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PRECAMBRIAN FOSSILS, PSEUDOFOSSILS, AND PROBLEMATICA IN CANADA

H. J. Hofmann

1971

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PRECAMBRIAN FOSSILS, PSEUDOFOSSILS, AND PROBLEMATICA IN CANADA

By

H. J. Hofmann

DEPARTMENT OF
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CANADA

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PREFACE

This report presents a comprehensive summary of our knowledge of remains reported as fossils, or possible fossils, from the Precambrian in Canada, and provides illustrations of most of the described forms. The study was undertaken in the autumn of 1966 to obtain an inventory of what has been accomplished during the last 100 years in collecting evidence of Precambrian life in Canada.

The report indicates that the evidence for biological activity in the ancient rocks is very widespread in the form of organosedimentary structures called stromatolites, but that morphologic remains or traces of the organisms themselves are very rare. Most of the forms that have been reported or described as metazoans are pseudofossils or problematica, that is, structures of non-biologic or undetermined origin.

Y. O. FORTIER
Director, Geological Survey of Canada

OTTAWA, April 15, 1969

BULLETIN 189 — Fossilien, Pseudofossilien und problematische Funde im Präkambrium Kanadas

Von H. J. Hofmann

Dieses Bulletin ist eine Zusammenfassung der Fossilien, Pseudofossilien und problematischen Funde im kanadischen Präkambrium und enthält eine umfangreiche Bibliographie.

БЮЛЛЕТЕНЬ 189 — Докембрийские окаменелости, псевдоокаменелости и проблематические остатки в Канаде.

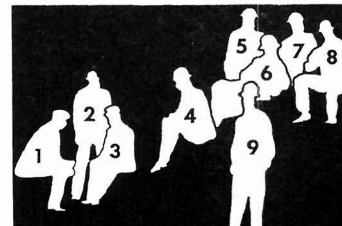
Г. Й. Хофманн

В этом бюллетене суммируются докембрийские окаменелости, псевдоокаменелости и проблематические остатки Канады; дается обширная литература.

The Inquest of Eozoon canadense

A photo by A. E. Barlow taken Saturday, May 15, 1897, on a field trip to the Côte St. Pierre type locality of Eozoon canadense, 10 miles (16 km) north-northwest of Papineauville, Quebec (Tyrrell, 1949, p. 89). The Eozoon locality is about 50 m from the boulder, behind and to the left of the camera. F. D. Adams is holding a slab containing the Eozoon structure. GSC photo 105979.

1. R.W. Ells
2. A.R.C. Selwyn
3. W. McInnes
4. J.B. Tyrrell
5. H. Fletcher
6. E.D. Ingall
7. R.W. Brock
8. F.D. Adams
9. R.G. McConnell



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Abstract

The literature of the last 100 years contains reports of biologic, or possibly biologic, Precambrian remains in Canada. The reported structures can be grouped according to whether they are fossils, pseudofossils (inorganic), or problematica (of undetermined origins); and whether they are Precambrian or not Precambrian. For discussion purposes, five convenient categories are considered here: macro-pseudofossils and macro-problematica, macrofossils, microfossils, micro-problematica, and stromatolites (including oncolites).

Stromatolites are the most widespread structural evidence of Precambrian biologic activity, occurring in almost every part of Canada where Precambrian sedimentary basins are preserved; they range from Late Archean(?) (*Cryptozoon walcotti* from the Steeprock Group) through the Proterozoic. Microfossils provide direct evidence of the morphologic expressions of Precambrian biota, but are at present known assuredly only from the Aphebian Gunflint Formation of the north shore of Lake Superior and the Hadrynian Hector Formation of the Rocky Mountains. Micro-problematica include three reported finds from the Archean and Proterozoic rocks. Macrofossils comprise one occurrence of Metazoa in the Conception Group (Hadrynian) of Newfoundland, and a small number of structures of biologic origin (trace and body fossils) from the Precambrian–Cambrian boundary zone, or from rocks originally considered Precambrian but now known to be Phanerozoic or probably Phanerozoic. Macro-pseudofossils and macro-problematica make up the largest number of described forms; they are chiefly from Proterozoic rocks of Ontario, Quebec, and the Atlantic Provinces. Included here, besides unnamed structures, are the following named forms.

ARCHAEOSPHERINA Dawson 1875
ARENICOLITES SPIRALIS Billings 1872
ASPIDELLA Billings 1872
ATIKOKANIA Walcott 1912
BELTINA Walcott (1899) 1911
CHUARIA (Allan 1913)
COLLINSIA Bain 1927
CTENICHNITES Matthew 1890
CYATHOSPONGIA? EOZOICA Matthew 1890
EOZOON Dawson 1864
HALICHONDRITES GRAPHITIFERUS Matthew 1890
KEMPIA Bain 1927
MEDUSICHNITES Matthew 1891 (TAONICHNITES Matthew 1890)
OLDHAMIA Murray 1868
RHYSONETRON Hofmann 1967

Résumé

Les écrits des 100 dernières années rapportent la présence au Canada de restes précambriens de nature biologique ou peut-être biologique. Les structures relevées peuvent être groupées en fossiles, pseudofossiles (inorganiques) et restes problématiques (d'origine incertaine), et selon leur origine précambrienne ou non précambrienne. Aux fins de la discussion, on a retenu cinq catégories pratiques de structures: macropseudofossiles et macroproblématiques, macrofossiles, microfossiles, microproblématiques et stromatolites (y compris les oncolites).

Les stromatolites constituent la preuve structurale la plus abondante d'activité biologique précambrienne; ils apparaissent dans presque toutes les régions du Canada où les bassins sédimentaires précambriens ont été préservés; ils datent de l'Archéen récent(?) (*Cryptozoon walcotti* du groupe de Steeprock) au Protérozoïque. Les microfossiles offrent une preuve directe des manifestations morphologiques de vie précambrienne, mais à l'heure actuelle on ne connaît leur existence de façon certaine que dans la formation de Gunflint (Aphébien), sur la rive nord du lac Supérieur, et la formation d'Hector (Hadrynien) dans les Rocheuses. Les structures microproblématiques comprennent trois découvertes effectuées dans les roches archéennes et protérozoïques. Les macrofossiles comprennent une venue de métazoaires dans le groupe de Conception (Hadrynien) de Terre-Neuve, et quelques structures d'origine biologique (traces et organismes fossiles) provenant de la zone frontière précambrienne-cambrienne ou de roches considérées à l'origine comme précambriennes, mais reconnues aujourd'hui comme phanérozoïques ou probablement phanérozoïques. Les macropseudofossiles et les macroproblématiques constituent les plus nombreuses formes décrites; ils proviennent principalement des roches protérozoïques de l'Ontario, du Québec et des provinces de l'Atlantique. Outre les structures non désignées, on a relevé les formes désignées suivantes:

ARCHAEOSPHERINA Dawson 1875
ARENICOLITES SPIRALIS Billings 1872
ASPIDELLA Billings 1872
ATIKOKANIA Walcott 1912
BELTINA Walcott (1899) 1911
CHUARIA (Allan 1913)
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HALICHONDRITES GRAPHITIFERUS Matthew 1890
KEMPIA Bain 1927
MEDUSICHNITES Matthew 1891 (TAONICHNITES Matthew 1890)
OLDHAMIA Murray 1868
RHYSONETRON Hofmann 1967

INTRODUCTION

For more than a century the occurrence of fossils in rocks older than the Cambrian has been a fascinating but frustrating topic—fascinating in theoretical considerations (or speculation) of the origin and early development of life on our planet, and frustrating from the standpoint of obtaining sufficient factual data to support the various hypotheses. Although stromatolites and, in some areas, microfossils abound in Precambrian sediments, conclusive evidence for the presence of remains of the higher forms of life is still very scarce and is confined mainly to the very latest portion of the Precambrian. Many times in the past purported new finds of Precambrian fossils have received uncritical acclaim, only to be revealed later as not fossils or as not Precambrian. For recent reviews of the status of Precambrian paleontology in general see Rutten (1962), Glaessner (1962, 1966), Schopf (1967), and Cloud (1968).

The purpose of this report is to summarize our knowledge of the Precambrian fossil and pseudofossil record of Canada to the beginning of 1969. In a study of this kind one is confronted with two main geologic problems: (1) is the structure Precambrian, and if so, how old is it? (2) is the structure of biologic origin, and if so, what are its affinities? The first problem is now solved more easily with the available methods of radiometric age determinations. The second remains difficult for several reasons, but mainly because Precambrian fossils lack hard parts and tend to have unpredictable morphologies or simple morphologies resembling various inorganic structures. In addition, the general insufficiency of the fossil record and the poorly preserved nature of many specimens often do not afford sufficient comparative evidence to remove gross uncertainties in interpretations. Nor is the study made easier by incomplete information on collecting locality, geologic setting, and the whereabouts of type specimens; and by a lack of good illustrations in some of the papers in which the structures were originally described. Many forms have been discussed again and again in the literature, but, with certain exceptions, only a small amount of new factual or illustrative material has been added in the process, inasmuch as the papers concentrated mainly on new interpretations of old data.

The Precambrian remains considered in this bulletin can be grouped into fossils, problematica, and pseudofossils. It has been found useful to grade these remains on an arbitrary scale of 1–5 as follows: (1) inorganic, (2) probably inorganic, (3) undecided, (4) probably biologic, (5) biologic (*see* Fig. 1, *in pocket*). Between end members 1 and 5 are structures whose questionable origin is not yet resolved for a variety of reasons, such as insufficient information about the specimens or geologic setting,

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Author's address: Department of Geology, Université de Montréal, Montréal, Québec.

incomplete or lost specimens, poor preservation, lack of comparative material, or inability on the part of the investigator to provide a satisfactory explanation. Assignment to a particular category is subjective, depending, among other factors, on the experience or background of the investigator. The above scheme is less rigid, but at the same time is more precise than fossil-inorganic alternatives in conveying one's interpretation of a structure; it is also flexible in that it provides for reassignment of a structure when new information warrants it. Fossils are those structures furnishing undoubted evidence of organic origin (category 5). Pseudofossils are objects that have a deceptive resemblance to biogenic structures, but are of inorganic origin (category 1); included are sedimentary, diagenetic, metamorphic, igneous, or tectonic structures that were originally interpreted as biologic, or probably biologic, and given Linnéan names. Problematica are structures of unknown origin (categories 2–4).

Excluded from this bulletin are pseudofossils that originally were not interpreted as biologic (category 1) (e.g., Hogarth, 1964). Also excluded are chemofossils, that is, chemical evidence of the existence of Precambrian biota (e.g., chlorophyll derivatives, C^{13}/C^{12} isotopic ratios). The reported Precambrian forms from Canada are further categorized as macro- and micro-structures, with stromatolites (including oncolites) considered as a separate group of macro-structures.

An attempt is made here to assemble in one volume widely scattered information, both published and unpublished, including data on historical aspects, descriptions, photographs, geographic and stratigraphic distribution, location of type specimens, present interpretations of the structures, and a comprehensive, though not complete, bibliography. Most data are summarized on Figures 1–3 (*in pocket*). Hopefully, the data brought together here will promote and facilitate future studies of Precambrian fossils and pseudofossils in Canada, and also prevent, or at least reduce, errors made in interpreting newly discovered ones.

In all, fifty-five reported occurrences are discussed, comprising twenty-seven entities classed as macro-pseudofossils and macro-problematica, four macrofossils, eighteen microfossils, three micro-problematica, and three formally named stromatolites. These are listed alphabetically on Figure 1 (*in pocket*). The order of discussion in the text, however follows closely, but not entirely, the order of discovery of the remains in each category.[1]

The present study would have been much more formidable without the assistance of many individuals from various institutions who contributed specimens, photographs, discussion, information, or other assistance. Of particular benefit were discussions with E. S. Barghoorn, P. E. Cloud, J. A. Donaldson, and J. W. Schopf. Colleagues at the Geological Survey of Canada contributed information and discussion; and staff members of the Survey library, photographic section, and laboratories provided major technical assistance. G. W. Bain and E. S. Belt (Amherst College), T. H. Clark (McGill University), S. W. Gorham (New Brunswick Museum), W. C. Gussow (Union Oil Co. of California), R. D. Hughes (Memorial University of Newfoundland), A. W. Jolliffe (Queen's University), B. Kummel (Harvard University),

[1]See Addendum, p. 64.

G. O. Livo (Gulf Oil Corp.), J. E. Merida (United States National Museum), B. R. Rust (University of Ottawa), L. S. Stevenson (Redpath Museum), B. L. Stinchcomb (Florissant Valley Community College), and G. M. Young (University of Western Ontario) arranged for loans of specimens from their private or institutional collections; some donated specimens for the Survey type collection, and these are acknowledged where appropriate.

MACRO-PSEUDOFOSSILS AND MACRO-PROBLEMATICA

The category of Precambrian remains containing the earliest as well as the most numerous described forms are the macro-pseudofossils. Linnéan names have been given to many of the structures because they were originally interpreted as biologic, or probably biologic. Subsequent studies have shown them to be inorganic, or probably inorganic, thus leaving them without biologic significance and without taxonomic status in paleontology. For purposes of discussion, cataloguing, and reference, it has nevertheless been useful to have such forms designated by special names. Experience shows that references to forms that have been described but not named have tended to get "lost" in the literature. (This applies especially to described Phanerozoic trace fossils that are not listed in recent catalogues or treatises on the subject.)

Problematica are generally of little interest to geologists or paleontologists working with rocks containing abundant fossils. The structures assume importance in rocks that are mostly devoid of obvious organic remains, especially Precambrian sediments. Structures found in rocks formed during the first 80 per cent of Earth history therefore receive special attention with regard to possible biologic origin. If the opinion is that they are the remains of organisms, they are named according to international rules of zoological or botanical nomenclature. If they are trace fossils, matters are more complicated; and if they are stromatolites or problematica, there is an unresolved problem inasmuch as there are no international rules of nomenclature for such structures.

Problematica are not always satisfactorily explained at the time of first description because they may be of questionable biologic, sedimentologic, diagenetic, tectonic, or other origins. A precise descriptive designation, therefore, may be desirable or necessary; such a designation should be easy to recognize in the major languages of science. Careful consideration is required, however, to avoid unnecessary proliferation of names akin to those in paleontology where synonyms abound. Certain pseudofossils that have received Linnéan names might continue to be referred to by the same name, but not be italicized. We may thus speak of the *Eozoon canadense* described by Dawson as Eozoon canadense, or eozoon structure, therefore designating a particular type of structure by a precise name that is of use in discussion and indexing. Names used in this way might then have a value similar to such Greek- or Latin-derived words as electron, calcium chloride, pyrite, oölith, or stylolite, which enjoy the advantage of universality.

Eozoon canadense, Dawson 1864

Plate 1, figures 1–4; Plate 2; Plate 3, figures 1, 2, 4

Supposed fossil, Logan 1863, Geol. Can., pp. 48, 49, figs. 3, 4.

Eozoon Canadense, Dawson 1864, Quart. J. Geol. Soc. London, vol. 21, p. 54, pls. 6, 7; Carpenter 1864, fig. p. 61, pls. 8, 9.

Eozoon Canadense var. *minor*, Dawson 1875, The dawn of life, pp. 135, 236, (presented orally on May 12, 1875 (Dawson, 1876, Quart. J. Geol. Soc. London, vol. 32, p. 69)).

Eozoon Canadense var. *acervulina*, Dawson 1875, The dawn of life, pp. 135, 236, (presented orally on May 12, 1875 (Dawson, 1876, Quart. J. Geol. Soc. London, vol. 32, p. 70, figs. 1–4)).

Eozoon Canadense, Tudor specimen, Dawson 1867, Quart. J. Geol. Soc. London, vol. 23, pp. 257–260, pl. 11; pl. 12, fig. 1; Gregory, 1891, Quart. J. Geol. Soc. London, vol. 47, pp. 348–355, figs. 1–4.

Eophyllum canadense, Hahn 1880, p. 71

Eozoon canadense var. *latior*, Dawson 1893, p. 130

Eozoon canadense, Rothpletz, 1916, pp. 26–60; pl. 3, figs. 1–6; pl. 4, figs. 2–5; pl. 5, figs. 1, 2.

The Eozoon controversy of the 19th century is known to most geologists. To recapitulate the whole of this would require a book by itself, as the volume of literature on this subject is enormous, exceeding many times that of all other described Canadian Precambrian fossils and pseudofossils combined. A summary of the controversy, as part of a broader study of the career of Sir William Dawson, was prepared by O'Brien (1968). Important older summaries are those of Dawson (1875b, 1888c, 1897b), King and Rowney (1881), and Merrill (1924). In the present section only a brief outline of the essential facts relating to Eozoon will be given, together with some observations and photographs of type specimens in the Survey collections, and a substantial bibliography. A graphical historical summary is presented on Figure 4 (*in pocket*). References dealing with Eozoon, and plotted on Figure 4, are marked with an asterisk in the bibliography.

Eozoon canadense ("the dawn animal of Canada") is a name applied to rhythmically banded structures of thin (millimetre-thick), frequently branching layers composed of two main minerals of contrasting physical and chemical properties, and found in metamorphic rocks of the Grenville Province; a complex dendritic microstructure may be present. At least five types of occurrences to which this name has been applied are known from Ontario and Quebec, each differing from the others by its texture and mineral assemblage; they are grouped here as follows:

1. Burgess
2. Grand Calumet
3. Côte St. Pierre
4. Tudor
5. Huntingdon

Burgess Type (Pl. 3, fig. 4)

The first specimens of the laminated structures later called *Eozoon canadense* were collected several years before 1858 by James Wilson of Perth, a Canadian mineralogist, on lot 2 or 3, concession 9, North Burgess township; they were sent to Sir William Logan as mineral specimens (Logan, 1866, p. 8). Several topotype specimens are preserved in the Survey collection (GSC types 139, 140, 168, 198–201), and are labelled as coming from lots 2 and 11, concession 9, North Burgess township, Lanark county, Ontario (localities several miles to the south of Perth). An account of their field relationships is given in Vennor (1876).

The Burgess type of Eozoon is characterized by alternating, more or less uniform bands of dark green serpentine ("loganite" of T. S. Hunt, the Survey chemist at the time) and grains of spinel, and thinner bands of light grey dolomite. The layers appear to have been deformed, and the boundaries between them are very irregular. At the time of discovery these specimens did not attract much interest and were not considered as being possibly of biologic origin.

Grand Calumet Type (Pl. 1, figs. 1, 2)

In 1858, several years after the original find, other specimens of Eozoon were found in the Grenville limestone on the Grand Calumet Rapids near Bryson, Quebec (Dawson, 1875b, p. 37), by John McMullen[1], an explorer with the Geological Survey. This type of Eozoon (GSC type 165, 165a) is composed of alternating, irregularly concentric, tapering, and branching bands of resistant-weathering, light grey clinopyroxene (probably diopside); and thinner, also branching, tapering, and intersecting bands of recessively weathering calcite.

Logan at once considered the possibility of an organic origin for these structures because of their resemblance to certain stromatoporoids found in the Ordovician of the Ottawa Valley. He exhibited them as probable Precambrian fossils at the August 1859 meeting of the American Association for the Advancement of Science, in Springfield, Massachusetts (Logan, 1859, p. 300), but apparently without much positive response. (In November of the same year Darwin published the first edition of his "Origin of Species".) In 1862 Logan exhibited the structures again, this time in London, England; but once again, he was met with much skepticism. The first published illustration of Eozoon canadense appears, unnamed as yet, in his "Geology of Canada" (1863, p. 49).

Côte St. Pierre Type (Pl. 2; Pl. 3, fig. 1)

In 1863 James Lowe, another Survey explorer, discovered a third Eozoon locality near Grenville, Quebec, on the Ottawa River (lot 2, range 1 of the Augmentation of Grenville) (Logan, 1866, p. 15), in the type area of the Grenville "series". Lowe subsequently found additional specimens of the same kind at Côte St. Pierre (Dawson, 1875b, p. 43). Here are found the forms with the controversial dendritic microstructure (Pl. 3, fig. 1). If there is such a thing as a "typical" locality for Eozoon canadense, this would best qualify, because this is the locality from which most of the much discussed structures (Eozoon canadense *sensu stricto*) were collected. The locality is in an area of abandoned small quarries on the east slope of a hill located in woods northwest of Lac Allard, on the west side of the road between Côte St. Pierre and St. André-Avellin, 2.7 miles (4.3 km) north-northwest of the latter village (45°45′29″N, 75°04′24″W). Geological maps of this locality are provided by Stansfield

[1]In some publications this name appears erroneously as J. McCulloch.

(1913, facing p. 96) and Rothpletz (1916, Pl. 5, fig. 3); the area is covered by a map on the scale of 1:63,360 by Faessler (1948). The Eozoon occurs in a band adjacent to a gabbro intrusive (*see* Osann, 1902, p. 61 O for petrologic description), and it forms aureoles around masses of serpentine.

Still later, specimens of this type were collected at Long Lake, another 25 miles (40 km) north of the Côte St. Pierre locality (Logan, 1867a, pp. 254, 260), and at other places.

The Côte St. Pierre type of Eozoon is distinguished by alternating layers of white calcite and light green serpentine. The layers form shells around pockets of serpentine, or serpentine with diopside cores, and are gradually and systematically thinner and more closely spaced away from the cores, and merge gradually with a mottled pattern of millimetre-sized serpentine grains distributed more or less randomly throughout a calcite matrix. (This mottled pattern, typical of ophicalcite, was later also found in Bohemia, and named *Eozoon bohemicum* by Fritsch in 1869.) A thin section shows that the thicker calcite layers may contain a myrmekite-like, three-dimensional, dendritic microstructure of serpentine (Pl. 3, fig. 1) or dolomite (the "tubuli" or "canals" of Dawson and Carpenter). It was this microstructure, first noticed by T. C. Weston of the Geological Survey of Canada (Weston, 1899, p. 22), but claimed by Dawson (1875b, p. 40; 1888c, p. 95), that led Dawson and Carpenter to regard the structures as biogenic, and to suggest that the structures are gigantic Foraminifera. However, the serpentine dendrites have a flat, rather than tube-like structure.

The first publication of the name *Eozoon Canadense* seems to have been on May 7, 1864, when Logan (1864b, p. 160) mentioned that this is what Dawson would be calling the structures. This reference is to Dawson's presidential address to the Natural History Society of Montreal, delivered on May 18, 1864, and published in June 1864 (Dawson, 1864a, p. 220). But it was not until 1865 that the original description and discussions by Logan, Dawson, Carpenter, and Hunt appeared.

The first published objections to the organic nature came from two professors at Queen's College in Dublin on June 10 of the same year (King and Rowney, 1865, p. 660), and the Eozoon controversy was under way, amiable at first, but increasingly bitter for many years (*see* Fig. 4 for frequency of publication). At stake, of course, was the acceptance or rejection of these structures as geologic evidence for the oldest known forms of life on our planet. The controversy coincided with the period of discussion of Darwin's theory of evolution.

From the material of the Côte St. Pierre type Dawson later (1875b, pp. 135, 236; 1876d, pp. 69–70) named two varieties: *E. canadense minor* and *E. canadense acervulina*. The variety *minor* was proposed for the small forms with the appearance of very finely laminated serpentine and calcite and the presence of abundant fine vertical partitions; the variety *acervulina* was proposed for the structures in which the thick laminar layers pass "upward" into heaps or layers of irregular, rounded or cylindrical (acervuline) "cells" of serpentine. Where these globules are less crowded they give the impression of being separate entities, and for these Dawson (1875b, pp. 139, 236; 1876d, p. 71) coined the name *Archaeospherina* (*see* separate description of these structures). Still later, Dawson (1893, p. 130) claimed to have named yet another form, *latior*, for its breadth and uniformity of laminae, but a search of the reference cited (Dawson, 1888c) failed to reveal the description.

Tudor Type (Pl. 1, figs. 3, 4)

As might be expected, the start of the controversy sparked the search for additional specimens. In 1866, H. G. Vennor of the Geological Survey collected a weathered specimen from a heap of boulders in a field on the east side of the old road 0.7 mile (1.1 km) southeast of Millbridge, Ontario, 14 miles (22.5 km) north-northwest of Madoc (lot 15, Hastings Road range (E), Tudor township, Hastings county, (Adams and Barlow, 1910, p. 225)). As the specimen was collected loose, nothing is known about its original geologic setting. At about the same time Logan had collected other specimens in the limestone at Madoc (Logan, 1867a, p. 254), structures in which Dawson claimed to have observed the "canals". The Tudor specimens were thought to be of the greatest importance in establishing conclusively the organic nature of Eozoon (Dawson and Carpenter, 1867a, p. 257).

The Tudor type of Eozoon represents a mode of formation and preservation different from the other types, but resembles the Grand Calumet type. The illustrated specimen is in a block of deformed, dark grey, medium-grained limestone, with the Eozoon pattern exposed on a weathered surface and on a sawn face perpendicular to it. The pattern comprises a series of parallel crescentic, in part branching, veinlets of coarse white calcite. The veinlets lie with their longest dimension parallel to a compositional banding that was regarded as bedding by Dawson, and as cleavage by Gregory (1891, p. 350). They are confined to one of the thin, texturally distinct, compositional bands close to the weathered surface. The crescents are 1–2 mm wide, and most of them taper out before reaching a depth of 3 mm. On one side they end along a well-defined curved line where they appear to merge into a distinct lateral wall-like marking (Pl. 1, fig. 3). The distinct lateral termination of the crescents is the result of the oblique, but nearly parallel, intersection of the slightly undulating weathering surface with the thin, compositionally distinct layer containing the crescents. The terminal phenomenon seen in plan view is not visible in the perpendicular section. Folded, paper-thin veinlets of calcite, regarded as deformed bedding by Gregory (1891, p. 350), cut across the slab and some cross one another; these can best be seen in a vertical section along the top of Plate 1, figure 3 (section not illustrated here), but also are visible at the bottom right in Plate 1, figure 4.

These relationships indicate that the paper-thin veinlets are not bedding plane features as intimated by Gregory. The compositional banding, accentuated by deformation parallel to it, is interpreted here as palimpsest bedding.

In general view the specimen presents a uniformly organized appearance that initially suggested an organic origin, but in close view the spacing of the crescents and their cross-sections are highly variable, irregularly branching, and ill defined.

Huntingdon Type (Pl. 3, fig. 2)

A fifth type of structure to which the name Eozoon canadense has been applied is found in the vicinity of Madoc and in the Belmont Lake area. The forms were illustrated by Miller and Knight (1914, pp. 13, 22, 24), Wilson (1926, pl. 4; 1931, pl. 1; 1939, Pl. 6A), and Wynne-Edwards (1967, p. 253, Pl. 1H).

This type is composed of resistant-weathering quartz bands and recessive-weathering bands of tremolite and calcite, or tremolite and dolomite. The irregular yet continuous banding in mound-like patterns that have a certain resemblance to lamellar stromatolites is well shown in Wilson's illustrations. This resemblance is only superficial, however; the convexities do not face consistently in one direction, the boundaries are ragged, they branch or form supernumerary laminae (Pl. 3, fig. 2), and the individual mineral bands are considerably thicker than in stromatolitic structure.

The geologic setting of the occurrence in Huntingdon township, on the south-eastern outskirts of Madoc, is described by Wilson (1926, pp. 18, 78, figs. 2, 14), Hewitt (1968, pp. 30–37), and in an unpublished M. Sc. thesis by Sandomirsky (1954). The structures occur close to intrusion in a northeasterly trending belt of intricately folded, low to moderate grade metamorphic rocks.

For purposes of discussing the origin of Eozoon canadense, the five types can be grouped into three classes: (a) the Burgess and Huntingdon types, (b) the Côte St. Pierre type, and (c) the Tudor and Grand Calumet types.

(a) The problem of the origin of the first two classes lies within the realms of metamorphic petrology and mineralogy, as such specimens are found in moderate grade metamorphic rocks derived from sedimentary carbonates and located near intrusives and within regionally metamorphosed terranes. The two types of the first class differ in their mineral assemblages, indicating different metamorphic facies. According to the metamorphic paragenesis in derivatives of dolomitic carbonate suites (Winkler, 1967), the Huntingdon type (quartz–tremolite–dolomite or calcite) represents a lower grade of metamorphism than the Burgess type (mainly serpentine–dolomite which has unstable relicts of spinel). The obvious characteristic common to both types is the rhythmic banding in which layers have more or less uniform thickness and spacing. The banding may be parallel to the original bedding, or be due to segregation and crystallization either in a homogeneous mass under anisotropic stress or recrystallization under more or less uniform stress but influenced by compositional differences in the beds of the original sedimentary rock. The exact mechanism still needs to be investigated.

(b) The inorganic origin of the Côte St. Pierre type, with its layers of systematically variable spacing and thickness, has been discussed in detail by King and Rowney (1866, 1870, 1881), Möbius (1878, 1879a, 1879b), Johnston-Lavis and Gregory (1894), and Rothpletz (1916). A convincing case for an origin by contact metamorphism, whole or partial fusion of the carbonate, and silica metasomatism was made by Johnston-Lavis and Gregory (1894b, pp. 264, 273), who showed clearly that geologically recent, thermal, metasomatic processes had produced structures identical with Eozoon in Mesozoic limestone blocks in Monte Somma and Vesuvius. Rothpletz (1916), in a very thorough study of the Côte St. Pierre Eozoon, also concluded that its formation was the result of contact metamorphism and metasomatism. However, these authors were unable to provide a totally satisfactory explanation for the cause of the rhythmic banding and the serpentine dendrite microstructure in the calcite bands, nor has this been accomplished by others who have discussed the genesis of the layering in banded serpentine–calcite rocks (ophicalcites) (Liesegang, 1913; Linck, 1914; Rost and Hochstetter, 1964). The diffusion hypothesis of Liesegang is most appealing, but presents difficulties, some of which Rothpletz (1916, pp. 55, 56) has pointed out. Experimental data on relative diffusion rates of the five or more components making up this complex system, and under varying conditions, are not available.

Although the inorganic origin of this type of Eozoon can be considered established, because its occurrence has a demonstrable relation to an intrusion, the exact process producing the banding has not yet been adequately explained. Appropriate pressure-bomb experiments on siliceous dolomites or other magnesian rocks could perhaps contribute to an understanding of this process. The possibility should also be investigated that the serpentine dendrites may be eutectic intergrowths, or alterations thereof, in calcite.

(c) With regard to the origin of the Tudor type of Eozoon, King and Rowney (1870, p. 511) and Gregory (1891, p. 352) suggested that the calcite crescents were simply fillings of cracks. As stated previously, the crescents are confined to a thin, texturally distinct limestone seam. This seam appears to have behaved in a brittle manner compared with a more ductile layer adjacent to it. During deformation the brittle layer developed rhythmic cracks and formed regions of lower pressure which were later filled by calcite derived from the immediate vicinity. This explanation remains hypothetical because the field relations at the source of the samples are not known.

The Grand Calumet type also appears to be a fracture-filling phenomenon, namely of calcite in a diopside block. On Plate 1, figure 1 the brecciated appearance of the specimen is well shown; the left third is characterized by closely spaced veinlets that are curved and appear drawn out. Some of them intersect, as at the middle. The right two thirds contains widely spaced, irregular veinlets perpendicular to the long dimension of the diopside fragment, but they are slightly bent in a direction opposite to those of the left third. Along the middle there are subsidiary fillings parallel to the contact. This zone (as seen in the photograph) appears to be one of slight right-lateral dislocation.

Before concluding the section on Eozoon canadense it may be of value to note the following interesting aspects of the Eozoon controversy. First, E. Billings, the official Survey paleontologist at the time, declined to study the structures or to be drawn into the controversy, and did not publish anything on Eozoon.

Secondly, for many years the emphasis of the controversy was on fragments of Eozoon and their microstructure, and the importance of field relationships was completely neglected. Only in 1895 did Bonney show that at Côte St. Pierre Eozoon occurs as thin aureoles around masses of serpentine and pyroxene. (His Figure 2 and several of his observations are now known to be in error, however.) It was not until the 1913 International Congress in Canada that the first detailed map (1 inch to 400 feet) of this locality was published (Stansfield, 1913), almost half a century after the original description.

Thirdly, in 1888, members of the International Geologic Congress sub-committee on the Archean in America voted on the question "In your opinion is Eozoon Canadense of organic origin?" (Frazer, 1888, p. 175; 1891, p. A74). The result was nine to four against an organic origin. Those who voted in the affirmative were Dawson, Hunt, Walcott, and A. Winchell; those against were Dana, LeConte, Irving, Emmons, G. H. Williams, N. H. Winchell, Wadsworth, Emerson, and Pumpelly. Fortunately for science, but unfortunately for its students, scientific problems are not settled by majority vote.

Archaeospherina, Dawson 1875

Plate 2; Plate 3, figure 3

Rounded siliceous bodies, Dawson 1867. Quart. J. Geol. Soc. London, vol. 23, pp. 260, 261, pl. 12, fig. 3.
Archaeospherina, Dawson 1875, The dawn of life, pp. 67, 137–139, 148, 236, figs. 18, 32, 33, 34.
Archaeosphaerina, Dawson 1876, Quart. J. Geol. Soc. London, vol. 32, pp. 71, 73, 74, figs. 1–4, pl. 11, figs. 4–10. Dawson 1888, Mem. Peter Redpath Museum, p. 29, fig. 10; Dawson 1893, p. 123, fig. 10; Dawson 1897, pp. 199, 200, 208–210, 308, 309, figs. 51, 53, 54.
Archeosphaerina, Rothpletz 1916, p. 42, pl. 5, fig. 2.

The small, millimetre-sized, globular grains of serpentine, intimately associated with Eozoon canadense in ophicalcite, were illustrated by Dawson (1867) and interpreted as casts of cavities and tubes of calcareous Foraminifera. They occur in a variety of shapes and display a wide range of patterns of surface ornamentation.

Dawson (1875b, pp. 139, 236; 1876d, p. 71) later proposed to name them *Archaeospherina*. At that later time he considered the bodies as possibly representing (1) fragments of the acervuline portions of Eozoon, (2) germs or buds growing out from Eozoon, or (3) separate small Foraminifera similar to *Globigerina*; the last he thought most probable. He subsequently favoured the view that they are fragments broken off the upper surface of the acervuline portions of Eozoon and scattered over the sea bottom (Dawson, 1888c, p. 29). He then apparently reverted again to his earlier view, however, and reprinted, with minor modifications, the previous interpretation that they are distinct organisms (Dawson, 1897b, pp. 308, 309).

The structures were never much discussed by others in the literature. Rothpletz (1916, p. 42) reported that some of the serpentine grains contained cores or remnants of olivine. Cushman (1948, p. 47) and Reitlinger (1959, p. 5) remarked on the similarity of Archaeospherina to the Foraminifera (or Radiolaria) reported by Cayeux

(1894) from the Precambrian of Brittany, and named *Cayeuxina precambrica* by Galloway (1933, p. 156). This resemblance is most superficial, however, for the geologic settings of the two occurrences are not comparable, and the size of the Archaeospherina exceeds that of the structures from Brittany by two orders of magnitude.

The structures named Archaeospherina are inorganic for the same reason that the Côte St. Pierre type of Eozoon is inorganic. They are globular grains, almost exclusively of serpentine, distributed more or less homogeneously throughout ophicalcite. They occur in rocks that have undergone a high degree of contact metamorphic alteration, leaving no visible trace of what might confidently be regarded as a primary sedimentary structure. The size, shape, and distribution of the magnesium silicate grains are the result of physiochemical processes in a high-temperature environment, and subsequent retrograde metamorphism. The process responsible for the growth of the magnesium silicate grains around the dispersed nucleation centres within the ophicalcite still needs investigation.

Worm burrows at Madoc, Dawson 1866

Plate 4, figures 2–6

Worm burrows, spicules, and lenticular bodies, Dawson 1866, Quart. J. Geol. Soc. London, vol. 22, pp. 608, 609, figs. 1–3 (4, 5); Can. Naturalist Geologist, 1868, 2nd ser., vol. 3, pp. 321, 322.

Annelid burrows, Dawson 1875, The dawn of life, pp. 132–133, 139, fig. 35; 1897, Relics of primeval life, p. 67, fig. 15.

Dawson recorded certain perforations resembling burrows of worms from calcareous quartzite or impure limestone of the Grenville at Madoc, Ontario. The structures were described as cylindrical fillings of rounded quartz grains. The cylinders, accentuated peripherally by dark, resistant-weathering, carbonaceous or ferruginous matter, are commonly perpendicular to bedding, but may be parallel to it. Although no size ranges were given, the caption on one illustration indicated that the perforations are 1 to 2 mm across. Dawson interpreted these structures as probable worm burrows similar to *Skolithos*, but considered alternative origins such as worm tubes or cavities left by decaying algae.

