Precambrian Research, 43 (1989) 253–294
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

Organic-Walled Microfossils from Earliest Cambrian or Latest Proterozoic Tindir Group Rocks, Northwest Canada

CAROL WAGNER ALLISON

Marine Science Institute, University of California, Santa Barbara, CA 93106 (U.S.A.)

STANLEY M. AWRAMIK

Department of Geological Sciences, Preston Cloud Research Laboratory, University of California, Santa Barbara, CA 93106 (U.S.A.)

(Received April 13, 1988; revision accepted November 23, 1988)

Abstract

Allison, C.W. and Awramik, S.M., 1989. Organic-walled microfossils from earliest Cambrian or latest Proterozoic Tindir Group rocks, northwest Canada. Precambrian Res., 43: 253–294.

Uppermost Tindir Group limestones exposed in the headwaters of Tindir Creek, Yukon Territory, Canada, contain a diverse and abundant microbiota of mineralized and organic-walled microfossils. Preserved primarily in chert nodules and chert beds, the organic-walled forms include mat-building cyanobacterial filaments and coccoids accompanied by less common bacteria, fungi and forms of uncertain affinity as well as planktonic coccoidal cyanobacteria and acritarchs. Several lines of evidence support interpretation of an Early Cambrian age whereas others suggest a Late Proterozoic age. Of the 54 organic-walled taxa recognized, 12 are newly described: *Yukonosphaeridion interior* Awramik, n. gen., n. sp., *Microagglomeratus borealis* Awramik n. gen., n. sp., *Phacelogeminus lineatus* Awramik n. gen., n. sp., *Palaeoanacystis magna* Awramik, n. sp., *Cephalophytarion majesticum* Allison n. sp., *Heliconema bulbosa* Allison n. sp., *Trachyhystrichosphaera magna* Allison n. sp., *Fusilabellum brevistriatum* Awramik n. gen., n. sp., *Sphaeranasillos irregularis* Allison n. gen., n. sp., *Hyalocyrillium clardyi* Allison n. gen., n. sp., *Eophycomyces herkoides* Allison n. gen., n. sp. and *Archeomyces dimakeloides* Allison n. gen., n. sp.

Introduction

The transition from the Proterozoic to the Cambrian records one of the greatest events in the history of life: the appearance and diversification of many phyla of well-skeletonized marine animals at the base of the Cambrian. This interval of time, commonly referred to as the Precambrian–Cambrian boundary, is receiving a great deal of attention from paleontologists in an attempt to understand the timing of appearances and the diversification patterns of these newly evolved animals, in addition to their distribution and biological affinities (Sepkoski and Knoll, 1983; Mount and Signor, 1985; Conway Morris, 1987). The Protista also appear to have undergone major radiations during this transition (Vidal and Knoll, 1982; Riding and Voronova, 1984; Allison and Hilgert, 1986).

The radiation of all these organisms brought about major changes in the marine biosphere and ended the micro-organism-dominated world of the Proterozoic. The demise of widespread Proterozoic-type ecosystems did not oc-

0301-9268/89/$03.50

cur abruptly at this time but was the culmination of events that may have spread over the last 100 Ma of the Proterozoic. Stromatolites show marked decline in diversity during the Vendian, probably reflecting the feeding and sediment-disruptive activities of the evolving pre-skeletal metazoans (Awramik, 1971; Walter and Heys, 1985). Acritarchs have been reported to suffer a similar diversity reduction during this interval (Vidal and Knoll, 1982), but the cause of this change is obscure. However, several of the taxa thought to appear first in the Cambrian are now known to occur in the Vendian (Awramik et al., 1985; Zang and Walter, 1989) and this alters Vidal and Knoll's diversity analysis.

Animals appeared in the Vendian; numerous soft-bodied metazoans belonging to the so-called Ediacaran fauna are known from about 17 localities on five continents (Runnegar, 1982). Burrows are also associated with this fauna (Glaessner, 1984). The fate of the Ediacaran fauna across the Precambrian–Cambrian boundary is uncertain. Whether they gave rise to major Paleozoic animal clades (Glaessner, 1984) or whether the non-cnidarian groups were an evolutionary dead end (Seilacher, 1984) is contentious.

Proterozoic deposits older than 700 Ma contain numerous examples of microbial fossils preserved in chert. The understanding of these microbiotas has become rather sophisticated in terms of their paleoecology, paleobiology, and evolutionary significance (Awramik and Barghoorn, 1977; Knoll and Golubic, 1979; Knoll, 1984; Nyberg and Schopf, 1984). Unfortunately, chert microbiotas from the Vendian are rare and from the Cambrian even rarer. Hence, an incomplete picture of these microbiotas exists across the Proterozoic–Cambrian boundary. Nevertheless, the few well-preserved chert microbiotas known provide some valuable information. Notable finds include the Siberian Yudomian (latest Proterozoic) microbiota (Lo, 1980; Mendelson and Schopf, 1982), Chinese Sinian (Late Proterozoic) microbiotas from the Yangtze Gorges (Zhang, 1982; Awramik et al., 1985) and Sinian and Meishucunian (earliest Cambrian) microbiotas from Yunnan (Wang et al., 1983; Song, 1984), a limited microbiota from the Saudi Arabian Jubaylah Group (probably pre-Cambrian) (Cloud et al., 1978), and the upper Tindir Group microbiota of Canada (Allison and Hilgert, 1986, and presented here).

No apparent patterns of decreases in diversity have been recognized in the chert microbiotas. If anything, photoautotrophic micro-organisms in shallow, subtidal settings undergo some morphological innovations involving size increase (Schopf, 1977; Awramik et al., 1986). The Late Proterozoic Doushantuo Formation of the Yangtze Gorges contains a variety of new morphotypes (Awramik et al., 1985; Awramik and Yin, in preparation) which, when combined with the upper Tindir microbiota (Allison and Hilgert, 1986, and this report) and Australian microfossils (Zang and Walter, 1989) present the first striking evidence that some significant evolutionary changes occurred in benthic and planktonic microbiotas during the Proterozoic–Cambrian transition.

The biotas of the upper Tindir consist of well-preserved and diverse microbial fossils representing four kingdoms: Procaryotae, Protista, Fungi and Animalia. Fossils found thus far are microscopic and occur in chert, shale and limestone. Chert nodules in the limestone contain the richest, most diverse and best-preserved biotas and include benthic and planktonic cyanobacteria, bacteria, acritarchs, fungi, sac-like morphs and mineralized spicular structures (Awramik and Allison, 1980; Allison, 1981, 1980). Co-occurring protistan scales have also been described (Allison and Hilgert, 1986). No trace, body, impression, or compression macroscopic fossils have been detected.

Because of the diversity of microbial fossils preserved at both the prokaryotic and eukaryotic grades, the occurrence of benthic and planktonic forms, the excellent preservation, the abundance of these microfossils in many thin sections, and their Late Proterozoic or

Early Cambrian age, the Tindir microbiota provides a datum with which to compare and contrast the evolutionary changes of microbes during the transition to the metazoan-dominated marine biosphere of the Phanerozoic. To achieve a full understanding of the complexity of the transition from a Proterozoic world dominated by prokaryotes to a world visibly dominated by metazoans and metaphytes in the Phanerozoic, it is critical to document fully all fossils found during this interval and to interpret them in the context of the changing biosphere. The upper Tindir provides a unique window onto the complexities of microbial life in shallow, well-lit and oxygenated marine waters sometime during the transition and hence will play a significant role in reconstructing these ancient, presumably highly interactive, ecosystems.

Geological setting, stratigraphy and age

The upper Tindir Creek fossiliferous rocks in the study area are exposed 3 km east of the U.S.A.–Canada boundary between 65°15′N and 65°17′N latitude and 141°56′W and 141°57′W longitude (Fig. 1). The geology in the region was discussed by Brabb (1967) and Brabb and Churkin (1969). Young (1982) presented much new information on Tindir Group rocks including the exposures at upper Tindir Creek, discussed most recently by Allison and Hilgert (1986). The Early Cambrian Funnel Creek Limestone is underlain at upper Tindir Creek and throughout the region by the uppermost Tindir Group unit, characterized principally by dark gray to black, thin-bedded, platy limestone with a pronounced fetid odor. Although widely exposed and now reasonably well known, this and other recognized Tindir Group units have not been formally named. In a recent stratigraphic report on the area, the uppermost subdivision was called 'Unit 5' by Young (1982).

The microfossils come from four measured sections (Fig. 2) and from additional collections made along the strike in the contact zone between the Tindir and Funnel Creek. Measured Section 3 (Fig. 3) has yielded the most abundant fossils and exposes the greatest thickness of the fossiliferous chert-rich beds. The lowest exposures at Section 3 are chiefly recessive-weathering black shales that have to date yielded few well-preserved microfossils. Passing up-section, chert occurs as in situ and transported small (up to 15 mm in diameter) nodules and thin layers (up to 2 cm thick) in the limestone (Figs. 4.1, 4.2 and 4.5). These nodules occur intermittently throughout the remainder of the Tindir and into the lower beds of the Funnel Creek Limestone. More detailed discussion of chert formation in these beds was presented by Allison and Hilgert (1986). Replacement of the chert by secondary carbonate (Figs. 4.3 and 4.4) increases up-section in the Tindir and the strata become more massively bedded and paler gray in color. This is the dominant lithology near and above the contact with the Funnel Creek. Extensive secondary silicification of the limestone, complete carbonate replacement of the chert, and more prominent development of vugs in the Funnel Creek tend to obliterate the fact that it shares the typically thin-bedded, flat-laminated character of the uppermost Tindir limestone. However, overall change in the contact zone is less abrupt than the color change might indicate.

Placement of the Funnel Creek–Tindir contact in Sections 1, 2 and 3 follows that of Young (1982; note: Young's Section 4 = Section 3 of this paper). In Section 4 (this paper), not examined by Young, identification of the contact is more difficult because the change from darker to lighter color of the limestone occurs well below the zone where more massive bedding appears. The shift from thin, laminated limestone with unreplaced chert characteristic of the Tindir also takes place well above the color change at Section 4. For this section the contact is tentatively placed in the zone where extensive silification of the limestone matrix and carbonate replacement of the cherts occur rather than at the change in color.

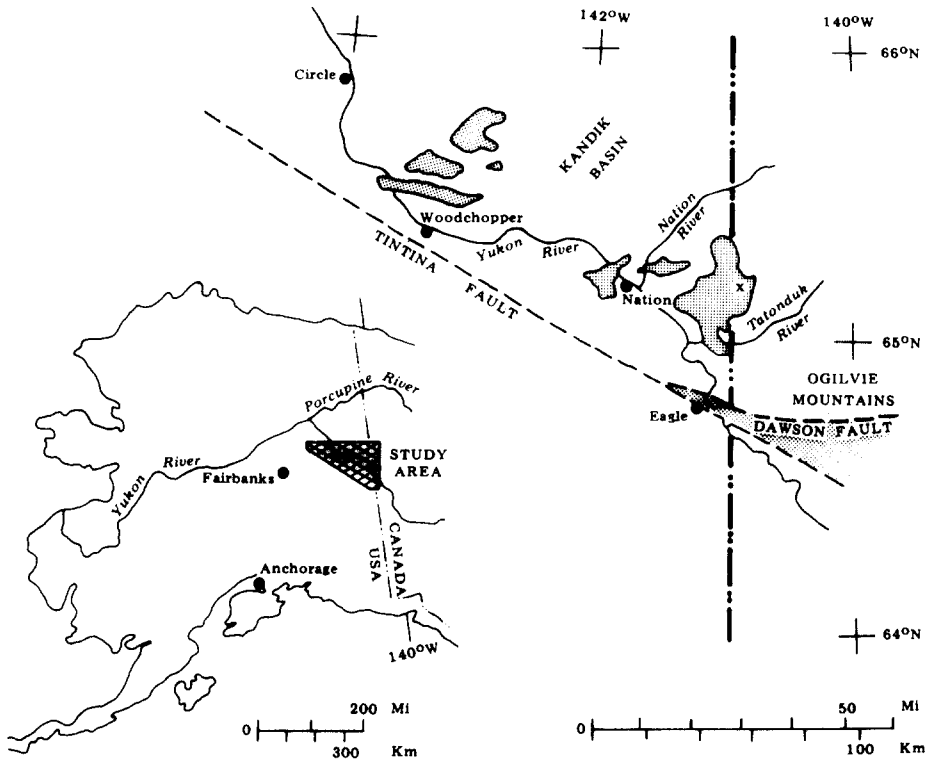


Fig. 1. Outcrops of Proterozoic and earliest Cambrian rocks (shaded areas) in the vicinity of the Yukon River and north of the Tintina Fault. Upper Tindir Creek area marked by X.

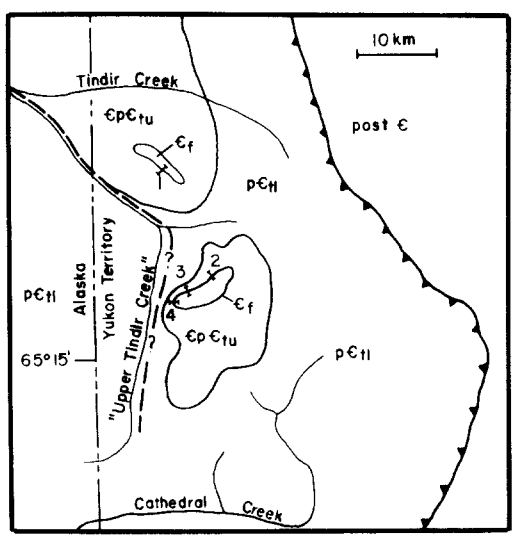


Fig. 2. Generalized geologic map and location of measured sections, upper Tindir Creek. p-€ tl, lower Tindir Group; -€ p-€ tu, upper Tindir Group; -€ f, Funnel Creek Limestone.

Young (1982) concluded, on the basis of similarity of the upper Tindir Group to the Rapitan Group and overlying units to the east, that a major regional unconformity exists between the Tindir and Funnel Creek Limestone (and coeval lower Jones Ridge Limestone, Brabb, 1967). He placed the Proterozoic–Cambrian boundary at this contact (Young, 1982, pp. 778–780). Several lines of evidence suggest that an alternative interpretation is possible. Although the Funnel Creek and lower Jones Ridge Limestones lie on apparently different lithologies of Tindir Unit 5 in different areas, this may not signal a major regional break. Over the 1500 km^2 of known exposure, the Funnel Creek (or lower Jones Ridge) always lies on Unit 5. With the one exception of a slump at Hard Luck Creek reported by Young (1982, p. 778), this relationship is invariably without change in dip. Young (1982, figs. 7 and 22) showed well the rapid ver-

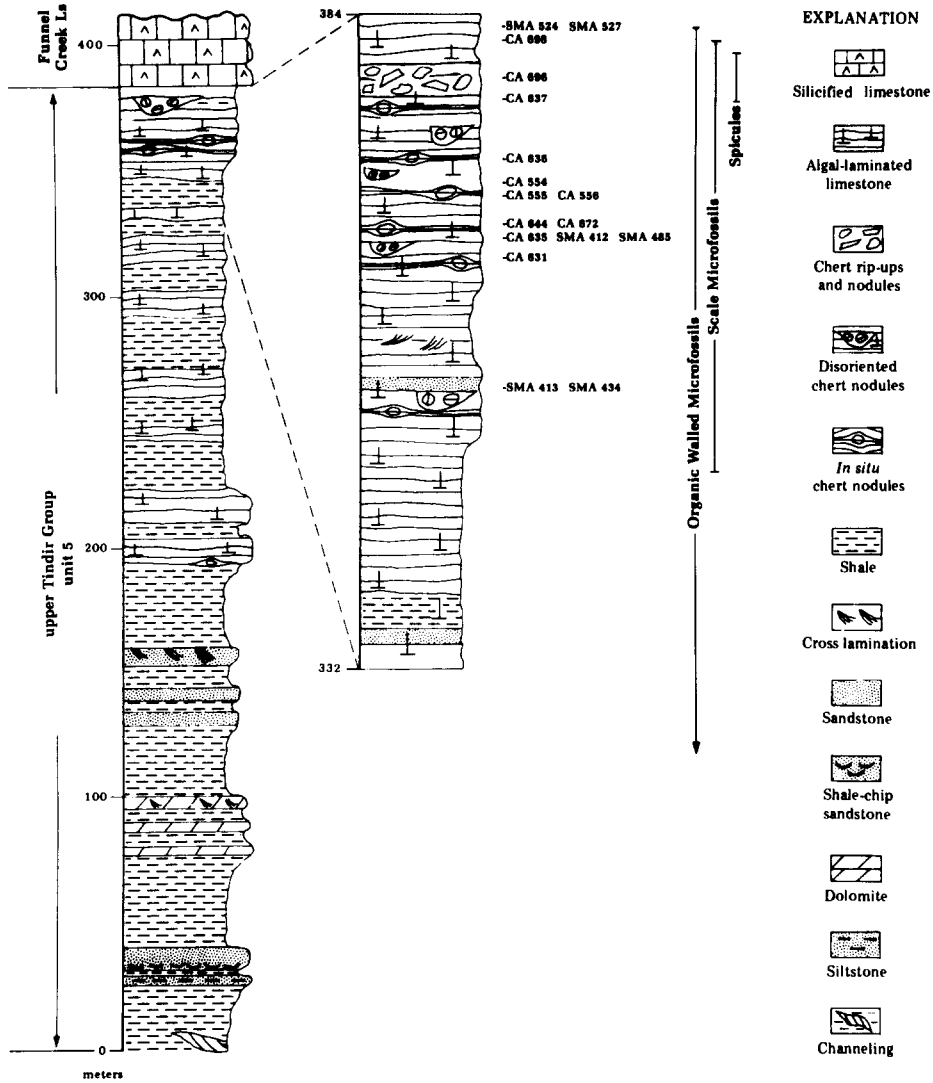


Fig. 3. Stratigraphic column for Measured Section 3, upper Tindir Creek. CA and BC75 = University of Alaska Museum samples; SMA = University of California, Santa Barbara, samples.

tical and lateral facies changes and variations in thickness characteristic of the upper Tindir that dictate caution in long-distance correlation of single beds or groups of beds. Indeed, the local absence of entire upper Tindir units or major portions of them (Young, 1982, figs. 7, 22 and 28), suggests local variation but does not indicate a region-wide break because apparently complete sections exist.

