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Acritarchs from the Upper Proterozoic and Lower Cambrian of East Greenland

by

Gonzalo Vidal

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Abstract

Acritarchs are described from rocks of the Upper Proterozoic Eleonore Bay Group and Tillite Group and from the Lower Cambrian Bastion Formation and Ella Island Formation. Twenty-four previously described acritarch taxa have been identified. The state of preservation is variable perhaps depending on variable thermal alteration due to thickness of overburden, tectonic deformation and metamorphism. Palaeoenvironmental aspects of some acritarchs are discussed. The acritarchs of the Ella Island Formation and Upper Bastion Formation indicate a late Early Cambrian age in agreement with the age indicated by shelly faunas. A Vendian age is ascribed to the Tillite Group. The upper part of the Eleonore Bay Group is regarded as Late Riphean. Correlations of these units with Lower Cambrian and Upper Proterozoic sequences in the Russian Platform, Scandinavia and elsewhere are presented.

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Акритархи верхнего протерозоя и нижнего кембрия восточной Гренландии

Гонзало Видаль

Приводится описание ископаемых микроорганизмов с нерастворимыми органическими стенками (акритархи) пород групп Элеонор-Бэй и Тиллитовой (верхний протерозой) и формаций Бастион и Элла-Э (нижний кембрий) восточной Гренландии. Всего было изучено 130 образцов. Акритархи различной сохранности были выделены из 69 образцов. Как правило, наиболее сохранившиеся формы обнаруживались в образцах из верхов Известняково-доломитовой 'серии' (слой 19), Тиллитовой группы, формации Бастион и формации Элла-Э. Было определено 24 вида ранее описанных акритарх. Акритархи плохой сохранности были получены из некоторых образцов Пестроцветной, Кварцитовой и верхней Глинисто-песчанистой 'серий'. Определимые акритархи не были найдены в Известково-глинистой и нижней Глинисто-песчанистой 'сериях'. Сохранность акритарх колеблется как в изученных слоях, так и по всему изученному району. Вероятно, это зависит от неравномерного термального изменения, вследствие совокупности таких факторов, как мощность перекрывающих пород, тектонические деформации и метаморфизм. Обсуждаются палеоэкологичиеские аспекты некоторых таксонов акритарх. Акритархи формации Элла-Э указывают на нижнекембрийский возраст, что подтверждается и трилобитовой фауной. Образцы формации Бастион содержали только долгоживущие виды акритарх. Полученные ранее макро- и микропалеонтологические данные этой формации и их стратиграфическое значение также обсуждаются. Предполагается, что верхняя часть формации Бастион примерно того же возраста, что и формация Элла-Э. Обсуждается корреляция этих отложений с нижнекембрийскими разрезами Прибалтики, Польши и др. Предполагается, что значительные перерывы разделяют верхнюю и нижнюю части формации Бастион, а также подстилающую ее формацию Клофтэльв. Несогласие между формацией Клофтэльв и Тиллитовой группой также указывает на наличие перерыва. Этот перерыв предположительно охватывает большую часть верхнего венда на Русской платформе. Тиллитовая группа дала сравнительно хорошо сохранившиеся акритархи, указывающие на вендский возраст. Несогласно подстилающая ее группа Элеонор-Бэй (Известняково-доломитовая 'серия') содержит богатый комплекс акритарх, указывающий на самый поздний рифей. Таким образом, между этими группами существует значительный перерыв. Представлено сопоставление разрезов Тиллитовой группы с разрезами Швеции, Норвегии и Русской платформы. Обсуждается палеоклиматическое значение этих сопоставлений для осадков некоторых из этих районов и других мест. Известняково-доломитовая 'серия' и подстилающие ее слои группы Элеонор-Бэй, содержащие ископаемые микроорганизмы, согласуются с нижними, средними и нижней частью верхних слоев Висингсо южной Швеции.

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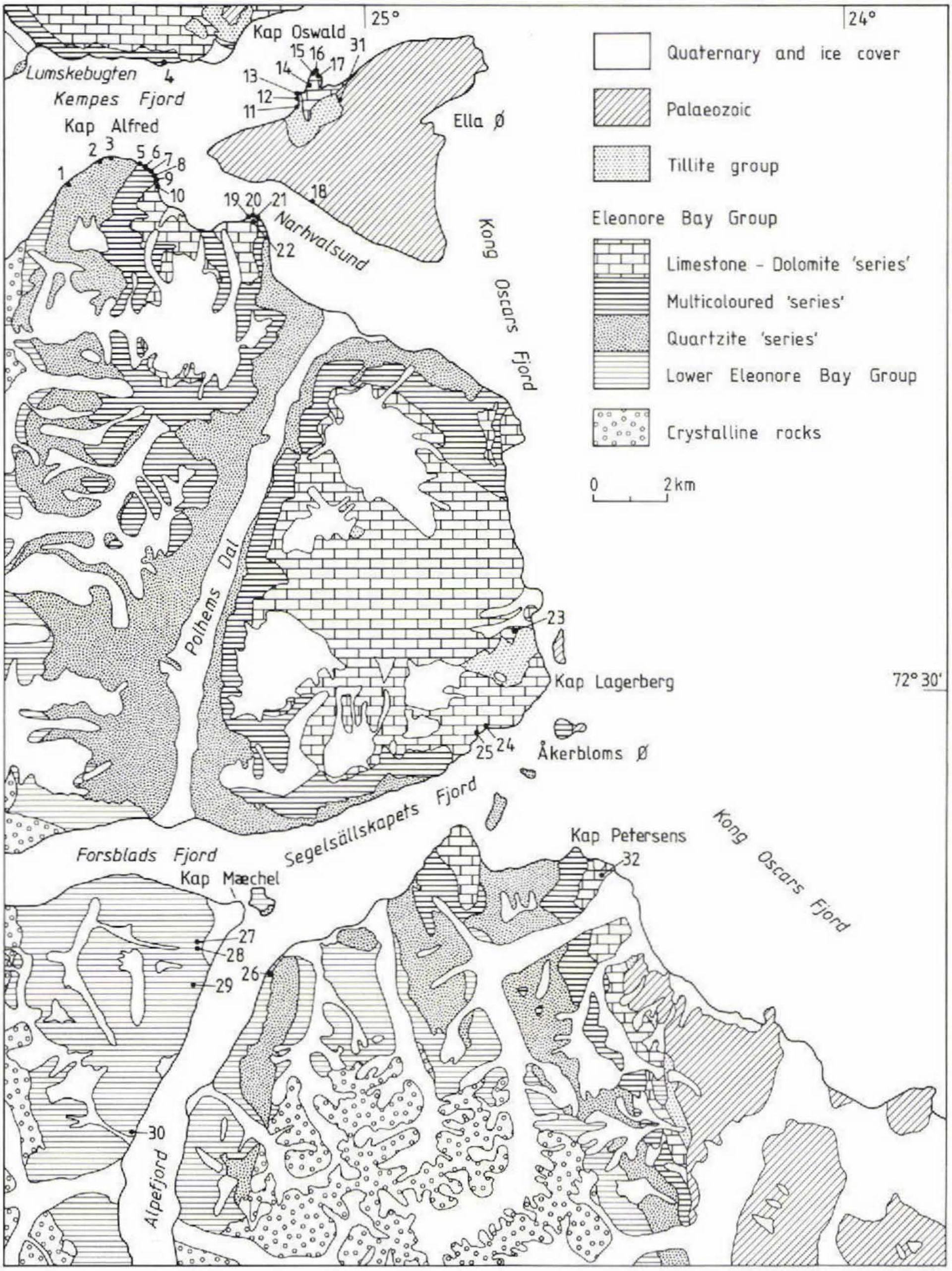


Fig. 1. Simplified geological map of the Kong Oscars Fjord showing the distribution of investigated rock units (after Koch & Haller, 1971). The figures in the map indicate the location of sampled localities as follows: **1** GGU 185467–474, **2** GGU 185475–494, **3** GGU 185495–499, **4** GGU 185540–542, **5** GGU 185500–504, **6** GGU 185505–508, **7** GGU 185509–512, **8** GGU 185513, **9** GGU 185514–515, **10** GGU 185516–525, **11** GGU 185446–456, **12** GGU 185434–445, **13** GGU 185429–433, **14** GGU 185421–428, **15** GGU 185416–420, **16** GGU 185408–415, **17** GGU 185403–407, **18** GGU 185538–539, **19–21** GGU 185529–537, **22** GGU 185526–528, **23** GGU 185549–551, **24** GGU 185546–548, **25** GGU 185543–545, **26** GGU 185562–563, **27** GGU 185559–561, **28** GGU 185552–553, **29** GGU 185554–558, **30** GGU 185401–402, **31** GGU 185457–466, **32** GGU 142342.

INTRODUCTION

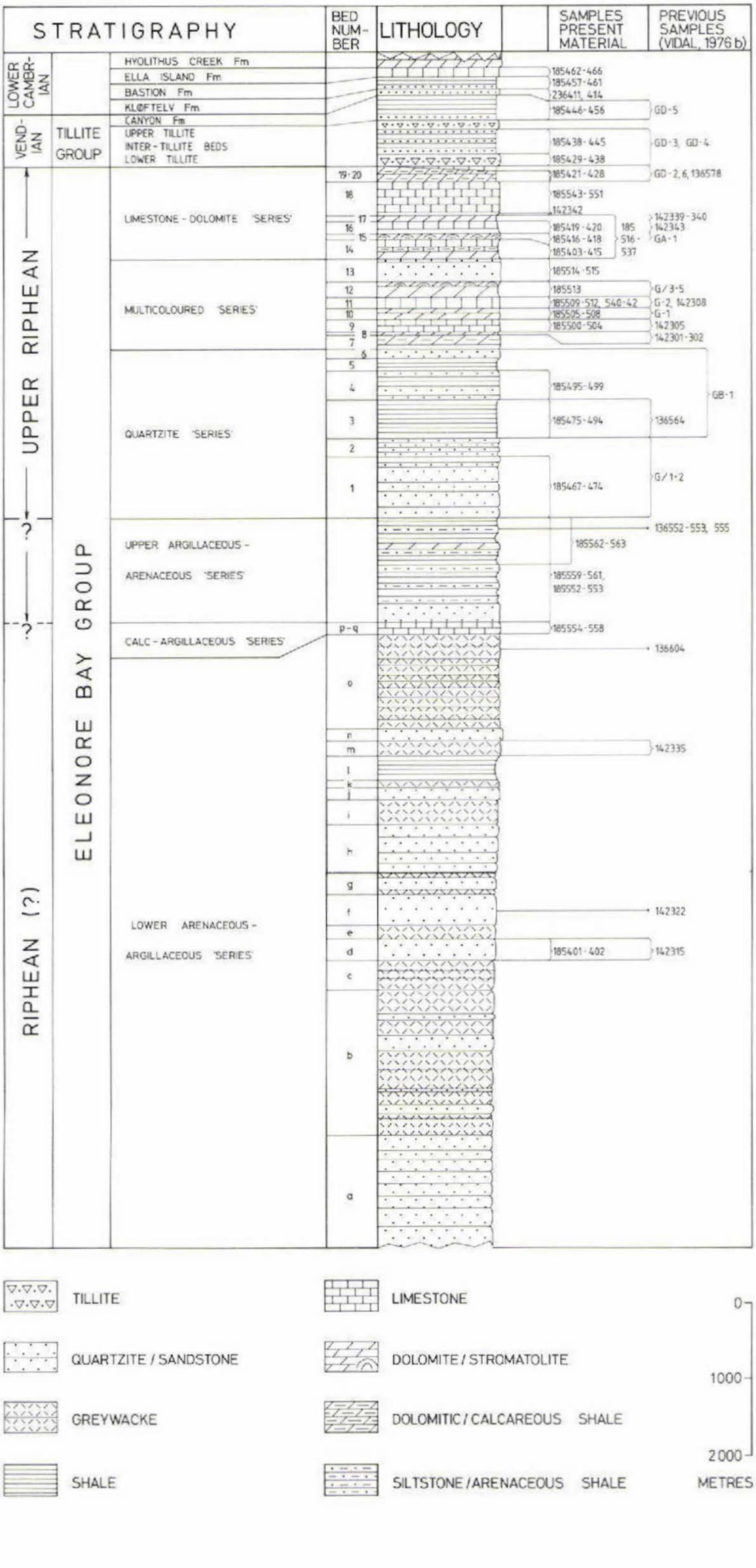
This paper deals with the results of a micropalaeontological investigation of the Upper Proterozoic and Lower Cambrian sequence in the Caledonian fold belt of East Greenland in the area west of Kong Oscars Fjord (fig. 1). Reference is made in the present paper to my previous account on the microfossils of the Visingsö Beds in southern Sweden (Vidal, 1976a) which includes a compilation of most of the relevant data available at the time. Most of the acritarch taxa found in the material from East Greenland show no significant differences to those from the Visingsö Beds. Descriptions are therefore short and concise, and reference is made to previous data where necessary.

GEOLOGY

The Caledonian geosynclinal sequence in East Greenland is bordered to the west by metamorphic crystalline complexes. A thick pile of sedimentary Upper Proterozoic and Lower Palaeozoic rocks exhibit major folding with generally N–S axial trends and slight metamorphism towards the contacts with the metamorphic crystalline complexes. The investigated part of the Caledonian sequence is within the Eleonore Bay Group, Tillite Group and Lower Cambrian. The Upper Proterozoic Eleonore Bay Group, whose thickness locally reaches up to about 13 000 m, is divided in descending stratigraphic order into the following rock units; Limestone-Dolomite 'Series', Multicoloured 'Series', Quartzite 'Series', Upper Argillaceous-Arenaceous 'Series', Calc-Argillaceous 'Series', Lower Arenaceous-Argillaceous 'Series' (Haller, 1971; and fig. 2). These units, those of the Tillite Group and the Lower Cambrian sequence, are described below in descending stratigraphic order.

MATERIAL AND METHODS

A total of 163 rock samples from the Eleonore Bay Group, Tillite Group and Lower Cambrian (Lower Bastion Formation and lower part of the Ella Island Formation) were collected during the summer 1974 by H. Stendal and N. Frandsen (Copenhagen) and given to the author by Niels Henriksen of the Geological Survey of Greenland. Two samples of the lower and upper part of the Kløftelv Formation were also provided by A. K. Higgins of the Geological Survey of Greenland. Of the


STRATIGRAPHY
BED NUMBER
LITHOLOGY
SAMPLES PRESENT MATERIAL
PREVIOUS SAMPLES (VIDAL, 1976 b)
LOWER CAMBRIAN
HYOLITHUS CREEK Fm
ELLA ISLAND Fm
BASTION Fm
KLØFTELV Fm
CANYON Fm
VENDIAN
TILLITE GROUP
UPPER TILLITE
INTER-TILLITE BEDS
LOWER TILLITE
UPPER RIPHEAN
RIPHEAN (?)
ELEONORE BAY GROUP
LIMESTONE - DOLOMITE 'SERIES'
MULTICOLOURED 'SERIES'
QUARTZITE 'SERIES'
UPPER ARGILLACEOUS - ARENACEOUS 'SERIES'
CALC - ARGILLACEOUS 'SERIES'
LOWER ARENACEOUS - ARGILLACEOUS 'SERIES'
19-20
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
p-q
o
n
m
l
k
j
i
h
g
f
e
d
c
b
a
185462-466
185457-461
236411, 414
185446-456
GD-5
185438-445
GD-3, GD-4
185429-438
185421-428
GD-2, 6, 136578
185543-551
142342
185419-420
185416-418
185403-415
185 516-537
142339-340
142343
GA-1
185514-515
185513
G/3-5
185509-512, 540-42
G-2, 142308
185505-508
G-1
185500-504
142305
142301-302
185495-499
GB-1
185475-494
136564
185467-474
G/1-2
136552-553, 555
185562-563
185559-561, 185552-553
185554-558
136604
142335
142322
185401-402
142315
TILLITE
QUARTZITE / SANDSTONE
GREYWACKE
SHALE
LIMESTONE
DOLOMITE / STROMATOLITE
DOLOMITIC / CALCAREOUS SHALE
SILTSTONE / ARENACEOUS SHALE
0
1000
2000
METRES

163 available samples 130 samples were processed and the remaining 33 discarded as unsuitable for the extraction of acid-resistant, organic-walled microfossils, either because they were too cleaved or deformed or because the lithologies were not regarded as sufficiently promising.

