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The Jurassic of North-East Greenland

Edited by

Lars Stemmerik and Svend Stouge

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Ammonites, Boreal, dinoflagellate cysts, Jurassic, North-East Greenland, palaeogeography, rifting, siliciclastic sediments, stratigraphy

Cover

Eastwards-dipping Middle–Upper Jurassic sandstones (yellow) and interbedded marine mudstones (dark) at the base of the coastal cliffs along the south-east coast of Traill Ø. The Jurassic succession is described by Vosgerau *et al.* (this volume). It is disconformably overlain by poorly exposed Cretaceous siltstones with numerous volcanic intrusions that form ledges towards the top of the c. 1050 m high cliff. Photo: Lars Stemmerik.

Frontispiece: facing page

Middle Jurassic and Lower Cretaceous sandstones exposed on the western slopes of Steensby Bjerg, Hold with Hope, viewed towards the north-east with Finsch Øer in the centre and Clavering Ø in the far distance. On Hold with Hope, a more than 500 m thick sedimentary succession of Triassic–Cretaceous age is exposed in the north-facing coastal cliffs. The Jurassic succession, which was not recognised until field work in 1996, is preserved in the downfaulted hangingwall blocks of a series of rotated half-grabens formed during the main East Greenland rifting phase in the latest Jurassic to earliest Cretaceous. Lower Cretaceous sandstones, up to 170 m thick, unconformably overlie the rift succession. Photo: Michael Larsen.

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Preface

The Jurassic sedimentary succession in East and North-East Greenland reflects deposition during the early stages of rifting between Greenland and Norway. Jurassic sediments are exposed over a distance of more than 600 km, from Jameson Land in the south to Store Koldewey in the north (Fig. 1), and form one of the best-known exposed ancient rift successions. The sediments have been intensely studied over the last 25 years and a synthesis of the Jurassic System in Greenland was recently given in Geological Survey of Denmark and Greenland Bulletin 1 (Surlyk 2003).

This collection of papers deals with stratigraphic and depositional aspects of the Middle–Upper Jurassic sediments from isolated and less well-known localities outside the main outcrop areas, and thus adds to the tremendous amount of new data generated from the classical Jurassic successions of Jameson Land and the Wollaston Forland area (Ineson & Surlyk 2003). Most papers are based on fieldwork in 1996 and 1997, carried out within the framework of the project ‘Resources of the sedimentary basins of North and East Greenland’ supported by the Danish Research Councils (see Stemmerik *et al.* 1997). Papers dealing with the Jurassic at Store Koldewey and Hochstetter Forland are based on material collected during regional mapping in 1989 (Stemmerik & Piasecki 1990).

During Middle–Late Jurassic times, rifting took place along major N–S-trending synthetic faults that delimited wide westwards-tilted fault blocks (Surlyk 1977, 2003). This resulted in the development of elongated marine embayments with major rivers entering from the north and dominantly axial sediment transport towards the south (Surlyk 1978, 2003; Engkilde & Surlyk 2003). The Jurassic syn-rift succession on south-eastern Traill Ø is an exception to this general pattern (Vosgerau *et al.* 2004a, this volume). Sedimentation took place on an eastwards-tilted fault block; the succession shows an eastwards proximal–distal decrease in sandstone–mudstone ratio, reflecting increasing water depths to the east. On the adjacent fault block to the west, a new lithostratigraphic unit, the Bristol Elv Formation, has been erected to describe a succession of fluvio-lacustrine sediments at the base of the Middle Jurassic rift succession (Therkelsen & Surlyk 2004, this volume). The non-marine succession is overlain by shallow marine sandstones of the Pelion Formation (Upper Bajocian), succeeded in turn by 25–30 m of black silty mudstones of the Fossilbjerget Formation

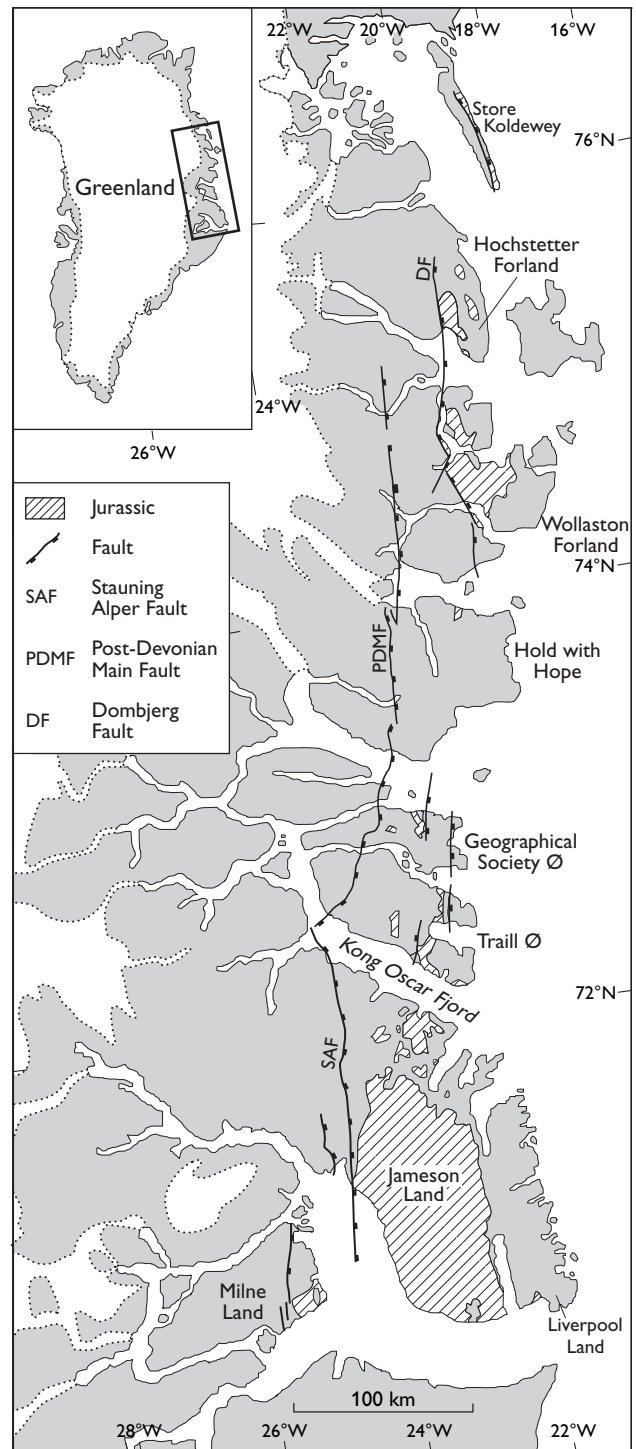


Fig. 1. Simplified geological map of East and North-East Greenland showing the distribution of Jurassic sediments. Modified from Surlyk (2003).

(Alsen & Surlyk 2004, this volume). The presence of the Fossilbjerget Formation on southern Traill Ø indicates complete drowning of the sandy Pelion system during maximum Middle Jurassic transgression (Alsen & Surlyk 2004, this volume).

A new Middle–Upper Jurassic succession was found in the hangingwalls of small fault blocks at Hold with Hope during fieldwork in 1996 (Stemmerik *et al.* 1997). The up to 360 m thick succession and its stratigraphy are described in detail by Vosgerau *et al.* (2004b, this volume) and Piasecki *et al.* (2004a, this volume). The succession resembles that seen at Wollaston Forland and Kuhn Ø. The Hold with Hope area was flooded during late Middle Jurassic time; Lower–Middle Callovian shallow marine sandstones of the Pelion Formation overlie Lower Triassic sediments (Vosgerau *et al.* 2004b, this volume). The overlying sandstones of the Payer Dal Formation are of Middle–Late Oxfordian age. The uppermost part of the succession belongs to the Bernbjerg Formation. The youngest sediments are of Late Oxfordian – Early Kimmeridgian age based on dinoflagellate cysts (Piasecki *et al.* 2004a, this volume). Dinoflagellate cysts have also been used to date the scattered outcrops of Middle–Upper Jurassic sediments at Hochstetter Forland and Store Koldewey further to the north (Piasecki & Stemmerik 2004, this volume; Piasecki *et al.* 2004b, this volume). The dinoflagellate cyst assemblages of these northern outliers are readily correlated to assemblages described from the Middle–Upper Jurassic further to the south in East Greenland, and also show some resemblance to assemblages described from North Greenland (Piasecki *et al.* 2004b, this volume).

Lars Stemmerik

References

Alsen, P. & Surlyk, F. 2004: Maximum Middle Jurassic transgression in East Greenland: evidence from new ammonite finds, Bjørnedal, Traill Ø. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 31–49 (this volume).

Engkilde, M. & Surlyk, F. 2003: Shallow marine syn-rift sedimentation: Middle Jurassic Pelion Formation, Jameson Land, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 813–863.

Ineson, J.R. & Surlyk, F. (eds) 2003: The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 948 pp.

Piasecki, S. & Stemmerik, L. 2004: Jurassic dinoflagellate cysts from Hochstetter Forland, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 89–97 (this volume).

Piasecki, S., Larsen, M., Therkelsen, J. & Vosgerau, H. 2004a: Jurassic dinoflagellate cyst stratigraphy of Hold with Hope, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 73–88 (this volume).

Piasecki, S., Callomon, J.H. & Stemmerik, L. 2004b: Jurassic dinoflagellate cyst stratigraphy of Store Koldewey, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 99–112 (this volume).

Stemmerik, L. & Piasecki, S. 1990: Post-Caledonian sediments in North-East Greenland between 76° and 78°30'N. Rapport Grønlands Geologiske Undersøgelse **148**, 123–126.

Stemmerik, L., Clausen, O.R., Korstgård, J., Larsen, M., Piasecki, S., Seidler, L., Surlyk, F. & Therkelsen, J. 1997: Petroleum geological investigations in East Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. Geology of Greenland Survey Bulletin **176**, 29–38.

Surlyk, F. 1977: Stratigraphy, tectonics and palaeogeography of the Jurassic sediments of the areas north of Kong Oscars Fjord, East Greenland. Bulletin Grønlands Geologiske Undersøgelse **123**, 56 pp.

Surlyk, F. 1978: Jurassic basin evolution of East Greenland. Nature **274**(5667), 130–133.

Surlyk, F. 2003: The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 659–722.

Therkelsen, J. & Surlyk, F. 2004: The fluvialite Bristol Elv Formation, a new Middle Jurassic lithostratigraphic unit from Traill Ø, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 19–29 (this volume).

Vosgerau, H., Alsen, P., Carr, I.D., Therkelsen, J., Stemmerik, L. & Surlyk, F. 2004a: Jurassic syn-rift sedimentation on a seawards-tilted fault block, Traill Ø, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 9–18 (this volume).

Vosgerau, H., Larsen, M., Piasecki, S. & Therkelsen, J. 2004b: A new Middle–Upper Jurassic succession on Hold with Hope, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 51–71 (this volume).

Jurassic syn-rift sedimentation on a seawards-tilted fault block, Traill Ø, North-East Greenland

Henrik Vosgerau, Peter Alsen, Ian D. Carr, Jens Therkelsen, Lars Stemmerik and Finn Surlyk

Middle–Late Jurassic rifting in East Greenland was marked by westwards tilting of wide fault blocks bounded by major N–S-trending east-dipping synthetic faults. The syn-rift successions thicken westwards towards the faults and shallow marine sandstones show mainly southwards axial transport directions. An exception to this general pattern is found in south-east Traill Ø, which constitutes the E-tilted Bjørnedal Block, which is bounded to the west by the westwards-dipping antithetic Vældal Fault. The stratigraphic development of the Jurassic succession on this block shows important differences to the adjacent areas reflecting a different tectonic development. Shallow marine sand seems initially to have filled accommodation space of the immediately adjacent block to the west. This block subsequently acted as a bypass area and much of the sediment was spilled eastwards onto the hangingwall of the east-dipping Bjørnedal Block. The succession on the Bjørnedal Block shows an eastwards proximal–distal decrease in sandstone–mudstone ratio, reflecting increasing water depth and progressive under-filling of the subbasin towards the east in agreement with the dip direction of the fault block. The transverse, mainly south-eastwards palaeocurrents, the eastwards increase in water depths and decrease in sandstone–mudstone ratio on the Bjørnedal Block are at variance with the standard picture of west-tilted blocks with southwards-directed palaeocurrents and decrease in grain size. Earlier palaeogeographic reconstructions have to be modified to account for the east-dipping hanging-wall and different stratigraphic development of the area. The sea was thus open towards the east and there is no direct indication of a barrier or shoal east of Traill Ø.

Keywords: Bjørnedal Block, Jurassic, North-East Greenland, palaeocurrents, rifting, Traill Ø

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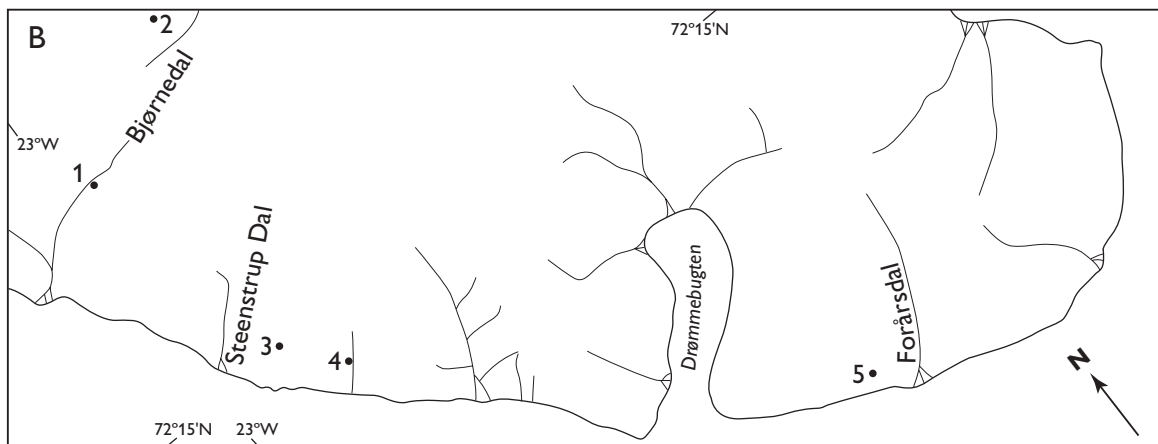
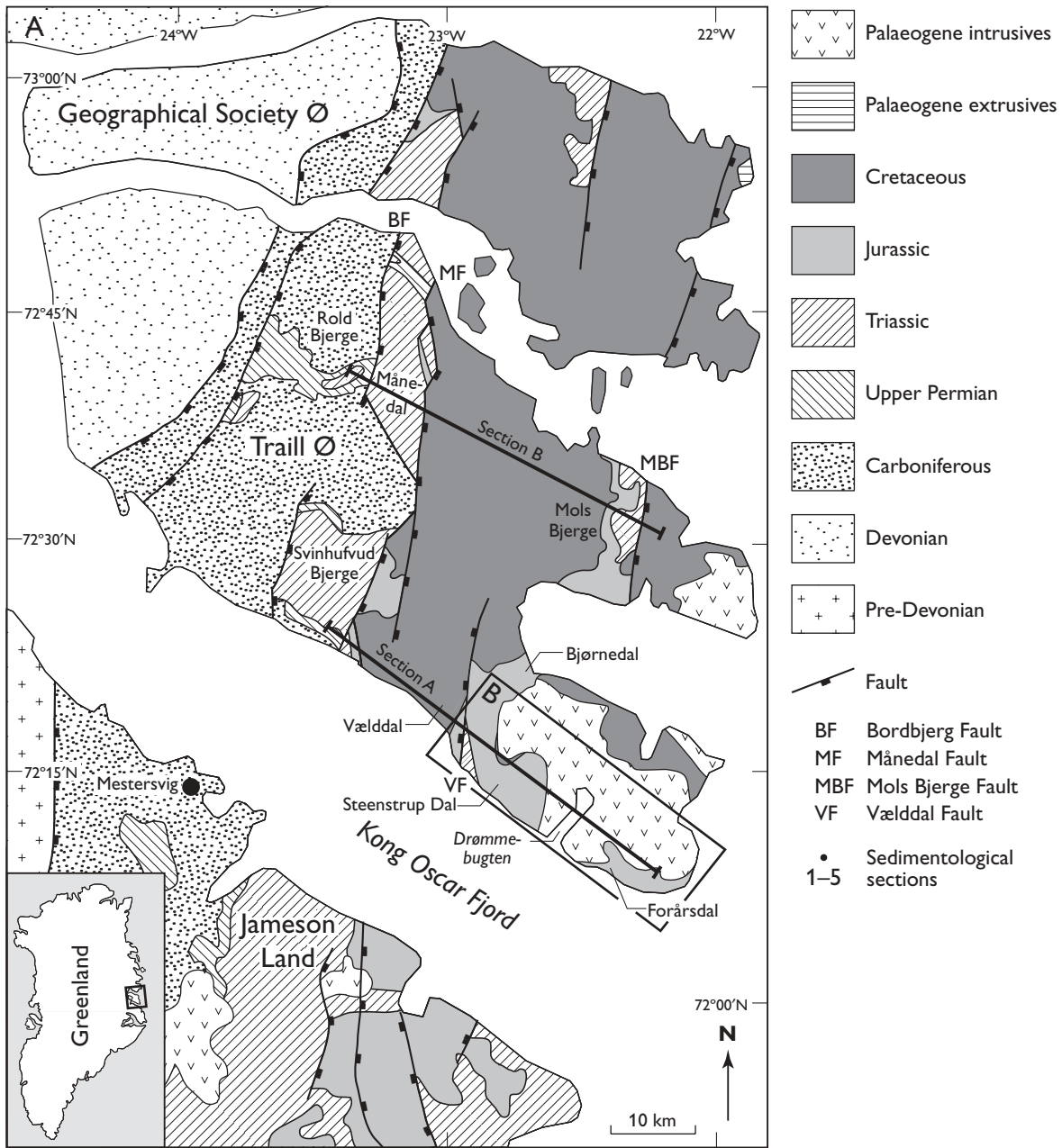
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The main Mesozoic rift phase in East Greenland was initiated in mid-Bajocian time, intensified during Bathonian–Oxfordian time, and culminated in the Kimmeridgian–Volgian. Rifting was accommodated along major north–south-trending and east-dipping normal faults limiting wide westwards-tilted blocks. This resulted in the development of elongated fault-controlled marine embayments open to the south and with

major rivers entering the northern heads of the embayments located in relay zones where the border faults shifted en échelon to the east (Surlyk 1977a, 1978, 2003; Surlyk & Clemmensen 1983). Transport of sand, silt and clay by marine currents was mainly axial towards the south. Initial Late Bajocian progradation of shallow marine sands reached the southern end of the exposed basin. The sandy system (Pelion Formation)



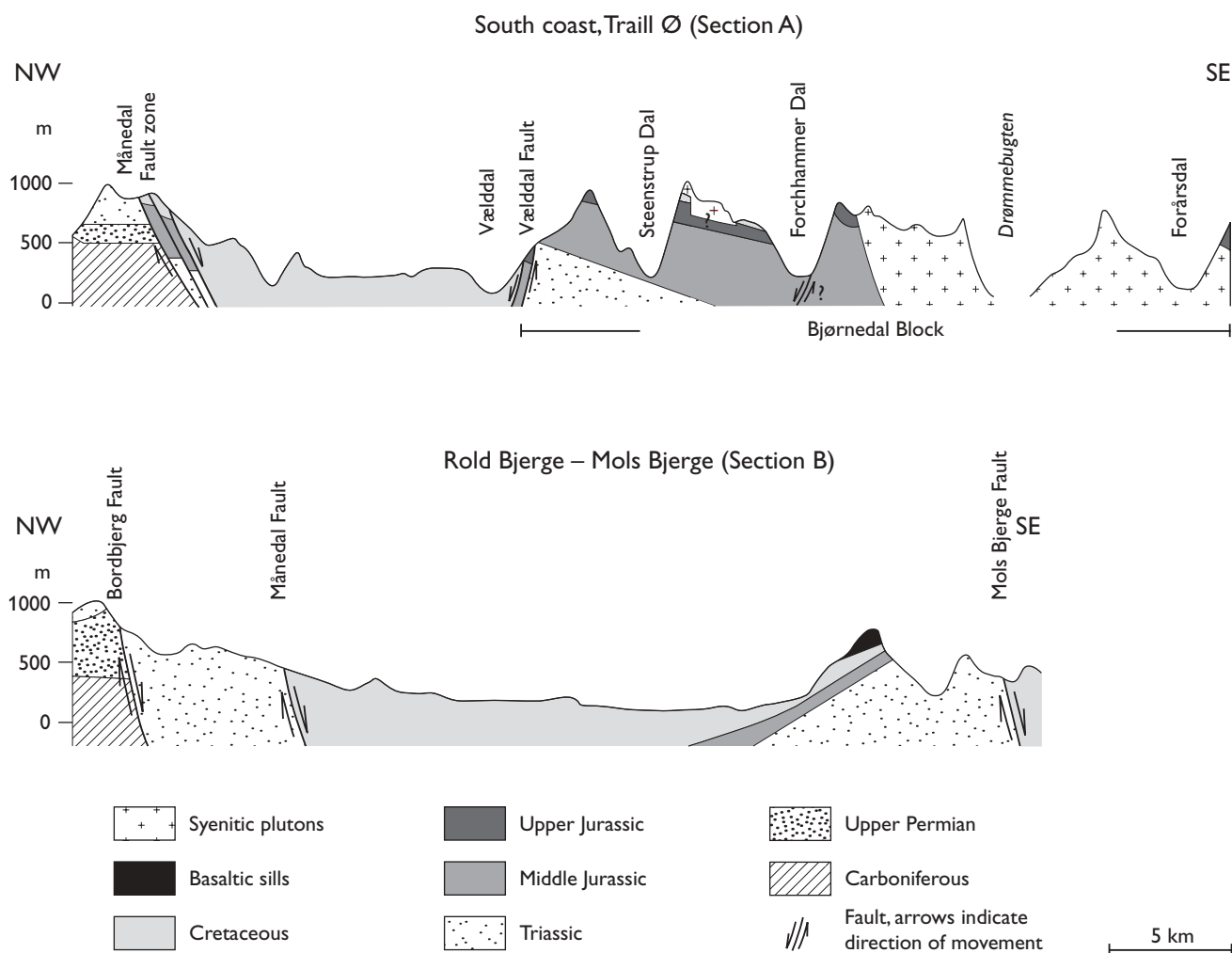


Fig. 2. NW–SE-oriented cross-sections showing the geological structure of eastern Traill Ø. Note the west-dipping Vælddal Fault, which forms the western limit of the Bjørnedal Block. Virtually all other Mesozoic faults in East Greenland dip towards the east and delimit westwards-tilted blocks. The positions of the sections are indicated on Fig. 1. Based on Koch & Haller (1971).

progressively backstepped during the Bathonian and was eventually drowned in the Late Callovian due to increased rates of extension and a long-term eustatic rise in sea level (Engkilde & Surlyk 2003; Surlyk 2003).

An exception to this simple pattern is found in south-eastern Traill Ø, where an east-dipping fault block, more than 30 km wide, was formed during early rifting (Figs 1, 2; Carr 1998). It was limited to the west by the west-dipping Vælddal Fault (Donovan 1953; Carr 1998). The block, which is here termed the Bjørnedal Block,

probably continues southwards into northern Jameson Land where poorly exposed east-dipping correlative strata occur on the south side of Kong Oscar Fjord (Fig. 1).

The aim of this study is to compare and contrast the syn-rift Middle–Late Jurassic stratigraphic syn-rift development on the eastwards-dipping Bjørnedal Block on south-east Traill Ø with the rest of the Jurassic basin of East Greenland, which is characterised by westwards-tilted blocks.

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Fig. 1. Map of Traill Ø area showing the main faults and outcrops of the Jurassic succession. Positions of the structural cross sections (A, B) on Fig. 2 are indicated. Inset map (B) shows location of measured sedimentological sections (1–5).

The south coast of Traill Ø

Upper Palaeozoic – Triassic deposits are exposed along the western part of the south coast of Traill Ø, whereas Jurassic and younger sediments are restricted to the eastern part (Fig. 1). The Jurassic succession is bounded to the west by the Månedal Fault and is cut by the Vælddal Fault situated 15 km further to the east (Figs 1, 2). The peninsula east of the Vælddal Fault is made up mainly by the Palaeogene Kap Simpson syenite complex which extends for about 30 km in a NW–SE direction parallel to the coast (Fig. 1). The coastal cliffs are high and steep, and numerous Palaeogene sills and dykes intrude the Jurassic succession. It has accordingly received very little attention. It was assigned to the Yellow and Black Series by Donovan (1953) and this was followed in the geological map of Koch & Haller (1971). The Yellow Series was very loosely defined and covered Middle and lower Upper Jurassic sandstone-dominated successions. On Traill Ø, it includes the Pelion and Olympen Formations of current usage. The Black Series includes Upper Jurassic dark grey mudstones and black shales corresponding in part to the Bernbjerg Formation (Surlyk 1977b). Successively younger Jurassic strata are exposed from west to east along the coast east of the Vælddal Fault (Fig. 2). The succession includes Lower Bajocian sandstones and mudstones of the Bristol Elv Formation, Upper Bajocian – Lower Callovian sandstones of the Pelion Formation, Callovian mudstones of the Fossilbjerget Formation, intercalated with sandstones of the Parnas Member (top member of the Pelion Formation), overlain by Lower–Middle Oxfordian mudstones and sandstones of the Olympen Formation, and Upper Oxfordian – Kimmeridgian dark grey and black mudstones of the Bernbjerg Formation (Fig. 3). The exposures along the coastal cliffs vary in quality. From a stratigraphic point of view they are generally good, whereas sedimentary structures commonly are obliterated by the effects of the Palaeogene sills and dykes.

For this study, five sedimentological sections were measured along the coast allowing construction of a W–E dip section (Fig. 3). The sections are correlated by lateral tracing of major sedimentary packages and drowning surfaces in the field and on a high-quality photo-mosaic, and by ammonite dating of a number of levels. The succession dips about 13° to the east except in the easternmost section where it dips 9° towards the north, but in this area dip-directions reflect disturbances by the immediately adjacent syenite complex (Fig. 1).

The oldest strata are exposed to the west immediately east of the Vælddal Fault where Jurassic strata rest directly on Triassic redbeds of the Fleming Fjord Formation (Stauber 1942). The base of the Middle Jurassic sandstones is not exposed further east, but fluvial to marginal marine sandstones and mudstones of the Bristol Elv Formation (Price & Whitham 1997; Stemmerik *et al.* 1997; Therkelsen & Surlyk 2004, this volume) occur below marine Upper Bajocian sandstones of the Pelion Formation in two sections. Three of the measured sections (Fig. 3, sections 1–3) reach up into black mudstones of the Upper Oxfordian – Kimmeridgian Bernbjerg Formation.

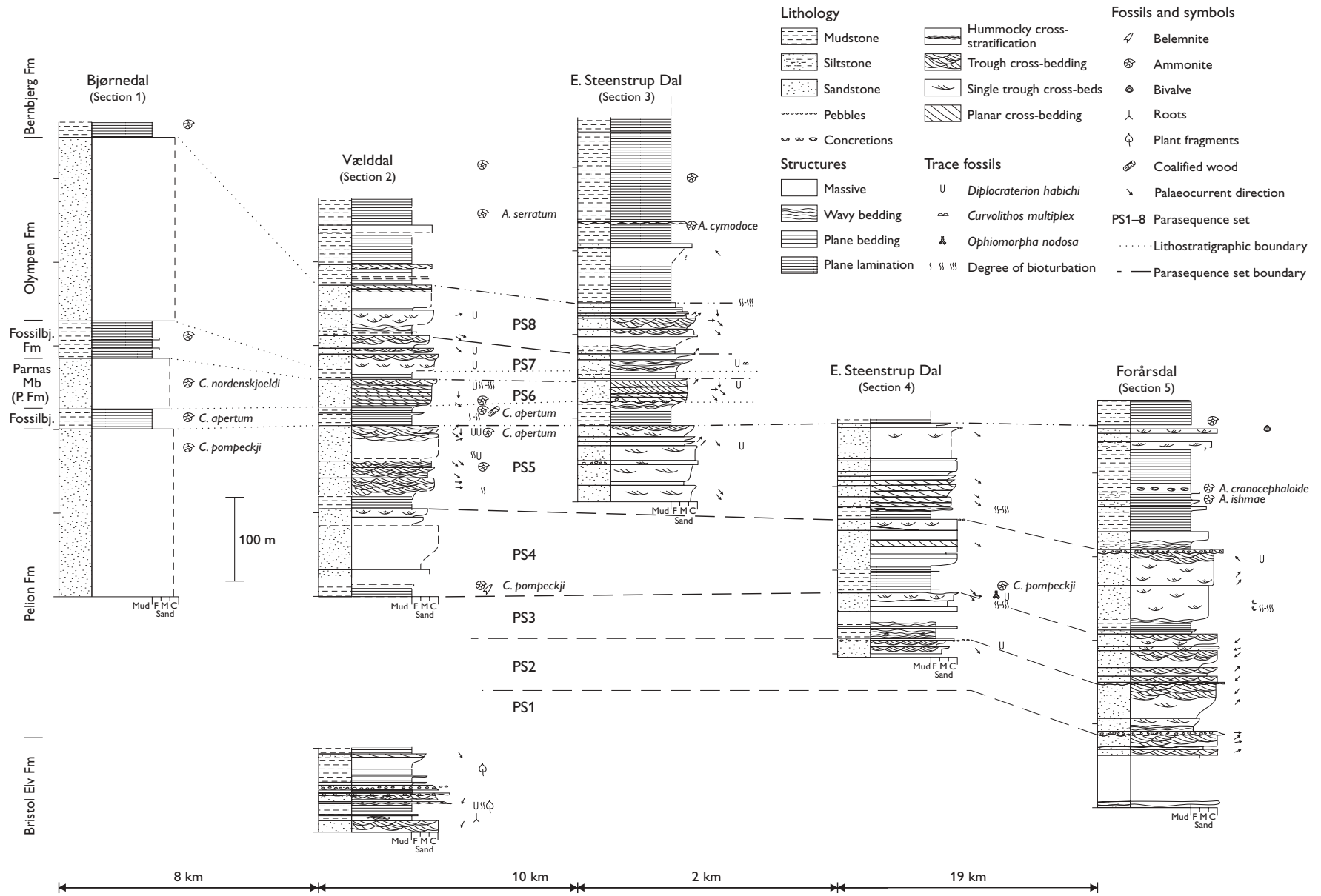
Stratigraphic development

The basal part of the Jurassic succession consists of channelised, trough cross-bedded pebbly sandstones interbedded with dark grey laminated shales occasionally with thin sandstone ripples. Crude fining-upwards trends can be recognised, and rootlet beds are common. Palaeocurrents are mainly towards the south-west (Fig. 3). The interbedded shales contain abundant leaves and scattered tree trunks. Both facies contain scattered trace fossils of marine affinity.

The sandstones are interpreted as having been deposited in coastal rivers and the shales were formed by drowning of the fluvial system either due to delta switching and abandonment or to base-level rise. The trace fossils suggest some marine influence and deposition of the shales probably took place under estuarine conditions or in interdistributary bays. A succession of fluvial deposits at the base of the Jurassic succession of Traill Ø was recognised independently by

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Fig. 3. NW–SE-oriented dip-parallel correlation panel of the Bjørnedal Block, based on five measured sections along the south coast of Traill Ø (for location, see Fig. 1B). Note the eastwards, down-dip decrease in sandstone–mudstone ratio and increase in the thickness of mudstone packages. The key motif is a coarsening-upwards parasequence composed of offshore mudstones, overlain by offshore transition zone heteroliths followed by shoreface sandstones. The parasequences stack into parasequence sets, numbered **PS1–8** from below. The succession belongs from below to the dominantly fluvial Bristol Elv Formation, the marine sandstone-dominated Pelion Formation, the mudstone-dominated Fossilbjerget Formation, the Olympen Formation of interbedded marine sandstones and mudstones, and the dark, deeper marine mudstone-dominated Bernbjerg Formation. **P.**, Pelion.



