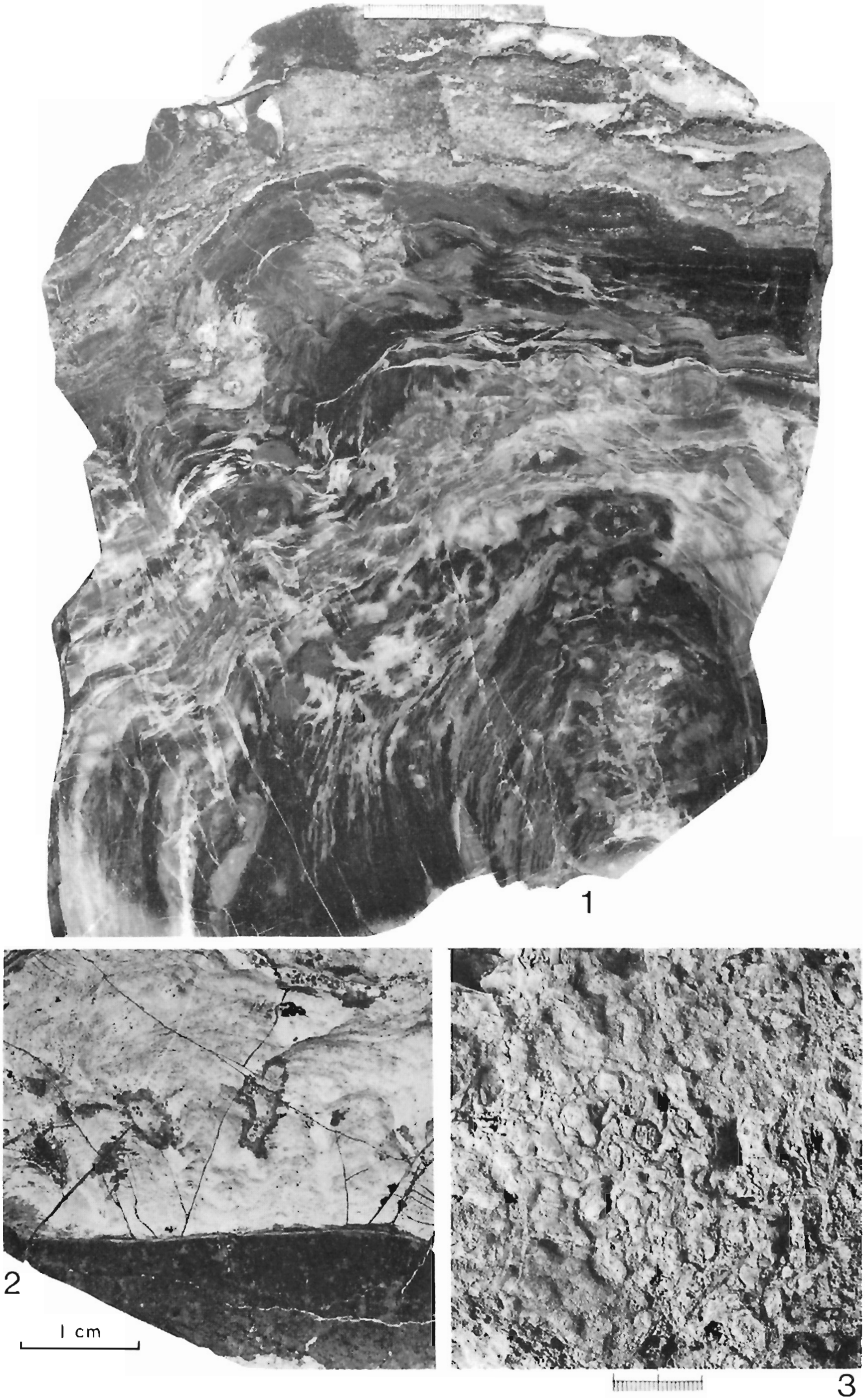

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PLATE 12

Form F

1. Polished vertical section from an encrusting, reeflike mass of very closely spaced, subparallel, branching columns. The specimen is from the Winston Point locality (see Fig. 6).

   GSC locality 78418a. GSC type 24549. GSC photo 200919-C.

2. Vertical thin section from a portion of the specimen in Figure 1 above, showing the very close spacing, diffuse lamination, branching, and the enveloping nature of the dark, organic laminations, giving a smooth, walled appearance to the columns. Rounded detritus is present in the intercolumnar space.

   GSC locality 78418a. GSC type 24549a. GSC photo 200919-A.

3. Horizontal polished section across the basal portion of an encrusting, reeflike mass, illustrating the lobate to vermiculate cross-sections of the columns and their very close spacing. The sample was obtained from a loose block at Winston Point, and was presumably derived from the basal part of the Gunflint Formation below water, off the beach.

   GSC locality 78418b. GSC type 24548. GSC photo 200919-B.

4. Near vertical, oblique polished section of Form F with large dimensions, showing very close crowding, branching, and coalescence of the columns.

   The specimen is from another large loose, angular block at Winston Point, presumably transported to the shore from the basal Gunflint below water off shore; the same block contained small encrusting specimen of Form F only centimetres away. For thin section view see Plate 13, Figure 1.

   GSC locality 78418b. GSC type 24547. GSC photo 200919-D.

