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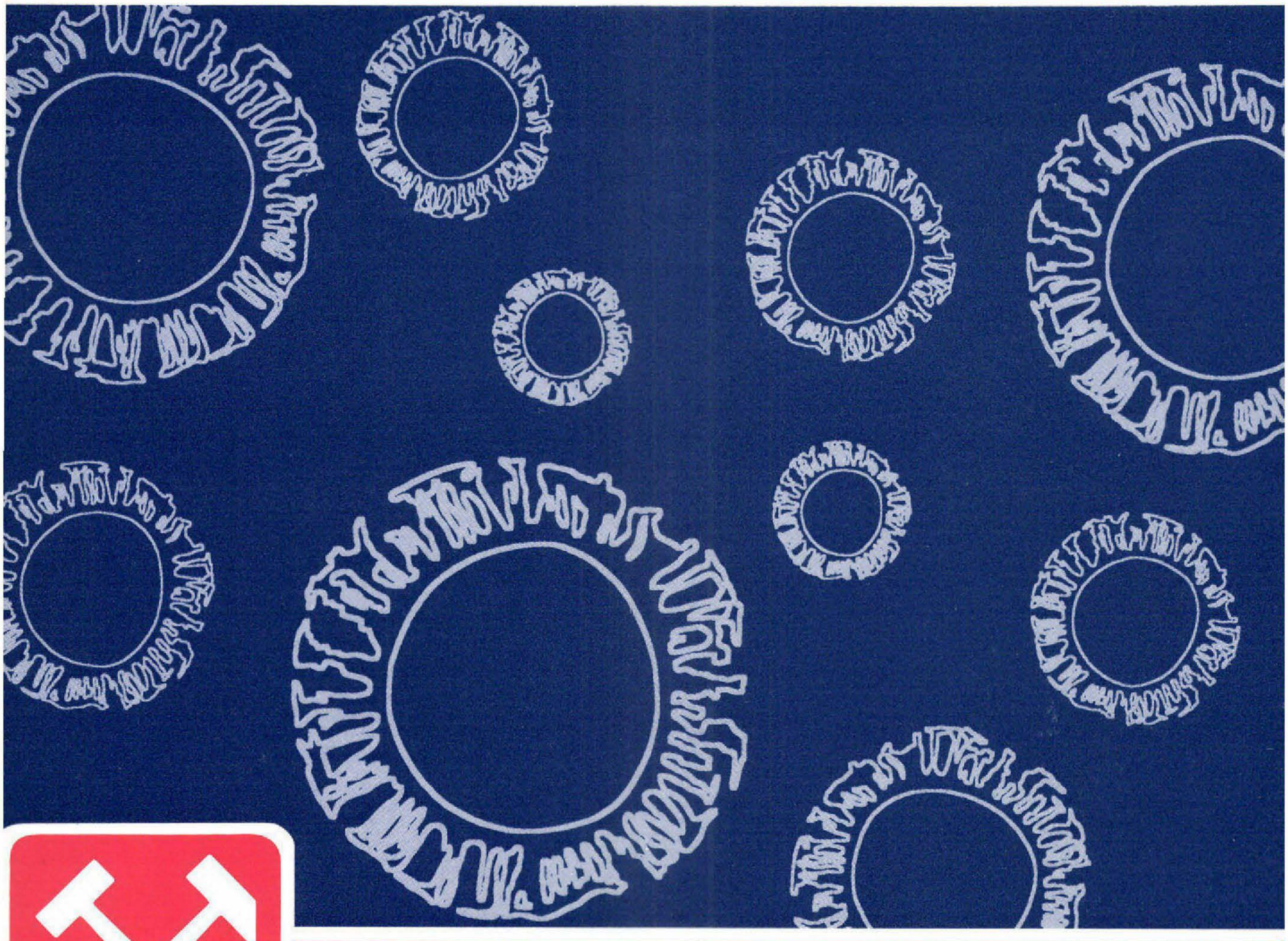

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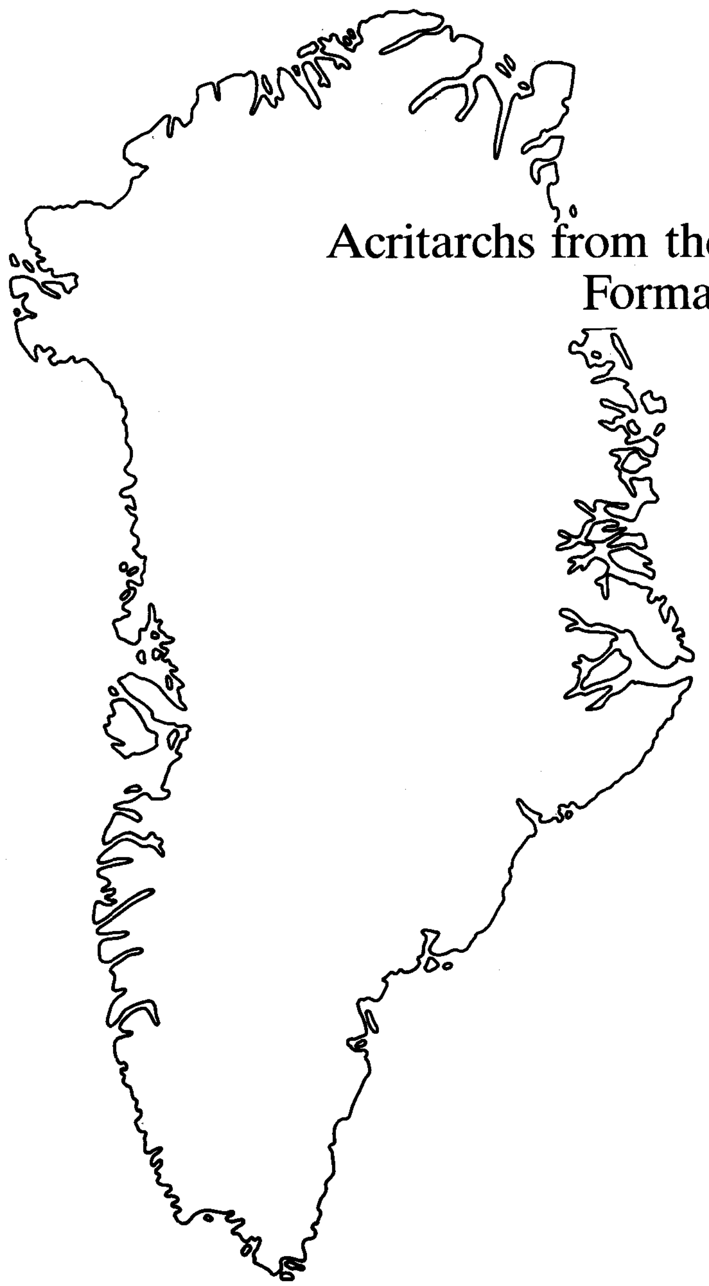

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Acritarchs (organic-walled phytoplankton) are described from the siliciclastic rocks of the Buen Formation. A total of 52 form taxa are reported from a small number of extremely fossiliferous samples from the deeper shelf portion of the formation. The preservation of acritarchs is excellent and, in the light of their abundance, the taphonomy and palaeobiology of the Buen Formation are discussed. Three new acritarch form taxa are erected and two more, obviously also new, are left under open nomenclature. Large-size acanthomorphic acritarchs represented by extremely rare finds of two new taxa (*Comasphaeridium? densispinosum* n. sp. and *Comasphaeridium longispinosum* n. sp.) are recorded for the first time in Lower Cambrian strata. Large acanthomorphs are otherwise important in Neoproterozoic strata and the significance of the present finds is discussed. The remaining acritarchs are known from numerous world-wide earlier occurrences. Comparisons are particularly important and relevant with classical Lower Cambrian rock successions in Baltoscandia, various areas of the East European Platform, Svalbard, Scotland and North-East Greenland. In all, the recovered acritarch assemblage conclusively confirms the previously proposed late Early Cambrian age for the Buen Formation, most likely corresponding to the *Heliosphaeridium dissimilare – Skiagia ciliosa* (= Vergale 'horizon') and perhaps the *Volkovia dentifera – Liepaina plana* (= Rausve 'horizon') acritarch zones in the East European Platform and counterparts in Baltoscandia.

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Geological Survey of Greenland

The Geological Survey of Greenland (GGU) is a research institute affiliated to the Mineral Resources Administration for Greenland (MRA) within the Danish Ministry of Energy. As with all other activities involving the non-living resources in Greenland, GGU's investigations are carried out within the framework of the policies decided jointly by the Greenland Home Rule Authority and the Danish State.

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Contents

Dansk sammendrag

Dette arbejde beskriver acritarcher (fytoplankton med organisk væg) fra Buen Formationen (nedre Kambrium) i Nordgrønland. I alt rapporteres der om 52 arter fra få men særdeles fossilrige prøver, der repræsenterer den dybere del af shelfen i Buen Formationen. På baggrund af det store indhold af velbevarede acritarcher diskuteres formationens tafonomi og palæobiologi. Tre nye arter af acritarcher opstilles, mens to andre, tydeligvis også nye, placeres under åben nomenklatur. Store acantomorfe acritarcher er for første gang registreret i lag fra nedre Kambrium. Disse former er ellers kun beskrevet fra neoproterozoiske aflejringer. De resterende acritarcher kendes fra talrige tidligere forekomster verden over. Det er især vigtigt at sammenligne med de klassiske aflejringer fra nedre Kambrium i Baltoscandia, forskellige områder på den østeuropæiske platform, Svalbard, Skotland og Nordøstgrønland. Acritarch-sammensætningen bekræfter fuldtud den tidligere foreslåede datering af Buen Formationen til den sene del af tidlig Kambrium, højst sansynligt svarende til *Heliosphaeridium dissimilare – Skiagia ciliosa* (= Vergale 'horizon') og måske *Volkovia dentifera – Liepaina plana* (= Rausve 'horizon') acritarch-zonerne på den østeuropæiske platform og tilsvarende zoner i Baltoscandia.

Imaqarnersiuineq

Nalunaarusiami uvani imaani naasuaqqat, acritarchit, Avannaarsuani ujaqqani immikkoortuni Buen Formationimeersut ukiut immikkoortut Kambriumip aallartinnerani pinngorsimasut eqqartorneqarput. Ujaqqani amerlanngikkaluartutuni naasuaqqanilli ujaranngorsimasunik amerlaqisunik akulinni, architarchit immikkoortut 52-t siumorneqarsimapput, taakkulu Buen Formationip atsinnerusortaani nassaarineqarsimapput. Architarcherpassuit ujaranngorsimagaluarlutik ilusaat allanngorsimanngitsut tunngavigalugit qangarsuaq sumi inuusimanerat eqqartorneqarpoq. Architarchit immikkoortut nutaat pingasut suunerat aalajangerneqarsimavoq, allalli marluk qularnanngitsumik nutaajusut suli erseqqissumik taaguuserneqarsimanngillat. Aatsaat siullerpaamik acritarchit annertoqisut ukiut 570 milliunit matuma siornatigut pinngorsimasut allaaserineqarput, taamaattut ujaqqani pisoqaanerusuni taamaallat siornatigut allaaserineqartarsimagamik. Acritarchit sinneri silarsuarmi ujaqqani allarpassuarni siornatigut allaatigineqarsimasuni ilisimaneqarput. Ujaqqat architarchiqarfiusut pingaarnerit 570 milliunit missaanni pisoqaassusillit Baltoscandiami, Europami kangilliup nunavissuani, Svalbardimi, Skotlandimi Tunumilu Avannaarsuani sanilliussallugit pingaartorujussuuvoq. Architarchit assigiinngitsorpassuit ataatsimoortut tunngavigalugit ujaqqat imikkoortut Buen Formationip pisoqaassusaasa Kambriumip aallartinnerani pinngorsimasutut aalajangerneqarsimanerat maannakkut erseqqissumik uppernarsineqarsimavoq.

Introduction

The organic-walled envelopes of presumably motile and/or encysted life stages of Early Palaeozoic protists (Dale, 1977; Tappan, 1980) are among the most abundant fossils in shallow to moderately deep shelf deposits (Downie, 1973). Near the Proterozoic/Phanerozoic boundary eukaryotic plankton underwent a radiation (Moczydłowska & Vidal, 1986) comparable in magnitude to that formerly reported among ichnofossils (Crimes, 1987) and skeletised faunas (Conway Morris, 1987). Assemblages of acritarch taxa which in a geologic perspective, arose and declined rapidly, are becoming increasingly well-known in numerous regions (see Moczydłowska, 1991 for a recent review). Together with shelly faunas, they provide the basis for increasingly refined biostratigraphy which allows the correlation of Early Phanerozoic radiation events. In addition, organic-walled phytoplankton provide valuable information about conditions of deposition and organic diagenesis.

In this paper following previous preliminary reports (Vidal & Peel, 1984; Moczydłowska & Vidal, 1986) we deal with the palaeobiology, taxonomy and biostratigraphy of the abundant acritarchs of the Buen Formation of North Greenland. One additional point of interest circles around the taphonomic significance of acritarchs in the Buen Formation in the light of the previously reported occurrence of an exceptionally preserved fauna of poorly skeletised macrofossils from the same formation (Conway Morris *et al.*, 1987; Conway Morris & Peel, 1990; Peel, 1990; Peel *et al.*, 1992).

Geological framework

The Buen Formation forms part of a southern shelf sequence within the Lower Palaeozoic Franklinian Basin succession of the Canadian Arctic Islands and northern Greenland (Higgins *et al.*, 1991; Surlyk, 1991). This carbonate-dominated shelf sequence unconformably overlies crystalline basement of the Greenland Shield and Proterozoic sedimentary basins to the south. To the north, the shelf sequence passes into an equivalent deep-water trough sequence but the northern margin of this Franklinian Basin succession is poorly constrained.

The Buen Formation contrasts with most units within the Franklinian shelf sequence of northern Greenland in being composed of siliciclastic sediments. This siliciclastic interval can be traced east–west across northern Greenland, either as the Buen Formation itself (Fig. 1) or as the correlative Dallas Bugt Formation and Humboldt Formation of the area around Kane Basin, to the west (Peel 1982; Peel & Christie, 1982).

In central and eastern North Greenland (Fig. 1) the Buen Formation overlies marine platform carbonate sediments of the Portfjeld Formation. The latter formation is poorly fossiliferous but has yielded the cyanobacteria *Spirellus* Jiang, 1982, *Obruchevella* Reitlinger, 1948 and *Jiangispirellus* Peel, 1988 of probable Early Cambrian age (Peel, 1988).

The Buen Formation is overlain by a progradational shelf sequence referred to the Brønlund Fjord Group and the overlying Tavsens Iskappe Group throughout most of central and eastern North Greenland. Strata assigned to these groups form a complex of prograding, diachronous carbonates and subordinate siliciclastic sediments. Shelly macrofossils are conspicuous at many horizons within the two groups and indicate an age from late Early Cambrian to earliest Ordovician.

The Buen Formation varies in thickness from about 425–500 m in its southern outcrop in Peary Land but thins to about half this amount in the small outcrops in northern Freuchen Land and northern Wulff Land (Fig. 1). Farther north, the succession thickens greatly as the formation grades into the turbidite trough sequence of the Polkorridoren Group. Typically, the formation can be divided into a lower sandstone-dominated unit and an overlying recessive unit dominated by mudstones. The sandstone-dominated unit is most prominent in southern outcrops from Wulff Land to southern Peary Land but mudstones dominate in north-east Peary Land and outcrops along the northern coast of Greenland, to the west. The characteristic transition from sandstone-dominated inner shelf deposits to finer grained outer shelf deposits reflects a regional rise in sea level within Buen time.