Young (1982) concluded that the upper Tindir Creek exposures offer the best evidence for unconformity between Unit 5 and the Funnel Creek/lower Jones Ridge Limestone; however, the reverse may be the case. In addition to the lithologic and stratigraphic evidence cited above, upper Tindir Creek Unit 5 microfossils, most notably several highly distinctive scale taxa, occur below and in the contact zone at and between Sections 2, 3 and 4 (of this paper) and above the contact at Section 1 (the same in this paper and in Young (1982)). We conclude, therefore, that a depositional hiatus between

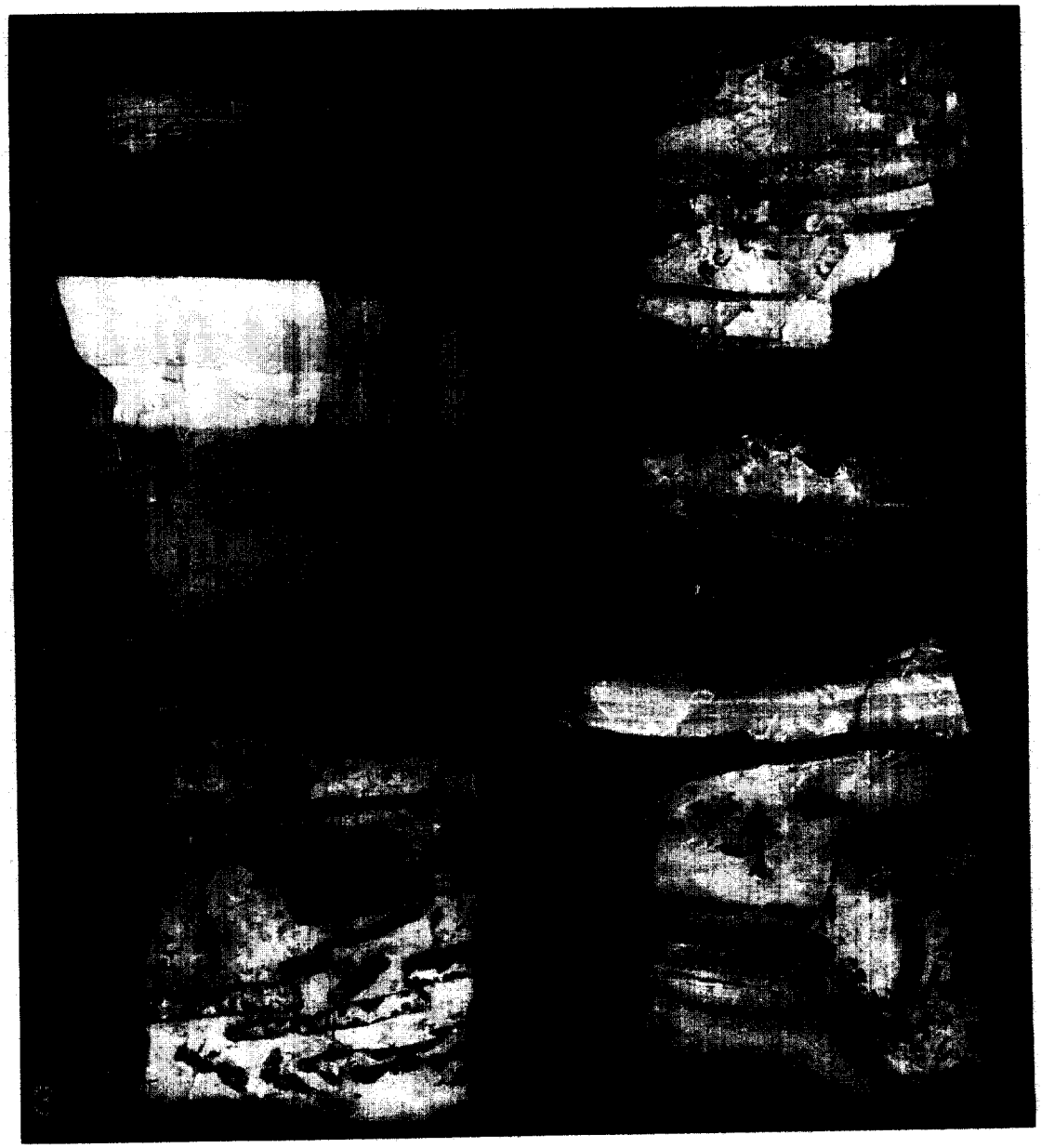


Fig. 4. Fossiliferous cherty limestones from Tindir Group Unit 5, upper Tindir Creek. 1, In situ chert nodules formed prior to compaction, CA 552. 2, Transported chert nodules in small-scale channel, CA 688. 3, Chert beds showing brittle deformation and replacement of dark chert by pale secondary carbonate, CA 698. 4, Chert lenses partially replaced, BC75 46. 5, Elongated dark chert nodules formed after compaction, CA 556. 6, Synsedimentary slumping and brittle deformation of thin chert beds, CA 672. Specimens shown in 1–5 from Measured Section 3; CA 672 from 40 m below the Tindir–Funnel Creek contact, Measured Section 4.

Unit 5 and the Funnel Creek Limestone is not confirmed in the upper Tindir Creek area.

There is disagreement on the precise age of the upper Tindir at Tindir Creek. Attempts at radiometric dating of volcanic units further down in the section did not yield reliable results (D.L. Turner, unpublished data), and attempts at paleomagnetic analysis of Unit 5 rocks to the

southwest also did not yield any reliable data that could help resolve the problem (C. Palmer, unpublished data).

Age: paleontological data

Fossils thus far known from Unit 5 in upper Tindir Creek, although varied and abundant, include few taxa indicative of a Cambrian versus Proterozoic age. The authors do not agree on the precise age assignment for the upper Tindir based on available paleontological and stratigraphical data and hence we present our individual interpretations.

Allison favors an Early Cambrian age for Unit 5 of the upper Tindir. Of the many organic-walled taxa at upper Tindir Creek, only the acritarchs and sac-like forms are currently thought to be of biostratigraphic usefulness, as recently reviewed by Vidal (1984). However, except for the north European, Eurasian and North Atlantic regions, the stratigraphic ranges of these typical 'shale facies' fossils are poorly known. Even in areas where the ranges are better documented they are subject to continuing revision; for example, the sac-like fossils until recently reported only in Proterozoic rocks are now known in the Early Cambrian (G. Vidal, personal communication, 1987). More importantly, mineralized spicular structures (Fig. 5) occur in the matrix of chert clast-rich horizons 3 m below the Tindir–Funnel Creek contact at Section 3, and 7 m below the contact 340 m along the strike to the north. Petrographic examination of these spicules indicates a biogenic origin and that the spicules were probably originally thin-walled and hollow (J. Boles, R.L. Hay and H. Lowenstam, personal communications). They are similar in the latter respect to multirayed and monaxon spicules occurring in Washington Creek northwest of Tindir Creek that are referable to the Chancelloriidae (Allison, 1988), but differ in being entirely monaxons and without the inflated profile characteristic of chancelloriid rays. Mineralized spicules of the type found at Tindir Creek are not confirmed in rocks older than Cambrian (A.R. Palmer, personal communication, 1986). Thus, following currently used criteria, Allison concludes that the fossiliferous beds at Tindir Creek are better considered of Cambrian age rather than of Proterozoic age. If so, the presence of mid to late Early Cambrian Bonnia–Olenellus Zone age trilobites in a unit overlying the Funnel Creek Limestone to the west (Palmer, 1968), and of Lenian and probable Atdabanian age archaeocyathans near the base of the lower Jones Ridge Limestone (R.A. Gangloff, personal communication, 1979), points to an older Early Cambrian age for the upper Tindir Creek biotas.

Awramik, on the other hand, contends that the evidence for confident assignment of the upper Tindir Unit 5 to either the Cambrian or the Proterozoic is equivocal. Several lines of evidence suggest a pre-Cambrian age for these Tindir rocks:

(1) Apart from the cyanobacterial microfossils (discussed below), the chert contains some morphs that have only been found in Proterozoic rocks. *Trachyhystrichosphaera*, until now, has only been known from the Upper Riphean, from clastic rocks (Timofeev et al., 1976; Jankauskas, 1982) and chert (Knoll, 1984).

(2) There is no evidence of bioturbation. The upper Tindir Creek limestones were deposited in a shallow, well-lit, predominantly quiet-water, subtidal setting that was intermittently agitated and contained abundant benthic and planktonic photoautotrophs. This environment should have harbored metazoans, if any were around. The lack of metazoan traces tends to suggest a Proterozoic age.

(3) There are no microfossils in Tindir chert or other Tindir lithology that are known only from the Cambrian.

(4) The shale found below the Unit 5 limestone, although only subjected to very preliminary study, contains abundant organic matter but has a poorly preserved, low abundance, low diversity acritarch microbiota composed mainly of undiagnostic leiosphaerids (McMenamin and Awramik, 1982). None of the distinctive acri-

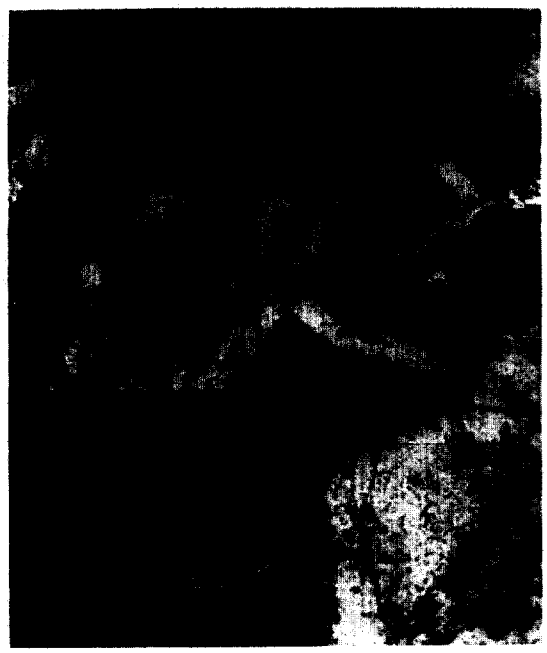


Fig. 5. Spicules from CA 637, Tindir Group Unit 5, 7 m below the Tindir–Funnel Creek contact, Measured Section 3. Figure is 2.2 mm wide.

tarchs with numerous processes, normally diagnostic of Cambrian and younger sediments, have yet been found in the shale or in the chert. Organic-rich shale with simple acritarchs of low diversity is common elsewhere in the world in Late Proterozoic strata above glaciogenic rocks (Knoll et al., 1981; Vidal and Moczydłowska, personal communication, 1987).

(5) Mineralized spicular structures of biogenic origin, presumably from an animal, are known from limestone of the post-tillite–pre-small shelly fossil Doushantuo Formation in the Yangtze Gorges of China (Tang et al., 1978). Hence, the presence of spicules cannot be used to infer a Cambrian age.

Taken as a whole, the cyanobacterial microfossils closely resemble those found in chert from several Late Proterozoic localities, such as the ~850-Ma-old Bitter Springs microbiota (Schopf, 1968; Schopf and Blacic, 1971), the 700–800-Ma-old Draken Conglomerate microbiota (Knoll, 1982), the 750–800-Ma-old Hunnberg microbiota (Knoll, 1984), and the ~625 Ma-old Yudoma microbiota (Lo, 1980). However, because of the great degree of morphological conservatism within cyanobacteria, no age significance, at this time, can be placed on similarities of Tindir cyanobacterial fossils with those from known Proterozoic deposits. Also, most Proterozoic cyanobacterial taxa are morphologically almost identical to extant cyanobacteria (Knoll and Golubic, 1979; Awramik, 1984a), so the Tindir cyanobacterial microfossils, although they most closely resemble several Late Proterozoic microbiotas, cannot be used with confidence to help clarify the precise age assignment of the upper Tindir.

Cambrian or younger Paleozoic cherty microbiotas are not well known (Cambrian: Wang et al., 1983; Song, 1984; Devonian: Baschnagel, 1942, 1966; Wicander and Schopf, 1974; Fairchild et al., 1973; Edwards and Lyon, 1983). Of potential, but not yet understood, significance, Devonian chert microbiotas, containing both algae and cyanobacteria, are the most abundant. These do not resemble the upper Tindir Creek microbiota.

The chert–phosphorite Meishucunian microbiota from Yunnan, China, is the best preserved and most diverse thus far known from the Early Cambrian. Except for *Obruchevella* (Wang et al., 1983; Song, 1984), the Chinese microbiota does not share any common elements with the Tindir Creek microbiota. With regard to *Obruchevella*, it is known from Unit 5 Tindir rocks southwest of upper Tindir Creek (Kline, 1977; Allison, 1988) and in upper Tindir Creek (this report). The locality southwest of upper Tindir Creek contains *Obruchevella* with external coil diameters that range from 37 to 252 μm, and it was the large upper range of the diameter that was once thought to indicate a Cambrian age (Cloud et al., 1979). However, subsequent finds of large diameter (110–115 μm) *Obruchevella* have been made in the Upper Riphean of Siberia (Yakshin and Luchinina, 1981), and at upper Tindir Creek, an *Obruchevella* with external coil diameters of 16.5–18 μm (the smallest yet reported) occurs in Unit

5. At present, little time-stratigraphic significance should be placed on such a long-ranging taxon.

In summary, Awramik concludes there is no compelling paleontological evidence on the precise age of the upper Tindir Creek microbiota. Because chert microbiotas from the Proterozoic–Cambrian transition are rare and not well understood, the diverse and well-preserved Tindir microbiota, at a minimum, presents important micropaleontological data for the eventual better understanding of microbiotic events during this critical interval of Earth history.

Depositional environment

The persistent thin (mm-scale), planar laminated character of limestone of upper Tindir Creek Unit 5 indicates a dominantly low-energy depositional setting with occasional, local, higher-energy pulses that are reflected in centimeter-scale channel structures (Fig. 4.2). Synsedimentary small-scale slumping, intermittently recorded throughout the section, is especially well shown by deformed chert beds underlain and overlain by undisturbed limestones (Fig. 4.5) and suggests that the basin floor in this area had some slight slope. We have located no evidence of mud cracks, evaporate minerals or other indications of subaerial exposure, or of herring-bone cross-bedding suggestive of littoral conditions, or of ripple marks implying wave influence, and hence conclude that the fossiliferous limestones represent subtidal accumulation below wave base. The abundant and diverse benthic cyanobacteria indicate accumulation within the photic zone. The absence of non-carbonate grains in the limestone points to a wholly carbonate regime. In view of the persistent fine lamination, low sediment input apparently prevailed throughout accumulation of the fossiliferous rocks. More persistent fragmentation and slight disarrangement of chert layers toward the Tindir–Funnel Creek contact (Figs. 4.3, 4.4) suggest higher-energy conditions for the uppermost part of the section. Although there were energetic pulses that ripped up previously deposited material including microfossiliferous chert, we have not detected any significant unconformities within Unit 5 and conclude that the redeposited material resulted from the centimeter-scale channeling and possibly storms.

Preservation

The upper Tindir Creek microfossils are best preserved in chert, present in varying abundances throughout the upper 30 m of Unit 5 at Section 3, and in the basal beds of the Funnel Creek Limestone at Section 1. The chert occurs as in situ and transported nodules and as thin layers and beds. Microbial mat-like layers composed of organic material and containing occasional cells in all stages of compression and degradation are easily identified within the limestone matrix. Within the chert, the layers appear to be slightly compressed, if at all. Fossil microbial mat-like layers are identifiable in the transported as well as the in situ nodules and clasts. Transported chert clasts contain the same microfossil species and thus indicate that the clasts are probably locally derived and penecontemporaneous in age. Occasional coccoids and, more commonly, filamentous sheaths are present in the limestone. These tend to be poorly preserved and they have not been used in the delineation of taxa described herein.

Within the chert, fossil coccoids (both solitary and pluricellular aggregates) and filaments are commonly seen as individual entities or in a complex association of several taxa. The trichomes of filaments range in color from medium to dark amber brown. Sheaths, where preserved, are typically colorless to hyaline pale yellow. Walls of coccoid forms are also commonly pale to dark amber brown but may be very pale yellow to virtually colorless with envelopes, where preserved, that are light amber brown to almost colorless.

Some of the coccoid cells contain dark spots and granular inclusions. Most inclusions are

relatively small ($< 3\ \mu m$) and tend to lie closer to the wall than to the center of the cell. These blebs probably represent degraded cytoplasmic residues (and possibly cell wall and some envelope material) that collected at a locus defined by internal chemical and pressure gradients within the confining boundary layer. In certain taxa, such as *Gloeodiniopsis*, the presence of these blebs is almost diagnostic and might reflect some of the original properties of the taxon, such as cytoplasmic chemistry or preferential wall collapse. A peculiar degradational history cannot be ruled out. For instance, some degradation could occur on (for benthic microbes) or above (for planktonic microbes) the sediment–fluid interface rather than within the geochemically dynamic sediment–microorganism milieu just below the sediment surface. We conclude that these internal blebs are primarily degradational remnants of prokaryotes and not the preserved remains of eukaryotic organelles (Awramik et al., 1972; Knoll and Golubic, 1979).

Secondary opaque minerals are generally not common in upper Tindir Creek fossiliferous rocks, although some thin sections contain numerous pyrite crystals. Where present, these minerals tend to occur as small, more or less angular bodies on or within cells and, very infrequently, as a complete replacement. The low abundance of pyrite in the chert might indicate that reducing conditions were not prevalent at the time of silicification and that chert nodules and layers formed near the sediment surface.

Interpretation of original size and shape of coccoid cells is in many cases based on observation of hundreds, or even thousands, of cells. For the less-commonly preserved trichomes, measurements are based on a few to, at most, 20 specimens of a given taxon. We are guided in the interpretation of original cell size and shape by the previous work of others on comparable material, especially that of Schopf (1968) and Schopf and Blacic (1971) on filamentous taxa and Hofmann (1976) on coccoid taxa. This has resulted in some cases in expanding the limits of cell sizes and shapes of species given in original descriptions by earlier workers, a practice we conclude to be preferable to the erection of new taxa that differ only slightly in cell size or shape.

Preserved trichomes are uncommon whereas preserved empty filamentous sheaths are widely present, a circumstance suggesting strong preservational selection against the cells of filamentous taxa (Horodyski et al., 1977). Chert that has preserved trichomes tends to contain several taxa that are spatially separated from one another, and that occur in regions of the chert that contain relatively smaller abundances not only of coccoid morphs but also of empty filament sheaths. This indicates regions of luxuriant and diverse filament growth and a complex taphonomic history that locally favored trichomes over sheaths.

Paleocommunity structure

Recognition of a benthic versus a planktonic habit for many of the 54 organic-walled taxa identified in the Tindir Creek biota is conjectural because none is seen exclusively in recognizable mat layers. Even for taxa that commonly occur in layers, we are not confident that mat builders can be separated from dwellers within the mat or from planktonic micro-organisms deposited with the layers. Of the genera that occur in both the Tindir Creek and the Draken Conglomerate biotas, Knoll (1982) interpreted *Eomycetopsis*, *Siphonophycus*, *Sphaerophycus*, *Tetraphycus* and *Eosynechococcus* as mat-builders or -dwellers and *Myxococcoides* as a member of the plankton in the Draken biota. Based on comparisons with other ancient microfossil occurrences, it is likely that the Tindir Creek taxa *Leiosphaeridia asperata*, *Trachyhystrichosphaera vidalii*, *T. magna*, *Cymatiosphaeroides kullingii*, *Sphaeranasillos irregularia*, Unnamed Form D of Knoll, Unnamed Coccoid forms A, B, C and D, the Unnamed Bulbous and Triangular acritarchs, *Melanocyrillium* sp., and *Hyalocyrillium clar-*

dyii were members of the plankton. Beyond this we are not willing to speculate further.

Tindir Creek taxa that occur in monospecific layers, or in layers in which they are overwhelmingly dominant, are *Eomycetopsis robusta*, *Myxococcoides cantabrigiensis*, *Fusilibellum brevistriatum*, *Tetraphycus major* and *Sphaerophycus parvum*. A preserved set of eight essentially monospecific layers in thin section CA 644-5 contains, in sequence, the following taxa: *Myxococcoides cantabrigiensis*, *Eomycetopsis robusta*, indeterminate compressed filamentous sheaths (*Eomycetopsis*?), compressed coccoids similar to *Fusilibellum brevistriatum*, *Myxococcoides cantabrigiensis*, *Eomycetopsis robusta*, and a layer of mixed coccoids including *Myxococcoides*, *Tetraphycus* and *Sphaerophycus*. Layers organized like this suggest a microbial mat produced by cyanobacteria. Several pale layers within this stack contain ghost-like membranes but no recognizable cells. An extremely cell-dense set of two layers preserved in a redeposited nodule in CA 637B-1 contains one layer of *Tetraphycus major* and an immediately adjacent layer of *Palaeoanacystis vulgaris*.

