

THE GUNFLINT MICROBIOTA*

STANLEY M. AWRAMIK and ELSO S. BARGHOORN

Department of Geological Sciences, University of California, Santa Barbara, Calif. 93106 (U.S.A.)

The Biological Laboratories, Harvard University, Cambridge, Mass. 02138 (U.S.A.)

ABSTRACT

Awramik, S.M. and Barghoorn, E.S., 1977. The Gunflint microbiota. *Precambrian Res.*, 5: 121–142.

The microbiota of the Gunflint Iron Formation (~2 Ga old) is sufficiently great in diversity as to represent a “benchmark” in the level of evolution at a time only somewhat less than intermediate between the origin of the earth and the present.

To date, thirty entities from these ~2 Ga old microfossiliferous cherts have been described and all but two systematically categorized. From our continuing detailed study of the Gunflint microbiota (ESB for over 20 years) and, in light of our recent investigations on blue-green algal cell degradation, we conclude that: (1) A considerable number of the taxa systematically described are either of doubtful biological origin, doubtful taxonomic assignment, and/or morphologically indistinguishable from previously described Gunflint microorganisms. (2) The microbiota is wholly prokaryotic.

At present, we recognize sixteen taxa falling within three categories: (1) blue-green algae (6 taxa; e.g. *Gunflintia minuta*); (2) budding bacteria (4 taxa; e.g. *Eoastrion simplex*); and (3) unknown affinities (6 taxa; e.g. *Eosphaera tyleri*). Organisms of undoubted eukaryotic affinities have yet to be found in the Gunflint.

The Gunflint assemblage includes a high percentage of morphologic entities of obscure taxonomic position.

Recently, Walter (1975) and Knoll and Barghoorn (1975) reported Gunflint-type microbiotas of approximately the same age as the Gunflint from two localities in Australia. The dominant morphotypes of the Gunflint microbiota appear to be cosmopolitan and the striking similarity of the three assemblages may strengthen the potential of ancient microbiotas for use in Precambrian biostratigraphy.

INTRODUCTION

Through a remarkable combination of biological, sedimentological and geochemical events there is preserved in black cherts of the Gunflint Iron Formation an assemblage of microorganisms of immense significance in the known Precambrian record of life. The Gunflint microbiota is sufficiently diverse as to represent a “benchmark” in the level of evolution at a time only somewhat less than intermediate between the origin of the earth and the present.

*Contribution No. 64 of the Biogeology Clean Laboratory, University of California, Santa Barbara, Calif. 93106, U.S.A.

The potential importance of the Gunflint in the emerging field of Precambrian paleobiology was first noted in a brief preliminary paper by Tyler and Barghoorn (1954) which was expanded in a subsequent report (Barghoorn and Tyler, 1965) and by other authors (Cloud, 1965; Cloud and Hagan, 1965; Deflandre, 1968; Licari and Cloud, 1968; Hofmann, 1969; 1971; Edhorn, 1973; Darby, 1974; Kaźmierczak, 1976; Tapman, 1976).

To date thirty morphotypes from these $\sim 2 \cdot 10^9$ year old microfossiliferous cherts have been described and all but two systematically categorized (Table I; the two bacterial morphotypes reported in Schopf et al. (1965) have not been classified). From our continuing detailed study of the microbiota (ESB for over twenty years) and, in light of our recent investigations on blue-green algal cell degradation (Awramik et al., 1972; Knoll and Barghoorn, 1975) we consider that (1) many of the described taxa are of doubtful biological origin, doubtful taxonomic assignment, or vaguely described (Table I), and most important, (2) we interpret the microbiota as wholly prokaryotic.

At present, we recognize sixteen taxa, six of which are new and here described; one emended; the nine remaining taxa are retained, but we report additional data based on new observations of *Gunflintia* and *Huroniospora*. These sixteen taxa fall within three categories: (1) blue-green algae, (2) budding bacteria, and (3) unknown affinities (Table II).

The Gunflint type of microbiota is now represented by three other localities of approximately the same age: (1) the Duck Creek Dolomite, northwestern Australia (Knoll and Barghoorn, 1975); (2) the Frere Formation in the Nabberu Basin, Western Australia (Walter et al., 1976); and (3) the Belcher Islands, N.W.T., Canada (Hofmann and Jackson, 1969; Hofmann, 1976). All but the Belcher Islands microbiota share many common elements (except certain rare and bizarre morphotypes at present known only from the Gunflint, most of which are presented here for the first time). Based on preliminary reports, the Duck Creek and Frere microbiotas are dominated by forms also abundant in the Gunflint. It thus appears that the Gunflint microbiota was cosmopolitan and represents an accurate representation of the level of evolution some 2 Ga ago.

GEOLOGIC SETTING AND LOCALITIES

The Gunflint Iron Formation is exposed in almost continuous outcrop from west of Gunflint Lake to Thunder Bay some 180 km to the east and continues eastward in isolated exposures on the north shore of Lake Superior, an additional distance of some 120 km, to an area just west of Schreiber, Ontario, Canada (Fig.1).

The geologic setting of the Gunflint has been described in detail (Goodwin, 1960; Moorhouse, 1960; Barghoorn and Tyler, 1965; Cloud, 1965; Hofmann, 1969; Morey, 1973) and only new information on a previously unreported locality need be presented here.

The microfossils described in this report were discovered in cherts from

TABLE I

Taxa reported from the Gunflint Iron Formation and their provisional status

Taxon	Accepted here	Taxon revised or additional studies needed (see below)
1. <i>Anabaenidium barghoornii</i> Edhorn 1973		2
2. <i>Animikiea septata</i> Barghoorn 1965		1
3. <i>Archaeorestis schreiberensis</i> Barghoorn 1965	x	
4. <i>Chlamydomonopsis primordialis</i> Edhorn 1973		2
5. <i>Cumulusphaera lamellosa</i> Edhorn 1973		2
6. <i>Entosphaeroides amplius</i> Barghoorn 1965		7
7. <i>Eoastrion bifurcatum</i> Barghoorn 1965		5
8. <i>Eoastrion simplex</i> Barghoorn 1965	5	5
9. <i>Eomicrhystridium aremoricum</i> Deflandre 1968	x	
10. <i>Eosphaera tyleri</i> Barghoorn 1968	x	
11. <i>Glenobotrydion aenigmatis</i> Schopf 1968 (see Edhorn 1973)		2
12. <i>Gunflintia grandis</i> Barghoorn 1965	x	
13. <i>Gunflintia minuta</i> Barghoorn 1965	x	
14. <i>Huroniospora macroreticulata</i> Barghoorn 1965		1
15. <i>Huroniospora microreticulata</i> Barghoorn 1965		1
16. <i>Huroniospora psilata</i> Barghoorn 1965		1
17. <i>Kakabekia umbellata</i> Barghoorn 1965	x	
18. <i>Palaeoanacystis irregularis</i> Edhorn		2
19. <i>Palaeorivularia ontarica</i> Korde 1958 (see Oehler 1976)		6
20. <i>Palaeoscytonema moorhousi</i> Edhorn 1973		2
21. <i>Palaeospiralina minuta</i> Edhorn 1973		2
22. <i>Palaeospiralis canadensis</i> Edhorn 1973		2
23. <i>Palaeospirulina arcuata</i> Edhorn 1973		2
24. <i>Primorivularia thunderbayensis</i> Edhorn 1973		2
25. " <i>Schizothrix</i> " <i>atavia</i> Edhorn 1973		2
26. <i>Sphaerophycus gigas</i> Edhorn 1973		2
27. <i>Veryhachium?</i> sp. Hofmann 1971		? 3
28. <i>Menneria levis</i> Lopukhin, 1971 (see also Lopukhin, 1975)		4