In limestones associated with the perforated beds Dawson also found fragments of Eozoon with spicules and lenticular bodies of unknown nature (Pl. 4, figs. 5, 6). Specimens are said to be in the Geological Survey collections, but none could be located. A 2-day search was made for topotype material "at Madoc", but this was also unsuccessful. The structures were briefly mentioned in subsequent papers (e.g., Dawson, 1867, p. 260; 1893, p. 172; Matthew, 1890, p. 29; Packard, 1898, p. 323). Schindewolf (1956, p. 472) considered them to be possibly organic, and compared them with similar forms described by Laitakari (1925) from Jotnian sandstone of Finland.

Without specimens and further study nothing can be added to the discussion of the "Madoc tubes" and associated structures.

Oldhamia, Murray 1868

Plate 4, figure 10

Oldhamia, Murray 1868, Rept. Geol. Surv. Newfoundland, p. 13; 1881, p. 145; Weston 1895, Trans. Nova Scotia Inst. Sci., vol. 8, p. 139, fig. 2; 1898, Trans. Nova Scotia Inst. Sci., vol. 9, p. 1, fig. 1; 1899, Reminiscences, p. 293, fig. opposite p. 292; Walcott 1899, Bull. Geol. Soc. Am., vol. 10, p. 231.

Alexander Murray (1868, p. 13) referred to *Oldhamia* certain markings he found in the alternating red, green, and purple slates of his Division *c*, which corresponds to the 'Torbay slate', or the upper part of the Conception Group (Rose 1952, p. 17). In a footnote added in the reprinted edition of his report, Murray (1881, p. 144) stated that ". . . the forms in question were supposed to resemble the *Oldhamii* of Bray Head [in the Cambrian, 13 mi southeast of Dublin, Ireland] but were pronounced upon examination by the late E. Billings to be indeterminable. He doubted their organic origin altogether."

Walcott (1899, p. 231) added "I have not been able to obtain specimens of the Oldhamia mentioned by Dr Murray as occurring near the summit of the slates that I have designated the Torbay slates." Walcott did not refer to any of Weston's papers, which provide the only known illustrations of the structures. The 1895 paper, which was read before the Nova Scotian Institute of Science in 1891, contains a brief but interesting historical account concerning the specimens. Weston's observations (1895a, p. 139; 1898b, p. 152) that the structures lay "transverse to the bedding" and the photograph he published show a close resemblance to the Permian concretionary structures from the Fulwell quarry so superbly illustrated by Abbott (1914c). Unfortunately Weston did not provide a scale for his photograph. The specimens are from green argillite near St. John's and are supposed to be in the Survey collections at Ottawa. The whereabouts of the type specimen is not known, and no new material has been obtained. Rose (1952), who mapped the Torbay area, did not report any new finds of the structures.

Aspidella terranovica, Billings 1872

Plate 5, figures 1, 5, 6; [?] figures 2–4

Aspidella terranovica, Billings 1872, Can. Naturalist Geologist, vol. 6, No. 4, p. 478, fig. 14; 1873, Geol. Surv. Newfoundland, Rept. 1872, pp. 16, 17; 1874, Geol. Surv. Can., vol. 2, pt. 1, pp. 76, 77, fig. 45; 1881 Geol. Surv. Newfoundland, Repts. to 1880, pp. 286, 287; 1882, Geol. Surv. Newfoundland, Rept. Prog. 1881, App., p. 23, fig. 1; 1918, p. 23; Dawson 1897, Relics of primeval life, p. 54, fig. 13.

[?] *Aspidella terranovica*, Walcott 1899, Bull. Geol. Soc. Am., vol. 10, pp. 230, 231, pl. 27, figs. 7, 8; Häntzschel 1962, Treat. Inv. Pal., p. W232, fig. 145, *3a, 3b;* 1965, Fossilium Catalogus, pp. 11, 12.

In 1872, Billings named, described, and illustrated *Aspidella terranovica* from the Late Proterozoic rocks near St. John's, Newfoundland. These structures were first collected in 1866 and reported by A. Murray (1868, pp. 11, 12) in the St. John's Formation (Rose, 1952, p. 23), a unit which was also known as the "Aspidella slates" (Murray, 1873, 1881) and as the "Momable slate" (Walcott, 1899). Murray (1873, pp. 16, 17, 31; 1881, pp. 287, 295–297) subsequently reported similar structures from equivalent strata along Trinity Bay (Snows Pond Formation of McCartney, 1967, p. 42), at several places along the valley of the Rocky River, and at Ferryland.

The original description was again published in 1873, 1874, and 1882 with the statement that " . . . a more detailed description will be given hereafter." The only discernible difference between the descriptions is, in fact, the orientation of the same woodcut used for illustrating the holotype slab—in 1872 it is "right side up", in 1874 upside down, and in 1882, sideways. To my knowledge, Billings apparently never published his promised detailed description.

The holotype slab (GSC type 221) is missing from the collections of the Geological Survey of Canada, but a plastotype (cast?) (Pl. 5, fig. 1) of the holotype is fortunately available for study (GSC type 221c). This metal plastotype slab bears the outlines of two parallel-oriented, elliptical specimens of Aspidella terranovica. The larger one measures 12.0 by 9.1 mm and has a raised ring-like border 1.2 mm wide. The smaller one, which is better preserved, measures 10.2 by 7.8 mm, and has a depressed ring-like border 0.8 mm wide. A slight roof-like ridge occupies the central portion of each ellipse. These are about 0.75 mm high and bear fine radial ridges and grooves that are most distinct in the near-central raised area, and extend faintly across the ring-like border to the periphery.

Two other specimens, which may not belong to this "species" but are labelled *Aspidella terranovica*, are in the same collection as the plastotype. These are the black siltstone specimens discussed and illustrated by Walcott (1899, Pl. 27, figs. 7, 8) and Häntzschel (1962, Fig. 145, *3a*, *3b*); they appear to be somewhat distinct from the structures of the plastotype. Specimen 221a (Pl. 5, fig. 2) is from Ferryland, 38 miles (62 km) south-southwest of St. John's. It measures 19.8 by 14.9 mm and lacks a distinct ring-like border. Instead of a central ridge it has a nearly flat, slightly eccentric depression and radial ridges and grooves that pass from the depression to the periphery.

Specimen 221b (Pl. 5, fig. 3) is from St. John's and has dimensions of 23.5 by 18.5 mm. It does not have a central roof-like ridge, radial ridges and grooves, or a ring-like border. Instead, its surface bears a series of three concentric wrinkles, and locally (bottom of figure) short subradial striations. The concentric wrinkles are apparently surface expressions of concentric toroidal shear surfaces that converge below the exposed part of the bodies.

The structures have been variously interpreted as organic (mollusks, crustaceans) and inorganic (striated concretions, sites of gas vents, pressure cones, gas bubble craters, spall marks) (*see* Fig. 5). They have some resemblance to structures described under the names *Palaeotrochis*, *Guilielmites*, and *Chuaria*, all of which are now considered by Häntzschel (1965) to be inorganic.

FIGURE 5. Summary of references to Aspidella Billings 1872

Author	Date	Interpretation of Aspidella Billings
Hofmann	present	X Of mechanical origin; focussed surfaces of rupture
Cloud	1968	X Concretion or spall mark
Häntzschel	1965	X Inorganic; pressure cone or gas bubble crater
Glaessner	1962	X Inorganic; cites Walcott 1900 and Schindewolf 1956
Häntzschel	1962	X Inorganic; resembles *Guilielmites* Geinitz
A. E. Wilson	1957	? No opinion; cites interpretation of earlier authors
Schindewolf	1956	X Diagenetic; pressure cones or buckling through escaping gas bubbles
Rose	1952	? No opinion; quotes Walcott's (1900) interpretation
M. E. Wilson	1939	? No opinion; quotes Matthew's (1898) interpretation
M. E. Wilson	1931	? No opinion; quotes Matthew's (1898) interpretation
Metzger	1927	? Of questionable nature; like *Chuaria*, which Walcott considered a brachiopod
Clark	1923	X Sites of vents from which gas escaped
Buddington	1919	O Possible fossil
Van Hise and Leith	1909	O Page 80: organic origin is denied; p. 100: probably organic, but questionable
Sollas	1909	O Plainly organic
Walcott	1901	X Inorganic
Walcott	1900	X Spherulitic concretion
Walcott	1899	O Probably organic, but it may be questioned
Matthew	1898	X Slickensided mud concretion striated by pressure
Packard	1898	O Mollusk
Weston	1898 (1896)	X Probably concretion
Dawson	1897	O Problematic; may be crustacean or mollusk allied to limpets
Murray	1873 (1881)	O Fossil
Billings	1872 (1874, 1882, 1918)	O Fossils; resemble, but are different from *Chiton* or *Patella*
Murray	1868	O Obscure organic remains [resembling "Oldhamia"]

X Inorganic, or probably inorganic.
O Organic, or possibly organic.

One aspect bearing on the interpretation of Aspidella is the field relationship. Many good exposures are available for examination in the outcrop belt of the St. John's Formation. One of the better and most easily accessible is at the entrance to the store of Atlantic Films, at 22 Prescott Street, St. John's. The outcrop on the north side of the driveway is comprised of dark grey to black, thin-bedded siltstones and sandstones striking 032° and dipping 73°E. The bedding planes are covered with elliptical specimens of Aspidella, ranging from small ones to ones as large as 3 by 4 cm (Pl. 5, fig. 6), all oriented in one direction parallel to a lineation that pitches 75°S. In the large roadside cut along the main road in Ferryland the beds strike 015° and dip 65°E; the Aspidellas pitch 55°S.

The pattern of preferred orientation constitutes a characteristic feature and was encountered in all the outcrops visited, from Ferryland to Torbay. The elongation of

Aspidella can reasonably be attributed to tectonic deformation, and the structure itself is interpreted to be of mechanical origin resulting from differential movement of mud. The structures appear to be bodies containing deformed (axially compressed) conical surfaces of rupture with radial striations, localized in material slightly more rigid than the matrix. How this different material came to be localized in small patches was not clear from the specimens examined. Some of the structures occur in finely interlaminated calcareous siltstone and shale, and some discoidal bodies may have formed by local breakup of the silt layers and subsequent sinking of the pockets into the shale layer, later to be sheared and striated; or they may be short, vertical, silt-filled cylinders or pits (burrows?, gas vents?) that were later axially compressed during compaction. Others may be flattened concretions. Still others appear to be wrinkled laminae of coarse siltstone, possibly made cohesive through binding by algae.

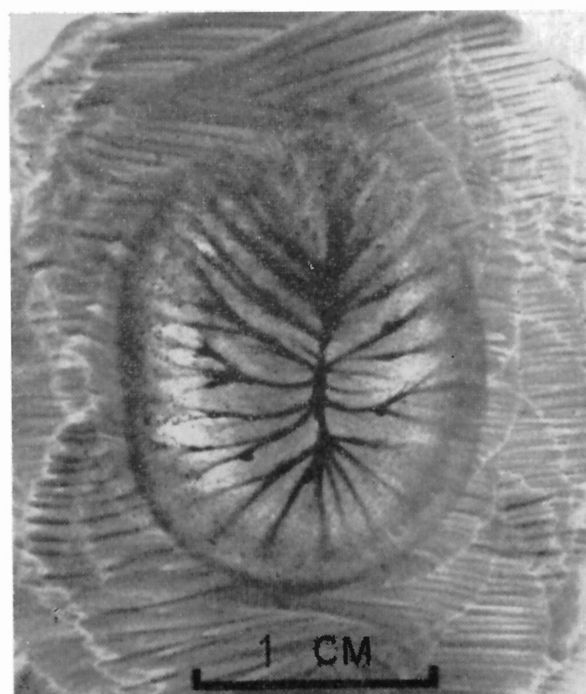

FIGURE 6

Aspidella-like pattern produced experimentally. The structure is a fingerprint pattern developed on a film of oil (SAE 30 grade) mixed with grinding powder (5 μ aluminum oxide), and placed on a glass slide. The slurry was spread more or less evenly over the slide and touched with a finger. Upon removal of the pressure the slurry drew together and left behind a radial pattern, with annulus and medial ridge, that bears a striking resemblance to Aspidella terranovica Billings 1872. The experiment suggests that Aspidella is of mechanical origin.

Similar impressions with the annulus, the radiating ribs, as well as the roof-like medial ridge, can be reproduced experimentally. The aspidella pattern is formed by pressing one's finger on a smooth flat surface evenly covered with a fluid of moderate viscosity, such as a glass slide covered with oil containing suspended fine powder. Upon removal of the finger, the aspidella pattern appears (Fig. 6); the slurry draws together into a dendritic pattern when tension is applied to it.

Arenicolites spiralis, Billings 1872 (Murray 1868)

Plate 4, figure 7

Shelly casing of some description of 'Annelid' [*Arenicolites*], Murray 1868, Rept. Geol. Surv. Newfoundland, p. 13; 1881, p. 145.
Arenicolites spiralis, Billings 1872, Can. Naturalist Geologist, vol. 6, No. 4, p. 478; 1873, Rept. Geol. Surv. Newfoundland, 1872, p. 16; 1874, Geol. Surv. Can., vol. 2, pt. 1, p. 77; 1881, Reprint of 1873 paper, p. 286; 1882, Geol. Surv. Newfoundland, Rept. Prog. 1881, p. 23; 1918, Reprint of 1882 paper, p. 23.
Arenicolites (*Spiroscolex*) *spirales*, Dawson 1897, Relics of primeval life, pp. 53, 54, fig. 13.

Murray (1868, p. 13) was the first to report remains "... supposed to be the shelly casing of some description of 'Annelid'", which were later (Murray, 1881, p. 145) identified as *Arenicolites*. These were found in association with Aspidella terranovica in his Division *d* in an area located, according to his cross-section 2, near St. John's in rocks now assigned to the St. John's Formation (Rose, 1952, p. 23).

Billings (1872, p. 478; and in all later reprinted descriptions of Aspidella terranovica) compared the markings with the *Arenicolites spiralis* described by Torrell (1869, p. LXVII) from Cambrian sandstones of Sweden. (Billings may not have been aware that Torrell (1870, p. 12) had already renamed his Swedish structures *Spiroscolex spiralis*.)

The first and only known published illustration—a crude drawing—was provided by Sir William Dawson (1897, p. 54), who also stated that the structures are well-characterized spiral worm castings. Packard (1898, p. 323) regarded them as worm traces. Walcott (1899, pp. 230, 231) made reference to them in the following words: "It appears to be impracticable to ascertain what the Arenicolite-like fossil is that Mr. E. Billings mentions as associated with Aspidella. No specimens are known to me to be accessible either in the collections of the Geological Survey of Canada or in those of Newfoundland". He later considered the forms to be inorganic (Walcott, 1901, p. 311). A comparison of Dawson's figure (1897, fig. 13) with those of *Helminthoidichnites*? *spiralis* (Walcott, 1899, Pl. 24, figs. 5, 6; 1914a, Pl. 21, figs. 5, 6) from the Greyson shale (Belt Supergroup) of Deep Creek Canyon, 12 miles east of Townsend, Montana, shows a remarkable resemblance of form.

The structures from Newfoundland do not appear to have been studied further, though they were briefly mentioned by Van Hise and Leith (1909, p. 80), who considered them inorganic, and by Rose (1952, p. 24). The original specimen has not been located. Efforts to obtain topotype material in 1967 were unsuccessful.

Medusichnites, Matthew 1891 (Taonichnites, Matthew 1890)

Plate 4, figure 1

Taonichnites, Matthew (*in* Selwyn) 1890, Am. J. Sci., p. 146.
Medusichnites "Form γ", Matthew 1891, Trans. Roy. Soc. Can., sect. 4, vol. 8, p. 143, pl. 12, fig. 3.
Medusichnites, Walcott 1898, U.S. Geol. Surv., Monograph 30, p. 100, pl. 46, fig. 1.
Longitudinal ridge marks, Craig and Walton 1962, Trans. Edinburgh Geol. Soc., vol. 19, pt. 1, p. 106.

In 1890, A. R. C. Selwyn, then Director of the Geological Survey of Canada, published a letter sent to him at his request by G. F. Matthew concerning supposed traces of fossils from the Animikie Group of Lake Superior. (The exact locality is unknown, but lies in the Thunder Bay area, according to a letter by Selwyn to Matthew dated December 21, 1889.) The specimens were collected in 1882 by E. D. Ingall of the Survey and sent to Matthew for examination. In a letter dated January 3, 1890, Matthew reported that there are two types of structures on the "pieces of flagstone and shale". One type he compared to *Eophyton* Torell, but found it different; he proposed to name it *Ctenichnites*. The other, which he compared with *Taonurus* Fischer-Ooster (at that time interpreted as a seaweed), he proposed to call *Taonichnites* because he thought it was trace fossil.

His description consists of the statement that the *Taonurus*-like impression "... exhibits a group of striae converging from a furrowed margin, and becoming more or less parallel and approximate." He interpreted these as successive drag markings of an animal having numerous tentacles with hooks or horny protuberances at their extremities.

Several months later, at the Royal Society of Canada meeting in Ottawa in May 1890, he presented a paper (published in 1891) in which he erected a new genus, *Medusichnites*, to specifically include *Taonichnites*, and abandoned the latter term. (*Taonichnites* is thus surely one of the shortest-lived generic names.) In that paper he described, among others, the form from the Animikie (form γ), illustrated it by a drawing, and interpreted it as drag marks made by a medusoid with a set of forty tentacles.

The original specimens were next examined by C. D. Walcott, who later published the only known photographic illustration (1898, Pl. 46, fig. 1) of the type specimen of "*Medusichnites*, form γ" from the Precambrian. Walcott concluded that, with the exception of a Paleozoic specimen, all varieties of *Medusichnites* are inorganic. The specimen from the Animikie was reported to be in the Museum of the Geological and Natural History Survey of Canada (Matthew, 1891, p. 164), but efforts to locate it have been unsuccessful thus far. The structures were mentioned in several later articles, e.g., Packard (1898, pp. 321, 322), Sarle (1906, p. 211), and Van Hise and Leith (1909, p. 270), but these added nothing significant.

In 1931, T. L. Tanton published a detailed study of the Thunder Bay area and mentioned the structures described by Matthew. He stated that he had obtained mud-flow structures on Mount McKay that exhibited the characteristics of the supposed fossils. Tanton (1931, pp. 45, 46) also quoted Ingall's interpretation of the original structures as mud-flow marks.

Häntzschel (1962, p. W234; 1965, pp. 55, 56, 90) considered *Medusichnites*, together with *Ctenichnites*, synonymous with *Eophyton* Torell, which he interpreted as drag markings, either organic or inorganic.

Examination of Walcott's photograph of the type specimen shows a very close resemblance to some structures from the Silurian of southern Scotland described by Craig and Walton (1962, pp. 105, 106) as "longitudinal ridge marks". These were interpreted as sole markings, produced on soft bottom sediments by scouring during a late, low-energy phase of turbid current flow when movement near the base of the flow occurred in lines or stringers (pp. 105, 116); vertical movement within the stringers was sufficient to erode the sediment. After successful flume experiments to reproduce such structures in the laboratory, Dzulynski and Walton (1963) modified this interpretation slightly, and suggested the use of the new terms "longitudinal furrows" and "dendritic ridges" (p. 286) for this series of closely related and transitional phenomena. They also cited other terms given to these structures by various authors (pp. 287, 288).

Dzulynski and Simpson (1966a, p. 288; 1966b, pp. 206–212) later reported additional experimental studies. Their most recent interpretation of the origin of longitudinal ridges is that they are formed by bottom shear drag of a flowing suspension, acting normal to the main flow direction on a soft substrate. They stress the importance of the following factors: (1) the gradational nature and close genetic relationship (dependent on flow velocity) between polygonal or curvate ridge patterns and the longitudinal ridges; (2) the existence of cells of convection-like motion caused by reversed density gradients brought about by settling within the boundary layer where current velocity decreases because of viscous drag, or by emplacement of low-density material; (3) the nature of viscosity distribution in the flowing suspension, and the viscosity of the bottom material; the viscosity contrast between suspension and bottom sediment determines the type of interfacial deformation, that is, whether ridges or furrows form.

The analogy between *Medusichnites* from the Animikie and the structures produced experimentally by Dzulynski, Walton, Simpson, and others is so close as to make an organic interpretation for the Precambrian structure untenable.

Ctenichnites, Matthew 1890

Ctenichnites, Matthew (*in* Selwyn) 1890, Am. J. Sci., p. 147.

In the same letter to Selwyn in which he discussed Taonichnites, Matthew (1890a) also described another piece of flagstone with markings quite different from the *Taonurus*-like impression. "These are straight and parallel, and in sets which often cross at a small angle. They look exceedingly like the glacial striae found on rock surfaces, in which, in a similar manner, the different sets interfere with each other." He compared the markings to similar but somewhat coarser and more widely spaced ones from the Cambrian of the St. John (New Brunswick) area, which he considered to be drag marks of some squid with at least three sets of arms beset with sharp spines or hooks.

In a subsequent paper Matthew (1891) does not mention any specimens of *Ctenichnites* from the Animikie rocks, though Paleozoic forms of this "genus" are described and illustrated. His illustrations of the Cambrian specimens suggest tool marks, or perhaps trilobite scratch marks.

Although reference to Ctenichnites is made by later authors, sometime between January 3, 1890 and the Royal Society of Canada meeting in May 1890 Matthew seems to have abandoned the interpretation that any of the Animikiean structures should be assigned to *Ctenichnites*. The specimens from the Animikie apparently were never illustrated; nor is it known where they were collected or deposited.

Tanton (1931, p. 211) published a photograph of "mud flow structures" (probably flute marks) from Pie Island. These resemble somewhat the hook- or crescent-shaped "*Ctenichnites ingens*" from the St. John Group (Matthew, 1891, Pl. 14, figs. 1–12). In view of the known abundance of such markings in the Thunder Bay area, it seems quite likely that the Animikiean Ctenichnites structures are sole markings, perhaps a combination of tool and flute marks.

Cyathospongia (?) eozoica, Matthew 1890

Plate 4, figure 9

Cyathospongia (?) Eozoica, Matthew 1890, Bull. Nat. Hist. Soc. N.B., vol. 2, No. 9, pp. 42, 43, fig. 1.

In 1889 G. F. Matthew collected fragments of peculiar structures that occur on certain smooth surfaces in layers of quartzite in the Green Head Group at Drury Cove, about 4 miles (6.5 km) north-northeast of St. John, New Brunswick. He first reported on these at the annual meeting of the Natural History Society of New Brunswick on Nov. 3, 1890 (Matthew, 1890d, p. 42). He also mentioned them in his presidential address to that society (Matthew, 1890b), where he compared them to *Cyathospongia* (= *Cyathophycus* Walcott 1879), and named them *Cyathospongia* (?) *eozoica*. They were diagnosed as follows.

> Skeleton of parallel and some forked spicules, crossed by other spicules at right angles, or nearly so. The spicules are of two sets of different sizes—one larger, forming a fenestral framework to the sponge; the other smaller, producing a minute network in the interspaces of the larger spicules. Spaces between the bars of the framework about one fourhundredth of an inch [= 0.0635 mm], the finer spicules are made visible by a one-fourth inch [= 6.35 mm] objective.

Neither the exact locality of the find nor the whereabouts of the original specimens are known.

Matthew's report of Precambrian sponges was soon questioned by H. Rauff (1893, p. 59; 1893–94, p. 114), an authority on sponges. Rauff remarked on, and was suspicious of, the extremely small size of the "spicules" compared to recent ones, the occurrence of such fragile bodies in quartzites, and the lack of precise mineralogic and microscopic analyses of the structures. He raised serious questions, and expressed the hope that Matthew would soon publish a more thorough and more critical study to substantiate his claims that the structures are spicules. This did not take place. Although Schwindewolf (1956, p. 472) and Häntzschel (1962, p. W234) state that Rauff (1893) considered *Cyathospongia* (?) *eozoica* to be of inorganic origin, Rauff only went so far as to express strong doubt about the affinity with the sponges, and provided no alternative interpretation.

F. J. Alcock published a geological report of the St. John area in which he merely made passing reference (1938, p. 11) to Matthew's structures. P. E. Cloud (1968, p. 57) interprets them as "probably crystals".

Halichondrites graphitiferus, Matthew 1890

Plate 4, figure 8

Halichondrites graphitiferus, Matthew 1890, Bull. Nat. Hist. Soc. N.B., vol. 2, No. 9, p. 49, fig. 2.

In the same papers in which he treated Cyathospongia (?) eozoica Matthew (1890b, p. 32; 1890d, p. 43) also described other supposed sponge spicules under the name *Halichondrites graphitiferus*. These are from graphitic shales in the Green Head Group near the Reversing Falls of the Saint John River, at Saint John. (Matthew also reported sponge spicules from graphitic beds in the vicinity of Drury Cove, but did not make it clear whether he considered them to belong to this "species".) He noted that these graphitic beds proved remarkably rich in spicules, and described them (p. 43) as ". . . immense numbers of simple spicules; long, acerate, and mostly in parallel sets. The sets of spicules lie across each other at all angles." He expressed uncertainty as to whether to consider them monactinellid or hexactinellid, but referred them to *Halichondrites* Dawson, a lyssakid hyalosponge. He also wondered why sponge spicules should be so plentiful in graphitic shale, and suggested that their morphology was preserved, but that the silica was replaced by some other mineral which he did not identify, presumably graphite.

Rauff (1893) wrote a very critical paper, more than twice as long as Matthew's, in which he presented strong arguments against the spongal affinities of Halichondrites graphitiferus. He questioned Matthew's interpretation on several grounds: (1) contradictory statements regarding preservation of external form of the sponges; (2) lack of a mineralogical study of the "spicules" and the replacement of silica by graphite; and (3) especially the manner in which the "spicules" cross at angles close to 60 degrees. Rauff compared them to scaly aggregates of graphite crystals in quartz from Ceylon (his fig. 3), which show surface markings corresponding to crystallographic planes. Another possibility mentioned was that the "spicules" represent percussion marks (Schlagfiguren).

Although the original specimens are not available for study, a mineralogical explanation for these structures may be considered. Graphite has a perfect basal {0001} cleavage, and the cleavage planes often have bundles of triangular striations resulting from gliding along an undetermined second-order pyramid (Hurlbut, 1959, p. 245). It is therefore possible that such a pattern on many thin flakes of graphite, with different orientations, could account for the observed pattern on the graphitic shales of the Green Head Group.

Another possibility is that the "spicules" are striations on slickensided surfaces, made by mineral impurities such as fine pyrite grains, or are scratches made during handling of the specimen. This possibility is suggested by a large number of small graphite specimens from the Green Head Group at the Reversing Falls; these are in the collections of The New Brunswick Museum, and labelled (incorrectly) "*Plectella prima*". (One of these specimens was kindly made available for inclusion in the GSC type collection (GSC type 24378) by the New Brunswick Museum.) These specimens show lineations in various directions on the slickensided surfaces, but whether they are the same as Matthew's Halichondrites graphitiferus is still unresolved.

Beltina danai, Walcott (1899) 1911

Plate 11, figures 3, 4

Beltina danai, Walcott 1899, Bull. Geol. Soc. Am., vol. 10, pp. 238, 239, pls. 25, 26; pl. 27, figs. 2–6.
Beltina danai, Walcott 1911, Smithsonian Misc. Collections, vol. 57, No. 2, p. 21, pl. 7, figs. 2, 2a, 3. Daly 1912, Geol. Surv. Can., Mem. 38, pt. 1, pp. 65, 183; Drysdale 1917, Geol. Surv. Can., Sum. Rept. 1916, pp. 58, 59.
Beltina danai?, Fenton and Fenton 1931, J. Geol., vol. 31, p. 686.
Beltina cf. *danai*, Fenton and Fenton 1937, Bull. Geol. Soc. Am., vol. 48, p. 1949, pl. 2, fig. 4.

Under the name *Beltina danai*, Walcott (1899) described thin, angular millimetre- to centimetre-sized, fragmentary remains of chitinous or carbonaceous films from calcareous shales of the Greyson Formation (Belt Supergroup) in the vicinity of Neihart, Montana. The fragments are abundant and generally without any regular outline and without ornamentation. He interpreted these as forms allied to crustaceans, comparing them to *Pterygotus* or *Eurypterus* fragments from the Lower Paleozoic of New York.

Similar structures with ornamentation, determined by Walcott as *Beltina danai*, were subsequently found in the Altyn Formation (Purcell Supergroup) in the Cameron Valley of Waterton Lakes National Park and west of Pincher Creek, Alberta (Walcott, 1911, p. 21; Daly, 1912, pp. 65, 183; Fenton and Fenton, 1931, p. 686). Others, identified by L. D. Burling of the Geological Survey of Canada as probably *Beltina*, were obtained from argillaceous beds at the top of the Aldridge Formation (Purcell Supergroup) in the Purcell Mountains, about 28 miles (45 km) west of Cranbrook, British Columbia, on the divide between the headwaters of Meachem Creek and the east fork of Goat River.

Beltina was later interpreted as partly inorganic (segregated carbon) and partly organic remains (broken fragments of thallophytes comparable to the modern *Scytosiphon*) (White, 1929, p. 393; Fenton and Fenton, 1931, p. 686; 1937, p. 1949; Fenton, 1943, p. 84). Raymond (1935, p. 382) considered these structures as biologic, probably the remains of brown algae, though he interpreted the forms from Waterton Lakes Park as arthropods. Häntzschel (1965, p. 15) listed *Beltina* as a valid genus, but in an earlier publication (Häntzschel, 1962, p. W238) he listed it with "unrecognized and unrecognizable 'genera'" under Miscellanea.

The two specimens illustrated by Walcott (U.S.N.M. types 57501, 57502) were examined, but no further information was obtained to enable a closer determination of the character of these remains. They are here considered as probably impressions of algae, and as possibly related to Morania antiqua (Fenton and Fenton, 1937, pp. 1949, 1950), or to the graphitic compressions from the Labrador Trough (Stinchcomb *et al.*, 1965, pp. 75, 76) or those from the Nastapoka Islands (Low, 1903, pp. 16DD, 31DD) (problematica of category 4).

Chuaria (Allan 1913)

Plate 11, figures 5–7

Brachiopod-like fossil in Hector Formation, Allan 1913, Geol. Surv. Can., Guide Book No. 8, pp. 174, 192.

Allan (1913, pp. 174, 192) reported having found brachiopod-like shells, about 3 mm in diameter, in a 50-cm shale layer about 16 m below the top of the Hector Formation (Latest Precambrian). The locality is at the eastern base of Storm Mountain, 30 km west of Banff, Alberta. The forms were not described further or illustrated, and no additional references were obtained.

With directions given by Allan shortly before his death, W. C. Gussow was able to locate the original locality and to collect specimens (Gussow, pers. com. 1968). Several of these were kindly donated to the Geological Survey of Canada (GSC types 24409, 24410). The structures are small, shallow depressions and low elevations of rather uniform size, about 3 mm in diameter, bearing concentric wrinkles, and scattered along bedding planes of shaly, maroon siltstone. Small smooth pimples without corrugations appear to be mounds containing buried wrinkled lensoids.

The bodies are indistinguishable from *Chuaria* Walcott (1899, p. 234) found in the Late Proterozoic of the Grand Canyon, but they appear to lack a thin bituminous layer. There is some resemblance to Aspidella-like structures (*see* Pl. 5, fig. 4), but these are much larger. It is evident that the wrinkling is of mechanical origin, resulting from compaction of small globular entities. Although some workers (Schindewolf, 1956, p. 463; Häntzschel, 1962, pp. W232, W233; 1965, p. 22) have expressed their opinion in favour of a definite inorganic origin of Chuaria (clay galls, concretions), the possibility remains that they are biologic remains, perhaps compressed planktonic spheroids, Foraminifera (Eisenack, 1966), or small medusoids similar to ones illustrated by Wade (1969, pl. 69, figs. 5–7).

Atikokania, Walcott 1912

Plate 6, figures 1, 2; Plate 10, figure 1

Atikokania lawsoni, Walcott 1912, Geol. Surv. Can., Mem. 28, pp. 18, 19, pl. 1 figs. 1–5; pl. 2, fig. 2.
Atikokania irregularis, Walcott 1912, Geol. Surv. Can., Mem. 28, p. 19, pl. 2, fig. 1.
Atikokania Lawsoni, Rothpletz 1916, Abhandl. Bayer. Akad. Wiss., Math.-Physik. Kl., vol. 28, No. 4, pp. 73–81, pl. 4, fig. 1; pl. 6, figs. 1, 2, 4–7; pl. 7, figs. 1, 3–4; text-fig. 8.
[Hyparchistylus irregularis, Raymond MS. 1923?]
[Aparchistylus symthi, Raymond MS. 1923?]

The original discovery of Atikokania structures was made by A. C. Lawson during the field season of 1911 in limestones of the Archean (?) Steeprock Group[1], on a ledge on the east side of Trueman Point, along the former shoreline of the east bay of Steep Rock Lake, Ontario (Uglow, 1913, p. 51).

The structures were the subject of a paper read by C. D. Walcott at the Geological Society of America Meeting in Washington, D.C. on December 28, 1911. This was published in the following year as a note in Lawson's memoir on the Steep Rock Lake

[1]For a recent summary of the geology of the Steep Rock area *see* Jolliffe (1966).

area. Walcott named the forms *Atikokania*[1]; described two species, *A. lawsoni* and *A. irregularis*; and observed that one or two other species were indicated, but that the material was not sufficiently complete for specific description. The genus was characterized as follows.

> General form cylindrical, pear-shaped or somewhat irregularly elongated, semi-globose. Central cavity more or less cylindrical and of varied form and proportions.
>
> *Walls.*—The outer and inner walls are more or less well-defined, and they are united by a series of small, more or less hexagonal tubes that radiate outward and upward at varying angles. The walls of the radial tubes are perforate, and divided by more or less incomplete septa.
>
> *Growth.*—The mode of growth appears to have been essentially the same as that of the *Archaeocyathinae*, where individuals press against each other that appear to have united at the point of contact by a more or less confused compact growth.

Walcott first considered the structures to be the remains of a group of organisms related to the sponges or the archaeocyathids. He expressed a preference for the former (1912, p. 18), but later (1914a, p. 98) said they were ". . . probably a spongoid of a rather advanced stage of development, although it suggests the Archaeocyathinae". At the time the find was widely hailed as the oldest fossil, and the Steep Rock Lake locality became an area of special interest—a half-day side trip on the transcontinental field excursion arranged in conjunction with the 12th International Geological Congress held in Toronto in 1913 and led by F. D. Adams, A. C. Lawson, and W. L. Uglow (Uglow, 1913, pp. 46, 50–52).

But the claim that Atikokania is the oldest fossil did not remain unchallenged for very long. Shortly after publication of Walcott's second paper on the structures (1914a), Abbott and Abbott (1914, p. 478) questioned the organic nature. In this paper and in others, Abbott (1914a, b, c) described and presented photographs of structures from Permian limestones of the Fulwell Hill quarry near Sunderland, Durham district, England, that somewhat resemble Atikokania, and attributed them to the physio-chemical effects of "segregation or to osmotic influence". Abbott (1914a, pp. 607, 608) inferred two processes involved in the formation of the structures: (1) production of rod structures starting at every possible angle from "bands of origin", and lying parallel to or divergent from one another; the rods often form a double series pointing in opposite directions; (2) the formation of concentric deposits by a process similar to that producing Liesegang rings.

Walcott (1914b, p. 478) replied to Abbott's objections, stating that he had not been aware of these remarkable structures from Sunderland, and that he now ". . . should *not* be inclined to refer the latter [Atikokania] to the sponges or to the Archaeocyathinae". Thus, 2 years after the original publication, Walcott had accepted the idea that Atikokania might not be a fossil.

Next to study Atikokania was Rothpletz who collected specimens at Steep Rock Lake in August 1913, on the International Geological Congress field trip. The results of his examinations were published in 1916, but apparently without the knowledge of Abbott's papers and that of Walcott (1914b), for there is no reference to them. He

[1]Atikokan is the Chippewa Indian word for deerhorn, and the name of the nearby town and river.

provided detailed descriptions and photographs of petrographic relationships, and emended Walcott's diagnosis of the "genus", stating (1916; p. 73) that the radial tubes never have regular hexagonal cross-sections, but are always irregular. Also, he did not find any evidence for the presence of outer or inner walls, septa (p. 73), or a central cavity (p. 76), and observed (p. 77) that a reliable picture of the external form of Atikokania is not known. Rothpletz also included a drawing (Fig. 8, p. 79) that shows his interpretation of what the structure looks like in vertical section. In discussing the systematic position of Atikokania, he drew a close analogy between it and the Lower Paleozoic lithistid sponge *Aulocopium*, and remarked that Atikokania has *only* radial canals and no central cavity.