A different view of original overall community composition is seen in thin section BC75 44-5, which is cut parallel to the bedding in a horizon containing only in situ nodules. The area of the three nodules in this thin section totals 35 mm^2 and contains representatives of one coccoid and one filamentous bacterial species, 10 filamentous and coccoid cyanobacteria, one acritarch, seven species of uncertain affinity and one fungal species. Undoubted planktonic forms including *Hyalocyrillium* are also present.

Many of the Tindir microfossils described here occur in chert nodules that formed in laminated limestones. In one thin section cut perpendicular to the lamination, 62 mat-like layers were counted in the limestone over a distance of 22 mm and these can be traced laterally into the chert. Lamina preservation in nodules is variable, with well-preserved laminae consisting of thinner, dark-colored laminae that alternate with thicker, light-colored laminae. The boundary between light and dark laminae is commonly gradational. Well-preserved laminae resemble microbial mat (stromatolite) fabrics F_3, F_4 and F_5 described by Knoll and Golubic (1979) from the Ellery Creek member of the Bitter Springs Formation, although the Tindir laminae are not disrupted like those found in the Ellery Creek example, which was subjected to periodic desiccation. Filaments, in particular preserved sheaths, can be found oriented parallel or subparallel to dark-colored laminae and at high angles to lamination in light-colored laminae. Filaments are also found in light-colored, non-laminated regions of the chert. Pluricellular coccoid aggregates such as *Myxococcoides cantabrigiensis*, *Phacelogeminus lineatus*, *Tetraphycus major* and *Sphaerophycus parvum* commonly occur in an extensive, layered to indistinctly layered organic matrix (Figs. 6.1, 6.2). This organic matrix is suggestive of the abundant gel found enclosing diverse microbes in the recent subtidal stromatolites off Lee Stocking Island, Bahamas (Awramik, unpublished).

Although mat and mat-like fabrics are preserved in Tindir chert nodules, we do not imply that these represent stratiform stromatolites. Stromatolites are organo-sedimentary structures produced by microbial activity (see Awramik, 1984a). The microbes influence sedimentary processes and exercise control on the accretion and growth of the structure. In the Tindir, we postulate that benthic microbes lived on the sediment surface but not necessarily in great enough abundance, proper taxonomic composition, and/or with a sufficient supply of allochthonous sediment, to influence sedimentation and produce stromatolitic structures.

Preserved mat layers are less common in the chert lenses and beds approaching the Tindir–Funnel Creek Limestone contact than in the in situ and transported nodules in and below the contact zone. The 'bedded' cherts contain relatively more apparently planktonic forms, but

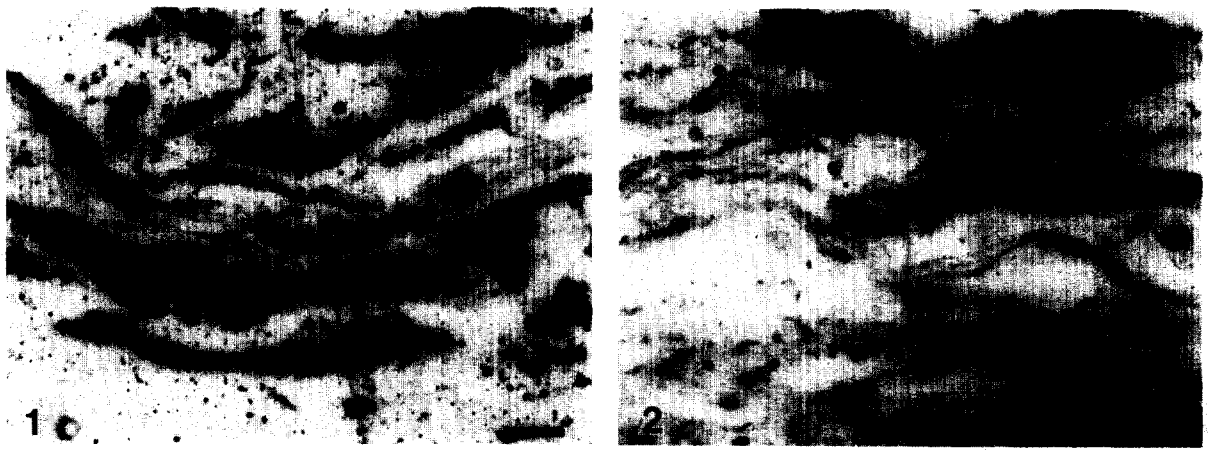


Fig. 6. Microbial mat-like textures in upper Tindir Group chert nodules. All bar scales = 75 μm. 1, Layered organic-rich matrix with coccoidal cells and few poorly preserved filaments. The matrix probably represents extracellular sheath/envelope material; SMA 412. 2, Layered organic-rich matrix similar with coccoidal microfossils and poorly preserved filaments; SMA 524.

probable mat inhabitants more common in the nodules are present also in the lenses and beds. Probable planktonic forms are well represented in the in situ and transported nodules well down into the Tindir. In view of the rarity of occurrence of most of the apparent planktonic species such as the acritarchs (although we describe a chert microbiota, we use the term acritarch for those morphs which have been described in the acritarch literature, e.g. *Leiosphaeridia* and *Trachyhystrichosphaera*), which are mostly represented by only one or two specimens within the entire biota seen, we conclude that available data do not support recognition of more than one facies or biostratigraphic zone even though a gradual trend toward higher-energy conditions can be seen from about the middle of the fossiliferous beds into the contact zone.

The two fungal species are very rare. They occur in all three instances near cyanobacterial species in horizons with in situ nodules. The highly distinctive sac-like *Hyalocyrillium* is present in five samples ranging from near the bottom to the top of the fossiliferous section, and in both in situ and transported nodules, a distribution suggesting that this organism was a persistent but rare local resident.

Method of study and sample repository

The upper Tindir Creek microfossils are described primarily on the basis of observation of specimens in thin section using ordinary light microscopy, aided in some instances by phase contrast or Nomarski equipment. Over 525 thin sections have been examined, cut from samples collected throughout the measured sections and elsewhere along the strike. Attempts to free the fossils from the matrix, both chert and limestone, by various maceration techniques have met with little success.

Awramik is primarily responsible for delineation and description of coccoid cyanobacteria, and Allison primarily for filamentous cyanobacteria, fungi and other non-cyanobacterial morphs, and for stratigraphic, paleoenvironmental and regional geologic analysis. Primary type specimens are, by prior agreement with the Canadian Government, placed on permanent deposit in the National Type Collection, Ottawa. Thin sections containing other illustrated specimens, rock specimens and comparative material are deposited in the University of Alaska Museum at Fairbanks (CA and BC samples) and Preston Cloud Research Laboratory (PCRL), University of California, Santa

TABLE 1

Type numbers, location information and illustration numbers of upper Tindir Creek organic-walled microfossils (ho = holotype; hy = hypotype)

GSC number	Taxon	Type	Thin section	Coordinates (in mm from reference point)		Figure
				x	*y*	
81867	*Yukonosphaeridion interior*	ho	SMA 524	35.2	14.2	7.1
81868	*Microagglomeratus borealis*	ho	SMA 527	34.6	15.4	7.2
81869	*Glenobotrydion aenigmatis*	hy	SMA 485	6.9	5.9	7.3
81870	*Phacelogeminus lineatus*	ho	SMA 412	14.9	14.6	7.4
81871	*Palaeoanacystis magna*	ho	SMA 524	27.9	15.6	7.6
81872	*Gloeodiniopsis lamellosa*	hy	SMA 524	20.9	3.8	8.1
81873	*Eosynechococcus* sp. Knoll	hy	BC75 44-5	2.8	5.7	8.2
81874	*Sphaerophycus parvum*	hy	SMA 524	28.9	8.5	7.5
81875	*Myxococcoides cantabrigiensis*	hy	SMA 413	25.1	3.6	8.3
81876	*Balbariniella praestans*	hy	SMA 424	13.6	8.7	9.13
81877	*Cephalophytarion majesticum*	ho	CA 635	36.9	18.4	8.7,8.8
81878	*Filiconstrictus diminutus*	hy	CA 554	10.0	7.0	8.4
81879	*Heliconema australiensis*	hy	CA 555-1	24.1	14.2	8.5
81880	*H. bulbosa*	ho	BC75 44-5	5.6	6.9	8.6
81881	*Eomycetopsis robusta*	hy	BC75 44-5	42.5	2.3	8.9
81882	*Fusilibellum brevistriatum*	ho	BC75 44-7	30.9	14.6	9.1,9.2
81883	*Sphaeranasillos irregularis*	ho	BC75 46-3	10.6	8.3	9.3,9.4
81884	Unnamed Form D of Knoll	hy	BC75 46-3	11.0	4.4	9.5
81885	Unnamed Coccoid Form A	hy	CA 644-5	16.0	22.8	9.7
81886	Unnamed Coccoid Form B	hy	CA 644-5	10.4	19.6	9.6
81887	Unnamed Coccoid Form C	hy	BC75 44-9	42.5	16.0	9.8
81888	Unnamed Coccoid Form D	hy	BC75 44-8	30.7	6.7	9.9
81889	*Obruchevella minuta*	ho	BC75 44-8	10.1	11.9	9.10
81890	*?Obruchevella* sp.	hy	CA 554	24.6	15.8	9.11
81891	Unnamed Filament Form A	hy	BC75 44-5	41.4	2.1	9.12
81892	Unnamed Filament Form B	hy	BC75 44-5	41.1	2.3	10.1
81893	Unnamed Filament Form B	hy	BC75 46-7	29.7	13.1	10.2
81894	Unnamed Filament Form C	hy	CA 555-3	18.1	14.9	10.3,10.4
81895	Unnamed Bulbous Form	hy	CA 555-3	23.9	9.2	10.5
81896	Spiral Grooved Form	hy	SMA 524	29.2	8.6	10.6
81897	*Tindiromacula hofmanni*	ho	BC75 44-5	42.1	2.2	10.7,10.8
81898	*Hyalocyrillium claridyi*	hy	CA 635	35.7	19.1	10.9
81899	*H. claridyi*	hy	CA 635	37.1	18.3	10.10
81900	*H. claridyi*	ho	CA 635	36.1	18.3	10.11
81901	*Leiosphaeridia asperata*	hy	BC75 44-9	8.5	11.8	11.4
81902	*Cymatiosphaeroides kullingii*	hy	CA 644-4	36.7	20.0	11.1-11.3
81903	*Trachyhystrichosphaera magna*	ho	BC75 46-3	11.0	7.9	11.5-11.8
81904	*T. vidalii*	hy	CA 698-1	14.9	10.2	11.9,11.10
81905	Unnamed Triangular Form	hy	BC75 44-9	10.1	11.9	11.11
81906	*Eophycomyces herkoides*	ho	CA 644-2	4.1	19.9	12.5-12.7
81907	*Archeomyces dimakeloides*	ho	BC75 44-5	5.4	8.1	12.1-12.4

Barbara (SMA samples), as indicated in the systematic descriptions. Individual specimens are located in mm from reference points: for SMA thin sections, the scribed 'X' in the lower left corner (SMA number to the left of the viewer) and for CA and BC thin sections, the

lower left-hand corner of the cover slip (thin section number to the left of the viewer). Coordinates for type and other illustrated material are given in Table 1.

Systematic paleontology

Fifty-four organic-walled, microbial fossil taxa have been identified from upper Tindir Creek rock samples. We have described and illustrated 38 taxa, 12 of which are new. To conserve space, we have elected to follow a practice that has long been in use for reports of post-Proterozoic fossil biotas in not illustrating or discussing the 16 taxa that are known and well described from reports on other fossil deposits. Upper Tindir Creek forms not described or illustrated in this paper are listed with their stratigraphic occurrence, abundance and reference sources in Table 2.

Kingdom Procaryotae Murray, 1968
Phylum uncertain
Genus *Yukonosphaeridion* Awramik n. gen

Type species. Yukonosphaeridion interior Awramik n. sp.

Diagnosis. Spherical to spheroidal solitary cells, with well-formed single walls. There are no envelopes around cells. There is no geometric arrangement of cells, and the interior is structureless. Reproductive structures are not observed; however, elongation of cells implies reproduction by means of binary fission.

Etymology. After the Yukon Territory, where it was discovered, and from the Latin *sphaeridion* = small ball.

Yukonosphaeridion interior Awramik n. sp. (Fig. 7.1)

Diagnosis. Qualitatively, as for genus. Cells range from 0.6 to 1.3 μm in diameter ($\bar{x}=0.95$ μm; $N=20$). All cells were found within degraded trichome cells.

Type specimen. SMA 524 at 35.2×14.2.

Etymology. From the Latin *interior* = inner, with reference to occurrence within cyanobacterial cells.

Discussion. This microfossil does not resem-

TABLE 2

Organic-walled microfossils present in the upper Tindir Creek microbiota in addition to those described in the systematic paleontology section

Biocatenoides Schopf, 1968	C	BC75 44, BC75 46
Palaeoanacystis vulgaris Schopf, 1968	C	CA 554, CA 555, CA 636, CA 637, SMA 413
Myxococcoides cf. *m. minor* Schopf, 1968	C	CA 554, CA 636, CA 637, ?BC75 44, ?CA 551, ?CA 555
Tetraphycus major Oehler, 1978	C	BC75 44, BC75 46, CA 637, SMA 524, ?BC75 46, ?CA 644
Cephalophytarion grande Schopf, 1968	R	BC75 46, SMA 435, SMA 524
Palaeolyngbya barghoorniana Schopf, 1968	R	BC75 44, CA 636, CA 554, SMA 524
P. minor Schopf and Blacic, 1971	R	BC75 44
Oscillatoriopsis obtusa Schopf, 1968	R	BC75 44, CA 554
Obconicophycus amadeus Schopf and Blacic, 1971	R	CA 636
Cyanonema inflatum Oehler, 1977	R	CA 554
Halythrix cf. *H. nodosa* Schopf, 1968	R	BC75 44, SMA 524
Calyptothrix annulata Schopf, 1968	R	BC75 44, SMA 524
Siphonophycus Schopf, 1968	R	BC75 44, CA 635, CA 644
Caudiculophycus Schopf, 1968	R	BC75 44, CA 554, CA 636
Veteronostocale cf. *V. amoenum* Schopf and Blacic, 1971	R	BC75 44
Melanocyrillium Bloesser, 1985	R	SMA 524

Abundance: R(rare) = 1–10 specimens observed; C(common) = 11–50 specimens observed; A(abundant) = over 50 specimens observed. Locality numbers refer to stratigraphic positions shown on Fig. 3.

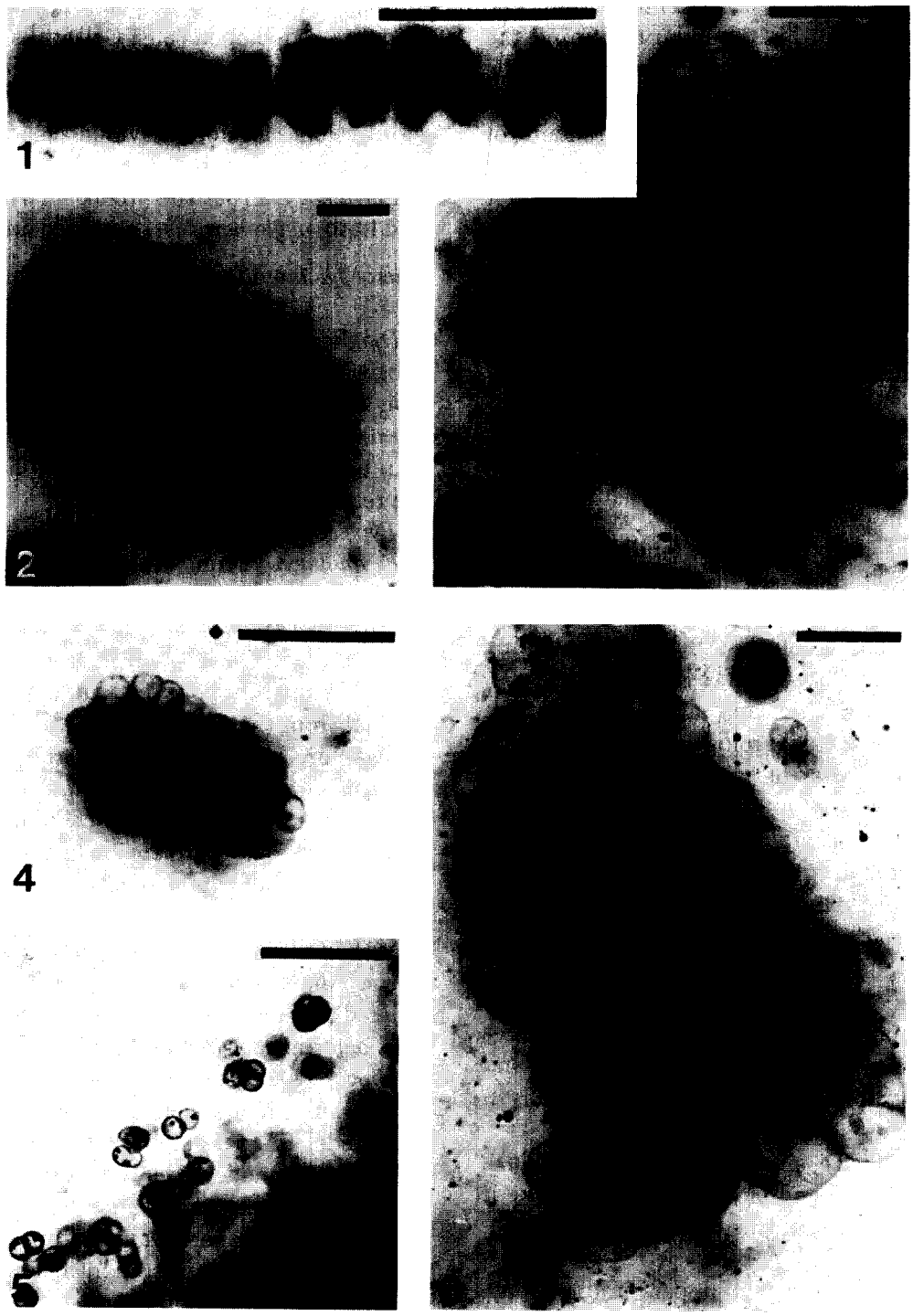


Fig. 7. Bacteria and coccoid cyanobacteria from upper Tindir Group Unit 5, upper Tindir Creek. All scale bars = 20 μm. 1, *Yukonosphaeridion interior* Awramik n. gen., n. sp. GSC 81867. 2, *Microagglomeratus borealis* Awramik n. gen., n. sp. GSC 81868. 3, *Glenobotrydion aenigmatis* Schopf GSC 81869. 4, *Phacelogeminus lineatus* Awramik n. gen., n. sp. GSC 81870. 5, *Sphaerophycus parvum* Schopf GSC 81874. 6, *Palaeoanacystis magna* Awramik n. sp. GSC 81871.

ble any other reported coccoid microfossil. The well-formed, wall-like boundary defining the spheroids and the lack of contents in any of the spheroids lead us to conclude that *Yukonosphaeridion interior* is the preserved remains of micro-organisms rather than coalesced trichome cell contents of the trichome in which it is found. Endophytic bacteria are known to grow inside living cyanobacterial cells (see Wujek, 1979) and can also grow within the anaerobic microenvironment of degrading trichome cells. Superficially similar spheroids were illustrated from the interior of *Eosynechococcus thuleënsis* cells and were interpreted as degradational features (Strother et al., 1983). These could be the remains of endophytic cells rather than degradational products.

It is possible that these Tindir spheroidal bodies could represent organic-coated intracellular granules. For instance granules of sulfur occur in the colorless filamentous gliding bacterial genus *Beggiatoa* (Fjerdingstad, 1979). However, the lack of any material other than chert within the spheroids argues against this possibility unless the granules have been totally obliterated.