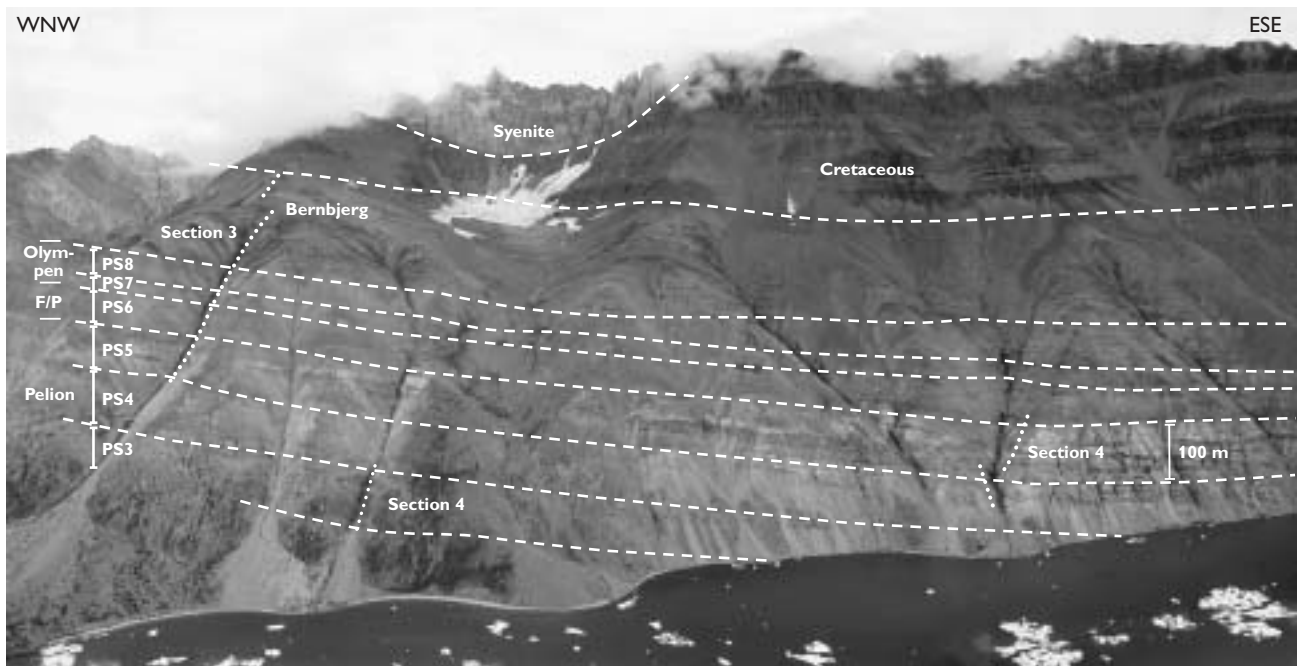


Fig. 4. The coastal section of the Bjørnedal Block, immediately east of Steenstrup Dal, showing yellow sandstones of the Pelion Formation below, overlain at a pronounced drowning surface by dark grey mudstones of the Fossilbjerget Formation followed by alternating sandstones and mudstones of the Olympen Formation, and finally by dark grey mudstones of the Bernbjerg Formation. The height of the cliff is approximately 1000 m. **PS3–8**, parasequence sets; **stippled lines**, major flooding surfaces; **F/P**, Fossilbjerget and Pelion (Parnas Mb) Formations.

Price & Whitham (1997) and Stemmerik *et al.* (1997) and is placed in the new Bristol Elv Formation by Therkelsen & Surlyk (2004, this volume), who refer it tentatively to the Early Bajocian. The deposits described here from the south coast of Traill Ø are also referred to the Bristol Elv Formation on the basis of the dominant pebbly sandstone lithology and the fluvial style of deposition. The boundary between the Bristol Elv Formation and the overlying marine sandstones of the Pelion Formation is not exposed.

The Bristol Elv Formation is overlain by marine sandstones and thin mudstones of the Pelion, Fossilbjerget and Olympen Formations, which are composed of coarsening-upwards units a few to several tens of metres thick. These units start with dark grey laminated to bioturbated offshore mudstones with thin subordinate beds of silty fine-grained sandstone or medium-grained sandstone, overlain by heterolithic deposits, which give way to medium- to coarse-grained trough and planar cross-bedded sandstones. The boundary between the mudstones and the sandstones is usually gradational but is sharp and erosional in a few cases. The transitional interval shows hummocky cross-stratification in some sections. The top of the coarsening-upwards units is a sharp drowning surface, overlain

by offshore mudstones of the next unit, occasionally with an intervening pebble lag composed of subrounded to rounded quartzite pebbles up to 3 cm long. Metre-long U-burrows of *Diplocraterion habichi* extend downwards from the drowning surface.

The coarsening-upwards units were formed by progradation of shoreface sands across offshore transition zone heteroliths and offshore mudstones and are bounded by drowning surfaces. In some cases these surfaces have been modified by transgressive shoreface erosion and may conceal subtle sequence boundaries. The thickest and coarsest pebble lag, which occurs in the most distal section, suggests bypass of the beach during sea-level fall and subsequent transgressive shoreface winnowing and erosion. The units thus represent parasequences or simple sequences, but in this context they are for simplicity termed parasequences throughout. In some of the parasequences, the sandstone part has a sharp base formed by shoreface erosion during progradation under sea-level fall and interpreted as a forced regressive surface of erosion. The parasequences stack in parasequence sets, which are numbered PS1–8 (Fig. 3).

A total of six parasequence sets are recognised in the Pelion Formation. Parasequence set 6 is much finer

grained than the lower parasequence sets and lithostratigraphically it represents interfingering between mudstones of the Fossilbjerget Formation and the Lower Callovian Parnas Member of the Pelion Formation (Alsen & Surlyk 2004, this volume). The Pelion–Fossilbjerget parasequence sets thus constitute a composite aggradational to retrogradational package (Figs 3, 4).

Sandstones and mudstones of the Olympen Formation overlie the interfingering Pelion–Fossilbjerget couplet. This unit has not yielded any ammonites in the studied sections, but is elsewhere of Early–Middle Oxfordian age (Surlyk 1978; Price & Whitham 1997) and this age assignment is corroborated by the bracketing Callovian age of the top of the Fossilbjerget Formation and Late Oxfordian base of the overlying Bernbjerg Formation. The Olympen Formation is composed of about five stacked coarsening-upwards units, which are thinner and finer grained than those of the Pelion Formation. They are interpreted as parasequences and form two parasequence sets, PS7–8, the lower of which includes the uppermost mudstones of the Fossilbjerget Formation (Fig. 3). This development is similar to the type area in central Jameson Land, where the formation also comprises two thick sandstone units and an intervening mudstone unit (Larsen & Surlyk 2003). The Olympen Formation is overlain by black offshore mudstones with a few thin sandstones of the Upper Oxfordian – Kimmeridgian Bernbjerg Formation, reflecting final drowning of the sandy depositional systems.

The marine Middle and Upper Jurassic succession of south-east Traill Ø thus shows a stepwise backstepping trend. It commences with the lower aggradational to retrogradational parasequence sets of the Pelion Formation dominated by rather coarse-grained sandstones topped by the intertonguing Fossilbjerget Formation mudstones and finer grained sandstones of the Parnas Member (Pelion Formation). Then follows the overall finer grained Olympen Formation, which is overlain by the Bernbjerg Formation mudstones. The main backstepping events can be roughly dated to the Callovian–Oxfordian and Middle–Late Oxfordian boundaries.

Major drowning surfaces

The drowning surfaces separating the thicker parasequence sets can be traced between the sections. It is difficult to evaluate their significance and regional extent but the drowning surfaces topping parasequence

sets 3 and 5 are well dated palaeontologically and seem to represent regional flooding events (Figs 3, 4). *Cranoccephalites pompeckji* thus characterises one such event, which can be traced from southern Jameson Land to Traill Ø and possibly as far north as Hold with Hope (Vosgerau *et al.* 2004, this volume). The *C. pompeckji* Chronozone is Upper Bajocian, possibly reaching up into the lowermost Bathonian (Callomon 1993). *Cadoceras apertum*, which marks the base of the Callovian (i.e. = *C. apertum* Chronozone of Callomon 1993, p. 103) is found 200 m above *C. pompeckji*. It seems likewise to represent a major regional flooding event (Piasecki & Larsen 1998; Engkilde & Surlyk 2003).

Palaeocurrents

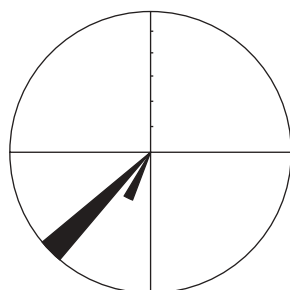
Fluvial and marine palaeocurrents in the Middle Jurassic deposits of East Greenland are mainly axial towards the south with a subordinate northwards tidal component. The Bjørnedal Block represents a significant exception to this pattern. The fluvial Bristol Elv Formation shows palaeocurrents towards the south-west in the western part of the dip transect (Figs 3, 5). The palaeocurrents of the overlying marine sandstones of the Pelion and Olympen Formations are, however, mainly towards the south-east and north-east (Figs 3, 5), and marine currents thus essentially moved down the hangingwall slope in an offshore direction. A subordinate SW–NE-oriented tidal system is recorded in the easternmost section (Figs 3, 5).

Down-dip facies development on the Bjørnedal Block

A marked change in facies is recorded down the hangingwall of the Bjørnedal Block (Fig. 3). The up-dip western sections are more sand-rich, and mudstone units are relatively thin. Down-dip, the mudstone units become thicker and the whole succession expands in thickness. The interval from the Upper Bajocian *Cadoceras pompeckji* Chronozone to the Lower Callovian *C. apertum* Chronozone is thus about 200 m thick towards the west and increases to at least 250 m at the eastern down-dip end of the section. The thicknesses are measured between the correlative drowning surfaces, and the down-dip thickness increase thus amounts to 50 m over 20 km. The western up-dip area is thus slightly condensed compared to the down-dip area, and was bypassed by much of the finer-grained

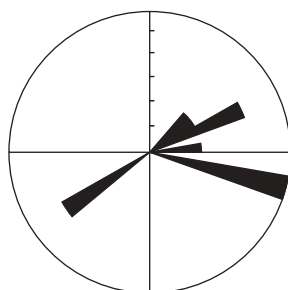
Bristol Elv Fm

Vælddal and E. Steenstrup Dal



N = 5 Circle = 60%

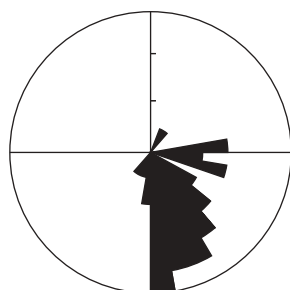
Forårsdal



N = 10 Circle = 30%

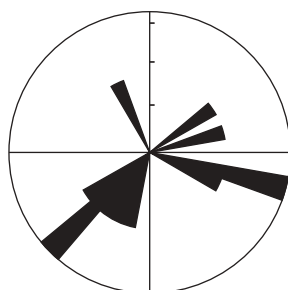
Pelion Fm

Vælddal and E. Steenstrup Dal



N = 40 Circle = 15%

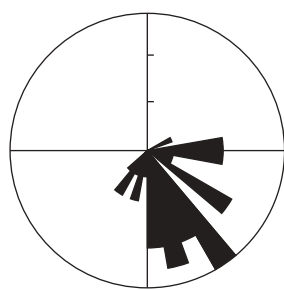
Forårsdal



N = 12 Circle = 15%

Olympen Fm

Vælddal, E. Steenstrup Dal and Forårsdal



N = 39 Circle = 15%

Fig. 5. Palaeocurrent roses for the Bristol Elv, Pelion and Olympen Formations. Measurements of cross-bed foreset dip azimuths. Note the dominance of E-SE down-dip directions which contrasts markedly with the dominant S-SSW directions of the Pelion and Olympen Formations elsewhere in East Greenland.

sediment, which was deposited on the lower parts of the hangingwall slope where creation of accommodation space was greater.

Comparison of stratigraphy on W- and E-dipping blocks

The eastwards-dipping Bjørnedal Block contains thick mudstone units at the base of the parasequence sets. This contrasts markedly with the Pelion Formation parasequences on the wide westwards-dipping blocks elsewhere in East Greenland, which consist almost exclusively of sandstones (Engkilde & Surlyk 2003). The marine palaeocurrents are mainly towards the south-east on the Bjørnedal Block, whereas they are towards the south or SSW on the westwards-dipping blocks. The succession similarly shales out towards the south-east on the Bjørnedal Block and towards the S-SSW on the latter blocks. The most important difference is that sediment influx to the Bjørnedal Block was derived from bypass and overspill of the adjacent block to the west, as also noted by Carr (1998), whereas sediment influx to the west-dipping blocks was directly from rivers at the heads of the structurally controlled embayments.

Stratigraphic implications

The marine Middle Jurassic deposits in adjacent parts of East Greenland, notably in Jameson Land are placed in the proximal sandy Pelion Formation and the distal mudstone-dominated Fossilbjerget Formation. There is little interfingering between the two formations except for the upper part where the uppermost tongue of the Pelion Formation (Parnas Member) is intercalated within the top Fossilbjerget Formation (Heinberg & Birkelund 1984; Engkilde & Surlyk 2003).

The stratigraphic development of the Bjørnedal Block differs in its regular alternation between mudstones and sandstones, which form a composite aggradational to retrogradational stack of parasequence sets culminating in the black mudstones of the Bernbjerg Formation. A pragmatic solution to this stratigraphic problem is to place the lower sandstone-dominated yellow sandstone package of parasequence sets 1-5 in the Pelion Formation. The overlying dark grey mudstone (lower part of parasequence set 6) is placed in the Fossilbjerget Formation and the overlying sandstone of parasequence set 6 in the Parnas Member of

the Pelion Formation. The mudstone–sandstone boundary in parasequence set 6 is characteristically sharp and is well suited as a lithostratigraphic boundary. The mudstone of the lower part of parasequence set 7 forms the top tongue of the Fossilbjerget Formation (Alsen & Surlyk 2004, this volume). The Olympen Formation comprises the sandstone-dominated upper part of parasequence set 7 and parasequence set 8 (Fig. 3).

The ages of the three formations, as here defined, fit well with other areas in East Greenland. The base of the Pelion Formation is not exposed or has not yielded any fossils but is thought to belong to the Upper Bajocian *Cadoceras borealis* Chronozone, in agreement with evidence from nearby areas in central Traill Ø. Parasequence sets 4 and 5 from the upper part of the formation belong to the *C. pompeckji* and *C. apertum* Chronozones, and the top of the formation (Parnas Member) falls in the basal part of the *C. nordenskjoldi* Chronozone (Fig. 3). The lower wedge of the Fossilbjerget Formation is only 25 m thick and belongs to the *C. apertum* Chronozone. The age of the top wedge of the Fossilbjerget Formation (base of parasequence set 7) is poorly constrained but is probably still Callovian. This development is similar to that found in nearby Bjørnedal (Alsen & Surlyk 2004, this volume) and in central Jameson Land (Engkilde & Surlyk 2003).

Palaeogeographic implications

The south-eastwards down-dip palaeocurrent directions and proximal to distal facies changes of the Jurassic succession on the Bjørnedal Block indicate that the sea was open and deepest towards the east (Fig. 6). This contrasts with the adjacent parts of the Middle Jurassic basin of East Greenland which are characterised by N–S-oriented marine embayments limited to the east by elongated peninsulas, islands or submarine shoals formed by uplifted crests of westwards-tilted blocks. These embayments were open and deepest towards the south as shown by overall southwards-directed palaeocurrents and decrease in grain size (Surlyk 1977b, 1978, 2003; Surlyk & Clemmensen 1983).

Conclusions

The Bjørnedal Block was formed during rifting initiated in Late Bajocian time (Carr 1998). The block is bounded to the west by the west-dipping Vælddal Fault and is tilted towards the east in contrast to the Middle–

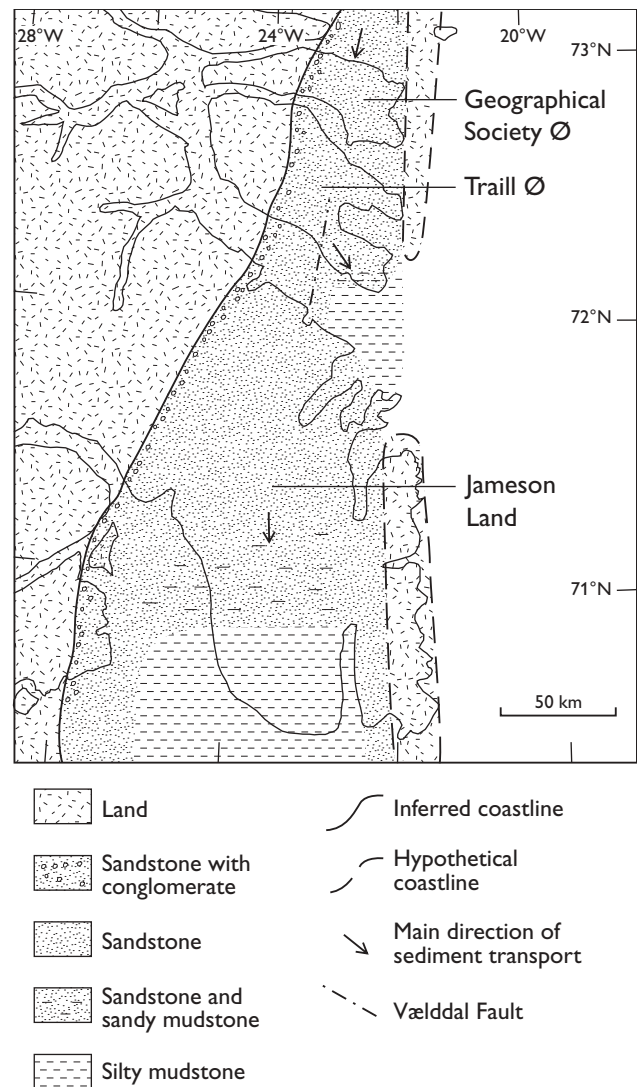


Fig. 6. Generalised Bathonian (Middle Jurassic) palaeogeography and facies distribution in the Geographical Society Ø, Traill Ø and Jameson Land region. The sea was open towards the east in the area comprising south-eastern Traill Ø and north-eastern Jameson Land due to the east-dipping nature of the more than 30 km wide Bjørnedal Block, which was formed during early rifting. This contrasts with the remaining parts of the Jurassic basin of East Greenland where N–S-oriented marine embayments were limited to the east by elongated peninsulas, islands or submarine shoals formed by uplifted crests of westwards-tilted blocks. Based on Surlyk (1977b).

Late Jurassic west-dipping blocks characterising the rest of the Jurassic basin of East Greenland. The Middle – lower Upper Jurassic succession in East Greenland shows mainly axial, southwards-directed palaeocurrents and sediment entered the basins at the head of fault-controlled embayments. The succession on the Bjørnedal Block differs in showing east- and south-east-directed palaeocurrents and associated proximal

to distal facies changes, transverse to the axis of the rift basin. The Middle Jurassic sediments bypassed the block west of the Væddal Fault (Carr 1998) and spilled over onto the eastwards-dipping hangingwall of the Bjørnedal Block. Existing palaeogeographic reconstructions have thus been modified to account for the eastwards dip of the Bjørnedal Block. In this area the sea was open and deepened towards the east and there is no indication of a barrier or shoal to the east.

Acknowledgements

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References

- Alsen, P. & Surlyk, F. 2004: Maximum Middle Jurassic transgression in East Greenland: evidence from new ammonite finds, Bjørnedal, Traill Ø. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 31–49 (this volume).
- Callomon, J.H. 1993: The ammonite succession in Middle Jurassic of East Greenland. Bulletin of the Geological Society of Denmark **40**, 83–113.
- Carr, I.D. 1998: Facies analysis and reservoir characterisation of Jurassic sandstones from Bjørnedal, central East Greenland, 245 pp. Unpublished Ph.D. thesis, Institute for Sedimentology, University of Reading, UK.
- Donovan, D.T. 1953: The Jurassic and Cretaceous stratigraphy and palaeontology of Traill Ø, East Greenland. Meddelelser om Grønland **111**(4), 150 pp.
- Engkilde, M. & Surlyk, F. 2003: Shallow marine syn-rift sedimentation: Middle Jurassic Pelion Formation, Jameson Land, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 813–863.
- Heinberg, C. & Birkelund, T. 1984: Trace-fossil assemblages and basin evolution of the Vardekløft Formation (Middle Jurassic, central East Greenland). Journal of Paleontology **58**(2), 362–397.
- Koch, L. & Haller, J. 1971: Geological map of East Greenland 72°–76°N. Lat. (1:250 000). Meddelelser om Grønland **183**, 26 pp., 13 maps.
- Larsen, M. & Surlyk, F. 2003: Shelf-edge delta and slope deposition in the Upper Callovian – Middle Oxfordian Olympen Formation, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 931–948.
- Piasecki, S. & Larsen, M. 1998: Biofacies and sequence stratigraphy in an intracratonic seaway, Middle to Upper Jurassic, East Greenland. Abstracts (CD-ROM), American Association of Petroleum Geologists 1998 annual meeting, Salt Lake City (Utah), 2 pp.
- Price, S.P. & Whitham, A.G. 1997: Exhumed hydrocarbon traps in East Greenland: analogs for the Lower–Middle Jurassic play of Northwest Europe. American Association of Petroleum Geologists Bulletin **81**, 196–221.
- Stauber, H. 1942: Die Triasablagerungen von Ostgrønland. Meddelelser om Grønland **132**(1), 325 pp.
- Stemmerik, L., Clausen, O.R., Korstgård, J., Larsen, M., Piasecki, S., Seidler, L., Surlyk, F. & Therkelsen, J. 1997: Petroleum geological investigations in East Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. Geology of Greenland Survey Bulletin **176**, 29–38.
- Surlyk, F. 1977a: Mesozoic faulting in East Greenland. In: Frost, R.T.C. & Dijkers, A.J. (eds): Fault tectonics in N.W. Europe. Geologie en Mijnbouw **56**, 311–327.
- Surlyk, F. 1977b: Stratigraphy, tectonics and palaeogeography of the Jurassic sediments of the areas north of Kong Oscars Fjord, East Greenland. Bulletin Grønlands Geologiske Undersøgelse **123**, 56 pp.
- Surlyk, F. 1978: Jurassic basin evolution of East Greenland. Nature **274**(5667), 130–133.
- Surlyk, F. 2003: The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 659–722.
- Surlyk, F. & Clemmensen, L.B. 1983: Rift propagation and eustasy as controlling factors during Jurassic inshore and shelf sedimentation in northern East Greenland. Sedimentary Geology **34**, 119–143.
- Therkelsen, J. & Surlyk, F. 2004: The fluvial Bristol Elv Formation, a new Middle Jurassic lithostratigraphic unit from Traill Ø, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 19–29 (this volume).
- Vosgerau, H., Larsen, M., Piasecki, S. & Therkelsen, J. 2004: A new Middle–Upper Jurassic succession on Hold with Hope, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 51–71 (this volume).

The fluviatile Bristol Elv Formation, a new Middle Jurassic lithostratigraphic unit from Traill Ø, North-East Greenland

Jens Therkelsen and Finn Surlyk

A new lithostratigraphic unit, the Bristol Elv Formation, is erected in this paper. It is only known from Traill Ø, East Greenland, where it unconformably overlies Triassic redbeds of the Fleming Fjord Formation and is overlain by lithologically similar shallow marine Upper Bajocian sandstones of the Pelion Formation. The age of the formation is not well constrained but is probably Early Bajocian. The Bristol Elv Formation is at least 155 m thick and consists of conglomerates, coarse-grained pebbly sandstones and subordinate mudstones, deposited in braided rivers. A finer-grained lacustrine/floodplain unit, *c.* 37 m thick, is interbedded with the fluvial sandstones at one locality. Deposition of the fluvio-lacustrine Bristol Elv Formation marks a major change in basin configuration and drainage patterns, reflecting the onset of the important, protracted Middle–Late Jurassic rift event in East Greenland.

Keywords: fluvial, lacustrine, Middle Jurassic sediments, new formation, North-East Greenland

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The first detailed description of the Jurassic sandstones on the islands of Traill Ø and Geographical Society Ø (Fig. 1) was presented by Donovan (1953, 1955, 1957) who grouped the deposits in the Yellow Series of Maync (1947). Donovan's work was focused on the sediments exposed in the Bjørnedal area in south-eastern Traill Ø while the sandstones exposed at Mols Bjerger and Svinhufvud Bjerger received less attention. Donovan (1953, p. 64) suggested that black shales interbedded with sandstones and occasional conglomerates, which he termed the Plant Beds, were deposited in a marine embayment, or possibly on the subaerial part of a debris fan. Higher in the sandstone unit, he found evidence for periodic marine incursions as indicated by occasional ammonite-bearing levels.

A lithostratigraphic scheme covering the Jurassic of Jameson Land in East Greenland was erected by Surlyk *et al.* (1973) and was extended to the areas north of Kong Oscar Fjord by Surlyk (1977). The Middle Juras-

sic sandstones of Traill Ø and Geographical Society Ø were placed in the Pelion Member of the Vardekløft Formation. This scheme has recently been revised in the light of much new work in the region resulting in rank changes and establishment of new formations and members (see Surlyk 2003, fig. 5).

Fieldwork in the Traill Ø area has revealed that sandstones formerly referred exclusively to the shallow marine Pelion Formation (Pelion Member in: Surlyk 1977) actually consist of a lower fluvial unit overlain by marine sandstones (Price & Whitham 1997; Stemmerik *et al.* 1997). The fluviatile deposits are placed in a new lithostratigraphic unit, the Bristol Elv Formation, which is erected here as the basal unit of the Middle Jurassic Vardekløft Group on Traill Ø (Fig. 2). The new formation consists dominantly of conglomerates, coarse-grained pebbly sandstones and subordinate mudstones and was deposited in a braided river environment, probably in Middle Jurassic, Early Bajo-

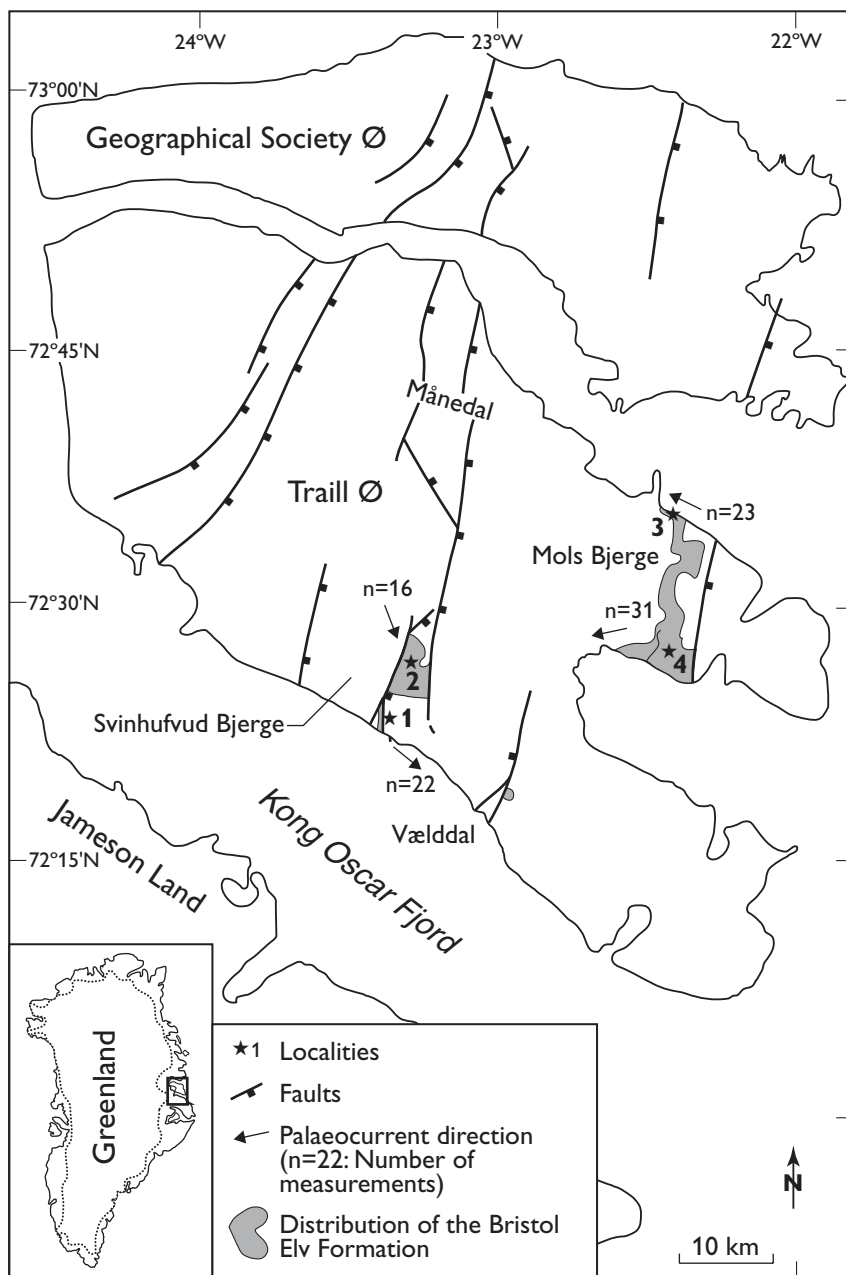


Fig. 1. Map showing the distribution of the Bristol Elv Formation in the Trail Ø area, the position of localities and palaeocurrent directions. The map is modified from Stemmerik *et al.* (1997).

cian time. In one section, fine-grained sandstones, mudstones, medium- to coarse-grained sandstone beds and thin coal seams occur intercalated with the fluvial sandstones, and are interpreted as lacustrine or flood-plain deposits.

Bristol Elv Formation

new formation

History. The strata assigned here to the new Bristol Elv Formation were included in the Yellow Series (Maync 1947) by Donovan (1953) and were referred to the Pelion Member of the Vardekløft Formation by Surlyk (1977). The fluvial nature of the lower part of the succession was recognised independently by Price & Whitham (1997) and Stemmerik *et al.* (1997), and labelled PM1 by the former authors.

Name. After the river Bristol Elv in the southern part of Mols Bjerge, Traill Ø (Fig. 1).

Type section. Southern part of Svinhufvud Bjerge (Fig. 1, Locality 1) on the south coast of Traill Ø (Figs 1, 3).

Reference sections. North-eastern Svinhufvud Bjerge (Fig. 1, Locality 2), northern and southern Mols Bjerge (Locations 3, 4) and Vælddal, all on Traill Ø (Figs 1, 4).

Thickness. The formation is at least 155 m thick in the southern part of Svinhufvud Bjerge, whereas thicknesses in excess of 80 m are recorded in northern Mols Bjerge and at Bristol Elv in the southern part of Mols Bjerge. Thicknesses of 280 m and 520 m in the southern and northern Svinhufvud Bjerge areas, respectively, and 310 m in northern Mols Bjerge were stated by Price & Whitham (1997), but these large values have not been corroborated by our study (Surlyk & Noe-Nygaard 2001).

Lithology. The Bristol Elv Formation consists mainly of conglomerates, pebbly sandstones and sandstones in the Mols Bjerge area, whereas more fine-grained deposits are intercalated in the Svinhufvud Bjerge area. The bulk of the formation consists of yellowish to whitish, poorly sorted, coarse-grained sandstones, pebbly sandstones and fine pebble conglomerates with subrounded to well-rounded quartzite pebbles and mudstone intraclasts. Black to dark grey mudstones with centimetre-thick autochthonous coal beds occur intercalated with the sandstones and conglomerates at several levels. The coarse-grained deposits show large-scale trough cross-bedding, but the structures are mostly poorly defined. The cross-bedded sets are 0.15–2.0 m thick, and form cosets up to 7 m thick. Also observed are large-scale scour-and-fill structures (Fig. 5), planar cross-bedding, planar lamination, rare water escape structures and imprints of tree trunks, which may be found in accumulations. The sediments commonly form fining-upwards units, up to 16 m thick. On the south coast of Traill Ø, a sandstone unit, c. 19 m thick, shows evidence of gently dipping bedforms (Fig. 6, corresponding to the 134–153 m interval in Fig. 3). At Svinhufvud Bjerge, the coarse-grained units are separated by mudstone units up to 6 m thick, while the coarse-grained units at Mols Bjerge are amalgamated without any fine-grained interbeds.

The mudstones in the Svinhufvud Bjerge area are very uniform in grain size and overlie the sandstones with a sharp boundary. They show a well-developed

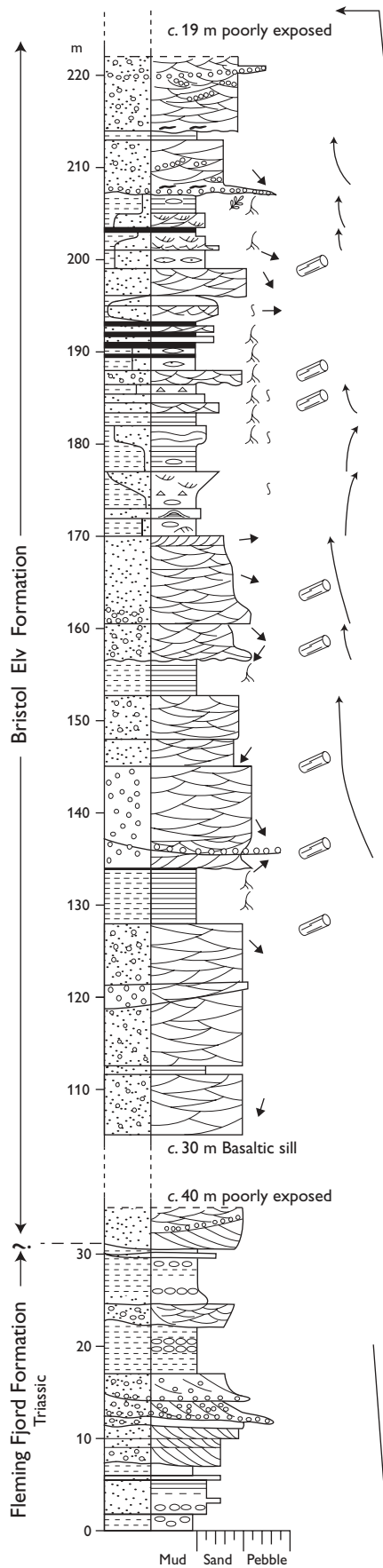
System	Stage		Group	Formation	
Jurassic	Upper	Kimmeridgian	Hall Bredning	Bernbjerg	
					U
		Oxfordian	M	Vardekløft	Olympen
			L		
	Calloviaian	U	Parnas Mb		
		M			
		L	Fossilbjerget		
	Bathonian	U			Pelion
		M			
		L			
	Bajocian	U	Bristol Elv		
		L			
	Hiatus				
	Triassic			Scoresby Land	Fleming Fjord

Fig. 2. Lithostratigraphic scheme of the Jurassic succession in the Traill Ø area. The age of the Bristol Elv Formation is poorly constrained, but an Early Bajocian age is the most likely. Based on Clemmensen (1980) and D. Strogon (personal communication 2000); see also Surlyk (2003).

to faint lamination, which is commonly disturbed by rooting. A few centimetre-thick layers of medium-grained sandstone occur in the upper part of the mudstone units at the same level as the rootlets.

