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Palynology and deposition in the Wandel Sea Basin, eastern North Greenland

Edited by
Lars Stemmerik

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Cover
Upper Carboniferous (Moscovian) shelf carbonates and siliciclastics of the Kap Jungersen and Foldedal Formations at Depotfjeld, southern Holm Land. The yellowish cliff-forming beds are composed of shelf limestones with abundant calcareous algae (see Mamet & Stemmerik p. 79). The reddish weathering recessive units consist of fine-grained sandstone and siltstone. The thick red unit forming the top of the main ridge is a coarse-grained conglomerate at the base of the Foldedal Formation. The cliff reaches approximately 450 m above sea level. Photo: Lars Stemmerik.

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Phone: +45 38 14 20 00, fax: +45 38 14 20 50, e-mail: geus@geus.dk
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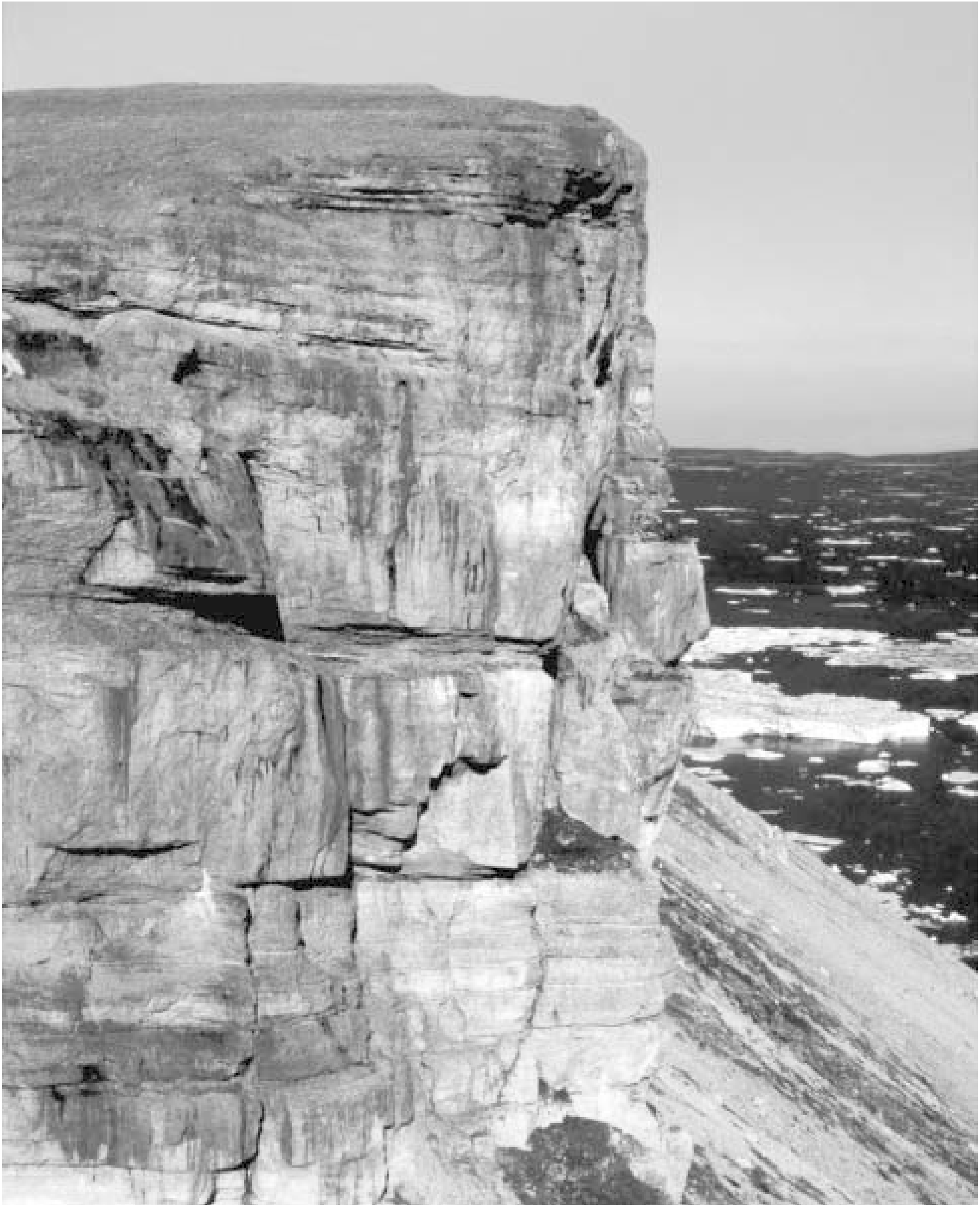


Frontispiece. Cliff-forming carbonates of the Upper Carboniferous Foldedal Formation, southern Holm Land. The carbonates are biogenic wackestones and packstones; the massive beds in the middle are parts of two tabular reef complexes. The carbonates contain abundant calcareous algae as described in the paper by Mamet & Stemmerik on pages 79–101. The cliff is approximately 100 m high.

Preface

This collection of papers adds to the understanding of the stratigraphic, depositional and structural history of the Wandel Sea Basin in eastern North Greenland (Fig. 1). Most importantly, the ages of the initial (Carboniferous) and final (Palaeogene) depositional events are now much better constrained than previously, allowing correlation with the successions in East Greenland, Svalbard and the Barents Sea.

The Wandel Sea Basin was an area of accumulation through the Early Carboniferous to the Palaeogene period, located at the margins of the stable Greenland craton where the Caledonian and Ellesmerian orogenic belts intersect (Fig. 1). Two main epochs of basin evolution have been recognised during previous studies of the basin fill: a Late Palaeozoic – Early Triassic epoch characterised by a fairly simple system of grabens and half-grabens, and a Mesozoic epoch dominated by strike-slip movements (Håkansson & Stemmerik 1989). The Mesozoic epoch only influenced that part of the basin north of the Trolle Land fault zone and its eastward extension (Fig. 1). Thus the northern and southern parts of the basin have very different structural and depositional histories, and accordingly different thermal histories and hydrocarbon potential as exemplified by the tectono-stratigraphic study of northern Amdrup Land by Stemmerik *et al.* (2000, this volume). This study shows that the Sommerterrasserne fault is the south-eastern extension of the Trolle Land fault zone, dividing Amdrup Land into two areas with different stratigraphic and structural histories. Sediments of the Upper Permian Midnatfjeld Formation are restricted to north-east of the Sommerterrasserne fault where they are conformably overlain by Upper Jurassic sediments. In this area the Carboniferous – Upper Jurassic succession is folded in broad domal folds with NE–SW-oriented axes, whereas the Upper Palaeozoic sediments are gently dipping south-west of the fault. Folding most likely took place during the latest Cretaceous correlating with compressional events that also affected the sedimentary basins at Kilen and Prinsesse Ingeborg Halvø further to the north in the Trolle Land fault zone.

The upper age limit of the compressional event is given by the flat-lying, undeformed Thyra Ø Formation. These sediments are the youngest preserved deposits of the Wandel Sea Basin and precise dating is important for a minimum age of the youngest phases of compressional tectonism in the northern part of the basin. The formation was previously dated as Paleocene on the basis of the macroflora and rare dinoflagellates (Håkansson & Pedersen 1982; Håkansson *et al.* 1991). However, a new study (Lyck & Stemmerik 2000,

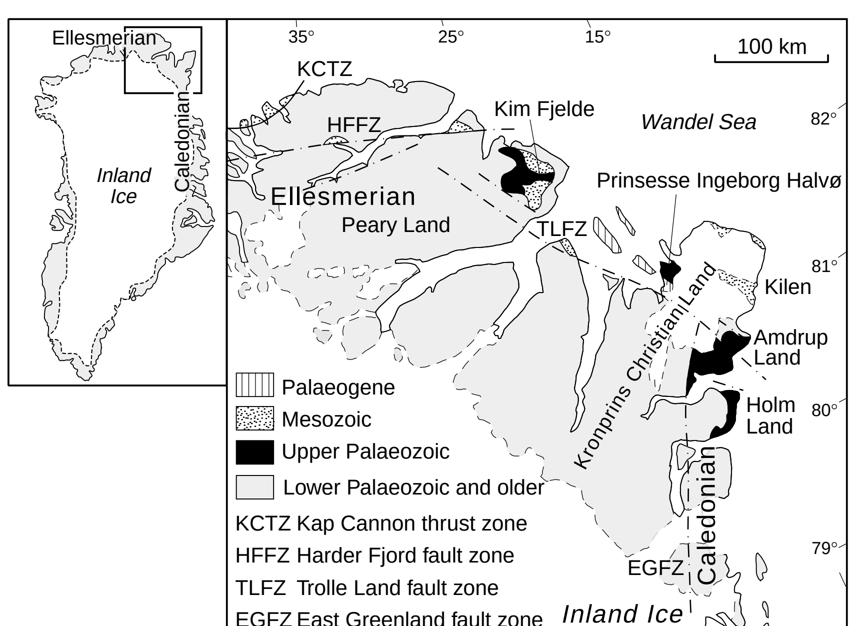


Fig. 1. Simplified map of the Wandel Sea Basin in North Greenland showing the distribution of the Upper Palaeozoic – Palaeogene sediments. The area north of the Trolle Land fault zone is deformed as the result of Mesozoic compressional events. The northernmost outcrops of the Wandel Sea Basin along the KCTZ and HFFZ are not dealt with in this bulletin. Modified after Håkansson & Stemmerik (1989).

this volume) shows a more diversified microflora of spores, pollen and dinoflagellates in the sediments. The previously suggested Paleocene age is supported by the presence of *Cerodinium speciosum* and *Spinidinium pilatum*. The occurrence of *Cerodinium markovae*, with a Paleocene–Eocene range, and *Spinidinium sagittula*, which has been reported from sediments of Early Eocene age, suggest that the Thyra Ø Formation may range into the Early Eocene. A latest Paleocene – Early Eocene age is suggested opening the possibility of an Early Paleocene age for the youngest compressional phase in the Wandel Sea Basin.

New stratigraphic and sedimentological data on the earliest phases in the evolution of the Wandel Sea Basin are presented in two papers dealing with the Sortebakker Formation (Dalhoff & Stemmerik 2000, this volume; Dalhoff *et al.* 2000, this volume). This Lower Carboniferous formation is the oldest post-Caledonian unit in the basin. It consists of more than 1000 m of fluvial deposits that so far have been regarded as Early Carboniferous in age based on a poorly preserved macro-flora. The paper by Dalhoff *et al.* (2000, this volume) provides a more precise age of the formation based on the presence of a poorly preserved but stratigraphically confined microflora in its upper part. The presence of *Tripartites distinctus*, *Potoniespores delicatus* and *Savitrisporites* spp. dates the succession to the late Viséan TC and NM Miospore Biozones of western Europe, and confirms correlation to time-equivalent non-marine deposits on Bjørnøya, Svalbard, East Greenland and the southern Barents Sea. Dalhoff & Stemmerik (2000, this volume) give the first detailed description of the sediments. Six facies associations are identified and together describe a fluviatile–lacustrine depositional system. Five of the associations characterise different parts of a meandering river-dominated flood plain, and the formation mostly consists of stacked, fining-upward fluvial cycles.

The final paper describes the calcareous algal flora in the marine Upper Carboniferous, Moscovian–Gzelian, carbonates of the Kap Jungersen and Foldedal Formations (*sensu* Stemmerik *et al.* 1996) in Holm Land and Amdrup Land (Mamet & Stemmerik 2000, this volume; see *Frontispiece*). Calcareous algae are found to be an important grain producer in the Moscovian shelf carbonates. The flora of 25 species, dominated by rhodophytes and chlorophytes, shows profound affinity to that of the Sverdrup Basin, Arctic Canada, belonging to the *Uraloporella* flora of the present-day northern hemisphere (Arctic Canada, Svalbard and Arctic Russia). The one new genus and species erected, *Groenlandella enigmatica* n.gen. et n.sp., is apparently endemic to the Wandel Sea Basin.

References

Dalhoff, F. & Stemmerik, L. 2000: Depositional history of the fluvial Lower Carboniferous Sortebakker Formation, Wandel Sea Basin, eastern North Greenland. In: Stemmerik, L. (ed.): Palynology and deposition in the Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin **187**, 65–77 (this volume).

Dalhoff, F., Vigran, J.O. & Stemmerik, L. 2000: Stratigraphy and palynology of the Lower Carboniferous Sortebakker Formation, Wandel Sea Basin, eastern North Greenland. In: Stemmerik, L. (ed.): Palynology and deposition in the Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin **187**, 51–63 (this volume).

Håkansson, E. & Pedersen, S.A.S. 1982: Late Paleozoic to Tertiary tectonic evolution of the continental margin in North Greenland. In: Embry, A.F. & Balkwill, H.R. (eds): Arctic geology and geophysics. Canadian Society of Petroleum Geologists Memoir **8**, 331–348.

Håkansson, E. & Stemmerik, L. 1989: Wandel Sea basin – A new synthesis of the late Paleozoic to Tertiary accumulation in North Greenland. Geology **17**, 683–686.

Håkansson, E., Heinberg, C. & Stemmerik, L. 1991: Mesozoic and Cenozoic history of the Wandel Sea Basin area, North Greenland. In: Peel, J.S. & Sønderholm, M. (eds): Sedimentary basins of North Greenland. Bulletin Grønlands Geologiske Undersøgelse **160**, 153–164.

Lyck, J.M. & Stemmerik, L. 2000: Palynology and depositional history of the Paleocene? Thyra Ø Formation, Wandel Sea Basin, eastern North Greenland. In: Stemmerik, L. (ed.): Palynology and deposition in the Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin **187**, 21–49 (this volume).

Mamet, B.L. & Stemmerik, L. 2000: Carboniferous algal microflora, Kap Jungersen and Foldedal Formations, Holm Land and Amdrup Land, eastern North Greenland. In: Stemmerik, L. (ed.): Palynology and deposition in the Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin **187**, 79–101 (this volume).

Stemmerik, L., Håkansson, E., Madsen, L., Nilsson, I., Piasecki, S., Pinard, S. & Rasmussen, J.A. 1996: Stratigraphy and depositional evolution of the Upper Palaeozoic sedimentary succession in eastern Peary Land, North Greenland. Bulletin Grønlands Geologiske Undersøgelse **171**, 45–71.

Stemmerik, L., Larsen, B.D. & Dalhoff, F. 2000: Tectonostratigraphic history of northern Amdrup Land, eastern North Greenland: implications for the northernmost East Greenland shelf. In: Stemmerik, L. (ed.): Palynology and deposition in the Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin **187**, 7–19 (this volume).

Lars Stemmerik

Tectono-stratigraphic history of northern Amdrup Land, eastern North Greenland: implications for the northernmost East Greenland shelf

Lars Stemmerik, Birgitte D. Larsen and Finn Dalhoff

The NW–SE-oriented Sommerterrasserne fault in Amdrup Land marks the southern limit of Mesozoic compression related to the transform plate boundary between North Greenland and Svalbard. Structural style in Amdrup Land changes across the fault; Carboniferous, Permian and Jurassic sediments in northern Amdrup Land north-east of the fault are gently folded, with NE–SW-trending fold axes, whereas they are gently dipping south of the fault. The Sommerterrasserne fault is regarded as the south-eastern extension of the Trolle Land fault zone of eastern Peary Land. Upper Moscovian carbonates of the Foldedal Formation rest unconformably on isoclinally folded Upper Proterozoic sediments of the Independence Fjord Group in northern Amdrup Land and are conformably overlain by chert-rich limestones of the Permian Kim Fjelde and Midnatfjeld Formations. Locally, up to 70 m of Jurassic sandstone and siltstone are preserved in the axes of the synclines, resting conformably on Permian limestones; the folding thus post-dates their deposition. The folding of the sediments to the north-east of the Sommerterrasserne fault most likely took place during the latest Cretaceous; it is post-dated by a post-Paleocene extensional event.

L.S. & F.D., *Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark.* E-mail: *ls@geus.dk*
B.D.L., *Geological Institute, University of Aarhus, DK-8000 Århus C, Denmark.*

Keywords: Carboniferous–Jurassic, North Greenland, structural geology, Wandel Sea Basin

The Wandel Sea Basin in the north-easternmost part of Greenland was an area of accumulation during the Early Carboniferous to Palaeogene. It is located at the margin of the stable Greenland craton, at the intersection of the Caledonian and Ellesmerian orogenic belts (Fig. 1; Dawes & Soper 1973; Håkansson & Stemmerik 1989). The onshore deposits in Greenland form part of a large system of interconnected intracratonic basins that cover the Barents Shelf and the northern part of the East Greenland shelf. The structural and depositional history of the western Barents Shelf has been described in considerable detail over the past 15 years as the result of hydrocarbon exploration in the area (Gabrielsen *et al*. 1990; Johansen *et al*. 1993). In contrast, data from the northern East Greenland shelf are limited; most information comes from regional aeromagnetic and gravimetric surveys (Dawes 1990). There is sparse seismic data from the area south of 80°N but most data are confidential and information is only available in a generalised form (Escher & Pulvertaft 1995).

The main structural elements controlling the evolution of the Wandel Sea Basin are the East Greenland, Trolle Land and Harder Fjord fault zones (Fig. 1; Håkansson & Stemmerik 1989). The Trolle Land fault zone in eastern Peary Land forms the southern part of the Trolle Land fault system (Håkansson & Pedersen 1982; Zinck-Jørgensen 1994). This fault system constitutes an important structural element related to the development of the transform plate boundary between eastern North Greenland and Svalbard (Håkansson & Pedersen 1982). The fault system is well exposed in eastern Peary Land where it is composed of five major NW–SE-striking, sub-vertical faults with a lateral distance of 7–10 km (Zinck-Jørgensen 1994). These faults are suggested as continuing towards the south-east to Kronprins Christian Land, where they are largely unexposed due to extensive ice cover (Fig. 1).

This paper discusses the tectono-stratigraphic his-

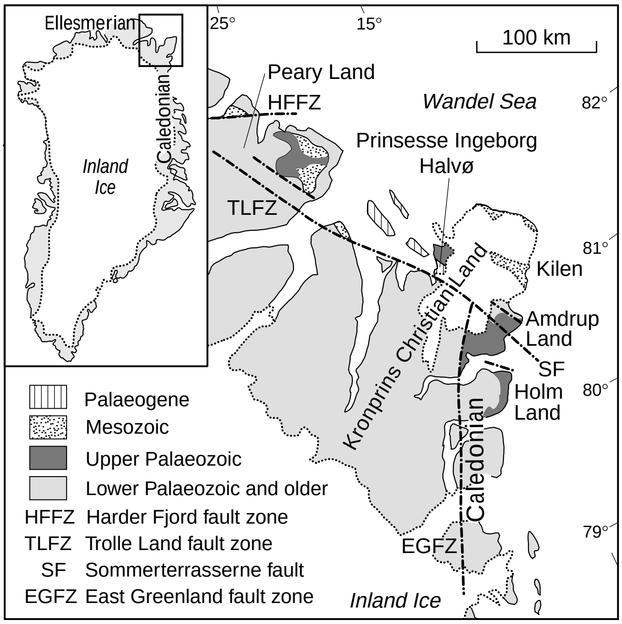


Fig. 1. Map of the eastern part of the Wandel Sea Basin showing the major structural lineaments. The blank area on northern Kronprins Christian Land is ice. Modified from Håkansson & Stemmerik (1989).

tory of northern Amdrup Land and its implications for the East Greenland shelf areas based on new structural, biostratigraphic and sedimentological observations. The Sommerterrasserne fault in northern Amdrup Land forms the easternmost extent of the Trolle Land fault zone. It divides structurally deformed Carboniferous and younger deposits from flat-lying undeformed Upper Palaeozoic sediments. The depositional record and structural style of northern Amdrup Land differ significantly from that recognised at Kilen and Prinsesse Ingeborg Halvø further to the north in the Trolle Land fault system in Kronprins Christian Land (Håkansson *et al.* 1989, 1992, 1993). The preserved Upper Palaeozoic succession is much thinner than that recorded from northern Prinsesse Ingeborg Halvø by Håkansson *et al.* (1989); it resembles that of Holm Land and southern Amdrup Land (Fig. 2; Stemmerik unpublished data). Also, the Mesozoic succession is thinner and stratigraphically condensed compared to Kilen (Håkansson *et al.* 1991). Northern Amdrup Land thus forms a unique area within the Wandel Sea Basin where the Upper Palaeozoic depositional evolution is related to the Holm Land – Amdrup Land segment of the basin and the structural style to the Trolle Land fault system. This may have some important implications for the petroleum potential of the adjacent shelf areas and for the structural evolution of the region.

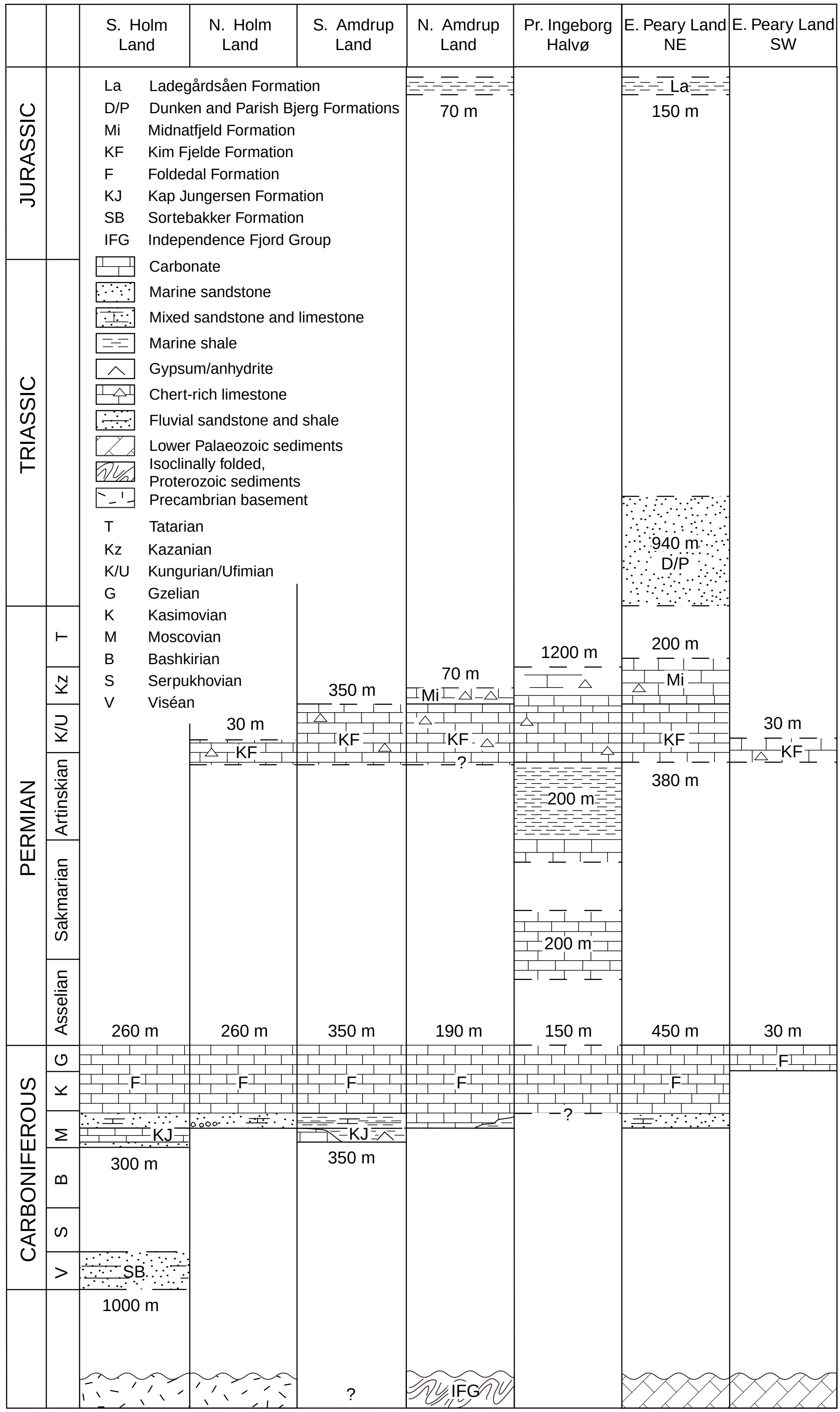
Geological framework

The post-Caledonian Wandel Sea Basin is located in a narrow fringe along the margins of the stable Greenland craton. The depositional area is delineated by the Harder Fjord, Trolle Land and East Greenland fault zones (Fig. 1; Håkansson & Stemmerik 1989). The Wandel Sea Basin deposits rest with a regional unconformity on Precambrian to Silurian rocks, which were deformed during the Caledonian and Ellesmerian orogenies.

Two main epochs of basin evolution have been recognised during previous studies of the basin fill; the earlier, Late Palaeozoic epoch is characterised by a fairly simple system of grabens and half-grabens (Stemmerik & Håkansson 1989; Stemmerik 1996) whereas the later, Mesozoic epoch is dominated by strike-slip movements and deposition in isolated pull-apart basins (Håkansson *et al.* 1991). The Mesozoic structural events only influenced the northern part of the basin, north of the Trolle Land fault zone and its eastward continuation (Fig. 1).

The Wandel Sea Basin deposits in northern Amdrup Land are located north of the Trolle Land fault zone and are affected by post-Jurassic structural events. They were deposited east of the East Greenland fault zone near the northern limit of a depositional area that connects southwards to the sedimentary basins of East Greenland and is dominated by east–west extension along Caledonian lineaments. The area is separated by a NW–SE-trending fault, the Sommerterrasserne fault (see Fig. 3), from the areas to the south that are unaffected by Mesozoic compression related to the transform plate boundary between eastern North Greenland and Svalbard. The Kilen and Prinsesse Ingeborg Halvø areas further to the north in the Trolle Land fault system have been affected by four tectonic pulses of mid-Jurassic to post-Paleocene age (Håkansson *et al.* 1989, 1992, 1993). These events are also documented in the Trolle Land fault system further to the west in eastern Peary Land (Zinck-Jørgensen 1994). They include the mid-Jurassic Ingeborg event, the mid-Cretaceous Kilen event, a latest Cretaceous strike-slip event and post-Paleocene extension (Håkansson *et al.* 1989, 1992, 1993).

Fig. 2. Lithostratigraphy and thickness of Upper Palaeozoic and Mesozoic sediments on Holm Land, Amdrup Land, Prinsesse Ingeborg Halvø and eastern Peary Land. Data from Håkansson *et al.* (1989) and Stemmerik *et al.* (1996).


S. Holm Land
N. Holm Land
S. Amdrup Land
N. Amdrup Land
Pr. Ingeborg Halvø
E. Peary Land NE
E. Peary Land SW
JURASSIC
TRIASSIC
PERMIAN
CARBONIFEROUS
T
Kz
K/U
Artinskian
Sakmarian
Asselian
G
K
M
B
S
V
La Ladegårdsåen Formation
D/P Dunken and Parish Bjerg Formations
Mi Midnatfjeld Formation
KF Kim Fjelde Formation
F Foldedal Formation
KJ Kap Jungersen Formation
SB Sortebakker Formation
IFG Independence Fjord Group
Carbonate
Marine sandstone
Mixed sandstone and limestone
Marine shale
Gypsum/anhydrite
Chert-rich limestone
Fluvial sandstone and shale
Lower Palaeozoic sediments
Isoclinally folded, Proterozoic sediments
Precambrian basement
T Tatarian
Kz Kazanian
K/U Kungurian/Ufimian
G Gzelian
K Kasimovian
M Moscovian
B Bashkirian
S Serpukhovian
V Viséan
70 m
La
150 m
940 m
D/P
1200 m
200 m
70 m
Mi
350 m
30 m
KF
380 m
200 m
200 m
260 m
260 m
350 m
190 m
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F
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KJ
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SB
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IFG

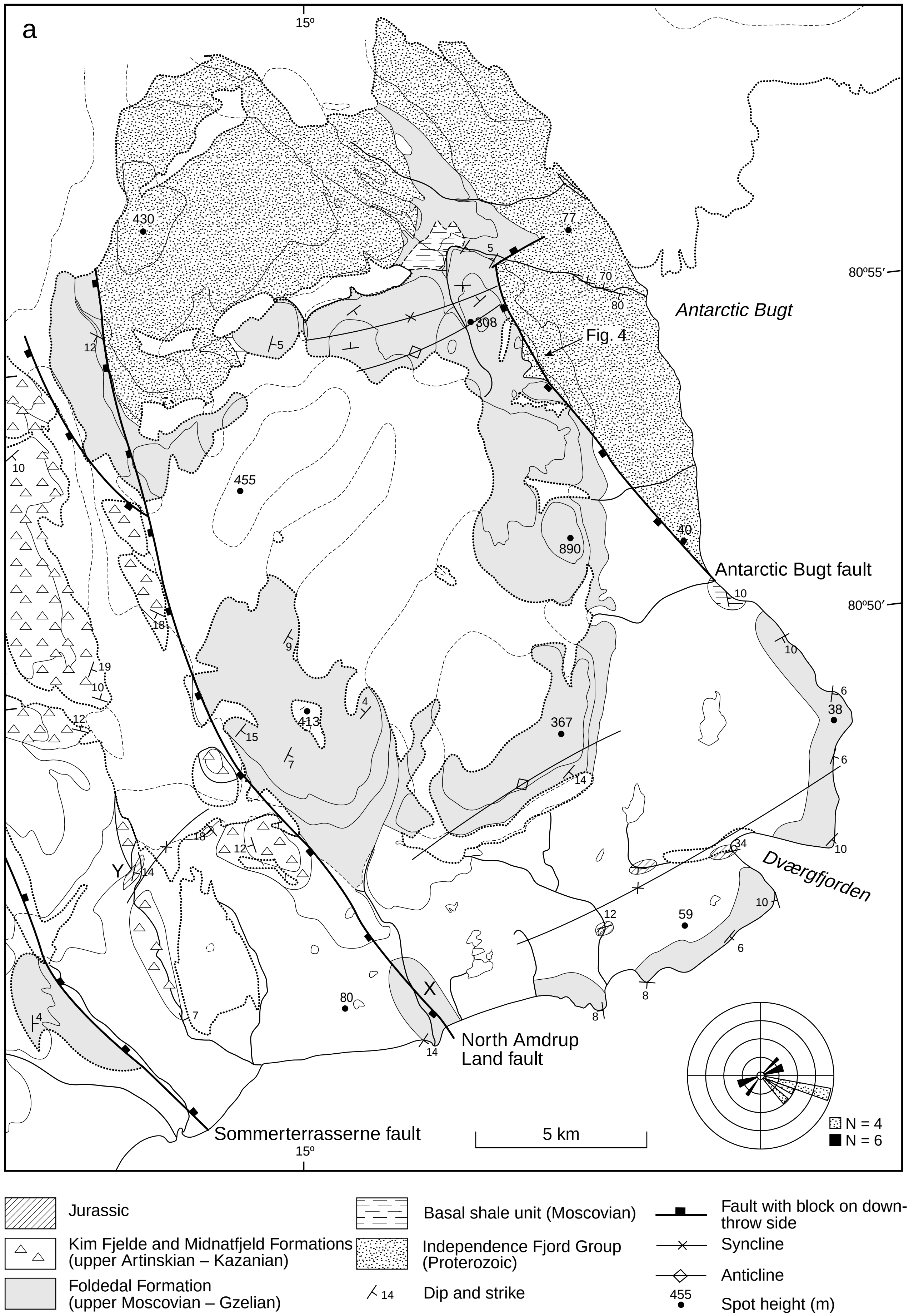

Fig. 3. *See facing page for caption.*

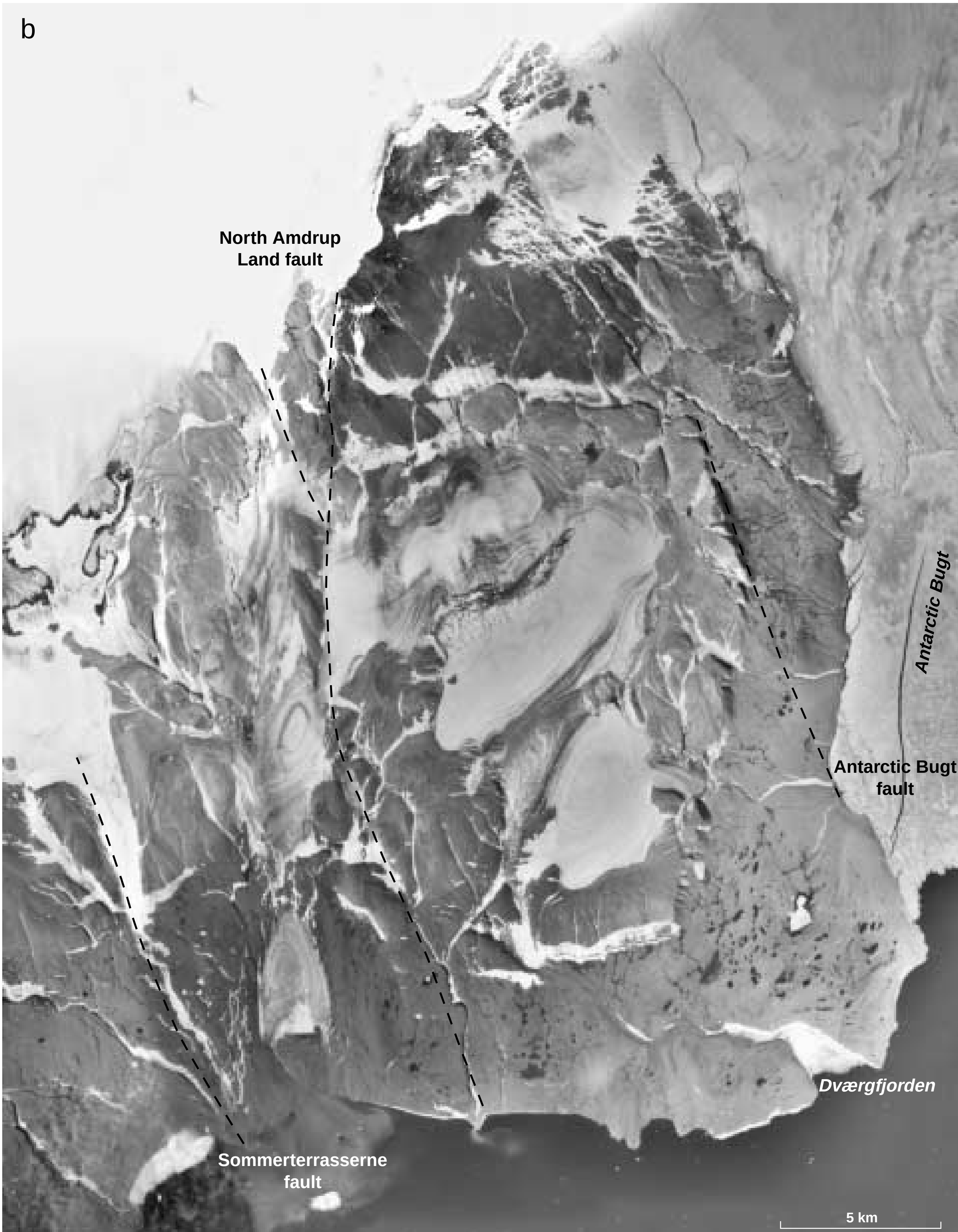

Fig. 3. **a**: Geological map of northern Amdrup Land showing sediment outcrops and major structural elements. Based on field observations and photogrammetric interpretations. **X** and **Y** refer to localities mentioned in the text. The rose diagram shows the directions of fold axes in the area between the Sommerterrasserne and north Amdrup Land faults (**black**) and between the north Amdrup Land and Antarctic Bugt faults (**stippled**). Spot heights in metres. **b**: Aerial photograph of northern Amdrup Land at the same scale as the map showing the topographic expression of the main structural elements. Photo: 876L 2864 (with parts of 876K 1831, 1834), August 1978, National Survey and Cadastre, Copenhagen, Denmark.

Fig. 4. Upper Moscovian carbonates (**UM**) onlapping Independence Fjord Group strata (**IF**) immediately south-west of the Antarctic Bugt fault. Note the topographic scarp defined by the fault; for location, see Fig. 3. The cliff is approximately 200 m high.

Stratigraphy

In northern Amdrup Land, the Wandel Sea Basin deposits rest unconformably on strongly deformed Proterozoic sediments and volcanics of the Independence Fjord Group (Figs 2–4). The Proterozoic rocks are isoclinally folded with axes plunging 10° towards WNW (285°–315°). They crop out mainly in the northern part of the study area and on the wide coastal plain along Antarctic Bugt (Fig. 3).

The oldest post-Caledonian sediments are black shales with thin beds of resedimented carbonates. These, so far undated sediments crop out locally along a NNW–SSE-trending topographic lineament that possibly corresponds to a major fault, the Antarctic Bugt fault (Figs 3, 4). They are laterally confined to this zone; elsewhere shallow marine carbonates or locally sandstones rest on the irregular basement surface. The oldest carbonates are dated as late Moscovian and they can be correlated to the lower part of the Foldedal Formation in southern Amdrup Land (Fig. 2). Lower Moscovian deposits, equivalent to the Kap Jungersen Formation in southern Amdrup Land and southern Holm Land, are not present in northern Amdrup Land. The upper Moscovian – Gzelian succession attains a maximum thickness of about 190 m compared to more than 350 m at Kap Jungersen in southern Amdrup Land (Fig. 2). These sediments dominate the outcrops north-east of the north Amdrup Land fault (Fig. 3). They are faulted against younger Carboniferous, Gzelian carbonates of the upper Foldedal Formation in the southern part of the study area (locality X in Fig. 3a).

Mid- to Upper Permian limestones, cherty limestones and cherty shales of the Kim Fjelde and Midnatfjeld

Fig. 5. Upper Jurassic sandstone (**J**) conformably overlying Upper Permian limestone (**P**). The sediments form the northern flank of a synform, locality Y in Fig. 3. **Q**: Quaternary sediments. The outcrop is approximately 30 m high.

Fig. 6. **a**: The basal part of the Wandel Sea Basin succession in northern Amdrup Land. Black shales are conformably overlain by upper Moscovian carbonates (**UM**). Note the gentle folding of the sediments in the distant outcrops that are approximately 200 m high. **b**: Detail of upper right corner of Fig. 6a showing domal folding of the Carboniferous carbonates. Width of ridged ground in the middle distance is about 200 m.

Formations are widely exposed in the down-faulted area between the Sommerterrasserne and north Amdrup Land faults. North-east of the north Amdrup Land fault, sediments of Middle to Late Permian age are confined to a narrow zone north-west of Dværgfjorden (Fig. 3). Sediments belonging to the Kim Fjelde Formation are widespread in southern Amdrup Land whereas the Midnatfjeld Formation is unknown from Holm Land and southern Amdrup Land (Fig. 2). The latter formation is present in eastern Peary Land but only in the north-eastern exposures (Håkansson 1979; Stemmerik *et al.* 1996).

Sediments of Triassic – Middle Jurassic age are not known from Amdrup Land. Upper Jurassic sediments occur locally in the cores of two synforms in the southern and eastern parts of the study area where they rest conformably on Permian carbonates (Figs 3, 5). The Jurassic succession attains a maximum thickness of 70 m in the southernmost outcrops where the sediments are unconformably overlain by Quaternary fluvial deposits. The sediments are dated as Oxfordian based on the finds of two ammonites (J.H. Callomon, personal communication 1996) and they correspond in age to the basal part of the Ladegårdsåen Formation of eastern Peary Land. There is no evidence of younger Mesozoic or Palaeogene sediments in Amdrup Land although there are more than 2000 m of Cretaceous sediments at Kilen immediately to the north (Håkansson *et al.* 1991). Post-Permian sediments are not known from the areas south of the Sommerterrasserne fault.

Structural geology

Northern Amdrup Land is relatively poorly exposed and the present structural study of the Wandel Sea Basin sediments therefore focused on major lineaments and folds. It is based on a combination of photogrammetric analysis of aerial photographs at a scale of 1:50 000 and field observations (Larsen 1996). The study forms an integrated part of the regional mapping between 78°N and 81°N at a scale of 1:500 000 (Henriksen 1995, 1996) where another GEUS mapping team was responsible for mapping of the pre-Wandel Sea Basin rocks (Hull & Friderichsen 1995).

The structural style in Amdrup Land changes across the NW–SE-oriented Sommerterrasserne fault (Fig. 3). South-west of this fault sediments have not seen compressional deformation; they are dipping gently (< 4°) towards the east and south-east with some disturbance along minor N–S-trending faults. In contrast, the Wandel Sea Basin sediments are gently folded with NE–SW fold axes north-east of the fault (Figs 3, 6). The Sommerterrasserne fault, defining the southern limit of the Trolle Land fault system in Kronprins Christian Land, is poorly exposed and the fault has not been observed in the field. Outcrops south-west of the fault consist of eastwards dipping carbonates of the Upper Carboniferous Foldedal Formation whereas folded Permian sediments of the Kim Fjelde and Midnatsfjeld Formations are exposed north-east of the fault (Fig. 3). This indicates a downthrow of the area to the north-east of at least 120 m. The NW–SE-striking north Amdrup Land fault, 7–8 km further to the north defines the northern limits of a narrow graben where outcrops are dominated by folded Permian and Jurassic sediments. The fault is exposed in a creek on the eastern coastal plain (locality X in Fig. 3a) where it strikes 150° and dips 70° towards the south-west. At this locality, Gzelian sediments are down-thrown at least 60 m compared to older Carboniferous sediments north-east of the fault. A possible third fault, the Antarctic Bugt fault, is suggested in the northern part of the study area (Fig. 3). On the coastal plain north of this lineament, isoclinally folded sediments of the Proterozoic Independence Fjord Group are faulted against upper Moscovian sediments by a normal fault striking 44° and dipping 50° to the north-west (Fig. 7). The throw on this fault exceeds 50 m. Immediately to the east of this fault, the basal black shales of the Wandel Sea Basin are thrust over younger Moscovian carbonates along a fault plane striking 178° and dipping 66° to the west (Fig. 7).

In the graben area between the Sommerterrasserne fault and the north Amdrup Land fault, the succession dips gently towards the south-east. The Permian and Jurassic strata are folded in gentle, *en echelon* domal folds with an amplitude of approximately 100 m, a wave length of 1–1.5 km and a lateral extent of 4–4.5 km (Figs 3, 8). Fold axes strike north-east with some local variations. North-east of the north Amdrup Land fault, the Moscovian sediments are folded in somewhat larger domal folds following a more easterly trend, and a larger domal synform with an amplitude of 250–300 m, a wave length of 3.5 km and a lateral extent of 7.3 km exposes Carboniferous, Permian and Jurassic sediments near Dværgfjorden (Figs 3, 8).

Fig. 7. Faulted contact between the Independence Fjord Group (**IF**) and Moscovian carbonates (**UM**). Immediately to the south of this view, the basal Moscovian shales (**BS**) are thrust over younger carbonates. The foreground exposures are approximately 30 m high.

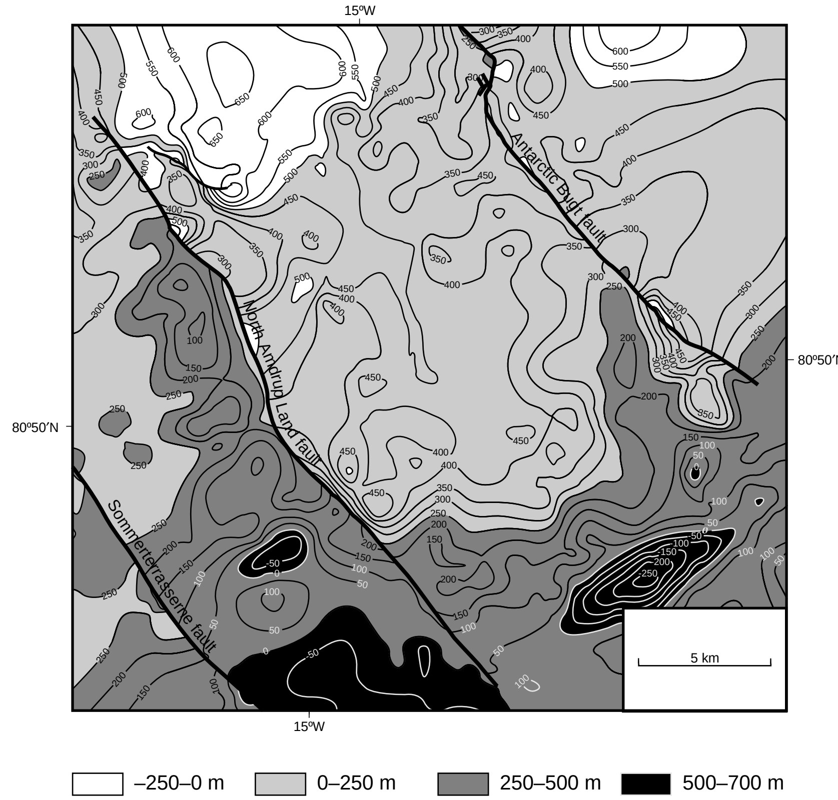

Fig. 8. Synthetic structural map of the base of the Kim Fjelde Formation based on constructed cross-sections. Note the large domal folds and the overall south-eastwards dip of the strata. The map area corresponds roughly to that of Fig. 3a. The main faults are marked and the depression towards the south-east corresponds to the Dværgfjorden syncline in Fig. 3a.

Discussion

The change of structural style across the Sommerterrasserne fault shows that this fault defines the southern limit of deformation related to the plate movements between Greenland and Spitsbergen in Amdrup Land, and therefore forms the easternmost landward part of the Trolle Land fault zone.

The conformal structural relationships between the Upper Permian strata and the Upper Jurassic sediments in northern Amdrup Land suggest minor tectonic activity during the Early Mesozoic. This is different from the pattern seen at Kilen and Prinsesse Ingeborg Halvø in northern Kronprins Christian Land and in eastern Peary Land where a major tectonic event, the Ingeborg event, has been recognised. In eastern Peary Land, the Upper Jurassic Ladegårdsåen Formation rests unconformably on tectonically disturbed Carboniferous – Middle Triassic strata (Håkansson 1979; Zinck-Jørgensen 1994).