A section through the formation at its type locality is shown in Fig. 2 and most samples processed for acritarchs in the present study were either derived from this section or from outcrops close by. The lower sandstone-dominated unit contains strata interpreted as inner shelf

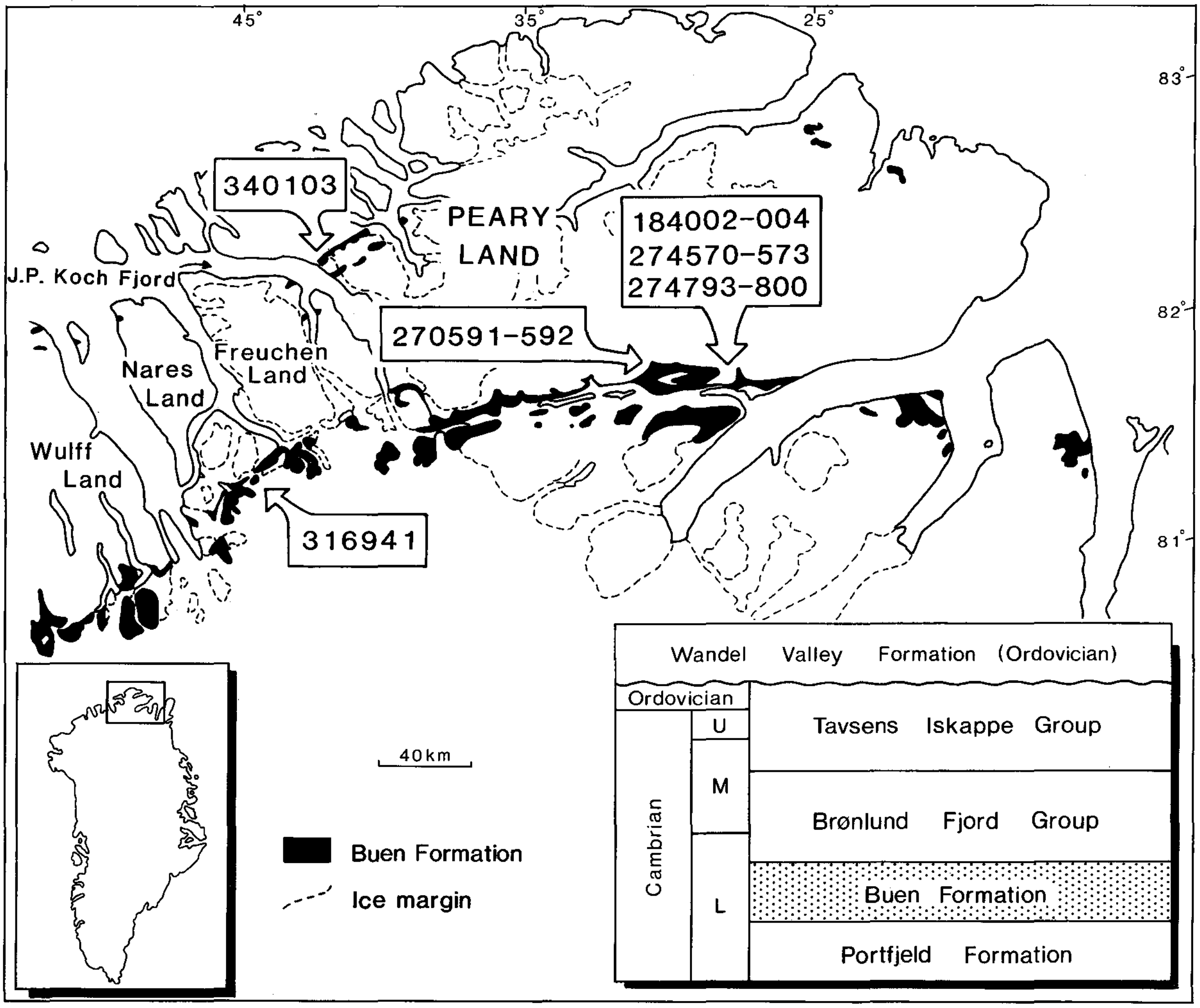


Fig. 1. Outcrops of the Buen Formation in central North Greenland showing the derivation of fossiliferous samples.

and tidal deposits. The abrupt sedimentological change from sandstone domination to mudstone at about 270 m above the base of the section indicates maximum transgression of the shelf and the establishment of a deep shelf environment. Subsequent strata are mudstone-dominated, with thin beds of storm deposited sandstones; they represent a sequence shallowing to inner shelf environments but not as shallow as the sandstone-dominated lower unit of the formation. A detailed sedimentary profile through the lower part of the formation in the un-named land area south of Nares Land (locality for GGU 316941 in Fig. 1) was presented by Bryant & Pickerill (1990, fig. 2).

The lower sandstone-dominated unit of the Buen Formation in southern outcrops has not yielded macrofossils, although trace fossils have been described by Bryant & Pickerill (1990). In the vicinity of the type locality in southern Peary Land, well preserved and abundant macrofossils occur within the deep shelf mudstones from the same samples as those yielding acritarchs in the present investigation (e.g., GGU samples 184002–184004; GGU 270591–270592). Olenellacean trilobites include *Olenellus hyperboreus* (Poulsen, 1974), associated with hyolithids, bradoriids. *Pelagiella, Hyolithellus* and inarticulate brachiopods (cf. Poulsen, 1974; Palmer & Peel, 1979). *Olenellus* is also reported from the highest beds of the formation in eastern Peary Land (Palmer & Peel, 1979), while Bergström & Peel (1988) described trace fossils from the same interval in southern Peary Land.

In north-western Peary Land (Fig. 1, GGU 340103) outer shelf mudstones in the lower part of the Buen Formation have yielded a rich fauna of poorly skeletised macrofossils associated with the nevadiid olenellacean *Buenellus higginsi* Blaker, 1988. The fauna is dominated by arthropods and worms, the latter including articulated halkieriids (Conway Morris *et al.*, 1987; Conway Morris & Peel, 1990; Peel, 1990; see also Blaker, 1988). Acritarchs have not been recovered from this locality.

Sample register

The relative stratigraphic position of samples processed for acritarchs is indicated in Fig. 2.

GGU 184002–184004: Buen Formation at Brillesø, east side of the valley of Børglum Elv, southern Peary Land, a few kilometres north-east of the type locality of the formation (cf. Figs 1, 2). Samples collected by J. S. Peel, 1974.

GGU 270591, 270592: Buen Formation on the northern side of Sæterdal, southern Peary Land, about 20 km west of the type locality (cf. Figs 1, 2). Samples collected by J. S. Peel, 1978.

GGU 274793–274800, 274570–274573: Buen Formation at its type locality, north side of Jørgen Brønlund Fjord, immediately west of the mouth of Børglum Elv in southern Peary Land (Figs 1, 2). Samples collected by H. A. Armstrong and J. R. Ineson, 1980.

GGU 340103: Lower Buen Formation, Sirius Passet, northwest Peary Land (Fig. 1). Collected by S. Conway Morris and J. S. Peel, 1989.

GGU 316941: 54.8 m above the base of the Buen Formation, un-named land area south of Nares Land (see Figs 1, 2). Collected by I. D. Bryant, 1984 (see Bryant & Pickerill, 1990).

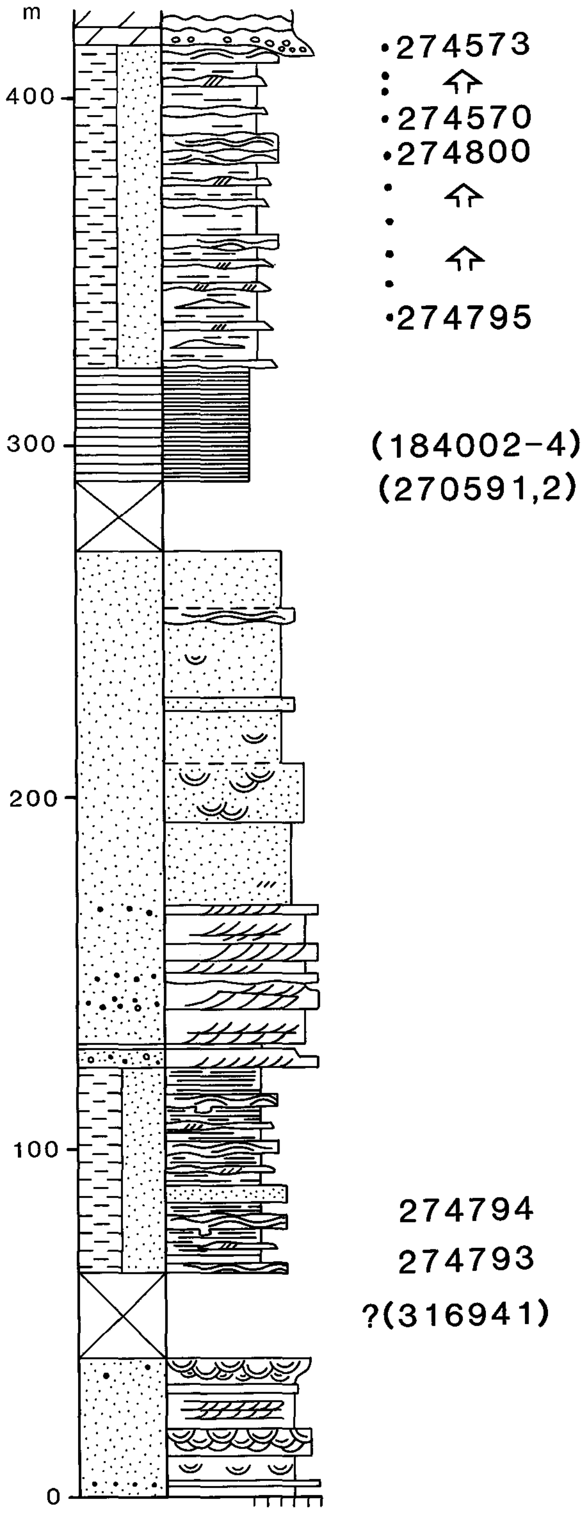


Fig. 2. Section through the Buen Formation at its type locality, west of the mouth of Børglum Elv on the northern shore of Jørgen Brønlund Fjord, southern Peary Land, showing the location of GGU samples. Numbers in brackets indicate samples collected at other localities (see Fig. 1) and correlated with the type section. The succession shows two shallowing-up cycles. The lower part of the section (0–270 m) represents an inner shelf succession characterised by storm beds which are succeeded at about 120 m by sediments showing a tidal influence. Deep shelf mudstones (*c.* 270–325 m) represent the period of maximum transgression of the shelf; subsequent sediments indicate shallowing to inner shelf conditions, but not as shallow as the lower cycle.

Taxon	GGU 316 941	GGU 270 592	GGU 270 591	GGU 184 002	GGU 184 003	GGU 184 004	GGU 274 795	GGU 274 796	GGU 274 797	GGU 274 798	GGU 274 799	GGU 274 800	GGU 274 570	GGU 274 571	GGU 274 572	GGU 274 573A	GGU 274 573B
Leiosphaeridia sp.	●		●	●	●	●	●		●		●	●		●	●		●
Trachysphaeridium timofeevi	●						●			●						●	
Skiagia ornata		●	●	●	●	●	●	●	●		●	●	●	●			
Comasphaeridium mackenziana			●	●	●								●	●			
Comasphaeridium molliculum			●				●										
Leiovalia tenera			●	●													
Skiagia ciliosa type A			●	●	●	●		●	●	●	●	●	●	●	●	●	●
Skiagia ciliosa type B			●			●							●	●	●		
Comasphaeridium ? *densispinosum* n. sp.				●	●	●											
Comasphaeridium longispinosum n. sp.						●											
Comasphaeridium sp. A Downie						●				●			●	●			
Comasphaeridium strigosum						●		●	●		●	●	●	●	●		●
Cymatiosphaera sp.						●	●	●			●						
Granomarginata squamacea				●		●											
Heliosphaeridium dissimilare				●	●	●	●	●	●		●		●	●			
Heliosphaeridium obscurum				●		●											
Heliosphaeridium sp.						●	●										
Lophosphaeridium truncatum						●		●									●
Pterospermella sp.						●											
Retisphaeridium dichamerum				●	●	●		●		●	●	●					
Comasphaeridium cf. *strigosum*					●				●					●			
Comasphaeridium spp.				●	●						●						
Goniosphaeridium varium					●												
Skiagia scottica				●	●		●	●	●		●	●	●	●	●		
Asteridium ordensis				●													●
Asteridium lanatum				●				●			●		●	●			
Cymatiosphaera postii											●			●			
Elektoriskos sp. A.				●													
Goniosphaeridium sp. A.								●									
Goniosphaeridium volkovae				●													
Heliosphaeridium coniferum				●				●									
Lophosphaeridium tentativum				●				●									
Skiagia orbiculare				●			●	●	●				●		?		●
Skiagia compressa							●	●	●			●	●	●	●		●
Archaeodiscina umbonulata								●									
Fimbriaglomerella membranacea								●									
Fimbriaglomerella minuta								●									
Globosphaeridium cerinum								●					●				
Goniosphaeridium primarium								●									
Lophosphaeridium dubium								●					●	●			
Multiplicisphaeridium dendroideum								●	●			●					
Tasmanites bobrowskae								●	●		●	●	●	●			
Tasmanites tenellus								●				●					
Heliosphaeridium lubomlense									●								
Tasmanites volkovae									●				●				
Heliosphaeridium notatum										●							
? *Celtiberium geminum*											●						
Dictyotidium perforatum n. sp.											●	●					
Dictyotidium priscum												●					
Skiagia ciliosa type C													●				
Comasphaeridium agglutinatum														●			
Asteridium tornatum														●			
Goniosphaeridium sp.					●									●			
Lophosphaeridium sp.																	●

Fig. 3. Chart showing the occurrence of acritarchs in processed samples from the Buen Formation.

Material and methods

Spot samples and samples collected from stratigraphic sections through the Buen Formation are included in this study. Acid-resistant organic-walled residues were isolated from a total of 20 samples using a method fully described by Vidal (1988). Sixteen samples proved fossiliferous, a figure that by any accounts is to be considered as a very high yield.

Acritarch preservation

The preservation of acritarchs and other organic microfossils in the investigated samples is generally good to excellent. The most productive samples (e.g. GGU samples 184002–184004, 274570–274572, 274795–274799) are rich in yellowish to brown, granular or flaky, organic sapropel. Compaction and flattening of microfossils is moderate and certain samples (notably GGU 184004 and 274571, 274796, 274797) yielded three-dimensionally preserved acritarchs. The reason for this is unclear, but comparable preservation has been observed elsewhere in Lower Cambrian rocks with high phosphate contents (Mcczydłowska & Vidal, 1992). It cannot be excluded that the investigated black mudstones and shales may include early diagenetic phosphatised portions, thus accounting for the unusually good preservation of acritarchs. but such intervals have not been detected.

The colour of acritarchs, cyanobacterial microfossils and amorphous organic matter ranges from light yellow to brown and this suggests thermal alteration index (TAI) values around 2 to 2+ (immature to mature; Pearson, 1984). These data are in agreement with a thermal alteration corresponding to temperatures between 50 and <150°C. Exceptionally, one sample (GGU 340103) of thinly laminated black pyritous shale yielded dark-grey to black bacterial microfossils and sapropel-like organic debris indicating thermal alteration (TAI 4− to 4) in the order of 200°C or higher. This sample, collected from the locality in Sirius Passet, northern Peary Land, which yield the poorly skeletised fauna described by Conway Morris *et al.* (1987) and Conway Morris & Peel (1990) lies on the southern margin of the North Greenland fold belt (Dawes, 1976; Higgins *et al.*, 1991). The higher degree of thermal alteration reflects metamorphism associated with the fold belt.

Taphonomy and palaeobiology

It appears possible that the accumulation of Early Palaeozoic acritarchs may have followed patterns comparable to those of the geologically more recent phytoplankton groups (Knoll, 1985), such as dinoflagellates (Evitt, 1985; Vidal & Nystuen, 1990a).