The orientation of cross-bed trough axes and foreset azimuths of planar cross-beds in the sandstones at Mols Bjerge generally indicates westerly palaeocurrent directions, whereas the directions in the Svinhufvud Bjerge area are generally towards the south-east. Stylolites are common in the coarse-grained sandstones and fine-grained conglomerates at Mols Bjerge but have not been observed at Svinhufvud Bjerge.

A succession of mainly black to dark grey mudstones and fine-grained sandstones, c. 37 m thick, with intercalated coal beds and coarse-grained sandstones occurs in the type section at Svinhufvud Bjerge (Fig. 3, 170–207 m in log). The sandstones are trough cross-bedded, structureless, cross-laminated or lenticular



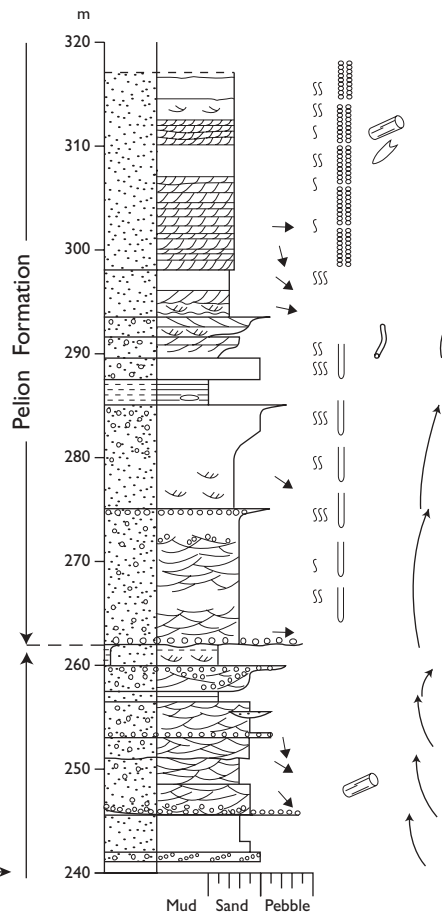
Lithology

- Mudstone
- Sandstone
- Pebbly sandstone
- Conglomerate
- Coal
- Mudstone clasts
- Concretion

Structures

- Structureless sand
- Structureless conglomerate
- Parallel lamination
- Wavy bedding
- Cross-lamination
- Tabular cross-bedding
- Trough cross-bedding
- Lenticular bedding

- Slump
- Hummocky and swaley cross-stratification
- Palaeocurrent direction
- Degree of bioturbation
- Belemnite
- Rootlets
- Stems/logs
- Plant fragments
- Stylolites
- Coalified logs
- Diplocraterion habichi*
- Ophiomorpha nodosa*
- Sub-vertical burrows
- Coarsening-upwards
- Fining-upwards



bedded, and display both sheet-like and lenticular geometries. Some of the sandstones show poorly developed wavy surfaces, are weakly bioturbated and contain rare mudstone flasers. The mudstones are mainly laminated or weakly laminated and contain conspicuous root horizons, *in situ* tree stumps, fern leaves and early diagenetic sideritic concretions. Sandstone beds up to 10 cm thick with wave ripple cross-stratification, similar to micro-hummocky cross-stratification, occur in the mudstones. The ripples have wavelengths up to 30 cm and heights up to 5 cm. Immediately above one of these sandstone beds, rounded pebbles up to 4 cm in diameter are present. A sandstone bed, c. 1 m thick, showing swaley cross-stratification occurs intercalated in the mudstones (Fig. 3, 172–173 m in log, Fig. 7b).

The wave-rippled and swaley cross-stratified beds form part of two small coarsening-upwards units, 7 m and 5 m thick, in the lowest part of the succession (Fig. 3, 170–182 m in log, Fig. 7a). The lower part of the units consists of laminated and faintly laminated mudstones, which in the lowest unit are intercalated with wave-rippled and swaley cross-stratified sandstone beds. The units grade upwards into very fine-grained sandstones, showing poorly developed wavy surfaces, cross-lamination, lenticular bedding and rare mudstone flasers. Unidentified trace fossils occur in both units and the top beds in the upper coarsening-upwards unit are penetrated by rootlets. Above these two units, coal beds up to 0.45 m thick and thin mudstone beds occur together with 0.2–2.5 m thick beds of trough cross-bedded, medium-grained sandstone to fine pebble conglomerate with sharp basal surfaces, showing palaeocurrents towards the east-south-east (Fig. 3, 182–207 m in log). Locally, these beds are overlain by fine- to very fine-grained sandstones, forming poorly defined fining-upwards successions.

Pyrite is not present in the coals, but occasionally replaces organic detritus in the sandstones. The coals consist almost entirely of non-detrital vitrinite, which together with the presence of root horizons beneath the coal beds show that they are autochthonous.

Boundaries. The formation unconformably overlies the Upper Triassic Fleming Fjord Formation at Svinhufvud Bjerger and Mols Bjerger as well as in Vælddal

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Fig. 3. Type section (Locality 1) of the Bristol Elv Formation. South Svinhufvud Bjerger, Traill Ø. Position shown in Fig. 1.

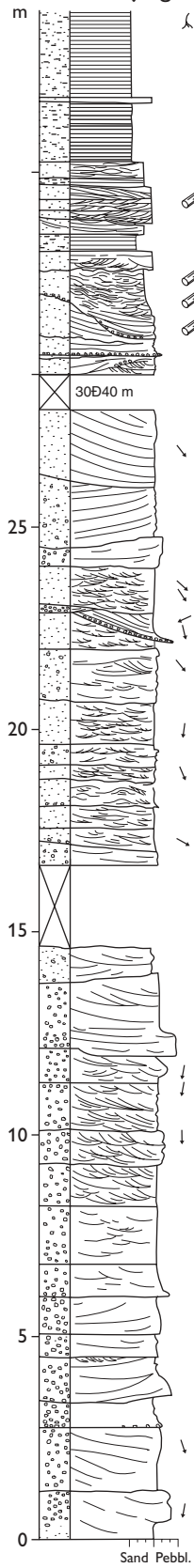
(Clemmensen 1980; D. Strogen, personal communication 2000). The upper boundary is placed at an erosional surface draped by a pebble lag overlain by marine sandstones of the Pelion Formation, which is dominated by medium- to coarse-grained, planar cross-bedded and structureless sandstones with ammonites, belemnites, bivalves and marine trace fossils.

Distribution. The formation is known only from Svinhufvud Bjerger, Mols Bjerger and Vælddal in eastern Traill Ø (Fig. 1). The lacustrine/backswamp unit described from the type section is probably correlative to the Plant Beds of Donovan (1953, 1957), which occur in Vælddal (Henrik Vosgerau, personal communication 1998).

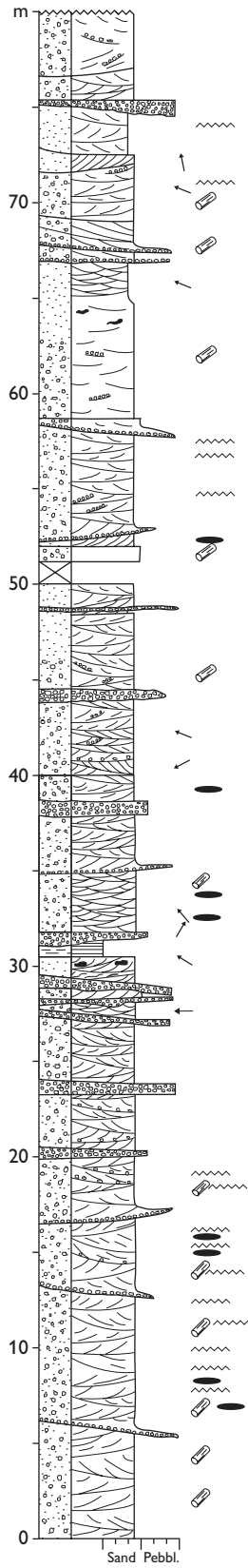
Geological age. No macrofaunas were found within the Bristol Elv Formation. A few relatively well preserved but as yet unidentified fern leaves were retrieved from a single bed in the lacustrine/floodplain unit in the southern part of Svinhufvud Bjerger. Harris (1946) reported a stem identified as *Equisetites* sp. A. of inferred Early Jurassic age from Kap Palander in the northernmost Mols Bjerger. Harris (1946) pointed out, however, that this specimen also resembles species of Late Triassic or Middle Jurassic ages, and that it does not give any precise age indication.

Preliminary palynological analysis of samples from the lacustrine/backswamp deposits suggests a broad Late Toarcian – Bathonian age (Karen Dybkjær, personal communication 1998). Age diagnostic palynomorphs include *Callialasporites dampieri* (late Early Toarcian or younger), *Callialasporites turbatus* (Late Toarcian or younger), *Callialasporites segmentatus* (late Early Toarcian or younger) and *Foraminisporis jurassicus* (Middle Rhaetian – Bajocian) (Batten & Koppelhus 1996). The Upper Bajocian *Cranocephalites borealis* Zone is represented in the immediately overlying Pelion Formation sandstones (Donovan 1953, 1957; Callomon 1993; Alsen 1998). This is the lowest Middle Jurassic ammonite zone recognised in East Greenland. In Jameson Land, the Pelion Formation contains a relatively thick marine sandstone unit without ammonites below the lowest occurrence of *Cranocephalites borealis*. This unit overlies dark mudstones of the Sortehat Formation the top of which is of Early Bajocian age (Underhill & Partington 1993; Koppelhus & Hansen 2003). The unit is thought to be a distal marine correlative of the Bristol Elv Formation. This is supported by the stratigraphic position of both units, underlying marine Pelion sandstones of the *C. borealis* Chronozone

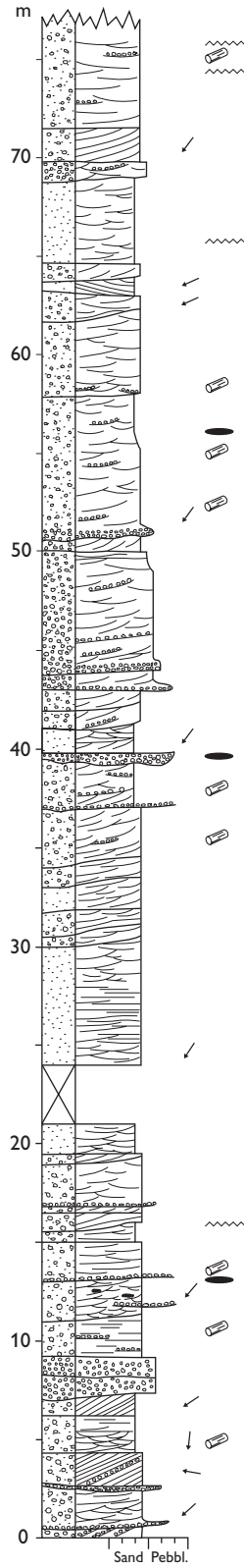
Locality 2
North-eastern
Svinhufvud Bjerge



Locality 3
Northern
Mols Bjerge



Locality 4
Southern
Mols Bjerge



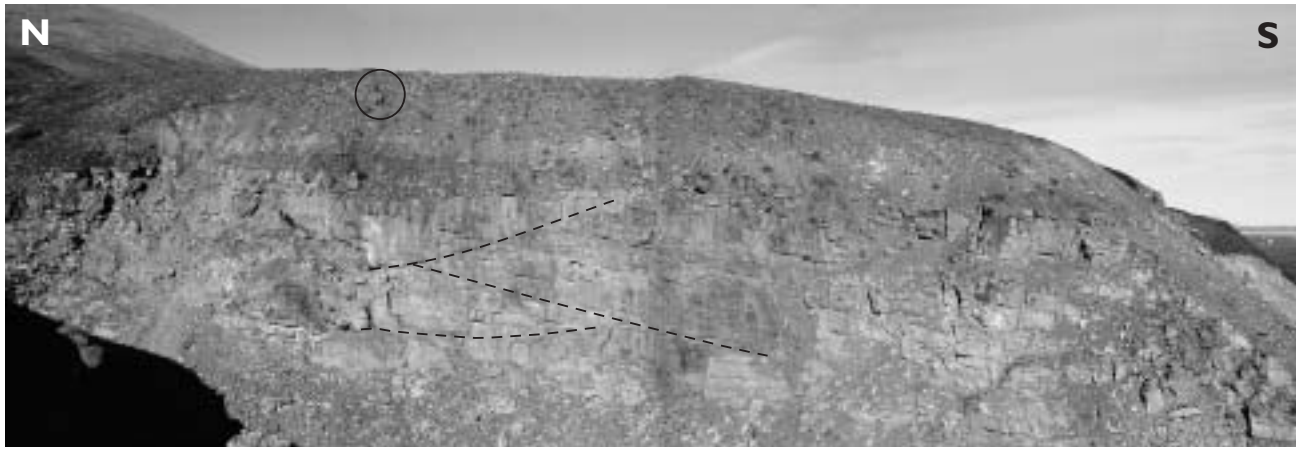


Fig. 5. Coarse-grained sandstone and fine-grained conglomerate with large-scale scour-and-fill structures (indicated by **dashed** lines below **encircled** person). Bristol Elv Formation; north-eastern Svinhufvud Bjerge.

and by the marked lithological similarity of the Pelion and Bristol Elv Formations. Lower Jurassic rocks have never been documented outside Jameson Land and all available data thus point towards an Early Bajocian age for the Bristol Elv Formation.

Depositional environment

The coarse-grain size, the presence of fining-upwards units and trough cross-bedding, the unidirectional palaeocurrents towards the west (in Mols Bjerge) and south-east (in Svinhufvud Bjerge) and the abundance of mudstone intraclasts, the absence of dinoflagellate cysts and marine body and trace fossils indicate that the main part of the Bristol Elv Formation was deposited in a high-energy fluvial environment. Studied samples all show very low total sulphur (TS) contents (max. 0.43%) and high C/S values (> 10). These data support the interpretation of a terrestrial environment of deposition (Berner & Raiswell 1984).

In the Svinhufvud Bjerge area, one sandstone unit, approximately 20 m thick, shows macroforms interpreted as downstream or lateral accretion structures such as epsilon cross-bedding (Allen 1963; Fig. 6). The lower *c.* 13 m of this unit displays a fining-upwards

trend, possibly representing lateral channel migration (Allen 1964, 1965). The depth of the channel corresponds to at least the thickness of the macroform (Leeder 1973). If the interpretation of the macroforms is correct, the channel depths were in the 10–13 m range.

Fluvial styles and models were categorised in terms of channel sinuosity/braiding, sediment type and characteristic architectural elements by Miall (1985, 1996). The depositional features of the Bristol Elv Formation, especially concerning the within-channel element and the relatively large channel depths suggest deposition in the ‘perennial deep braided river’ type of Miall (1996). Reliable interpretation of a fluvial system cannot, however, be based on vertical sections alone (Miall 1996). Analysis of bounding surfaces, and extent, shape and facies relations of the architectural elements has, however, not been possible in the present case due to the nature of the outcrop.

The interbedded mudstones may, due to the sharp boundary to the underlying coarse sandstones and conglomerates, represent relatively abrupt channel abandonment and subsequent passive in-filling of channels and thus cover a confined area, or they may be more extensive bodies covering the entire floodplain area. The studied exposures do not allow conclusions on the lateral extent of the mudstone units. The fine-grained homogeneous nature of the mudstones, however, suggests that the distance to the nearest active fluvial channel must have been relatively large leading to deposition of only the finest grain sizes. The sudden change from very coarse sandstone to homogeneous mudstone also indicates a very abrupt abandon-

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Fig. 4. Composite detailed reference section from north-eastern Svinhufvud Bjerge (Locality 2) and reference sections from northern and southern Mols Bjerge (Localities 3, 4). Positions shown in Fig. 1. For legend, see Fig. 3.



Fig. 6. Fluvial, floodplain and lacustrine deposits on the south coast of Traill Ø (Locality 1). Note the 20 m thick sandstone body in the centre (see Fig. 3, 134–153 m in log) showing down-stream or lateral accretion structures (**dashed** lines) with bedforms dipping gently to the right (east). The sandstone body overlies dark floodplain mudstones. Type section of the Bristol Elv Formation.

ment of the active channels, which in a relatively short time shifted to a position farther away.

Floodplains in braided river systems are not commonly described in the literature, but studies by Reinfelds & Nanson (1993) of the Waimakariri River, New Zealand, show that braided rivers, contrary to the common conception, may include large areas of fine-grained floodplains. During avulsion events, extensive wetland areas were established and contributed greatly to trapping and deposition of large volumes of fine-grained material (e.g. Smith *et al.* 1989). A similar situation may have occurred at least twice during the lifetime of the Bristol Elv Formation river system, as shown by the occurrence of 3–6 m thick floodplain mudrocks in the section on the south coast of Traill Ø (Figs 1, 6). The presence of root horizons and thin coal beds shows that the floodplain was densely vegetated and developed into peat swamps, before the river channel migrated back over the area and peat formation ceased.

Fine-grained sediment present in the middle part of

the type section in Svinhufvud Bjerge is interpreted to have been deposited in a lacustrine/backswamp environment. Fine-grained sandstones intercalated with black and dark grey mudstone in the lower part of this lacustrine/backswamp unit show swaley cross-stratification and wave ripple cross-lamination associated with a pebble lag (Figs 3, 7). Swaley cross-stratification is interpreted as the result of storm-wave deposition above fairweather wave base and has been described from very shallow depths in the large Lake Superior (Greenwood & Sherman 1986; Sherman & Greenwood 1989). The wave ripple cross-lamination shows that some vigorous agitation must have occurred, probably during storm events (e.g. Allen 1982). The structures and the associated pebble lag are probably the result of shore-face erosion during storms, and subsequent transport into deeper waters by storm-induced currents (cf. Dam & Surlyk 1992, 1993). In the uppermost part of the lacustrine succession, the occurrence of a unit that shows coarsening-upwards from mudstone to very fine-

Fig. 7. Lacustrine deposits from the Bristol Elv Formation, south coast of Traill Ø (Locality 1). Length of knife is 21 cm.

A: Thin micro-hummocky cross-stratified / wave ripple cross-laminated sandstone intercalated with laminated mudstone.

B: Sandstone bed showing swaley cross-stratification.



grained sandstone (Fig. 3, 177–182 m) possibly records in-filling of the lake, resulting in lake shoreline progradation and gradual shallowing. The presence of rootlets shows that the lake was sufficiently shallow to allow colonisation of vegetation. Higher in the succession (Fig. 3, 182–207 m), abundant conspicuous root horizons show that vegetation spread across the shores of the lake, which eventually turned into a backswamp environment. The repeated development of autochthonous coal beds in the middle and upper part of the unit suggests that the backswamps were densely vegetated. The 0.2–2.5 m thick trough cross-bedded sandstone beds associated with the coal beds, probably represent splays into the backswamp from active chan-

nels, which were possibly situated north-west of the area. The lack of pyrite in the coal is a good indication of deposition in a freshwater environment (Cohen *et al.* 1984; Brown & Cohen 1995; Phillips & Bustin 1996).

The Plant Beds of Donovan (1953, 1957) in Vælddal are interbedded with coarse-grained sandstones and conglomerates dominated by large-scale trough cross-bedding, while hummocky and/or swaley cross-stratification, small-scale cross-lamination, root horizons and fossilised leaves occur in the finer grained sediments (Henrik Vosgerau, personal communication 1998). If the Plant Beds of Donovan (1953, 1957) are correlatives of the mudstone-dominated part of the Bristol Elv Formation type section in Svinhufvud Bjerger, a system with

scattered lakes may have existed in the area. The lateral extent of this system must have been at least 20 km.

Gradual in-filling of the lake resulted in development of a wetland area with peat swamps, which was periodically covered by sheet-sands and cut by confined channels where sand was deposited. Thin coarsening-upwards units, which probably represent crevasse splays or deltas, show that active fluvial channels were present in the adjacent area, and the lake system was eventually replaced by a fluvial braided channel system, represented by trough cross-bedded coarse-grained pebbly sandstones. This environment persisted until the area was transgressed by the sea and the shallow marine sandstones of the Pelion Formation were deposited.

Acknowledgements

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References

- 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 fluvial sedimentation: six cyclothems from the Lower Old Red Sandstone, Anglo-Welsh basin. *Sedimentology* **3**, 163–198.
- Allen, J.R.L. 1965: A review of the origin and characteristics of recent alluvial sediments. *Sedimentology* **5**, 89–191.
- Allen, J.R.L. 1982: Sedimentary structures; their character and physical basis. *Developments in sedimentology* **30A/B**, 1266 pp. Amsterdam: Elsevier.
- Alsen, P. 1998: Middle Jurassic ammonite biostratigraphy in the Traill Ø region, central East Greenland. Abstract. 23rd Nordic Geological Winter Meeting, Aarhus, Denmark (13–16 January), 17 only.
- Batten, D.J. & Koppelhus, E.B. 1996: Biostratigraphic significance of uppermost Triassic and Jurassic miospores in Northwest Europe. In: Jansonius, J. & McGregor, D.C. (eds): *Palynology: principles and applications*. American Association of Stratigraphic Palynologists Foundation **2**, 795–806.
- Berner, R.A. & Raiswell, R. 1984: C/S method for distinguishing freshwater from marine sedimentary rocks. *Geology* **12**, 365–368.
- Brown, K.E. & Cohen, A.D. 1995: Stratigraphic and micropetrographic occurrences of pyrite in sediments at the confluence of carbonate and peat-forming depositional systems, southern Florida, U.S.A. *Organic Geochemistry* **22**, 105–126.
- Callomon, J.H. 1993: The ammonite succession in the Middle Jurassic of East Greenland. *Bulletin of the Geological Society of Denmark* **40**, 83–113.
- Clemmensen, L.B. 1980: Triassic lithostratigraphy of East Greenland between Scoresby Sund and Kejser Franz Josephs Fjord. *Bulletin Grønlands Geologiske Undersøgelse* **139**, 56 pp.
- Cohen, A.D., Spackman, W. & Dolsen, P. 1984: Occurrence and distribution of sulfur in peat-forming environments of southern Florida. *International Journal of Coal Geology* **4**, 73–96.
- Dam, G. & Surlyk, F. 1992: Forced regressions in a large wave- and storm-dominated anoxic lake, Rhaetian–Sinemurian Kap Stewart Formation, East Greenland. *Geology* **20**, 749–752.
- Dam, G. & Surlyk, F. 1993: Cyclic sedimentation in a large wave- and storm-dominated anoxic lake; Kap Stewart Formation (Rhaetian–Sinemurian), Jameson Land, East Greenland. In: Posamentier, H.W. *et al.* (eds): *Sequence stratigraphy and facies associations*. International Association of Sedimentologists Special Publication **18**, 419–448.
- Donovan, D.T. 1953: The Jurassic and Cretaceous stratigraphy and palaeontology of Traill Ø, East Greenland. *Meddelelser om Grønland* **111**(4), 150 pp.
- Donovan, D.T. 1955: The stratigraphy of the Jurassic and Cretaceous rocks of Geographical Society Ø, East Greenland. *Meddelelser om Grønland* **103**(9), 60 pp.
- Donovan, D.T. 1957: The Jurassic and Cretaceous systems in East Greenland. *Meddelelser om Grønland* **155**(4), 214 pp.
- Greenwood, B. & Sherman, D.J. 1986: Hummocky cross-stratification in the surf zone: flow parameters and bedding genesis. *Sedimentology* **33**, 33–46.
- Harris, T.M. 1946: Liassic and Rhaetic Plants collected in 1936–38 from East Greenland. *Meddelelser om Grønland* **114**(9), 39 pp.
- Koppelhus, E.B. & Hansen, C.F. 2003: Palynostratigraphy and palaeoenvironment of the Middle Jurassic Sortehat Formation (Neill Klinger Group), Jameson Land, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): *The Jurassic of Denmark and Greenland*. Geological Survey of Denmark and Greenland Bulletin **1**, 777–811.
- Leeder, M.R. 1973: Fluvial fining-upwards cycles and the magnitude of palaeochannels. *Geological Magazine* **110**(3), 265–276.
- Maync, W. 1947: Stratigraphie der Jurabildungen Ostgrönlands zwischen Hochstetterbugten (75°N) und dem Kejser Franz Joseph Fjord (73°N). *Meddelelser om Grønland* **132**(2), 223 pp.
- Miall, A.D. 1985: Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. *Earth-Science Reviews* **22**(4), 261–308.
- Miall, A.D. 1996: *The geology of fluvial deposits: sedimentary facies, basin analysis and petroleum geology*, 582 pp. Berlin: Springer-Verlag.
- Phillips, S. & Bustin, R.M. 1996: Sulfur in the Changuinola peat deposit, Panama, as an indicator of the environments of

- deposition of peat and coal. *Journal of Sedimentary Research* **66**(1), 184–196.
- Price, S.P. & Whitham, A.G. 1997: Exhumed hydrocarbon traps in East Greenland: analogs for the Lower–Middle Jurassic play of Northwest Europe. *American Association of Petroleum Geologists Bulletin* **81**(2), 196–221.
- Reinfelds, I. & Nanson, G. 1993: Formation of braided river floodplains, Waimakariri River, New Zealand. *Sedimentology* **40**, 1113–1127.
- Sherman, D.J. & Greenwood, B. 1989: Hummocky cross-stratification and post-vortex ripples: length scales and hydraulic analysis. *Sedimentology* **36**, 981–986.
- Smith, N.D., Cross, T.A., Dufficy, J.P. & Clough, S.R. 1989: Anatomy of an avulsion. *Sedimentology* **36**, 1–24.
- Stemmerik, L., Clausen, O.R., Korstgård, J., Larsen, M., Piasecki, S., Seidler, L., Surlyk, F. & Therkelsen, J. 1997: Petroleum geological investigations in East Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. *Geology of Greenland Survey Bulletin* **176**, 29–38.
- Surlyk, F. 1977: Stratigraphy, tectonics and palaeogeography of the Jurassic sediments of the areas north of Kong Oscars Fjord, East Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **123**, 56 pp.
- Surlyk, F. 2003: The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting. In: Ineson, J.R. & Surlyk, F. (eds): *The Jurassic of Denmark and Greenland*. Geological Survey of Denmark and Greenland Bulletin **1**, 659–722.
- Surlyk, F. & Noe-Nygaard, N. 2001: Cretaceous faulting and associated coarse-grained marine gravity flow sedimentation, Traill Ø, East Greenland. In: Martinsen, O.J. & Dreyer, T. (eds): *Sedimentary environments offshore Norway – Palaeozoic to Recent*. Norwegian Petroleum Society (NPF) Special Publication **10**, 293–319.
- Surlyk, F., Callomon, J.H., Bromley, R.G. & Birkelund, T. 1973: Stratigraphy of the Jurassic – Lower Cretaceous sediments of Jameson Land and Scoresby Land, East Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **105**, 76 pp.
- Underhill, J. & Partington, M.A. 1993: Use of genetic sequence stratigraphy in defining and determining a regional tectonic control on the 'Mid-Cimmerian Unconformity' – implications for North Sea basin development and the global sea-level chart. In: Weimer, P. & Posamentier, H.W. (eds): *Siliciclastic sequence stratigraphy: recent developments and applications*. American Association of Petroleum Geologists Memoir **58**, 449–484.

Maximum Middle Jurassic transgression in East Greenland: evidence from new ammonite finds, Bjørnedal, Traill Ø

Peter Alsen and Finn Surlyk

With an appendix by John H. Callomon: Description of a new species of ammonite, *Kepplerites tenuifasciculatus* n. sp., from the Middle Jurassic, Lower Callovian of East Greenland

A Middle – lower Upper Jurassic sandstone-dominated succession, more than 550 m thick, with mudstone intercalations in the middle part is exposed in Bjørnedal on Traill Ø, North-East Greenland. A number of ammonite assemblages have been found, mainly in the mudstones. They indicate the presence of the Lower Callovian *Cadoceras apertum* and *C. nordenskjoldi* Chronozones. The mudstones represent northern wedges of the Fossilbjerget Formation hitherto known only from Jameson Land to the south. In Bjørnedal they interfinger with sandstones of the Pelion and Olympen Formations. The presence of the Fossilbjerget Formation in this region indicates complete drowning of the Middle Jurassic sandstone-dominated Pelion Formation during maximum Middle Jurassic transgression.

A new species, *Kepplerites tenuifasciculatus*, is described in the appendix by J.H. Callomon. The holotype and paratype are from Jameson Land, East Greenland, but the species is also found in Bjørnedal, Traill Ø, North-East Greenland.

Keywords: ammonites, Fossilbjerget Formation, Middle Jurassic, *Kepplerites tenuifasciculatus* Callomon, Pelion Formation

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The Mesozoic deposits of the Traill Ø area in North-East Greenland were studied by Donovan (1953) during Lauge Koch's East Greenland expeditions (Fig. 1). Middle Jurassic exposures are few and scattered and fossils are scarce, allowing only a few tie-points to the biostratigraphically well-dated succession in Jameson Land to the south (Callomon 1993). A succession of dark micaceous, silty mudstones in an otherwise sandstone-dominated succession in the Bjørnedal valley, south-east Traill Ø was described by Donovan (1953; Fig. 2). Only a few poorly preserved and unidentifiable ammonite fragments were recovered. Hence the exact stratigraphic position and age of the mudstones were unknown and have remained as such until re-examination of the locality and intensive search for

ammonites was carried out during fieldwork in the Traill Ø area in 1996 (Alsen 1998). New finds of ammonites indicate an Early Callovian age (*Cadoceras apertum* Chronozone) of the mudstones (Fig. 3), which are referred to the Fossilbjerget Formation, previously known only from Jameson Land (Surlyk *et al.* 1973). This paper presents the new finds of ammonites in the Bjørnedal area and the implications of these for the sequence stratigraphic interpretation of the basin.

The Traill Ø area forms the northwards continuation of the Jurassic Jameson Land Basin within the East Greenland rift basin. Huge amounts of sand-dominated sediments were introduced into the basin mainly from the north in Middle Jurassic times and were transported southwards by marine currents along the basin axis. A

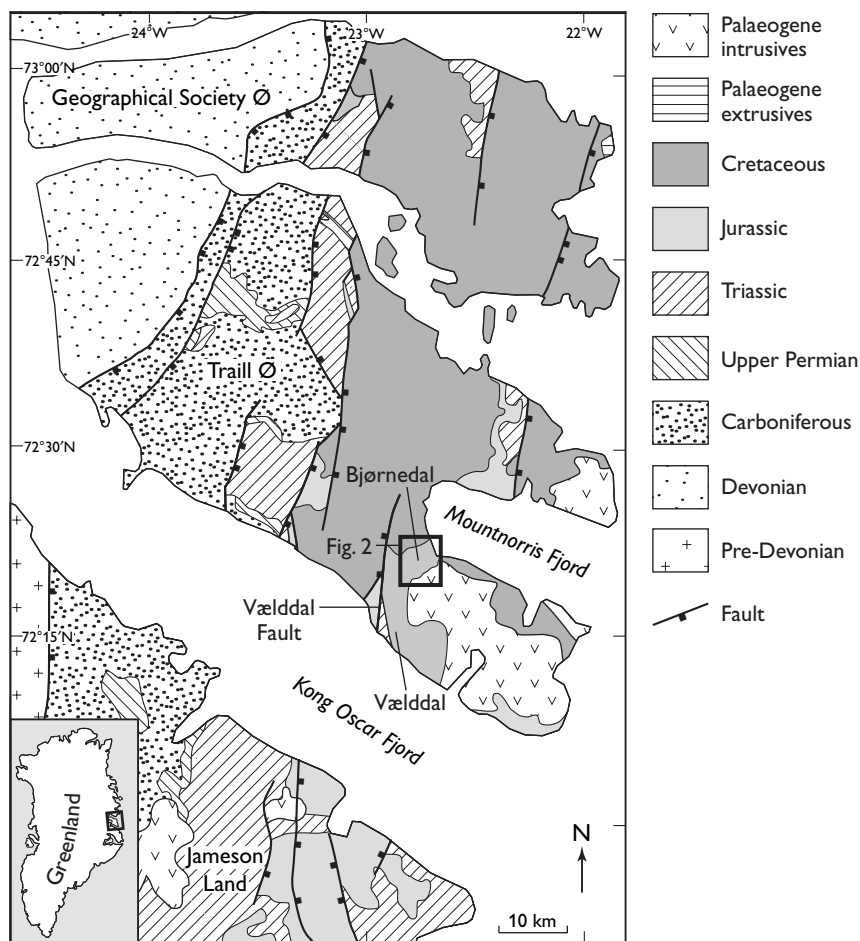


Fig. 1. Simplified geological map of the Traill Ø area. Location of study area (Fig. 2) is indicated.

thick succession of Middle Jurassic marine sediments, mainly sandstones, was deposited in northern Jameson Land and progressively thins distally towards the south. The proximal areas in Traill Ø acted as a bypass area for much of late Middle Jurassic time and the succession is generally thinner compared with the more distal areas in Jameson Land (Surlyk 2003).

The south-easternmost part of Traill Ø constituted an eastwards-tilted fault block, in contrast to other Jurassic fault blocks in East Greenland which are tilted westwards (Donovan 1953; Carr 1998; Surlyk 2003). A detailed analysis of the Middle Jurassic succession in the Vælddal area close to the crest of the eastwards-tilted block was recently undertaken by Carr (1998; Fig. 1). He demonstrated that as a result of synsedimentary movements of the Vælddal Fault during Middle Jurassic time the sedimentary evolution of the Bjørnedal area differed somewhat from that of other parts of the region. The Middle Jurassic succession in this block shows palaeocurrent directions to the east in contrast to the axial, southwards-oriented palaeocur-

rent directions seen elsewhere. The sandstone/mudstone ratio also decreases and the succession shows proximal to distal facies changes in the same direction (Vosgerau *et al.* 2004, this volume).