FIGURE 7. Summary of references to Atikokania Walcott 1912

Author	Date	Interpretation of Atikokania Walcott
Hofmann	present	X Chemical; radial crystal growth, diffusion and replacement
Cloud	1968	X Replacement structure
Jolliffe	1966	O Possible fossil
Häntzschel	1965	X Inorganic
Glaessner	1962	X Structure of tectonically deformed and metamorphically altered sediments
Rezvoy *et al.*	1962	O Listed as genus of Porifera *incertae sedis*
Häntzschel	1962	X Inorganic (Raymond, 1935)
Voytkevich and Belokrys	1960	X Inorganic (Abbott and Abbott, 1914; Raymond, 1935)
A. E. Wilson	1957	X Probably inorganic (Abbott and Abbott, 1914; Raymond, 1935)
Schindewolf	1956	X Diagenetic
Seilacher	1956	X Inorganic
De Laubenfels	1955	O Listed as genus of Porifera, class uncertain
Okulitch	1955	O Listed as a genus of Archaeocyatha
Shrock and Twenhofel	1953	X Sponge nature has been discredited (Raymond, 1935)
Fritz	1949	X Inorganic
A. E. Wilson	1948	X Organic origin is doubted
Moore	1940	O At least one of Walcott's figures is a fossil
Moore	1938	X Inorganic
Raymond	1935	X { *A. lawsoni*: concretionary structure; replacement of limestone by dolomite starting along joints and cracks *A. irregularis*: aggregates of quartz crystals
M. E. Wilson	1931	X Inorganic
Osborne	1931	O Sponge
Metzger	1927	X Inorganic
Bain	1927	O Sponge
Seward	1923	? Not determinable whether organic or inorganic
Rothpletz	1916	O Sponge; compared with *Aulocopium*
Walcott	1914b	X Not a sponge or an archaeocyathid
Abbott and Abbott	1914	X Due to segregation or to osmotic influence; diffusion
Walcott	1914a	O Probably a spongoid of a rather advanced stage of development
Uglow	1913	O Related to the sponges
Walcott	1912	O Archaeocyathid or, more probably, a sponge
Lawson	1912	O Fossil Structure found by Lawson; reported by Walcott at G.S.A. Meeting, Dec. 28, 1911

X Inorganic, or probably inorganic.
O Organic, or possibly organic.

Since 1916 the structures have been interpreted variously as organic, inorganic, or of questionable nature (Fig. 7), but not much new information has come to light.

The paper by Raymond (1935) deserves special mention, as he is cited in several later ones as an authority on the inorganic origin of Atikokania. Raymond studied the type material as well as additional specimens donated to Harvard University (MCZ collection) in 1923 by H. L. Smyth[1] (letter by Smyth to P. E. Raymond, dated Oct. 31, 1923).

At some time during the 1920s Raymond produced a manuscript in which he described Aparchistylus smythi n. gen. n. sp. and renamed one of Walcott's species Hyparchistylus irregularis; this was never published (the manuscript is in the MCZ collection with the specimens). Aparchistylus was diagnosed as having ". . . radially arranged, closely packed prismatic tubes, within which there is a septum corresponding to each of the variable number of sides of the prism". Raymond considered it as probably a coelenterate, closely resembling the Ordovician tabulate coral *Tetradium*. In the same manuscript he cited Abbott (1914a) and Holtedahl (1921), and interpreted Atikokania as inorganic.

In his discussion of Atikokania irregularis, Raymond (1935, p. 381) referred to "some very excellent specimens" he had studied, and stated that ". . . thin sections show that it is composed of aggregates of quartz crystals, imbedded in a matrix of limestone. It is, therefore, purely of inorganic origin." In my opinion, these "excellent specimens" are those in the Harvard collection (GSC photo 200391, not illustrated here) for which he had once proposed the name Aparchistylus smythi, a name he later abandoned after reinterpretation of the structures as inorganic.

I have had the opportunity to examine both the GSC and MCZ specimens, as well as my own collections, and have concluded that all the structures are assignable to "Atikokania lawsoni", and that these should be regarded as inorganic for the same reasons that the remarkable Permian structures illustrated by Abbott (1914c) and clusters of radiating crystals are considered inorganic. The structures from the Steeprock Group are considerably more altered, recrystallized, and deformed than those from England.

Kempia huronense, Bain 1927

Plate 7, figures 1–3

Kempia huronense, Bain 1927, Pan-Am. Geol., vol. 47, pp. 281, 282, pl. 38 figs. A-B; pl. 39, figs. B-C.
Possible stromatolitic structures, Young 1967, Can. J. Earth Sci., vol. 4, p. 566, figs. 2, 3.

In 1923, while mapping the area of Huronian rocks extending northward from Hunter Lake north of Espanola, Ontario, G. W. Bain found some peculiar structures which he later (1927) described under the name *Kempia huronense*. They occur in massive quartzite 30 feet below the top of the Mississagi Quartzite (Lower Huronian) in the southwestern part of lot 9, range 1, Vernon township (46°27′25″N, 81°47′04″W), and at the same horizon at another locality 2 miles to the south in Porter township (Bain, pers. com., 1967).

[1]H. L. Smyth (1891, Am. J. Sci., vol. 42, pp. 317–331) had carried out early geologic mapping in the Steep Rock district.

A large sample taken from the Vernon township locality has the structure partly preserved. It is composed of rhythmic, curved, and branching laminae of silica and more recessive weathering material (Pl. 7, fig. 1). On one side, at what Bain considered the base from which the laminae emanate, is a development of a pattern of alternating resistant and more recessive weathering cellular layers, each about 1 mm thick (Pl. 7, fig. 2; the thickness appears to be greater because the photograph is an oblique view; the layers dip to the top left of the figure). There also is another, but indistinct, set of laminae intersecting the resistant layers, producing the effect of septate chambers (Pl. 7, fig. 3). Between the resistant laminae is a development of a delicate complex pattern of fine tubuli or platelets, which are about 0.2 mm wide (Pl. 7, fig. 2). The specimen is small and not sufficiently well preserved to allow the determination of the geometric characteristics of this intricate pattern, although it appears to be irregular.

The structure was interpreted by Bain (1927, p. 282) as probably the wall housing of a colonial organism " . . . which in the gerontic stage closely resembled a stromatoporoid and which in the nepionic stage had doubtful affinities"; the basal portion is composed of an elaborate pore system (with some resemblance to the wall structure of certain archaeocyathids), whereas the upper part is a simple filamentous structure. An inorganic origin was considered unlikely for the following reasons: (1) the laminae in the upper portion branch into two layers as they pass further from the central part and do not join again, as in structures caused by silicification and silication; (2) the presence of definite septa; (3) the structures are not caused by sedimentation, because the upper laminae end against radiating walls instead of being continuous, and they are convex downward with respect to the bedding where present, instead of being parallel; (4) they are not concretions because of the regular branching character of the laminae and the system of basal tubuli.

After the publication of the original description the structures were apparently not discussed again in print. Young (1967, figs. 2, 3) described and figured a structure that resembles the branching laminated structure of Kempia huronense (*see* Pl. 7, fig. 4; Pl. 8, figs. 1, 2). This is from the Gowganda Formation, 29 miles (50 km) east-northeast of Sudbury, Ontario.

Another specimen from the Gowganda Formation, 4 miles (6.5 km) northeast of Iron Bridge, Ontario, collected by P. W. Hay in 1960 and not heretofore described, also shows the Kempia structure (Pl. 9, figs. 1–3). It is in a piece of dark grey, finely laminated, and slightly folded argillite. The rhythmic, curved, branching, resistant- and recessive-weathering laminae transect the bedding lamination at nearly right angles. Their widths range from 4 mm down to less than 1 mm. Within the recessive-weathering bands is a network of very fine, rhythmic, resistant and recessive bands concordant with the larger bands; these average 0.1 mm in thickness (Pl. 9, fig. 3). It seems that the irregular tubuli in the cellular layers of the Kempia specimen of Bain are represented in Hay's specimen by regular minute laminae.

The resemblance between the two specimens in size range and appearance is apparent, and one is led to conclude that they probably had similar origins. Inasmuch as the coarse and delicate laminae of Hay's specimen cut across the bedding, they are clearly later than the primary sedimentary lamination, and hence cannot represent the walls of a colonial, skeleton-secreting organism. A reasonable alternative explanation is that they represent a physiochemical phenomenon—rhythmic precipitation or diffusion banding. Geometrically, the structures are not too different from the Newlandia of Walcott (1914a) and Eozoon.

Collinsia mississagiense, Bain 1927

Plate 8, figure 3

Collinsia mississagiense, Bain 1927, Pan-Am. Geol., vol. 47, pp. 282, 283, pl. 39, fig. A.

This structure was found in massive quartzite 40 feet below the top of the Mississagi Quartzite in Vernon township, Ontario, near the Kempia huronense locality.

Bain (1927, p. 283) described it as a body composed of sericite and quartz, 90 to 120 cm long[1] with ellipsoidal cross-section, 5 by 12.5 cm. It contains a series of hollow ellipsoids 1.3 to 6.4 mm long, with walls, 0.77 mm thick, of sericitized clay cemented by silica and filled with later quartz. The ellipsoids are irregularly grouped around a layered core of nearly oval cross-section; they increase in size and their cell walls increase in thickness with increasing distance from the nucleus. Certain ones may have had walls with microscopic cellular structure.

Bain compared the ellipsoids to pisolites, but ruled out an inorganic concretionary and accretionary origin, stating that the bodies were hollow casings which were later filled with secondary quartz. He preferred to consider them as colonies of algal cells that surrounded their soft parts with clayey matter cemented with silica.

For the present study only one of the original thin sections that shows several of the ellipsoids was available (Pl. 8, fig. 3), hence not much can be added to the discussion. The section shows a tight fold outlined by compositional banding that is probably primary bedding and is transected by an axial plane foliation. The long axes of the elliptical cross-sections seen in the upper left of the illustration are parallel to the axial plane of the fold, indicating that the flattening is deformational. No trace of the cellular structure was seen in this thin section. The "cell walls" are composed of a very fine grained (25 μ) brown biotite (?), and the centres are quartz and sericite of similar grain size, indistinguishable from the quartz–sericite matrix. It is doubtful that the ellipsoids were originally hollow and that they represent replacements or fillings of organic structures. If they were particulate spheroids (either organic or inorganic), one would expect them to have been deposited on bedding planes, but Bain's photograph indicates that no preferred accumulation parallel to the folded band exists. Their size, mineralogy, and geologic setting do not allow a useful comparison with the problematic spheroids of much smaller dimensions described under the names *Archaesphaera* (and *Calcisphaera*), and considered as questionably representing Foraminifera or plant remains of the oögonia type (Reitlinger, 1959, p. 7). Comparable spheroids have recently been described from Proterozoic dolomite of southwestern Greenland under the name *Vallenia erlingi* (Pedersen, 1966, p. 40; Pedersen, *in* Bondesen *et al.*, 1967, p. 20).

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[1]Bain's original measurements in British units.

Elliptical structures in Grenville limestone, Osborne 1931

Plate 23, figures 1–4; Plate 24, figures 1–4

Elliptical structures in Grenville limestone, Osborne 1931, Can. J. Res., vol. 4, pp. 570–573, pl. 1, fig. 1.
Cryptozoön-like structure, Wilson 1939, Geol. Erde. N. Am., vol. 1, p. 307, pl. 4B.

In 1931 Osborne reported on some structures from the Grenville at L'Amable near Bancroft, Ontario, which he compared to stromatolites, but which he interpreted as probably not biogenic. The occurrence is apparently unique, as no other finds have been made by geologists mapping the area (Adams and Barlow, 1910; Hewitt and James, 1956). Figure 8 shows the exact locality.

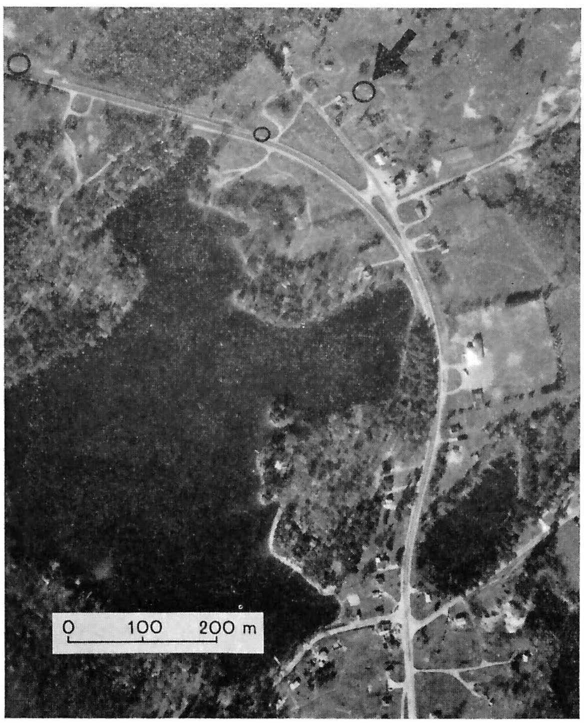

FIGURE 8

Location of elliptical structures in Grenville Limestone at L'Amable, Ontario, 4.2 miles (7 km) southeast of Bancroft. Large circle with arrow indicates the outcrop illustrated on Plate 23, figs. 1–4; the smaller circle marks the roadcut 150 m to the west-southwest that exhibits the folds illustrated on Figure 9. The elliptical structures are also found in the roadcut indicated by the large circle at the left margin.

The structures occur in marble of the Dungannon Formation (Mayo Group) of Hewitt and James (1956, pp. 20–24). The unit is part of the broad category generally referred to as "Hastings-type metasediments". At L'Amable the outcrop belt trends easterly and comprises rocks of a lower grade of metamorphism (amphibolite facies) than the gneissic and granitized rocks 2 miles to the north; relict bedding is well preserved in many of the exposures. To the south the marble is interbedded with "feather amphibolite"—bands of psammitic and pelitic metasediments composed of quartz, plagioclase, and stellate clusters of hornblende parallel to the original bedding.

The structures originally reported are seen on the south-facing glaciated surface of the small outcrop area of coarse-grained marble. They appear as closely packed, concentrically laminated, pointed ellipses, measuring about 27 by 10 cm and striking 045° (Pl. 23). Certain distinct laminae occur at definite distances from the centres of the ellipses, giving the appearance of being "marker laminae" that might possibly allow microstratigraphical correlation between adjoining columns. More deformed and less well preserved structures are found over a larger area in the outcrop to the east, southeast, and northeast.

Hewitt and James (1956, Map 1955-8) show a south-southeast dipping attitude of the bedding at this general locality. However, the structures of interest plunge steeply to the south. Several typical examples of the bodies were illustrated by Osborne (1931, Pl. 1, fig. 1) and again by M. E. Wilson (1939, p. 307). Nevertheless, in neither paper is the three-dimensional configuration of the structures discussed. This may have been due partly to the difficulty in obtaining specimens from the smooth outcrop.

Oriented polished sections of portions of several bodies show that the structures appear to have a flattened cylindrical shape and that the drawn-out elliptical sections seen in outcrop represent oblique sections across the flattened cylinders (Pl. 24, figs. 1, 2). The erosion plane lies about 45° to the axes of the cylinders and approximately parallel to the minor axes of the ellipses. A recalculation of measurements made on the erosion surface indicates average elliptical cross-sections of the columns of 19 by 10 cm, or an elongation of about 2:1 in the direction of 045°. No values are available for the average height of the columns, though a minimum of 30 cm is indicated. How the columns terminate at the extremities is also unknown.

The sections show a concentrically laminated structure of calcite and dolomite, and darker, more recessive weathering laminae containing minute flakes of graphite and pyrite (Pl. 24, figs. 3, 4). The dark bands are not continuous and are thinner than the lighter ones and somewhat irregular, with variable spacing (ranging from 1 to 10 mm in longitudinal sections parallel to the short axes of the ellipses). The laminae are arched (Pl. 24, fig. 1), forming acute but rounded conical shells. Transverse sections show dislocations and incipient foliation – tectonic effects. Irregular suture patterns outlined by graphitic concentrations are also visible and may be deformed stylolites. Where individual columns are not juxtaposed the intercolumnar space contains a more resistant weathering, olive-coloured, sugary, dolomitic filling that contrasts sharply with the coarse-grained calcite of the columns. Some parts of this olive intercolumnar filling also contain pockets of light coloured column material, but with a blotchy arrangement of the graphite concentrations.

In the original article Osborne (1931, p. 571) compared the structures with stromatolites of Proterozoic sequences. He considered the possibility that they might represent metamorphosed, mineralogically differentiated heads or columns that underwent recrystallization without flowage. Nevertheless, he thought it more likely that they were inorganic structures, developed after deformation by recrystallization under stress, and metasomatism. The reason given was that the structures at the best exposure have not been drawn out to a considerable extent, but to the north deformation has been greater, producing the "Eozoon" mentioned by him. He thought it unlikely that one part of the rock should have been protected while the adjoining part underwent deformation. In spite of this argument, a probable algal origin for the structures was favoured by M. E. Wilson (1939, p. 308), and has been accepted by some textbook authors (Dunbar, 1949, p. 124; Eardley, 1965, p. 317).

A reconsideration of the evidence for a stromatolite hypothesis is in order. The gross morphology, internal structure, distribution pattern, marker laminae, and bulk lithology are very much like a great many stromatolite occurrences in undeformed Proterozoic carbonate sequences. What distinguishes those at L'Amable is the coarse grain size, the non-regularity and large spacing of the darker laminae, and the deformed (squeezed) nature, all of which could be attributed to the effects of high-grade metamorphism. The notion that a relatively little deformed remnant of marble should be preserved in a more severely squeezed, plastically deformed belt need not invalidate the stromatolite interpretation, because the occurrence of breccia in the area just to the northwest demonstrates that parts of the marble have failed by fracture and brecciation rather than by flowage (Hewitt and James, 1956, p. 20). In addition, there are abundant outcrops showing well-preserved primary bedding (Hewitt and James, 1956, pp. 19, 21), so it is possible to have a favourably situated block containing remnants of primary sedimentary features.

The internal lamination presents a certain difficulty. The graphitic laminae, in the stromatolite interpretation, would represent the metamorphosed residue of carbonaceous material accumulated in the laminae of a growing algal column. In undeformed stromatolites the alternating dark and light laminae are more or less regularly spaced and very thin, as a rule not exceeding 1 mm in thickness. The laminae in the structures from L'Amable are more widely spaced and more irregular. One possible explanation is that carbonaceous material was not deposited or preserved with every lamina; another is that it was deposited regularly, but was remobilized during metamorphism and migrated to the present sites. There is at least one occurrence of stromatolites which has a strong resemblance to the structures, and that is *Archaeozoon acadiense* Matthew from the Green Head Group at Saint John, New Brunswick (Pl. 18, fig. 2). That stromatolite has much flatter arches, but this may be because the enclosing rocks never reached as high a degree of metamorphism.

Although a stromatolite origin for the original structures at L'Amable is reasonable, it is not considered proven. One is left to consider possible alternative explanations of inorganic origin. The idea of their formation by recrystallization and metasomatism *after* flowage presents some difficulties in view of the obscurity of the type of mechanism involved. If they are post-deformational, something must have localized the formation of closely packed columns of elongated concentrically laminated shells of calcite and graphite, and accumulated the silica and dolomite in the intercolumnar regions. In any case, the structures certainly predate the last deformational movements, as evidenced by offsets of laminae, drawing out of columns to produce pointed elliptical cross-sections, and possible remnants of stylolites. To account for an organic origin, one may look for a suitable chemical or mechanical explanation. One such explanation is provided in a new roadcut, 150 m west-southwest of the occurrence, in an exposure that was not available for investigation in the 1930s. Here, comparable structures can be traced into practically unfolded carbonate beds within a distance of 2 m (Fig. 9). They are of an unusual deformational origin, possibly representing an

FIGURE 9. Elliptical structures grading into practically unfolded beds at left. Vertical section exposed in roadcut on Ontario highway 62 at L'Amable. The axes of the folds are nearly perpendicular to the face of the cut. Metre stick gives scale.

interference pattern of superposed folds of the similar type (Ramsay, 1962). In another roadcut, 350 m to the west-northwest of the one just mentioned, the structures appear as elongated ellipsoids, possibly of concretionary origin.

Algae or colloidal bodies, Fenton and Fenton 1939

Plate 11, figures 1, 2

Algae or colloidal bodies, Fenton and Fenton 1939, Bull. Geol. Soc. Am., vol. 50, pp. 91, 92, pl. 1, figs. 3, 4.
Spherical to strung-out bodies, Thurber 1946, Geol. Surv. Can., Spec. Rept., pp. 2, 3.

In 1932 D. F. Kidd and A. W. Jolliffe of the Geological Survey of Canada observed and photographed certain problematic structures in cherts of the lower part of the Echo Bay Group on the eastern tip of Mystery Island, Echo Bay, Great Bear Lake (4.5 km south-southwest of Port Radium). These were later described from Kidd's photographs by the Fentons as ". . . concentrically laminated balls and irregularly laminated expansions whose character is shown by the illustrations. Some resemble small algal colonies; others suggest distorted masses of colloidal silica." No specimens were studied.

Thurber (1946, pp. 2, 3) added further observations, stating that these spherical aggregates are composed of chlorite, are 2.5 to 10 cm in diameter, and are strung out parallel to bedding. The structures have not been discussed since, and as no samples are available for study, details remain obscure and interpretations can be based only on the photographs and descriptions.

With the exception of the concentric pattern, the structures lack the characteristics comparable to algal (stromatolite) structures. Some seem to lie along rectilinear cracks (Pl. 11, fig. 1) and others appear as bands, which suggests that they may have formed after lithification. The forms are interpreted here to be of chemical origin.

Algal-like forms, Thomson 1960

Plate 8, figure 4

Ore zone carbonate, Thomson 1957, p. 48, figs. on p. 49.
Algal-like forms, Thomson 1960, Trans. Roy. Soc. Can., 3rd ser., vol. 54, pp. 67–71, fig. 1.

From the Whitewater Group (Aphebian) of the Sudbury Basin, Thomson described and illustrated structures which he originally interpreted as probably vein fillings, but later decided that they had formed under hot springs conditions under the influence of algae. Although he compared them to travertine deposits at Mammoth Hot Springs in Yellowstone Park, he pointed out that the evidence for a biologic origin of the Sudbury forms is not conclusive.

The laminated structures, which comprise both planar and concentric patterns, are found in brecciated, graphitic limestone of the Vermilion Formation, and can be collected as brown-weathering blocks in the dumps of the Errington No. 2 and

Vermilion mines, 13 miles (20 km) west-northwest and 17 miles (27 km) west of Sudbury, respectively. The locations of these mines and a detailed description of the geologic setting are given by Thomson (1957; Map 1965-1).

Typical forms have laminae varying from 0.05 to 2.5 mm in thickness. The laminae alternate between black graphitic and light carbonate bands. They are crenulated or mammillary, with some well-arched hemispherical or cabbage-like forms; but neither stacked hemispheroids, typical of columnar stromatolites, nor organic microstructures have been observed (Thomson, 1960, p. 68).

Successive laminae vary greatly in thickness, but individual laminae are remarkably uniform in this respect. The bands show cross-cutting relationships and mirror-image disposition: homologous (synchronous) laminae are symmetrically disposed, and crenulation convexities and bundles of diverging calcite fibres (cockscomb structure) face each other (e.g., the laminae on both sides of the thick dark band in the upper centre, and the laminae in the thick dark band along the bottom of Pl. 8, fig. 4). Collectively and individually these features are not characteristic of laminated algal structures; they strongly indicate that the laminae originated as direct chemical precipitates in a succession of fissures, without the activity of organisms. In the absence of stable carbon isotope determinations from this material, the origin of the graphite remains a problem, and its nonbiologic origin cannot be eliminated yet.

Graphitic compressions, Stinchcomb *et al.* 1965

Plate 10, figures 2–4

Graphitic compressions, Stinchcomb, Levin, and Echols, 1965, Science, vol. 148, pp. 75, 76, figs. 1a–1e.
[?] Carbonaceous markings, Low 1903, Geol. Surv. Can., Ann. Rept., vol. 13, pp. 16DD, 31DD.

Elliptical graphitic bodies of probable biologic origin were found in 1964 at two localities in Aphebian black shales of the Labrador Trough. They were first observed in a 1.2-metre-thick carbonaceous fissile black shale 0.8 km southwest of High Falls on the Swampy Bay River in rocks correlated with the Menihek Formation (upper part of the Knob Lake Group) (formation 10 of Dimroth, 1965, p. 17). The compressions here are mostly elliptical, but vary from circular to irregular. Major axes of the larger forms range from 1.5 to 4.5 mm, and the minor ones from 1.0 to 3.5 mm, with an average axial ratio of 1.67. They are abundant with as many as eight to ten within a square centimetre.

A second occurrence is in hard, brittle, carbonaceous shales of the Attikamagen Formation in the lower part of the Knob Lake Group at Schefferville, Quebec. The exact locality is the borrow pit at the northeast edge of the town, near the road to Squaw Lake. The specimens here are larger and better preserved than those at High Falls. They exhibit a granular texture. Their observed size ranges from 5.0 to 37:0 mm in major diameter, and 2.2 to 28.0 in minor diameter; their ellipticity is more pronounced, with an average axial ratio of 2.09.

These bodies differ little from those of the black shales of the Aphebian Michigamme Formation of the Iron River district in Michigan, studied by Tyler, Barghoorn, and Barrett (1957) and interpreted by them as compressed remains comparable to modern free-floating colonies of blue-green algae such as *Nostoc*.

Such structures have been described and illustrated from the Vindhyan Rhotas Limestone of India (Misra and Bhatnagar, 1950, fig. 1). The *Fermoria* (Chapman, 1935) from the Vindhyan Suket Shale, and the "Fermoria?" from the Chapoghlu Shale of the Soltanieh Dolomite (pre-Middle Cambrian) in northern Iran (Stöcklin *et al.*, 1964, p. 14, figs. 3–5) may possibly be similar structures also. Fenton and Fenton (1937, p. 1949) have given similar carbonaceous films from the Altyn Formation (Belt Supergroup) in Glacier National Park the name *Morania antiqua*.

In Canada, other structures that are possibly comparable to those from the Labrador Trough occur in the Nastapoka Islands (Locality 38), where Low (1903, pp. 16DD, 31DD) reported "... curious irregular markings, made by very thin deposits of black carbonaceous matter" in sandstone on the east side of Cotter Island, in the lower 50 feet of a 105-foot measured section. They may also possibly be similar to the Beltina danai from the Belt Supergroup (Walcott, 1911, p. 21; Daly, 1912, pp. 65, 183; Drysdale, 1917, pp. 58, 59; Fenton and Fenton, 1931, p. 686).

Rhysonetron, Hofmann 1967

Plate 12, figures 1, 2; Plate 13, figures 1–5.

Possible metazoans, Frarey and McLaren 1963, Nature, vol. 200, pp. 461, 462, fig. 1.
Rhysonetron lahtii, Hofmann 1967, Science, vol. 156, p. 504, figs. 4, 5.
Rhysonetron byei, Hofmann 1967, Science, vol. 156, p. 504, figs. 7, 8.
Possible organic structures, Young 1967, Can. J. Earth Sci., vol. 4, pp. 566, 567, fig. 4; 1969, vol. 6, pp. 795–799, figs. 2, 3.
Spindle-shaped sand bodies, Cloud 1968, *in* Evolution and environment, E. T. Drake, *editor*, p. 34, fig. 6A.

In 1960 C. E. Bye, a prospector from Sault Ste. Marie, collected a slab with vermiform markings on a parting plane within red arkosic sandstone of the Lorrain Formation (Upper Huronian), 2.6 km northeast of Desbarats, Ontario (Pl. 12, fig. 2). The structures were described by Frarey and McLaren (1963) and Frarey, Ginsburg, and McLaren (1963), and interpreted as fillings of bodies analogous to the curved, tapering, and branching parchment tubes of modern annelids, in particular *Chaetopterus variopedatus*. The markings are evenly curved spindles, as much as 140 mm long and 7 mm across, and preserved in a lithology identical with the matrix. An origin by desiccation crack filling was considered, but ruled out because of (1) lack of argillaceous material that could undergo shrinkage, (2) grain size similarity above and below the bedding plane, (3) clear separation of bodies from the matrix, (4) flattened form with longitudinal marking, (5) constancy of size and morphology, and (6) overlap of different spindles.

During a subsequent re-examination, faint corrugations were observed on some of the spindles, and a further specimen exhibiting a vertical section across the layer with the spindles was obtained (Pl. 12, fig. 1). The specimen shows that the spindles are flattened, and that the argillaceous parting plane has a maximum thickness of about 150 microns, but is only present in a few small patches.

In 1965, V. Lahti of Elliot Lake found similar specimens with well-developed corrugations in the Bar River Formation (Upper Huronian), in a roadcut on Ontario highway 639 east of Flack Lake, 23.3 km north-northwest of Elliot Lake, Ontario. These were described by Hofmann (1967), who considered them as questionably organic. Speculations as to origin included the tube-fill interpretation advanced previously for the spindles found by Bye in the Lorrain Formation, and also a comparison with casts of certain Paleozoic sponges. An inorganic origin was not ruled out, however, and the possibility that they are mudcrack fillings, injection, or crystal growth structures was considered, though not favoured. For purposes of reference and distinction they were given the names *Rhysonetron lahtii* and *Rhysonetron byei*.

Young (1967) independently found and reported the forms from Flack Lake, and also thought an organic origin likely. A new interpretation of the origin of these vermiform structures, through deformation of an algal mat, was advanced by Donaldson (1967b) and illustrated by him with photographs of modern structures. Lauerma and Piispanen (1967) have described rhysonetron structures from Proterozoic quartzites in northeastern Finland.

At the suggestion of J. W. Schopf (then at Harvard University), the writer submitted four polished sections of Lahti's Rhysonetron for microprobe analysis of carbon distribution to determine whether this element was concentrated in the periphery of the spindles, as might be expected if the structures were fillings of tubes of organic material. The analyses were inconclusive (J. W. Schopf, pers. com., 1967).

During the 1967 field season the first slab with several complete, corrugated specimens was obtained from the Flack Lake roadcut by G. O. Livo (Gulf Oil Corporation, Denver) (Pl. 13, fig. 5). This slab shows conclusively that the corrugated spindles (Rhysonetron lahti) are arranged in a distinct shrinkage crack pattern, and that a biogenic origin can no longer be considered.

What previously posed a problem with a mudcrack hypothesis for these structures was the origin of the well-developed corrugations, the clean separation of the spindles from the matrix, the elliptical or circular cross-sections, the paucity of mud, and the overlap exhibited by the structures—all factors not generally characteristic of occurrences of mudcrack fillings. Also, I am not aware of reports of corrugated mudcracks from the Phanerozoic record.

However, the specimens found by Livo make it evident that the rhysonetron structure is a Manchuriophycus-type pattern that has undergone unusual diagenetic modification. This modification must involve the reduction, if not elimination, of the pelitic layer, possibly by solution under considerable pressures. The presumed mode

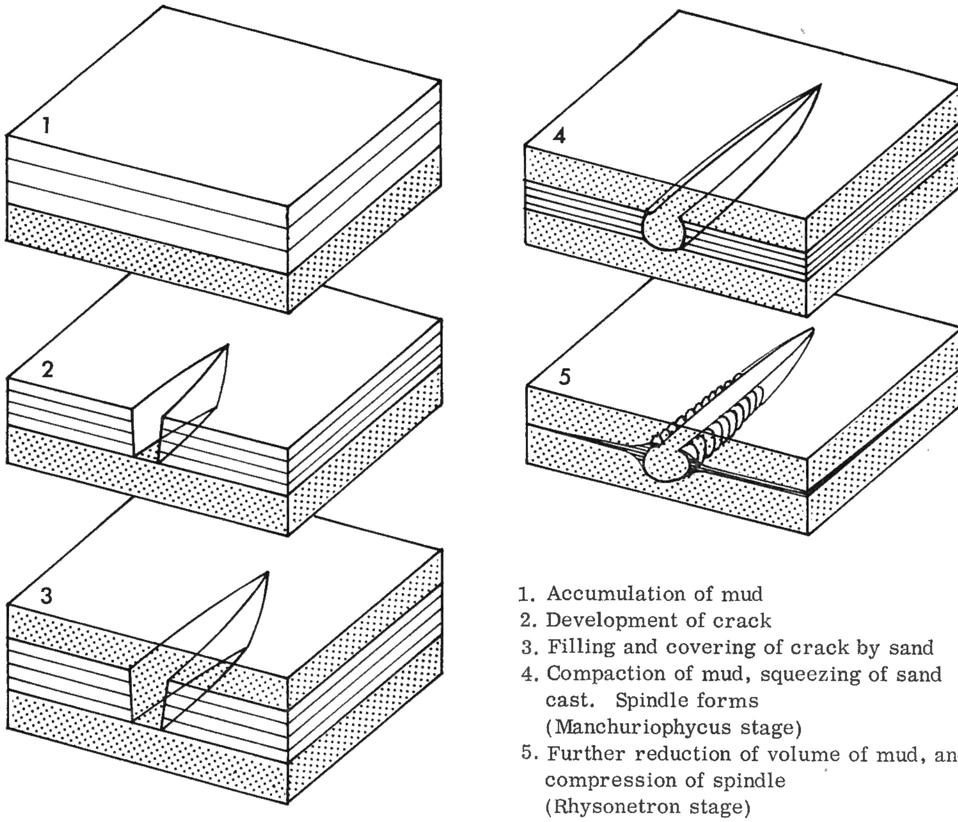

FIGURE 10. Presumed stages of development of rhysonetron structure.

of formation is as follows (*see* Fig. 10). A crack with angular cross-section forms in the argillaceous layer is filled with sand-sized material, and both undergo burial and compaction. The compaction of the mud exceeds that of the sand cast, causing a vertically directed pressure differential between the cast and mud layers. If vertical compression is not great, or if the sand filling has sufficient rigidity, the filling will not be deformed perceptibly. However, if the vertical pressure differential is excessive, the filling becomes plastic, buckles, and squeezes horizontally. The deformation will initially be mainly in the direction perpendicular to the long axis of the filling and result in a rounded cross-section. If the deformation in this horizontal direction relieves the pressure differential, and further flowage is inhibited, the continued vertical compression may result in flowage of material parallel to the long direction of the spindle until differential pressures are neutralized. The longitudinal, axial flowage of material will then produce an effect analogous to the shortening of an elastic bar, throwing the cast into wrinkles. These explanations would account for the interpenetration of specimens, and the opposed sets of corrugations in one of the specimens (specimen 1 of Hofmann, 1967, fig. 3). The medial longitudinal marking would be explained as the original suture of the mudcrack.

It is noteworthy that in Bye's Rhysonetron the amount of argillaceous material left as residue is extremely small and is confined to a few patches of a thin, stylolitic film. The pelitic layer in Lahti's rhysonetron structure is thicker (Pl. 13, fig. 1); X-ray diffraction analysis showed it to be without expandable clay minerals, and composed mainly of a mixture of $2M_1$, 1M, and (probably) 1Md polymorphs of mica with quartz and minor K-feldspar (analysis by R. S. Dean, Mines Branch, Ottawa; Mineralogical report MP-MIN-1053).

The other main difficulty has been the overlap shown especially well by Bye's Rhysonetron. To explain this on the basis of the mudcrack hypothesis it is necessary to infer that more than one layer developed cracks which were filled with sand, and then the whole was compressed and almost all the argillaceous material reduced to a small residue of a paper-thin film.

From these considerations it is concluded that despite the convincingly organic aspect of some specimens, Rhysonetron is a sedimentary–diagenetic structure, resulting from shrinkage crack filling, modified by compaction and injection processes, and impressed into the substrate and superstrate, accompanied by almost total removal of the pelitic layer.

Skolithos-like tubes, Hoffman 1968

Plate 25, figure 3

cf. *Scolithus*, Hoffman, *in* Siever 1968, Science, vol. 161, p. 711.
Skolithos-like tubes, Hoffman 1968, Geol. Surv. Can., Paper 68-42, p. 13.

Abundant brown-weathering, vertical, cylindrical structures 5 to 7 mm wide, and similar in form to *Skolithos* burrows, were reported by P. F. Hoffman in white, crossbedded, glauconitic quartz sandstone. They were observed at only one outcrop of the Akaitcho River Formation (upper part of Sosan Group), on the north shore of Charlton Bay near Reliance, at the eastern end of Great Slave Lake (62°44′N, 109° 4½′W; Hoffman, pers. com., June, 1968). Illustrations and further descriptions of the structures were not published.

