Planktonic, Acid-resistant Microfossils from the Upper Proterozoic Strata of the Barents Sea Region of Varanger Peninsula, East Finnmark, Northern Norway

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Planktonic, acid-resistant microfossils (acritarchs) occur in the Kongsfjord, Båsnæring and Båtsfjord Formations of the Barents Sea Group and in the Styret Formation of the Løkvikfjell Group. Two new taxa are described and additional data are presented on the previously known species. The state of preservation of the acritarchs is highly variable and may be related to a combination of depositional environment, diagenetic and thermal alteration phenomena and degree of structural deformation. The acritarch assemblages recovered from the Båsnæring and Båtsfjord formations are in agreement with the previously inferred Late Riphean to Early Vendian (?= Kudashian) age for the bulk of the Barents Sea Group. The Riphean-Vendian boundary most probably occurs within the lower Båtsfjord Formation. The Barents Sea Group is time-equivalent to the Vadsø and Tanafjord Groups of the Tanafjord-Varangerfjord Region of East Finnmark. There is also a fairly good time correlation between the bulk of the Barents Sea Group, the pre-Moelv Tillite part of the Hedmark Group and the Visingsö Beds in southern Scandinavia. Late Precambrian sequences of arctic U.S.S.R., Svalbard and East Greenland appear to be time-equivalent with the Kongsfjord–Båsnæring-basal Båtsfjord part of the Barents Sea Group.

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Introduction

The intrinsic palaeobiological interest in Precambrian microfossils has been amply documented through numerous finds throughout the world (e.g. Schopf 1968, Timofeev 1966, 1969, 1974, Hofman 1976, Awramik & Barghoorn 1977, Knoll & Golubic 1979, Vidal 1976, 1979, 1981). Evidence supporting the biostratigraphic significance of planktonic microfossils in the correlation of Upper Proterozoic sequences seems to have been convincingly assessed (Timofeev 1979, Timofeev et al. 1976, Schopf 1977, Vidal 1981, Vidal & Knoll, in press).

The purpose of this paper is to complement previously presented data on the micropalaeontology and biostratigraphy of Upper Proterozoic rock units of Varanger Peninsula, northern Norway. Additional investigations on a variety of presumably contemporaneous, younger and older rock units in easternmost Finnmark are in progress.

Geological setting

Upper Proterozoic strata occur in northern Norway both within the Caledonian Nappes and as autochthonous cover of older Proterozoic basement. On the
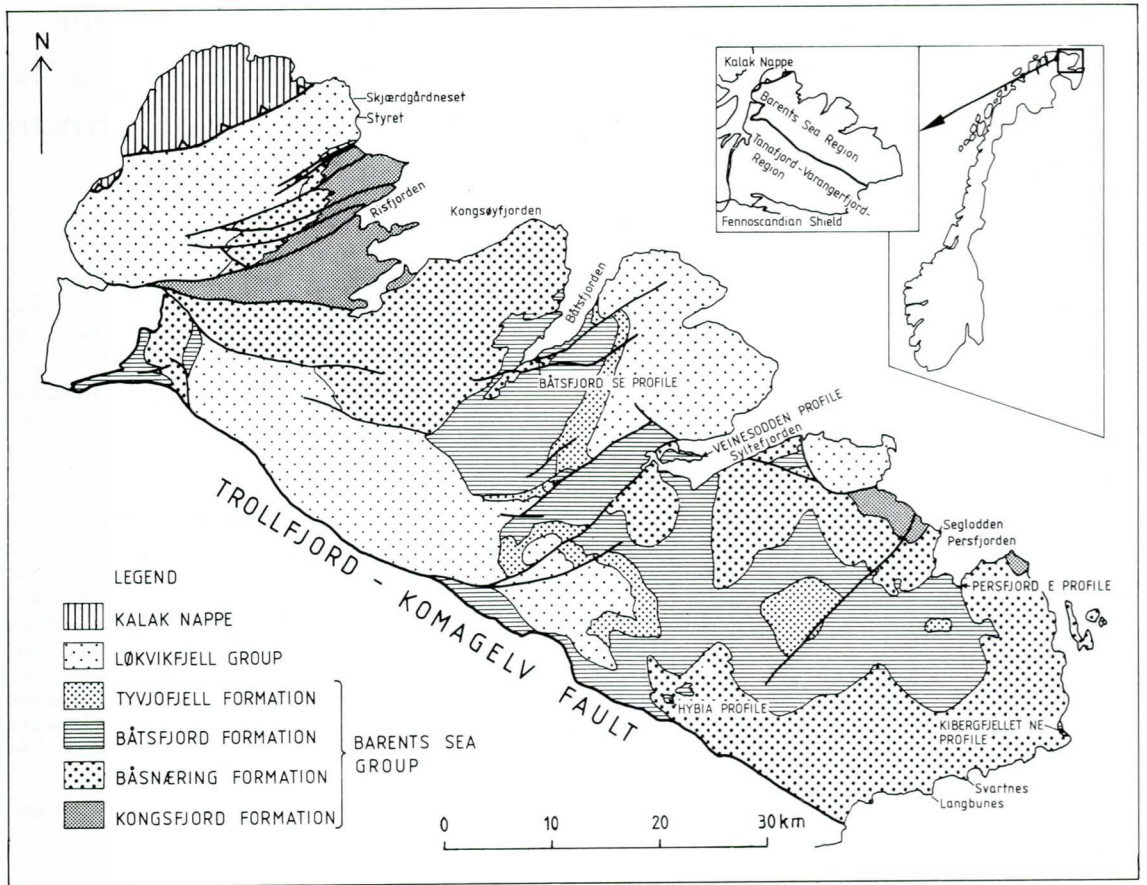
Fig. 1. Geological map of the Barents Sea Region (Varanger Peninsula) showing distribution of the main rock units, sample localities and profiles.

Varanger Peninsula, there are two different Late Precambrian sedimentary successions separated from each other by the Trollfjord–Komagelv Fault (Siedlecka & Siedlecki 1967) (Fig. 1). Stratigraphy and correlation of the Upper Proterozoic strata across Finnmark were originally established on the basis of lithostratigraphic comparisons, where Varangian tillites have traditionally played a crucial role as a time-stratigraphic marker horizon (Føyn 1937, 1964, Siedlecka & Siedlecki 1967). This age assignment was subsequently confirmed by radiometric techniques (Pringle 1973, Beckinsale et al. 1975, Råheim, *in* Siedlecka & Edwards 1980, Taylor & Pickering 1981). Findings of trace and body fossils later permitted the establishment of a more detailed stratigraphy of the Upper Proterozoic succession, and a precise localisation of the boundary between the latter and the Lower Paleozoic strata (Føyn 1967, Banks 1970, 1973, Føyn & Glaessner 1979, Bertrand-Sarfati & Siedlecka 1980).

Micropalaeontological work on the Upper Proterozoic deposits of Finnmark is of more recent date than the other stratigraphic methods. It was only recently that Vidal (1980a) confirmed the Upper Riphean and Vendian age of the bulk of the strata underlying the Tanafjord–Varangerfjord region of Varanger Peninsula and outlined a correlation with rock units in other areas of Scandinavia, the Russian Platform and East Central Greenland. Late Precambrian strata in the north-eastern half of Varanger Peninsula, the Barents Sea and Løkvikfjell Groups (Fig. 1), constitute a somewhat unique element in the bedrock geology of Finnmark. The age of the Løkvikfjell Group and its possible correlation with other rock units of Finnmark are uncertain. The Barents Sea Group, which is the primary subject of this paper, has no lithostratigraphic equivalents in the remainder of Finnmark and cannot be traced westwards outside the Barents Sea Region of Varanger Peninsula (Fig. 1) (Siedlecka & Siedlecki 1967, Beckinsale et al. 1975, Kjøde et al. 1978). The Late Precambrian age of the Barents Sea Group was assumed on the basis of lithostratigraphic correlation with the Eleonore Bay Group of East Central Greenland and with successions on Kanin Peninsula, in the Timan Mountains and in the Urals (Siedlecka & Siedlecki 1967, Siedlecka 1975, Siedlecki 1975). It was the radiometric age determinations which, though uncertain, placed the Barents Sea Group within Upper Proterozoic (Beckinsale et al. 1975, Råheim, *in* Siedlecka & Edwards 1980).

The results of the micropalaeontological work presented in this paper confirm the previous assumptions on age and permit the establishment of a more precise time-stratigraphy for the Barents Sea Group, and also help in outlining its relationship to other Upper Proterozoic sedimentary successions. Microfossils so far recovered from the Løkvikfjell Group have little stratigraphic significance.

The Barents Sea Group is a ca. 9000m-thick pile of conformable strata representing a huge regressive sequence. The base of the succession is unknown; its oldest exposed formation is representative of submarine fan accumulation grading upwards into deltaic and shallow water coastal and fluvial sediments. Tectonic deformation of the group is variable, but generally decreases eastwards and metamorphic alteration reaches only the lowermost greenschist facies (Roberts 1972). The group has been subdivided into four formations: Kongsfjord (lowermost), Båsnæring, Båtsfjord and Tyvjofjell (Siedlecka & Siedlecki 1967, 1972). Only the last-named formation has not been sampled for microfossils; as it is mostly arenaceous and red-coloured, is seems unlikely that any microfossils could be preserved in this unit. The remaining formations contain dark-grey fine-grained clayey-silty beds and the majority of samples from these beds have provided microfossils. The best preserved, abundant and varied assemblage was found in the Båtsfjord Formation.

The Barents Sea Group is overlain transgressively and with angular unconformity by the Løkvikfjell Group. This group is entirely terrigenous and is interpreted as shallow-marine and fluvial in origin (Siedlecki & Levell 1978, Levell 1980). The late Precambrian age of the Løkvikfjell Group is indicated by the 640 Ma. B.P. K/Ar dates (Beckinsale et al. 1975) obtained on dolerite dykes cross-cutting both its strata and the basal unconformity (Siedlecki & Levell 1978).

Laboratory methods

Rock samples collected from outcrops were treated in the laboratory and the organic residues concentrated and studied by use of the method fully described in Vidal (1976).

The vesicles of acritarchs consist of complex organic compounds that are susceptible to mechanical and thermal alteration (cf. Vidal 1981b). Sampling efforts therefore were concentrated in regions and/or parts of the Barents Sea Group which include rocks that have undergone as little tectonic and thermal alteration as possible. Microfossils were examined in permanent mounts under a Leitz Dialux 20 microscope and micrographs of selected specimens taken with a Leitz Vario-Orthomat automatic camera system. Panchromatic roll-film (Kodak Pan X) with a speed of 32 ASA was used. Figured specimens are provided with a slide number followed by a code which refers to England Finder coordinates (cf. Vidal 1976, 1979, 1981a). Examination of specimens under the Scanning Electron Microscope (SEM) was carried out on most samples. However, with just a few exceptions, materials from the Barents Sea Group are partly corroded. This condition clearly restricted the suitability of the present material for SEM studies.

Figured specimens and remains of rock samples are stored at the Department of Historical Geology and Palaeontology, Micropalaeontological Laboratory, University of Lund.

Sampling and results

BARENTS SEA GROUP

Kongsfjord Formation

The Kongsfjord Formation is a flysch-like turbidite sequence consisting of about 3500 m of interbedded, grey, immature sandstones, cleaved mudstones and shales or slates accumulated on a submarine fan (Siedlecka 1972, Pickering 1981).

An unpublished preliminary Rb/Sr whole rock dating on mudstone of the Kongsfjord Formation resulted in an age of 828 ± 60 Ma B.P. (A. Råheim, pers. Comm. 1977, *in* Siedlecka & Edwards 1980; recalculated according to $^{87}Rb\lambda$ = $1.42.10^{-11}a^{-1}$ the age is 810 ± 60 Ma B.P.; see also Siedlecki 1980). A recent Rb/Sr dating of cleaved mudstones of the Kongsfjord Formation yielded an isochron indicating an age of 520 ± 47 Ma B.P. for the formation of slaty cleavage (Taylor & Pickering 1982).

Ten samples of cleaved mudstone and black slate of the Kongsfjord Formation were collected in 1978 along the coast of Risfjorden (Fig. 1). Attempts to obtain microfossils from these samples invariably turned out negative and only carbonaceous matter was recovered. A further samples of laminated, light- to dark-grey mudstone were collected in 1981 from carefully selected spots within a continuously exposed section at Kongsøyfjorden (Fig. 1). This section belongs to the upper, ca. 1000 m thick part of the formation and represents the distal part of the Kongsfjord submarine fan (Pickering 1981). This time, specimens were collected of rocks which were as little cleaved as possible (samples F-81-25 to 30). All these samples yielded abundant dark-coloured organic detritus, variable numbers of

scattered single robust spherical vesicles ca. 4.5–26 μm across and aggregates of minute (1μm) spherical cells identified as *Bavlinella faveolata*. The best results derive from sample F-81-25, which yielded abundant specimens of well preserved, dark-brown to greyish-coloured, previously unknown microfossils (see the section on Taxonomy).

Båsnæring Formation

The Båsnæring Formation (Siedlecka & Siedlecki 1967) is a 2500–3500 m-thick succession of sandstone, siltstone and claystone accumulated on a lobate delta. It has been subdivided into 4 members: Næringselva (lowermost), Seglodden, Godkeila, and Hestmann (Siedlecka & Edwards 1980).