Stratigraphy

The lithostratigraphical scheme for the Jurassic of East Greenland was erected by Surlyk *et al.* (1973), Surlyk (1977, 1978) and Birkelund *et al.* (1984). The scheme is under revision and many units have been raised in rank (see Surlyk 2003, fig. 5). In the Traill Ø area, the Middle – lower Upper Jurassic succession now includes the Bristol Elv, Pelion, Fossilbjerget and Olympen Formations in ascending order (Fig. 4). The Bristol Elv Formation is probably not exposed in Bjørnedal. It is of pre-Late Bajocian but probably still Middle Jurassic age and includes fluvial pebbly sandstones and thin coaly shales (Therkelsen & Surlyk 2004, this volume). The Pelion Formation consists of shallow-marine sand-

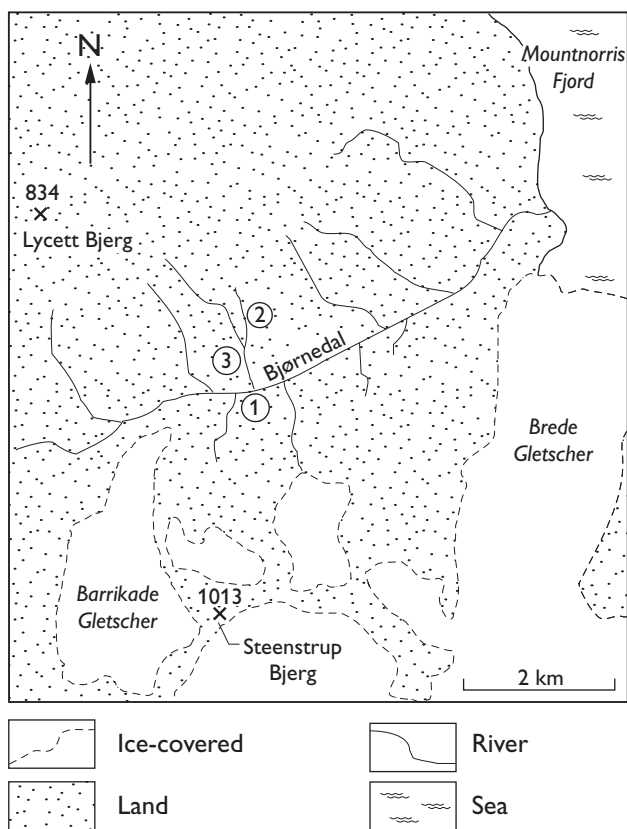


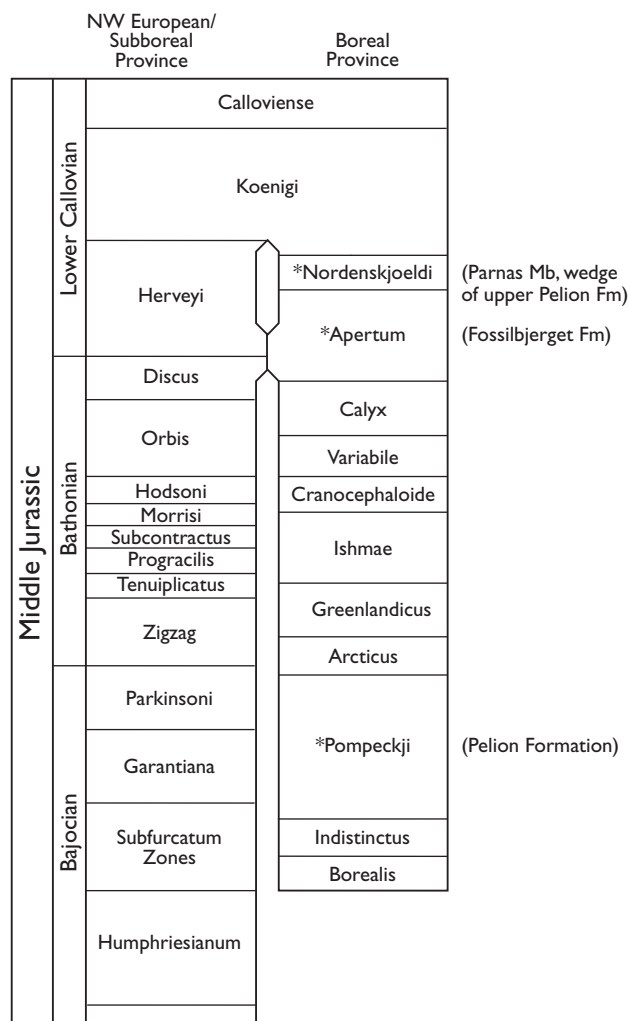
Fig. 2. Map of the Bjørnedal area, Traill Ø showing locations of sections and ammonite localities. **1**, Locality 1 with section JTH-15/96; **2**, Locality 2 with section JTH-14/96; **3**, Locality 3. Altitude of mountains in metres.

stones with bivalves, belemnites, ammonites and plant fragments. The formation rests on Triassic strata or on the Bristol Elv Formation. It is overlain by, or interfingers at the top with, offshore, dark, micaceous, silty mudstones of the Fossilbjerget Formation. A regressive wedge in the top part of the Pelion Formation interrupts the overall backstepping Pelion–Fossilbjerget couplet, and belongs to the Parnas Member of the Pelion Formation (Surlyk 2003). The Fossilbjerget Formation is overlain by the lower Upper Jurassic Olympen Formation, which also consists of shallow marine sandstones themselves quite similar to the sandstones of the Pelion Formation below, making recognition of the Olympen Formation difficult.

The Middle Jurassic succession in the Bjørnedal area is poorly exposed. The area described here corresponds to the ‘northern part of Bjørnedal’ of Donovan (1953). An intensive search for ammonites was made in dark, silty, micaceous mudstones exposed in small sections along the Bjørnedal river, Locality 1, and in a small section in a gully at Locality 2 (Figs 2, 5). Three ammo-

nite assemblages were recovered; two ammonite species have been identified, one of them previously known from Jameson Land but hitherto undescribed.

The description of the Middle Jurassic succession in Bjørnedal is based mainly on Donovan (1953), since fieldwork was focused solely on the mudstones in its middle part. The succession is subdivided into five lithological units, A–E in ascending order (Figs 4, 5). Unit A belongs to the Pelion Formation and consists of about 200 m of sandstones containing *Cranocephalites*, which suggests correlation with the Upper Bajocian *C. pompeckji* Chronozone (Fig. 3) and indetermi-



* Zones identified in the Bjørnedal area

Fig. 3. Scheme of standard ammonite zones in the Upper Bajocian – Lower Callovian, Middle Jurassic. Due to faunal provincialism close correlation between zones in East Greenland (right column) and the NW European/Subboreal (left column) is not possible. The East Greenland ammonite zonation represents a secondary standard chronostratigraphical scheme for the Boreal Province. Modified from Callomon (2003).

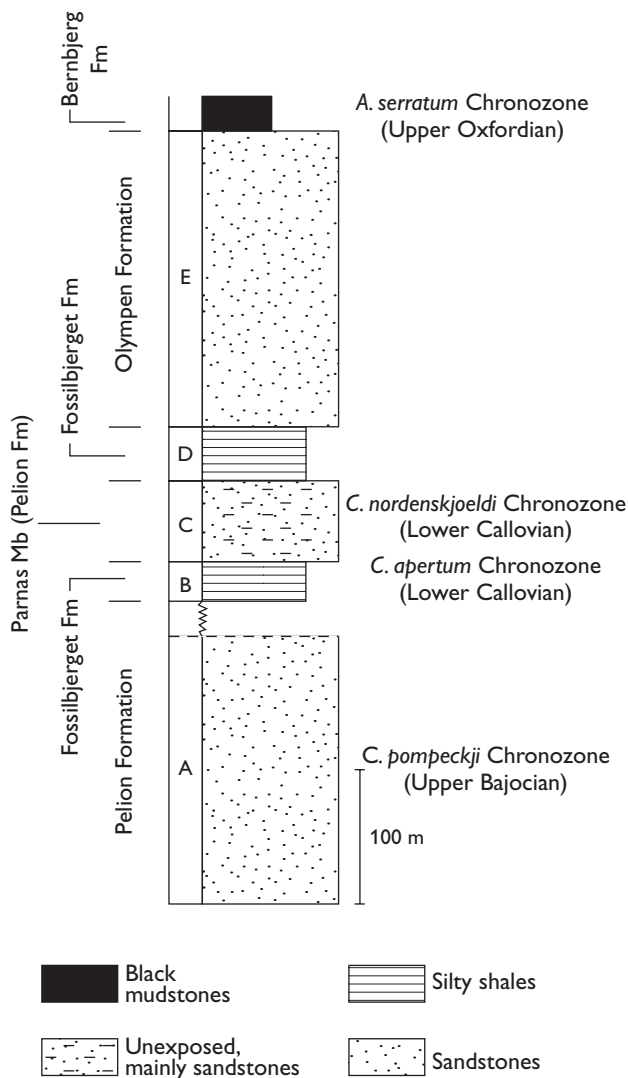


Fig. 4. Schematic section of the Middle Jurassic succession in Bjørnedal, based on Donovan (1953) and new data.

nate plant remains (Donovan 1953). The unit is exposed north-west of the mouth of the valley on the north-eastern slope of mount Lycett Bjerg facing Mountnorris Fjord (Fig. 2). The strata dip towards the south-east and disappear beneath the succession exposed in Bjørnedal. The base of the unit is not exposed. Unit B belongs to the Fossilbjerget Formation and consists of 25–30 m of soft, black, micaceous, silty mudstones with pyritic concretions and indeterminate plant impressions. The species of *Kepplerites* found indicates an Early Callovian age (*Cardioceras apertum* Chron; Fig. 3). Unit C is a mainly scree-covered interval, about 60 m thick, probably consisting mostly of sandstones. Finds of *Cadoceras* sp. in loose blocks in the scree indicate an Early Callovian age (*Cardioceras nordenskjoldi* Chron; Fig. 3). The unit belongs to the

Parnas Member, representing the last regressive tongue of the overall backstepping Pelion Formation. Unit D consists of about 40–50 m of black, silty mudstones with intercalated sandstones and indeterminate ammonites. It belongs to the upper part of the Fossilbjerget Formation. A 50 m core (GGU 303124) drilled at Locality 2 (Fig. 2) through most of this unit records a development from offshore black mudstones with occasional storm sandstone beds, 5–10 cm thick, into offshore transition zone mudstones with an upwards increasing content of fine-grained sandstone (Fig. 6). At the top, a syenite sill, c. 3 m thick, occurs between the mudstones and the base of the sandstones of the overlying lower Upper Jurassic Olympen Formation (Unit E). This formation consists of about 220 m of apparently massive sandstones interbedded with irregular beds of dark micaceous mudstones with traces of plants (Donovan 1953). It is overlain by Upper Jurassic black mudstones of the Bernbjerg Formation containing Late Oxfordian ammonites (*Amoeboceras serratum* Sowerby 1813; Price & Whitham 1997).

Discussion

The sequence stratigraphical development of the Middle Jurassic succession of Jameson Land was interpreted by Surlyk (1990, 1991), Surlyk *et al.* (1993) and in more detail by Engkilde & Surlyk (2003). It is difficult to trace or correlate key surfaces from Jameson Land across Kong Oscar Fjord to the Traill Ø area, in part because of the rather limited and generally poor outcrops on Traill Ø. In Jameson Land, the base of the Pelion Formation appears to be almost isochronous everywhere and of early Late Bajocian age (*Cadoceras borealis* Chron; Fig. 3). The formation is overlain by the Fossilbjerget Formation, with a strongly diachronous boundary younging sourcewards towards the north. This reflects the overall backstepping of the sandy Pelion system caused by a combination of increasing rifting and eustatic sea-level rise. During maximum transgression in the Early–Middle Callovian, deposition of offshore Fossilbjerget mudstones reached its northernmost extent. The presence of the Fossilbjerget Formation in Bjørnedal, Traill Ø, extends the known distributional area of the formation northwards by about 100 km. This reflects drowning of the marine sand-dominated depositional systems of the Pelion Formation during the Middle Jurassic at maximum transgression. A sandstone wedge of the Parnas Member (Pelion Formation) is intercalated in the Fossilbjerget Forma-

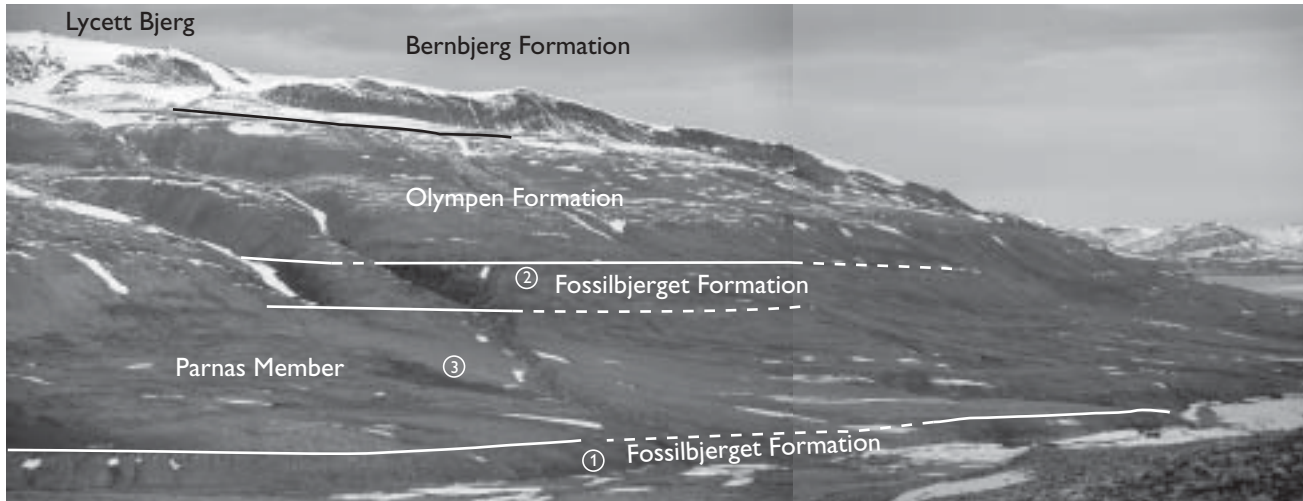


Fig. 5. View of Bjørnedal towards the north-west. The succession exposed on the southern flank of Lycett Bjerg is subdivided into lithostratigraphical units. 1–3, indicate localities (Fig. 2). The Fossilbjerget Formation section in the centre of the photograph is 40–50 m thick. (Photo: S. Piasecki).

tion and represents the last, Early Callovian, regressive tongue of the overall backstepping Pelion Formation. The Fossilbjerget Formation is overlain by the prograding sandstones of the Olympen Formation.

Systematic palaeontology

Specimens with MGUH numbers are stored at the Geological Museum, University of Copenhagen, Denmark.

Superfamily Stephanocerataceae Neumayr 1875

Family Kosmocerotidae Haug 1887

Genus *Kepplerites* Neumayr & Uhlig 1892

Kepplerites cf. *tenuifasciculatus* Callomon 2004

Plate 1, fig. 1

Material. One fragmented specimen (MGUH 25762 from GGU 429773).

Horizon. The specimen was found loose in unit B at Locality 1 (Figs 2, 4, 5).

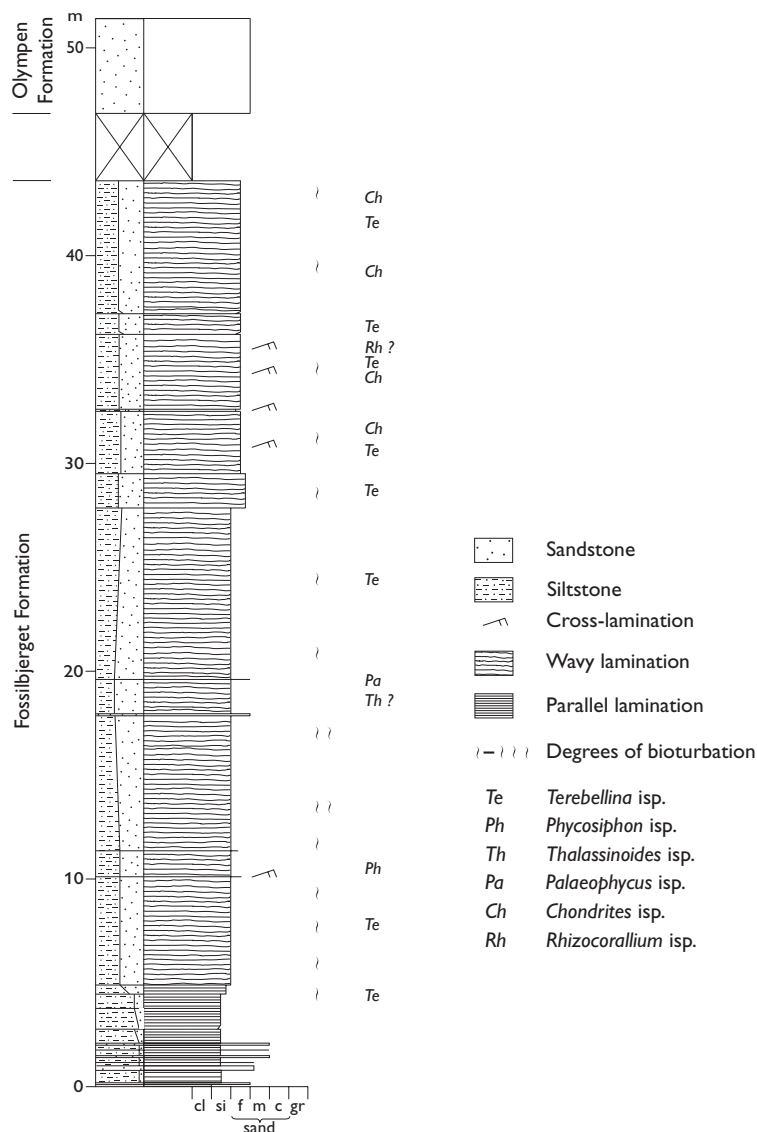
Description. Only two-fifths of the last whorl is preserved, as an imprint in silty mudstone. The fragment, a macroconch, comprises most of the body chamber

of an adult specimen with an estimated maximum diameter of 130 mm. Its umbilical seam is uncoiling and the ribs near the aperture are strongly projected forward. Primary ribs are coarse and strongly curved. Each primary rib gives rise to four secondary ribs, which persist to the venter. Secondary ribbing is very fine and dense. Secondary ribs are almost straight but seem to curve slightly backwards near the venter giving an overall sinuous appearance of the primary and secondary ribs.

Comparison. The species is consistently more densely, finely ribbed than any other species of *Kepplerites* from East Greenland, with little, if any, modification of the primary ribbing in the adult stage.

Age and distribution. *K. tenuifasciculatus* occurs in central Jameson Land and on Traill Ø. In central Jameson Land it is found at a level above *K. traillensis* (faunas 24–26 of Callomon 1993). *K. traillensis* is thought to correlate closely with the horizon of *K. keppleri* in Europe, which defines the base of the Callovian. *K. tenuifasciculatus* is thus of Early Callovian age (*C. apertum* Chron; Fig. 3).

Fig. 6. Sedimentological log of core GGU 303124, measured by J. Therkelsen and P. Alsen. For location, see Figs 2, 5.



Family *Cardioceratidae* von Siemiradzky 1891

Genus *Cadoceras* Fischer 1882

Cadoceras sp.

Plate 1, figs 2A–C, 3

Material. Several fragments preserved as imprints in black shale (MGUH 25763–766 from GGU 429771; GGU 429772). The assemblage includes well-preserved small specimens of microconchs, some of which are almost complete (Plate 1, figs 2A–C).

Horizon. The assemblage was collected at a small exposure in the streambed of the Bjørnedal River in

Bjørnedal, Traill Ø. The succession was not measured, but belongs to unit B (Fig. 4).

Description. The fragments seem to be those of macroconchs. They are densely ribbed with relatively coarse, strong primaries and secondaries. Size cannot be estimated. The microconchs are small and evolute with dense, very fine ribbing. Ribbing becomes somewhat coarser near the final peristome. The maximum diameter is on average about 16 mm.

Age. The specimens are early *Cadoceras* (J.H. Callomon, personal communication 1997) probably from the *C. apertum* or *C. nordenskjoldi* Chronozones (Fig. 3; faunas 27–30 of Callomon 1993). The assemblage thus indicates an Early Callovian age.

***Cadoceras cf. nordenskjoldi* Callomon & Birkelund 1985**

Plate 1, fig. 4A–C

1904 *Olcostephanus* Neumayr (?*Simbirskites* Pavlow & Lamplugh) nov. sp. – Madsen, p. 195, plate 10, fig. 2.

cf. 1985 *Cadoceras nordenskjoldi* n. sp. Callomon & Birkelund, p. 84, pl. 1, fig. 4; pl. 4, figs 1–6.

Material. Several fragments (MGUH 25767–769 from GGU 429768). The fragments are small and crushed macroconchs and are poorly preserved in hard, reddish sandstone. Complete specimens and microconchs have not been identified.

Horizon. The assemblage was found loose in unit C at Locality 3 between the mudstones exposed at Localities 1 and 2 (Figs 2, 4, 5).

Description. The inner whorls are finely and densely ribbed and seem to be evolute. The outer whorls are evolute, with very coarse and blunt primary and secondary ribbing. The whole assemblage seems to consist of fairly slim variants.

Comparisons. The specimens are referred to as *C. cf. nordenskjoldi*, which has the above-mentioned characteristic style of ribbing. This is supported by their stratigraphical position above *K. tenuifasciculatus*.

Age and distribution. This is the first find of the species outside the Fossilbjerget and Olympen areas in central Jameson Land. *C. cf. nordenskjoldi* indicates an Early Callovian age (*C. nordenskjoldi* Chron; Fig. 3).

***Cadoceras* sp. indet.**

Plate 1, fig. 5

Material. Two specimens and fragments (MGUH 25770 from GGU 429767; GGU 429769–770). One specimen is a poorly preserved macroconch (Plate 1, fig. 5); the other is a poorly preserved microconch. Both are imprints in mudstones.

Horizon. The ammonites were collected at Locality 2 from level 29–30.6 m in section JT-14 (Fig. 2) in mudstones of unit D (Figs 2, 4, 5).

Description. The macroconch is medium-sized and

evolute, and comprises most of a whorl of the body-chamber. Ribbing is dense and relatively strong up to the aperture. Primaries divide into secondaries on the middle of the flank. The specimen shows no adult modification and could be a juvenile. Maximum diameter measures 61.5 mm. The other specimen, probably a microconch, is small and relatively evolute. Ribbing is dense and sharp with primaries and secondaries. Maximum diameter is 30 mm.

Age. The assemblage is too poorly preserved for determination to specific level. The specimens are possibly early *Cadoceras* of Early Callovian age (J.H. Callomon, personal communication 1997; Fig. 3).

Acknowledgements

We acknowledge generous support by the Danish Research Councils (Project: ‘Resources of the sedimentary basins of North and East Greenland’) and thank Jette Halskov for drafting, Jens Therkelsen, who provided the measured sections, John H. Callomon and Lars Stemmerik for reading the manuscript critically, and Walter K. Christiansen and G. Bloos for useful reviews.

References

Including references cited in Appendix

Alsen, P. 1998: Middle Jurassic ammonite biostratigraphy in the Traill Ø region, central East Greenland. Abstracts – 23rd Nordiske Geologiske Vintermøde Århus, Denmark, 1998, 17 only.

Birkelund, T., Callomon, J.H. & Fürsich, F.T. 1984: The stratigraphy of the Upper Jurassic and Lower Cretaceous sediments of Milne Land, central East Greenland. Bulletin Grønlands Geologiske Undersøgelse **147**, 56 pp.

Buckman, S.S. 1922: Type Ammonites **4**, 67 pp., pls 267–422. London: Wheldon & Wesley.

Callomon, J.H. 1993: The ammonite succession in the Middle Jurassic of East Greenland. Bulletin of the Geological Society of Denmark **40**, 83–113.

Callomon, J.H. 2003: The Middle Jurassic of western and northern Europe: its subdivisions, geochronology and correlations. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 61–73.

Callomon, J.H. 2004: Description of a new species of ammonite, *Kepplerites tenuifasciculatus* n. sp., from the Middle Jurassic, Lower Callovian of East Greenland. Appendix in:

- Alsen, P. & Surlyk, F.: Maximum Middle Jurassic transgression in East Greenland: evidence from new ammonite finds, Bjørnedal, Traill Ø. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 31–49 (this volume).
- Callomon, J.H. & Birkelund, T. 1985: Description of three new species. In: Callomon, J.H.: The evolution of the Jurassic ammonite family Cardioceratidae. Special Papers in Palaeontology **33**, 78–86 (appendix). London: Palaeontological Association.
- Carr, I.D. 1998: Facies analysis and reservoir characterisation of Jurassic sandstones from Bjørnedal, Central East Greenland, 247 pp. Unpublished Ph.D. thesis, Institute for Sedimentology, University of Reading, UK.
- Dietl, G. & Callomon, J.H. 1988: The Orbis Oolite in the Upper Bathonian (Middle Jurassic) of Sengenthal/Opf., Franconian Alb, and its significance for the correlation and subdivision of the Orbis Zone. Stuttgarter Beiträge zur Naturkunde B **142**, 31 pp.
- Donovan, D.T. 1953: The Jurassic and Cretaceous stratigraphy and palaeontology of Traill Ø, East Greenland. Meddelelser om Grønland **111**(4), 150 pp.
- Engkilde, M. & Surlyk, F. 2003: Shallow marine syn-rift sedimentation: Middle Jurassic Pelion Formation, Jameson Land, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 813–863.
- Fischer, P. 1880–1887: Manuel de conchyliologie et de paléontologie, 1369 pp. Paris: F. Savy.
- Haug, E. 1887: Über die 'Polymorphidae', eine neue Ammonitenfamilie aus dem Lias. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie **2**, 89–163.
- Larsen, M. & Surlyk, F. 2003: Shelf-edge delta and slope deposition in the Upper Callovian – Middle Oxfordian Olympen Formation, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 931–948.
- Madsen, V. 1904: On Jurassic fossils from East Greenland. Meddelelser om Grønland **29**, 157–211.
- Neumayr, M. 1875: Die Ammoniten der Kreide und die Systematik der Ammonitiden. Zeitschrift der Deutschen Geologischen Gesellschaft **27**, 854–892.
- Neumayr, M. & Uhlig, V. 1892: Über die von K. Abich im Kaukasus gesammelten Jurafossilien. Denkschrift der Akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche Klasse **59**, 1–122.
- Oppel, A. 1862: Über jurassische Cephalopoden. Palaeontologische Mitteilungen aus dem Museum des Koeniglich-Bayerischen Staates Berlin **1**(1–2), 1–125.
- Page, K.N. 1989: A stratigraphical revision for the English Lower Callovian. Proceedings of the Geologists' Association (London) **100**, 363–382.
- Price, S.P. & Whitham, A.G. 1997: Exhumed hydrocarbon traps in East Greenland: analogs for the Lower–Middle Jurassic play of Northwest Europe. American Association of Petroleum Geologists Bulletin **81**, 196–221.
- Quenstedt, F.A. 1886–1887: Die Ammoniten des Schwäbischen Jura. II. Atlas, 55–90. Stuttgart: Schweizerbart.
- Sokolov, D.N. & Bodylevsky, V.I. 1931: Jura- und Kreidefaunen von Spitsbergen. Skrifter om Svalbard og Ishavet **35**, 151 pp.
- Sowerby, J. 1813–1821: The mineral conchology of Great Britain **1–6**, 1236 pp. London: J. de C. Sowerby.
- Spath, L.F. 1932: The invertebrate faunas of the Bathonian–Callovian deposits of Jameson Land (East Greenland). Meddelelser om Grønland **87**(7), 158 pp.
- Surlyk, F. 1977: Stratigraphy, tectonics and palaeogeography of the Jurassic sediments of the areas north of Kong Oscars Fjord, East Greenland. Bulletin Grønlands Geologiske Undersøgelse **123**, 56 pp.
- Surlyk, F. 1978: Submarine fan sedimentation along fault scarps on tilted fault blocks (Jurassic–Cretaceous boundary, East Greenland). Bulletin Grønlands Geologiske Undersøgelse **128**, 108 pp.
- Surlyk, F. 1990: A Jurassic sea-level curve for East Greenland. Palaeogeography, Palaeoclimatology, Palaeoecology **78**, 71–85.
- Surlyk, F. 1991: Sequence stratigraphy of the Jurassic – Lowermost Cretaceous of East Greenland. American Association of Petroleum Geologists Bulletin **75**, 1468–1488.
- Surlyk, F. 2003: The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 659–722.
- Surlyk, F., Callomon, J.H., Bromley, R.G. & Birkelund, T. 1973: Stratigraphy of the Jurassic – Lower Cretaceous sediments of Jameson Land and Scoresby Land, East Greenland. Bulletin Grønlands Geologiske Undersøgelse **105**, 76 pp.
- Surlyk, F., Noe-Nygaard, N. & Dam, G. 1993: High and low resolution sequence stratigraphy in lithological prediction – examples from the Mesozoic around the northern North Atlantic. In: Parker, J.R. (ed.): Petroleum geology of Northwest Europe: proceedings of the 4th conference, 199–214. London: Geological Society.
- Therkelsen, J. & Surlyk, F. 2004: The fluvialite Bristol Elv Formation, a new Middle Jurassic lithostratigraphic unit from Traill Ø, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 19–29 (this volume).
- von Siemiradzky, J. 1891: Fauna kopalna warstw oksfordzkich i Kimerydzkich w okregu krakowskim i przyleglych czesciach Królestwa Polskiego. Czesc I: Glowonigi. Parnietnik Akademii umietjosci w Krakowie, wydzial matematycznoprzyrodniczy, tomu oseinnastego Zeszyt I **18**, 92 pp.
- Vosgerau, H., Alsen, P., Carr, I.D., Therkelsen, J., Stemmerik, L. & Surlyk, F. 2004: Jurassic syn-rift sedimentation on a seawards-tilted fault block, Traill Ø, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 9–18 (this volume).

Plate 1

Plate 1

All specimens are figured natural size.

Fig. 1. *Kepplerites* cf. *tenuifasciculatus* Callomon.

Adult macroconch.

MGUH 25762 from GGU 429773.

Fig. 2. *Cadoceras* sp.

A: MGUH 25763 from GGU 429772b.

B: MGUH 25764 from GGU 429772a.

C: MGUH 25765 from GGU 429772c.

Fig. 3. *Cadoceras* sp.

MGUH 25766 from GGU 429772e.

Fig. 4. *Cadoceras* cf. *nordenskjoldi* Callomon & Birkelund

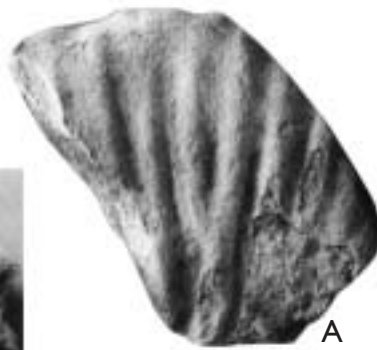
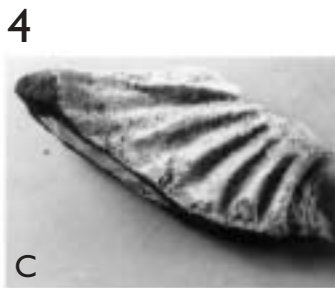
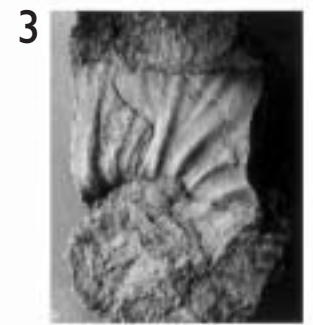
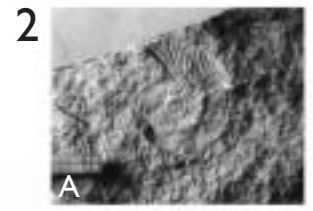
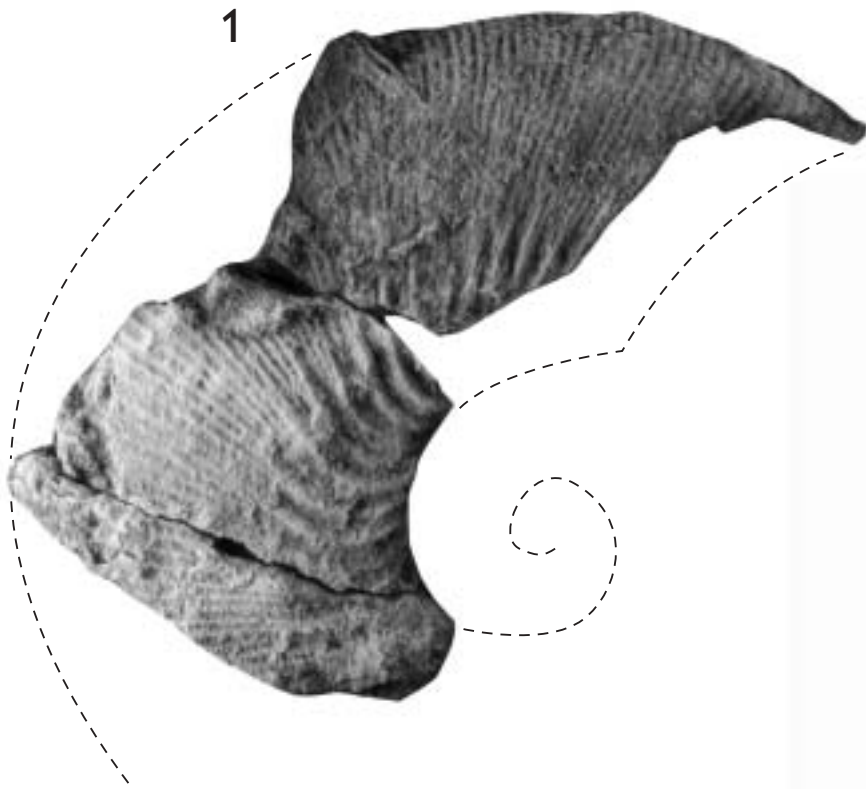
A: MGUH 25767 from GGU 429768a.