1. Revised or emended description herein.
2. Poor preservation, insufficient data, and in the light of degradation studies of Recent algae, probably related to better preserved taxa.
3. Biogenicity uncertain.
4. Not found in thin section. Additional data needed.
5. See Kline 1975 and in preparation.
6. Abiogenic.
7. Internal bodies may be degraded trichome cells, endospores, or prokaryotic guests.

two localities (see Fig.1B); (1) the black stromatolitic cherts from the Schreiber Beach locality (Barghoorn and Tyler, 1965; Cloud, 1965) located along the north shore of Lake Superior (Fig.2). This area is approximately 6.4 km west of Schreiber Beach proper; and (2) non-stromatolitic, thinly bedded, gray to blue-gray cherts from a new microfossiliferous locality,

TABLE II

Affinities of Gunflint morphotypes

Blue-green algae

X	<i>Gunflintia minuta</i>	trichome
X	<i>Gunflintia grandis</i>	trichome
X	<i>Animikiea septata</i>	sheath
X	<i>Huroniospora</i> spp.	coccoid-solitary
X	<i>Corymbococcus hodgkissii</i>	coccoid-colonial aggregates
X	<i>Enterospaeroides amplus</i>	?sheath

Budding bacteria

	<i>Eoastrion simplex</i>	
X	<i>Archaeorestis schreiberensis</i>	
X	<i>Archaeorestis magna</i> (?)	
	<i>Kakabekia umbellata</i>	

Unassignable affinities

X	<i>Eomicrhystridium aremoricatum</i>
X	<i>Eosphaera tyleri</i>
X	<i>Xenothrix inconcreta</i>
X	<i>Thymos halis</i>
X	<i>Exochobrachium triangulum</i>
	<i>Galaxiopsis melanocentra</i>

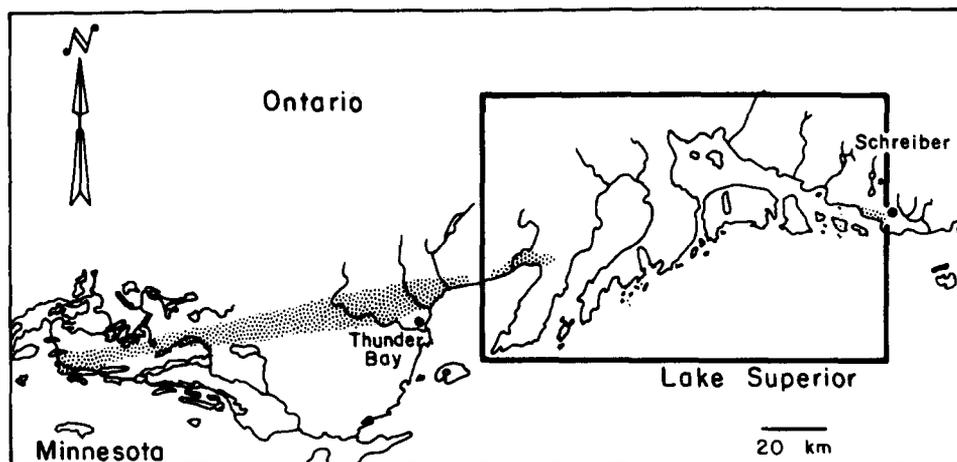
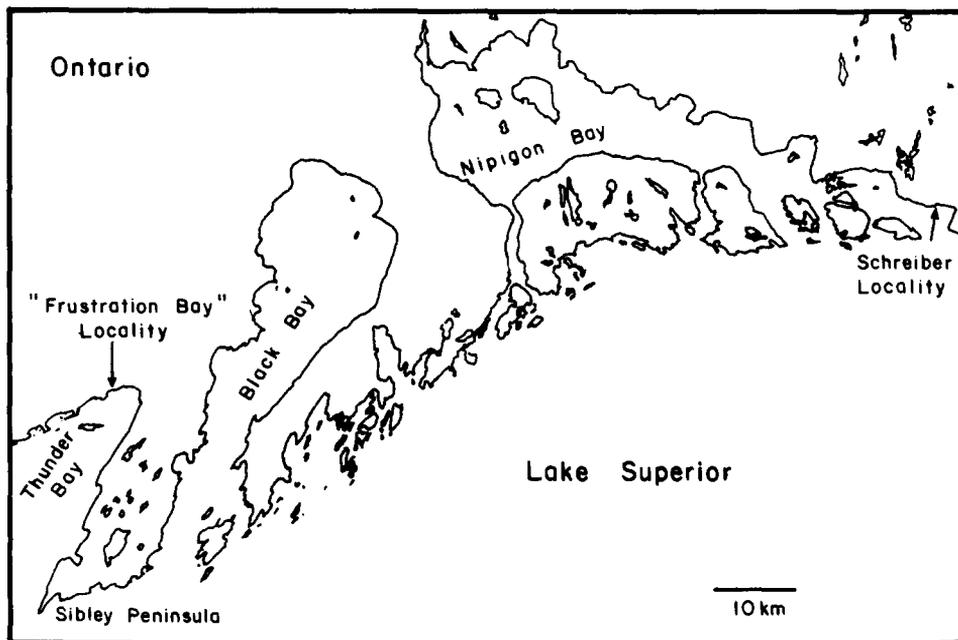
X Found almost exclusively within stromatolitic laminae.

1 kilometer west of the mouth of the Blende River, along the north shore of Lake Superior west of the Sibley Peninsula (Fig.3).

The new locality, which we informally call "Frustration Bay", occurs in the Upper Gunflint member west of the Blende River along the north shore of Lake Superior. Rock types consist of gray to blue-gray finely laminated cherts with subordinate black layers (Fig.2) interbedded with ferruginous carbonates. The cherts are non-stromatolitic and frequently are brecciated within a ferruginous carbonate matrix. The Upper Gunflint member is very complex with extensive lateral variations in facies (Moorhouse, 1960). Poor exposure and lack of lateral continuity at this locality make detailed field relations difficult to interpret.

AGE OF THE GUNFLINT

The Gunflint Iron Formation has a generally accepted age of approximately 2 Ga (Barghoorn and Tyler, 1965; Cloud, 1965). Though this 2 Ga old Animikie age is widely accepted, radiogenic ages range from 1685 ± 24 Ma (a minimum age; Faure and Kovach, 1969) to 1900 ± 200 Ma (Hurley et al., 1962).

**A****B**

dgc 1976

Fig.1. Map showing location of Gunflint Iron Formation.

A. Stippled area shows outcrops of the iron formation.

B. Enlargement of insert on Map A showing location of "Frustration Bay" and Schreiber localities.



Fig. 2. Stromatolitic black chert from Schreiber containing *Gunflintia-Huroniospora* assemblage. The stromatolite is *Gruneria* sp.; bar equals 1 cm.

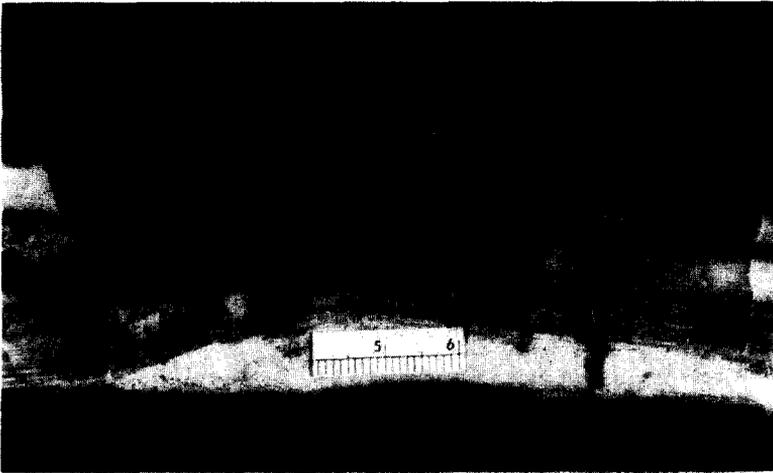


Fig. 3. Thinly bedded non-stromatolitic chert from "Frustration Bay" which contains the *Eoastrion* assemblage. Centimeter scale.