The folding of the Wandel Sea Basin deposits north-east of the Sommerterrasserne fault took place after deposition of the Upper Jurassic sediments. It should therefore be correlated to either the mid-Cretaceous Kilen event or the latest Cretaceous strike-slip event of Pedersen (1988). The mid-Cretaceous Kilen event is described as a dextral extensional event along the NNW–SSE-trending faults in the Trolle Land fault system (Håkansson & Pedersen 1982). Several pull-apart basins, including the Kilen basin that has more than 1500 m of Upper Cretaceous sediments, were formed during this event. Thermal maturity data from the Jurassic sediments in northern Amdrup Land indicate a maximum overburden of 200–300 m (Stemmerik *et al.* 1998), and evidently the Kilen event did not lead to major subsidence of northern Amdrup Land. The NE–SW-trending fault that separates the Wandel Sea Basin sediments from the Proterozoic basement north-east of the Antarctic Bugt fault (locality Y in Fig. 3a) may be related to dextral extensional movements during the Kilen event.

The folding of the Wandel Sea Basin sediments in northern Amdrup Land most likely took place during the latest Cretaceous strike-slip event. This event is described as a dextral compressional event that in the Trolle Land fault system mainly led to E–W-trending domal folds and N–S-oriented thrusts (Håkansson *et al.* 1989). The observed ESE–WNW to ENE–WSW *en echelon* orientation of the folds corresponds to a dextral sense of displacement along the Sommerterrasserne, north Amdrup Land and Antarctic Bugt faults. From the structural map (Fig. 8) it is evident that the north Amdrup Land and Sommerterrasserne faults were active during this event. The north-easterly orientation of the fold axes in the graben area between the Sommerterrasserne and north Amdrup Land faults compared to the more easterly directions north-east of the north Amdrup Land fault may imply that the graben area saw the highest strike-slip intensity. However, the structural deformation of northern Amdrup Land is much less intense than seen further to the north in Kronprins Christian Land where the domal folds are associated with deformed thrust complexes (Håkansson *et al.* 1989, 1992, 1993).

The latest structural event in the area is extension along the Sommerterrasserne and north Amdrup Land faults. This event post-dates folding and led to formation of a graben between these faults. It is suggested that it correlates with a post-Paleocene extensional event described from other parts of the Trolle Land fault system (Håkansson *et al.* 1991).

Tectono-stratigraphic evolution

Deposition in northern Amdrup Land started during the mid-Moscovian. This is later than in southern Amdrup Land and southern Holm Land where it started during the early Moscovian but synchronous with the onset of sedimentation in northern Holm Land and eastern Peary Land (Fig. 2; Stemmerik & Håkansson 1989, 1991; Stemmerik *et al.* 1996). The depositional patterns led Stemmerik & Håkansson (1989, 1991) to suggest deposition on isolated fault blocks separated by NW–SE-trending lineaments (Fig. 1). Possibly, the Sommerterrasserne or north Amdrup Land faults, or both, were active during the late Carboniferous, forming the southern limits of a narrow block with a condensed late Carboniferous succession (190 m compared to > 350 m in southern Amdrup Land). Condensation is also seen on the southernmost fault block of the Trolle Land fault system in eastern Peary Land where Gzelian carbonates rest directly on Lower Palaeozoic rocks (Fig. 2; Stemmerik *et al.* 1996). The northern limits of the block most likely were defined by the Antarctic Bugt fault. This could explain the distribution of the basal shale unit, which is confined to the down-dip northern parts of the fault block whereas more coarse-grained sandy sediments occur up-dip along the north Amdrup Land fault.

The Early Permian event of non-deposition and prolonged subaerial exposure recorded elsewhere in the basin (Stemmerik *et al.* 1996) also affected northern Amdrup Land. Deposition started again during the mid-Permian and during Late Permian times, deeper shelf carbonates and cherty shales were deposited. There is no direct evidence of Triassic or Lower Jurassic sediments in the area. However, comparing thermal maturity of the Upper Permian and the immediately overlying Upper Jurassic (Oxfordian) sediments suggests deposition and removal of nearly 2000 m of post-Permian sediments prior to deposition of the Oxfordian sediments (Stemmerik *et al.* 1998). This is taken as indirect evidence of tectonic uplift and erosion during the mid-Jurassic Ingeborg event. The Upper Jurassic sandstones and siltstones were deposited in shallow marine environments. They form the youngest deposits in northern Amdrup Land and there is no evidence of extensive sedimentation in post-Oxfordian times.

The mid-Cretaceous Kilen event only affected the areas north-east of the Antarctic Bugt fault whereas strike-slip movements along the three major faults led to folding of the sediments of the Wandel Sea Basin possibly during the latest Cretaceous. Later, post-Paleocene movements led to formation of a graben between the Sommerterrasserne and north Amdrup Land faults.

Implications for the East Greenland shelf

The shelf areas east of Amdrup Land are regarded as the northernmost parts of the N–S-elongated Kronprins Christian Land basin (Haimila *et al.* 1990). Geophysical information from this northern part of the shelf is limited due to the ice conditions and consists mainly of regional aeromagnetic and gravimetric surveys with some additional refraction seismic data (Dawes 1990). Geophysical data from the shelf areas south of 80°N indicate that a series of N–S-oriented basins dominate this part of the shelf (Larsen 1990; Hinz *et al.* 1991; Escher & Pulvertaft 1995). Unpublished gravity data combined with the structural style of unpublished seismic lines acquired by Nunaoil A/S allowed Escher & Pulvertaft (1995) to outline a large salt basin between *c.* 76°30´N and 79°N; the northern limit is uncertain due to lack of data (Fig. 9). The absence of detailed geophysical information means that at present the geological understanding of the northernmost parts of the East Greenland shelf is based on onshore data.

The structural study of northern Amdrup Land shows that the Sommerterrasserne fault forms a continuation of the Trolle Land fault zone and that this lineament marks the southern limit of Late Mesozoic structural deformation. In eastern Peary Land it marks the boundary between the stable Greenland craton to the south

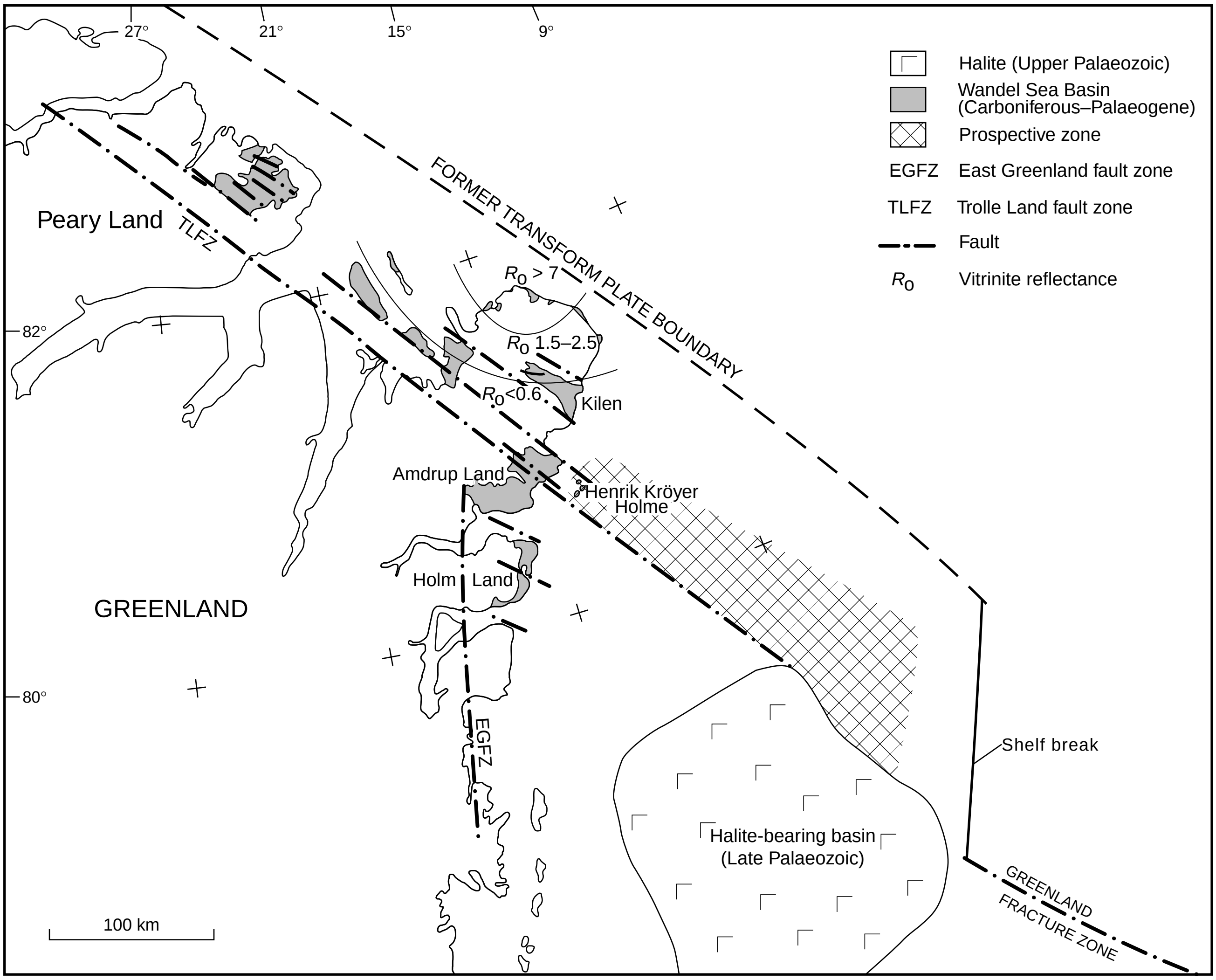

Fig. 9. Map of north-eastern Greenland and the northern part of the East Greenland shelf showing position of major depositional basins with inferred structural and thermal data. Vitrinite reflectance data (R_o) from Håkansson *et al.* (1994). The outline of the Palaeozoic salt basin and the general outline of the shelf are based on Escher & Pulvertaft (1995). Ice cover is not shown.

and the Carboniferous and younger depositional basins to the north (Håkansson & Stemmerik 1984, 1989; Stemmerik & Håkansson 1989; Stemmerik *et al.* 1996). In Amdrup Land, the East Greenland fault zone takes up this position and the Sommerterrasserne fault transects the area of deposition (Stemmerik & Håkansson 1989, 1991). It is therefore suggested that deposition occurred both north-east and south-west of the Trolle Land lineament in the offshore areas from the Carboniferous and onwards (Stemmerik & Worsley 1989, 1995). The eastward continuation of the structural style described from northern Amdrup Land into the offshore areas is confirmed by observations on the small islands of Henrik Kröyer Holme some 40 km east of Amdrup Land where folded Carboniferous carbonates crop out (Fig. 9).

Based on structural and stratigraphic studies in northern Kronprins Christian Land it is therefore assumed that the entire East Greenland shelf north of the Trolle Land fault zone was affected by late Mesozoic deformation. Structural studies of Kilen and Prinsesse Ingeborg Halvø in northern Kronprins Christian Land have outlined intense deformation associated with the latest Cretaceous strike-slip movements in these areas. Furthermore, thermal maturity studies of Carboniferous to Cretaceous sediments suggest that these northern areas were affected by a latest Cretaceous to Palaeogene thermal event that has destroyed most organic material (Christiansen *et al.* 1991; Håkansson *et al.* 1994). The combined structural and thermal maturity data therefore suggest that the pre-Paleocene sediments are post-mature with respect to petroleum generation and of limited economic interest in the northernmost parts of the shelf. In contrast, the sediments east of northern Amdrup Land and Antarctic Bugt are assumed to have lower thermal maturity based on data from the onshore areas. There, the Permian sediments are early mature with respect to hydrocarbon generation whereas the Upper Jurassic sediments are immature (Stemmerik *et al.* 1998). We therefore suggest that there is a prospective zone parallel to and immediately north of the Trolle Land fault zone with large domal structures and adequate thermal maturity (Fig. 9). South of this zone a very different structural style dominated by extensional structures is to be expected.

Acknowledgements

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References

Christiansen, F.G., Piasecki, S. & Stemmerik, L. 1991: Petroleum resources, North Greenland. In: Trettin, H.P. (ed.): Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada **3**, 525–529. Ottawa: Geological Survey of Canada (also The geology of North America **E**, Geological Society of America).

Dawes, P.R. 1990: The North Greenland continental margin. In: Grantz, A., Johnson, L. & Sweeney, J.F. (eds): The Arctic region. The geology of North America **L**, 211–226. Boulder: Geological Society of America.

Dawes, P.R. & Soper, N.J. 1973: Pre-Quaternary history of North Greenland. In: Pitcher, M.G. (ed.): Arctic geology. American Association of Petroleum Geologists Memoir **19**, 117–134.

Escher, J.C. & Pulvertaft, T.C.R. 1995: Geological map of Greenland, 1: 2 500 000. Copenhagen: Geological Survey of Greenland.

Gabrielsen, R.H., Færseth, R.B., Jensen, L.N., Kalheim, J.E. & Riis, F. 1990: Structural elements of the Norwegian continental shelf – Part I: The Barents Sea Region. Norwegian Petroleum Directorate Bulletin **6**, 33 pp.

Haimila, N.E., Kirschner, C.E., Nassichuk, W.W., Ulmichek, G. & Procter, R.M. 1990: Sedimentary basins and petroleum resource potential of the Arctic Ocean region. In: Grantz, A., Johnson, L. & Sweeney, J.F. (eds): The Arctic region. The geology of North America **L**, 503–538. Boulder: Geological Society of America.

Håkansson, E. 1979: Carboniferous to Tertiary development of the Wandel Sea Basin, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **88**, 73–84.

Håkansson, E. & Pedersen, S.A.S. 1982: Late Paleozoic to Tertiary tectonic evolution of the continental margin in North Greenland. In: Embry, A.F. & Balkwill, H.R. (eds): Arctic geology and geophysics. Canadian Society of Petroleum Geologists Memoir **8**, 331–348.

Håkansson, E. & Stemmerik, L. 1984: Wandel Sea Basin – The North Greenland equivalent to Svalbard and the Barents Shelf. In: Spencer, A.M. *et al.* (eds): Petroleum geology of the north European margin, 97–107. London: Graham & Trotman for the Norwegian Petroleum Society.

Håkansson, E. & Stemmerik, L. 1989: Wandel Sea basin – A new synthesis of the late Paleozoic to Tertiary accumulation in North Greenland. Geology **17**, 683–686.

Håkansson, E., Madsen, L. & Pedersen, S.A.S. 1989: Geological investigations of Prinsesse Ingeborg Halvø, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **145**, 113–118.

Håkansson, E., Heinberg, C. & Stemmerik, L. 1991: Mesozoic and Cenozoic history of the Wandel Sea Basin area, North Greenland. In: Peel, J.S. & Sønderholm, M. (eds): Sedimentary basins of North Greenland. Bulletin Grønlands Geologiske Undersøgelse **160**, 153–164.

Håkansson, E., Pedersen, S.A.S. & Zinck-Jørgensen, K. 1992: Structural styles of the Wandel Hav strike-slip mobile belt, North Greenland. International conference on arctic margins, Anchorage, September 1992, 1 p. (unpaginated).

Håkansson, E., Birkelund, T., Heinberg, C., Hjort, C., Mølgaard, P. & Pedersen, S.A.S. 1993: The Kilen Expedition 1985. Bulletin of the Geological Society of Denmark **40**, 9–32.

Håkansson, E., Piasecki, S., Konnerup-Madsen, J., Springer, N. & Thomsen, E. 1994: A late, thermal event in the Wandel Sea Basin; eastern North Greenland. In: Håkansson, E. (ed.): Wandel Sea Basin: basin analysis. Technical & scientific reports **22**, 13 pp. Unpublished report, University of Copenhagen, Denmark.

Henriksen, N. 1995: Eastern North Greenland 1994, the 1:500 000 mapping project. Rapport Grønlands Geologiske Undersøgelse **165**, 53–58.

Henriksen, N. 1996: Conclusion of the 1:500 000 field mapping in eastern North Greenland. Bulletin Grønlands Geologiske Undersøgelse **172**, 42–48.

Hinz, K., Meyer, H. & Miller, H. 1991: North-east Greenland shelf north of 79°N: results of a reflection seismic experiment in sea ice. Marine and Petroleum Geology **8**, 461–467.

Hull, J.M. & Friderichsen, J.D. 1995: Geology of basement rocks in northern North-East and eastern North Greenland. In: Higgins, A.K. (ed.): Express report: eastern North Greenland and North-East Greenland, 11–21. Unpublished report, Geological Survey of Greenland, Copenhagen, Denmark.

Johansen, S.E., Ostisty, B.K., Birkeland, Ø., Federovsky, Y.F., Martirosjan, V.N., Christensen, O.B., Cheredeev, S.I., Ignatenko, E.A. & Margulis, L.S. 1993: Hydrocarbon potential in the Barents Sea region: play distribution and potential. In: Vorren, T.O. *et al.* (eds): Arctic geology and petroleum potential. Norwegian Petroleum Society (NPF) Special Publication **2**, 273–320. Amsterdam: Elsevier.

Larsen, B.D. 1996: Strukturel udvikling af det nordlige Amdrup Land, Nordøst Grønland, 83 pp. Unpublished cand. scient. thesis, Aarhus Universitet, Danmark.

Larsen, H.C. 1990: The East Greenland shelf. In: Grantz, A., Johnson, L. & Sweeney, J.F. (eds): The Arctic region. The geology of North America **L**, 185–210. Boulder: Geological Society of America.

Pedersen, S.A.S. 1988: Model of structural events in the Late Mesozoic platform break up between Greenland and Svalbard. Rapport Norsk Polarinstitut **46**, 99–100.

Stemmerik, L. 1996: High frequency sequence stratigraphy of a siliciclastic influenced carbonate platform, lower Moscovian, Amdrup Land, North Greenland. In: Howell, J.A. & Aitken, J.F. (eds): High resolution sequence stratigraphy: innovations and applications. Geological Society Special Publication (London) **104**, 347–365.

Stemmerik, L. & Håkansson, E. 1989: Stratigraphy and depositional history of the Upper Palaeozoic and Triassic sediments in the Wandel Sea Basin, eastern and central North Greenland. Rapport Grønlands Geologiske Undersøgelse **143**, 21–44.

Stemmerik, L. & Håkansson, E. 1991: Carboniferous and Permian history of the Wandel Sea Basin, eastern North Greenland. In: Peel, J.S. & Sønderholm, M. (eds): Sedimentary basins of North Greenland. Bulletin Grønlands Geologiske Undersøgelse **160**, 141–151.

Stemmerik, L. & Worsley, D. 1989: Late Palaeozoic sequence correlations, North Greenland, Svalbard and the Barents Shelf. In: Collinson, J.D. (ed.): Correlation in hydrocarbon exploration, 99–111. London: Graham & Trotman for the Norwegian Petroleum Society.

Stemmerik, L. & Worsley, D. 1995: Permian history of the Barents Shelf area. In: Scholle, P.A., Peryt, T.M. & Ulmer-Scholle, D.S. (eds): The Permian of northern Pangea. Sedimentary basins and economic resources **2**, 81–97. Berlin: Springer Verlag.

Stemmerik, L., Håkansson, E., Madsen, L., Nilsson, I., Piasecki, S., Pinard, S. & Rasmussen, J.A. 1996: Stratigraphy and depositional evolution of the Upper Palaeozoic sedimentary succession in eastern Peary Land, North Greenland. Bulletin Grønlands Geologiske Undersøgelse **171**, 45–71.

Stemmerik, L., Dalhoff, F., Larsen, B.D., Lyck, J., Mathiesen, A. & Nilsson, I. 1998: Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin **180**, 55–62.

Zinck-Jørgensen, K. 1994: The Trolle Land fault system, Kim Fjelde, eastern Peary Land. In: Håkansson, E. (ed.): Wandel Sea Basin: basin analysis. Technical & scientific reports **18**, 17 pp. Unpublished report, University of Copenhagen, Denmark.

Palynology and depositional history of the Paleocene? Thyra Ø Formation, Wandel Sea Basin, eastern North Greenland

Jens M. Lyck and Lars Stemmerik

The Thyra Ø Formation in eastern North Greenland has been dated as Late Paleocene to possibly earliest Eocene based on its content of palynomorphs. The palynomorph assemblage is dominated by long ranging taxa and reworked Upper Cretaceous species. The Late Paleocene age of the formation is based on the occurrence of *Cerodinium speciosum* and *Spinidinium pilatum*. However, the presence of *Cerodinium markovae, Spinidinium sagittula,* and *?Ilexpollenites* sp. suggests that the formation may range into the earliest Eocene.

J.M.L., *Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark*. Present address: *Theklavej 9, DK-2400 Copenhagen NV, Denmark*. E-mail: *jens.lyck@get2net.dk*
L.S., *Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark*. E-mail: *ls@geus.dk*

Keywords: Dinoflagellate cysts, North Greenland, Paleocene, palynomorphs, Wandel Sea Basin

The Early Carboniferous to Palaeogene Wandel Sea Basin of North Greenland and the surrounding shelf areas are located in a geologically complex area at the junction between the Palaeozoic Caledonian fold belt in East Greenland and the Ellesmerian fold belt in North Greenland, and along the zone of Palaeogene continental break-up (Fig. 1; Håkansson & Stemmerik 1989). The basin history is accordingly very complex in the northern part of the basin where Late Palaeozoic to Early Triassic rifting was followed by a series of transtensional to extensional events in the mid-Jurassic to Late Cretaceous. The youngest preserved sediments within the basin are marginal marine and fluvial deposits of the Thyra Ø Formation (Håkansson *et al.* 1981, 1991). Following mapping of the area in 1978 a few samples were processed palynologically and a Paleocene age was suggested based on a few poorly preserved dinoflagellate cysts (Håkansson & Pedersen 1982). More precise age assignments of these deposits are important as they form the only sediments in the basin that have not been affected by compressive tectonism related to lateral movements between North Greenland and Svalbard thus placing an upper age limit on these movements (Håkansson & Stemmerik 1989; Håkansson *et al.* 1991). However, during mapping of the Wandel Sea Basin in 1978 to 1980 (Håkansson 1979; Håkansson *et al.* 1981) little attention was paid to the Thyra Ø Formation.

The present study forms an integrated part of modelling the basin that was initiated in 1994 (Stemmerik *et al.* 1995). It gives the first comprehensive description of the microflora of the formation based on material from Prinsesse Thyra Ø, Prinsesse Dagmar Ø and Prinsesse Ingeborg Halvø in the easternmost part of North Greenland (Fig. 1). There the Thyra Ø Formation consists of interbedded fine-grained sandstones, siltstones and coal with a composite thickness of 50 m. Based on sedimentological observations, the sediments were originally interpreted as dominantly fluviatile, possibly deposited on a broad fluvial plain (Håkansson *et al.* 1991). However, the present study documents dinoflagellate cysts to be common in many samples, suggesting that deposition took place in a marine influenced environment.

The Thyra Ø Formation sediments were affected by a Palaeogene thermal event centred over northern Kronprins Christian Land (Fig. 1; Håkansson & Pedersen 1982; Christiansen *et al.* 1991). The least thermally af-

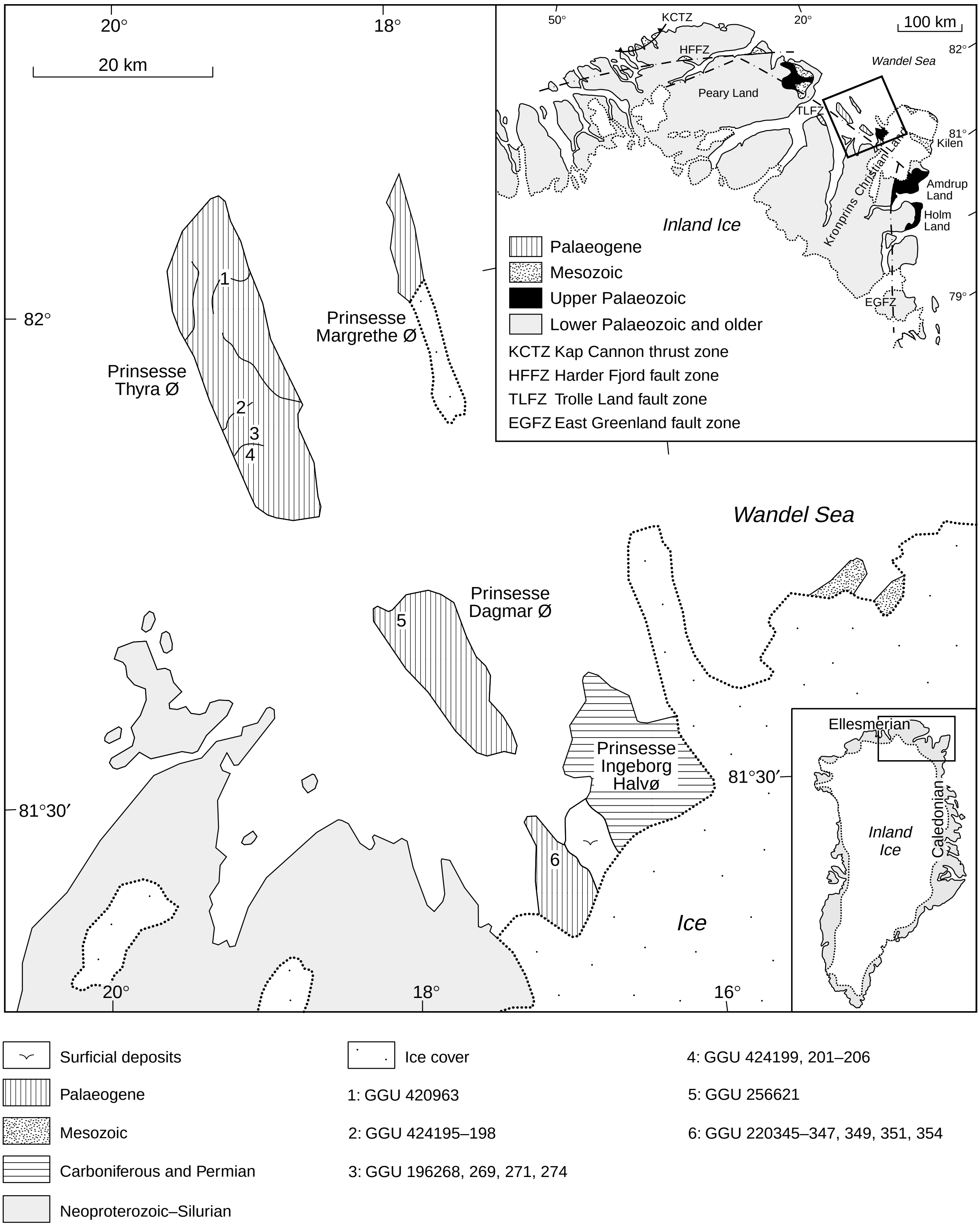


Fig. 1. Simplified geological maps of north-eastern Greenland and the islands investigated in this study. The position of the samples referred to in Tables 1 and 2 are shown on the large map. Blank areas on the upper inset map are ice.

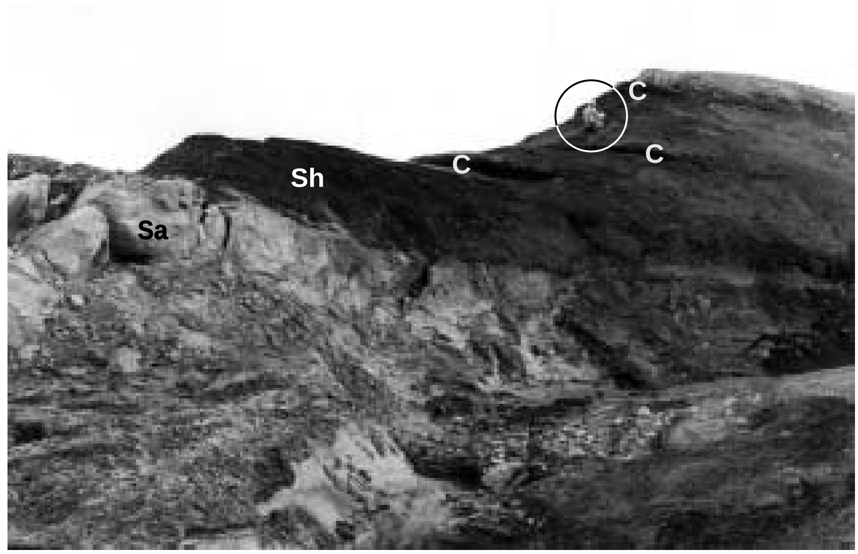


Fig. 2. Interbedded sandstone (**Sa**), siltstone (**Sh**) and coal (**C**) characterising the Thyra Ø Formation at southern Prinsesse Ingeborg Halvø. Person for scale encircled.

fected and most productive samples come from the south-easternmost parts of the study area, i.e. southern Prinsesse Ingeborg Halvø where light, transparent dinoflagellate cysts are common. In contrast, material from Prinsesse Thyra Ø is darker and more extensively corroded.

Regional setting

The Wandel Sea Basin is the northernmost of a series of fault-bounded Late Palaeozoic – Mesozoic basins exposed along the eastern margin of Greenland. The basin developed during the Carboniferous as a result of extension and rifting between Greenland and Norway, and Greenland and Svalbard (Håkansson & Stemmerik 1989; Gudlaugsson *et al.* 1998). The depositional basins are separated from the stable Greenland craton by the East Greenland, Trolle Land and Harder Fjord fault zones, and the areas to the west and south of these fault zones have been land for most of the Late Palaeozoic and Mesozoic (Fig. 1; Håkansson & Stemmerik 1989).

Deposition began during the Early Carboniferous in the southernmost part of the basin and was followed by widespread Late Carboniferous to Late Permian marine sediments (Stemmerik & Håkansson 1989, 1991). Following Middle Triassic sedimentation, the basin was uplifted and eroded during the mid-Triassic to mid-Jurassic (Håkansson & Pedersen 1982). Sedimentation started again in the northern part of the basin during the Late Jurassic, and Late Mesozoic sedimentation was mainly confined to small pull apart basins within the NW–SE-striking Trolle Land fault zone (Fig. 1; Håkansson & Stemmerik 1989; Håkansson *et al.* 1991).

Outcrops of the Thyra Ø Formation are located in the southern part of the Trolle Land fault zone (Fig. 1). In contrast to the Mesozoic and older sediments, they are not affected by deformation related to strike slip movements in this fault system and they are therefore regarded as post-dating these movements. Based on correlation of fault trends in eastern Peary Land and Kronprins Christian Land it is likely that Prinsesse Thyra Ø and Prinsesse Ingeborg Halvø were located on two different fault blocks within the Trolle Land fault zone.

The base of the Thyra Ø Formation is not known, and the formation is directly overlain by Quaternary marine sediments.

Depositional facies

The Thyra Ø Formation is generally poorly exposed, and most information comes from isolated outcrops along rivers on southern Prinsesse Thyra Ø and Prinsesse Ingeborg Halvø (Fig. 1). The formation is dominated by laminated, organic-poor siltstones and fine-grained sandstones with coal seams (Håkansson *et al.* 1991). The poor quality outcrops do not allow any detailed facies analysis; the presence of coal seams was used by Håkansson *et al.* (1991) to propose a fluvial origin of the sediments. However, the presence of marine dinoflagellates in all investigated siltstones indicates that sedimentation of these units took place in a marine environment. The lack of bioturbation or the absence of marine macrofossils may indicate a bio-

Table 1. Distribution and abundance (rough counts) of dinoflagellates in the Thyra Ø Formation

Taxa	GGU sample number																						
	420963	424195	424196	424197	424198	424199	424201	424202	424203	424204	424205	424206	196268	196269	196271	196274	256621	220345	220346	220347	220349	220351	220354
Achomosphaera spp.			1																1	1			
Alterbidinium sp.										1	5			1	?	?		?		5	5	?	
Areoligera spp.			5						1			1	1	1	5	5	5	1	5	1	1		
Cerodinium diebelii												1	1		5	1		1			1		
Cerodinium markovae																?		10			5		
Cerodinium speciosum		1	1	5	10	1		1	1	5	5	5	1		1			5	1	5	5		
Cerodinium striatum	?	1	1	1	5					1	5	5		1	5			?	2	?	1		
Cerodinium sp.						1		5									1	1	1		5	?	5
Chatangiella granulifera	5		5	5	1	10		5	5	5	5	5	5	10		1	5	1	1	5	5	5	1
Chatangiella spp.	1		1		5				1					1			5	1		1	1		
Circulodinium distinctum	?	1	1		1	1		1				1			1		5	1	5			1	
Cleistosphaeridium spp.		1	1									1	1	1			5	1	1		1	5	1
Desmocysta plekta																			10	1			5
Fromea fragilis														1								1	1
Glaphyrocysta ordinata			5	1							5	10			10	5	1	1	5	?			
Hystrichosphaeridium tubiferum		5	1		1			1	5		5			1	5	1		1	5		1	?	1
Isabelidinium aff. *I. acuminatum*																	1					?	
Isabelidinium aff. *I. viborgense*			1		5						?	1			?		1				5		
Isabelidinium spp.			1			5							5	5			1	1	1				
Laciniadinium arcticum	1			1		5				1			5	1	1	1	5	5	?	5	?	10	
Laciniadinium? sp.														?									5
Odontochitina operculata																	1	1			?	5	
Oligosphaeridium spp.			1		1							1					5		5		1		
Palaeocystodinium lidiae			1	1	5				?		1		1	1		5	5		5	5			1
Palaeocystodinium australinum			1					5							1	1	1	5	1	1	5	5	
Palaeoperidinium pyrophorum			5	1					?			?	5		5	?	>15	5	1	1	1	5	
Paralecaniella indentata			1		5					?	?		1		1		1	5	>15		5	1	
Phelodinium kozlowskii																	1						
Pterodinium spp.																	1					1	
Quadrina pallida											?							10					
Senegalinium aff. *S. dilwynense*			?							1											1		
Senegalinium microgranulatum		1	1		1				?		1		5	1	5	1		?	1	?	1		
Senegalinium obscurum	?	10	5	5	5				1	1	1	5	5	1	5	5	1	1	5	?	5	5	5
Senegalinium sp.		5								1							1		10			?	
Spinidinium cf. *S. clavus*								?	?			?						5			1		
Spinidinium densispinatum			?	?								?				1			1	1	5	?	
Spinidinium essoi					?							?			5							1	
Spinidinium pilatum			10	10	5			1			5	1	5	5	1						1	1	
Spinidinium sagittula																		?			10		
Spinidinium spp.			1		5			5		1					1	5	5					1	
Spiniferites spp.				1				5	1	5			5		1	1	1	1			1	1	1
Spongodinium delitiense			1	5					1	1	5	1	10		5	5	>15	5	1	1	1		1
Trithyrodinium evittii		5	>15	10	5	10		5		5	10	5	5	1	10	1	1	10					
Trithyrodinium fragile			5	1				?				1	1		5	1	1					5	
Trithyrodinium ornatum					1	1		1	1			1					1				5	1	
Trithyrodinium sp.		15						5		1		5		1	5	1	1		5		5	?	?
Trithyrodinium? sp.																			15		10	5	

Table 2. Distribution and abundance (rough counts) of terrestrial palynomorphs in the Thyra Ø Formation

Taxa	420963	424195	424196	424197	424198	424199	424201	424202	424203	424204	424205	424206	196268	196269	196271	196274	256621	220345	220346	220347	220349	220351	220354
	GGU sample number																						
Gleicheniidites spp.	5		5	1		1	10				1	1	5		5	1		15	10	10	5	10	
Lycopodiumsporites spp.		1		1		1			1			5		1					5	1	10	1	
Osmundacidites spp.	5	5		5	5	10	>15	1	1		5	15	1	10			1				5	5	1
Triplanosporites spp.	10		5	5		1	5	5	1			5	5							10	5	1	
Hazaria sheopiariae	1											1						5			5	10	
Ilexpollenites spp.																						?	
Laevigatosporites spp.		1				5		1	1			5	5	1							1	5	
Bisaccate pollen	>15	5		10				>15				>15	>15	15	15		>15	5	5		5	>15	
Taxodiaceae, papillate spp.	1												5								5		
Taxodiaceae, split spp.											?		1	10				5			10	10	5
Inaperturopollenites magnus													1	1	1					?	1		1
Ovoidites spp.								1	1					1								1	
Alnipollenites spp.						?			1			1						1	1		10	5	
Caryapollenites spp.		?		1					?			1	5								5	5	
Myricipites speciosus	5						1				1	5		10	5	1		5			10	5	5
Other porate pollen												?		1							?	?	
Extratriporopollenites spp.																		5		1	5	5	
Colporate spp.						1		1				15						5					
Colpate spp.	5			5				1													1		
Aquilapollenites spp.					1	1		1		5	10	5	1	10	5		5		5	1	5	10	5
Aquilapollenites spp, dark										1					5	>15						1	
Grevilloideaepites spp.			?		?						5		5					1		1	5	1	
Mancicorpus spp.				1									10					1			1	10	5
Orbiculapollis spp.					?								?				?					1	?
Pseudointegricorpus spp.	1								1		1	?	1		1	1				1			
Trudopollis spp.														1			1						
Wodehouseia spinata			?												10	1					5		
Pesavis sp.																					?	1	
Palambages sp.															5			1	1				
Ulvella nannae			1															15			10	5	
Fungal palynomorphs indet.																		10	1		1	1	
Black phytoclasts			10				>15	5						5				15					10
Brown phytoclasts			15			>15							>15	>15	15			>15					>15
Cuticle				15			?	15															

logically stressed environment during deposition of the siltstones. Most sandstones are very fine grained with non-erosive planar bases. They are homogeneous, low-angle trough cross-bedded or contain small-scale cross lamination.

All three measured sections show an overall fining upwards tendency and are dominated by siltstones and coal in the upper part (Fig. 2). The close association of siltstones and coal indicates deposition in a shallow, protected environment, and most likely deposition took place in shallow-marine lagoons and marshes. The small amount of available data indicates that the thickness of the coal beds increases south-eastwards suggesting that land was located to the south of the outcrop area. This is in accordance with the palaeogeography seen in the Late Palaeozoic and Mesozoic (Håkansson *et al.* 1991; Stemmerik & Håkansson 1991).

Palynomorph assemblages

A total of 24 surface samples from Prinsesse Thyra Ø, Prinsesse Dagmar Ø, Prinsesse Margrethe Ø and Prinsesse Ingeborg Halvø have been examined palynologically (Fig. 1; Tables 1, 2). Of these, 23 samples were found to be palynologically productive. Only a sample from Prinsesse Margrethe Ø was found to be barren of palynomorphs; it only contains hairy, chitinous (insect?) tubes. The processing procedures described by Hansen & Gudmundsson (1979) have been adapted to enrich the palynomorph content in the organic residues. Different fractions of the residues were isolated according to their specific weight and floating properties. Strew mounts representing the different fractions were mounted in a permanent medium Eukitt®. The quantitative data listed in the distribution chart represent rough counts of several slides, where available (Tables 1, 2).

The palynomorph assemblages in the Thyra Ø Formation are mixed, with a consistently large, moderately diverse terrestrial fraction, and a marine fraction of very variable size and diversity. All samples are dominated by degraded brown phytoclasts, with large bisaccate pollen dominant among the palynomorphs. Preservation of the palynomorphs is generally poor, they are worn, torn and pitted. There is no obvious difference in state of preservation between palynomorphs of terrestrial and marine origin in individual samples, but regional preservational differences exist within the study area. The material from Prinsesse Ingeborg Halvø in the south-eastern part of the study area is lighter in colour and less thermally altered than the material from northern Prinsesse Thyra Ø.

The dominant *terrestrial* component is degraded brown wood, followed in abundance by smaller angular to rounded inertinite particles. Large cuticular fragments are very common in some samples, particularly from Prinsesse Thyra Ø. The most prominent among the palynomorphs, and next in overall abundance are large bisaccate pollen. They dominate the palynomorph assemblage completely in northern Prinsesse Thyra Ø, and are also very common in other samples. Thick-walled trilete spores, particularly *Osmundacidites wellmanii*, are common in some samples, and smooth *Gleicheniidites*-type spores are locally common. Monolete spores like *Hazaria sheopiariae* and *Laevigatosporites* sp. are less abundant. Porate angiosperm pollen are usually present, increasing in abundance towards the south. They are generally smaller and less conspicuous than the spores, and their preservation in conjunction with their original relatively featureless character precludes a precise identification in most cases. The most common of these porate types is identified as *Myricipites speciosus*, a species also found in the Palaeogene of Svalbard. In some samples (e.g. GGU 424206) many pollen grains seem to have pores, but the grains are very corroded and these characters may well be artefacts produced by corrosion or crystal growth in the palynomorph wall. Representatives of the *Aquilapollenites* group (*sensu lato*) are larger and more conspicuous; they are locally common in Prinsesse Ingeborg Halvø. *Pseudointegricorpus protrusum* and *Wodehouseia spinata* are rare. Fungal palynomorphs are only recognised in a few samples from southern Prinsesse Ingeborg Halvø (e.g. GGU 220345, Table 2). The recognised forms are primarily known from Early Palaeogene and younger deposits (Elsik 1976; Day 1991; Gregory & Hart 1995; Tyson 1995) but probably range into the Late Cretaceous. *Ulvella nannae*, a marine, encrusting green alga, described by Hansen (1980b) from the Maastrichtian and Lower Palaeogene deposits of West Greenland, is common in a few samples.

The *marine* component is completely dominated by peridinioid dinoflagellate cysts of the genera *Senegalinium*, *Spinidinium*, *Trithyrodinium*, *Cerodinium* and *Palaeoperidinium*, which are considered to be common in nearshore environments. The few representatives of gonyaulacoid cysts mainly belong to *Glaphyrocysta* and *Spongodinium*, although a few *Spiniferites* spp. are present in many samples, and *Hystrichosphaeridium tubiferum* and possibly *Areoligera* spp. are occasionally found.

A large percentage of the dinoflagellate cysts and terrestrial palynomorphs are considered to be *reworked* from older deposits in the area as they belong to Cretaceous taxa, whereas age diagnostic palynomorphs point towards a Late Paleocene or earliest Eocene age of the formation. Most abundant among the reworked dinoflagellate cysts are *Chatangiella* spp. and *Isabelidinium* spp. whereas *Aquilapollenites* spp. (including *Mancicorpus* spp.) are most common among the terrestrially derived grains.

The composition of the organic material changes slightly from Prinsesse Thyra Ø to Prinsesse Ingeborg Halvø and possibly two different assemblages are present. The Prinsesse Ingeborg Halvø assemblage is the most diverse and is characterised by the presence of thin-walled dinoflagellate cysts, particularly *Cerodinium markovae* and *Spinidinium sagittula*, light, hyaline *Palaeocystodinium australinum*, light and more common *Glaphyrocysta ordinata*. Furthermore, the assemblage has a much higher proportion of taxodiaceous pollen, *Hazaria sheopiariae*, fungal palynomorphs and more common *Myricipites speciosus* than the material from Prinsesse Thyra Ø. The regional differences may be due to preservational factors, i.e. the extra elements in the Prinsesse Ingeborg Halvø assemblage may be missing in material from Prinsesse Thyra Ø due to degradation. Alternatively, there may be slight differences in the depositional environment or age.

Comparison with the material of Manum & Throndsen (1986) from Svalbard indicates that the Thyra Ø Formation has some features in common with the Basilika Formation which, based on dinoflagellate cyst evidence, is considered to be transitional Early to Late Paleocene in age. Earlier work by Manum (1960, 1962) on spores and pollen from Svalbard, though extensive, has not given any precise age indications. The macroflora of Spitsbergen indicates that gymnosperms and ferns producing taxodiaceous pollen and *Osmundacidites* spp. were very common in the Early Palaeogene; these pollen and spores are moderately common in the Thyra Ø Formation.

Age of the Thyra Ø Formation

The age of the Thyra Ø Formation is thought to be Late Paleocene to possibly earliest Eocene, even though many of the more conspicuous palynomorphs are of Late Cretaceous (Santonian–Maastrichtian) age. Others are known from both Maastrichtian and Early Palaeogene deposits. Several of the *Spinidinium* species, *Spongodinium delitiense*, *Trithyrodinium evittii* and *Senegalinium obscurum* have a known range crossing the Cretaceous–Tertiary boundary. These taxa indicate a general Late Cretaceous – Early Palaeogene age for the Thyra Ø Formation, but are less useful deciding the precise age for the formation. Representatives of *Chatangiella* are considered to be confined to deposits of Early Maastrichtian or older age, and are thus regarded as reworked. The same is true for the *Aquilapollenites* group (*sensu lato*) as well as *Pseudointegricorpus protrusum* and *Wodehouseia spinata* that are typical of (Upper Campanian –)Maastrichtian deposits.

From the suite of palynomorphs listed in Table 2, few taxa are considered both to be in place and to be sufficiently short ranging to be age diagnostic. *Cerodinium speciosum*, thought to indicate a (Late) Paleocene age (Hansen 1980a; Heilmann-Clausen 1985; Powell 1992) and *Spinidinium pilatum* indicating a Paleocene age (Stanley 1965) are the most diagnostic. Representatives of the *Cerodinium speciosum* group of cysts have been reported in low numbers from the Maastrichtian of USA (*C.* aff. *C. speciosum;* Benson 1976) and Late Campanian of Canada (*C. speciosum glabrum*; Kurita & McIntyre 1994) – although they are more typical of Lower Palaeogene than of Upper Cretaceous deposits. In the southern North Sea *Cerodinium speciosum sensu* Powell and Heilmann-Clausen is confined to the early Late Paleocene (Heilmann-Clausen 1985; Powell 1992), and unpublished work by Hansen (1980a) expresses the same opinion on West Greenland and Danish material. Thus, the occurrence of *Cerodinium speciosum* in the Thyra Ø Formation is interpreted as indicating a Late Paleocene age, although there is a slight possibility that it may represent older material. *Cerodinium markovae* has been reported from western Siberia where it has a Paleocene–Eocene range (Lentin & Vozzhennikova 1990) and *Spinidinium sagittula* has been reported from sediments of Early Eocene age (Drugg 1970). Other dinoflagellate cysts found in the Thyra Ø Formation are less reliable age indicators due to poor preservation leading to problems with precise identification. A few specimens of *Isabelidinium* aff. *I viborgense* fall in this category.

Many of the terrestrial taxa, e.g. the porate pollen, are more typical of Early Palaeogene than of Cretaceous deposits. The presence of a few specimens of ?*Ilexpollenites* sp. may indicate an Early Eocene age which is also suggested by the presence of the dinoflagellate cysts *Cerodinium markovae* and *Spinidinium sagittula*.

Systematic palynology

Selected palynomorphs from the Thyra Ø Formation are discussed below because they are considered to have stratigraphic or palaeoenvironmental significance. The entire microflora is illustrated in Figs 3–13.

Dinoflagellate cysts

The genera and species names cited below are in accordance with Lentin & Williams (1993).