12

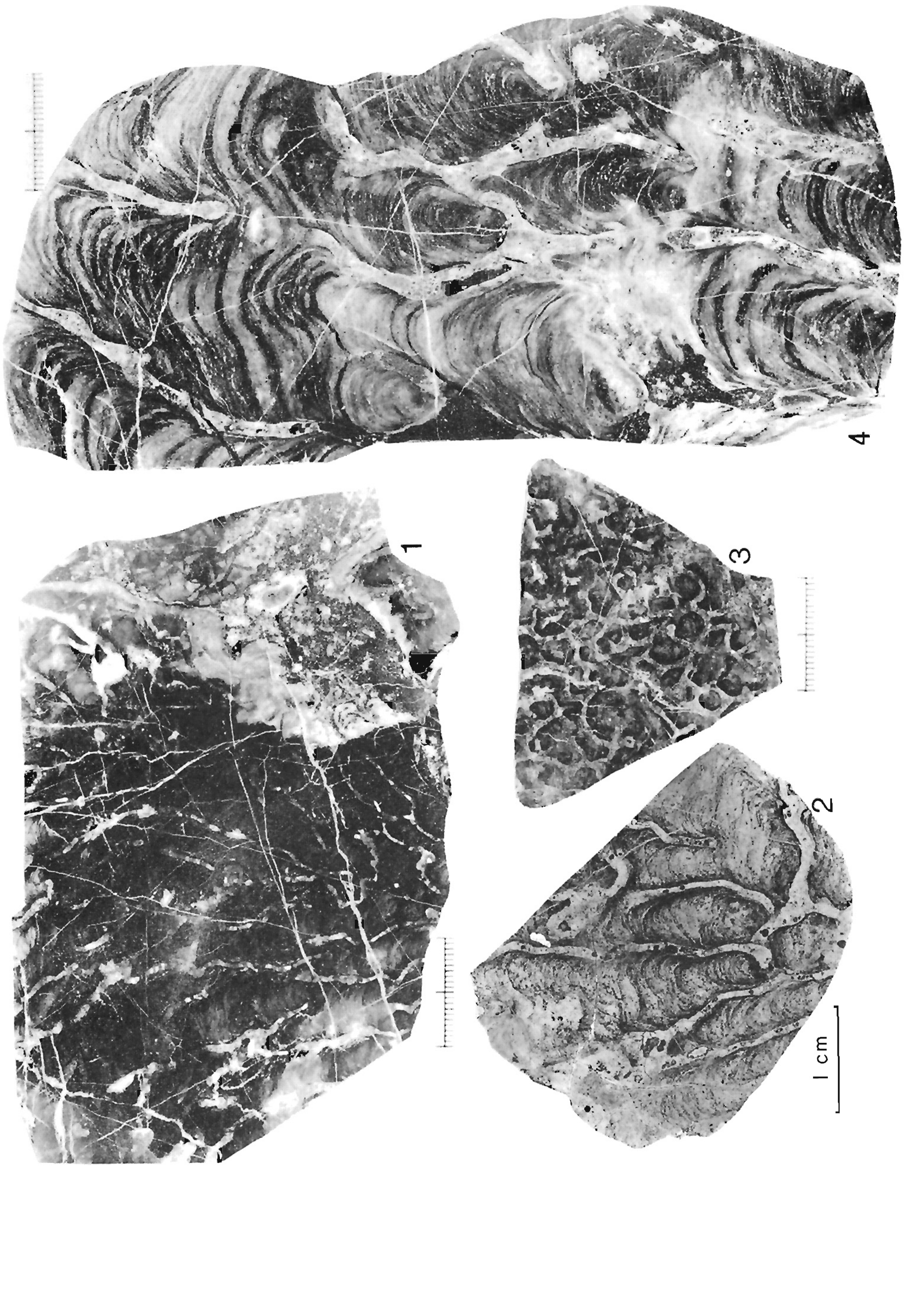


PLATE 13

Form F

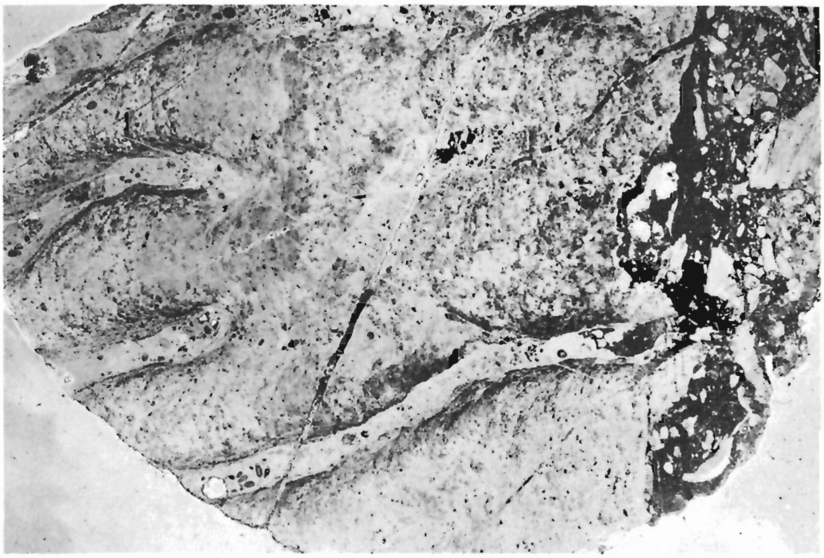
1. Vertical thin section in plain, transmitted light, of comparatively large, branching, columnar stromatolites with 'walls' and without interconnecting laminae. The pattern resembles that of Archaeozoon Matthew and Gymnosolen Steinmann. The dark lamellae are composed of organic matter and microfossils. Spheroid accumulations are predominant between the columns. Section is from the same block as that illustrated in Plate 12, Figure 4.

   GSC locality 78418b. GSC type 24547a. GSC photo 200907-B.

2. Vertical thin section in plain, transmitted light, of small specimens of Form F, showing bifurcation, coalescence, and trifurcation, and the lack of connecting laminae between the columns. The growths are encrusting a boulder of impure sandstone. Organic matter and microfossils comprise the indistinctly appearing dark lamellae.

   The sample is from another boulder at the same locality as that in Figure 1 above, and also presumably from the basal part of the Gunflint offshore.

   GSC locality 78418b. GSC type 24550. GSC photo 200907-C.