Clean cut pieces of rock with a variable weight, were processed as described by Vidal (1976a). Sample numbers refer to the Geological Survey of Greenland collection, where samples are deposited.

Of the 130 samples processed 69 yielded identifiable acritarchs in variable states of preservation. Fourteen samples gave unidentifiable or only tentatively identifiable acritarchs. Only the samples yielding fully identifiable microfossils are considered, and the results indicate that roughly 52 per cent of the processed samples are fossiliferous (details of samples from each investigated unit are available from GGU). This is regarded as a fairly good result considering that the material examined comes from rocks which have been deformed by folding and affected to a variable extent by low grade metamorphism.

Microphotographs of embedded specimens were taken with a Zeiss Photomicroscope II. Panchromatic roll film with a speed of 50 ASA (Ilford Pan F) was used. Figured embedded specimens can be relocated in the permanent mounts with the help of an England Finder using the coordinates given after the colon following the 6 figure sample number. In this investigation the use of stereoscanning electron microscope techniques has been limited by the fact that in most samples the number of available specimens of each studied taxon is usually small. Therefore, only a few numerically abundant taxa could be satisfactorily studied under the SEM. Scanning electron micrographs were taken with a Cambridge Mark IIa scanning electron microscope. Preparations containing figured specimens have a 6 figure number engraved which indicates the GGU sample number. The figured material is deposited in the collections of the Geological Museum, Copenhagen, all other material including slides is in the Geological Survey of Greenland.

RESULTS

General results of each investigated rock unit are given here. Detailed information concerning each processed sample kept at the Geological Survey of Greenland (Copenhagen) can be obtained on request.

Ella Island Formation (Lower Cambrian)

The Ella Island Formation has a thickness of 80–102 m and consists almost entirely of sandy limestones (Haller, 1971). The limestones are often cross-bedded and contain slumping structures and intraformational conglomerates. Shaly beds in the middle of the unit contain trace fossils (e.g. *Cruziana, Diplichnites, Plagiomus*) and *Scolithos* burrows (Cowie &

Fig. 2. Simplified composite section of the Eleonore Bay Group, Tillite Group and Lower Cambrian in East Greenland showing approximate stratigraphic position of investigated samples. Compiled from several illustrations in Haller (1971).

Spencer, 1970). The carbonates of the Ella Island Formation have yielded a shelly fauna including olenellid and eodiscid trilobites, hyolithids and brachiopods, (Poulsen, 1932; Cowie & Adams, 1957). Five samples from the lower part ('Lower Limestones') of the Ella Island Formation were processed (figs 1, 2). All were fossiliferous and the following taxa were recovered; *Baltisphaeridium* sp. (Plate 2a, b), *B. compressum* Volkova (1968), *B. orbiculare* Volkova (1968), *B.? strigosum* Yankauskas (1976), *Granomarginata* cf. *prima* Naumova (1960), *Leiosphaeridia* sp., *Tasmanites variabilis* Volkova (1968), *Trachysphaeridium levis* (Lopukhin) Vidal (1974) and *T. timofeevi* Vidal (1976) (fig. 4).

Bastion Formation (Lower Cambrian)

The Bastion Formation is about 152 m thick. Its lower part is made up in ascending order of sandstones, siltstones and arenaceous shales, generally ferruginous or glauconitic (Haller, 1971). A basal conglomerate contains phosphatic bodies indicating a stratigraphic gap between this unit and the underlying Kløftelv Formation (cf. Cowie & Spencer, 1970; fig. 182 in Henriksen & Higgins, 1976; fig. 4). This part of the unit contains trace fossils (i.e. *Scolicia, Planolites, Phycoides*) and burrows (probably *Scolithos* and *Arenicolites*) (Cowie & Spencer, 1970). The lower part of the Upper Bastion Formation ('Lower Shell-Limestone') is conglomeratic in places and contains phosphatic pebbles. Hence, a disconformity may be present between the Lower and Upper Bastion Formation (Haller, 1971). The 'Lower Shell-Limestone' and 'Lower Shales' contain olenellid trilobites, brachiopods and hyolithids (Poulsen, 1932; Cowie & Adams, 1957). The overlying 'Upper Shell-Limestone' contains eodiscid and olenellid trilobites (Cowie, 1961) and is overlain by the 'Upper Shales'.

Five samples, from the lower glauconitic sandstones of the Lower Bastion Formation were processed and examined (figs 1, 2). All are fossiliferous and yielded the following taxa; *Leiosphaeridia* sp., *Protosphaeridium* cf. *flexuosum* Timofeev (1966), *P. Laccatum* (Timofeev) Vidal (1974), *T. levis* (Lopukhin) Vidal (1974) and *T. timofeevi* Vidal (1976) (fig. 3).

Kløftelv Formation (Lower Cambrian?)

The Kløftelv Formation has a thickness of about 70 m and is made up of alternating quartzites and sandstones. The uniformity of thickness and lithology suggests rapid marine transgression over a peneplaned area (and therefore a major stratigraphic gap between this unit and the underlying Tillite Group). Swett & Smit (1972) suggested deposition by tidal marine processes on a generally southwards directed palaeoslope. The lower sandstones of this unit contain structures which may be caused by organisms or desiccation (Cowie & Spencer, 1970). Possible worm trails and casts were recorded by Cowie & Adams (1957) from a locality in Hudson Land and drifted boulders with *Scolithos linearis*, possibly derived from the Kløftelv Formation, are mentioned by Cowie & Adams (1957). A disconformity separates this unit from the overlying Bastion Formation (see above).

Two red-brown coloured sandstone samples (GGU 236411 and 236414; fig. 2) from the bottom and top parts of the Kløftelv Formation (cliff section east of Kløftelv at Ella Ø, fig. 1), were processed and found barren.

Tillite Group

The Tillite Group has a thickness of about 300–1300 m, but is usually 500–800 m thick (Haller, 1971). It is divided into five units, i.e. Lower Tillite, Inter-tillite beds, Upper Tillite, Canyon Formation, Spiral Creek Formation. The Tillite Group contains a number of mixtite beds interpreted as glaciomarine (Haller, 1971; Poulsen, 1930; Vidal, 1976b). These are usually correlated with Upper Proterozoic or Eocambrian possibly glacial mixtite beds elsewhere, supposed to have been deposited during a global glacial event; the Eocambrian, Varangian* or Vendian glacial event (Harland, 1964a, b). However, the glacial origin of the mixtites of the Tillite Group is still open to discussion (Haller, 1971, p. 105) and has been strongly questioned by Schermerhorn (1974, p. 726) who also questioned the glacial origin of many other Proterozoic mixtites and favoured mudflows as the mechanism responsible for the deposition of the mixtites of the Tillite Group. The Tillite Group overlies the Limestone-Dolomite 'Series' of the Upper Eleonore Bay Group sometimes disconformably (fig. 4) and elsewhere with a transitional contact (Haller, 1971). Haller (1971) suggested that this apparently local break may indicate an important regional unconformity, representing a considerable period of time. This suggestion was favoured by Vidal (1976a, b).

Of twenty-eight samples from the Tillite Group one sample was discarded because it was not regarded sufficiently promising, one sample was rejected during processing due to the formation of insoluble fluorides, ten samples were barren and 15 yielded microfossils. Acritarchs were previously reported from the Inter-tillite beds and the Lower Tillite of the Tillite Group by Vidal (1976b) (fig. 2).

Processed samples of the Lower Tillite and Inter-tillite beds (figs 1, 2) yielded the following acritarch taxa; *Bavlinella faveolata* (Shepeleva) Vidal (1976), *Chuaria circularis* Walcott (1899), *Kildinella* sp., *Leiosphaeridia* sp., *Octoedryxium truncatum* (Rudavskaya) Vidal (1976), *P. laccatum* (Timofeev) Vidal (1974), cf. *Stictosphaeridium* sp., *T. levis* (Lopukhin) Vidal (1974) and *T. timofeevi* Vidal (1976) (fig. 3).

Samples of the Canyon Formation (figs 1, 2) yielded the following acritarch taxa; *B. faveolata* (Shepeleva) Vidal (1976), *P. laccatum* (Timofeev) Vidal (1974), cf. *Sticto-sphaeridium* sp., *Synsphaeridium* sp. and *T. levis* (Lopukhin) Vidal (1974) (fig. 3).

Upper Eleonore Bay Group

Limestone-Dolomite 'Series'

The Limestone-Dolomite 'Series' is a sequence of limestones and dolostones with minor shale and marlstone showing great local variations in both lithological composition and thickness (Haller, 1971). The calcareous and dolomitic rocks of this unit may be stromatolitic, oolitic and pisolitic, thus indicating shallow marine conditions, intraformational conglomerates, local pebbly conglomerates and erosional disconformities within the sequence indicating unstable conditions (Haller, 1971). Local subtidal zone conditions are indicated by stromatolitic biostromes (Caby, 1972). Seven beds are distinguished in this unit (beds 14–20). Beds 19 and 20 consist of dolomites, limestones, silty shales, and uniform dark-grey limestone, respectively. The boundary between these beds is transitional and bed 20 varies

* Surely this should be Varangerian after Varangerfjord.

in thickness from 0–80 m. On Ella Ø (fig. 1), a dark, brecciated limestone is regarded as the correlative of bed 20 (Haller, 1971). Schaub (1950) described a gradual transition from this brecciated limestone into silty shales, which form the base of the Lower Tillite of the Tillite Group. However, an erosional surface has been observed at Kap Oswald on Ella Ø (fig. 1) (Christian Hjort, Lund, pers. comm.). Erosional surfaces have also been observed on Strindberg Land, where the calcareous top of the Eleonore Bay Group is a weathered, limonitized surface bearing evidence of slight erosion (Katz, 1954, p. 14).

Acritarchs have been reported from beds 19 and 17 of this unit (Vidal, 1976b).

Nine samples from bed 19 (location 14 in fig. 1; fig. 2) and 7 samples from bed 18 (locations 23–25 and 32, fig. 1; fig. 2) of the Upper Limestone-Dolomite 'Series' were processed. One sample from bed 19 was barren. The remaining yielded abundant and well preserved acritarchs. The following taxa were recovered: *C. circularis* Walcott (1899), *Kildinella hyperboreica* Timofeev (1966), *K. sinica* Timofeev (1966), *K. vesljanica* Timofeev (1966), cf. *Stictosphaeridium* sp., *S. verrucatum* Vidal (1976), *Synsphaeridium* sp. and *Trachysphaeridium laminaritum* (Tim.) Vidal (1976) (fig. 3).

Only one sample from bed 18 was fossiliferous (location spot 32, fig. 1; fig. 2). This sample yielded extremely abundant specimens of black, full-relief preserved 'chitinozoan-like' microfossils (fig. 3). Barren samples generally yielded abundant carbonaceous matter.

Eighteen samples from the Lower Limestone-Dolomite 'Series' were processed. Previously investigated samples (Vidal, 1976b) are shown in fig. 2.

One out of two processed samples from bed 16 (figs 1, 2) yielded abundant specimens of *P.? densicoronata* Vidal (1976), scattered specimens of *Turuchanica* sp. and abundant specimens of 'chitinozoan-like' microfossils.

Two out of three processed samples from bed 15 (figs 1, 2) yielded the following acritarch taxa; *C. circularis* Walcott (1899), *P.? densicoronata* Vidal (1976), cf. *Stictosphaeridium* sp. and *T. levis* (Lopukhin) Vidal (1974).

Only two out of 13 processed samples from bed 14 (figs 1, 2) yielded acritarchs. The acritarchs in these samples consist of poorly preserved specimens of *Trachysphaeridium* sp., *T. levis* (Lopukhin) Vidal (1974) and *T. timofeevi* Vidal (1976). The samples also yielded abundant, mostly fragmentary, black, large sphaeromorphs which can be ascribed to *C. circularis* Walcott (1899).

Nine samples from the Lower Limestone-Dolomite 'Series' (no bed numbers distinguished) at location 10 (fig. 1) were processed. One (185517) yielded one specimen of *T. levis* (Lopukhin) Vidal (1974). The remaining samples are barren and contain abundant carbonaceous matter.

Multicoloured 'Series'

The Multicoloured 'Series' is a 900–100 m thick unit made up of shales, flaggy mudstones, arenaceous dolomites, limestones, dolomitic shales, sandstones and shales of variable colours deposited on a stable marine shelf (Haller, 1971). Seven beds are distinguished in this unit (beds 7–13).

Fifteen samples from the Multicoloured 'Series' were processed (figs 1, 2). Most samples yielded only abundant dark organic matter. One sample (185502) contains unidentifiable grey-coloured sphaeromorphs. Only two samples yielded identifiable acritarchs (185504 and 185511). The following acritarch taxa were recovered; *P.*? cf. *densicoronata* Vidal (1976), *T. levis* (Lopukhin) Vidal (1974) and corroded and fragmentary specimens of *C. circularis* Walcott (1899).

Quartzite 'Series'

The Quartzite 'Series' has a thickness of 1800–2200 m and is made up of well-sorted sandstones, quartzites, silty shales and shales. Cross-bedding, ripple-marks, mud-cracks, graded and rythmic bedding are common in this unit and indicate sedimentation under shallow water conditions (Haller, 1971). This unit is subdivided into 6 beds (1–6). Bed contacts are often sharp indicationg pronounced changes in sedimentation; but no direct evidence of disconformities has been found (Haller, 1971).

Twenty-three samples of the Quartzite 'Series' were processed from beds 1–4 (figs 1, 2). Most of them yielded only carbonaceous material. The only recovered microfossils are from bed 3. Samples 185478 and 185481 yielded scattered, poorly preserved specimens of *Kildinella* sp. and a few specimens of large, carbonized, flattened sphaeromorphs; probably *C. circularis* Walcott (1899). Poor, unidentifiable sphaeromorphs were recovered from one sample of bed 3 (185486).

Previous samples from the Quartzite 'Series' have given comparable results (Vidal, 1976b) (fig. 2).

Lower Eleonore Bay Group

Upper Argillaceous-Arenaceous 'Series'

The Upper Argillaceous-Arenaceous 'Series' has a total thickness of 1200–1400 m and is made up of thin-bedded quartzites, slates and shales with some dolomite in the upper part (Haller, 1971).

Five samples were processed and poorly preserved, small, grey-coloured sphaeromorphs were recovered from sample 185553. Carbonized, flattened, large sphaeromorphs, which could be ascribed to *C. circularis* Walcott (1899), were recovered from the above sample and from sample 185561. The remaining processed samples yielded only abundant carbonaceous fragments.

Calc-Argillaceous 'Series'

The Calc-Argillaceous 'Series' is a 150 m thick sequence of alternating siliceous limestones, shales and minor thin-bedded quartzites.

Four samples from the Calc-Argillaceous 'Series' were processed. Scattered large specimens of *T. levis* (Lopukhin) Vidal (1974) were recovered from sample 185554. Sample 185557 yielded abundant fragmentary specimens of black, flattened, large sphaeromorphs (*C. circularis*?).

Lower Arenaceous-Argillaceous 'Series'

In the Alpefjord area the Lower Arenaceous-Argillaceous 'Series' has a thickness of about 8000 m (Fränkl, 1951; Haller, 1971). This sequence is made up of alternating pure quartzites and fine-grained greywackes. Current bedding is common in the quartzites and small-scale grading, ripple bedding and load structures in the greywackes (Haller, 1971).

One processed sample of this unit (185401) was found barren. Previously investigated samples from the series (cf. Vidal, 1976b) are shown in fig. 2.