Genus *Cerodinium* Vozzhennikova 1963; emend. Lentin & Williams 1987

***Cerodinium diebelii* (Alberti 1959) Lentin & Williams 1987**
Fig. 3d

Comments. *Cerodinium diebelii* is slender, elongate with long apical and antapical horns and a finely striate periphragm. All but one of the specimens found are dark brown and in most specimens the distal parts of the horns are missing.

Occurrence in the Thyra Ø Formation. Rare specimens occur in samples from southern Prinsesse Ingeborg Halvø.

Previous occurrences. The species is known from many localities including the North Sea area where it occurs in the Late Campanian to Late Paleocene (Powell 1992). Ioannides (1986) reported it from the Maastrichtian to Early Paleocene of Arctic Canada, and Nøhr-Hansen (1996) from the Early Maastrichtian to Late Paleocene of West Greenland.

***Cerodinium markovae* (Vozzhennikova 1967) Lentin & Williams 1987**
Fig. 3a–c

Comments. Large *Cerodinium* species with very thin, smooth periphragm and a granular endophragm. The apical and antapical horns are typically short, wide, tapering to a pointed tip, although a few specimens have a long apical horn with a rounded tip. The antapical horns do not diverge and they are finely serrate on the inner (centrally oriented) side as seen on text figure 16 in Lentin & Vozzhennikova (1990). The paracingulum is often poorly defined. The specimens from the Thyra Ø Formation therefore compare well to the rather poor type material, although they are smaller, ranging from 90 to 120 µm in length, as compared to the size range of 120–132 µm given for the type material.

Occurrence in the Thyra Ø Formation. Common in GGU 220345 from southern Prinsesse Ingeborg Halvø, a few specimens are found in the other samples from that area.

Previous occurrences. Cerodinium markovae has been previously recorded from the Paleocene–Eocene of Western Siberia by Vozzhennikova (1967).

***Cerodinium speciosum* (Alberti 1959) Lentin & Williams 1987**
Fig. 3g–i, k

Comments. The specimens from the Thyra Ø Formation are rather small (approximately 80 µm long) compared to specimens of *C. speciosum* reported from Europe and the North Sea, which are often 150 µm long (e.g. Heilmann-Clausen 1985). However, specimens from West Greenland illustrated by Nøhr-Hansen (1996) are not much larger than the Thyra Ø Formation specimens, and Kurita & McIntyre (1995) demonstrated a large variation in size in material from Manitoba, Canada. The Greenland material may thus be one (small) end-member of a north–south size-trend within *Cerodinium*. *Cerodinium speciosum* has a large, granular endocyst which almost fills the central part of the thin pericyst, thus making the cyst essentially cornucavate. Parasutural and non-tabular coni are present on the pericyst. The species often has a compressed appearance, and short apical and antapical horns. It is distinguished from *C. striatum* by the lack of linearly arranged non-tabular coni and crenulations and its wider, more delicate horns. The specimens shown as Fig. 3g, h seem to be very similar to an unpublished specimen from West Greenland recorded by Hansen (1980a).

Occurrence in the Thyra Ø Formation. Relatively common in samples from the southern part of Prinsesse Thyra Ø, especially in GGU 424196 and GGU 424205, and in samples from the southern part of Prinsesse Ingeborg Halvø.

Previous occurrences. In the southern North Sea area *C. speciosum speciosum* is a relatively short ranging form indicative of the early part of the Late Paleocene (Heilmann-Clausen 1985; Powell 1992). Williams *et al.* (1993) on the other hand indicated a considerably longer range (Late Maastrichtian to the Early Eocene) for this form in the northern hemisphere, and Kurita & McIntyre (1995) stated that the species ranges from Campanian to Paleocene. Neither McIntyre (1974) nor Ioannides (1986) reported it from the Cretaceous of the Canadian Arctic; Ioannides (1986) reported it from the Early Paleocene. Benson (1976) reported a few specimens of *C.* cf. *C. speciosum* from Upper Maastrichtian sediments of Maryland, USA, Kurita & McIntyre (1994) reported rare *C. speciosum glabrum* from the Upper Campanian of Alberta, Canada, but these seem to be the only reports of *Cerodinium speciosum*-type cysts from sediments older than the Paleocene, and the possibility that the specimens recorded from the Cretaceous are not true *C. speciosum* cannot be excluded.

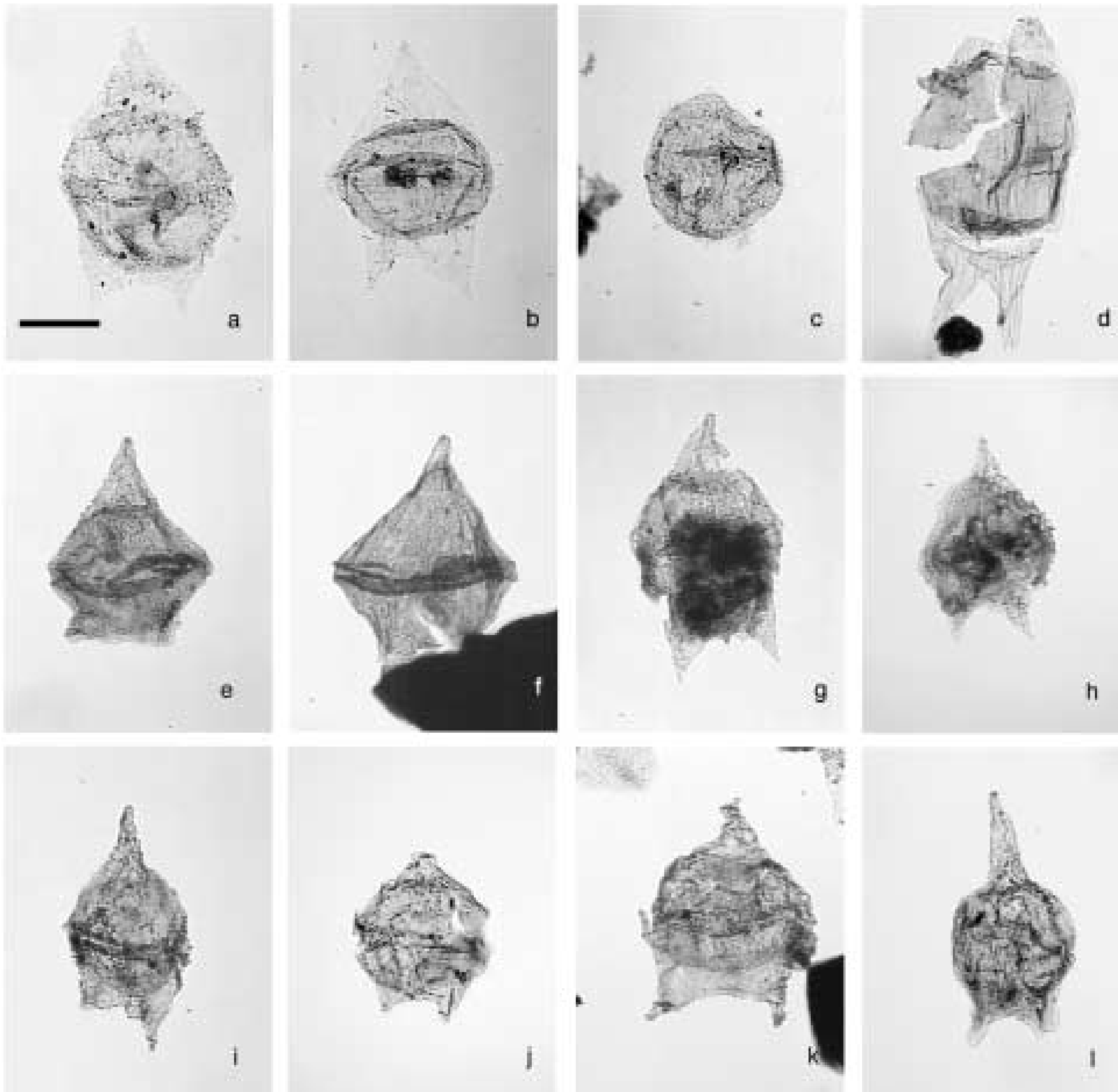


Fig. 3. *Cerodinium* spp. Scale bar is 30 µm; all figures are the same size. **a**: *Cerodinium markovae* MGUH 24887 from GGU 220345, MI 5300; **b**: *Cerodinium markovae* MGUH 24888 from GGU 220345, MI 5301; **c**: *Cerodinium markovae* (endocyst) MGUH 24889 from GGU 220345, MI 5833; **d**: *Cerodinium diebelii* (light specimen) MGUH 24890 from GGU 220345, MI 5298; **e**: *Cerodinium* aff. *C. striatum* (echinate ectophragm) MGUH 24891 from GGU 196271, MI 5619; **f**: *Phelodinium kozlowskii* MGUH 24892 from GGU 256621, MI 5057; **g**: *Cerodinium speciosum* MGUH 24893 from GGU 220345, MI 5227; **h**: *Cerodinium speciosum* MGUH 24894 from GGU 424196, MI 5835; **i**: *Cerodinium speciosum* MGUH 24895 from GGU 424195, MI 5347; **j**: *Cerodinium* sp. (short, wide) MGUH 24896 from GGU 424199, MI 5837; **k**: *Cerodinium speciosum* (wide, large cavation) MGUH 24897 from GGU 424206, MI 5840; **l**: *Cerodinium striatum* MGUH 24898 from GGU 196271, MI 5834.

***Cerodinium striatum* (Drugg 1967) Lentin & Williams 1987**
Fig. 3e, l

Comments. Echinate, robust forms with a triangular epipericyst and pointed subparallel antapical horns which may be reduced. The robustness and a striation consisting of aligned coni and longitudinal wrinkles of the periphragm over most of the cyst separate this species from other forms of *Cerodinium* in the material. The species is often found as dark brown specimens.

Occurrence in the Thyra Ø Formation. This species is never common, but occurs regularly in samples from the southern part of Prinsesse Thyra Ø, and sporadically in most other sections.

Previous occurrences. In the North Sea area *Cerodinium striatum* occurs in the mid-Paleocene, i.e. in the late Early Paleocene and the early Late Paleocene (Powell 1992). From the Arctic it has previously been reported from Paleocene strata in West Greenland (Hansen 1980a; Piasecki *et al.* 1992).

Genus *Chatangiella* Vozzhennikova 1967; emend. Lentin & Williams 1976; emend. Marshall 1988

***Chatangiella granulifera* (Manum 1963) Lentin & Williams 1976**
Fig. 4b, c

Comments. The specimens conform to the description of Manum (1963). Specimens are often less corroded than most of the other palynomorphs present in the samples. Possibly they are more resistant to corrosion.

Occurrence in the Thyra Ø Formation. A few specimens are found in most samples; they are considered to be reworked from Upper Cretaceous sediments, most probably Campanian or Santonian.

Previous occurrences. Manum (1963) and Manum & Cookson (1964) described *Chatangiella granulifera* from the Upper Cretaceous of Arctic Canada. McIntyre (1974) reported this species from the Santonian to ?Early Maastrichtian of Arctic Canada. From the same region, Ioannides (1986) reported *Chatangiella granulifera* from the Santonian to Campanian, and reworked in the Paleocene. Nøhr-Hansen (1996) reported it from Campanian and older deposits of West Greenland.

Genus *Glaphyrocysta* Stover & Evitt 1978

***Glaphyrocysta ordinata* (Williams & Downie 1966) Stover & Evitt 1978**
Fig. 5a–c, f

Comments. The species is large, with a smooth to finely granular central body and has very robust elkhorn-like trabeculate processes (a few have more delicate processes and more elaborate trabeculae). All specimens are torn to some degree, so the complete configuration of the processes could not be determined.

Occurrence in the Thyra Ø Formation. The species is found in the southern part of Prinsesse Thyra Ø (GGU 424205), and is common in a few samples from the southern part of Prinsesse Ingeborg Halvø.

Previous occurrences. The species was originally described from the Early Eocene of England by Williams & Downie (1966). It occurs in deposits of Late Paleocene age in the North Sea area (Powell 1992). Ioannides (1986) reported the species from the Early Paleocene of Arctic Canada. Williams *et al.* (1993) indicated a Late Paleocene to Early Eocene range in the northern hemisphere for this species.

Genus *Laciniadinium* McIntyre 1975

***Laciniadinium arcticum* (Manum & Cookson 1964) Lentin & Williams 1980**
Fig. 6j, k

Comments. Species with a short, relatively blunt apical horn and one well-developed off-centered, pointed antapical horn; a second, rudimentary antapical horn is often present.

Occurrence in the Thyra Ø Formation. A few specimens are found in most samples from Prinsesse Dagmar Ø and southern Prinsesse Ingeborg Halvø.

Previous occurrences. McIntyre (1974) reported the species consistently from the Santonian to the ?Early Maastrichtian. Nøhr-Hansen (1996) reported it from the ?Coniacian–Campanian of West Greenland, questionably also from the Early Maastrichtian and Paleocene. Dinoflagellate sp. E of Ioannides (1986) from the Maastrichtian of the Canadian Arctic resembles the specimens here recorded as *Laciniadinium arcticum*.

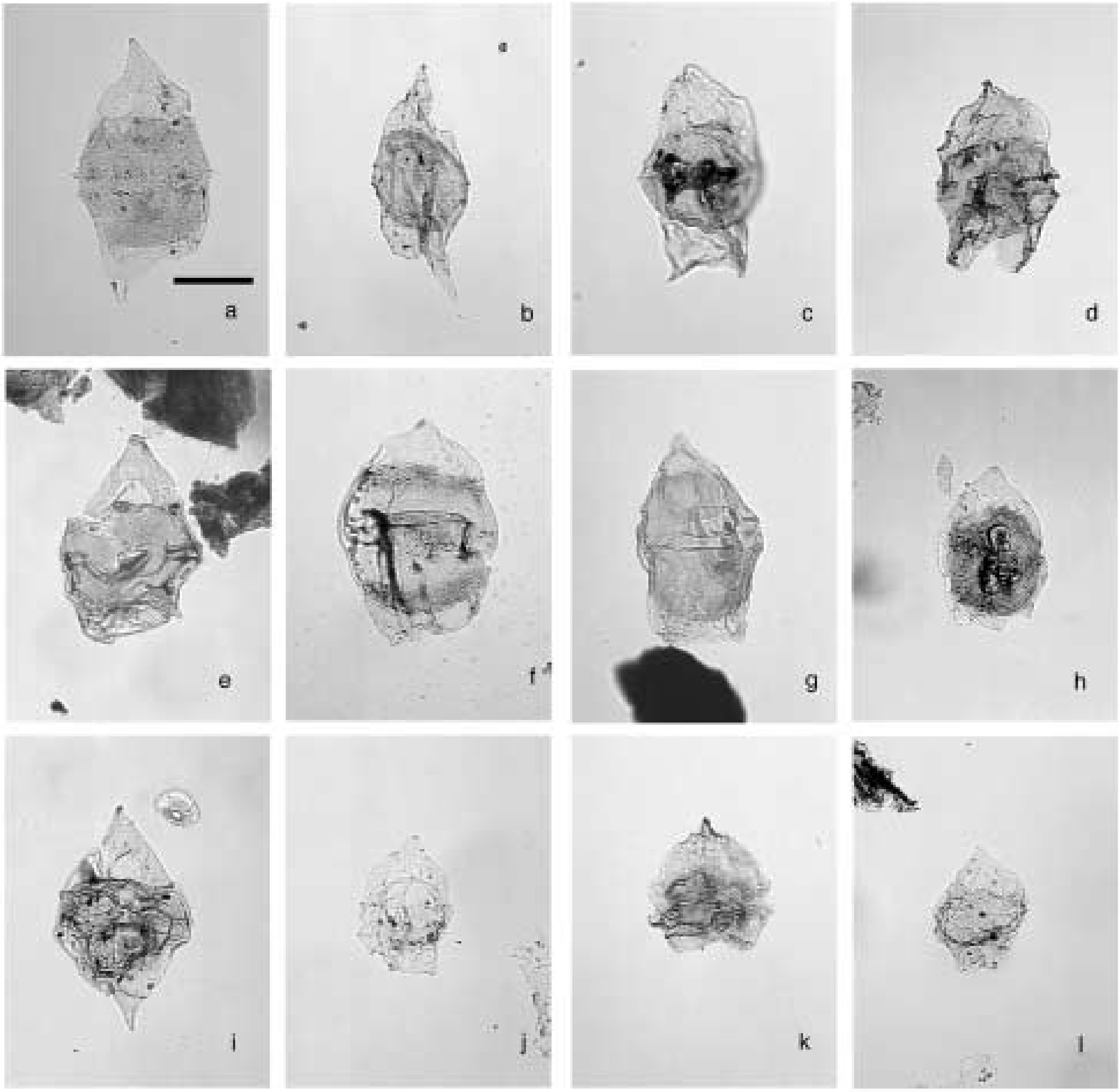


Fig. 4. *Chatangiella*, *Isabelidinium* spp. Scale bar is 30 µm; all figures are the same size. **a**: *Chatangiella* sp. MGUH 24899 from GGU 220345, MI 5299; **b**: *Chatangiella granulifera* (long and slender specimen) MGUH 24900 from GGU 196271, MI 5099; **c**: *Chatangiella granulifera* MGUH 24901 from GGU 256621, MI 5858; **d**: *Chatangiella* sp. MGUH 24902 from GGU 424195, MI 5646; **e**: *Isabelidinium/Chatangiella* sp. MGUH 24903 from GGU 256621, MI 5051; **f**: *Isabelidinium* sp. (aff. *Chatangiella dakotaensis*) MGUH 24904 from GGU 220351, MI 5563; **g**: ?*Alterbidinium* sp. MGUH 24905 from GGU 424204, MI 5317; **h**: ?*Alterbidinium* sp. MGUH 24906 from GGU 220349, MI 5474; **i**: *Isabelidinium* sp. MGUH 24907 from GGU 256621, MI 5056; **j**: Aff. *Isabelidinium viborgense* MGUH 24908 from GGU 220345, MI 5425; **k**: Aff. *Isabelidinium viborgense* MGUH 24909 from GGU 424196, MI 5649; **l**: Aff. *Senegalinium dilwynense* MGUH 24910 from GGU 220349, MI 5465.

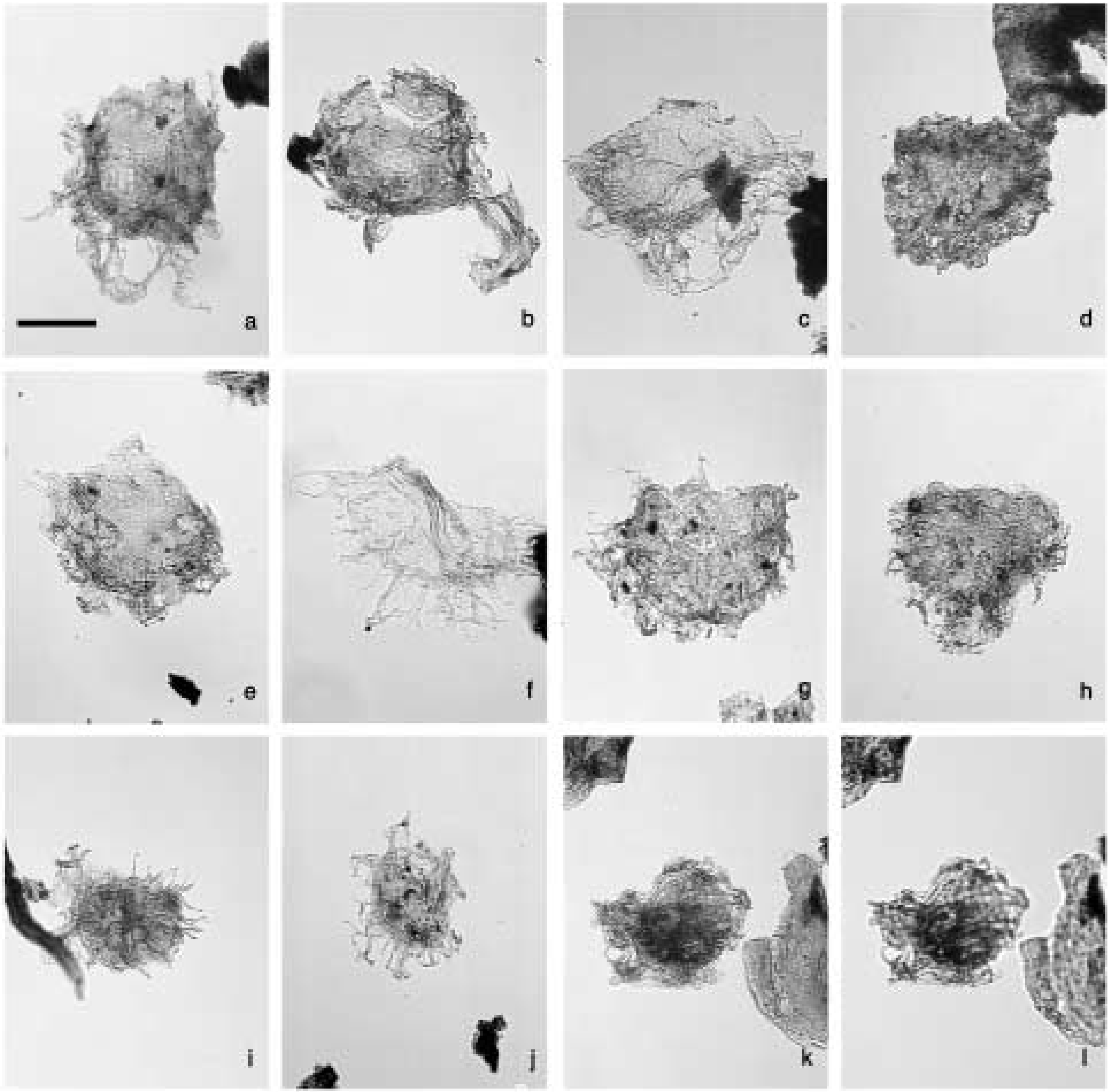


Fig. 5. *Glaphyrocysta*, *Areoligera*. Scale bar is 30 µm; all figures are the same size. **a**: *Glaphyrocysta ordinata* MGUH 24959 from GGU 196274, MI 5182; **b**: *Glaphyrocysta* ?*ordinata* MGUH 24960 from GGU 196271, MI 5615; **c**: *Glaphyrocysta ordinata* MGUH 24961 from GGU 220345, MI 5268; **d**: *Glaphyrocysta* ?*divaricata* MGUH 24962 from GGU 196271, MI 5087; **e**: *Glaphyrocysta* sp. MGUH 24963 from GGU 424206, MI 5651; **f**: *Glaphyrocysta* ?*ordinata* MGUH 24964 from GGU 220346, MI 5848; **g**: *Glaphyrocysta* sp. MGUH 24965 from GGU 220345, MI 5625; **h**: *Glaphyrocysta*/*Areoligera* sp. MGUH 24966 from GGU 424203, MI 5652; **i**: Aff. *Areoligera gippingensis* (small) MGUH 24967 from GGU 196271, MI 5623; **j**: *Spiniferites* sp. MGUH 24968 from GGU 196269, MI 5210; **k**, **l**: *Adnatosphaeridium*/*Nematosphaeropsis*? sp. MGUH 24969 from GGU 424196, MI 5653.

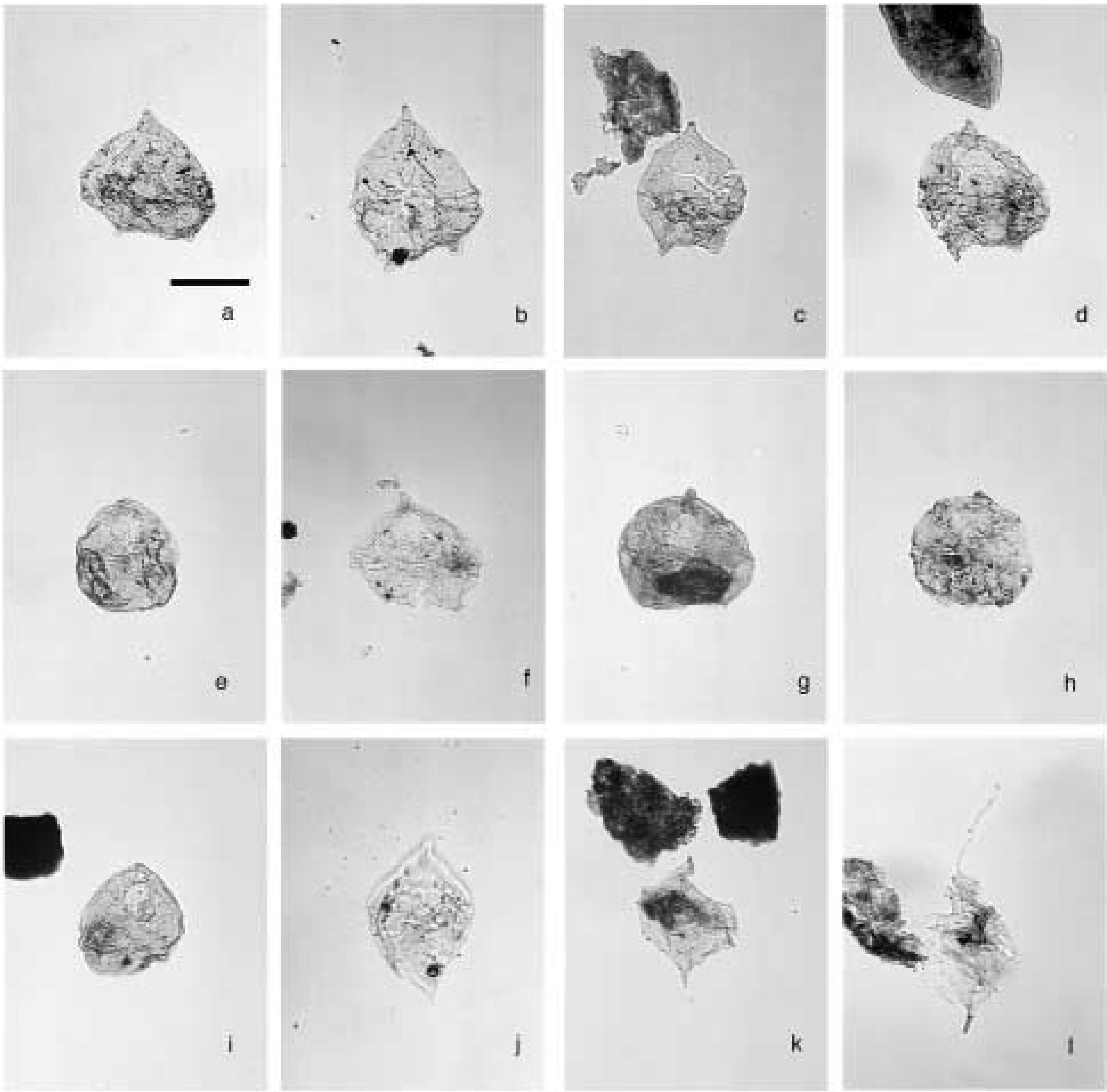


Fig. 6. *Senegalinium* spp. Scale bar is 30 µm; all figures are the same size. **a**: *Senegalinium* ?*microgranulatum* MGUH 24911 from GGU 196274, MI 5186; **b**: *Senegalinium microgranulatum* MGUH 24912 from GGU 196269, MI 5212; **c**: *Senegalinium* sp. MGUH 24913 from GGU 220345, MI 5288; **d**: *Senegalinium* ?*microgranulatum* MGUH 24914 from GGU 424196, MI 5642; **e**: *Senegalinium* sp. (close to *Trithyrodinium evittii* endocyst) MGUH 24915 from GGU 424196, MI 5338; **f**: *Senegalinium* sp. (delicate specimen with well developed paratabulation) MGUH 24916 from GGU 220349, MI 5479; **g**: *Senegalinium obscurum* MGUH 24917 from GGU 424196, MI 5339; **h**: *Senegalinium obscurum* MGUH 24918 from GGU 424195, MI 5346; **i**: ?*Senegalinium obscurum*/*Trithyrodinium evittii*? MGUH 24919 from GGU 424196, MI 5337; **j**: *Laciniadinium arcticum* MGUH 24920 from GGU 220351, MI 5501; **k**: *Laciniadinium arcticum* MGUH 24921 from GGU 196271, MI 5080; **l**: ?*Laciniadinium* sp. (long apical horn) MGUH 24922 from GGU 220349, MI 5633.

Genus *Palaeocystodinium* Alberti 1961

***Palaeocystodinium lidiae* (Górka 1963) Davey 1969**
Fig. 7a, b

Comments. Specimens of *Palaeocystodinium* with the endocoel filled with dark brown organic matter. As noted by Lindgren (1984), this taxon has the same structure between the wall layers as *Trithyrodinium fragile* Davey (1969), i.e. it is broken up into irregular, angular pieces.

Occurrence in the Thyra Ø Formation. Palaeocystodinium lidiae is found in samples from Prinsesse Thyra Ø and from the southern part of Prinsesse Ingeborg Halvø.

Previous occurrences. Górka (1963) originally described this species from the Maastrichtian of Poland and Davey (1969) reported it from sediments of the same age in South Africa. Lindgren (1984) reported it from the Maastrichtian of Sweden and Denmark. Similar, dark specimens are known from Paleocene deposits of the North Sea (G. Mangerud & L. Søyseth, personal communication 1996).

Genus *Senegalinium* Jain & Millepied 1973; emend. Stover & Evitt 1978

***Senegalinium microgranulatum* (Stanley 1965) Stover & Evitt 1978**
Fig. 6a, b, d

Comments. Specimens recorded as *Senegalinium microgranulatum* are very thin walled, with a finely granular endocyst, which gives the cyst a slightly greyish appearance. They have well-defined, small apical and equal or unequal antapical horns and a single-plate intercalary archaeopyle. The paracingulum is indicated by low ridges and an ambital bulge. The endocyst is rarely discernible. Paratabulation is generally better developed than in specimens of *Senegalinium obscurum* recorded in the material. Stanley (1965) mentioned that *Senegalinium microgranulatum* may be synonymous with *Subtilisphaera ventriosa*, and Ioannides (1986) did not exclude the possibility that *Senegalinium obscurum* (and probably *Subtilisphaera ventriosa*) may be conspecific with *Senegalinium microgranulatum*.

Occurence in the Thyra Ø Formation. Senegalinium microgranulatum is found in the southern part of Prinsesse Thyra Ø (GGU 424196) and southern Prinsesse Ingeborg Halvø.

Previous occurrences. Stanley (1965) described this species from a Paleocene sample from South Dakota, USA. Kurita & McIntyre (1995) reported it from the Paleocene of Manitoba, Canada.

***Senegalinium obscurum* (Drugg 1967) Stover & Evitt 1978**
Fig. 6g–i

Comments. Small, sac-like, thin-walled peridinioid cyst with a single-plate I archaeopyle. A small apical horn is often developed, in addition to one or two distinct to poorly developed antapical horns. An endocyst may or may not be discernible. In some specimens the paracingulum is well marked by low ridges resulting in an ambital notch, in others it is hardly visible. Other parts of the paratabulation are rarely expressed. In deformed, non-tabular specimens the single-plate intercalary archaeopyle may be misidentified as a 3I archaeopyle (characteristic of the genus *Trithyrodinium*, especially the smooth, thin-walled *T. evittii*, specimens of which are often found as isolated endocysts). In specimens of *S. obscurum* where the endocyst is not visible, it may be difficult to tell the two cyst genera apart, but usually the narrower (single plate) archaeopyle will identify the *Senegalinium*.

Occurrence in the Thyra Ø Formation. Senegalinium obscurum is the most common and consistently occurring dinoflagellate cyst taxon in the material studied.

Previous occurrences. Drugg (1967) described the species from the Maastrichtian–Paleocene of California, USA; he reported it to be abundant in the Danian part of the section, while occurring only sporadically in what he interpreted as being of Maastrichtian age. Kurita & McIntyre (1995) reported it from the Lower Paleocene of Manitoba, Canada.

Genus *Spinidinium* Cookson & Eisenack 1962; emend. Lentin & Williams 1976

Comments. There is much confusion in the literature concerning what characters to rely on and accept for

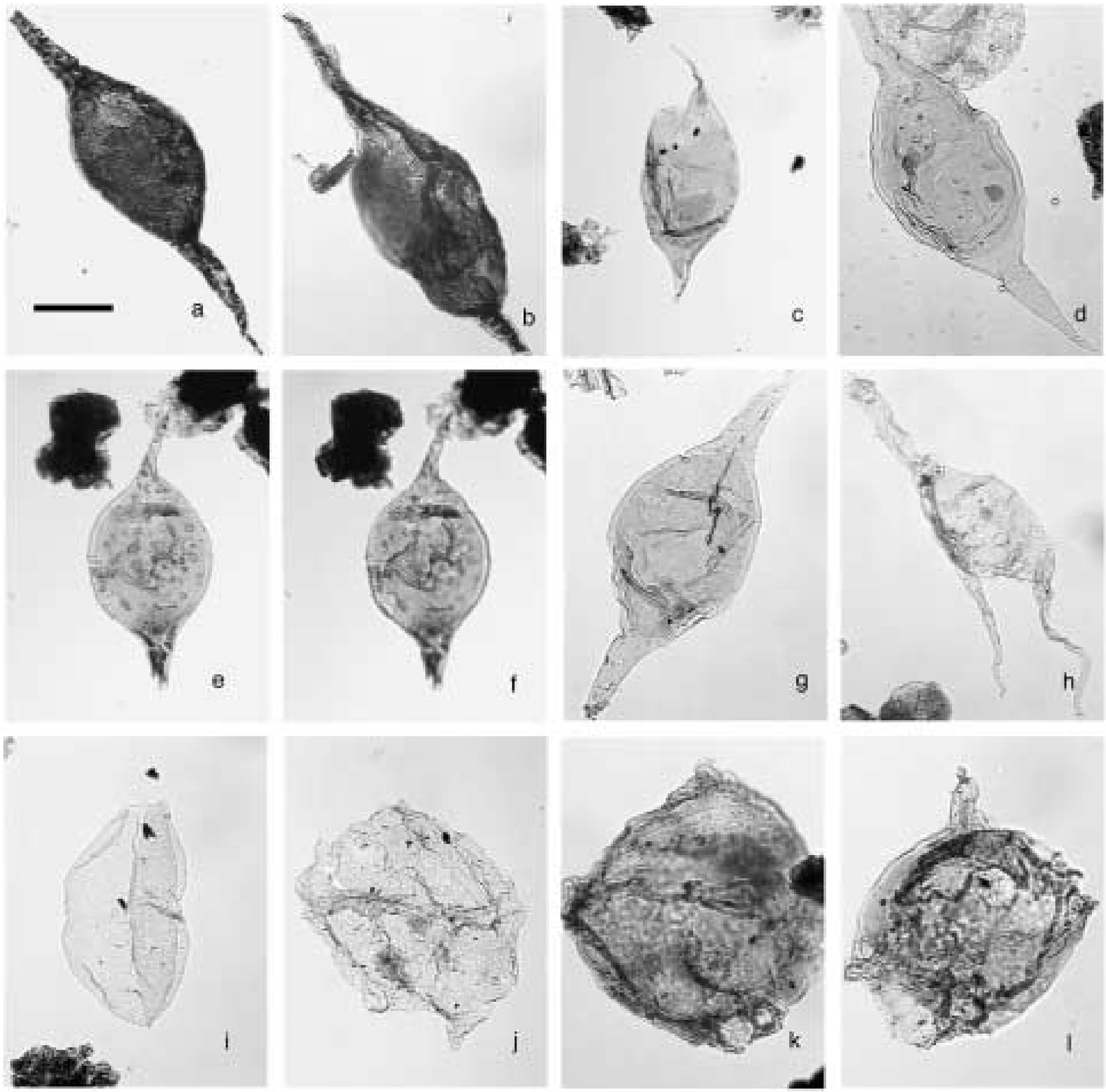


Fig. 7. *Palaeocystodinium* spp. Scale bar is 30 µm; all figures are the same size. **a**: *Palaeocystodinium lidiae* MGUH 24948 from GGU 196274, MI 5622; **b**: *Palaeocystodinium lidiae* MGUH 24949 from GGU 220351, MI 5539; **c**: *Palaeocystodinium* ?*bulliforme* MGUH 24950 from GGU 220345, MI 5294; **d**: *Palaeocystodinium* ?*australinum* MGUH 24951 from GGU 220351, MI 5527; **e**, **f**: *Palaeocystodinium* ?*bulliforme* (with initial '*P. lidiae*-like' charcoal-like structure in antapical horn) MGUH 24952 from GGU 220345, MI 5295; **g**: *Palaeocystodinium* ?*australinum* MGUH 24953 from GGU 220349, MI 5001; **h**: *Odontochitina operculata* MGUH 24954 from GGU 256621, MI 5640; **i**: *Fromea fragilis* MGUH 24955 from GGU 220349, MI 5632; **j**: *Palaeoperidinium pyrophorum* MGUH 24956 from GGU 220349, MI 5630; **k**: *Spongodinium delitiense* MGUH 24957 from GGU 220347, MI 5849; **l**: *Spongodinium delitiense* MGUH 24958 from GGU 220347, MI 5850.

each species within the *S. densispinatum – S. echinoideum – S. microceratum* – ?*S. pilatum* – ?*S. clavus – S. essoi* group of cysts (*S. essoi* has as yet only been reported from the southern hemisphere). A revision is needed, as in several cases the same character is said to be specific for several species. Furthermore, poor preservation of the present material renders identification to the species level somewhat uncertain. Here, the following criteria have been used to distinguish between the members of the group: size and development of the horns, distribution of the spines, and the size and form of spines.

?*Spinidinium pilatum* (Stanley 1965) Costa & Downie 1979

Fig. 8d–f, l

Comments. Specimens assigned to this taxon are elongate (approximately 60 µm long and 30–35 µm wide) with a moderately sparse cover of 2–3 µm long, robust, capitate spines. The distribution of the spines is uncertain due to poor preservation, but is nontabular as well as penitabular. The antapical horns are unequally developed, the left horn being markedly longer than the very reduced right one. The apical horn is 5–8 µm long, box-shaped, slightly tapering and concave at the tip, which bears a few spines.

Occurrence in the Thyra Ø Formation. ?*Spinidinium pilatum* occurs in most of the sections studied. The best preserved specimens are found in samples from the southern part of Prinsesse Ingeborg Halvø.

Previous occurrences. Stanley (1965) described this species from the Paleocene of South Dakota, USA, Benson (1976) reported rare specimens from Maryland, USA, and Kurita & McIntyre (1995) reported it from Paleocene deposits of Manitoba, Canada. The specimens illustrated by Kurita & McIntyre (1995, plate 2, figs 9, 10) bear penitabular spines only, a character which, according to the original description, is more characteristic of ?*Spinidinium clavus*.

Spinidinium sagittula (Drugg 1970) Lentin & Williams 1976

Fig. 8a–c

Comments. A large, extremely thin-walled species with paratabulation indicated by penitabular echinae.

Occurrence in the Thyra Ø Formation. The species is only found in the southern part of Prinsesse Ingeborg Halvø where it is rare.

Previous occurrences. Spinidinium sagittula was described by Drugg (1970) from Lower Eocene sediments of the American Gulf Coast.

Genus *Spongodinium* Deflandre 1936; emend. Stover & Evitt 1978; emend. Lucas-Clark 1987

Spongodinium delitiense (Ehrenberg, 1838) Deflandre 1936; emend. Lucas-Clark 1987

Fig. 7k, l

Comments. This species is very large, 110–120 µm long and 105–110 µm wide. It is thick walled, irregularly shaped with a large precingular archaeopyle. An apical horn, antapical and paracingular flanges are developed to a variable extent. The cyst wall is never as delicately spongy as seen in the specimens illustrated by Lucas-Clark (1987) and Ioannides (1986), but loose opercula seen in the preparations resemble those illustrated by Ioannides (1986) in shape and degree of sponginess.

Occurrences in the Thyra Ø Formation. This species occurs in samples from Prinsesse Thyra Ø, Prinsesse Dagmar Ø and southern Prinsesse Ingeborg Halvø.

Previous occurrences. Lucas-Clark (1987) reported *Spongodinium delitiense* in deposits of Late Campanian age in Montana, USA, in Maastrichtian sediments of the Arctic Ocean and in Paleocene deposits of New Jersey, USA. McIntyre (1974) reported the species from Santonian to Maastrichtian deposits from the Canadian Arctic, and has seen it in abundance in Maastrichtian deposits of southern Manitoba, Canada (D.J. McIntyre, personal communication 1997). Ioannides (1986) reported *Spongodinium delitiense* from Santonian to Paleocene sediments from the Canadian Arctic. Morgenroth (1968) reported the species from Danian deposits of Northern Europe. It occurs in abundance in a thin Early Paleocene interval on Nuussuaq, West Greenland (Nøhr-Hansen & Dam 1997).

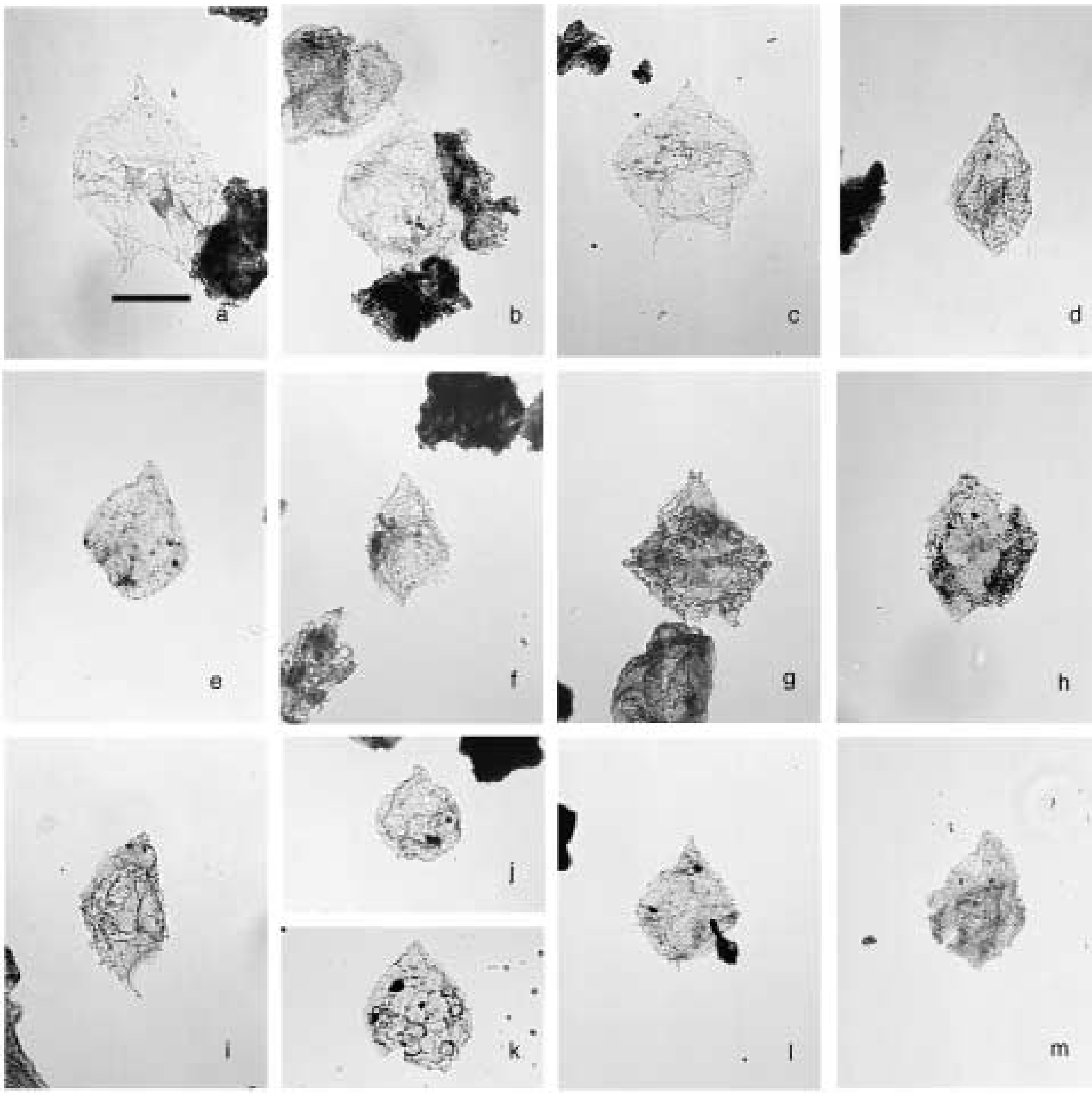


Fig. 8. *Spinidinium* spp. Scale bar is 30 µm; all figures are the same size. **a**: *Spinidinium sagittula* MGUH 24923 from GGU 220349, MI 5467; **b**: *Spinidinium sagittula* MGUH 24924 from GGU 220349, MI 5468; **c**: *Spinidinium* ?*sagittula* MGUH 24925 from GGU 220345, MI 5280; **d**: ?*Spinidinium pilatum* MGUH 24926 from GGU 220345, MI 5843; **e**: ?*Spinidinium pilatum* MGUH 24927 from GGU 424205, MI 5841; **f**: ?*Spinidinium pilatum* MGUH 24928 from GGU 220345, MI 5842; **g**: *Spinidinium* sp. MGUH 24929 from GGU 424196, MI 5654; **h**: ?*Spinidinium* sp. MGUH 24930 from GGU 424196, MI 5648; **i**: *Spinidinium* ?*essoi* MGUH 24931 from GGU 424206, MI 5847; **j**: *Spinidinium* sp. MGUH 24932 from GGU 424202, MI 5845; **k**: *Spinidinium* ?*clavus* MGUH 24933 from GGU 424206, MI 5846; **l**: ?*Spinidinium pilatum* MGUH 24934 from GGU 196271, MI 5081; **m**: *Spinidinium* ?*densispinatum* MGUH 24935 from GGU 196271, MI 5079.

Genus *Trithyrodinium* Drugg 1967

Trithyrodinium evittii Drugg 1967

Fig. 9a–c

Comments. Species with a delicate periphragm with pointed, broad-based horns, and a slightly more robust, granular, rounded endocyst. The species is often found as isolated endocysts due to the fragile nature of the periphragm. Length of complete specimens 65–100 µm, width 50–90 µm, i.e. rather variable. Paraplates 1a and 3a are often seen to be fused in the midline anterior to plate 2a, as noted by Benson (1976, p. 197). This feature was neither shown by Drugg (1967, plate 9, fig. 2) nor Evitt (1985, p. 131) in their schematic representations of the *Trithyrodinium* archaeopyle.

Some specimens from the southern part of Prinsesse Thyra Ø have more thick-walled endocysts than usual, like the specimen described by Drugg, (1967, plate 3, fig. 3), as 'heavily encysted'.