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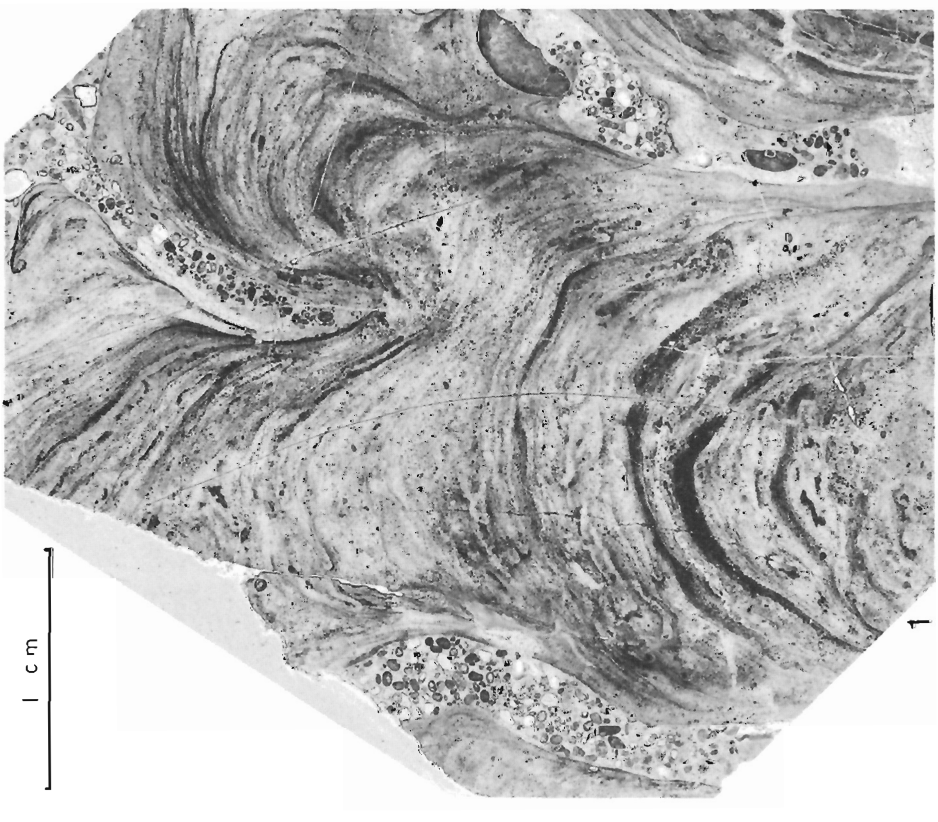


1 cm

1

PLATE 14

Form G

Osagia Twenhofel

1. View of 4 spheroids with rounded detrital nuclei and encapsulating laminae of variable thickness. The photograph is of the 4 spheroids in the upper left portion of the slide illustrated in Plate 10, Figure 1. These oncolites are of different growth durations. The one in the upper left corner is 'young', with only a thin coating; the one at the centre, which is enlarged in Figure 2 below, has many laminae and a thick coating. Stage co-ordinates 115.0/34.5.

   GSC locality 78410. GSC type 24544a. GSC photo 200931-A.

2. View of a portion of the large spheroid in Figure 1 above under higher magnification, showing the simple distinct nature of the laminae. Stage co-ordinates 115.0/34.5.

   GSC locality 78410. GSC type 24544a. GSC photo 200931-D.

3. Compound oncolite with syneresis cracks. The photograph is of the large oncolite just below and to the left of the centre of the photograph in Plate 10, Figure 1. Stage co-ordinates 106.3/26.0.

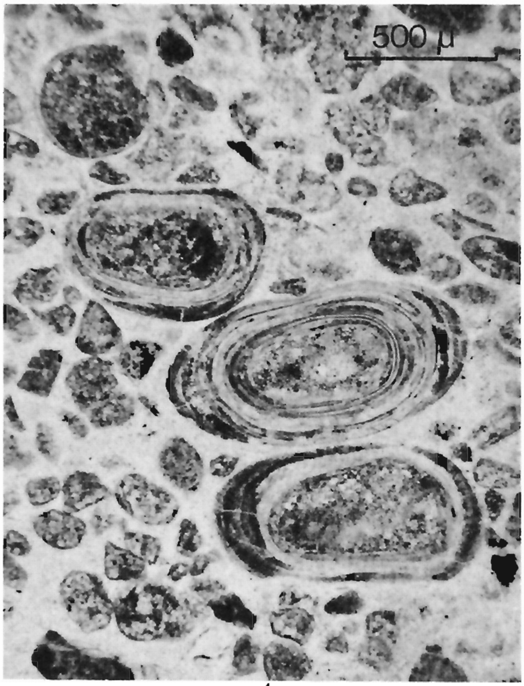
   GSC locality 78410. GSC type 24544a. GSC photo 200931-B.

4. Specimen of Form G, with incomplete encapsulation of laminae suggesting a low degree of mobility of the spheroid in its environment of growth. The photograph is of the dark grain at the right margin, just above the centre, in Plate 10, Figure 1. The grain was buried in the overturned position, but is illustrated here in its presumed growth position. Stage co-ordinates 110.0/13.9.

   GSC locality 78410. GSC type 24544a. GSC photo 200931-C.

5. Enlargement of the oncolite at the top margin above the large dark triangular clast in the upper left corner of Plate 10, Figure 1. This spheroid shows very well the uneven thicknesses and incomplete nature of the laminae, characteristics which distinguish it from an oolite. Stage co-ordinates 118.2/31.8.

   GSC locality 78410. GSC type 24544a. GSC photo 200931-E.