Outcrop photographs and several specimens were available for examination. One of these specimens has been placed in the type collection of the Geological Survey of Canada at Ottawa (GSC type 24969; *see* Pl. 25, fig. 3). The others have now been destroyed in the process of separating the glauconite for radiometric age determinations in the Geochronology Laboratories of the Geological Survey of Canada.

Although accentuated on the weathered surface by a brownish coloration, no difference in microfabric between the cylinders and the matrix is noticeable in thin sections: the structures are mesoscopic phenomena which are not optically resolved in thin sections. Both the cylinders and the matrix of the samples examined are fine- to medium-grained sandstone (predominant grain size 0.1–0.4 mm) composed of subangular grains of quartz and some feldspar, well-rounded glauconite, and a coarser, secondary mode of grains (0.7–1 mm across) of well-rounded quartz, and some mudstone chips and muscovite platelets. The grains are cemented by ferruginous dolomite (non-effervescent in cold 10 per cent HCl; stained blue by potassium ferricyanide). Minor amounts of clay are also present.

The bedding planes pass across the cylinders without being disrupted, and as seen in polished sections, the boundaries of the cylinders are not distinct. These observations rule out a burrow origin and indicate a chemical origin for the structures. From the darker weathering colour it seems that they are segregations with a slightly higher ferruginous content than the adjacent matrix. However, a satisfactory explanation for their shape, attitude, and localization is still to be formulated. The erect attitude of the structures suggests a gravitational control over the originating mechanism. They possibly represent degassing or dewatering channels that were only very slightly more permeable than the matrix. Flow velocities must have been too slow to effect a noticeable reorganization of the fabric. Alternatively, they may be due to iron-enrichment or replacement in zones of downwardly percolating waters.

MACROFOSSILS

Under this heading are included all those structures whose biogenic origin is not doubted. This should include most of the remains described as stromatolites, but these are excluded from discussion in this chapter because they are more profitably discussed as a separate group in a later chapter.

Of all the non-stromatolite macrostructures reported from the Precambrian in Canada, only four forms are regarded here as undoubted fossils, and of these, two are now considered to be Cambrian or younger; one is definitely Precambrian; and the fourth is from beds tentatively regarded here as latest Precambrian (Random Formation of Newfoundland). A final age assignment of this fourth form must await the development of a practical method of placing the Cambrian–Precambrian boundary in conformable successions, something which has eluded geologists for a long time.

Annelid trails in Random Formation, Walcott 1900

Plate 10, figure 5

Annelid trails, Walcott 1900, Bull. Geol. Soc. Am., vol. 11, pp. 3–5.

The Random Formation is a distinct unit of arenites, with interbeds of shale, that straddles the 'Cambrian–Precambrian boundary' (Jenness, 1963, p. 56; McCartney, 1967, p. 62) in eastern Newfoundland.

Walcott (1900, pp. 4, 5) reported annelid trails from three localities on Trinity Bay: (1) at Hickmans Harbour, between 10 and 78 feet below the top of the Random, where he found several varieties including one about 5 mm broad, one slender form 0.5 mm broad, and an annulated trail 2 to 3 mm in width; (2) at Smith Point, in the lower 51 feet of a 107-foot exposed section; and (3) at Heart's Delight harbour, between 45 and 270 feet below the top of the Random. However, as the Random section at Heart's Delight is only 45 feet thick, according to McCartney (1967, p. 60), the supposed trails would therefore have come from beds now considered to be part of the underlying Snows Pond Formation of the Hodgewater Group. Mention of Walcott's trails appeared in later papers (Matthew, 1912, p. 558; Christie, 1950, pp. 19, 21, 26; Jenness, 1963, pp. 56, 158), but the structures were not illustrated, and no additional information was published.

The Hickmans Harbour locality was visited in 1967 to collect topotype material. Only deformed shrinkage crack fillings were seen in the Random Formation, but poorly preserved *Gordia*-like trails were noted in the shale–siltstone interbeds in the Cambrian Bonavista Formation immediately above the Random.

Outcrops mapped as Random Formation along the shore at the abandoned settlement of White Rock on Smith Sound (Walcott's Smith Point section) consist of interbedded thin siltstones and shales with some arenite beds. A measured section of these rocks is given by Walcott (1900) and reproduced by Jenness (1963, fig. 7). Topotype material of *Gordia*-like traces was obtained from the unit mapped as Random, confirming the presence of fossils at this locality. However, the section is lithologically quite distinct from the Random Formation at the Hickmans Harbour type section. Also, the beds immediately above the thin conglomeratic sandstone taken as the top of the Random in the Smith Point section (Jenness, 1963, fig. 7) are similar to those below and contain similar trace fossils. There is thus some question about the stratigraphic identity of the beds as well as the validity of the formational contact determined by Walcott. As mapped by Jenness (1963, Map 1130A), the Random Formation pinches out within a short distance to the north of this locality, and it is possible that the beds included in the Random Formation may actually belong to another stratigraphic unit, though the difference in lithology may merely represent a change in lithofacies from that of the type section.

The traces seen at White Rock (Pl. 10, fig. 5) are poorly developed, simple, nondescript trails or burrows, uniformly 1 to 2 mm across, that resemble *Gordia* Emmons 1844 or *Helminthoidichnites* Fitch 1850 in pattern. Further collections yielding better specimens are required before the forms can be assigned to a particular ichnogenus.

Brachiopods from Victoria Island, McNair 1965

Brachiopods, McNair 1965, Progr. Ann. Mtg. Geol. Soc. Am., p. 105; Geol. Soc. Am., Spec. Paper 87, p. 107.

Primitive, thin-shelled brachiopods, and other fossils, occur in a thin glauconitic shale and sandstone horizon within the outcrop belt of the Precambrian Shaler Group on western Victoria Island, N.W.T. (McNair, 1965a). Radiometric age determinations of 720 million years on glauconite from the fossiliferous unit, cited originally in support of a Precambrian age, were later revised to 445 million years by the commercial firm that performed the analysis (McNair, 1965b). Subsequently, a Cambrian age for the fossils was accepted (McNair, 1967). The fossils are derived from beds that represent an outlier of Cambrian rocks within the belt of outcrops of the Shaler Group, and therefore are not discussed further in the present work.

Organic burrows from Somerset Island, Tuke *et al.* 1966

Plate 14

Organic burrows, Tuke, Dineley, and Rust, 1966, Can. J. Earth Sci., vol. 3, p. 704.

Trace fossils were reported from rocks mapped as Hunting Formation in the northwestern part of Somerset Island, 4 km southeast of the mouth of the Hunting River (location G *in* Tuke *et al.*, 1966, fig. 3, p. 700; B. R. Rust, pers. com., 1968).

These rocks were presumed to be Helikian (Blackadar, 1967, p. 26), though Tuke *et al.* (1966) considered a Paleozoic age more probable because of the apparent conformity with overlying fossiliferous Ordovician beds.

Although originally thought to be of no use for age determination, these particular trace fossils, which were not illustrated in the paper by Tuke *et al.* (1966, p. 708), do at least indicate a Phanerozoic age for the source rocks. This is based on the variety and complexity of the forms exhibited by the slab illustrated on Pl. 14. They include teichichnian feeding burrows and *Palaeophycus*- and *Chondrites*-like tunnels, common in sandy beds of Phanerozoic age. To produce such structures complex metazoans are required. Faint (scratch?) markings on the larger structures suggest possible arthropod originators.

As the structures are not regarded here as Precambrian, they are not discussed further.

Metazoans from Conception Group, Anderson and Misra 1968

Plate 25, figures 1, 2

Soft-bodied Metazoa, Anderson and Misra 1968, Nature, vol. 220, pp. 680, 681, fig. 3., Misra 1969, Bull. Geol. Soc. Am., vol. 80, pp. 2133–2139, pls. 1–8.

The only assemblage of definite macrofossils known from Precambrian sequences in Canada was reported by Anderson and Misra (1968) from the upper part of the Conception Group (Hadrynian) of southeastern Newfoundland.

The fossils are preserved as impressions on ripple-marked surfaces in fine-grained psammites. The most abundant forms are bilaterally symmetrical, oblong plumose structures, ranging from 6 to 30 cm or more in length. Judging from the photographs, they appear to be composed of a distinct rhachis, and narrow, perpendicular, alternating or symmetrically paired primary branches bearing acutely diverging secondary markings.

A strong morphologic resemblance to the Charnian and Ediacaran pennatulacean genera *Charnia*, *Rangea*, and *Arborea* is evident (*see* Glaessner and Wade, 1966, p. 613), and it is likely that the Conception Group metazoans are North American representatives of the cosmopolitan Late Precambrian fauna previously known from Australia, Southwest Africa, England, and the Soviet Union.

The fossils were observed at five horizons within a relatively small thickness in the upper part of the Conception Group in the cliffs along the coast just west of Mistaken Point, 20 km southeast of the village of Trepassey on the southeastern tip of Newfoundland's Avalon Peninsula (46° 37.5′N, 53° 10′W).[1]

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[1]See Addendum, p. 64.

MICROFOSSILS

Although possible Precambrian microfossils in North America were reported by Leith (1903) and Walcott (1914a), it was not until 1918 that Moore (1918a, p. 427) described the first of such structures from Canada. These were obtained from the Early Proterozoic (Aphebian) Kipalu Formation of the Belcher Islands.

No further finds appear to have been made until 1953, when S. A. Tyler found extraordinarily well preserved fossil microorganisms in black chert in the basal part of the Aphebian Gunflint Formation on the north shore of Lake Superior. A preliminary report was published the following year by Tyler and Barghoorn (1954); five morphologically distinct forms were briefly described and three illustrated. Of the five forms, two were interpreted as algal, two as fungal, and one as probably a calcareous flagellate.

The next reference to Precambrian microfossils in Canada was that by Madison (1958) who reported fifteen different structures from Archean rocks of the Schreiber area on the north shore of Lake Superior. Based on the published evidence, however, the organic nature of these structures is very doubtful.

In the 1960s the number of papers dealing with the Gunflint material increased rapidly: Moorhouse and Beales (1962), Rutten (1962), Barghoorn and Tyler (1963, 1965a, b), Oró *et al.* (1965), Schopf, Barghoorn, Maser, and Gordon (1965), Cloud (1965), Cloud and Hagen (1965), Schopf (1967a, b), and Licari and Cloud (1968a). The most comprehensive paper on the Gunflint microflora is that of Barghoorn and Tyler (1965a) in which eight new genera and twelve new species were established. Reproductive structures of some of the Gunflint forms were discussed by Licari and Cloud (1968a), and the organic geochemistry of the fossiliferous chert was studied by Oró *et al.* (1965).

Presumed microfossils were also reported from three other Precambrian formations in Canada: actinomycetes in the sulphide minerals of varved argillites in the Gowganda Formation (Jackson, 1967), and poorly preserved spheroidal structures from cherts in the Kipalu Formation of the Belcher Islands and the Temiscamie Formation of Lake Albanel (LaBerge, 1966, 1967); eucaryotic nannofossils were found in the Hector Formation near Banff, Alberta (Licari and Cloud, 1968b).[1]

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[1]See Addendum, p. 64.

Gunflint Microfossils

By far the best known, best preserved, and most diverse assemblage of microfossils in the Precambrian of North America is that from the Gunflint, in particular from localities 6.4 km west of Schreiber, and 1.2 km west of Kakabeka Falls. Thus far sixteen different forms have been described, and fourteen have been formally named. In addition, there are many other types which are not yet described (Barghoorn and Tyler, 1965a, pp. 570, 573). The bodies are structurally and organically preserved, yielding organic compounds that are considered derivatives of chlorophyll.

Other types of problematic, possibly organic, microstructures from the Gunflint were described and illustrated by Moorhouse and Beales (1962), namely:

1. Rumpled filaments 20 to 40 μ thick
2. Spherulitic structures of carbonate 40 to 70 μ across with brownish cores up to 23 μ in diameter, resembling *Palaeorivularia ontarica* in size and form
3. Spherical carbonate grains 20 to 80 μ across with a dark carbonaceous or iron silicate core 10 to 20 μ wide
4. Clusters of spherical bodies 100 μ across with multiple walls
5. Iron silicate granules 9 to 20 μ in diameter
6. Various types of spicular structures
7. Some rare, more highly organized microstructures which were illustrated but not described

Inasmuch as the references to this microflora are so recent and so generally available, the forms will be commented on only very briefly, and only those that have received formal designation, or have otherwise been adequately described and illustrated, are included. Topotype material was collected for the Geological Survey of Canada, and the illustrations used on Plates 15 and 25 utilize this topotype material as much as possible.

Animikiea septata, Barghoorn 1965

Plate 15, figure 1; [?] figure 7

Animikiea septata, Barghoorn, *in* Barghoorn and Tyler, 1965, Science, vol. 147, p. 576; fig. 3–1, 2, 3.
Category 3 microfossils, Cloud 1965, Science, vol. 148, p. 31, fig. 3c.

This fossil was diagnosed as multicellular, unbranched filaments 7–10 μ in diameter, 100 μ or more long, straight or curved, with a thick granular sheath and closely spaced septa; cell length $\frac{1}{6}$ to $\frac{1}{10}$ the diameter of the filament. Barghoorn compared the forms to certain extant filamentous blue-green algae such as *Oscillatoria* and *Lyngbya*.

The multicellular nature of the type specimen, as exhibited in its photograph, is a rare feature; in most specimens the septa are generally not distinct, making it difficult to determine whether the transverse markings are present, and if so, whether they represent cell walls or are a surface feature.

Entosphaeroides amplus, Barghoorn 1965

Plate 15, figure 8; [?] figure 7

Entosphaeroides amplus, Barghoorn, *in* Barghoorn and Tyler 1965, Science, vol. 147, p. 576; figs. 3–3, 4; 4–2, 5.

Under this category are included nonseptate, unbranched filaments, 5 to 6 μ in diameter, 100 μ or more in length, straight or curved, with a distinct sheath that is not conspicuously granular. Lumina of filaments contain randomly distributed, spherical to ellipsoidal sporelike bodies, 2.5–3 μ in major diameter. Comparable modern forms occur in some blue-green algae and in iron bacteria (*Crenothrix*).

Specimens without sporelike bodies are indistinguishable from specimens of *Animikiea septata* whose transverse markings are not preserved. *Entosphaeroides* is a comparatively rare structure in the Gunflint, and was not encountered in the GSC collections.

Gunflintia minuta, Barghoorn 1965

Plate 15, figures 2, 3, 6

Fungal hyphae, Tyler and Barghoorn 1954, Science, vol. 119, p. 607, figs. 3, 4.
Primitive fungal plants, Rutten 1962, figs. 22a, 22b, 23a.
Gunflintia minuta, Barghoorn, *in* Barghoorn and Tyler 1965, Science, vol. 147, p. 576; figs. 4–6, 4–8, 6–1.
Category 1 (? and category 2) microstructures, Cloud 1965, Science, vol. 148, p. 30, figs. 2–C to 2–G, 3.
Filaments, Cloud and Hagen 1965, Proc. Natl. Acad. Sci., vol. 54, p. 4, figs. 1, 3, 4, 8–14.
Type F structure, LaBerge 1967, Bull. Geol. Soc. Am., vol. 78, p. 4, figs. 7, 8.

Multicellular, unbranched filaments, straight or curved; diameter less than 2 μ, usually 1.1 μ, may be more than 300 μ long, of uniform diameter throughout; septa distinct, cells equidimensional or longer than wide and of uniform size and shape. Comparable modern structures are seen among the blue-green algae and iron bacteria. They were originally interpreted as fungal hyphae (Tyler and Barghoorn, 1954), and most recently as nostocalean blue-green algae (Licari and Cloud, 1968).

This species is the type of the genus *Gunflintia*; it is the most abundant and most widespread form in the Gunflint, aside from the acritarchs, forming tangled masses visible in most of the thin sections of black stromatolitic chert from the Gunflint. The septate nature is not always apparent and depends on the state of preservation. Some specimens in an advanced state of degradation show an apparent spiral structure. Probable heterocysts and akinetes were described by Licari and Cloud (1968). This microorganism may have been the one chiefly responsible for the development of the stromatolite structure that characterizes the chert in which the microfossils occur, but this is by no means clearly established (Hofmann, 1969a, p. 19).

Gunflintia grandis, Barghoorn 1965

Plate 15, figure 4

Gunflintia grandis, Barghoorn, *in* Barghoorn and Tyler, 1965, Science, vol. 147, p. 576; figs. 4–1, 4–4.
[?] Category 3 microfossils, Cloud 1965, Science, vol. 148, p. 31, fig. 3c.

Multicellular, unbranched filaments, as in *G. minuta*, but diameter 2.5 to 5 μ, usually about 3.5 μ; filaments may also show constrictions at the septa; cells equidimensional or as much as three times longer than wide. This form is also widespread in the basal Gunflint, but is not as common as *G. minuta*. Its taxonomic distinctness from *G. minuta* has been questioned (Licari and Cloud, 1968).

Archaeorestis schreiberensis, Barghoorn 1965

Plate 15, figure 5

Archaeorestis schreiberensis, Barghoorn, *in* Barghoorn and Tyler 1965, Science, vol. 147, p. 576; figs. 5–5 to 5–8.

Nonseptate tubular, occasionally branched filaments, commonly with rugose walls, 200 μ or more in length, uniformly 2 to 10 μ thick except at bulbous swellings that are randomly spaced and less than twice the diameter of the filament. This structure is very rare and its phylogenetic affinity is problematic. According to Barghoorn and Tyler (1965a, p. 568) it is somewhat comparable to certain of the coenocytic green algae of the Vaucheriaceae.

Huroniospora microreticulata, Barghoorn 1965

Plate 15, figures 9, 10

Primitive plant, Rutten 1962, fig. 23c.
Huroniospora microreticulata, Barghoorn, *in* Barghoorn and Tyler 1965, Science, vol. 147, p. 576; fig. 5–1.
[?] Category 6 and 7 microstructures, Cloud 1965, Science, vol. 148, p. 31, figs. 4–D to 4–J.
Globular to ellipsoidal bodies, Cloud and Hagen 1965, Proc. Natl. Acad. Sci., vol. 54, p. 4, figs. 23, 24.
Type E structure, LaBerge 1967, Bull. Geol. Soc. Am., vol. 78, pl. 4, figs. 1–8.

Spheroidal to ellipsoidal unattached bodies 1 to 16 μ in major diameter; ellipsoidal bodies may exhibit a minute aperture at the more constricted end; wall thick, with regular reticulate sculpture.

Huroniospora macroreticulata, Barghoorn 1965

Plate 15, figure 11

Huroniospora macroreticulata, Barghoorn, *in* Barghoorn and Tyler 1965, Science, vol. 147, p. 576; figs. 4–7, 5–3.
Globular to ellipsoidal bodies, Cloud and Hagen 1965, Proc. Natl. Acad. Sci., vol. 54, p. 4, figs. 14–22.

Spheroidal to ellipsoidal bodies, as in type species, but walls thick and regularly murate.

Huroniospora psilata, Barghoorn 1965

Plate 15, figure 12

Huroniospora psilata, Barghoorn, *in* Barghoorn and Tyler 1965, Science, vol. 147, p. 576, fig. 5–4.
Fine-textured ovoid bodies, Cloud and Hagen 1965, Proc. Natl. Acad. Sci., vol. 54, p. 4, fig. 15.

Spheroidal to ellipsoidal bodies, as in type species, but walls relatively thin and unornamented.

The spheroidal structures assigned to the genus *Huroniospora* are widespread in cherty beds of the Gunflint Formation. Their affinities are difficult to determine, and their origin is probably diverse. They may be unicellular blue-green algae, spores of blue-green algae, bacteria, or fungi; or planktonic dinoflagellates (Barghoorn and Tyler, 1965a, p. 571). Such spheroidal forms are now suitably and non-committally classified in the Group Acritarcha Evitt (1963, p. 300) and the Subgroup Sphaeromorphitae Downie, Evitt, and Sarjeant (1963, p. 8). These forms require more detailed study.

Eoastrion simplex, Barghoorn 1965

Plate 15, figures 13, 14, [?] 19

Eoastrion simplex, Barghoorn, *in* Barghoorn and Tyler 1965, Science, vol. 147, p. 576, figs. 6–2 to 6–6.
Category 5 microfossils, Cloud 1965, Science, vol. 148, p. 31, figs. 4–A, 4–B.

Septate filaments, 3 to 8 μ long, about 1.5 μ across, of variable number but approximately equal in length, radiating from an irregular, opaque to membranous central body 2 to 8 μ or more long; diameter of central body $\frac{1}{5}$ to $\frac{1}{3}$ the length of filaments. This is the type species of *Eoastrion*. The structure is fairly common, but also of problematic affinities. It resembles the Mn- and Fe-oxidizing colonial bacterium *Metallogenium personatum* Perfil'yev 1961 (*see* Cloud, 1965, p. 31; Kusnetsov *et al.* 1963, p. 172, Fig. 57).

Eoastrion bifurcatum, Barghoorn 1965

[?] Plate 15, figure 15

Eoastrion bifurcatum, Barghoorn, *in* Barghoorn and Tyler 1965, Science, vol. 147, pp. 576, 577, figs. 5–2, 6–7, 6–8.

Septate, radiating filaments, as in type species, but filaments bifurcate and central body usually opaque and variable in size. This structure is apparently rare, as it was not encountered in any of the thin sections of the GSC collection made from material of the type locality. Some of the specimens of *Eoastrion* in this collection appear to show bifurcation, but one cannot be certain that the "branching" is not due to filaments being appressed or overlying each other.

Kakabekia umbellata, Barghoorn 1965

Plate 15, figure 16

Kakabekia umbellata, Barghoorn, *in* Barghoorn and Tyler 1965, Science, vol. 147, p. 577, fig. 7.

Structures having tripartite organization, consisting of spheroidal bulb, slender stipe, and umbrella-like crown 5 to 30 μ across; radiating, vein-like, occasionally dichotomously branched thickenings in crown are often tetramerous; overall length 12 to 30 μ. Size of bulb commonly varies inversely with size of mantle; perimeter of crown varying from scalloped, to lacerate, to tentacular.

This form is abundant at the Kakabeka Falls locality, but is rare elsewhere in the Gunflint. A living form similar in size and morphology has recently been found in soil samples at Harlech, Wales (Siegel *et al.*, 1967), and cultures grown under ammonia in the laboratory allowed study of the morphology of different growth stages; but the phylogenetic affinity of this microorganism is still obscure. The terminal structure may be a reproductive feature (Licari and Cloud 1968a, p. 1058).

Eosphaera tyleri, Barghoorn 1965

Plate 15, figure 17

Primitive plant, Rutten 1962, fig. 23b.
Eosphaera tyleri, Barghoorn, *in* Barghoorn and Tyler 1965, Science, vol. 147, p. 577, fig. 8.
Eosphaera tyleri, LaBerge 1967, Bull. Geol. Soc. Am., vol. 78, pl. 2, figs. 1–3.

Complex spheroidal structures consisting of a thick-walled inner sphere 20 to 24 μ across, bearing 0 to 15 randomly distributed spheroidal tubercles 2.5 μ in major diameter; inner sphere and tubercles encompassed by an outer thin-walled spherical membrane 28 to 32 μ across. This structure is rare and has been only found at the locality 6.4 km west of Schreiber. Its biological affinities are problematic.

Palaeorivularia ontarica, Korde 1958

Plate 15, figures 18, [?] 19

Structurally preserved plants, Tyler and Barghoorn 1954, Science, vol. 119, p. 606, figs. 1, 2.
Palaeorivularia ontarica, Korde 1958, Mat. Osn. Paleontol., vol. 2, p. 116, pl. 4, fig. 10.
Colonial alga, Voytkevich and Belokrys 1960, Soviet Geol., No. 4, p. 12, fig. 9.
Globose algal colony, Rutten 1962, figs. 20, 21.

Colonial actinomorphic aggregates of short, unbranching, radiating filaments embedded in a globular mass; central aggregates about 15 μ across, and filaments approximately 1.5 μ across.

The type specimen is now damaged, following breakage of the thin section in the mail (Barghoorn, pers. com., 1966). These structures were originally compared to the Rivulariaceae. They are not very common.

In the photograph of the type specimen (fig. 1 of Tyler and Barghoorn, 1954) fine dark lines can be seen to radiate from the central mass, perpendicular to and across the gelatinous "sheath", which suggests that a physiochemical mechanism may be responsible for the development of the "sheath". The central mass resembles *Eoastrion* in morphology, and it is possible that *Palaeorivularia* is an *Eoastrion* modified by centrifugal migration of the dark organic matter during diagenesis.

Eomicrhystridium barghoorni, Deflandre 1968

Plate 25, figures 4–7, 8?

Eomicrhystridium barghoorni, Deflandre 1968, Compt. Rend. Acad. Sci. Paris, vol. 266, p. 2387, pl. 1, figs. 1–3, text-fig. 1.

This species comprises organically preserved, globular to polyhedral microfossils, bearing short, nearly pointed, conical thorns or simple spines. The cells are generally less than 20 μ across, the diameter of the holotype being 13 μ.

Deflandre illustrated only one specimen, the holotype, from the Schreiber locality, and did not make any statements concerning the morphologic variability of the cells. He assigned the specimen to the Acritarcha, Subgroup Acanthomorphitae Downie, Evitt, and Sarjeant (1963), and compared it to one of the specimens of *Eoastrion bifurcatum* illustrated by Barghoorn (Barghoorn and Tyler, 1965, Fig. 5, pt. 2).

Cells referable to *Eomicrhystridium barghoorni*, and measuring between 10 and 15 μ in diameter, were observed in thin sections from the chert at the type locality 6.4 km west of Schreiber. Five of these specimens are illustrated on Plate 25. The number of conical spines on cells of the new material ranges between 4 and 20, the most common being between 10 and 14.

Rod-shaped bacteria, Schopf *et al.*, 1965

Plate 16, figure 1

Rod-shaped bacteria, Schopf *et al.* 1965, Science, vol. 149, figs. 1–4 and cover.

Rod-shaped structures, 1.1 by 0.55 μ, frequently clumped in groups of six or eight, or in chains as long as seven cells; surrounded by amorphous organic material.

Coccoid bacteria, Schopf *et al.*, 1965

Plate 16, figure 2

Coccoid bacteria, Schopf *et al.*, 1965, Science, vol. 149, figs. 5, 6.

Spherical, rough-surfaced bodies, about 0.35 μ across; cell walls sometimes broken and showing surficial folding; thickness of cell wall up to 0.15 μ.

Rod and coccoid types of bacteria were first recognized in chert from the Schreiber locality, but they appear to be widespread. They can barely be recognized with the optical microscope under 1000× magnification (Pl. 15, fig. 20).

The two forms are very common among living bacteria, and the structures from the Gunflint resemble some modern iron bacteria; in particular the coccoid form is close to *Siderocapsa* and *Siderococcus* (Schopf *et al.*, 1965, p. 1367; Schopf, 1967b, p. 28). However, the assignment of the fossil forms to a taxonomic category was thought to be unsatisfactory without a knowledge of their physiological processes. Nevertheless, it may eventually be useful for purposes of discussion and reference to have a formal name for them, as was done in the case of the Gunflint acritarchs.

Actinomycetes from Gowganda Formation

Gowganda actinomycetes, Jackson 1967

Plate 16, figure 3

Actinomycetes and other bacteria, Jackson 1967, Science, vol. 155, pp. 1003–1005, figs. 1–3.

Microstructures were reported from sulphide crystals in varved argillites of the Huronian (Aphebian) Gowganda Formation north of Lake Huron. One locality is the cliff exposure on the west side of Ontario highway 129, in the northeast corner of Wells township, just south of the turnoff to Kynoch (46°26′18″N, 83°20′05″W). The other is in the east-central part of township 169, near the northeast corner of a small lake on a small dirt road that goes east from a cluster of cabins on Ontario road 546 (T. A. Jackson, 1967, pers. com.).

The structures, described and illustrated with electron-microscope photographs, are of two types: (1) fragments of branching nonseptate filaments 0.05 to 0.1 μ wide, associated with amorphous material and spheroidal bodies, and considered to be hyphae of actinomycetes; (2) chains of crumpled rod-shaped bodies up to 0.14 μ long and 0.08 μ wide, some of which contain opaque rounded bodies; these were interpreted as probably bacterial cells, or perhaps spores of actinomycetes.

The possibility that these structures are contaminants was ruled out for several reasons: (1) the filaments appear to be completely flat, whereas recent microorganisms would have a three-dimensional aspect and more sharply defined outlines; (2) the filaments become thinner and less dense away from the tip, as if planed down during polishing; (3) a contaminant is unlikely to appear as disconnected fragments; (4) the rod-shaped bodies appear embedded in the mineral.

Nevertheless, one must consider the possibility that the structures, at least the filaments, are not indigenous to the mineral, in particular the structure shown on Plate 16, figure 3. Jackson (1967, p. 1003) briefly described the technique used to obtain the carbon replicas of the polished sections, and stated that the replicas were shadowed with germanium, but he did not provide specific information regarding shadowing direction and angle. Inspection of the original photographs, kindly provided by Jackson, permits two observations: (1) the curved filament and its branches, as well as the amorphous material, do not have a shadow; but the replica may be shadowed on the reverse side; (2) the lower left of the photograph shows that this same filament passes, without break, across a crack in the replica and across overlapping portions of the broken replica; (3) two of the short branches appear to overlie the main filament, as shown by differences in shading. It is evident that the image is of the filament itself, rather than of a shadowed mould. That such a delicate structure could have been stripped from the rock and carried through the procedures of replication without damage is questionable. Filamentous contaminants resembling Precambrian microfossils have been illustrated by Cloud and Hagen (1965, p. 3). These observations suggest that the filament may be a contaminant that has come to rest on the replica at some stage before the final photograph was taken.

Eucaryotic Nannofossils from Hector Formation

Eucaryotic nannofossils from Hector Formation, Licari and Cloud 1968

Eucaryotic nannofossils, Licari and Cloud 1968, Geol. Soc. Am., Progr. 1968 Ann. Meetings, Mexico, abs., pp. 174, 175.

Abundant microfossils were reported from the kerogen fraction of shales in the Hadrynian Hector Formation of the Banff area, Alberta. The most common types are alveolar, reticulately ornamented, globular unicells, 6 to 10 μ in diameter, resembling representatives of the modern green algal family Oöcystaceae. Another type, also resembling green algae, is represented by thin-walled, globular unicells 5 to 9 μ across, with an internal dark spot. These cells are sometimes associated in colonial aggregates.

MICRO-PROBLEMATICA

Under this heading are included a small number of microstructures of undetermined origin, described from Archean and Proterozoic rocks of Canada.

Belcher Islands Microstructures

Algal cell structures, Moore 1918

Plate 17, figure 4

Algal cell structures, Moore 1918, J. Geol., vol. 26, p. 427, fig. 14.

Moore found two types of microstructures composed of iron oxide near the base of the Kipalu Iron Formation along the Kipalu Peninsula, Belcher Islands (Moore, 1918a, p. 430). One type comprises spherical forms 0.5 to 10 μ across; the other is a filamentous structure composed of rows of spheroidal cells with diameters of 1 to 2 μ.

He submitted the samples to J. B. Hill, a botanist and colleague at Pennsylvania State College. Hill remarked on the resemblance of the spherical forms to the blue-green algae *Chroococcus* or *Gloeocapsa* and of the filaments to *Nostoc* or *Anabaena*, and provided a line drawing, which is incorporated in Moore's paper.

Moore and Hill favoured an organic origin for these structures because they felt that the sizes, shapes, and arrangement are too regular to be the result of simple replacement (Moore, 1918a, p. 427). The whereabouts of this collection is not known, and no additional samples have been obtained.

Microspherulitic structures, LaBerge 1967

Plate 17, figures 1–3

Type A structure, LaBerge 1967, Bull. Geol. Soc. Am., vol. 78, p. 334, pl. 1, figs. 7–11.

These microstructures were reported from the Kipalu Iron Formation of the Belcher Islands and the Temiscamie Formation of the Lake Albanel area. They also occur in the Gunflint Formation and the Biwabik Formation of Minnesota.

The structures from the Kipalu Iron Formation were found in samples collected in 1958 by G. D. Jackson of the Geological Survey of Canada. The sample illustrated by LaBerge (GSC No. JD-214-A) is derived from chert in the uppermost part of unit 12 of Jackson (1960, Map 28-1960) on Broomfield Island (southeast part of Belcher Islands), near the locality marked "Cu" on Jackson's map (55°43′40″N, 79°10′50″W).

The objects are spheroids, 15 to 40 μ in diameter, composed of "carbonaceous chert or iron minerals" with surfaces covered by curved or looped, vermicular fibres less than 0.5 μ across. They occur almost exclusively in granule-bearing silicate iron-formation, and there is a resemblance to the spherulitic structures described by Moorhouse and Beales (1962, pp. 103, 106, figs. 2d, 2e, 3a).

Some significant observations should be added to LaBerge's description of his type A structure. One is that the great majority of structures in the sample from the Kipalu Iron Formation occupy a position at the junction of two or more silica grains. This is especially noticeable when viewed under crossed nicols (Pl. 17, fig. 2). Furthermore, their size is in general directly related to the size of the adjacent silica grains; where the grains are small the spheroids tend to be small, and vice versa.

A second observation is that there is a distinct lack of alignment of the microspherulites along any plane, that is, clastic texture is not evident (Pl. 17, fig. 3) with regard to the spherulites. The structures tend to cluster around and to occur in the fine sand-sized grains, often surrounded by decoloration haloes, or lying in decolored "cracks" of these grains (Pl. 17, figs. 1, 3).

A third observation, and perhaps the most significant, is that the sample (GSC No. JD-214-A; GSC type 24379) comes from very near a diabase intrusion (G. D. Jackson, pers. com., 1968).

The evidence previously published in support of organic origin of these structures is not conclusive. Crystallization or coacervation may produce non-biologic structures of similar size and organization (e.g., Govett, 1966, p. 1198), and without a knowledge of the organic geochemistry, or in the absence of associated structures with more complex morphology such as occur in the Gunflint, the Kipalu and Temiscamie type A structures can at best only be considered as probably organic. With the additional observations just noted above, however, it is likely that these structures are of diagenetic or metamorphic origin.

Protozoans from Keewatin

Keewatin protozoans, Madison 1958

Plate 17, figures 5–11

Keewatin protozoans, Madison 1958, Trans. Illinois State Acad. Sci., vol. 50, p. 287, figs. 1–8.

Madison (1958) reported fifteen types of microstructures from black Keewatin cherts collected in 1955–56 in the roadcut on Ontario highway 17, 0.8 mile (1.3 km) northwest of Schreiber, Ontario. The structures are said to include bacteria, blue-green, green, and red algae, and seven species of protozoans. The protozoans were illustrated by line drawings, and identified on morphologic grounds with the following modern taxa:

Euglena sp.1
Euglena sp. 2
Oikomonas sp.
Ancyromonas contorta (?)
Ancyromonas sp. 2
Amphimonas globosa (?)
Sphaerastrum sp.

Glaessner (1966, p. 35) has expressed some doubt about their stratigraphic and morphologic distinctness from Tyler and Barghoorn's Gunflint material. However, there can be little doubt that the structures are, in fact, distinct from the Gunflint material. The rocks with the reported protozoans are pre-Aphebian (Archean); they occur 2.1 miles (3.5 km) northeast of the famous Gunflint locality near Schreiber, where the field relationships, that is the nonconformable contact between the Gunflint and the Kenoran basement of which the Keewatin iron-formation with the supposed protozoans is a part, are very clearly shown (*see* Harcourt, 1939).

Based on the published evidence, and without a knowledge of their organic chemistry, the biologic nature of the structures is very dubious. A plausible alternative inorganic interpretation is that the individual microstructures, which appear as detailed brown stains, are oxidation and hydration products (limonite) of the minute opaque iron-mineral grains within the bodies (the "coalified internal structures" of Madison). This interpretation is favoured for structures seen in thin section of chert (fine-grained quartzite) collected at the reported locality, but whether these are identical to Madison's is not known.

STROMATOLITES

The term stromatolite is used to refer to distinct, rounded, millimetre- to dekametre-sized, internally laminated, organosedimentary structures whose growth is recorded by a succession of laminae that represent intervals of accumulation of fine particulate matter on surfaces presumed to have been populated by benthonic microorganisms. The accumulation of preservable mineral matter is believed to occur by trapping of particles from suspension on the organic films, or by direct or indirect precipitation resulting from the metabolic activity of the microorganisms. The term oncolite refers to a spheroidal stromatolite that experienced passive mobility on the basin floor.