The lower Næringselva Member (1000–<1200 m) consists of greenish-grey, locally variegated and red-violet mudstones with slump and redeposition struc- tures, interpreted by Siedlecka & Edwards (1980) as prodelta slope deposits; these pass upwards into stratified sandstones interpreted as a delta front. The overlying Seglodden (350–<100 m), Godkeila (1450–500 m) and Hestmann (600 – c. 1300 m). Members consist of delta-top fluvial sandstones and marginal, inter- distributary, wave and tide-dominated sandstones and mudstones, arranged in coarsening-up sequences and commonly greenish-grey or red-violet in colour (Siedlecka & Edwards 1980).

Three samples of the Båsnæring Formation were processed. These were collected from the Næringselva Member at Svartnes (sample FA–11/77) and Langbunes (NMb/L) and from the upper part of the Godkeila Member (FA–2/77, ca. 60 m below the boundary with the Hestman Member) in the coastal section between Seglodden and Persfjorden (Fig. 1).

Sample FA 11/77 yielded a few specimens of *Kildinosphaera* sp. and *Trachysphaeridium* sp.. Sample NMb/L yielded abundant specimens of *Leios- phaeridia asperata* and *Kildinosphaera chagrinata,* and scattered specimens of cf. *Stictosphaeridium* sp. (often clustered), *Trachysphaeridium* sp., and *K. granulata*. The sample also yielded a few small dark-brown to opaque-black, specimens (often < 125μm) of *Chuaria circularis*. A single specimen of an unidentified double- walled acritarch (Fig. 4 H–I) was also recovered. The sample collected from the Godkeila Member turned out to be barren.
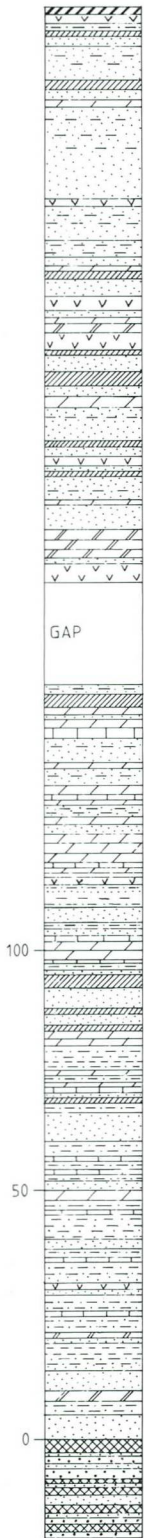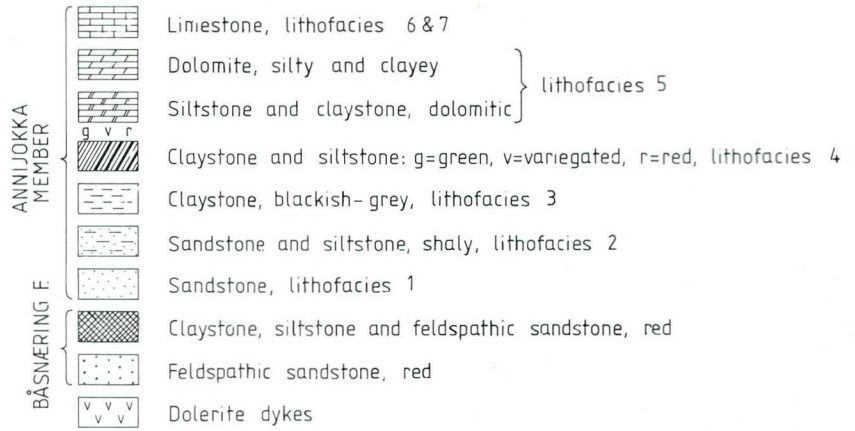
Båtsfjord Formation

The Båtsfjord Formation (Siedlecka & Siedlecki 1967) concordantly overlies the Båsnæring Formation. It is approximately 1500 m thick and consists of terrigenous and carbonate deposits. The lower Annijokka Member of the formation is up to 300 m thick and consists of grey, greenish-grey and dark-grey arenaceous to clayey siliciclastic rocks; it also contains dolomite and stromatolite-bearing limestone beds. The Annijokka Member has been interpreted as a peritidal sequence in which terrigenous carbonate sequences reflect shallowing-up conditions (Siedlecka 1978). Algal stromatolites occur in a supratidal pond facies, possibly largely accumulated in fresh water (Siedlecka 1978, 1982).

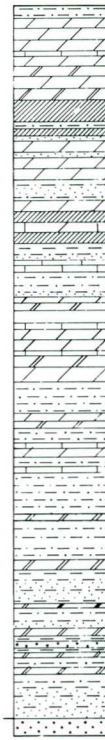The upper part of the formation consists of multicoloured terrigenous strata.
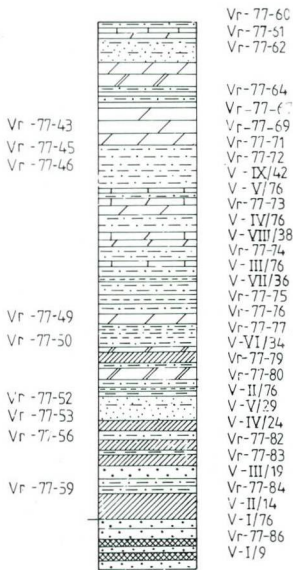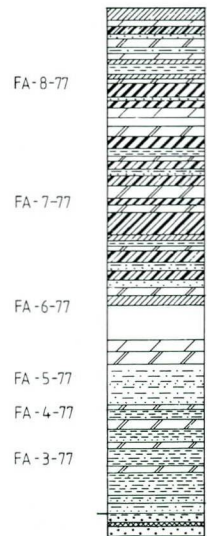
BÅTSFJORD SE

LEGEND

GAP

100

50

0

HYBIA

PERSFJORD E

VEINESODDEN

KIBERGSFJELLET NE

Vr -77-43
Vr -77-45
Vr -77-46

Vr -77-49
Vr -77-50

Vr -77-52
Vr -77-53
Vr -77-56

Vr -77-59

Vr-77-60
Vr-77-61
Vr-77-62

Vr-77-64
Vr-77-6?
Vr-77-69
Vr-77-71
Vr-77-72
V - IX/42
V - V/76
Vr-77-73
V - IV/76
V-VIII/38
Vr-77-74
V - III/76
V-VII/36
Vr-77-75
Vr-77-76
Vr-77-77
V-VI/34
Vr-77-79
Vr-77-80
V - II/76
V-V/29
V-IV/24
Vr-77-82
Vr-77-83
V-III/19
Vr-77-84
V-II/14
V-I/76
Vr-77-86
V-I/9

FA-8-77

FA-7-77

FA-6-77

FA-5-77

FA-4-77

FA-3-77

FA - 11-74

Dolerite dykes cutting through strata of the Båtsfjord Formation have yielded a K/Ar whole-rock isochron age of 651 ± 19 Ma (Beckinsale et al. 1975), recalculated to about 640 Ma B.P.

A total of 57 samples of the Båtsfjord Formation were processed and examined for acid-resistant, organic-walled microfossils (acritarchs). All samples were collected from rocks of the Annijokka Member lithofacies (2) and (3) of Siedlecka (1978), interpreted as having accumulated on (muddy) tidal flats and in euxinic standing bodies of water (inter-tidal to supratidal semi-closed bays or ponds), respectively. The samples were collected from the Persfjord E profile (Figs. 1 and 2; samples FA–3/77 to FA–8/77), the Veinesodden profile in Syltefjorden (Figs. 1 and 2; samples V–I/76 to V–V/76, V–I/9, V–II/14; V–III/19; V–IV/24; V–V/29; V–VI/34; V–VII/36; V–VIII/38; V–IX/42; Vr–77–60; 61; 62; 64; 67; 68; 69; 71; 72; 73; 74; 75; 76; 79; 80; 82; 83; 84; 86), the Båtsfjord SE profile (Figs. 1 and 2); samples Vr—77–43, 45, 46, 49, 50, 52, 53, 56, 59), and Kibergsfjellet NE (Figs. 1 and 2; samples Vr–77–27, 28, 29 from the profile, five additional samples: 77ME–3, collected by Dr. M.B. Edwards, Austin, Texas, from claystone of the basal part of the Båtsfjord Formation at Kibergfjellet); and samples Vr–77–34, 36, 38, 39 from a flat-lying sequence of alternating black and grey, laminated mudstones and yellowich weathered carbonates of the Annijokka Member in a small abandoned quarry approximately at the base of the Kibergfjellet NE profile.

Generally abundant acritarchs reflecting rather variable states of preservation (poor to fair) were recovered from 37 fossiliferous samples. The taxonomic composition of the assemblages is shown in Fig. 3 and the stratigraphic position of the samples in Figs. 2 and 3; only the fossiliferous samples are included.

LØKVIKFJELL GROUP

The Løkvikfjell Group has a total thickness of about 5600 m and consists of 5 formations: Sandfjord (lowermost), Styret, Skjærgårdnes, Stordalselva and Skidnefjell Formations.

Outcrops of rocks of the Løkvikfjell Group were visited briefly (by Vidal) during the summer of 1978. Eight samples (Vr–78–36 to 43) were collected from vertically dipping alternating siltstones and sandstones belonging to the upper part of the Styret Formation, exposed continuously on the west side of the road at Styret and Skjærgårdneset (Fig. 1). All samples yielded carbonaceous organic detritus; samples VR–78–36 and 37 also yielded small, scattered dark-grey to dark-brown specimens of acritarchs attributed to *Kildinosphaera* sp. (generally 20μm across, robust walled vesicles) and *Leiosphaeridia* sp. (generally small, 9–12 μm across,

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Fig. 2. Simplified measured sections of the Annijokka Member of the Båtsfjord Formation (after Siedlecka 1978). Lithofacies 1 – sandstone with herring-bone stratification; lithofacies 2 – sandstone, siltstone and claystone with flaser or lenticular bedding and with shaly partings; lithofacies 3 – claystone, parallel-laminated; lithofacies 4 – claystone and siltstone, parallel-laminated, rippled, with desiccation cracks and brecciation; lithofacies 5 – impute dolomite and dolomitic and sandy mudstone; lithofacies 6 – stromatolitic limestone; lithofacies 7 – intrasparite and intraformational conglomerate.

Fig. 3. Stratigraphic distribution of acritarch taxa in the Annijokka Member of the Båtsfjord Formation.

thin spherical vesicles) and small clusters of vesicles attributed to *Synsphaeridium* sp.. The acritarchs have little stratigraphic significance, and their only merit is the fact that they indicate that at least the two fossiliferous mudstone samples of the Styret Formation probably formed under marine conditions (the Styret Formation has been interpreted as the result of fluvial deposition; Siedlecki & Levell 1978). The present results indicate that further micropalaeontological work on units of the Løkvikfjell Group may be rewarding.

State of Preservation of microfossils

The state of preservation of acritarchs from the Båsnæring and Båtsfjord Formations is highly variable. Acritarchs present in two samples of the Båsnæring Formation collected in nearby areas show this variability clearly: the acritarchs recovered from sample FA–11/77 are dark-grey to black in colour and heavily corroded, while acritarchs from sample NMb/L are dark-brown coloured and relatively well preserved. This reflects local variations in the thermal alteration which has affected the strata and their organic contents. The colour of acritarchs in the Båtsfjord Formation usually varies from light-grey to dark-brown, suggesting moderate to high thermal alteration. However, flat-lying mudstones and clay partings in sandstones involved in only large wavelength folding at Kibergsfjellet (Fig. 1) yielded virtually unaltered acritarchs. Thus, estimates of depth of burial based on coloration as a result of thermal alteration of particulate organic matter (e.g. acritarchs) do not appear to be reliable when applied to thick sequences which are characterized by sedimentary facies variations and affected by a varying degree of structural deformation (cf. Vidal 1979, 1981b).

Poor preservation including corrosion may also be the result of redeposition (Vidal 1981a). This is true for the acritarchs recovered from the Båtsfjord Formation which display extremely variable states of preservation even within a single geological section.

The majority of the investigated samples from the Båtsfjord Formation are of black to dark-grey mudstones, representing lithofacies (2) and (3) of Siedlecka (1978; see above and Fig. 2). A few additional samples are of thinly laminated, grey-coloured limestones, representing lithofacies (5) of Siedlecka (1978). Taxonomic diversity, expressed in the number of actual form-taxa (i.e. form-species), is low in most examined samples. Thus, no single sample yielded more than 7 recognized acritarch species (Fig. 3). This is a feature found in most of the previously reported, supposedly contemporaneous acritarch assemblages elsewhere. For example, the taxonomic diversity in the siltstones of the Klubbnes Formation and Andersby Formation of the Vadsø Group in the Tanafjord–Varangerfjord region of Varanger Peninsula (Fig. 1; Vidal 1981a) is roughly comparable to that reported from the Båtsfjord Formation. The same comparison holds true for the probably contemporaneous Upper Eleonore Bay Group in East Greenland (Vidal 1979a) and for the time-equivalent middle Visingsö Beds in southern Sweden (cf. Vidal 1974, 1976).