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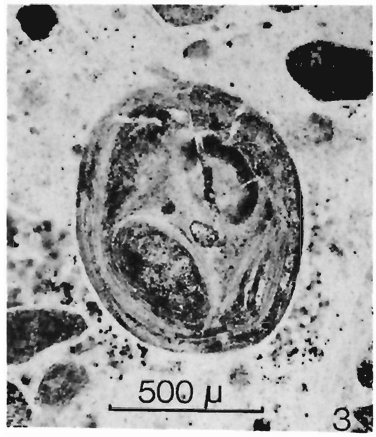

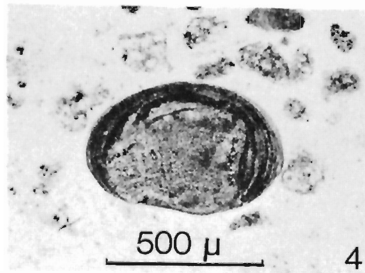

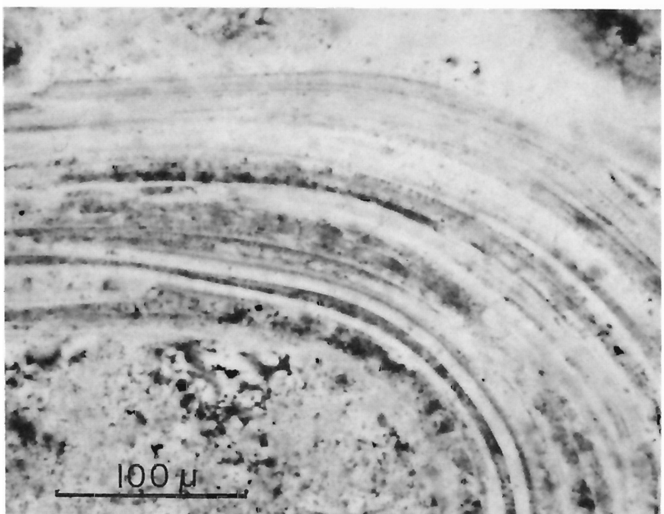

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5

PLATE 15

Form G

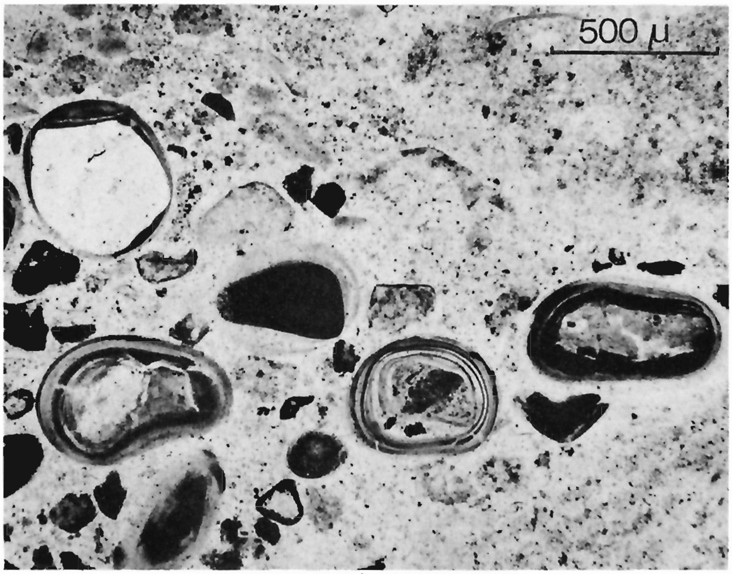
Osagia Twenhofel

1. Thin section view of a group of oncolites illustrating various phenomena, such as diversity of petrology of nucleus, thickness of laminar coating, and diagenetic effects. The light nucleus in the upper left is a quartz grain which is surrounded by a thin envelope. The other large grains show syneresis cracks, suggesting a gel-like consistency of the material originally. The large grain below and to the right of centre, which is enlarged in Figure 2 below, has a thick coat of laminae which has formed around a nucleus of chert that bears preserved microfossils.

   GSC locality 78417. GSC type 24552. GSC photo 200931-F.

2. Enlargement of a portion of the spheroid below and to the right of the centre of Figure 1 above. The laminae are simple and distinct, and incomplete near the nucleus. The nucleus is of chert with slightly degraded spheroidal and filamentous microfossils that are indistinguishable from Huroniospora and Gunflintia. It is probable that the fragment represents penecontemporaneously eroded Gunflint chert. Stage co-ordinates 111.1/21.3.

   GSC locality 78417. GSC type 24552. GSC photo 200931-G.



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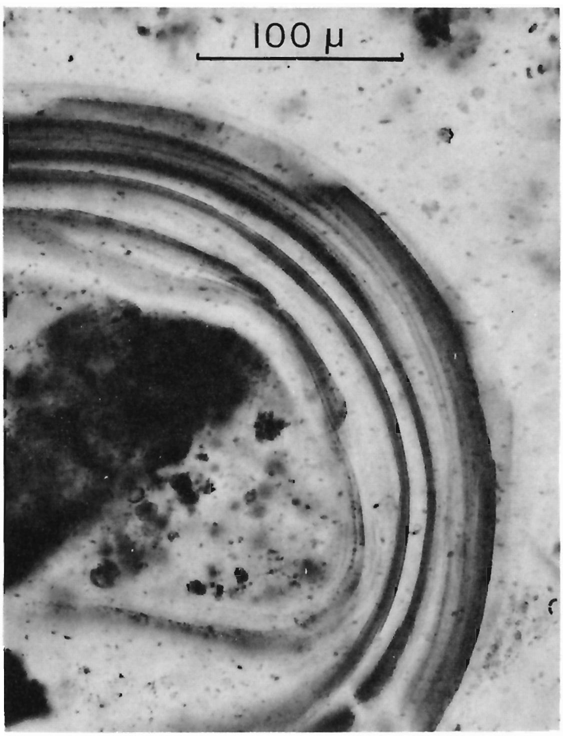

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PLATE 16

Conophyton

1. General, oblique view of a weathered, overturned block with closely packed columns of Conophyton, in dolomite of the Sibley Group, 61 km (38 miles) WNW. of Nipigon, Ontario.

   GSC locality 79195. GSC photo 133384.

2. Oblique view of a block of Conophyton columns, showing the appearance of the conical laminae. For plan and profile views of outlines of laminae see Plate 17, Figures 1 and 2. Same locality as specimen illustrated in Figure 1 of this plate.