Despite generally low Total Organic Carbon (TOC) values around 0.1%, (except the above mentioned sample 340103 with TOC 2.0%) finely laminated and carbon-rich rocks from the Buen Formation yield large amounts of organic sapropel and acritarchs that seem to bear witness of quiet water conditions and slow deposition. Thus for example, sapropel A is believed to form in low energy lacustrine or marine environments where abundant organic matter accumulates under restricted circulation and dysaerobic conditions (Staplin *et al.*, 1973, cited in Venkatachala, 1981).

As pointed out above (see Geological framework) an abrupt sedimentological change is observed from the lower sandstone to the upper mudstone-dominated portion of the Buen Formation. These changes correlate well with the recorded lack, respectively abundance, of macrofossils and microfossils. Thus, except for ichnofossils (Bryant & Pickerill, 1990), the dominantly arenaceous portions of the investigated section (Fig. 2) are barren, whereas the deeper shelf mudstones (samples GGU 274796, 274797, 274800, 274570; Figs 2, 3) yield abundant acritarchs (Vidal & Peel, 1988); rich shelly faunas are best known from the deepest part of the succession (e.g. GGU samples 184002–4; Poulsen, 1974; Palmer & Peel, 1979). Furthermore, the frequency of discrete palynomorph taxa varies considerably in the investigated samples and certain taxa (e.g.

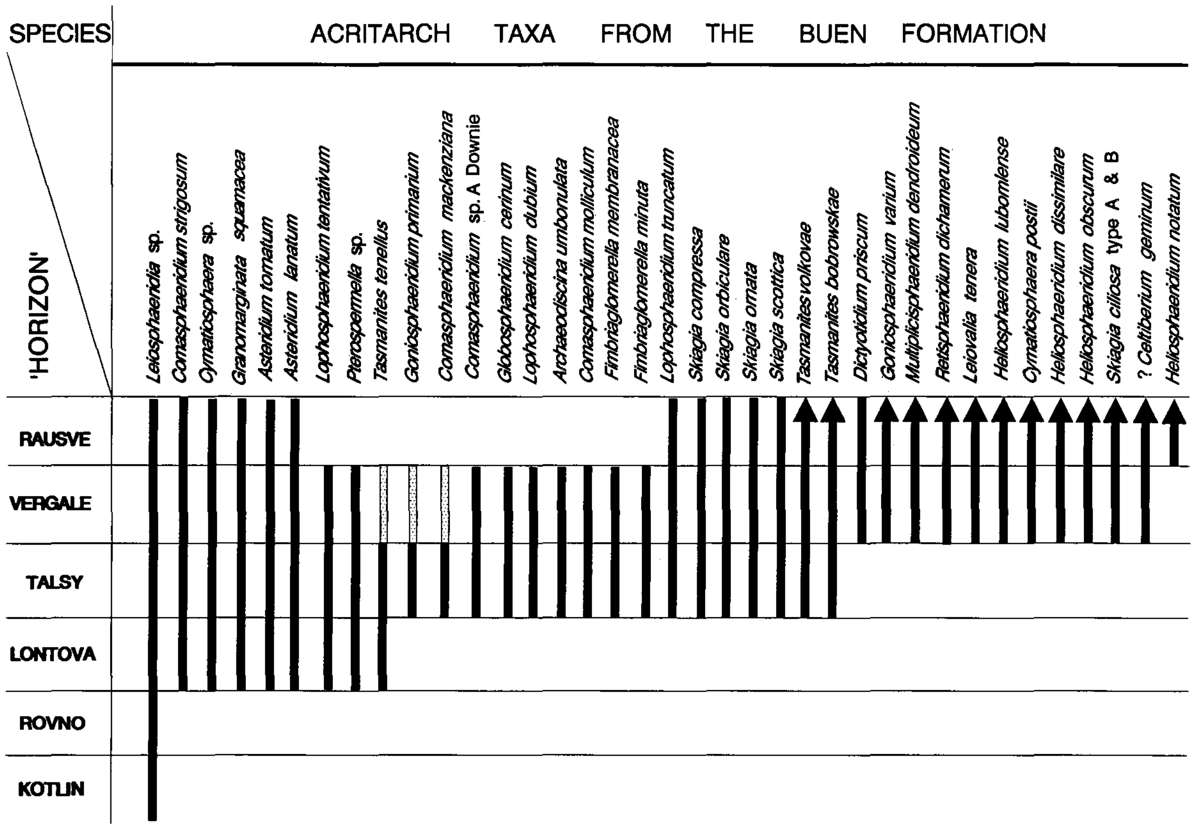


Fig. 4. Stratigraphic ranges of acritarchs in samples from the Buen Formation according to previous occurrences in various parts of the East European Plątform (Volkova *et al.*, 1983; Moczydłowska, 1991). Taxa with stratigraphically poorly constrained ranges are omitted.

Skiagia ornata, S. ciliosa, S. scottica form the bulk of the total palynomorph population in most samples. In terms of the taxonomic diversity among acritarchs, the Buen Formation is roughly comparable to the diversity recorded in time-equivalent Early Cambrian rock units in Baltoscandia (Eklund, 1990; Hagenfeldt, 1989; Moczydłowska & Vidal, 1986; Moczydłowska, 1991).

Lower Cambrian units in Baltoscandia represent deposition in pericratonic basins under generally shallow water conditions as demonstrated by the abundance of sedimentary rocks displaying various features indicating shallow shelf to littoral deposition (cf. Eklund, 1990; Vidal & Nystuen, 1990b). Although abundant phytoplankton can be recovered from generally shallow marine sequences (Moczydłowska & Vidal, 1992), a general trend towards decreasing taxonomic diversity is pervasive in littoral sequences (Vidal & Nystuen, 1990a; Palacios & Vidal, 1992) as compared to contemporaneous deeper shelf settings. Depositional settings and post-burial degradation processes are of extreme importance for the preservation potential of delicate organic-walled remains (Butterfield, 1990).

Rocks of the Buen Formation at Sirius Passet in north-western Peary Land (GGU 340103 in Fig. 1) yield a fauna of arthropods, worms, sponges and halkieriids (Conway Morris *et al.*, 1987; Conway Morris & Peel, 1990; Peel, 1990; Peel *et al.*, 1992). One single processed sample (GGU 340103) from this important locality yielded only thermally altered possibly bacterial microfossils attributed to *Sphaerocongregus variabilis* Moorman, 1974 that have been interpreted as probable cyanobacteria (Knoll & Swett, 1985; Moorman, 1974; Mansuy & Vidal, 1983) or photosynthetic anoxygenic bacteria (Vidal & Nystuen, 1990a). Interestingly, and parallel to well-studied dysaerobic late Neoproterozoic basins in Spain (Palacios, 1989) and Baltoscandia (Vidal & Nystuen, 1990a), acritarchs are also absent from this fossiliferous Buen sample (GGU 340103). Other records of exceptionally preserved Cambrian faunas share with the Buen Formation the probably significant feature of occurring in 'deeper water shales' (Conway Morris, 1987). A detailed study of organic, non-mineralising organisms in the Burgess Shale (Butterfield, 1990) revealed that the Burgess Shale, contrary to the present case, yields abundant leiosphaerid and rare papillose (Butterfield, 1990) and small spiny acritarchs (Vidal, unpublished observation). Furthermore, Butterfied (1990) concluded that carbon isotopic values for the Burgess Shale reflect normal conditions. No such data are available for the Buen Formation. The investigated Buen sample comes from a succession where bioturbation is present in certain beds, but the soft bodied fauna is collected from laminated horizons with only a few horizontal burrows in part of the section where bioturbated and non-bioturbated horizons alternate. It can be concluded that the presence of abundant organic matter and pyrite in the investigated sample from north-western Peary Land and the recovered biotas are consistent with sparse bioturbation, enhanced carbon burial and perhaps oxygen-depleted bottom water.

In this context, the contrasting abundance of acritarchs in the mudstone-dominated deeper shelf portion of the Buen Formation in more southern outcrops is here seen as indicating a preserved sample of accumulated encysted and/or motile life stages of algal protists. This feature may indicate accumulation in organic-rich sediments overlain by nutrient-rich oxic waters in the mixed layer or, alternatively represent the accumulated phytoplankton that occupied productivity 'hot spots' in denitrified anoxic waters along the narrow chemical gradients at the boundary of the oxygen-minimum zone (Berry *et al.*, 1989). The latter has existing parallels in blooms produced by dinoflagellates under conditions suitable to denitrification (Eppley *et al.*, 1969).

Proposed anoxitropy, implying anoxic conditions beneath the wind-mixed surface layer, in Early Palaeozoic oceans could accommodate conditions involving high productivity (as implied by the rich acritarch record) and a fair preservation potential in the offshore 'black shale' facies (Berry *et al.*, 1989).

Large acanthomorphic acritarchs

Rare specimens of large (90–180 μm in vesicle diameter) acanthomorphic acritarchs (Fig. 6a, c, d) occur in GGU samples 184002–184004 from the Buen Formation (Fig. 3). Generally, acritarchs average between 50 and 100 μm (Tappan, 1980), although the normal range of Early Palaeozoic non-tasmanitid acritarchs is about 5–100 μm. By contrast, morphologically diagnostic large (>100 μm) acanthomorphic acritarchs, although generally rare, appear widespread in Neoproterozoic sequences (Awramik *et al.*, 1985; Butterfield *et al.*, 1988; Jankauskas, 1979; Keller & Jankauskas, 1980; Knoll & Ohta, 1988; Knoll, 1984; Knoll & Calder, 1983; Knoll *et al.*, 1991; Pjatiletov & Rudavskaya, 1985; Vidal, 1990; Yin, 1985; Zang, 1988; Zang & Walter, 1989). In general (although often imprecisely expressed) the within-sample numbers of large acanthomorphs in late Proterozoic occurrences are low (Zang Wenlong, V. A. Rudavskaya, personal demonstration, 1990; M. Moczydłowska, G. Vidal & V. A. Rudavskaya, unpublished data), often amounting to a few specimens in a normal palynological sample. This feature has a parallel in the notable rarity of large acanthomorphs in the present Early Cambrian material. Small or large, acanthomorphic acritarchs are generally rare in Late Proterozoic successions but the rarity of the large acanthomorphs must be considered as puzzling when compared with the vast numbers of accompanying 'normal size' (*c.* 5–70 μm) typical Early Cambrian taxa.

Certain Proterozoic and Early Palaeozoic acritarchs (e.g. *Tasmanites, Baltisphaeridium* and *Veryhachium*) were compared to the phycoma stages of prasinophycean green algae (Jux, 1971; 1975) on the basis of their wall ultrastructure. Such studies have not been applied to Neoproterozoic and Early Cambrian acritarchs, although the incremental growth pattern of the prasinophycean phycomata from an initial size of about 10 μm to about 100–175 μm at a mature stage (Tappan, 1980), as compared to the dimensions and growth patterns of some Neoproterozoic species of large acanthomorphs, are supposed to indicate possible prasinophycean affinity (Knoll *et al.*, 1991; Vidal, 1990).

The large acanthomorphs from the Buen Formation (Fig. 6a, c, d) have processes and other morphological features that are present among typically Lower Cambrian smaller counterparts. Here, because they display distinctive morphologic attributes (apart from their larger dimensions), they are attributed to different taxa. Their presence in only three of the investigated samples that apparently do not differ from other processed samples is puzzling, but probably not more so than the presence or absence of 'normal' Cambrian-type taxa in the same samples (see Moczydłowska & Vidal, 1992 for a discussion on related subjects).

	Biozones (after Moczydłowska, 1989)			Rock units	
	Scandinavia	USSR acritarch 'horizons'	Poland Biozones	Poland Lublin slope	S. Sweden Östergötland
M. C.	ECCAPARADOXIDES OELANDICUS	Kibartai	E. OELANDICUS	Kostrzyn Fm	OELANDICUS mudst glauconite sst
Lower Cambrian	PROAMPYX LINNARSSONI	Rausve	PROTOLENUS	Radzyn & Kaplonosy Fms	Lingulid Sandstone
	HOLMIA KJERULFI grp HOLMIA INUSITATA	Vergale	HOLMIA		MICKWITZIA Sandstone
	MOBERGELLA SCHMIDTIELLUS RUSOPHYCUS	Talsy	SCHMIDTIELLUS		
	PLATYSOLENITES ANTIQUISSIMUS	Lontova	PLATYSOLENITES	Mazowsze Fm	
PreC.	SABELLIDITES CAMBRIENSIS	Rovno	SABELLIDITES-VENDOTAENIA	Włodowa Fm	
		'Kotlin'		Lublin Fm	

Biostratigraphy

From previously reported macrofossil finds (Palmer & Peel, 1979; Poulsen, 1974), the age of the Buen Formation can be conclusively established as late Early Cambrian (Bryant & Pickerill, 1990). The acritarch assemblage recovered from the Buen Formation compares well with assemblages from Early Cambrian successions in the East European Platform, Baltoscandia (Eklund, 1990; Hagenfeldt, 1989; Moczydłowska, 1991; Moczydłowska & Vidal, 1986; Vidal & Nystuen, 1990b; Volkova *et al.*, 1983), Scotland (Downie, 1982), Spain (Palacios & Vidal, 1992; Gamez *et al.*, in press); Svalbard (Knoll & Sweet, 1987), central East Greenland (Downie, 1982; Moczydłowska & Vidal, 1986) and Canada (Baudet *et al.*, 1989; Figs 3–5).

No age diagnostic microfossils were recovered from samples from the lower arenaceous part of the Buen Formation. Investigated samples from the upper part of the Buen Formation are generally rich in phytoplankton, although some samples from the mudstone-dominated deep shelf portion are also poorly fossiliferous (particularly GGU samples 270591–270592; Figs 2, 3). In the light of the distribution of acritarchs in the above mentioned areas, most of the upper mud-dominated member thus appears to be of Vergale age (*Heliosphaeridium dissimilare – Skiagia ciliosa* acritarch zone; Moczydłowska, 1991). However, this assumption may imply stratigraphic extended ranges for three species (*Tasmanites tenellus, Goniosphaeridium primarium,* and perhaps *Comasphaeridium mackenziana* (as indicated in Fig. 4). In the case of the latter species the previously established range is poorly constrained.

The 3 specimens of *H. notatum* in GGU sample 274798 could perhaps suggest that a part of the investigated succession may as well be of Rausve age (equivalent to the *Volkovia dentifera – Liepaina plana* acritarch zone; Moczydłowska, 1991), although it could alternatively have an earlier appearance in the Buen Formation.

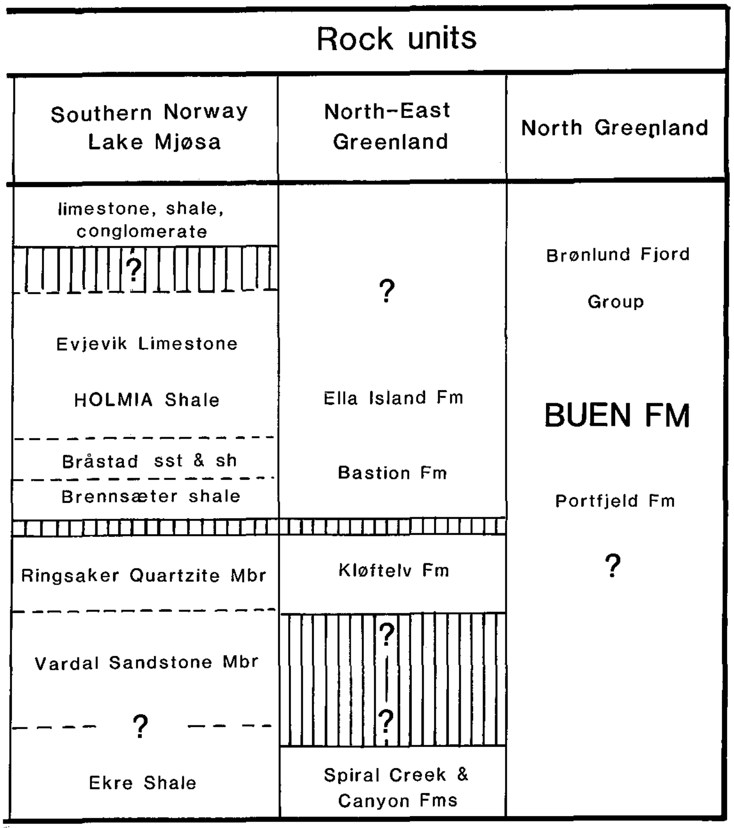


Fig. 5. Suggested biostratigraphic correlation of the Buen Formation in the context of Lower Cambrian biozonation for the East European Platform and Baltoscandia and suggested correlations of rock successions in North-East Greenland.