There are several other microfossils that consist of small spheres within a larger organic structure: *Eosphaera tyleri* Barghoorn and *Enterosphaeroides amplus* Barghoorn (Barghoorn and Tyler, 1965), and *Thymos halis* Awramik and Barghoorn (1977) all from the Gunflint Iron Formation. The Gunflint internal spheres are much larger than those of the Tindir and also the structure containing the small cells in the Gunflint is problematical.

The small size, simple morphology, and lack of physiological and biochemical data make it impossible to assign this taxon to any one prokaryotic division.

Occurrence. SMA 524, upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Microagglomeratus* Awramik n. gen.

Type species. Microagglomeratus borealis Awramik n. sp.

Diagnosis. Agglomeration of small, spheroidal to rod-shaped cells. Cell walls are moderately thin and apparently particulate. There is no geometric order to arrangement of cells. No envelopes around individual cells or around cluster are observed.

Etymology. From the Greek *mikros* = small, and Latin *agglomeratus* = gathered into a mass.

Microagglomeratus borealis Awramik n. sp. (Fig. 7.2)

Diagnosis. Qualitatively, as for genus. Cells range from 0.7 to 1.1 μm in the shorter dimension and 0.9 to 2.2 μm in the longer dimension ($\bar{x}=0.9\ \mu m \times 1.4\ \mu m$; $N=30$). The cell wall is thin and finely granular. Cells are not tightly adpressed.

Type specimen. SMA 527 at 39.1×14.5.

Etymology. From the Latin *borealis* = northern, in reference to the locality at a high northern latitude.

Discussion. These small microfossils do not resemble any other pluricellular aggregates described from the fossil record. Affinities of *M. borealis* are uncertain. Among recent Cyanobacteria, *Aphanothece clathrata* W. and G.S. West, has small rod-shaped cells of 1 μm diameter in the short dimension but with long dimension 3.5–4.5 μm (Geitler, 1932, pp. 166–167). Species of *Aphanothece* as well as *Gloeothece* have a common envelope, which is absent in the Tindir microfossil. It is possible, but considered unlikely, that this fossil represents cyanobacterial baocytes without the parental cell. However, baocytes are commonly spherical (Waterbury, 1976) whereas *M. borealis* cells are spheroidal to rod-shaped. No dyads or other evidence for mode of reproduction was found. The minute size, and the lack of a preserved envelope and other cyanobacterial features, suggest that *M. borealis* might belong to some other eubacterial group.

Among the modern bacteria, there are numerous forms similar in size, shape and organization to *M. borealis*. In modern microbial mats and other regions where there is genera-

tion and accumulation of organic material under photic conditions, purple sulfur bacteria are commonly found in the anaerobic zone below the active cyanobacterial region (see Stolz, 1983, for microbial mats). The specimen in BC75 44 occurs in an in situ chert nodule with preserved mat fabric and many mat-inhabiting microbes whereas the type specimen occurs in a transported nodule without preserved mat layers. The association of purple sulfur bacteria such as *Chromatium* with cyanobacteria in both benthic (Gibson et al., 1984) and flocculant (Cohen, 1984) mats and the morphological similarity of these bacteria with the Tindir form make a comparison attractive. It must be stressed, however, that we have no evidence of the physiology of *M. borealis*, knowledge essential in bacterial systematics, and can only compare morphological attributes.

Occurrence. BC75 44, SMA 527; upper Tindir Group, Unit 5, upper Tindir Creek.

Phyllum Cyanobacteria Stanier et al., 1979
Order Chroococcales Wettstein, 1924
Family Chroococcacae Nägeli, 1849
Genus *Palaeoanacystis* Schopf, 1968

Type species. Palaeoanacystis vulgaris Schopf, 1968.

Palaeoanacystis magna Awramik n. sp. (Fig. 7.6)

Diagnosis. Cumulate aggregate of tightly adpressed, large, polyhedral cell-like units with thin walls. Polyhedral cells range in size from 5.1 to 11.4 μm in the short dimension ($\bar{x}=7.5$ μm) and from 6.8 to 12.5 μm in the long dimension ($\bar{x}=9.7$ μm; $N=50$). Cells may contain a single irregular granular inclusion, which is rarely organized into a discrete spot. A distinct common envelope around aggregates is not observed, but a faint, thin, organic matrix is present. Dyads within aggregates suggest reproduction by binary fission in one direction.

Type specimen. SMA 524 at 28.9×16.9.

Etymology. From the Latin *magna* = large.

Discussion. Lack of planar tetrads, presence of dyads within the aggregate, and the tightly adpressed polyhedral cells forming rounded aggregates are consistent with placement of these Tindir microfossils into *Palaeoanacystis*. The new species is established on the basis of its large size. It is the largest member of the genus; *P. vulgaris* from the Kasegalik Formation (Hofmann, 1976), the largest previously known species, has a maximum cell size of 8.0 μm. Inclusions in the Tindir cells most probably represent degraded cytoplasm rather than organelles because of the variability in the size and shape of these spots. The presence of abundant inclusions probably reflects the very early silicification of lysing cells. The botryoidal habit of the joined rounded clusters may indicate lack of turbulence during growth and calm conditions of deposition.

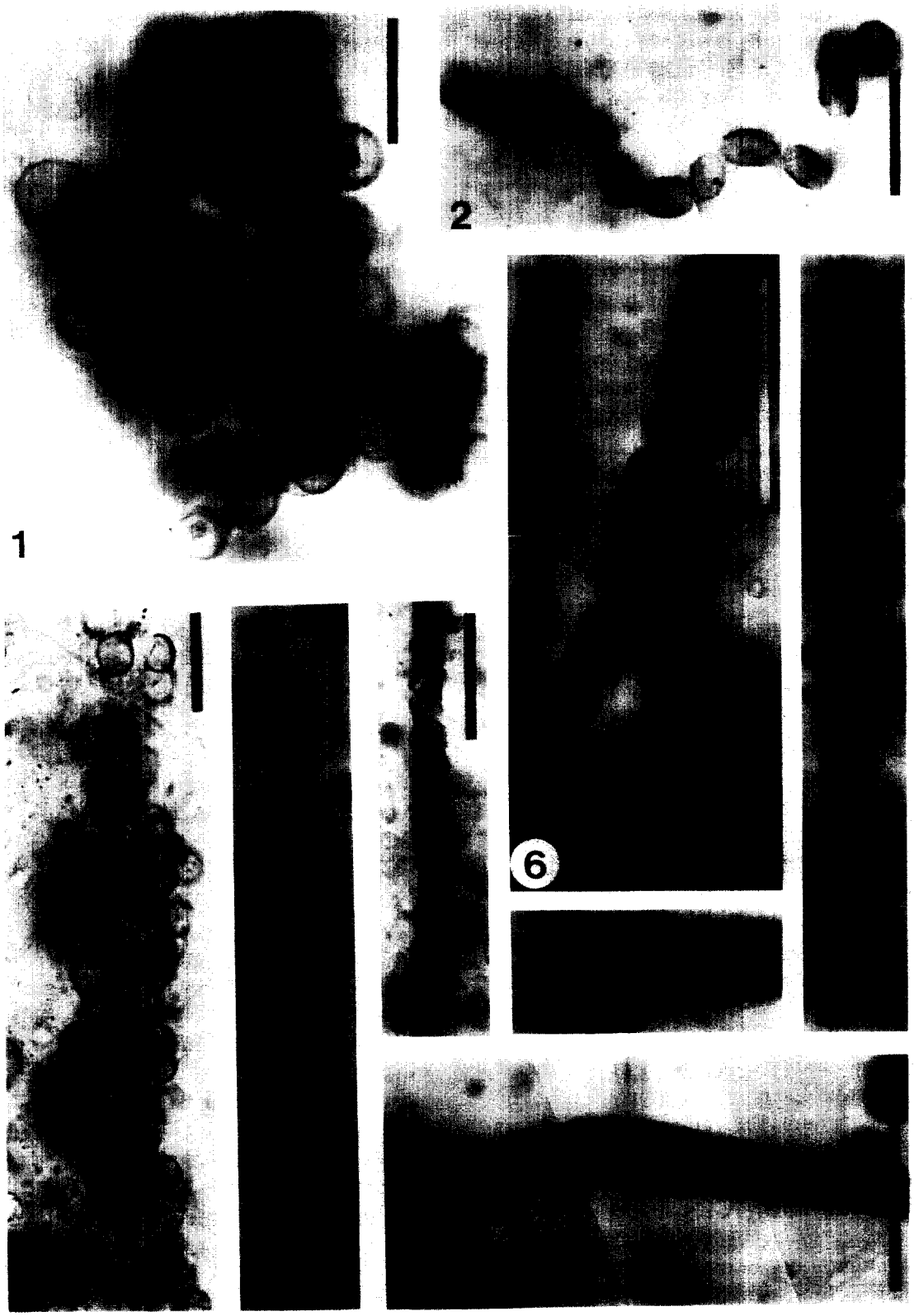
Occurrence. CA 554, CA 555, CA 636, SMA 524; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Gloeodiniopsis* Schopf, 1968 em. Knoll and Golubic, 1979

Type species. Gloeodiniopsis lamellosa Schopf, 1968 em. Knoll and Golubic, 1979.

Gloeodiniopsis lamellosa Schopf, 1968 em. Knoll and Golubic, 1979 (Fig. 8.1).

Description. Spherical to slightly spheroidal, predominantly double-walled monads, dyads and, rarely, triads occurring singly or in groups of five to almost 100 cells within an organic matrix. Inner diameter 6.3–10 μm ($\bar{x}=8.4$ μm; $N=47$); outer diameter 8.1–12.5 μm ($\bar{x}=10.6$ μm; $N=47$). Rarely, one to several, very thin, irregularly shaped concentric layers are found interior to the internal wall/envelope. Most well preserved cells contain a single dark, internal spheroidal organic structure (degraded cytoplasm) 3.1–3.8 μm in diameter, which is the same color as the cell walls. Degraded cells are commonly single-walled and contain a central or eccentric, single, black, granular bleb >1 μm in diameter, or a stellate-shaped, black organic inclusion. Dyads occur singly or grouped and are found along with single cells. Dyads are commonly double-walled, occasionally single-


1
2
6

walled (degraded), and are contained within a predominantly single-walled ellipsoidal envelope. Dyads make up from 10 to 75% of the units ($\bar{x}=23\%$; seven groups composed of 239 units) within a group of cells. Cell aggregates are imbedded in a wall-less, organic matrix.

Discussion. The size, shape and organization of the Tindir *Gloeodiniopsis lamellosa* closely resembles the type material described from the Bitter Springs Formation by Schopf (1968) as emended by Knoll and Golubic (1979). Like Knoll (1982), we interpret the inner wall as the remains of the cell wall (some specimens show constriction suggesting cell division), or it could be the internal envelope adjacent to the cell. We interpret the outer wall as an external envelope. Well-preserved examples displaying the characteristic double-walled organization, internal bleb, and dyads contained within an envelope make this taxon easily recognizable in Tindir thin sections. Single-walled morphs occurring singly or within pluricellular aggregates, with or without internal blebs, can be confused with representatives of *Myxococcoides* and *Glenobotrydion*. Single-walled morphs are assigned to *Gloeodiniopsis* when closely associated with unmistakable *Gloeodiniopsis*. Otherwise, it is difficult to assign unambiguously to taxa morphs with such overlapping morphological attributes.

This taxon is a common member of the Tindir microbiota co-occurring with many other taxa and with no apparent distributional pattern. The solitary and globular nature of its occurrence indicates that this morph was part of the plankton.

Occurrence. BC75 44, CA 631, CA 636, SMA 524; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Eosynechococcus* Hofmann, 1976

Type species. Eosynechococcus moorei Hofmann, 1976.

Eosynechococcus sp. Knoll, 1982 (Fig. 8.2).

Description. Cells are elongate to slightly barrel-shaped, with faintly to markedly rounded ends, commonly aligned single-file. They are 3.6–5 μm wide, 6–11 μm long, with width-to-length ratios from 1:1.5 to 1:2.2 ($N=20$). The wall is robust and moderately dark with a finely to moderately granular surface. One or two dark inclusions, ~1 μm in diameter, angular to spheroidal in shape, are present in some cells.

Discussion. Eosynechococcus is not common in upper Tindir Creek samples and has not been observed in an obvious mat layer. The illustrated example includes 18 cells in a distinctive flexed, more or less continuous series. Eight of the cells are too obliquely oriented to permit accurate measurement. Although similar to *E. grandis* of Hofmann (1976), the size range of the Tindir cells and their robust wall suggest closest affinity with *Eosynechococcus* sp. described by Knoll (1982) from the Draken Conglomerate of Svalbard. However, the linear arrangement, if found in additional examples in the Tindir and elsewhere, could provide an additional taxonomic criterion.

Occurrence. BC75 44, CA 554, CA 635; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Sphaerophycus* Schopf, 1968

Type species. Sphaerophycus parvum Schopf, 1968.

Sphaerophycus parvum Schopf, 1968 (Fig. 7.5).

Description. Small spherical to spheroidal, single-walled cells, of 2.0–3.5 μm diameter ($\bar{x}=2.7$ μm; $N=36$); they occur singly and in pairs. There is a well-defined cleavage plane between pairs. The cell wall surface is psilate to

Fig. 8. Coccoid and filamentous cyanobacteria from upper Tindir Group Unit 5, upper Tindir Creek. Scale bars for 1–8 = 20 μm, and for 9 = 10 μm. 1, *Gloeodiniopsis lamellosa* Schopf GSC 81872. 2, *Eosynechococcus* sp. Knoll GSC 81873. 3, *Myxococcoides cantabrigiensis* Knoll GSC 81875. 4, *Filiconstrictus diminutus* Schopf and Blacic GSC 81878. 5, *Heliconema australiensis* Schopf GSC 81879. 6, *Heliconema bulbosa* Allison, n. sp. GSC 81880. 8, *Cephalophytarion majesticum* Allison, n. sp. GSC 81877. 9, *Eomycetopsis robusta* Schopf emend. Knoll and Golubic GSC 81881.

finely granular but is well formed and thin (≤ 0.5 μm). Some spheroids have a small dark internal spot. No individual envelope or common envelope is present, but some cells are found in an organic matrix.

Discussion. These spheroids are slightly larger than *S. parvum* reported from the Bitter Springs Formation (range 2.1–3.6 μm, $\bar{x}=2.8$; Schopf, 1968) and from the Kasegalik Formation (1.5–3.5 μm; $\bar{x}=2.6$; Hofmann, 1976), but are morphologically indistinguishable from this taxon in all other characteristics. The internal, eccentrically located spots are interpreted as coalesced cell contents (Hofmann, 1976); in a few of the Tindir cells an irregularly shaped dark mass is found just interior to the cell wall and resembles an early stage in a degradation sequence (see Golubic and Barghoorn, 1977, plate 1, fig. 3).

Cells found in an organic matrix are commonly associated with *Palaeoanacystis* sp. and *Eomycetopsis robusta* in a mat-like fabric.

Occurrence. BC75 44, CA 554, CA 635, CA 636, CA 644, SMA 524, ?BC75 46; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Myxococcoides* Schopf, 1968

Type species. Myxococcoides minor Schopf, 1968.

Myxococcoides cantabrigiensis Knoll, 1982 (Fig. 8.3).

Description. The cells are spherical to spheroidal, 8–15 μm in diameter ($\bar{x}=10.8$; $N=86$), with a moderately thick (<1 μm), well-formed, smooth to granular wall. They occur singly, or in loosely aggregated clusters from a few cells to several tens of cells embedded in a diffuse organic matrix. Cells in loose clusters vary from isolated entities separated by a few micrometers to cells touching one another. Planar boundaries between adpressed cells are less than half a cell diameter; adpressed cells retain most of their sphericity. Cells and aggregates occur free and in a layered, mat-like mucus. Some cells contain a peripherally located, small (<1 μm) spot or inclusion.

Discussion. In terms of cell size, morphology and spatial relationships, the Tindir morphs resemble *M. cantabrigiensis* from the Late Proterozoic Draken Conglomerate (Knoll, 1982) and the Hunnberg Formation (Knoll, 1984), Svalbard. The Tindir forms differ in having an organic matrix (presumably extracellular mucilage) that encloses the pluricellular aggregates. Also, unlike Draken examples, some of the Tindir forms occur within layered, mat-like mucus and in cell-rich arrangements, suggesting that the taxon was benthic at times and may have participated in microbial mat construction and sediment stabilization. The solitary cells were probably planktonic. However, these differences do not warrant assigning the Tindir morphs to another taxon.

Knoll (1982) places *M. cantabrigiensis* and other Svalbard *Myxococcoides* among microorganisms *incertae sedis*, based on the combination of several characters (large cell size, thick wall and lack of evidence for cell division) that suggest eukaryotic affinities rather than the often-prescribed cyanobacterial affinities (e.g. Schopf, 1968; Lo, 1980; McMenamin et al., 1983). As Knoll points out, the cell size is very close to the mean cell size of chlorophyte unicells and well within the size limits of cyanobacteria, indicating that cell size is of limited application. He further suggests that lack of evidence for cell division might indicate eukaryotic affinities, but that this criterion is also inconclusive. The lack of evidence for cell division cannot be used to infer systematic position; in both algae and cyanobacteria, cell division might be very rapid and represent only a small percentage of the total time for growth and reproduction (R. Trench, personal communication, 1987). We prefer to include *M. cantabrigiensis* within the cyanobacteria, as do most other researchers; there is no compelling evidence to indicate otherwise.

Occurrence. BC75 44, BC75 46, CA 551, CA 555, CA 635, CA 636, CA 637B, CA 644; upper Tindir Group, Unit 5, upper Tindir Creek.

Order Chroococales (?)
Family Chroococcaceae (?), or
Order Pleurocsapsales (?)
Family Pleurocapaceae (?)
Genus *Phacelogeminus* Awramik n. gen.

Type species. Phacelogeminus lineatus Awramik n. sp.

Diagnosis. Hemispherically shaped cells in dyads, triads and planar tetrads organized into a cluster of tens of units. The walls are distinct and thin. There is no individual or common envelope. Dyads are commonly arranged with their cleavage plane normal to long dimension of the cluster producing apparently linear arrays of cells. Binary fission is predominantly in one direction, with occasional expression in a second direction.

Etymology. From the Greek *phakelos* = cluster, and Latin *geminus* = twin, in reference to pairs of cells forming clusters.

Phacelogeminus lineatus Awramik n. sp. (Fig. 7.4).

Diagnosis. Qualitatively, as for the genus. The cell size ranges from 1.6 to 3.6 μm. A cleavage plane is well developed between dyads; this is usually shorter than the diameter of the hemisphere. The surface texture is smooth to finely granular. There are occasional minute granular inclusions in cells.

Type specimen. SMA 412 at 14.9×14.6.

Etymology. From the Latin *lineatus* = linear, in reference to the linear array of dyads.

Discussion. This new morph most closely resembles *Sphaerophycus parvum* described by Hofmann (1976) from the Kasegalik Formation. It differs from *Sphaerophycus* in its colonial habit, the semi-linear array of dyads and the marked hemispherical shape of individual cells. The Tindir *S. parvum* occur as solitary cells and in dyads but are never found forming a colonial aggregate. The occasional spot within cells is interpreted as congealed cytoplasm.

Although the arrangement of the cells is reminiscent of pleuricapsalean cyanobacteria (e.g. *Pleurocapsa minor* in Geitler, 1932, pp. 348–352), confident placement of *Phacelogeminus lineatus* in this order depends on whether or not reproduction was also by multiple fission (Rippka et al., 1979). Although this Tindir taxon exhibits binary fission, there are no cells that suggest baocyte formation, thus the precise position of this taxon within the cyanobacteria is uncertain.