B: MGUH 25768 from GGU 429768c.

C: MGUH 25769 from GGU 429768b.

Fig. 5. *Cadoceras* sp. indet.

MGUH 25770 from GGU 429767.



Appendix

Description of a new species of ammonite, *Keplerites tenuifasciculatus* n. sp., from the Middle Jurassic, Lower Callovian of East Greenland

John H. Callomon

A new species of ammonite, *Keplerites tenuifasciculatus* n. sp., is described. Its type locality is at Fossilbjerget in central Jameson Land, East Greenland and its type horizon lies in the Apertum Zone, the lowest zone in the Lower Callovian Stage of the Middle Jurassic. It has a narrow stratigraphical range and hence makes a good guide-fossil for stratigraphical time correlation.

Keywords: ammonite, East Greenland, Fossilbjerget, Jameson Land, *Keplerites tenuifasciculatus* n. sp., Middle Jurassic

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The revision of the biostratigraphy and biochronology of the ammonite faunas of the Middle Jurassic of East Greenland has revealed a number of hitherto unknown species that characterize very narrow chronostratigraphic intervals and hence make excellent guide-fossils for time correlations (Callomon 1993). One of these is now described. It represents a transient – chronospecies of some authors – in the evolution of one of the two evolutionary lineages, the Kosmoceratidae, whose members inhabited East Greenland during the Late Bathonian and Callovian, the other being the much longer-ranging Cardioceratidae.

Superfamily Stephanocerataceae Neumayr 1875

Family Kosmoceratidae Haug 1887

Genus *Keplerites* Neumayr & Uhlig 1892

Type species. *Amm. kepleri* Oppel 1862.

Keplerites tenuifasciculatus n. sp.

Plate 1, figs 1–2

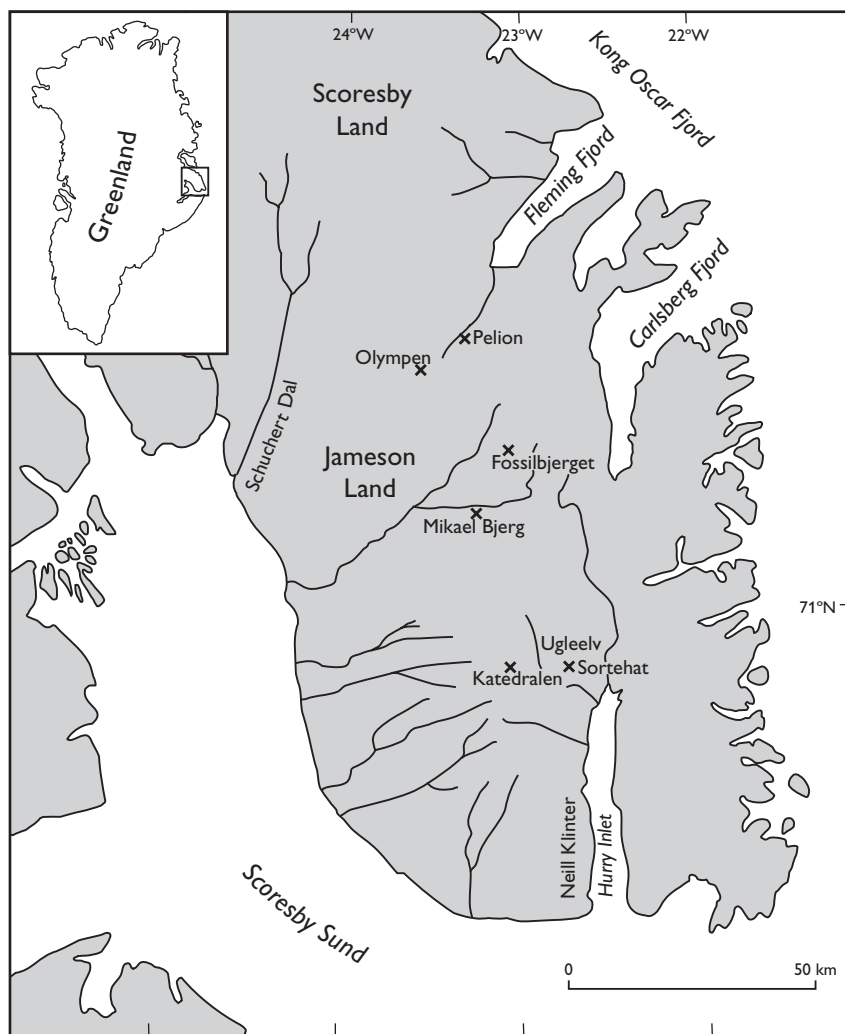
1993 *Keplerites* sp. nov. J [*tenuifasciculatus* MS] Callomon, p. 103.

Holotype. Plate 1, fig. 1, MGUH 25310 from GGU 185614a (T. Birkelund and C. Heinberg collection 1974) Jameson Land, Fossilbjerget, section 43, bed 14, horizon J27 (Figs 1, 2).

Other material. Paratypes I, II, MGUH 25311–312 from GGU 185614b, c; paratype III, MGUH 25313 from JHC 4475 (Plate 1, fig. 2; T. Birkelund and J.H. Callomon collection 1971), same locality and bed; JHC 4469–4471, section 42, bed 18 (see Fig. 2); GGU 144191–192 from south slopes of mount Mikael Bjerg, section 31 (Birkelund coll. 1971; Fig. 1). Numerous other specimens seen *in situ* were too poorly preserved to be worth collecting.

Stratigraphical horizon. The southern slopes of Fossilbjerget are marked by three ridges, running southwards, on which sections have been recorded, numbered 41–43 from east to west (Callomon 1993, fig. 1).

Fig. 1. Sketch-map of the Jameson Land area with place names mentioned in the text.



The sections span the shaly Fossilbjerget Formation underlain by the sandy Pelion Formation and capped by the sandstones and shales of the Olympen Formation (Surlyk *et al.* 1973; Larsen & Surlyk 2003). The three sections differ only in detail. Section 43 is shown in weathering-profile in Figure 2. It was previously shown in outline by Surlyk *et al.* (1973, fig. 23). Lithologically, the sediments consist predominantly of shaly siltstones or very fine-grained sandstones, barely consolidated except in concretionary layers that punctuate the succession as markers or in scattered calcitic or phosphatic concretions. Some of the beds are highly glauconitic, indicating condensed, sediment-starved intervals and comparison with adjacent areas, *e.g.* at the mountains Olympen and Mikael Bjerg (Fig. 1), shows that the succession incorporates numerous hiatuses of variable durations. The age-diagnostic ammonites can be recovered only from the hard beds. Their biostratigraphy in terms of faunal horizons, however,

is with only few exceptions as close to complete as present knowledge allows (Callomon 1993, fig. 4). The only horizon in the interval under discussion not so far recognized in the Fossilbjerget–Olympen area is J23, that of *Kepplerites vardekloeftensis*. It may have been lost in a hiatus, marked by a sharp lithological break, under the glauconitic ironstones of beds 9–13 (Fig. 2, Section 43). The type-horizon of *Kepplerites tenuifasciculatus*, J27, is bed 14, an indurated, shaly, non-glauconitic, light brown fine-grained sandstone, 0.2 m thick, lying with sharp contact on the hard, ferruginous and highly glauconitic sandstone marker of bed 13 below (Fig. 2, Section 43). The contact probably marks another hiatus that would account for the considerable break, both in composition and morphologies, between the faunas of beds 13 and 14. The fauna of bed 13 consists predominantly of *Cadoceras (apertum)*, with only minor *Kepplerites* (*cf. trailensis*). That of bed 14 is dominated by monospecific

Section 43

— 3 km —

Section 42

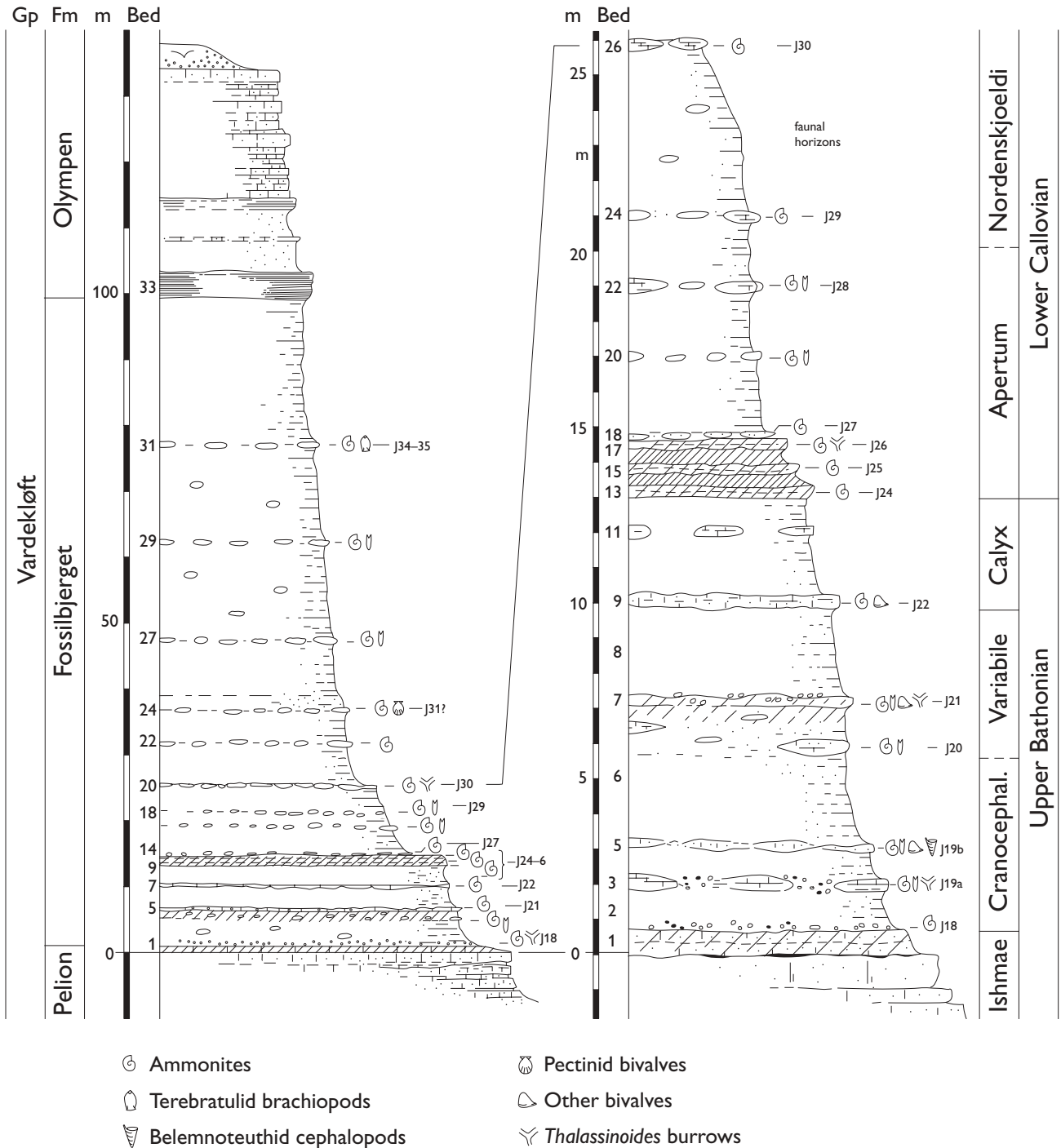


Fig. 2. Diagrammatic sections in weathering profile through the Fossilbjerget Formation at its type locality on the southern slopes of Fossilbjerget, central Jameson Land; section 43 is located 3 km west of section 42. Note that the beds in the two sections are numbered independently – discussion of bed numbers in the text refers to those in Section 43. Lithostratigraphy at left, standard chronostratigraphy – substages and zones – at right. Diagonal hatching: glauconitic. Numbers J18–J35: the ammonite faunal horizons recognized in Jameson Land (see Callomon 1993). The horizon of *Kepplerites tenuifasciculatus* is J27. **Cranocephal.**, Cranocephaloide.

Table 1. Measurement of dimensions

	Holotype	Paratype III
Maximum diameter	137 mm	140 mm
Septate to	c. 100 mm	c. 90 mm
Length of bodychamber, whorl	0.70	0.75
Fractional umbilical width at last septum	0.23	0.22
Fractional umbilical width at aperture	c. 0.34	c. 0.33
Primary ribs per whorl		
– at diameter 125–130 mm	51	57
– at diameter 85–95 mm	40	46
Ratio of secondaries:primaries around last septum	3.8	3.4

Keplerites (tenuifasciculatus) with only occasional crushed, indeterminate *Cadoceras*.

Description. All the available material consists of crushed internal moulds and measurements of dimensions (Table 1) are of limited value. The figured specimens are typical; both are complete adult macroconchs with strongly uncoiling seams on the last whorl. The microconchs remain unknown. The ribbing is characteristically dense and fine, the primaries rising retro-radially on the umbilical wall, then swinging in a strongly forwards-directed curve on the umbilical shoulder into accentuated prorsiradiate ribbing on the whorlside, dividing into fasciculate sheaves (tenuifasciculate) of secondaries at about a third flank-height, rising uncurved to the venter, persisting with little or no loss of strength to the simple, somewhat sinuous peristome. There is no evidence of the lateral accentuation of the primaries into tubercles seen in other species of *Keplerites*, especially in the younger ones and subsequently in the descendant, *Kosmoceras*. Inner whorls are not seen, so whether the earliest stages already have tabulate venters is not known.

Comparisons. The evolution of major morphological characters in the genus *Keplerites*, leading to *Kosmoceras* in the Middle Callovian, was very gradual. Differentiation of successive transients relies on relatively minor variations of size and ribbing, often perceptible only by the trained eye in assemblages of more than a single specimen in which the range of intraspecific variability can be assessed. Changes were not

continuously orthogenetic: characters could ‘progress’ and ‘regress’ with time largely independently, leading to frequent partial homoeomorphies.

In descending order:

1. *Keplerites traillensis* Donovan 1953 (plate 17, figs 1a, b, holotype; plate 18, figs 1a, b), faunal horizons 24–26, is similar in size, coiling and style of ribbing but significantly less densely ribbed, with only c. 31 primaries per whorl (before the onset of the modifications on the final stage of the adult bodychamber found in all the *Kosmoceratidae*). The type material came from mount Morris Bjerg on Traill Ø, about 5 km north-east of the coast of Kong Oscar Fjord to the south-west. It was found in isolation, both stratigraphically and faunistically, so the position of its faunal horizon in the general succession has to be deduced by correlation with the more continuous successions in Jameson Land. The closest resemblance is to the forms found also on the southern slopes of Fossilbjerget, sections 42 and 43, horizons 24–26, as minor components in faunas dominated by *Cadoceras apertum* (Callomon & Birkelund 1985).
2. *Keplerites vardekloeftensis* Callomon 1993 (p. 102), faunal horizon 23. The holotype (Spath 1932, plate 25, figs 2a, b, complete adult) and paratype (Spath 1932, plate 25, figs 1a, b, complete adult phragmocone) came from the calyx limestone, a prominent concretionary marker-bed in the Fossilbjerget Formation along the length of the outcrops above Neill Klint, the line of cliffs on the west side of Hurry Inlet and traceable inland as far as Katedralen on Ugleelv (Fig. 1); level 560 m in sections of Rosenkrantz reproduced by Spath (1932, p. 126, fig. 10). The species resembles *K. tenuifasciculatus* in coiling, size and density of primary ribbing but the secondary ribbing is coarser and fades on the

bodychamber. The two species are closely homoeomorphic but stratigraphically separated by the transients described above, which differ appreciably.

3. *Kepplerites svalbardensis* Sokolov & Bodylevsky (1931, p. 79, plate 5, figs 1, 2) resembles *K. tenuifasciculatus* in coiling and finesse of ribbing, but is smaller: adult size 105 mm, septate to 70 mm. The ribbing (45 primaries per whorl) differs, however, on the whorl-side in that, after the initial forwards twist at the umbilical margin, it curves backwards again, the secondaries reaching the venter rectiradially.

The species occurs in Greenland as a minor component in fauna 22, the dominant element of which is *K. peramplus* Spath. The latter is so distinctive, characterised by its great size (adult diameters 200 mm or more), involute and compressed inner whorls (see also Dietl & Callomon 1988, figs 4, 5), that there seems little doubt about the separate biospecific identities of the two taxa. They are not linked by intermediates and represent one of the rare cases in which the specific diversity at one horizon of an

evolving generic clade rises above the monospecific. The faunal horizon can be followed from southern Hurry Inlet (types of *K. peramplus*) as far as the mountains Mikael Bjerg and Fossilbjerget, sections 42 and 43 (see above; Fig. 1).

Upwards, the record of *Kepplerites* in Greenland becomes tenuous. Occasional specimens have been found in the Nordenskjöldi Zone, horizons 28–29, but the preservation is too poor to be able to say much of interest other than that they are still of the general appearance and size of *K. traillensis* or *K. tenuifasciculatus*. The next horizon to yield keppleritids is horizon 32. The forms at this horizon are, however, quite distinct: small, evolute and round-whorled, typical of the chronosubgenus *Gowericeras* that makes an abrupt appearance in much of northern Europe and thereby characterizes the Koenigi Zone.

Age and distribution. Lower Callovian, Apertum Zone, faunal horizon 27. Central Jameson Land, southern slopes of Fossilbjerget, sections 42–43, and around Mikael Bjerg (Fig. 1), sections 31, 33.

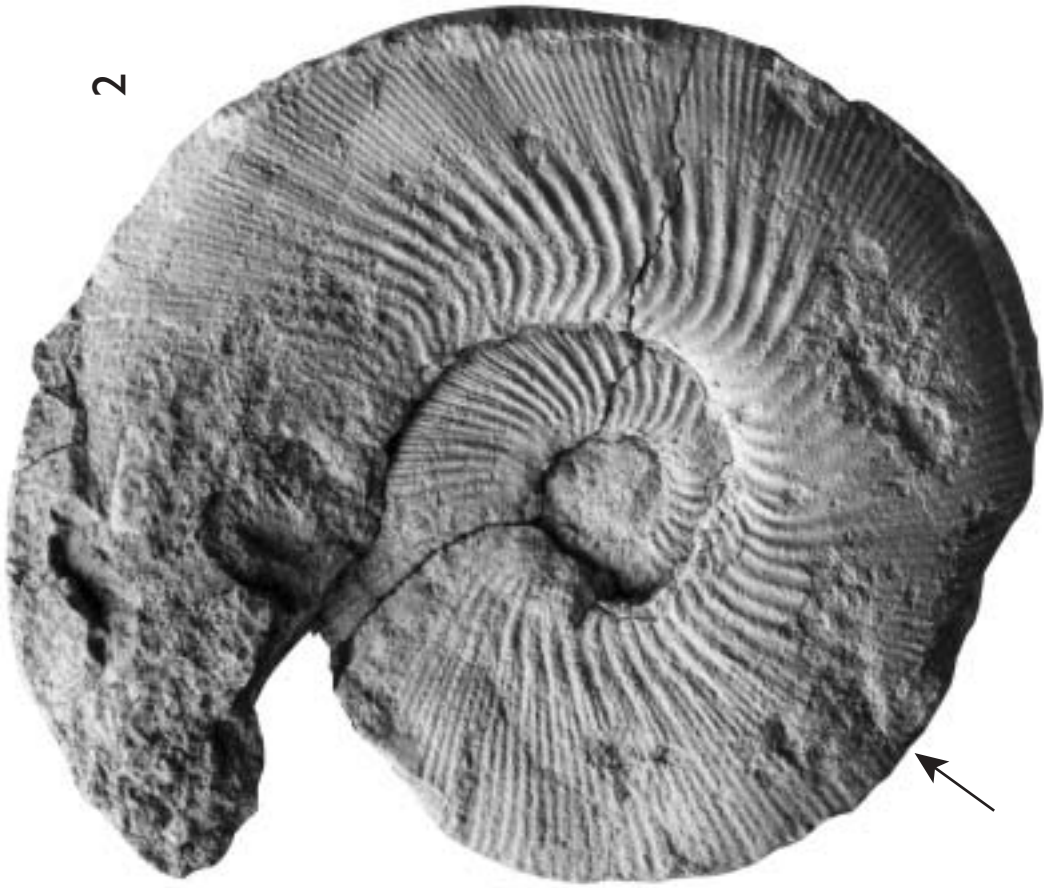
Plate 1

Plate 1

Complete adults, natural size; arrows mark the position of the last septum at the onset of the adult bodychamber.

Fig. 1. *Kepplerites tenuifasciculatus* n. sp.
Holotype, MGUH 25310 from GGU 185614a.
Fossilbjerget, section 43, bed 14, faunal horizon J27.
Lower Callovian, Apertum Zone.

Fig. 2. *Kepplerites tenuifasciculatus* n. sp.
Paratype III, MGUH 25313 from JHC 4475.
Section, bed and faunal horizon as above.



2



1

A new Middle–Upper Jurassic succession on Hold with Hope, North-East Greenland

Henrik Vosgerau, Michael Larsen, Stefan Piasecki and Jens Therkelsen

A succession of marine, Jurassic sediments was recently discovered on Hold with Hope, North-East Greenland. The discovery shows that the area was covered by the sea during Middle–Late Jurassic transgressive events and thus adds to the understanding of the palaeogeography of the area. The Jurassic succession on northern Hold with Hope is exposed in the hangingwalls of small fault blocks formed by rifting in Late Jurassic – Early Cretaceous times. It unconformably overlies Lower Triassic siltstones and sandstones and is overlain by Lower Cretaceous coarse-grained sandstones with an angular unconformity. The succession is up to 360 m thick and includes sandstones of the Lower–Upper Callovian Pelion and Middle–Upper Oxfordian Payer Dal Formations (Vardekløft Group) and heteroliths and mudstones of the Upper Oxfordian – Lower Kimmeridgian Bernbjerg Formation (Hall Bredning Group). The Pelion Formation includes the new Spath Plateau Member (defined herein).

The palaeogeographic setting was a narrow rift-controlled embayment along the western margin of the rifted Jurassic seaway between Greenland and Norway. It was open to marine circulation to the south as indicated by the distribution and lateral facies variations and a dominant south-westwards marine palaeocurrent direction. The Pelion and Payer Dal Formations represent upper shoreface and tidally influenced delta deposits formed by the migration of dunes in distributary channels and mouthbars over the delta front. The boundary between the two formations is unconformable and represents a Late Callovian – Middle Oxfordian hiatus. It is interpreted to have formed by subaerial erosion related to a sea-level fall combined with minor tilting of fault blocks and erosion of uplifted block crests.

In Late Jurassic time, the sand-rich depositional systems of the Pelion and Payer Dal Formations drowned and offshore transition – lower shoreface heteroliths and offshore mudstones of the Bernbjerg Formation accumulated. The fault block crest forming the eastern basin margin was inundated by a rise in relative sea level. Major fault activity probably occurred in latest Jurassic – Early Cretaceous times when the major fault block originally defining the Hold with Hope basin was split into smaller blocks.

Keywords: Hall Bredning Group, Hold with Hope, lithostratigraphy, North-East Greenland, palaeogeography, sedimentology, shallow marine, Spath Plateau Member, Vardekløft Group

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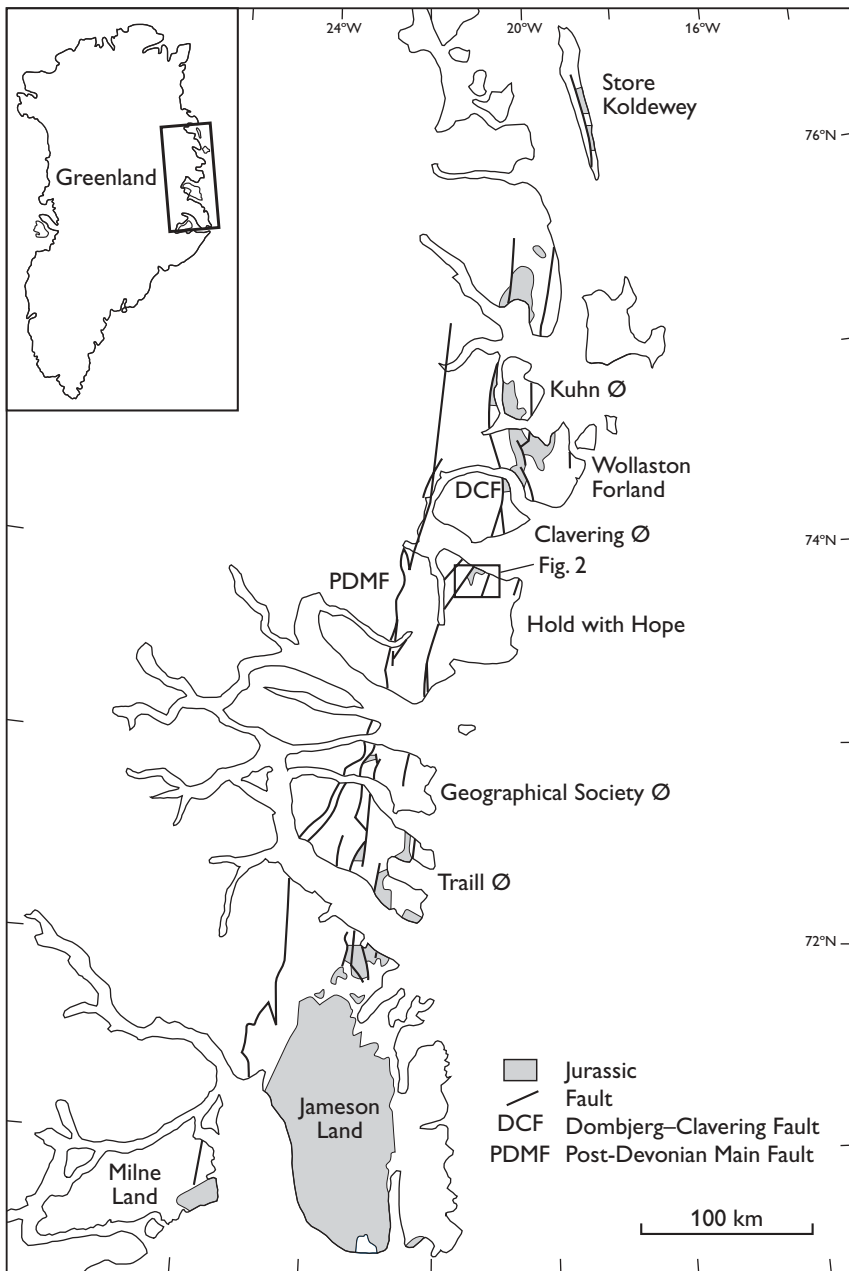


Fig. 1. Map of East Greenland showing the distribution of Jurassic sediments and major faults. Rectangle marks the investigated area on northern Hold with Hope, shown in more detail in Figure 2. Modified from Koch & Haller (1971) and Surlyk *et al.* (1973).

A new Middle–Upper Jurassic succession, up to 360 m thick, was found recently on northern Hold with Hope, North-East Greenland (Fig. 1; Stemmerik *et al.* 1997; Kelly *et al.* 1998; Larsen *et al.* 1998). It spans the Early Callovian – Early Kimmeridgian time interval as indicated by dinoflagellate cysts and ammonites, and consists of coarse-grained sandstones overlain by heteroliths and mudstones. The sandstone-dominated lower part of the succession assigned here to the Pelion Formation was originally studied by Koch (1932) and Maync (1949) and was tentatively given an Early Cre-

taceous age, although W. Maync noted the resemblance to the Middle Jurassic succession on Wollaston Forland.

The apparent absence of Jurassic sediments in the Hold with Hope area was explained differently by Maync (1947), Donovan (1957), Surlyk (1977) and Stemmerik *et al.* (1993). Maync (1947) and Surlyk (1977) suggested that during the Jurassic the area formed a landmass between the Wollaston Forland Basin to the north and the Jameson Land Basin to the south, implying that the lack of sediments was primarily due to non-deposition. Donovan (1957) in contrary found it

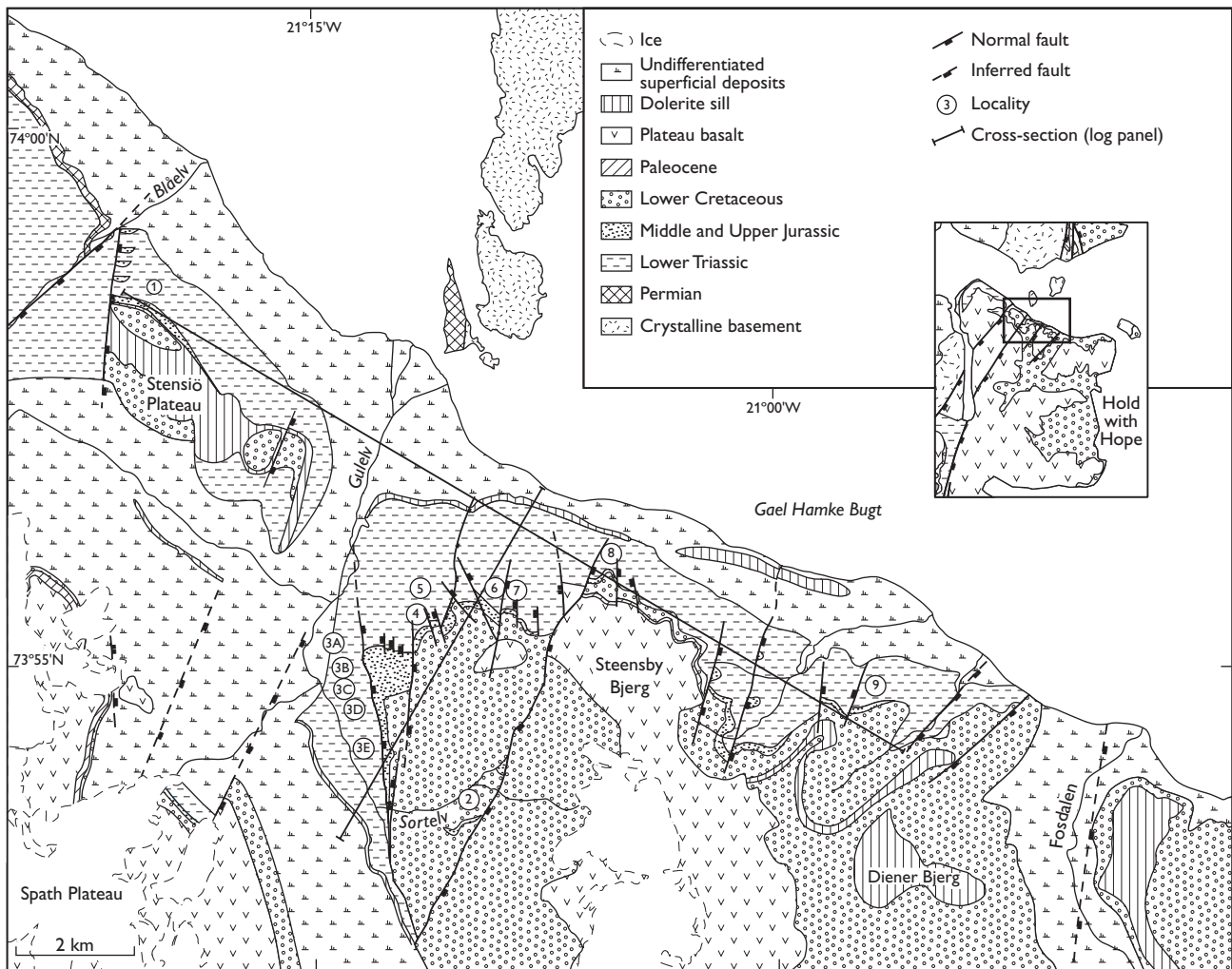


Fig. 2. Geological map of part of northern Hold with Hope including position of localities mentioned in text. The composite section from Gulelv (Fig. 5) was compiled from five part-sections (A–E). The solid lines show schematically the orientation of the NE–SW and NW–SE log panels in Figures 7 and 8, respectively.

most likely that the absence was secondary owing to pre-Aptian erosion of the Jurassic rocks. Based on comparison with nearby Clavering Ø, Stemmerik *et al.* (1993) suggested that Middle–Upper Jurassic sediments were present in the subsurface east of the continuation of the Dombjerg–Clavering Fault on Hold with Hope (Fig. 1, DCF).

The present investigations confirm that Hold with Hope formed a landmass between the Wollaston Forland and Jameson Land Basins during much of the Middle Jurassic time interval. The discovery on Hold with Hope of a marine succession of Early Callovian – Kimmeridgian age, however, shows that the land mass was flooded in late Middle Jurassic time and continued to be sea-covered for most of the remaining Jurassic period.

The Jurassic succession on Hold with Hope is subdivided into shallow marine sandstones of the Pelion and Payer Dal Formations (Vardekloft Group) and lower shoreface – offshore transition heteroliths and offshore mudstones of the Bernbjerg Formation (Hall Bredning Group). The Pelion Formation includes the new Spath Plateau Member, which contains abundant sandy heteroliths in contrast to the dominant clean sandstone lithology of the Pelion Formation. The sedimentary facies of the units are described and the depositional environments interpreted. The Jurassic succession is placed within a regional framework including the Wollaston Forland and Jameson Land Basins to the north and south, respectively.