Stromatolites are found in almost every Proterozoic sedimentary basin in Canada (*see* Fig. 2); a notable exception is the type Huronian. The forms have been variously reported under names such as "concretionary structures", "contorted bedding", "algal structures", as well as by their accepted scientific name, and have received relatively little attention from geologists. Although known for many years, the stromatolites in Canada, with two or three exceptions, until recently have not been studied in detail with regard to their morphologic variability and stratigraphic significance.

Inasmuch as the Precambrian stromatolites of Canada form the basis of a separate study that is now in progress, they are not discussed in this bulletin (except for three forms that have received binary Linnéan names) and can be considered paleontologic forms, though not as biologic taxa. They are included in this paper to complete the inventory of Precambrian remains formally named in Canada. Other stromatolites are mentioned and their occurrence is plotted, but they are not discussed further.

The naming and classification of stromatolites are still subjects of much disagreement, and no new ideas are offered at this time. The pros and cons of a binomial nomenclature have been argued in the literature, but the problem is still unresolved. In the present chapter the structures are named according to the practice followed by the original author.

Archaeozoon acadiense, Matthew 1890

Plate 18, figures 1, 2; Plate 19, figures 1–3

Eozoon Acadiense, Matthew 1890, Bull. Nat. Hist. Soc. N.B., vol. 2, No. 9, p. 32.
Archaeozoon Acadiense, Matthew 1890, Bull. Nat. Hist. Soc. N.B., No. 9, pp. 38–41, 67, fig. p. 40.
Archaeozoon Acadiense, Dawson 1897, Relics of primaeval life, pp. 214, 215, 309, 310; 1897 (1896), Can. Records Sci., vol. 7, pp. 208, 209.
Archaeozoon Acadiense, Matthew 1907, Bull. Nat. Hist. Soc. N.B., vol. 5, pt. 5, pp. 547–552, pl. 11, figs. 2–4.
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G. F. Matthew first reported on these structures from the Precambrian Green Head Group near Saint John in his presidential address to the Natural History Society of New Brunswick (Matthew, 1890b, p. 32) and referred to them as *Eozoon acadiense.* In another article in the same issue (read on October 7, 1890) he described and discussed them and provided an illustration (Matthew, 1890c, p. 38); however the forms were first named *Archaeozoon Acadiense* in a supplementary note to the second article, dated December 3, 1890 (Matthew, 1890c, p. 67).

The essential characteristics of *Archaeozoon acadiense*, as described in Matthew's papers, can be summarized as follows: closely set, branching columns of calcareous and siliceous (dolomitic) laminae; domical arches are convex up and may be bluntly pointed to flat; columns are 2.5 to 7.5 cm across and several decimetres in length, bordered by a casing of more siliceous matter 5 or more mm thick, and separated from adjoining columns by narrow non-laminated filling; minute branching canals were reported but not illustrated. Matthew compared the fossil to the Upper Cambrian *Cryptozoon proliferum* described by James Hall in 1883, which, however, has a bulbous habit; as the names indicate they were interpreted as protozoans. Dawson (1897a, p. 212; 1897b, p. 215) regarded *Archaeozoon* as possibly another giant foraminifer, somewhat related to his *Eozoon.*

In response to reports of similar structures from the Beltian Siyeh Limestone of Montana, Matthew later (1907) reprinted the information of the 1890 papers, and also included further illustrations and information on three additional localities. It was not until 1914 that the modern interpretation of *Archaeozoon acadiense* as a stromatolite was suggested by Walcott (1914a, p. 114). Two decades later Hayes and Howell (1937, pp. 24, 25) described and illustrated the geological setting of this stromatolite. Subsequently, brief discussions of the occurrence and a small-scale map of the Green Head rocks were provided by Leavitt (1963) and Hamilton (1965). More recently, the type locality of *Archaeozoon* was on the itinerary of a field excursion held in connection with the 1966 annual meeting of the Geological Association of Canada (Brown and Pajari, 1966, pp. 13, 14). This locality, which is near the northwest tip of the Green Head Peninsula near Saint John (45°16′46″N, 66°07′57″W), is accessible without difficulty, and was examined and sampled to obtain topotype material for the collection of the Geological Survey of Canada. According to Matthew (1907, p. 552) the other localities of *Archaeozoon* are (1) on the east shore of the Saint John River, 1 mile (1.6 km) east-northeast of the type locality; (2) "at Douglas Avenue" in Saint John; (3) in small boulders in a red Carboniferous conglomerate on New Brunswick road 825 to Black River, 12 miles (19 km) east of Saint John. A brief search for stromatolites at the last two localities failed to provide any specimens.

At the type locality the stromatolites occur as a biohermal development in limestone beds lying between steeply dipping, northeast-trending fault zones. As might be expected, away from the faults the stromatolites are somewhat deformed, but not as much as near the faults where they are so drawn out that they are barely recognizable as stromatolites.

In modern terms of characterizing stromatolites, *Archaeozoon acadiense* Matthew 1890 can be said to belong to the actively branching columnar stromatolites (Komar, 1966), resembling yet distinct from some forms from the Middle and Upper Riphean of the Siberian Platform. A comparison of the Russian forms with *Archaeozoon* is difficult because of the deformed nature of the Green Head stromatolites. The branching pattern and gross morphology are similar to the groups *Minjaria*, *Inzeria*, and *Baicalia* proposed by Krylov (1963). Constrictions at the points of branching, such as illustrated on Pl. 18, fig. 1, are not always present, and the morphology of the enveloping surfaces depends to a great extent on the degree of deformation. The flat conical sections seen in some side views (Hayes and Howell, 1937, Pl. 1, fig. 2) remind one of *Conophyton*, but these stromatolites are definitely not assignable to this group (as emended by Komar, Raaben, and Semikhatov, 1965) because of the lack of axial zonation and their abundant branching.

In gross morphology *Archaeozoon acadiense* resembles Middle and Upper Proterozoic forms from the USSR, which suggests, if there is a valid basis for a stromatolite stratigraphy, that the Green Head Group should no longer be considered as probably Archean (Weeks, 1957, p. 133), but as probably Middle or Late Proterozoic. However, it also resembles *Archaeozoon septentrionale* (Fenton and Fenton, 1939) from the Lower Proterozoic Snare Group.

Hayes and Howell (1937, p. 24) expressed difficulty in deciding whether the base of the section at Green Head is in the south or the north. The attitude of the convexity, coupled with the attitude of the branching of the stromatolites, shows that the beds face north.

Cryptozoon walcotti, Rothpletz 1916 (?Walcott 1912)

Plate 21, figures 1, 2; Plate 22, figures 1–3

[?] Cryptozoan ?? sp. indet., Walcott 1912, Geol. Surv. Can., Mem. 28, pp. 17, 22; pl. 2, fig. 3.
Cryptozoon walcotti Rothpletz 1916, Abhandl. Bayer. Akad. Wiss., Math.-physik. Kl., vol. 28, No. 4, pp. 22, 80–82, pl. 2, fig. 6; pl. 8, figs. 1, 2.

Walcott (1912) illustrated, but did not describe, a thick thin section ". . . of what may be a form allied to the Precambrian Cryptozoan of the Grand Canyon section of Arizona." The thin section and the specimen from which it was made are in the type collections of the Geological Survey (GSC type 8059f). The specimen was collected in 1911 by A. C. Lawson in rocks associated with Atikokania in the Steeprock Limestone in the east arm of Steep Rock Lake.

The structure is developed in a dark grey, fine-grained (50 to 500 μ) limestone with a spotted appearance due to segregation of the dark and light components of the rock. Where the colour is more homogeneously dark grey, a fine crenulated lamination is visible, with dark decimicron-sized bands of carbonaceous flakes interlaminated with wider (0.1–1 mm) and lighter coloured bands of granular calcite. The lamination is affected by a later, oblique tectonic fabric that caused the development of crenulations. The sample appears to be deformed, and it is probable that the lamination of this particular specimen is a tectonic foliation and not stromatolitic.

These stromatolite-like laminae can be seen in the steeply dipping limestone on the south side of Trueman Point, a prominent knob on the former east arm of Steep Rock Lake. Field relationships here indicate that the convexity of the "Cryptozoan??" is oriented towards the bottom of the stratigraphic succession as given by Jolliffe (1966).

The "Cryptozoan??" of Walcott appears to be distinct from unquestionable stromatolites present in the Steeprock Limestone (Pl. 21, figs. 1, 2; Pl. 22, figs. 2, 3). Similar forms were investigated by Rothpletz on his brief visit during the 1913 International Geological Congress; they were later named after C. D. Walcott and interpreted as stromatoporoids (Rothpletz, 1916). Rothpletz's diagnosis of the form and his illustrations are not adequate to allow a comparison with other stromatolites except in the broadest of terms. The whereabouts of his specimens are not known. Rothpletz described the growth forms as separate columns composed of strongly curved, more or less concentric yet irregular laminations; the columns enlarge little and are so closely packed as to give the appearance of being laterally grown together. He reported the presence of microscopic tubes, but his illustration is unconvincing. Rothpletz noted the resemblance of the forms to *Newlandia concentrica*, *Collenia occidentale*, and *Weedia tuberosa* of Walcott (1914a)—structures of diverse morphology and origin.

In addition to the three localities along the east arm of Steep Rock Lake (Uglow, 1913), stromatolites are known also from the northwest part of the lake (Rothpletz, 1916, p. 81), and on the south and west sides of the former Elbow Point (Wegenast, 1954, p. 41, map).

One large sample collected by J. W. Greig, and now in the collections of the Geology Department of Queen's University, Kingston, was kindly provided for study by A. W. Jolliffe. It is a block of dark grey limestone, measuring 10 × 15 × 30 cm; it contains portions of at least a dozen small centimetre- to decimetre-sized columnar stromatolites (Pl. 21, figs. 1, 2; Pl. 22, figs. 2, 3). The stromatolites are composed of fine-grained carbonate and silica; they grew more or less isolated, and weather distinctively. They are surrounded by bedded, medium to coarse sand-sized carbonate and quartz. Some of the laminae can be traced from one column to the next across the intermound detritus, indicating that an algal community was able at times to populate the intermound areas and accumulate fine sediment, only to be buried by influxes of more coarse material while continuing to grow on the mounds. Later deformation produced the tectonic flattening of the columns and abundant calcite veins.

The forms are classifiable as wall-less, columnar stromatolites in the terminology of Korolyuk (1960); they appear to be a combination of the branching columnar and columnar–lamellar types of Krylov (1963); the structures in the polished section are assignable to the passively branching columnar stromatolite type of Komar (1966). No cellular microstructure was observed. The V-shaped junction of closely packed, wall-less columns reminds one of the much larger Aphebian stromatolite *Collenia kona* of Twenhofel (1919), and the sack-like intercolumn pocket of coarse detritus resembles those of *Collenia ferrata* and *C. biwabikensis* of Grout and Broderick (1919).

Archaeozoon septentrionale, (Fenton and Fenton 1939)

Plate 20, figures 1–3

Collenia septentrionalis, Fenton and Fenton 1939, Bull. Geol. Soc. Am., vol. 50, p. 91, pl. 1, figs. 1, 2.

This stromatolite is characterized by small, irregular, closely packed, actively branching columns, several centimetres across and as much as several decimetres long. The laminae are convex-up and uniformly curved or wrinkled. The intercolumn space is filled with detritus that weathers more resistantly than the columns.

These structures were found and photographed by A. W. Jolliffe in 1935 on a dolomite outcrop of the Snare Group (Aphebian) on a small island in Marian Lake (62°59′02″N, 116°17′45″W), 71 miles (115 km) northwest of Yellowknife (Jolliffe, 1936, p. 2). The Fentons compared this form to *Collenia kona* of Michigan (Twenhofel, 1919), *Collenia columnaris* Fenton and Fenton 1937 (= *Collenia frequens* of Walcott), and the stromatolites from the Great Slave Supergroup (Rutherford, 1929), but the resemblance is close only between it and the last two.

The assignment of the Marian Lake structures to *Collenia* is not acceptable in view of their columnar nature, compared to the nodular and oncolitic habit of the type form of *Collenia*, *Collenia undosa* Walcott 1914. The close spacing, general pattern, branching, and the presence of the intercolumn detritus of lithologically distinct material all conform to the characteristics of *Archaeozoon* Matthew 1890, and they are therefore assigned to this group until further studies have been carried out. As the form is generally somewhat smaller than the *A. acadiense*, and geographically remote from it, the stromatolite *A. septentrionale* is retained as a form distinct from that of the Green Head Group of New Brunswick.

A paratype was deposited in the Survey collections (GSC type 24408); the holotype is at Princeton University (Princeton type 24011). Further collecting and study are necessary to determine the variability of the macro- and micro-structure of this stromatolite form.

Other Stromatolites

There are many reports of Precambrian stromatolites, but most are one-word (or one-sentence) references stating that the structures are present in a certain formation. On Figure 2 most of the references are listed and the localities plotted.

Although some of the stromatolites have been assigned to *Cryptozoon* or *Collenia*, the information provided in most of the references is insufficient to allow the forms to be identified. One exception is the paper by Fenton and Fenton (1937): ten forms of *Collenia* are described from the Belt Supergroup of Montana, eight of which are also said to range into Canada. Other papers with detailed descriptions and discussions are those of Cloud (1942), Donaldson (1963), and Hofmann (1969a).

The Fentons reported the following forms from the Purcell (Belt) of Waterton Lakes National Park (exact localities are not specified):

Collenia albertensis Fenton and Fenton 1937
C. clappii Fenton and Fenton 1937
C. columnaris Fenton and Fenton 1931
C. frequens Walcott (1906) 1914
C. symmetrica Fenton and Fenton 1931
C. undosa Walcott 1914
C. versiformis Fenton and Fenton 1937
C. willisii Fenton and Fenton 1937

With the exception of *Collenia undosa*, which is the "type species", the assignment of the other forms to *Collenia* is open to question, as is the validity of the forms or "species", described in 1937. According to Rezak (1957, pp. 133, 134), *C. columnaris, C. versiformis*, and *C. albertensis* are synonymous with *C. frequens*; *C. clappii* is synonymous with *C. symmetrica*; and *C. willisii* is partly synonymous with *C. undosa* and partly with *C. multiflabella* Rezak 1957. The above list for the Purcell of Waterton Lakes Park then reduces to only three forms:

C. frequens Walcott (1906) 1914
C. symmetrica Fenton and Fenton 1931
C. undosa Walcott 1914

The assignment of one of these is further refined by reference to the recent Russian literature. *Collenia* has for a long time served as a receptacle for too many forms—most of the stromatolites described in the world literature were placed in this group, which thus has become "overloaded". Russian workers have therefore proposed new names for many of the forms formerly assigned to *Collenia*. The *Collenia frequens* Walcott has been assigned to *Colonnella* Komar 1964 (*see* Komar, 1966, p. 69), a non-branching, columnar stromatolite. The *Collenia symmetrica* of Rezak (1957) appears to be a composite group, however, and some of the forms may be *Collenia*. The Purcell stromatolites should be restudied and compared with the Riphean stromatolites described in the Russian literature.

The stromatolites reported by Cloud (1942) from limestone beds now included in the Kilian Formation (Shaler Group) of Victoria Island occur in small biohermal masses as much as 3.7 m across and 1.2 m high. Individual structures are branching columns 1 to 3 cm across, and spaced a similar distance apart. Cloud (1942, p. 367) compared the forms to *Gymnosolen ramsayi* Steinmann, but identified them only as "digitate stromatolites (gymnosolen)" because he favoured abandonment of binomial names for stromatolites.

Donaldson (1963) described stromatolites from the Marion Lake area in the Labrador Trough, utilizing a 'descriptive adjective classification'. He recognized six forms in the Denault Formation (Knob Lake Group):

hemispherical stromatolites (*Collenia* Walcott)
bulbous stromatolites (*Cryptozoon* Hall)

columnar stromatolites (*Archaeozoon* Matthew)
digitate stromatolites (*Gymnosolen* Steinmann)
pisolitic stromatolites (*Pycnostroma* Gürich)
undulatory stromatolites (*Weedia* Walcott)

His paper also contains a general discussion on stromatolites as well as a summary of occurrences in Proterozoic rocks of Canada.

One very puzzling and distinct group of stromatolites is *Conophyton* Maslov (as emended by Komar, Raaben, and Semikhatov, 1965), which appears to be an index to the Precambrian and to show promise in stromatolite zonation in the Middle and Upper Proterozoic (Komar, Raaben, and Semikhatov, 1965). However, not much work has been done in North America to corroborate this. *Conophyton* is widespread in the Soviet Union Riphean, but has so far been identified in Canada only in the Helikian: the Siyeh Formation of Alberta, the Parry Bay Formation and Hornby Bay Group in the District of Mackenzie (McNeely, 1963; Donaldson, 1969), and the Sibley Group north of Lake Superior (Hofmann, 1969a, p. 22).

SUMMARY

The present study is a synthesis of widely scattered data on Precambrian remains in Canada, and it provides an inventory that forms a basis for future studies on Precambrian fossils and pseudofossils. A number of important conclusions have been reached, and these are given below.

Morphologic evidence for the presence of Precambrian microorganisms in Canada is widespread in the form of stromatolites, and ranges in age from Late Archean? (Steeprock Group) into the Phanerozoic. Morphologic expression of the biota is scarce, and at this time known with assurance only through the microfossils from the Gunflint Formation (*Aphebian*) of the Lake Superior area, the lower part of the Belcher Supergroup (*Aphebian*) of the Belcher Islands, and the Hector Formation (*Hadrynian*) of the Rocky Mountains. Other described microstructures are problematica and structures not of Precambrian age.

Macrofossils are found in the form of metazoan impressions in the Conception Group and as trace fossils in the Random Formation, which is of questionable Precambrian age. Other reported macrostructures are of inorganic or doubtful origins and cannot be considered as genuine fossils; or, they are genuine fossils, but of younger age. Some of the problematica, such as the graphitic compressions from the Labrador geosyncline and Beltina danai from the Purcell, are probably of organic origin, but their true nature is still to be ascertained.

We are thus left with the following remains that can be considered as genuine fossils: the metazoans from the Conception Group, the microfossils from the Gunflint and Hector Formations, the Belcher Supergroup, trace fossils in rocks of questionable, Precambrian age, and a large, but unknown number of stromatolite forms.

Finally, it may be observed that the Precambrian pseudofossils most often described and interpreted as of biologic origin are those structures that exhibit a certain radial, cellular, or rhythmic pattern. This indicates that one must come to appreciate that chemical and mechanical processes, active in a variety of geological materials and environments, can produce such periodic phenomena and imitate the architecture of organisms. Or, better, one should consider the converse, as Sir D'Arcy Thompson (1942) has so eloquently done, namely that it is the inorganic configuration, dependent on basic chemical, physical, and mathematical factors, which is imitated in the shape of living things.

ADDENDUM

(added in proof)

Several new papers concerning Precambrian remains have appeared since the manuscript was submitted. This material was received too late for inclusion in the body of the report, but is here briefly summarized. The developments are as follows:

(1) Hofmann and Jackson (1969) described a small microbiota from black chert in the lowermost exposed parts of the Belcher Supergroup in the north-central part of the Belcher Islands (56°27′N, 79°31′W). Microfossils include forms of probable algal, fungal, and bacterial affinities:

Biocatenoides sp.
Type 1 (clumps of coccoid cells)
Eomycetopsis sp.
cf. *Archaeotrichion*
Huroniospora sp.

In addition, three other types of microstructures (micro-problematica) of possible or probable biologic origin, and one micro-pseudofossil ("*Palaeomicrocoleus*"), were described.

(2) The biogenic nature of the metazoans from the turbidite sequence in the Conception Group reported by Anderson and Misra (1968) from southeastern Newfoundland was questioned by Goldring (1969). This discussion also contains a reply by Anderson and Misra setting forth reasons for considering these as biogenic. Shortly thereafter Misra (1969) published a fuller description and illustrations of four categories of structures:

spindle-shaped organisms
leaf-shaped organisms
round lobate organisms
dendrite-like organisms

The forms are most probably soft-bodied coelenterates. The first two, and particularly the leaf-shaped form, appear to have a grade of organization similar to that of *Charnia* or *Rangea* from Late Precambrian rocks of England and Australia; the lobate forms appear to be imprints of medusoids. These fossils still require detailed study.

(3) Small rounded structures, possibly of biologic origin, were reported from Aphebian or Archean chert in the Beaverlodge area, northern Saskatchewan (Beck, 1969, p. 12, Pl. 12A). The locality is near the Nesbitt Labine Eagle mine, about 4 miles (6.5 km) east of Uranium City.

These micro-problematica are light coloured ellipsoids, about 50 to 100 microns in diameter, containing a dark, elongate central mass whose size appears to be related to the dimensions of the ellipsoids. A possible alternative to the biologic interpretation is that the bodies represent chemical or radioactive alteration zones around the dark coloured masses.

(4) A description of stromatolites in the Animikie and Sibley Groups north of Lake Superior (Hofmann, 1969a) and a general discussion on stromatolites (Hofmann, 1969b) were published, as well as an increasing number of incidental references to Precambrian stromatolites (many authors).

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PLATES 1 to 25

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 thin sections 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

Eozoon canadense

Figure 1. Eozoon canadense, Grand Calumet type, Logan 1863 (PAGE 7)
Cross-section of the specimen collected by J. McMullen in 1858, and first illustrated by Logan (1863, p. 49). The recessive laminae are calcite, and the resistant ones are light coloured clinopyroxene. The calcite laminae in the left third taper to the right, and some branch or intersect; they merge within a zone that is probably a plane of dislocation. In the right two-thirds the calcite veins are thicker, more widely spaced and slightly bent in a direction opposite to those on the left. The specimen is from "Grenville limestone" at the rapids of the Grand Calumet channel of the Ottawa River, near Bryson, Quebec.
GSC type 165 GSC photo 200446–A

Figure 2. Eozoon canadense, same specimen as in fig. 1 (PAGE 7)
Top view, illustrating the curvature, size, and branching of the laminae.
GSC types 165 (left part) and 165a (right part) GSC photo 200446–F

Figure 3. Eozoon canadense, Tudor type, Dawson 1867 (PAGE 9)
Top view of specimen collected by G. H. Vennor in 1866. The white crescentic bands are medium crystalline calcite, and are embedded in fine-grained, medium grey limestone. Paper-thin calcite veinlets cut across the slab from top centre to bottom left. The specimen is from a heap of boulders in a field on the northeast side of the old road to Millbridge, 0.7 mile (1.1 km) southeast of Millbridge, Tudor township, Ontario.
GSC type 157 GSC photo 200446–D

Figure 4. Eozoon canadense, Tudor type, same specimen as in fig. 3 (PAGE 9)
Side view of sawn surface, showing that the calcite bands do not extend into the specimen more than about 3 mm. Also seen are the horizontal compositional banding, most likely palimpsest bedding, and intersecting calcite veinlets in the lower right.
GSC type 157 GSC photo 200446–J

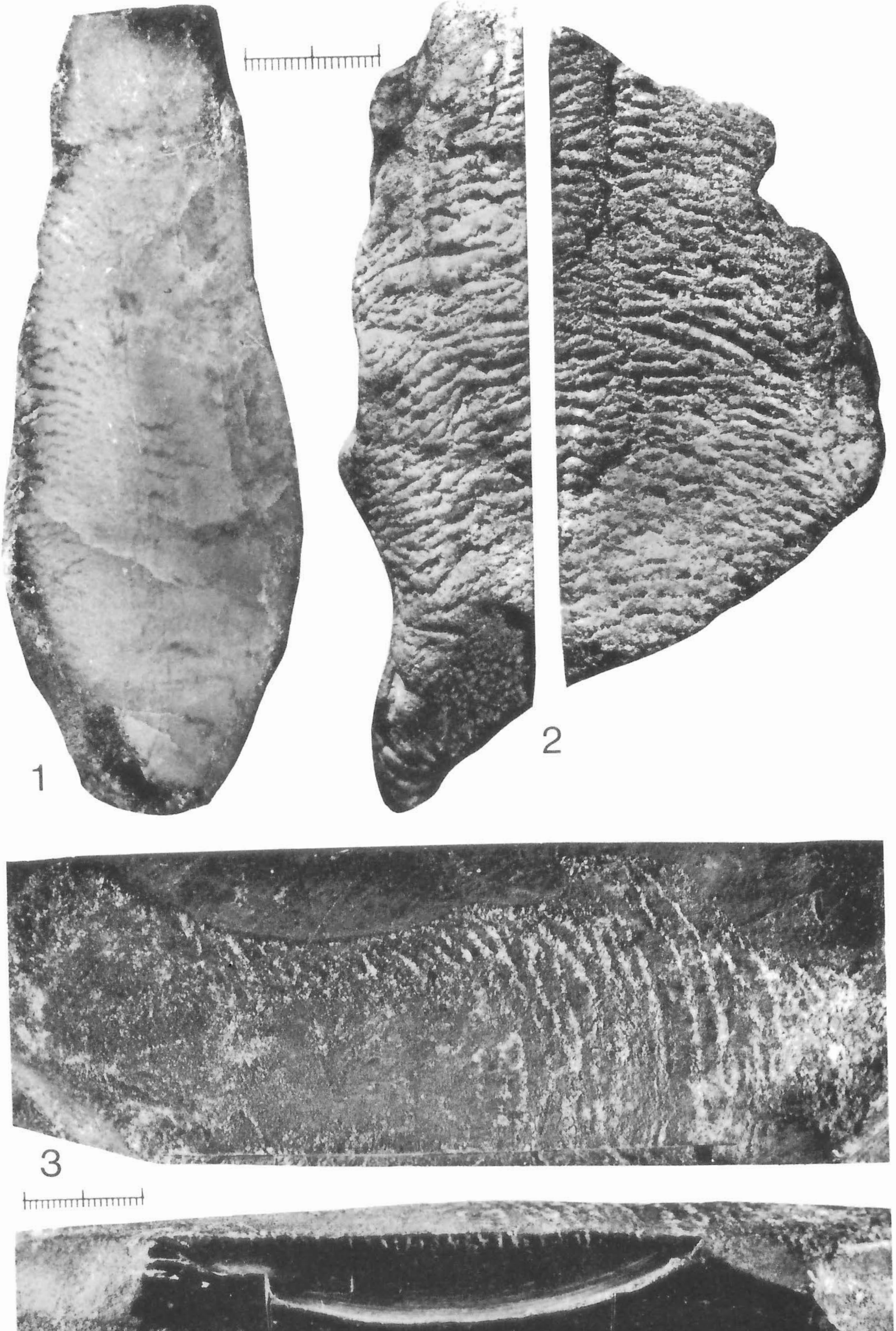
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PLATE 2

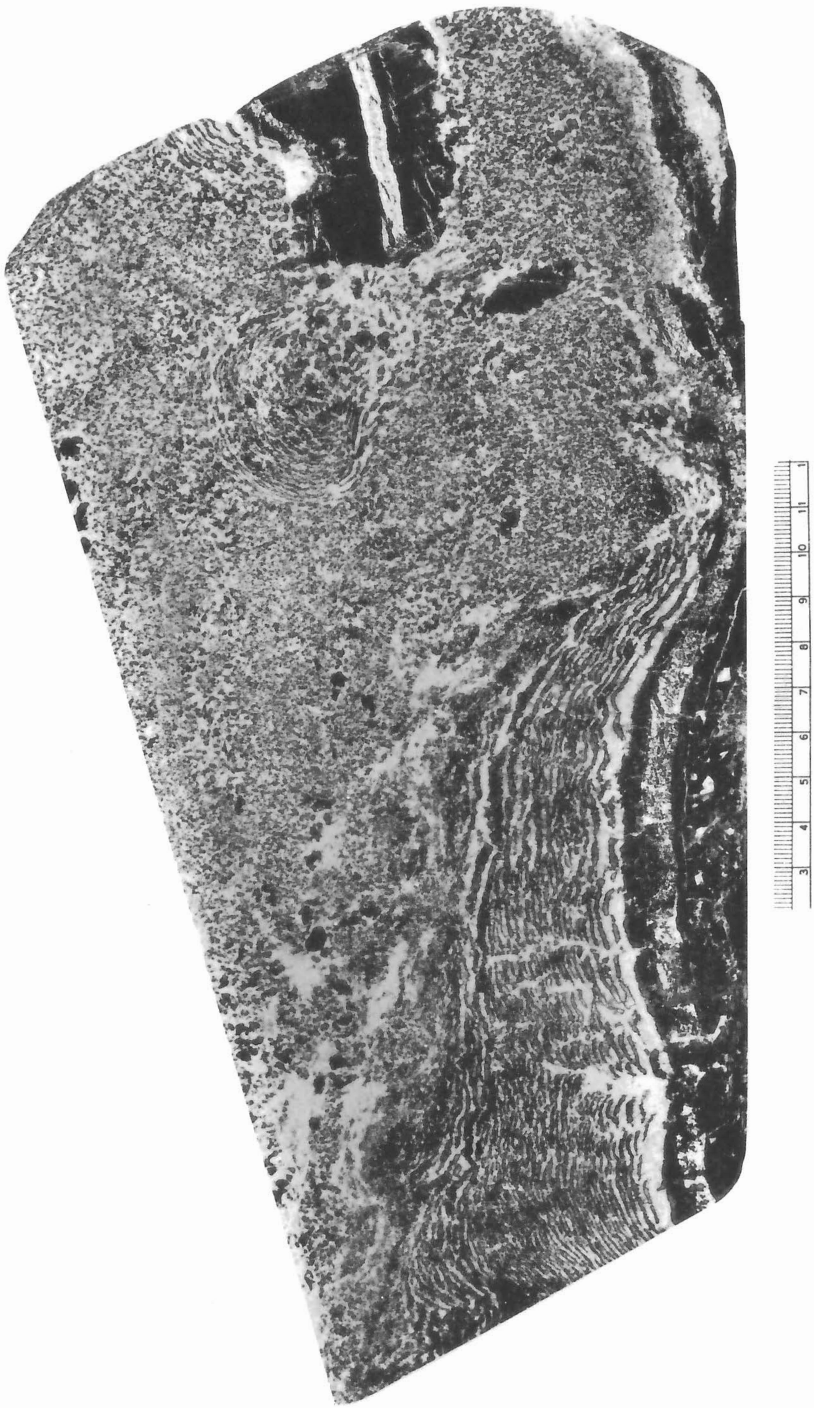


Plate 2

Eozoon canadense; Archaeospherina

Eozoon canadense, Côte St. Pierre type, Dawson 1864; and Archaeospherina, Dawson 1875 (Page 7)

This is a large polished slab of topotype material collected at the famous Côte St. Pierre locality, from which the specimens with "canals" (Pl. 3, fig. 1) were first observed by T. C. Weston, and later described by Dawson and Carpenter. The dark material is serpentine and the light is calcite; the grey mottled band in the mass of serpentine at the right and the white band in the dark mass at the top are chrysotile veinlets. The central and upper portions are evenly mottled ophicalcite, regarded as an "acervuline variety of Eozoon" (the *Eozoon canadense* var. *acervulina* of Dawson 1875). The serpentine grains were also named *Archaeospherina* by Dawson and considered as solitary chambers or distinct organisms. "Grenville series", 2.7 mi (4.3 km) north-northwest of St. André-Avellin, Quebec.
GSC type 24368 GSC photo 200446–C

Plate 3

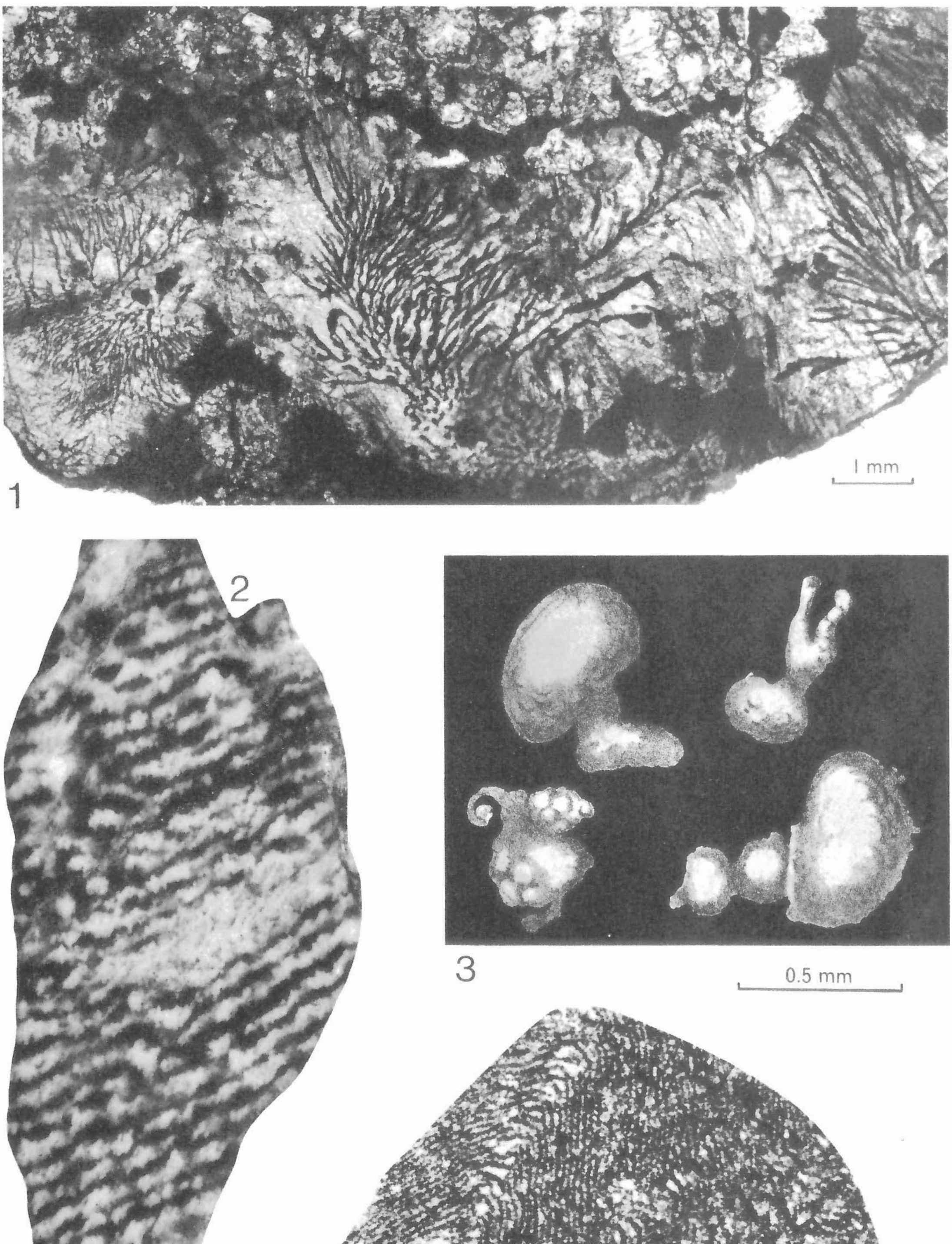
Eozoon canadense; Archaeospherina

Figure 1. Eozoon canadense, Côte St. Pierre type, Dawson 1864 (Page 7)
Thin section showing the "canals" described by Dawson and Carpenter. These are composed of serpentine and usually only occur within the thickest of the calcite layers that alternate with serpentine layers. The photograph is of one of the original thin sections prepared by T. C. Weston.
GSC type 152 GSC photos 200329–P and –Q

Figure 2. Eozoon canadense, Huntingdon type (Page 10)
A specimen from the western quarry of Canada Talc Industries Ltd., on the southeast outskirts of Madoc, Ontario. The dark bands are fine granular quartz, and the light layers are tremolite–carbonate. Note the branching of some layers producing supernumerary bands of the other mineral. The specimen is from the locality illustrated by Wilson (1926, p. 131; 1931, Pl. 1; 1939, Pl. 6A) and Wynne-Edwards (1967, p. 253). Compare illustration also with Miller and Knight (1914, Figs. 2a, 4, 5).
GSC type 24369 GSC photo 200745–A

Figure 3. Archaeospherina, Dawson 1875 (1867) (Page 12)
"Siliceous bodies (internal casts?) from a specimen of *Eozoon* from Wentworth", reproduced from Dawson (1867, Pl. 12). Considered at one time as chamber fillings of Eozoon, and at other times as possibly distinct organisms; the structures are serpentine grains in calcite, and were formed during metamorphism.