Occurrence. BC75 44, SMA 412, ?CA 636; upper Tindir Group, Unit 5, upper Tindir Creek.

Order Nostocales Geitler, 1932
Family Oscillatoriaceae (S.F. Gray) Dumortier ex Kirchner, 1899
Genus *Cephalophytarion* Schopf, 1968

Type species. Cephalophytarion grande Schopf, 1968.

Cephalophytarion majesticum Allison n. sp. (Figs. 8.7, 8.8).

Diagnosis. Trichome uniseriate, unbranched, slightly to moderately constricted at septa. The septae are typically distinct, finely granular. The sheath, if present, is indistinct and <1 μm thick. The trichome is solitary, slightly to strongly curved, gradually tapered toward both ends, and has a fine granular surface texture. The maximum observed length of a complete trichome is 225 μm, composed of 102 cells. Cells are cylindrical to very slightly cask-shaped, 7.7–10.8 μm wide and 3.9–8.3 μm long (115 cells measured in 10 trichomes). The cells become more rounded and equidimensional near the trichome ends. The terminal cell is a simple rounded cone.

Type specimen. CA 554 at 32.6×20.2.

Etymology. From the Latin *majorinus* = of a larger kind.

Discussion. Cephalophytarion majesticum is represented by at least 15 specimens. It is generally similar to species of the genus described from the Bitter Springs Formation, Australia (Schopf, 1968; Schopf and Blacic, 1971), but differs in its typically larger cell size and lack of a distinct neck-like constriction in the apical portion in *Cephalophytarion* from the Bitter Springs; this has been interpreted by Golubic

and Barghoorn (1977) and Knoll (1981) as a diagenetic phenomenon.

Occurrence. BC75 46, CA 554, CA 555, CA 636, SMA 524; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Filiconstrictus* Schopf and Blacic, 1971

Type species. Filiconstrictus majusculus Schopf and Blacic, 1971.

Filiconstrictus diminutus Schopf and Blacic, 1971 (Fig. 8.4).

Discussion. Filiconstrictus diminutus is represented by six well-preserved and two poorly preserved specimens. Marked uniformity in cell shape, and distinct, even constriction of cross-walls distinguish *F. diminutus* from other filamentous species in the biota. The Tindir representatives differ from the type material from the Bitter Springs Formation of Australia only in having slightly greater average cell length. In the single Tindir specimen with a preserved terminal portion the penultimate cells are slightly narrower and shorter than the medial trichome cells, and the terminal cell is blunt conical, 4.6 μm wide at the base and 2.9 μm long. The maximum observed trichome length is 175 μm.

Occurrence. CA 554, CA 555, SMA 524; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Heliconema* Schopf, 1968

Type species. Heliconema australiensis Schopf, 1968.

Heliconema australiensis Schopf, 1968 (Fig. 8.5).

Description. A flattened filament, uniseriate, apparently non-septate, 6.0 μm wide, and coiled at ~45° to the long axis into a regular, tight helix. The surface texture is irregularly finely granular, with two faint lines parallel to the filament edge which appear to divide the outer surface into thirds. Successive coils are 2.0–2.3 μm apart, with a slightly spool-shaped profile. The coiled filament is 5.8–6.0 μm wide and 83.8 μm long (incomplete), and consists of eight coils. Terminal structures are unknown.

Discussion. Although *Heliconema australiensis* is represented by only one relatively well-preserved and one less well-preserved specimen, it differs from previously described material. Specimens described by Schopf (1968) have narrower filaments (2.5–2.8 μm wide) and more irregular, attenuated coils. It is distinguished from *H. bulbosa* by its very regular, tighter coiling, flatter profile and greater filament width.

Occurrence. CA 554, CA 555; upper Tindir Group, Unit 5, upper Tindir Creek.

Heliconema bulbosa Allison n. sp. (Fig. 8.6).

Diagnosis. A tubular filament, apparently cylindrical, non-septate, uniseriate, unbranched, slightly curved, and coiled at an angle of ~45° to the long axis into a more or less regular helix. The surface has uneven granular texture. The maximum observed length (incomplete specimen) is 113 μm, and the maximum width is 2.9–3.2 μm. Coil diameter varies from 4 to 5 μm wide (18 spirals were observed), and successive coils are distinctly separated. Terminal structures are unknown. A sheath is not observed.

Type specimen. BC75 44-5 at 112.2×17.3.

Etymology. From the Greek *bolbos*=bulb, with reference to rounded appearance of coils.

Discussion. This distinctive specimen is clearly similar to the modern oscillatoriacean *Spirulina.* Among described fossil taxa it is most similar to *Heliconema funiculum* of Schopf and Blacic (1971), which differs in having a wider (4.0–4.7 μm) filament, and more closely and evenly spaced coils.

Occurrence. BC75 44, ?CA 554; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Eomycetopsis* Schopf, 1968, em. Knoll and Golubic, 1979

Type species. Eomycetopsis robusta Schopf, 1968, em. Knoll and Golubic, 1979. *Eomycetopsis robusta* Schopf, 1968, em. Knoll and Golubic, 1979 (Fig. 8.9).

Discussion. Long, commonly sinuous, hollow filaments referable to *E. robusta* are present in a number of Tindir thin sections, in some cases clearly forming a monospecific mat layer. In two

exceptionally well-preserved occurrences, the very long filaments are closely associated with coccoids. Filaments in these groupings range in diameter from 1.5 to 2.8 μm, with some specimens that have an outer membrane forming filaments of 3.9–4.8 μm total diameter.

Occurrence. BC75 44, CA 631, CA 636, CA 637, CA 644, SMA 524; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Obruchevella* Reitinger, 1948

Type species. Obruchevella parva Reitlinger, 1959.

Obruchevella minuta Allison n. sp. (Fig. 9.10).

Diagnosis. Tightly coiled, tubular filaments ~0.8 μm in diameter. The outside coil diameters are 7–8 μm. No cells or septae are observed. Twenty-one coils are present in specimen 18.3 μm long; the successive coils touch.

Type specimen. BC75 44-9 at 10.1×11.9.

Etymology. From the Latin *minutus*=small.

Discussion. This form is described from two well-preserved specimens in in situ chert nodules at BC75 44. *Obruchevella minuta* is distinguished by its small tube diameter and coil diameter and its close, even coiling.

Tubular, helically coiled microfossils from Proterozoic and Early Phanerozoic rocks are usually interpreted as empty sheaths of oscillatoriacean cyanobacteria. Specimens described from thin sections of chert are commonly placed in the genus *Obruchevella*, now widely reported in Riphean to Early Cambrian rocks of the U.S.S.R., China, Saudi Arabia and Alaska, as recently reviewed by Golovenok and Belova (1983), Song (1984) and Peel (1988). *Obruchevella* is also reported in Upper Cambrian or possibly Ordovician carbonates of the Siberian Platform by Reitinger (1959), and in Ordovician rocks of southeastern Canada by Guilbault (1975). Similar coiled tubes with internal cellular remains have been reported in the Chinese Early Cambrian *O. parva*, *O. parvissima* and *O. meishucunensis* by Song (1984). Wang et al. (1983) referred to *Palaeolyngbya* an open-coiled, sheathed, septate form containing cellular remains. Coiled tubular microfossils separated from shale and other clastic rocks, on the other hand, are commonly placed in *Spiromorpha*, *Toromorpha* or *Volyniella* (see, for example, Shepeleva, 1973; Timofeev, 1973; Asseva, 1976; Tynni and Donner, 1980).

In most cases, species referred to *Obruchevella* have a large coil diameter relative to the tube diameter, but in *O. pusilla*, described from the Riphean of the Patom Highland, U.S.S.R., by Golovenok and Belova (1983), the inner coil diameter is reported to be only 2–3 μm, and the tube diameter to be 1–2 μm. This size and configuration clearly impinges on material referred to the oscillatoriacean *Heliconema*, identified in cherts as old as 800 Ma in Australia (Schopf, 1968) and at Tindir Creek, and on the modern *Spirulina* and some species of *Lyngbya* (Geitler, 1932). Although the possibility exists that morphologically similar, helically coiled tubes seen in chert and in separations from clastic rocks may not represent different taxonomic entities, the specimens described here and an additional larger form described below are tentatively placed in *Obruchevella*. In addition, although it was suggested that increase in tube diameter from older to younger occurrences might be a biostratigraphically useful criterion (Cloud et al., 1979), this seems an unlikely postulate in view of the fact that *O. minuta* has the smallest tube diameter. Forms with much larger tubes and coil diameters occur in stratigraphically lower Tindir Unit 5 cherts 22 km southwest of upper Tindir Creek (Kline, 1977; Cloud et al., 1979; Allison, 1988).

Occurrence. BC75 44; upper Tindir Group, Unit 5, upper Tindir Creek.

?*Obruchevella* sp. (Fig. 9.11).

Description. Cylindrical, composed of one or more coiled, empty, ?non-septate tubes 1.0–1.4 μm in diameter. Inside coil diameter is about 15.5 μm; outside coil diameter is 16.5–18.0 μm.

Discussion. A single specimen of this distinctive fossil has been observed in a thin section containing also well-preserved coccoids and fi-

lamentous trichomes of many different taxa. About four coils are preserved. Faint evidence of subdivision is present in the coils and two show slight separation at one point where membranes appear to cover the ends of the tubes.

In addition to possible subdivision, this specimen differs from *O. minuta* in having a much larger coil diameter and slightly larger tube diameter. Among previously described forms referred to *Obruchevella*, *O. parvissima* from the earliest Cambrian Yuhucun Formation of Yunnan Province, China (Song, 1984), is most similar to this Tindir specimen; however, *O. parvissima* has distinct cross-walls, a tube diameter of 3–4 μm, and a coil diameter of 20–24 μm (Song, 1984).

Occurrence. CA 554; upper Tindir Group, Unit 5, upper Tindir Creek.

Kingdom Procaryotae or Kingdom Protista
Group Incertae Sedis

Of the taxa described under this heading, several may (should additional material become available) be referrable with greater confidence to a specific protistan subgroup, or removed from the Protista. As cited in the discussions of a few of the following taxa, an alternative assignment to the Procaryotae can be considered.

Genus *Balbariniella* Oehler, 1978

Type species. Balbiriniella praestans Oehler, 1978.

Balbariniella praestans Oehler, 1978 (Fig. 9.13).

Description. Cells are polyhedral to spheroidal with planar boundaries common to tightly adpressed cells. The cell boundary wall is well formed and distinct. The minor and major axes of the polyhedral cells range in size from 14×18 to 27×33 μm. Cells are commonly grouped into aggregates of three to seven cells. In turn, these aggregates make up a larger unit 100–150 μm in size. Envelopes surround the smaller cell aggregates, but the large mass does not appear to have a common envelope. Most cells contain irregularly shaped, dense, granular inclusions; these vary in position and in size from 5 to 19 μm across.

Discussion. The well-preserved Tindir *Balbiriniella* resembles the Australian type species in most major characteristics: adpressed polyhedral to unconfined spheroidal cells, cell size, marked variation in cell size, cells organized into aggregates, envelope and cellular inclusions. It differs in lacking a well-preserved double wall, the larger cells lack thicker walls, and no bubble-like protrusions were seen. We do not consider that these differences are sufficiently great to place this morph in a new taxon.

Oehler (1978) made comparisons of *Balbariniella* with chlorococcalean green algae but also noted the similarities with cyanobacteria and red algae. The Tindir specimens do not shed any new light on this problem. If the small internal bodies are endospores, they might be baocytes and hence *Balbarinella* could be a pleurocapsalean cyanobacterium. Nevertheless, its affinity remains uncertain.

Occurrence. CA 637, SMA 434, SMA 524, ?CA 554; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Glenobotrydion* Schopf, 1968 em. Nyberg and Schopf, 1984

Type species. Glenobotrydion aenigmatis Schopf, 1968 em. Nyberg and Schopf, 1984.

Glenobotrydion aenigmatis Schopf, 1968. em. Nyberg and Schopf, 1984 (Fig. 7.3).

Description. Cells are spherical to spheroidal, tending toward polyhedral shapes of adpressed cells in clusters, and are solitary or arranged in clusters of tens of cells within an organic matrix. No pseudofilamentous aggregates are observed. Eccentrically located granular inclusions are common. There is no sac-like internal structure. Cells range in size from 5.4 to 11.4 μm ($\bar{x}=8.2$ μm, $N=40$). Internal inclusions are 1–4 μm in diameter; larger inclusions are irregularly shaped and distinctly granular.

Discussion. In shape, size and presence of an internal spot, these cells closely resemble *G. aenigmatis* from the Bitter Springs Formation

(Schopf, 1968). However, the Tindir specimens do not exhibit the pseudofilamentous habit (Schopf, p. 968, plate 84, fig. 5) that is characteristic (but not diagnostic) of the genus (Nyberg and Schopf, 1984). If these cells lacked internal spots they would probably be placed within the cyanobacterial genus *Myxococcoides*. In addition to the Bitter Springs Formation, similar *G. aenigmatis* have been described from the Ryssö Formation (Knoll and Calder, 1983). In overall morphology, but of smaller size, the Tindir examples resemble some specimens of *G. majorinum* (Nyberg and Schopf, 1984, fig. 17H).

We have placed the Tindir *Glenobotrydion aenigmatis* within our *incertae sedis* because taxonomic assignment of this form is controversial and the Tindir specimens offer no new information that could help resolve the issue. Nyberg and Schopf (1984) placed *G. aenigmatis* within the eukaryotic ?Chlorophyta or ?Rhodophyta, based on their interpretation of internal cell organization, as did Hofmann (1976) and Zhang Yun (1981). Knoll and Calder (1983), taking a conservative approach, placed it in *incertae sedis*. Unlike Nyberg and Schopf (1984), and Oehler (1977) before them, we do not view the evidence for a eukaryotic origin for the genus (persistence of internal body, sac-like structure, difference in electron densities, examples of preserved nuclei-like structures from the Phanerozoic) as compelling. The cells are clearly degraded, and the range of degradational features, compared with degraded modern cyanobacterial analogs (Awramik et al., 1972; Knoll and Barghoorn, 1975; Golubic and Barghoorn, 1977), suggests caution in recognizing a eukaryotic affinity on these grounds.

Occurrence. SMA 485, BC75 44, BC75 46, CA 554, CA 555, CA 635, CA 636, CA 637; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Fusilabellum* Awramik n. gen.

Type species. Fusilabellum brevistriatum Awramik n. sp.

Diagnosis. A fusiform, lemon-shaped, thick-walled, solitary vesicle with longitudinally oriented short striations on the surface. The surface is commonly crossed by a single, ~ 1 μm wide furrow-like, clear stripe parallel to the long axis of the cell, the furrow terminates near the slightly pointed end or lip. The wall is thick and dark. There is no pylome or unambigous median split. The vesicle occurs singly and in loose aggregates, and there is no extra-vesicular envelope.

Etymology. From the Latin *fusus* = spindle, and *labellum*, diminutive of *labrum* = lip, in reference to small protrusions at ends of fusiform body.

Fusilabellum brevistriatum Awramik n. sp. (Figs. 9.1, 9.2).

Diagnosis. Qualitatively, as for genus. Vesicles measure 7–10 μm in the short dimension and 17–19 μm in the long dimension ($\bar{x}$ 14×17 μm; $N = 27$).

Type specimen. BC75 44-7 at 30.9×14.6.

Etymology. From the Latin *brevus* = short and *striatus* = line, in reference to the short, linear striations on the vesicle surface.

Discussion. This taxon is erected on the basis of typological criteria. Longitudinally furrowed and minutely striated, spindle-shaped, thick-walled vesicles are easily recognized in a number of Tindir thin sections. Occasionally these cells are associated with unnamed spherical to spheroidal thick-walled, commonly striated vesicles. *Fusilabellum brevistratum* may represent a taphonomic end member of the spherical morphs; however, intermediates are not clearly represented. Deriving the furrow from taphonomic/diagenetic processes is difficult; the furrow does not appear to be the simple result of shrinkage or swelling (the fusiform shape would suggest compression), and its origin is uncertain. The lemon shape might arise by the compression of a longitudinally striated, thick-walled vesicle.

Such fusiform microfossils are rare in chert. Knoll (1982; plate 4, fig. 6) illustrates a spin-


2
3
9
12

dle-shaped variant of *Eosynechococcus* sp., but this morph does not resemble the Tindir specimens. Spindle-shaped morphs are known among the acritarchs, e.g. variants of leiosphaerids.

Occurrence. BC75 44, CA 635, CA 644, CA 551, CA 555, CA 644, ?CA 636, SMA 412; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Sphaeranasillos* Allison n. gen.

Type species. Sphaeranasillos irregularis Allison n. sp.

Diagnosis. Spherical solitary cell ~18 μm in diameter. Fine, short, bristle-like structures arise at the base of the wall and are distributed singly or in small groups around the cell's outer surface. The wall is indistinct and apparently porous.

Etymology. From the Greek *sphaira* = ball and *anasillos* = bristling hair.

Sphaeranasillos irregularis Allison n. sp. (Figs. 9.3, 9.4).

Diagnosis. Qualitatively, as for genus. The cell is 18.2 μm in diameter. The wall is 0.7 μm thick and milky pale yellow, with apparent minutely porous structure. Bristle-like structures occur perpendicular to the wall; these are ~3.5 μm long, slightly bulbous at the base, straight throughout their length or sinuous near the blunt or minutely branched tip. They occur singly or in random clusters of two or three. Internal cell structure is unknown.

Type specimen. BC75 46-3 at 10.6×8.3.

Etymology. From the Latin *in* = not, and *regularis* = according to rule, referring to the inequally distributed processes.

Discussion. Sphaeranasillos irregularis, although described from a single specimen, is sufficiently distinct to warrant separate taxonomic treatment. It differs from all other cells in the Tindir biota in having bristle-like structures around the cell and an apparently porous wall. The wall is not sharply defined, appearing to be made up of alternating slightly lighter and darker markings ~1 μm apart and arranged radially with respect to the cell center. The specimen lies well down in the thin section, and thus is not easily examined. Depending on the light level and angle, there appear to be pale, hair-like structures corresponding to the light markings in the wall, which protrude outward from it and are ~15 μm long with tapered tips. The larger, definite processes are unusual in that they are selectively and completely replaced with an opaque metallic mineral that appears dull gold in reflected light. The wall structure and highly irregular distribution of the bristle-like structures preclude referral of *Sphaeranasillos* to the baltisphaerids or other 'spiny acritarchs', and it does not resemble known cyanobacteria.

Occurrence. BC75 46; upper Tindir Group, Unit 5, upper Tindir Creek.

Unnamed Form D Knoll, 1984 (Fig. 9.5).

Discussion. A single robust, ovoid Tindir cell suggests affinity with the somewhat smaller but generally similar Unnamed Form D reported by Knoll (1984) from the Hunnberg Formation, Svalbard. The Tindir specimen has maximum and minimum diameters of 120 and 96 μm respectively. The smooth, milky pale yellow wall is 1.9–2.2 μm thick, surrounded by an in-part minutely granular, in part colorless spherulitic, mineralized envelope of irregular thickness and secondary origin. As preserved, the cell surface

Fig. 9. Microfossils *incertae sedis* from upper Tindir Group Unit 5, upper Tindir Creek. Scale bars for 1 and 5 = 50 μm; for 2–4, 6–9 and 13 = 20 μm; for 10 and 11 = 10 μm; and for 12 = 5 μm. 1,2, *Fusilibellum brevistriatum* Awramik n. gen., n. sp. 1, several cells. 2, Type specimen shown at different focal depths to illustrate profile and surface texture GSC 81882. 3, 4, *Sphaeranasillos irregularis* Allison n. gen., n. sp. GSC 81883, shown at different focal depths to illustrate irregular distribution of dark, bristle-like structures. 5, Unnamed Form D of Knoll GSC 81884. 6, Unnamed Coccoid Form B, portion of partially collapsed specimen GSC 81886. 7, Unnamed Coccoid Form A GSC 81885. 8, Unnamed Coccoid Form C GSC 81887. 9, Unnamed Coccoid Form D GSC 81888. 11, ?*Obruchevella* sp. GSC 81890. 12, Unnamed Filament Form A GSC 81891. 13, *Balbariniella praestans* Oehler, GSC 81876.

bears numerous angular, opaque black grains of irregular size, shape and distribution. The internal area has a distinctive, minutely grainy appearance.