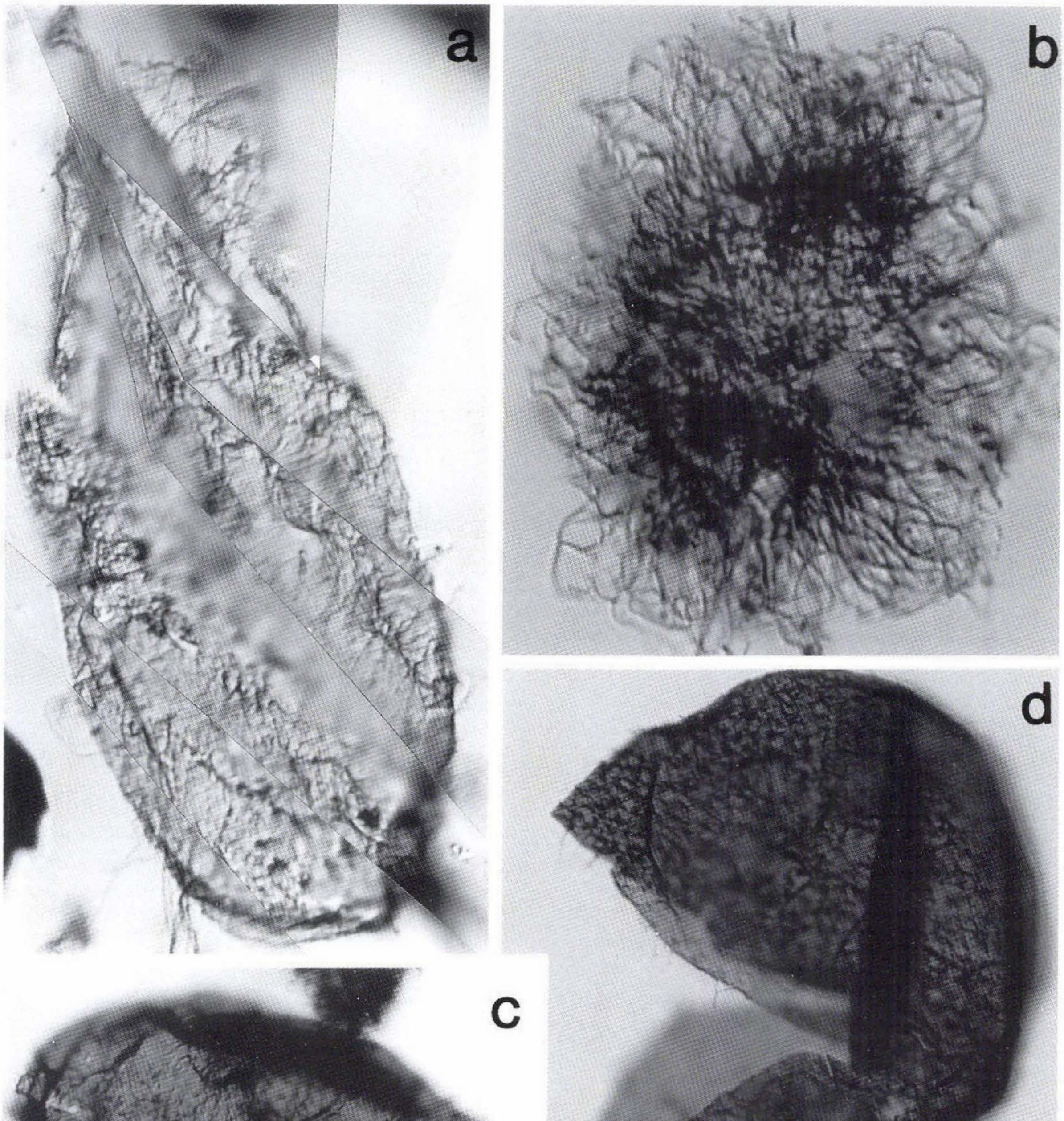
Conclusions

Acritarchs are extremely abundant and quite well-preserved in deeper shelf mudstones (Figs 2, 3) of the Buen Formation. Individual abundance and taxonomic diversity are substantially lower following a shallowing-up trend to alternating fine-grained sandstone and siltstone of inner shelf facies (Figs 2, 3). By contrast, GGU samples 274793–274794 from mudstones, interpreted as inner shelf storm beds (Figs 2, 3), are totally barren. This seems in agreement with previously observed trends of decreasing taxonomic diversity in littoral sequences as compared to contemporaneous deeper shelf settings.

High taxonomic diversity (as recorded in GGU samples 274570–274571, 274796–274800, 184002–184004) correlates positively with the presence of organic sapropel. This latter feature appears to be in agreement with suggested quiet water conditions and slow deposition resulting in the accumulation and preservation of abundant organic matter, perhaps under restricted circulation and dysaerobic conditions (see above).

Large-size (vesicle diameter 90–180 μm) acanthomorphic acritarchs occur in small numbers (GGU samples 184002–184004) in the deep shelf portion of the Buen Formation. These acanthomorphs are here described as two new species of the acritarch genus *Comasphaeridium*. As it is the case with large Neoproterozoic acanthomorphs, they are rare components among the small to normal size (vesicle diameter 5–70 μm) characteristic Early Cambrian acritarch taxa in the Buen Formation.

By inference with the stratigraphic ranges of acritarchs elsewhere, the investigated upper mud-dominated member of the Buen Formation may be correlated with rocks of the *Heliosphaeridium dissimilare – Skiagia ciliosa* acritarch zone (Vergale 'horizon') and perhaps the *Volkovia dentifera – Liepaina plana* acritarch zone (Rausve 'horizon'; Fig. 5).



Taxonomy

The Buen Formation has yielded a rich and diverse acritarch assemblage including species of *Archaeodiscina, Asteridium, Comasphaeridium, ?Celtiberium, Cymatiosphaera, Dictyotidium, Elektoriskos, Fimbriaglomerella, Globosphaeridium, Goniosphaeridium, Heliosphaeridium, Leiosphaeridia, Leiovalia, Lophosphaeridium, Multiplicisphaeridium, Pterospermella, Retisphaeridium, Skiagia* and *Tasmanites.* These form genera comprise 52 form taxa, of which 9 are only identified at the form-genus level (Fig. 3).

The taxonomy of Early Cambrian acritarchs is based on gross morphological features and elements of ornamentation such as processes. Recent work on Early Cambrian acritarchs (e.g. Downie, 1982; Moczydłowska, 1988, 1991; Moczydłowska & Vidal, 1988; Volkova *et al.*, 1983) has resulted in a satisfactory state of taxonomic stability and understanding. Consequently, to avoid unnecessary repetition, in this paper we refrain from providing a complete taxonomic treatment of previously known taxa; these are only briefly described. More or less complete and recent synonymies, taxonomic information and geographic and stratigraphic distributions can be retrieved from papers by Downie (1982), Hagenfeldt (1989), Knoll & Sweet (1987), Moczydłowska & Vidal (1988), Moczydłowska (1988), Volkova (1968, 1981a, 1981b) and Volkova *et al.* (1983). The most recent and complete source of information can be found in Moczydłowska (1991).

Collection numbers prefixed by GGU refer to samples collected by the Geological Survey of Greenland. Figured specimens with numbers prefixed MGUH are kept in the Geological Museum, University of Copenhagen.

Dimensions are generally based on measurements of the best preserved material available and are given as the number of specimens (N), mean ($\bar{x}$) for vesicle diameter and process length and (σ) for standard deviation.

Fig. 6. Acritarchs from the Buen Formation, North Greenland. a, *Comasphaeridium longispinosum* n. sp., MGUH 21.516: H/46 from GGU sample 184004–B: 1, holotype. b, *Comasphaeridium* cf. *strigosum* (Jankauskas) Downie, 1982, MGUH 21.517: Y/35–4 from GGU sample 184003: 1. c, d, *Comasphaeridium? densispinosum* n. sp., specimen at c, MGUH 21.518: E/36–4 from GGU sample 184002: 1; specimen at d, MGUH 21.519: Z/47–3 (below) from GGU sample 184003: 1, holotype. Bar under c represents 10 μm for a, c; 4 μm for b and 16 μm for d.

Archaeodiscina umbonulata Volkova, 1968

Fig. 11e

This is represented by a single well-preserved specimen recovered from GGU sample 274796. Previous occurrences are given in Hagenfeldt (1989) and Moczydłowska & Vidal (1986).

Asteridium Moczydłowska 1991

The genus *Asteridium* Moczydłowska, 1991 is represented in the Buen Formation by *Asteridium lanatum* (Volkova, 1969) Moczydłowska, 1991, *A. (= Micrhystridium) ordensis* (Downie, 1982) comb. nov. and *A. tornatum* (Volkova, 1968) Moczydłowska, 1991.

Asteridium lanatum (Volkova, 1969) Moczydłowska, 1991

Asteridium lanatum (Volkova, 1969) Moczydłowska, 1991 occurs in small numbers in several samples from the Buen Formation (Fig. 3). The dimensions of well preserved specimens indicate vesicle diameter $\bar{x}$ = 10.8 μm (N = 8) and process length $\bar{x}$ = 0.7 μm (N = 8). This taxon was selected by Moczydłowska (1991) as type species of the new form-genus *Asteridium,* thus transferring several species previously attributed to the form-genus *Micrhystridium* (Deflandre, 1937) Sarjeant, 1967 to the new form-genus. Previous occurrences were recently listed by Hagenfeldt (1989) and Moczydłowska (1991).

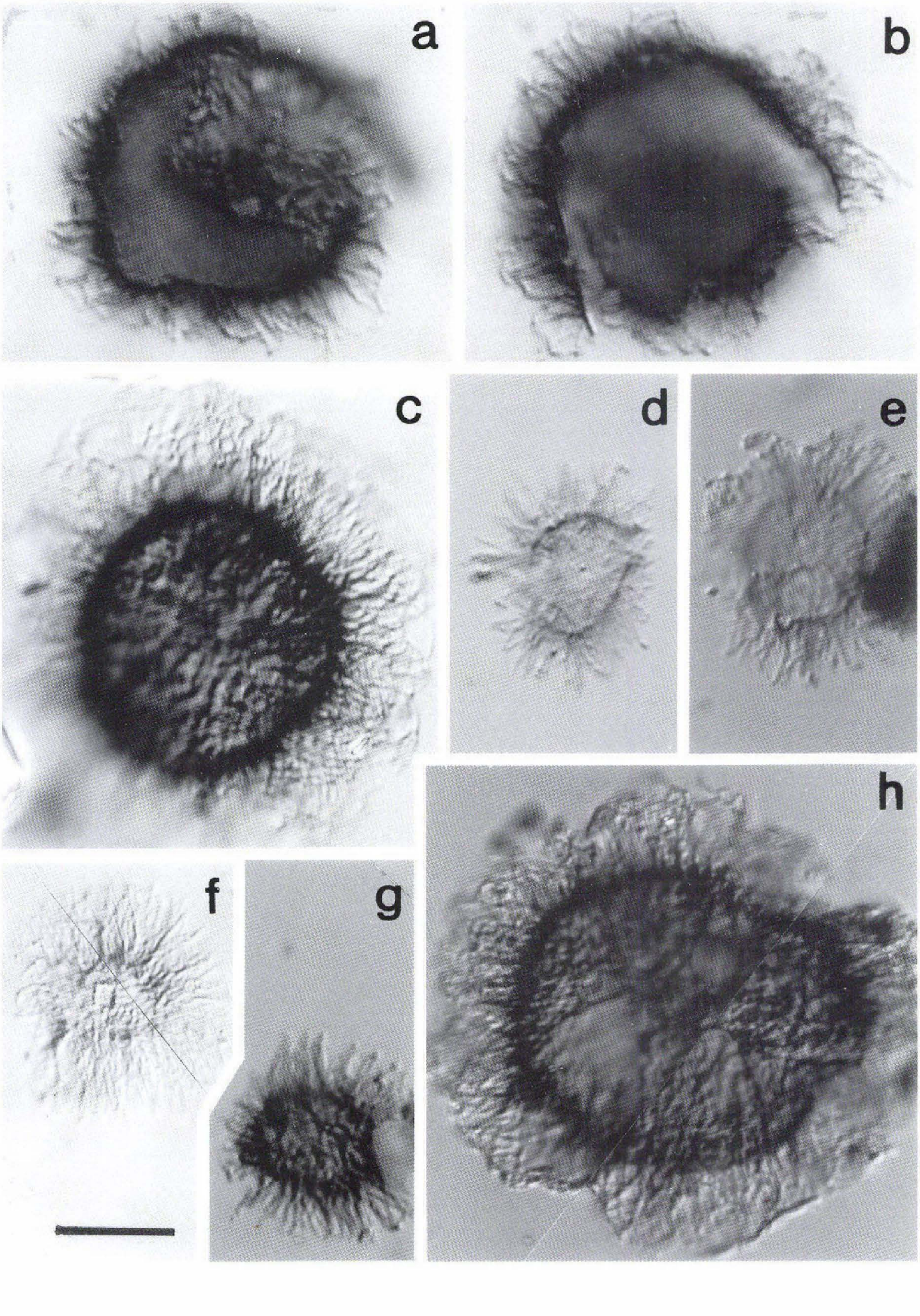
Asteridium ordensis (Downie, 1982), comb. nov.

Fig. 9b

1982 *Micrhystridium ordensis* sp. nov. Downie, p. 262, figs 6ff-hh, 7a.

Material. Four well-preserved specimens.

Emended diagnosis. Organic-walled spheroidal vesicle with numerous medium length, straight, thin processes of equal width with blunt distal ends.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Remarks. The morphotype attributed by Downie (1982) to *Micrhystridium ordensis* displays morphological attributes established to the form-genus *Asteridium* Moczydłowska, 1991. *A. ordensis* differs from other species of the genus by its straight, widely-spaced and more robust processes, with blunt distal ends.

Dimensions. Vesicle diameter 7–8 μm, process length 1.5–4 μm.

Occurrence and stratigraphic range. Lower Cambrian Buen Formation of North Greenland (Figs 3, 4). Lower Cambrian Fucoid Beds in Scotland, Bastion Formation in North-East Greenland, Gog Formation and Mt. Whyte Formation in Alberta, Canada.

Asteridium tornatum (Volkova, 1968) Moczydłowska, 1991

Fig. 9a

Asteridium tornatum (Volkova, 1968) Moczydłowska, 1991 is rare in the investigated samples from the Buen Formation (Fig. 3). It consists of organic-walled circular to oval vesicles 8–21 μm in diameter covered by evenly distributed short, thorn-like processes 1–2 μm in length. Previous occurrences were listed by Volkova (1969a, b), Volkova *et al.* (1979) and Moczydłowska (1991).

Fig. 7. Acritarchs from the Buen Formation, North Greenland. a–b, *Comasphaeridium molliculum* Moczydłowska & Vidal, 1988, two focal levels, MGUH 21.520: K/46–4 from GGU sample 274795: A1. c, h, *Comasphaeridium* cf. *strigosum* (Jankauskas) Downie, 1982, specimen at c, MGUH 21.521: U/41–3 from GGU sample 274797: G1; specimen at h, MGUH 21.526: U/50–3 from GGU sample 274571: G2. d, e *Comasphaeridium mackenziana* Baudet, Aitken & Vanguestaine, 1989, specimen at d, MGUH 21.522: S/47 from GGU sample 274796: G1; specimen at e, MGUH 21.523: K/27 from GGU sample 274571: G2. f, *Comasphaeridium* sp., MGUH 21.524: D/43 from GGU sample 274799: A1. g, *Comasphaeridium strigosum* (Jankauskas) Downie, 1982, MGUH 21.525: Z/32 (below) from GGU sample 184003: 1. Bar under f represents 10 μm.