Figure 4. Eozoon canadense, Burgess type (Page 6)
Polished surface of a specimen from the first known locality of Eozoon, in the Grenville in North Burgess township, several miles to the south of Perth, Ontario. The specimen is composed of dark green bands of serpentine (loganite of T. S. Hunt) and spinel, and light coloured bands of dolomite; some of the layers branch, as near the middle of the specimen, to the right of the axial plane of the fold.
GSC type 168 GSC photo 200459–H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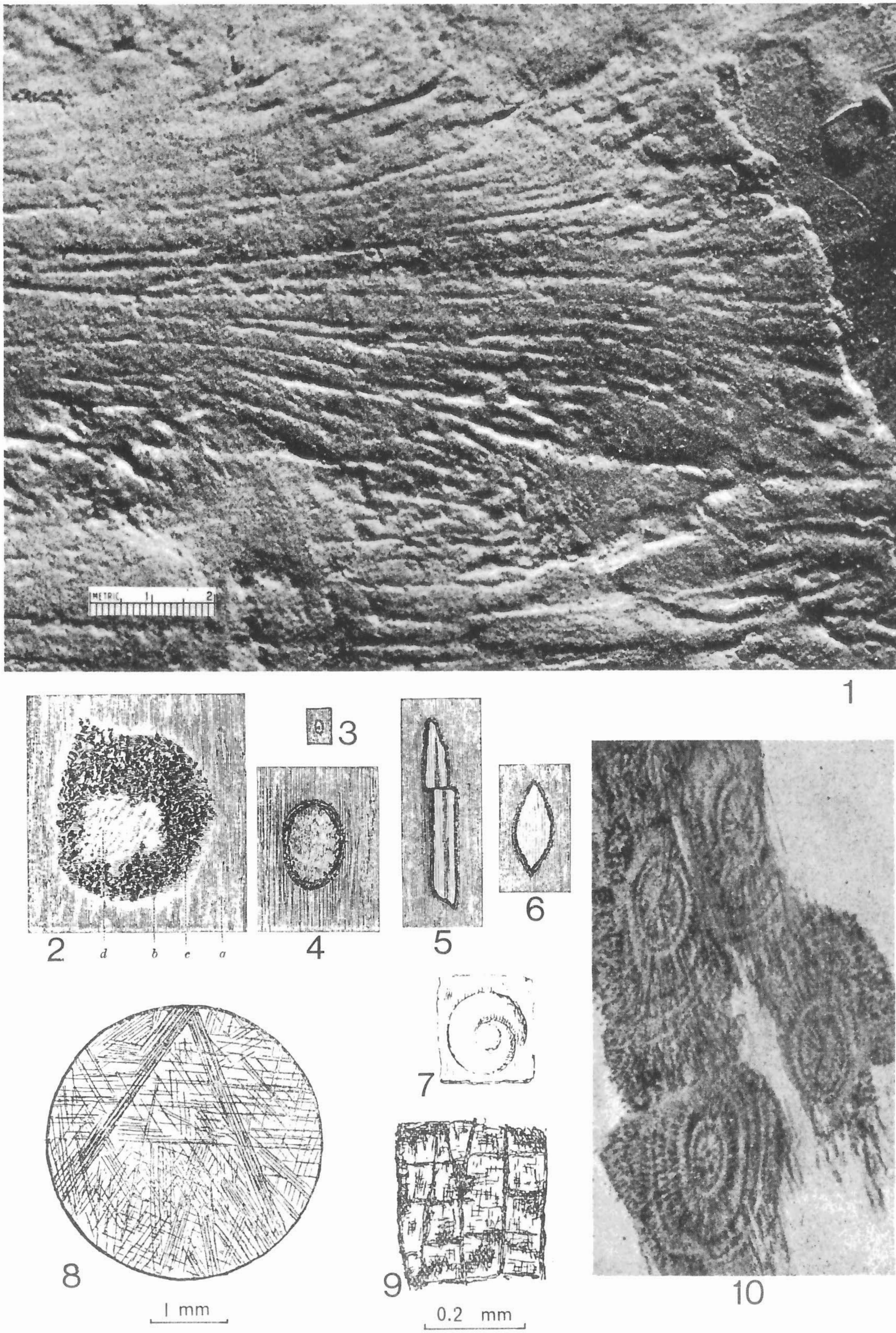
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Plate 4

Miscellanea

Figure 1. Medusichnites "form γ", Matthew 1891 (Taonichnites, Matthew 1890) (Page 18)
This is the holotype photographed by Walcott (1898, Pl. 46, fig. 1). The structures are now interpreted as sole marks. Whereabouts of holotype not known. Animikie Group (Rove Formation?), northwest shore of Lake Superior, Ontario.

Figures 2–6. Supposed Annelid tubes, Dawson 1866 (Page 13)
Reproductions of original illustrations.
2. Transverse section of thin section; magnification not known. "a) calcareo-siliceous rock. b) space filled with calcareous spar. c) sand agglutinated and stained black. d) sand less agglutinated and uncoloured."
3. "Transverse section of Worm-burrow on weathered surface. Natural size."
4. "The same, magnified."
5. "Spicule", magnification not known.
6. "Lenticular body", magnification not known.
The structures shown in figs. 2–6 were found "at Madoc", Ontario; neither the exact locality nor the whereabouts of the specimens are known. Those in figs. 5 and 6 were said to occur in "fragments of *Eozoon*" in limestone beds associated with tube-bearing quartzites.

Figure 7. Arenicolites spiralis, Billings 1872 (Page 18)
Reproduction of view of specimen illustrated by Dawson (1897, fig. 13). Magnification and location of holotype not known. St. John's Formation, near St. John's, Newfoundland.

Figure 8. Halichondrites graphitiferus, Matthew 1890 (Page 22)
Reproduction of original illustration. Location of specimen not known. Green Head Group, near Reversing Falls of Saint John River, Saint John, New Brunswick.

Figure 9. Cyathospongia (?) eozoica, Matthew 1890 (Page 21)
Reproduction of original illustration. Location of specimen not known. Green Head Group, Drury Cove, 4 mi (6.5 km) north-northeast of Saint John, New Brunswick.

Figure 10. Oldhamia, Murray 1868 (Page 14)
Reproduction of specimen illustrated by Weston (1895, fig. 2). Magnification and location of specimen not known. Upper part of Conception Group ('Torbay slate') near St. John's, Newfoundland.

PLATE 5

Aspidella (PAGE 14)

Figure 1. Aspidella terranovica, Billings 1872
Plastotype of holotype. St. John's Formation, near St. John's, Newfoundland.
GSC type 221c GSC photo 200344–D

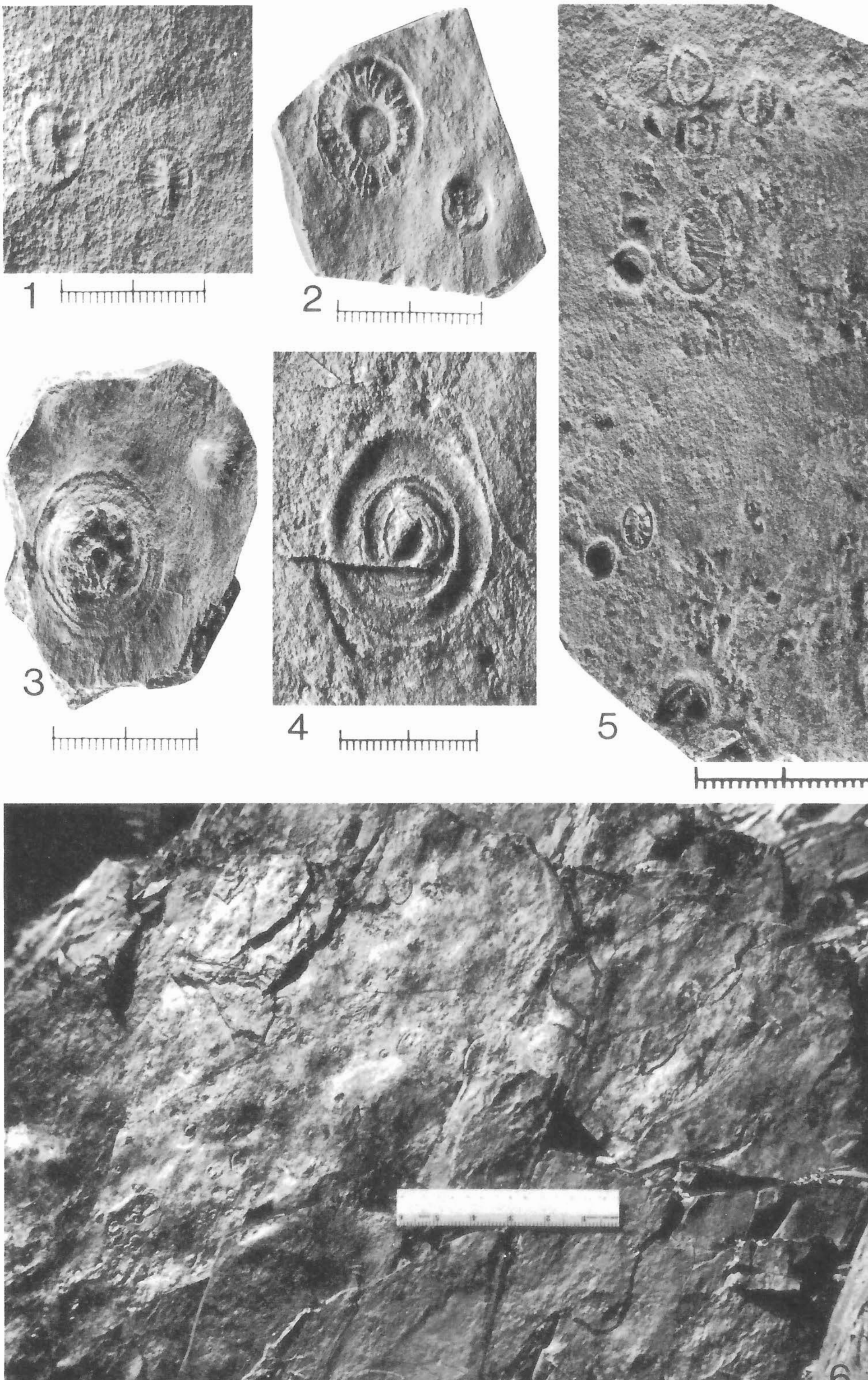
Figure 2. Aspidella terranovica, Walcott 1899
St. John's Formation, Ferryland Harbour, Newfoundland.
GSC type 221a GSC photo 200344–C

Figure 3. Aspidella terranovica, Walcott 1899
St. John's Formation, St. John's, Newfoundland.
GSC type 221b GSC photo 200344–A

Figure 4. Aspidella-like structure
St. John's Formation, roadcut 1.8 mi (2.9 km) north-northeast of Torbay, Newfoundland.
GSC type 24370a GSC photo 200460–B

Figure 5. Aspidella terranovica
Slab with several specimens showing preferred orientation. St. John's Formation, basement of Court House, St. John's, Newfoundland. Specimen collected by Bryan Greene and R. D. Hughes, Sept. 1962.
GSC type 24371 GSC photo 200329–K

Figure 6. Aspidella terranovica
Outcrop view, St. John's Formation, entrance to store of Atlantic Films, 22 Prescott St., St. John's, Newfoundland.
GSC photo 133414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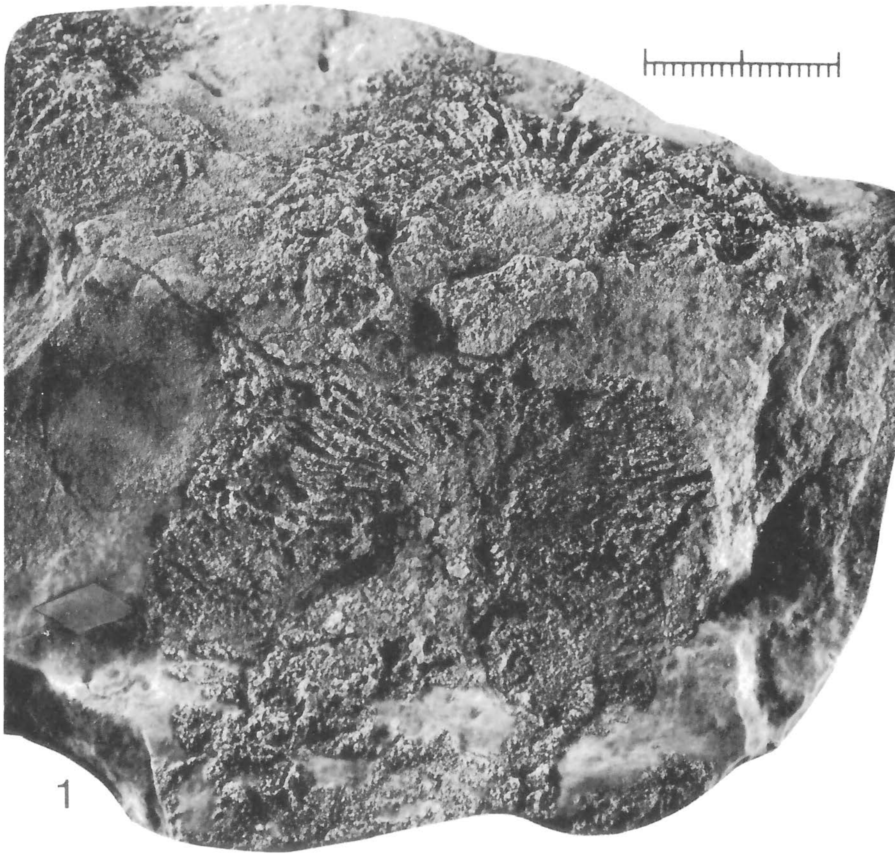

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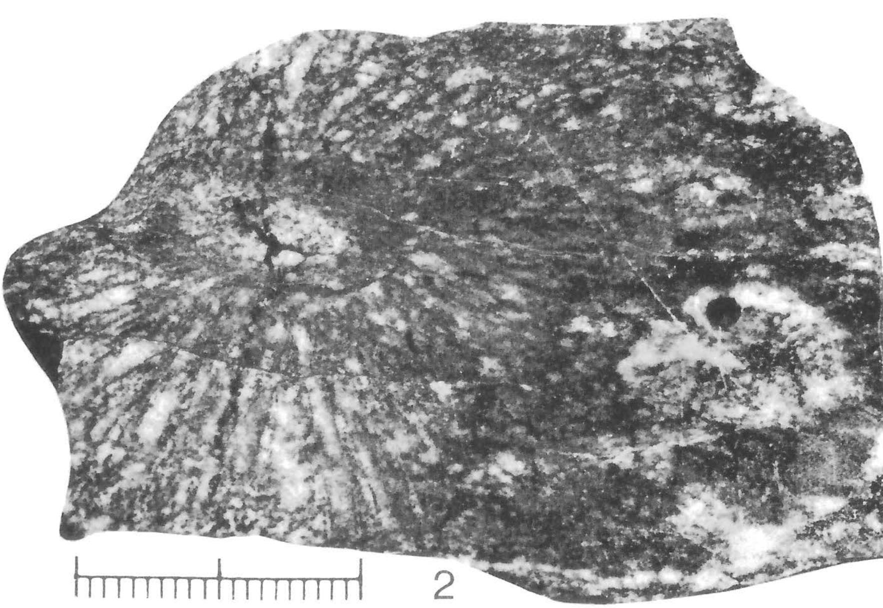

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PLATE 6

Atikokania (PAGE 24)

Figure 1. Atikokania lawsoni, Walcott 1912
Weathered surface showing resistant radial and concentric patterns of quartz in limestone. Steeprock Group, east shore of former Steep Rock Lake, 4 mi (6.5 km) north-northeast of Atikokan, Ontario.
GSC cotype 8059a GSC photo 200329–F

Figure 2. Atikokania lawsoni, Walcott 1912
Polished, oblique section, showing radial pattern and two "central cavities". The lighter material is calcite, the darker is ferruginous. Steeprock Group, along shore of former Steep Rock Lake, Ontario.
GSC cotype 8059c GSC photo 200329–J

PLATE 7

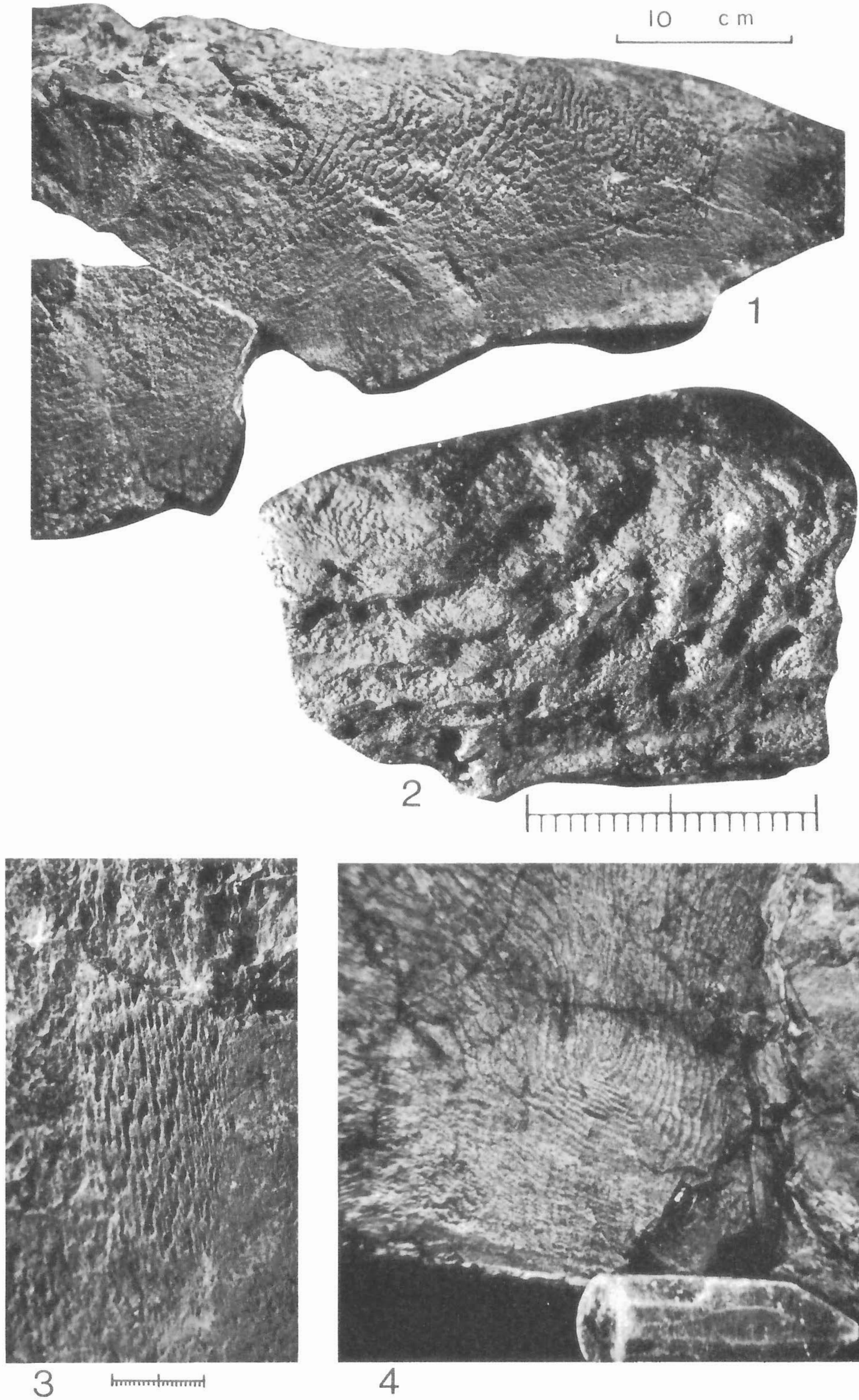
Kempia

Figure 1. Kempia huronense, Bain 1927 (PAGE 27)
Side view of large specimen showing branching and differentially weathering laminae. From 30 feet below top of Mississagi Formation, southwest part of lot 9, rge. 1, Vernon tp., Ontario.
Pratt Museum, Amherst College, No. Pz-1 — Photo by E. S. Belt

Figure 2. Kempia huronense, Bain 1927 (PAGE 27)
Small fragment, showing the cellular structure developed in recessively weathering laminae. The fragment is from the area just left of the lower part of the large specimen illustrated on fig. 1.
Pratt Museum, Amherst College, No. Pz-2 — GSC photo 200446–G

Figure 3. Kempia huronense, Bain 1927 (PAGE 27)
View of weathering pattern on the large specimen on fig. 1; the view is on a surface nearly perpendicular to, and to the left of the surface shown on fig. 1.
Pratt Museum, Amherst College, No. Pz-1 — Photo by E. S. Belt

Figure 4. Kempia, (Young 1967, Pl. 1, fig. 2) (PAGE 28)
Branching laminar structure arranged around argillite clast. The laminations consist of alternating chlorite- and quartz-rich material. Hammer head is 10 cm long.
From a thin bed in a small cliff on the east side of Washagami Lake, Davis tp., Ontario.
Photo by G. M. Young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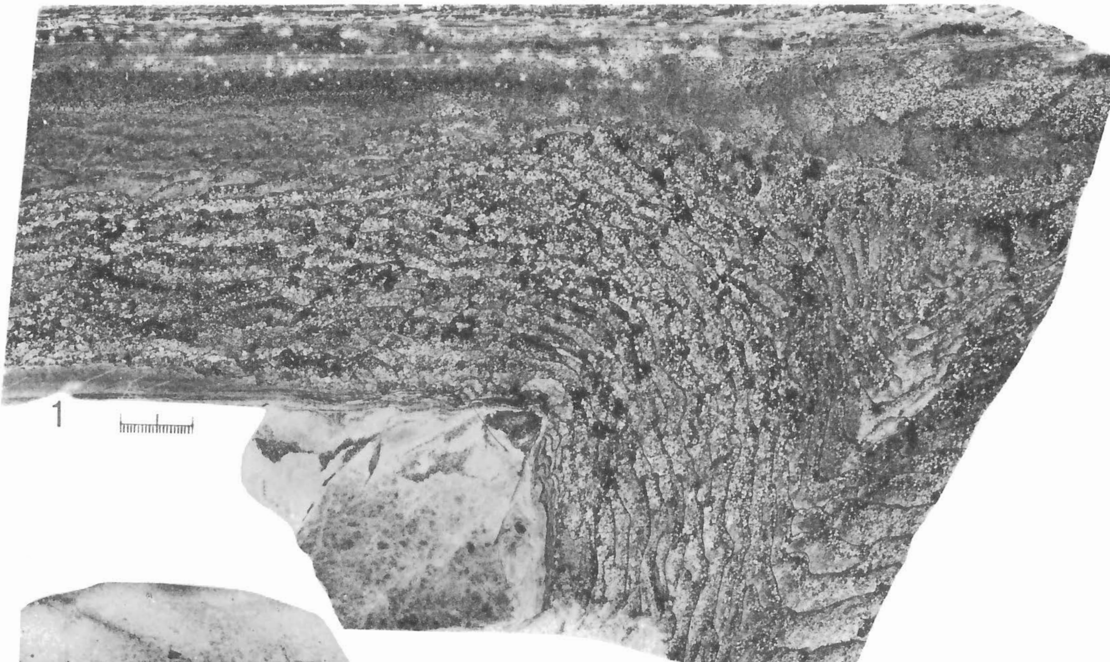

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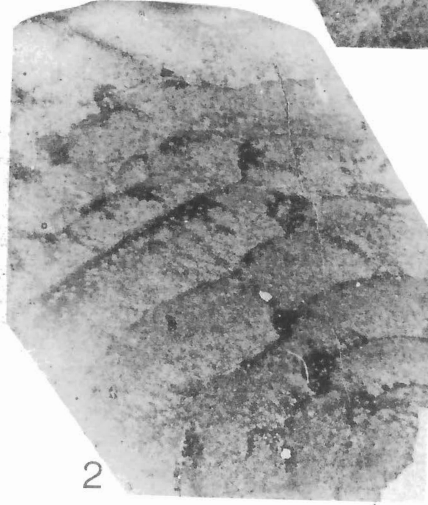

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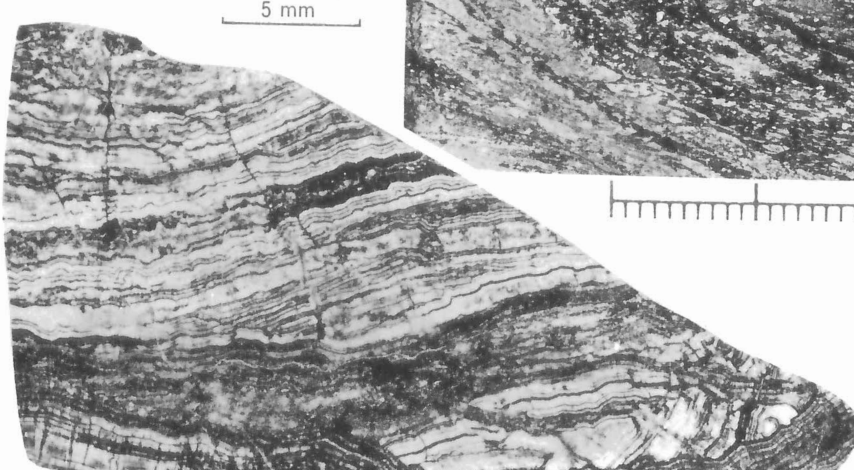

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PLATE 8

Kempia; Collinsia; algal-like forms

Figure 1. Kempia, (Young 1967) (PAGE 28)
Polished surface of same specimen as in Pl. 7, fig. 4. Section is perpendicular to bedding, which is visible at top. At lower left is a clast of coarser material, which probably was the source of some of the material forming the surrounding rhythmic diffusion bands. Note the branching and variable spacing of the dark laminae.
GSC type 24372, collected by G. M. Young GSC photo 200744–G

Figure 2. Kempia, (Young 1967) (PAGE 28)
Thin section taken from the slanted surface at left of fig. 1, approximately perpendicular to polished surface and bedding.
GSC type 24372a GSC photo 200743–G

Figure 3. Collinsia mississagiense, Bain 1927 (PAGE 29)
Thin section of the type specimen showing the ellipsoidal cross-sections of supposed algal cells at top left, and a small tight fold.
G. W. Bain collection GSC photo 200446–I

Figure 4. Algal-like forms, Thomson 1960 (PAGE 34)
Polished surface of laminated limestone; Vermilion Formation, dump of Errington No. 2 mine, 4 mi (6.5 km) southwest of Chelmsford, Ont. Note the uniformity and symmetrical, mirror-image disposition of homologous (synchronous) bands, the variation in thickness of successive bands, and the type of truncation of some laminae; collectively these features are not characteristic of algal activity.
GSC type 24373 GSC photo 200745–C

PLATE 9

Kempia

Figures 1–3. Kempia (PAGE 28)

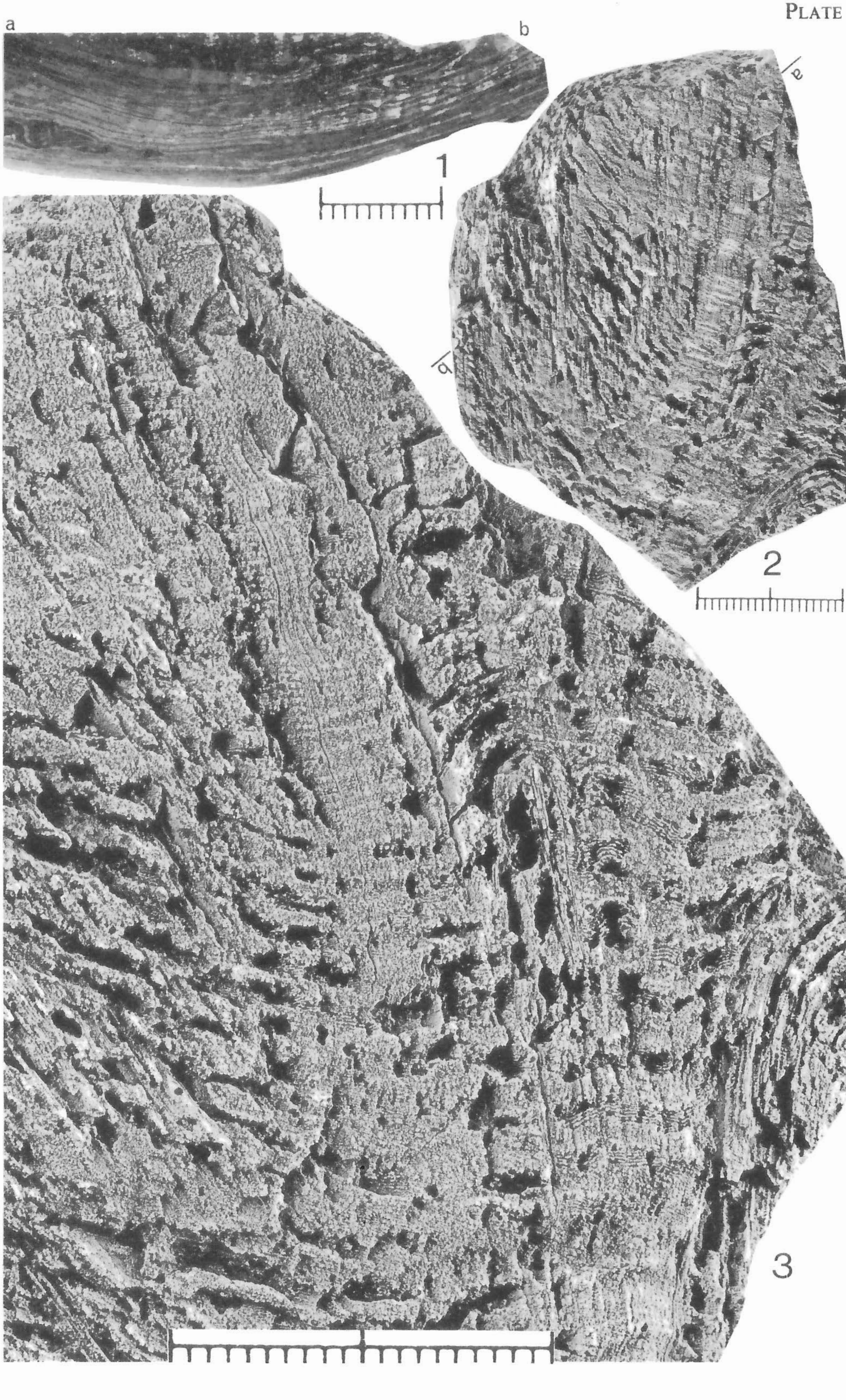
Specimen of dark grey argillite with rhythmic banding, from the Gowganda Formation on the southeast side of the creek draining Alma Lake, 4 mi (6.5 km) northeast of Iron Bridge, Ontario, 0.2 mile (320 m) east of the north–south road to Patton.

Specimen collected by P. W. Hay in 1960

1. Vertical thin section, showing tightly folded bedding lamination, and cross-cutting rhythmic pattern, indicating post-deformational origin of the periodic banding.
GSC type 24374a GSC photo 200450–I

2. General top view of specimen, showing the similarity to Bain's structures from the Mississagi Quartzite, and to Young's structures from the Gowganda at Washagami Lake. The position of the thin section of fig. 1 is indicated by the marks at a and b.
GSC type 24374 GSC photo 200450–A

3. Enlarged top view, showing more clearly the fine subsidiary laminae between the large rhythmic bands, transecting bedding lamination.
GSC type 24374 GSC photo 200451–C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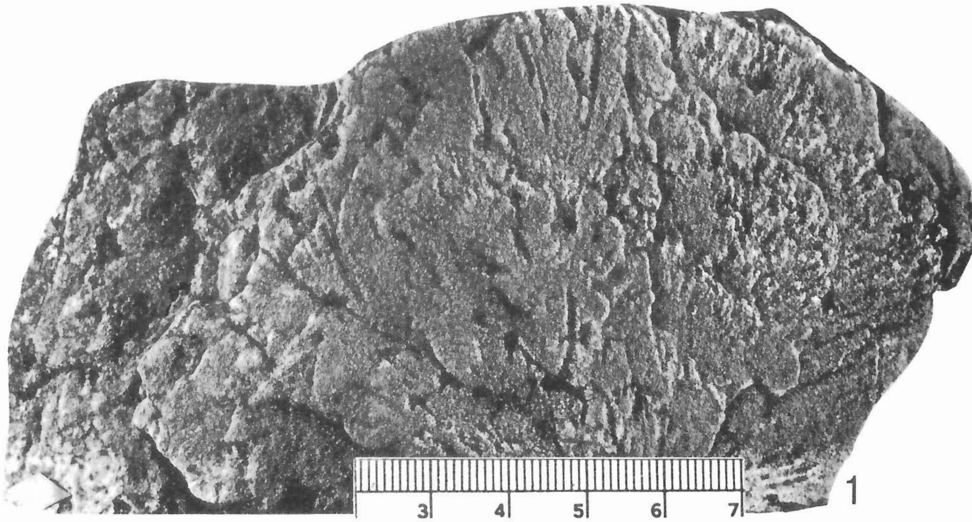

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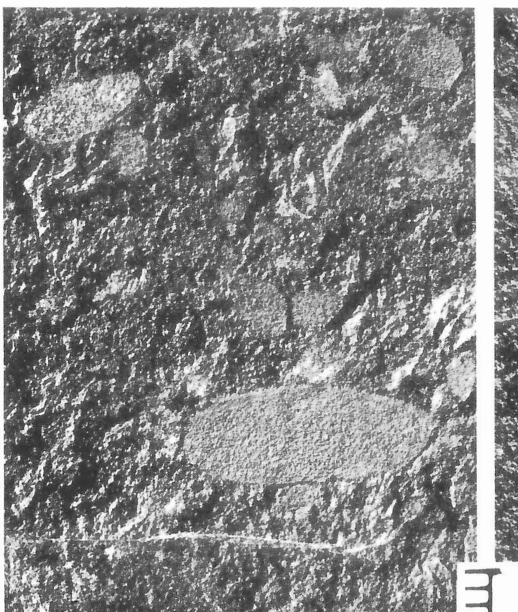
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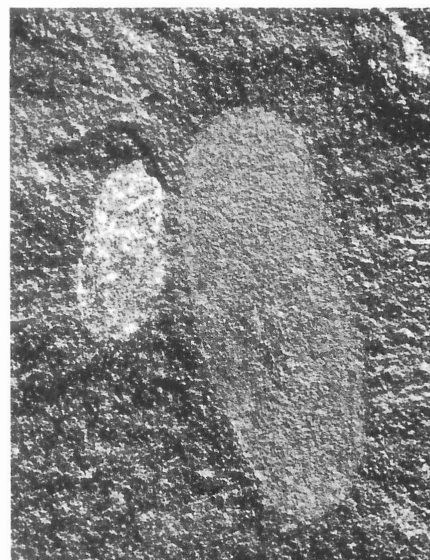
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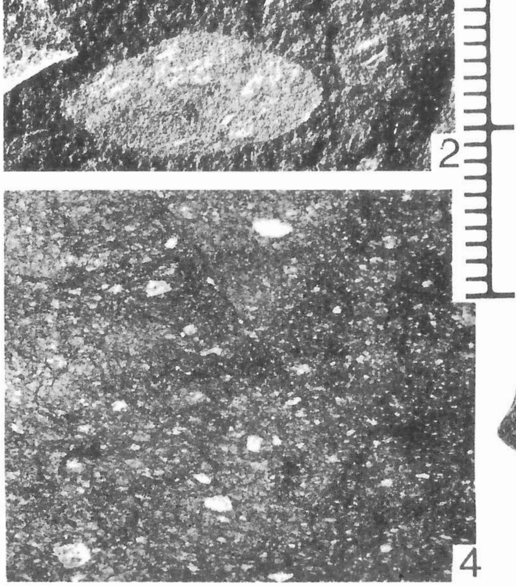
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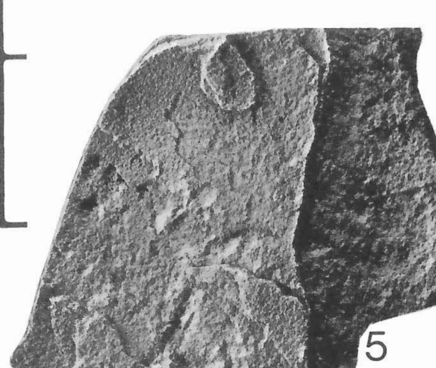
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PLATE 10

Atikokania; graphitic compressions; trace fossil

Figure 1. Atikokania irregularis Walcott 1912 (PAGE 24)
View of the weathered surface of the type specimen. Steeprock Group, Steep Rock Lake, Ontario.
GSC holotype 8059d GSC photo 200329–H