ACRITARCHS

State of preservation

As a rule, the state of preservation of acritarchs is relatively good. Acritarchs preserved in full relief are restricted to a few samples of the Bastion Formation, Tillite Group and Limestone-Dolomite 'Series'. The colour of acritarchs in samples from these units and from the Ella Island Formation ranges from yellowish to dark brown. Thus, carbonization or coalification has only marginally affected the acritarchs in these units. However, with the exception of the Bastion Formation and Ella Island Formation (which yielded only light coloured acritarchs), acritarchs of the Tillite Group and Eleonore Bay Group display variable states of preservation and colour. Samples of the Upper Limestone-Dolomite 'Series' and Tillite Group, within a restricted area (fig. 1), gave both well (yellow to dark brown) and poorly preserved, strongly coalified or carbonized (cf. Gray & Boucot, 1975) acritarchs. Well preserved acritarchs (yellowish in colour) were recovered from a level as low in the Eleonore Bay Group as the Calc-Argillaceous 'Series'. This patchy distribution in the state of preservation of acritarchs can be ascribed neither to variable state of coalification due to overburden pressure conditions nor to low grade regional metamorphism (cf. Vidal, 1976b), which could be expected to result in a gradational pattern in the preservation and colour of the acritarchs. Variation in the state of preservation of acritarchs is probably due to carbonization resulting from locally variable tectonic pressure. Lack of brittle deformation in the acritarchs recovered, implies that the organic walls of the acritarchs were hardly altered prior to tectonic deformation (cf. Gray & Boucot, 1975) in this part of the Caledonian fold belt. Thus, according to Wilson (1971) state of preservation and colour of the best preserved acritarchs recovered should indicate that the thickness of the rock cover was never in excess of 1900 m and the temperature never exceeded 38°C. However, field evidence indicates that the Cambrian to Ordovician succession alone is up to 3000 m thick (Haller, 1971, p. 124).

The poorest preserved acritarchs recovered from the present material are considerably carbonized. Small acritarchs display light to dark grey colours and large specimens are usually opaque black or completely carbonized, indicating considerable thermal alteration, possibly at around 159 to ≥ 180°C (Correia, 1967).

Comparable states of preservation have been noted in acritarchs recovered from rocks metamorphosed into prehnite-pumpellyite facies (Vidal, 1976b). It cannot be excluded that carbonization of acritarchs in the stratigraphically lowest investigated rock units (Lower Arenaceous-Argillaceous 'Series') may depend on thermal alteration due to combined overburden pressure conditions, tectonic deformation and mild metamorphism.

Environmental comments

The acritarch taxa recovered from the Limestone-Dolomite 'Series' were regarded by Vidal (1976a) as restricted to fine-grained rocks, deposited in a shallow marine environment. These taxa are now also known to occur in mudstones and turbidite-like deposits which for several reasons are regarded as deposited in a deeper marine environment. However, the taxa in question are much more sparsely represented in these rocks.

The acritarch assemblage in rocks of the Bastion Formation is depleted and poorly diversified. It consists of very simple sphaeromorphs known to be particularly common in rocks representing extremely shallow marine environments (cf. Vidal, 1976a). The present material shows that these taxa have very long stratigraphic ranges. They probably were adapted to extremely shallow marine environments and (maybe therefore) extremely conservative. The apparent lack of acritarchs redeposited from older units in the rocks of the Tillite Group has been noted elsewhere (Vidal, 1976b). Evidence of redeposition and reworking in the Tillite Group is restricted to the presence of corroded and pitted, fragmentary specimens of *C. circularis* in one sample of the Lower Tillite (185436). In contrast, results (unpublished) obtained from tillite samples of the Mortensens Tillite and Smalfjord Tillite in northern Norway show that these units only contain derived acritarchs (fig. 4). *C. Circularis*, cf. *Stictosphaeridium* sp., *T. levis* and *T. timofeevi* occur also in units underlying the Tillite Group. However, *T. levis* and *T. timofeevi* have (as pointed out below) long stratigraphic ranges (fig. 3), and the specimens found in the samples of the Tillite Group show no traces of redeposition or reworking. Some of the samples of the Tillite Group are slightly bituminous and contain pyrite (cf. Vidal, 1976b; see also above), possibly indicating that at least some of the fossiliferous mixtites of the Tillite Group were deposited in a marine environment.

MICROFOSSILS \ STRATIGRAPHY	UPPER RIPHEAN – ELEONORE BAY GROUP					VENDIAN – TILLITE GROUP		LOWER CAMBRIAN		VISINGSÖ BEDS (S. SWEDEN)		
	9	8	7	6	5	4	3	2	1	L	M	U
BALTISPHAERIDIUM sp.									●			
B. COMPRESSUM VOL.									●			
B. ORBICULARE VOL.									●			
B.? STRIGOSUM YAN.									●			
BAVLINELLA FAVEOLATA (SHEP.)						●	●					●
CHUARIA CIRCULARIS WAL.	?	●	●	●	●	●				●	●	●
GRANOMARGINATA cf. *PRIMA* NAU.									●			
KILDINELLA sp.		●				●						
K. HYPERBOREICA TIM.					●					●	●	●
K. SINICA TIM.					●					●	●	●
K. VESLJANICA TIM.					●					●	●	●
LEIOSPHAERIDIA sp.						●		●	●			
OCTOEDRYXIUM TRUNCATUM (RUD.)						●						●
PROTOSPHAERIDIUM cf. *FLEXUOSUM* (TIM.)								●				●
P. cf. *PATELLIFORME* TIM.		○										
P. LACCATUM TIM.						●	●	●		●	●	●
PTEROSPERMOPSIMORPHA? DENSICORONATA VID.			●	●							●	●
cf. *STICTOSPHAERIDIUM* sp.			○	●	●	●	●				●	●
S. cf. *SINAPTICULIFERUM* TIM.					○							●
S. VERRUCATUM VID.					●							●
SYNSPHAERIDIUM sp.	○	○	○	○	●		●				●	●
TASMANITES VARIABILIS VOL.									●			
TRACHYSPHAERIDIUM sp.				●								
T. LAMINARITUM (TIM.)					●					●	●	●
T. LAUFELDI VID.					○						●	●
T. LEVIS (LOP.)	●		●	●		●	●	●	●	●	●	●
T. TIMOFEEVI VID.			cf.	●		●		●	●	●	●	●
'CHITINOZOAN' - LIKE MICROFOSSIL				●								

Fig. 3. Stratigraphic distribution of microfossil taxa in the Lower Cambrian (**1** Ella Island Formation, **2** Bastion Formation), Upper Proterozoic Tillite Group (**3** Canyon Formation, **4** Lower Tillite and Inter-tillite beds), Upper Eleonore Bay Group (**5** Upper Limestone-Dolomite 'Series', **6** Lower Limestone-Dolomite 'Series', **7** Multicoloured 'Series', **8** Quartzite 'Series'), Lower Eleonore Bay Group (**9** Upper Argillaceous-Arenaceous 'Series' and Calc-Argillaceous 'Series') in East Greenland and Visingsö Beds in southern Sweden.

Genus *Baltisphaeridium* Eisenack, 1958, emend. Eisenack, 1969

Baltisphaeridium compressum Volkova, 1968

Plate 1 b, d, f

Baltisphaeridium compressum Volkova, 1968; p. 19, Pl. 2: 7, 9, Pl. 11: 2.

Description. A *Baltisphaeridium* sp. with single walled, sphaerical to avoidal vesicle with numerous processes. The processes are conical, their length never exceeding the vesicle diameter. The bases of the processes are constricted and their distal ends are bifurcated or thickened.

Dimensions. Measurements were carried out on distorted specimens. The vesicle diameter of measured specimens is 23–37 µm. The length of processes is 3–9 µm.

Remarks. The identification of this species is somewhat uncertain, since the length of processes of *B. compressum* in Volkova's material is 9–18 µm, while in the present material it is 3–9 µm. Some of the specimens found are quite distorted and show compressional wrinkles on their vesicles. Processes are 30–50 in number but in some specimens are detached or broken so that accurate quantification is difficult. Pyrite grains were observed inside the vesicles of a number of specimens. Some vesicles are completely occupied by a single pyrite framboid and consequently strongly deformed.

Occurrence. B. compressum was reported by Volkova (1968) from the upper part of the Lontova Formation (i.e. Lükati Formation; see below) in the boreholes Uljaste, Ranna-Pungerja and Palamuse in Estonia. Volkova (1969) reported *B. compressum* from the upper Lower Cambrian *Protolenus* Beds (Upper Radzyn 'Series') and upper part of Lower Cambrian *Holmia* Beds (upper Lower Radzyn 'Series') in the borehole Radzyn in Poland. In eastern Greenland *B. compressum* occurs in the lower part of the Ella Island Formation ('Lower Limestones') at Ella Ø (see fig. 3).

Stratigraphic range. Lower Cambrian.

Baltisphaeridium orbiculare Volkova, 1968

Plate 1 c, e

Baltisphaeridium orbiculare Volkova, 1968, p. 19, Pl. 2: 1, 3–5, Pl. 11: 3.

Description. A *Baltisphaeridium* species with compressed, somewhat flattened and wrinkled, single walled, circular to ovoidal, smooth vesicle with numerous (≥ 50) processes. The processes are somewhat wider at their bases and distal ends.

Dimensions. Measured specimens are somewhat flattened and distorted. The vesicle diameter is 30–35 µm and the length of processes 5–6 µm. Vesicle of specimens in Volkova (1968) are 22–34 µm in diameter and the length of processes 6–11 µm.

Remarks. All the specimens of *B. orbiculare* found are more or less diagenetically compressed and display clear wrinkles on their massive vesicles. A number of specimens with broken, partially or totally detached processes were found. Vesicles lacking processes look similar to *Leiosphaeridia* spp., but the presence of preserved proximal parts of processes, particularly along the margins of the vesicles identify them as baltisphaerids.

Occurrence. B. orbiculare was reported by Volkova (1968) from the upper part of the Lontova Formation in the boreholes Uljaste, Ranna-Pungerja and Palamuse in Estonia. In eastern Greenland *B. orbiculare* is found in the lower part of the Ella Island Formation ('Lower Limestones') at Ella Ø (see fig. 3). The species is reported by Birkis *et al.* (1970) from the lower member of the Venta Formation in western Latvia.

Stratigraphic range. Lower Cambrian.

Baltisphaeridium? *strigosum* Yankauskas, 1976

Plate 1 a

Baltisphaeridium? *strigosum* Yankauskas. Yankauskas & Posti, 1976: pp. 146–147, Pl. 1:14.

Description. A species of *Baltisphaeridium*? with sphaerical to ovoidal, somewhat distorted, single walled vesicle with extremely numerous tightly arranged processes. The processes have a ciliated appearance. Remains of a thin organic membrane appear to be attached to the visible distal ends of processes. These could be the remains of a poorly preserved peteinos.

Dimensions. Only a few specimens of *B.*? *strigosum* were found. The vesicle of recovered specimens are 22–24 μm in diameter. The processes are 5–7 μm in length. The dimensions of *B.* ? *strigosum* given by Yankauskas & Posti (1976) are about 30 μm for the vesicle diameter and about 10 μm for the length of processes.

Occurrence. B.? *strigosum* was reported by Yankauskas & Posti (1976) from the Vergale 'Horizon' in the boreholes Kibartai 22 (at 1388–1383 m), Stonisjkaj (at 2109 m) and Jatjonis 299 (at 321 m) in Lithuania and from the Rausve 'Horizon' in the boreholes Seliste 173 (at 493 m) (southern Estonia), Kibartai 22 (at 1355 m) (Lithuania), and Ludza 15 (at 693 m) (eastern Latvia). In eastern Greenland *B.*? *strigosum* occurs in two samples of the lower part of the Ella Island Formation.

Stratigraphic range. Lower Cambrian.

Genus *Bavlinella* (Shepeleva, 1962) Vidal, 1976
Bavlinella faveolata (Shepeleva, 1962) Vidal, 1976

Plate 3 c-d

Synonymy. See Vidal (1976a).

Description. See Vidal (1976).

Dimensions. Measurements are based on both full-relief and slightly distorted specimens. Fifty specimens were measured. The diameter of cell-aggregates is 10–20 μm and a major size distribution is found at the interval 15–20 μm. Discrete cells of cell-aggregates are in all cases about 1 μm in diameter.

Remarks. The biogenic origin of *B. faveolata* was questioned by Muir (1977), and Volkova (1974) regarded specimens (previously attributed by her to *B. faveolata*) of the Upper Vendian Kotlin Formation in Estonia as a result of pyrite framboids. This origin was also suggested by Muir (1977) for the specimens of *B. faveolata* described by Vidal (1976a) from the upper Visingsö Beds in southern Sweden. However, objections against this have been discussed by Vidal (1977) who still regards *B. faveolata* (*sensu* Vidal, 1976a) as an authentic microfossil. It deserves mentioning that possible endosporangia of *Sphaerocongreus variabilis* Moorman (cf. Moorman, 1974), synonymyzed with *B. faveolata* by Vidal (1976a), are evidently regarded as authentic microfossils by Cloud (1976). In my opinion, the biogenic origin of *S. variabilis* is amply proved by the TEM micrograph of an ultrathin section of an endosporangium in Cloud (1976, plate 3, p. 13). Discrete organic-walled, sphaerical vesicles occupied by pyrite framboids, are common in the acid-resistant residues of some pyritous sedimentary rocks. Occasionally, pyrite framboids can be found inside vesicles of microfossils (Neves & Sullivan, 1964). Framboidal structures on microfossils have also been reported by Vidal (1974) from pyrite-free sediments whose pyrite was probably oxidized at some stage. Moreover, pyrite framboids may completely occupy the vesicles of small microfossils (Plate 3, a-b). The resulting features consist of clear, sharp edges which reflect the outline of each discrete micro-crystal building up the enclosed framboid. These structures are clearly visible under the SEM (Plate 3, b). When examined on poor quality transmitted light microphotographs, these structures could appear similar to *B. faveolata.* However, they should not be confused with the artificially or naturally detachable more or less spherical cells (cf. Vidal, 1977) which build up the cell-aggregates (sporangia?) of *B. faveolata* (*sensu* Vidal, 1976a).

Occurrence. See Vidal (1976a, b). In eastern Greenland *B. faveolata* is only found in samples of the Canyon Formation, Inter-tillite beds and Lower Tillite of the Tillite Group. Previously reported occurrences of *B. faveolata* in the Kotlin Formation in Estonia (Volkova, 1968) should be disregarded (cf. Volkova, 1974). The species has been recently found in the Lower Cambrian (la$_{\alpha}$) at the Bråstadelva (southern Norway) together with micrhystrid and baltisphaerid acritarchs (author's unpublished data).

Stratigraphic range. Upper Riphean(?), Vendian and Lower Cambrian (Zone with *Schmidtiellus mickwitzi* and *Holmia mobergi*).

Genus *Chuaria* Walcott, 1899

Chuaria circularis Walcott, 1899

Plate 4 a-b

Synonymy. See Ford & Breed (1972, 1973) and Vidal (1974, 1976a).

Description. See Ford & Breed (1973) and Vidal (1974, 1976a).

Dimensions. The diameter ranges given here are based on the measurement of 50 flattened specimens. They are 100–410 μm across with two major size distributions centred at 100–150 μm and 200–250 μm. However, as in previously studied material (Vidal, 1974, 1976a), there are abundant fragments and fragmentary specimens suggesting much larger dimensions (up to 2000 μm or more across).