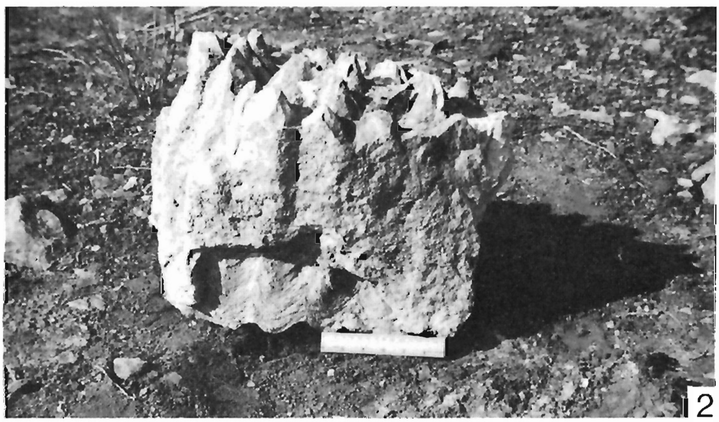
   GSC locality 79195. GSC type 24543. GSC photo 133385.

3. Lower surface view of dolomite block with closely packed columns of Conophyton exhibiting polygonal to dentate plan outlines of laminae. Sibley Group, 9.5 km (6 miles) S. of locality of Figures 1 and 2 of this plate.

   GSC locality 79194. GSC photo 133381.

16

1



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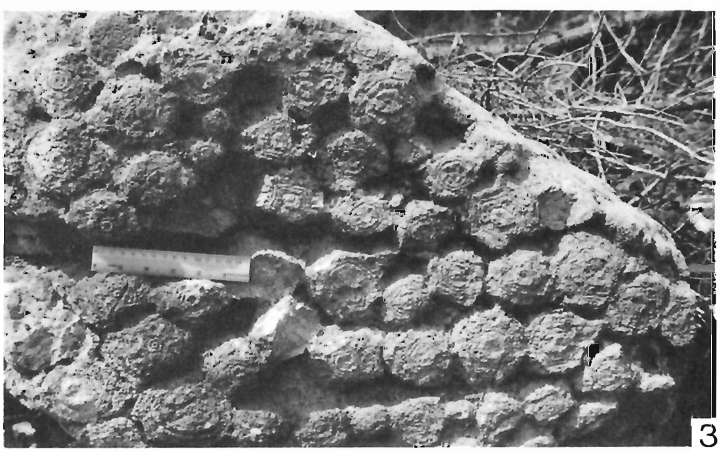


3

PLATE 17

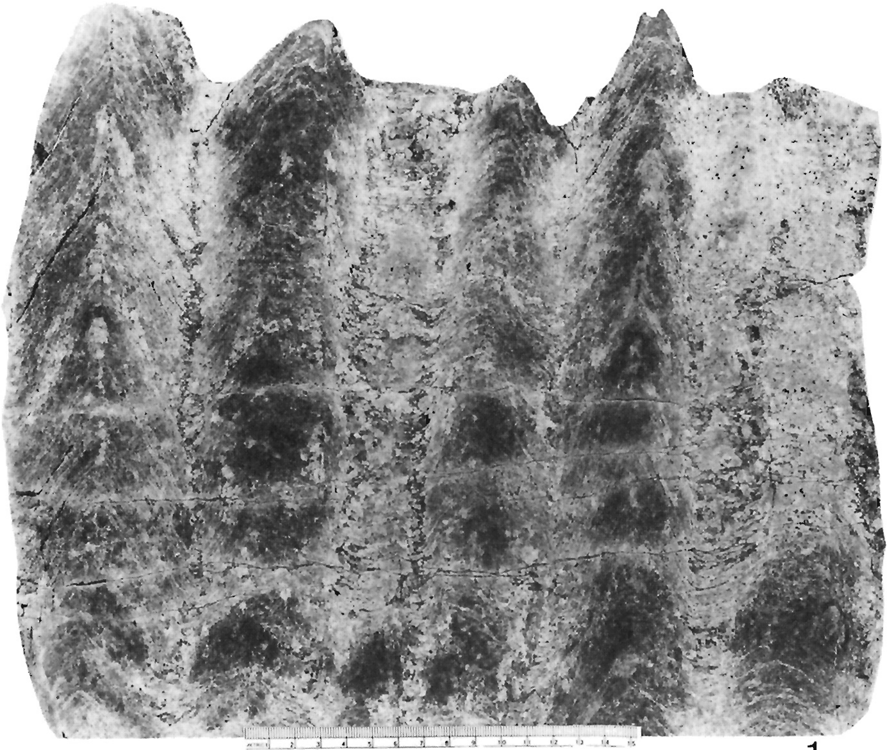
Conophyton

1. A vertical section of the specimen illustrated in Plate 16, Figure 2, showing the angulate profile of the laminae. The apical angle averages 60°. The first and fourth columns from the left are axially sectioned, and reveal the narrow (here 1.5 mm) axial zone, a diagnostic characteristic of the stromatolite group Conophyton. The connecting bridges in the more coarsely crystalline matrix between the 2nd and 3rd and 4th and 5th columns from the left are obtusely concave.

   GSC locality 79195. GSC type 24543a. GSC photo 200459-D.

2. Horizontal section complementing Figure 1 of this plate and showing subcircular, polygonal, slightly dentate, and lobate plan outlines of laminae. A slight preferred orientation of the longer axes is evident. The darker colour of the columns is due to the fine grain size, and to microstructural features not present in the coarse and more porous matrix. The columns range from 2 to 6.5 cm in width.

   GSC locality 79195. GSC type 24543b. GSC photo 200459-G.