Microfossils larger than 100 μm from rocks of the above mentione facies (2)

and (3) of Siedlecka (1978) are usually markedly worn and corroded. Corrosion could be a result of *post-mortem* degradation of planktonic «drops-in» under alkaline conditions in standing euxinic supratidal ponds, this being in agreement with the facies interpretation of Siedlecka (1978). The physical destruction of organic vesicles can be explained by repeated redeposition in the tidal flat environment (cf. facies interpretation by Siedlecka, 1978). Unfortunately the present material is insufficient to allow comparison with the previously reported, anomalous, specific size-range distribution of discrete form-taxa in different lithofacies (cf. Vidal 1981a).

Taxonomy

As is the case in many other fields of palaeontology, literature dealing with Proterozoic planktonic microfossils carries numerous inconsistencies, synonymic taxa, and descriptions of degradational forms, contaminants and pseudofossils. In common with prevoius papers by the senior author dealing with Proterozoic microfossils, the form-taxa presented in this paper have therefore not been identified on the sole basis of comparisons with taxa described and often unsatisfactorily illustrated in published reports. Instead, original type materials of these (and other) taxa were examined directly (by G. Vidal).

As in previous papers, suprageneric nomenclatures (e.g. Timofeev 1969) have not been followed. Genera and suprageneric taxa are, in the case of acritarchs, decidedly artificial. Species (form-species) is the only objective (and acceptable) taxonomic entity and is defined, as in most other palaeontological conceptions, as the smallest morphologically definable unit that is consistently recognizable and capable of differentiation in both time and space (Niklas et al. 1980). Ordering requirements could undoubtedly be satisfied by plain alphabetic ordering of form-species (cf. Loeblich 1970, Vidal 1976).

Genus *Chuaria* Walcott, 1899
Chuaria circularis Walcott, 1899
C. circularis is an acritarch species which may occasionally reach megascopic dimensions, and has been discussed by a number of writers (e.g. Ford & Breed 1972, 1973, Vidal 1974, 1976, 1979, 1981a, Hofmann 1976). The species has been reported from geographically widely distributed Upper Proterozoic sequences throughout the world; these have been listed by Ford & Breed (1972, 1973) and Vidal (1974, 1976, 1979, 1981a).

Specimens of *C. circularis* in the present material are generally quite poorly preserved, being either corroded and fragmentary or affected by thermal alternation (i.e. opaque-black). Recovered complete specimens have a dimensional range of 85–333 μm, but are too few to give a quantitatively sound size-range distribution of the species in the present material.

Genus *Kildinosphaera* Vidal n.gen.
Derivation of name – Referring to Kildin Island in arctic U.S.S.R., where

Proterozoic sequences have previously yielded acritarch taxa in part comparable to species of this form-genus.

Type species – *Kildinosphaera chagrinata* n.sp.

Species – *Kildinosphaera chagrinata* n. sp.; *K. granulata* n. sp.; *K. verrucata* n. sp.; *K. lophostriata* (Jankauskas) comb. nov.

Diagnosis – Acritarchs consisting of medium- to large-size, robust, spherical vesicles. The vesicles are often compressed and display elongated compressional folds. As occasionally observed the mechanism of excystment was evidently by 'median split'. The vesicles display a variety of sculpture patterns (i.e. chagrinate, granulate, verrucate, striate).

Remarks – The type species of the form-genus *Kildinella* Timofeev (*K. hyperboreica* Timofeev) was transferred by Lindgren (1982) to the form-genus *Leiosphaeridia* Eisenack. The new taxonomic combination is *Leiosphaeridia asperata* (Naumova) Lindgren 1982.

Kildinella sinica Timofeev 1966 comprises, as circumscribed by Timofeev (1966, 1969), specimens which on morphological criteria alone could be attributed to *L. asperara* (= *K. hyperboreica*) and (at least in part) to a number of rather inconsequently discriminated form-taxa (e.g. *K. sinica, K. vesljanica, K. jatulica, K. rifeica, K. miroedichia, K. nordia*). It also includes forms here attributed to *Kildinosphaera chagrinata* n.sp.

Kildinosphaera chagrinata Vidal n.sp.

Fig. 4: A–B.

Derivation of name. – Referring to the chagrinata nature of the surface texture of the vesicle.

Synonymy – *Kildinella sinica* Timofeev, 1966. – Vidal, 1974: 6, Pl. 1:8, 10. *Kildinella sinica* Timofeev, 1966. – Vidal, 1979:22, Pl. 5:a.

Holotype – Specimen BV/50.8–2:X/53–1 *(Kildinella* cf. *sinica)* from the Kumlaby borehole, 50.8 m level, Visingsö Island, southern Sweden: Vidal (1976: 21–22: Fig. 10:A).

Paratypes – Specimens VR–77–11:U/40 and A74–03;Q/35 *(Kildinella sinica)* from the Andersby Formation of the Vadsø Group, Varanger Peninsula, northern Norway; Vidal (1981a: 31; Fig. 15: E–F and G–H, respectively).

Original material – Extremely numerous specimens from the Visingsö Beds in southern Sweden (Vidal 1974, 1976), the upper Eleonore Bay Group in East Greenland (Vidal 1979), and the Vadsø and Tanafjord Groups in Varanger Peninsula, northern Norway (Vidal 1981a).

Diagnosis – Circular (originally spherical), single-walled organic vesicles attributed to the form-genus *Kildinosphaera*. The vesicle is robust and its external texture varies, being psilate in smaller specimens and finely granular in the larger ones. Excystment is by 'median split'. The vesicle is highly flexible and displays well-developed clear and sharp compressional folds.

Dimensions – The dimensions of *K. chagrinata* derive from a variety of materials (e.g. Vidal 1974, 1976, 1979, 1981a). Nevertheless, all sources indicate dimensions within the size range 25–70 μm and a polymodal size distribution.
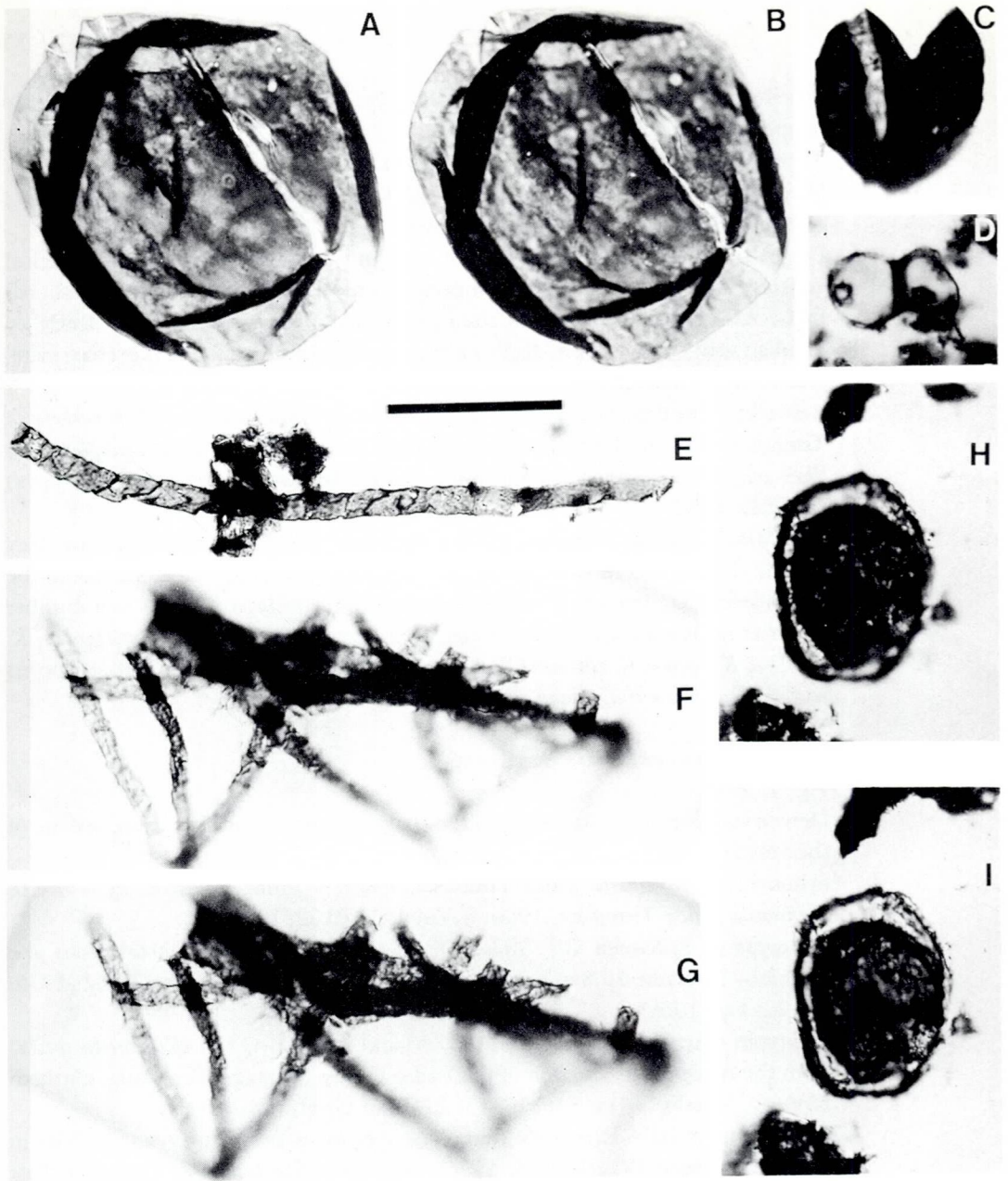
Fig. 4. A–B: *Kildinosphaera chagrinata* Vidal n.sp. displaying incipient median split (upper left corner). Oil immersion at two focus levels. Specimen 77ME–3:Q/44–2 from the lower Båtsfjord Formation. C: *K. chagrinata* Vidal n.sp. displaying effected excystment by median split. Oil immersion, interference contrast. Specimen FA–3/77:W/37–1 from the Annijokka Member of the Båtsfjord Formation. D: Joined, possibly cyanophycean spaeromorphs (vegetative cell division?) displaying probable accumulations of coagulated cell contents. Oil immersion, interference contrast. Specimen Vr–77–68:K/33–1/2 from the lower Båtsfjord Formation. E–G: Empty sheaths of filamentous cyanobacteria: *Archeotrichion* sp. Oil immersion, interference contrast. Specimen at E; FA–11/74:M/41–4 from the lower Båtsfjord Formation. Specimen at F–G; 77ME–3:Z/36 from the lower Båtsfjord Formation. H–I: Unidentified double-walled acritarch. Oil immersion, interference contrast. Specimen NMb/L:Z/28 from the Næringselva Member of the Båsnæring Formation. Bar above E equals 26 μm for A–B, F–G; 20 μm for C, H–I; 16 μm for D; 40 μm for E.

The dimensions of specimens in the present material from the Barents Sea Group coincide with the middle-upper size range recorded for previous materials.

Remarks – *Kildinosphaera chagrinata* is herein circumscribed to include chagrinate to finely granular, robust, organic-walled, solitary vesicles which occiasonally display excystment by 'median split'. This segregates *K. chagrinata* from the otherwise coenobia-forming, isolated, smooth vesicles (probably representing a vegetative stage; Lindgren 1982) of *Leiosphaeridia asperata* (= *Kildinella hyperboreica*). Thus, the more robust and ornamented vesicles of *K. chagrinata* (occasionally displaying effected excystment; Vidal & Knoll in press) could be interpreted as resting cysts or as cyst-like non-motile stages of prasinophycean green algae.

Most specimens of *K. chagrinata* display sharp-bounded compressional folds. Additionally, compactionally introduced cracks and angular fractures may occur. The latter seem to depend on the relatively high rigidity of the vesicles (cf. Vidal 1981a:31 concerning *K. sinica* = *K. chagrinata*) if compared with the soft flexible vesicles of *L. asperata* (= *Kildinella hyperboreica*).

Forms previously attributed to the form-genus *Kildinella* (e.g. *K. sinica, K. vesljanica, K. jatulica, K. rifeica, K. miroedichia, K. nordia*) could, in their simplicity, evidently be conspecific with *Kildinosphaera chagrinata*. However, their simple synonymic listing can not be regarded as sound without prior examination of the complete material on which the taxa were erected. This is obviously necessary as considerable inconsistency has been observed regarding the way in which these taxa were circumscribed. Obviously, this depends on the almost complete lack of real diagnostic characteristics. Thus, the taxonomic criteria used to discriminate these taxa appear to be completely accidental (e.g. the shape of compressionally introduced folds; cf. Timofeev 1966, 1969). Furthermore, the existence or absence of the critical excystment mechanism is in no case stated in the diagnosis. *K. chagrinata* is thus erected with the hope that future studies of Soviet material will allow the establishment of taxonomic identity on the basis of sculptural elements and excystment features (if present).

Occurrence – Occurrences of *Kildinosphaera chagrinata* are geographically widespread. Conspecific forms previously attributed to *Kildinella sinica* were listed in Vidal (1976, 1979, 1981a).

Stratigraphic range – The recognized stratigraphic range of the species is Upper Riphean and Vendian.