Remarks. In discussing the modal size distribution of *C. circularis* from the Red Pine Shale in Utah, Hofmann (1976) supported the impossibility (cf. Vidal, 1974) of a suggested 0.5 mm size limit for *C. circularis* (Ford & Breed, 1973). I agree with Hofmann (1976) that fossils attributed to *Chuaria* may contain a variety of biological groups, including planktonic algae, and possibly medusoids. The latter is true of the largest reported specimens of supposed *Chuaria* which apparently (although often not stated) lack any trace of organic wall or carbonaceous film and which consist of simple imprints on a rock surface. However, material obtained using maceration techniques is acid resistant and may be regarded as biologically homogeneous and taxonomically uniform. In my opinion the occurrence of *Chuaria* specimens in acid resistant residues provides the only acceptable evidence for establishing whether or not simple imprints (as those mentioned above) may be ascribed to *Chuaria.*

C. circularis appears to be restricted to fine-grained rocks (Vidal, 1974, 1976a; see also below).

Megaspecimens of *Chuaria* are not particularly common in material from the Eleonore Bay Group in East Greenland, although fragments and fragmentary specimens of larger specimens do occur. There are certain pecularities concerning the occurrence of *C. circularis.* Macerated material from shales of the Visingsö Beds containing megaspecimens of *C. circularis* shows a much wider size distribution than that observed in rocks where megaspecimens are rare. Full relief preserved specimens of *C. circularis* are never found. The latter has an obvious explanation when the enclosing rock matrix is an argillite or generally a fine-grained rock where all other acritarchs are also found compressed. However, *C. circularis* has also been found in carbonate rock and phosphate nodules containing other acritarch taxa in an excellent state of preservation (cf. Vidal, 1976a, table 1). *C. circularis* is also found in a compressed state of preservation in such cases. This might indicate that not all specimens of *C. circularis* were flattened due to sediment compaction. An alternative explanation to this is that the specimens were already collapsed before they were covered by sediment. The shales in which they occur suggest deposition in a shallow, intertidal, marine environment, where *C. circularis* assemblages found suitable conditions and developed into full-grown individuals. Large specimens of *C. circularis* are often corroded, pitted and burrowed(?) and show frequent pyrite damage. The latter is common even in samples where no pyrite damage is observed on the organic walls of other acritarchs. This suggests that reducing conditions prevailed in the sediments resulting in the formation of pyrite which affected the organic wall of *Chuaria* specimens. Eventually, these sediments were either preserved by continued burial or reworked, the latter resulting in mixed assemblages of smaller (younger) specimens and fragmentary or poorly preserved megaspecimens of *C. circularis*. Reworking, sorting and selective destruction may account for the polymodal size distribution and different size ranges observable in *C. circularis* populations.

Occurrence. See Ford & Breed (1973), Vidal (1974, 1976a). *C. circularis* was recently reported by Hofmann (1976) from the Upper Proterozoic Red Pine Shale of the Uinta Mountain Group, Utah. Indisputable specimens of *C. circularis* occur in bed 19 of the Limestone-Dolomite 'Series' and bed 9 and bed 11 of the Multicoloured 'Series'. Poorly preserved, possibly reworked, specimens occur in the Lower Tillite Formation. Somewhat uncertain, poorly preserved specimens of *C. circularis* occur in samples of the Lower Limestone-Dolomite 'Series', Quartzite 'Series' and Upper Argillaceous-Arenaceous 'Series' (fig. 3).

Stratigraphic range. Upper Riphean and Vendian.

Genus *Kildinella* Timofeev (1963) 1966

Remarks. Clusters of two or more vesicles are fairly common among *Kildinella* spp. These clusters are not accidental and are particularly common among small individuals (Plate 4, c-d). This circumstance could indicate that the clusters represent an early ontogenetic stage of *Kildinella.*

In the Upper Vendian and Lower Cambrian of Estonia, Volkova (1968) regarded a distinction between *Kildinella* and *Leiosphaeridia* as impossible. She introduced a system of subdivision based on diameter ranges. The author disagrees with this practice and considers it possible to distinguish three species of *Kildinella* (i.e. *K. hyperboreica, K. sinica* and *K. vesljanica*). In his opinion, *Leiosphaeridia* (although significantly different from *Kildinella*) lacks sufficiently diagnostic features to allow taxonomic subdivision.

Kildinella hyperboreica Timofeev, 1966

Plate 5 b

Synonymy. See Vidal (1976a).

Description. See Vidal (1976a).
Dimensions. Measurements were carried out on 50 flattened specimens. The diameter is 35–62 μm, with a major mode centred at 45 μm.
Remarks. All specimens of *K. hyperboreica* found in the eastern Greenland material are flattened and show clear, wide and narrow wrinkles.

Occurrence. See Vidal (1974, 1976a). *K. hyperboreica* occurs in samples of the Limestone-Dolomite 'Series' and possibly in the Quartzite 'Series' (fig. 4).

Stratigraphic range. Riphean to Lower Cambrian.

Kildinella sinica Timofeev, 1966
Plate 5 a

Synonymy. See Vidal (1976a).

Description. See Vidal (1976a).

Dimensions. Fifty flattened specimens were measured. The vesicle is 42–72 μm across, with a major mode centred at 40 μm.

Occurrence. See Vidal (1976a). *K. sinica* is found in the Upper Limestone-Dolomite 'Series'.

Stratigraphic range. Riphean and Vendian.

Genus Octoedryxium Rudavskaya, 1973
Octoedryxium truncatum (Rudavskaya, 1973) Vidal, 1976
Plate 2 f, g

Synonymy. See Vidal (1976a).

Description. See Vidal (1976a).

Dimensions. Only two specimens of *O. truncatum* were recorded from the present material. These measure 16 μm and 12 μm across. Specimens of the upper Visingsö Beds reported by Vidal (1976a) are 15–80 μm across with major modes at 30 and 40 μm.

Occurrence. See Vidal 1976a). *O. truncatum* was found in one sample of the Lower Tillite of the Tillite Group.

Stratigraphic range. O. truncatum appears to be restricted to the Vendian. However, the species was first reported from the Motsk Beds in the Irkutsk area which on micropalaeontological evidence were regarded as Vendian to Early Cambrian and not older than 650 m.y. (Rudavskaya, 1971, p. 97). An acritarch complex from the lower part of the Motsk Beds was regarded by Rudavskaya (1971) as similar to assemblages from the Vendian Upper Valdai 'Series' of the Russian Platform. An upper assemblage (from the Markovo Beds) was regarded as comparable with assemblages from the lower part of the Blue Clay (Lower Cambrian) in Volhynia and in the Baltic region. However, most of the acritarch taxa of the Motsk Beds are extremely simple, small sphaeromorphs restricted to extremely shallow marine environments (author's unpublished data) and having extremely long stratigraphic ranges. However, the nature of some of them (as indicated by Rudavskaya, 1971) is dubious. Thus, a speculative Early Cambrian age for parts of the Motsk Beds has still to be proved. The reported occurrence of *Bavlinella* in the Motsk Beds could indicate a Vendian age. However, the poor quality of the illustrations in Rudavskaya's paper does not allow precise determination.

Genus *Tasmanites* Newton, 1875
Tasmanites variabilis Volkova, 1968
Plate 2 c-d

Tasmanites variabilis Volkova, 1968, p. 29, Pl. 5: 9–12, Pl. 11: 9.

Description. A species of *Tasmanites* with circular to oval, compressed and folded, single walled vesicle. The vesicle surface shows a large number of very small pores which are regularly distributed over the whole surface of the vesicle.

Dimensions. Only two specimens of *T. variabilis* were found. However, there are numerous fragmentary specimens. Complete specimens (2) measure 175 and 184 µm across.

Occurrence. T. variabilis is reported by Volkova (1968) from the upper part of the Lontova Formation (i.e. Lükati Formation; see below) in the boreholes Uljaste, Ranna-Pungerja and Palamuse in Estonia and from the lower Radzyn 'Series' (*Holmia* Beds) in the borehole Radzyn in Poland (Volkova, 1969). *T. variabilis* was recovered from two samples of the lower part of the Ella Island Formation ('Lower Limestones') at Ella Ø.

Stratigraphic range. Lower Cambrian Holmia Beds.

OTHER MICROFOSSILS

Among the microfossils recovered from eastern Greenland there are several species which occur in limited numbers. Other species, although numerically common, are briefly discussed here as they are covered in greater detail elsewhere (Vidal, 1974, 1976a).

Granomarginata cf. *prima* Naumova (*sensu* Volkova, 1968) is sparsely represented in the Ella Island Formation. *G. prima* was reported by Volkova (1968) from boreholes penetrating the Lower Cambrian Lontova Formation (also Lontova Formation) in Estonia. The species has also been reported from the Mazoviecky 'Series' (lower Sub-*Holmia* Beds) in the Radzyn borehole in Poland (Volkova, 1969) and from the Lower Cambrian Moletay Formation in eastern Lithuania (cf. fig. 4).

Leiosphaeridia sp. (Plate 2 e) is occasionally found in samples of the Ella Island Formation, Bastion Formation and Lower Tillite.

Protosphaeridium cf. *flexuosum* Timofeev, 1966 is fairly common in the Bastion Formation. The species has an extremely long stratigraphic range (Proterozoic to Middle Cambrian; cf. Vidal, 1976a), but is interesting from the environmental point of view, as it appears to be restricted to very shallow marine environments and is almost exclusively and abundantly found in impure sandstones.

Protosphaeridium laccatum Timofeev, 1966 (*sensu* Vidal, 1974, 1976a) is extremely rare in the present material. Scattered specimens are found in some samples of the Bastion

Formation and Tillite Group (Canyon Formation and Lower Tillite). The species has a long stratigraphic range (Proterozoic to Ordovician; Vidal, 1974, 1976a) and like *P.* cf. *flexuosum* appears to be particularly common in near shore environments (cf. Vidal, 1974, 1976a).

Pterospermopsimorpha? *densicoronata* Vidal, 1976 occurs in samples of the Limestone-Dolomite 'Series' and Multicoloured 'Series'. The species is previously known from the middle and upper Visingsö Beds in Sweden (Vidal, 1976a).

Cf. *Stictosphaeridium* sp. (*sensu* Vidal, 1976a) (Plate 5 c-d) is an important component of the Limestone-Dolomite 'Series' assemblage and is found occasionally in the Multicoloured 'Series', Lower Limestone-Dolomite 'Series' (Vidal, 1976b) and Tillite Group. Clustered vesicles (Plate 5 c-d) are very common in the Limestone-Dolomite 'Series'. Dark spots are quite often observed in the central part of vesicles (Plate 5 c-d).

Stictosphaeridium verrucatum Vidal, 1976 is abundant in one sample of the Limestone-Dolomite 'Series'. The species is otherwise only known from the uppermost part of the upper Visingsö Beds in Sweden (Vidal, 1976a). Its presence in the Limestone-Dolomite 'series' may place its lowest stratigraphic occurrence in the Upper Riphean.

Synsphaeridium sp. (*sensu* Vidal, 1976a) is abundant in some samples of the Limestone-Dolomite 'Series'. One specimen was found in one sample of the Canyon Formation (Tillite Group). Previously reported finds (Vidal, 1976b) are from the Lower Limestone-Dolomite 'Series', Multicoloured 'Series', Quartzite 'Series' and Upper Argillaceous-Arenaceous 'Series'.

Trachysphaeridium laminaritum (Timofeev, 1966) Vidal (1976a) is relatively abundant in a sample of the Limestone-Dolomite 'Series' (bed 19). Its stratigraphic range appears to be Upper Riphean to Vendian (Vidal, unpublished).

Trachysphaeridium levis (Lopukhin, 1971) Vidal, 1974 is plentiful, having been recovered from the Ella Island Formation, Tillite Group, Limestone-Dolomite 'Series' and Multicoloured 'Series'. Thus, the stratigraphic range of the species given by Vidal (1976a) as Upper Riphean to Lower Cambrian is supported by its occurrences in the undoubtedly Lower Cambrian Bastion Formation and Ella Island Formation.

Trachysphaeridium timofeevi Vidal, 1976 is fairly common in the Bastion Formation and is occasional in samples of the Ella Island Formation, Tillite Group and Limestone-Dolomite 'Series'. Scattered, somewhat tentatively identified (due to poor preservation) specimens occur in one sample of the Multicoloured 'Series' (Vidal, 1976a). The stratigraphic range of *T. timofeevi* was previously regarded as possibly uppermost Riphean and Vendian (Vidal, 1976a). However, the present material extends its range into the upper Lower Cambrian (Ella Island Formation).

'Chitinozoan-like' microfossils

Enigmatic, tear-shaped microfossils are quite abundant in a sample of the Upper Limestone-Dolomite 'Series' from the basal part of bed 18 (142342). These enigmatic microfossils have the same general tear-shaped appearance as some of the simplest forms of chitinozoa (e.g. *Conochitina*). However, this does not imply that they are related to Palaeozoic chitinozoan taxa. This very simple shape could, doubtless, be attained by organisms (or parts of organisms) of very different taxonomic position. Further, there are no known records of 'real' chitinozoans older than Early Ordovician. The present microfossils appear to be similar to tear-shaped microfossils reported from the Kwagun Formation of the Upper Proterozoic Chuar Group in Arizona (Bloeser *et al.*, 1977). Similar microfossils also occur in a sample of bed 16 (185420) of the Lower Limestone-Dolomite 'Series'. These microfossils are poorly preserved, the part of the vesicle opposite to the 'aboral region' is broken (Plate 7 a, d). The vesicles are heavily corroded and have large perforations (Plate 7 a–b, d). Pyrite framboids observable inside blister-shaped cavities within the vesicles are probably responsible for the perforations. The vesicles are yellowish brown and translucent under transmitted light. The length of the vesicles is 50–265 μm. The 'aboral region' is about half of the vesicle length. The blister-shaped cavities are about 10–11 μm across. Problematic microfossils in the sample from bed 18 of the Upper Limestone-Dolomite 'Series' have the same general shape. However, some of the largest specimens in this sample (1 mm long and 0.5 mm wide) have a more elongated shape (Plate 6 a-d) than the smaller specimens which are more typically tear shaped (Plate 7 a-d). Like specimens in bed 16, those from bed 18 have pyrite framboid and crystal openings and are also corroded in the region opposite to the 'aboral area'.

Microfossils attributable to *Turuchanica* Rudavskaya (1964) occur sporadically in sample 185420 of bed 16 of the Limestone-Dolomite 'Series'. This form genus is regarded by Timofeev (1969) as consisting of deformed (flattened) specimens of *Protosphaeridium* and other sphaeromorphic acritarch taxa. The specimens are reddish brown and their central part is almost opaque under transmitted light. The translucent margins have a foamy structure. Recovered specimens are 190–200 μm across and show clear radially arranged compressional fractures.

STRATIGRAPHIC COMMENTS

Ella Island Formation, Bastion Formation, Kløftelv Formation

The acritarch assemblage of the Ella Island Formation is characterized by diagnostic baltisphaerids and differs completely from those of other rock units in eastern Greenland. This assemblage contains four species in common with the assemblage described by Volkova (1968) from the uppermost Lontova Formation (Lükati Formation according to N. A. Volkova's personal communication; cf. Yankauskas, 1973; fig. 4) in Estonia. One species (*B. orbiculare*) is also reported by Yankauskas (1973) from the Lükati Formation. A second species, (*B. compressum*) is reported by the same author (Yankauskas, 1973) both from the Lükati Formation and from the overlying Kakumägi Formation in Estonia. The acritarch assemblages of these units are remarkably different from that of the underlying Lontova Formation (cf. Yankauskas & Posti, 1973, table 2; fig. 4). The Lontova Formation and Lükati Formation are separated by a hiatus which comprises the Rovno 'Horizon' (Yankauskas & Posti, 1973; Plisov *et al.*, 1975). Separating the two units there is a conglomerate containing phosphatized siltstone pebbles derived from the Lontova Formation (Mens & Pirrus, 1975), interpreted as indicating denudation and erosion of the upper regressive part of the Lontova Formation.