?*Celtiberium geminum* Fombella, 1977

Fig. 8d, e

A single acritarch specimen from GGU sample 274799 is attributed to ?*Celtiberium geminum* Fombella, 1977. It has a spherical central vesicle (6 μm in diameter) whose cavity seems to be in communication with tapering conical processes (2–2.5 μm in length) with rounded apical ends. *C. geminum* is formerly known from Middle Cambrian rocks in northern Spain (Fombella, 1977) and was recently reported by Eklund (1990) from the lower Middle Cambrian glauconite sandstone unit in Östergötland, southern Sweden.

Comasphaeridium sp. A Downie, 1982

Fig. 8j

1982 *Comasphaeridium* sp. A. Downie, p. 260, fig. 6m.
1989 *Comasphaeridium* sp. A in Downie, 1982 Baudet, Aitken & Vanguestaine, p. 140, pl. 1, figs 18–19.

Material. Eight well-preserved specimens.

Description. Organic-walled sphaeroidal vesicle with numerous clearly defined processes tightly arranged and tapering towards the sharp tips.

Remarks. This species of *Comasphaeridium* differs form *C. velvetum* Moczydłowska, 1988 and *C. agglutinatum* Moczydłowska, 1988 by having free-standing and unpasted, longer and tapering, sharp pointed processes. It also differs from *Comasphaeridium strigosum* (Jankauskas) Downie, 1982 through its clearly defined, not pasted and longer processes, and by the clearly delimited outline of the vesicle.

Dimensions. Vesicle diameter: $N = 6$, $\bar{x} = 8.6$ μm, processes: $N = 6$, $\bar{x} = 5.5$ μm.

Occurrence and stratigraphic range. Lower Cambrian Buen Formation of North Greenland (Figs 3, 4). Lower Cambrian Fucoid Beds in Scotland, *Holmia* Shales in southern Norway and Gog Formation in Alberta, Canada (Downie, 1982); upper part of Lower Cambrian Vampire Formation and Sekwi Formation in northwestern Canada (Baudet *et al.*, 1989).

Acritarchs clearly belonging to the genus *Comasphaeridium,* but not being clearly attributable to any known form species of this genus, are here referred to *Comasphaeridium* spp. in Fig. 3.

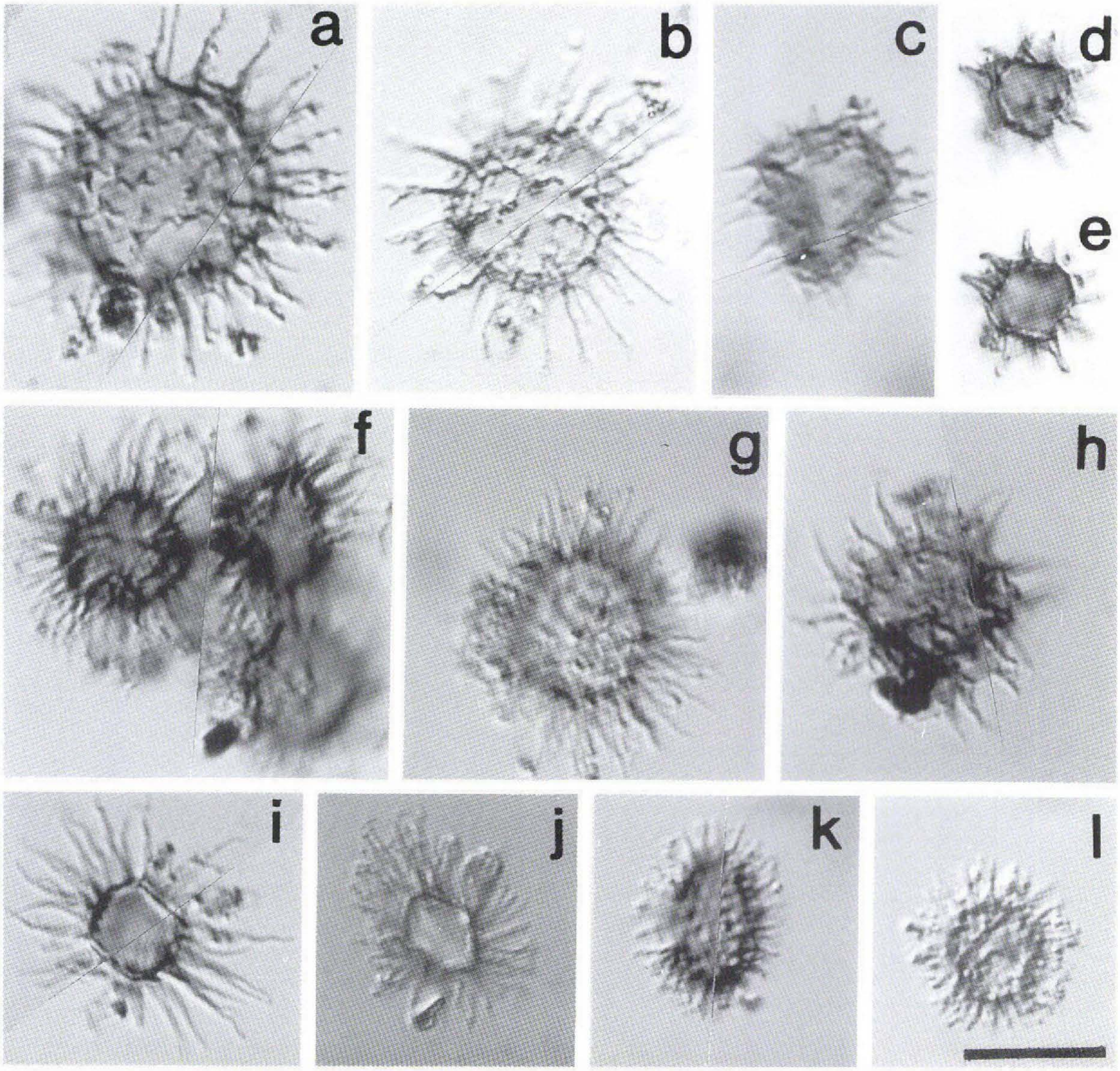


Fig. 8. Acritarchs from the Buen Formation, North Greenland. a, b, *Heliosphaeridium lubomlense* (Kirjanov, 1974) Moczydłowska, 1991, MGUH 21.527: W/30–4 and MGUH 21.528: R/43–1/3 from GGU sample 274797: G1. c, *Heliosphaeridium obscurum* (Volkova, 1969) Moczydłowska, 1991, MGUH 21.529: N/42–3 from GGU sample 184002: 1. d, e, ?*Celtiberium geminum* Fombella, 1977 at two focal levels, MGUH 21.530: K/26 from GGU sample 274799: A1. f, clustered specimens of *Comasphaeridium mackenziana* Baudet, Aitken & Vanguestaine, 1989, MGUH 21.531: T/48–4 from GGU sample 184002: 1. g, k, *Heliosphaeridium coniferum* (Downie, 1982) Moczydłowska, 1991, specimen at g, MGUH 21.532: R/45–3 from GGU sample 274796: G1; specimen at k; MGUH 21.533: R/45–3 from GGU sample 274796: G1. h, *Goniosphaeridium volkovae* Hagenfeldt, 1989, MGUH 21.534: Z/48–3 (below) from GGU sample 184002: 1. i, *Goniosphaeridium* sp. A, MGUH 21.535: Z/49–3 (below) from GGU sample 274796: G1. j, *Comasphaeridium* sp. A Downie, 1982, MGUH 21.536: E/40 from GGU sample 274796: G1. l, *Comasphaeridium agglutinatum* Moczydłowska, 1988, MGUH 21.537: Z/43–2 from GGU sample 274571: G2. Bar under l represents 13 μm for a 10 μm for b-l.

Comasphaeridium agglutinatum Moczydłowska, 1988
Fig. 8l

Two specimens recovered from GGU sample 274571 (Fig. 3) are attributed to *Comasphaeridium agglutinatum*. They consist of a spheroidal vesicle ranging 6–8 μm in diameter and surrounded by densely arranged agglutinated processes. The species is previously known only from the lower part of the Włodawa Formation and the Mazowsze Formation in Poland (Moczydłowska, 1991).

Comasphaeridium mackenziana Baudet, Aitken & Vanguestaine, 1989
Fig. 7d, e

1989 *Comasphaeridium mackenziana* n. sp. Baudet, Aitken & Vanguestaine, p. 138–140, pl. 1, figs 14–17.

Material. Thirteen well-preserved specimens; abundant in GGU sample 184002 from the Buen Formation (Figs 3, 4).

Description. Small acritarchs consisting of a central spherical vesicle having a smooth outer surface covered by numerous, well-defined, closely arranged, filiform and flexible processes of equal thickness.

Dimensions. Vesicle diameter: $N = 12$, $\bar{x} = 8.08$ μm, processes: $N = 12$, $\bar{x} = 3.08$ μm.

Occurrence and stratigraphic range. Lower Cambrian Buen Formation, (Figs 3–4), North Greenland. Previous occurrences are 14 m above the lower junction of the Lower Cambrian Sekwi Formation and 2 and 8 m below the upper junction of the Vampire Formation in the central Mackenzie Mountains, north-western Canada (Baudet *et al.*, 1989).

Comasphaeridium molliculum Moczydłowska & Vidal, 1988
Fig. 7a, b

For synonyms see Moczydłowska & Vidal (1988) and Hagenfeldt (1989). Acritarchs consisting of a central spherical vesicle (vesicle diameter: $N = 6$, 65–70 μm) with smooth outer surface covered by numerous, closely arranged filiform and flexible processes (process length: 5–7 μm). Excystment (not seen in the present material) by median split (Moczydłowska & Vidal, 1988). Previous occurrences were listed by Moczydłowska & Vidal (1988), Hagenfeldt (1989) and Vidal & Nystuen (1990b).

Comasphaeridium? *densispinosum* Vidal n. sp.
Fig. 6c, d

Derivation of name. Latin *densum*, dense, and *spina*, spine; relating to the densely arranged crown of processes covering the vesicle.

Material. Eight well-preserved specimens.

Diagnosis. An acritarch species with spheroidal vesicle densely covered with short, minute, simple ciliar-like processes. The processes are generally simple, but may in some instances display a distinct, low, conical, proximal attachment to which a ciliar-like portion of the process is attached. Excystment by median split.

Description. The generic assignation of this taxon is uncertain, being attributed with certain reservations to *Comasphaeridium*? This is because most specimens display process dimorphism, possessing abundant ciliar-like short processes together with few processes that display a conical-shaped basal attachment, a feature absent among species of *Comasphaeridium*.

Dimensions. Vesicle diameter: $N = 8$, $\bar{x} = 94.1$ μm, $\sigma = 36.9$ μm. Process length: $\bar{x} = 1$ μm. Width of process attachment $\bar{x} = 1$ μm, height of process attachment $\bar{x} = 1$ μm.

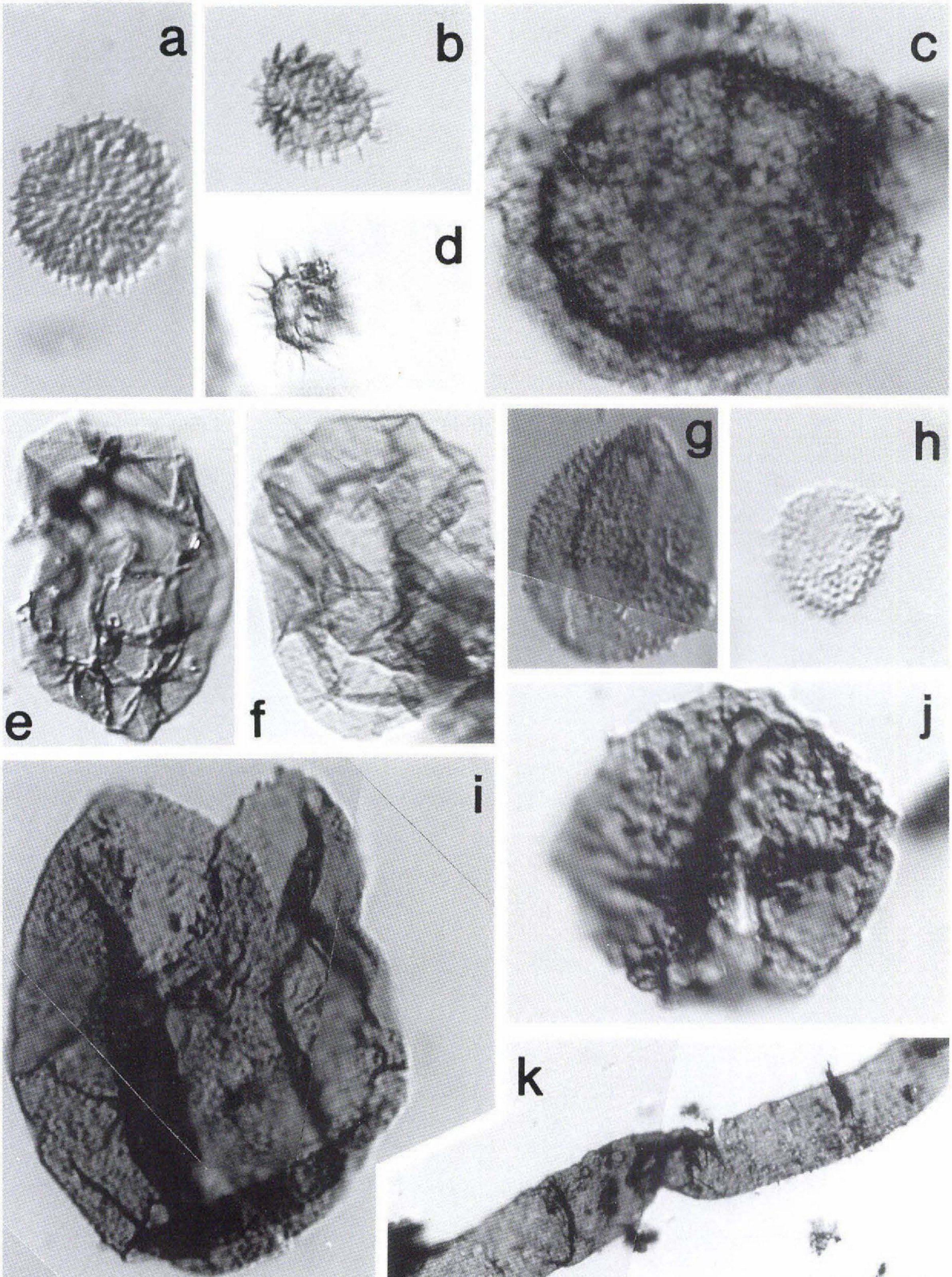
Occurrence and stratigraphic range. Lower Cambrian Buen Formation in North Greenland (Figs 3–4).

Comasphaeridium longispinosum Vidal n. sp.
Fig. 6a

Derivation of name. Latin *longum*, long and *spina*, spine; relating to the extremely long processes covering the vesicle.

Material. A single specimen from GGU sample 184004-B.

Description. Acritarch with large spheroidal to ovoidal vesicle covered by densely interwoven and, in relation to the vesicle diameter, long, slender and very thin processes.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Dimensions. The single recovered specimen has a vesicle diameter of $\bar{x}$ = 180 μm, whereas the sub-micron wide processes are $\bar{x}$ = 20 μm in length.

Occurrence and stratigraphic range. Lower Cambrian Buen Formation in North Greenland (Figs 3, 4).