Kildinosphaera granulata Vidal n.sp.
Fig. 5: H–J.
Derivation of name – From latin *granum,* referring to the tightly granular texture of the vesicle surface.
Holotype – Specimen K74–05:W/31–2 from the Klubbnes Formation (Vadsø Group; Vidal, 1981a: Fig. 11:D–F).
Paratypes – Specimen VR–77–14:U/32–1 (Vidal. 1981a: Fig. 11:A–C) and VR–77–12:Z/25–1 (Vidal 1981a: Fig. 11:G–H) from the Andersby Formation (Vadsø Group), Varanger Peninsula, northern Norway.
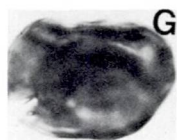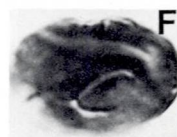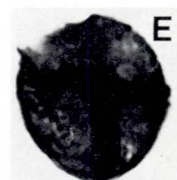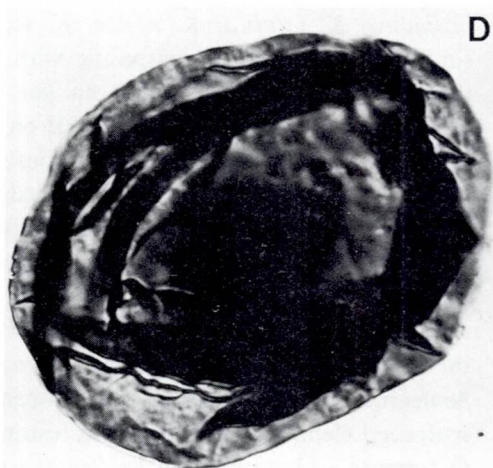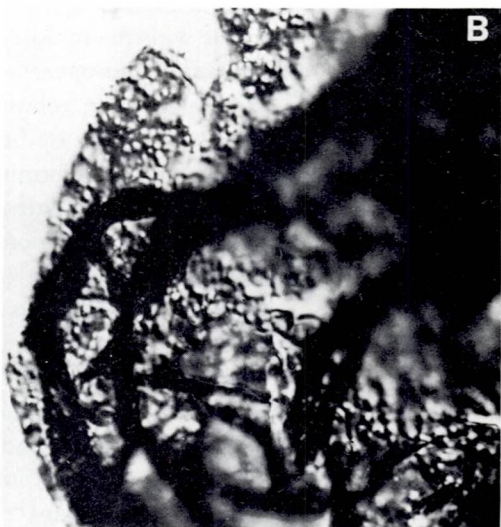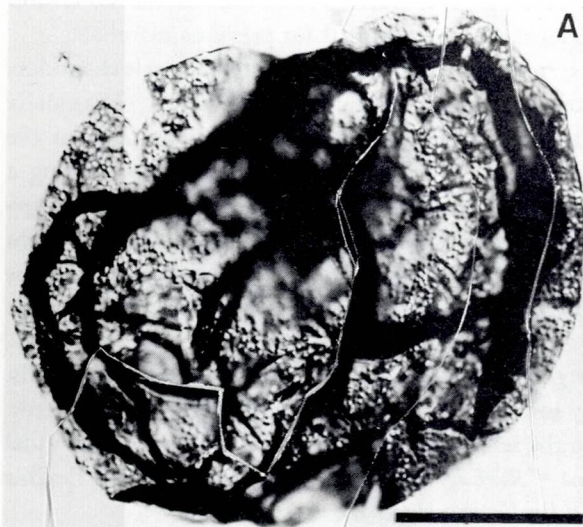
Original material – Eight specimens from the Vadsø Group and ten specimens from the Båtsfjord Formation.

Diagnosis – Circular (originally spherical), single-walled, organic vesicles attributed to the form-genus *Kildinosphaera*. The vesicle is robust and its surface displays numerous, small (c. 0.5μm across) tightly packed bulbous granulae. The thickness of the vesicle is comparable to that of other species of *Kildinosphaera;* the vesicle is highly flexible and this circumstance results in the presence of well developed, clear and sharp folds. No excystment structures have been observed.

Dimensions – Specimens of *K. granulata* are too few to allow statistically reliable measurements. Those found are in the range 45–60μm across.

Remarks – Specimens of *K. granulata* are extremely unusual in all investigated samples. The species is diagnostic in that it displays a clear granular surface texture which is far more conspicuous than the finely granular surface texture of the larger specimens of *K. chagrinata*. Thus, the coarser granular texture of *K. granulata* is observable throughout the whole size range recorded for the few specimens so far recovered. The dimensional range of *K. granulata* overlaps the upper-middle size range recorded for specimens of *K. chagrinata*.

Occurrence – *K. granulata* has been reported from the Klubbnes Formation and Andersby Formation of the Vadsø Group in East Finnmark (Vidal 1981a). The species occurs in scattered numbers in the Annijokka Member of the lower Båtsfjord Formation (upper Barents Sea Group); Fig. 3.

Scattered specimens have been recovered from the Kwagunt Formation of the upper Chuar Group in the Grand Canyon, Northern Arizona (Vidal, unpublished data).

Stratigraphic range – Most likely Upper Riphean.

Kildinosphaera lophostriata (Jankauskas) comb. nov.

Fig. 6:A–G.

Synonymy – *Kildinella lophostriata* Jankauskas, sp.n. – Jankauskas 1979: 192, Fig. 1:13–15. *Kildinella lophostritata* Jankauskas. – Vidal & Knoll, in press: Fig. 1:D–E.

Material – Fifty, mostly fragmentary specimens from the Båtsfjord Formation.

Description – Circular to sub-circular (originally spherical), single-walled organic vesicles attributed to the form-genus *Kildinosphaera*. The vesicle is of medium thickness (comparable to that of *K. chagrinata*) and flexibility. This results in

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Fig. 5. A–B. *Tasmanites rifejicus* Jankauskas; Oil immersion, interference contrast. A is a composite micrograph and B a close up. Specimen K74–01:L/35 from the Klubbnes Formation, Vadsø Group, East Finnmark. C: *Kildinosphaera verrucata* Vidal n.sp. Oil immersion, interference contrast, composite micrograph. Specimen 77ME–3:D/40–1 from the lower Båtsfjord Formation. D: *Leiosphaeridia asperata* (Naumova) Lindgren. Oil immersion, interference contrast. Specimen 77ME–3:W/46–3 from the lower Båtsfjord Formation. E: *Synsphaeridium* sp. Cell detached from a cluster. Oil immersion. Specimen FA–3/77:X/42–1 from the Annijokka Member of the lower Båtsfjord Formation. F–G: *Protosphaeridium* sp. Oil immersion, interference contrast. Specimen 77ME–3:Z/40–3 from the lower Båtsfjord Formation. H–J: *Kildinosphaera granulata* Vidal n. sp. Oil immersion, interference contrast. Specimen NMb/L:Z/43–3 from the Næringselva Member of the Båsnæring Formation. Bar below A equals 26 μm for A, C, H–J; 16 μm for B, D–G.
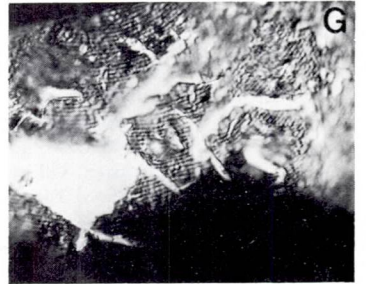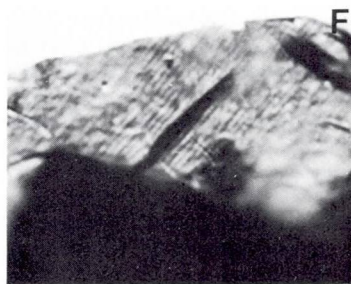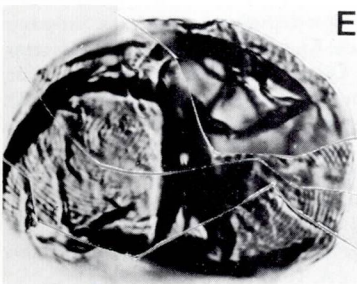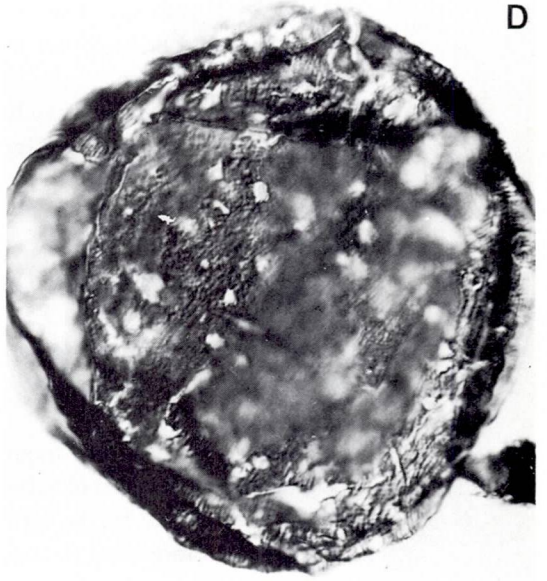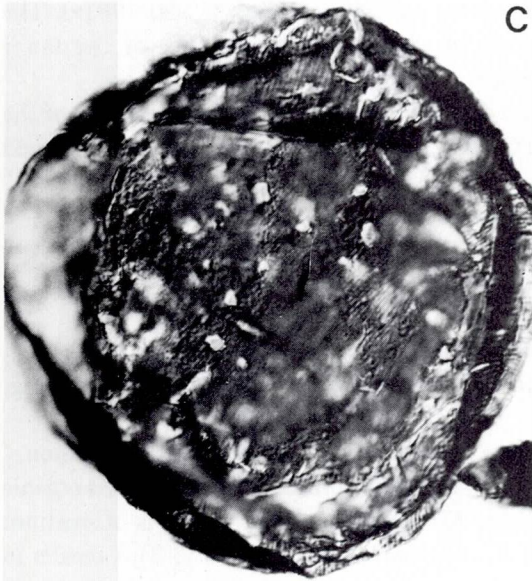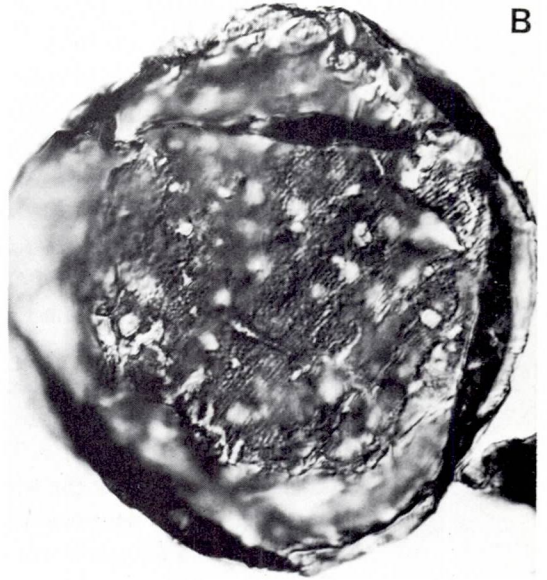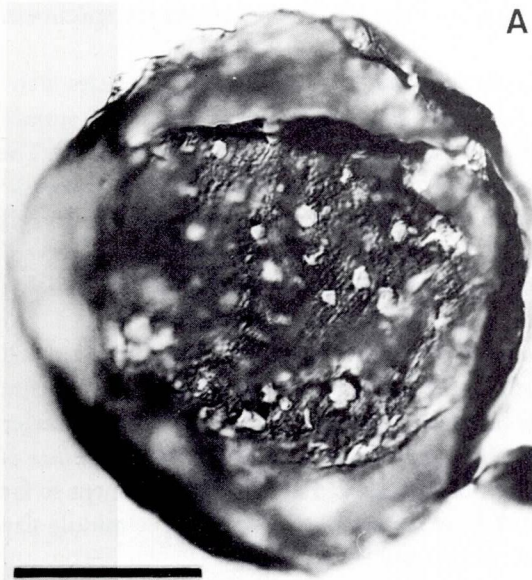
well-developed, clear and sharp-bounded folds. No excystment mechanism has been recorded. Most specimens are fractured, cracked or incomplete (partidularly the larger ones). The vesicle displays an extremely diagnostic polarly arranged, hemispherical sculptural pattern, which consists of parellel, tightly packed striae (roughly comparable to the recording tracks of a gramophone record). The striae are extremely thin, their thickness and elevation being less than $1/4\mu$; thus, they are hardly resolvable individually under conventional transmission-light optics. However, the sculptural pattern of the larger specimens (which consist of individual fragments) reveals that the striae consist of tightly arranged linear sequences of extremely tiny granulae. Thus, the possibility of optical resolution of this peculiar type of ornamentation is directly proportional to the diametral dimensions of the specimen.

Dimensions – Complete specimens of *K. lophostriata* are rare in the present material. However, the recovered specimens are clearly much smaller (104–230μm) than the specimens described by Jankauskas (1979), which are in the range 700–450 μm across. The same is generally also true of materials previously recovered from the Klubbnes and Andersby Formations of the Vadsø Group in East Finnmark (Vidal 1981a:50) which include specimens comparable to the lower limit recorded by Jankauskas (1979) as well as much smaller specimens (60–70 μm). The dimensions of published materials from the upper Chuar Group (Kwagunt Formation) in Arizona (Vidal unpublished data) are comparable to those of the Scandinavian samples, including previously unreported and recently discovered scattered specimens from the lower upper Visingsö Beds in Southern Sweden.