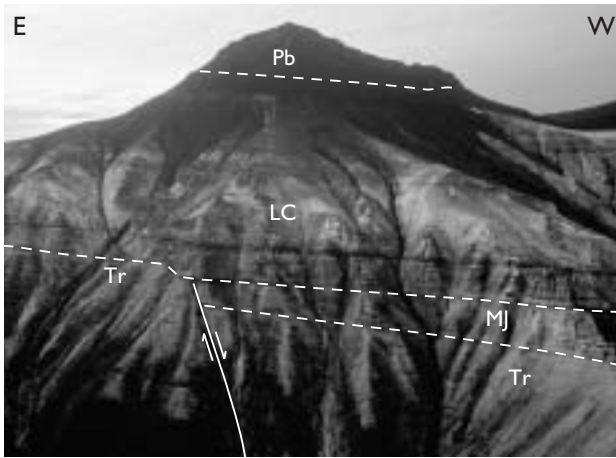


Fig. 3. Triassic–Paleocene succession exposed at Steensby Bjerg, northern Hold with Hope, viewed towards the south. The Triassic (**Tr**) and Middle Jurassic (**MJ**) sediments dip towards the south-west and are unconformably overlain by Lower Cretaceous (**LC**) sediments. A post-Kimmeridgian – pre-Barremian normal fault striking north–south offsets the Triassic and Jurassic sediments by at least 30 m. View towards the south. From Larsen *et al.* (1998). The exposure shown is *c.* 200 m high and capped by Paleocene basalts (**Pb**).

Geological setting

The Late Palaeozoic – Mesozoic extensional basin complex in East Greenland is about 700 km long in a north–south direction. This complex is situated over structurally controlled *en echelon* troughs and forms a wedge-shaped embayment with the narrowest onshore part to the north. Jurassic sediments are present in the Wollaston Forland and Jameson Land Basins situated on the western margin of the rift complex. In both basins, sediment transport in Middle Jurassic time was mainly longitudinal from north to south along a low gradient basin floor, which was not differentiated into a shelf, slope and deep-water basin (Surlyk 1977, 1990, 1991; Surlyk *et al.* 1981; Surlyk & Clemmensen 1983).

In the Wollaston Forland Basin, rifting was initiated in Middle Jurassic time, and marine Bajocian–Bathonian sandstones onlap weathered Caledonian basement rocks or Upper Permian carbonates. Deposition took place on the hangingwall of wide W–SW-tilted fault blocks. Jurassic rifting culminated in the Volgian with strong rotational block faulting associated with conglomeratic submarine fan sedimentation (Surlyk 1978). During this tectonic episode, the wide fault blocks originally defining the Wollaston Forland Basin were split into smaller blocks (Vischer 1943; Surlyk 1978).

The Jurassic sediments on Hold with Hope occur

on the hangingwall of small fault blocks that dip mainly towards the west and south-west (Fig. 2). Bedding planes within the Triassic and Jurassic successions seem to be parallel whereas the boundary to the overlying Cretaceous succession is an angular unconformity (Fig. 3).

The Jurassic succession shows marked lateral thickness variations depending on its position on the hangingwall. The thickness increases down-dip whereas it is missing up-dip due to Early Cretaceous erosion on some of the block crests. Faults locally cut the Triassic and Jurassic successions, but not the overlying Cretaceous succession showing that fault activity took place in post-Kimmeridgian, but pre-Barremian time (Fig. 3). Most faults in the area, however, were reactivated during Cretaceous and Cenozoic times.

Stratigraphy and sedimentology

The Jurassic succession on Hold with Hope is subdivided into lithostratigraphic units known from Wollaston Forland and Kuhn Ø (Fig. 4). Stratigraphic ages of the Jurassic succession are based on ammonites and dinoflagellate cysts (Piasecki *et al.* 2004, this volume). The oldest Jurassic ammonite found on northern Hold with Hope is *Cranocephalites* sp. indicating the Upper Bajocian *C. pompeckji* Chronozone (J.H. Callomon and P. Alsen, personal communications 1997). The ammonite was, however, not found *in situ* but in the basal Cretaceous conglomerate at Locality 4 and *c.* 150 m east of Locality 8 (Fig. 2).

The Jurassic outcrops occur between Stensiö Plateau in the west and Diener Bjerg in the east (Fig. 2). Towards the south, the Jurassic sediments are exposed along the eastern side of the Gulelv river and on the southern side of the Sortelv river. A composite section, 360 m thick, was measured in a north–south direction along Gulelv on the hangingwall of a fault block dipping *c.* 15° towards the SSW and comprises segments 3A–E (Figs 5, 6). Lateral facies variations are illustrated by cross-sections oriented parallel (NE–SW) and perpendicular (NW–SE) to the overall palaeocurrent direction (Figs 2, 7, 8).

Pelion Formation

The Pelion Formation in the Jameson Land and Wollaston Forland Basins consists of shallow marine, medium- to coarse-grained sandstones of Late Bajocian – Late Callovian age (Engkilde & Surlyk 2003). On Hold

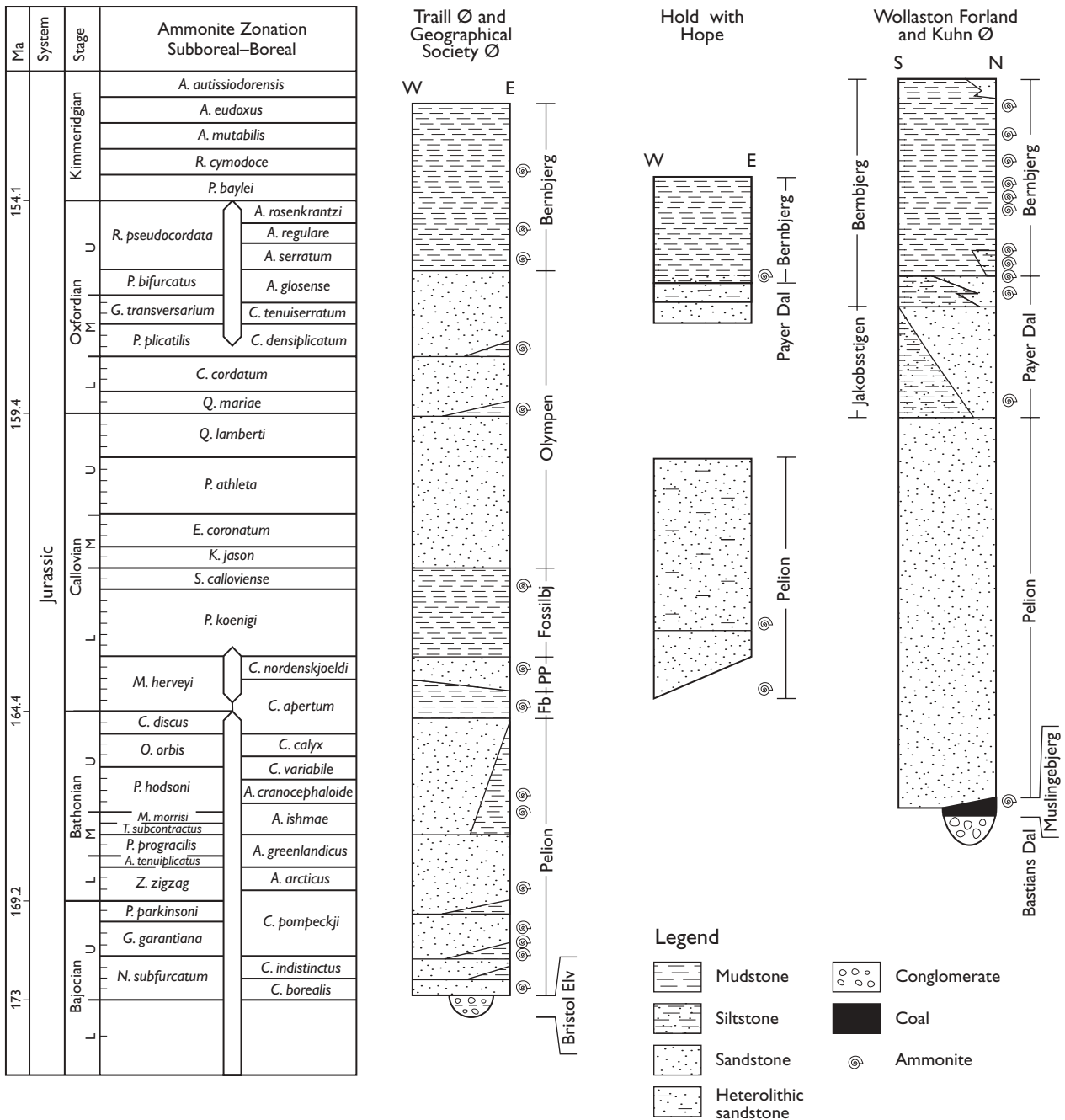
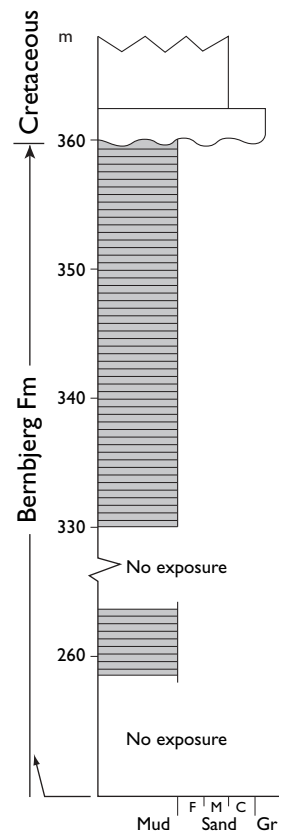
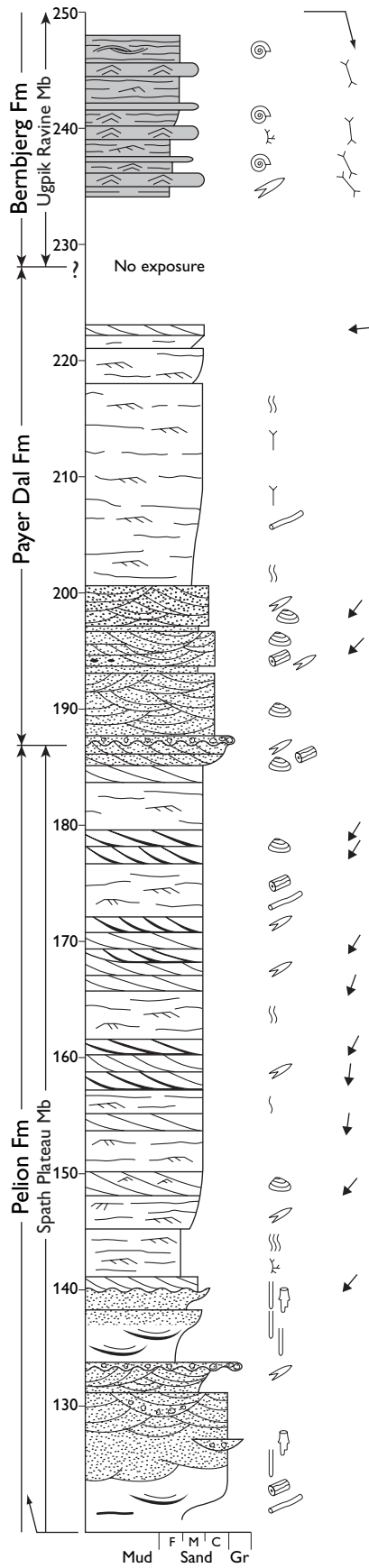
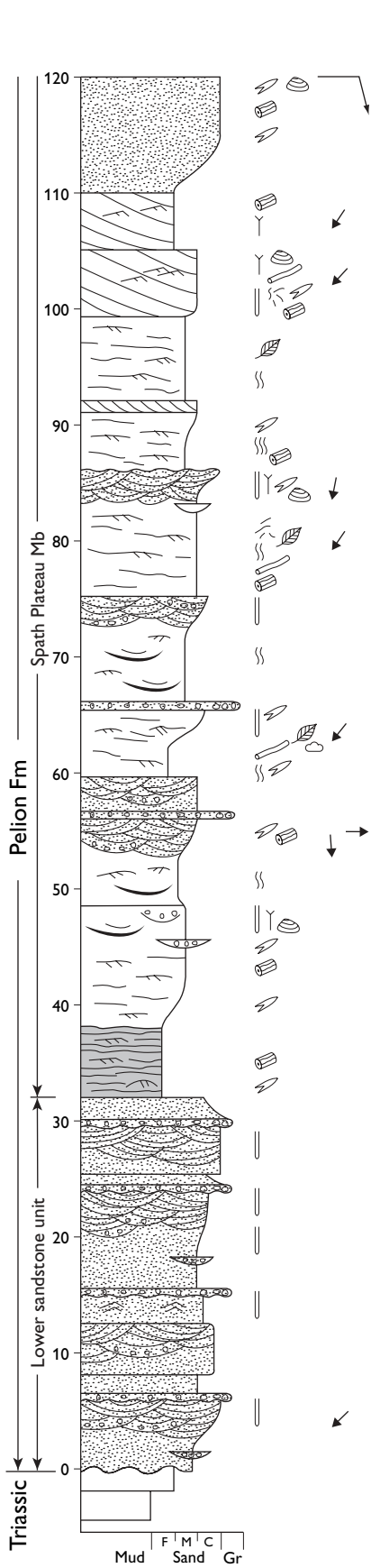
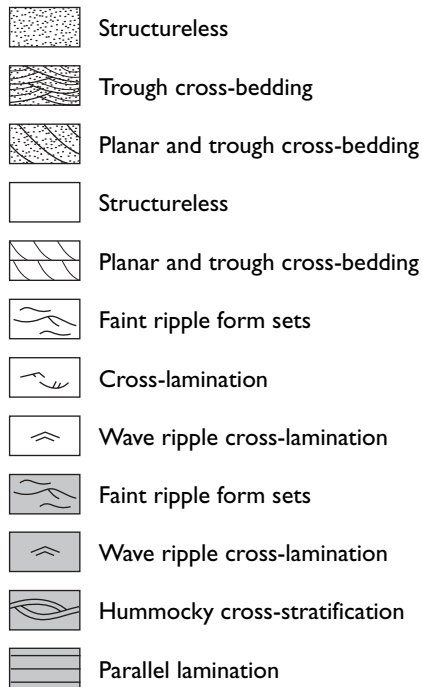


Fig. 4. Jurassic litho- and biostratigraphy (Lower Jurassic and Volgian not included) of the Traill Ø – Geographical Society Ø region, Hold with Hope and Wollaston Forland. Based on Surlyk (1977, 1978, 1990, 1991), Price & Whitham (1997), Alsgaard *et al.* (2003), Alsen & Surlyk (2004, this volume), Vosgerau *et al.* (2004, this volume) and own observations in the Traill Ø and northern Hold with Hope areas. **Fossilbj/Fb**, Fossilbjerget; **PP**, Pelion (Parnas Mb).



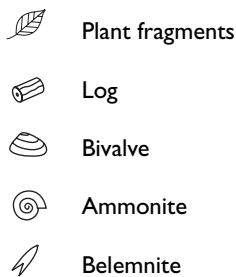
Sedimentary structures



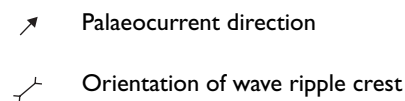
○ ○ ○ ○ Pebbles

— ● Mudstone drapes and clasts

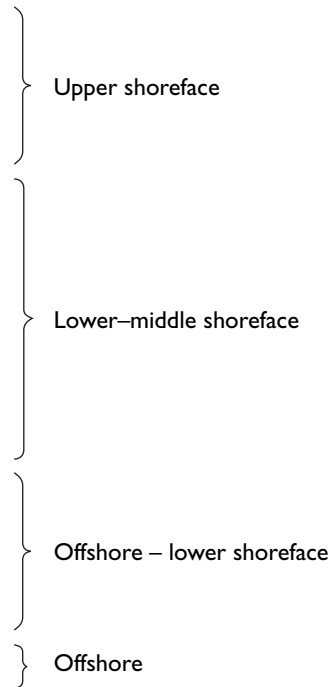
Biota



Miscellaneous features



Facies associations



Trace fossils

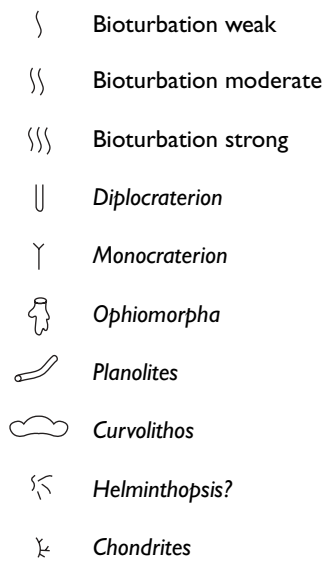


Fig. 5. Composite sedimentary section of the Middle–Upper Jurassic succession at Gulelv (Locality 3). The section was compiled from five part-sections located in a north–south direction along Gulelv (Figs 2, 6). Modified from Larsen *et al.* (1998).

with Hope, a Lower–Middle Callovian sandy succession, c. 190 m thick, overlying the Lower Triassic Wordie Creek Formation is referred to the Pelion Formation (Fig. 5). The succession is divided into two units. The lower unit is 30–40 m thick and consists of medium- to coarse-grained sandstones topped by silty, fine-grained sandstones. The upper unit is up to 155 m thick and differs from the clean sandstones that typify the for-

mation by containing abundant sandy heteroliths interbedded with cross-bedded sandstones and is included in the Spath Plateau Member (Fig. 5). The lower sandstone unit and the Spath Plateau Member are described and interpreted separately below; the latter member is defined formally as a new member of the Pelion Formation.

Lower sandstone unit

The lower sandstone unit overlies siltstones and fine-grained sandstones of the Lower Triassic Wordie Creek Formation with a sharp erosional boundary. The upper boundary is placed where coarse-grained sandstones are overlain by silty, very fine-grained sandstones of the Spath Plateau Member (Figs 5, 9).

The ammonite *Cadoceras* cf. *breve* indicating the Lower Callovian *C. apertum* Chronozone (J.H. Callomon and P. Alsen, personal communications 1997) was found 10 m above the Triassic–Jurassic boundary at Stensiö Plateau (Fig. 2, Locality 1). The basal part of the unit seems to be younger east of Stensiö Plateau (Fig. 2, Localities 4–9) where dinoflagellate cysts indicate the Lower Callovian *P. koenigi* Chronozone. The age of the upper boundary is constrained by an ammonite and by dinoflagellate cysts found in the basal part of the overlying Spath Plateau Member indicating the Lower Callovian *P. koenigi* Chronozone (see below).

The lower sandstone unit consists of pebbly, medium- to coarse-grained quartz sandstones, which are trough cross-bedded with sets up to 0.5 m thick or locally appear structureless. Small scour-fills with pebbles, up to 3 cm in diameter, are common. Dip-directions of foresets show a dominance towards the SW, but directions towards the NW also occur (Fig. 10). The sandstones commonly form coarsening-upwards units, 6–8 m thick, which locally are overlain by an erosionally based pebbly sandstone lag. The top part of the coarsening-upwards units is commonly calcite

cemented and contains abundant vertical trace fossils of *Diplocraterion habichii*. Other trace fossils include *Monocraterion tentaculatum* and locally *Ophiomorpha nodosa*. Belemnites, bivalves and silicified wood are common. The unit is slightly finer grained in places and medium-grained sandstones occur at Locality 1, Stensiö Plateau (Fig. 8). They contain low-relief scour surfaces draped by organic-rich mudstone and are strongly bioturbated with both horizontal and vertical burrows. The lower sandstone unit increases in thickness from c. 30 to 40 m from the SW towards the NE (Fig. 7).

Deposition took place in a marine environment as reflected by marine macrofossils and trace fossils. The coarse-grained and pebbly sandstones and the dominance of vertical burrows suggest shallow-water deposition under high-energy conditions. The scour-fills are interpreted to have been formed by strong currents related to storm surges (e.g. Clifton *et al.* 1971; Hunter *et al.* 1979). The trough cross-bedded sandstones probably reflect 3-D dunes migrating seawards to the south-west in rip channels and partly longshore in runnels towards the north-west. Erosionally-based pebbly sandstones with marine macrofossils form the uppermost beds of some of the coarsening-upwards units and are interpreted as marine lag deposits, formed by wave winnowing of underlying upper shoreface and foreshore deposits. The coarsening-upwards units are interpreted to have formed mainly by shallow marine shoreface progradation. The probable source of the calcite cement in the top part of the coarsening-up-

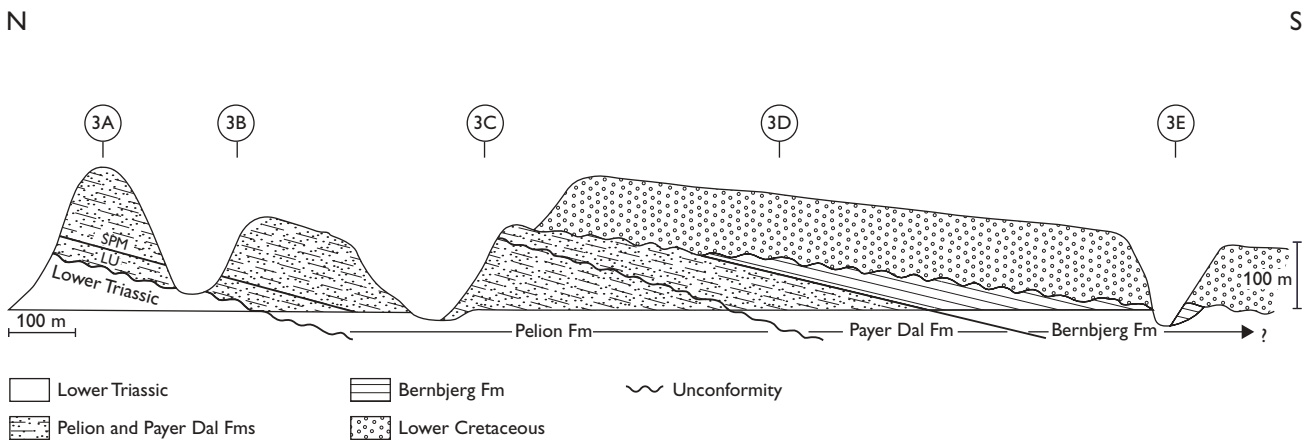


Fig. 6. Sketch of Triassic–Cretaceous succession exposed in a fault block on the eastern side of the Gulelv river (Fig. 2). The location of the part-sections that make up the composite section in Figure 5 are shown. The Triassic and Jurassic sediments dip c. 15° towards SSW and are unconformably overlain by Cretaceous sediments, which dip c. 10° towards the south. An angular unconformity between the Pelion and Payer Dal Formations is observed on the north-facing valleyside at 3C (see Fig. 11). **LU**, Lower sandstone unit; **SPM**, Spath Plateau Member.

wards units is biogenic carbonate derived from calcareous shells accumulated on the marine omission surfaces (Alsgaard *et al.* 2003; Engkilde & Surlyk 2003).

The strong bioturbation and the thin mudstone layers in the medium-grained sandstones at Stensiö Plateau suggest deposition under lower energy conditions. The mudstone drapes on the scour-surfaces formed by suspension fall-out during fair-weather conditions following erosional storm events. The sandstones were probably deposited in a slightly deeper, middle shoreface environment, than the medium- to coarse-grained sandstones that dominate the lower sandstone unit east of Stensiö Plateau.

The decrease in thickness of the sandstone unit from NE to SW combined with the dominant south-westwards palaeocurrent directions may reflect a NE–SW proximal–distal trend. In the proximal areas, a large sediment supply may have delayed the overall drowning recorded by the boundary to the overlying Spath Plateau Member. The increase in thickness towards the NE may, however, also reflect the relief of the palaeo-shoreface.

Spath Plateau Member

new member

General. The member comprises mainly cross-bedded sandstones and sandy heteroliths forming the upper part of the Pelion Formation on northern Hold with Hope.

Name. After the ice-covered basalt plateau south-west of Gulelv, northern Hold with Hope.

Type locality. East side of Gulelv (Figs 2, 6, Locality 3) where the composite type section (Fig. 5) is defined from sub-sections A–C.

Thickness. 155 m.

Lithology. The Spath Plateau Member consists of quartzitic sandstones and sandy heteroliths. A silty, very fine-grained sandstone bed occurs in the basal part of the member. Belemnites, bivalves, silicified and coalified wood and impressions of leaf fragments are common.

Boundaries. The lower boundary is marked by an abrupt change from coarse-grained sandstone of the

lower sandstone unit of the Pelion Formation to silty, fine-grained sandstone. The upper boundary is sharp and erosional and is overlain by pebbly sandstone and sandy heteroliths of the Payer Dal Formation.

Distribution. The member occurs on northern Hold with Hope.

Age. Early–Late Callovian based on an ammonite found at the base of the member and dinoflagellate cysts (Fig. 7, Locality 6). The ammonite is a microconch and resembles *Cadoceras septentrionale* indicating the lowermost part of the Lower Callovian *P. koenigi* Chronozone (P. Alsen, personal communication 1998). Dinoflagellate cysts from the base of the member also indicate the *C. apertum* – *P. koenigi* Chronozones (Piasecki *et al.* 2004, this volume). Dinoflagellate cysts in the upper part of the member indicate the Upper Callovian *P. atbleta* Chronozone (Piasecki *et al.* 2004, this volume).

Facies description. The basal part of the member consists of dark brown, silty sandstones forming a 6 m thick marker bed, situated 30–40 m above the base of the Jurassic succession (Figs 5, 7, 9). The basal 0.5 m of the bed locally contain scattered fine pebbles up to 6 mm in diameter, but otherwise the unit coarsens upwards from silty, very fine-grained sandstone into silty fine-grained sandstone. The sandstones are horizontally laminated, structureless or show subtle wave or current cross-lamination with thin organic-rich mudstone drapes, but primary structures are to a large extent obscured due to weathering or strong bioturbation. In a few places, laminae of silty sandstone are deflected around small, elongate carbonate-cemented concretions. Coalified wood fragments up to 30 cm long and belemnites are abundant in the basal part of the bed, and a few bivalves and gastropods were found immediately above the lower boundary at Locality 6 (Fig. 7) together with the ammonite *Cadoceras septentrionale*. The organic content (TOC) is low, about 1 wt%.

The fine-grained marker bed forms the base of the Spath Plateau Member and sharply overlies trough cross-bedded sandstones or conglomerates of the lower sandstone unit of the Pelion Formation. However, at Locality 9 (Fig. 8), the basal unit of the member consists of a ripple cross-laminated sandy heterolith unit, c. 0.4 m thick, followed by medium- to coarse-grained, planar cross-bedded sandstones. The upper boundary to the overlying ripple cross-laminated sandy heteroliths is gradational.

SW
(Distal)

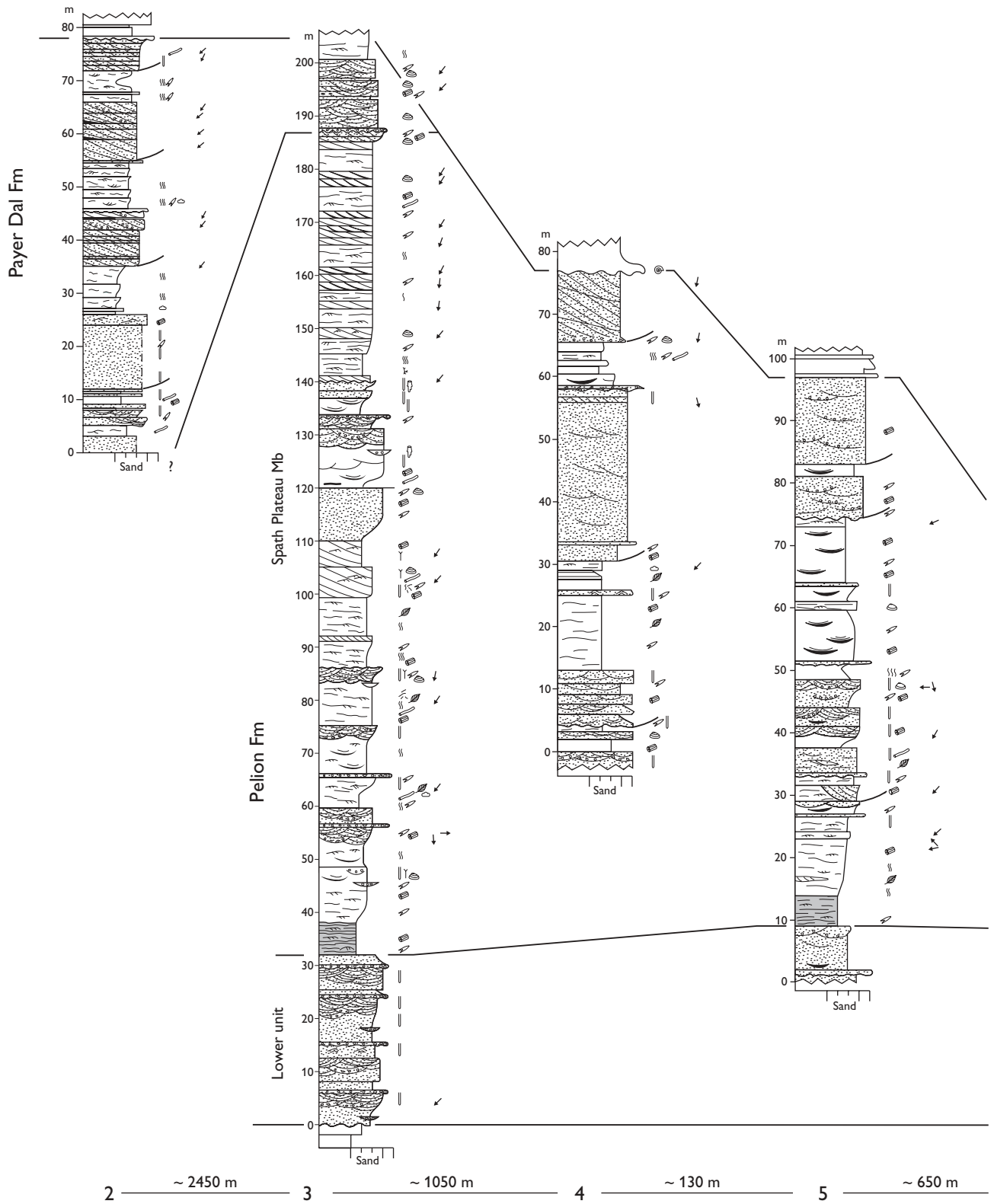
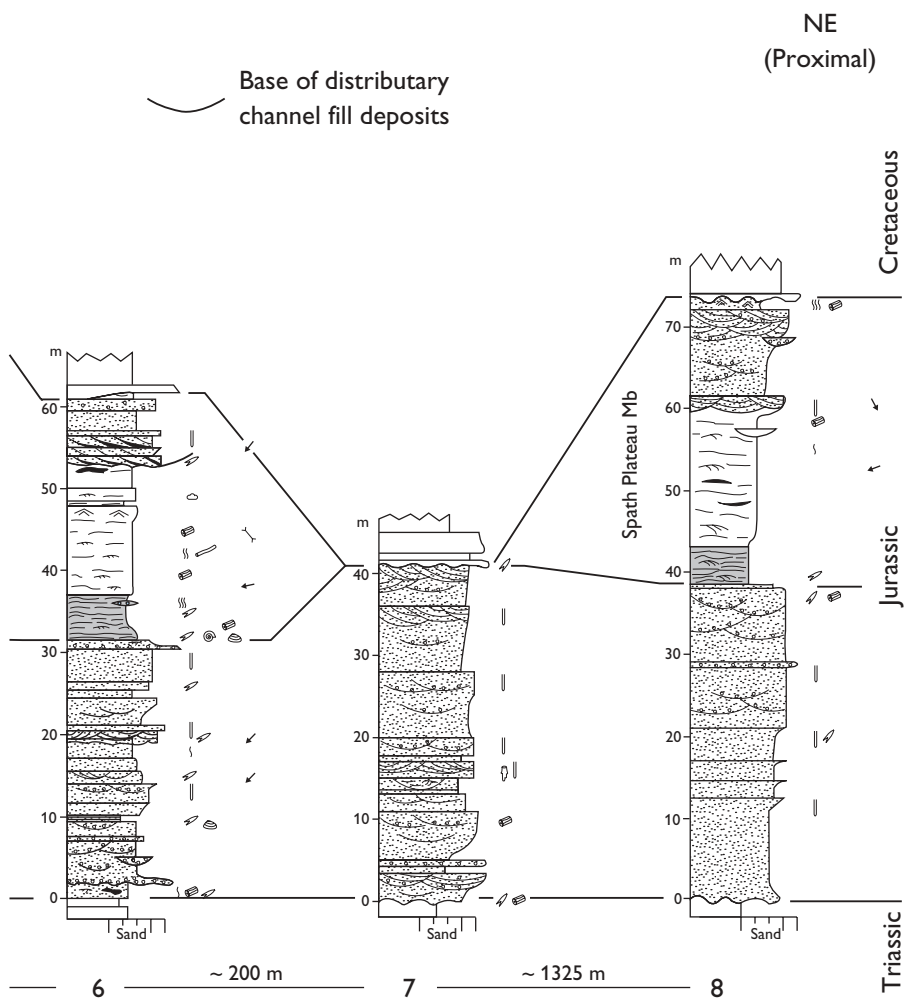


Fig. 7. Log panel giving a broadly NE (proximal) to SW (distal) cross-section. For legend, see Fig. 5; for localities, see Fig. 2.