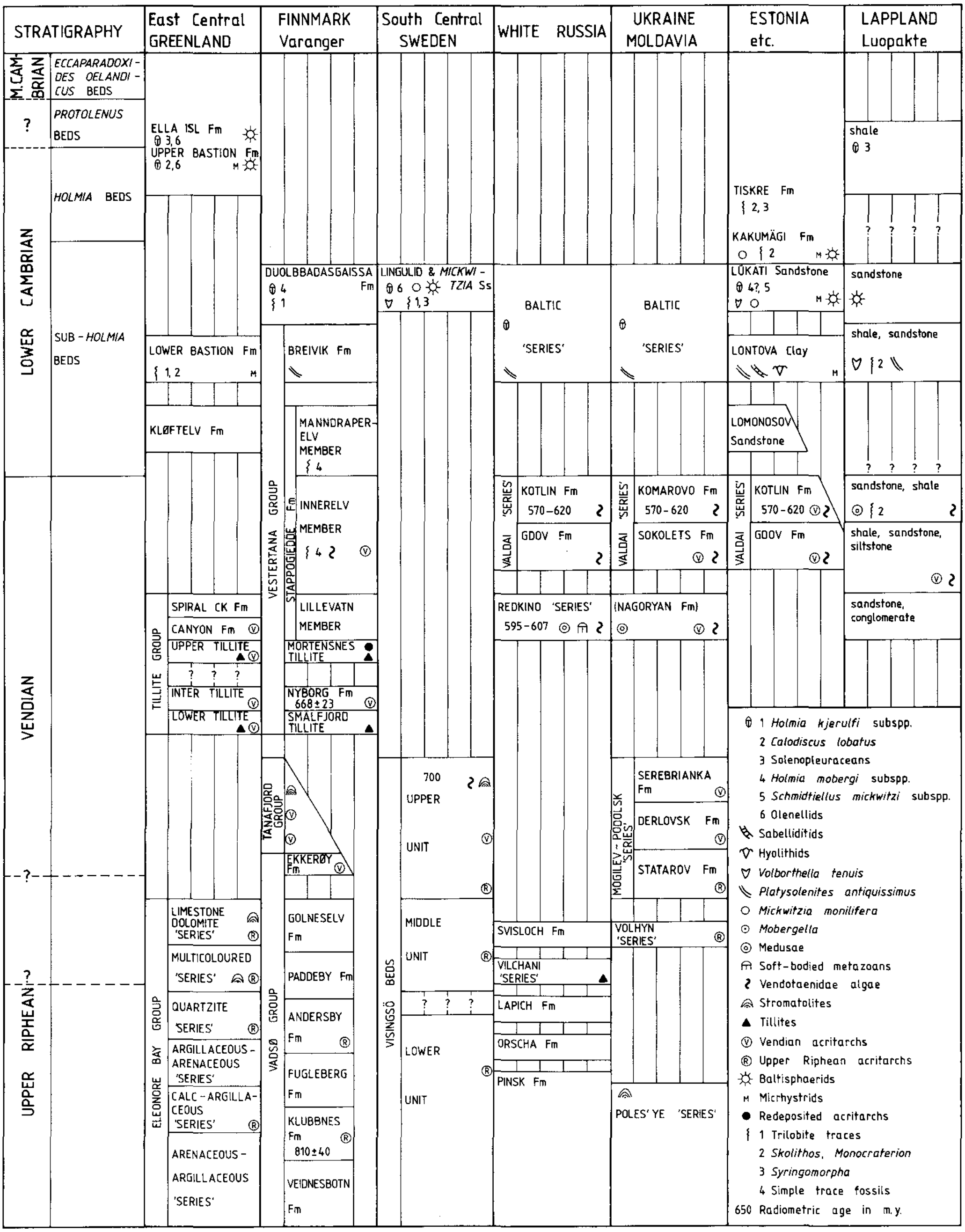
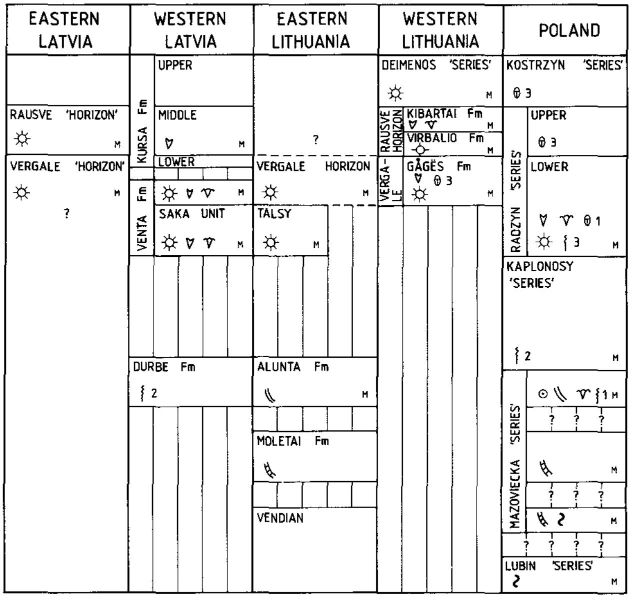


Fig. 4. Correlation table of the Upper Proterozoic and Cambrian. Stratigraphic and macropalaeontological information is compiled from different sources (see chapter on stratigraphic comments). Micropalaeontological data on Finnmark and Lappland sequences are according to unpublished data of the writer. Two alternative positions for the Riphean-Vendian boundary are indicated. The lower alternative is according to Russian practice. The higher boundary is a suggested alternative position based on micropalaeontological evidence as indicated by the appearance of elaborated acritarch taxa.



Thus this hiatus separates pre-trilobite strata (Lontova Formation) from trilobite-bearing beds (Lükati Formation). Earlier records of trilobites (i.e. *Schmidtiellus*) in the Lontova Formation are therefore erroneous (Mardla *et al.*, 1968, p. 26; cf. Yankauskas & Posti, 1973, table 2). The equivalents of the Lükati and Lontova Formations in the Leningrad area show a similar hiatus (A. Y. Rozanov, Moscow, pers. comm. through Brian Daily, Adelaide). Therefore in the type area of the Baltic 'Series' in Estonia the appearance of trilobites in the Lükati Formation is contemporaneous with the appearance of baltisphaerid acritarchs. The acritarch assemblage in the Lontova Formation is dominated by sphaeromorphic acritarchs and a few micrhystrid acritarchs (cf. Yankauskas & Posti, 1973), the latter having long stratigraphic ranges (cf. Yankauskas & Posti, 1973; fig. 4).

In the Lower and Upper Bastion Formations Downie (1974) indicated the presence of acritarch assemblages comparable with those of the Lontova and Lükati Formation respectively (named by Downie the Lomonosov and Lontova) (fig. 4). A comparable assemblage has not been found in the present investigation of the Bastion Formation, which only contains long range acritarchs. Evidence from the Ella Island Formation indicates that the assemblage in Downie's zone 5 (cf. Downie, 1974) in the Upper Bastion Formation extends into the 'Lower Limestones' of the Ella Island Formation. Downie also found a similar assemblage in the Lower Cambrian (North American *Olenellus* Zone; cf. Cowie *et al.*, 1972) Fucoid Beds in Scotland and in the *Holmia* Shale in southern Norway. Thus, available sparse data could indicate that these units can be correlated. The Lükati Formation contains *Volborthella tenuis, Schmidtiellus mickwitzi, Mickwitzia monilifera, Diplocraterion,* *Spiroscolex, medusoids and Eophyton.* The Ella Island Formation contains trilobites of the genus *Wanneria*, but it is uncertain whether they are comparable with *Wanneria? lundgreni* from the Lower Cambrian Norretorp Sandstone in Scania, southern Sweden (Jan Bergström, Lund, pers.comm.). However, the upper part of the Bastion Formation contains the trilobite *Calodiscus lobatus* which has also been found in Jämtland, Sweden together with an unidentifiable ellipsocephalid trilobite (Jan Bergström, pers. comm.). Ellipsocephalids generally appear with other more advanced *Holmia* species (i.e. *H. kjerulfi* and *H. sulcata*) (Jan Bergström, pers.comm.). Thus, trilobite evidence supports the possibility that the Upper Bastion Formation and the lower part of the Ella Island Formation represent parts of the Lower Cambrian sequence stratigraphically higher than the Lükati Formation of Estonia. Acritarch evidence is in accordance with this since Yankauskas & Posti (1973) showed that most Lükati acritarchs range into the overlying Kakumägi Formation. The Lükati Formation might therefore be correlated with the Norretorp Sandstone in Scania and the beds bearing *H. mobergi, Mobergella* sp. and *Platysolenites antiquissimus* in southern Norway (Jan Bergström, pers.comm.). In eastern Greenland, this implies a considerable hiatus between the Upper and Lower Bastion Formations.

The Lower Bastion Formation could therefore be correlated with the Lontova Formation in Estonia, the Hardeberga Quartzite in Scania and the Ringsaker Quartzite Member of the Vangsås Formation in southern Norway. An implication of this correlation is that comparable baltisphaerid acritarchs in Estonia and Greenland therefore appear at different stratigraphic levels. This is further supported by available palaeontological evidence from Latvia, Lithuania and Poland. There are several elements in common between the Upper Bastion and Ella Island Formations in Greenland, the Lükati and Kakumägi Formations in Estonia, Vergale 'Horizon', Rausve 'Horizon' and Deimenos 'Series' in western Lithuania and *Holmia* Beds, *Protolenus* Beds and lowermost *Paradoxides oelandicus* Beds (Middle Cambrian) in Poland (fig. 4). A baltisphaerid species (*Baltisphaeridium? strigosum*) occurs in the Ella Island Formation and the Vergale 'Horizon' and overlying Rausve 'Horizon' in Latvia and Lithuania. A second species (*B. varium*) is reported by Downie (1974) from the Upper Bastion Formation. Yankauskas (1974) reported the species from the Vergale 'Horizon' and Deimenos 'Series' in Lithuania (fig. 4). The Rausve 'Horizon' is correlated with the middle Kursa Formation in Latvia (correlated with the *Protolenus* Beds) which contains Middle Cambrian acritarchs in its upper part (Yankauskas, 1972). The Virbaris and Kirbartai Formations in Lithuania are assigned to the Rausve 'Horizon' (Yankauskas, 1974; fig. 4). The Virbaris Formation contains baltisphaerids, micrhystrids, tasmanitids, and sphaeromorphs (Yankauskas, 1974). The overlying Kibartai Formation contains similar acritarchs (fig. 4) and *Lingulella, Volborthella* and hyolithids (Yankauskas, 1974). These formations are underlain by the Gåges Formation (Gegerskaya Suite in Yankauskas, 1972) which is assigned to the Vergale 'Horizon' (Yankauskas, 1972, 1974). This unit contains *Volborthella* and ellipsocephalid trilobites (Yankauskas, 1974). At its type section, the Vergale 'Horizon' (in borehole Shakyay 42, at 1420–1440m) contains baltisphaerids, micrhystrids and *Volborthella* (Yankauskas, 1972).

In western Lithuania, the Vergale 'Horizon' rests directly on crystalline basement. A comparison with western Latvia shows that there are three acritarch species in common between the Upper Bastion Formation, the lower part of the Ella Island Formation and the lower part of the Venta Formation, which is separated from underlying units by a sharp unconformity and contains *Volborthella tenuis, Platysolenites antiquissimus* and hyolithids (Birkis *et al.*, 1970). There are also four acritarch species in common with the top of the Venta Formation which also contains *V. tenuis*, hyolithids, and other shelly fossils. Units above the Venta Formation (Kursa Formation and 'Izhora' Formation in ascending order) are correlated with the *Holmia* Beds and *Protolenus* Beds in Poland and with the Vergale 'Horizon' and Rausve 'Horizon' in Lithuania (Birkis *et al.*, 1970).

The acritarchs of the Upper Bastion Formation (Downie, 1974) and the lower part of the Ella Island Formation are similar to those of the *Holmia* Beds (lower Radzyn 'Series'), *Protolenus* Beds (upper Radzyn 'Series') and lower part of Kostrzyn 'Series' (Middle Cambrian) in Poland (fig. 4). Correlation of the Upper Bastion Formation and the lower part of the Ella Island Formation with the above units in Latvia, Lithuania and Poland is therefore possible and in agreement with correlation by macrofaunal elements.

In Poland, no micropalaeontological information is available from beds between the lowest baltisphaerid-bearing level in the Radzyn borehole (lower Radzyn 'Series'; cf. Lendzion, 1972 and Volkova, 1969) and the Kaplonosy 'Series' (cf. Aren & Lendzion, 1974) of the upper Sub-*Holmia* Beds. The Kaplonosy 'Series' and underlying units contain micrhystrids (i.e. *Micrhystridium tornatum* which has a very long stratigraphic range) and sphaeromorphs (Aren & Lendzion, 1974). The first appearance of *M. tornatum* in the Radzyn borehole is at 1630.8 m (Aren & Lendzion, 1974) which is below the Cambrian-Vendian boundary as placed by Lendzion (1968, 1972) and Aren & Lendzion (1974). If the Cambrian-Proterozoic boundary is placed at the first appearance of *Micrhystridium* (Downie, 1974), then the supposed Vendian part of the Radzyn borehole should be regarded as Cambrian (but see below). From the scant evidence available the Sub-*Holmia* Beds in the Radzyn borehole can be tentatively correlated with the Lontova Formation in Estonia. It is, however, impossible to place a 'Lükati Lontova' boundary or transition in the sub-*Holmia* Polish sequence. The results obtained from the Bastion Formation are inconclusive. Downie (1974) regarded acritarchs in one sample of the Lower Bastion Formation as characterized by the presence of micrhystrids. He also regarded the assemblage in this part of the Bastion Formation as corresponding to that of the Lomonosov Formation and lower Lontova Formation (i.e. Lontova Formation as used above) and to that described by Volkova (1969) from the

Kostrzyn 'Series' in Poland and to the assemblage of the *Platysolenites* Sandstone (Bråstad Sandstone; $1a\alpha_1$?) in southern Norway (Downie, 1974). Downie's statement concerning the Polish sequence is inadequate since the lower Kostrzyn 'Series' being Middle Cambrian, contains acritarchs also present in the stratigraphically lower units studied by Volkova (1969). The main interest (as also expressed by Downie, 1974) lies in the first appearance of micrhystrids (see above). The tentative correlation of the Polish Sub-*Holmia* Beds with the Lontova Formation and Lükati Formation in Estonia, if feasible, is relevant to Lower Cambrian regional correlations and requires further investigation.

Correlatives of the Mazoviecki 'Series' (cf. Lendzion, 1972) in the borehole Tuszcz contain *Mobergella* (= *Discinella braastadi*) although Bengtson (1977) questioned the identification. However, the species occurs in the upper part of beds which Lendzion (1969) regarded as correlatives of the Mazoviecki 'Series' (which in their lower part contain acritarchs also found in the Lontova Formation in Estonia). This is interesting since Downie (1974) reported 'Lontova' acritarchs from the *Platysolenites* Sandstone in southern Norway. A reported occurrence of *Mobergella* at the Bråstadelva in southern Norway is regarded by Skjeseth (1963) as contemporary with an occurrence of *P. antiquissimus* from Stensviken, Ringsaker (southern Norway). However, *Mobergella* does apparently occur stratigraphically above *Holmia mobergi* in an undisturbed sequence (see Daily, 1972 for a different opinion). *H. mobergi* is also found in the Lükati Formation in Estonia. Thus, *Mobergella* bearing beds in Scandinavia would be correlated with the Lükati Beds; implying that *Mobergella* may have a considerable stratigraphic range.

Faunistic and micropalaeontological data, where available, indicate that breaks in the above sequences match. This is also true for the Lükati-Lontova, Lontova-Lomonosov and Lomonosov-Kotlin boundaries in Estonia (cf. Plisov *et al.*, 1975) and the Upper Bastion Formation – Lower Bastion Formation, Lower Bastion Formation – Kløftelv Formation, and Kløftelv Formation – Tillite Group contacts in eastern Greenland. These units may be widely separated in time by hiati.

Tillite Group

Previously reported acritarchs from units of the Tillite Group were interpreted as indicating a Vendian age (Vidal, 1976b; fig. 4). This assemblage differs greatly from those recovered from the Eleonore Bay Group and Lower Cambrian sequence. The Tillite Group has nine acritarch taxa in common with the Eleonore Bay Group and with the investigated Cambrian units. However, with the exception of *C. circularis* which is found on both sides of the disconformable contact between the Tillite Group and the Eleonore Bay Group, these acritarch taxa have a long stratigraphic range (Vidal, 1976a). Specimens of *C. circularis* recovered from one mixtite sample (185436) of the Lower Tillite Formation are unique in that they are strongly corroded and probably redeposited. This is the only trace of redeposition observed among acritarchs recovered from the Tillite Group. However, *C. circularis* has also been found in Vendian sequences elsewhere. Its sporadic occurrence in the Tillite Group together with *O. truncatum* and *B. faveolata* (also recorded in the upper Visingsö Beds; Vidal, 1976a, and in Upper Proterozoic units in north Sweden and South West Africa; author's unpublished data) appears to agree with a Vendian age.