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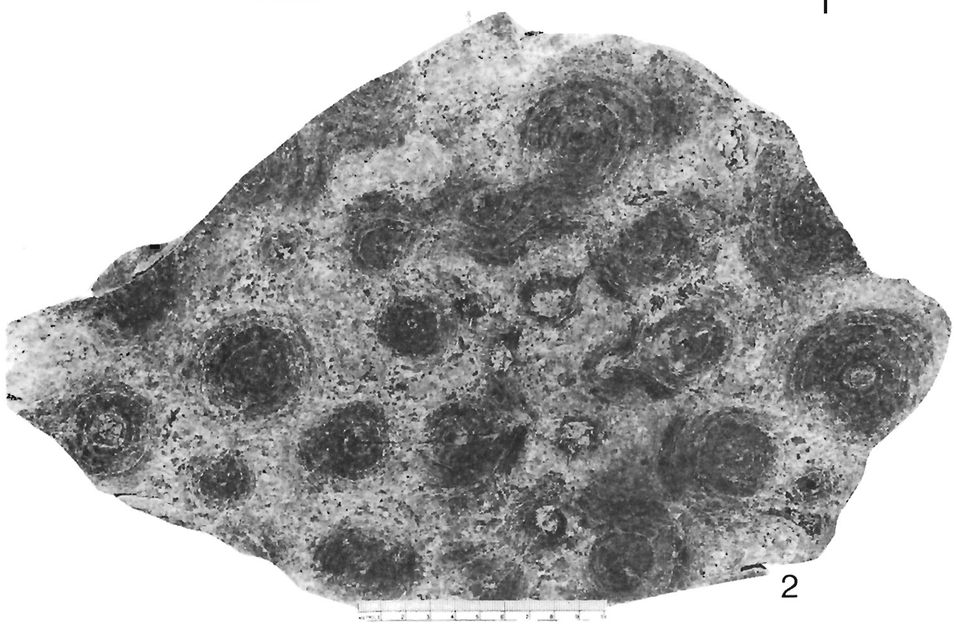


2

PLATE 18

Conophyton, cf. C. garganicus

1. Polished surface of axial (in centre) and near axial (in upper part) section of a portion of a Conophyton column from buff Sibley dolomite near the NW. corner of Disraeli Lake, 55 km (34.3 miles) WNW. of Nipigon, Ontario. The laminae are angulate, with apical angle of 60°, and some of them continue in a concave manner as connecting bridges across the evenly textured aphanitic dolomite matrix to an adjoining column. The columns are more vuggy than the matrix, and some pores are filled with copper sulfides and malachite.

   GSC locality 79193. GSC type 24554. GSC photo 200459-F.

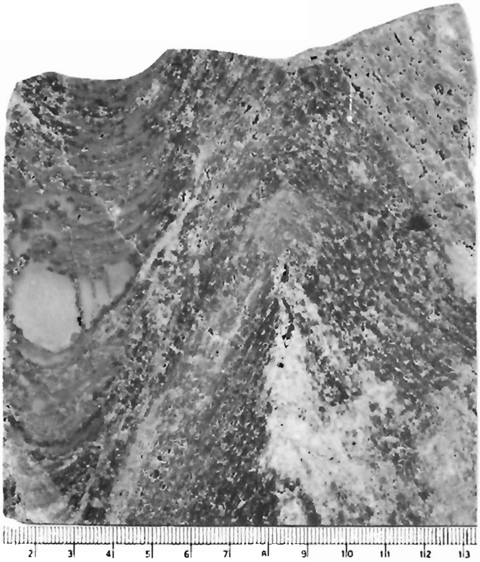
2. Horizontal section, in reflected light, of the same specimen as in Figure 1, showing lanceloid or acuminate-elliptical, and lobate plan outlines of laminae, and 2 radial ribs directed toward the points of inflection; evenly textured, dolomitic intercolumn matrix at bottom right. The dark laminations, which are actually the light lamellae as seen in transmitted light, average 0.5 mm in width and have a uniform pattern in parts, but are lumpy near the centre.

   GSC locality 79193. GSC type 24554a. GSC photo 200459-E.

3. Horizontal thin section of same specimen as in Figures 1 and 2, illustrating the striated microstructure of the laminae in transmitted light. Light lamellae are 0.05-0.7 mm wide, and dark ones are 0.05-0.5 mm wide. Vugs appear white and dolomitic matrix appears as evenly textured, dark grey patches. A stylolite passes obliquely across the centre and brings different portions of the stromatolite into angular juxtaposition at left.

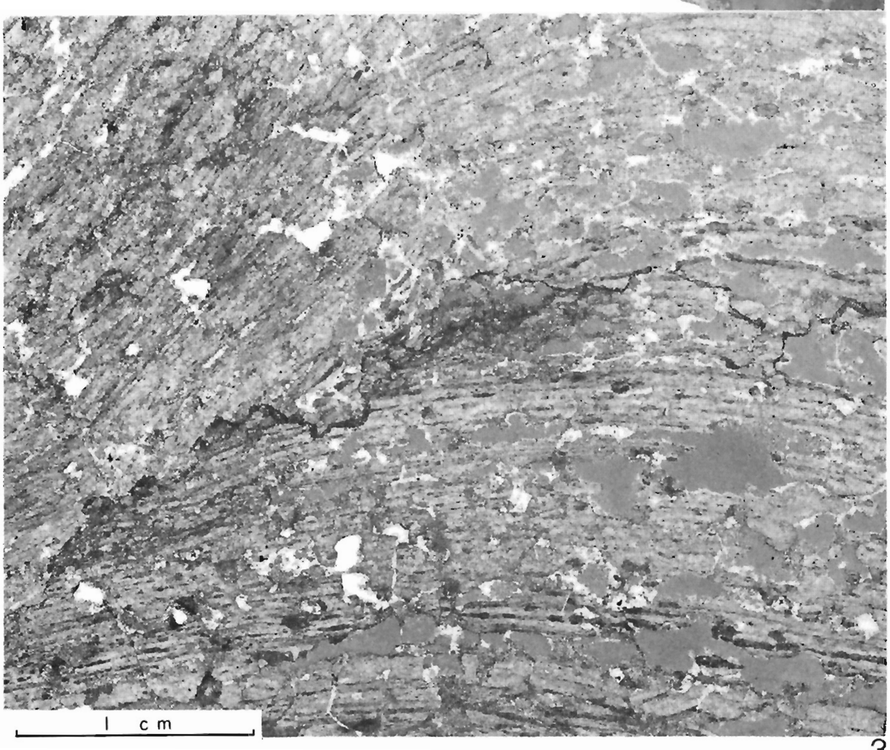
   GSC locality 79193. GSC type 24554b. GSC photo 200812-A.