Occurrence – *Kildinosphaera lophostriata* has a geographically widespread occurrence. The species was reported by Jankauskas (1979) from rocks attributed to the Middle Riphean Zigalgin and Zigazino-Komarov Formations penetrated in the drillhole Kobakovo-2 (depths 5099.4–5100.6 m and 4762–4765 m). However, these rocks are now regarded as part of the Upper Riphean (Jankauskas, written comm. 1980). Vidal (1981a) reported the species from the Klubbnes and Andersby Formations of the Vadsø Group in East Finnmark, northern Norway. The species is also known from the Upper 'Riphean' lower Upper Visingsö Beds in southern Sweden and from the possibly contemporaneous (cf. Vidal 1976, Vidal & Knoll, in press) Kwagunt Formation of the Chuar Group in Arizona.

Stratigraphic range – Evidently Upper Riphean.

Fig. 6. A–G: *Kildinosphaera lophostriata* (Jankauskas) Vidal. Oil immersion, interference contrast. A–D: Specimen Vr–77–13:J/34–3 from the Klubbnes Formation, Vadsø Group, East Finnmark. E: Composite micrograph, specimen 77ME–3:F/38 from the lower Båtsfjord Formation. F: Detail of striated surface texture of specimen 77ME–3: Q/45–1/3 from the lower Båtsfjord Formation. G: Detail of the striated surface texture of specimen K–74–1:V/42–2 from the Klubbnes Formation, Vadsø Group, East Finnmark. Bar below A equals 26 μm for A–D; 20 μm for E; 16 μm for F; 33 μm for G.

Kildinosphaera verrucata Vidal n.sp.

Fig. 5:C.

Derivation of name – From latin *verruca,* referring to the warty texture of the vesicle.

Holotype – Specimen E74–02: V/47 from the Ekkerøy Formation; Vidal (1981a:26–30; Fig. 13:A–D).

Five specimens from the Båtsfjord Formation and 34 specimens from the Vadsø Group.

Diagnosis – Circular, single-walled, thin vesicles (originally spherical) attributed to the form-genus *Kildinosphaera.* The surface of the vesicle displays diagenetically introduced compaction folds and wrinkles, irregularly distributed all over the vesicle surface. The surface is tightly covered with clearly spaced, circular, bulbous verrucae which are 1 to 1,5 μm in diameter. No excystment structures have been observed.

Dimensions – As with other acritarch taxa the dimension range of *K. verrucata* varies widely. The present material from the Båtsfjord Formation consists of 5 specimens. These are a poor complement to the previous material of the Vadsø Group (cf. Vidal 1981a). The dimensions of the present specimens fall within the middle-upper size limit of the measured specimens of the Vadsø Group which range 40–135 μm across.

Remarks – *K. verrucata* is an extremely diagnostic taxon and is distinguished from other spheromorphic acritarch taxa by its distinctly ornamented outer surface and comparatively large dimensions. As pointed out elsewhere (Vidal 1981a:27–28), Timofeev (1966, 1969) reported a relatively large number of taxa that he attributed to the form-genus *Kildinella.* The validity of some of these taxa is questionable and some of them were erected on the basis of quantitatively restricted materials. It is possible that some of Timofeev's more ornamented acritarch taxa attributed to *Kildinella* (e.g. *K. exculpta* and *K. tschapomica*) may in fact be part of the *K. verrucata* and *K. granulata* form taxa. Furthermore, it is preferable that Upper Proterozoic taxa displaying features as diagnostic as those of *K. verrucosa* should be formalized. This is particularly pertinent in view of the fact that such taxa seem to have a wide geographic distribution.

Occurrence – Vadsø Group; Klubbnes, Andersby and Ekkerøy Formation in East Finnmark, northern Norway (Vidal 1981a).

In the present material the species was found in only one sample of the lower Båtsfjord Formation (Fig. 3).

Stratigraphic range – Probably Upper Riphean and Lower Vendian (? = Kudashian).

Leiosphaeridia asperata (Naumova) Lindgren, 1982

Fig. 5:D.

Specimens of acritarchs previously attributed to *K. hyperboreica* Timofeev by Vidal (1974, 1976, 1979, 1981a) are herein identified with the presumably detached vesicles of coenobial aggregates of *L. asperata* (cf. Lindgren 1982).

Isolated vesicles attributable to *L. asperata* are rather common in the present material from the Barents Sea Group. For further details concerning *K. hyperboreica* (= *L. asperata*) see Vidal (1974, 1976, 1979, 1981a) and Lindgren (1981, 1982).

Specimens from the Båsnæring and Båtsfjord Formations consist of thin, circular, psilate, single-walled and highly flexible vesicles. The vesicles are usually compactionally deformed and display clear, sharp folds.

The dimensions of specimens from the Barents Sea Group are in the range 15–60 μm across. These figures coincide well with those reported for materials of *K. hyperboreica* from the Vadsø Group (Vidal 1981a). They are, however, slightly larger than isolated vesicles reported by Lindgren (1982).

The stratigraphic range of *L. asperata* appears to be Upper Riphean and Vendian. Previous reports from the Lower Cambrian remain unconfirmed (cf. Vidal 1979b, 1981a).

Genus *Octoedryxium* Rudavskaya, 1973
Octoedryxium truncatum (Rudavskaya 1973) Vidal, 1976
Fig. 7:E–G.
Synonymy – See Vidal (1976), *Octoedryxium truncatum* (Rudavskaya, 1973) Vidal, 1976. – Vidal 1979:22, Pl. 2:f, g, *Octaedrixium truncatum* Rud. – Timofeev et al. 1976:49, Pl. 19:2–5, *Octoedryxium truncatum* (Rudavskaya) Vidal. – Vidal & Knoll 1982; Fig. 2:E-F.
Description – The present material has yielded scattered microfossils which are attributed to *O. truncatum*. These are comparable to previously described specimens of this taxon (cf. Vidal 1976). Accompanying these specimens are also scattered polygonal (octahedral) microfossils that differ somewhat from typical specimens of *O. truncatum*. These microfossils consist of smooth to indistinctly psilate octahedral, somewhat distorted vesicles. (Fig. 7:H–K). Thus, the external texture of the vesicles differs considerably from that observed in usual specimens of *O. truncatum,* which are spongy (cf. Vidal 1976:22). Furthermore, the cusps of converging faces are less sharply edged than in characteristic specimens of *O. truncatum,* although there is great variation in the species in this respect (cf. Vidal, 1976:23). These more unusual specimens are left under open nomenclature, i.e. they are not attributed to *O. truncatum*.
Dimensions – Specimens of *O. truncatum* and *Octoedryxium* sp. in the present material are of small dimensions; 20–40 μm.
Occurrence – Occurrences of *O. truncatum* were listed by Vidal (1976:24–25). Additional occurrences are in the Vendian Lower Tillite Formation of the Tillite Group in East Greenland (probably reworked from older strata; cf. Vidal 1979:33) and in the Biri Formation of the Hedmark Group in southern Norway (Vidal, 1981a:45).

Timofeev et al. (1976) reported the species from the Upper Riphean (see below) Lakhanda Formation (Group according to Chumakov & Semikhatov 1981:244) near River Maya, in the Uchur-Maya region of Siberia, U.S.S.R.
Stratigraphic range – Available evidence indicates that the stratigraphic range of *O. truncatum* may be restricted to the Vendian (cf. Vidal 1979:22).
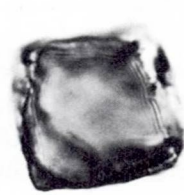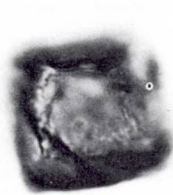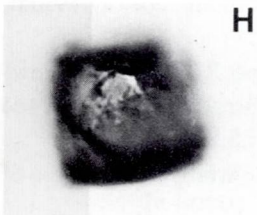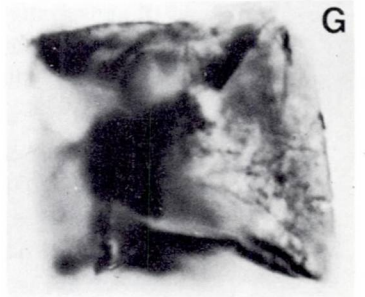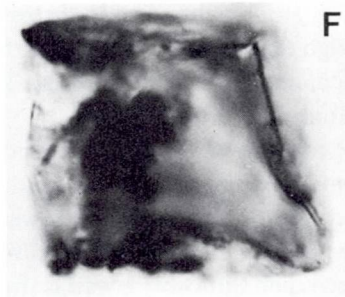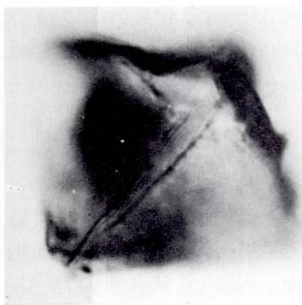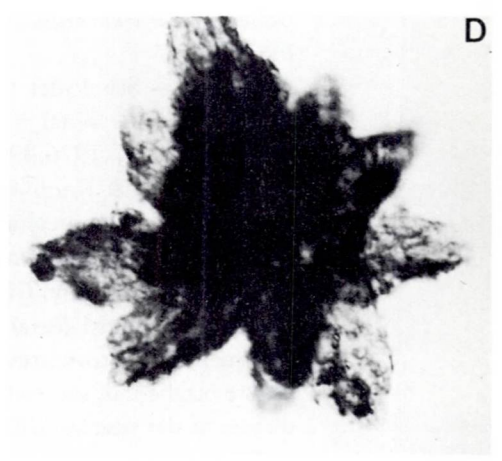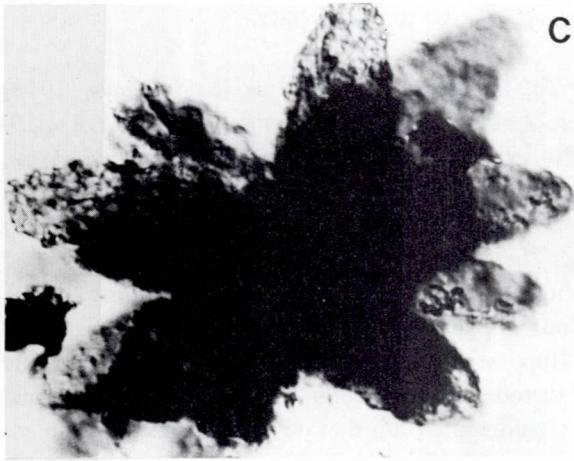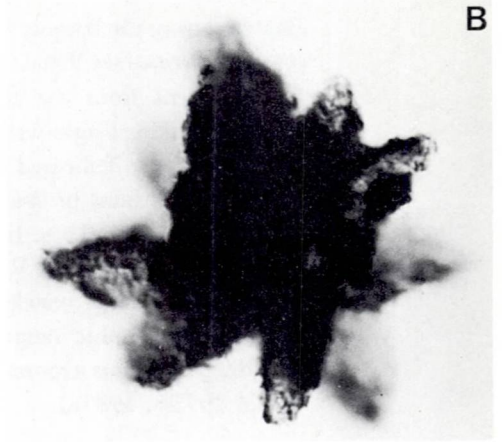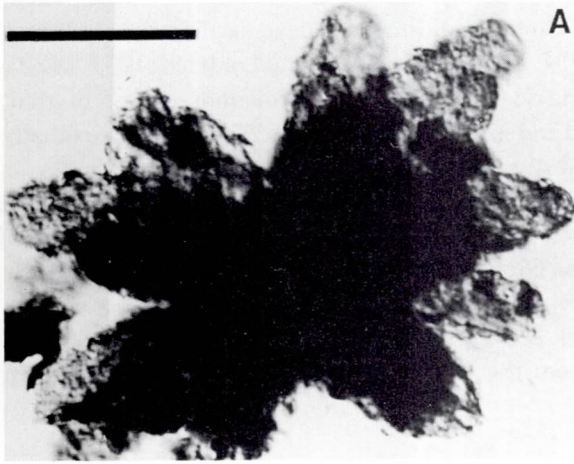
Genus *Podolina* Hermann, 1976

Translation of original diagnosis – Oval-elliptical vesicles, the relationship between width and length being 1:3. The edges are split, one of them having a small projecting part. The cells are metabolizing(?) (question mark by Gonzalo Vidal) and display great variability in shape. It is possible to follow a longitudinal type of division. The vesicles have different thickness and the dimensions vary greatly. Surface sculpture is nuclear-vermicular, striated. It is possible to distinguish 3 species that differ from each other concerning dimensions, the character of metabolism(?) (question mark by Gonzalo Vidal), type of division and ornamentation (spines on the surface of vesicle).