SIGNIFICANCE OF THE GUNFLINT MICROBIOTA

The microbiota found in the cherts of the Gunflint Iron Formation, unlike other ancient microbiotas described, is unique in preserving a variety of odd and complex morphotypes of unknown taxonomic affinities (Table II).

In addition, well represented within the Gunflint are morphotypes similar to ancient microorganisms, described from other localities, and also to extant blue-green algae (see Schopf, 1975). In the Gunflint, we found trichomes

(*Gunflintia minuta*, Fig.4A); empty blue-green algal sheaths (Figs.4B, 4C); trichomes within sheaths (Fig.4D); solitary coccoids (*Huroniospora*, Figs. 4E, F); and colonial aggregates of coccoids (*Corymbococcus*, Figs. 5A,B).

The morphotypes with blue-green algal affinities are found almost exclusively within stromatolitic laminae and presumably were instrumental in building the stromatolites (Barghoorn and Tyler, 1965; Cloud, 1965; Awramik, 1976a and b). Blue-green algae are the prime builders of Recent stromatolites (Golubic, 1976) and the association of the Gunflint stromatolites with

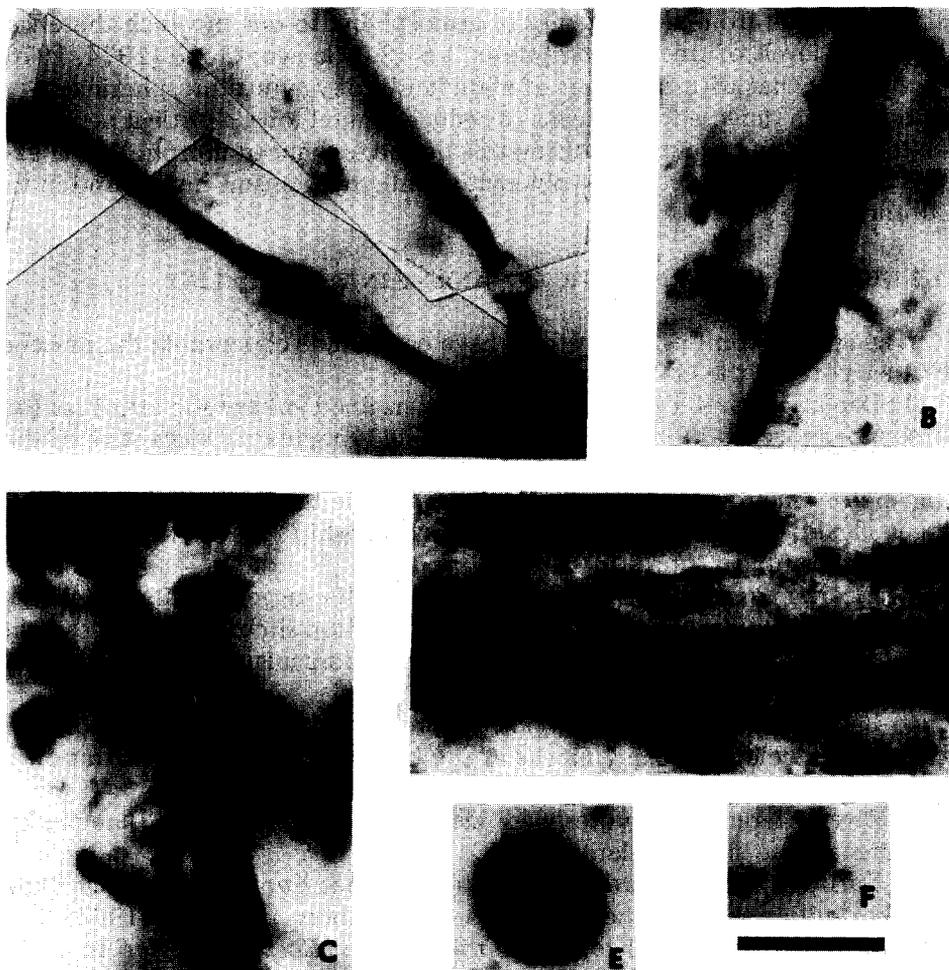


Fig.4. Cyanophytes from the Gunflint (all at the same magnification). Bar equals 10 μm .
 A. Trichome of *Gunflintia minuta* with possible heterocysts.
 B. and C. Empty sheaths.
 D. Two *Gunflintia minuta* trichomes within common sheath.
 E. *Huroniospora* > 3 μm .
 F. *Huroniospora* < 3 μm .

a rich cyanophytic microbiota is consistent with an interpreted benthic, stromatolitic habit.

Five of the six taxa of phylogenetically unassignable affinities (Table II) are also found within stromatolitic laminae. The affinities of the morphologically bizarre and complex microorganisms are problematical. We have concluded that these forms may reflect morphological "experimentation" and variation within certain prokaryotic groups at a critical time in the evolution of the atmosphere and hydrosphere (Awramik and Barghoorn 1975). The time of deposition of the Gunflint corresponds approximately to the postulated transition from an oxygen-poor atmosphere, to one in which there were significant levels of free oxygen [about 1.8–2.0 Ga ago; Cloud (1974, 1976)]. We visualize that with the onset of abundantly oxygenic atmospheric conditions which depleted the oceans of reduced metal ions, a critical period in the history of life occurred. During this period, enhanced morphological experimentation produced the problematical microorganisms now found in the Gunflint.

THE QUESTION OF EUKARYOTIC ORGANISMS IN THE GUNFLINT

In assigning affinities, suggestions have been made concerning the presence of eukaryotes in the Gunflint microbiota:

(1) Barghoorn and Tyler (1965) first entertained eukaryotic affinities for three morphotypes: (a) *Gunflintia grandis*: cell irregularity suggestive of the Ulotrichaceae (green algae); (b) *Archaeorestis schreiberensis*: non-septate, branched tubular filaments somewhat comparable to the Vaucheriaceae (green algae); (c) *Huroniospora*: possible relationship to free-swimming dinoflagellates or fungal spores.

(2) Licari and Cloud (1968) did not exclude the suggested dinoflagellate affinity for *Huroniospora* but indicated that caution should be exercised when trying to establish eukaryotic affinities for microorganisms as old as the Gunflint.

(3) Barghoorn (1971) pointed out the presence of internal features suggestive of a nucleus in large unicells of the Gunflint from the "Frustration Bay" locality.

(4) Five different eukaryotes were identified by Edhorn (1973) and referred to as green algae and radiolarians.

(5) Darby (1974) considered the possibility that *Huroniospora* might have fungal affinities, reviving the suggestion of Barghoorn and Tyler (1965).

(6) Kaźmierczak (1976) compared the Gunflint *Eosphaera tyleri* to a Devonian form he discovered, *Eovolvox* (Kaźmierczak, 1975), and compares both to the extant coenobial Volvocales (green algae).

(7) Tappan (1976) has compared *Huroniospora* and *Eosphaera* to members of the red algal order Porphyridiales.