Occurrence in the Thyra Ø Formation. Trithyrodinium evittii is common in samples from the southern part of Prinsesse Thyra Ø (e.g. GGU 424196) and from southern Prinsesse Ingeborg Halvø.

Previous occurrences. This species was originally described by Drugg (1967) from Danian deposits of California, and it has been reported from many Late Cretaceous – Early Paleocene sections (e.g. Benson 1976; Kurita & McIntyre 1995).

Trithyrodinium fragile Davey 1969

Fig. 9g–i

Comments. This species has a thick-walled, ovoidal, nearly opaque endocyst and a very thin periphragm produced into short, box-like apical and antapical horns. The endocyst is dark brown and cracked in the few recorded specimens. The 3I archaeopyle, when discernible, is large.

In a large (90 µm) and a smaller (60 µm) partially broken down specimen, irregular scales of semi-opaque brown material seems to adhere to the otherwise translucent endocysts. This observation seems to support Davey's (1969) suggestion that the wall of the endocyst is two-layered, an observation which was contested by Lindgren (1984). Similar cysts have been recognised by Nøhr-Hansen & Dam (1997) in lowermost Paleocene sediments from West Greenland. The degradation of the semi-opaque layer may be due either to natural processes or to the chemical processing of the samples.

Occurrence in the Thyra Ø Formation. This species occurs in Prinsesse Dagmar Ø, the southern part of Prinsesse Thyra Ø and in a single sample from southern Prinsesse Ingeborg Halvø.

Previous occurrences. Trithyrodinium fragile was originally described by Davey (1969) from Maastrichtian–?Danian sediments of South Africa. Lindgren (1984) has recorded it from the Maastrichtian of Scania, southern Sweden.

Trithyrodinium sp.

Fig. 9d–f

Comments. This rather inconspicuous species is smaller and more diffuse than *Trithyrodinium fragile*. It has a brownish endocyst and a thin pericyst, which may be essentially shapeless or relatively well defined, with small apical and antapical protrusions. The 3I archaeopyle, when discernible, is narrower than usual for the genus.

Occurrence in the Thyra Ø Formation. This species occurs in samples from Prinsesse Dagmar Ø, the southern part of Prinsesse Thyra Ø and Prinsesse Ingeborg Halvø.

Spores and pollen

Genus *Caryapollenites* Raatz & Potonié 1960; emend. Krutzch 1961

Caryapollenites sp.

Fig. 11i, k, l

Comments. Relatively large, almost featureless, rounded, ?oblate grains, a few possibly with indications of three simple pores on the same hemisphere. In a few grains, a slight thinning of the polar area is suggested.

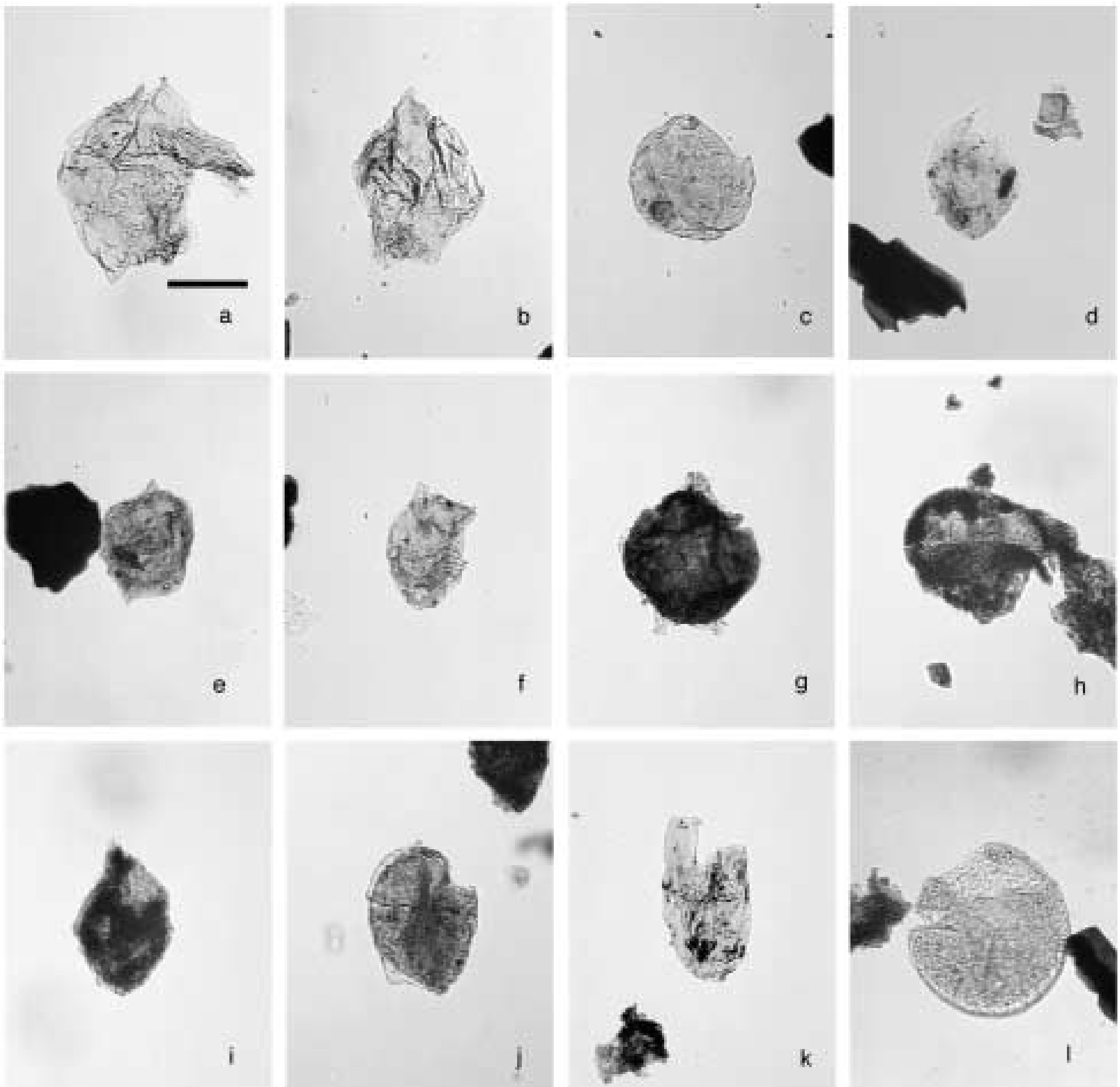


Fig. 9. *Trithyrodinium* spp. Scale bar is 30 µm; all figures are the same size. **a**: *Trithyrodinium evittii* MGUH 24936 from GGU 424196, MI 5643; **b**: *Trithyrodinium evittii* MGUH 24937 from GGU 424199, MI 5650; **c**: *Trithyrodinium evittii* (endocyst) MGUH 24938 from GGU 424196, MI 5334; **d**: *Trithyrodinium* sp. MGUH 24939 from GGU 220345, MI 5253; **e**: *Trithyrodinium* sp. MGUH 24940 from GGU, MI 5621; **f**: *Trithyrodinium* sp. MGUH 24941 from GGU 196271, MI 5155; **g**: *Trithyrodinium fragile* MGUH 24942 from GGU 196274, MI 5178; **h**: *Trithyrodinium fragile* MGUH 24943 from GGU 424196, MI 5647; **i**: *Trithyrodinium fragile* MGUH 24944 from GGU 424196, MI 5644; **j**: *Trithyrodinium* aff. *fragile* MGUH 24945 from GGU 424206, MI 5851; **k**: *Trithyrodinium* sp. MGUH 24946 from GGU 196269, MI 5886; **l**: *Trithyrodinium suspectum* MGUH 24947 from GGU 220351, MI 5571.

Occurrence in the Thyra Ø Formation. Rare in samples from southern Prinsesse Ingeborg Halvø.

Genus *Extratriporopollenites* Pflug 1953; emend. Skarby 1968

Extratriporopollenites sp.

Fig. 11b

Comments. This species is oblate, slightly rounded triangular in ambitus, with open pore invaginations and a diameter of 35–40 µm. It resembles *Extratriporopollenites* sp. 2 of McIntyre (1974) in overall appearance and size, but has less pronounced sculptural elements. The species also has some morphological affinity with *Trudopollis rotundus* of Manum (1962, plate XII, fig. 30) and the *Momipites* group, especially *Momipites wyomingensis* of Nichols & Ott (1978), but is considerably larger than the illustrated specimens. Nichols & Ott (1978), on the other hand, mention that their specimens are smaller than the very similar *Momipites coryloides* described by Wodehouse (1933) from the Eocene Green River Shale. *Momipites* sp. 2 of Gregory & Hart (1995) from Paleocene sediments of Louisiana resembles *Extratriporopollenites* sp. in outline and size (45 µm) but seems to be less sculptured.

Occurrence in the Thyra Ø Formation. Southern part of Prinsesse Ingeborg Halvø.

Genus *Hazaria* Srivastava 1971

Hazaria sheopiariae Srivastava 1971

Fig. 12a

Comments. Thick-walled monolete spore with an echino-foveolate appearance due to its tectate wall.

Occurrence in the Thyra Ø Formation. The species is practically confined to the samples from the southern part of Prinsesse Ingeborg Halvø, and is common in GGU 220351.

Previous occurrences. Srivastava (1971) described the species from Maastrichtian deposits of Alberta, Canada. Jerzykiewicz & Sweet (1986) reported it as spanning the Maastrichtian–Paleocene boundary in Alberta, Canada, and McIntyre (1994) reported it from the Paleocene of the Canadian Arctic Archipelago. D.J. McIntyre (personal communication 1997) has not seen the taxon in material older than the Early Campanian.

Genus *Myricipites* Wodehouse 1933

Myricipites speciosus Manum 1962

Fig. 11a, d

Comments. Scabrate, triporate pollen, oblate with a rounded triangular ambitus and slightly protruding pore areas with annular thickenings situated at the corners of the triangle. Equatorial diameter approximately 30 µm.

Occurrence in the Thyra Ø Formation. This species is never common, but occurs more commonly in the southern part of Prinsesse Ingeborg Halvø than further north.

Previous occurrences. Manum (1962) described the species from Palaeogene deposits of Spitsbergen, but several records of this (or very similar) species exist in the literature. Samoilovitch (1967) and Bratzeva (1967) both illustrated similar specimens as *Comptonia sibirica* and *Comptonia* sp. from Upper Senonian to Danian, and Paleocene–Eocene deposits of Siberia. Stanley (1965) erected the new species *Carpinus subtriangula* for similar pollen, allegedly without annular thickenings in the pore areas, even though those seem to be present on his illustrations. Russell & Singh (1978) reported *Carpinus subtriangula* as characterising (together with *Wodehouseia fimbriata* and *Alnus trina*, and without *Aquilapollenites* spp.) the Paleocene interval in Alberta, Canada. Hjortkjær (1991) recorded rather similar forms as *Triatriopollenites bituitus* and *Triporopollenites* sp. 1 from the Paleocene deposits of Disko and Nuussuaq, West Greenland. Kalkreuth *et al.* (1993, 1996) reported similar triporate pollen as *Triporopollenites mullensis* from the Paleocene – Early Eocene of Arctic Canada and Jerzykiewicz & Sweet (1986, plate 3, fig. 3) illustrated a similar type as 'Betulaceae–Myricaceae pollen' and reported it to span the Cretaceous–Tertiary boundary in Alberta, Canada.

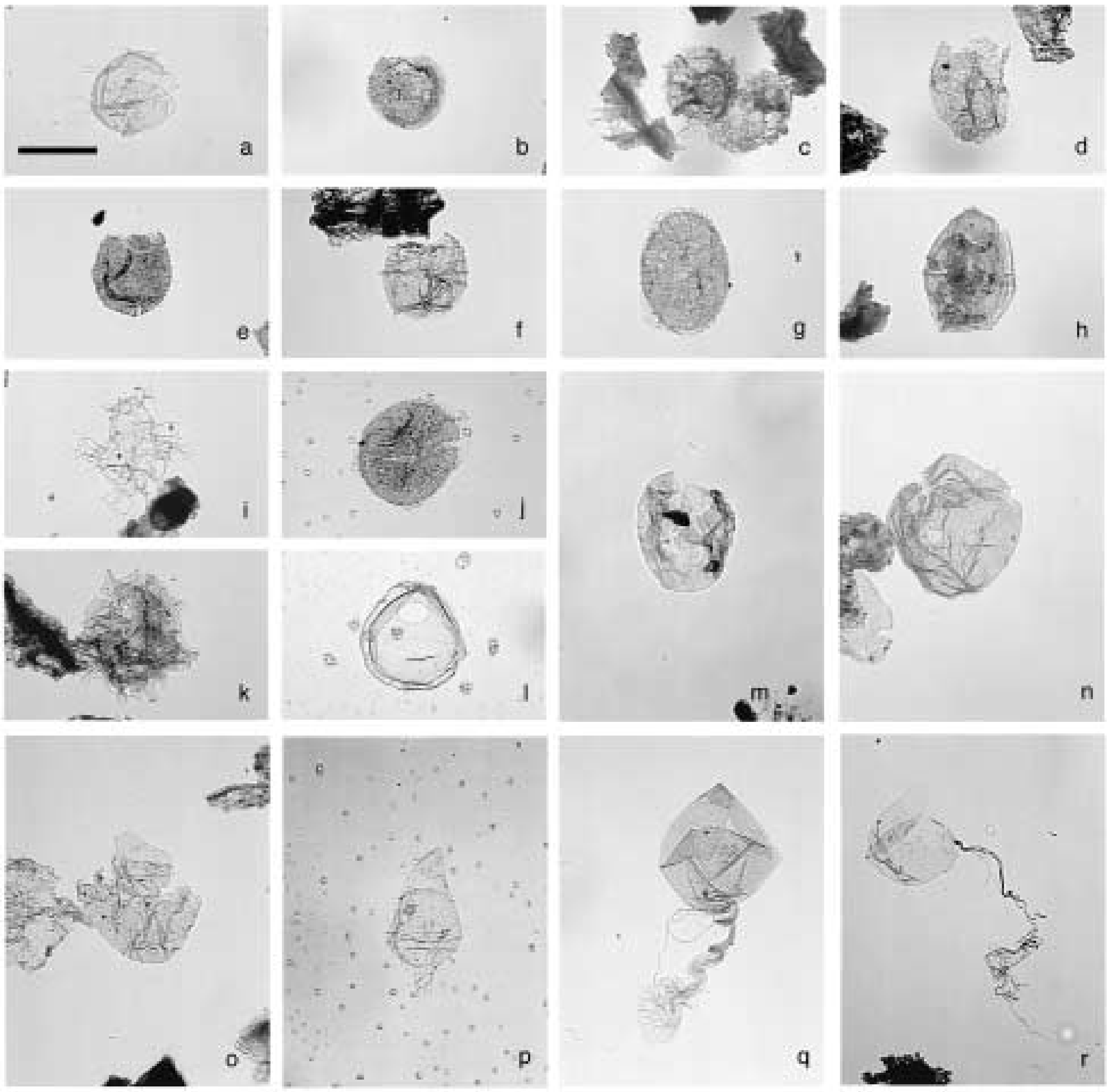


Fig. 10. Miscellaneous dinoflagellate cysts. Scale bar is 30 µm; all figures are the same size. **a**: ?*Trithyrodinium* sp. MGUH 24970 from GGU 220345, MI 5254; **b**: *Kallosphaeridium helbyi* MGUH 24971 from GGU 220349, MI 5018; **c**: ?*Microdinium* sp. MGUH 24972 from GGU 220345, MI 5281; **d**: *Membranosphaera* sp. of Drugg (1967) MGUH 24973 from GGU 220345, MI 5424; **e**: ?*Cerebrocysta* sp. MGUH 24974 from GGU 220345, MI 5258; **f**: *Microdinium ornatum* MGUH 24975 from GGU 220349, MI 5463; **g**: Dinoflagellate Type D of Ioannides (1986) MGUH 24976 from GGU 220351, MI 5546; **h**: *Microdinium ornatum* MGUH 24977 from GGU 220351, MI 5587; **i**: Aff. *Quadrina pallida* MGUH 24978 from GGU 220345, MI 5260; **j**: Dinoflagellate Type D of Ioannides 1986 MGUH 24979 from GGU 220351, MI 5556; **k**: *Pterodinium* sp. MGUH 24980 from GGU 220345, MI 5286; **l**: *Paralecaniella indentata* MGUH 24981 from GGU 220346, MI 5627; **m**: Smooth proximate sp. MGUH 24982 from GGU 220349, MI 5472; **n**: ?*Escharisphaeridia* sp. MGUH 24983 from GGU 220349, MI 5464; **o**: ?*Escharisphaeridia* sp. MGUH 24984 from GGU 220349, MI 5259; **p**: *Palaeohystrichophora infusorioides* MGUH 24985 from GGU 220351, MI 5505; **q**: *Desmocysta plekta* MGUH 24986 from GGU 220346, MI 5857; **r**: *Desmocysta plekta* MGUH 24987 from GGU 220345, MI 5287.

Genus *Trivestibulopollenites* Pflug 1953

Trivestibulopollenites betuloides **Pflug 1953**
Fig. 11c

Comments. Triangular, triporate pollen with protruding pore areas. The pollen wall is smooth and hyaline.

Occurrence in the Thyra Ø Formation. This species is very rare in samples from northern Prinsesse Thyra Ø (GGU 420963) and in the southern part of Prinsesse Ingeborg Halvø (GGU 220345).

Previous occurrences. Similar pollen were reported by Lund (1989) from deposits of Late Paleocene age from the Faeroe Islands and by Hjortkjær (1991) from mid-Paleocene sediments of West Greenland. The species recorded as *Triporopollenites* sp. 1 (cf. *Betula*) by McIntyre (1974, plate 22, fig. 13) from the Campanian and Maastrichtian of the Canadian Arctic appears very similar, and it may be wiser to see it as a general type simply implying a Late Cretaceous or younger age.

Genus *Trudopollis* Pflug 1953

Trudopollis **sp.**
Fig. 11f

Occurrences in the Thyra Ø Formation. A few representatives of this genus were found in samples from the southern part of Prinsesse Thyra Ø and Prinsesse Dagmar Ø.

Previous occurrences. Manum (1962, p. 92) reported the very common occurrence of *Trudopollis* spp. in material from Spitsbergen. He stated the stratigraphical range of this group of pollen to be Late Cretaceous to Middle Eocene.

Triprojectacites Group (*Aquilapollenites sensu lato*)

Comments. This characteristic group, consisting of the genera *Aquilapollenites*, *Mancicorpus*, *Integricorpus*, and *Pseudointegricorpus* is a conspicuous constituent of the Thyra Ø Formation microflora. Members of the group are never numerically prominent in the samples, but commonly occur in numbers from 2 to 10 specimens per slide. Preservation is somewhat variable, but a general trait is that the original features of the grains are blurred, a fact which mostly hampers determination to the species level. Preservation is immensely better, however, than the charred material reported by Batten (1982) from the Kap Washington Group of volcanics further to the north-west in Greenland, and the characteristic outline of the grains allows a tentative determination. This pollen group is characteristic of Upper Campanian to Maastrichtian deposits, consequently, specimens occurring in the Thyra Ø Formation are considered to be reworked from deposits of this age.

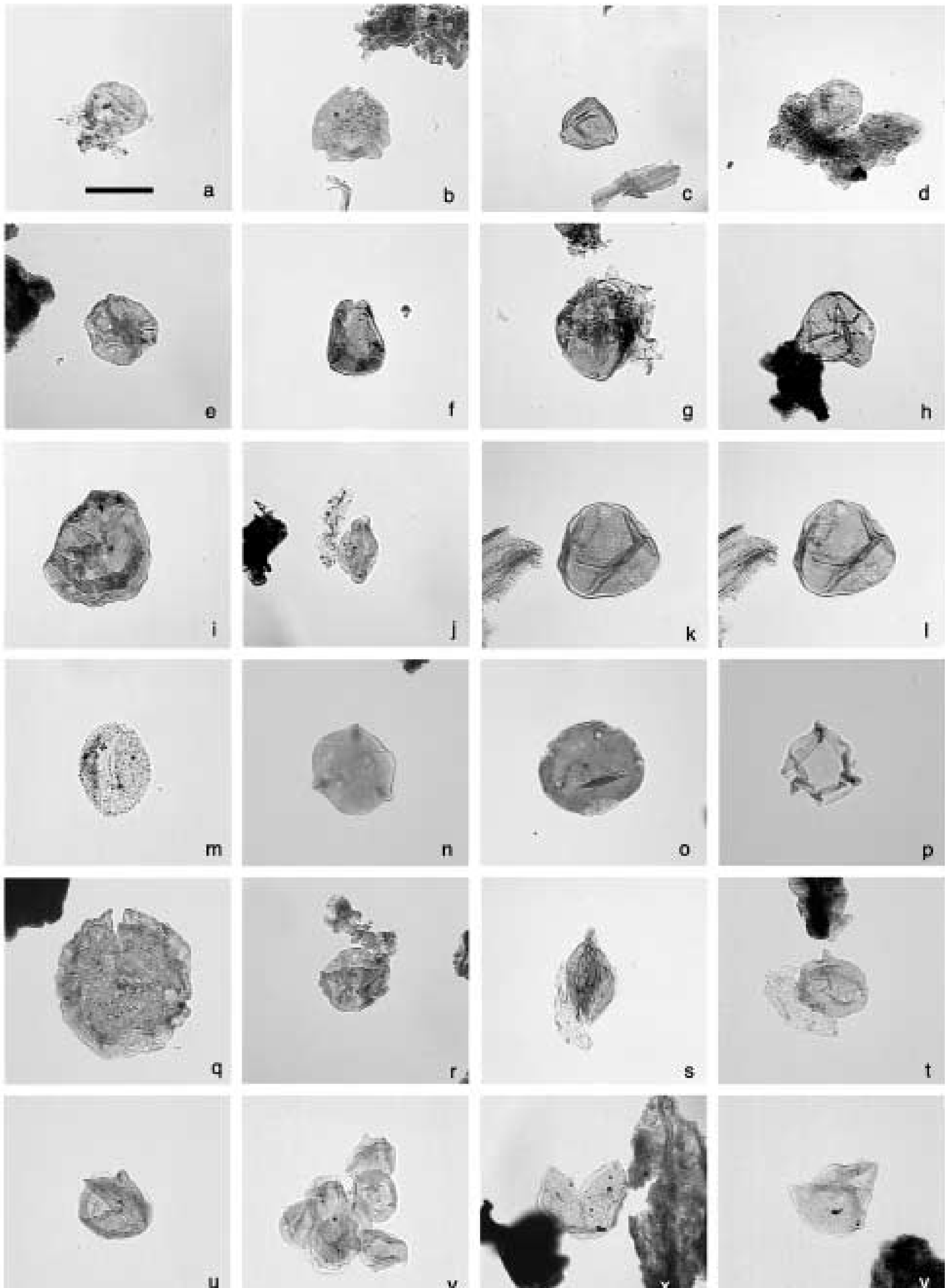
Genus *Aquilapollenites* Rouse 1957; emend. Funkhouser 1961

Aquilapollenites conatus **Norton 1965**
Fig. 13f

Occurrence in Thyra Ø Formation. Prinsesse Dagmar Ø as a single broken specimen in GGU 256621.

Previous occurrences. Sweet (1986) ascribes it to his

Fig. 11. Pollen. Scale bar is 30 μm; all figures are the same size. **a**: *Myricipites speciosus* MGUH 25000 from GGU 220345, MI 5293; **b**: *Extratriporopollenites* sp. MGUH 25001 from GGU 220345, MI 5292; **c**: *Trivestibulopollenites betuloides* MGUH 25002 from GGU 220345, MI 5660; **d**: *Myricipites speciosus* MGUH 25003 from GGU 196274, MI 5662; **e**: Porate sp. MGUH 25004 GGU 220345, MI 5658; **f**: *Trudopollis* sp. MGUH 25005 from GGU 196269, MI 5883; **g**: ?*Rugubivesiculites* sp. MGUH 25006 from GGU 220345, MI 5257; **h**: ?*Triporopollenites* sp. MGUH 25007 from GGU 196268, MI 5060; **i**: ?*Caryapollenites* sp. MGUH 25008 from GGU 424203, MI 5316; **j**: Aff. *Tricolporopollenites villensis* MGUH 25009 from GGU 220345, MI 5661; **k**, **l**: *Caryapollenites* sp. MGUH 25010 from GGU 424199, MI 5663; **m**: ?*Ilexpollenites* sp. MGUH 25011 from GGU 220351, MI 5873; **n**: *Kurzipites trispissatus* MGUH 25012 from GGU 220351, MI 5879; **o**: *Caryapollenites* sp. MGUH 25013 from GGU 256621, MI 5681; **p**: *Alnipollenites* sp. MGUH 25014 from GGU 220351, MI 5872; **q**: *Inaperturopollenites magnus* MGUH 25015 from GGU 196271, MI 5074; **r**: *Triporopollenites* sp. MGUH 25016 from GGU 220345, MI 5657; **s**: *Metasequoia papillapollenites* MGUH 25017 from GGU 220349, MI 4988; **t**: *Sequoiapollenites* sp. MGUH 25018 from GGU 220351, MI 5875; **u**: *Taxodiaceaepollenites* sp. MGUH 25019 from GGU 220351, MI 5876; **v**: *Sequoiapollenites* spp. MGUH 25020 from GGU 220351, MI 5874; **x**: *Taxodiaceaepollenites hiatus* MGUH 25021 from GGU 220351, MI 5877; **y**: *Taxodiaceaepollenites hiatus* MGUH 25022 from GGU 220351, MI 5878.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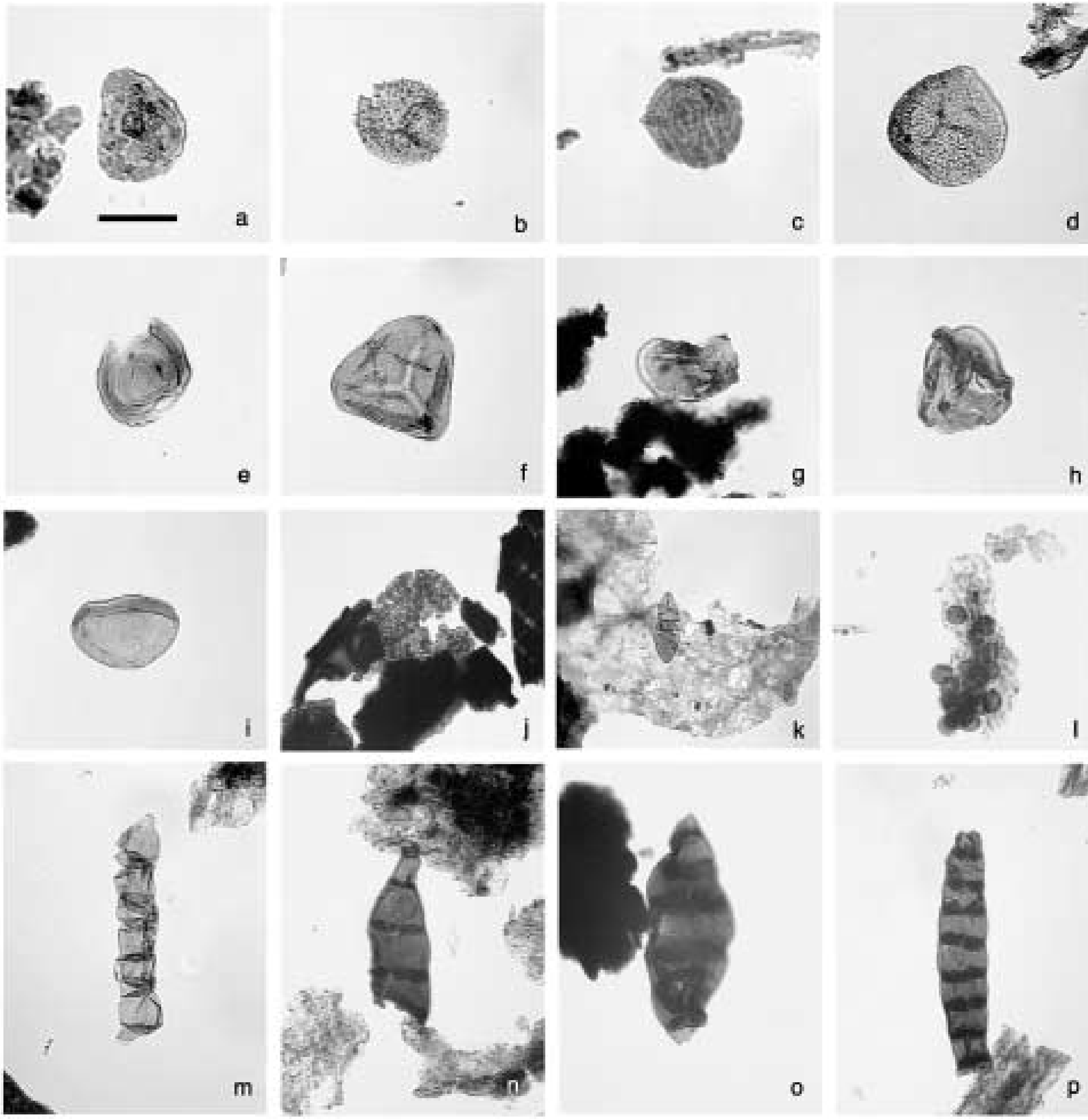

Fig. 12. Spores, fungal palynomorphs. Scale bar is 30 µm; all figures are the same size. **a**: *Hazaria sheopiariae* MGUH 25023 from GGU 220345, MI 5882; **b**: ?*Osmundacidites wellmanii* MGUH 25024 from GGU 220349, MI 4996; **c**: *Radialisporis radialis* MGUH 25025 from GGU 220349, MI 4998; **d**: *Osmundacidites* ?*coumauensis* MGUH 25026 from GGU 196268, MI 5059; **e**: Aff. *Chomotriletes minor* MGUH 25027 from GGU 220349, MI 5000; **f**: *Gleicheniidites* sp. MGUH 25028 from GGU 220349, MI 4997; **g**: Mono?colpate, gemmate sp. MGUH 25029 from GGU 196268, MI 5061; **h**: *Triplanosporites* sp. MGUH 25030 from GGU 196268, MI 5063; **i**: *Laevigatosporites* sp. MGUH 25031 from GGU 196268, MI 5067; **j**: *Foveotriletes subtriangularis* MGUH 25032 from GGU 196271, MI 5072; **k**: ?*Dicellaesporites* sp. MGUH 25033 from GGU 220345, MI 5667; **l**: *Inapertisporites* spp. MGUH 25034 from GGU 220345, MI 5668; **m**: *Multicellaesporites* sp. MGUH 25035 from GGU 220345, MI 5669; **n**: ?*Pleuricellaesporites* sp. MGUH 25036 from GGU 220345, MI 5670; **o**: Aff. *Diporicellaesporites reticulatus* MGUH 25037 from GGU 220345, MI 5672; **p**: ?*Pleuricellaesporites* sp. MGUH 25038 from GGU 220345, MI 5671.

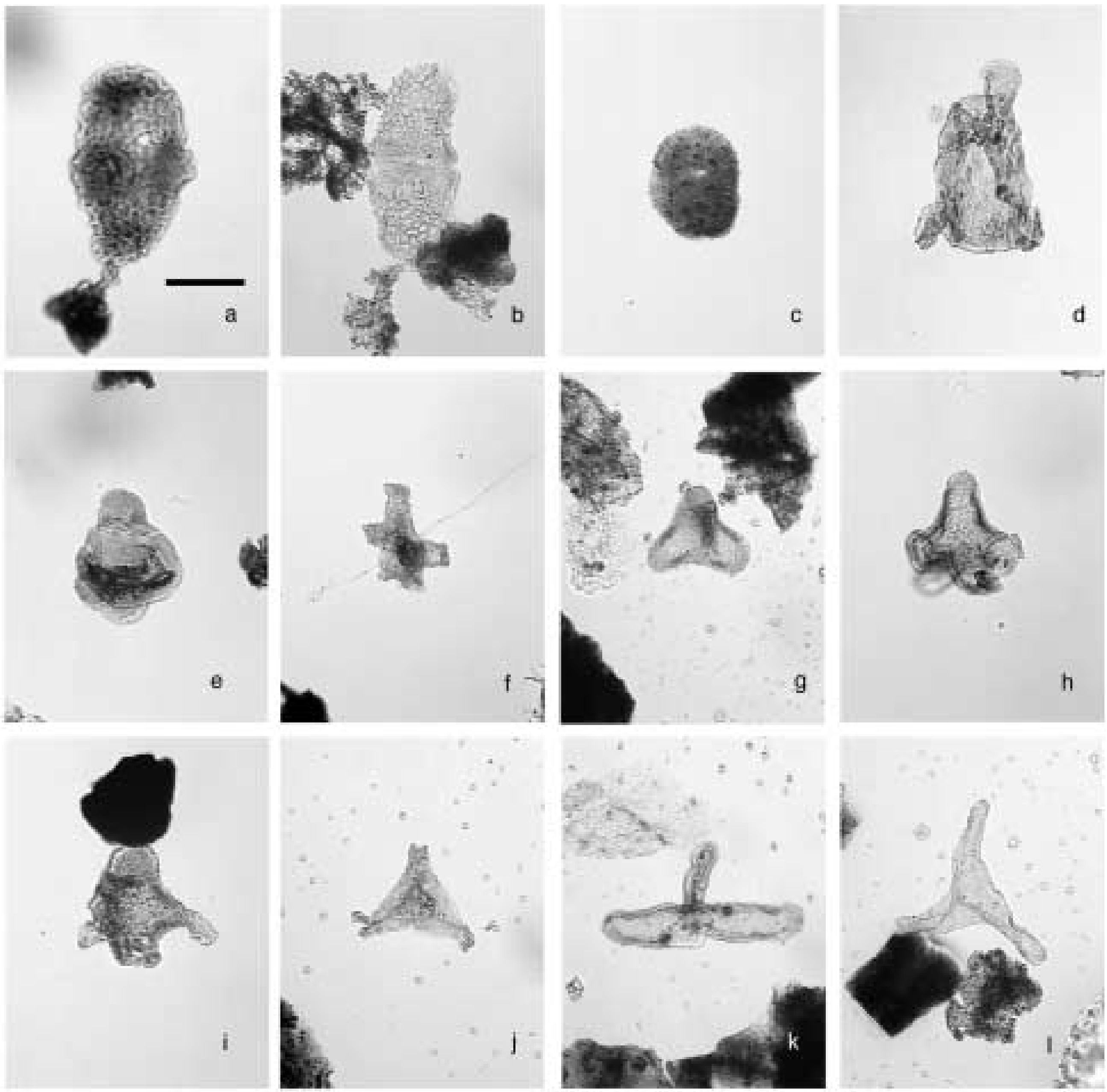

Fig. 13. *Aquilapollenites* spp. (*sensu lato*). Scale bar is 30 µm; all figures are the same size. **a**: *Pseudointegricorpus protrusum* MGUH 24988 from GGU 196274, MI 5620; **b**: *Pseudointegricorpus protrusum* MGUH 24989 from GGU 220347, MI 5459; **c**: *Wodehouseia spinata* MGUH 24990 from GGU 196271, MI 5071; **d**: ?*Grevilloideaepites* sp. MGUH 24991 from GGU 424205, MI 5678; **e**: ?*Grevilloideaepites* sp. MGUH 24992 from GGU 220347, MI 5461; **f**: *Aquilapollenites conatus* MGUH 24993 from GGU 256621, MI 5682; **g**: *Mancicorpus* sp. MGUH 24994 from GGU 220351, MI 5683; **h**: *Aquilapollenites* sp. MGUH 24995 from GGU 220347, MI 5460; **i**: *Aquilapollenites* ?*sentus* MGUH 24996 from GGU 424205, MI 5679; **j**: *Mancicorpus* ?*notabile* (polar view) MGUH 24997 from GGU 220351, MI 5685; **k**: *Mancicorpus notabile* MGUH 24998 from GGU 220351, MI 5684; **l**: *Mancicorpus notabile* MGUH 24999 from GGU 220351, MI 5687.

latest Maastrichtian *Wodehouseia spinata* assemblage. The species has been recorded from many localities in western Canada.

Genus *Mancicorpus* Mtchedlishvili 1961, emend. Srivastava 1968

Mancicorpus notabile Mtchedlishvili 1961
Fig. 13j–l

Comments. This is a large, smooth, thin-walled member of the genus, with three well-defined projections and triangular in polar view.

Occurrence in the Thyra Ø Formation. The species is a very conspicuous and common element in GGU 220351 from the southern part of Prinsesse Ingeborg Halvø.

Previous occurrences. Mtchedlishvili (1961) described the species from Upper Cretaceous deposits of western Siberia. Batten (1981) reported it from sediments of Late Campanian age from the northern North Sea and McIntyre (1974) reported it from the Maastrichtian of Arctic Canada.

Genus *Pseudointegricorpus* Takahashi & Shimono 1982

Pseudointegricorpus protrusum Takahashi & Shimono (Samoilovitch 1967)
Fig. 13a, b

Comments. Most recorded specimens of this characteristic taxon are dark brown, a few are light yellow.

Occurrences in the Thyra Ø Formation. Rare, dark brown specimens occur on southern Prinsesse Ingeborg Halvø and southern Prinsesse Thyra Ø. In GGU 420963 from northern Prinsesse Thyra Ø, a couple of well-preserved, yellow specimens were found.

Previous occurrences. Samoilovitch (1967) originally described the species as *Integricorpus* sp. 1 from Siberia. McIntyre (1974) reported it from the Maastrichtian of the Horton River section, Canada as *Integricorpus* sp., referring to Samoilovitch (1967). He also recorded the species from the Canadian Arctic Islands (McIntyre 1994). Nøhr-Hansen (1996) reported *Pseudointegricorpus protrusum* from West Greenland from his Late Maastrichtian *Wodehouseia spinata* zone.

Genus *Wodehouseia* Stanley 1961

Wodehouseia spinata Stanley 1961
Fig. 13c

Comments. Specimens of this characteristic oculate angiospermous taxon are all dark brown, and the features are somewhat blurred due to chemical or physical degradation.

Occurrence in Thyra Ø Formation. The species was found sporadically in samples from Prinsesse Thyra Ø and Prinsesse Dagmar Ø, but in only one sample were more than two specimens recorded.

Previous occurrences. This species is a well established Maastrichtian marker, but is known also from the latest Campanian. It was originally described by Stanley (1961) from South Dakota. Later, it has been reported by numerous other authors from Late Maastrichtian sections in North America, (e.g. Norton & Hall 1967; Evitt 1973; Sweet *et al.* 1990; Nichols & Brown 1992). McIntyre (1974) reported it from Arctic Canada, Batten (1981) from Maastrichtian strata from west of the Shetland Islands. Croxton (1980) and Nøhr-Hansen (1994b, 1996) reported *Wodehouseia spinata* from the Maastrichtian of West Greenland. Nøhr-Hansen (1994a) also reported a few, probably reworked specimens from sediments in West Greenland dated as Paleocene.

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References

Batten, D.J. 1981: Stratigraphic, palaeogeographic and evolutionary significance of Late Cretaceous and early Tertiary Normapolles pollen. Review of Palaeobotany and Palynology **35**, 125–137.

Batten, D.J. 1982: Palynology of shales associated with the Kap Washington Group volcanics, central North Greenland. In: Peel, J.S. (ed.): Palaeontology of Greenland: short contributions. Rapport Grønlands Geologiske Undersøgelse **108**, 15–23.

Benson, D.G. 1976: Dinoflagellate taxonomy and biostratigraphy at the Cretaceous–Tertiary boundary, Round Bay, Maryland. In: Skinner, H.C. (ed.): Tulane Studies in Geology and Paleontology **12**, 169–234.

Bratzeva, G.M. 1967: The problem of the Tsagaiansk Flora with regard to spore-and-pollen analytical data. Review of Palaeobotany and Palynology **2**, 119–126.

Christiansen, F.G., Piasecki, S. & Stemmerik, L. 1991: Petroleum resources, North Greenland. In: Trettin, H.P. (ed.): Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada **3**, 525–529. Ottawa: Geological Survey of Canada (also The geology of North America **E**, Geological Society of America).

Costa, L.I. & Downie, C. 1979: The Wetzeliellaceae; Palaeogene dinoflagellates. Proceedings IV International Palynology Conference, Lucknow **2**, 34–46.

Croxton, C.A. 1980: *Aquilapollenites* from the late Cretaceous – Paleocene (?) of central West Greenland. Rapport Grønlands Geologiske Undersøgelse **101**, 5–27.

Davey, R. J. 1969: Some dinoflagellate cysts from the Upper Cretaceous of Northern Natal, South Africa. Palaeontologia Africana **12**, 1–15.

Day, R.G. 1991: An overview of fossil fungi in the Geodetic Hills Fossil Forest, Axel Heiberg Island, N. W. T. In: Christie, R.L. & McMillan, N.J. (eds): Tertiary fossil forests of the Geodetic Hills, Axel Heiberg Island, Arctic Archipelago. Geological Survey of Canada Bulletin **403**, 99–121.

Drugg, W.S. 1967: Palynology of the upper Moreno Formation (Late Cretaceous –Paleocene) Escarpado Canyon, California. Palaeontographica Abteilung **B 120**, 1–71.

Drugg, W.S. 1970: Some new genera, species, and combinations of phytoplankton from the Lower Tertiary of the Gulf Coast, U.S.A. Proceedings of the North American Paleontological Convention, Chicago, 1969, Part **G**, 809–843.

Elsik, W.C. 1976: Microscopic fungal remains and Cenozoic palynostratigraphy. Geoscience and Man **15**, 115–120.

Evitt, W.R. 1973: Maastrichtian *Aquilapollenites* in Texas, Maryland and New Jersey. Geoscience and Man **7**, 31–38.

Evitt, W.R. 1985: Sporopollenin dinoflagellate cysts. Their morphology and interpretation, 333 pp. Austin, Texas: American Association of Stratigraphic Palynologists Foundation.

Górka, H. 1963: Coccolithophoridés, dinoflagellés, hystrichosphaeridés et microfossiles incertae sedis du Crétacé supérieur de Pologne. Acta Palaeontologica Polonica **8**, 1–83.

Gregory, W.A. & Hart, G.F. 1995: Distribution of pollen and spores in a subsurface marine Wilcox (Paleocene–Eocene) section in southwest Louisiana. Palynology **19**, 1–43.

Gudlaugsson, S.T., Faleide, J.I., Johansen, S.E. & Breivik, A.J. 1998: Late Palaeozoic structural development of the southwestern Barents Sea. Marine and Petroleum Geology **15**, 73–102.

Håkansson, E. 1979: Carboniferous to Tertiary development of the Wandel Sea Basin, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **88**, 73–84.

Håkansson, E. & Pedersen, S.A.S. 1982: Late Paleozoic to Tertiary tectonic evolution of the continental margin in North Greenland. In: Embry, A.F. & Balkwill, H.R. (eds): Arctic geology and geophysics. Canadian Society of Petroleum Geologists Memoir **8**, 331–348.

Håkansson, E. & Stemmerik, L. 1989: Wandel Sea basin – a new synthesis of the late Paleozoic to Tertiary accumulation in North Greenland. Geology **17**, 683–686.

Håkansson, E., Heinberg, C. & Stemmerik, L. 1981: The Wandel Sea Basin from Holm Land to Lockwood Ø, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **106**, 47–64.

Håkansson, E., Heinberg, C. & Stemmerik, L. 1991: Mesozoic and Cenozoic history of the Wandel Sea Basin area, North Greenland. In: Peel, J.S. & Sønderholm, M. (eds): Sedimentary basins of North Greenland. Bulletin Grønlands Geologiske Undersøgelse **160**, 153–164.

Hansen, J.M. 1980a: Stratigraphy and structure of the Paleocene in central West Greenland and Denmark, 156 pp. Unpublished lic. scient. thesis, University of Copenhagen, Denmark.

Hansen, J.M. 1980b: Morphological characterization of encrusting, palynomorph green algae from the Cretaceous–Tertiary of central West Greenland and Denmark. Grana **19**, 67–77.

Hansen, J.M. & Gudmundsson, L. 1979: A method for separating acid-insoluble microfossils from organic debris. Micropaleontology **25**, 113–117.

Heilmann-Clausen, C. 1985: Dinoflagellate stratigraphy of the uppermost Danian to Ypresian in the Viborg 1 borehole, central Jylland, Denmark. Danmarks Geologiske Undersøgelse Serie A **7,** 69 pp.

Hjortkjær, B.F. 1991: A palynological investigation of Tertiary shales from Disko and Nuussuaq, 94 pp. Unpublished M. Sc. thesis, University of Copenhagen, Denmark.

Ioannides, N.S. 1986: Dinoflagellate cysts from Upper Cretaceous – Lower Tertiary sections, Bylot and Devon Islands, Arctic Archipelago. Geological Survey of Canada Bulletin **371**, 99 pp.

Jerzykiewicz, T. & Sweet, A.R. 1986: The Cretaceous–Tertiary boundary in the central Alberta Foothills. I: Stratigraphy. Canadian Journal of Earth Sciences **23**, 1356–1374.

Kalkreuth, W.D., McIntyre, D.J. & Richardson, R.J.H. 1993: The geology, petrography and palynology of Tertiary coals from the Eureka Sound Group at Strathcona Fiord and Bache Peninsula, Ellesmere Island, Arctic Canada. International Journal of Coal Geology **24**, 75–111.

Kalkreuth, W.D., Riediger, C.L., McIntyre, D.J., Richardson, R.J.H., Fowler, M.G. & Marchioni, D. 1996: Petrological, palynological and geochemical characteristics of Eureka Sound Group coals

(Stenkul Fiord, southern Ellesmere Island, Arctic Canada). International Journal of Coal Geology **30**, 151–182.

Kurita, H. & McIntyre, D.J. 1994: Dinoflagellate assemblages and depositional environments of the Campanian Bearpaw Formation, Alberta. Geological Survey of Canada Bulletin **479,** 67–83.

Kurita, H. & McIntyre, D.J. 1995: Paleocene dinoflagellates from the Turtle Mountain Formation, southwestern Manitoba, Canada. Palynology **19**, 119–136.

Lentin, J.K. & Vozzhennikova, T.F. 1990: Fossil dinoflagellates from the Jurassic, Cretaceous and Palaeogene deposits of the USSR – a re-study. American Association of Stratigraphic Palynologists Contribution Series **23,** 211 pp.

Lentin, J.K. & Williams G.L. 1976: A monograph of fossil peridinoid dinoflagellate cysts. Bedford Institute of Oceanography Report Series **BI-R-81-12**, 1–345.