Complemented diagnosis – Acid-resistant, organic-walled microfossils consisting of mucilagous-like material. The shape of vesicles varies from elongated elliptical, cross-shaped to star-shaped. Single, elongated elliptical specimens often display splitting edges, suggestive of longitudinal division. Successive divisions and subsequent rotation of division entities at nearly right-angles might result into one, two or more new and equally long 'processes' (Fig. 7:A–D), thus producing radially arranged multi-'process' aggregates (Fig. 7:A–D). The 'processes' may as well have developed by division at right-angles from the central part of elongated thickenings (Fig. 8:C–D) on the elongated elliptical vesicles. The 'processes' of aggregates are digitate, being wider at their proximal ends and tapering at the distal ends. Single elongated-elliptical, and multi-'process' vesicles belong undoubtedly to the same organisms; most likely representing different stages of their life cycle. Surface textures are irregularly granular and spongy (Fig. 8:A–B, E–G).

Remarks – Three species of *Podolina* (the type species being *P. minuta*) were erected by Hermann (in Timofeev et al. 1976); i.e., *P. minuta, P. angulata, P. echinata.* These are regarded as conspecific.

The organic-walled, acid-resistant vesicles of *Podolina* resemble the radiating cell-clusters of certain Chlorococcacean algae. These are the result of repeated cross-wise division of cells, usually into 8 parts, being attached to each other at the proximal ends by mucilage.

Podolina minuta (Hermann, 1976) Vidal

Figs. 7:A–D, 8:A–G.

Synonymy – *Podolina angulata* Hermann sp.n.. – Timofeev et al. 1976:56; Pl. 23:1, 3–6, Pl. 24:3. *Podolina minuta* Hermann sp.n.. – Timofeev et al. 1976:57; Pl. 24:1, 7. *Podolina echinata* Hermann sp.n.. – Timofeev et al. 1976:57–58, Pl. 23:13, Pl. 24:13.

Material – 2450 specimens from the Båtsfjord Formation.

Complemented diagnosis – As for the Genus *Podolina* (see above).

Fig. 7. A–D: *Podolina minuta* (Hermann) Vidal. Oil immersion, interference contrast at two focus levels. All specimens from sample V–IV/76 from the lower Båtsfjord Formation. A, C; V–IV/76:Y/45–1, B, D; V–IV/76:Z/42. E–G: *Octoedryxium truncatum* (Rudavskaya) Vidal. Oil immersion, interference contrast at 3 different focus levels. Specimen Vr–77–72:Z/33–3 from the lower Båtsfjord Formation. H–K: *Octoedryxium* sp. Oil immersion, interference contrast at 4 different focus levels. Specimen FA–6/77 from the lower Båtsfjord Formation. Bar above A equals 16 μm for A–G; 20 μm for H–K.

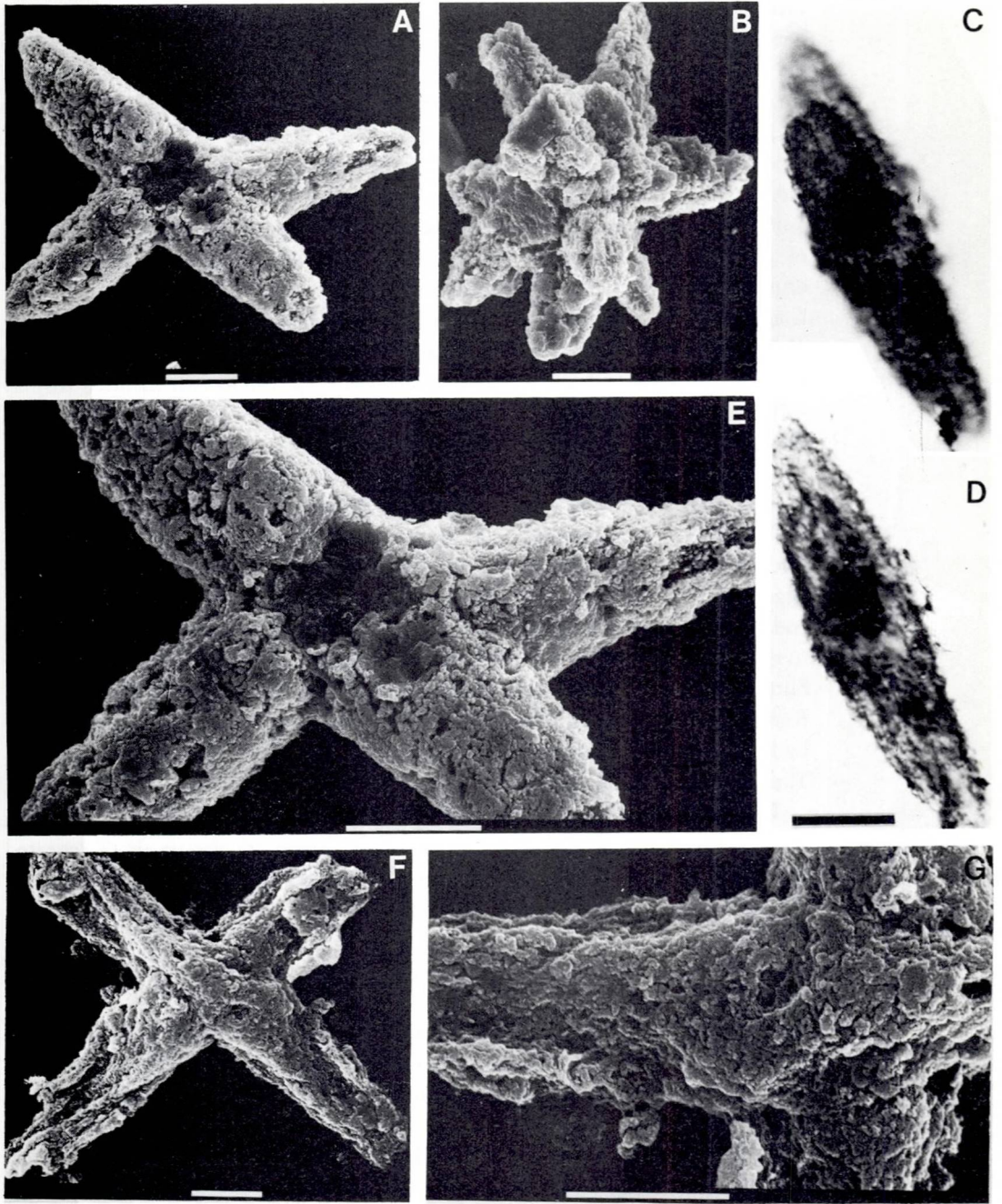*Fig. 8.* A–G: *Podolina minuta* (Hermann) Vidal. A, B, E–G: Star-shaped multi-'process' vesicle. Note place of detached 'process' in central part of specimen at A and E. All specimens from SEM–V–IV/76 from the Båtsfjord Formation. C–D: Single, elongated elliptical specimen displaying splitting upper edge. Oil immersion, interference contrast. Specimen V–IV/76:Y/44 from the lower Båtsfjord Formation. All bars equal 10 μm.

Dimensions – One hundred uncompressed specimens measured indicate dimensions ranging 40–80 μm across. However, the dimensions of single, elongated elliptical vesicles are, in general, larger than those of multi-'process' aggregates. It is, nevertheless, difficult to estimate the significance of this difference, since the single, elongated elliptical vesicles are quite rare.

Occurrence – *P. angulata* is reported by Hermann (in Timofeev et al. 1976) from the Vendian Lyadova Beds of the Derlovsk Formation in River Dnestr (the Ukraine). *P. minuta* and *P. echinata* are reported from exposures of the same rock units at the Borshochov ravine near Mogilev-Podolsk (the Ukraine).

Scattered specimens of this taxon were reported by Vidal (1981a) under the name *P. angulata* from the Biri Formation of the Hedmark Group in southern Norway.

Stratigraphical range – Evidently Vendian.

OTHER ACRITARCH TAXA

In addition to the above-mentioned acritarch taxa, rocks of the Barents Sea Group have yielded variable numbers of acritarchs attributed to *Protosphaeridium* sp. (Fig. 5:F–G); a few small (30 μm across) specimens recovered from sampled V–II/14 and Vr–77–75), cf. *Stictosphaeridium* sp. (cf. Vidal 1976) consisting of single or clustered empty circular vesicles ranging c. 10–30 μm across, *Synsphaeridium* sp. (*sensu* Vidal 1976; consisting of aggregates of thick, massive, folded and wrinkled vesicles; the discrete vesicles ranging 10–14 μm across; Fig. 5:E, *Trachysphaeridium* sp. (scattered medium size, empty, weakly folded vesicles recovered from three samples), *Trachysphaeridium* cf. *laufeldi* (one single extremely poorly preserved and uncertainly identified specimen from sample FA–11–74), *T*. cf. *laminaritum* (one single poorly) preserved and uncertainly identified specimen from sample 77–ME–3), *T. levis* (abundant, large; 105–225 μm across, poorly preserved specimens, recovered from 13 samples), sphaeromorphs sp. indet. (unidentifiable, small (15 μm across), smooth, single or clustered cells; Fig. 4:D and shagrinate larger compressed vesicles; Fig. 9:H, recovered from 7 samples; Fig. 3). In addition, one sample yielded a number of scattered groupings of tangled and twisted, 5 μm-wide, flattened algal filaments (Fig. 4:E–G). The filaments are completely smooth and structureless. They most likely represent empty sheaths of filamentous cyanophycean algae and are assigned to *Taeniatum* sp. (cf. Hofmann & Aitken 1979). Similar filaments were reported from Upper Proterozoic units in East Finnmark (Grasdal, Dakkovarre and Andersby Formations; 1981a:39–40).

Numerous specimens of previously unknown microfossils were recovered from sample F–81–25 of the Kongsfjord Formation. The microfossils consist of single-walled, robust, spherical vesicles with dimensions ranging 14–40 μm across. The vesicles are occasionally found enclosed within a much thinner, clearly translucent, spherical organic envelope (Fig. 9:A–G). The vesicles generally display opaque to semi-opaque organic contents; most likely degraded cell remains. These are usually irregularly shaped, but in some instances they are almost spherical or slightly constricted-elliptical.
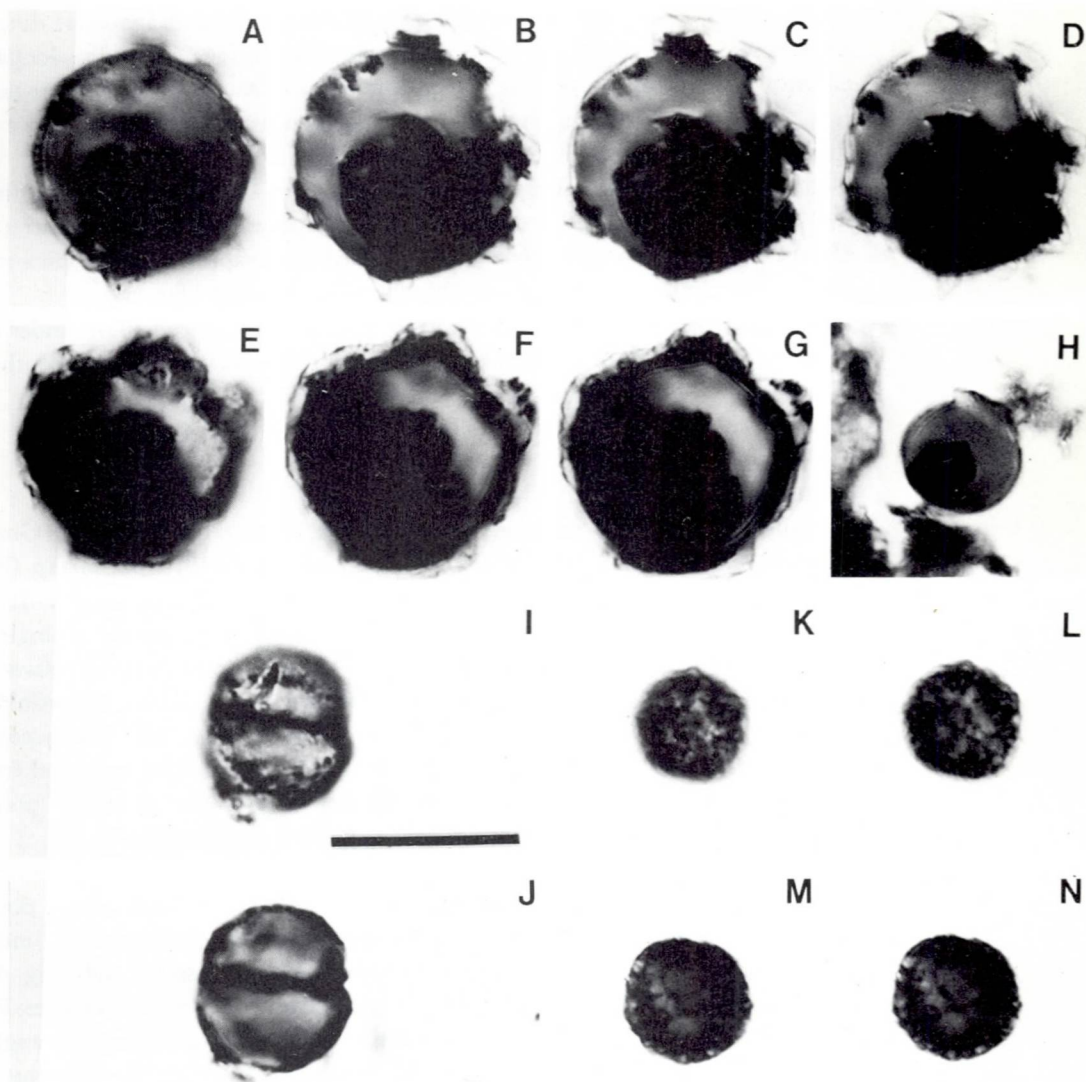
Fig. 9. A–G: Enigmatic sphaeromorphic acritarchs. Note the opaque degraded cell remnants(?) inside vesicles, and globular processes on periphery of vesicle. Oil immersion, interference contrast at different focus levels. Specimen A–C; F–81–25:Y/28 and E–G; F–81–25:U/38 from the Kongsfjord Formation. H: Smooth algal microfossil. Oil immersion, interference contrast. Specimen F–81–25:Z/34–3. I–J: Possible vegetative cell division of sphaeromorph comparable to specimen at H. Oil immersion, interference contrast. Specimen F–81–30:Z/43–3 from the Kongsfjord Formation. K–N: *Bavlinella faveolata* (Shepeleva) Vidal. Specimen at 4 different focus levels (high to low). Immersion oil, interference contrast. Specimen F–81–28:M/36–4 from the Kongsfjord Formation. Bar below I equals 16 μm.