Edhorn (1973) reported five different eukaryotes from the Gunflint: *Chlamydomonopsis primordialis*, *Glenobotrydion*, *Cumulosphaera lamellosa*,

Palaeospiralis canadensis, and a group collectively called "eucaryotic cells", some resembling radiolarians. Unfortunately, the material which Edhorn studied showed poor cellular preservation. *Chlamydomonopsis primordialis* was compared to members of the Chlamydomonocae based primarily on the frequent presence of a spot within the cells. We contend that the presence of such an internal spot is not a reliable criterion for eukaryotic organization. Such internal spots are commonly the product of cellular degradation and cytoplasmic coagulation in Recent cyanophytes and are found also in ancient analogues of degraded cells (see Golubic and Hofmann, 1976). Based on similar size and shape, we interpret *C. primordialis* as a *Huroniospora*. Edhorn's identification of *Glenobotrydion* (Chlorococcales) from the Gunflint was based on a superficial resemblance to the Bitter Springs form but it does not contain the ubiquitous internal dark body. We consider that these "*Glenobotrydion*"-like cells are cyanophytes similar in morphology and habit, but smaller than, *Corymbococcus* herein described. *Cumulosphaera lamellosa* Edhorn may superficially resemble the extant *Gloecystis* (Chlorophyta) but the lack of readily identifiable tetrads and stigmata make this assignment questionable. *Palaeospirulina canadensis* is too poorly preserved to justify comparisons with extant chlorophytes. Spiral patterns reported from *P. canadensis* can occur in the sheaths of filamentous cyanophytes (S. Golubic, pers. comm. 1976), thus this criterion alone for a eukaryotic assignment is not warranted.

The group of cells, collectively called "eukaryotes" by Edhorn, some with internal dark spots, most closely resembles blue-green algae with cytoplasmic coagulation. Size, shape, and surface texture are similar to that commonly found in *Huroniospora*.

Edhorn's microfossils are found preserved in jaspers and taconites from the western outcrops of the Gunflint Iron Formation. It has been our experience that preservation in rocks other than dark gray to black cherts is poor, particularly in the west, and classification of such poorly preserved material is unusually subjective and fraught with complications resulting from degradation.

Darby (1974), Kaźmierczak (1976) and Tappan (1976) based their Gunflint eukaryotic comparisons on well-preserved material from the eastern facies. Darby's (1974) consideration that *Huroniospora* might have fungal affinities was based on the occurrence of projections on *Huroniospora* cells that resemble the buds found in fungi. Darby suggested that budding may have occurred in blue-green algae, but that this mode of reproduction has since been lost. Blue-green algae can exhibit irregular growth habits at times resembling budding (Desikachary, 1959, p. 38; Padmaja, 1972). Budding similar to that observed in *Huroniospora* can be found in the budding bacteria (Hirsch, 1974, fig.1, p. 393; fig.4, p. 411). Budding bacteria are generally an order of magnitude smaller than *Huroniospora*, therefore we do not consider this comparison the most consistent with available data.

Tappan (1976) compared the *Huroniospora* bud-like projections to those

observed in the red algal order Porphyridiales (subclass Bangiophycidae). Based on size, "budding" and general morphologic similarities, *Huroniospora* superficially resembles primitive members of the red algae. But the paleoecology of *Huroniospora* is unlike that reported by Tappan (1976) for these red algae. We infer a benthic, stromatolitic habit for *Huroniospora* based on the almost exclusive occurrence in stromatolitic laminae and absence in the non-stromatolitic facies discussed earlier (see also Awramik, 1976). The stromatolitic habit interpreted for *Huroniospora* is consistent with its present assignment to the blue-green algae, and as noted above, "buds" can occur on blue-green algae.

The taxonomic affinity of *Eosphaera tyleri* remains uncertain. Recently, Kaźmierczak (1976) and Tappan (1976) have proposed a eukaryotic affinity for *Eosphaera*. Kaźmierczak's (1976) comparisons are based on resemblances of *Eosphaera* to *Eovolvox*, an interpreted volvoclean from the Devonian (Kaźmierczak, 1975). Superficially this resemblance is striking but *Eosphaera* is smaller than *Eovolvox* (28–30 μm compared to 42–135 μm for *Eovolvox*), lacks a well-defined thick inner wall as exhibited in *Eovolvox*, and, perhaps most important, lacks any evidence of internal daughter colonies.

Tappan (1976) compared *Eosphaera tyleri* to members of the extant algal genus *Porphyridium*. *Porphyridium purpureum* exhibits peripheral budding and, with the external envelope, produces a morphology similar to *Eosphaera* (Tappan, 1976). Cells of *P. purpureum* are commonly smaller than *Eosphaera* (5–8 μm compared to the latter's 28–30 μm) but can approach 60 μm in older cultures. While the comparison is rather compelling, multiple fission has not been observed in *Eosphaera* and *Porphyridium* lacks the distinctive invagination seen in *Eosphaera*.

In order to draw a convincing comparison between morphotypes in the Gunflint and extant eukaryotes all morphologic criteria must be satisfied, and ecology should be considered. By far the most compelling line of evidence is a morphologic feature known only to occur in eukaryotes, such as cysts. Morphologic features such as budding occur in both prokaryotes and eukaryotes.

SUMMARY

A continuing micropaleontological study of the ca. 2 Ga old Gunflint Iron Formation has yielded six new morphotypes and shed light on the taxonomic assignment and biological significance of previously described taxa. Two different types of assemblages are recognized, one stromatolitic, dominated by cyanophytes (the *Gunflintia-Huroniospora* assemblage) while the other is non-stromatolitic and possibly planktonic (the *Eoastrion* assemblage). The Gunflint, unlike other previously reported Precambrian microfossiliferous cherts, contains a microbiota with a high percentage of morphologic entities of unknown affinity (six of the sixteen taxa here recognized). This relatively high proportion of morphologic oddities may reflect morphological "experimentation" within prokaryotic groups during the early Proterozoic.

The overall appearance of the Gunflint microbiota is primitive compared to the one Ga younger Bitter Springs chert of central Australia. Diversity is low in comparison and those taxa with assignable affinities are only made up of possibly 6 cyanophytes, while the Bitter Springs chert numbers 38 cyanophytes, with suggested eukaryotes (Schopf and Blacic, 1971; Schopf and Oehler, 1976). The Belcher Islands microbiota, approximately coeval with the Gunflint, morphologically is more similar to the Bitter Springs microbiota than the Gunflint (Hofmann, 1976). The Gunflint, Duck Creek and Nabberu Basin microbiotas, all of approximately the same age, share many common morphotypes and are unlike the Belcher Islands biota.

The differences between the Belcher Islands microbiota and the Gunflint microbiota apparently were environmentally controlled. Available data suggest that the Gunflint stromatolitic and non-stromatolitic cherts were deposited in shallow subtidal environments (Awramik, 1976). The microbiota from the Belcher Islands stromatolitic cherts represent an intertidal to supratidal facies (Hofmann, 1976; pers. comm., 1976). The Belcher microbiota from addition to sharing many similar morphotypes with the Bitter Springs, is also similar in content to the ~ 1.5 Ga old Amelia Dolomite (Muir, 1976) and Balbirini Dolomite (D.Z. Oehler, 1976). The Belcher Islands, Amelia, Balbirini and Bitter Springs microbiotas are all interpreted as representing intertidal to supratidal deposits. Thus, an important difference between the Belcher Islands and Gunflint microbiotas is one of facies. The intertidal microbiotas mentioned here support the concept of morphological conservatism in blue-green algae (Awramik et al., 1976). Subtidal microbiotas, as the Gunflint and various shale microbiotas, may yield a more faithful picture of the diversity and complexity of life than the highly specialized microbiotas restricted to intertidal and supratidal environments.