18



1

2



3

PLATE 19

Conophyton, cf. C. garganicus

Vertical section from the upper left portion of the specimen in Plate 18, Figure 1, illustrating, in transmitted light, the ribboned to striated microstructure pattern of the laminae in the column, and their concave extensions in the evenly dark grey patches of aphanitic dolomitic matrix at left. Also visible are numerous vugs (white patches), and stylolites at right.

GSC locality 79193. GSC type 24554c. GSC photo 200812-B.

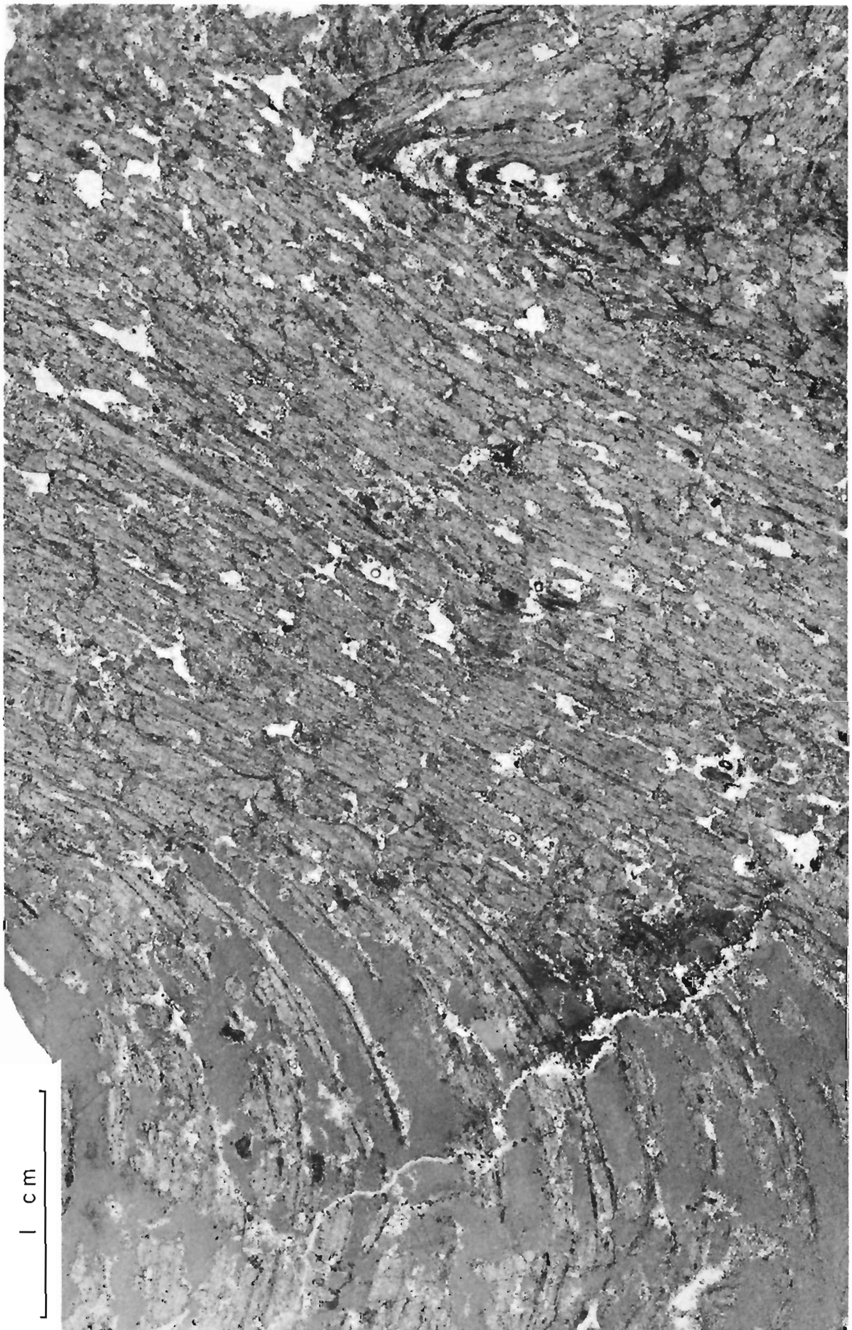

1 cm

PLATE 20

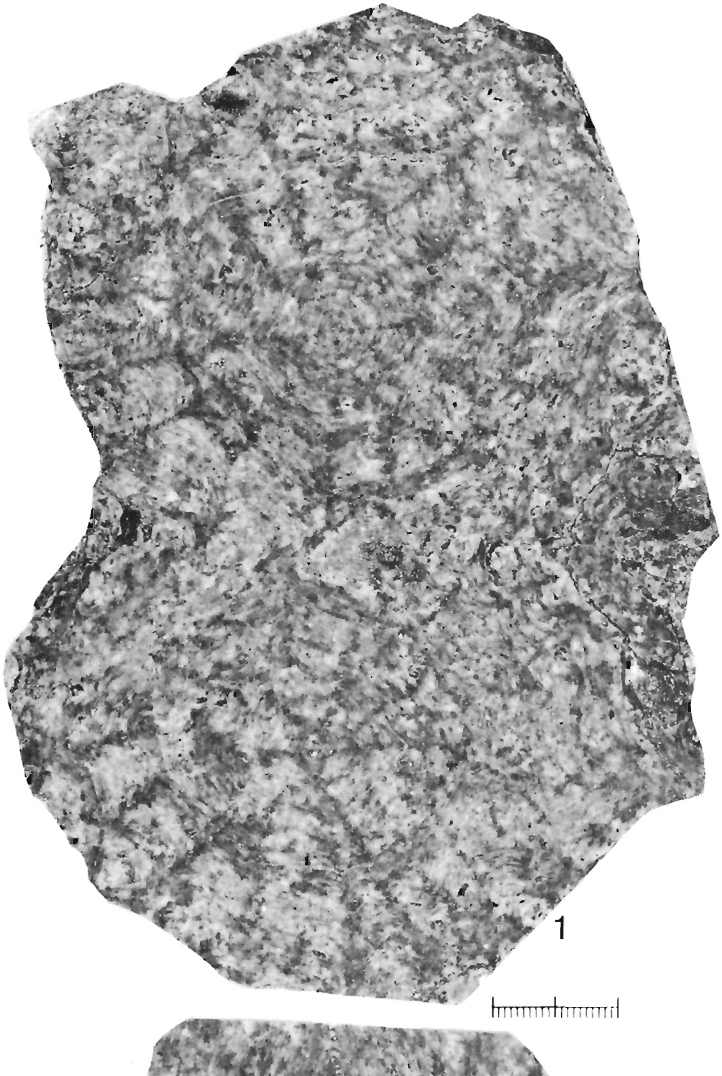
Conophyton

1. Horizontal section, in reflected light, of 2 columns of Conophyton from the same locality as that in Plate 16, Figure 3. Specimens from this occurrence are closely crowded and have polygonal to dentate laminae, as seen in plan view. The number of sides varies considerably within the same bed, and even from one level to another within the same column. Radial ribs, resembling spokes, emanate from the axial regions and are directed towards the cusps of the dentate outline, sometimes bifurcating in the process. The ribs are traces of subvertical planar features which distort the conical laminae to give a pyramidal shape to the Conophyton 'cone'. The microstructure of the laminae is indistinct.

   GSC locality 79194. GSC type 24555. GSC photo 200744-D.