The outer surface of vesicles which were found without surrounding envelope display a number of tiny, nearly spherical blister-shaped processes.

These processes are completely translucent and differ considerably from the thick wall of the vesicles. The processes seem to be attached to the vesicle by a

constricted neck (Fig. 9:B–C). The nature of these structures is doubtful, although somewhat comparable (if not identical) structures have been reported from Palaeozoic acritarchs. Although admittedly speculative, it seems possible that the vesicles represent abandoned cysts provided with a kind of buoyancy-promoting blister-shaped processes. The enclosing transparent envelopes could perhaps indicate a possible dinophycean affinity, although admittedly they could as well represent a blind alley in the evolution of an early dinoflagellate-like stock.

Samples F–81–27, 28, 30 of the Kongsfjord Formation yielded spherical aggregates of small (c. 1 µm across) spherical cells (Fig. 9:K–N). The aggregates range 6–12 µm across and are here identified with *Bavlinella faveolata* (Shepeleva) Vidal and other taxa which were regarded as conspecific by Vidal (1976). Most likely these spherical aggregates represent endosporangia of pleurocapsacean cyanobacteria (Knoll et al. 1981, Chauvel & Mansuy 1982). Clusters of cells, the diameter of discrete cells being 4–5 µm, consisting of groupings of up to 15 cells seem to differ from *B. faveolata* only in dimensions (cf. Vidal 1979, 1981a), a feature often observed within presumably monospecific form-taxa (cf. Vidal 1979, 1981a).

Cell-clusters attributed to *B. faveolata* have a long stratigraphic range and, although particularly common in Upper Riphean (cf. Vidal 1976) and Vendian deposits (Vidal 1976, 1979, 1981a), apparently comparable forms are presently known to range into rocks belonging to the Middle Cambrian *Paradoxides oelandicus* Zone in Sweden (Vidal, unpublished data).

Comments on biological affinities of some form-taxa

The biological affinity of Proterozoic acritarchs remains uncertain. Nevertheless, it appears quite evident that considerable morphological variety had been attained by Late Riphean-Early Vendian (? = Kudashian) times (cf. Vidal 1981b, Vidal & Knoll in press). The acritarchs attributed to the form-genera *Kildinosphaera* and *Trachysphaeridium* most likely represent abandoned cyst-like vesicles resulting from non-motile stages of prasinophycean algae (Vidal 1981b, Vidal & Knoll in press). Some specific entities attributed to the form-genus *Kildinosphaera* (e.g. *K. lophostriata K. verrucata*) display diagnostic and rather advanced sculptural patterns, and attain considerable dimensions which overlap the size-range recorded for the maga-acritarch *Chuaria circularis*.

The polygonomorph acritarchs *Octoedryxium truncatum* and *Podolina minuta* could perhaps be tentatively compared to desmicean and chlorococcacean algae, respectively.

Unnamed acritarchs from the Kongsfjord Formation consist of thick vesicles enclosed in translucent envelopes which may indicate a dinophycean affinity. In fact, although superficial and perhaps not significant, similarity can be found with fossil chorate gonyaulacacean cysts (e.g. *Aireiana*). Affinity with dinophyceans, or with components of a possible dinophycean-like stock, seems to be supported by the turbidite origin of sediments of the Kongsfjord Formation. The latter is also in agreement with a planktonic habit.

Stratigraphy and correlation: A Discussion

The stratigraphic ranges of all the acritarch species described in this paper are within the Upper Proterozoic part-sequences of the North Atlantic region (Vidal 1981b). These sequences are considered to be contemporaneous with the Upper Riphean and Lower Vendian* of the Russian Platform and the Southern Urals of the U.S.S.R. The stratigraphic position of the Barents Sea Group within this long time span and correlation with some of the most important Upper Proterozoic sequences in Scandinavia and elsewhere are discussed below.

The age of the Barents Sea Group

The biostratigraphic data reported here confirm the previously postulated Late Precambrian age of the Barents Sea Group, and provide some more detail concerning the precise stratigraphic position of the formations within this group. The lowermost known part of the group, the Kongsfjord Formation, provided numerous specimens of previously unknown microfossils and of *Bavlinella faveolata,* a species which although having a long stratigraphic range (up to Middle Cambrian) is known to be particularly common in the Vendian (Knoll et al. 1981). This fact, combined with the reported (p. 5) isotopic age of 810 ± 60 Ma B.P., makes it reasonable to assume a Late Riphean age for at least the upper part of the formation.

Scattered acritarchs recovered from a few fossiliferous samples of the Båsnæring Formation constitute a taxonomically poor assemblage. The assemblage is dominated by species of *Kildinosphaera* (i.e. *K. chagrinata, K. granulata*), *Leosphaeridia asperata, Trachysphaeridium sp., C. circularis,* and cf. *Stictospaeridium* sp.. This assemblage is comparable to previously reported Upper Riphean acritarch assemblages from East Finnmark and elsewhere (Vidal 1981a). The junction between the Båsnæring Formation and the overlying Båtsfjord Formation is transitional and thus, not surprisingly, most of the acritachs recovered from the samples of the Båtsfjord Formation are comparable to those of the Båsnæring Formation (cf. Fig. 3). However, the Båtsfjord assemblage contains a number of diagnostic acritarch taxa not found in the Båsnæring Formation. This circumstance could be explained either by insufficient sampling from the Båsnæring Formation, or by a generally lower representation of microfossils in fluvial-deltaic, predominantly arenaceous sediments, probably accumulated at considerably higher rates than for the peritidal deposits of the Båtsfjord Formation. However, some samples of the Båtsfjord Formation have also yielded depauperate acritarch assemblages (cf. Fig. 3).

The acritach assemblage of the Båtsfjord Formation includes evidently biostratigraphically time-diagnostic Precambrian taxa. e.g. *K. verrucata, O. truncatum,*

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* The four-fold stratigraphic subdivision of the Upper Proterozoic in the U.S.S.R. consists of Lower, Middle and Upper Riphean and Vendian. Some geologists include Vendian in the Upper Riphean and adopt the designations Uppermost or Terminal Riphean (e.g. Keller & Semikhatow 1968, Semikhatow 1976). In other schemes a separate unit, Riphean R$_4$ or Kudashian, separates the Upper Riphean R$_3$ from Vendian (cf. Chumakov & Semikhatov 1981). We consider the Lower Vendian beds as possibly equivalent to the Riphean R$_4$ (Kudashian) strata (cf. Vidal 1981b).

?? Russian R3

= RIPHEAN R4 =
KUDASHIAN

UPPER 'RIPHEAN'	LOWER VENDIAN	VARANGERIAN	

BARENTS SEA GROUP — BARENTS SEA REGION

KONGSFJORD FM. 810 ± 19 ? — BÅSNÆRING FM. — BÅTSFJORD FM. — TYVJO-FJELL FM. (CHRONO-STRATIGRA-PHIC PO-SITION UNCERTAIN) — LOWER PARTS OF LAKSEFJORD AND LØKVIKFJELL GROUPS > 640

VADSØ GROUP / TANAFJORD GR. — TANAFJORD - VARANGERFJORD R

VEINESBOTN FM. — KLUBBNES FM. 807 ± 19 — FUGLEBERG FM. — ANDERSBY FM. — PADDEBY FM. — GOLNESELV FM. — EKKERØY FM. — SMALFJORD TILLITE — NYBORG FM. 653.7 — MORTENSNES TILLITE

HEDMARK GROUP — SOUTH CENTRAL NORWAY

? — BRØTTUM FM. — BIRI FM. — BISKOP-ÅS FM. — RING, RENDAL FMS. — HIATUS ? — MOELV TILLITE

VISINGSÖ BEDS — SOUTH CENTRAL SWEDEN

LOWER UNIT — MIDDLE UNIT — UPPER UNIT 707 ± 37

RYBACHIY GROUP 887 Ma ? 715 ? — RYBACHIY PENINSULA — 1989

KILDIN GROUP — SREDNIY PENINSULA

CHRONOSTRATIGRAPHIC POSITION OF THE VOLOKOV GROUP UNCERTAIN = U. Riphean Lyubcov et al. 1989

LOWER ELEONORE BAY GROUP — QUARTZITE 'SERIES' — MULTICOLOURED 'SERIES' — LIMESTONE-DOLOMITE 'SERIES' — **TILLITE GROUP** — LOWER TILLITE — INTER-TILLITE FM. — UPPER TILLITE FM. — EAST GREEN-LAND

MIDDLE HECLA HOEK — BASAL UPPER HECLA HOEK — SVALBARD

Fig. 10. Tentative correlation of the Upper Proterozoic sequences in Scandinavia, North U.S.S.R., East Greenland and Svalbard. Not to scale. Undulating lines indicate angular unconformities.

P. minuta and *K. lophostriata*. *K. lophostriata* is known to be restricted to Upper 'Riphean' strata (see pp. 17–18). Interestingly, this form occurs only in the basal part of the Båtsfjord Formation (up to some 25 m from the base; see Figs. 2 and 3). This fact suggests that the Riphean/Vendian boundary is located within the lower Båtsfjord Formation (Annijokka Member; cf. Siedlecka 1978) and that the bulk of the formation may be considered as Early Vendian in age (Fig. 10).

The upper time limit for the accumulation of the Barents Sea Group is uncertain. Multicoloured and red beds of the upper Båtsfjord and Tyvjofjell Formations do not look promising with respect to microfossil preservation and have not been sampled. The Løkvikfjell Group, unconformably overlying the Barents Sea Group, though fossiliferous, has not provided any time-diagnostic acritarch taxa. A radiometric age of 640 Ma B.P. for the dolerite dyke transecting both groups (p. 51) provides an upper time limit (minimum age) for the group, an age corresponding roughly to the end of Early Vendian time. This places the Barents Sea/Løkvikfjell intra-Vendian unconformity in an interesting context if compared with the upper Vendian age of the Varangerian (Laplandian) glaciation of the Tanafjord–Varangerfjord Region and adjacent areas (cf. Vidal 1981a and the chapter below).

Although the micropalaeontological results from the Løkvikfjell Group are inconclusive, it can be speculatively suggested that the age of this group may be (?Late) Vendian and that at least parts of the group are time-equivalent to the tillites known from other successions. This line of reasoning is in agreement with the previously proposed correlations between the Vestertana, Laksefjord and earlier Raggo Groups. It is also in line with the proposed glacial origin of the Ifjord Conglomerate (Føyn 1969, Laird 1972). This last interpretation has more recently been rejected in favour of a debris-flow hypothesis (Chapman 1980), but conclusive evidence for one or other of the proposed mechanisms of accumulation of the Ifjord Conglomerate diamictites has not yet been found.

It is noteworthy that the dated dolerite dyke actually cuts the Barents Sea/Løkvikfjell unconformity and *only* the lower, Sandfjord Formation of the Løkvikfjell Group. It is therefore not impossible that higher portions of this group may have been accumulated in post–640 m.y. time. As yet, however, no disconformity or hiatus has been reported from within the Løkvikfjell Group (cf. Siedlecki & Levell 1978) which would support the above assumption. Further considerations on this topic must therefore await new data.

Correlation with the Vadsø–Tanafjord Groups in East Finnmark
The acritarch assemblage of the basal Båtsfjord Formation is notably similar to the assemblages from the Klubbnes and Andersby Formations of the Vadsø Group, which are considered on biostratigraphic grounds to be Late Riphean in age (Vidal 1981a) and dated to 807 ± 19 Ma B.). (Sturt et al. 1975). As suggested by Vidal (1981a), the Riphean/Vendian boundary is located within the upper Vadsø Group (Fig. 10) and is marked by a hiatus embracing the terminal part of the Riphean and the initial Early Vendian. This hiatus could perhaps explain the absence of *O. truncatum* and *P. minuta* in the Vadsø Group, although an

ecological explanation cannot be excluded. These taxa occur in the lowermost Båtsfjord Formation which is considered to be Early Vendian in age.