ACKNOWLEDGEMENTS

We wish to thank Dr. Lesly Garay, The Botanical Museum, Harvard University, for nomenclatural assistance. D.G. Crouch (UCSB) drafted the figures; K. Morrison and D. Doerner (UCSB) prepared final photographs. The manuscript was critically read by D.E. Pierce and M.R. Walter. Financial support was supplied by NSF grant GA-138/21 and NASA-NGL-22-007-069 to ESB.

SYSTEMATIC PALEONTOLOGY

Five new genera and one species are described from the Gunflint cherts, together with an emendation of a previously described taxon. New observations on some taxa previously described in Barghoorn and Tyler (1965) have broadened our understanding but do not warrant new systematic descriptions or emendations at this time; *Huroniospora* and *Gunflintia minuta* are discussed in this light. The Gunflint continues to yield new morphotypes. A previously unreported locality from a non-stromatolitic facies west of Blende

River has only just begun to shed additional light on the richness and varied nature of the total microbiota.

Taxonomic problems are difficult in studies of microbiotas preserved in cherts (Schopf and Blacic, 1971). Cell degradation, and variations in the fidelity of preservation make: (a) recognition of a biological entity difficult, and (b) taxonomic assignment questionable. Only well-preserved, morphologically distinct specimens are here described. Hopefully, a degradation series illustrating progressive morphological changes that occur after death and possibly due in part to silicification (see J.H. Oehler, 1976) can be established utilizing data in both extant and fossil microorganisms.

LOCATION OF FIGURED SPECIMENS

Stage coordinates are given for a Zeiss Opton microscope used by the first author while working in the Paleobotanical Laboratory of the Botanical Museum of Harvard University, with thin section label to the right. Thin sections are deposited in the Paleobotanical Collections of Harvard University.

SYSTEMATIC DESCRIPTIONS AND BIOLOGIC RELATIONSHIPS

Division Cyanophyta

Class Cyanophyceae

Order Chroococcales

Family Chroococcaceae

Genus *Corymbococcus* Awramik and Barghoorn n. gen.

Type Species: Corymbococcus hodgkissii Awramik and Barghoorn n. sp.

Diagnosis: Spheroidal to slightly ellipsoidal thick-walled ($\sim 1.5 \mu\text{m}$ thick) unicells 5–18 μm in diameter aggregated into colonies. Individuals average 12.5 μm in diameter (Fig.6). Entire colony encompassed in common unlamellated sheath. Individual cells within colonies are not enclosed by a sheath. Cell surface texture is coarsely but irregularly granular. Cell division is irregular and does not appear to follow any preferred planes of binary fission.

Etymology: From the Latin *corymbus* meaning cluster and *cocum* meaning berry or seed.

Corymbococcus hodgkissii Awramik and Barghoorn n. sp. (Figs.5A,B).

Fig.5. New Gunflint morphotypes (all at the same magnification, bar equals 10 μm , except A, where bar equals 20 μm). Slide number, stage coordinates, and Paleobotanical Collection, Harvard University number are given for each.

A. *Corymbococcus hodgkissii*; Sch-W-CF-11; 35/99.4, 44480.

B. *Corymbococcus hodgkissii*; Sch-W-CF-11; 35/99.4, 44480; arrow points to type.

C. *Thymos halis*; Sch-W-CF-11, 37.5/100.0, 44481

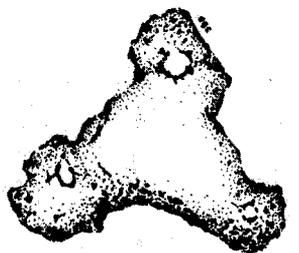
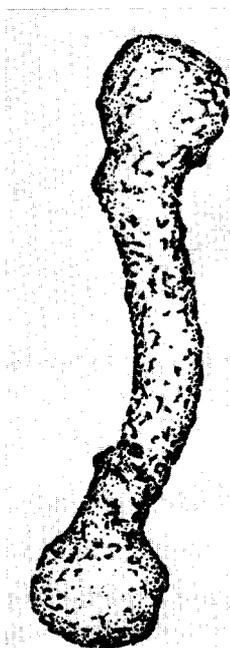
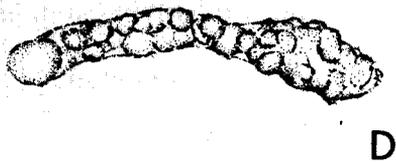
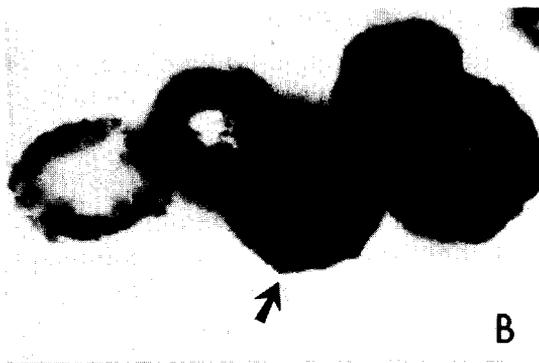
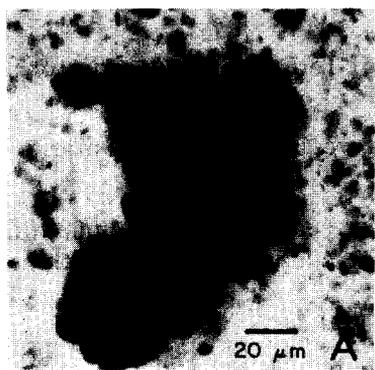
D. *Thymos halis*; drawing of type.

E. *Xenothrix inconcreta*; Sch-W-CF-11; 29.6/97.5; 44482.

F. *Xenothrix inconcreta*; drawing of type.

G. *Exochobrachium triangulum*; Sch-W-CF-11; 36.35/100/85, 44483.

H. *Exochobrachium triangulum*; drawing of type.



F

H

Diagnosis: As for genus.

Etymology: In honor of Mr. Stanley Hodgkiss of Terrace Bay, Ontario for his enthusiasm and assistance in the field.

Type locality: Lower Gunflint member; 6.4 km west of Schreiber, Ontario along the north shore of Lake Superior.

Type specimen: The arrowed cell in Fig.5B is cited as the type specimen. (Thin Section Sch-W-CF-11; stage coordinates 35/93.4; Paleobotanical Collections, Harvard University No. 44480.)

Discussion: Most of the unicells in the Gunflint, in particular *Huroniospora*, occur solitary and only very rarely in pairs. *Corymbococcus hodgkissii* is the first documented occurrence of colonial aggregates in the Gunflint. The cells of *C. hodgkissii* are enclosed in a common envelope (Fig.5A) and resemble the extant blue-green alga *Aphanocapsa* in size and habit (see Geitler, 1932). *C. hodgkissii* is rare; only five clusters are known and all occur in laminae of columnar stromatolites of the *Gruneria*-type from Schreiber Beach.

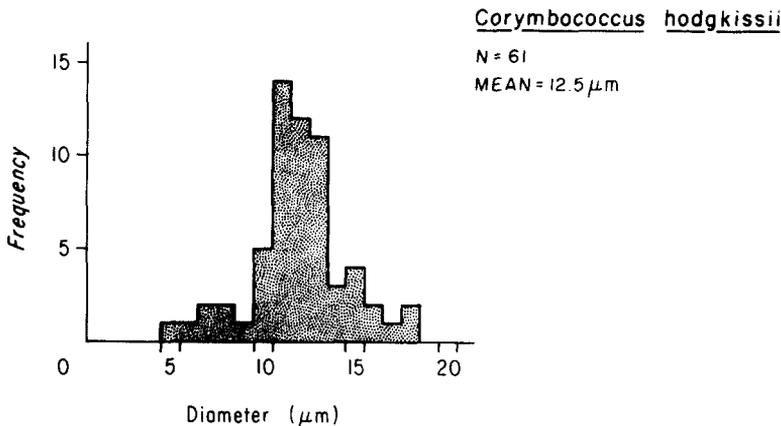


Fig.6. Frequency diagram showing size range of *Corymbococcus hodgkissii*.