Vendian age diagnostic acritarchs have not been found underlying or overlying the Tillite Group, and this may indicate that the slightly disconformable contact between the Tillite Group and Eleonore Bay Group and also the regional unconformity between the Tillite Group and Lower Cambrian, could represent comprehensive hiati (Vidal, 1976b).

Comparison with other areas shows that in the Russian Platform (especially White Russia) the Vendian Volhyn 'Series', with glacial units (cf. Schermerhorn, 1974, p. 759) at its base (Vilchani 'Series'; cf. Chumakov, 1971), is a transgressive (and therefore time-transgressive) sequence. The Vilchani 'Series' (Grussakaya Formation) rests disconformably on several units of the Polesye 'Series', which in its upper part may range into the Vendian (Maknaya *et al.*, 1974), and is disconformably overlain by the Gorbatshev Formation and/or by the Svisloch Formation (also Volhyn 'Series') (Maknaya *et al.*, 1974). The glacial units of the Volhyn 'Series' pinch out in the central Russian Platform and are replaced in the Moscow basin by sandstone and mudstone sequences (Kirsanov, 1968). Chumakov (1971, p. 69) regarded the Volhyn 'Series' and its glacials as "originally more widespread and presently found only in buried depressions, where their thickness was at a maximum and the subsequent erosion minimal". Therefore no glacial units are present in the westernmost part of the Russian Platform where the Upper Vendian Gdov Formation (see below) rests directly on crystalline basement (cf. Plisov *et al.*, 1975).

In the Dniester area the Yaryshev Formation with the Yampol Sandstone Beds at its base (equivalent to the uppermost part of the Mogilev Formation of Zanka-Novashky & Tretyak, 1974), transgressively overlying older units, is regarded by Sokolov (1971) as the correlate of the Volhyn 'Series' in the Moscow basin (Yartsevo Formation). However, Bukatchuk *et al.* (1974) regard the Yaryshev Formation in Ukraine and Moldavia as a correlate of the upper part of the Mogilev-Podolsk 'Series' (Serebrianka Formation and Derlovsk Formation) which overlie the Volhyn 'Series'. The Mogilev Formation is regarded by them as the lateral equivalent of the lower Mogilev-Podolsk 'Series' (Starotatarov Formation) and upper part of the Volhyn Formation (Krustov Formation). This formation rests disconformably on the older units of the Volhyn 'Series'. Locally, the Volhyn 'Series' and overlying Mogilev-Podolsk 'Series' are missing as the overlying Nagoryan Formation rests disconformably on older units. According to Maknaya *et* *al.* (1974) the uppermost part of the Volhyn 'Series' (Redkino Formation) in Bielorussia is only locally developed, as the overlying lower unit of the Valdai 'Series' (Gdov Formation) rests disconformably on this unit. The Redkino Formation is regarded by Sokolov (1973) as a transgressive sequence resting directly on basement in many places north of the Moscow graben. Sokolov (1973, 1974) places this fossiliferous unit between the Volhyn 'Series' (below) and Valdai 'Series' (above) (Maknaya *et al.*, 1974), but Plisov *et al.* (1975) regard it as a correlate of the Gdov Formation (lower Valdai 'Series') in the western part of the Russian Platform. Sokolov (1973) considered the Dzhurzhecka Formation, Kalýa Formation and Solkuska Formation (Nagoryan 'Series') as the Ukranian and Moldavian corrrelates of the Redkino Formation. The Nagoryan 'Series' rests disconformably on the Mogilev-Podolsk 'Series' (cf. Bukatchuk *et al.*, 1974). The overlying Sokolets Formation and younger units are regarded by Sokolov (1973) as equivalent to the Vendian Valdai 'Series' (Gdov Formation and Kotlin Formation). The Valdai 'Series' is disconformably overlain by the Lower Cambrian Baltic 'Series'.

The uppermost Volhyn 'Series' in the Ukraine (Krustov Formation) and the overlying lowermost Mogilev-Podolsk 'Series' (Starotatarov Formation) contain Upper Riphean acritarch assemblages (Timofeev, 1973). The Mogilev-Podolsk 'Series' (Derlovsk Formation and Serebrianka Formation) and the overlying Nagoryan Formation contain Vendian acritarch assemblages (Timofeev, 1973). According to Timofeev (1973) the Derlovsk, Serebrianka and Nagoryan Formations also contain *Laminarites.* The Derlovsk Formation of the Mogilev-Podolsk 'Series' is regarded as a correlative of the Yaryshev Formation in the Dniester area (Bukatchuk *et al.*, 1974), which has yielded soft-bodied metazoans (Sokolov, 1973). The acritarch assemblage in the Derlovsk Formation of the Mogilev-Podolsk 'Series' in the Ukraine shows striking similarity to the acritarch assemblage recovered from the upper Visingsö Beds in southern Sweden (cf. Vidal, 1976a). The Tillite Group in eastern Greenland has several species in common with the upper Visingsö Beds (fig. 3).

Throughout the Russian Platform the Valdai 'Series' contain vendotaenid algae (Sokolov, 1973) (i.e. *Vendotaenia* and *Tyrassotaenia;* Gnilovskaya, 1971, 1976). These fossils are usually found together with acritarchs diagnostic of Vendian age (e.g. in South West Africa, and northern Sweden; author's unpublished data). However, *Tyrassotaenia* is reported by Arén & Lendzion (1974) from the lowermost part of the Sub-*Holmia* Horizon (Mazoviecky 'Series') in the Radzyn borehole in Poland where it occurs together with *Sabellidites* sp. These beds contain an acritarch assemblage of micrhystrids and leiosphaerids (Arén & Lendzion, 1974). The same assemblage is also present, together with *Vendotaenia,* in beds below the apparently arbitrarily placed Vendian-Cambrian boundary (Lubin 'Series').

Fedonkin (1977, fig. 1) apparently regards the Vendian Cambrian boundary in the Radzyn borehole as disconformable and located at a depth of 1611 m; namely within the lower part of the Sub-*Holmia* Mazowiecka 'Series' in Arén & Lendzion (1974, fig. 2). Therefore, there are insufficient data supporting an Early Cambrian age for the *Tyrassotaenia*-bearing lowermost part of the Mazowiecka 'Series', particularly since sabelliditids are also known from Upper Vendian strata (Sokolov, 1972).

Considering the data above it appears interesting that the upper units of the Volhyn 'Series' and lower unit of the Mogilev-Podolsk 'Series' have yielded Upper Riphean acritarch assemblages. Rocks below these units, belonging to the lower Volhyn 'Series', contain gravels and conglomerates and may be equivalent to the possibly glacial units in the Vilchani 'Series'. The situation is therefore strikingly similar to that in the middle Visingsö Beds, where thick boulder beds are successively overlain by Upper Riphean and Vendian strata, the acritarch assemblage of the latter being similar to that in the Derlovsk Formation of the Mogilev-Podolsk 'Series'. The fact that the Tillite Group in eastern Greenland appears to be Vendian throughout contrasts with the stratigraphic position of the Volhyn 'Series'. Therefore the Tillite Group is probably younger than the Vilchani 'Series'. There are two possible alternatives in interpreting the data above which are based on two different interpretations of the microfossil record of the Tillite Group; i.e. the microfossils of the Tillite Group are either (1) contemporaneous with the rocks (as suggested by Vidal, 1976b), or (2) redeposited from eroded strata. If the microfossils are contemporaneous with the rocks, then time equivalence (within the limits allowed by biostratigraphic resolution) between the Tillite Group and upper Visingsö Beds (about 700 m.y., a preliminary Rb-Sr date by Erik Welin, Stockholm) would imply that stromatolitic algal carbonates in the upper Visingsö Beds (Vidal, 1972) are more or less contemporaneous with 'glacial' mixtites in the Tillite Group. However, time equivalence is not necessarily implied. The microfossils concerned might have (and some of them evidently have) higher stratigraphic ranges than presently known and correspond to higher levels of the Vendian sequence not represented due to erosion or non-deposition.

The second alternative implies that the Tillite Group is younger than the upper Visingsö Beds and the probably time equivalent Derlovsk Formation. This does not affect the Vendian age assumed for the Tillite Group, as interbedded and overlying shales yielded Vendian microfossils. This facilitates correlation with the Upper Proterozoic sequence in northern Norway as the Nyborg Formation (668 ± 23 m.y. radiometric age; Pringle, 1973) has yielded Vendian acritarchs (writer's unpublished data). Further, an acritarch assemblage with several taxa in common with that from the upper Visingsö Beds (thus indicating a Vendian age) has been recovered from the Ekkerøy Formation (uppermost Vadsö Group), and Vendian acritarchs occur in several units of the overlying Tanafjord Group (writer's unpublished data). Nevertheless, despite the occurrence of algal carbonates in the upper Visingsö Beds, it appears possible that the Tillite Group, upper Visingsö Beds and

Derlovsk Formation may be almost time equivalent. A close stratigraphic association of rocks indicating cold and warm climatic conditions has been reported from many Upper Proterozoic sequences (Williams, 1975; Schermerhorn, 1974; Spencer, 1970). Williams (1975) suggested that these contradictory rock associations may be resolved by postulating a considerable increased obliquity of the ecliptic in Late Precambrian times. An alternative explanation for reported Upper Proterozoic associations of carbonates and tillites is given by Bjørlykke *et al.* (1978) who suggest that in the Late Precambrian times carbonates were probably chemically or biochemically precipitated by blue-green algae. Therefore, their precipitation may have been possible at low temperatures.

High average Ca/Mg ratios perhaps indicating deposition in relatively cold water, has been reported by Germs (1973) in limestones of the Upper Proterozoic Nama Group in South West Africa. Certain features in the rocks of the Nama Group have been interpreted as the result of glacial phenomena (Germs, 1973, 1974; Kröner & Rankama, 1973), and a Vendian age Ediacara-type fauna (Germs, 1974), together with Vendian age diagnostic microfossils (author's unpublished data), occurs in several formations of the Nama Group.

Upper Proterozoic glacial mixtites and associated glacial phenomena are known from all continents except Antarctica (Harland, 1966). The problem of the glacial or non-glacial genesis of Upper Proterozoic mixtites is outside the scope of this work, but it is impossible to discuss Upper Proterozoic and Lower Cambrian correlations withouth reference to the problem. Several glacial events could be represented in the Upper Riphean and Vendian. It is equally evident that the presence of regional or local hiati in these sequences imply that erosion reaching different depths may have completely or partially removed traces of these events in certain areas. Therefore, Upper Proterozoic glacial deposits may not be contemporaneous even in geographically restricted areas as the North Atlantic region and Russian Platform. Crawford & Daily (1971) arrived at the same conclusion based on other factors. It seems evident that biostratigraphy can aid correlation of glacial units. Some of the supposedly Upper Proterozoic glacial units so far investigated are overlain and/or underlain by thick sedimentary sequences containing Vendian microfossils (e.g. in northern Norway). However, the tillite units of the Tillite Group rest on Upper Riphean strata and are overlain by Lower Cambrian rocks.

Limestone-Dolomite 'Series'

The richest recovered acritarch assemblage, both in number of taxa and specimens, is derived from the Upper Limestone-Dolomite 'Series' (especially bed 19). Acritarchs have been previously reported from beds 19 and 17 and possibly from bed 15 (Vidal, 1976b).

The presence of *Chuaria circularis* in the Limestone-Dolomite 'Series', previously reported with some uncertainty (Vidal, 1976b), has now been established in beds 14–16 and 19. The assemblage is characterized by the abundance of *C. circularis* and *Kildinella* spp. and is almost identical with that of the middle and lower upper Visingsö Beds in southern Sweden (fig. 3). Only two species present in the middle Visingsö Beds have not been found in the Upper Limestone-Dolomite 'Series' (i.e. *Favososphaeridium favosum* and *P. laccatum*). This assemblage is interpreted as Late Riphean in age, which is in disagreement with a Vendian age apparently indicated by algal stromatolites in the Upper Limestone-Dolomite 'Series' in Canning Land (Bertrand-Sarfati & Caby, 1976). The problematic tear-shaped microfossils in samples 142342 (at the base of bed 18) and 185420 (bed 16) are similar to microfossils described by Bloeser *et al.* (1977) from the Kwagun Formation (Walcott Member) of the upper Chuar Group of the Grand Canyon, Arizona. The Kwagun Formation has yielded acritarchs (Downie, 1969), algal filaments and unicells (Schopf *et al.*, 1973) and *C. circularis* (Ford & Breed, 1973). Therefore, it is tempting to correlate the Upper Limestone-Dolomite 'Series', the upper Chuar Group and the (postulated time equivalent) middle and lower units of the upper Visingsö Beds. Radiometric dating of the Cardenas Lavas (about 200 m below the base of the Chuar Group) has given a minimum age of 845 ± 15 m.y. (Ford & Breed, 1972). Thus, the Chuar Group is regarded as deposited between 600 and 1200 m.y. ago (Ford & Breed, 1972). The age inferred for the Chuar Group corresponds with the radiometric absolute age inferred for the Visingsö Beds. Available radiometric data indicate that the Visingsö Beds are younger than 985 and 1060 m.y. (Magnusson, 1960; Vidal, 1974) and the preliminary date (Rb-Sr) of the upper Visingsö Beds suggests an age of about 700 m.y. (Erik Welin, pers.comm.). Vidal (1974) estimated the age of the lower Visingsö Beds to be 750–800 m.y. He also gave a 650 m.y. estimate for the upper age limit of the Visingsö Beds.

Multicoloured 'Series'

Samples of the Multicoloured 'Series' are sparsely fossiliferous and only one sample of bed 8 yielded microfossils (Vidal, 1976b). Beds 9 and 11 yielded specimens of *C. circularis.* This implies that previously reported unidentifiable black, large sphaeromorphs in a sample of bed 8 (Vidal, 1976b) may also be *C. circularis.* The sparse acritarch content and the conformable contact between this unit and the Limestone-Dolomite 'Series' above suggests a Late Riphean age.

Quartzite 'Series' (beds 1–6)

Previously reported fossiliferous samples of the Quartzite 'Series' are from beds 1–2 and 3–6 (Vidal, 1976b). The only fossiliferous samples in the present material are from bed 3. Acritarchs are extremely scarce and poorly preserved but contain large, black sphaeromorphs which may be ascribed to *C. circularis*. This, and the conformable position of the unit in relation to the overlying Multicoloured 'Series', suggests a Late Riphean age.

Upper Argillaceous-Arenaceous 'Series'

Samples of this series are mostly barren (Vidal, 1976b), large, black and flattened sphaeromorphs (possibly *C. circularis*) being recovered from two samples. The author considers more data necessary before the age can be determined.

Lower Arenaceous-Argillaceous 'Series'

All samples of this series were unfossiliferous. Since the age of the overlying Upper Argillaceous-Arenaceous 'Series' could not be determined, no conclusions can be drawn about the age of this unit.

CONCLUSIONS

(1) Identifiable microfossils in the Upper Proterozoic – Lower Cambrian sequence in eastern Greenland are restricted to the Ella Island Formation, Bastion Formation, Tillite Group, Upper Limestone-Dolomite 'Series' and Multicoloured 'Series'. Altered and poorly preserved acritarchs as well as coalified or carbonized organic material are found in all units. This is likely to depend on local variations in deformation or thermal alteration of rocks within the East Greenland Caledonian fold belt. The best preserved acritarchs recovered are virtually unaltered. This could be interpreted as indicating that temperatures never exceeded 38°C and that the thickness of the overburden was never in excess of 1900 m. The latter disagrees with field evidence.

(2) The acritarch assemblage from rocks of the Bastion Formation is poorly diversified and indicative of shallow marine depositional conditions. Individual taxa from this unit have long stratigraphic ranges.