Comasphaeridium strigosum (Jankauskas) Downie, 1982
Fig. 7g

Acritarchs attributed to *C. strigosum* are rare, but occur through most of the sampled succession of the Buen Formation. The vesicle diameters range from 18–22 μm, whereas the length of processes is 3–6 μm. For synonymies and previous occurrences see Hagenfeldt (1989) and Moczydłowska (1991).

Comasphaeridium cf. *strigosum* (Jankauskas) Downie, 1982
Figs 6b, 7c, h

Acritarchs attributed to this species consist of a central spherical vesicle (diameter $\bar{x}$ = 20.3 μm, σ = 5.0 μm, N = 13) surrounded by densely arranged simple processes (process length $\bar{x}$ = 6.1 μm, σ = 2.2 μm, N = 13).

Fig. 9. Acritarchs from the Buen Formation, North Greenland. a, *Asteridium tornatum* (Volkova, 1968) Moczydłowska, 1991, MGUH 21.538: C/42 from GGU sample 274571: G2. b, *Asteridium (= Micrhystridium) ordensis* (Downie, 1982) comb. nov., MGUH 21.539: V/45–2 from GGU sample 184002: 1. c, *Heliosphaeridium dissimilare* (Volkova, 1969) Moczydłowska, 1991, MGUH 21.540: R/45–2 from GGU sample 274799: A1. d, *Pterospermella* sp., MGUH 21.541: S/43 from GGU sample 184004: A1. e, *Retisphaeridium dichamerum* Staplin, Jansonius & Pocock, 1965, MGUH 21.542: B/43–4 from GGU sample 274798: A1. f, *Retisphaeridium dichamerum* Staplin, Jansonius & Pocock, 1965, MGUH 21.543: L/49 from GGU sample 274796: G1. g, *Lophosphaeridium dubium* (Volkova, 1968) Moczydłowska, 1991, MGUH 21.544: K/43–4 from GGU sample 274571: G2. h, *Lophosphaeridium tentativum* Volkova, 1968, MGUH 21.545: J/26–4 from GGU sample 274573B: G1. i, *Lophosphaeridium* sp., MGUH 21.546: V/32–4 from GGU sample 184003: 1. j, *Lophosphaeridium truncatum* Volkova, 1969, MGUH 21.547: N/27–4 from GGU sample 274796: G1. k, Cyanobacterial sheath, MGUH 21.548: Z/28 from GGU sample 184002: 1. Bar under k represents 10 μm for a-j and 15.5 μm for k.

Cymatiosphaera postii (Jankauskas, 1976) Jankauskas, 1979

Only 2 specimens of *C. postii* were recovered (Fig. 3). Overall dimensions range from 20–25 μm whereas the diameter of the inner body is 16 μm. Synonymy and previous occurrences in Lower Cambrian strata were listed by Hagenfeldt (1989) and Moczydłowska (1991).

Cymatiosphaera sp.
Fig. 10c, d

Acritarchs here attributed to *Cymatiosphaera* sp. (*sensu* Volkova *et al.*, 1979) are very rare and restricted to 4 samples (Fig. 3). They are comparable to forms from the Vergale 'horizon' in Latvia illustrated by Volkova *et al.* (1979, pl. 15, figs 1–2) under the name *Cymatiosphaera* div. sp. Four specimens recovered have a mean vesicle diameter of 33 μm.

Dictyotidium Eisenack, 1955 emend. Staplin, 1961

Type species. Leiosphaera (= Dictyotidium) dictyotum Eisenack, 1938, p. 27–28, pl. 3; figs 8a-c.

Dictyotidium perforatum Vidal n. sp.
Fig. 10a

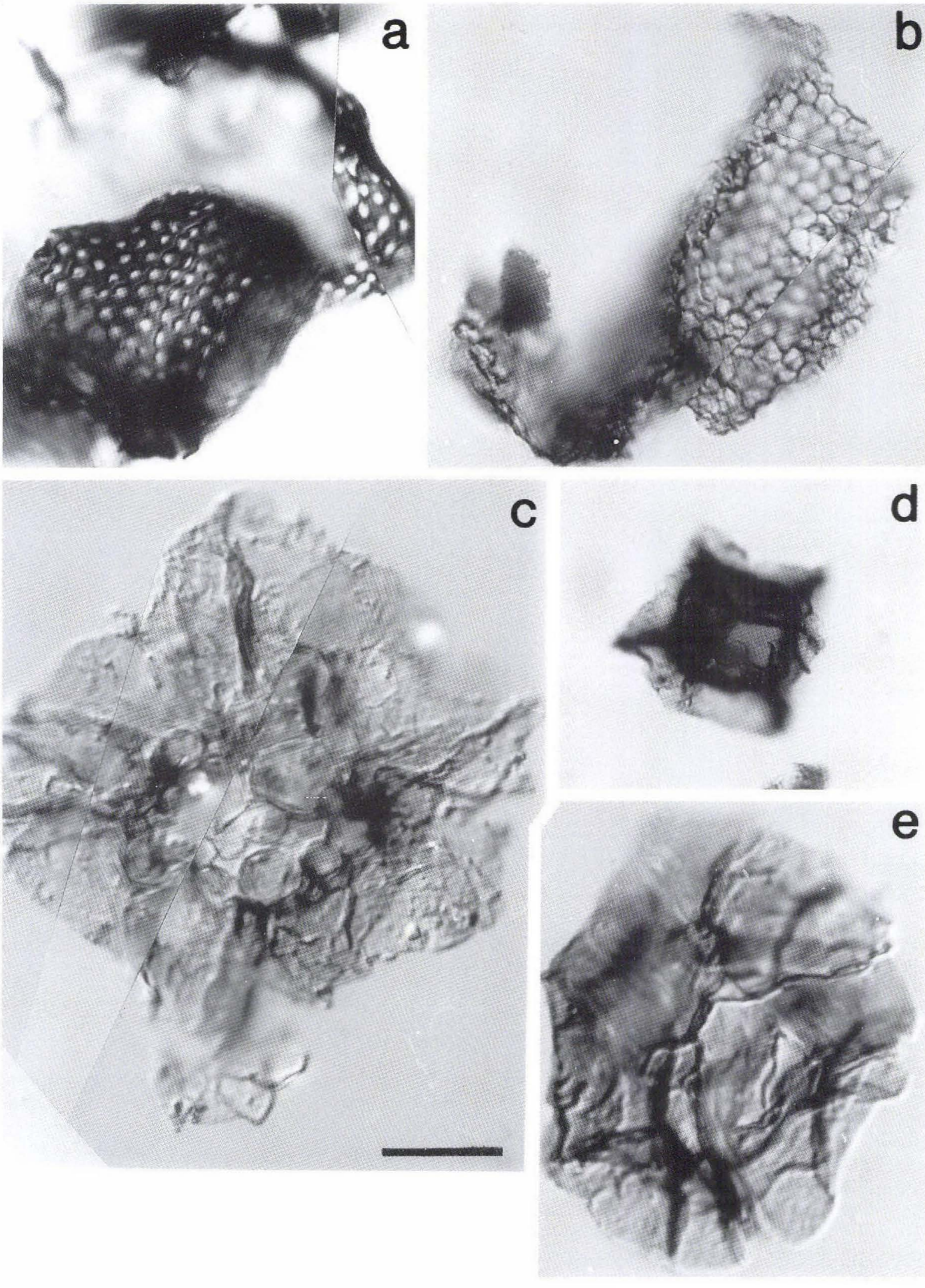
Derivation of name. Latin *perforatum*, perforated; relating to the perforations observed on the fields limited by the reticular ornamentation of the vesicle.

Material. Three specimens from GGU samples 274799 and 274800.

Diagnosis. Spheroidal vesicle with reticular surface sculpture. The areas limited by reticula have clearly defined circular pores.

Dimensions. The overall dimensions are derived from the measurement of 3 deformed specimens and suggest a diameter of >60–>80 μm. The lumina of the reticular sculpture are $\bar{x}$ = 1–2 μm wide. Diameter of pores <1 μm.

Remarks. The actual microfossils display a strong overall similarity with *D. priscum* Kirjanov & Volkova, 1979 (Fig. 10b). Specimens attributable to the latter species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occur in GGU sample 274800. Despite comparable dimensions, they differ from the present taxon by the obvious lack of well-defined pores and the much lower relief of the reticular sculpture. An additional species of *Dictyotidium (D. birvetense* Paškevičiene, 1979) has smaller overall dimensions (26–45 μm) and possesses a reticular sculpture defining much larger (5–9 μm) and apparently less regular fields.

Occurrence and stratigraphic range. Lower Cambrian Buen Formation of North Greenland (Figs 3, 4).

Elektoriskos sp. A
Fig. 13b

This species of *Elektoriskos* Loeblich, 1970 is represented by a single distinctive specimen in GGU sample 184002 (Fig. 3). It consists of a small (4.5 μm in diameter) spherical vesicle densely covered with slender, meandering processes 5 μm in length that stand on slightly inflated proximal attachments. The specimen differs substantially from other species of small acritarchs such as *Heliosphaeridium* and *Asteridium* by the character of the processes and their proximal attachments.

Fimbriaglomerella Loeblich & Drugg, 1968
Fig. 14e, f

This genus is represented by two species, *Fimbriaglomerella membranacea* (Kirjanov, 1974) Moczydłowska & Vidal, 1988 (Fig. 14e) and *F. minuta* (Jankauskas, 1979) Moczydłowska & Vidal, 1988 (Fig. 14f), both of which are represented by single well-preserved specimens in GGU sample 274796. Contrary to specimens reported by Moczydłowska & Vidal (1988), the present specimens are flattened by sediment compaction.

Fig. 10. Acritarchs from the Buen Formation, North Greenland. a, *Dictyotidium perforatum* Vidal n. sp., MGUH 21.549: F/37 from GGU sample 274799: A1, holotype. b, *Dictyotidium priscum* Kirjanov & Volkova, 1979, MGUH 21.550: J/50–3 from GGU sample 274800: A1. c–e, *Cymatiosphaera* sp., specimen at c, MGUH 21.551: R/43–1 from GGU sample 274796: G1; specimen at d, MGUH 21.552: E/38–1 from GGU sample 274795: A1; specimen at e, MGUH 21.553: O/50–2 from GGU sample 274800: A–1. Bar under c represents 10 μm for a, c, e; 15.5 μm for b; 25 μm for d.

Globosphaeridium cerinum (Volkova) Moczydłowska, 1991
Fig. 13c

This is present in GGU samples 274570 and 274796. The vesicle diameter and process length of 4 recovered specimens ranges 32–35 μm and 5 μm, respectively.

Moczydłowska (1991) transferred acritarchs attributed to *Baltisphaeridium cerinum* Volkova, 1968 and *Electoriskos cerinus* (Volkova) Vanguestaine, 1968 to the new genus *Globosphaeridium*. Previous occurrences and synonymy were listed by Hagenfeldt (1989).

Goniosphaeridium primarium (Jankauskas) Downie, 1982
Fig. 11a

Microfossils here attributed to the acritarch genus *Goniosphaeridium* Eisenack, 1969 emend. Kjellström, 1971 are here referred to *G. primarium* (Jankauskas) Downie, 1982 recorded as 2 specimens (vesicle diameter 28–48 μm, process length 20–30 μm, width of process base 7–9 μm) in GGU sample 274796. Previous occurrences were listed by Volkova *et al.* (1979) and additional occurrences in the Lower Cambrian of Baltoscandia were reported by Vidal & Nystuen (1991b).

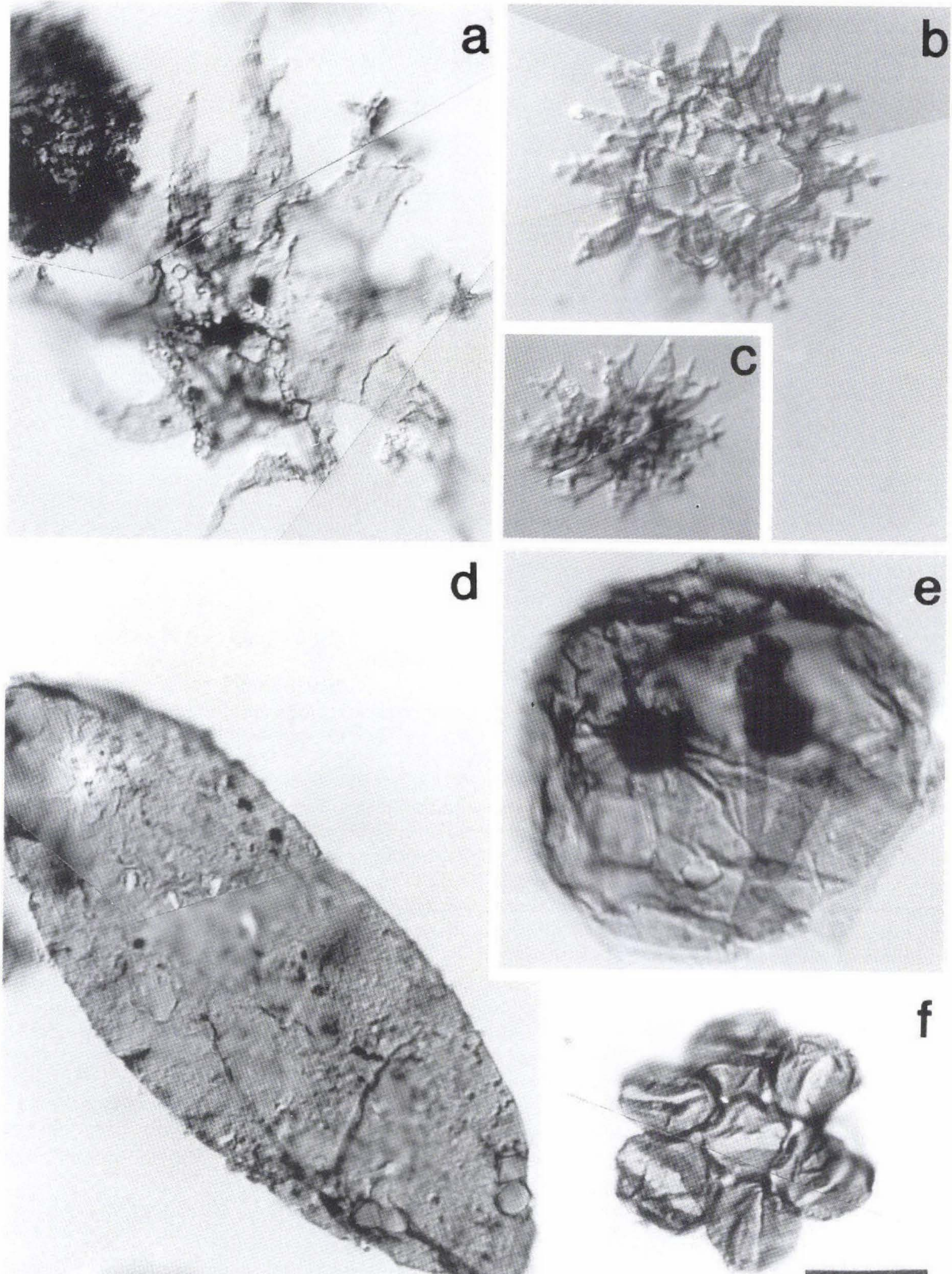
One specimen uncertainly identified as *Goniosphaeridium* sp. was also recovered from GGU sample 274571.

Goniosphaeridium sp. A
Fig. 8i

Rare acritarchs uncertainly attributed to genus *Goniosphaeridium* are here referred to *Goniosphaeridium* sp. A. The conical nature of the compressed processes is evident and may suggest original connection between processes and the inner vesicle cavity. However, this feature cannot be ascertained in the specimens available.