INCERTAE SEDIS

Genus *Thymos* Awramik and Barghoorn n. gen.

Type species: *Thymos halis* Awramik and Barghoorn n. sp.

Diagnosis: Nonseptate, unbranched, tubular structure greater than 30 μm long and 4.6 μm wide with pronounced swelling at one end forming a bulbous head 6 μm wide and 9 μm long. Wall structure very thin (less than 0.5 μm thick) with finely reticulate surface. Unswelled end is open, and randomly

distributed within the hollow tube are spherical bodies; the bulbous head is covered with small, kidney-shaped, attached external structures 1.5–3.0 μm in diameter. Reproductive structures uncertain but may be the internal or the external small bodies.

Etymology: From the Greek *thymos* meaning warty.

Thymos halis Awramik and Barghoorn n. sp. (Figs.5C,D)

Diagnosis: As for genus.

Etymology: From the Greek *halis* meaning abundance.

Type locality: Lower Gunflint member; 6.4 km west of Schreiber, Ontario, along north shore of Lake Superior.

Type specimen: Figures 5C and 5D illustrate salient morphologic features of species. Fig.5C is cited as the type specimen. (Thin Section Sch-W-CF-11; stage coordinates 37.5/100.0; Paleobotanical Collections, Harvard University No. 44481.)

Discussion: Although only one well-preserved specimen of *Thymos halis* has yet been discovered from columnar stromatolitic cherts (of the *Gruneria*-type) at the Schreiber locality, the most unusual and bizarre appearance of this morphotype makes it a highly distinctive member of the Gunflint microbiota. To the best of our knowledge, *T. halis* does not resemble any previously described fossil or extant microorganism, either prokaryotic or eukaryotic.

Genus *Xenothrix* Awramik and Barghoorn n. gen.

Type species: *Xenothrix inconcreta* Awramik and Barghoorn n. sp.

Diagnosis: Nonseptate, dumbbell-shaped microfossil 64 μm long; spheres at ends 12.6 μm in diameter with the curved tube connecting the spheres 5.5 μm in diameter. Surface sculpture is finely reticulate to crustose. No internal structures known. Reproductive structures unknown.

Etymology: From the Greek *xenos* meaning stranger and *thrix* meaning thread.

Xenothrix inconcreta Awramik and Barghoorn n. sp. (Figs.5E,F)

Diagnosis: As for genus.

Etymology: From the Latin *inconcretus* meaning soft, delicate.

Type locality: Lower Gunflint member; 6.4 km west of Schreiber, Ontario.

Type specimen: Figs. 5E and F illustrate salient morphologic features of species. Fig.5E is cited as the type specimen. (Thin section Sch-W-CF-11; stage coordinates 29.6/97.5; Paleobotanical Collections, Harvard University No. 44482.)

Discussion: One well-preserved specimen of *Xenothrix inconcreta* is known from *Gruneria*-type stromatolites at the Schreiber locality. The unique morphology of this microfossil makes it a distinctive member of the microbiota. To the best of our knowledge, *X. inconcreta* does not resemble any previously described fossil or extant microorganism, either prokaryotic or eukaryotic.

Genus *Exochobrachium* Awramik and Barghoorn n. gen.

Type species: *Exobrachium triangulum* Awramik and Barghoorn n. sp.

Diagnosis: Microstructure 20 μm in diameter with three arms radiating from central body in a tri-radiate arrangement. Arms are swollen at the ends, each with a small sphere 1.5–3.0 μm in diameter subcentral within each swollen end. Surface ornamentation is finely reticulate for the central body to coarsely reticulate at the ends of the arms.

Etymology: From the Greek *exochos* meaning projecting and *brachion* meaning arm.

Exochobrachium triangulum Awramik and Barghoorn n. sp. (Figs. 5G, H)

Diagnosis: As for genus.

Etymology: From the Latin *triangulus* meaning three angles.

Type locality: Lower Gunflint member; 6.4 km west of Schreiber, Ontario along north shore of Lake Superior.

Type specimen: Figs. 5G and H illustrate salient features of species and Fig. 5G is cited as the type specimen. (Thin section Sch-W-CF-11; stage coordinates 36.35/100.85; Paleobotanical Collections, Harvard University No. 44483.)

Discussion: Only one specimen of *Exochobrachium triangulum* is known and this is from stromatolitic cherts at the Schreiber locality. To our knowledge *E. triangulum* does not resemble any extant microorganism and hence is of unassignable affinity.

Genus *Galaxiopsis* Awramik and Barghoorn n. gen.

Type species: *Galaxiopsis melanocentra* Awramik and Barghoorn n. sp.

Diagnosis: Irregularly shaped structure 20–30 μm in diameter with two or three radiating arms resembling pseudopodia. Outside surface reticulate. Outer “pseudopodial” layer is thick (>.5 μm). Dense internal sphere 15 μm or less in diameter with no wall structure evident. Reproductive structures not recognized.

Etymology: In reference to the galaxy-like appearance (Greek *opsis*: appearance).

Galaxiopsis melanocentra Awramik and Barghoorn n. sp. (Figs.7E,F).

Diagnosis: As for genus.

Etymology: From the Greek *melanos* meaning black; and refers to the central position of the dark body.

Type locality: Upper Gunflint member; 1 km west of mouth of Blende River (Sibley Peninsula) along north shore of Lake Superior, Canada.

Type specimen: Fig.7F is cited as the type specimen. (Thin section FB4; stage coordinates 47.4/93.3; Paleobotanical Collections, Harvard University No. 44484.)

Discussion: *Galaxiopsis melanocentra* is locally abundant in thin sections from the non-stromatolitic cherts of the Upper Gunflint, 1 km west of the mouth of the Blende River. The shape of the outer envelope is variable but all specimens contain the distinctive internal dense sphere. Most likely the outer irregular structure is the deformed envelope of a coccoid cyanophyte while the internal sphere is the cell; however, studies on the *post mortem* degradation of extant coccoid cyanophytes have failed to yield morphological counterparts. *G. melanocentra* is very rare in the stromatolitic cherts from the Schreiber area. The distinctive morphology of this microfossil makes it a useful morphotype characterizing the non-stromatolitic cherts from the Upper Gunflint. *G. melanocentra* is commonly found associated with *Eoastrion simplex* in this facies.

Genus *Archaeorestis* Barghoorn 1965

Type species: *Archaeorestis schreiberensis* Barghoorn

Archaeorestis magna Awramik and Barghoorn n. sp. (Fig.7B)

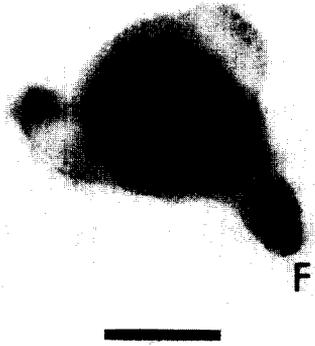
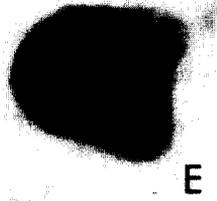
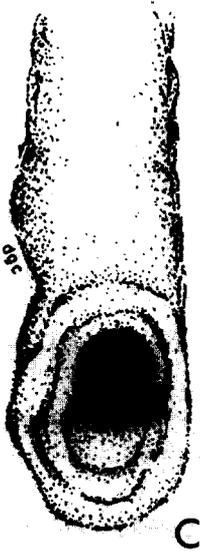
Diagnosis: Large ($9.36 \times 88.14 \mu\text{m}$) nonseptate tubular branched filament with finely reticulate surface texture. No internal structure. Branching is at 85° and the branched ends are closed while the unbranched portion of the tube remains open. Bulbous swelling not evident. Reproductive structures not recognized.