Occurrence. BC75 46, CA 554; upper Tindir Group, Unit 5, upper Tindir Creek.

Unnamed Coccoid Form A (Fig. 9.7).

Description. A spherical unicell with an outer radially divided layer; the inner and outer diameters are 18 and 22 μm respectively. The cell wall is very dark, 0.4 μm thick and finely granular. The outer layer apparently has numerous pillar-like structures ~1.4 μm apart. The outer surface is granular with some specks markedly darker than others. A pale yellowish ?sheath (1–2 μm thick) is intermittently present around the vesicle, forming a third layer.

Discussion. These complex specimens grossly resemble the much larger *Cymatiosphaeroides vidalii* Knoll present in another thin section from the same horizon, but in Unnamed Coccoid Form A it is not certain that the pillar-like structures are processes rather than wall material around the channels in a perforate or a deeply reticulate surface.

Occurrence. BC75 44, BC75 46, CA 554, CA 555, CA 635, CA 636, CA 637, CA 644; upper Tindir Group, Unit 5, upper Tindir Creek.

Unnamed Coccoid Form B (Fig. 9.6).

Description. The vesicle is apparently spheroidal, from 72 to at least 100 μm in diameter. The wall is colorless, smooth, hyaline, single-layered and 3 μm thick. The internal area is featureless. No vesicle opening is observed.

Discussion. Two specimens of this extremely pale form have been observed, lying close together and within multiple mat layers. One is preserved as a circular structure that increases radially from 62 to 73 μm in diameter in the slice visible in the thin section; the other specimen is broken, with a preserved circumference of 215 μm, suggesting a diameter < 100 μm. The wall is consistent in thickness, even where collapsed inward in the broken specimen (Fig. 9.6). Form B is generally similar to Unnamed Form C of Knoll (1984) but has a better defined, thicker wall and does not have the surface granularity distinctive of the form described by Knoll.

Unnamed Coccoid Form C (Fig. 9.8)

Description. A spherical cell, solitary, 22–27 μm in diameter, of concentric construction. The outer layer is dark brown, ~0.5 μm thick, with a reticulate honeycomb-like surface, separated from the inner layer by 1–3.5 μm. The inner layer is dark brown, ~0.5 μm thick, with a granular surface. The central body is medium brown, finely granular, and 10–12 μm in diameter.

Discussion. The concentric structure of these cells may reflect degradation in a form in which inner and outer wall layers originally were more nearly adjacent, as shown by several specimens not illustrated. However, a tendency toward separation of the two layers is marked in all specimens and the form is distinguished by its strongly reticulated surface. The double-layered wall, moderately large diameter and prominent large central body suggest that this is probably not a cyanobacterial form.

Occurrence. BC75 44, CA 555; upper Tindir Group, Unit 5, upper Tindir Creek.

Unnamed Coccoid Form D (Fig. 9.9)

Description. A spherical cell, solitary, multiple layered, 45 μm in diameter. The outer wall layer is milky pale tan, 2 μm thick, and underlain by a zone 4.8–5 μm thick containing several indistinct concentric membranes ~1.3 μm apart. The central area is pale and featureless, and contains an eccentrically located, finely granular medium brown body 14 μm in diameter. The outer surface of the outer wall layer is apparently smooth, and is obscured by ragged ?sheath remains.

Discussion. This cell is distinguished by the presence of a multiple membrane layer inside the well-defined outer layer, and by the large internal body, which may represent coalesced material that originally occupied the entire area internal to the innermost wall membrane. It

differs from the forms called pterospermopsimorphids by Timofeev (1962) and Knoll (1984) in having a multiple rather than single inner wall layer.

Occurrence. BC75 44; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Tindiromacula* Allison n. gen.

Type species. Tindiromacula hofmanni Allison n. sp.

Diagnosis. Narrow, unbranched, non-septate filaments containing closely spaced, uniserially arranged cylindrical structures with rounded ends; the cylindrical structures contain multiple, more-or-less evenly spaced dark spots.

Etymology. Named for the Tindir Group and from the Latin *macula* = spot.

Tindiromacula hofmanni Allison n. sp. (Figs. 10.7, 10.8).

Diagnosis. Qualitatively as for genus. Filaments are 4.0–4.3 μm in diameter with a smooth hyaline wall 0.5 μm thick, with internal cylindrical structures 15–25 μm long, and well-rounded ends, each containing somewhat irregularly arranged dark spots ~1 μm in diameter and 3.3–4.5 μm apart. A sheath with fine granular surface, about 0.5 μm thick, is seen in another specimen in the thin section containing the type.

Type specimen. BC75 44-5 at 42.1×2.2.

Etymology. Named in honor of Hans J. Hofmann.

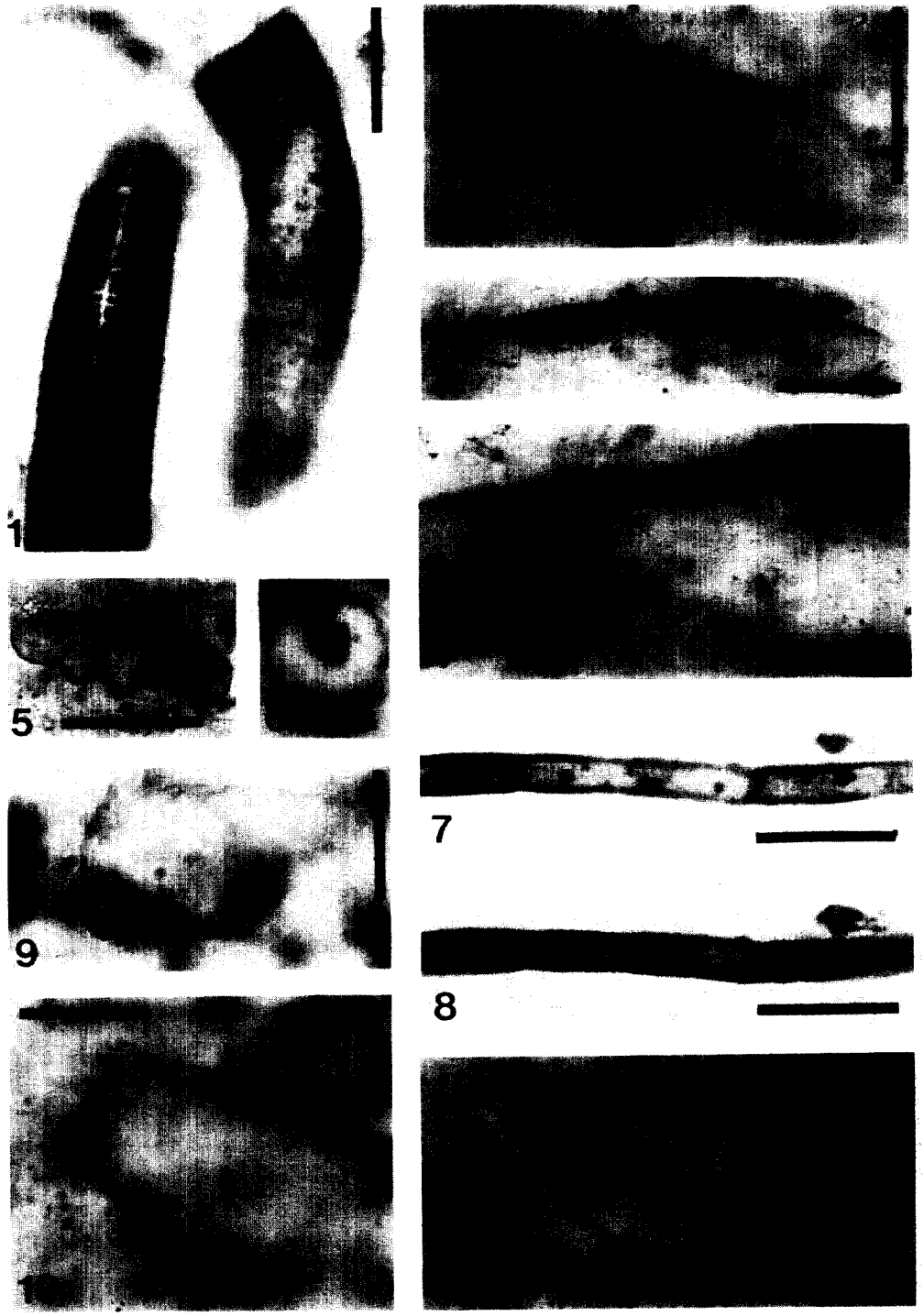
Discussion. A well-preserved piece of filament containing three, and a separate piece containing one, cylindrical structures are referred to *T. hofmanni.* These occur in association with numerous similar to slightly narrower empty filamentous sheaths referable to *Eomycetopsis robusta* Schopf and mixed coccoids including *Myxococcoides cantabrigiensis, Glenobotrydion aenigmatis,* and *Sphaerophycus parvum* in an in situ chert nodule cut parallel to the microbial mat lamination in BC75 44. In the holotype specimen (Figs. 10.7 and 10.8), the adjacent cylindrical structures within the sheath are separated from one another by ~1.5 μm in an oscillatoriacean hormogone-like array in which they define intervening areas that appear as septa. However, these do not contain partitioning membranes and are simply somewhat darker spaces between the cylindrical structures. The dark internal spots are subrounded and are not arranged in obvious single or multiple rows or in one plane.

Interpretation of *T. hofmanni* is complicated by its close spatial association with *Eomycetopsis* and *Eomycetopsis*-like empty sheaths (Fig. 8.9), many of which approach *T. hofmanni* in diameter, presence of a thin sheath, and possession of a fine granular surface. As interpreted at present, *Eomycetopsis* is of cyanobacterial affinity and is, in some occurrences, an important microbial mat-builder (Knoll, 1982, 1984), as it may have been also in the upper Tindir Creek mats, where it occurs in well-defined monospecific layers in several chert nodules. The dark spots, and especially their consistent size and non-linear but more-or-less even spacing in the cylindrical structures, in *T. hofmanni* have not been reported in *Eomycetopsis.* The spots could be the condensed internal contents of sequential single series cells in hormogones, now represented only by their outer walls, of an oscillatoriacean cyanobacterium. This interpretation is not, however, consistent with the fact that although coccoidal morphs are well known to preserve spot-like condensed cell contents, a preservational mode in which the trichome cell end membranes are missing but the cell side-walls are preserved as a smooth membrane with the cell contents present as condensed spots is not known in the Tindir Creek or other chert biotas. Degradation of spheroidal cells within a tubular algal, or fungal, form appears to be a more likely explanation for *Tindiromacula.*

Occurrence. BC75 44; upper Tindir Group, Unit 5, upper Tindir Creek.

Unnamed Filament Form A (Fig. 9.12).

Description. A uniseriate filament, slightly curved, evenly tapered toward apices, com-


1
5
9
7
8

posed of occasional cells 1–1.3 μm long and 3 μm wide distinctly separated by slightly narrower portions of filament (?cells) ~2–2.5 μm wide and 4–5 μm long. Maximum length (incomplete trichome) is 38 μm. Apical portions are without distinctive cells, and taper gradually to a cone shape. Cell walls are <0.5 μm thick, with a granular appearing surface. A sheath is not observed.

Discussion. These unusual structures could be partially degraded specimens of an organism that originally contained even more cells, but the regular spacing of short, wider cells between longer and slightly narrower ?filament portions suggest some representation of original differentiation. Other taxa that taper toward one or both apices lie nearby, but have cells of consistent shape that are wider and occur in longer filaments. Although of a diameter consistent with cyanobacterial filaments, the nature of cell differentiation present in Form A is not typical of cyanobacteria.

Occurrence. BC75 44, SMA 524; upper Tindir Group, Unit 5, upper Tindir Creek.

Unnamed Filament Form B (Figs. 10.1, 10.2).

Description. An apparently tubular filament, solitary, unbranched, slightly curved, which may be evenly tapered to the blunt apices; partial ?cross walls may be present. A sheath is absent. The surface has faint, even, annular ribbing appearing as granular lines 0.8–1.4 μm wide and 1 μm apart. The maximum observed length (incomplete specimen) is 83 μm; maximum width is 12.5 μm. The internal area is featureless, without an observable enclosing membrane.

Discussion. This unusual fossil is described from two specimens near one another in thin section BC75 44-5 and one each in CA 635 and CA 644. At the upper surface on the longer specimen, seen at the left in Fig. 10.1, in BC75 44-5 a straight ?break ~1 μm wide bisects the fossil, curving slightly downward toward one end, as does the specimen. This feature can be followed toward the other end where the specimen appears to be slightly twisted because the ?break, which does not extend into the matrix at either end of the specimen, does not turn toward the preserved, tapered tip. No membrane is observed to run along the margins of this feature, which are marked by the rounded ends of the granular lines that form annular surface ribs. The latter are not clearly seen to be paired as would be expected if they represented top and bottom membranes of individual cells, although such an interpretation is possible. Thickness and structure of the wall are difficult to confirm. What can be observed in focusing from the surface toward the internal area indicates that it is ~3 μm thick. However, in all specimens the maximum observable width of the central 'cavity' is 7 μm, bordered by 'walls' made up of perpendicularly arranged successive membranes of the thickness and spacing of the annulations seen on the outer surface.

Affinities of this fossil are not certain. One possible interpretation is that it represents a filamentous cyanobacterium such as an oscillatoriacian with wide, extremely short cells of which only the peripheral portions of the upper and lower membranes are preserved. Another

Fig. 10. Microfossils *incertae sedis* from upper Tindir Group Unit 5, upper Tindir Creek. Scale bars for 1-6, 9 and 10=20 μm; for 7 and 8=10 μm; and for 11=50 μm. 1,2, Unnamed Filament Form B, 1, GSC 81892 with specimen on left focused to illustrate surface texture and enigmatic ?break along filament. 2, GSC 81893 illustrating typical empty appearance of internal area. 3,4, Unnamed Filament Form C, GSC 81894 shown at different focal depths to illustrate profile and plan views of minute thread wound spirally around tubular structure. 5, Unnamed Bulbous Form GSC 81895. 6, Spiral Grooved Form. GSC 81896. 7,8, *Tindiromacula hofmanni* Allison n. gen., n. sp., GSC 81897, shown at different focal depths to illustrate enigmatic internal spots. 9-11, *Hyalocyrillium clardyi* Allison n. gen., n. sp., 9, GSC 81898 showing wrinkling of very thin, apparent soft wall and closed pole; 10, GSC 81899 showing slight thickening of wall near open pole and apparent extremely thin cover; 11, GSC 81900 on left, focused to show simple open pole structure, smaller specimen on right replaced internally with small, secondary carbonate rhombs.

interpretation is that these fossils represent sheath material with annular lamellar construction. Support for this interpretation could lie in the presence, near the ?broken right end of the longer specimen shown in Fig. 10.1, of an apparent trichome, composed of about 18 cells, each ~1 μm long and 2–5 μm wide, that is tapered at each end. A third interpretation is that this fossil does not represent a cyanobacterium or an alga, in which case the distinctive 'break' may reflect a significant morphological feature.

Specimens of generally similar, annularly ribbed structures occurring in other thin sections may represent the same taxon. One (Fig. 10.2), shows a distinct split from a wide-diameter portion into two tubular 'branches' of lesser diameter. Even larger diameter, annularly ribbed, empty tubes that occur with *Obruchevella* in Tindir Unit 5 near the Tatonduk River (Allison, 1988) may represent the same taxon.

Occurrence. BC75 44, BC75 46, CA 554; upper Tindir Group, Unit 5, upper Tindir Creek.

Unnamed Filament Form C (Fig. 10.3, 10.4).

Description. A tubular filament, 23–29 μm in diameter and 160 μm long (incomplete). The wall is 0.8 μm thick, dark and single layered. Long threadlike structures about 0.6 μm in diameter are tightly coiled around outside of tube, forming subparallel rib-like features nearly perpendicular to the long axis of tube; the coils are ~2.5 μm apart. The internal area is featureless.

Discussion. This enigmatic tubular fossil, which is open on both ends, is represented by a single well-preserved specimen and several apparently similar structures. It is slightly infolded at one point along one side, and appears to have been soft. It is generally similar to *Siphonophycus* Schopf (1968) except for the intimately associated, presumably ?bacterial, threads coiled around the tube. A possibly comparable association has been reported in the 3500-Ma-old Warrawoona Group microbiota of Western Australia in which a thread of <1 μm diameter is coiled around a partitioned tubular structure 4–6 μm in diameter (Awramik, 1984b, fig. 2). It is not certain whether the larger-diameter Tindir 'host' tube is of cyanobacterial or non-cyanobacterial affinity.

Occurrence. CA 555; upper Tindir Group, Unit 5, upper Tindir Creek.

Unnamed Spiral Grooved Form (Fig. 10.6).

Description. An apparently tubular filament, 42–44 μm in diameter, with spiral V-shaped grooves 6–12 μm apart, about 3 μm deep and of 3–4 μm maximum width at the outer surface of tube; 10 grooves are visible around the periphery of a specimen of 44 μm maximum diameter. The wall is single layered, ~0.3 μm thick, and very finely granular with a smooth surface. The internal area is pale, with a wispy-shaped patch of granular dark brown material.

Discussion. This distinctive fossil is described from two specimens, one cut perpendicular and another slightly oblique to the long axis of an apparently tubular structure. Inasmuch as this fossil has not been seen in longitudinal view, the length and possible terminal structures are not known. The specimen shown in Fig. 10.6 occurs between closely spaced, thin, brown, organic-rich layers without other identifiable fossils, near empty sheaths of *Eomycetopsis* and two partially collapsed specimens of *Hyalocyrillium clardyi*.

Occurrence. SMA 524; upper Tindir Group, Unit 5, upper Tindir Creek.

Unnamed Bulbous Form (Fig. 10.5).

Description. An elongated vesicle, irregularly bulbous, ranging from 67 μm in length at 30 μm maximum width to 154 μm length and 58 μm width. The wall is dark brown, single layered, hyaline, ~0.5 μm thick, and has a finely psilate surface. The internal area is featureless.

Discussion. Two specimens of this markedly lumpy form have been observed. The very thin but apparently very durable wall passes smoothly over the sides and domelike surfaces of the somewhat irregularly placed bulbous expansions without wrinkling or thinning. The nature of the wall discourages interpretation as

a membrane originally surrounding packets of cyanobacterial coccoids, of which several examples have been observed, all clearly reflecting the typical shape of the packets and with a finely granular rather than hyaline appearance.

Occurrence. CA 555; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Hyalocyrillium* Allison n. gen.

Type species. Hyalocyrillium clardyi Allison n. sp.

Diagnosis. An elongate, sac-like fossil, with an apparently circular opening at one pole; the opposite pole is smoothly rounded. It is ~20–45 μm in maximum diameter, and from 45 to over 192 μm long. The wall is smooth, hyaline, typically colorless, ~1 μm thick, and apparently single layered and imperforate. The internal area is featureless.