Goniosphaeridium varium (Volkova, 1969) Downie, 1982

This is represented by a single poorly preserved specimen about 44 μm in diameter (Fig. 3, GGU sample 184003).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Goniosphaeridium volkovae Hagenfeldt, 1989

Fig. 8h

Acritarchs here attributed to *Goniosphaeridium volkovae* Hagenfeldt, 1989 (Hagenfeldt, 1989, pl. 3; fig 1) consist of 20 variably preserved specimens in GGU sample 184002. They consistently possess a central ovoidal to spherical vesicle tightly covered by discrete conical, sharp-pointed, processes, apparently in communication with the inner cavity of the vesicle. The maximal vesicle diameter ranges from 7–8 μm, ($\bar{x}$ = 7.2 μm), and the length of processes ranges from 1.5–4 μm ($\bar{x}$ = 2.8 μm).

Hagenfeldt (1989) listed occurrences in the USSR and in Scandinavia, where the species occurs in beds attributed to the Lower Cambrian Vergale and Rausve 'horizons', the lower Middle Cambrian Kibartai 'horizon' and *Eccaparadoxides oelandicus* Zone.

Granomarginata squamacea Volkova, 1968

A few specimens placed here show a central vesicle diameter of 20 μm and outer wing diameter ranging 30–40 μm. Synonymies and previous occurrences were mentioned by Hagenfeldt (1989) and Moczydłowska (1991).

Heliosphaeridium sp.

Acritarchs identified as *Heliosphaeridium* sp. occur in two samples (Fig. 3); they are small forms which can not be identified at the specific level.

Fig. 11. Acritarchs from the Buen Formation, North Greenland. a, *Goniosphaeridium primarium* (Jankauskas) Downie, 1982, MGUH 21.554: Z/36–3 from GGU sample 274796: G1. b, c, *Multiplicisphaeridium dendroideum* (Jankauskas, 1976) Jankauskas & Kirjanov, 1979, specimen at b, MGUH 21.555: Z/36 from GGU sample 274796: G1; specimen at c, MGUH 21.556: X/39–1 from GGU sample 274796: G1. d, *Leiovalia tenera* Kirjanov, 1974, MGUH 21.557: H/37–4 from GGU sample 184002: 1. e, *Archaeodiscina umbonulata* Volkova, 1968, MGUH 21.558: Z/29 from GGU sample 274796: G1. f, *Leiosphaeridia* sp., MGUH 21.559: O/25 from GGU sample 274799: A1. Bar under f represents 15.5 μm for a, d; 10 μm for b–c, e–f.

Heliosphaeridium coniferum (Downie, 1982) Moczydłowska, 1991

Fig. 8g, k

Heliosphaeridium coniferum (vesicle diameter 5–9 μm, process length <2–2 μm) was recently emended by Moczydłowska (1991) who provided a list of previous citations. The species is present in small numbers in GGU sample 184002 and more abundantly in GGU sample 274496. Specimens from the Buen Formation closely correspond to specimens from eastern Poland illustrated by Moczydłowska (1991), whereas they seem quite different from specimens from the lower part of the 'Fucoid' Beds in Scotland illustrated by Downie (1982).

Heliosphaeridium dissimilare (Volkova, 1969) Moczydłowska, 1991

Fig. 9c

The species (vesicle diameter 7–10 μm, $\bar{x}$ = 10.7 μm, σ = 3.2, N = 36; process length 2–4 μm, $\bar{x}$ = 3.6 μm, σ = 1.03, N = 58) was also emended by Moczydłowska (1991), who listed previous occurrences (see also Vidal & Nystuen, 1990b).

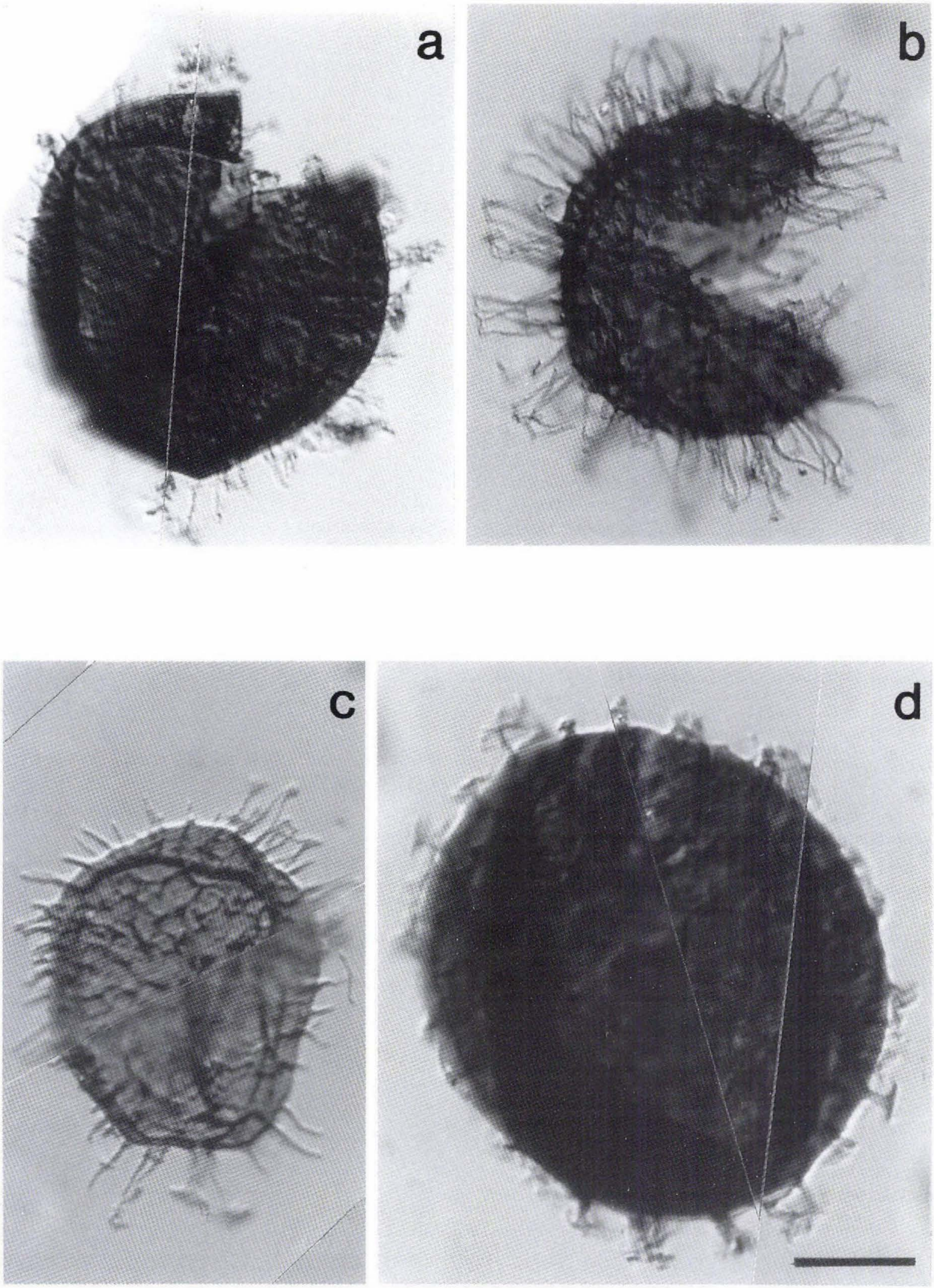
Heliosphaeridium lubomlense (Kirjanov, 1974) Moczydłowska, 1991

Fig. 8a, b

Heliosphaeridium lubomlense consists of acritarchs with a distinctive spherical vesicle 12–15 μm in diameter, with irregular circular outline and possessing numerous straight and equally distributed processes. The processes (5–7 μm in length) have conical proximal portions tapering in the central part and are slightly widened at the distal portion.

Heliosphaeridium notatum (Volkova, 1969) Moczydłowska, 1991

This species is extremely rare in the present material, being only represented by 3 specimens unsuitable for illustration (vesicle diameter 22–24 μm; process length >2–3 μm) in GGU sample 274798. Synonymy and previous occurrences were listed by Hagenfeldt (1989).



Heliosphaeridium obscurum (Volkova, 1969) Moczydłowska, 1991
Fig. 8c

Heliosphaeridium obscurum is a rare component in GGU sample 184002 (6 specimens; vesicle diameter 5–6 μm; process length 1.5–2 μm). Synonymy and former occurrences were listed by Hagenfeldt (1991) and Moczydłowska (1991).

Leiosphaeridia Eisenack, 1958 emend. Downie & Sarjeant, 1963
Fig. 11f

The genus *Leiosphaeridia* is here represented by sphaeromorphic acritarchs that are not identified to the specific level since morphological features are restricted to vesicle dimensions and relative wall thickness. The microfossils have circular to oval vesicles with smooth surface. The wall of the vesicle is generally sturdy and thick, and displays compression folds that are irregular both in shape and distribution. Excystment, when present, is by median split. The diameter of the vesicle ranges $\bar{x}$ 20–80 μm.

Specimens recorded in the Buen Formation (Fig. 3) may consist of solitary, discrete vesicles or more or less regular coenobial cell clusters of up to 8 cells (Fig. 11f). The latter are usually within the lower recorded diameter range of the discrete cells.

In general, microfossils attributed to *Leiosphaeridia* constitute one of the most common and abundant acritarch taxa in Neoproterozoic and Cambrian strata. On account of a lack of diagnostic features, an apparent stratigraphic range from Proterozoic to Tertiary has been recorded (Downie & Sarjeant, 1964; Tappan, 1980; Lindgren, 1982a, b).

Fig. 12. Acritarchs from the Buen Formation, North Greenland. a, c, *Skiagia ciliosa* (Volkova, 1969) Downie, 1982 (morphotype A), specimen at a MGUH 21.560: Z/39–1 from GGU sample 274796: G1; specimen at c, MGUH 21.562: Z/31 from GGU sample 274570: 1. b, *Skiagia ciliosa* (Volkova, 1969) Downie, 1982 (morphotype B), MGUH 21.561: Y/32 from GGU sample 184003: 1. d, *Skiagia ciliosa* (Volkova, 1969) Downie, 1982 (morphotype C), MGUH 21.563: Z/30 from GGU sample 274570: 1. Bar under d represents 10 μm.

Leiovalia tenera Kirjanov, 1974
Fig. 11d

Leiovalia tenera is represented by 2 well-preserved specimens (Fig. 3). It consists of elongated, oval shaped flattened vesicles with smooth surface, often displaying thin compactional folds; the length ranges 87–90 μm, whereas the vesicle width ranges 34–40 μm. Previous occurrences were mentioned by Hagenfeldt (1989) and Eklund (1990).

Lophosphaeridium dubium (Volkova, 1968) Moczydłowska, 1991
Fig. 9g

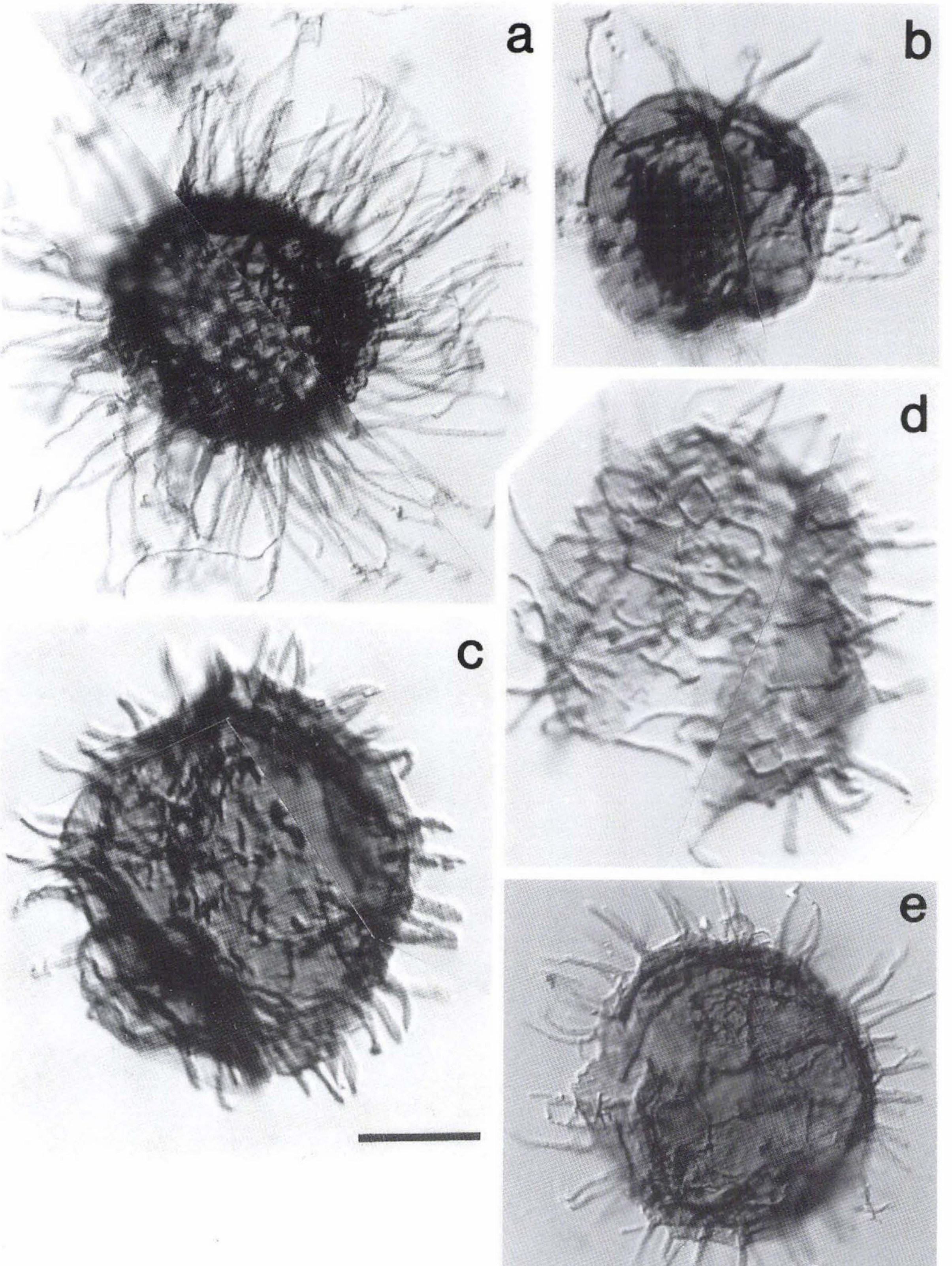
This consists of sphaeroidal vesicles tightly covered by small and short conical protuberances. Five recovered specimens indicate a vesicle diameter 19–36 μm, whereas process length is <1 μm. The species was transferred to the genus *Lophosphaeridium* by Moczydłowska (1991), who also listed synonymies and former occurrences (see also Hagenfeldt, 1989). The species is extremely rare in GGU samples 274570, 274571, 274796).

Lophosphaeridium tentativum Volkova, 1968
Fig. 9h

Lophosphaeridium tentativum is represented in 2 samples (Fig. 3) from the upper part of the sampled interval of the Buen Formation. It consists of spherical, flattened vesicles 11–45 μm in diameter and covered with tightly arranged small granulae. For synonymy and previous occurrences see Hagenfeldt (1989) and Moczydłowska (1991).

Lophosphaeridium truncatum Volkova, 1969
Fig. 9j

This species occurs in very small numbers in 3 samples (Fig. 3) of the Buen Formation. It consists of spherical vesicles ($N = 6$, vesicle diameter 26–36 μm) covered by rounded, clavate, coarse grains and discrete granulae (<1–1 μm in diameter). Previous occurrences and synonymies were given by Hagenfeldt (1989) and Moczydłowska (1991).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Lophosphaeridium sp.
Fig. 9i

Acritarchs attributed to *Lophosphaeridium* sp. consist of sphaeroidal vesicles ranging around 40 μm in diameter which are densely covered by small sub-micron granulae.

Multiplicisphaeridium dendroideum (Jankauskas, 1976) Jankauskas & Kirjanov, 1979
Fig. 11b, c

Multiplicisphaeridium dendroideum, although found in 3 samples, is represented in the present material by 2 well-preserved specimens consisting of a central vesicle in communication with numerous (>15) conical, dimorphic, evexate processes, often with ramified terminal portions. The overall dimensions are 18–26 μm, processes included, whereas the length and basal width of the processes is 3–4 μm and 2–3 μm, respectively.