Lentin, J.K. & Williams G.L. 1980: Dinoflagellate provincialism with emphasis on Campanian peridiniaceans. American Association of Stratigraphic Palynologists Contribution Series **7**, 1–47.

Lentin, J.K. & Williams G.L. 1987: Status of the fossil dinoflagellate genera *Ceratiopsis* Vozzhennikova 1963 and *Cerodinium* Vozzhennikova 1963 emend. Palynology **11**, 113–116.

Lentin, J.K. & Williams G.L. 1993: Fossil dinoflagellates: index to genera and species 1993 edition. American Association of Stratigraphic Palynologists Contribution Series **28,** 856 pp.

Lindgren, S. 1984: Acid resistant peridinioid dinoflagellates from the Maastrichtian of Trelleborg, southern Sweden. Stockholm Contributions in Geology **39**, 145–201.

Lucas-Clark, J. 1987: *Wigginsiella* n.gen, *Spongodinium*, and *Apteodinium* as members of the *Aptiana–Ventriosum* complex (fossil Dinophyceae). Palynology **11**, 155–184.

Lund, J. 1989: A late Paleocene non-marine microflora from the interbasaltic coals of the Faeroe Islands, North Atlantic. Bulletin of the Geological Society of Denmark **37**, 181–203.

McIntyre, D.J. 1974: Palynology of an Upper Cretaceous section, Horton River, District of Mackenzie, N.W.T. Geological Survey of Canada Paper **74-14**, 57 pp.

McIntyre, D.J. 1994: Palynology, Appendix 1. In: Ricketts, B.D. 1994: Basin analysis, Eureka Sound Group, Axel Heiberg Islands, Canadian Arctic Archipelago. Geological Survey of Canada Memoir **439**, 85–101.

Manum, S.[B.] 1960: Some dinoflagellates and hystrichosphaerids from the Lower Tertiary of Spitsbergen. Nytt Magasin for Botanikk **8**, 17–26.

Manum, S.[B.] 1962: Studies in the Tertiary Flora of Spitsbergen with notes on the Tertiary floras of Ellesmere Island, Greenland, and Iceland. A palynological investigation. Norsk Polarinstitutt Skrifter **125**, 127 pp.

Manum S.[B.] 1963: Some new species of *Deflandrea* and their probable affinity with *Peridinium*. Norsk Polarinstitutt Årbok **1962**, 55–67.

Manum, S.[B.] & Cookson, I.C. 1964: Cretaceous microplankton in a sample from Graham Island, Arctic Canada, collected during the second 'Fram'-Expedition (1898–1902). With notes on microplankton from the Hassel Formation, Ellef Ringnes Island. Skrifter utgitt av Det Norske Videnskaps-Akademi i Oslo, I. Mathematisk og Naturvidenskapelig Klasse, Ny Serie **17**, 1–35.

Manum, S.B. & Throndsen, T. 1986: Age of Tertiary formations on Spitsbergen. Polar Research **4**, 103–131.

Morgenroth, P. 1968: Zur Kenntnis der Dinoflagellaten und Hystrichosphaeridien des Daniens. Geologisches Jahrbuch **86**, 533–578.

Mtchedlishvili, N.D. 1961: Palynological characteristic of the Cretaceous sediments of the West-Siberian depression (Cenomanian, Turonian, Danian). In: Samoilovitch, S.R. (ed.): Pollen and Spores of Western Siberia. Trudy Vsesoyuznyy Nauchno-Issledovatel'skiy Geologorazvedochniy Neftyanoy Institut (VNIGRI) **177**, 291–298 and 329–332 (in Russian).

Nichols, D.J. & Brown, J.L. 1992: Palynostratigraphy of the Tullock Member (lower Paleocene) of the Fort Union Formation in the Powder River Basin, Montana and Wyoming. U. S. Geological Survey Bulletin **1917-F**, 1–35.

Nichols, D.J. & Ott, H.L. 1978: Biostratigraphy and evolution of the *Momipites–Caryapollenites* lineage in the Early Tertiary in the Wind River Basin, Wyoming. Palynology **2**, 93–112.

Nøhr-Hansen, H. 1994a: Dinoflagellate cyst biostratigraphy of the Upper Cretaceous black mudstones on Svartenhuk Halvø, West Greenland. Open File Series Grønlands Geologiske Undersøgelse **94/9**, 25 pp.

Nøhr-Hansen H. 1994b: Dinoflagellate cyst biostratigraphy of the Upper Cretaceous black mudstones in central Nuussuaq, West Greenland. Open File Series Grønlands Geologiske Undersøgelse **94/12**, 26 pp.

Nøhr-Hansen H. 1994c: Dinoflagellate cyst biostratigraphy of the Upper Cretaceous black mudstones between Niaqornat and Ikorfat on the north coast of Nuussuaq, West Greenland. Open File Series Grønlands Geologiske Undersøgelse **94/14**, 24 pp.

Nøhr-Hansen, H. 1996: Upper Cretaceous dinoflagellate cyst stratigraphy, onshore West Greenland. Bulletin Grønlands Geologiske Undersøgelse **170**, 104 pp.

Nøhr-Hansen, H. & Dam, G. 1997: Palynology and sedimentology across a new marine Cretaceous–Tertiary boundary section on Nuussuaq, West Greenland. Geology **25**, 851–854.

Norton, N.J. 1965: Three new species of *Aquilapollenites* from the Hell Creek Formation, Garfield County, Montana. Pollen et Spores **7**, 136–143.

Norton, N.J. & Hall, J.W. 1967: Guide sporomorphae in the Upper Cretaceous – Lower Tertiary of eastern Montana (U.S.A.). Review of Palaeobotany and Palynology **2**, 99–110.

Pflug, H.D. 1953: Zur Entstehung und Entwicklung des Angiospermiden Pollens in der Erdgeschichte. Palaeontographica B **95**, 60–171.

Piasecki, S., Larsen, L.M., Pedersen, A.K. & Pedersen, G.K. 1992: Palynostratigraphy of the Lower Tertiary volcanics and marine clastic sediments in the southern part of West Greenland Basin: implications for the timing and duration of the volcanism. Rapport Grønlands Geologiske Undersøgelse **154**, 13–31.

Powell, A.J. 1992: Dinoflagellate cysts of the Tertiary System. In: Powell, A.J. (ed.): A stratigraphic Index of dinoflagellate cysts, 155–252. London: British Micropalaeontological Society.

Russell, D.A. & Singh, C. 1978: The Cretaceous–Tertiary boundary in south-central Alberta – a reappraisal based on dinosaurian and microfloral extinctions. Canadian Journal of Earth Sciences **15**, 284–292.

Samoilovitch, S.R. 1967: Tentative botanico-geographical subdivision of northern Asia in Late Cretaceous time. Review of Palaeobotany and Palynology **2**, 127–139.

Skarby, A. 1968: *Extratriporopollenites* (Pflug) emend. from the Upper Cretaceous of Scania, Sweden. Stockholm Contributions in Geology **16**, 1–30.

Srivastava, S.K. 1971: Monolete spores from the Edmonton Formation (Maestrichtian), Alberta, Canada. Palaeontographica Abteilung **B 139**, 1–46.

Stanley, E.A. 1961: A new sporomorph genus from South Dakota. Pollen et Spores **3**, 155–162.

Stanley, E.A. 1965: Upper Cretaceous and Paleocene plant microfossils and Paleocene dinoflagellates and hystrichosphaerids from northwestern South Dakota. Bulletin of American Paleontology **49**, 175–384.

Stemmerik, L. & Håkansson, E. 1989: Stratigraphy and depositional history of the Upper Palaeozoic and Triassic sediments in the Wandel Sea Basin, eastern and central North Greenland. Rapport Grønlands Geologiske Undersøgelse **143**, 21–44.

Stemmerik, L. & Håkansson, E. 1991: Carboniferous and Permian history of the Wandel Sea Basin, eastern North Greenland. In: Peel, J.S. & Sønderholm, M. (eds): Sedimentary basins of North Greenland. Bulletin Grønlands Geologiske Undersøgelse **160**, 141–151.

Stemmerik, L., Dalhoff, F. & Nilsson, I. 1995: Petroleum geology and thermal maturity of eastern North Greenland – a new energy research project. Rapport Grønlands Geologiske Undersøgelse **165**, 49–52.

Stover, L.E. & Evitt, W.R. 1978: Analyses of pre-Pleistocene organic-walled dinoflagellates. Stanford University Publications Geological Sciences **15**, 1–300.

Sweet, A.R. 1986: The Cretaceous–Tertiary boundary in the central Alberta foothills; II, Miospore and pollen taxonomy. Canadian Journal of Earth Sciences **23**, 1375–1388.

Sweet, A.R., Braman, D.R. & Lerbekmo, J.F. 1990: Palynoflora response to K/T boundary events; A transitory interruption within a dynamic system. In: Sharpton, V.L. & Ward, P.D. (eds): Global catastrophes in Earth history; an interdisciplinary conference on impacts, volcanism and mass mortality. Geological Society of America Special Paper **247**, 457–469.

Tyson, R.V. 1995: Sedimentary organic matter. Organic facies and palynofacies, 615 pp. London: Chapman & Hall.

Vozzhennikova, T.F. 1967: Fossilized peridinian algae of the Jurassic, Cretaceous and Palaeogene deposits of the USSR. Trudy Akademiya Nauk SSSR, Sibirskoye Otdeleniye Institut Geologii i Geofiziki, 347 pp. (English translation by Lees, E. & Sarjeant, W.A.S. (eds) 1971 National lending Library for Science and Technology, 453 pp).

Williams, G.L. & Bujak, J.P. 1977: Cenozoic palynostratigraphy of offshore eastern Canada. American Association of Stratigraphic Palynologists Contribution Series **5A**, 14–33.

Williams, G.L. & Downie, C. 1966: Further dinoflagellate cysts from the London Clay. In: Davey, R.J. *et al.* (eds): Studies on Mesozoic and Cainozoic dinoflagellate cysts. Bulletin of the British Museum (Natural History) Geology, Supplement **3**, 215–235.

Williams, G.L., Stover, L.E. & Kidson, E.J. 1993: Morphology and stratigraphic ranges of selected Mesozoic–Cenozoic dinoflagellate taxa in the northern hemisphere. Geological Survey of Canada Paper **92-10,** 137 pp.

Wodehouse, R.P. 1933: Tertiary pollen. II The oil shales of the Eocene Green River formation. Torrey Botanical Club Bulletin **60**, 479–524.

Stratigraphy and palynology of the Lower Carboniferous Sortebakker Formation, Wandel Sea Basin, eastern North Greenland

Finn Dalhoff, Jorunn Os Vigran and Lars Stemmerik

Two palynological assemblages of Early Carboniferous age have been recorded from the upper parts of the non-marine, fluvial-dominated Sortebakker Formation in the Wandel Sea Basin. The stratigraphically lower assemblage includes poorly preserved *Cingulizonates* spp., *Densosporites* spp., *Lycospora* spp. and *Schulzospora* spp. whereas the upper assemblage contains a more diversified microflora including the stratigraphically important *Tripartites distinctus*, *Potoniespores delicatus* and *Savitrisporites* spp. The microflora enables correlation and dating of the succession to the late Viséan Perotrilites tessellatus – Schulzospora campyloptera (TC) and Raistrickia nigra – Triquitrites marginatus (NM) miospore Biozones of western Europe. The depositional facies correspond to those seen in time equivalent deposits from East Greenland, Svalbard, Bjørnøya and the Barents Sea.

F.D. & L.S., *Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark*. E-mail: *fd@geus.dk*
J.O.V., *IKU Petroleum Research, N-7034 Trondheim, Norway*. Present address: *Hans Hagerups Gate 10, N-7012 Trondheim, Norway.*

Keywords: Carboniferous, North Greenland, palynostratigraphy, Sortebakker Formation, Wandel Sea Basin

The Sortebakker Formation in North Greenland and the roughly time equivalent non-marine deposits in East Greenland, Svalbard, Bjørnøya and the offshore areas of the Barents Sea form a distinctive depositional event related to initial rifting in the region (Stemmerik & Worsley 1989; Stemmerik *et al.* 1991). Deposition started in East Greenland and on Svalbard during the latest Devonian (Strunian part of the Famennian) and throughout the region fluvial sedimentation continued into the Viséan (Stemmerik *et al.* 1991; Bugge *et al.* 1995; Vigran *et al.* 1999). So far, dating of the Sortebakker Formation has been based on a poorly preserved macroflora that suggests a general Early Carboniferous age for these deposits (Nathorst 1911; Stemmerik & Håkansson 1989). This broad age assignment has hampered detailed correlation of this thick succession of mainly fluviatile deposits with the time equivalent Billefjorden Group of Svalbard and Traill Ø Group of East Greenland.

The Sortebakker Formation is geographically limited to the south coast of Holm Land in eastern North Greenland (see Fig. 1) where it overlies Caledonian-affected basement and is unconformably overlain by Upper Carboniferous (Moscovian) marine deposits of the Kap Jungersen Formation (Håkansson *et al.* 1981; Stemmerik *et al.* 1995a). The Sortebakker Formation deposits were faulted and thermally affected prior to deposition of the Kap Jungersen Formation (Håkansson *et al.* 1981; Christiansen *et al.* 1991), and previous attempts at dating of the formation by miospores have failed due to thermal destruction of the organic material in the sampled sections. However, following renewed field work in 1994, miospores were obtained from shales in the uppermost part of the formation in outcrops located to the west of the previous study areas (Fig. 1; Stemmerik *et al.* 1995b). The miospores, although poorly preserved, define two stratigraphically significant Viséan assemblages that enable, for the first time, relative age assignment of, at least, the upper part of the formation and a more reliable correlation with comparable deposits in East Greenland, Svalbard and Bjørnøya (Fig. 2).

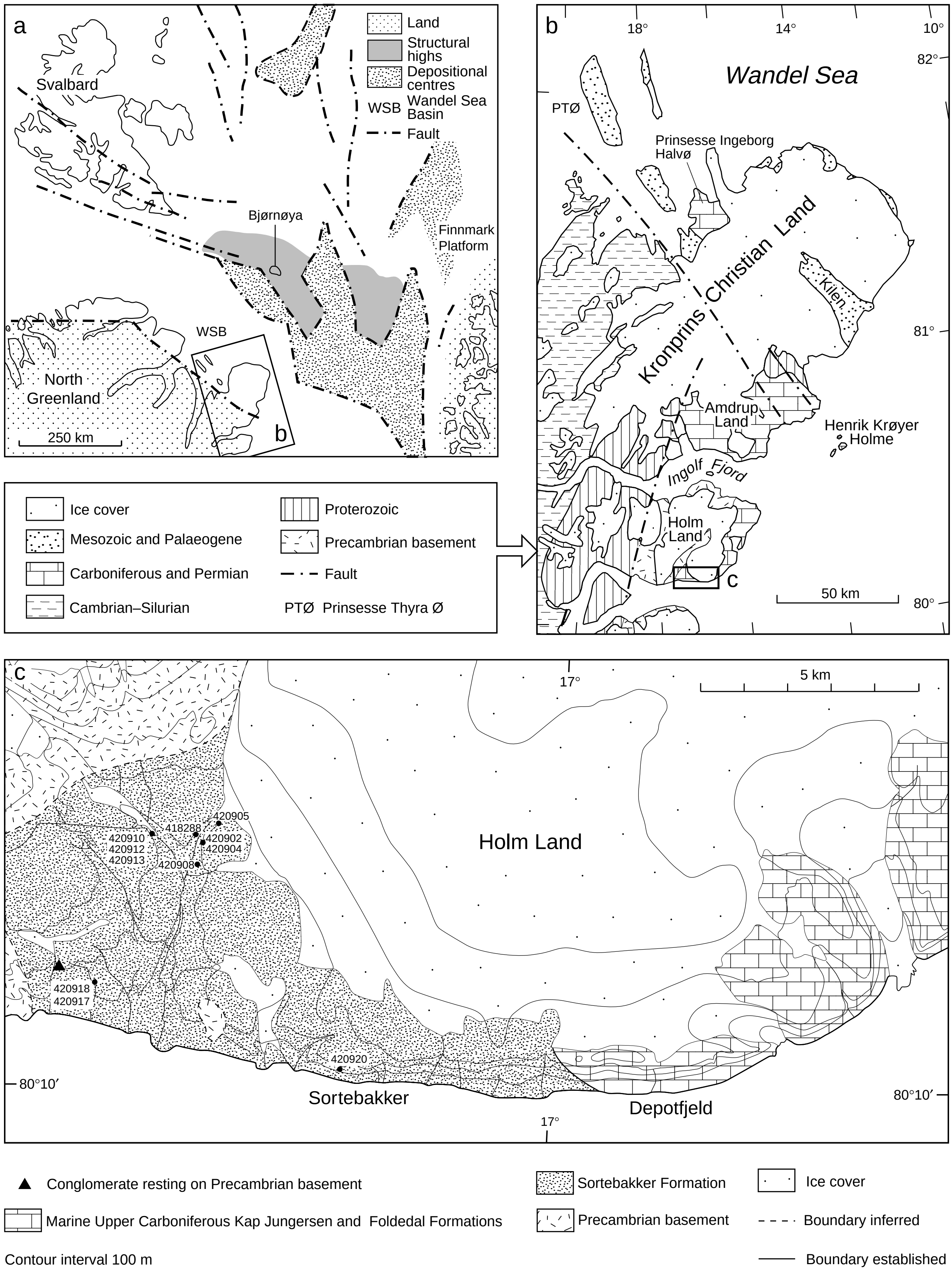
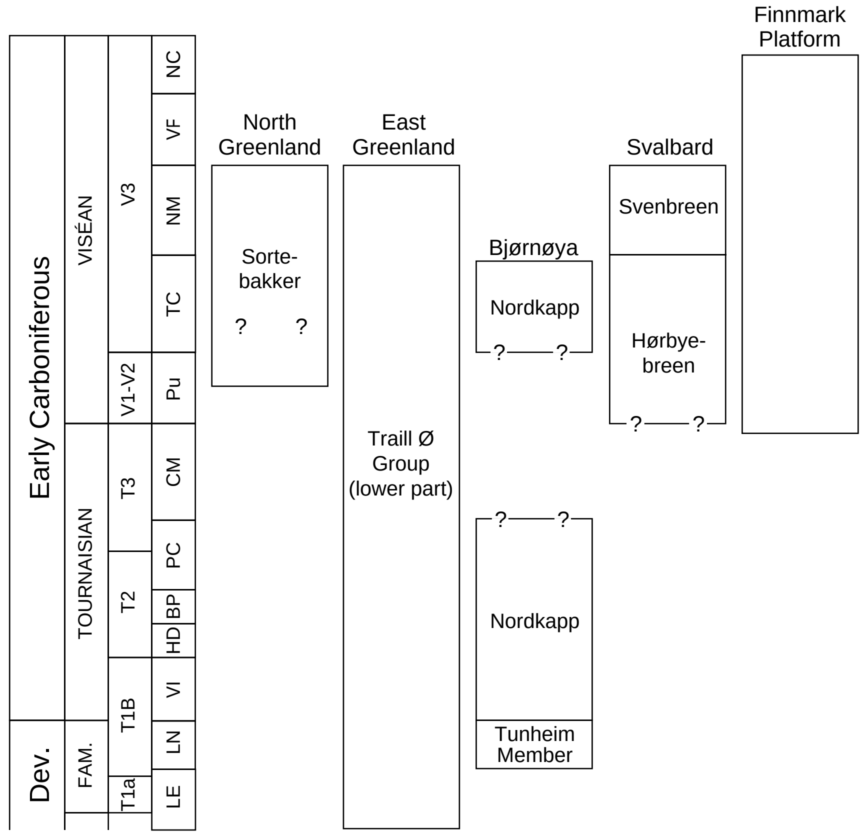

a
Land
Structural highs
Depositional centres
WSB Wandel Sea Basin
Fault
Svalbard
Bjørnøya
Finnmark Platform
WSB
North Greenland
250 km
b
Ice cover
Mesozoic and Palaeogene
Carboniferous and Permian
Cambrian–Silurian
Proterozoic
Precambrian basement
Fault
PTØ Prinsesse Thyra Ø
18°
14°
10°
82°
81°
80°
Wandel Sea
PTØ
Prinsesse Ingeborg Halvø
Kronprins Christian Land
Kilen
Amdrup Land
Henrik Krøyer Holme
Ingolf Fjord
Holm Land
c
50 km
c
17°
5 km
Holm Land
420905
418288
420910
420912
420913
420902
420904
420908
420918
420917
420920
80°10′
Sortebakker
Depotfjeld
80°10′
17°
Conglomerate resting on Precambrian basement
Marine Upper Carboniferous Kap Jungersen and Foldedal Formations
Contour interval 100 m
Sortebakker Formation
Precambrian basement
Ice cover
Boundary inferred
Boundary established

Fig. 2. Stratigraphic scheme showing proposed correlation of Lower Carboniferous sediments in eastern North Greenland, Bjørnøya, Svalbard and the Barents Sea. **FAM**: Famennian (Strunian). **LE–NC** miospore Biozones of Clayton *et al.* (1977) and Higgs *et al.* (1988).



This paper describes the miospore assemblages found in the upper part of the Sortebakker Formation (Fig. 3). Dating of these assemblages is based on correlation with miospore assemblages from East Greenland and western Europe (Neves *et al.* 1973; Clayton *et al.* 1977; Higgs *et al.* 1988; Vigran *et al.* 1999).

Lithology

The Sortebakker Formation comprises a succession of non-marine, mainly fluviatile sediments exposed along the south coast of Holm Land in eastern North Greenland (Stemmerik & Håkansson 1989). The formation was originally proposed to be approximately 600 m thick but reliable thickness estimates were difficult due to structural disturbance of the section, and lack of outcrops of the base of the formation. During field work in 1995, the base of the formation was found in the western part of the outcrop area (Fig. 1). There, unusually coarse-grained facies rest directly on Caledonian-affected basement. Based on these new observations and correlation of detailed sedimentological sections from the coastal cliffs and river sections, the formation is now estimated to be *c.* 1000 m thick (Fig. 4). The formation is dominated by stacked fining-upward cycles of fluvial sandstones and shales with some lacustrine shale deposits towards the top (Fig. 5). Individual cycles can be traced laterally for at least 1–2 km, the limiting factor in most cases being the amount of exposure. The formation is divided by a low-angle disconformity into a lower unit of shale-dominated cycles and an upper unit of sandstone-dominated cycles (Fig. 4).

The succession consists of six lithofacies associations. Five of these characterise different parts of a meandering river system; the sixth represents a lacustrine system. Details of the sedimentology are given in

Fig. 1. **a**: Map with major structural outline and palaeogeographic reconstruction of the Wandel Sea and Barents Sea regions. Modified from Stemmerik & Worsley (1995). **b**: Simplified geological map of Kronprins Christian Land and environs showing the distribution of Upper Palaeozoic sediments. Modified from Stemmerik *et al.* (1994). For location, see Fig. 1a. **c**: Geological map of the southern part of Holm Land showing the distribution of the Sortebakker Formation and sample localities mentioned in the text. For location, see Fig. 1b.

Fig. 3. Interbedded fine-grained sandstones (**SS**) and shales (**Sh**) from the topmost part of the Sortebakker Formation yielding palynomorphs in sample GGU 418288. Exposed section is *c.* 15 m high. For location, see Fig. 1c.

Dalhoff & Stemmerik (2000, this volume) and a summary of the sedimentary associations are given in Table 1. All miospores are found in the overbank fines association described in more detail below.

Overbank fines association

This facies association comprises up to 10 m thick units of laminated to weakly laminated shale and siltstone separated by thin partings of massive sandstone and parallel laminated silty sandstone. In the lowermost part of the formation, rare very thin coal partings occur. The overbank fines association has a transitional or planar to irregular base and comprises mainly fining-upward units with flaser and lenticular bedding, though coarsening-upward units are observed locally. The sandstone partings are 2–10 cm thick with wavy or planar lower and upper boundaries. Sediments from the overbank fines association usually overlie sand-

Table 1. Summary of facies associations in the Sortebakker Formation

Facies association	Thickness	Dominant lithology	Characteristics
Channel	0.5–4 m (lower part) 10–13 m (upper part)	Upward-fining units of medium- to fine-grained sandstone	Sharp, erosive bases, mudflake clasts, pebbly lags, cross-bedding
Overbank fines	< 10 m	Laminated to weakly laminated shale and siltstone. Silty sandstone	Flaser and lenticular bedding
Crevasse splay	< 5 m	Medium- to fine-grained sandstone	Composite less than 1.5 m thick beds. Cross-bedding
Levee	Multistory, up to 10 m	Heterolithic units of weakly laminated clay and silt and medium- to fine-grained sandstone	
Lake	< 28 m	Laminated and non-laminated shale and siltstone	Rare, thin silty sandstones with ripple lamination
Swamp	< 1 m	Coal and shaly coal	Vertical tree stumps in growth position

For details, see Dalhoff & Stemmerik (2000, this volume)

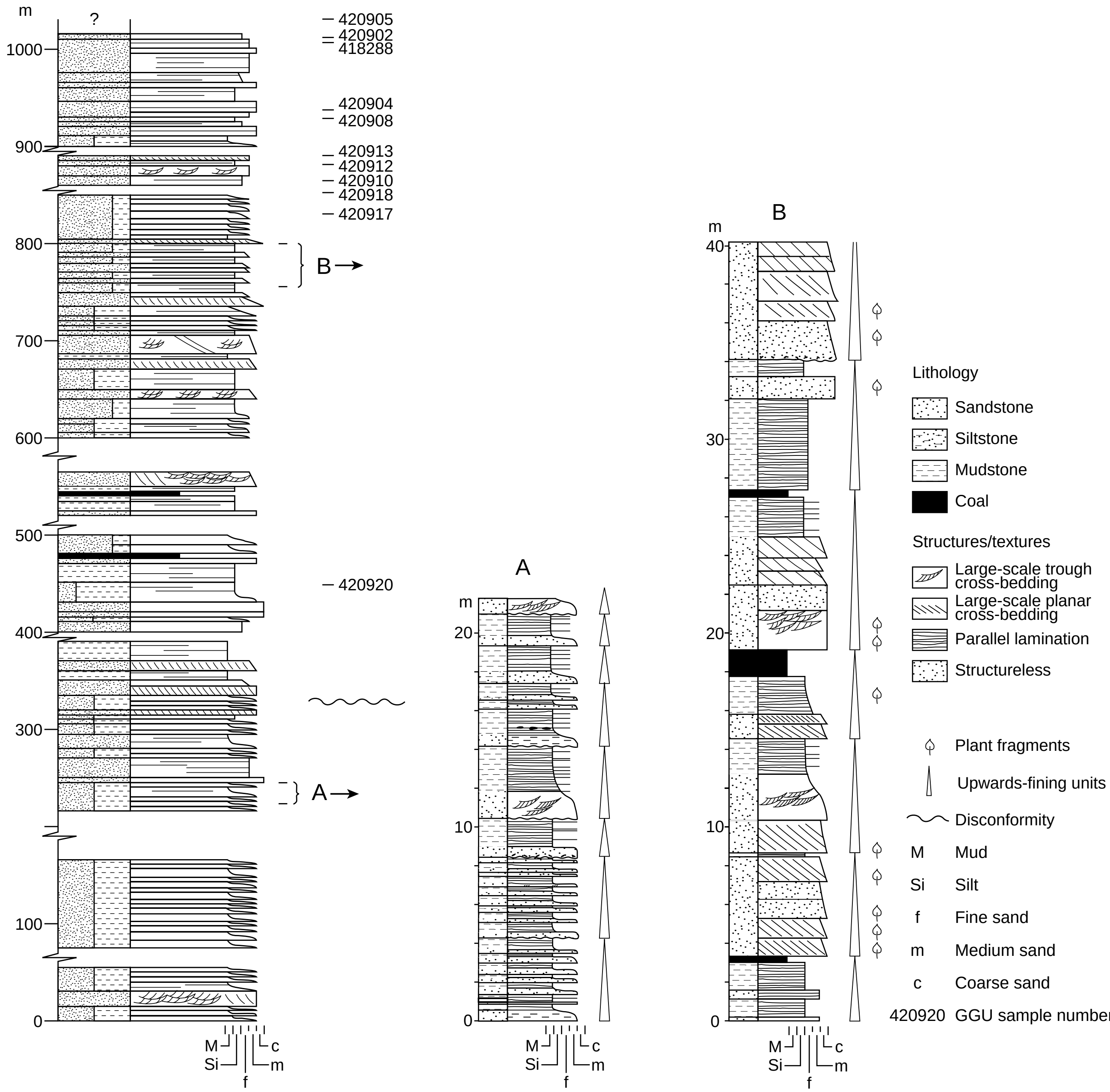


Fig. 4. Composite and detailed sedimentological logs of the Sortebakker Formation. The detailed logs show typical stacking patterns in the lower shale-dominated unit (**A**) and the upper sand-dominated unit (**B**). The total thickness is estimated to exceed 1000 m. Palynological sample localities are also shown.

stones from the channel association with a gradual transition (Fig. 6). Poorly preserved plant fragments are the only macrofossils recorded in this association. The facies association can be traced laterally for more than 1000 m.

Depositional evolution

The formation consists of stacked floodplain deposits that in the uppermost part pass into a succession of mixed fluvial and lacustrine deposits. The overall pattern shows a transition from thin shale-dominated cycles to thick sand-dominated cycles. This change is suggested to reflect a shift from a broad distal floodplain, where the meandering stream channels had limited influence on sedimentation, to a more proximal or laterally confined floodplain where channel sedimentation dominated. The final shift towards mixed lacustrine and fluvial deposition reflects a change in base level possibly due to increased rates of subsidence. The uppermost fluvial channels appear to be of the same size as those seen below in the upper flood-plain succession, but are laterally confined, and rather than forming tabular sand bodies they form isolated lenticular sand bodies.

Miospore correlation

The palynological investigation of the Lower Carboniferous Sortebakker Formation of North Greenland has shown the presence of two miospore assemblages. These can be correlated with the western European standard Carboniferous miospore zones of Clayton *et al.* (1977) and Higgs *et al.* (1988) which allows dating of the succession (Fig. 2; Tables 2, 3). There is also resemblance to assemblages described from East Greenland by Vigran *et al.* (1999). The organic residues are generally of poor but variable preservation. Processing procedures developed at the former Geological Survey of Greenland (GGU) have been adapted to enrich the palynomorph content (Hansen & Gudmundsson 1979). Different fractions of the residues were isolated according to their specific weight and floating properties. Smear slides mounted in Eukitt® represent the different fractions and show a variable relative palynological composition. The 'semiquantitative data' expressed rather briefly in the distribution chart represent estimates based on one or more slides (Table 2).

Two palynological assemblages (described below) are recognised on the basis of selected palynomorphs. The assemblages are numbered according to their stratigraphic position in the sections and their ages refer to the western European Miospore Biozones with modifications based on material from other Arctic areas (Playford 1962, 1963; Kaiser 1970; Bugge *et al.* 1995; Vigran *et al.* 1999).

Assemblage 1

Definition. The miospores encountered are *Cingulizonates* spp., *Densosporites* spp. and *Lycospora* spp. together with rare specimens of *Schulzospora* spp.

Palynofacies. The residues contain dominantly angular black fragments and only very rare miospores. The

Fig. 5. Cliff exposure of the upper sand-dominated unit. Note the thick laterally persistent cycles of interbedded channel sandstones (light) and overbank fines. Eastern Sortebakker, southern Holm Land. The cliff is approximately 350 m high.

Table 2. Distribution of miospores in the Sortebakker Formation

Taxa	GGU 420905	GGU 420902	GGU 418288	GGU 420904	GGU 420908	GGU 420913	GGU 420912	GGU 420910	GGU 420918	GGU 420917	GGU 420920
Densosporites spp.	3	1	3	3	3	2	3	3	2	1	1
Lycospora spp.	1		1	1	2	1	1	1	1	1	2
Schulzospora spp.	1	1	1	1	1		1	1	1	1	1
Cingulizonates spp.	1		1	1	1		1	1		1	
Discernisporites micromanifestus (Hacquebard & Barss) Sabry & Neves 1971			1				1	1		1	
Knoxisporites triradiatus Hoffmeister Staplin & Malloy 1955	1						1			1	
Lycospora pusilla (Ibrahim) Schopf, Wilson & Bentall 1944			1	1	1		1			1	
Punctatisporites pseudobesus Playford 1962										1	
Reticulatisporites variolatus Playford 1962	1		1	1	1	1	1	1		1	
Spelaeotriletes spp.			1							1	
Calamospora spp.				1			1	1			
Cingulizonates bialatus (Waltz) Smith & Butterworth 1967	1	2	1	1	1		1	1			
Cirratriradites spp.				1			1	1			
Convolutispora labiata Playford 1962			1					1			
Corbulispora cancellata (Waltz) Bharadwaj & Venkatachala 1961	1	1	1	1	1	1	1	1			
Densosporites spitsbergensis Playford 1963	1		1	1	1	1	1	1			
Diatomozonotriletes fragilis Clayton *in* Neves *et al.* 1973	1	1					1	1			
Diatomozonotriletes saetosus (Hacquebard & Barss) Hughes & Playford 1961		1			1	1	1	1			
Diatomozonotriletes spp.	1	1	1		1			1			
Knoxisporites dissidius Neves 1961			1					1			
Platyptera incisotriloba (Naumova) Braman & Hills 1977	1	1					1	1			
Punctatisporites spp.	1	1	1	1	1		1	2			
Raistrickia spp.	1		1			1	1	1			
Reticulatisporites peltatus Playford 1962			1			1		1			
Tricidarisporites arcuatus Neville *in* Neves *et al.* 1973	1	1				1		1			
Tricidarisporites rarus (Playford) Neville 1971	1	1	1				1	1			
Velamisporites spp.				1				1			
Verrucosisporites spp.		1					1	1			
Walzispora planiangulata Sullivan 1964	1	1					1	1			
Ahrensisporites duplicatus Neves *in* Neves *et al.* 1973	1						1				
Bisaccate pollen (indeterminate)		1		1			1				
Cingulizonates brevispinosus (Hoffmeister, Staplin & Malloy) n. comb.	1			1	1		1				
Endosporites spp.			1		1		1				
Knoxisporites stephanephorus Love 1960							1				
Microreticulatisporites spp.	1				1		1				
Murospora aurita (Waltz) Playford 1962							1				
Phyllothecotriletes rigidus Playford 1962							1				
Platyptera complanata (Staplin) Ravn 1991		1					1				
Raistrickia nigra Love 1960							1				
Savitrisporites nux (Butterworth & Williams) Smith & Butterworth 1967							1				
Savitrisporites spp.			1		1	1	1				
Simozonotriletes intortus (Waltz) Potonié & Kremp 1954							1				
Tetraporina horologia (Staplin) Playford 1963							1				
Triquitrites batillatus Hughes & Playford 1961	1		1		1	1	1				
Tumulispora variverrucata (Playford) Staplin & Jansonius 1964							1				
Cristatisporites bellus Bharadwaj & Venkatachala 1961	1					1					
Tripartites distinctus Williams *in* Neves *et al.* 1973		1	1			1					
Verrucosisporites eximius Playford 1962						1					
Schulzospora campyloptera (Waltz) Hoffmeister, Staplin & Malloy 1955		1	1	1							
Densosporites diatretus Playford 1963			1								
Laevigatosporites spp.			1								
Latosporites spp.			1								
Lophozonotriletes spp.			1								
Rugospora spp.			1								
Potoniespores delicatus Playford 1963		1									
Acanthotriletes cf. *A. haquebardii* Playford 1964	1										
Discernisporites macromanifestus (Hacquebard) Utting 1987	1										
Palynological Assemblage Zone	NM								TC		
Age	Late Viséan										

Frequency is illustrated by the numbers 1, 2 and 3 (highest)
For sample description, see Table 3
NM: Raistrickia nigra – Triquitrites marginatus Biozone
TC: Perotrilites tessellatus – Schulzospora campyloptera Biozone

Fig. 6. Typical fining-upward unit from the upper part of Sortebakker Formation. Fluvial sandstones erosively overlie the overbank fines from the preceding unit and pass upwards into new overbank fines. The exposed section is approximately 60 m thick and located at Sortebakker on the southern coast of Holm Land just east of sample locality 420920. For location, see Fig. 1.

productive samples all represent the overbank fines association.

Distribution. The assemblage is recorded in GGU 420917, 420918 and 420920 from two sub-sections in the upper part of the Sortebakker Formation. The samples occur stratigraphically below those containing the more diverse Assemblage 2.

Age. The presence of *Schulzospora* spp. indicates that the assemblage is no older than the Perotrilites tessellatus – Schulzospora campyloptera (TC) miospore Biozone of western Europe (Neves *et al*. 1973; Clayton *et al*. 1977). Similar low diversity assemblages have been recorded as Biozone 1 on the Finnmark Platform (Bugge *et al*. 1995). The deposits there represent a braided river system developing into a local floodplain and they are considered as representing the Nordkapp Formation (see Fig. 2).

Table 3. Description of eleven samples from the Sortebakker Formation (see Table 2)

GGU No.	Description
420905	Spore-dominated, sapropelised residue
420902	Spore-dominated, sapropelised residue
418288	Spore-dominated, sapropelised residue, some coal fragments
420904	Coal fragments and spores dominate sapropelised residue
420908	Spore-dominated, sapropelised residue, some coal fragments
420913	Coal fragments dominate the residue
420912	Coal fragments and fairly well-preserved spores dominate
420910	Spore-dominated, sapropelised residue, some coal fragments
420918	Coal fragments dominate the residue
420917	Coal fragments dominate the residue
420920	Coal fragments dominate the residue

Comment. The low diversity assemblage is suggested to represent a palynofacies different from the interval above rather than a distinctive stratigraphic level within the late Viséan. However, both assemblages come from the same lithofacies, the overbank fines.

Assemblage 2

Figs 7, 8

Definition. This assemblage includes *Cingulizonates* spp., *C. bialatus, Corbulispora cancellata, Densosporites* spp., *D. spitsbergensis, Diatomozonotriletes fragilis, D. saetosus, Discernisporites* spp., *D. micromanifestus, Knoxisporites dissidius, K. stephanephorus, K. triradiatus, Laevigatosporites* spp., *Lycospora pusilla, Murospora aurita, Platyptera complanata, P. incisotriloba, Potoniespores delicatus* (the highest sample), *Punctatisporites* sp., *Raistricka* spp., *R. nigra, Reticulatisporites variolatus, Savitrisporites* spp., *S. nux, Schulzospora* spp., *S. campyloptera, Tricidarisporites arcuatus, T. rarus* and *Tripartites distinctus.* Indeterminate alete bisaccate pollen occurs sporadically.

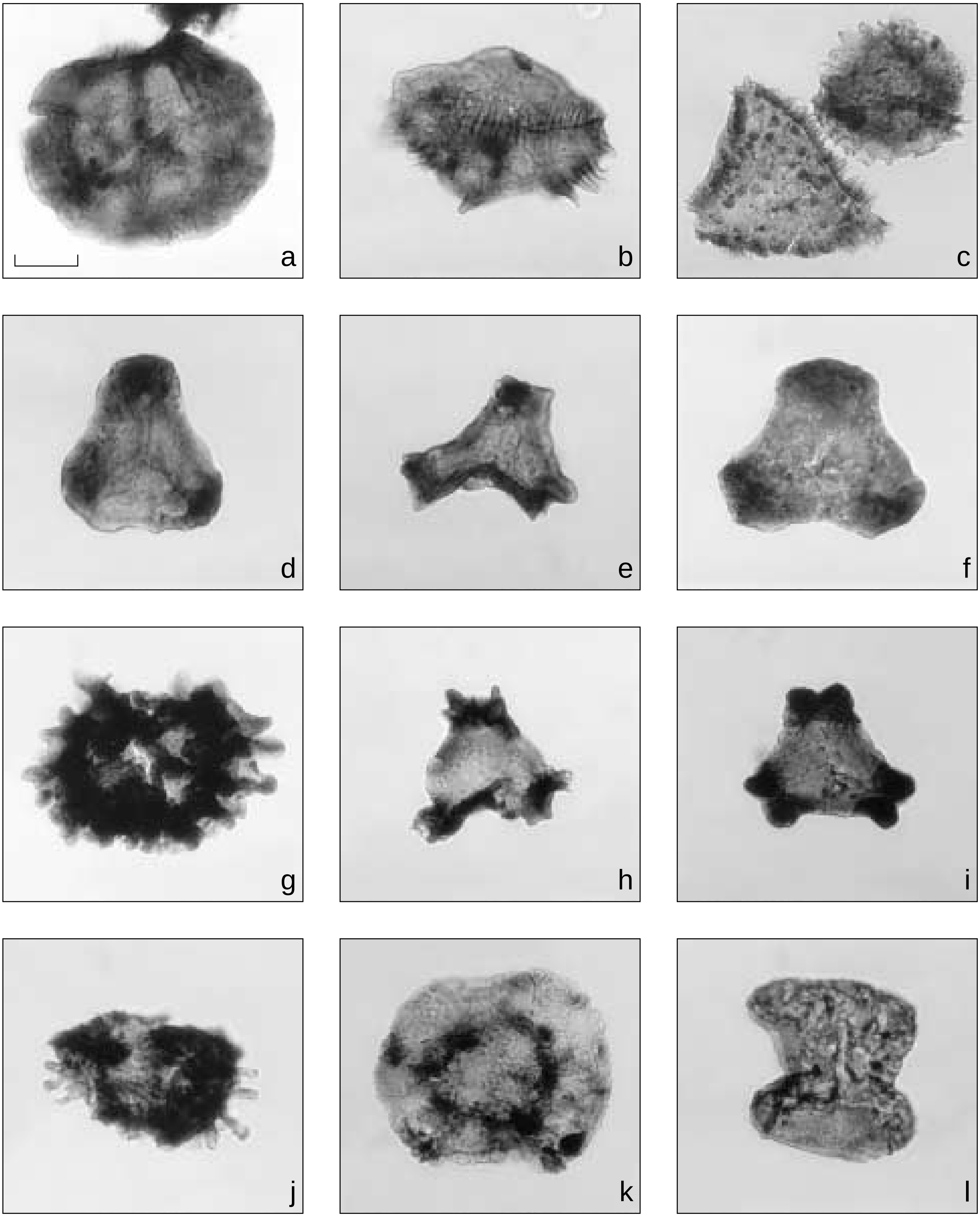


Fig. 7. Palynomorphs from Assemblage 2 in the Sortebakker Formation in southern Holm Land. Scale bar is 10 µm; all figures are the same size. **a**: *Schulzospora campyloptera*, MGUH 24807 from GGU 418288-5; **b**: *Diatomozonotriletes saetosus*, MGUH 24808 from GGU 420912-3; **c**: *Diatomozonotriletes fragilis*, MGUH 24809 from GGU 420912-3; **d**: *Triquitrites batillatus*, MGUH 24810 from GGU 420912-3; **e**: *Ahrensisporites duplicatus*, MGUH 24811 from GGU 420912-3; **f**: *Platyptera complanata*, MGUH 24812 from GGU 420912-3; **g**: *Reticulatisporites peltatus*, MGUH 24813 from GGU 418288-5; **h**: *Platyptera incisotriloba*, MGUH 24814 from GGU 420902-2; **i**: *Tripartites distinctus*, MGUH 24815 from GGU 420912-3; **j**: *Raistrickia* sp. cf. *Raistrickia corynoges*, MGUH 24816 from GGU 420912-3; **k**: *Endosporites* spp., MGUH 24817 from GGU 420908-3; **l**: *Tetraporina horologia*, MGUH 24818 from GGU 420912-3.

Palynofacies. Black angular fragments and miospores, of which *Lycospora* spp., *Densosporites* spp. and morphologically related genera are most common, dominate the residues. The diversity and composition of the assemblage varies within the studied material and possibly relates to variations in the lithofacies. The strong sapropelisation in some samples suggests material from more swampy areas. The variably dark colour of miospores within individual samples is most likely the result of post-depositional chemical processes, presumably related to circulation of hot water during a post-depositional mid-Carboniferous tectonic event (e.g. Stemmerik *et al.* 1998).

Age. The palynoflora of Assemblage 2 is correlated to the Raistrickia nigra – Triquitrites marginatus NM Biozone (Fig. 2). *Tripartites distinctus* and *Potoniespores delicatus* are among the taxa characterising the NM Biozone of western Europe (Neves *et al.* 1973). Assemblage 2 clearly is related to the *aurita* Assemblage from the upper part of the Billefjorden Group of Svalbard (Playford 1962, 1963). This diverse assemblage, although different in composition to the western European assemblages, may be correlated with the TC and NM Biozones, although *Raistrickia nigra* seems to be missing. The diverse assemblages from the Finnmark Platform that are characterised by *P. delicatus* and dominated by *Lycospora* spp. have been correlated with the NM Zone (Bugge *et al.* 1995; Fig. 2), and in East Greenland a *Lycospora*-dominated assemblage with *Schulzospora* and *Diatomozonotriletes saetosus* is correlated with the TC–NM Biozones (Vigran *et al.* 1999).

Sullivan (1965) showed that Lower Carboniferous palynofloras were distributed according to latitudinal control. The Sortebakker Formation microflora, together with the *aurita* Assemblage from Svalbard, belongs to the *Monilospora* suite which covered northern Europe and Canada between approximately 20º and 50º northern palaeo-latitude. Further to the south in the Early Carboniferous, close to the equatorial areas of western Europe, this microflora was replaced by a *Grandispora* suite. This latitudinal control on the palynoflora may explain why Assemblage 2 also includes some miospores that have their first appearance in younger Carboniferous miospore biozones in western Europe. They include *Diatomozonotriletes saetosus* and *Savitrisporites nux* which have their first appearance in the Tripartites vetustus – Rotaspora fracta (VF) Biozone, *Laevigatosporites* spp. which have their first appearance in the Lycospora subtriquetra – Kraeuselisporites ornatus (SO) Biozone and indeterminate bisaccate pollen which first appear in the Radiizonates aligerens (RA) Biozone of western Europe.

Distribution. The assemblage although recorded from different subsections is limited to lake and swamp deposits in the uppermost part of the Sortebakker Formation. The variation in composition and preservation reflects that deposition of the miospores took place more or less contemporaneously, but in different depositional environments. The dominance of *Densosporites* and related genera is in accordance with observations by Playford (1963) in coal samples from the upper part of the Billefjorden Group of Svalbard.