Etymology. From the Greek *hyalo* = glassy and *kyrillion* = jug with narrow neck.

Hyalocyrillium clardyi Allison n. sp. (Figs. 10.9–10.11).

Diagnosis. Qualitatively, as for genus. The size ranges from 21.2 μm in diameter and 45 μm long with an opening 9.1 μm in diameter, to 45.6 μm in diameter and 174.8 μm long with an opening 19 μm in diameter. The longest specimen observed is 192.6 μm long and of 43.3 μm maximum diameter, with the open pole not preserved. The wall thickens gradually to ~2 μm at the open pole. The internal area is featureless.

Type specimen. CA 635 at 36.1 × 18.3.

Etymology. Named in honor of Bruce I. Clardy, collector and donor of the samples in which the Tindir Creek biotas were discovered.

Discussion. Twelve specimens of this enigmatic fossil have been found in chert patches in CA 635 and one to several each in thin sections from five other horizons. Most lie oblique in the thin section, four exhibiting the open pole, eight the opposite pole, and four both poles. The others are crushed or cut across the sac. An oval–oblong shape, with the plane of the opening perpendicular to the long axis, is consistent although there is some variation in relative dimensions of length to diameter. Whether the opening, and the sac, are circular rather than oval in cross-section is difficult to confirm because no truly circular sections have been observed. One specimen, lying near a fracture, is partially obliterated by the growth of secondary carbonate crystals inside (Fig. 11.11). The others are most easily spotted by the absence of crystals or normal matrix material inside.

Ten specimens are fully inflated, with very smooth margins and apparently radial symmetry, but twisted and flattened specimens give clear evidence of a non-rigid wall and collapse without tearing of the wall, as does the slightly wrinkled specimen shown in Fig. 10.9. In the specimens in which the open pole is well preserved, the wall thickens slightly near the opening and extends slightly beyond a thin (< 0.5 μm) apparent membrane that ?covers the opening. This dips inward near the center (Fig. 10.10), but no pole has been confirmed in it. Other specimens exhibiting this pole appear to have a simple opening or, in three cases, possibly to have a plate-like cover over the entire open pole.

Generally similar fossils have been reported from Late Proterozoic clastic sediments from Sweden (Knoll and Vidal, 1980), Greenland (Vidal, 1979), Saudi Arabia (Binda and Bokhari, 1980) and Brazil (Fairchild et al., 1978). The well-preserved fossils described by Bloeser (1985) from the Late Proterozoic Chuar Group of Arizona clearly differ from the Tindir Creek specimens in having a thicker (5–7 μm), denser, opaque, psilate or granular wall with a markedly thickened, in some cases 'fringed' open pole and triangular 'deltapyle' opening covered by a distinctive triangular or circular plug.

Although any or all of these sac-like morphs could be phyletically related to the Tindir forms, the unnamed specimens illustrated by Vidal from the Eleonore Bay Group (Vidal, 1979, plate 6) are the most closely comparable fossils in terms of their apparently simple open pole area and thin wall.


1
2
3
4
5
9
10

Occurrence. BC75 44, BC75 46, CA 555, 635, 696, SMA 524; upper Tindir Group, Unit 5, upper Tindir Creek.

Group Acritarcha

Included under this heading are Tindir fossils clearly similar to previously described forms that are, by convention, placed in the Acritarcha. Although acritarchs are known mostly from shale facies, the Tindir specimens occur mainly in cherts. Acritarchs are thought to represent in many cases one of multiple life-cycle stages in green and other algae; however, the true phyletic affinities of many Acritarcha are not any better known than those of fossils described above under Group Uncertain.

Genus *Leiosphaeridia* Eisenack, 1958

Type species. Leiosphaeridia baltica Eisenack, 1958.

Leiosphaeridia asperata (Naumova) Lindgren, 1982 (Fig. 11.4).

Description. Wrinkled and folded dark vesicles, 25–30 μm in diameter ($N=27$). The vesicle surface is psilate, and the walls are single, ≤ 1 μm thickness. The fossil occurs singly or in clusters. The vesicles are empty, and without evidence of a median split.

Discussion. Thick-walled, folded vesicles are not abundant in upper Tindir Creek cherts. Those that are found are distinctively different from the organic-walled microfossils more characteristic of chert, which do not show a folded morphology when compressed. Vidal (in Vidal and Siedleska, 1983) defined the taxon *Kildinosphaera* for solitary, large-sized, compressionally folded vesicles, not associated in pluricellular (coenobial) aggregates or thought to occur in that form. Pluricellular aggregates and associated solitary morphs of the same morphology as those found in the Tindir are referred to *Leiosphaeridia asperata* (Lindgren, 1982).

Occurrence. BC75 44, CA 631, ?BC75 46; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Cymatiosphaeroides* Knoll, 1984

Type species. Cymatiosphaeroides kullingii Knoll, 1984.

Cymatiosphaeroides kullingii Knoll, 1984 (Figs. 11.1–11.3).

Discussion. This distinctive taxon is represented in the Tindir material by a single specimen. It measures 66 μm in maximum outer diameter, 57.6 μm in maximum inner diameter and bears processes 3.5–3.8 μm long. Processes are 3.0–3.8 μm apart, with bases resting on very slight conical protrusions of the inner membrane. The processes appear to branch at the tip, producing an effect on the outer surface of very short, sinuous dark lines and a faintly frothy rather than entirely smooth appearance as noted by Knoll (1984) in specimens from the Hunnberg Formation, Svalbard.

Occurrence. CA 644; upper Tindir Group, Unit 5, upper Tindir Creek.

Genus *Trachyhystrichosphaera* Timofeev and Hermann, 1976

Type species. Trachyhystrichosphaera aimika Hermann, 1976.

Trachyhystrichosphaera vidalii Knoll, 1984 (Figs. 11.9, 11.10).

Discussion. One poorly preserved Tindir vesicle is, on the basis of morphology and size, referable to *T. vidalii* described by Knoll (1984)

Fig. 11. Acritarchs from upper Tindir Group Unit 5, upper Tindir Creek. Scale bars for 1–4, 6–8, and 11 = 20 μm; for 5 = 500 μm; and for 10 = 100 μm. 1–3, *Cymatiosphaeroides kullingii* Knoll GSC 81902: 1, whole specimen; 2, enlargement showing processes and outer membrane; 3, surface view. 4, *Leiosphaeridia asperata* (Naumova) Lindgren GSC 81901. 5–8, *Trachyhystrichosphaera magna* Allison n. sp. GSC 81903: 5, whole vesicle with cylindrical invaginated area at top; 6, one of processes on outer surface arising at basal wall membrane; 7, multilayered vesicle wall with basal membrane to left; 8, large bulbous-based structure projecting into invaginated area. 9, 10, *Trachyhystrichosphaera vidalii* Knoll GSC 81904: 9, process on outer surface holding up outer membrane cover; 10, whole vesicle. 11, Unnamed Triangular Form GSC 81905; arrow points to stellate hole straddling edge of vesicle.

from the Hunnberg Formation, Svalbard. The Tindir specimen is oval in shape, 250 μm × 220 μm in size, and has a hyaline pale brown wall 7–10 μm thick. The few processes that are preserved are ~5 μm in diameter and up to 40 μm long (?incomplete), without evidence of tapering. Process bases are 25–30 μm apart. The outer wall layer reported in the type material, and present in the Tindir specimen described here as *Trachyhystrichosphaera magna*, is not present in the Tindir specimen referred to *T. vidalii*.

Occurrence. CA 698; upper Tindir Group, Unit 5, upper Tindir Creek.

Trachyhystrichosphaera magna Allison n. sp. (Figs. 11.5–11.8)

Diagnosis. An ovoid vesicle, 865 × 720 μm in maximum and minimum diameters, with a wall up to 18 μm thick and apparently triple-layered. The processes are cylindrical, up to 58 μm long and 5–7 μm in diameter, and they are typically slightly constricted near the base, tapered at tip, 30–38 μm apart, emerging from the outer wall layer about halfway towards the tip. The wall is depressed at the ?anterior end, forming a roughly cylindrical cavity 380 μm deep and about 95 μm in diameter. The cavity wall is without a cell outer layer, and has nonemergent processes of ~6 μm diameter and up to 50 μm long, which are well-spaced around the sides. The packed mass of tubular structures extends from the basal wall layer towards the center of the cell at the cavity base. A single bulbous-based emergent process 75 μm long extends into the cavity near the base on one side.

Type specimen. BC75 46-3 at 11.0 × 7.9.

Etymology. From the Latin *magnus* = large.

Discussion. This large vesicle resembles *T. vidalii* Knoll (1984) in overall morphology. In addition to its larger size, however, it differs in having a more complex wall (Figs. 11.6 and 11.7) composed of an inner 1–2 μm thick dark brown layer, a 9–12 μm thick transluscent yellow brown, locally alveolar, middle layer, and a 3.8–4.7 μm thick paler yellowish outer layer that thins markedly up the sides of the outer cell wall. The anterior indentation, oriented at the top of the vesicle in Fig. 11.5, differs from openings preserved in *T. vidalii* described and illustrated by Knoll (1984, p. 154, figs. 8A, B and F) in that it is lined only with the basal and middle wall layers and has at the base massed tubes opening directly to the cell interior, extending inward rather than outward from the basal wall layer. The single bulbous-based hollow structure extending into the cavity 285 μm down the left wall (Fig. 11.8) is distinctly larger than the processes elsewhere around the cavity or the outer cell wall.

If the cavity is interpreted simply as a depressed portion of an ovoid or spherical cell, the original diameter would have been in the neighborhood of 1100 μm. This interpretation, however, does not explain the mass of tubular structures at the base of the cavity in terms of possible relationship of this specimen to other known representatives of *Trachyhystrichosphaera.*

Occurrence. BC75 46; upper Tindir Group, Unit 5, upper Tindir Creek.

Unnamed Triangular Form (Fig. 11.11)

Description. A somewhat flattened vesicle, triangular in outline, 33–42 μm along the sides, with a flap-like extension on one side. The wall is hyaline, medium brown, and > 1 μm thick. The surface is finely psilate, wrinkled, and with a few short (1 μm), dark hair-like structures perpendicular to the surface. There are ?randomly placed polygonal to distinctly stellate openings in the wall, ~4–6 μm in maximum dimension.

Discussion. This unique fossil is notable for its angular outline and peculiarly shaped holes in the vesicle wall. These range from simple polygonal to slightly to strongly stellate in shape. They are clearly open through the slightly inflated triangular surface available for observation. One of the markedly stellate openings straddles the triangle margin near one apex. Elongate openings also present in the wall appear to be simple tears and contrast sharply with the polygonal holes.

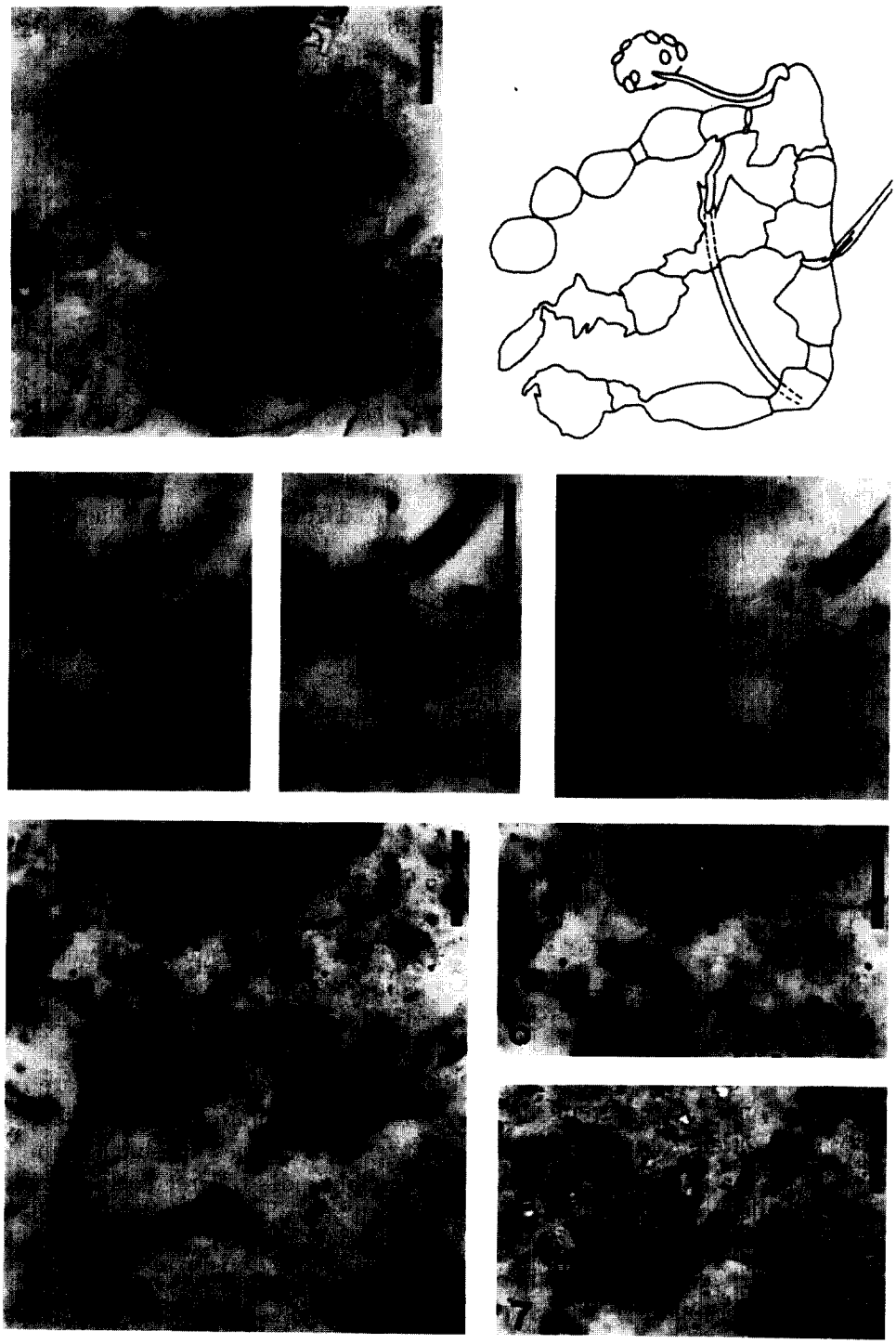


Fig. 12. Fungal microfossils from upper Tindir Group Unit 5, upper Tindir Creek. All scale bars = 20 μm; scale bar for 2–4 appears in 3. 1–4, *Archeomyces dimakeloides* Allison n. gen., n. sp. GSC 81907: 1, entire preserved specimen focused to show general outline (drawing to right is composite showing features seen at several focal depths). 2–4, Successive focal depths of area at center right side of specimen as shown in drawing illustrating base of tubular extension from cell. 5–7, *Eophycomyces herkoides* Allison n. gen., n. sp. GSC 81906; 5, folded portion of thallus focused to illustrate bulbous swelling; 6, enlargement of thumb-like protrusion of wall; 7, enlargement illustrating base of branch of thallus.

Late Proterozoic and younger acritarchs of more-or-less flattened triangular shape have been referred to *Veryhachium* of Deunff (1954, emended by Downie, 1959), a form characterized, however, by the presence of processes at the triangle apices and without the highly distinctive stellate openings of the Tindir specimen. Polygonal pylomes are present in a number of genera in the Acritarcha, in which pylome location may be an important taxonomic feature. However, the polygonal and stellate holes in the Tindir specimen are more likely to reflect mineral crystal growth or pressure marks (W.A.S. Sarjeant, personal communication, 1986). Although typically formed as paired triangular 'vesicles', the modern desmid chlorophycophyte *Staurastrum* includes species clearly similar to this Tindir morph.

Occurrence. BC75 44; upper Tindir Group, Unit 5, upper Tindir Creek.

Kingdom Fungi
Division Chytridiomycota
Eophycomyces Allison, n. gen.

Type species. Eophycomyces herkoides Allison n. sp.

Diagnosis. Tubular filaments, branched, septate, cylindrical with varying diameter, and gently to strongly curved. The surface texture is finely granular. The filament has thin walls, more or less circular in cross-section, rarely compressed or collapsed, and typically ~11 μm in diameter. Septae are infrequent, ~1 μm thick. Branches are one-half to seven-eighths of the diameter of the parent filament, and arise at angles up to 90° from the parent filament.

Etymology. From the Greek *eos* = dawn, *phykos* = seaweed, and *mykes* = fungus.

Discussion. The marked irregularly bulbous and septate nature and thumblike protrusions in this pale fossil (Fig. 12.6) do not invite referral of it to the algae, cyanobacteria or other bacteria. It can, however, be compared to oomycetous chytridiomycotes, perhaps most closely to *Allomyces* according to I.K. Ross (personal communication, 1986), who examined the specimen.

Eophycomyces herkoides Allison n. sp. (Figs. 12.5–12.7 and 13.5)

Diagnosis. Qualitatively, as for genus. The distance between septae may be as little as 40 μm, but one segment 130 μm long has none. Septae may be as close as 3.8 μm or as far as 45 μm from the point of branching. The filaments range in diameter from 7.6 to 19 μm.

Type specimen. CA 644-2 at 4.1 × 19.9.

Etymology. From the Greek *herkos* = wall.

Discussion. Branched non-septate tubular filaments as much as 10 μm in diameter, referred to the paleogenus *Archaeorestis*, are reported from the Gunflint chert (Barghoorn and Tyler, 1965; Awramik and Barghoorn, 1977). The presence of distinctive bulbous swelling in *E. herkos*, and lack of septae in *A. schreiberensis*, Barghoorn (in Barghoorn and Tyler, 1965), however, preclude assignment of *Eophycomyces* to this otherwise generally similar taxon.

Occurrence. CA 644; upper Tindir Group, Unit 5, upper Tindir Creek.

Archeomyces Allison n. gen.

Type species. Archeomyces dimakeloides Allison, n. sp.

Diagnosis. A multicellular thallus, irregularly branched, and made up of numerous irregularly shaped, very pale cells from 7 to 14 μm in maximum dimension. Walls and septae are apparently single-layered, <0.5 μm thick, very fine granular in appearance, and are randomly infolded but apparently not collapsed. The cells are highly varied in shape from oblong with straight sides to irregularly inflated to spherical. The septae are single or double, and may be sinuous rather than straight. The septae are commonly located at neck-like smallest-diameter portions near adjacent cells. Branches are at angles from 45° to 90°, with or without a septum near the base. Curving, non-septate tubular structures of 3 μm diameter and up to 70 μm long, with densely granular sheath, arise from the cells in several places.

Etymology. From the Greek *arche* = beginning and *mykos* = fungus.

Discussion. The several specimens of highly distinctive material on which this genus is based have pale walls and all lie well down in the thin sections. The most complete specimen, unfortunately, is partly obscured by overlying organic detritus. The markedly irregular cell shape, branching, double septae and, especially the tubular outgrowth preclude referral to the cyanobacteria or algae. A more likely relationship is with the oomycetous chytridiomycetes, and among known modern forms this organism is perhaps most comparable to *Laganidium* or *Allomyces* (I. Ross, personal communication, 1986).

Archeomyces dimakeloides Allison n. sp. (Figs. 12.1–12.4)

Diagnosis. Qualitatively, as for genus.

Type specimen. BC75 44-5 at 5.4×8.1.

Etymology. From the Greek *dis* = double and *makelon* = enclosure, referring to double septa.