2. Vertical, axial section of a specimen from the same bed as that of Figure 1 above, and also under reflected light. The 1 to 1.5 mm wide axial zone is visible in the middle; the apical angles of the laminae average 40°. Two structures, similar to those seen as radial ribs in the illustration of the horizontal section, appear here as upward and outward directed zones; they pass through points of inflection in the laminae.

   GSC locality 79194. GSC type 24556. GSC photo 200745-B.



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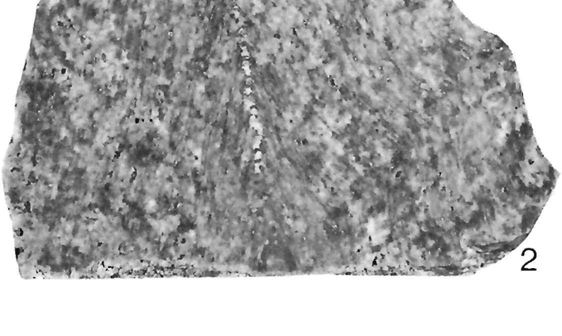

2

PLATE 21

Conophyton, cf. *C. garganicus*

Polished horizontal section, in reflected light, of a slab with 4 specimens showing preferential alignment of the long axes of the ellipses. The columns are not too closely spaced, and radial ribs are absent or rare.

Sibley dolomite, near the NW. corner of Disraeli Lake.

GSC locality 79193. GSC type 24557. GSC photo 200907-F.

21

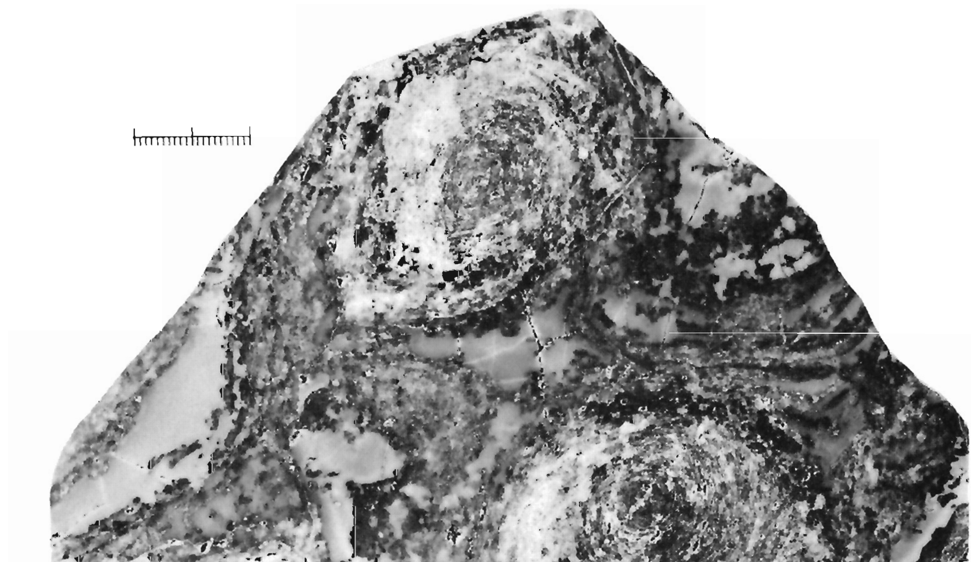

PLATE 22

Conophyton

Horizontal thin section of central portion of a column with radial ribs, in transmitted light. Dark lamellae are considerably obliterated and appear to be both striated and lumpy, though the original microstructure before dolomitization appears to have been striated. The large white patches are vugs in the dolomite. The specimen is from the group of columns shown in Plate 16, Figure 3, from the locality 6 km SW. of Disraeli Lake.

GSC locality 79194. GSC type 24558. GSC photo 200907-A.

22