Correlation with the Hedmark Group in South Norway and the Visingsö Beds in South Sweden

Acritarchs comparable to those found in the Kongsfjord Formation have been recorded from mudstones of the turbiditic Brøttum Formation of the Hedmark Group (G. Vidal, unpubl. data). This assemblage, similarly to the Kongsfjord Formation, includes abundant specimens of *B. faveolata*. This circumstance may be coincidental, perhaps reflecting accumulation from parallel plankton belts under similar depositional conditions, and may not be of stratigraphic importance. *B. faveolata* is known to have a long time-stratigraphic range and therefore no stratigraphic conclusions can be based solely on the presence of this form. However, acritarch assemblages recorded in the higher part of the lower Båtsfjord Formation and in the Ring and Biri Formations of the Hedmark Group have yielded *O. truncatum* and *P. minuta*. These forms have also been identified in the upper Visingsö Beds in South Sweden. These facts are by themselves sufficient to suggest time equivalence between the Biri/Ring Formations, the fossiliferous lower (but not basal) part of the Båtsfjord Formation and the upper Visingsö Beds (Fig. 10). The lower part of the upper Visingsö Beds on the other hand contains an acritarch assemblage analogous to that of the basal Båtsfjord Formation, although *K. granulata* and *K. verrucata* are absent there.

Part of the acritarch assemblage recorded in the Båtsfjord Formation is completely missing in the Hedmark Group; this fact, relating to different facies development, makes it difficult to place the Riphean/Vendian boundary within the latter group with any precision. This boundary seems to be located within the top part of the Brøttum Formation, perhaps crossing the Brøttum/Biri lithostratigraphic boundary (Fig. 4). Vidal (1981a) has tentatively suggested a Vendian age for the Brøttum Formation.

P. minuta (*P. angulata* in Vidal 1981a, 1981b) and *O. truncatum* are not known from the Vadsø and Tanafjord Groups in East Finnmark. Taxa related to some of those in the Tanafjord Group and in the Ekkerøy Formation of the uppermost Vadsø Group are common constituents of the assemblage of the upper Visingsö Beds. Those include a diagnostic species, *Vandalosphaeridium*, and vase-shaped heterotropic protists recovered from erratics in the Mortensnes Tillite derived from the Grasdal Formation. We thus conclude on the above circumstantial evidence that acritarchs from the investigated lower part of the Båtsfjord Formation appear in the same stratigraphic order as in presumably contemporaneous strata in East Finnmark, southern Sweden and southern Norway, which on micropalaeontological evidence are regarded as Upper Riphean to Lower Vendian (Vidal 1981a). The Lower Vendian sequences are micropalaeontologically comparable to the pre-Late Vendian (Valdian) sequences in the Ukraine (Vidal 1976), which are commonly considered to be likely correlatives of the Terminal Riphean (= Kudashian) in the Southern Urals (Chumakow & Semikhatov 1981). However, the palaeontological evidence supporting the latter correlation is extremely weak.

Because of this uncertainty the above-mentioned sequences are here placed stratigraphically in the Lower Vendian.

CORRELATION WITH RYBACKIY–SREDNIY AND KILDIN

Assumed tectonic-sedimentary relationships between Varanger Peninsula and the Aynov Islands, Rybachiy-Sredniy Peninsula and Kildin Island have been discussed by Siedlecka (1975). Upper Proterozoic microfossils have been described by Timofeev (1969 p. 32–36) from sequences on Rybachiy Peninsula, Sredniy Peninsula and the eastern part of Kildin Island. On regional-geological grounds, it is only the Ribachiy Group which may be regarded as a continuation of the Barents Sea Group. The Rybachiy Group consists of the Motov, Enja, Zubov and Cyp Naboloka Formations, which together constitute a ca. 5000 m-thick turbidite-like fining-up megasequence. It starts with coarse debris-flow diamictites, grading-up into proximal turbidites, and terminates with distal turbidites and pelagic deposits (Siedlecka 1975). This development has obvious parallels with the retrograding development of the turbidite Kongsfjord Formation and, on these grounds, a lithostratigraphic correlation between the Rybachiy Group and the Kongsfjord Formation has been suggested (Siedlecka 1975).

Shales of the Ejna Formation which have an isotopic age of 887 Ma (K/Ar on shale; Timofeev 1969 p. 33), have yielded an acritarch assemblage which is taxonomically clearly in accord with a Late Riphean age. The assemblage contains several taxa in common with the above-described assemblage of the Barents Sea Group. Shales and impure sandstones of the overlying Zubov Formation have yielded a thermally altered assemblage of acritarchs comparable to that of the Ejna Formation. The uppermost unit of the Rybachiy Group, the Cyp Naboloka Formation, has yielded a K/Ar age (whole-rock on shale) of 715 Ma (Timofeev 1969 p. 33) and a rather depauperate acritarch assemblage which contains acritarch taxa similar to those in the above-mentioned units.

Radiometric ages reported by Timofeev (1979) and others (in Siedlecka 1975) for the Rybachiy Group seem rather unreliable. Thus, the somewhat high (887 Ma) K/Ar age of the shale of the Ejna Formation may be interpreted as a result of excessive Ar derived from older detrital components, while the 715 Ma age for the Cyp Naboloka Formation would almost certainly be a late cooling age.

Facies equivalents to the deltaic and shallow-marine formations of the upper Barents Sea Group are missing on Rybachiy, possibly having been eroded away. The latest Riphean to Early Vendian (? = Kudashian) assemblage of microfossils of the Lower Båtsfjord Formation and the Late Riphean acritarchs of the Rybachiy Group confirm the previously suggested correlation between the latter group and the Kongsfjord Formation. The easterly palaeocurrent directions recorded in the Båsnæring and Båtsfjord Formations (Siedlecka & Edwards 1980, Pickering 1981) suggest that there might have been some southeastward progradation of lithofacies, with youning towards the east, and that the higher parts of the Rybackiy Group may thus be time-equivalent to the Båsnæring Formation (Fig. 10).

Strata of the Kildin Group are present on Kildin Island, Sredniy Peninsula and the Aynov Island. Rocks of this group in the eastern part of Kildin Island (5 km

west of the settlement Eastern Kildin) have yielded acritarch assemblages which are comparable to those from the Rybachiy Group and are in good agreement with a Late Riphean age. A similar but much poorer assemblage was reported by Timofeev (1969) from rocks of the Kildin Group on Sredniy Peninsula. Timofeev (1969) also reported a comparable but taxonomically much richer assemblage from the Volokov Group in the northern part of Sredniy Peninsula, rocks from which have yielded K/Ar ages of 920 Ma (on glauconite) and 770–670 Ma (on whole-rock shale interbeds in sandstone). An age of about 600 Ma has been reported from a dolerite dyke cross-cutting beds of the Volokov Group (Bekker et al. 1970).

The Vadsø and Tanafjord Groups were previously correlated with the Kildin Group and considered Late Riphean in age, while the Volokov and Vestertana Groups were regarded as equivalent and of Vendian age (Siedlecka 1975). These correlations and conclusions on age were based on regional geology, lithofacies, unconformities (between the Kildin and Volokov Groups and between the Tanafjord and Vestertana Groups) and on Russian radiometric ages. However, the spread of these radiometric ages is surprisingly large, extending over a time span of > 300 Ma. The ages appear to be the results of single determinations, and this makes their reliability doubtful. On the other hand, the micro-paleontological results presented by Vidal (1981a) have shown that the uppermost Vadsø and the whole of the Tanafjord Group are Early Vendian (? = Kudashian) in age while the micropaleontological data by Timofeev (1969) suggest a Late Riphean age for both the Kildin and the Volokov Groups. This coincides with current views on the age of the Kildin Group (Chumakow & Semikhatov 1981: Fig. 2), but contradicts the claim of a Vendian age for the Volokov Group (cf. Chumakov & Semikhatow 1981: Fig. 2). Correlation between the Volokov Group and the lithostratigraphic units of the Tanafjord–Varangerfjord Region is therefore uncertain. The Kildin Group seems to be equivalent to the bulk of the Vadsø Group and not to the Vadsø and Tanafjord Groups as previously suggested (Siedlecka 1975). Consequently, the Kildin Group could be time-equivalent to the Kongsfjord and Båsnæring Formations rather than to any other younger formation of the Barents Sea Group.

CORRELATION WITH EAST GREENLAND AND SVALBARD

The acritarch assemblages of the Barents Sea Group display consistent taxonomic similarities with assemblages present in the Upper Proterozoic of Central East Greenland and Svalbard as well as with the Upper Proterozoic sequences mentioned above. The Eleonore Bay Group of Central East Greenland was previously correlated with the Barents Sea Group on lithostratigraphic grounds (Siedlecka & Siedlecki 1967, Siedlecki 1975). The upper Eleonore Bay Group yielded Upper Riphean acritarch assemblages and was correlated by Vidal (1981a, 1981b) with the bulk of the Vadsø Group of the Tanafjord–Varangerfjord Region of Finnmark. This correlation, if extended to the Barents Sea Region, would mean that the lower Eleonore Bay Group is a correlative of the lower Kongsfjord Formation. By analogy, the upper Eleonore Bay Group would correspond to the upper Kongsfjord, Båsnæring and basal Båtsfjord Formations.

Acritarchs have recently been discovered in the Middle Hecla Hoek succession of Nordaustlandet (the Murchisonfjorden Supergroup), Svalbard. The Franklinsundet (oldest) and the Celsiusberget Groups of this succession contain acritarch assemblages suggestive of a Late Riphean age, while the Roaldtoppen Group has yielded an assemblage indicating a late Late Riphean age. The acritarch assemblages of the entire succession are clearly comparable with those of the Eleonore Bay Group of East Greenland (Knoll 1981, 1982).

The acritarch assemblage of the overlying, tillite-bearing Gotia Group (basal Upper Hecla Hoek) suggests that the Gotia succession is Vendian (Knoll 1982). The Hundeberg Formation of the Roaldtoppen Group and the Akademikerbreen Group (upper portion of the Middle Hecla Hoek) in Ny Friesland have also ʾielded Upper Riphean stromatolite assemblages (Golovanov & Raaben 1967, ʾemikhatov 1976). Some stromatolite forms suggest a Late Riphean/Vendian age ʾor the top part of the Middle Hecla Hoek in Ny Friesland (Raaben & Zabrodin ʾ972).

The Middle Hecla Hoek of Nordaustlandet (and of other parts of Svalbard as well) shows some similarities to the Barents Sea Group; both rock units exhibit considerable thicknesses and are predominantly terrigenous with carbonates in their upper parts. There are, however, also marked differences: the Middle Hecla Hoek contains columnar stromatolites in its upper part and is overlain by tillites of the Sveanor and Polarisbreen Groups. Both these features are missing in the Barents Sea Group and therefore a straightforward lithostratigraphic correlation is not possible. The Upper Riphean acritarch assemblage of the entire Middle Hecla Hoek (though contradictory to some possibly Vendian stromatolites; see above) suggests that only part of the Barents Sea Group (Kongsfjord, Båsnæring and lowermost Båtsfjord Formation) may, at the moment, be correlated with the Middle Hecla Hoek of Svalbard (Fig. 10).

Our present data have additional implications in that they allow correlation of the above-mentioned Upper Riphean sequences with the bulk of the Chuar Group in Arizona (Vidal, in prep.) dated to 750–800 Ma B.P. (Elston & McKee 1982) and the uppermost part of the time-equivalent Uinta Mountain Group in Utah.

SUMMARY OF THE STRATIGRAPHIC CORRELATIONS

Summing up, the acritarch assemblages of the Barents Sea Group show that:

(1) The Kongsfjord and Båsnæring Formations are Late Riphean in age;

(2) The Lower Båtsfjord Formation is of Late Riphean' to Early Vendian age;

(3) The Riphean/Vendian boundary is close to the boundary between the Båsnæring and Båtsfjord Formation and is most probably located within the lower Båtsfjord Formation.

The above conclusions have important consequences for correlation with Upper Proterozoic strata in other regions:

(a) Correlation with neighbouring succession in North Norway and Russia, which have different developments, suggests that the bulk of the Vadsø Group and the entire Kildin Group are time-equivalent with the greater part of the Barents Sea Group (Kongsfjord, Båsnæring and possibly part of the

Lower Båtsfjord Formation). The Ekkerøy Formation (top of the Vadsø Group) and the Tanafjord Group may be partial time-equivalents of the remainder of the Barents Sea Group. Correlation with the Volokov Group of the Sredniy Peninsula remains uncertain.

(b) Correlation with the Upper Proterozoic succession of Central South Norway shows probable time-equivalence between the turbiditic Brøttum and Kongsfjord Formations and also the overlying Båsnæring Formation. The lower part of the Båtsfjord Formation seems to be approximately equivalent to the Biri/Ring Formation of the Hedmark Group and to the lower upper Visingsö Beds – all being Early Vendian (? = Kudashian) in age.

(c) Correlations with the Upper Proterozoic successions of Svalbard, Central East Greenland and Rybachiy Peninsula, which all have a fairly similar lithostratigraphic development to the Barents Sea Group, suggest that the Kongsfjord and Båsnæring Formations and the lowermost part of the Båtsfjord Formation are time-equivalent to the above-mentioned rock units.

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