Discussion. A single very distinctive specimen is referred to this taxon, although rare occurrences of a few irregularly shaped similar structures seen elsewhere that do not exhibit the branching or associated tubes of the type specimen probably represent the same species. The drawing shown beside Fig. 12.1 combines information seen at successive focal depths in this distinctly non-planar fossil. In much of the preserved thallus the cells do not approach a spherical shape, but one branch, shown in upper center at left, is composed of an oblong straight-sided cell followed (to the left) by two inflated cells with a neck-like connection with a double septum, followed in turn by two more-or-less spherical, separated cells, the whole forming a single series chain ending in rounded cells independent of the parent thallus. Three of the tubes can be clearly traced to larger cells in the thallus. In two cases a smaller diameter basal portion connects the tube to the multicellular fossil as shown at successive focal depths in Figs. 12.2–12.4. At the distal end of the tube shown at the top in Fig. 12.1 there is an extremely faint spherical structure that contains several oval bodies ~3 μm wide and 4–5 μm long. Although very difficult to observe and interpret, proximity and similarity in appearance of the walls of this structure to the multicellular structure suggest that they are related forms.

A few of the cells contain dark hyaline spots more-or-less centered in the cell. Whether these represent original internal structures, shrunken cell contents, or are secondary phenomena is uncertain.

Occurrence. BC75 44; upper Tindir Group, Unit 5, upper Tindir Creek.

Acknowledgments

The authors wish to acknowledge the important contributions to this study made by others. Bruce I. Clardy collected the original samples in 1975 and made them available to Allison. The Louisiana Land and Exploration Company subsequently donated the samples to the University of Alaska Museum. Field assistance by Dirk Bodnar (1978, 1979, 1981), R.A. Gangloff (1978), N. Crozer (1979), G.M. Young (1979, 1980) and M.A.S. McMenamin (1980) added significantly to the success of this project. B.D. Sellars and M.A.S. McMenamin aided in the analysis of the biotas as graduate student assistants at the University of Alaska and the University of California, Santa Barbara, respectively. Yin Chongyu (Geological Institute, Beijing) assisted in coccoidal microfossil analyses. A.H. Knoll provided many helpful comments in review of an earlier version of this paper. The photographic assistance of D.P. Pierce (UCSB) is greatly appreciated. Permission to collect samples in Canada was provided by D.J. McLaren, then Director of the Geological Survey of Canada. Allison was on the faculty at the University of Alaska during the conduct of this research. Funding to support this research in whole and in part, was provided by National Science Foundation grants EAR79-03926 and

EAR80-15667 to CWA (with subcontract F-42986 to SMA).

References

Allison, C.W., 1981. Siliceous microfossils from the Lower Cambrian of northwest Canada: possible source for biogenic chert. Science, 211: 53-55.

Allison, C.W., 1988 Paleontology of Late Proterozoic and Early Cambrian rocks of east-central Alaska, U.S. Geol. Surv. Prof. Paper 1449, 50 pp.

Allison, C.W. and Hilgert, J.W., 1986. Scale microfossils from the Early Cambrian of northwest Canada. J. Paleontol., 60: 973-1015.

Asseva, E.A., 1976. Mikrofitofossilii i vodorosli iz otlozheniy verkhnego dokemriya Volyno Podolii. In: Paleontologiya i stratigraphyiya verkhnego dokembriya i nizhnego paleozoya-zpada Vostokno-Evropeyskoy platformy. Naukova Dumka, Kiev, pp. 40-63.

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

Awramik, S.M., 1984a. Ancient stromatolites and microbial mats. In: Y. Cohen, R.W. Castenholz and H.O. Halvorson (Editors), Microbial Mats: Stromatolites. Alan R. Liss, New York, pp. 1-22.

Awramik, S.M., 1984b. Cell (biology). In: S.B. Parker (Editor), McGraw-Hill Yearbook of Science and Technology 1985, McGraw-Hill, New York, pp. 103-105.

Awramik, S.M. and Allison, C.W., 1980. Earliest Cambrian blue-green algal communities from the Yukon Territory of Canada. Abstr. 26th Int. Geol. Congr., Paris, Vol. 1, p. 198.

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

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. Progr., 4: 438.

Awramik, S.M., McMenamin, D.S., Yin Chongyu, Zhao Zigiang Ding Qixiu and Zhang Shusen, 1985. Prokaryotic and eukaryotic microfossils from a Proterozoic/Phanerozoic transition in China. Nature, 315: 655-658.

Barghoorn, E.S. and Tyler, S.A., 1965. Microorganisms from the Gunflint chert. Science, 147: 563-577.

Baschnagel, R.A., 1942. Some microfossils from the Onondaga chert of central New York. Buffalo Soc. Nat. Sci., Bull., 17: 1-8.

Baschnagel, R.A., 1966. New fossil algae from the Middle Devonian of New York State. Trans. Am. Microsc. Soc., 85: 297-302.

Binda, P.L. and Bokhari, M.M., 1980. Chitinozoan-like microfossils in a late Precambrian dolostone from Saudi Arabia. Geology, 8: 70-71.

Bloeser, B., 1985. *Melanocyrillium*, a new genus of structurally complex Late Proterozoic microfossils from the Kwagunt Formation (Chuar Group), Grand Canyon, Arizona. J. Paleontol., 59: 741-765.

Brabb, E.E., 1967. Stratigraphy of the Cambrian and Ordovician rocks of east-central Alaska. U.S. Geol. Surv. Prof. Pap. 559-A, 30 pp.

Brabb, E.E. and Churkin, M., Jr., 1969. Geologic map of the Charley River Quadrangle, east-central Alaska. U.S. Geol. Surv. Misc. Invest. Map I-573.

Cloud, P., Awramik, S.M., Morrison, K. and Hadley, D.G., 1979. Earliest Phanerozoic or latest Proterozoic fossils from the Arabian Shield. Precambrian Res., 10: 73-93.

Cohen, Y., 1984. The Solar Lake cyanobacterial mats: strategies of photosynthetic life under sulfide. In: Y. Cohen, R.W. Castenholz and H.O. Halvorson (Editors), Microbial Mats: Stromatolites. Alan R. Liss, New York, pp. 133-148.

Conway Morris, S., 1987. The search for the Precambrian-Cambrian boundary. Am. Sci., 75: 156-167.

Deunff, J., 1954 *Veryhachium* genera nouveau d'Hystrichospheres du Primaire. Bull. Soc. Geol. France, C.R. Som. 13: 305-306.

Downie, C., 1959 Hystrichospheres From the Silurian Wenlock Shale of England. Palaeontology, 2: 56-71.

Edwards, D.S. and Lyon, A.G., 1983. Algae from the Rhynie Chert. Bot. J. Linn. Soc., 86: 37-55.

Eisenack, A., 1958 *Tasmanites* Newton 1875 und *Leiosphaerida* n.g. als Gattungen der Hystrichosphacrida. Palaeont. Abt. A, 110: 1-19.

Fairchild, T.R., Schopf, J.W. and Folk, R.L., 1973. Filamentous algal microfossils from the Caballos Novaculite, Devonian of Texas. J. Paleontol., 47: 946-952.

Fairchild, T.R., Barbour, A.P. and Haralyi, N.L.E., 1978. Microfossils in the "Eopaleozoic" Jacadigo Group at Urucum, Mato Grosso, southwest Brazil. Bol. Univ. São Paulo, Inst. Geosci., 9: 74-79.

Fjerdingstad, E., 1979. Sulfur bacteria. Am. Soc. Testing Mat., Spec. Tech. Publ. 650, 119 pp.

Geitler, L., 1932 (Reprinted 1971) Cyanophyceae. In: L. Rabenhorst (Editor), Kryptogamenflora von Deutschland, Österreich und der Schweiz. Vol. 14, Akademische Verlagsgeschellschaft, Leipzig, 1196 pp. Reprinted: Johnson Reprint Co; New York.

Gibson, J., Leadbetter, E.R. and Jannasch, H.W., 1984. Great Sippewisset Marsh: a summary of projects carried out by students in the microbial ecology course of the Marine Biology Laboratory, Woods Hole, during summers 1972-1981. In: Y. Cohen, R.W. Castenholz and H.O. Halvorson (Editors), Microbial Mats: Stromatolites. Alan R. Liss, New York, pp. 95-100.

Glaessner, M.F., 1984. The Dawn of Animal Life. Cambridge University Press, Cambridge, 244 pp.

Golovenok, V.K. and Belova, M.Y., 1983. *Obruchevella* from the Riphean of the Patom Highland and the Vendian of southern Kazakhstan. Dokl. Akad. Nauk SSSR, 272: 1462-1468 [in Russian; published in English in 1985. Dokl. Earth Sci. Sect., 272: 224-228].

Golubic, S. and Barghoorn, E.S., 1977. Interpretation of microbial fossils with special reference to the Precambrian. In: E. Flugel (Editor), Fossil Algae. Springer, Berlin, pp. 1-14.

Guilbault, J.P., 1975. Algues Ordoviciennes des Basses-Terres du Saint-Laurent et des regions limitrophes. Thesis, Dept. Geol., Univ. Montreal, 163 pp.

Hofmann, H.J., 1976. Precambrian microflora, Belcher Islands, Canada: significance and systematics. J. Paleontol., 50: 1040-1070.

Horodyski, R.J., Bloeser, B. and Van der Haar, S.P. 1977. Laminated algal mats from a coastal lagoon, Laguna Mormona, Baja California, Mexico. J. Sed. Petrol., 47: 680-699.

Jankauskas, T.V., 1982. Mikrofossilil rifeya Yuzhnogo, Urala. In: B.M. Keller (Editor), Stratotiy rifeya: paleontologiya, paleomagnetism. Akad. Nauk SSSR, Geol. Inst., Tr., 368: 84-120 (in Russian).

Kline, G.L., 1977. Earliest Cambrian (Tommotian) age of the upper Tindir Group, east-central Alaska. Geol. Soc. Am., Abstr. Progr., 9: 448.

Knoll, A.H. 1981. Paleoecology of Late Precambrian microbial assemblages. In: K.J. Niklas (Editor), Paleobotany, Paleoecology, and Evolution. Praeger, New York, pp. 17-54.

Knoll, A.H., 1982. Microfossils from the Late Precambrian Draken Conglomerate, Ny Friesland, Spitsbergen. J. Paleontol., 56: 755-790.

Knoll, A.H., 1984. Microbiotas of the Late Precambrian Hunnberg Formation, Nordaustlandet, Svalbard, J. Paleontol., 58: 131-162.

Knoll, A.H. and Barghoorn, E.S., 1975. Precambrian eukaryotic organisms: a reassessment of the evidence. Science, 190: 52-54.

Knoll, A.H. and Calder, S., 1983. Microbiotas of the late Precambrian Ryssö Formation, Nordaustlandet, Svalbard. Palaeontology, 26: 467-496.

Knoll, A.H. and Golubic, S., 1979. Anatomy and taphonomy of a Precambrian algal stromatolite. Precambrian Res., 10: 115-151.

Knoll, A.H. and Vidal, G., 1980. Later Proterozoic vase-shaped microfossils from the Visingo Beds, Sweden. Geol. Foren. Stockholm Fordhandl., 102: 207-211.

Knoll, A.H., Blick, N. and Awramik, S.M. 1981. Stratigraphic and ecologic implications of Late Precambrian microfossils From Utah. Am. J. Sci., 281: 247-263.

Lindgren, S., 1982. Algal coenobia and leiospheres from the Upper Riphean of the Turukhansk region, eastern Siberia. Stockholm Contrib. Geol., 38: 35-45.

Lo, S.C., 1980. Microbial fossils from the lower Yudoma Suite, earliest Phanerozoic, eastern Siberia. Precambrian Res., 13: 109-166.

McMenamin, M.A.S. and Awramik, S.M., 1982. Acid resistant microfossils (acritarchs) from the upper Tindir Group, Yukon Territory, Canada. Geol. Soc. Am., Abstr. Progr., 14(4): 214.

McMenamin, D.S., Kumar, G. and Awramik, S.M., 1983. Microbial fossils from the Kheinjua Formation, Middle Proterozoic Semri Group (Lower Vindhyan), Son Valley area, central India. Precambrian Res., 21: 127-271.

Mendelson, C.V. and Schopf, J.W., 1982. Proterozoic microfossils from the Sukhaya Tunguska, Shorikha, and Yudoma Formations of the Siberian Platform, U.S.S.R. J. Paleontol., 56: 42-83.

Mount, J.F. and Signor, P.W., 1985. Early Cambrian evolutionary innovation in low-stress environments: paleoenvironments of Early Cambrian fossils. Geology, 13: 730-733.

Nyberg, A.V. and Schopf, J.W., 1984. Microfossils in stromatolitic cherts from the Upper Proterozoic Min'yar Formation, southern Ural Mountains, U.S.S.R. J. Paleontol., 58: 738-772.

Oehler, D.Z., 1977. Pyrenoid-like structures in late Precambrian algae from the Bitter Springs Formation of Australia. J. Paleontol., 51: 885-901.

Oehler, D.Z., 1978. Microflora of the Middle Proterozoic Balbarini Dolomite (McArthur Group) of Australia. Alcheringa, 2: 269-309.

Palmer, A.R., 1968. Cambrian trilobites of east-central Alaska. U.S. Geol. Surv. Prof. Paper 559-B, 115 pp.

Peel, J.S. 1988. *Spirellus* and related helically coiled microfossils (cyanobacteria) From the Lower Cambrian of North Greenland. Rapp. Grønl. Geol. Unders., 137: 5-32.

Reitlinger, E.A. 1959 Atlas of microscopic organic remains and problematica from ancient rocks of Siberia. Tr. Inst. Geol. Akad. Nauk SSSR, 25, 62 pp (in Russian).

Riding, R. and Voronova, L., 1984. Assemblages of calcareous algae near the Precambrian/Cambrian boundary in Siberia and Mongolia. Geol. Mag., 121: 205-210.

Rippka, R., Dervelles, J., Waterbury, J.B., Herdman, M. and Stanier, R.Y., 1979. Generic assignments, strain histories and properties of pure cultures of Cyanobacteria. J. Gen. Microbiol., 111: 1-61.

Runnegar, B., 1982. Oxygen requirements, biology and phylogenetic significance of the late Precambrian worm *Dickinsonia*, and the evolution of the burrowing habit. Alcheringa, 6: 223-239.

Schopf, J.W., 1968. Microflora of the Bitter Springs Formation, Late Precambrian, central Australia. J. Paleontol., 42: 651-688.

Schopf, J.W., 1977. Biostratigraphic usefulness of stromatolitic Precambrian microbiotas: a preliminary analysis. Precambrian Res., 5: 143-173.

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.

Seilacher, A., 1984. Late Precambrian and Early Cambrian Metazoa: preservational or real extinctions? In: H.D. Holland and A.F. Trendall (Editors), Patterns of Change in Earth Evolution. Springer, Berlin, pp. 159-168.

Sepkoski, J.J. and Knoll, A.H., 1983. Precambrian-Cambrian boundary: the spike is driven and the monolith crumbles. Paleobiology, 9: 199–206.

Shepeleva, E.D., 1973. Acritarch-based zonation of Vendian deposits of the Russian Platform. In: Microfossils of the Oldest Deposits. Proc. 3rd Int. Palynological Conf. Nauka, Moscow, pp. 13–15 (in Russian).

Song Xueliang, 1984. *Obruchevella* from the early Cambrian Meishucun Stage of the Meishucun section, Jinning, Yunnan, China. Geol. Mag., 121: 179–183.

Stolz, J.F., 1983. Fine structure of the stratified microbial community at Laguna Figueroa, Baja California, Mexico. I. Methods of in situ study of the laminated sediments. Precambrian Res., 20: 479–492.

Strother, P.K., Knoll, A.H. and Barghoorn, E.S., 1983. Microorganisms from the Late Precambrian Narssarssuk Formation, north-western Greenland. Palaeontology, 26: 1–32.

Tang Tienfu, Zhang Junmin and Jiang Xianjian, 1978. Discovery and significance of the Late Sinian fauna from Hunan and west Hubei. Acta Strat. Sinica, 2(9): 32–44 (in Chinese).

Timofeev, B.V., 1962. Teodolitnyi paleontologischskii, stolik (novyi metod isseledovaniya iskopaemogo mikroplanktona). Tr. Vses. Neft. Nauch-Issled Geologoraz. Inst., No. 196 Paleontol. 563: 601–607.

Timofeev, B.V., 1973. Mikrofitofossilii dokembriya Ukrainy. Akademiya Nauk SSSR, Inst. Geol. Geokhronol. Dokemb. Nauka, Leningrad, 58 pp.

Timofeev, B.V., Hermann, T.N. and Mikhailova, M.S., 1976. Mikrofitofossilii dokembriya, kembriya i ordovika. Akad. Nauk SSSR, Inst. Geol. Geokhronol. Dokemb. Nauka, Leningrad, 106 pp.

Tynni, R. and Donner, J., 1980. A microfossil and sedimentation study of the Late Precambrian formation of Hailuoto, Finland. Geol. Surv. Finland Bull., 311: 27 pp.

Vidal, G., 1979. Acritarchs from the Upper Proterozoic and Lower Cambrian of East Greenland. Grønl. Geol. Unders. Bull., 134: 55 pp.

Vidal, G., 1981. Micropalaeontology and biostratigraphy of the Upper Proterozoic and Lower Cambrian sequence in East Finmark, northern Norway. Norges Geol. Unders. Bull., 59: 53 pp.

Vidal, G., 1984. The oldest eukaryotic cells. Sci. Am., 250: 48–57.

Vidal, G. and Knoll, A.H., 1982. Radiations and extinctions of plankton in the late Proterozoic and early Cambrian. Nature, 296: 57–60.

Vidal, G. and Siedleska, A., 1983. Planktonic, acid-resistant microfossils from the upper Proterozoic strata of the Barents Sea region of Varanger Peninsula, east Finnmark, northern Norway. Norges Geol. Unders. Bull., 382: 45–79.

Walter, M.R. and Heys, G.R., 1985. Links between the rise of the Metazoa and the decline of stromatolites. Precambrian Res., 29: 149–174.

Wang Fuxing, Zhang Xuanyang and Guo Ruihuan, 1983. The Sinian microfossils from Jinning, Yunnan, southeast China. Precambrian Res., 23: 133–175.

Waterbury, J.B., 1976. Purification and Properties of some Freshwater and Marine Cyanobacteria Belonging to the Orders Chamaesiphonales and Pleurocapsales. Ph.D. Thesis, University of California, Berkeley, 279 pp. (University Microfilms, Ann Arbor, MI, No. 77-4643).

Wicander, E.R. and Schopf, J.W., 1974. Microorganisms from the Kalkberg Limestone (Lower Devonian) of New York State. J. Paleontol., 48: 74–77.

Wujek, D.E., 1979. Intracellular bacteria in the blue-green alga *Pleurocapsa minor*. Trans. Am. Microsc. Soc., 98: 143–145.

Yakshin, M.S. and Luchinina, V.A., 1981. New materials of fossil alga Family Oscillatoriaceae (Kirchn.) Elenkin. Tr. Inst. Geol. Geofiz. Akad. Nauk SSSR Sibir. Ordel., 475: 28–34 (in Russian).

Young, G.M., 1982. The Late Proterozoic Tindir Group, east-central Alaska: Evolution of a continental margin. Geol. Soc. Am. Bull., 93: 759–783.

Zang, W.L. and Walter, M.R., 1989 Latest Proterozoic plankton from the Amadeus Basin in central Australia. Nature, 337: 642–645.

Zhang Yun, 1981. Proterozoic stromatolite microfloras of the Gaoyuzhuang Formation (Early Sinian: Riphean), Hebei, China. J. Paleontol., 55: 485–506.

Zhang Zhongying, 1982. Filamentous microfossils from the Doushantuo Formation (Late Sinian) of South China. J. Paleontol., 56: 1251–1256.