Regional implications

The miospore assemblages obtained in this study date the upper part of the Sortebakker Formation as late Viséan. Deposition took place within a time interval equivalent to the TC and NM Biozones of the western European miospore zonation (Fig. 2). Age equivalent deposits in East Greenland are restricted to Geographical Society Ø (72°30′N) where they consist of stacked floodplain cycles of trough cross-bedded medium-grained sandstones and coaly shales, occasionally capped by thin coal beds (Stemmerik *et al.* 1993; Vigran *et al.* 1999). These 2–15 m thick fining-upward cycles are associated with thicker lacustrine shales and the overall depositional environment resembles that inferred for the upper part of the Sortebakker Formation.

Age equivalent deposits on Bjørnøya belong to the upper part of the Nordkapp Formation (Fig. 2; Kaiser 1970). These sediments consist of lacustrine shales and interbedded sandstones, conglomerates and shales deposited in a braided-stream-dominated floodplain environment (Gjelberg 1981). The miospore assemblages of the upper Hørbyebreen Formation and the Svenbreen Formation of the Billefjorden Group of Svalbard were originally described by Playford (1963). These assemblages are here assigned to the TC and NM Biozones (Fig. 2). The sediments were deposited on broad, humid floodplains and towards the basin margins pass into more coarse-grained alluvial deposits (Steel & Worsley 1984). In contrast to the North Greenland deposits, these sediments include thick coal beds. In the offshore areas of the Finnmark Platform thick floodplain deposits with a miospore flora assigned to the TC and NM Biozones have been recorded (Fig. 2; Bugge *et al.* 1995). The depositional environments

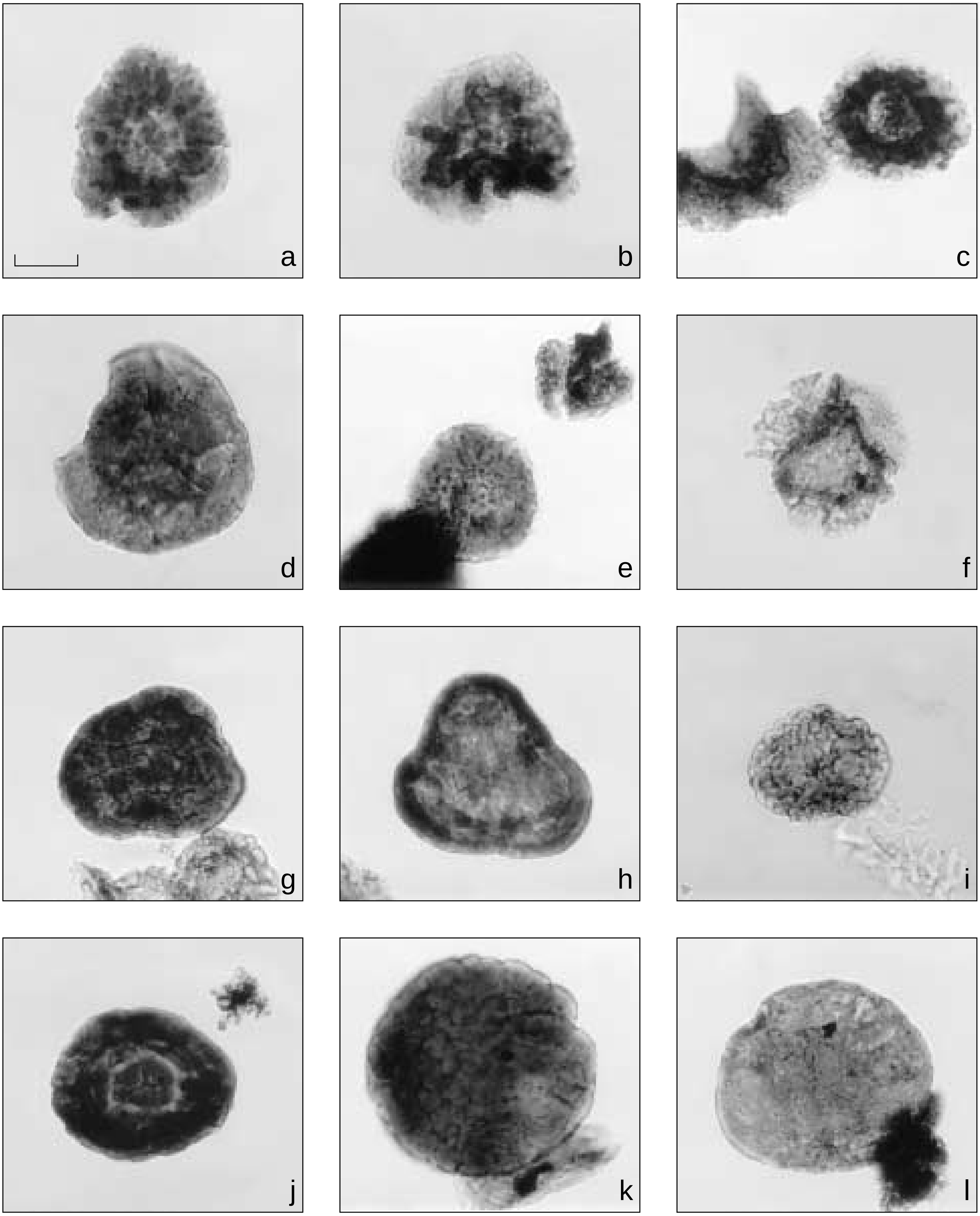


Fig. 8. Palynomorphs from Assemblage 2 in the Sortebakker Formation in southern Holm Land. Scale bar is 10 µm; all figures are the same size. **a**: *Densosporites spitsbergensis*, MGUH 24819 from GGU 420912-3; **b**: *Cristatisporites bellus*, MGUH 24820 from GGU 420912-3; **c**: *Cingulizonates brevispinosus*, MGUH 24821 from GGU 420912-2; **d**: *Discernisporites* spp., MGUH 24822 from GGU 420912-2; **e**: *Densosporites* sp. A, MGUH 24823 from GGU 420912-3; **f**: *Cingulizonates* sp., corroded specimen, MGUH 24824 from GGU 420912-3; **g**: *Tumulispora variverrucata*, MGUH 24825 from GGU 420912-3; **h**: *Simozonotriletes intortus*, MGUH 24826 from GGU 420912-3; **i**: *Rugospora minuta*, MGUH 24827 from GGU 420902-2; **j**: *Knoxisporites stephanephorus*, MGUH 24828 from GGU 420912-3; **k**: *Verrucosisporites eximius*, MGUH 24829 from GGU 420913-3; **l**: *Phyllothecotriletes rigidus*, MGUH 24830 from GGU 420912-2.

inferred for the upper parts of the Sortebakker Formation thus confirm that the region during the late Viséan formed a vast, humid lowland where sedimentation was dominated by meandering river deposits except for local areas along active fault blocks. The northeastward flow directions recorded on Holm Land are comparable to palaeocurrent data from the Finnmark Platform (Bugge *et al.* 1995) which suggests the rivers had their sources in the Greenland Shield and Baltic Shield, respectively. During the late Viséan (NM Biozone time) the Finnmark Platform was transgressed (Bugge *et al.* 1995). So far, evidence of marine deposits has not been recorded from Bjørnøya, Svalbard, North Greenland and East Greenland. However, the relative rise in sea level recorded on the Finnmark Platform may correlate with the shift from uniform floodplain sedimentation to more lacustrine-dominated environments near the top of the Sortebakker Formation.

The biostratigraphic data confirm that the youngest sediments, belonging to the Early Carboniferous rift sequence in North Greenland, are of late Viséan age and are roughly age equivalent to the uppermost parts of the lower Traill Ø Group in East Greenland (*sensu* Vigran *et al.* 1999) and the Billefjorden Group of Svalbard and Bjørnøya (Fig. 2). This strongly suggests that the hiatus between the Sortebakker Formation and the overlying Upper Carboniferous sediments of the Kap Jungersen Formation in North Greenland spans roughly the same time interval as the mid-Carboniferous hiatus in East Greenland and on Svalbard (Stemmerik *et al.* 1991), and was most likely caused by the same regional uplift. The intense faulting of the Sortebakker Formation and migration of hot water through the sediments prior to deposition of the overlying Upper Carboniferous sediments may imply movements along the East Greenland fault zone during this event.

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References

Bugge, T., Mangerud, G., Elvebakk, G., Mørk, A., Nilsson, I., Fanavoll, S. & Vigran, J.O. 1995: The Upper Paleozoic succession on the Finnmark Platform, Barents Sea. Norsk Geologisk Tidsskrift **75**, 3–30.

Christiansen, F.G., Piasecki, S. & Stemmerik, L. 1991: Petroleum resources, North Greenland. In: Trettin, H.P. (ed.): Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada **3**, 525–529. Ottawa: Geological Survey of Canada (also The geology of North America **E**, Geological Society of America).

Clayton, G., Coquel, R., Doubinger, J., Gueinn, K.J., Loboziak, S., Owens, B. & Streel, M. 1977: Carboniferous miospores of western Europe: Illustration and zonation. Mededelingen Rijks Geologische Dienst **29**, 71 pp.

Dalhoff, F. & Stemmerik, L. 2000: Depositional history of the fluvial Lower Carboniferous Sortebakker Formation, Wandel Sea Basin, eastern North Greenland. In: Stemmerik, L. (ed.): Palynology and deposition in the Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin **187,** 65–77 (this volume).

Gjelberg, J.G. 1981: Upper Devonian (Famennian) – Middle Carboniferous succession of Bjørnøya. Norsk Polarinstitutt Skrifter **174**, 1–67.

Håkansson, E., Heinberg, C. & Stemmerik, L. 1981: The Wandel Sea Basin from Holm Land to Lockwood Ø, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **106**, 47–64.

Hansen, J.M. & Gudmundsson, L. 1979: A method for separating acid-insoluble microfossils from organic debris. Micropaleontology **25**, 113–117.

Higgs, K., Clayton, G. & Keegan, J.B. 1988: Stratigraphic and systematic palynology of the Tournaisian rocks of Ireland. Geological Survey of Ireland Special Paper **7**, 83 pp.

Kaiser, H. 1970: Die Oberdevon-Flora der Bäreninsel 3. Mikroflora des höheren Oberdevons und des Unterkarbons. Palaeontographica B **129**, 71–124.

Nathorst, A.G. 1911: Contributions to the Carboniferous flora of Northeastern Greenland. Meddelelser om Grønland **43**(12), 34 pp.

Neves, R., Gueinn, K.J., Clayton, G., Ioannides, N.S., Neville, R.S.W. & Kruszewska, K. 1973: Palynological correlations within the Lower Carboniferous of Scotland and Northern England. Transactions Royal Society of Edinburgh **69**(2), 23–70.

Playford, G. 1962: Lower Carboniferous microfloras of Spitsbergen. Part 1. Palaeontology **5**, 550–618.

Playford, G. 1963: Lower Carboniferous microfloras of Spitsbergen. Part 2. Palaeontology **5**, 619–678.

Steel, R.J. & Worsley, D. 1984: Svalbard's Post-Caledonian strata: An atlas of sedimentational patterns and palaeogeographic evolution. In: Spencer, A.M. *et al.* (eds): Petroleum geology of the north European margin, 109–135. London: Graham & Trotman for the Norwegian Petroleum Society.

Stemmerik, L. & Håkansson, E. 1989: Stratigraphy and depositional history of the Upper Palaeozoic and Triassic sediments in the Wandel Sea Basin, eastern and central North Greenland. Rapport Grønlands Geologiske Undersøgelse **143**, 21–44.

Stemmerik, L. & Worsley, D. 1989: Late Palaeozoic sequence correlations, North Greenland, Svalbard and the Barents Shelf. In: Collinson, J.D. (ed.): Correlation in hydrocarbon exploration, 99–111. London: Graham & Trotman for the Norwegian Petroleum Society.

Stemmerik L. & Worsley, D. 1995: Permian history of the Barents Shelf area. In: Scholle, P.A., Peryt, T.M. & Ulmer-Scholle, D.S. (eds): The Permian of northern Pangea: sedimentary basins and economic resources **2**, 81–97. Berlin: Springer Verlag.

Stemmerik, L., Vigran, J.O. & Piasecki, S. 1991: Dating of late Paleozoic rifting events in the North Atlantic: new biostratigraphic data from the uppermost Devonian and Carboniferous of East Greenland. Geology **19**, 218–221.

Stemmerik, L., Christiansen, F.G., Piasecki, S., Jordt, B., Marcussen, C. & Nøhr-Hansen, H. 1993: Depositional history and petroleum geology of the Carboniferous to Cretaceous sediments in the northern part of East Greenland. In: Vorren, T.O. *et al.* (eds): Arctic geology and petroleum potential. Norwegian Petroleum Society (NPF) Special Publication **2**, 67–87. Amsterdam: Elsevier.

Stemmerik, L., Dalhoff, F. & Nilsson, I. 1994: Petroleum-geological studies in eastern North Greenland. In: Henriksen, N. (ed.): Express report, eastern North Greenland and North-East Greenland, 69–76. Unpublished report, Geological Survey of Greenland, Copenhagen, Denmark.

Stemmerik, L., Dalhoff, F., Larsen, B.D., Piasecki, S. & Thomsen, C. 1995a: Stratigraphical and structural studies of the Wandel Sea Basin. In: Higgins, A.K. (ed.): Express report eastern North Greenland and North-East Greenland, 127–132. Unpublished report, Geological Survey of Greenland, Copenhagen, Denmark.

Stemmerik, L., Dalhoff, F. & Nilsson, I. 1995b: Petroleum geology and thermal maturity of eastern North Greenland – a new energy research project. Rapport Grønlands Geologiske Undersøgelse **165**, 49–52.

Stemmerik, L., Dalhoff, F., Larsen, B.D., Lyck, J., Mathiesen, A. & Nilsson, I. 1998: Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin **180**, 55–62.

Sullivan, H.J. 1965: Palynological evidence concerning the regional differentiation of Upper Mississippian floras. Pollen et Spores **7**, 539–563.

Vigran, J.O., Stemmerik, L. & Piasecki, S. 1999: Stratigraphy and depositional evolution of the uppermost Devonian – Carboniferous (Tournaisian–Westphalian) non-marine deposits in North-East Greenland. Palynology **23**, 115–152.

Depositional history of the fluvial Lower Carboniferous Sortebakker Formation, Wandel Sea Basin, eastern North Greenland

Finn Dalhoff and Lars Stemmerik

The Lower Carboniferous non-marine Sortebakker Formation is restricted to the south coast of Holm Land. It is estimated to exceed 1000 m in thickness and is subdivided by a low-angle disconformity into a lower mudstone-dominated unit (*c.* 335 m) and an upper sand-dominated unit (*c.* 665 m). The lower mudstone-dominated succession consists of stacked 0.5–6 m thick fining-upward cycles of fine- to medium-grained sandstone and mudstone. Cycles in the upper part of the formation are up to 20 m thick. They are dominated by thick tabular sandstones up to 13 m thick overlain by shaly units that resemble those in the lower mudstone dominated cycles. Six facies associations are identified and together describe a fluviatile–lacustrine depositional system. Five of the facies associations characterise different parts of a meandering river-dominated flood plain whereas the sixth facies association represents more permanent lakes.

Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark.
E-mail: fd@geus.dk

Keywords: Carboniferous, depositional environments, North Greenland, Sortebakker Formation, Wandel Sea Basin

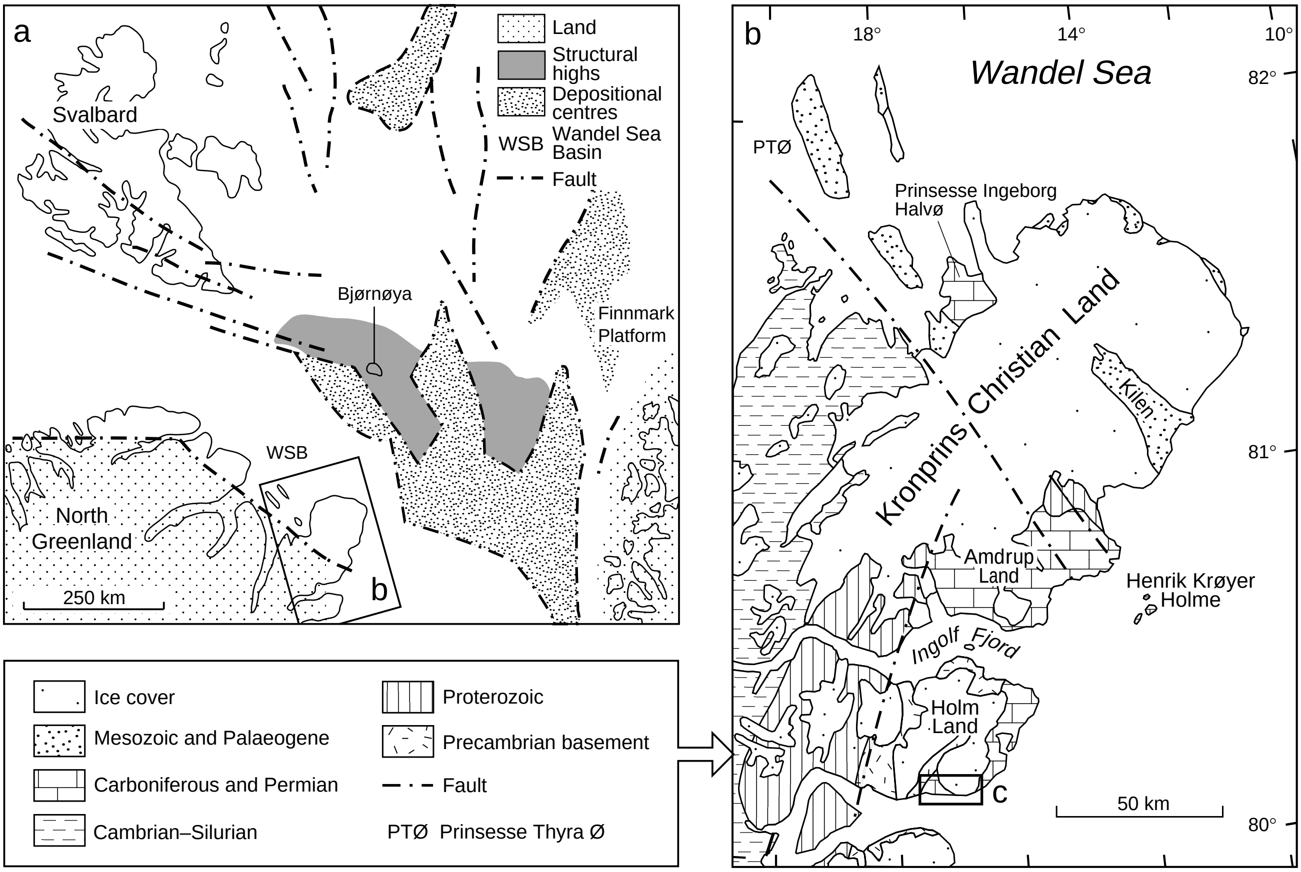
The Lower Carboniferous non-marine Sortebakker Formation in Holm Land, eastern North Greenland (Fig. 1), was deposited during the initial phase of Late Palaeozoic rifting of the northern North Atlantic and the Arctic Ocean. Time equivalent non-marine deposits are known from central East Greenland, Svalbard, western Barents Sea and Arctic Canada (e.g. Steel & Worsley 1984; Gjelberg 1987; Davies & Nassichuk 1988; Stemmerik *et al.* 1991; Bugge *et al.* 1995). Sedimentation took place in a humid climate and in most areas the sedimentary succession dominantly consists of humid-type fluvial deposits with some coal.

The Sortebakker Formation (Stemmerik & Håkansson 1989) consists of approximately 1000 m of stacked fining-upward cycles of fluvial sandstone and mudstone with minor lacustrine deposits in the upper part. The formation is divided by a low-angle disconformity into a lower mudstone-dominated unit (*c.* 335 m thick) composed of 0.5–6 m thick fining-upward cycles and an upper sand-dominated unit (*c.* 665 m thick) composed of up to 10–20 m thick fining-upward cycles. Even finer scale cyclicity is seen within the fine-grained parts of each cycle, and three levels of cyclicity are recognised within the succession.

This paper describes the depositional facies of the Sortebakker Formation and discusses the controls on the different levels of cyclicity seen within this fluvial succession.

Geological setting

In eastern North Greenland, Lower Carboniferous sediments are restricted to Sortebakker on the south coast of Holm Land (Fig. 1; Stemmerik & Håkansson 1989). The Sortebakker Formation is approximately 1000 m thick and rests directly on Precambrian basement. It is unconformably overlain by Upper Carboniferous (Moscovian), marine deposits (Håkansson & Stemmerik 1984). The Sortebakker Formation is internally subdivided by a low-angle, possibly tectonically induced disconformity. Prior to deposition of the overlying marine sediments, the formation was faulted and eroded; modelling data indicate that as much as 2000 m of


a
Svalbard
Land
Structural highs
Depositional centres
WSB Wandel Sea Basin
Fault
Bjørnøya
Finnmark Platform
WSB
North Greenland
250 km
b
b
18°
14°
10°
Wandel Sea
82°
81°
80°
PTØ
Prinsesse Ingeborg Halvø
Kronprins Christian Land
Kilen
Amdrup Land
Henrik Krøyer Holme
Ingolf Fjord
Holm Land
c
50 km
Ice cover
Mesozoic and Palaeogene
Carboniferous and Permian
Cambrian–Silurian
Proterozoic
Precambrian basement
Fault
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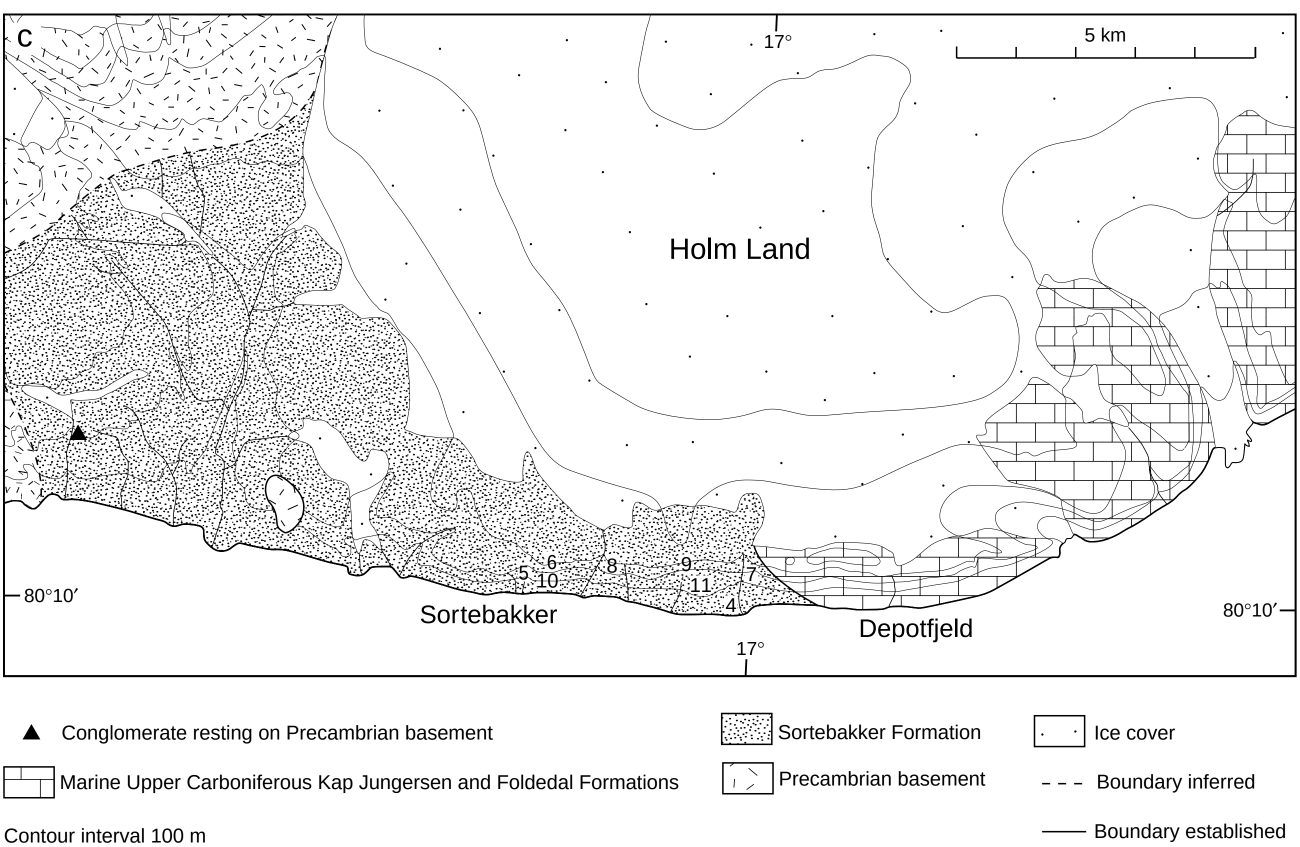
c
17°
5 km
Holm Land
5
6
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4
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80°10′
Sortebakker
Depotfjeld
17°
Conglomerate resting on Precambrian basement
Marine Upper Carboniferous Kap Jungersen and Foldedal Formations
Contour interval 100 m
Sortebakker Formation
Precambrian basement
Ice cover
Boundary inferred
Boundary established

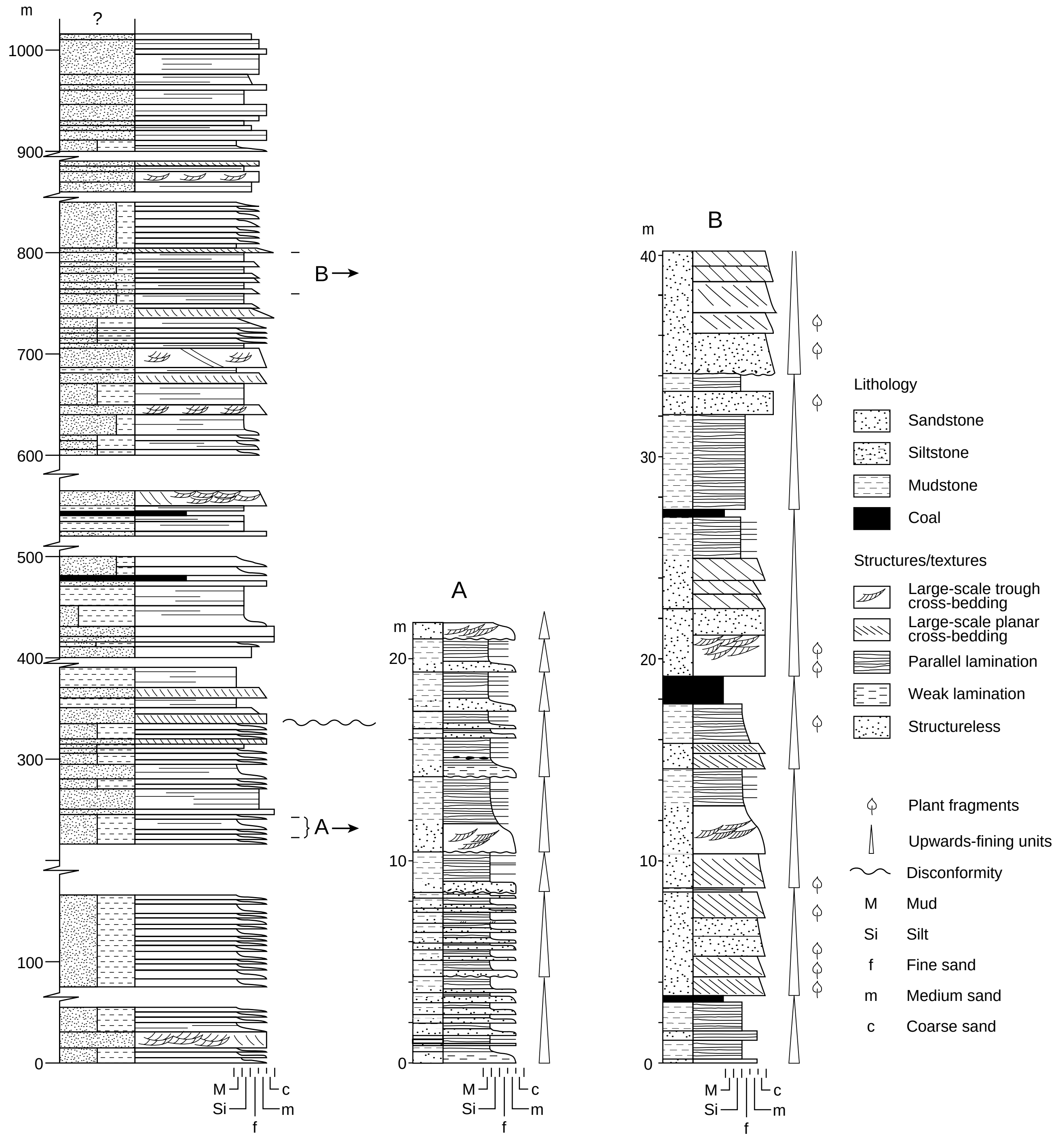
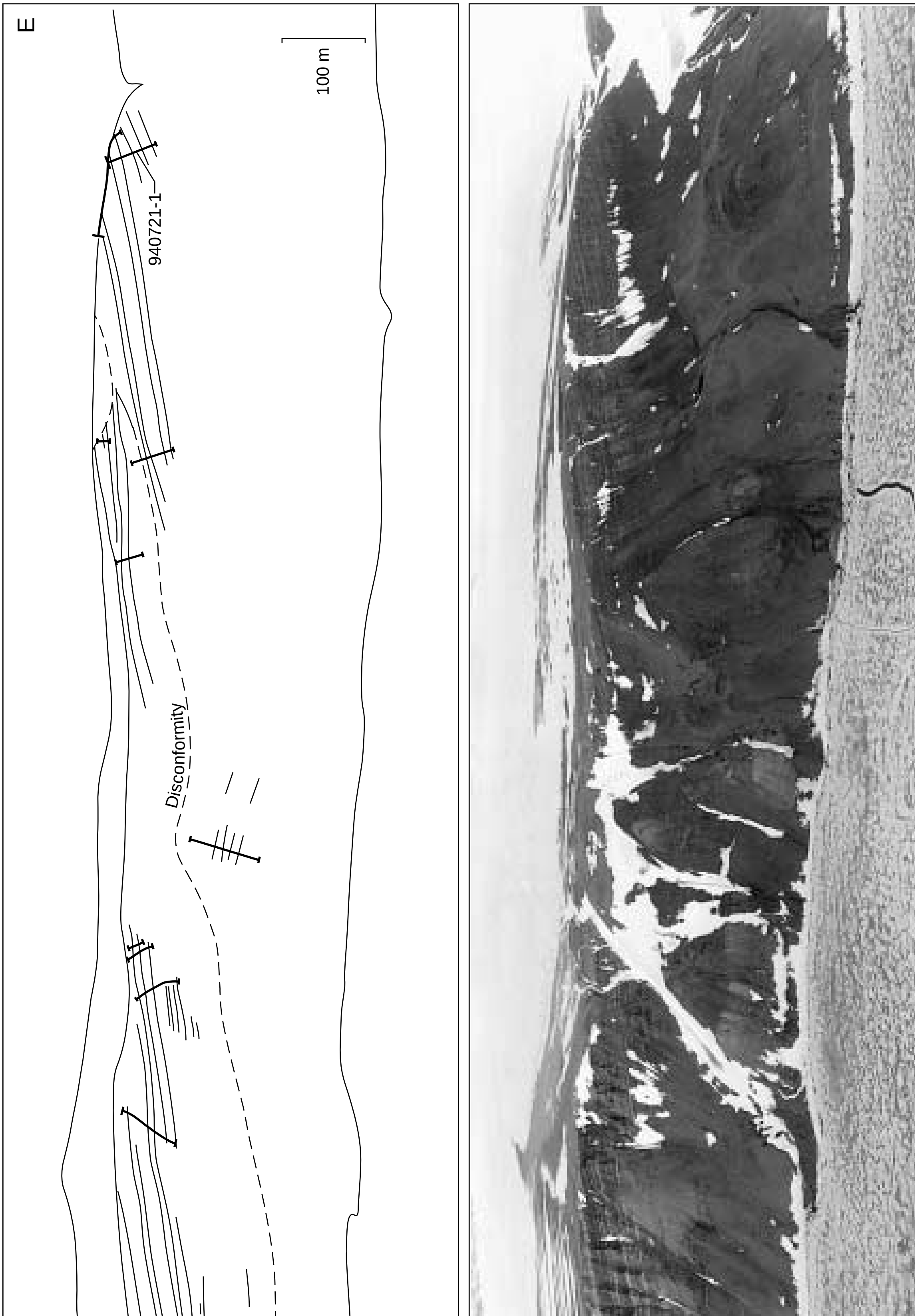


Fig. 1. **a**: Map with major structural outline and palaeogeographic reconstruction of the Wandel Sea and Barents Sea regions. Modified from Stemmerik & Worsley (1995). **b**: Simplified geological map of Kronprins Christian Land and environs showing the distribution of Upper Palaeozoic sediments. Modified from Stemmerik *et al.* (1994). For location, see Fig. 1a. **c**: Geological map of the southern part of Holm Land showing distribution of the Sortebakker Formation. **Numbers 4–11** indicate the locations of Figs 4–11. For location, see Fig. 1b.

Fig. 2. Composite sedimentological log from the Sortebakker Formation with two representative detailed vertical sections comprising several complete cycles as indicated by the triangles. **A**: from lower part; **B**: from upper part above the disconformity. For location of sections, see Fig. 3. The total thickness is estimated to exceed 1000 m.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E
100 m
940721-1
Disconformity

sediments were eroded away prior to the Late Carboniferous transgression (Stemmerik *et al.* 1998). The upper part of the formation is dated as Viséan (Dalhoff *et al.* 2000, this volume) which means that deposition was coeval with that of the lower part of the Traill Ø Group in East Greenland (Vigran *et al.* 1999) and the Billefjorden Group on Svalbard and its equivalents in the Barents Sea.

Sedimentation apparently took place in an isolated basin separated to the west by a major fault zone from the stable Greenland craton and to the north bounded by a basement high (Fig. 1). The western part of the depositional basin is not preserved and the studied outcrops are believed to represent deposition in the axial zone of the basin. The basin forms part of the Late Palaeozoic – Mesozoic rift system which started to form between Greenland and Norway during the Early Carboniferous (Stemmerik *et al.* 1991). The rift system extended westwards between North Greenland and Svalbard to the Sverdrup Basin of Arctic Canada and eastwards through the Nordkapp Basin in the Barents Sea. During Early Carboniferous times, non-marine sedimentation dominated within the rift system and marine deposits were limited to the Finnmark Platform in the easternmost parts of the rift (Bugge *et al.* 1995).

Sedimentary facies

Thirty-two sedimentological sections through various parts of the Sortebakker Formation in the coastal cliffs of Sortebakker form the basis for this study (Fig. 2). Correlation of individual sections is based on tracing beds in the field and on photographs. The outcrops allow firm lateral correlation of individual channel sands for approximately 500 m in the lower part of the succession and for more than 1000 m in the upper part (Fig. 3). Six facies associations are defined, five of which characterise different parts of a meandering river system and one facies association represents lacustrine sedimentation.

Facies association 1: channel sandstones

This association includes three different channel sandstones: (1) thin, tabular 0.5–4 m thick multistorey sandstone units, (2) thick, up to 13 m thick, units of tabular multistorey sandstone, and (3) isolated, laterally confined sandstone units.

(1) Thin tabular sandstone units. The thin tabular sandstones consist of 0.5–4 m thick, laterally persistent units

Fig. 3. Extensive fining-upward fluvial deposits from the eastern part of the Sortebakker Formation in a coastal cliff section between Sortebakker and Depotfjeld from 17°W and 1.5 km westward in Fig. 1. The line drawing shows correlation of the lower surface of some of the thickest channel sandstones. The dashed line marks the disconformity dividing the formation into a lower mudstone-dominated unit and an upper sand-dominated unit. The thick lines mark the positions of measured sedimentary sections. The detailed vertical section **A** in Fig. 2, forms the lower part of the sedimentary section 940721-1. Section **B** of Fig. 2 is located westward of the outcrops shown on the photograph. The cliff is approximately 350 m high.

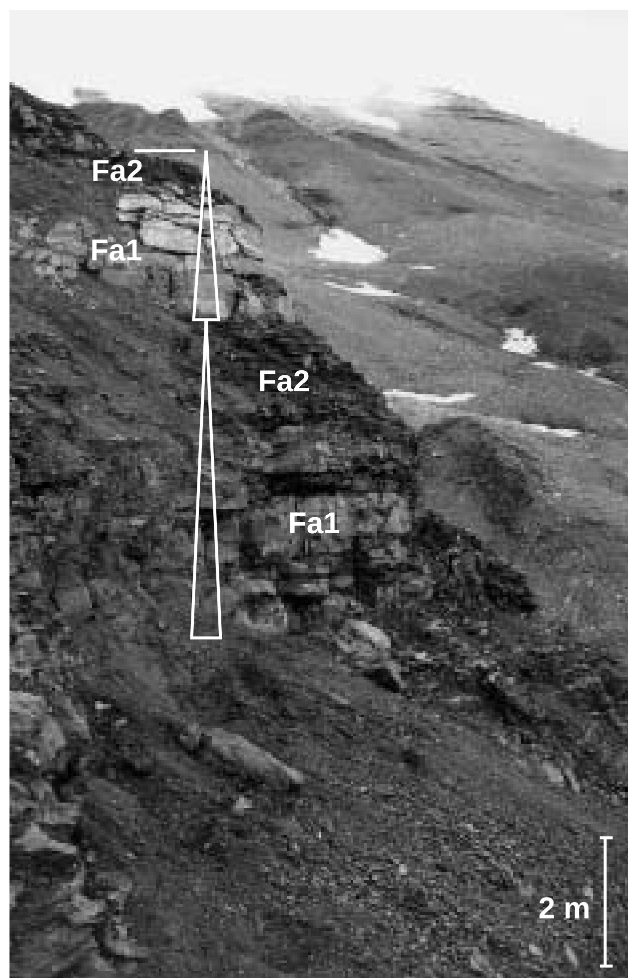


Fig. 4. Thin tabular sandstones of facies association 1 (**Fa1**) overlain by sediments of facies association 2 (**Fa2**), together forming stacked fining-upward fluvial cycles. Individual cycles are indicated by the triangles. Thickness of section shown on photograph is approximately 13 m. For location, see Fig. 1c.

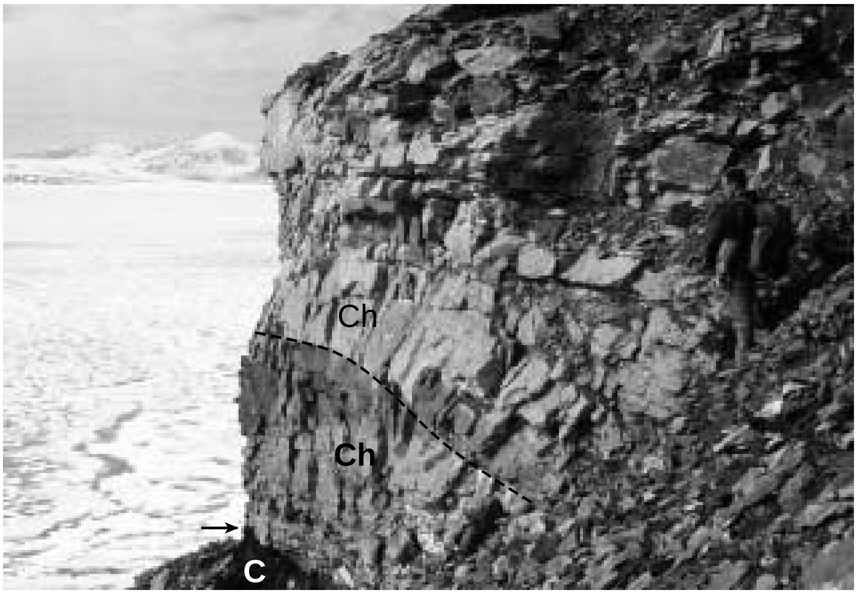


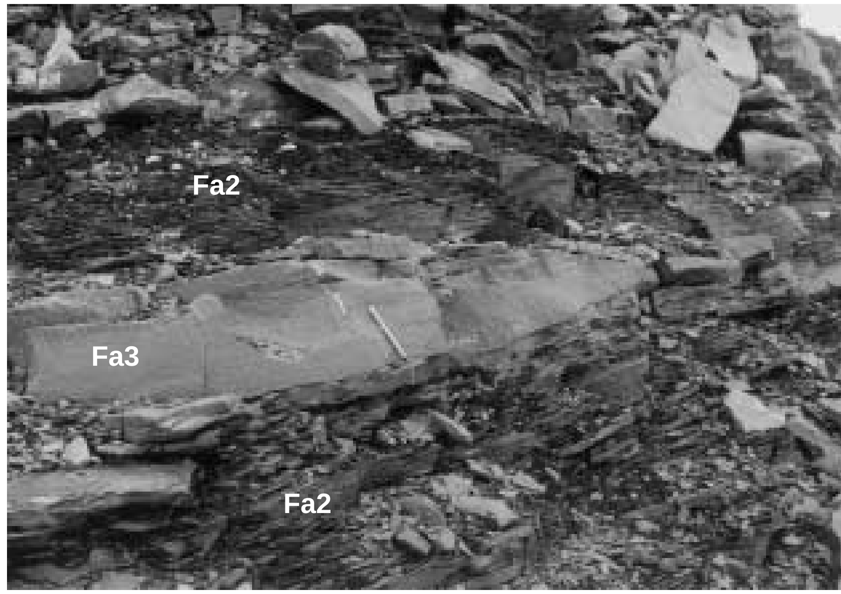
Fig. 5. Thick tabular sandstone unit (**Ch**: facies association 1) composed of two storeys, erosively overlying coals (**C**) from facies association 6. The arrow marks the erosive base of the channel sandstone. Person for scale. For location, see Fig. 1c.

of medium- to fine-grained sandstone. Individual beds may be up to 1 m thick, but are usually 0.3–0.5 m thick. The base of the sandstone bed is usually sharp and erosional, commonly with mudflake clasts. The sandstone is typically structureless; in rare cases, intervals of cross-bedded or cross-laminated sandstone occur. This facies is capped by mudstone or siltstone belonging to facies association 2 (Figs 3, 4). This facies is limited to the lower part of the formation, below the disconformity.

Fig. 6. Laterally confined sandstone units of facies association 1, marked by arrows, enclosed by fine-grained lake deposits. Thickness of illustrated section is approximately 65 m. For location, see Fig. 1c.

(2) Thick tabular sandstone units. The thick tabular sandstones form up to 13 m thick fining-upward units grading from medium- to fine-grained sandstone to mudstone; the thickest units are laterally persistent and have been traced for more than a kilometre (Figs 3, 5). Pebbly lag deposits occur rarely at the base of the sandstone where they consist of coarse-grained pebbly (< 1 cm) sandstone with large coaly plant fragments. Sedimentary structures are rare and mainly consist of trough cross-bedding. The sandstone passes upwards into fining-upward units of medium- to fine-grained sandstone. They are well sorted, light grey to yellowish in colour and display weak bedding, up to 2 m thick, but usually about 0.5 m thick. The sandstones may be structureless, or show planar or trough cross-bedding. The planar cross-bedding is seen as tabular sets; cosets of weak cross-bedded sandstone occur locally. Intraformational clasts of mudstone and silty mudstone, plant remains and groove marks are observed in the sandstone, and in places tree stumps in growth position are seen to extend vertically up from the underlying beds. The upper part of these sandstones display ripple cross-lamination and, locally, internal deformation structures such as convolute bedding. Mudstones or siltstones belonging to facies association 2 generally cap this facies. Transition from

Fig. 7. Wedge-shaped structureless sandstone bed of crevasse splay origin (**Fa3**: facies association 3) embedded in floodplain deposits of facies association 2 (**Fa2**) composed of laminated to weakly laminated mudstone. Pencil for scale. For location, see Fig. 1c.



facies association 1 to facies association 2 can be either gradational or abrupt. The thick tabular sandstone units are only present above the disconformity and inferred epsilon cross-stratification has only been observed in one, inaccessible locality.

(3) Isolated, laterally confined sandstone units. These sandstone bodies have a maximum thickness of 3–15 m and a maximum width of up to 25 m (Fig. 6). They have a concave and undulating erosional base, often showing groove marks, and they commonly consist of a basal coarse-grained to conglomeratic lag which passes upwards into medium-grained sandstone. The medium-grained sandstone consists of massive, planar and trough cross-bedded sets, 0.5–2 m thick, with abundant poorly preserved coaly plant fragments in the lower part. The erosional basal contact is typically incised into sediments belonging to facies association 4, and there is commonly a sharp boundary between the isolated, laterally confined sandstone units (1) and association 4.

Measurement of palaeocurrent directions in the three types of channel sandstone was only possible in a few places. Groove casts trend NE–SW and ripple cross-lamination indicates palaeocurrents towards the northeast.

Interpretation. The multistorey sandstones (1) and (2) are interpreted as fluvial channel deposits. The sandstones represent lateral and vertical accretion and the multistorey character of the sandstone bodies is the result of lateral meander loop migration during net aggradation (Allen 1963; Bridge 1975; Bridge & Diemer 1983; Diemer & Belt 1991). Each storey is a single point bar deposit which was superimposed on a previous point bar deposit (e.g. Bridge 1975). The scarcity of sedimentary structures and the presence of convolute bedding may reflect rapid fall out from suspension (Collinson & Thompson 1989), or it may be an artifact due to difficulties observing internal structures. However, the presence of *in situ* tree stumps indicates limited erosion and deposition from suspension. The thickness variations of the sandstone units probably reflect variable discharge with time, implying that the thickness of the channel deposits roughly equals the maximum depth of the channel, although the degree of accretion and erosion are also factors controlling bed thickness. A meandering system is the most obvious considering the scarcity of planar tabular cross-bedding which is typically produced by bars in sandy braided systems (Gersib & McCabe 1981); angular and trough-shaped cross-bedding are interpreted as the product of migration of dunes and sandwaves (Collinson & Thompson 1989).

The laterally confined sandstone units (3) are interpreted as channel-fill deposits from a fixed channel. Fixed channels produce laterally restricted sand ribbons commonly isolated in finer grained sediment (Collinson 1986). The infilling of sand enclosed by finer deposits suggests a combined load stream with a high suspended load. Furthermore, it implies a gradual waning of flow in the channel so bedload transport persisted approximately to the time of abandonment (Allen 1964; Collinson 1986).