Etymology: From the Latin *magnus* meaning large size.

Type locality: Lower Gunflint member; 6.4 km west of Schreiber, Ontario along north shore of Lake Superior.

Type specimen: Fig.7B illustrates salient features and is cited as the type specimen. (Thin Section Sch-W-57-CF-10; stage coordinates 38.9/103.7; Paleobotanical Collections, Harvard University No. 44485.)

Discussion : *Archaeorestis magna*, aside from the lack of bulbous swellings, conforms to the generic description of *Archaeorestis* Barghoorn 1965. However, because of the large size, and finely reticulate surface ornamentation, it



is referred to a new species. *A. magnis*. It is only known from one well-preserved specimen in a *Gruneria*-like stromatolite from Schreiber Beach. Taxonomic affinities of *A. magnis* are uncertain. The branching is unlike that encountered in blue-green and other algae but reminiscent of fungal branching as in the actinomycetes, but, without reproductive structures, assignment to a fungal group is impossible. *A. magnis* superficially resembles budding bacteria (see Hirsch, 1974), but is larger than known forms.

Taxonomic emendation

Division Cyanophyta

Class Cyanophyceae

Order Nostocales

Family Oscillatoriaceae

Genus *Animikiea* Barghoorn, 1965

Animikiea septata Barghoorn, 1965 (Fig.7A)

Animikiea septata Barghoorn and Tyler 1965, p. 576, fig.3, parts 1–3.

Description (emend.): Unbranched tubular sheath with corrugations giving appearance of multicellularity. Width of sheath 7–11 μm . Length may be greater than 100 μm . Sheath is thick-walled and granular.

Discussion: *Animikiea septata* was originally described by Barghoorn as a finely septate oscillatoriacean trichome. Study of extant oscillatoriaceans indicates that wrinkling of external sheaths can account for a septate appearance. Careful re-study of the type *Animikiea septata* (Barghoorn and Tyler, 1965) indicates that the described septa are actually surficial features and do not extend through the structure as should actual preserved septa. We reserve the taxon *A. septata* for large ($\sim 10 \mu\text{m}$) sheaths of presumed oscillatoriacean affinity. At present, *A. septata* is only known from *Gruneria*-like stromatolites from Schreiber Beach.

Fig.7. Gunflint morphotypes. Bar equals 10 μm .

A. *Animikiea septata*, type specimen from Barghoorn and Tyler (1965); arrow points to wrinkled sheath.

B. *Archaeorestis magna*; type, Sch-W-57-CF-10, 38.9/103.7, 44485.

C. Drawing of unnamed lamellated sheath.

D. Photomicrograph of unnamed sheath, 67-S, 86.7/17.8, 44486.

E. *Galaxiopsis melanocentra*, two arms.

F. *Galaxiopsis melanocentra*, type, FB4, 47.4/93.3, 44484.

Unnamed sheath (Figs.7C,D)

Diagnosis: Large lamellated sheath, circular to compressed in cross section; maximum outside diameter greater than 20 μm and minimum inside diameter of 8 μm . No trichomes present. Only one such structure found.

Locality: Lower Gunflint member; 6.4 km west of Schreiber, Ontario along north shore of Lake Superior.

Slide and location: (Thin section 67-S; stage coordinates 86.7/17.8; Paleobotanical Collections, Harvard University, No. 44486.)

Discussion: Schopf et al. (1976) indicate that sheaths larger than 10 μm are unknown prior to the Late Riphean. Though rare, this lamellated sheath indicates that broadsheathed oscillatoriaceans comparable to *Lyngbya* (see Geitler, 1932) were present by Gunflint time. This further supports Gebelein's (1974) suggestion that broad-sheathed oscillatoriaceans existed in pre-Riphean time. Only one specimen is known and this is from a *Gruneria*-like stromatolite from Schreiber Beach.

New data on previously described taxa

Revision of species of *Huroniospora*: This genus was described by Barghoorn (Barghoorn and Tyler, 1965) and the species were based on the wall-sculpture pattern. This criterion for delimiting species is considered unsatisfactory as surface sculpture may be due to diagenesis or precipitation of mineral matter on the growing surface of the cell, and may not be a primary biologic attribute. Cell size and mode of reproduction are probably primary criteria of high biological significance and should be used to define such taxa. Provisionally, forms of *Huroniospora* are grouped here as *Huroniospora* spp. awaiting completion of detailed studies of size and modes of reproduction (see Darby, 1974, for a study of the reproduction of *Huroniospora*).

***Gunflintia minuta*:** Barghoorn and Tyler (1965) originally compared *G. minuta* to the blue-green alga *Spirulina*, and to the iron bacterium *Gallionella*. Licari and Cloud (1968) reported specialized cells interpreted as heterocysts and akinites from *G. minuta*, which is consistent with a blue-green algal affinity (see Fig.4A). The occurrence of two trichomes within the same sheath as seen in Fig.4D further strengthens this interpretation, as known bacteria contain only one trichome per sheath. Sheaths like *Animikiea septata* may have surrounded the *Gunflintia minuta*-like trichomes.

REFERENCES

- Awramik, S.M., 1976. Gunflint stromatolites: microfossil distribution in relation to stromatolite morphology. In: M.R. Walter (Editor), *Stromatolites*. Elsevier, Amsterdam, pp. 311-320.
- Awramik, S.M., 1977. Paleobiology of stromatolites. *Origins of Life*.