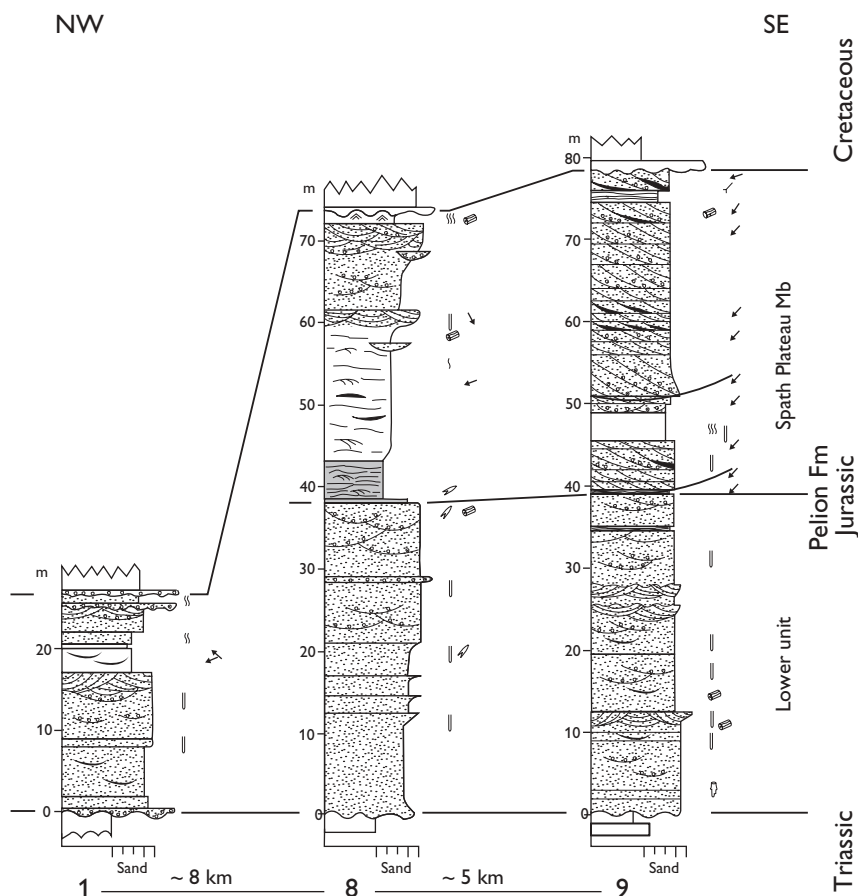


Fig. 8. Log panel giving a NW-SE strike section through the Jurassic succession. For legend, see Fig. 5; for localities, see Fig. 2.

The bulk of the member is made up of heteroliths forming units up to 10 m thick of cross-laminated, fine- to medium-grained sandstones with thin organic-rich mudstone drapes. Both symmetrical and asymmetrical ripples, 1–5 cm high and with wavelengths up to 10 cm, occur. The heteroliths locally form cross-strata, up to 1.5 m thick, with very low-angle foresets and set boundaries marked by indistinct toesets of dark, sandy mudstones, a few centimetres thick. Scour surfaces with a relief of up to 20 cm are common in the heteroliths. Locally, structureless sandstones overlie the surfaces. The degree of bioturbation varies from moderate to high (up to 100%) and the trace fossil assemblage includes *Planolites beverleyensis*, *Curvolithos multiplex*, *Monocraterion tentaculatum*, *Diplocraterion habichi* and possibly *Helminthopsis magna*. Silicified and coalified wood fragments up to 1 m long, together with impressions of leaf fragments, are abundant and belemnites occur locally.

Two types of cross-bedded sandstones occur closely associated with the heteroliths in the Spath Plateau Member. They both show foresets mainly dipping towards the south-west (Fig. 10). The first type consists

of planar or trough cross-bedded, fine- to coarse-grained sandstones occasionally with pebbles. Foresets are generally tangential and commonly separated by single and in places double, organic-rich mudstone drapes. Backflow ripples and reactivation surfaces occur locally. The sets are 0.5–5 m thick and form cosets up to 25 m thick. Set-boundaries are defined by organic-rich silty sandstone beds 1–10 cm thick, representing distal toesets. In one place, however, the toesets form a lenticular body of organic-rich shale, 40 m long and 0.5 m thick, with gently inclined laminae (to SW). The cross-bedded, coarse-grained sandstones commonly overlie ripple cross-laminated sandy heteroliths with a sharp erosional boundary, and contain belemnites, bivalve shells and coalified wood. The degree of bioturbation is low and the trace fossils include vertical burrows of *Monocraterion tentaculatum*, *Diplocraterion habichi* and *Arenicolites* isp. The first type of cross-bedded sandstones form a c. 40 m thick succession in the lower part of the Spath Plateau Member at Locality 9, Diener Bjerg, whereas heteroliths are abundant in the lower part at the other localities (Figs 7, 8).

The second type of cross-bedded sandstones is fine-



Fig. 9. Triassic siltstones and sandstones overlain by concretionary sandstones of the lower sandstone unit (LU) of the Pelion Formation. A marine drowning surface (**dashed** line) separates the lower sandstone unit from an overlying dark brown silty sandstone bed which form the basal part of the Spath Plateau Member (SPM), Pelion Formation. Fig. 2, Locality 6.

to medium-grained and consists of up to 5 m thick sets of low-angle master beds separated by thinner cross-bedded or ripple cross-laminated sets. The latter commonly show climbing ripple cross-lamination or locally bi-directional cross-laminae. The surfaces of the low-angle master beds may be wave or current rippled and separated by thin mudstone drapes. Set thickness is 1–5 m. The lower boundary to ripple laminated sandy heteroliths is generally gradational. The sandstones contain belemnites, bivalve shells and coalified wood. The degree of bioturbation is moderate to high. Trace fossils include vertical burrows of *Monocraterion tentaculatum*, *Diplocraterion habichi* and *Arenicolites* isp., forms that are also common in the first type of sandstones, together with horizontal burrows of *Planolites beverleyensis* and possibly *Helminthopsis magna* in the intervening mud drapes.

Trough cross-bedded sandstones similar to those in the lower sandstone unit of the Pelion Formation occur locally in the Spath Plateau Member (Fig. 7). They commonly form coarsening-upwards successions, up

to 5 m thick, the most complete of which have a lower part consisting of well-sorted, fine- to medium-grained sandstone with indistinct ripple cross-lamination, trough cross-bedding and shallow scour fills. The scour fills are 10–30 cm thick and are marked by thin, organic-rich mudstone layers above the lower erosional boundaries followed by laminated or structureless sandstones. The upper part of the coarsening-upwards units consists of trough cross-bedded, medium- to coarse-grained sandstones. Foresets dip mainly towards the south, but dip-directions towards the west and east also occur (Fig. 10). The upper part is commonly calcite cemented and capped by a sharp surface from which abundant *Diplocraterion habichi* descend; other trace fossils in the upper levels include *Monocraterion tentaculatum* and occasional *Ophiomorpha nodosa*. Horizontal burrows of *Planolites beverleyensis* are limited to the lower part of the coarsening-upwards units. Belemnites, bivalves and silicified wood are common.

Facies interpretation. The laminated silty sandstone

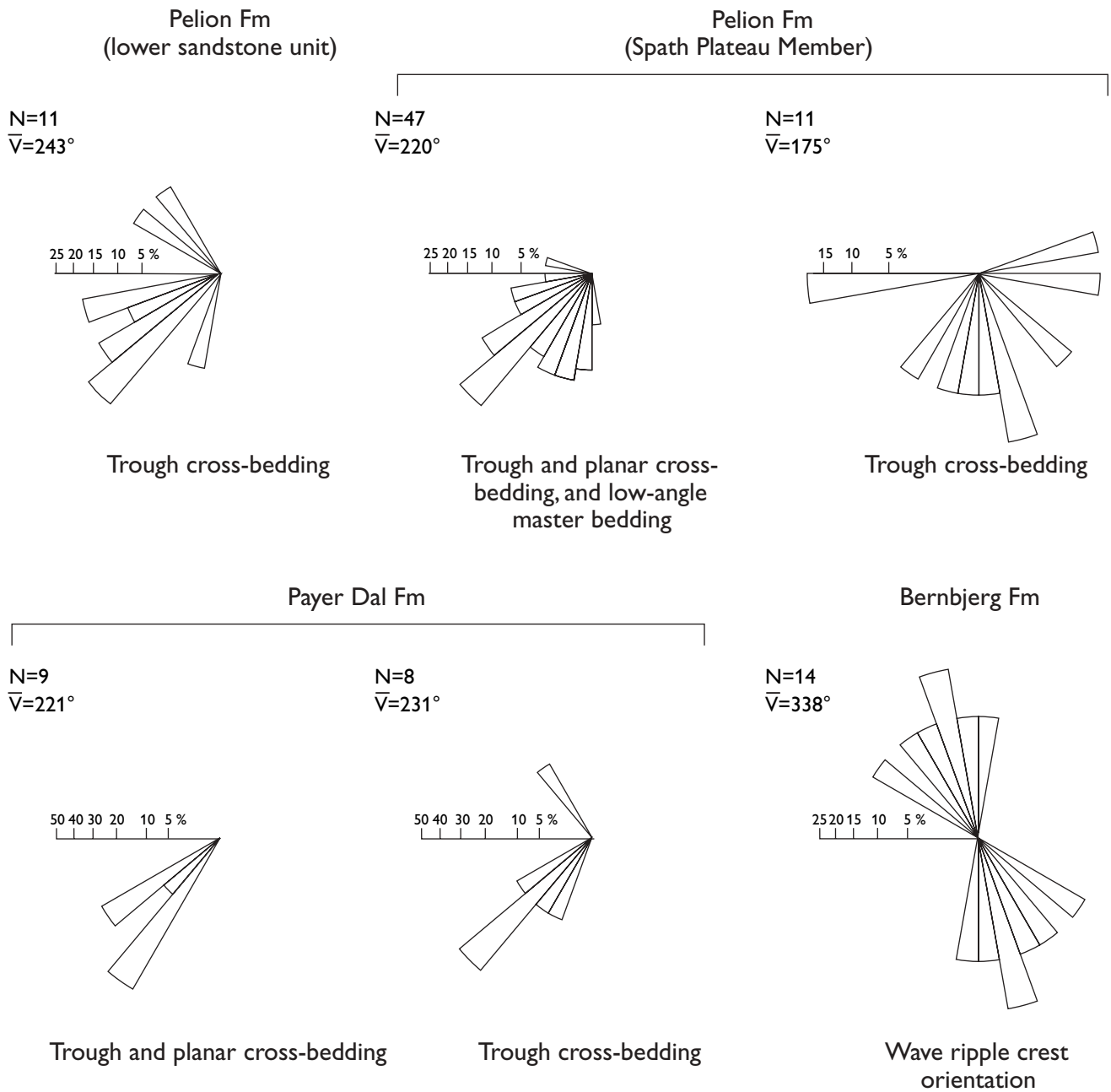


Fig. 10. Palaeocurrent and wave-ripple data from the Pelion, Payer Dal and Bernbjerg Formations. Rose diagrams are shown as true area plots. \bar{V} , vector mean; N , number of measurements.

bed of the basal Spath Plateau Member (except at Locality 9), was deposited in a marine environment as reflected by the marine dinoflagellate cysts and abundant belemnites. The horizontal lamination was formed by deposition from suspension fall-out whereas the subtle cross-lamination was probably formed by wave-induced currents in the offshore transition to lower shoreface zone. The sharp boundary to the underlying

upper shoreface sandstones of the lower sandstone unit represents a drowning surface. At Locality 9, Diener Bjerg, this surface is overlain by a sandy heterolith unit, *c.* 0.4 m thick, interpreted as having been deposited in the lower to middle shoreface zone. This lateral facies variation suggests that the palaeo-water depth decreased from west to east.

The alternation of ripple cross-laminated sandstones

and mudstone drapes reflects varying energy conditions and may be related to the alternation of fair-weather and storm-wave processes and perhaps tidal currents. The strongly bioturbated heteroliths reflect periods of slow sedimentation and little physical reworking whereas the scour surfaces and the overlying structureless sandstones which form part of the facies are interpreted as having formed by strong currents related to storm surges (Clifton *et al.* 1971; Hunter *et al.* 1979; Nemeč & Steel 1984). The abundant plant debris suggests a significant sediment supply from land.

The two types of cross-bedded sandstones are interpreted to represent SSW-migrating sandwaves. They were modified by waves and opposing tidal currents as seen by the presence of wave-ripples, mud drapes, reactivation surfaces and bimodal cross-lamination (Visser 1980; Boersma & Terwindt 1981; Wood & Hopkins 1989). The first type of cross-bedded sandstones was formed in shallow water, possibly the upper shoreface, as seen by the coarse grain-size and low degree of bioturbation. The sharp erosional lower boundaries to lower–middle shoreface heteroliths suggest that the migration of sandwaves took place in distributary channels. The marked lateral facies variation seen between Locality 9 and the other localities suggests that the thick cross-bedded succession at Locality 9 may represent a major distributary channel fill.

The second type of cross-bedded sandstones was formed in deeper water than the first type, as reflected by the generally finer grain-size, stronger bioturbation and the gradational boundary to underlying lower–middle shoreface heteroliths. The compound cross-bedded sandstones with climbing ripple cross-laminated

sets on the low-angle master bedding reflect suspension fall-out into deeper water and were possibly deposited in mouthbars (Elliott 1974; Gjelberg & Steel 1995).

The trough cross-bedded sandstones are similar to those in the lower sandstone unit of the Pelion Formation and are similarly interpreted as having formed by migration of 3-D dunes in a high energy, shallow marine environment. The coarse grain size of the trough cross-beds from the upper part of the coarsening-upwards units suggests sediment supply from nearby distributary channels. The dominant southwards palaeo-current direction indicates that land was situated towards the north, but the large variation in the palaeo-current measurements and the limited dataset preclude detailed interpretation of the palaeo-shoreline orientation. The coarsening-upwards units are interpreted to reflect progradation in the middle to upper shoreface.

Payer Dal Formation

In the type area on Kuhn Ø, the Payer Dal Formation consists of fine- to coarse-grained quartz sandstones locally with pebbly sandstone lags rich in marine bivalves and belemnites (Alsgaard *et al.* 2003). The formation is subdivided into a lower and an upper unit that have an Early–Middle Oxfordian and early Late Oxfordian age, respectively (Fig. 4). On Hold with Hope, a succession of cross-bedded, medium- to coarse-grained quartz sandstones, pebbly sandstone lags and sandy heteroliths overlying the Pelion Formation is referred to the Payer Dal Formation.

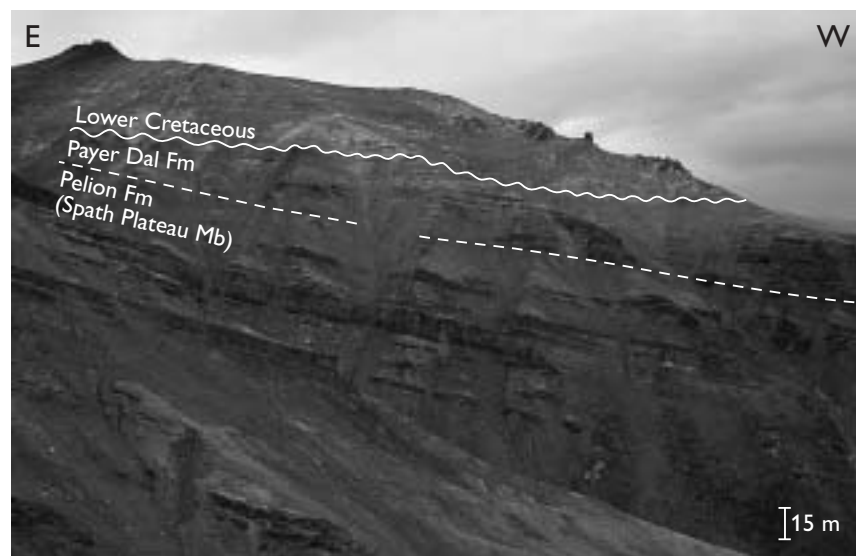


Fig. 11. The Spath Plateau Member (Pelion Formation), Payer Dal Formation and overlying Cretaceous sandstones. Note the slight angular discordance at the unconformity between the Pelion and Payer Dal Formations (**dashed** line). Fig. 2, Locality 3C; view towards south.

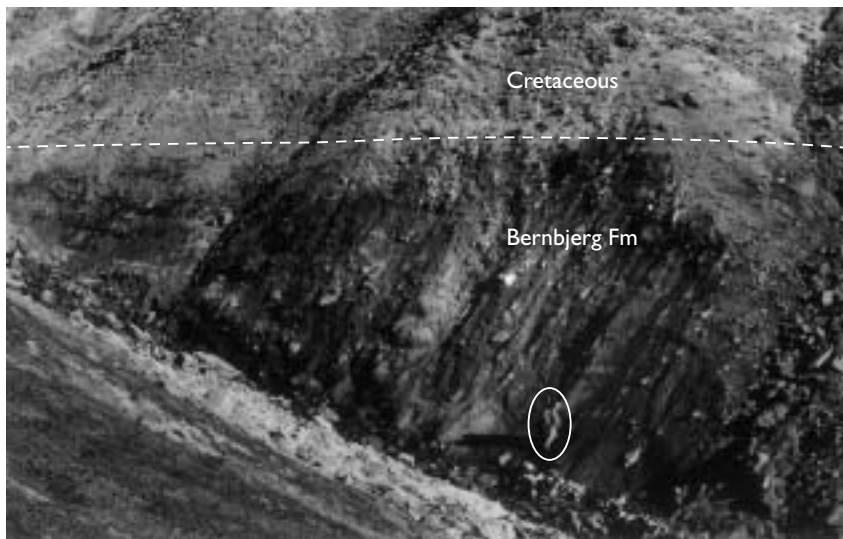


Fig. 12. Structureless and horizontally laminated dark mudstones of the Bernbjerg Formation erosionaly overlain by Cretaceous sandstone (Fig. 6, Locality 3E; 340–360 m in Fig. 5). Person (**encircled**) for scale.

The age of the Payer Dal Formation on Hold with Hope is Middle–Late Oxfordian. Dinoflagellate cysts from the lower part of the Formation indicate the Middle–Upper Oxfordian *C. tenuiserratum* – *A. glosense* Chronozones, similar to the upper unit of the Payer Dal Formation on Kuhn Ø. This suggests that the boundary between the Pelion and Payer Dal Formations on Hold with Hope represents a Late Callovian – Middle Oxfordian hiatus (Fig. 4).

The formation is exposed at Localities 2 and 3 (Figs 2, 5, 7). The lower boundary is only exposed at Locality 3, where it is represented by an erosional surface forming a minor angular unconformity between the Pelion and Payer Dal Formations (Fig. 11). The surface is overlain by a pebbly sandstone lag, up to 0.5 m thick, of quartz pebbles 3–5 mm in diameter, belemnites, bivalves and small logs, up to 0.4 m long. The lag is overlain by a coarse- to very coarse-grained sandstone succession, *c.* 15 m thick, which fines slightly upwards. The succession is dominated by trough cross-bedding but small sets of planar cross-beds and pebbly sandstone lags also occur. Dip directions of foresets are mainly towards the SW (Fig. 10). Pavements of bivalves are common, whereas belemnites, logs and rounded mudstone clasts, up to 5 cm in diameter, occur locally. The sandstone succession is capped by a sharp surface overlain by an overall coarsening-upwards unit (*c.* 25 m thick) of ripple cross-laminated sandy heteroliths, similar to those in the underlying Spath Plateau Member. At Locality 2, the formation is at least 70 m thick and consists of alternating ripple cross-laminated sandy heteroliths and sets of planar or

trough cross-bedded, coarse-grained sandstones similar to the first type of cross-bedded sandstones of the Spath Plateau Member. The foresets dip towards the south-west (Fig. 10). The upper boundary to the Bernbjerg Formation is covered by scree, but is probably situated somewhere between 223 m and 234 m in the composite section at Locality 3 (Fig. 5).

The basal pebbly sandstone at Locality 3 is interpreted as a marine lag deposit due to the coarse grain size, the presence of marine macrofossils and the erosional base. The overlying cross-bedded sandstone succession was deposited in a high energy, shallow marine environment as testified by the coarse grain size, the pebbly sandstone lags and the marine macrofossils. The cross-bedded sandstones are interpreted to reflect the seawards migration of dunes in the upper shoreface. The coarse grain size of the sandstone succession and the occurrence of logs and rounded clay clasts suggest sediment supply from nearby distributary channels. The sandstone succession is topped by a drowning surface.

A slightly different depositional environment is recorded by the succession at Locality 2 where planar and trough cross-bedded distributary channel-fill sandstones alternate with lower–middle shoreface heteroliths. These facies are very similar to the facies of the underlying Spath Plateau Member and are similarly interpreted to reflect migration of dunes in distributary channels and mouth bars associated with tidally influenced deltas (see above).

The considerable thickness variation of the Payer Dal Formation between Localities 2 and 3, together

with the presence of a minor angular unconformity at the base of the formation, might reflect differential subsidence due to the onset of fault-block tilting.

Bernbjerg Formation

The Upper Oxfordian – Lower Volgian Bernbjerg Formation in Wollaston Forland is dominated by dark-grey to black mudstones and strongly bioturbated heteroliths (Surlyk 1977; Surlyk & Clemmensen 1983). On Hold with Hope, the formation is poorly exposed along the Gulelv river (Figs 2, 6) where it is estimated to be c. 130 m thick based mainly on simple geometrical calculations. It has not been possible to study lateral facies variations within the Bernbjerg Formation.

The basal part of the Bernbjerg Formation on Hold with Hope has a Late Oxfordian, *A. glosense* Chron age based on the presence of the ammonite *Amoeboceras ilovaiskii* (J.H. Callomon and P. Alsen, personal communications 1997) and dinoflagellate cysts (Piasecki *et al.* 2004, this volume). In the upper part of the formation, dinoflagellate cysts indicate a Late Oxfordian – Early Kimmeridgian, *A. serratum* – *P. baylei* Chron age (Piasecki *et al.* 2004, this volume).

The basal part of the Bernbjerg Formation on Hold with Hope is dominated by organic-rich, silty, fine-grained sandstones, which are horizontally laminated or locally cross-laminated. Wave-rippled, medium- to coarse-grained sandstone beds, locally with pebbles up to 1 cm in diameter, are common. The wave ripples have NW–SE ripple crest orientations (Fig. 10; 234–248 m in Fig. 5). The silty fine-grained sandstones contain scattered *Chondrites* sp. Belemnites occur locally whereas ammonites are abundant. This lower coarser-grained unit of the Bernbjerg Formation is referred to the Ugpik Ravine Member (Surlyk 2003, fig. 5).

The succession above the basal part of the Bernbjerg Formation consists of structureless or horizontally laminated dark mudstones (Fig. 12). No macrofossils were found in the mudstones. Total organic carbon (TOC) content is about 2 wt% based on two samples. The lower boundary of the Bernbjerg Formation is not exposed, and the formation is erosionally overlain by Lower Cretaceous coarse-grained sandstones. The Bernbjerg Formation probably continues into the subsurface along Gulelv.

The horizontally laminated and locally cross-laminated silty fine-grained sandstones from the basal part of the Bernbjerg Formation reflect deposition from suspension fall-out and weak bottom currents during

fair-weather conditions. Storm-wave currents most likely deposited the interbedded wave-rippled, medium to coarse-grained sandstones. The orientations of the wave ripples suggest a NW–SE-trending coastline. The facies are interpreted to have been deposited in the offshore transition to lower shoreface zone. The overlying dark mudstones are interpreted to have been deposited offshore from suspension fall-out based on the fine grain size and dominant horizontal lamination.

Palaeoenvironments and basin configuration

The Jurassic succession on Hold with Hope shows a stepwise, but overall fining-upwards trend (Fig. 5) reflecting long-term transgression. The transgression was interrupted by a major relative sea-level fall within the Late Callovian – Middle Oxfordian time interval, represented by the unconformity separating the Pelion and Payer Dal Formations.

The basal Jurassic sediments seem to get younger from west to east as suggested by dinoflagellate cysts indicating the Lower Callovian *C. apertum* Chronozone at Stensiö Plateau and the Lower Callovian *P. koenigi* Chronozone at Steensby Bjerg and Diener Bjerg (Fig. 2). The age difference may reflect onset of rifting and associated onlap. Alternatively, the Stensiö Plateau formed a separate fault block, which was transgressed first. The N–S-trending fault situated at Blåelv, west of Stensiö Plateau, forms the western boundary of Jurassic sediments today (Fig. 2). The Jurassic sea, however, may have extended as far west as to the Post-Devonian Main Fault, which formed the western basin boundary during the Late Permian and Triassic (Vischer 1943; Birkelund & Perch-Nielsen 1976; Stemmerik *et al.* 1993). This would imply that older Jurassic sediments from the western part of the basin were eroded in post-Kimmeridgian time. Transport of eroded material towards the east may explain the occurrence of *Cranocephalites* sp., indicating the Upper Bajocian *C. pompeckji* Chronozone, in the Cretaceous basal conglomerate at Steensby Bjerg. The sediment source area may, however, also have been Clavering Ø, west of the Dombjerg–Clavering Fault, which is believed to have formed a palaeo-high in Jurassic times (Vischer 1943; Stemmerik *et al.* 1993).

Lateral facies variations within the Spath Plateau Member (Pelion Formation) indicate that palaeo-water depths decreased from west to east. This suggests a similar setting to that envisaged for the Wollaston For-

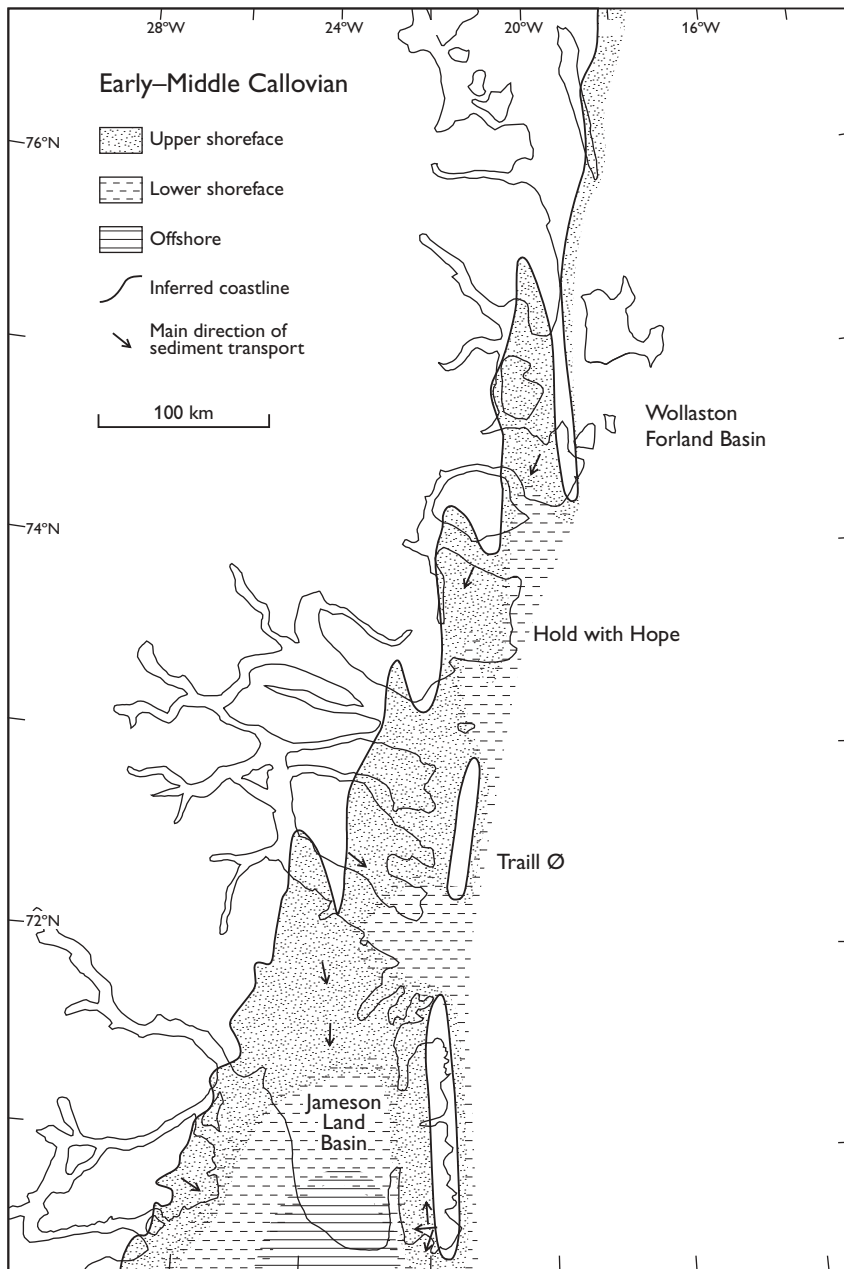


Fig. 13. Early–Middle Callovian palaeogeography and facies distribution in East Greenland. Based on Surlyk (1977), Engkilde & Surlyk (2003), Vosgerau *et al.* (2004, this volume), and new data from Hold with Hope.

land Basin where deposition took place on the W–SW-tilted hangingwalls of major fault blocks and the elevated fault block crests formed elongated islands or peninsulas to the east (Vischer 1943; Maync 1947; Donovan 1957; Surlyk 1977; Surlyk *et al.* 1981; Surlyk & Clemmensen 1983). The presence of the marine Pelion and Payer Dal Formations in the vicinity of the block crest excludes the occurrence of a major land area during Callovian and Middle Oxfordian time when the crest probably only formed elongated islands or submarine shoals.

The Hold with Hope area is thus interpreted to have formed a narrow embayment which was open for marine circulation towards the south and, during periods of high sea level, eastwards across the elevated fault block crest. Farther towards the east, the fault block was most likely limited by the continuation of the Dombjerg–Clavering Fault, which was active during the Jurassic (Maync 1947; Surlyk 1977; Stemmerik *et al.* 1993). The narrow head of the rift-basin occurs in an intermediate position between the Wollaston Forland and Jameson Land Basins that are situated to

the north-east and south-west, respectively (Fig. 13). The Hold with Hope region seems to have formed a land area during the Late Callovian – Middle Oxfordian time interval whereas it was covered by sea during maximum flooding in Late Bajocian, Early–Middle Callovian and Late Oxfordian – Kimmeridgian times.

A close comparison of the Jurassic successions in the Wollaston Forland, Hold with Hope and Jameson Land basins is hindered by limited biostratigraphic control at some levels due to the scarcity of ammonites and dinoflagellate cysts in the coarse sandstone facies. It is evident, however, that the Late Callovian – Middle Oxfordian hiatus in the Hold with Hope basin has not been demonstrated in the other two basins where sediments of Early–Middle Oxfordian age are well documented (Fig. 4).

The minor angular unconformity between the Pelion and Payer Dal Formations suggests that the hiatus was formed by minor tilting of fault blocks and erosion of uplifted block crests perhaps combined with eustatic sea-level falls. Sea-level falls, possibly eustatic, have been suggested to take place in Late Callovian time, at the Early–Middle Oxfordian boundary and in early Late Oxfordian time (Sahagian *et al.* 1996) and seem to correspond to changes in regional sea level documented in Jameson Land (Larsen & Surlyk 2003).

The dark mudstones of the Bernbjerg Formation reflect deposition in a quiet offshore environment indicating that the influence of basin topography was overprinted by rise in relative sea level. Fault block crests to the east were finally inundated during the Kimmeridgian.

Strong fault activity occurred at the boundary between the post-Kimmeridgian and pre-Barremian successions and the fault blocks originally defining the Hold with Hope basin were split into smaller blocks, a similar tectonic development to that seen in the Wollaston Forland Basin. Comparison with the Wollaston Forland Basin suggests that this tectonic episode took place in Volgian–Valanginian time.

Summary and conclusions

A new Middle–Upper Jurassic succession is described from northern Hold with Hope. The Jurassic sediments occur on the hangingwall of small fault blocks dipping towards the WSW. The sediments are locally eroded away on the uplifted block crests, whereas they increase in thickness down-dip on the hangingwalls. The Jurassic succession is up to 360 m thick and is referred

to the Pelion, Payer Dal and Bernbjerg Formations of Early Callovian – Early Kimmeridgian age. It overlies Lower Triassic siltstones and sandstones with a sharp boundary and is overlain by Cretaceous coarse-grained sandstones with an angular unconformity. The succession was deposited in a shoreface–offshore marine environment and reflects an overall transgression.

The Pelion Formation is *c.* 190 m thick and consists of a lower sandstone unit, 30–40 m thick, overlain by a drowning surface and sandy heteroliths and sandstones of the new Spath Plateau Member, *c.* 155 m thick. The lower sandstone unit spans the Lower Callovian *C. apertum*–*P. koenigi* Chronozones. It consists of medium to coarse-grained sandstones, which are trough cross-bedded or structureless and contain small pebbly scour-fills. The sandstones commonly form coarsening-upwards units, 6–8 m thick, the upper part of which are calcite cemented and contain abundant *Diplocraterion habichi*. The sandstones are interpreted to have been deposited in the middle to upper shoreface zone. The Spath Plateau Member is of late Early – Middle Callovian, *P. koenigi* – *P. athleta* Chron age based on ammonites and dinoflagellate cysts. It is dominated by lower–middle shoreface ripple cross-laminated sandy heteroliths and cross-bedded sandstones reflecting migration of 2-D and 3-D dunes in distributary channels and mouth bars associated with tidally influenced deltas.