Pterospermella Eisenack, 1972
Fig. 9d

Acritarchs attributed to the genus *Pterospermella* Eisenack, 1972 are rare and consist of forms with a solid circular central body ranging 25–30 μm in diameter surrounded by a translucent, 10–15 μm wide extremely delicate ala. Various gradings in the density of the central body are observed.

Retisphaeridium dichamerum Staplin, Jansonius & Pocock, 1965
Figs 9e, f, 10e

This species was recovered in generally small numbers from several samples of the Buen Formation. It consists of ellipsoidal to circular compressed vesicles 28–40 μm in diameter ($N = 4$) with psilate or very fine granular ornamentation displaying a transversal reticular pattern of folds. Synonymy and previous occurrences were given by Hagenfeldt (1989).

Fig. 13. Acritarchs from the Buen Formation, North Greenland. a, *Skiagia ornata* (Volkova, 1968) Downie, 1982, MGUH 21.564: F/29 from GGU sample 274796: G1. b, *Elektoriskos* sp. A., MGUH 21.565: K/33–4 from GGU sample 184002: 1. c, *Globosphaeridium cerinum* (Volkova) Moczydłowska, 1991, MGUH 21.566: R/25–3 from GGU sample 274570: 1. d, e, *Skiagia orbiculare* (Volkova, 1968) Downie, 1982, specimen at d, MGUH 21.567: T/50–4 from GGU sample 274795: A1; specimen at e, MGUH 21.568: X/42–3 from GGU sample 274571: G2. Bar under c represents 10 μm for a-d; 15.6 μm for e.

Skiagia Downie, 1982

Acritarchs attributed to the form-genus *Skiagia* form the bulk of the acritarch remains recovered from the Buen Formation. Synonymies and previous occurrences of the various species of this form-genus were treated by Downie (1982), Hagenfeldt (1989), Moczydłowska (1991) and Vidal & Nystuen (1990b).

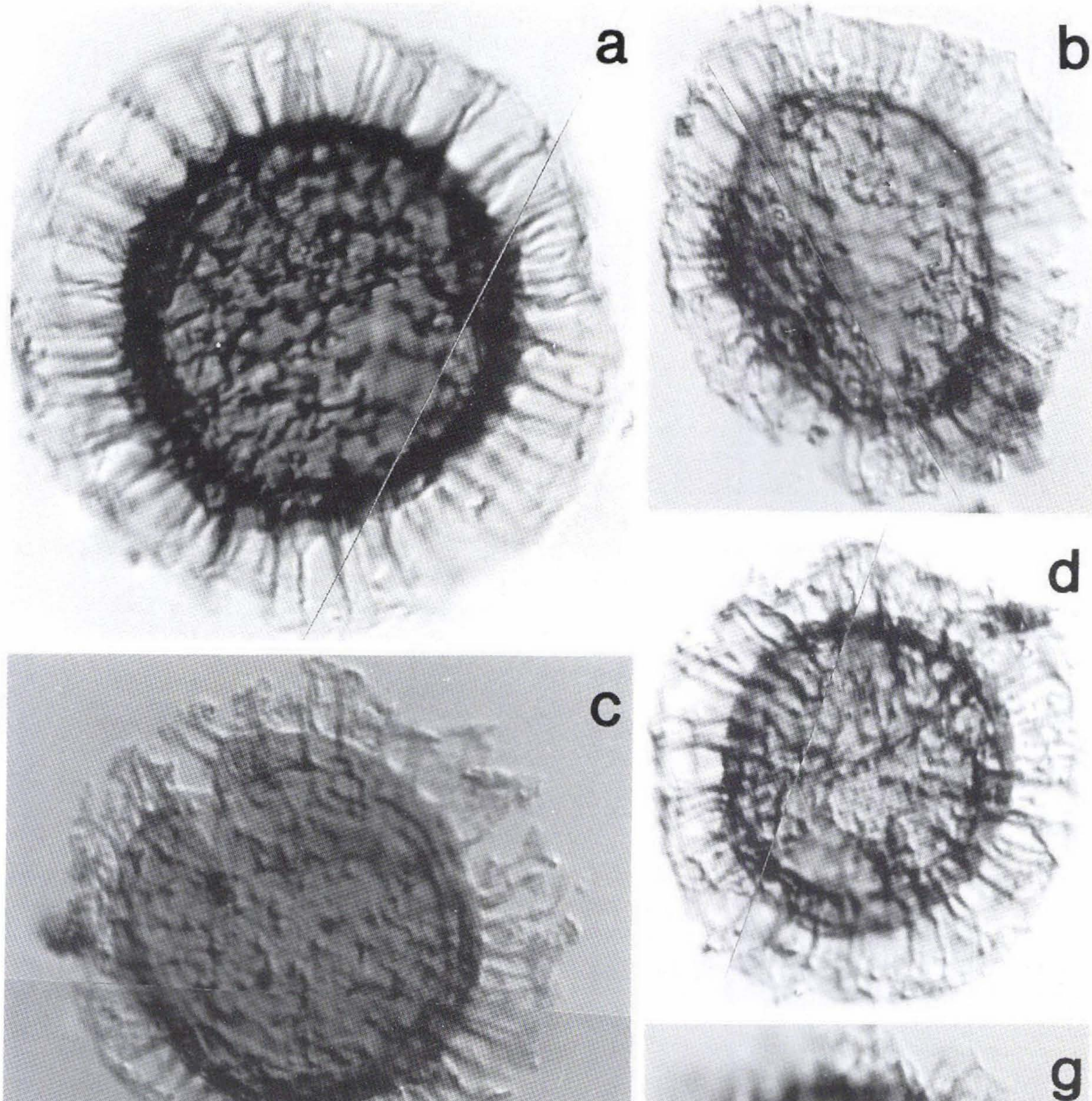
Skiagia ciliosa (Volkova, 1969) Downie, 1982
Fig. 12a-d

As is the case in former occurrences, three distinctive morphotypes of *Skiagia ciliosa* (Volkova, 1969) Downie, 1982, A, B and C, co-occur in discrete samples. Type A (Fig. 12a, c) has narrow process attachments and thin and slender process stems, whereas *Skiagia ciliosa* type B (Fig. 12b) possesses wider conical process attachments and processes stems, the processes being longer and provided with funnel-shaped apical ends. Shorter, less numerous and clearly evexate processes ornament the vesicle of morphotype C (Fig. 12d).

Acritarchs here referred to the three distinguished morphotypes (Fig. 12a-d) consist of circular to ovoidal vesicles (vesicle diameter: $N = 100$, $\bar{x} = 32.9$ μm) with numerous cylindrical processes (process length: $N = 100$, $\bar{x} = 3.9$ μm). In the present, relatively abundant material, the processes appear hollow and are clearly isolated from the vesicle cavity by a plug. The proximal attachments of the processes are generally conical, whereas the apical portions are funnel-shaped.

Skiagia compressa (Volkova 1968) Downie, 1982
Fig. 14g

Rare acritarchs here attributed to *Skiagia compressa* possess an oval-shaped vesicle (vesicle diameter: $N = 35$, $\bar{x} = 32.6$ μm) that bears numerous, proximally wide and conical-shaped processes (process length: $N = 35$, $\bar{x} = 5.7$ μm), thus resulting in diagnostically 'crenulated' periphery. Distally, the processes are funnel-shaped.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Skiagia orbiculare (Volkova, 1968) Downie, 1982
Fig. 13d, e

Acritarchs attributed to *Skiagia orbiculare* are common in the Buen Formation (Fig. 3) and have ovoidal to spheroidal vesicles (vesicle diameter: $N = 50$, $\bar{x} = 31.7$ μm) with numerous medium-length processes (process length: $N = 50$, $\bar{x} = 7.1$ μm) that are slender, tapering from the proximal part along their total length. Their distal portions are funnel-shaped.

Skiagia ornata (Volkova, 1968) Downie, 1982
Fig. 13a

Skiagia ornata is an extremely abundant acritarch species in the Buen Formation (Fig. 3) that possesses an spheroidal vesicle (diameter: $N = 140$, $\bar{x} = 33.7$ μm) with very numerous, long, slender cylindrical processes (process length: $N = 140$, $\bar{x} = 13.6$ μm) that are widened proximally and distally (funnel-shaped).

Skiagia scottica Downie, 1982
Fig. 14a-d

Together with *S. ornata,* this species is among the most abundantly occurring acritarchs in the Buen Formation (Fig. 3). It has a spheroidal to ovoidal vesicle (vesicle diameter: $N = 140$, $\bar{x} = 27.5$ μm) with numerous, tightly arranged processes that are of variable length (process length: $N = 140$, $\bar{x} = 6.1$ μm), slender and cylindrical, proximally slightly widened and distally opened into a wide funnel-shape, being often attached to one another at the distal funnel-shaped ends.

Fig. 14. Acritarchs from the Buen Formation, North Greenland. a–d, *Skiagia scottica* Downie, 1982, specimen at a, MGUH 21.569: Q/26–3 from GGU sample 184004–B; specimen at b, MGUH 21.570: Z/29 from GGU sample 274796: G1; specimen at c, MGUH 21.571: O/51–4 from GGU sample 274571: G2; specimen at d, MGUH 21.572: L/34–2 from GGU sample 274797: G1. e, *Fimbriaglomerella membranacea* (Kirjanov, 1974) Moczydłowska & Vidal, 1988, MGUH 21.573: Z/29–1 from GGU sample 274798: A1. f, *Fimbriaglomerella minuta* (Jankauskas, 1979) Moczydłowska & Vidal, 1988, MGUH 21.574: Z/49–3 from GGU sample 274796: G1. g, *Skiagia compressa* (Volkova, 1968) Downie, 1982, MGUH 21.575: K/48–2 from GGU sample 274796: G1. Bar under f represents 10 μm for a–f; 11 μm for g.

Tasmanites bobrowskae Ważyńska, 1967
Fig. 15b-c

Rare organic-walled spheroidal microfossils placed here are often compressed, having vesicles which are circular to oval in outline ($N = 7$, $\bar{x} = 90.4$ μm) and possessing a thick vesicle wall perforated by irregularly distributed large pores. For synonymy and previous occurrences see Hagenfeldt (1989) and Moczydłowska (1991).

Tasmanites tenellus Volkova, 1968
Fig. 15a

This species is very rare in the present material. It comprises organic-walled microfossils having circular to oval compressed vesicles (vesicle diameter: $N = 7$, $\bar{x} = 90$ μm) with a thin vesicle wall perforated by small, irregularly distributed pores. Synonymy and occurrences were recently listed by Hagenfeldt (1989) and Moczydłowska (1991).

Tasmanites volkovae Kirjanov, 1974
Fig. 15d

This is extremely rare in samples from the Buen Formation. The circular, organic-walled vesicle (vesicle diameter: 60–70 μm) possesses a thick perforated wall with abundant, regularly distributed pores located in funnel-like wall depressions, a diagnostic feature that results in the irregular periphery of the thick vesicle wall. For synonymy and previous occurrences see Hagenfeldt (1989) and Moczydłowska (1991).

Trachysphaeridium timofeevi Vidal, 1976

Trachysphaeridium timofeevi is a rare component in samples of the Buen Formation (Fig. 3). The ovoidal to ellipsoidal, walled and scabrate sculptured vesicle ranges 50–62 μm by 20–40 μm. Previous occurrences were listed by Hagenfeldt (1989).

Various tubular sheaths, possibly cyanobacterial, occur in the investigated samples of the Buen Formation (Fig. 9k). The sheaths are of quite variable length and range in width from 2–10 μm. These fossils were recorded in variable numbers in most processed samples.

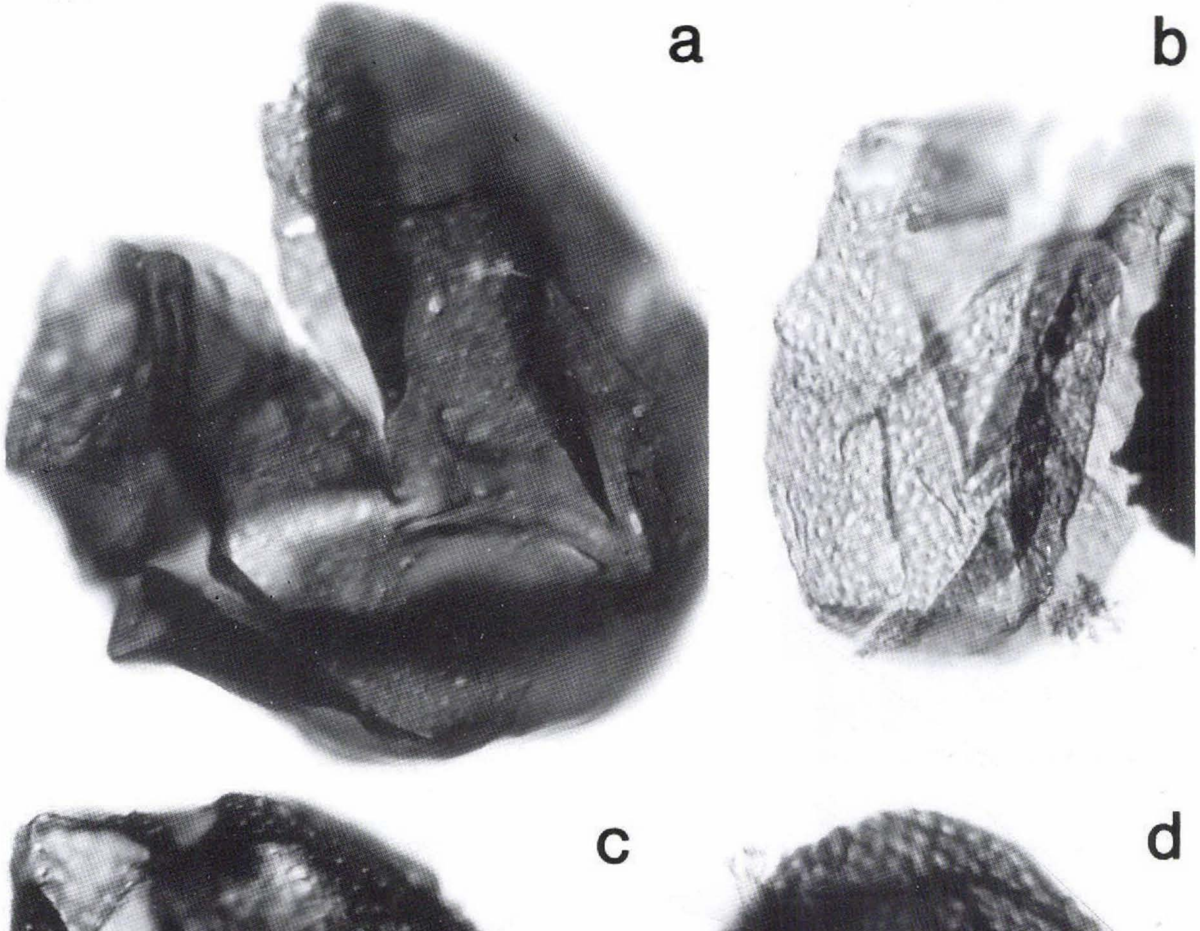

Fig. 15. Acritarchs from the Buen Formation, North Greenland. a, *Tasmanites tenellus* Volkova, 1968, MGUH 21.576: J/40–2 from GGU sample 274800: A1. b, c, *Tasmanites bobrowskae* Ważyńska, 1967, specimen at b, MGUH 21.577: Z/39–4 from GGU sample 274797: G1; specimen at c, MGUH 21.578: C/33–1 from GGU sample 274797: G1. d, *Tasmanites volkovae* Kirjanov, 1974, MGUH 21.579: Z/43 from GGU sample 274797: G1. Bar under c represents 10 μm for a-b, d; 14 μm for c.

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