Facies association 2: overbank fines

Description. This facies association comprises up to 10 m thick units of laminated to weakly laminated mudstone and siltstone interbedded with thin-bedded structureless sandstone and parallel-laminated silty sandstone (Fig. 7). In the lowermost part of the formation rare 0.5–3 cm thick coal streaks occur within this facies. The overbank fines association has a transitional or planar to irregular base and comprises mainly fining-upward units with flaser and lenticular bedding. Locally, coarsening-upward units are observed. The sandstone beds are 0.5–10 cm thick with wavy or planar lower and upper boundaries. Successions of this type usually overlie the channel sandstone of facies association 1. Poorly preserved plant fragments are the only fossils recorded in this association. The facies association can be traced laterally for more than a kilometre.

Interpretation. Facies association 2 records deposition of fine material from suspension and is closely comparable to facies 6 of Fielding (1984). Deposition took place in interchannel areas. The fine-grained units represent the result of vertical accretion of floodplain deposits. The thin intercalations of massive and ripple cross-laminated sandstone represent infrequent overbank flooding, where bedload capacity was sufficient to transport sand material into the flood basin areas (Fielding 1984; Farrell 1987; Diemer & Belt 1991). The coarsening-upward units are interpreted to represent infilling of the interchannel areas by fine-grained splay sediments as minor delta lobes. The thin coal streaks are thought to represent detrital organic matter transported into the interchannel areas during flooding (Alexander & Gawthorpe 1993).

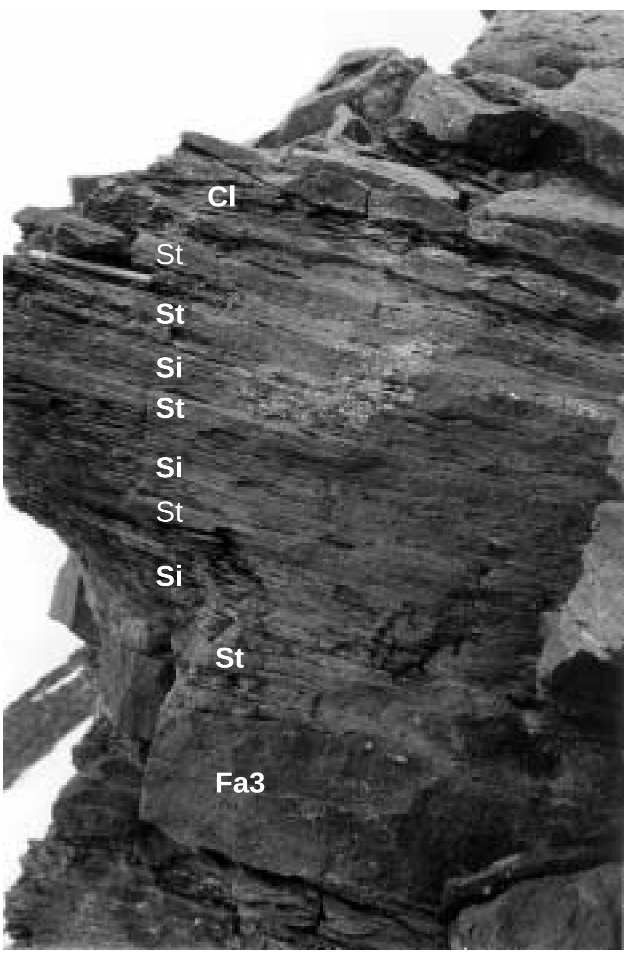


Fig. 8. Interbedded fine-grained sandstone (**St**) and siltstone (**Si**) from facies association 4 overlying a thin-bedded unit of fine-grained sandstone from facies association 3 (**Fa3**). Notice cross-lamination (**Cl**) above the pencil. For location, see Fig. 1c.

Facies association 3: crevasse splay sandstones

Description. Facies association 3 comprises up to 5 m thick units of composite medium- to fine-grained sandstone. Individual beds are up to 1.5 m thick and they locally contain lens-shaped clasts of mudstone up to 10 cm across (Fig. 7). The base is sharp, planar or wavy and erosional. The sandstone is structureless or planar cross-bedded, laminated or ripple cross-laminated. Flattened coaly clasts of plant debris and tree stumps are sometimes preserved, but no other fossils have been found. Individual beds are often wedge-shaped; when stacked into thicker units, they form tabular sheets. The thickest units are laterally persistent for more than 500 m along the cliff exposure and no channel forms are recognised. However, the sandstone may split laterally into 10–40 cm thick beds, alternating with mudstone and siltstone from facies association 2. In a few places, above the disconformity, structureless beds up to 40 cm thick are seen to be recumbently folded whilst bedding above and below are undisturbed.

Interpretation. The sediments were deposited by unconfined erosional flows. The stacked sandstones were deposited in a fluctuating discharge regime during several flood pulses. Comparable sediments have been described by McKee *et al.* (1967), Tunbridge (1981) and Fielding (1984). Tunbridge (1981) inter-

Fig. 9. Fine-grained sandstone with desiccation cracks (facies association 5). The hammer is 32 cm long. For location, see Fig. 1c.

preted laterally persistent sandy sediments with bed thickness of 0.4–2.5 m arranged in stacked sequences and with no indication of channelling having formed during high-stage flood deposition of sand followed by rapid waning of flow, with little or no low-stage reworking. The sediments represent vertical accretion at some distance from a feeder channel and are interpreted as crevasse splay deposits. The recumbently folded beds are interpreted as the result of syndepositional slump movements on the basis of the undisturbed nature of the bedding below and above.

Facies association 4: levee heteroliths

Description. Facies association 4 comprises thinly bedded heterolithic units, up to 0.9 m thick, consisting of weakly laminated or non-laminated mudstone to siltstone alternating with fine-grained sandstone. Such units commonly succeed sediments of facies association 1 (Fig. 8). The sandstone sets are generally 1–2 cm thick, massive or weakly cross-laminated, followed by 2–12 cm thick lamina sets of rippled siltstone to fine-grained sandstone. Only rare plant fragments have been observed. Locally this facies association forms coarsening-upward sequences in which sandstones become dominant towards the top. In one section the heterolithic units are arranged in multistorey sequences up to 10 m thick separated by up to 0.5 m thick erosional beds of sandstone. These sandstone beds are structureless or horizontally planar or ripple cross-laminated with an erosional base.

This facies association is difficult to trace laterally; it either interfingers with sediments of facies association 2 or is cut by sediments of facies association 1.

Interpretation. These units are interpreted as levee sediments where each sedimentary rhythm represents a flood event. Fielding (1984), Diemer & Belt (1991), and Platt & Keller (1992), among others, have described similar sediments were the heterolithic deposition is interpreted to represent variation in discharge. The coarsening-upward trend is considered to reflect infilling of interchannel areas by growth or encroachment of the levee. The erosionally based sandstone beds represent sediment-laden floods from the crevasse splay association and the scarcity of rootlets suggests subaqueous deposition (Fielding 1984).

Facies association 5: lake

Description. Facies association 5 consists of dark brown to reddish brown laminated to non-laminated mudstone and silty mudstone sequences up to 28 m thick. Poorly preserved plant fragments are common. Horizons enriched with iron and iron-rich concretions are locally present. Thin, sharp-based beds (5–10 cm) of structureless, laminated and ripple cross-laminated, fine-grained silty sandstone beds are common in these mudstones. They occasionally show desiccation cracks (Fig. 9).

This association is laterally persistent over several hundreds of metres. The lateral transition is not clearly

Fig. 10. A thick coal bed with thin intercalated fine-grained sandy beds overlain by thick tabular sandstone units (2) of facies association 1. Person for scale. For location, see Fig. 1c.

observed but the sediments seem to wedge out laterally. Facies association 5 is cut by laterally restricted, sharp-based channel deposits of facies association 1 (Fig. 6).

Interpretation. The uniform fine grain size and the scarcity of current generated structures suggest that facies association 5 was deposited from suspension in protected basins and accordingly this facies association is interpreted to represent shallow lake deposits. The thin sandstone beds represent distal flood deposits or events of lowered lake level and the basins were periodically subaerially exposed as indicated by the occurrence of desiccation cracks.

Facies association 6: swamp

Description. This facies association is composed of thin, generally less than 1 m thick, coal and shaly coal beds. Thin beds (< 0.1 m) of mudstone or silty mudstone and ripple-laminated or horizontal planar-laminated fine-grained sandstones are occasionally present within the coal (Fig. 10). The coal is black to brownish black with sparse rootlet horizons. Locally, vertical tree stumps in growth position are seen to penetrate upwards into the overlying sediments. Facies association 6 can only be traced laterally for about 200 m.

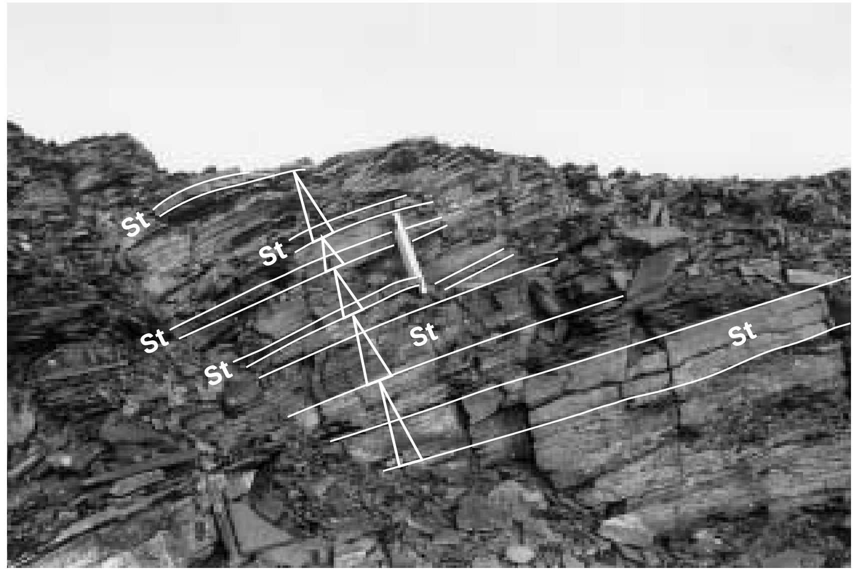
Interpretation. This association probably represents the organic deposits of peat swamps (Fielding 1984). The swamp evolved through the prolific growth of vegetation on the shallow submerged and abandoned surfaces of lake infills and channels. Whether these coals are entirely autochthonous is impossible to determine because of the scarcity of rootlet horizons below and within facies association 6 as a whole. The thickness and distribution of the coals may indicate an autocyclic origin whereas relatively thin and discontinuous coal seams can be interpreted to reflect local sedimentary control by the channels (Belt *et al*. 1992). The thin intercalated clastic beds are the result of overbank sedimentation in the swamp area (McCabe 1984).

Depositional environment

The lack of evidence of marine proximity or evidence of tidal current processes, the abundance of plant remains including *in situ* stems and coal beds and the stacking pattern of the six facies associations suggest deposition in a fluviatile sedimentary environment. The individual fining-upward successions and their characteristic sedimentary structures cannot be taken as proof of a meandering fluvial environment (Miall 1992). However, the overall stacking patterns and the distribution of facies associations 1–4 and 6 are in accordance with other inferred ancient meandering river deposits (e.g. Allen 1965; Leeder 1973; Puigdefabregas & Van Vliet 1978; Bridge & Diemer 1983; Diemer & Belt 1991; Alexander & Gawthorpe 1993), and the sediments are thought to represent a complete fossil meander belt where the sandstones represent the individual active channels.

Amalgamation of the channel sandstones reflects downstream progradation of the meanders in association with aggradation. The channel and floodplain

Fig. 11. Fine-grained sandstones (**St**) and silty mudstones from facies association 2 arranged in a cyclic pattern. Notice the overall fining-upward trend. The ruler as scale is 20 cm long. For location, see Fig. 1c.



deposits are interpreted to represent sedimentation in channels of moderate to high sinuosity on the adjacent floodplain. The channel sandstones are thought to have been deposited in moderately high sinuosity streams based on the few channel bodies observed. The finer sediments in facies associations 2 to 6 are laterally and vertically associated with facies association 1 and accumulated as flood basin, crevasse splay, levee, shallow lake and swamp deposits. The thick flood basin sequences probably reflect a more stable flood basin area, distant from the main meander belts, where stream channels had only minor influence on sedimentation. The final shift towards mixed lacustrine and fluvial deposition reflects a change in base level possibly due to increased rates of subsidence, changes in sediment supply or increased precipitation and thereby raised ground water level.

If the thickness of the sandstones corresponds to original channel depth (Collinson 1986), the maximum channel depths were in the order of 3 to 13 m for the upper part of the formation. The lower half of the formation is dominated by facies association 2 suggesting deposition from rivers with an even larger amount of suspended load leading to more extensive flood basin deposits. The channels were shallower than in the upper part with a maximum depth of *c.* 4 m.

Cyclicity

Two orders of cyclicity can be seen in the Lower Carboniferous succession. The thickest cycles consist of interbedded channel sandstones and overbank fines. Each cycle starts with lateral accretion or avulsion, and scouring of the underlying beds, followed by infilling of the channel or part of it by vertical accretion of sandstone. The cycle is terminated by overbank fines that are erosively overlain by sandstones of the following cycle.

Cycle thickness is 0.5–6 m below the disconformity with an average thickness around 2 m. Cycles from the upper part of the succession range from 3 to 20 m with an average around 11 m. They are dominated by thick tabular channel sandstones up to 13 m thick. This change in cycle thickness is abrupt and apparently reflects a shift from a broad distant floodplain, where the meandering stream channels had limited influence on sedimentation, to a more proximal or laterally confined floodplain where channels were more frequent. The change in cycle thickness and the associated shift from mudstone-dominated cycles below the disconformity to sand-dominated cycles above suggest an analogy with the 1st order cycles in alluvial sediments of Schumm (1977), McLean & Jerzykiewicz (1978) and Wescott (1993) and may be related to tectonic disturbance. Syntectonic disturbance is also indicated by the recumbent slump folds in facies association 3. This disturbance may have led to changes in base level followed by changes in discharge, sediment supply and the river transport capacity.

Cyclicity on an even finer scale is represented in the overbank fines. Each cycle consists of a basal thin-bedded, fine-grained sandstone followed by massive to planar or ripple cross-laminated, fine-grained silt and silty mudstone (Fig. 11). Cycle thickness ranges from a few tens of centimetres to about 1 m. These cycles represent vertical accretion deposits and are interpreted to be of autocyclic origin (McLean & Jerzykiewicz 1978; Farrell 1987). This type of cyclicity is comparable to the 3rd order cyclicity of McLean & Jerzykiewicz (1978) and the 3rd and 4th order cycles of Schumm (1977) and Wescott (1993).

Conclusions

The Sortebakker Formation consists of a variety of facies that together characterise deposition on a floodplain. The sediments stack in a cyclic fashion with a shift through time from thin mudstone-dominated cycles to thick sand-dominated cycles; the uppermost part of the succession consists of mixed fluvial and lacustrine deposits. The 1st order cyclicity that led to the development of an angular disconformity, is interpreted to have been allogenetic in origin. It was related to major changes in accommodation space and is thought to have been created by tectonic movement. The cyclicity below and above the disconformity is interpreted to have been controlled by autocyclic processes. The fining-upward fluvial cycles are interpreted to record unhindered meandering of a river across a floodplain under conditions of steady subsidence and sediment supply (e.g. Friend 1961; Allen 1964). This kind of cyclicity is referred to as 2nd order cyclicity by McLean & Jerzykiewicz (1978) and as 3rd order cyclicity by Schumm (1977) and Wescott (1993). Allocyclic mechanisms such as climatic fluctuations and base level changes are reported to produce cyclicity equivalent to that observed in the Sortebakker Formation, and these mechanisms may alternatively explain the observed patterns.

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References

Alexander, J. & Gawthorpe, R.L. 1993: The complex nature of a Jurassic multistorey, alluvial sandstone body, Whitby, North Yorkshire. In: North, C.P. & Prosser, D.J. (eds): Characterization of fluvial and aeolian reservoirs. Geological Society (London) Special Publications **73**, 123–142.

Allen, J.R.L. 1963: The classification of cross-stratified units, with notes on their origin. Sedimentology **2**, 93–114.

Allen, J.R.L. 1964: Studies in fluviatile sedimentation: Six cyclothems from the Lower Old Red Sandstone, Anglo-Welsh Basin. Sedimentology **3**, 163–198.

Allen, J.R.L. 1965: Fining-upwards cycles in alluvial successions. Geological Journal **4**, 229–246.

Belt, E.S., Sakimoto, S.E.H. & Rockwell, B.W. 1992: A drainage-diversion hypothesis for the origin of widespread coal beds in the Williston Basin: examples from Paleocene strata, eastern Montana. In: Scholes, M.A. & Vuke-Foster, S.M. (eds): Coal geology of Montana. Special Publication of Montana Bureau of Mines and Geology **102**, 21–60.

Bridge, J.S. 1975: Computer simulation of sedimentation in meandering streams. Sedimentology **22**, 3–43.

Bridge, J.S. & Diemer, J.A. 1983: Quantitative interpretation of an evolving ancient river system. Sedimentology **30**, 599–623.

Bugge, T., Mangerud, G., Elvebak, G., Mørk, A., Nilsson, I., Fanavoll, S. & Vigran, J.O. 1995: The Upper Palaeozoic succession on the Finnmark Platform, Barents Sea. Norsk Geologisk Tidsskrift **75**, 3–30.

Collinson, J.D. 1986: Alluvial sediments. In: Reading, H.G. (ed.): Sedimentary environments and facies, 2nd edition, 20–62. Oxford: Blackwell Scientific Publication.

Collinson, J.D. & Thompson, D.B. 1989: Sedimentary structures, 2nd edition, 207 pp. London: Unwin Hyman.

Dalhoff, F., Vigran, J.O. & Stemmerik, L. 2000: Stratigraphy and palynology of the Lower Carboniferous Sortebakker Formation, Wandel Sea Basin, eastern North Greenland. In: Stemmerik, L. (ed.): Palynology and deposition in the Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin **187**, 51–63 (this volume).

Davies, G.R. & Nassichuk, W.W. 1988: An Early Carboniferous (Viséan) lacustrine oil shale in Canadian Arctic Archipelago. American Association of Petroleum Geologists Bulletin **72**, 8–20.

Diemer, J.A. & Belt, E.S. 1991: Sedimentology and paleohydraulics of the meandering river systems of the Fort Union Formation, southeastern Montana. Sedimentary Geology **75**, 85–108.

Farrell, K.M. 1987: Sedimentology and facies architecture of overbank deposits of the Mississippi River, False River region, Louisiana. In: Ethridge, F.G., Flores, R.M. & Harvey, M.D. (eds): Recent developments in fluvial sedimentology. Society of Economic Paleontologists and Mineralogists Special Publication **39**, 111–120.

Fielding, C.R. 1984: Upper delta plain lacustrine and fluviolacustrine facies from the Westphalian of the Durham coalfield, NE England. Sedimentology **31**, 547–567.

Friend, P.F. 1961: The Devonian stratigraphy of north and central Vestspitsbergen. Proceedings of the Yorkshire Geological Society **33**, 77–118.

Gersib, G.A. & McCabe, P.J. 1981: Continental coal-bearing sediments of the Port Hood Formation (Carboniferous), Cape Linzee, Nova Scotia, Canada. In: Ethridge, F.G. & Flores, R.M. (eds): Recent and ancient nonmarine depositional environments. Society of Economic Paleontologists and Mineralogists Special Publication **31**, 95–108.

Gjelberg, J. 1987: Early Carboniferous graben style and sedimentation response, Svalbard. In: Miller, J., Adams, A.E. & Wright, V.P. (eds): European Dinantian environments, 93–113. Chichester: John Wiley.

Håkansson, E. & Stemmerik, L. 1984: Wandel Sea Basin – the North Greenland equivalent to Svalbard and the Barents Shelf. In: Spencer, A.M. *et al.* (eds): Petroleum geology of the north European margin, 97–107. London: Graham & Trotman for the Norwegian Petroleum Society,

Leeder, M. 1973: Sedimentology and palaeogeography of the Upper Old Red Sandstone in the Scottish Border Basin. Scottish Journal of Geology **9**, 117–144.

McCabe, P.J. 1984: Depositional environments of coal and coal-bearing strata. In: Rahmani, R.A. & Flores, R.M. (eds): Sedimentology of coal and coal-bearing sequences. International Association of Sedimentologists Special Publication **7**, 13–42.

McKee, E.D., Crosby, E.J. & Berryhill Jr, H.L. 1967: Flood deposits, Bijou Creek, Colorado, June 1965. Journal of Sedimentary Petrology **37**, 829–851.

McLean, J.R. & Jerzykiewicz, T. 1978: Cyclicity, tectonics and coal: some aspects of fluvial sedimentology in the Brazeau-Paskapoo Formations, Coal Valley area, Alberta, Canada. In: Miall, A.D. (ed.): Fluvial sedimentology. Canadian Society of Petroleum Geology Memoir **5**, 441–468.

Miall, A.D. 1992: Alluvial deposits. In: Walker, R.G. & James, N.P. (eds): Facies models, response to sea level change, 119–142. Ontario: Geological Association of Canada.

Platt, N.H. & Keller, B. 1992: Distal alluvial deposits in a foreland basin setting – the Lower Molasse (Lower Miocene), Switzerland: sedimentology, architecture and palaeosols. Sedimentology **39**, 545–565.

Puigdefabregas, C. & Van Vliet, A. 1978: Meandering stream deposits from the Tertiary of the southern Pyrenees. In: Miall, A.D. (ed.): Fluvial sedimentology. Canadian Society of Petroleum Geologists Memoir **5**, 469–485.

Schumm, S.A. 1977: The fluvial system, 338 pp. New York: John Wiley & Sons.

Steel, R.J. & Worsley, D. 1984: Svalbard's post-Caledonian strata – an atlas of sedimentational patterns and palaeogeographic evolution. In: Spencer, A.M. *et al.* (eds): Petroleum geology of the north European margin, 109–135. London: Graham & Trotman for the Norwegian Petroleum Society.

Stemmerik, L. & Håkansson, E. 1989: Stratigraphy and depositional history of the Upper Palaeozoic and Triassic sediments in the Wandel Sea Basin, central and eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **143**, 21–45.

Stemmerik, L. & Worsley, D. 1995: Permian history of the Barents Shelf area. In: Scholle, P.A., Peryt, T.M. & Ulmer-Scholle, D.S. (eds): The Permian of northern Pangea: sedimentary basins and economic resources **2**, 81–97. Berlin: Springer Verlag.

Stemmerik, L., Vigran, J.O. & Piasecki, S. 1991: Dating of late Paleozoic rifting events in the North Atlantic: new biostratigraphic data from the uppermost Devonian and Carboniferous of East Greenland. Geology **19**, 218–221.

Stemmerik, L., Dalhoff, F. & Nilsson, I. 1994: Petroleum-geological studies in eastern North Greenland. In: Henriksen, N. (ed.): Express report, eastern North Greenland and North-East Greenland, 69–76. Unpublished report, Geological Survey of Greenland, Copenhagen, Denmark.

Stemmerik, L., Dalhoff, F., Larsen, B.D., Lyck, J., Mathiesen, A. & Nilsson, I. 1998: Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin **180**, 55–62.

Tunbridge, I.P. 1981: Sandy high-energy flood sedimentation – some criteria for recognition, with an example from the Devonian of S. W. England. Sedimentary Geology **28**, 79–95.

Vigran, J.O., Stemmerik, L. & Piasecki, S. 1999: Stratigraphy and depositional evolution of the uppermost Devonian–Carboniferous (Tournaisian–Westphalian) non-marine deposits in North-East Greenland. Palynology **23**, 115–152.

Wescott, W.A. 1993: Geomorphic thresholds and complex response of fluvial systems – some implications for sequence stratigraphy. American Association of Petroleum Geologists Bulletin **77**, 1208–1218.

Carboniferous algal microflora, Kap Jungersen and Foldedal Formations, Holm Land and Amdrup Land, eastern North Greenland

Bernard L. Mamet and Lars Stemmerik

A diverse assemblage of calcareous algae was recorded from the Moscovian–Gzelian Kap Jungersen and Foldedal Formations in Amdrup Land and Holm Land. The flora, consisting of 25 species, is dominated by rhodophytes and chlorophytes, most of them similar to or identical with species previously recognised in the Sverdrup Basin of Arctic Canada. One new genus and species, *Groenlandella enigmatica* n.gen. et n.sp., has been erected and is apparently endemic to the Wandel Sea Basin. The composition of the Greenland algal flora indicates that it belongs to the *Uraloporella* flora of the present-day northern hemisphere (Arctic Canada, Svalbard and Arctic Russia).

B.L.M., *Département de géologie, Université de Montréal, C.P. 6128, Succursale Centre-ville Montréal, Québec H3C 3J7, Canada*. Present address: *Laboratoire de Géologie, Université de Bruxelles, 50 avenue F.D. Roosevelt, B-1000 Bruxelles, Belgium*.
L.S., *Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark*. E-mail: *ls@geus.dk*

Keywords: Calcareous algae, Carboniferous, *Groenlandella*, North Greenland, *Uraloporella*, Wandel Sea Basin

The Upper Palaeozoic microflora of the present-day northernmost hemisphere is relatively well studied in Arctic Canada and the Timan–Pechora Basin of Arctic Russia (Fig. 1; Korde 1950, 1951; Maslov 1956, 1962, 1976; Maslov & Kulik 1956; Chuvashov 1974; Mamet *et al.* 1979, 1987; Chuvashov *et al.* 1993). In contrast, little information is available from the Wandel Sea Basin of North Greenland. However, calcareous algae are found to be an important constituent of most shallow marine carbonates of the Moscovian Kap Jungersen Formation and the Moscovian–Gzelian Foldedal Formation of Holm Land and Amdrup Land in the southeastern part of the Wandel Sea Basin (Fig. 1).

This paper illustrates the algal microflora from the Upper Carboniferous formations of Holm Land and Amdrup Land (Figs 3–10). Twenty-five taxa are recognised based on observations in more than 300 thin sections of shallow marine carbonates. The flora is best preserved in outcrops in southern Holm Land where the succession is composed of limestones (see *Frontispiece*), and generally more poorly preserved in Amdrup Land where dolomitisation is widespread.

Geological overview

The Upper Carboniferous cyclic shelf carbonates and siliciclastics in Holm Land and Amdrup Land represent the feather-edge of a large depositional area that covered the marginal parts of northern Greenland, the North-East Greenland Shelf and the Barents Sea. During the Late Carboniferous, this region was located approximately 25° north of the equator (Fig. 1; Golonka *et al.* 1994). Westwards, the area was connected to the Sverdrup Basin of Arctic Canada and it extended to the east to include the Timan–Pechora Basin of Arctic Russia (Fig. 1). The Upper Carboniferous sediments in Holm Land and Amdrup Land are included in the lower Moscovian Kap Jungersen Formation and the upper Moscovian to Gzelian Foldedal Formation (cf. Stemmerik *et al.* 1996), and they lie unconformably on older Carboniferous non-marine sediments or Caledonian-affected basement (Fig. 2; Håkansson *et al.* 1981). The formations are separated by a major hiatus from Artinskian and younger Permian carbonates (Stemmerik & Elvebakk 1994).

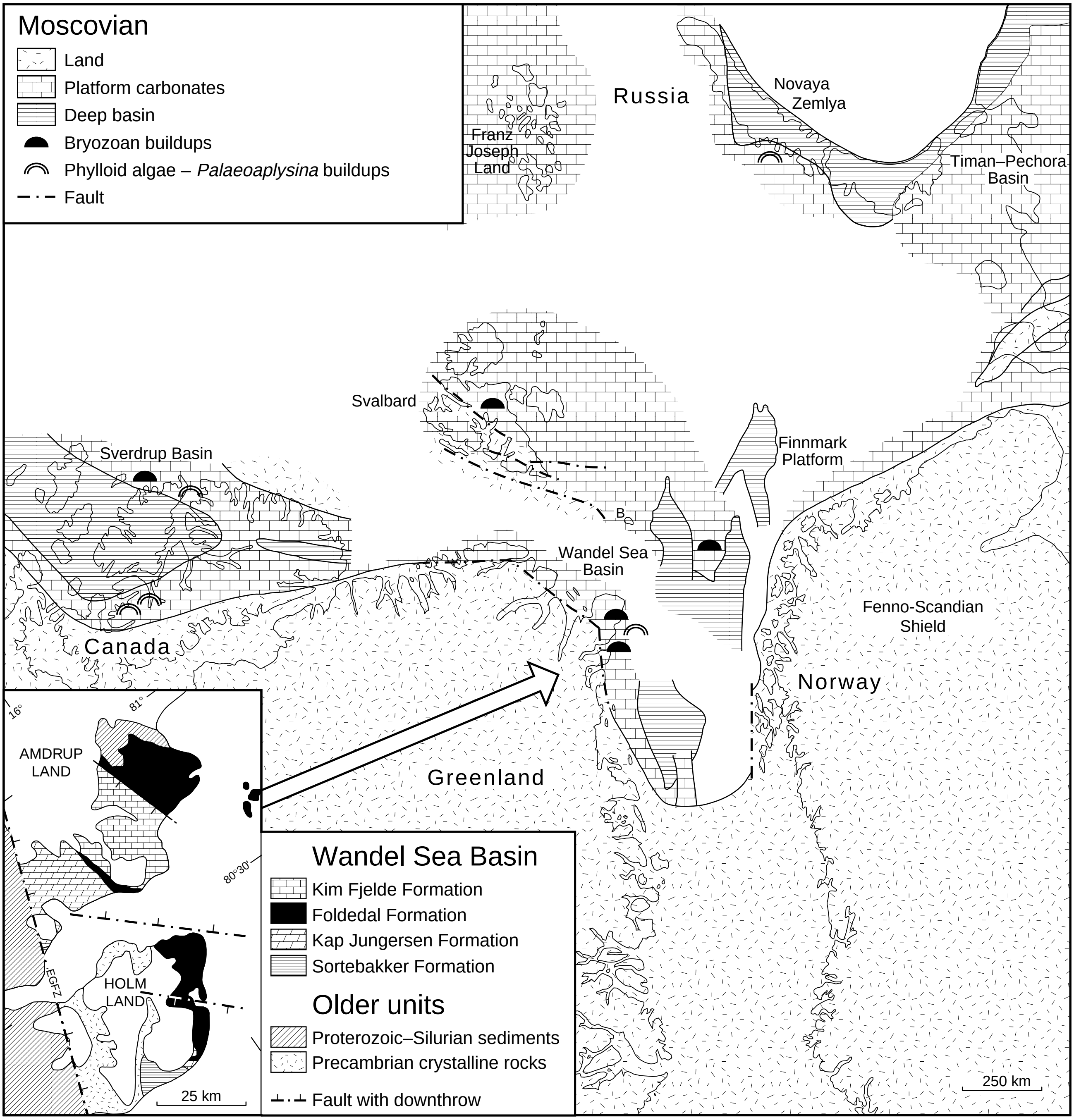
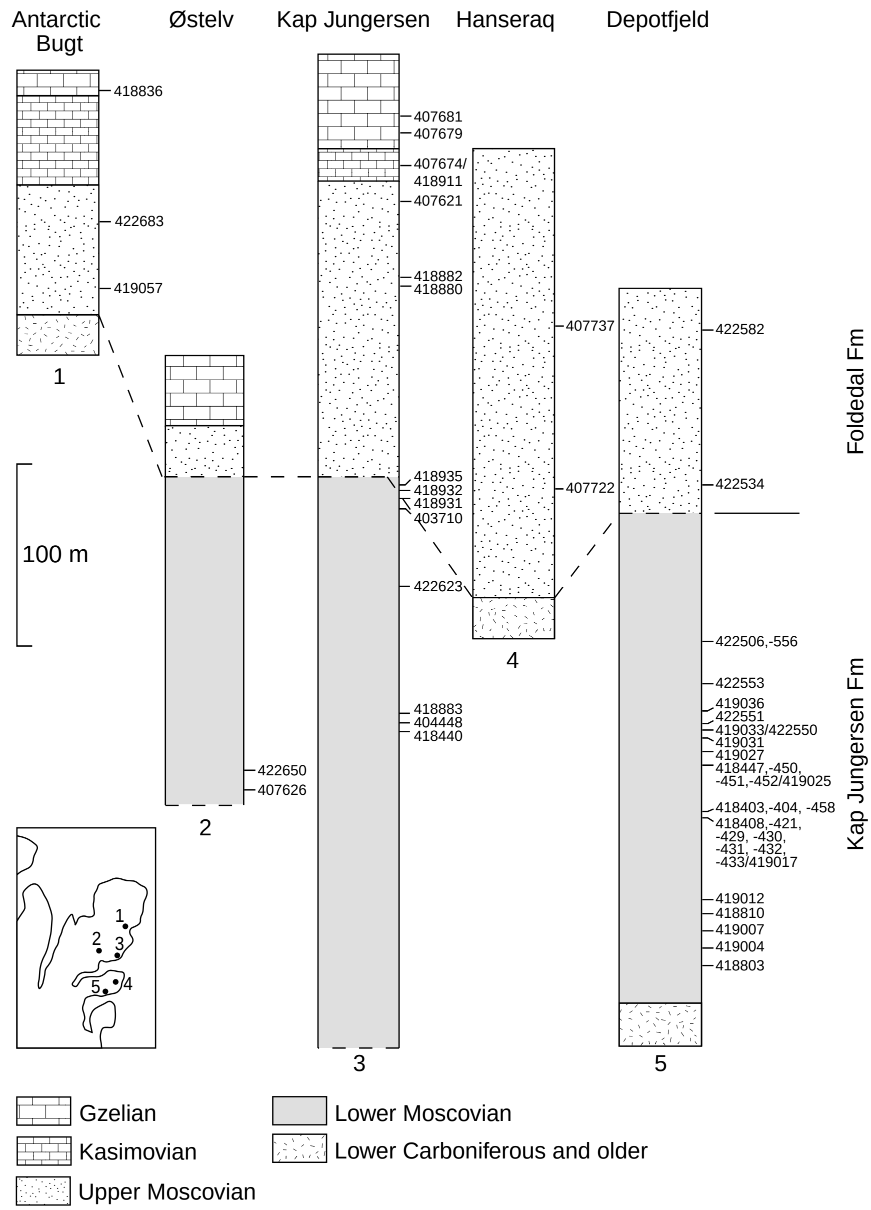


Fig. 1. Upper Carboniferous (Moscovian) palaeogeographic reconstruction of the northern margin of Pangea showing the positions of Wandel Sea Basin, Sverdrup Basin, Svalbard, Timan–Pechora Basin and other deposition sites. **B**: Bjørnøya. The inset map of Holm Land and Amdrup Land shows the outcrops of the Kap Jungersen and Foldedal Formations on which this paper is based; blank areas are ice. **EGFZ**: East Greenland fault zone. Modified from Stemmerik (2000).

Fig. 2. Correlation of the Upper Carboniferous Kap Jungersen and Foldedal Formations in Holm Land and Amdrup Land. The approximate position of investigated samples is shown. Ages based on Nilsson (1994) and V. Davydov & I. Nilsson, written communication (1999). For geological map of Holm Land and Amdrup Land, see Fig. 1.



The succession in southern Holm Land is composed of more than 300 m of stacked, laterally widespread cycles of shallow shelf limestones and siliciclastics, and cyclic limestones in the upper part. Cycles range in thickness from 2 to 20 m and are typically 4-8 m thick. The mixed cycles are composed of a lower unit of open marine mid-shelf to outer-shelf carbonate facies that were deposited during transgressions and early highstands and an upper unit of inner-shelf siliciclastic deposits. Carbonate buildups are absent in southern Holm Land and high energy carbonate sediments are restricted to isolated shoals that received little or no siliciclastic material. Calcareous algae are particularly important as grain producers in the outer-shelf facies while mid-shelf sediments are dominated by fusulinid- and crinoid-rich facies except for the presence of thin discrete tabular units of *Donezella*- and *Beresella*-dominated bafflestones.

In southern Amdrup Land, the succession consists of more than 400 m of stacked shelf carbonates and siliciclastics. Most carbonates are preserved as dolostones and limestones are only common in the upper part. The succession is much more variable in composition than the time-equivalent succession at southern Holm Land. The southern Amdrup Land succession is composed of a series of tabular to wedge-shaped depositional sequences, where the tabular sequences consist of cyclic siliciclastics and carbonates resembling those in southern Holm Land. The wedge-shaped sequences record time intervals where carbonate platforms, with a maximum relief of 50-100 m, covered the eastern part of the area. These platforms include abundant carbonate buildups flanked by biogenic grainstones and appear to have formed in shallower water than observed in southern Holm Land. However, most buildups and platform carbonates have been dolomitised and the preservation of the algal fragments is poor.

Algal flora

The Greenland algal flora, illustrated in Figs 3–10 (arranged at the end of the text, pp. 84–99), belongs to the *Uraloporella* flora of Mamet (1992). The volumetrically most important forms are red ungdarellids with *Ungdarella uralica* (Fig. 7A–D) as the dominant taxon. The other important red algae include *Komia abundans* (Fig. 7E–I), *Stacheoides meandiformis* (Fig. 8E), *Fourstonella*, and *Cuneiphycus*(?) *johnsoni* (Fig. 8G). The green algae are dominated by beresellids. *Beresella* (Fig. 4J, K; Fig. 5B, F–M; Fig. 6A–J, N), *Dvinella* (Fig. 5A; Fig. 6K–M) and *Uraloporella variabilis* (Fig. 4A–I) are present at most levels and form *in situ* or slightly reworked bafflestones. *Donezella lutugini* (Fig. 5C–E) and *Groenlandella enigmatica* n.gen. et n.sp. (Fig. 10A–N) apparently have similar habits, but these genera have a more restricted occurrence in the lower part of the Kap Jungersen Formation in the southern part of Holm Land. The phylloid algae *Ivanovia tenuissima* (Fig. 9A) is locally present but due to pervasive dolomitisation of most carbonate buildups it is not clear to what degree it contributed to the buildups described by Stemmerik & Elvebakk (1994) and Stemmerik (1996) from southern Amdrup Land.

Dasyclads are scarce in the Moscovian part of the succession, but become somewhat more diverse in the Kasimovian and Gzelian. The most common epimastoporid is *Epimastoporella* (Fig. 3F). However, dasyclad cysts, *Calcisphaera* (Fig. 3C), are quite common suggesting that these green algae were more widespread than recognised in this study.

The prolific *Tubiphytes obscurus* (here considered as a rhodophyte) (Fig. 9H–J) is particularly common in the Gzelian part of the succession where it encrusts sponges and stabilises the sediment. Another strong encruster, *Archaeolithophyllum missouriensum* (Fig. 8A–D), is usually associated with *Palaeoaplysina* and most common in the younger parts of the succession. Other encrusters like *Claracrusta* (Fig. 9B–F) and *Ellesmerella* sp. (Fig. 3B) form complex oncolites (‘*Osagia*’) and are particularly common in reworked grainstones along the margins of small carbonate platforms in the southern part of Amdrup Land.

Other important features to note are the scarcity of Cyanobacteria–Cyanophyta (Porostromata–Spongiostromata), the absence of girvanelles and the poor representation of nodular codiaceans and red solenoporids. The latter is represented by scattered *Parachaetetes* sp. (Fig. 8F).

Finally, the enigmatic *Microcodium* (Fig. 10O–P) is restricted to the uppermost parts of the Gzelian succession in southern Amdrup Land where it records a period of freshwater influx into the carbonate platform. This limited occurrence of *Microcodium* is surprising when considering its abundance in the time-equivalent successions of Svalbard and the Sverdrup Basin (e.g. Mamet *et al.* 1987).

The described microflora is strikingly similar to that observed in the Canadian Arctic (Mamet *et al.* 1987). Practically all species have their counterparts in the Sverdrup Basin. The Greenland flora also shows a progressive increase of green algae from the mid-Carboniferous to Early Permian as recognised in the Sverdrup Basin (Mamet *et al.* 1987). The Sverdrup Basin flora appears more diverse, but this is due to a number of unrelated factors. The present description of the Greenland flora is based on a rather limited number of thin sections with a biased environmental distribution of open marine shallow-water to semi-restricted facies and few deep-water, shallow reefal and restricted carbonate facies.

Taxonomy

A new genus and species is described from this algal assemblage.

Division Chlorophyta

Genus *Groenlandella* n. gen.

Type genus. Groenlandella enigmatica n. gen., n. sp.

Derivation of name. From latinisation of Grønland (Greenland).

Diagnosis. Thallus elongated, cylindrical, with outer constrictions, slowly tapering, with random dichotomy. Cells suboval, hemispheric, with binary arrangement. Wall calcareous, yellowish, hyaline, perforated by thin, unramified pores.

Comparison. The puzzling dichotomy is reminiscent of the Tournaisian *Kulikaella* Berchenko 1981. However, the poorly illustrated type of that genus (*Kulikaella unistratosa* Berchenko 1981) does not show constrictions.

Possible binary cell division is shown in the Serpukhovian *Kulikaella partita* Ivanova 1990, as illustrated by Ivanova & Bogush (1992) and Chuvashov *et al.* (1993). It is not obvious that *K. partita* belongs to Berchenko's genus.

The constrictions are similar to those of *Pseudokamaena* Mamet *in* Petryk & Mamet (1972), but the cells of that Palaeoberesella are undivided.

The Viséan *Frustulata* Saltovskaya 1984 also displays erratic dichotomy, but the shape of the cells is different.

In conclusion, the systematic position of *Groenlandella* (and that of *Kulikaella* and *Frustulata*) is not clear. They could be distant cousins of the Palaeoberesellidae, but the type of vertical cell division is not known among that tribe, and we cannot confidently assign it to that tribe.

Occurrence. Groenlandella is known only from the lower Moscovian Kap Jungersen Formation in western Depotfjeld, southern Holm Land (Figs 1, 2).

Groenlandella enigmatica **n.gen., n.sp.**
Fig. 10A–N

Holotype. MGUH 24758 from GGU 418429, Fig. 10F, here designated.

Derivation of name. From the puzzling systematic position.

Description. Thallus subcylindrical, ranging from 1000 to 2000 µm. Successions of 11–12 cells are between 900 and 1200 µm in length. Stouter thalli have 20 cells and are up to 1500–1800 µm long. Diameter increases slowly from 60 to 70 µm. Cells hemispherical, binary, divided by vertical partition that simulates a central 'axis' in thin section. Wall hyaline, ranging from 10 to 20 µm in thickness, finely perforated. Dichotomy very variable, sometimes at very low angle other times at right angle and erratic.

Occurrence. Same as genus.

Conclusions

Almost all of the reported specimens illustrated here are similar or identical to those described from the same stratigraphic level in the Sverdrup Basin of Arctic Canada. This is not surprising as the Wandel Sea Basin and the Sverdrup Basin were located at the same palaeolatitude in the Late Palaeozoic and formed part of a huge carbonate-dominated shelf along the northern margin of Pangaea (Golonka *et al.* 1994). The most obvious difference between the studied area of northern Greenland and other Arctic basins, is the limited occurrence of phylloid algal buildups in Greenland. Most buildups in southern Amdrup Land have the original fabric destroyed as a result of dolomitisation. Therefore, phylloids might have been more common than indicated by this study. The absence of phylloid algal, and other types of buildups in southern Holm Land, is in accordance with the updip position of the exposed section in a siliciclastic-influenced environment.

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Figures 3 to 10 are arranged on pages 84–99 followed by *References*.

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Fig. 3. Miscellaneous Moscovian–Kasimovian algae from Kap Jungersen and Depotfjeld.

A: *Mitcheldaenia distans* (Conil & Lys 1964). Intertwined tubes forming a bafflestone associated with bacterial pellets and a sponge. MGUH 24681 from GGU 403710, Kap Jungersen Formation, Moscovian, × 27.

B: Close up of a bafflestone-bindstone (‘*Osagia*’) composed of algal tubules (*Ellesmerella* sp.), sessile foraminifera (‘*Nubecularia*’), bacterial crusts and vagrant globivalvulinids. MGUH 24682 from GGU 404448, × 70.

C: Calcisphere-rich (*Calcisphaera pachysphaerica* (Pronina 1963) pelletoidal packstone. A few beresellid algae and endothyrid foraminifera. MGUH 24683 from GGU 418458, × 27.

D: *Anthracoporellopsis machaveii* Maslov 1956. MGUH 24684 from GGU 419007, × 70.

E: *Anthracoporellopsis machaveii* Maslov 1956. MGUH 24685 from GGU 422551, × 70.

F: *Epimastoporella japonica* (Endo 1951). MGUH 24686 from GGU 418880, × 27.

G: *Epimastoporella japonica* (Endo 1951). MGUH 24687 from GGU 418880, × 27.

H: *Epimastoporella hunzaensis* (Zanin Buri 1965). MGUH 24688 from GGU 407674, × 70.