(3) Acritarchs in the Tillite Group show no evidence of reworking. This could indicate that some of the investigated mixtite units of the Tillite Group were deposited in a marine environment.

(4) The acritarchs recovered from the Upper Eleonore Bay Group corroborate that these rocks were deposited under shallow marine conditions.

(5) 'Chitinozoan-like' microfossils were recovered from rocks of the Upper Eleonore Bay Group. They are regarded as comparable with 'chitinozoans' previously reported from the Upper Proterozoic Chuar Group in Arizona and are unrelated to Palaeozoic chitinozoans.

(6) Considering both shelly faunas and acritarchs, the Ella Island Formation and

Upper Bastion Formation are correlated with the *Protolenus* Beds and *Holmia* Beds in the western Russian Platform and Poland.

(7) The Tillite Group is regarded as Vendian. Possible correlatives of this unit are discussed.

(8) The Eleonore Bay Group is regarded as Late Riphean. Its upper units are correlated with the Upper Riphean of Sweden and elsewhere.

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Note added in proof

The stratigraphic ranges of *Kildinella hyperboreica* Timofeev, 1966 and *Trachysphaeridium laminaritum* (Timofeev, 1966) Vidal, 1976 recognised at present are Riphean and Vendian, and Upper Riphean and Vendian, respectively (Vidal, 1979).

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Plates

Plate 1

a: *Baltisphaeridium*? *strigosum* Yankauskas. Composite microphotograph. Oil immersion. Specimen MGUH 14441 from GGU 185463 (slide 185463–1: N/39–3).

b, d: *Baltisphaeridium compressum* Volkova. Specimen at two focus levels. Oil immersion. Specimen MGUH 14442 from GGU 185462 (slide 185462–1:G/45–1).

c, e: *Baltisphaeridium orbiculare* Volkova. Specimen at two focus levels. Oil immersion. Specimen MGUH 14443 from GGU 185463, (slide 185463–1:W/27).

f: *B. compressum* Volkova. Specimen at a low focus level. Oil immersion. Specimen MGUH 14444 from GGU 185463 (slide 185463–1:H/32–2).

Length of bars 25μm.

All specimens from the Ella Island Formation, Ella Ø.

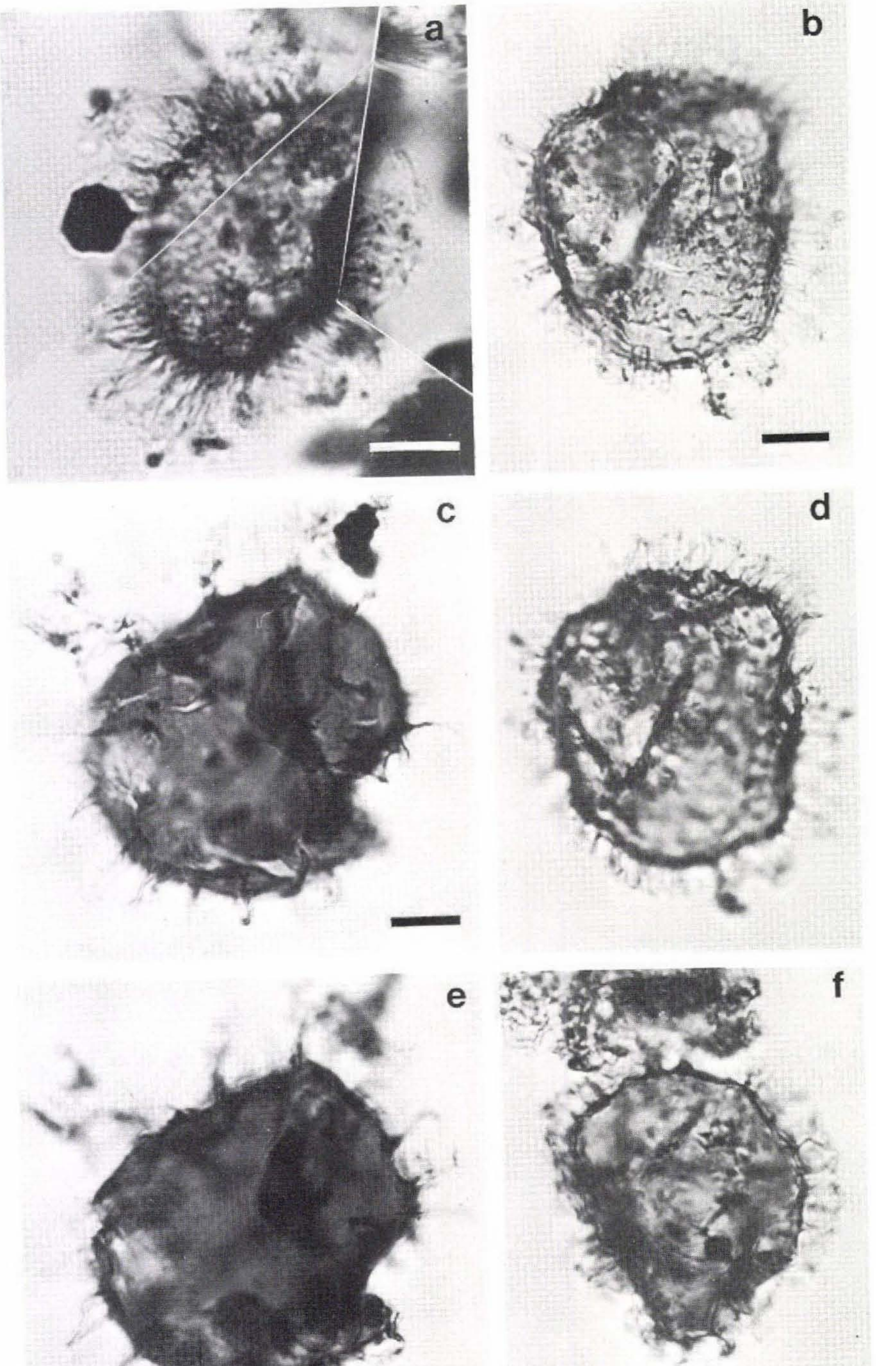
a
b
c
d
e
f

Plate 2

a-b: *Baltisphaeridium* sp. Specimen at two focus levels. Oil immersion. Specimen MGUH 14445 from GGU 185462 (slide 185462–1:D/43–1). Length of bar 25 μm.

c-d: *Tasmanites variabilis* Volkova. Specimen at two focus levels. Oil immersion. Specimen MGUH 14446 from GGU 185462 (slide 185462–1:E/39). Length of bar 25 μm.

e: *Leiosphaeridia* sp. Oil immersion. Specimen MGUH 14447 from GGU 185465 (slide 185465–1:Z/38–2). Length of bar 10 μm.

f-g: *Octoedryxium truncatum* (Rudavskaja) Vidal. Specimen at two focus levels. Oil immersion. Specimen MGUH 14448 from GGU 185436 (slide 185436–1:K/27). Length of bar 25 μm.

Specimens at a-e from the Ella Island Formation, Ella Ø. Specimen at f-g from the Tillite Group, Ella Ø.

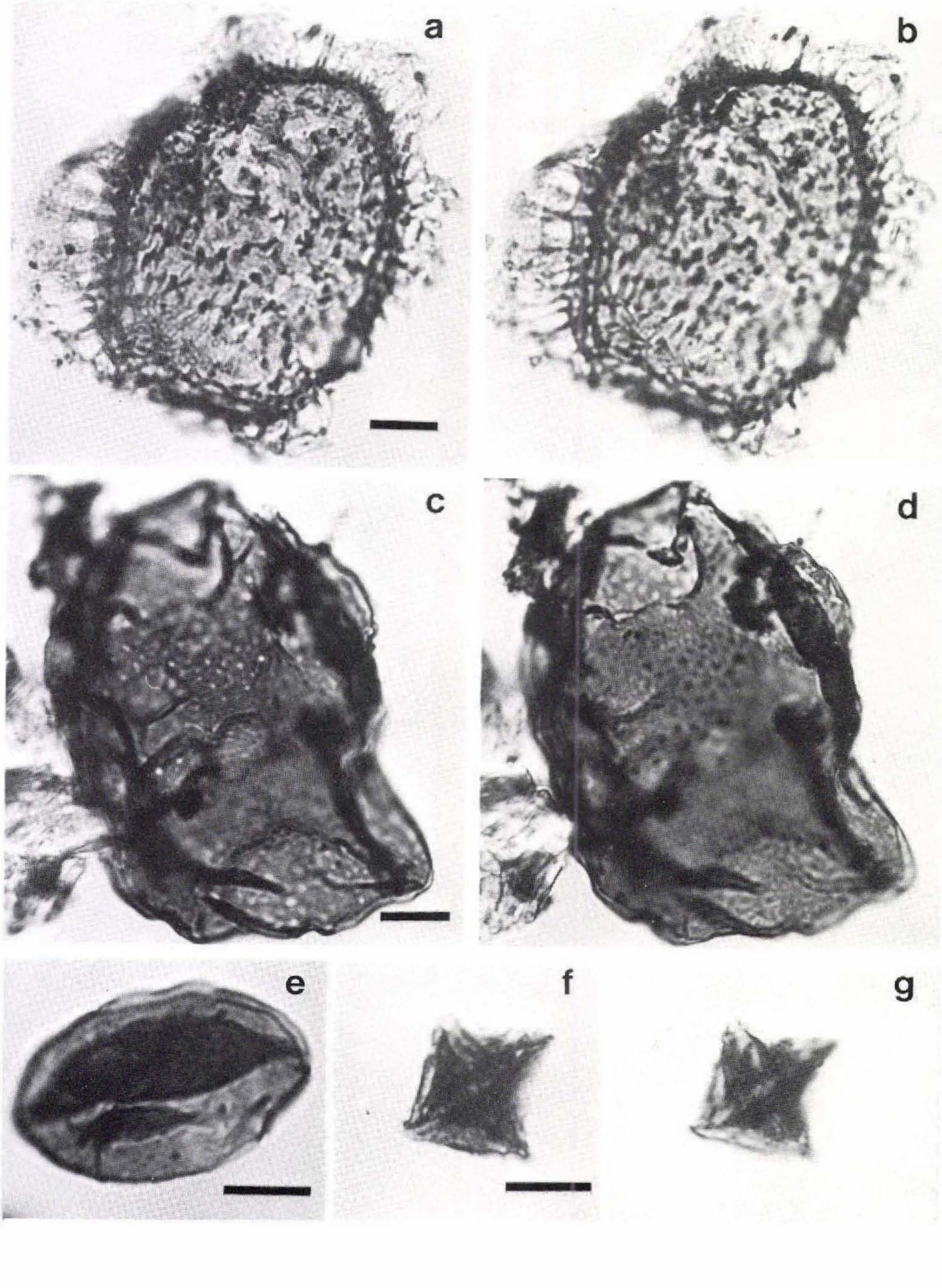
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Plate 3

Stereoscanning micrographs

a: Organic-walled vesicle showing deformation caused by framboidal pyrite. Specimen MGUH 14449 from GGU 185465 (Sp-185465). Length of bar 5 μm.

b: Detail of surface texture of the central part of the specimen showing microcrystalline imprints of discrete pyrite framboids on the organic wall of the vesicle. Length of bar 2 μm.

c: *Bavlinella faveolata* (Shepeleva) Vidal. Specimen MGUH 14450 from GGU 185434 (Sp-185434). Length of bar 5 μm.

d: Detail of surface texture of the upper right part of the specimen at c showing imploded discrete cells. Length of bar 2 μm.

Specimen at a-b from the Ella Island Formation, Ella Ø. Specimen at c-d from Tillite Group, Ella Ø.

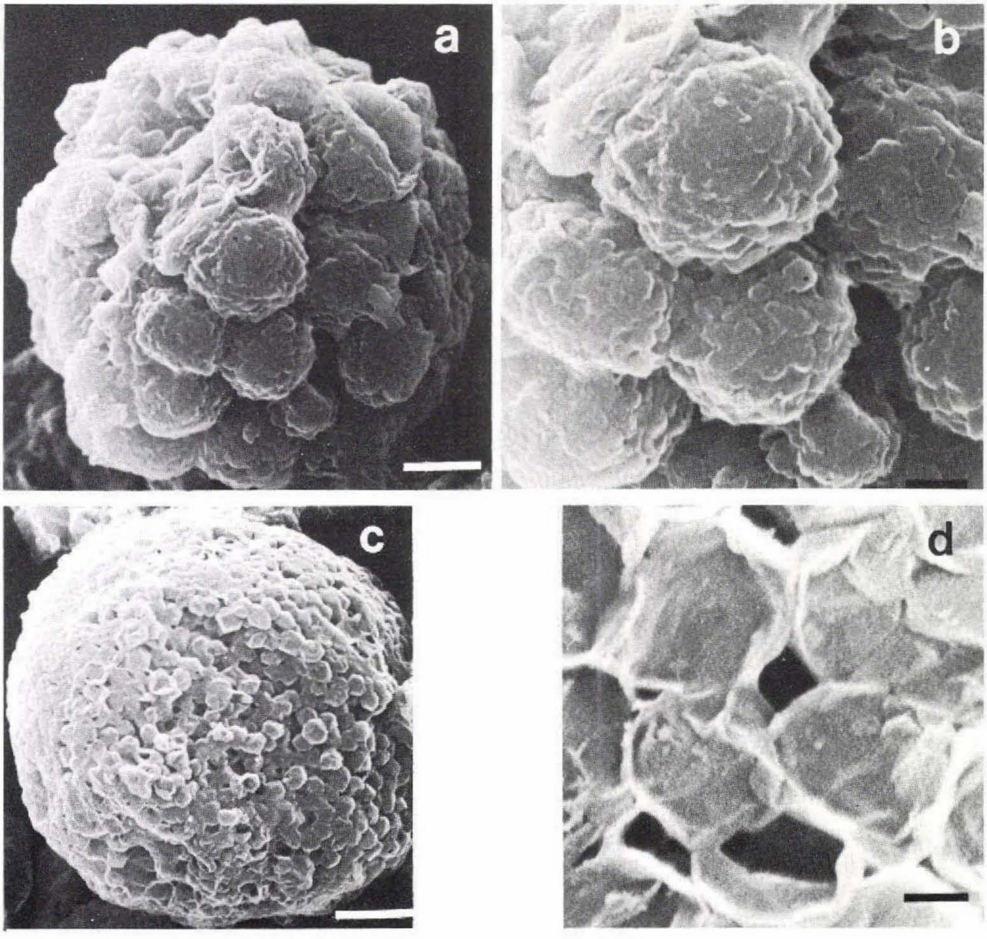

a
b
c
d

Plate 4

Stereoscanning micrographs

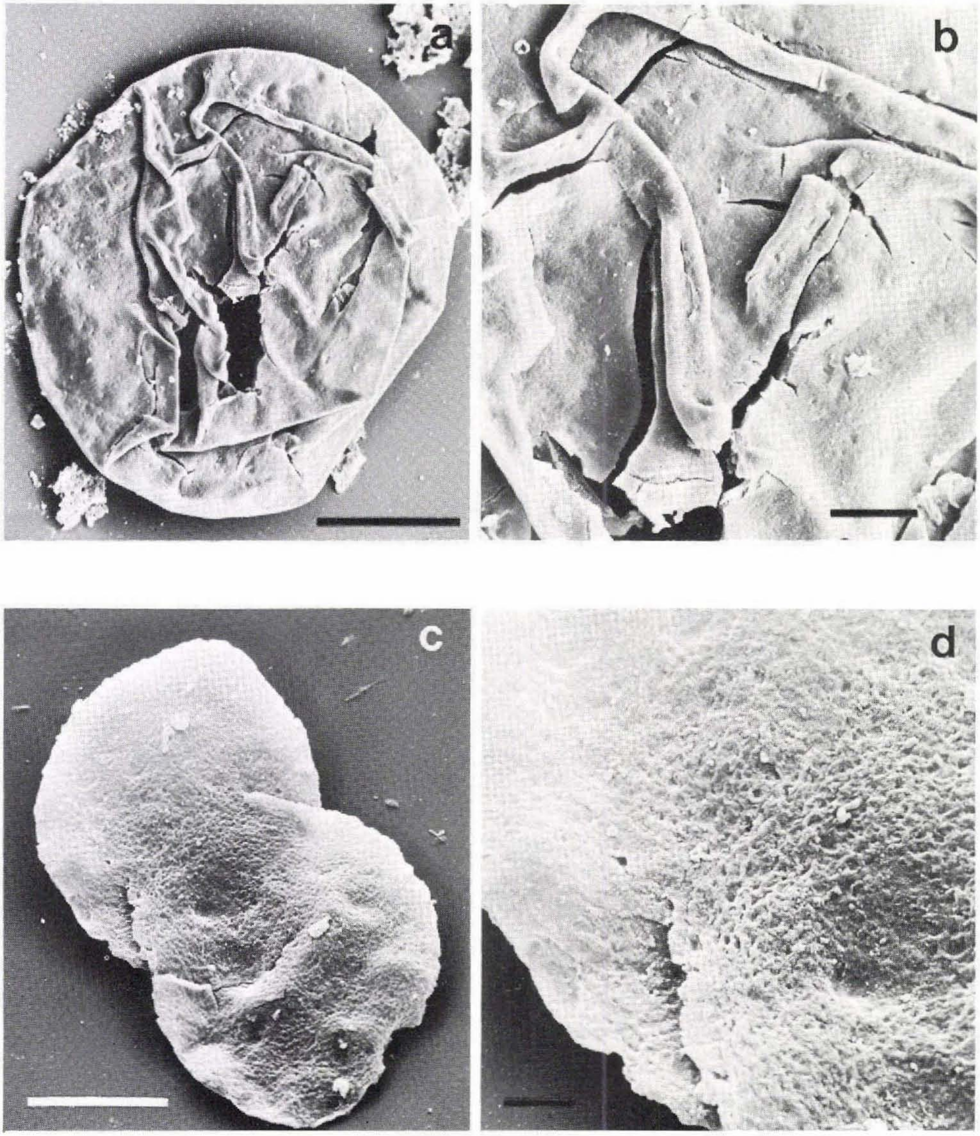
a: *Chuaria circularis* Walcott. Flattened and folded specimen. Specimen MGUH 14451 from GGU 185426 (Sp-185426). Length of bar 100 μm.