- Awramik, S.M. and Barghoorn, E.S., 1975. New paleobiological perspectives on microorganisms from the Gunflint chert. *Geol. Soc. Am., Abstr. Prog.*, 7(3): 291.
- Awramik, S.M., Golubic, S., and Barghoorn, E.S., 1972. Blue-green algal cell degradation and its implication for the fossil record. *Geol. Soc. Am., Abstr. Prog.*, 4(7): 438.
- Awramik, S.M., Margulis, L. and Barghoorn, E.S., 1976. Evolutionary processes in the formation of stromatolites. In: M.R. Walter (Editor), *Stromatolites*. Elsevier, Amsterdam, pp. 149-162.
- Barghoorn, E.S., 1971. The oldest fossils. *Sci. Am.*, 224(5): 30-42.
- Barghoorn, E.S. and Tyler, S.A., 1965. Microorganisms from the Gunflint chert. *Science*, 147: 563-577.
- Cloud, P.E., 1965. Significance of the Gunflint Precambrian microflora. *Science*, 148: 27-35.
- Cloud, P.E., 1968. Pre-metazoan evolution and the origins of the metazoans. In: E. Drake (Editor), *Evolution and Environment*, Yale Univ. Press, New Haven: pp. 1-72.
- Cloud, P.E., 1973. Paleoeological significance of the banded iron formations. *Econ. Geol.*, 68: 1135-1143.
- Cloud, P., 1974. Evolution of ecosystems. *Am. Sci.*, 62: 54-66.
- Cloud, P., 1976. Major features of crustal evolution. *Geol. Soc. S. Africa, Annexure Volume, 14th Ann. A. du Toit Mem. Lecture*, pp. 1-32.
- Cloud, P., 1976. Beginnings of biospheric evolution and their biogeochemical consequences. *Paleobiology*, 2(4): 351-387.
- Cloud, P. and Hagen, H., 1965. Electron microscopy of the Gunflint microflora: preliminary results. *Proc. Natl. Acad. Sci. USA*, 54: 1-8.
- Darby, D.G., 1974. Reproductive modes of *Huroniospora microreticulata* from cherts of the Precambrian Gunflint Iron Formation. *Geol. Soc. Am. Bull.*, 85: 1595-1596.
- Deflandre, G., 1968. Sur l'existence dès le Précambrien d'Acritarches du type Acanthomorpha: *Eomicrystidium* nov. gen. Typification du genre *Palaeocryptidium* Defl. 1955. *C.R. Acad. Sci., Paris*, 266: 2385-2389.
- Desikachary, T.V., 1959. *Cyanophyta*. New Delhi, Indian Council of Agricultural Research, 686 pp.
- Edhorn, A., 1973. Further investigations of fossils from the Animikie, Thunder Bay, Ontario. *Geol. Assoc. Can., Proc.*, 25: 37-66.
- Faure, G. and Kovach, J., 1969. The age of the Gunflint Iron Formation of the Animikie Series in Ontario, Canada. *Geol. Soc. Am. Bull.*, 80: 1725-1736.
- Gebelein, C.D., 1974. Biologic control of stromatolite microstructure: implications for Precambrian time stratigraphy. *Am. J. Sci.*, 274(6): 575-598.
- Geitler, L., 1932. *Cyanophyceae*. In: Rabenhorst's *Kryptogamen-Flora* (Akademische Verlagsgesellschaft m.b.H., Leipzig, Johnson Reprint Corporation, 1971), 14: 1196 pp.
- Golubic, S., 1976. Organisms that build stromatolites. In: M.R. Walter (Editor), *Stromatolites*. Elsevier, Amsterdam, pp. 113-126.
- Goodwin, A.M., 1960. Gunflint Iron Formation of the Whitefish Lake area. *Ont. Dept. Mines*, 69(7): 41-63.
- Hirsch, P., 1974. Budding bacteria. *Ann. Rev. Microbiology*, 28: 391-444.
- Hofmann, H.J., 1969. Stromatolites from the Proterozoic Animikie and Sibley groups. *Geol. Surv. Can., Pap.*, 68-69: 77 pp.
- Hofmann, H.J., 1971. Polygonomorph acritarchs from the Gunflint Formation (Precambrian). *J. Paleontol.*, 45: 522-524.
- Hofmann, H.J., 1976. Precambrian microflora, Belcher Islands, Canada: significance and systematics. *J. Paleontol.*, 50: 1040-1073.
- Hofmann, H.J. and Jackson, G.D., 1969. Precambrian (Aphebian) microfossils from Belcher Islands, Hudson Bay. *Can. J. Earth Sci.*, 6: 1137-1144.
- Hurley, P.M., Fairbairn, H.W., Pinson, W.H., and Hower, J., 1962. Unmetamorphosed minerals in the Gunflint formation used to test the age of the Animikie. *J. Geol.*, 70: 489-492.

- Kaźmierczak, J., 1975. Colonial Volvocales (Chlorophyta) from the Upper Devonian of Poland and their paleoenvironmental significance. *Acta Palaeont. Pol.*, 20: 73–85.
- Kaźmierczak, J., 1976. Devonian and modern relatives of the Precambrian *Eosphaera*: possible significance for the early eukaryotes. *Lethaia*, 9: 39–50.
- Kline, G.L., 1975. *Metallogenium*-like microorganisms from the Paradise Creek Formation Australia. *Geol. Soc. Am., Abstr. Prog.*, 7(3): 336.
- Knoll, A.H., and Barghoorn, E.S., 1975. A Gunflint-type flora from the Duck Creek Dolomite, Western Australia. In: *Chemical Evolution of the Precambrian*, College Park Colloquia on Chemical Evolution, College Park, Maryland, Abstracts, p. 61.
- Korde, K.B., 1958. Concerning several species of fossil blue-green algae. *Mater. Osn. Paleontol.*, 2 (1958): 113–118 (in Russian).
- Licari, G.R. and Cloud, P., 1968. Reproductive structures and taxonomic affinities of some nanofossils from the Gunflint Iron Formation. *Proc. Nat. Acad. Sci., USA*, 59: 1053–1060.
- Lopukhin, A.S., 1971. For unification of morphological terminology and diagnostic acritarchs. In: *Dispersal Remnants of Fossil Plants of Kirghizia*, IIIrd. Int. Palynol. Conf., Novosibirsk, Akad. Nauk Kirghizskoi SSR, Frunze, pp. 11–35 (in Russian).
- Lopukhin, A.S., 1975. Biofossils of the Precambrian and some problems of their study. In: *Probl. osadoch. geol. dokembriya*. Moscow, Nauka, 4(2): 169–173 (in Russian).
- Moorhouse, W.W., 1960. Gunflint Iron Range in the vicinity of Port Arthur. *Ontario Dept. Mines*, 69(7): 1–40.
- Morey, G.B., 1973. Mesabi, Gunflint and Cayuna Ranges, Minnesota. In: *Genesis of Precambrian Iron and Manganese Deposits*. UNESCO, Paris, pp. 193–208.
- Muir, M.D., 1976. Proterozoic microfossils from the Amelia Dolomite, McArthur Basin, Northern Territory. *Alcheringa*, 1: 143–158.
- Oehler, D.Z., 1976. Biology, mineralization, and biostratigraphic utility of microfossils from the mid-Proterozoic Balbirini Dolomite, McArthur Group, N.T., Australia. *Int. Geol. Congr., 25th Sess., Sydney, Abstr.*, 1:34.
- Oehler, J.H., 1976. Experimental studies in Precambrian paleontology: Structural and chemical changes in blue-green algae during simulated fossilization in synthetic chert. *Geol. Soc. Am. Bull.*, 87: 117–129.
- Padmaja, T.D., 1972. Studies on coccoid blue-green algae — II. In: T.V. Desikachary (Editor), *Taxonomy and Biology of Blue-Green Algae*. Madras, Centre for Advanced Studies, pp. 75–127.
- Schopf, J.W., 1968. Microflora of the Bitter Springs Formation, Late Precambrian, Central Australia. *J. Paleontol.*, 42(3): 651–688.
- Schopf, J.W., Barghoorn, E.S., Maser, M.D., and Gordon, R.O., 1965. Electron microscopy of fossil bacteria two billion years old. *Science*, 149: 1365–1367.
- Schopf, J.W., and Blacic, J.M., 1971. New microorganisms from the Bitter Springs Formation (Late Precambrian) of the north-central Amadeus Basin, Australia. *J. Paleontol.*, 45: 925–960.
- Schopf, J.W., Dolnik, T.A., Krylov, I.N., Mendelson, C.V., Nazarov, B.B., Nyberg, A.V., Sovietov, Y.K., and Yakshin, M.S., 1977. Six new stromatolitic microbiotas from the Proterozoic of the Soviet Union. *Precambrian Res.*, 4: 269–284.
- Tappan, H., 1976. Possible eukaryotic algae (Bangiophyceidae) among early Proterozoic microfossils. *Geol. Soc. Am. Bull.*, 87: 633–639.
- Tyler, S.A. and Barghoorn, E.S., 1954. Occurrence of structurally preserved plants in Precambrian rocks of the Canadian Shield. *Science*, 119: 606–608.
- Walter, M.R., Goode, A.D.T., and Hall, W.D.M., 1976. Microfossils from a newly discovered Precambrian stromatolitic iron formation in Western Australia. *Nature*, 261: 221–223.