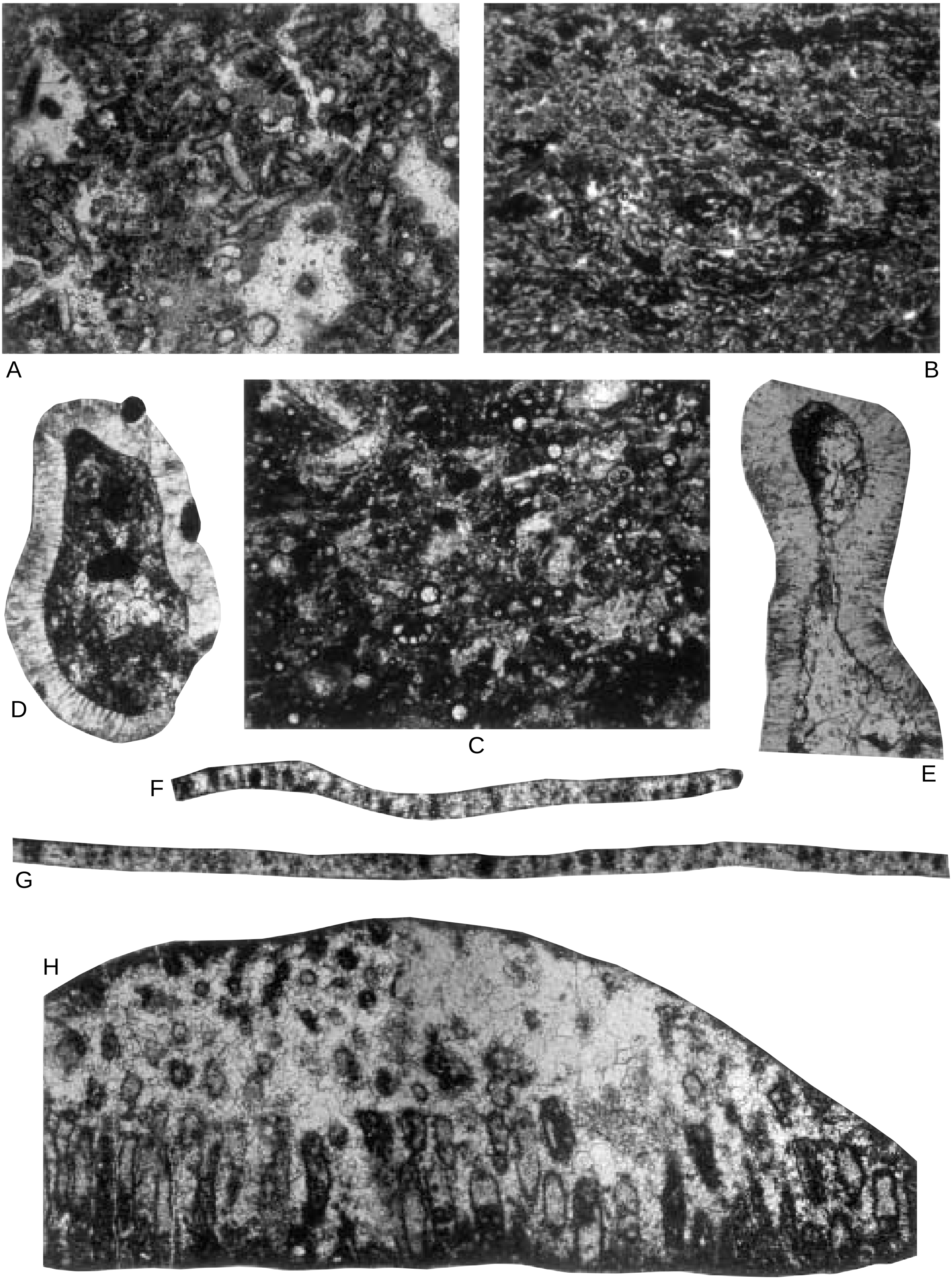
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Fig. 4. Moscovian beresellids from Depotfjeld and Antarctic Bugt.
A: *Uraloporella variabilis* Korde 1950. MGUH 24689 from GGU 419033, × 70.
B: *Uraloporella variabilis* Korde 1950. MGUH 24690 from GGU 422683, × 108.
C: *Uraloporella variabilis* Korde 1950. MGUH 24691 from GGU 419036, × 70.
D: *Uraloporella variabilis* Korde 1950. MGUH 24692 from GGU 419057, × 108.
E: *Uraloporella variabilis* Korde 1950. MGUH 24693 from GGU 419036, × 70.
F: *Uraloporella variabilis* Korde 1950. MGUH 24694 from GGU 419036, × 70.
G: *Uraloporella variabilis* Korde 1950. MGUH 24695 from GGU 418452, × 27.
H: *Uraloporella variabilis* Korde 1950. MGUH 24696 from GGU 418452, × 27.
I: *Uraloporella variabilis* Korde 1950. MGUH 24697 from GGU 418452, × 27.
G–I display erratic interruptions of the micritised pore rows that are probably related to the presence of parietal conceptacles.
J: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24698 from GGU 418447, × 70.
K: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24699 from GGU 419025, × 70.

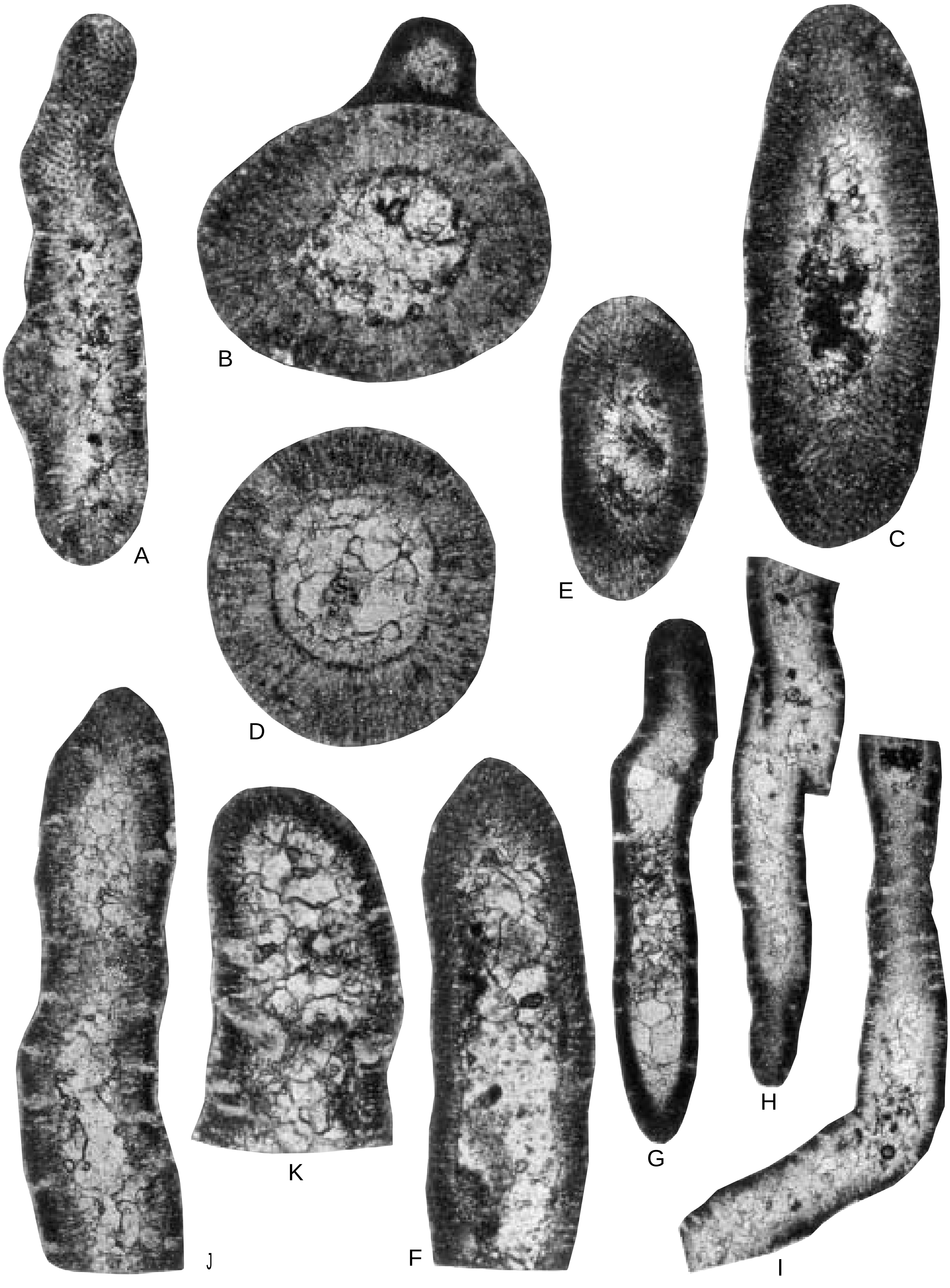
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Fig. 5. Moscovian beresellids from Depotfjeld, Kap Jungersen and Østelv.

A: A dense thicket of *in situ* beresellid algae (*Dvinella bifurcata* Maslov & Kulik 1956). MGUH 24700 from GGU 422582, × 27.

B: Reworked *Beresella* ex.gr. *B. ishimica* Kulik 1964 boundstone. Transportation is minimal as the external mucilaginous coating (now, clear cement) is preserved. MGUH 24701 from GGU 419017, × 70.

C: *Donezella lutugini* Maslov 1929. MGUH 24702 from GGU 419031, × 108.

D: *Donezella lutugini* Maslov 1929. MGUH 24703 from GGU 407626, × 108.

E: *Donezella lutugini* Maslov 1929. MGUH 24704 from GGU 407626, × 108.

F: *Beresella* ex.gr. *B. polyramosa* Kulik 1964. MGUH 24705 from GGU 418931, × 70.

G: *Beresella* ex.gr. *B. polyramosa* Kulik 1964. MGUH 24706 from GGU 419036, × 70.

H: *Beresella* ex.gr. *B. polyramosa* Kulik 1964. MGUH 24707 from GGU 422650, × 70.

I: *Beresella* ex.gr. *B. polyramosa* Kulik 1964. MGUH 24708 from GGU 422553, × 70.

J: *Beresella* ex.gr. *B. polyramosa* Kulik 1964. MGUH 24709 from GGU 419036, × 70.

K: *Beresella translucea* Kulik 1964. MGUH 24710 from GGU 419027, × 70. Note that the thallus has completely dissolved pores and that only the interpores are fossilised. In that state, the fossil is reminiscent of *Palaeoberesella* sp.

L: *Beresella translucea* Kulik 1964. MGUH 24711 from GGU 418440, × 70.

M: *Beresella translucea* Kulik 1964. MGUH 24712 from GGU 419036, × 70.

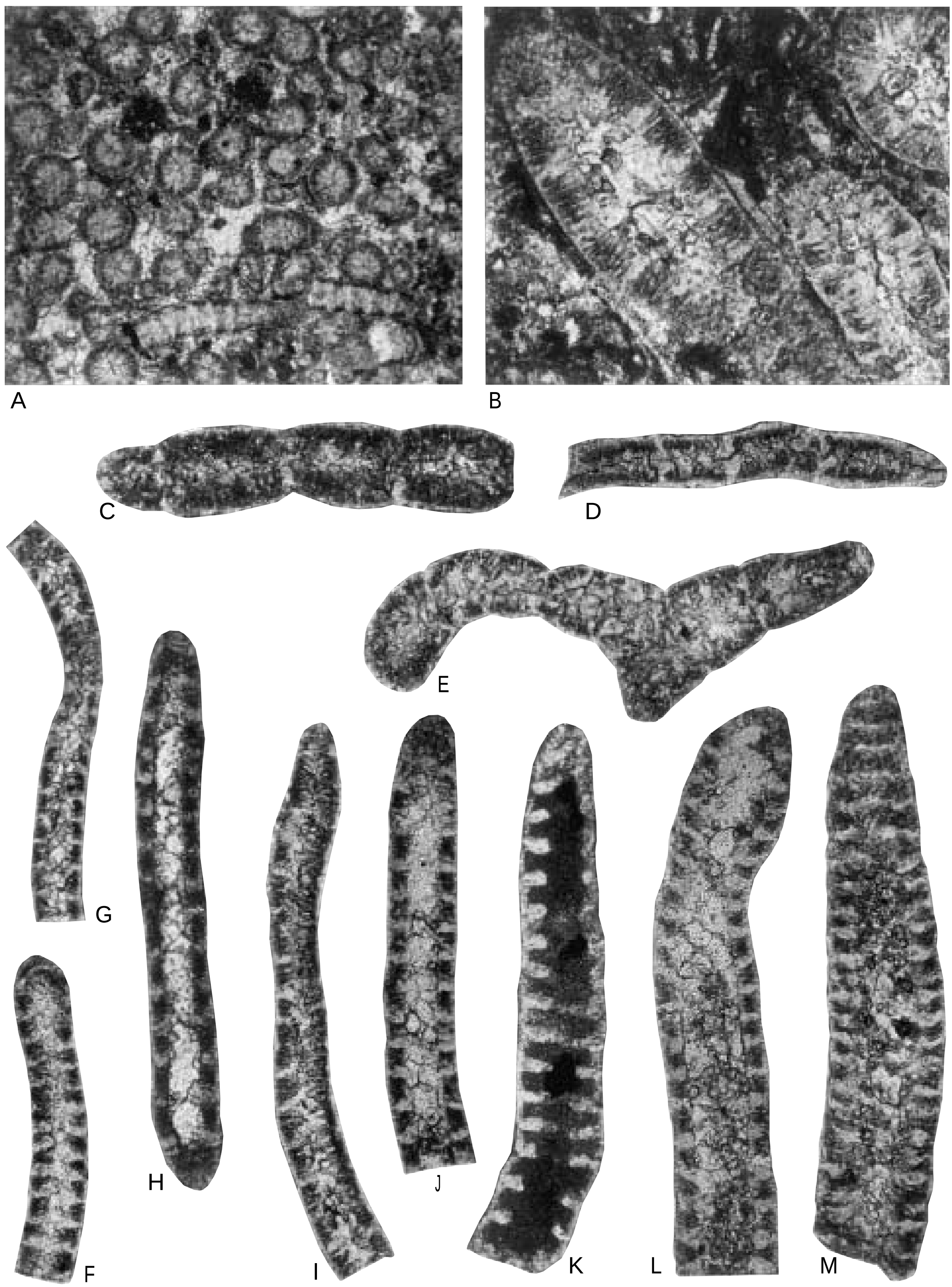
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Fig. 6. Moscovian beresellids from Depotfjeld and Kap Jungersen.
A: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24713 from GGU 418451, × 70.
B: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24714 from GGU 422556, × 70.
C: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24715 from GGU 418447, × 70.
D: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24716 from GGU 418932, × 70.
E: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24717 from GGU 418447, × 70.
F: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24718 from GGU 418403, × 70.
G: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24719 from GGU 418429, × 70.
H: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24720 from GGU 418408, × 70.
I: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24721 from GGU 418421, × 70.
J: *Beresella* ex.gr. *B. ishimica* Kulik 1964. MGUH 24722 from GGU 418450, × 70.
K: *Dvinella comata* Khvorova 1949. MGUH 24723 from GGU 419036, × 70.
L: *Dvinella comata* Khvorova 1949. MGUH 24724 from GGU 422550, × 70.
M: *Dvinella bifurcata* Maslov & Kulik 1956. MGUH 24725 from GGU 418911, × 70.
N: *Beresella* sp. Compare with *Beresella* sp. illustrated from the Canadian Arctic by Mamet & Rudloff 1972, plate V, figs 5–7. MGUH 24726 from GGU 418447, × 70.

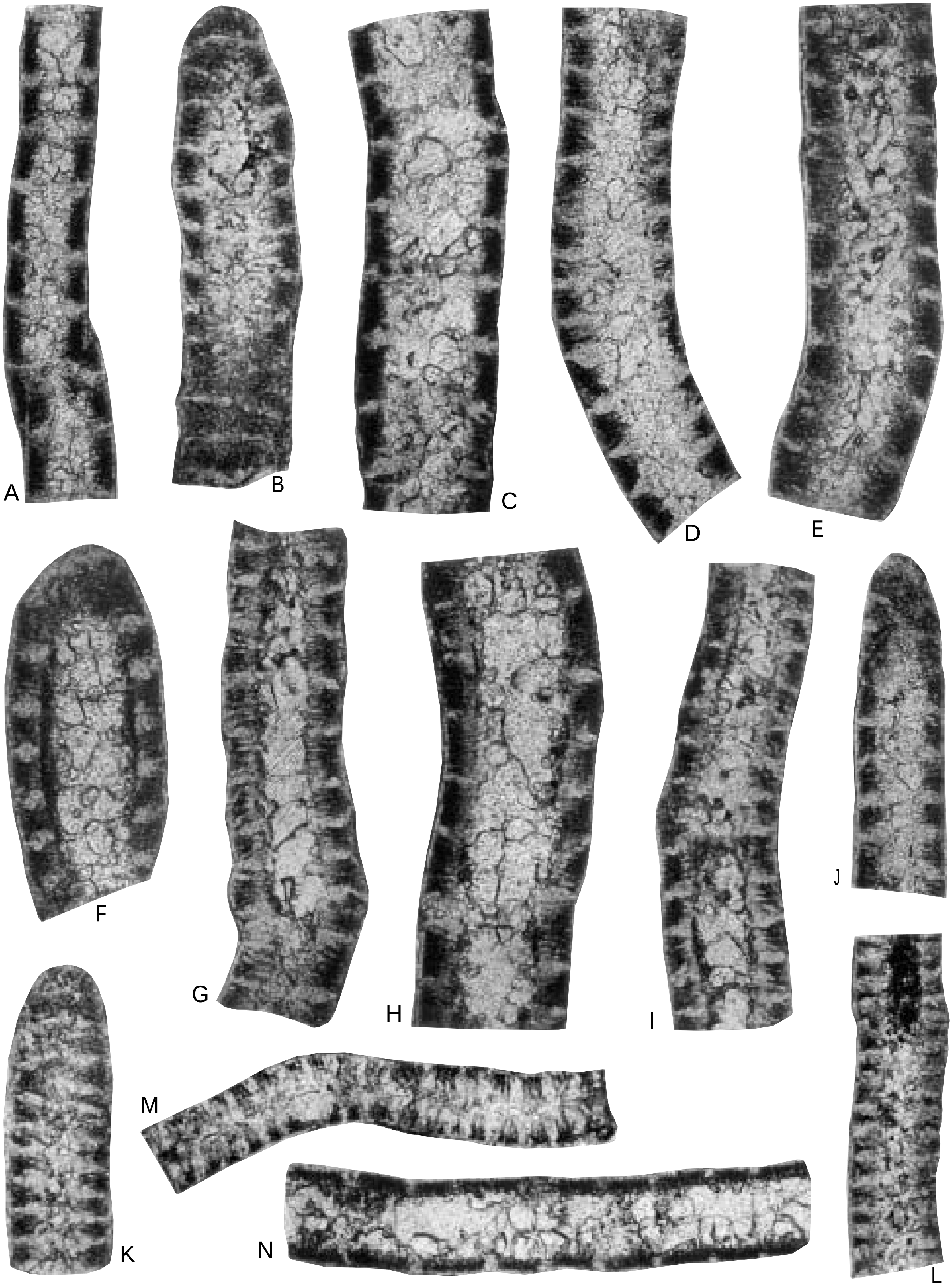
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Fig. 7. Moscovian ungdarellids from Depotfjeld, Hanseraq and Kap Jungersen.
A: *Ungdarella uralica* Maslov 1956. MGUH 24727 from GGU 407737, × 33.
B: *Ungdarella uralica* Maslov 1956. MGUH 24728 from GGU 422623, × 70.
C: *Ungdarella uralica* Maslov 1956. MGUH 24729 from GGU 419004, × 27.
D: *Ungdarella uralica* Maslov 1956. MGUH 24730 from GGU 418810, × 27.
E: *Komia abundans* Korde 1951. MGUH 24731 from GGU 422534, × 70.
F: *Komia abundans* Korde 1951. MGUH 24732 from GGU 422534, × 70.
G: *Komia abundans* Korde 1951. MGUH 24733 from GGU 422534, × 70.
H: *Komia abundans* Korde 1951. MGUH 24734 from GGU 422534, × 46.
I: *Komia abundans* Korde 1951. MGUH 24735 from GGU 422534, × 46.

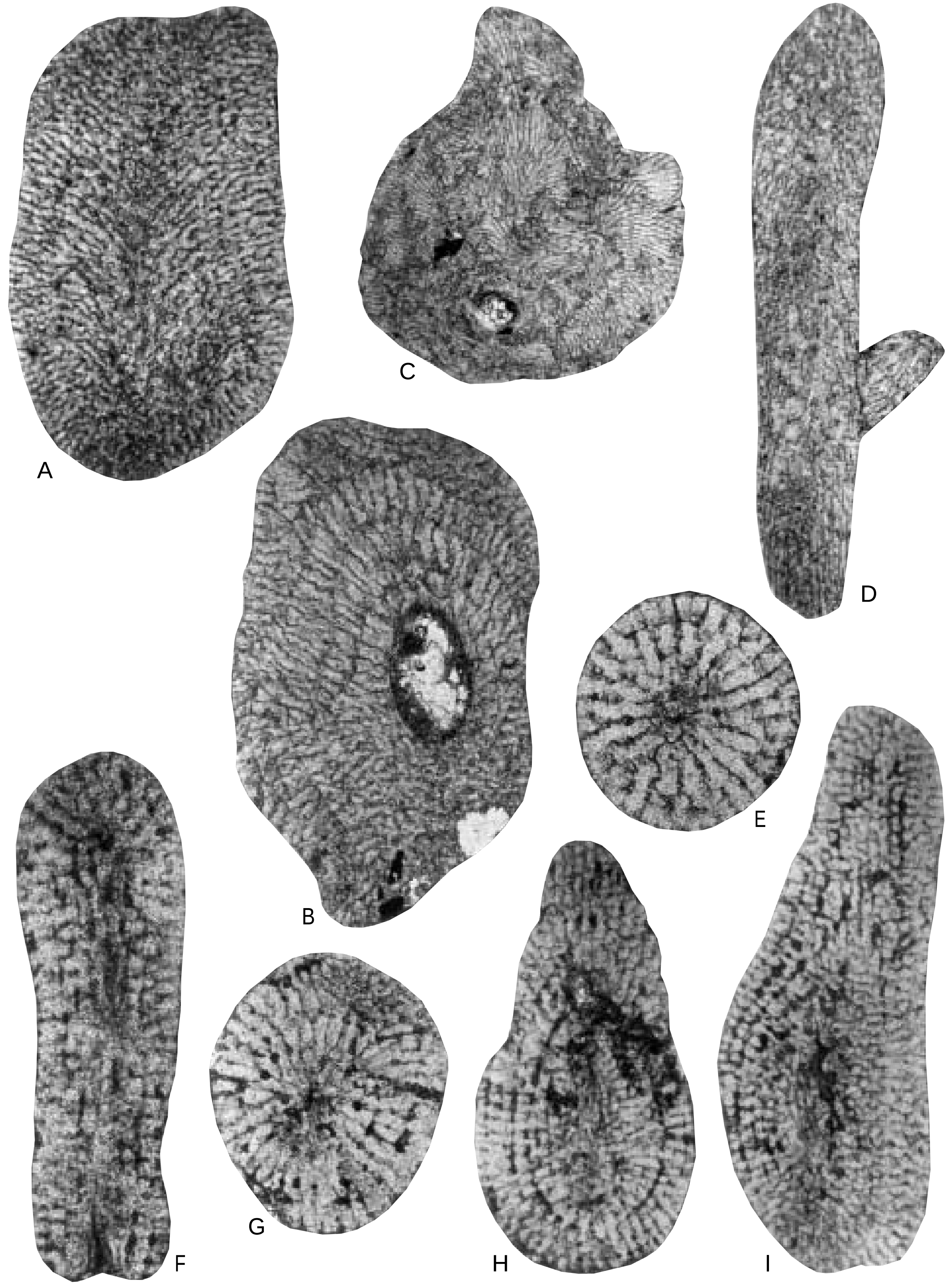
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Fig. 8. Miscellaneous Moscovian–Gzelian algae from Kap Jungersen, Antarctic Bugt and Depotfjeld.
A: *Archaeolithophyllum missouriensum* Johnson 1956 encrusting *Palaeoaplysina* sp. MGUH 24736 from GGU 418836, × 27.
B: *Archaeolithophyllum missouriensum* Johnson 1956 encrusting *Palaeoaplysina* sp. MGUH 24737 from GGU 407674, × 27.
C: *Archaeolithophyllum missouriensum* Johnson 1956 encrusting *Palaeoaplysina* sp. MGUH 24738 from GGU 407674, × 27.
D: *Archaeolithophyllum missouriensum* Johnson 1956 encrusting *Palaeoaplysina* sp. MGUH 24739 from GGU 407674, × 27.
E: *Stacheoides meandriformis* Mamet & Rudloff 1972. MGUH 24740 from GGU 418803, × 108.
F: *Parachaetetes* sp. MGUH 24741 from GGU 418935, × 70.
G: *Cuneiphycus*(?) *johnsoni* Flügel 1966. MGUH 24742 from GGU 418803, × 70.

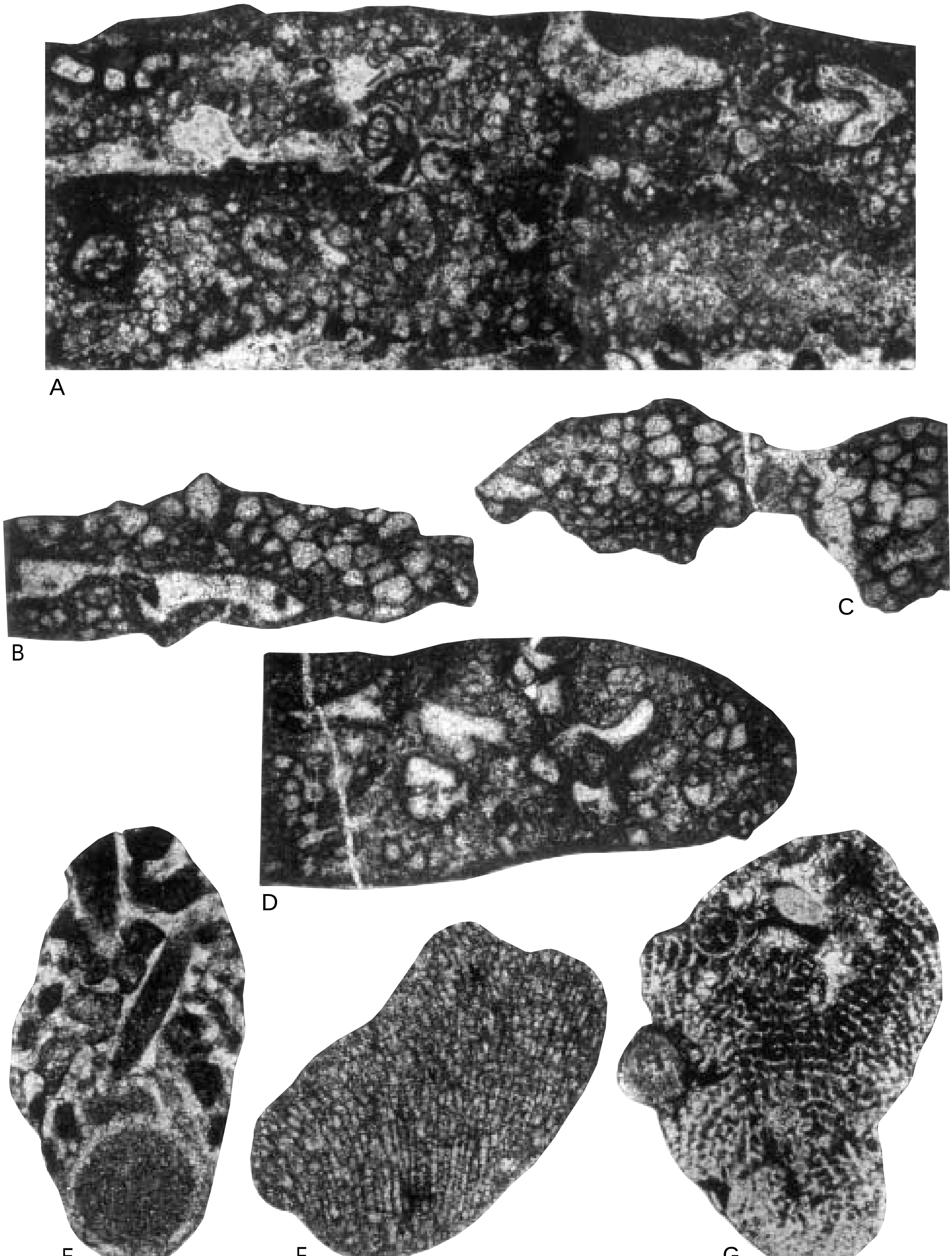
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Fig. 9. Miscellaneous Moscovian–Gzelian algae from Kap Jungersen, Hanseraq and Depotfjeld.

A: *Ivanovia tenuissima* Khvovora 1946. MGUH 24743 from GGU 418882, × 27.

B: *Claracrusta* sp. Cells partly or completely dissolved. The tallus could be confused with *Fasciella* sp. MGUH 24744 from GGU 407722, × 70.

C: *Claracrusta* sp. Cells partly or completely dissolved. The tallus could be confused with *Fasciella* sp. MGUH 24745 from GGU 407722, × 70.

D: *Claracrusta* sp. Cells partly or completely dissolved. The tallus could be confused with *Fasciella* sp. MGUH 24746 from GGU 419012, × 70.

E: *Claracrusta catenoides* (Homann 1972) (= *Berestovia* Berchenko 1982). MGUH 24747 from GGU 419007, × 46.

F: *Claracrusta catenoides* (Homann 1972) (= *Berestovia* Berchenko 1982). MGUH 24748 from GGU 418883, × 46.

G: *Nostocites vesiculosa* Maslov 1929 (=*Globochaete auct.*). Note the characteristic micritisation of the cells. MGUH 24749 from GGU 422506, × 70.

H: *Tubiphytes obscurus* Maslov 1956. Note the embedded sponge spicules and the *Claracrusta* strands. MGUH 24750 from GGU 407621, × 70.

I: *Tubiphytes obscurus* Maslov 1956. Note the embedded sponge spicules and the *Claracrusta* strands. MGUH 24751 from GGU 407679, × 27.

J: *Tubiphytes obscurus* Maslov 1956. Note the embedded sponge spicules and the *Claracrusta* strands. MGUH 24752 from GGU 407679, × 27.

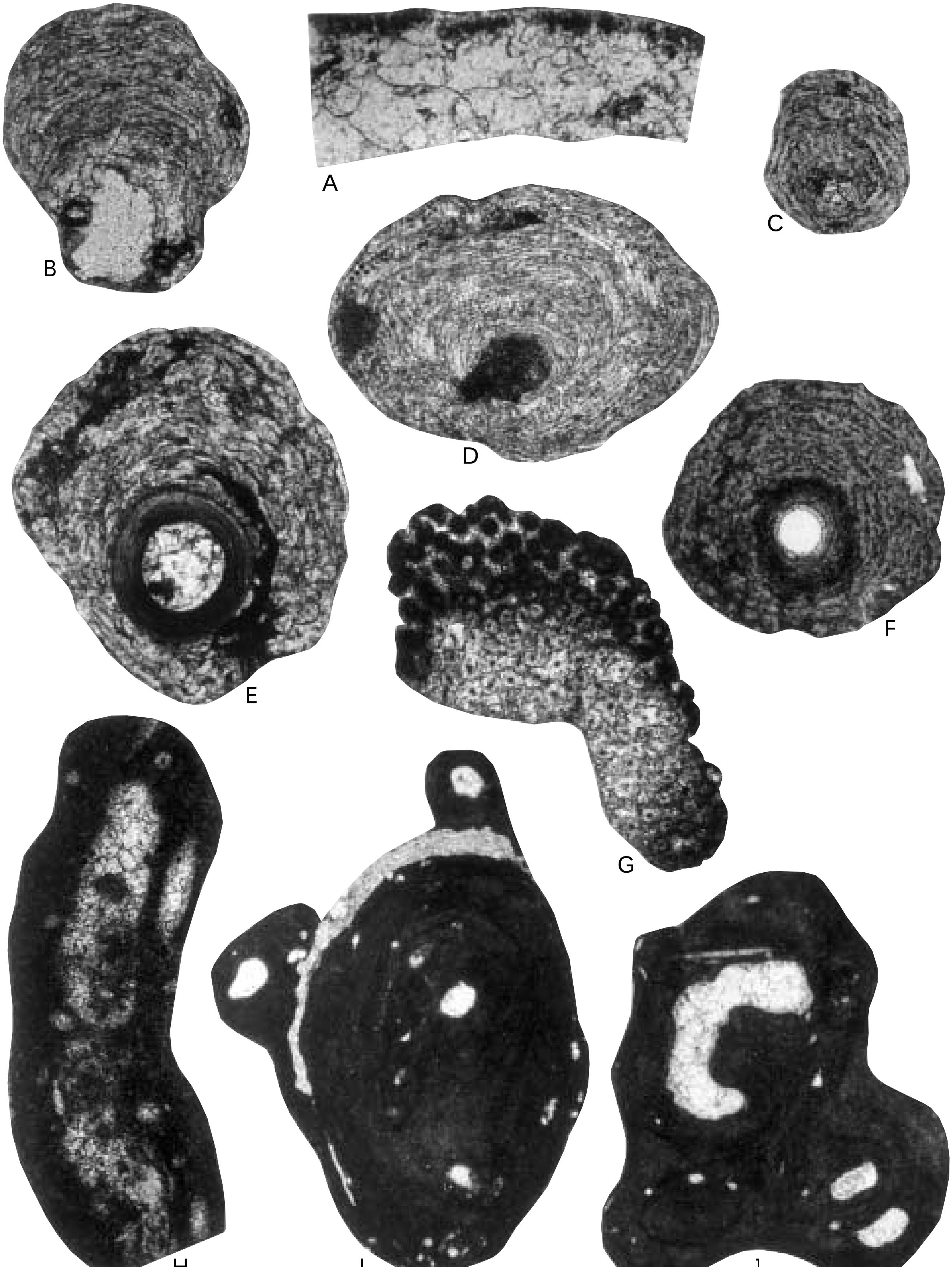
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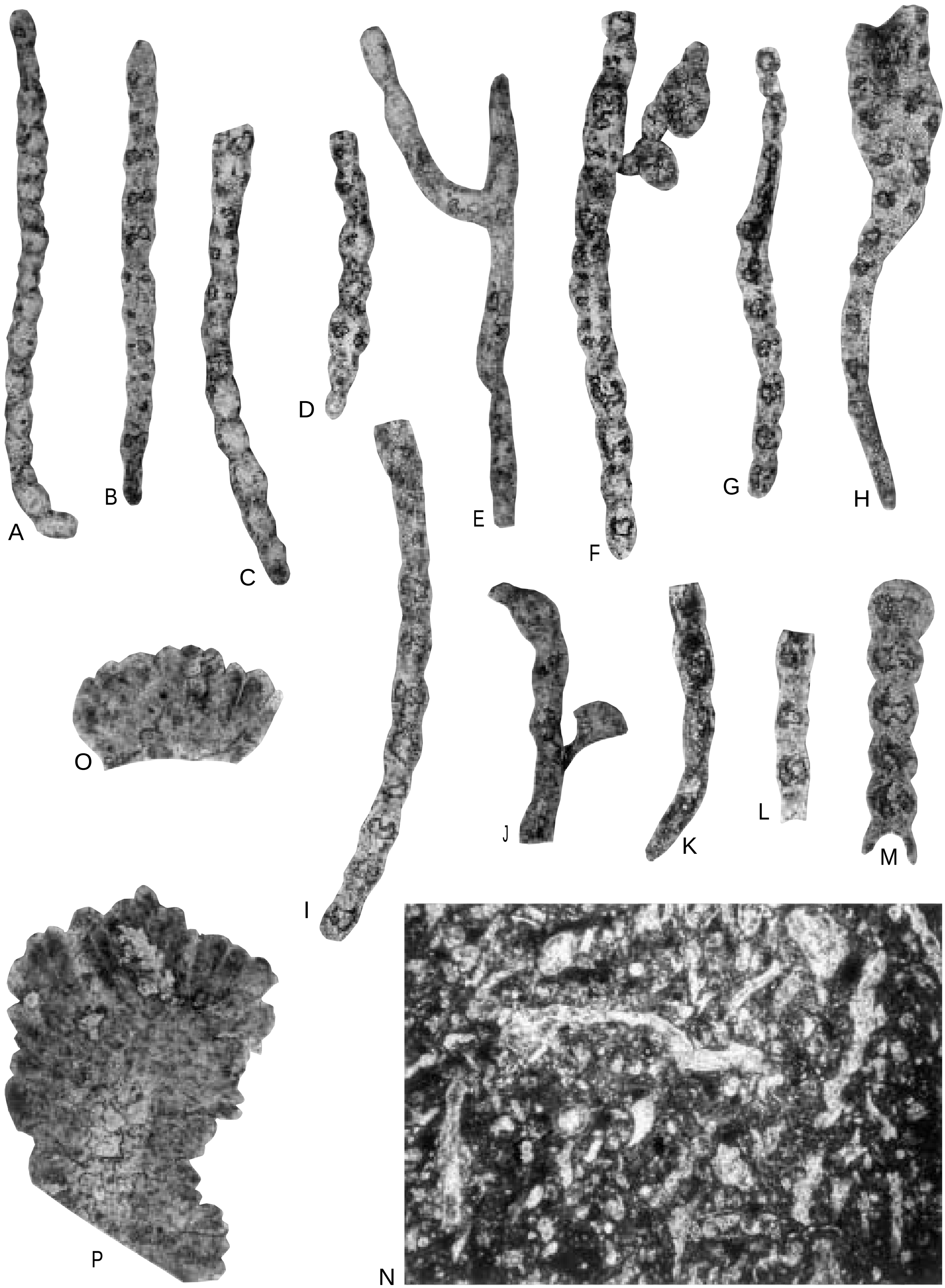
Fig. 10. *Groenlandella enigmatica* n.gen., n.sp. from the Moscovian of Holm Land and *Microcodium* sp. from the Gzelian of Amdrup Land.

A: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24753 from GGU 418430, Kap Jungersen Formation, Moscovian, × 70.
B: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24754 from GGU 418431, Kap Jungersen Formation, Moscovian, × 70.
C: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24755 from GGU 418430, Kap Jungersen Formation, Moscovian, × 70.
D: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24756 from GGU 418431, Kap Jungersen Formation, Moscovian, × 70.
E: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24757 from GGU 418431, Kap Jungersen Formation, Moscovian, × 70.
F: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24758 from GGU 418429, Kap Jungersen Formation, Moscovian, × 70. Holotype.
G: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24759 from GGU 418433, Kap Jungersen Formation, Moscovian, × 70.
H: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24760 from GGU 418432, Kap Jungersen Formation, Moscovian, × 70.
I: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24761 from GGU 418430, Kap Jungersen Formation, Moscovian, × 70.
J: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24762 from GGU 418431, Kap Jungersen Formation, Moscovian, × 70.
K: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24763 from GGU 418432, Kap Jungersen Formation, Moscovian, × 70.
L: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24764 from GGU 418431, Kap Jungersen Formation, Moscovian, × 70.
M: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24765 from GGU 418431, Kap Jungersen Formation, Moscovian, × 70.
N: *Groenlandella enigmatica* n.gen., n.sp. MGUH 24766 from GGU 418431, Kap Jungersen Formation, Moscovian, × 27. Illustrates the intertwined thalli associated with calcispheres, tuberitinids and beresellids.
O: *Microcodium* sp. MGUH 24767 from GGU 407681, Foldedal Formation, Gzelian, × 33.
P: *Microcodium* sp. MGUH 24768 from GGU 407681, Foldedal Formation, Gzelian, × 33.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References

Berchenko, O.G. 1981: Izvestkovye vodorosly turneyskikh otlozheniy Donbassa. (Tournaisian calcareous algae of the Donets Basin), 72 pp. Kiev, Ukraine: Naukova Dumka.

Berchenko, O.G. 1982: Novne violy zelenykh voolorosley iz otlozheniy verkhneserpukhovskoyo pool'yarasa Donbassa. (New species of calcareous algae of the upper Serpukhovian deposits of the Donbas depression.) In: Teslenko Yu.V. (ed.): Sistematica i evolyutsia drevnikh rasteniy Ukrainy, 51–55. Kiev, Ukraine: Naukova Dumka.

Chuvashov, B.I. 1974: Permskie izvestkovye vodorosli Urala. (Permian calcareous algae of the Urals.) Trudy Akademiya Nauk SSSR, Uralskiy Filial, Instituta Geologii i Geokhemii **109**, 76 pp.

Chuvashov, B.I., Shuysky, V.P. & Ivanova, R.M. 1993: Stratigraphical and facies complexes of the Paleozoic calcareous algae of the Urals. In: Barattolo, F.D. *et al.* (eds): Studies of fossil benthic algae. Bolletin Societa Paleontologia Italiana Special Publication **1**, 93–119.

Conil, R. & Lys, M. 1964: Matériaux pour l'étude micropaléontologique du Dinantien de la Belgique et de la France. Mémoires de l'Institut de Géologie de l'Université de Louvain **23**, 296 pp.

Endo, R. 1951: Stratigraphical and paleontological studies of the Later Paleozoic calcareous algae in Japan. 1- Several new species from the Sakamotozawa section, Hikoroichi-mura, Kesen-gun, in the Kitakami mountainous land. Transactions and Proceedings of the Paleontological Society of Japan **4**, 121–129.

Flügel, E. 1966: Algen aus dem Perm der karnischen Alpen. Carinthia Sonderheft **25**, 76 pp.

Golonka, J., Ross, M.I. & Scotese, C.R. 1994: Phanerozoic paleogeographic and paleoclimatic maps. In: Embry, A.F., Beauchamp, B. & Glass, D.J. (eds): PANGEA: Global environments and resources. Canadian Society of Petroleum Geologists Memoir **17**, 1–47.

Håkansson, E., Heinberg, C. & Stemmerik, L. 1981: The Wandel Sea Basin from Holm Land to Lockwood Ø, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **106**, 47–63.

Homann, W. 1972: Unter- und tief- mittelpermische Kalkalgen aus den Rattendorfer Schichten, dem Trogkofel-Kalk und dem Tressdorfer Kalk der karnischen Alpen (Österreich). Senckenbergiana Lethaea **53**, 135–313.

Ivanova, R.M. & Bogush, O.I. 1992: Algae as indicators of a biogeographical zonation in the early Carboniferous of the Urals, Siberia and Northeast Russia. Facies **27**, 235–244.

Johnson, J.H. 1956: *Archaeolithophyllum*, a new genus of Paleozoic coralline algae. Journal of Paleontology **30**(1), 53–55.

Khvorova, I.V. 1946: O novom rode vodoroslei iz srednekamenugolbiykh otlogennye moskovskoie sineklizy. (On a new genus of alga from the Middle Carboniferous deposits of the Moscow Basin.) Doklady Akademiya Nauk SSSR **53**(8), 737–739.

Khvorova, I.V. 1949: Novyi rod mutovchatykh sifoney iz srednego Karbona moskovskoy sineklizy. (New genus of a verticillated Siphonaea from the Middle Carboniferous, Moscow Basin.) Doklady Akademiya Nauk SSSR **65**(5), 749–752.

Korde, K.B. 1950: K morfologii mutovchatykh sifonei Karbona severnogo Urala. (On the morphology of verticilliated Siphonae from the Carboniferous of northern Urals.) Doklady Akademiya Nauk SSSR **73**(3), 569–571.

Korde, K.B. 1951: Novye rody i vidy izvestkovykh vodoroslei iz kamennugolnykh otlozhenii severnogo Urala. (New genera and species of calcareous algae from the Carboniferous deposits of northern Urals.) Trudy Moskovskoye Obshchestvo Ispytateley Prirody, Otdel Geologicheskii **1**, 175–182.

Kulik, E.L. 1964: Berezellidy Karbona russkoy platformy. (Carboniferous beresellids from the Russian Platform.) Paleontologicheskii Zhurnal **2**, 99-114 (in English as: Beresellids from the Carboniferous of the Russian Platform. International Geology Review **7**(9), 1643–1654 (1965)).

Mamet, B.L. 1992: Paléogéographie des algues calcaires marines carbonifères. Canadian Journal of Earth Sciences **29**(1), 174–194.

Mamet, B.[L.] & Rudloff, B. 1972: Algues carbonifères de la partie septentrionale de l'Amérique du Nord. Revue de Micropaléontologie **15**, 75–114.

Mamet, B.[L.], Nassichuk, W.[W.] & Roux, A. 1979: Algues et stratigraphie du Paléozoïque supérieur de l'Arctique canadien. Bulletin Centres Recherches Exploration-Production Elf-Aquitaine **3**(2), 669–683.

Mamet, B.L., Roux, A. & Nassichuk, W.W. 1987: Algues carbonifères et permiennes de l'Arctique canadien. Geological Survey of Canada Bulletin **342**, 143 pp.

Maslov, V.P. 1929: Microscopic algae of the Carboniferous limestones from the Donetz Basin. Bulletin du Comité Géologique **48**(10), 115–139 (in Russian with English summary).

Maslov, V.P. 1956: Iskopayemyye izvestkovye vodorosli SSSR. (Fossil calcareous algae of the USSR.) Akademiya Nauk SSSR, Trudy Geologicheskogo Instituta **160**, 301 pp.

Maslov, V.P. 1962: Iskopayemyye bagrianye vodorosli SSSR. (Fossil red algae from the USSR.) Akademiya Nauk SSSR, Trudy Geologicheskogo Instituta **53**, 222 pp.

Maslov, V.P. 1973: Atlas porodoobrazuyushchikh organizmov. (Atlas of rock-building organisms), 267 pp. Moscow: Izdatelnyie Nauka.

Maslov, V.P. & Kulik, E.L. 1956: Novaya triba vodorosley (Bereselleae) iz Karbona SSSR. (A new algal tribe (Bereselleae) in the Carboniferous of the USSR.) Doklady Akademiya Nauk SSSR **106**(1), 126–129.

Nilsson, I. 1994: Upper Palaeozoic fusulinid assemblages, Wandel Sea Basin, North Greenland. Rapport Grønlands Geologiske Undersøgelse **161**, 45–71.

Petryk, A.A. & Mamet, B.[L.] 1972: Lower Carboniferous algal microflora, southwestern Alberta. Canadian Journal of Earth Sciences **9**(7), 767–802.

Pronina, T.V. 1963: Foraninifery berezovskoie suity Karbona vostochnogo sklona yuznogo Urala Saltovskaya. (Carboniferous foraminifers of the Berezovo Series in the eastern slope of the southern Ural Mountains.) Trudy Akademiya Nauk SSSR, Uralskiy Filial, Institut Geologii **65**, 119–176.

Saltovskaya, V.D. 1984: Nekotorye izvestovye vodorosli Paleozoia Tadzhikistana. (On some new calcareous Paleozoic algae of Tadzhikistan.) Akademiya Nauk Tadzhikskoe SSR, Institut Geologi, 141–160.

Stemmerik, L. 1996: High frequency sequence stratigraphy of a siliciclastic influenced carbonate platform, lower Moscovian, Amdrup Land, North Greenland. In: Howell, J.A. & Aitken, J.F. (eds): High resolution sequence stratigraphy: innovations and applications. Geological Society Special Publication (London), **104**, 347–365.

Stemmerik, L. 2000: Late Palaeozoic evolution of the North Atlantic margin of Pangea. Palaeogeography, Palaeoclimatology, Palaeoecology **161**, 95–126.

Stemmerik, L. & Elvebakk, G. 1994: A newly discovered mid-Carboniferous - ?early Permian reef complex in the Wandel Sea Basin, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **161**, 39–44.

Stemmerik, L., Håkansson, E., Madsen, L., Nilsson, I., Piasecki, S., Pinard, S. & Rasmussen, J.A. 1996: Stratigraphy and depositional evolution of the Upper Palaeozoic sedimentary succession in eastern Peary Land, North Greenland. Bulletin Grønlands Geologiske Undersøgelse **171**, 45–71.

Zanin Buri, C. 1965: A new Permian *Epimastopora* (calcareous alga) from Hunza Valley (Western Karakorum). Italian Expedition Karakorum (K2) and Hindu Kush, Scientific Report IV, Paleontology, Zoology and Botany **1**(1), 77–88. Leiden: E.J. Brill.

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