b: Detail of surface texture of the specimen at a. Length of bar 25 μm.

c: *Kildinella* sp. Two clustered specimens. Specimen MGUH 14452 from GGU 185426 (Sp-185426). Length of bar 25 μm.

d: Detail of surface texture and junction area of the vesicles at c. Length of bar 5 μm.

All specimens from the Eleonore Bay Group, Upper Limestone-Dolomite 'Series', bed 19 at Ella Ø.


a
b
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d

Plate 5

a: *Kildinella sinica* Timofeev. Flattened and folded specimen. Stereoscanning micrograph. Specimen MGUH 14453 from GGU 185426 (Sp-185426). Length of bar 25 μm.

b: *Kildinella hyperboreica* Timofeev. Stereoscanning micrograph. Specimen MGUH 14454 from GGU 185426 (Sp-185426). Length of bar 10 μm.

c-d: cf. *Stictosphaeridium* sp. Cluster of 8 vesicles at two focus levels. Dark intracellular bodies are translucent and may be remnants of discrete organelles, possibly remnants of algal pyrenoids. Oil immersion. Specimen MGUH 14455 from GGU 185427 (slide 185427–1:Z/48–3). Length of bar 25 μm.

All specimens from the Eleonore Bay Group, Upper Limestone-Dolomite 'Series', bed 19 at Ella Ø.

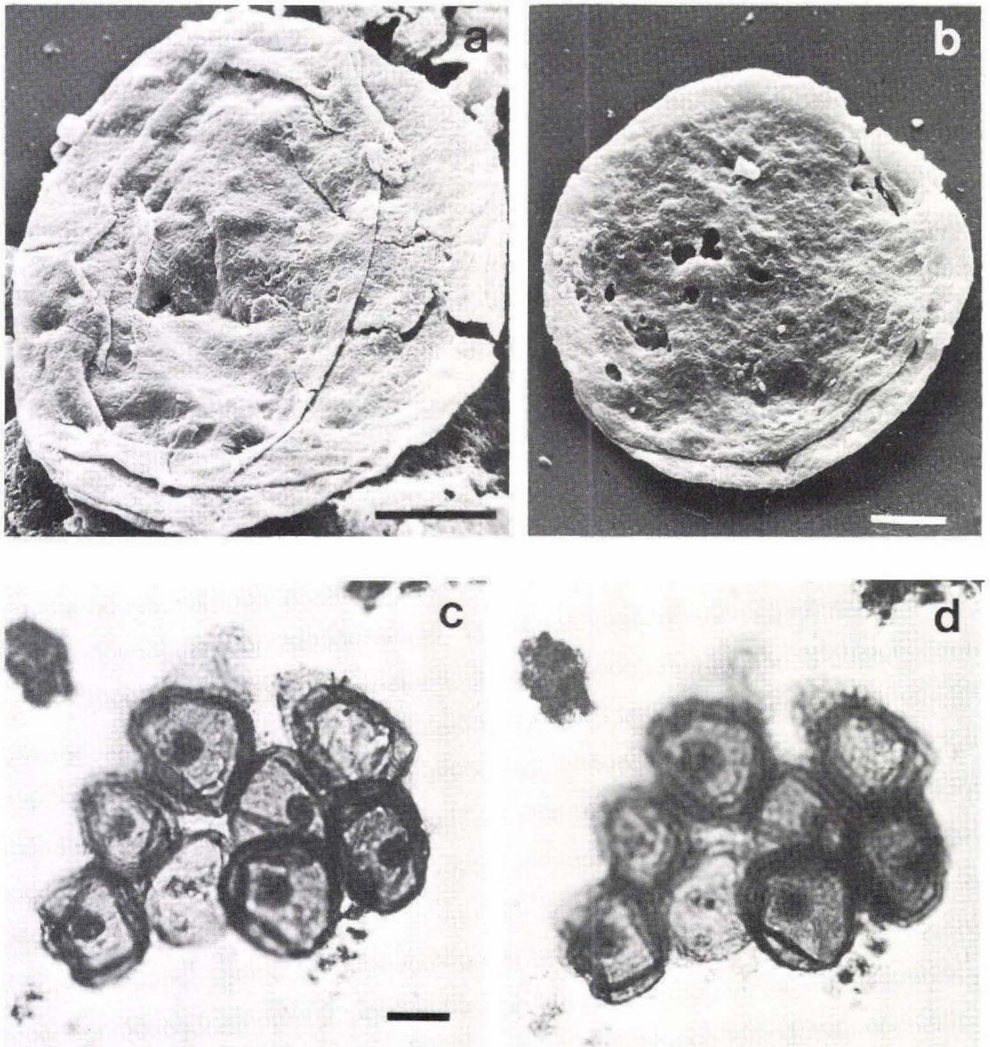
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Plate 6

Stereoscanning micrographs

Enigmatic, 'bag-shaped', 'chitinozoan-like' microfossils.

a: Intentionally broken specimen. Specimen MGUH 14456 from GGU 142342 (Sp-142342). Length of bar 25 μm.

b: Detail of the specimen at a. Length of bar 5 μm.

c: Specimen MGUH 14457 from GGU 142342 (Sp-142342). Length of bar 10 μm.

d: Specimen MGUH 14458 of GGU 142342 (Sp-142342). Length of bar 10 μm.

All specimens from the Eleonore Bay Group, Upper Limestone-Dolomite 'Series', bed 18 at Kap Petersens.

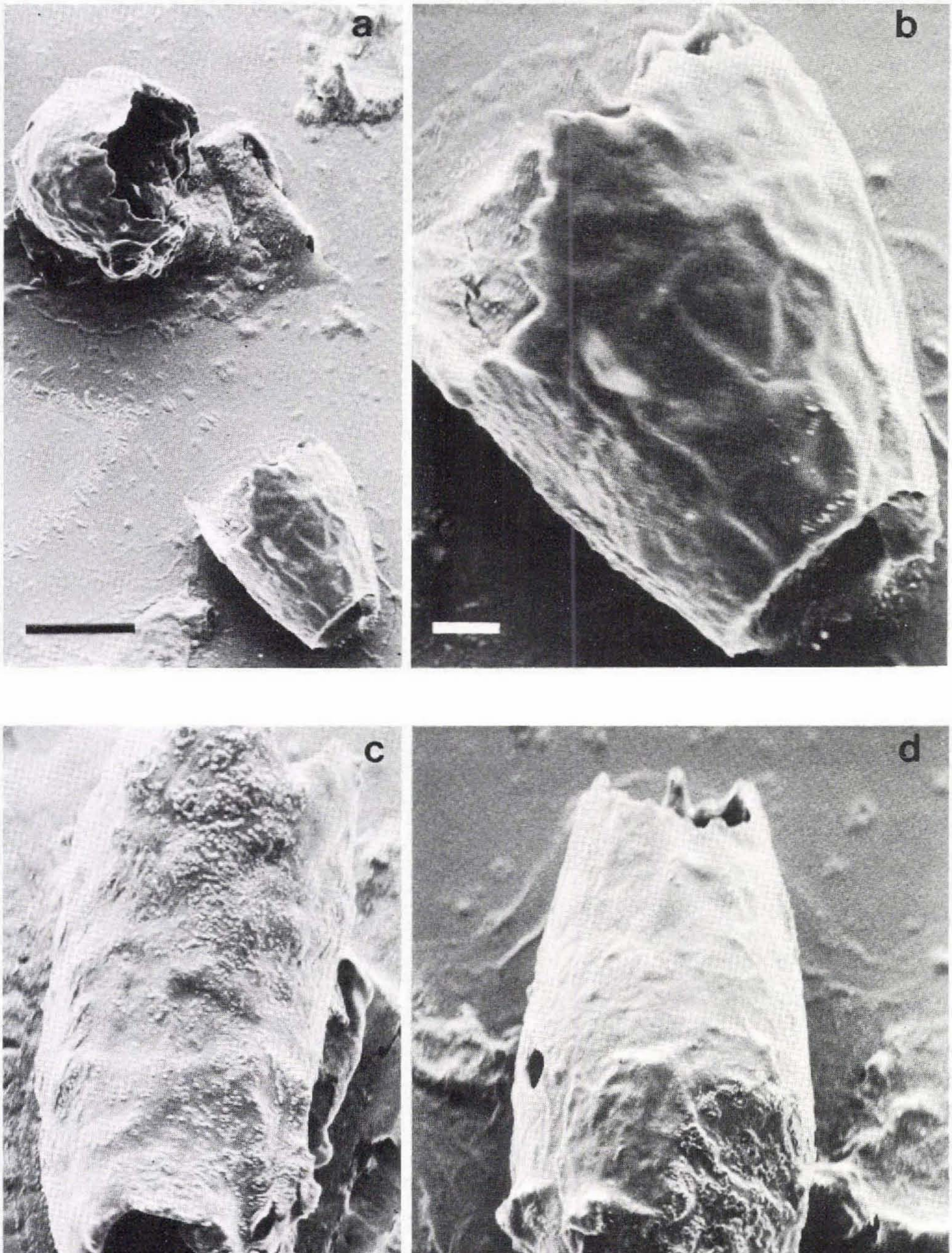

a
b
c
d

Plate 7

Stereoscanning micrographs

Enigmatic, tear-shaped microfossils.

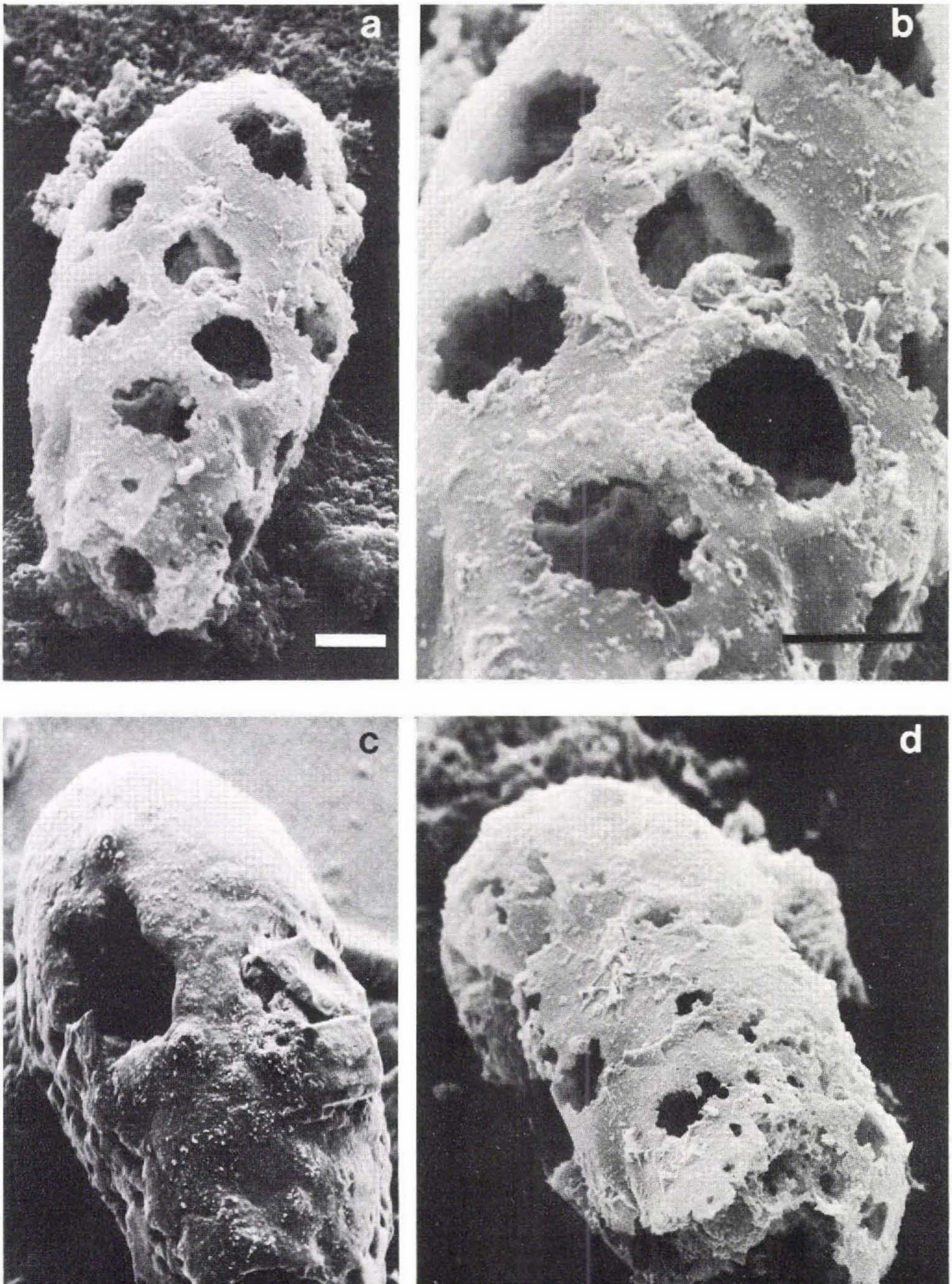
a: Specimen showing overall shape and accidental perforations (see text). Specimen MGUH 14459 from GGU 185420 (Sp-185420). Length of bar 5 μm.

b: Detail of specimen showing external openings related to blister-shaped internal cavities which may have been caused by pyrite framboids. Length of bar 5 μm.

c: Slightly distorted specimen. Specimen MGUH 14460 from GGU 142342 (Sp-142342). Length of bar 25 μm.

d: Specimen showing 'aboral end'. Specimen MGUH 14461 from GGU 185420 (Sp-185420). Length of bar 10 μm.

Specimens at a, b, d from the Eleonore Bay Group, Limestone-Dolomite 'Series', bed 16 at Ella Ø. Specimen at c also from the Limestone-Dolomite 'Series', bed 18 at Kap Petersens.


a
b
c
d