Figure 2. Graphitic compressions, Stinchcomb *et al.*, 1965 (PAGE 35)
General view of bedding surface of black shale with elongated impressions of various sizes. Attikamagen Formation, borrow pit near Indian settlement north of Schefferville, Quebec, about a mile north-northwest of Schefferville airport.
B. L. Stinchcomb collection GSC photo 200810–A

Figure 3. Graphitic compressions, Stinchcomb *et al.*, 1965 (PAGE 35)
View of a large impression. Same locality as fig. 2.
B. L. Stinchcomb collection GSC photo 200810–D

Figure 4. Graphitic compressions, Stinchcomb *et al.*, 1965 (PAGE 35)
View of small specimens on bedding surface. Graphitic shales, north side of Swampy Bay River, just below High Falls, west of Otelnuk Lake, Quebec.
B. L. Stinchcomb collection GSC photo 200810–C

Figure 5. Trace fossils, Walcott 1900 (PAGE 41)
Sigmoidal impression of unidentifiable trail or burrow. Topotype material from Random Formation on the beach at Smith Point, 6 mi (10 km) east-northeast of Clarenville, Newfoundland (base of section 18, fig. 7 of Jenness, 1963).
GSC type 24375 GSC photo 200460–A

PLATE 11

Algae or colloidal bodies; Beltina danai; Chuaria

Figure 1. Algae or colloidal bodies, Fenton and Fenton 1939 (PAGE 34)
View of outcrop with the banded bodies, photographed by D. F. Kidd in 1932. Note the alignment of the concentric structures and the symmetrical disposition of the bands along cracks at the left and the middle, suggesting a post-lithification origin for the structures. Echo Bay Group (Aphebian); Mystery Island, Echo Bay, Great Bear Lake, 4.5 km south-southwest of Port Radium, N.W.T.
GSC photo 76106

Figure 2. (PAGE 34)
Photograph from same outcrop area as on fig. 1, also taken by D. F. Kidd in 1932, and published by Fenton and Fenton (1939, Pl. 1, fig. 3).
GSC photo 76105

Figure 3. Beltina danai, Walcott 1911 (PAGE 23)
Thin, angular fragments along bedding plane. The large piece was interpreted by Walcott as an abdominal segment of a crustacean. Specimen is said to come from "... near the head of Johnson Creek on the Continental Divide west of Pincher Post Office, Alberta", but exact locality is not known.
U.S.N.M. type 57502 GSC photo 200880–C

Figure 4. Beltina danai, Walcott 1911 (PAGE 23)
Impression of a thin, corrugated fragment, interpreted by Walcott as a portion of a cephalothorax. Same locality as specimen on fig. 3.
U.S.N.M. type 57501 GSC photo 200880–B

Figures 5–7. Chuaria (Allan 1913) (PAGE 24)
Maroon siltstone from the Hector Formation at the eastern base of Storm Mountain, 30 km west of Banff, Alberta. Specimens collected by W. C. Gussow.
5. Small, concentrically wrinkled elevation on bedding surface.
GSC type 24409 GSC photo 200879–C
6. Concentrically wrinkled depression on same bedding surface as specimen on fig. 5.
GSC type 24409 GSC photo 200879–A
7. Concentrically wrinkled elevation on another bedding surface.
GSC type 24410 GSC photo 200879–B

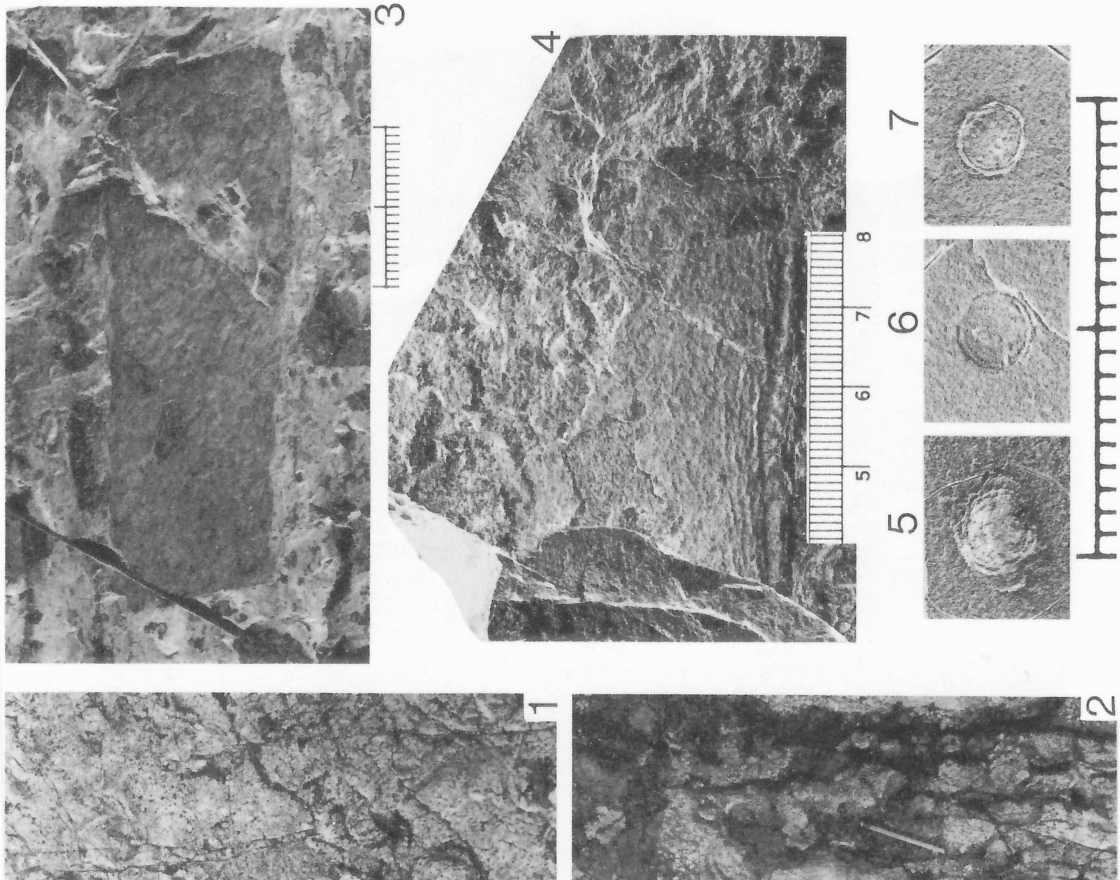

PLATE 12

Plate 12

Rhysonetron

Figure 1. Rhysonetron byei, Hofmann 1967 (Frarey and McLaren 1963) (Page 36)
Vertical section across layer with spindles. The spindles lie in the thin, light coloured, argillaceous parting plane near the middle right. The cross-section of one flattened spindle appears immediately to the right of where the light parting plane terminates, between the projections of the four markers at the margins. Specimen from the Lorrain Formation 1.6 mi (2.6 km) northeast of Desbarats, Ontario.
GSC type 22628 GSC photo 200142–F

Figure 2. Rhysonetron byei, Hofmann 1967 (Frarey and McLaren 1963) (Page 36)
View of the original slab collected by C. E. Bye in 1960.
Photograph of lower surface of a ripple-marked arenite with curved spindles of similar arenaceous material. Suggestions of corrugations on some of the spindles at the bottom; overlap of several specimens at top centre, bottom left, and bottom right; branching forms at bottom centre. Slab is from the same locality as that in fig. 1.
GSC type 15379 GSC photo 111984

PLATE 13

Rhysonetron (PAGE 36)

Figure 1. Rhysonetron lahtii, Hofmann 1967
Upper surface view of corrugated spindles of quartz arenite in ripple troughs of quartz arenite. Bar River Formation (Huronian), roadcut east of Flack Lake, 23.3 km north-northwest of Elliot Lake, Ontario.
GSC type 9876 GSC photo 200090–C

Figure 2. Enlargement of a spindle with well-developed corrugations and medial longitudinal marking.
GSC type 9876 GSC photo 200072–B

Figure 3. Polished surface of a section across the partial spindle shown in upper right of fig. 1 (specimen No. 5 of Hofmann 1967, p. 502). The light material along the lateral parts of the cylinder is argillaceous material, composed mostly of fine dioctahedral mica (a mixture of $2M_1$, 1M, and (probably) 1Md polymorphs) (R. S. Dean, analyst).
GSC type 9876a GSC photo 200344–F

Figure 4. Polished surface of section across partial spindle shown in upper left of fig. 1 (specimen No. 6 of Hofmann 1967, p. 502); view is slightly oblique.
GSC type 9876b GSC photo 200344–E

Figure 5. Rhysonetron lahtii
Large slab with several complete corrugated spindles; same locality as GSC 9876, and most probably from the same bed. Sample is in private collection of G. O. Livo, Gulf Oil Corporation, Denver, Colorado; a plastotype is in the GSC type collection.
(GSC type 24376) GSC photo (of specimen) 200446–B

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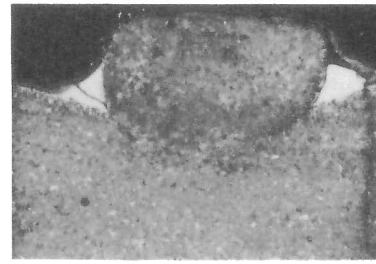

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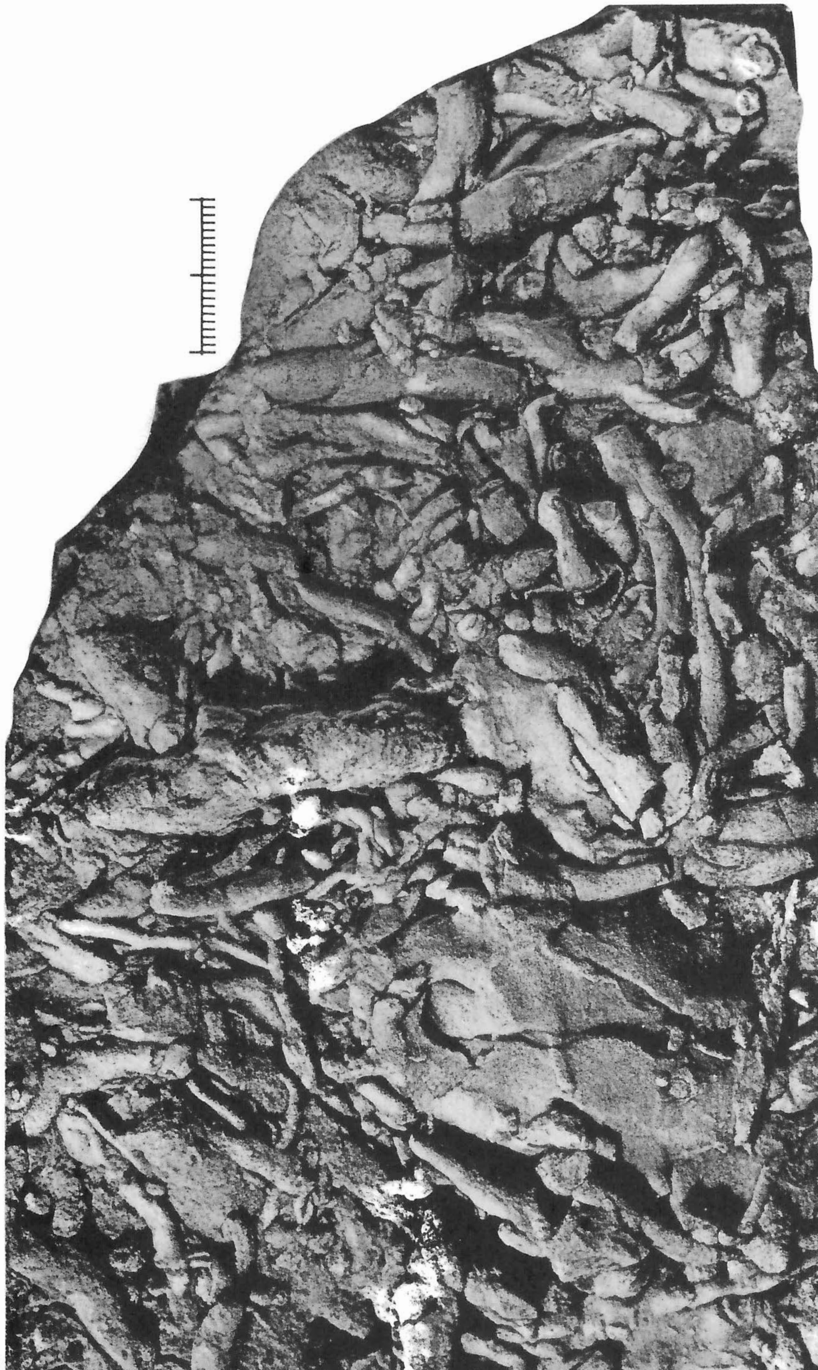

PLATE 14

Trace fossils (PAGE 42)

Organic burrows, reported by Tuke, Dineley, and Rust 1966, p. 704, from Hunting Formation on Somerset Island, N.W.T. The specimen is from locality G, 4 km southeast of the mouth of the Hunting River (*see* Tuke *et al.*, 1967, fig. 3, p. 700). The structures, not previously illustrated, are developed as hyporeliefs (underside of psammitic bed), and comprise at least two main types of burrows; the larger forms are teichichnian structures with upward burrow displacements, visible in side view as stacked, concave upward laminations; these are generally interpreted as feeding burrows. The smaller forms are branching and unbranched portions of *Palaeophycus*- and *Chondrites*-like tunnels, probably dwelling or feeding burrows. The trace fossil assemblage indicates a Phanerozoic age for the containing rocks.

Univ. of Ottawa, Geology Dept. coll. T7-19 GSC photo 200829

PLATE 15

Gunflint microfossils

Fig.	Taxon	GSC type No.	Leitz ORTHOLUX stage co-ordinates	GSC photo
1	*Animikiea septata*, Barghoorn 1965 (PAGE 45)	24381a	101.9/35.7	140936
2	*Gunflintia minuta*, Barghoorn 1965 (PAGE 46)	24380c	106.5/22.2	140939
3	*Gunflintia minuta*, Barghoorn 1965 (PAGE 46)	24380c	114.4/31.5	140940
4	*Gunflintia grandis*, Barghoorn 1965 (PAGE 47)	24380a	102.9/32.6	140938
5	*Archaeorestis schreiberensis*, Barghoorn 1965 (PAGE 47)	E. S. Barghoorn photograph of type specimen		
6	*Gunflintia minuta*, Barghoorn 1965, with apparent branch and sporelike bodies (PAGE 46)	24380c	110.4/27.9	
7	*Animikiea* or *Entosphaeroides*; large sheath with sporelike body inside at bottom left (PAGE 46)	24381b	105.3/29.8	140934 140935
8	*Entosphaeroides amplus*, Barghoorn 1965 (PAGE 46)	E. S. Barghoorn photograph of type specimen		
9	*Huroniospora microreticulata*, Barghoorn 1965 view of surface (PAGE 47)	24380c	113.9/33.2	140944
10	*Huroniospora microreticulata*, Barghoorn 1965 view of section (PAGE 47)	24380c	110.0/31.2	140943
11	*Huroniospora macroreticulata*, Barghoorn 1965 view of surface (PAGE 47)	24380c	114.4/28.8	140942
12	*Huroniospora psilata*, Barghoorn 1965 (PAGE 48)	24380c	114.4/34.0	140945
13	*Eoastrion simplex*, Barghoorn 1965 (PAGE 48)	24380c	98.9/22.8	140946
14	*Eoastrion simplex*, Barghoorn 1965 (PAGE 48)	24380b	114.5/21.4	140949
15	?*Eoastrion bifurcatum*, Barghoorn 1965; a fracture in the chert cuts across the specimen from bottom centre to upper right (PAGE 48)	24380c	113.7/22.4	140950
16	*Kakabekia umbellata*, Barghoorn 1965 (PAGE 49)	24380c	114.1/27.3	140941
17	*Eosphaera tyleri*, Barghoorn 1965 (PAGE 49)	24381b	101.4/31.5	140932
18	*Palaeorivularia ontarica*, Korde 1958 (PAGE 49)	24382	116.1/35.0	140931
19	*Eoastrion* or *Palaeorivularia* (Page 48)	24380b	110.3/28.0	140948
20	Cluster of bacteria (?) (PAGE 51)	24380c	114.7/35.2	140947

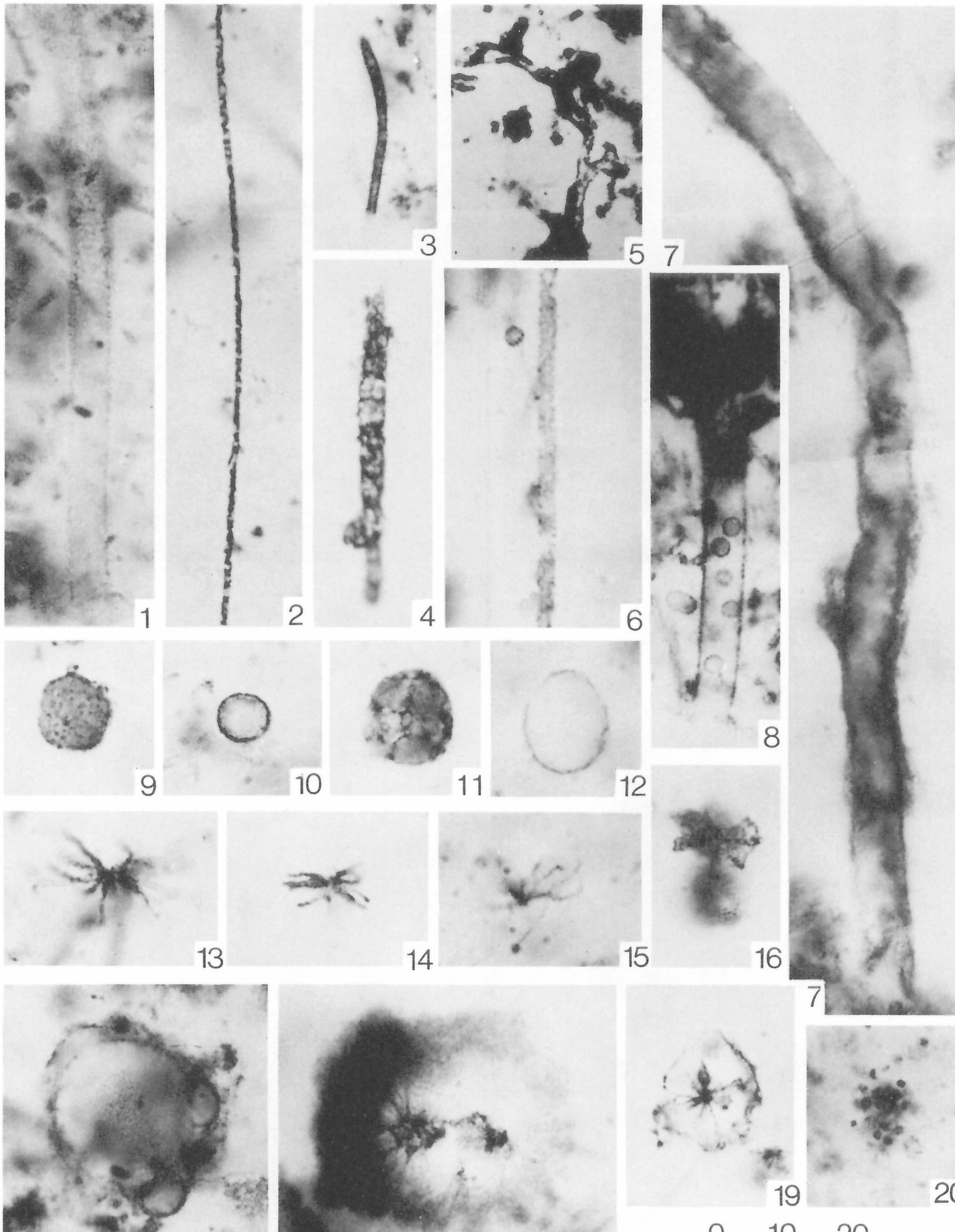
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PLATE 16

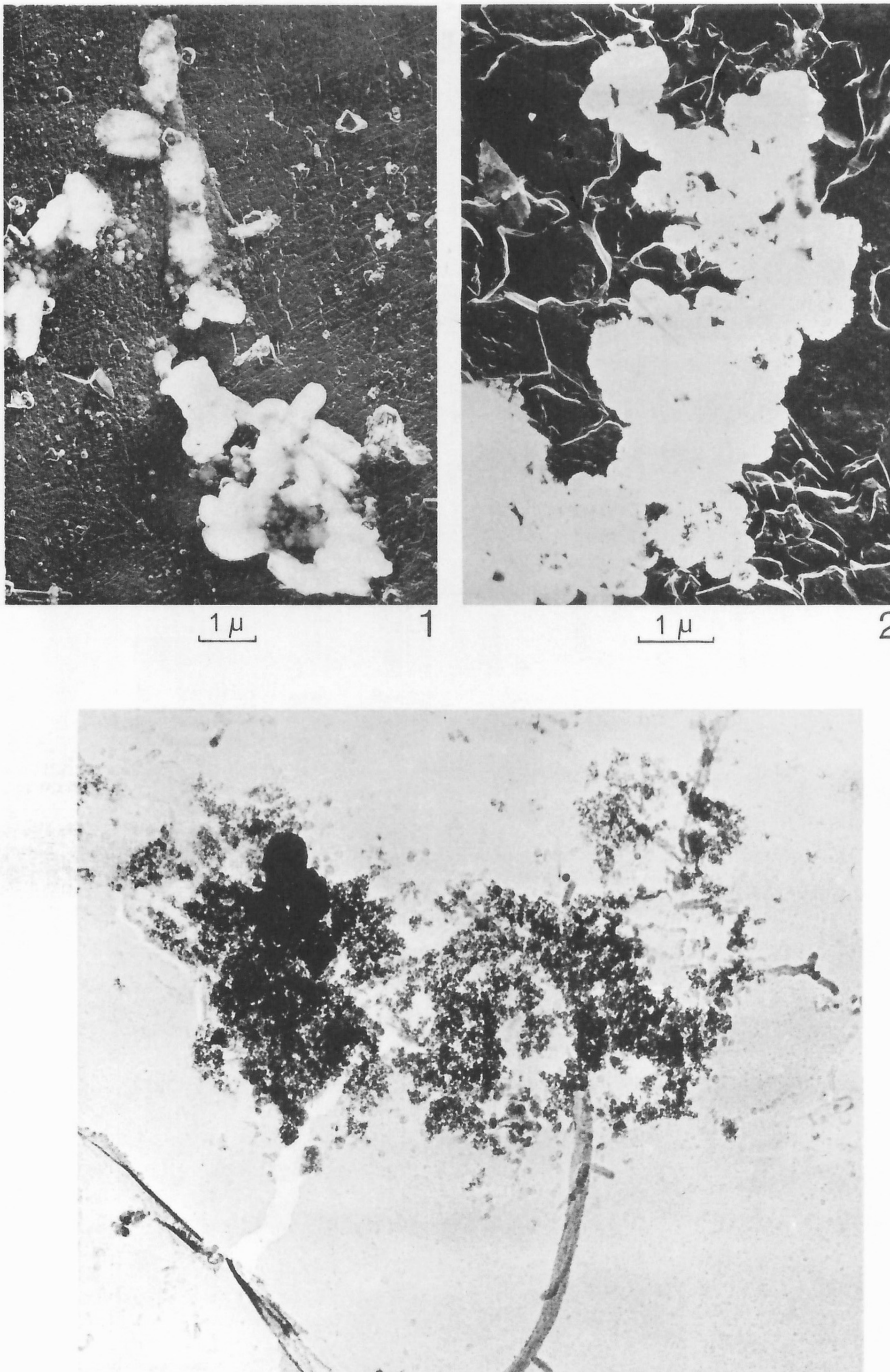


Plate 16

Gunflint microfossils; Gowganda actinomycetes

Figure 1. Rod-shaped bacterial cells (Page 50)
Gunflint Formation, Schreiber beach locality.
Photograph from Schopf, Barghoorn, Maser, and Gordon, 1965, fig. 2 and cover.

Figure 2. Coccoid bacteria (Page 50)
Gunflint Formation, Schreiber beach locality.
Photograph from Schopf, Barghoorn, Maser, and Gordon, 1965, fig. 5.

Figure 3. Gowganda actinomycetes (Page 51)
Photograph from Jackson, 1967, fig. 1.
The lack of a shadow along the large filament and the continuation of this filament across a break in the carbon replica suggest that this is a contaminant and not a fossil.

Plate 17

Belcher Islands microstructures; Keewatin protozoans

Figure 1. Type A structure of LaBerge, 1967 (Page 53)
Three specimens at different levels of focus; in same thin section as those illustrated by LaBerge (Pl. 1, figs. 7–9). GSC sample JD-214-A, uppermost part of Kipalu Iron Formation, south part of Broomfield Island, Belcher Islands. Microscope stage co-ordinates: 101.8/26.3.
GSC type 24379 GSC photo 200726–B

Figure 2. Same sample as fig. 1, with crossed nicols and lower magnification, showing the position of the microspherulitic structures at the grain contacts. Rectangle outlines field of fig. 1.
GSC photo 200726–C

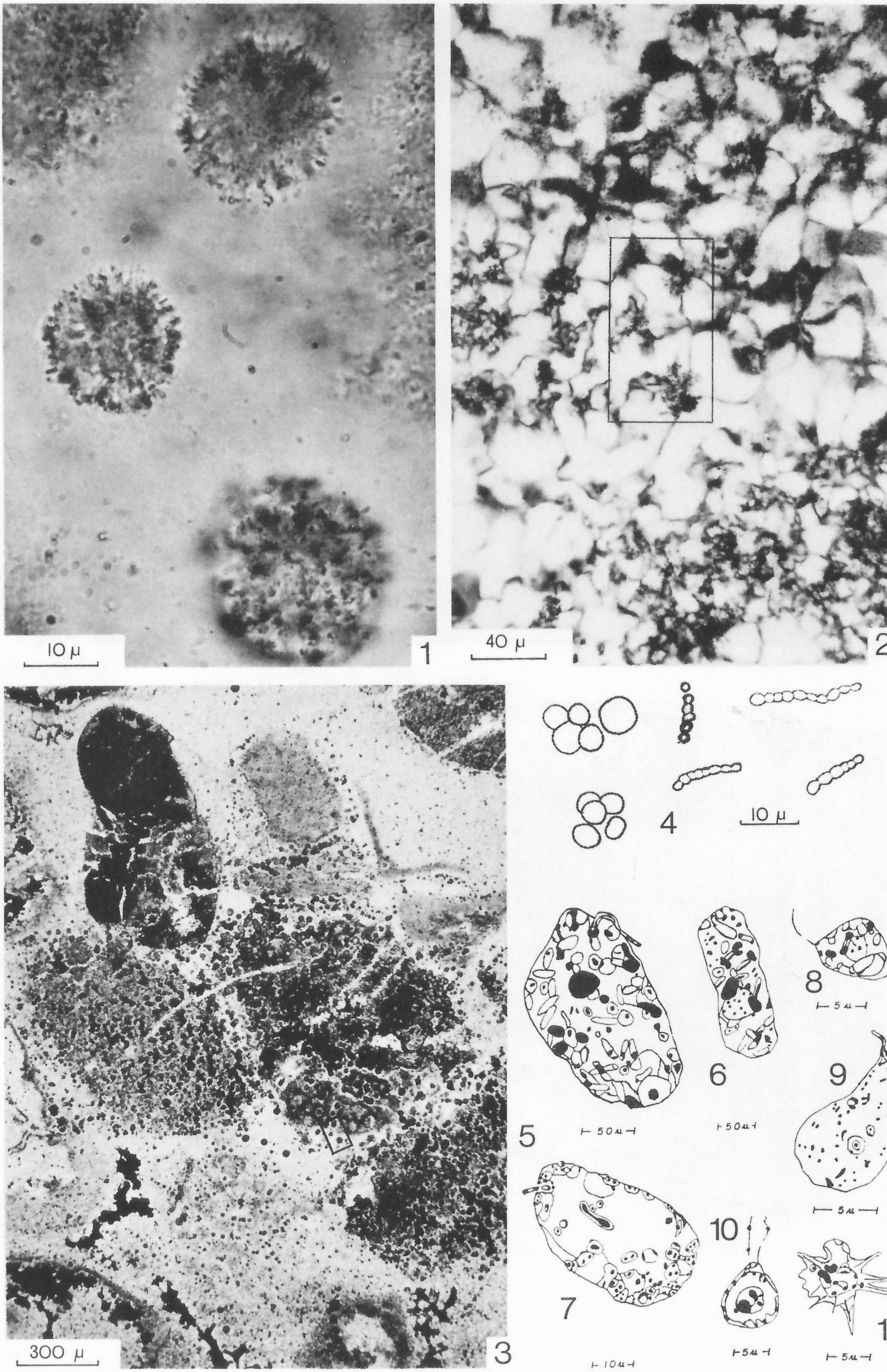
Figure 3. Same sample as figs. 1 and 2, under low magnification and plain light, showing detrital aspect of the sand-sized grains and the distribution of the microspherulitic structures. The bedding is parallel to the long axis of the large dark grain and to the long sides of the small rectangle which outlines the field of view of fig. 1. The lack of alignment of the microspherulites parallel to bedding and the decoloration haloes around the microspherulites are noteworthy. This discoloration is visible around the upper structure of fig. 1.
GSC photo 200726–A

Figure 4. Algal cell structures, Belcher Islands (Page 53)
Reproduced from Moore (1918, fig. 14).

Figures 5–11. Keewatin microstructures (Page 54)
From roadcut on Ontario highway 17, 1.3 km northwest of Schreiber, Ontario. Reproduced from Madison (1958, figs. 1–5, 7, 8). Madison regarded these as fossil protozoans and identified the following forms:

Fig. 5. *Euglena* sp.
6. *Euglena* sp.
7. *Oikomonas* sp.
8. *Ancyromonas contorta* (?)
9. *Ancyromonas* sp.
10. *Amphimonas globosa* (?)
11. *Sphaerastrum* sp.

The structures are considered here as probably inorganic.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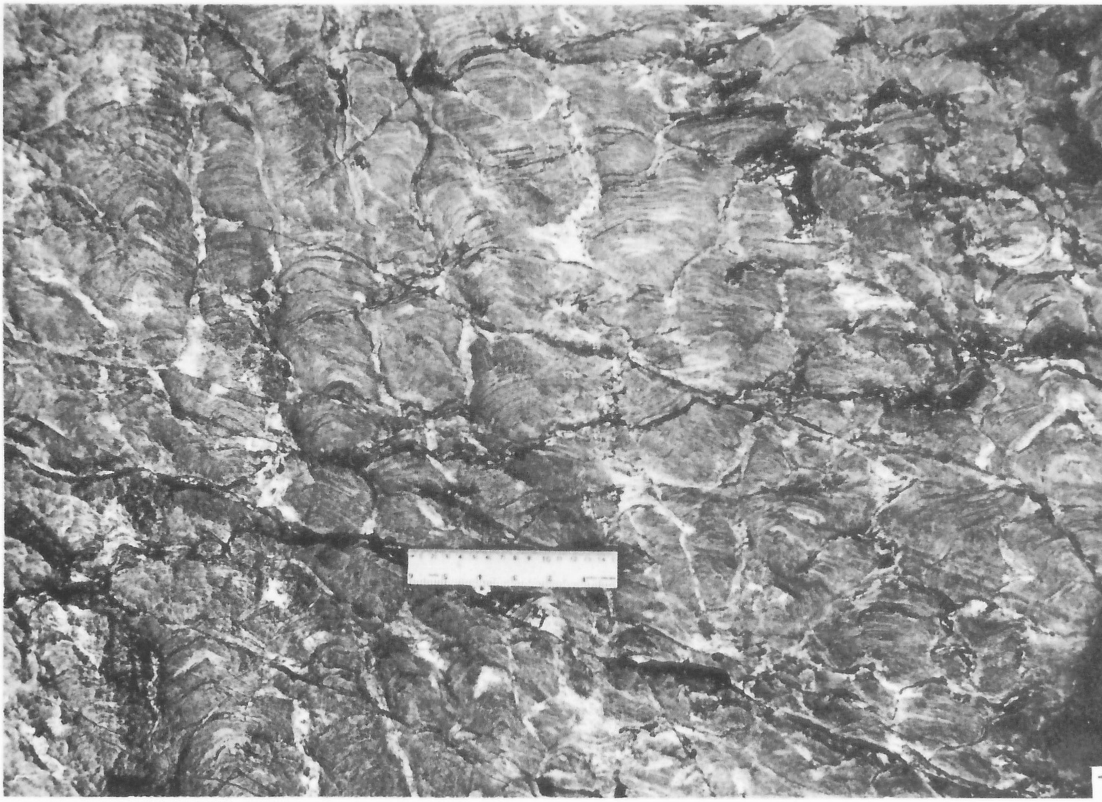

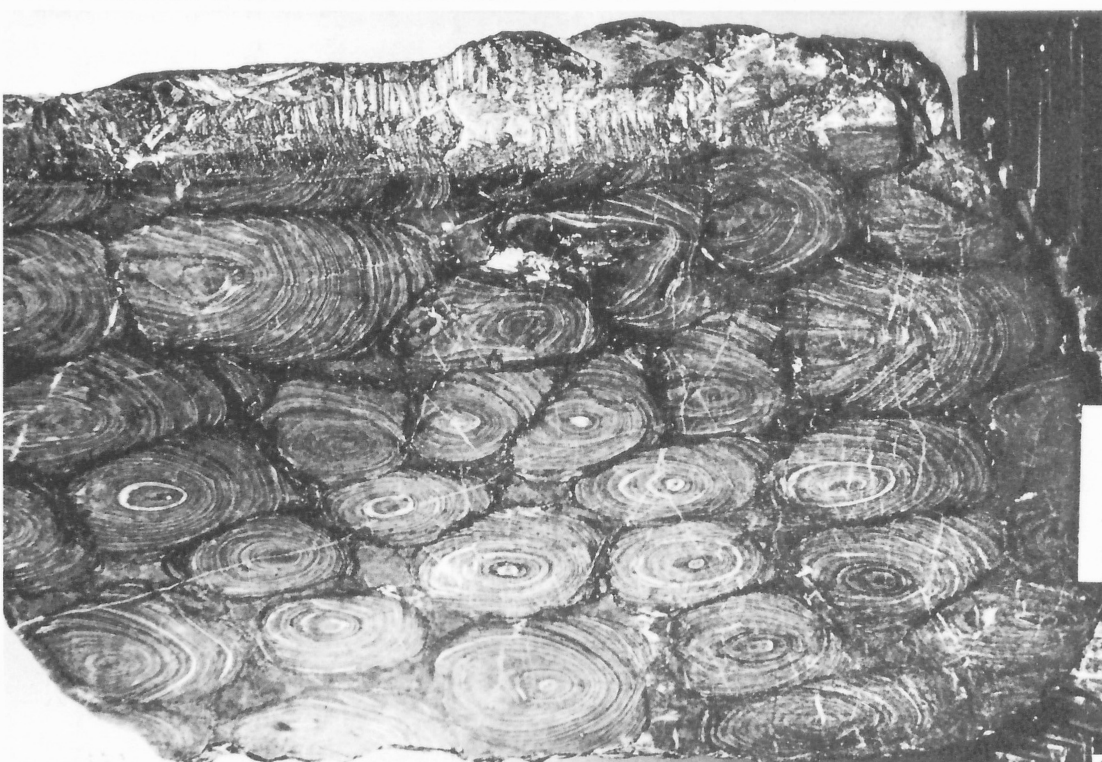

Plate 18

Archaeozoon acadiense (Page 56)

Figure 1. *Archaeozoon acadiense*, Matthew 1890
Vertical section, as seen in outcrop at the type locality at Green Head near Saint John, New Brunswick; this structure is a closely spaced, actively branching columnar stromatolite. Ashburn Formation, Green Head Group, northwest corner of Green Head Peninsula.

GSC photo 133422

Figure 2. *Archaeozoon acadiense*, Matthew 1890
Large oblique polished section, on display at the New Brunswick Museum, 277 Douglas Ave., Saint John, N.B. The section shows close crowding of columns, stylolite development along margins of the columns, and calcite-filled fractures. From Green Head Peninsula, Saint John.

GSC photo 200503

Plate 19

Archaeozoon acadiense (Page 56)

Figure 1. *Archaeozoon acadiense*, Matthew 1890
Vertical polished surface of this actively branching, columnar stromatolite. The columns are deformed and stylolites are abundant, especially along the margins of the columns. GSC locality 79211a, northwest corner of Green Head Peninsula, Saint John, New Brunswick; from southernmost band at this locality. Ashburn Formation, Green Head Group.
GSC type 24383a — GSC photo 200811

Figure 2. *Archaeozoon acadiense*, Matthew 1890
Horizontal thin section, cutting parts of two columns, and showing the textural contrast between laminated columns and detrital fill of intercolumn space; and the stylolite development, especially at column margins. Ashburn Formation, Green Head Group, northwest corner of Green Head Peninsula, Saint John, New Brunswick; from southernmost stromatolite band.
GSC type 24383b — GSC photo 200809–A

Figure 3. *Archaeozoon acadiense*, Matthew 1890
Vertical section of portions of two columns and intercolumn matrix. Stylolite development along margins of columns is minimal in this section. The photographs show that this stromatolite was built in discrete columns with narrow intercolumnar channels and presence of a wall (*sensu* Korolyuk 1960).
Ashburn Formation, Green Head Group, northwest corner of Green Head Peninsula, Saint John, New Brunswick. From middle of northern stromatolite band.
GSC types 24384a and 24384b — GSC photos 200809–B and –C

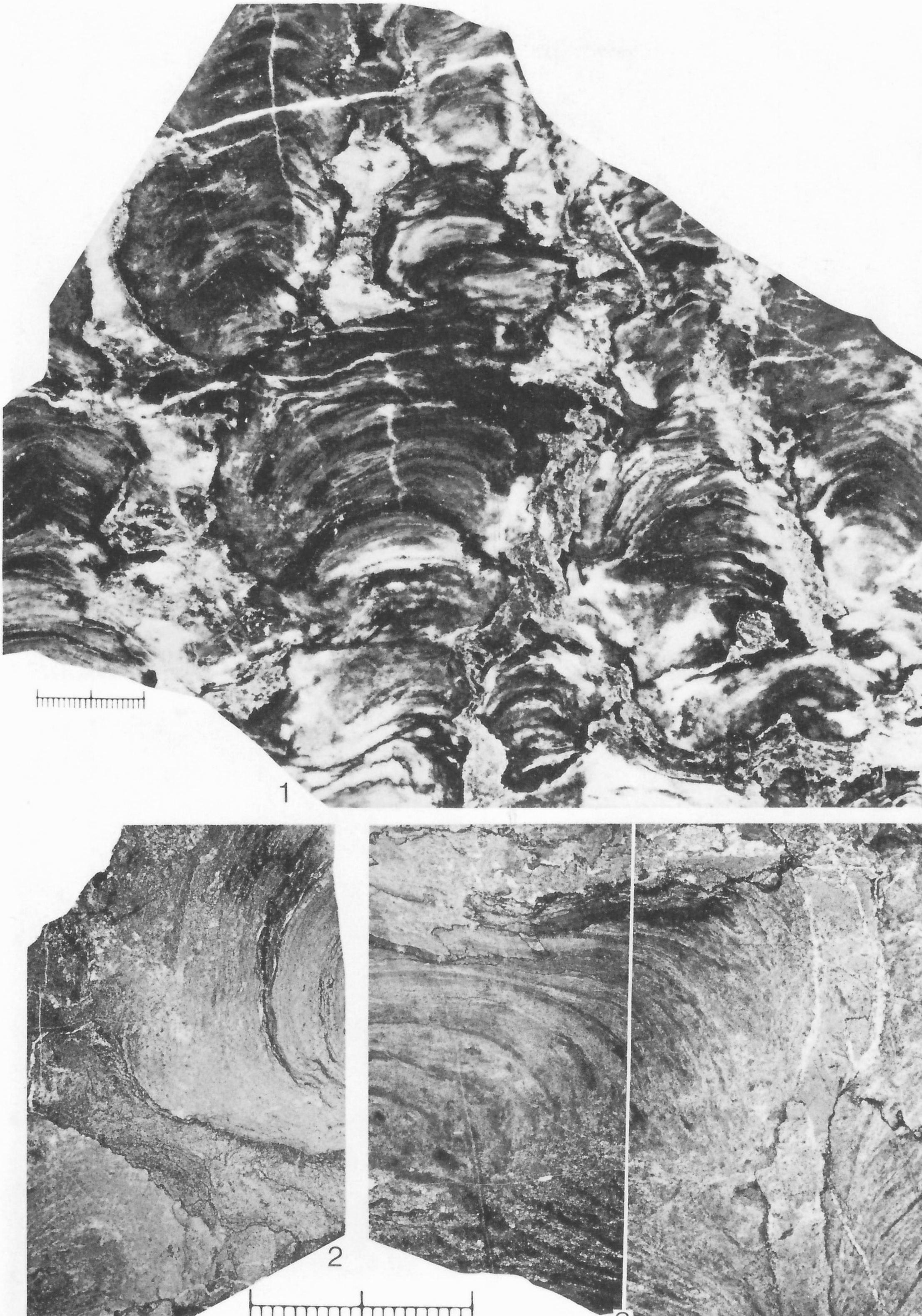
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PLATE 20

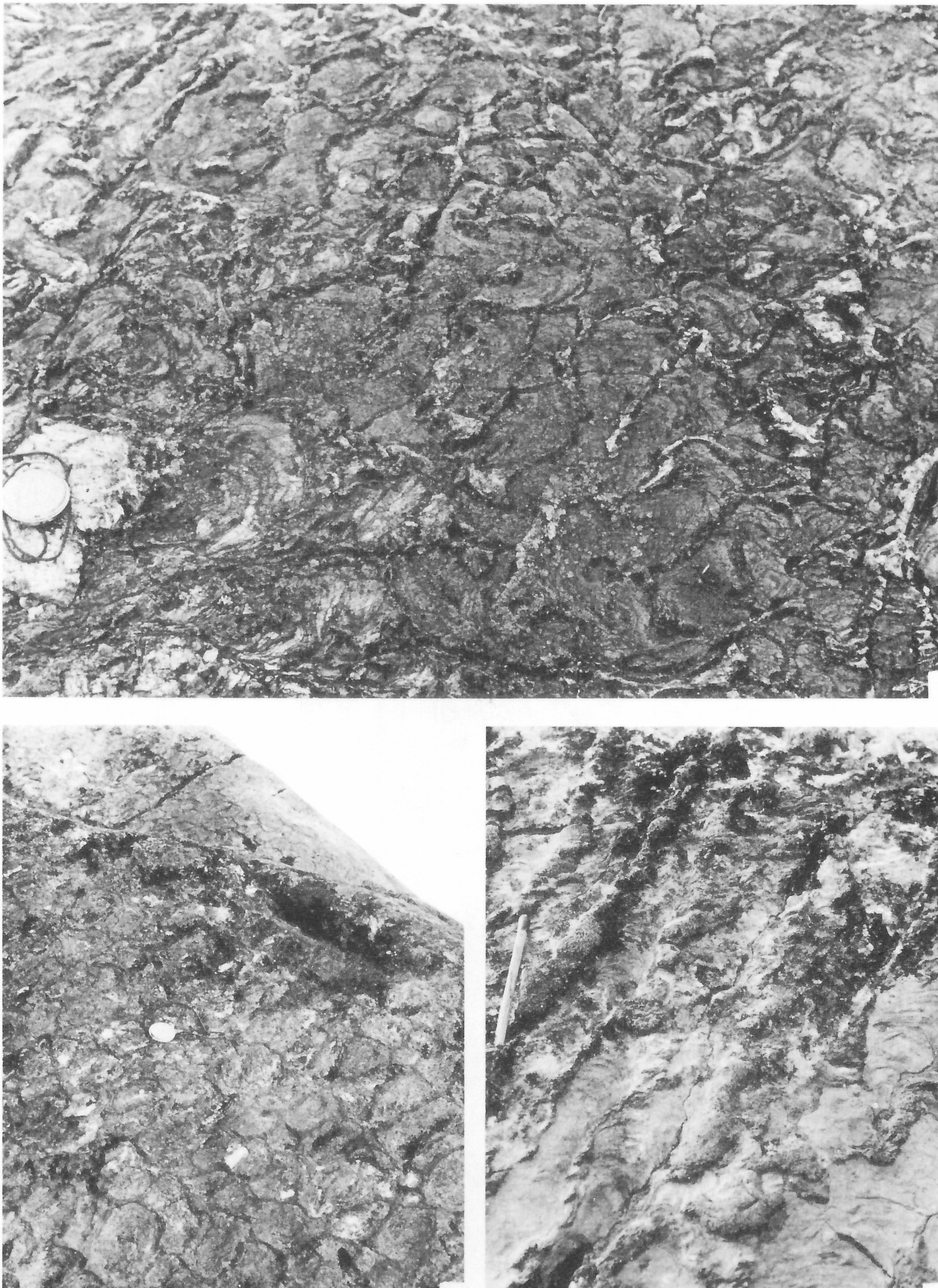


PLATE 20

Archaeozoon septentrionale (PAGE 60)

Figure 1. *Archaeozoon septentrionale*, (Fenton and Fenton 1939)
Oblique view showing the active branching of the columns and the resistant-weathering intercolumn detritus. Photo by A. W. Jolliffe, 1935, of an outcrop of Snare Group on a small island in Marian Lake (62°59′02″N, 116°17′45″W), 71 mi (115 km) northwest of Yellowknife.

GSC photo 79763

Figure 2. *Archaeozoon septentrionale*, (Fenton and Fenton 1939)
Outcrop view exhibiting longitudinal section. Photograph by A. W. Jolliffe, 1935, used by Fenton and Fenton (1939, Pl. 1, fig. 2). Same locality as on fig. 1.

GSC photo 79761

Figure 3. *Archaeozoon septentrionale*, (Fenton and Fenton 1939)
Outcrop view of transverse sections of columns. Photo by A. W. Jolliffe, 1935. Locality same as on fig. 1.

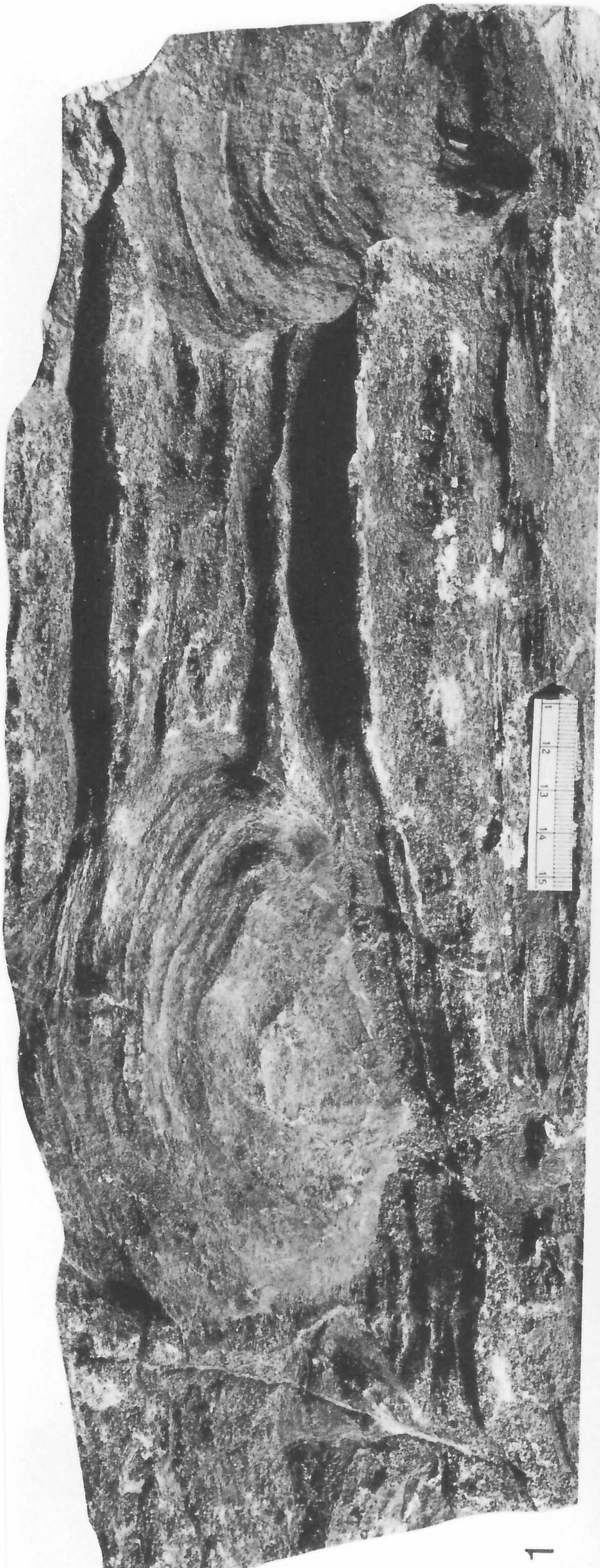
GSC photo 79760

PLATE 21

Cryptozoon walcotti (PAGE 58)

Figure 1. *Cryptozoon walcotti*, Rothpletz 1916
Side view of a slab showing two vertical columns embedded in coarse-grained clastic carbonate with bedding. Section is parallel to tectonic foliation.
Specimen collected loose by J. W. Greig on east bay of Steep Rock Lake, Ontario. Steeprock Group.
A. W. Jolliffe, Queen's University collection GSC photo 200451–B

Figure 2. *Cryptozoon walcotti*, Rothpletz 1916
Bottom view of same specimen as fig. 1, showing size and spacing of columns and tectonic elongation. The specimen illustrated on Pl. 22, fig. 2 is from the left part of the slab, cut across the centre of the large ellipse, as indicated by the markers.
GSC photo 200451–A



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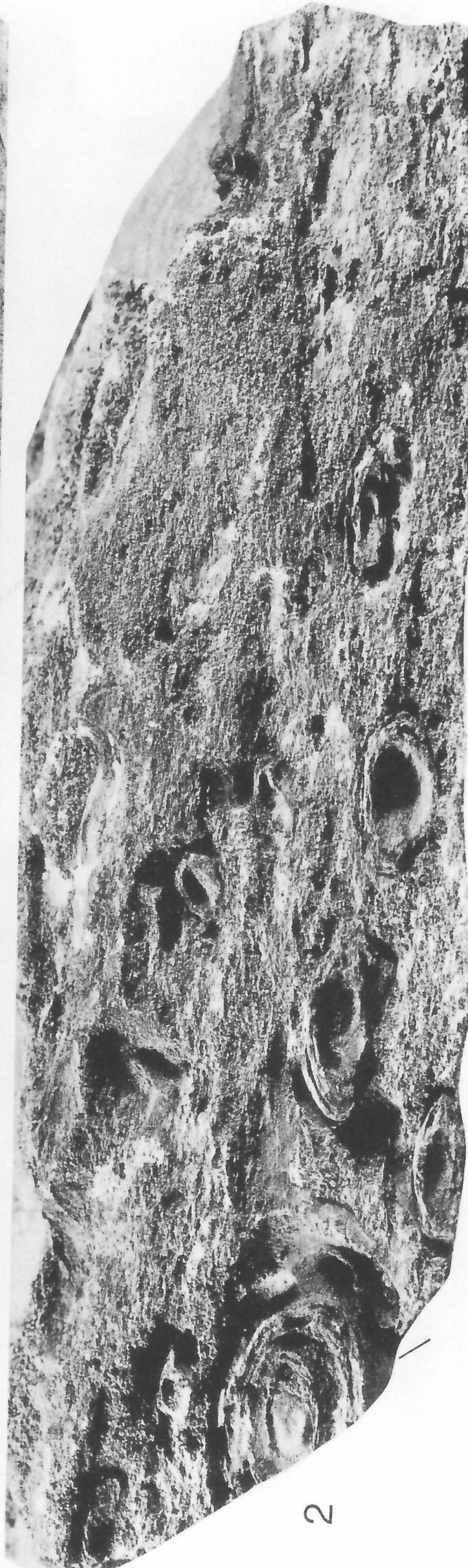

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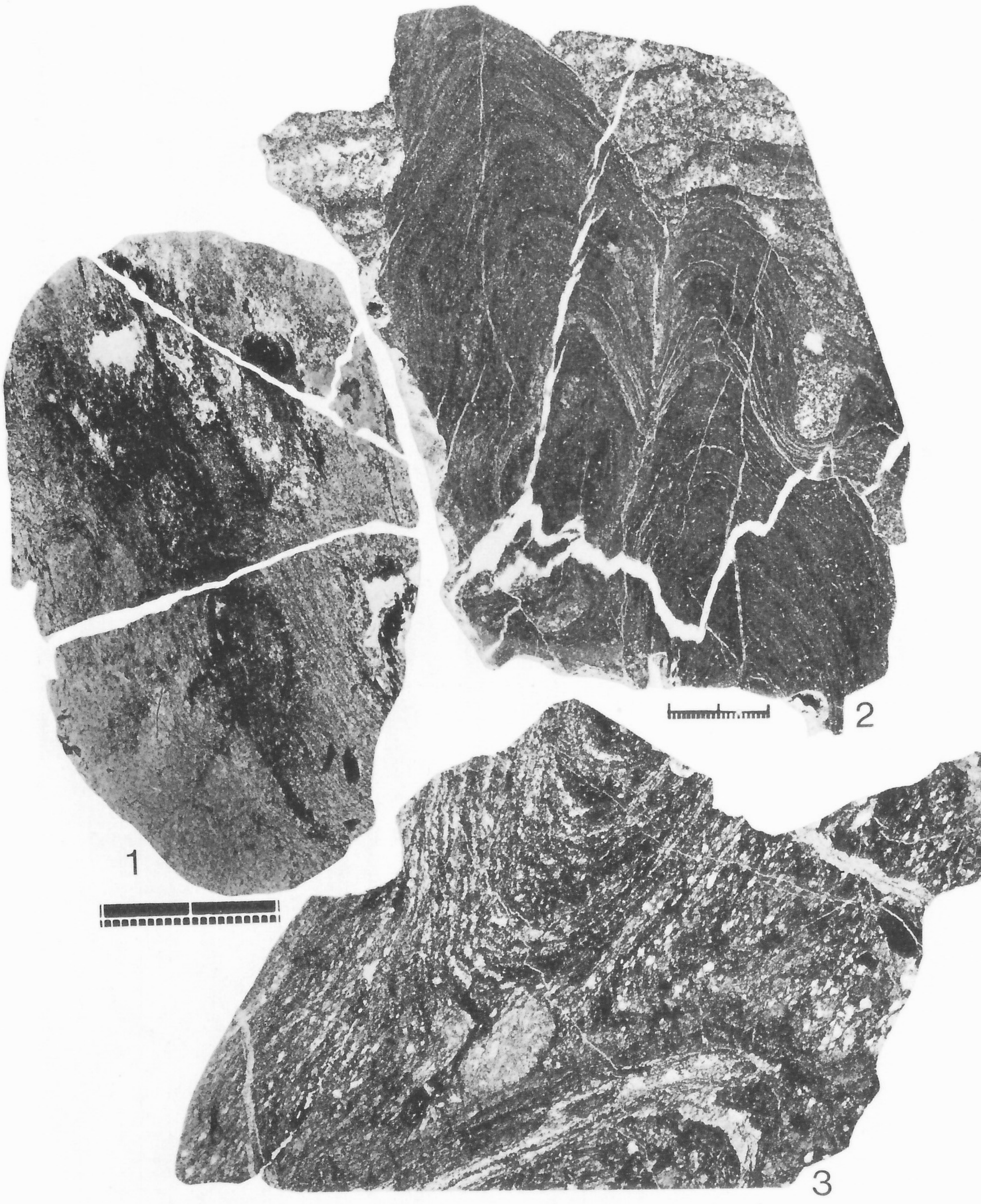
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PLATE 22

Cryptozoon walcotti (PAGE 58)

Figure 1. Cryptozoan ?? sp. indet., Walcott 1912
Thin section illustrated by Walcott. Note the folded laminae at left. This structure is unidentifiable as a stromatolite; the lamination may be tectonic. Steeprock Group, Steep Rock Lake, Ontario.
GSC type 8059f GSC photo 200329–C

Figure 2. *Cryptozoon walcotti*, Rothpletz 1916
Polished vertical surface, showing the columnar and passively branching habit. The form is also lamellar, inasmuch as some of the finer grained dark laminae pass from one head into the intercolumnar detritus, and across to another head. A small pocket of intercolumnar detritus is visible at right centre. The polished surface was obtained from the left portion of the large specimen shown on Pl. 21, figs. 1 and 2. From specimen collected by J. W. Greig, east bay of Steep Rock Lake, Ontario. Steeprock Group.
GSC type 24385 GSC photo 200451–K

Figure 3. *Cryptozoon walcotti*
Thin section made from parts of two columns of same specimen as on fig. 2; the cut is perpendicular to the columns and the tectonic foliation is evident. The light, coarse grains are quartz. No tubular microstructure is visible.
GSC type 24385a GSC photo 200743

PLATE 23

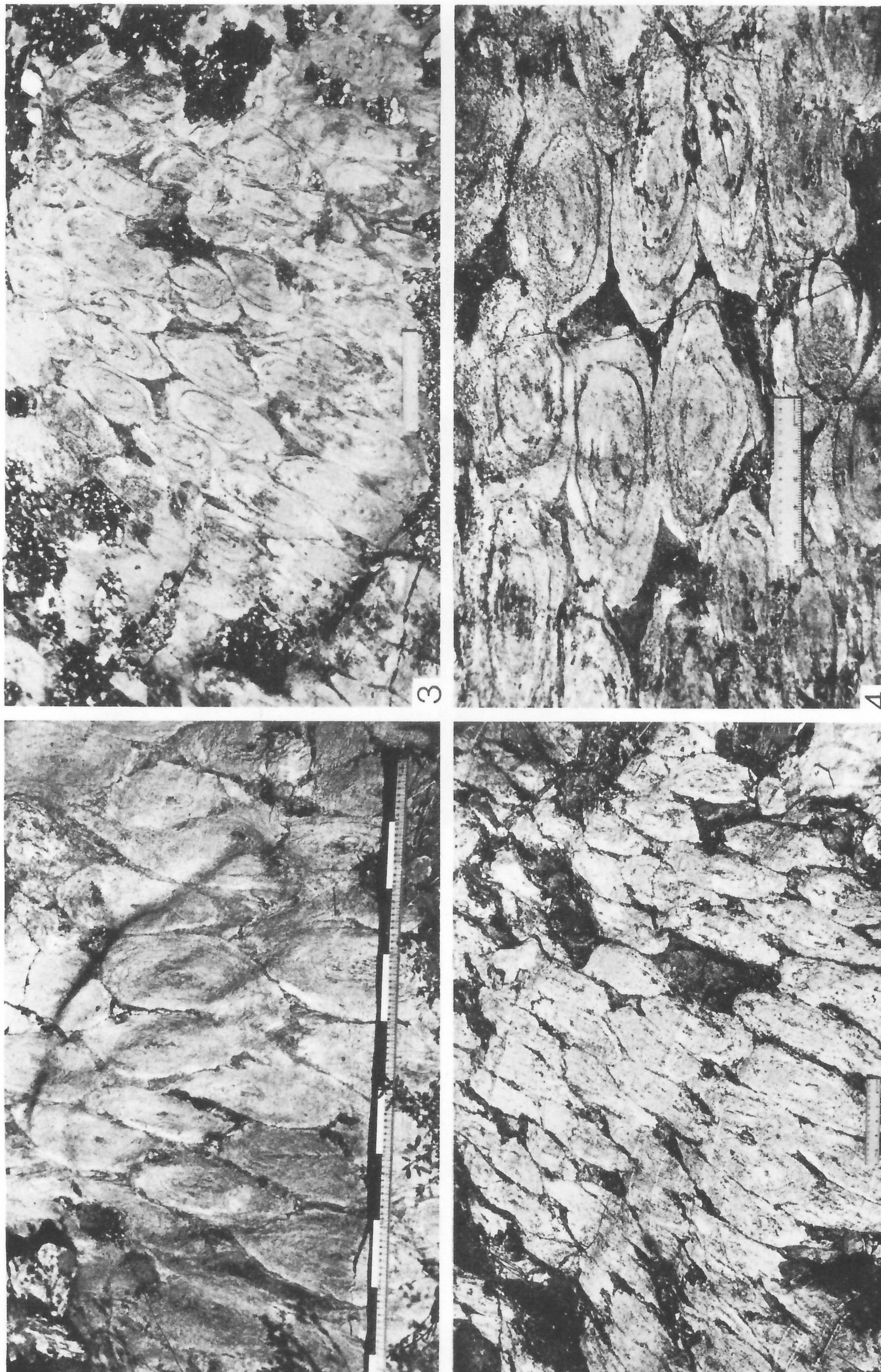
Elliptical structures from Grenville (PAGE 30)

Figure 1. Oblique view of the structures illustrated by Osborne (1931, fig. 1) and Wilson (1939, Pl. VI A). Oblique section shows drawn out ellipses with dolomitic centres, and stylolite-like sutures between several adjacent columns. Metre stick for scale.
Dungannon Formation, Mayo Group (Grenville); L'Amable, Ontario.
GSC locality 79212 GSC photo 134917

Figure 2. View of outcrop 25 m southwest of area in fig. 1. The erosion surface here is more steeply inclined, causing the elliptical cross-section to be more elongated than on fig. 1. 15-cm ruler for scale.
GSC locality 79212 GSC photo 134915

Figure 3. Another part of the same outcrop as on figs. 1 and 2, showing ellipsoids with systematically spaced dark bands that may be marker laminae of possible use in microcorrelation of the columns.
GSC photo 134913

Figure 4. Close-up of central part of fig. 3, showing the marker laminae, the intercolumnar dolomite filling, and the appressed nature of some of the columns.
GSC photo 134916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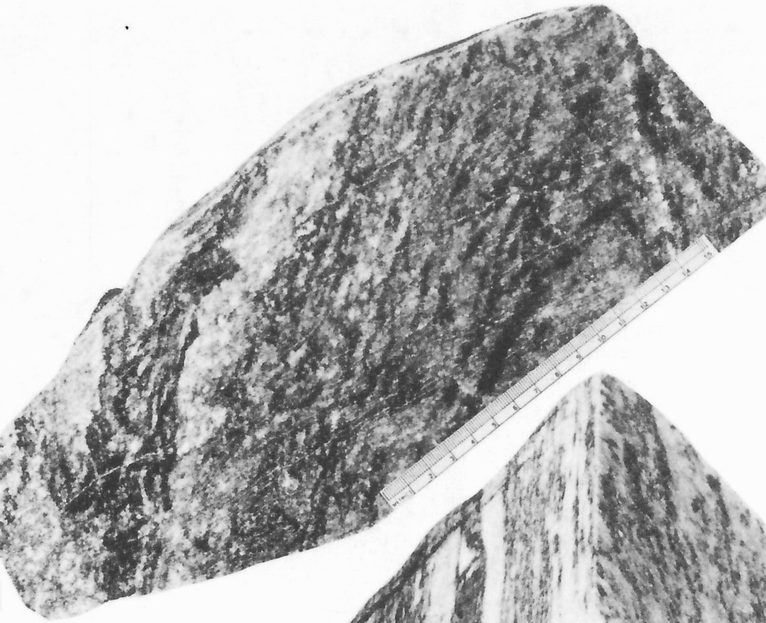

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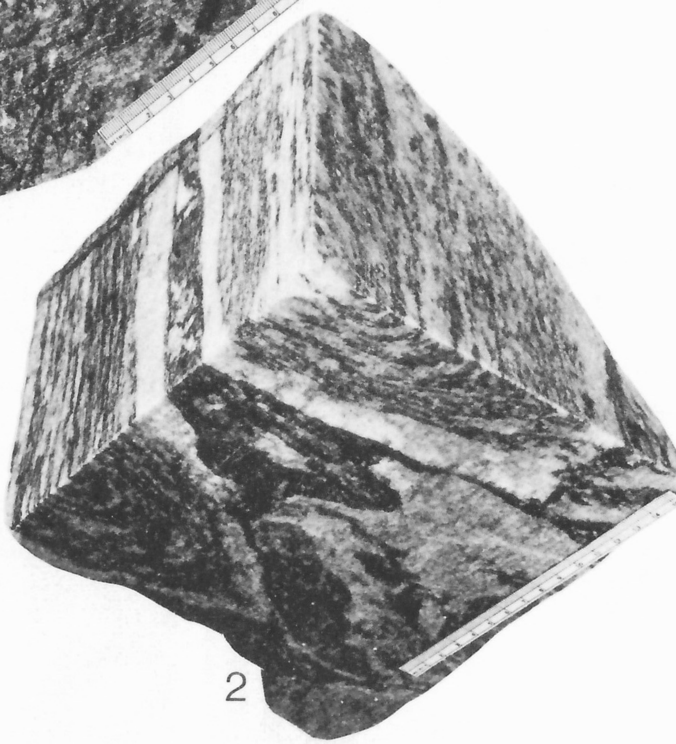

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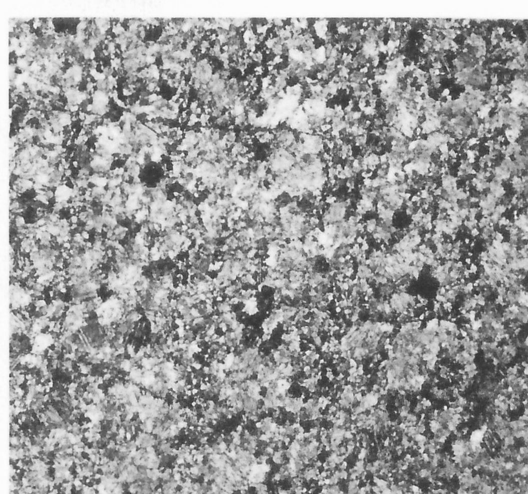

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PLATE 24

Elliptical structures from Grenville (PAGE 30)

Figure 1. Vertical axial section in plane of long axis of elliptical cross-section, showing the arches outlined by the dark laminae.
Specimen is oriented with cylindrical axis vertical. Dungannon Formation, Mayo Group (Grenville), L'Amable, Ontario.
GSC type 24377c GSC photo 200459–A

Figure 2. Oblique view from below of three mutually perpendicular sections, showing the columnar and laminated nature of the structures and their parallelism. The upper right surface is the counterpart of the upper half of fig. 1.
GSC type 24377 GSC photo 200459–B

Figure 3. Thin section, cut parallel to the long axis of the columns and the short axis of the elliptical cross-section, from the counterpart of the portion in the upper left of fig. 2. The spacing and the discontinuous nature of the darker graphitic and dolomitic laminae are evident.
GSC type 24377d GSC photo 200458–C

Figure 4. Same as fig. 3, with crossed nicols, showing the coarse granular calcite and the fine granular dolomite.
GSC photo 200458–B

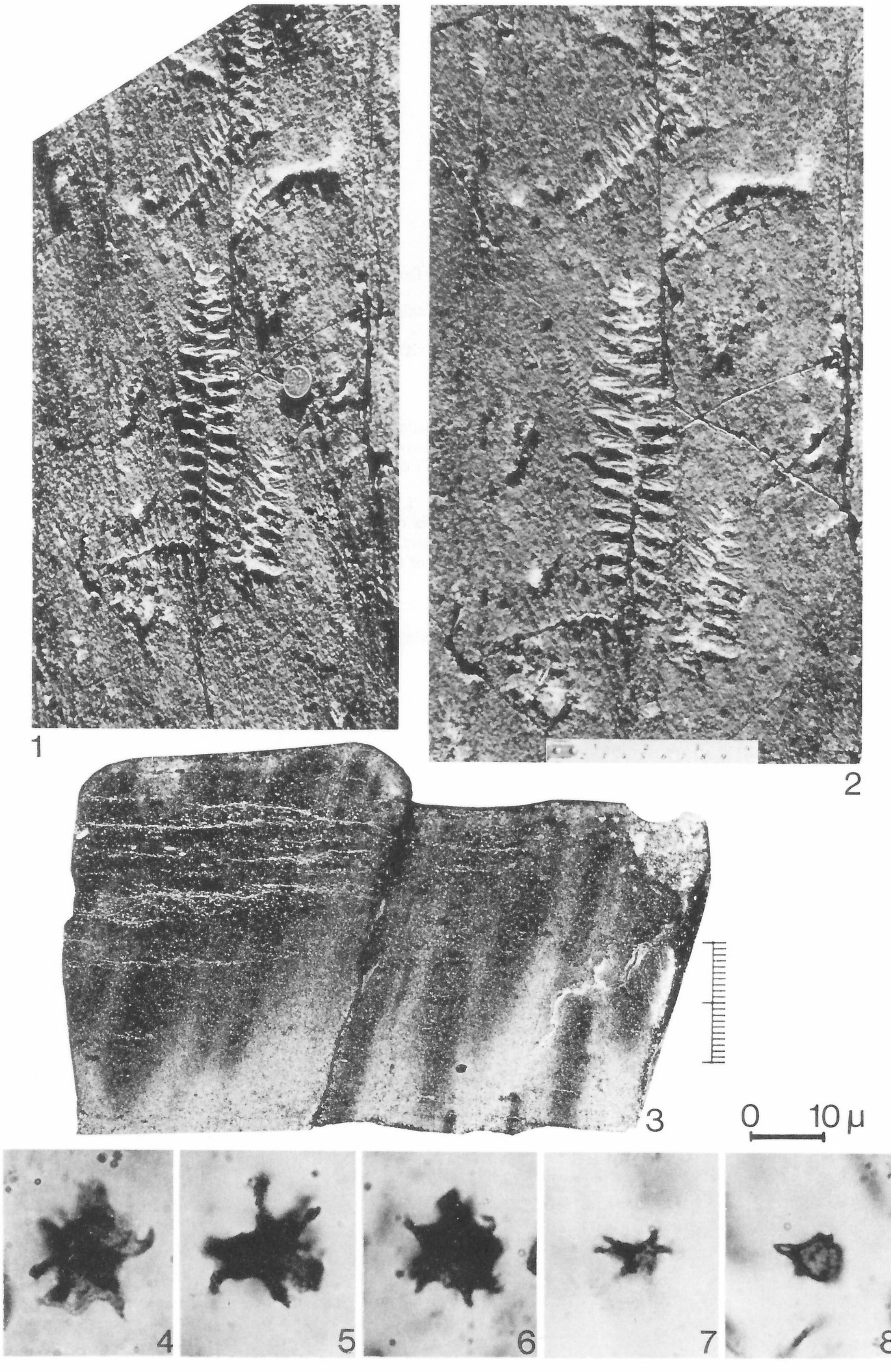
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Plate 25

Conception Group Metazoa; *Skolithos*-like tubes; Gunflint microfossils

Figures 1, 2. Metazoa from Conception Group, Anderson and Misra 1968 (Page 43)

1. Several specimens of the commonest type on weathered outcrop, showing the general appearance and variation in size. Illumination is low oblique, from upper right. Cliffs west of Mistaken Point, 7.7 km west-southwest of Cape Race, Nfld.
   Original photograph, courtesy of M.M. Anderson.
2. Same specimens as in fig. 1, under different lighting conditions. Illumination from top centre. Photograph: courtesy of H. Williams.

Figure 3. *Skolithos*-like tubes from Sosan Group, Hoffman 1968 (Page 39)

Polished vertical section of glauconitic, carbonate-cemented quartz sandstone with steeply inclined cylinders. The light grey horizontal streaks are composed of glauconite grains. These laminae pass across the cylinders without disruption, demonstrating that the structures are not burrows, but of secondary, chemical origin. North shore of Charlton Bay near Reliance, east arm of Great Slave Lake, District of Mackenzie.
GSC type 24969, coll. by P.F. Hoffman GSC locality HY-27L-67-SO2
GSC photo 201117

Figures 4–7. *Eomicrhystridium barghoorni*, Deflandre 1968 (Page 50)

Four specimens from black, stromatolitic chert at the base of the Gunflint Formation, 6.4 km west of Schreiber, Ontario. The structures are from the type locality of the species, and give an indication of its morphologic variability.

4. GSC type 24380a, co-ordinates 106.0/34.3 GSC photo 201116–A
5. GSC type 24380c, co-ordinates 115.3/24.9 GSC photo 201116–B
6. GSC type 24380c, co-ordinates 116.1/22.5 GSC photo 201116–D
7. GSC type 24380c, co-ordinates 115.6/22.6 GSC photo 201116–C

Figure 8. *Eomicrhystridium barghoorni*? (Page 50)

A small cell with few and short spines, possibly belonging to *E. barghoorni*, from Gunflint Formation, 6.4 km west of Schreiber.
GSC type 24380c, co-ordinates 115.7/24.8 GSC photo 201116–E

INDEX

Numbers in **bold face** type indicate pages where forms are described or where the most important reference appears