The Payer Dal Formation is more than 70 m thick and of Middle–Late Oxfordian, *C. tenuiserratum* – *A. glosense* Chron age. It consists of cross-bedded sandstones and sandy heteroliths showing considerable lateral thickness variations and reflects progradation of tidally influenced dunes and mouth bars. It is separated from the underlying Pelion Formation by an angular unconformity representing a Late Callovian – Middle Oxfordian hiatus, formed by subaerial erosion related to an eustatic sea-level fall, combined with minor tilting of fault blocks and erosion of uplifted block crests.

The Bernbjerg Formation is at least 130 m thick and spans the Upper Oxfordian – Lower Kimmeridgian (*A. glosense*–*P. baylei* Chronozones). The basal part consists of horizontally laminated and locally cross-laminated silty fine-grained sandstones interbedded with thin wave-rippled medium- to coarse-grained sandstones and is referred to the Ugpik Ravine Member. Deposition took place in the offshore transition to lower shoreface zone. The upper part of the formation consists of structureless or horizontally laminated dark mudstones reflecting offshore deposition in an outer shelf environment.

Deposition of the Jurassic succession on Hold with Hope took place in a narrow rift-controlled embayment as indicated by the distribution of the sediments and dominating south-westwards palaeocurrent directions in the Pelion and Payer Dal Formations. Lateral facies variations in the Spath Plateau Member indicate a decrease in palaeowater depth from west to east. The embayment was open to marine circulation to the south and probably partly to the east, where the crestal margin of a slightly westwards to south-westwards tilted block formed elongated narrow islands or submarine shoals. During the deposition of the Bernbjerg Formation, the influence of basin topography was overprinted by a rise in relative sea level and the fault block crest to the east was inundated. Towards the west, the Stensiö Plateau may have formed a separate block that was transgressed first, as indicated by the fact that the Pelion Formation is older at this locality than at Steensby Bjerg and Diener Bjerg.

The presence of an angular unconformity between the Jurassic and Cretaceous succession shows that block rotation took place in post-Kimmeridgian – pre-Barremian time. During this tectonic episode, the fault block originally defining the Hold with Hope basin was split into narrower blocks. This might have taken place in the Volgian–Valanginian as suggested by comparison with the Wollaston Forland Basin where a similar tectonic event took place during this time interval.

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References

- Alsen, P. & Surlyk, F. 2004: Maximum Middle Jurassic transgression in East Greenland: evidence from new ammonite finds, Bjørnedal, Traill Ø. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 31–49 (this volume).
- Alsgaard, P.C., Felt, V.L., Vosgerau, H. & Surlyk, F. 2003: The Jurassic of Kuhn Ø, North-East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 865–892.
- Birkelund, T. & Perch-Nielsen, K. 1976: Late Palaeozoic – Mesozoic evolution of central East Greenland. In: Escher, A. & Watt, W.S. (eds): Geology of Greenland, 304–339. Copenhagen: Geological Survey of Greenland.
- Boersma, J.R. & Terwindt, J.H.J. 1981: Neap-spring tide sequences of intertidal shoal deposits in a mesotidal estuary. *Sedimentology* **28**, 151–170.
- Clifton, H.E., Hunter, R.E. & Phillips, R.L. 1971: Depositional structures and processes in the non-barred high-energy near-shore. *Journal of Sedimentary Petrology* **41**, 651–670.
- Donovan, D.T. 1957: The Jurassic and Cretaceous systems in East Greenland. *Meddelelser om Grønland* **155**(4), 214 pp.
- Elliott, T. 1974: Intertributary bay sequences and their genesis. *Sedimentology* **21**, 611–622.
- Engkilde, M. & Surlyk, F. 2003: Shallow marine syn-rift sedimentation: Middle Jurassic Pelion Formation, Jameson Land, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 813–863.
- Gjelberg, J. & Steel, R.J. 1995: Helvetiafjellet Formation (Barremian–Aptian), Spitsbergen: characteristics of a transgressive succession. In: Steel, R.J., Felt, V., Johannessen, E.P. & Mathieu, C. (eds): Sequence stratigraphy on the Northwest European Margin. Norwegian Petroleum Society (NPF) Special Publication **5**, 571–593. Amsterdam: Elsevier.
- Hunter, R.E., Clifton, H.E. & Phillips, R.L. 1979: Depositional processes, sedimentary structures and predicted vertical sequences in barred nearshore systems, southern Oregon coast. *Journal of Sedimentary Petrology* **49**, 711–726.
- Kelly, S.R.A., Whitham, A.G., Koraini, A.M. & Price, S.P. 1998: Lithostratigraphy of the Cretaceous (Barremian–Santonian) Hold with Hope Group, NE Greenland. *Journal of the Geological Society of London* **155**, 993–1008.
- Koch, L. 1932: Carboniferous and Triassic stratigraphy of East Greenland. *Meddelelser om Grønland* **83**(2), 100 pp.
- Koch, L. & Haller, J. 1971: Geological map of East Greenland 72°–76°N. Lat. (1:250 000). *Meddelelser om Grønland* **183**, 26 pp., 13 maps.
- Larsen, M. & Surlyk, F. 2003: Shelf-edge delta and slope deposition in the Upper Callovian – Middle Oxfordian Olympen Formation, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 931–948.
- Larsen, M., Piasecki, S., Preuss, T., Seidler, L., Stemmerik, L., Therkelsen, J. & Vosgerau, H. 1998: Petroleum geological activities in East Greenland in 1997. *Geology of Greenland Survey Bulletin* **180**, 35–42.
- Maync, W. 1947: Stratigraphie der Jurabildungen Ostgrönlands zwischen Hochstetterbugten (75°N) und dem Kejser Frantz Joseph Fjord (73°N). *Meddelelser om Grønland* **132**(2), 223 pp.
- Maync, W. 1949: The Cretaceous beds between Kuhn Island and Cape Franklin (Gauss Peninsula), northern East Greenland. *Meddelelser om Grønland* **133**(3), 291 pp.
- Nemec, W. & Steel, R.J. 1984: Alluvial and coastal conglomerates: their significant features and some comments on grav-

- elly mass-flow deposits. In: Koster, E.H. & Steel, R.J. (eds): Sedimentology of gravels and conglomerates. Canadian Society of Petroleum Geologists Memoir **10**, 1–31.
- Piasecki, S., Larsen, M., Therkelsen, J. & Vosgerau, H. 2004: Jurassic dinoflagellate cyst stratigraphy of Hold with Hope, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 73–88 (this volume).
- Price, S.P. & Whitham, A.G. 1997: Exhumed hydrocarbon traps in East Greenland: analogs for the Lower–Middle Jurassic play of Northwest Europe. American Association of Petroleum Geologists Bulletin **81**, 196–221.
- Sahagian, D., Pinous, O., Olfieriev, A. & Zakharov, V. 1996: Eustatic curve for the Middle Jurassic – Cretaceous based on Russian platform and Siberian stratigraphy: zonal resolution. American Association of Petroleum Geologists Bulletin **80**, 1433–1458.
- Stemmerik, L., Christiansen, F.G., Piasecki, S., Jordt, B., Marcusen, 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., Bergsager, E., Dahl-Stamnes, Ø.A., Holter, E., Johansen, B., Lie, E. & Lund, T.B. (eds): Arctic geology and petroleum potential. Norwegian Petroleum Society (NPF) Special Publication **5**, 67–68. Amsterdam: Elsevier.
- Stemmerik, L., Clausen, O.R., Korstgård, J., Larsen, M., Piasecki, S., Seidler, L., Surlyk, F. & Therkelsen, J. 1997: Petroleum geological investigations in East Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. Geology of Greenland Survey Bulletin **176**, 29–38.
- Surlyk, F. 1977: Stratigraphy, tectonics and palaeography of the Jurassic sediments of the areas north of Kong Oscar Fjord, East Greenland. Bulletin Grønlands Geologiske Undersøgelse **123**, 56 pp.
- Surlyk, F. 1978: Submarine fan sedimentation along fault scarps on tilted fault blocks (Jurassic–Cretaceous boundary, East Greenland). Bulletin Grønlands Geologiske Undersøgelse **128**, 108 pp.
- Surlyk, F. 1990: Timing, style and sedimentary evolution of Late Palaeozoic – Mesozoic extensional basins of East Greenland. In: Hardman R.F.P. & Brooks, J. (eds): Tectonic events responsible for Britain's oil and gas reserves. Geological Society Special Publication (London) **55**, 107–125.
- Surlyk, F. 1991: Sequence stratigraphy of the Jurassic – lowermost Cretaceous of East Greenland. American Association of Petroleum Geologists Bulletin **75**, 1468–1488.
- Surlyk, F. 2003: The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 659–722.
- Surlyk, F. & Clemmensen, L.B. 1983: Rift propagation and eustasy as controlling factors during Jurassic inshore and shelf sedimentation in northern East Greenland. Sedimentary Geology **34**, 119–143.
- Surlyk, F., Callomon, J.H., Bromley, R.G. & Birkelund, T. 1973: Stratigraphy of the Jurassic – Lower Cretaceous sediments of Jameson Land and Scoresby Land, East Greenland. Bulletin Grønlands Geologiske Undersøgelse **105**, 76 pp.
- Surlyk, F., Clemmensen, L.B. & Larsen, H.C. 1981: Post-Paleozoic evolution of the East Greenland continental margin. In: Kerr, J.W. & Fergusson, A.J. (eds): Geology of the North Atlantic borderlands. Canadian Society of Petroleum Geologists Memoir **7**, 611–645.
- Vischer, A. 1943: Die postdevonische Tektonik von Ostgrönland zwischen 74° und 75°N Br. Kuhn Ø, Wollaston Forland, Clavering Ø und angrenzende Gebiete. Meddelelser om Grønland **133**(1), 195 pp.
- Visser, M.J. 1980: Neap-spring cycles reflected in Holocene subtidal large-scale bedform deposits: a preliminary note. Geology **8**, 543–546.
- Vosgerau, H., Alsen, P., Carr, I.D., Therkelsen, J., Stemmerik, L. & Surlyk, F. 2004: Jurassic syn-rift sedimentation on a seawards-tilted fault block, Traill Ø, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 9–18 (this volume).
- Wood, J.M. & Hopkins, J.C. 1989: Reservoir sandstone bodies in estuarine valley fill: Lower Cretaceous Glauconitic Member, Little Bow Field, Alberta, Canada. American Association of Petroleum Geologists Bulletin **73**, 1361–1382.

Jurassic dinoflagellate cyst stratigraphy of Hold with Hope, North-East Greenland

Stefan Piasecki, Michael Larsen, Jens Therkelsen and Henrik Vosgerau

Dinoflagellate cysts of the Middle–Upper Jurassic succession on northern Hold with Hope have been studied in order to establish a biostratigraphic framework and to date the succession. The Pelion Formation is characterised by abundant *Chytroeisphaeridia hyalina* and *Sentusidinium* spp., with some *Ctenidodinium thulium* and *Paragonyaulacysta retiphragmata* in the lower part. *Mendicodinium groenlandicum* appears higher in the formation followed by *Trichodinium scarburghense* in the upper part. The succeeding Payer Dal Formation contains *Scriniodinium crystallinum*, *Rigaudella aemula* and *Leptodinium subtile* in the lower part and *Dingodinium jurassicum* and *Prolixosphaeridium granulosum* in the uppermost part. The Bernbjerg Formation contains abundant *Sirmiodinium grossii* and *Gonyaulacysta jurassica*. *Adnatospaeridium* sp., *Cribroperidinium granuligerum*, *Glossodinium* cf. *dimorphum* and *Scriniodinium irregulare* appear in the lower part of the formation, followed by *Avellodinium* spp. in the highest part. The dinoflagellate cyst assemblages in the Pelion Formation indicate an Early–Late Callovian age (*C. apertum* – *P. athleta* Chronozones). This is supported by ammonites in the lower part of the formation, which refer to the *C. apertum* and *P. koenigi* Chronozones. A significant hiatus, from Late Callovian to Middle Oxfordian, is present between the Pelion Formation and the overlying Payer Dal Formation. The age of the Payer Dal Formation is Middle Oxfordian to earliest Late Oxfordian (*C. tenuiserratum* – *A. glosense* Chronozones). The Payer Dal Formation is conformably overlain by the Bernbjerg Formation of Late Oxfordian to possibly earliest Kimmeridgian age (*A. glosense* – *P. baylei* Chronozones). The *A. glosense* Chronozone is also documented by abundant ammonites in the lowermost part of the formation.

Keywords: ammonites, dinoflagellate cysts, Jurassic, North-East Greenland, stratigraphy

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The recognition of Middle–Upper Jurassic sediments on northern Hold with Hope added a missing link to the chain of Jurassic sedimentary exposures along the east coast of Greenland (Figs 1, 2; Stemmerik *et al.* 1997; Kelly *et al.* 1998; Larsen *et al.* 1997; Vosgerau *et al.* 2004, this volume). Sedimentological and biostratigraphical analysis of the succession formed the basis for correlation with lithostratigraphical units in Wollaston Forland and Jameson Land, and subdivision into the Pelion, Payer Dal and Bernbjerg Formations (Fig.

3). A new member of the Pelion Formation, the Spath Plateau Member, was erected (Vosgerau *et al.* 2004, this volume). Correlation was based on very few, poorly preserved Middle Jurassic ammonites *in situ* in the lower sandstone-dominated part of the succession, and more abundant Upper Jurassic ammonites of the Upper Oxfordian, the *A. glosense* Zone, in the mudstone-dominated upper part of the succession. The content of dinoflagellate cysts was studied in order to improve the biostratigraphic dating of the succession, and to

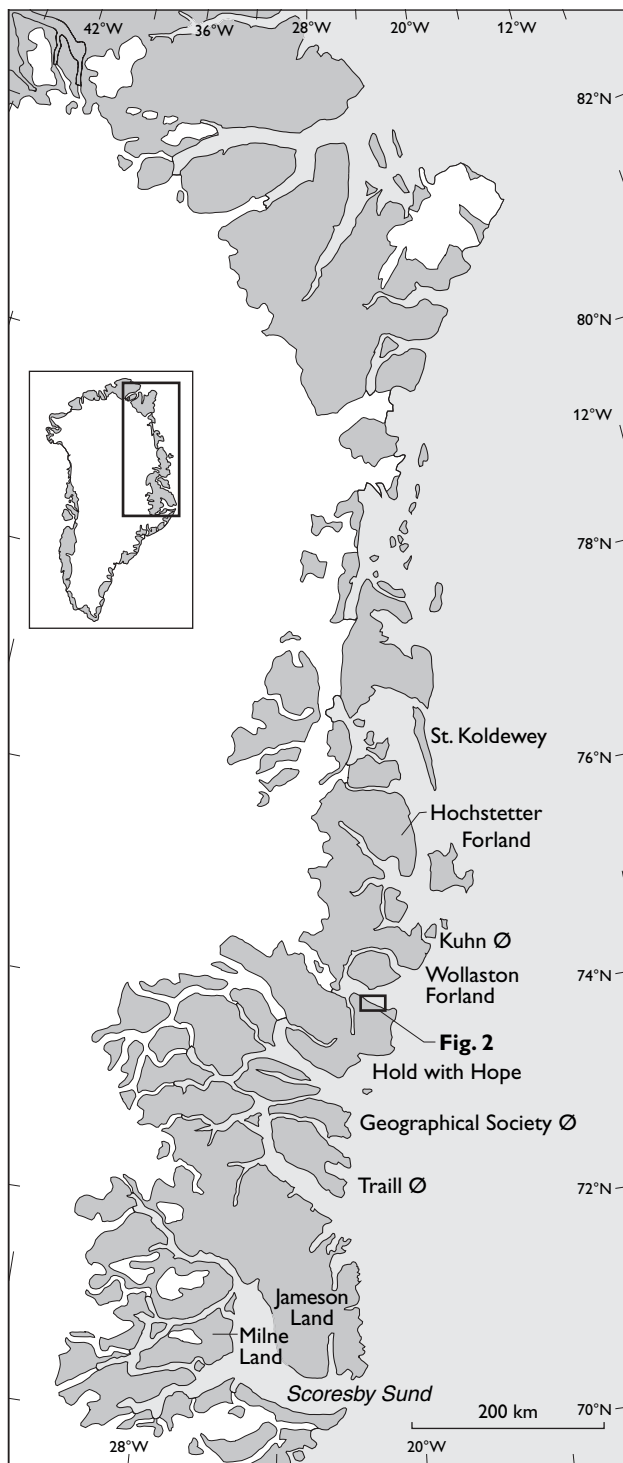


Fig. 1. Locality map of East Greenland and eastern North Greenland. The **white** region illustrates the permanent inland ice cap of Greenland, the **grey** areas are ice-free. Hold with Hope is located between 73°N and 74°N.

improve the knowledge of Jurassic dinoflagellate cysts in this region in general. The results reported here allow correlation with corresponding assemblages from Store Koldewey and Hochstetter Forland in the north and Jameson Land – Milne Land in the south (Fig. 1).

Geological setting

The Late Palaeozoic – Mesozoic extensional basin complex in East Greenland is approximately 700 km long in a north–south direction. Jurassic sediments are present and exposed from Jameson Land in the south to Store Koldewey in the north (Surlyk 1977). In the northern part of the rift system, e.g. the Wollaston Forland Basin, rifting was initiated in Middle Jurassic time, and marine Bajocian–Bathonian sandstones onlap Caledonian basement rocks or Permian carbonates (Vischer 1943; Surlyk 1978). Deposition took place on the hangingwall of W–SW-tilted fault blocks. Jurassic rifting culminated in the Volgian with strong rotational block faulting (Surlyk 1978). During this episode the wide original fault blocks, defining the Wollaston Forland Basin, were divided into smaller blocks (Vischer 1943; Surlyk 1978). A similar tectonic development may have occurred in the Geographical Society Ø and Traill Ø area towards the south (Donovan 1957; Price & Whitham 1997). The Cretaceous period was generally characterised by subsidence controlled by thermal contraction (Surlyk *et al.* 1981; Price & Whitham 1997). The East Greenland rift basin complex was uplifted during the Cenozoic.

Sediments of Jurassic age were first recognised on Hold with Hope by Stemmerik *et al.* (1997). They are limited to the north coast of Hold with Hope from Stensiö Plateau to Steensby Bjerg (Fig. 2), where they occur on the hangingwall of small fault blocks that dip mainly to the west and south-west. Bedding planes within the Triassic and Jurassic seem to be parallel, whereas the boundary with the overlying Cretaceous succession is an angular unconformity (Vosgerau *et al.* 2004, this volume). The thickness of the Jurassic succession varies significantly depending on its position on the hangingwall and the depth of Cretaceous erosion. The Jurassic succession includes shallow marine sandstones of the Pelion and Payer Dal Formations (Vardekløft Group), and offshore transition – lower shoreface heteroliths and offshore mudstones of the Bernbjerg Formation, Hall Bredning Group (Fig. 3). The Spath Plateau Member of the Pelion Formation was erected to accommodate sandy heteroliths and

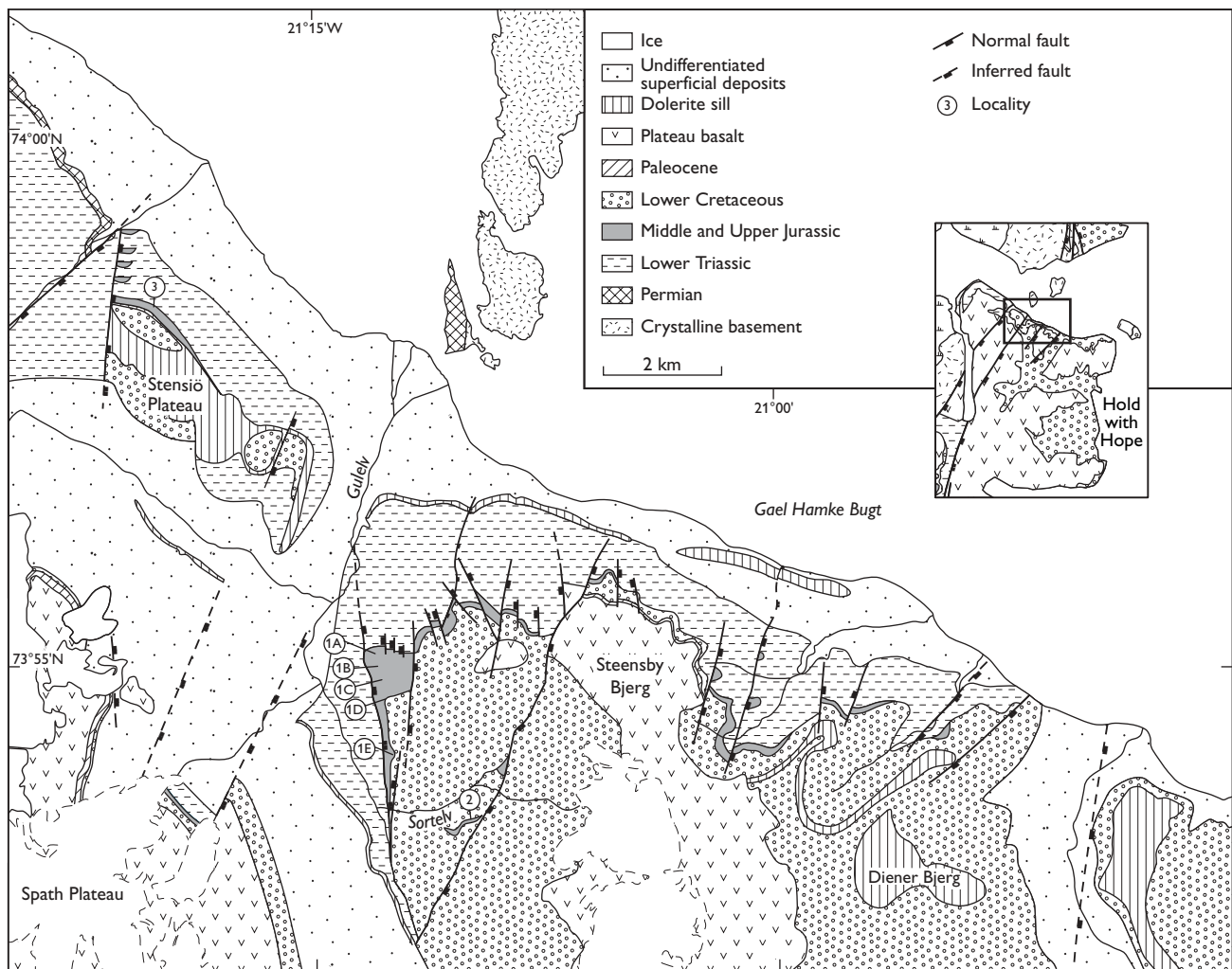


Fig. 2. Geological map of the northern Hold with Hope which illustrates the distribution of the studied Jurassic succession. Localities 1, 2 and 3 are marked; the succession at Locality 1 has been compiled from a number of short laterally correlated sections (1A–1E).

offshore mudstones that contrast with the generally coarse-grained sandstone facies of the Pelion Formation (Vosgerau *et al.* 2004, this volume). The succession on Hold with Hope resembles the well-known Jurassic succession in the Wollaston Forland and Jameson Land Basins towards the north and south. The Middle Jurassic Pelion Formation is c. 190 m thick, the Upper Jurassic Payer Dal Formation is 50–80 m thick and the Bernbjerg Formation is estimated to be c. 130 m thick (Fig. 4; Vosgerau *et al.* 2004, this volume).

Samples and methods

The dinoflagellate cysts have been studied in three sections (Fig. 4), in combination with a number of geographically and stratigraphically scattered samples

on northern Hold with Hope. The main area of exposure is located on the northern and western slopes of Steensby Bjerg towards Gael Hamke Bugt and along the Gulelv river (Fig. 2, Locality 1). Samples from a number of short, vertical sections are combined into a composite section representing the entire succession (Fig. 2, Locality 1, sections A–E). The Payer Dal Formation was also sampled at the Sortelv river, south of Steensby Bjerg (Fig. 2, Locality 2). Samples from a third section through the Pelion Formation at Stensiö Plateau (Fig. 2, Locality 3) provide good supplementary material from the lowermost part of the succession, which is poorly represented in the section at Steensby Bjerg. Most of the analysed samples are from fine-grained thin beds or lamina in the otherwise coarse-grained, sandy Pelion and Payer Dal Formations. The number of samples and their stratigraphical distribu-

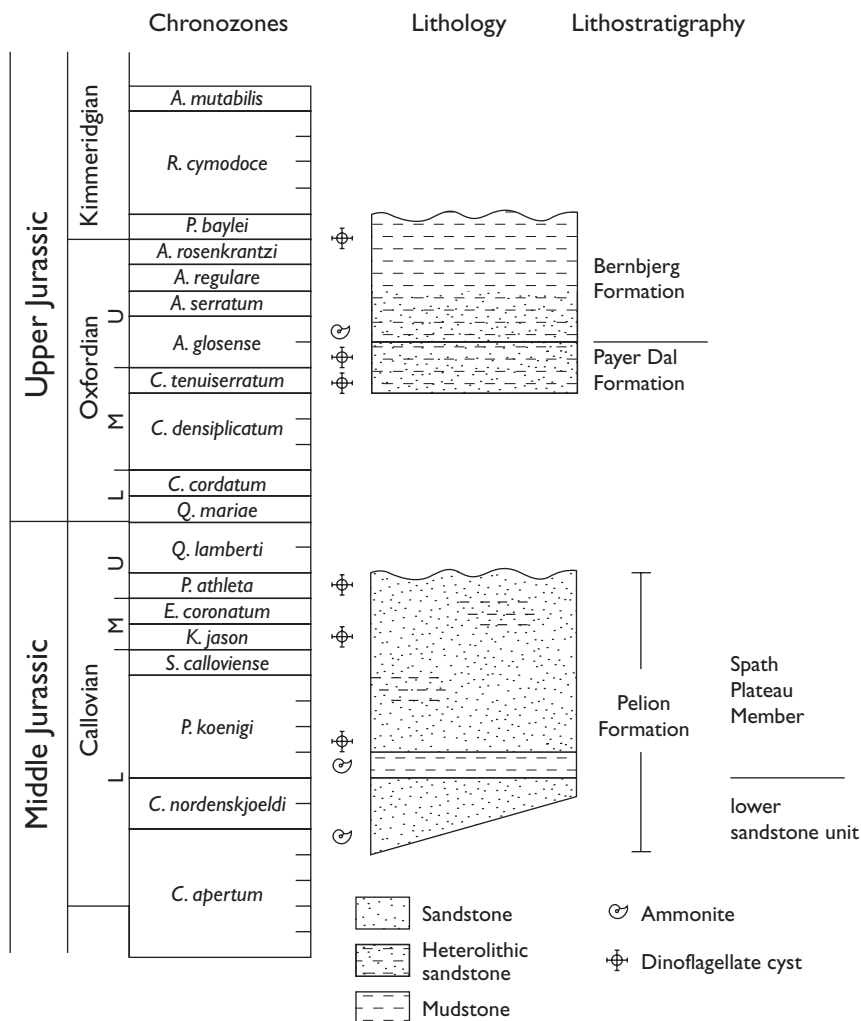


Fig. 3. Schematic correlation of the Jurassic succession on northern Hold with Hope. The lithostratigraphical units are correlated with the Middle to Upper Jurassic chronozonation on the basis of ammonites and dinoflagellate cysts. Points of correlation to chronozones are indicated by ammonite or dinoflagellate cyst signatures. The subdivision of the chronozones corresponds to the ammonite faunas in the biozonation.

tion are controlled by the occurrence and accessibility of these fine-grained beds. In contrast, the shale of the Bernbjerg Formation provides productive samples throughout the formation.

Standard palynological preparation has been performed on most samples. A minority of the samples were prepared by the tank-preparation method (Poulsen *et al.* 1990). Both methods involve treatment with hydrofluoric (HF) and hydrochloric acids (HCl) followed by filtering at 20 µm mesh size, short oxidation by nitric acid (HNO₃) and washing in low concentration potassium hydroxide (KOH).

Biostratigraphy

The ammonites and dinoflagellate cysts have been analysed and correlated to the Boreal ammonite and dinoflagellate stratigraphy, i.e. East Greenland strati-

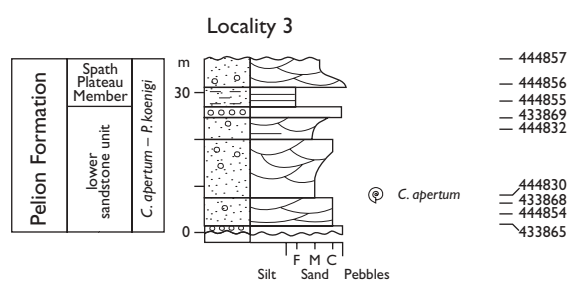
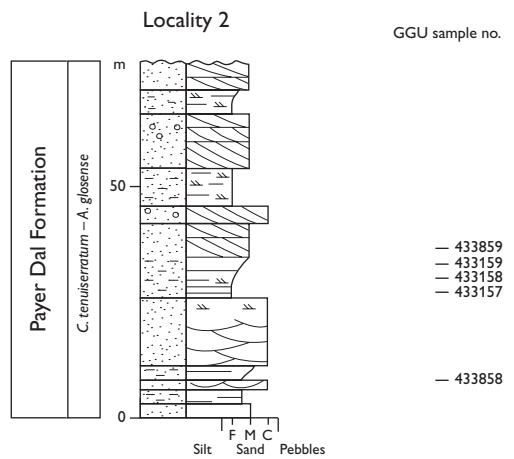
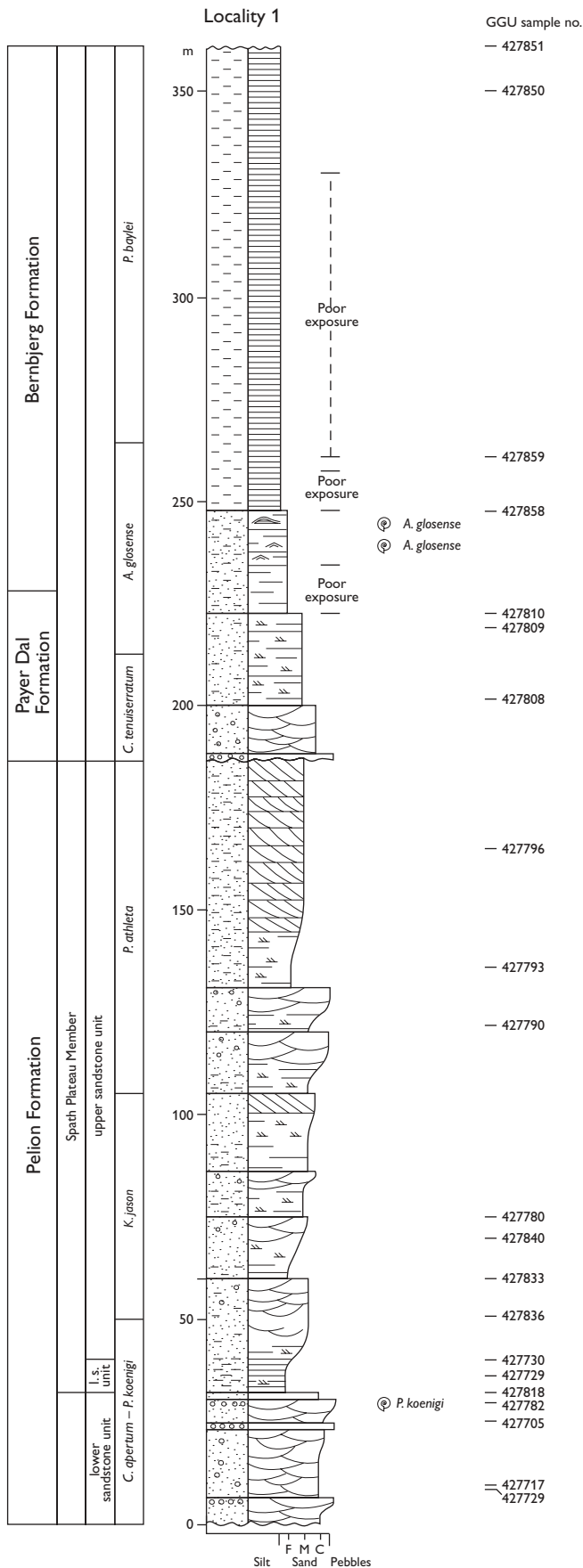
graphy (Callomon 1993; Milner & Piasecki 1996; Piasecki 1996; Piasecki & Stemmerik 2004, this volume; Piasecki *et al.* 2004, this volume).

Ammonites

Ammonites are very restricted in the Jurassic succession on Hold with Hope, and only three horizons have been dated and correlated with the standard Boreal ammonite stratigraphy (Callomon 1993). A specimen referred to *Cadoceras cf. breve* (J.H. Callomon and P. Alsen, personal communications 1997) was found 10 m

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Fig. 4. Simplified sedimentological logs of the Jurassic succession from Localities 1, 2 and 3 on northern Hold with Hope. The formal and informal lithostratigraphic units are indicated together with the ammonite horizons; **l.s.**, lower shale.



above the base of the lower sandstone unit in the Pelion Formation and indicates the *Cadoceras apertum* Zone (Fig. 4). A poorly preserved ammonite referred tentatively to *Cadoceras septentrionale* (P. Alsen, personal communication 1998) in the lowermost Spath Plateau Member of the Pelion Formation indicates the *Proplanulites koenigi* Zone. Much higher in the succession, in the basal Bernbjerg Formation, the presence of *Amoeboceras ilovaiskii* (J.H. Callomon and P. Alsen, personal communications 1997) indicates the *Amoeboceras glosense* Zone.

These three ammonite horizons occur at separate localities (Fig. 4). The *C. apertum* Zone is identified in the succession at Stensiö Plateau (Locality 3), the *P. koenigi* Zone is identified in the succession at Gulelv (Locality 1) and the *A. glosense* Zone is identified in the section at Sortelv (Locality 2). A calcareous concretion with a specimen of *Cranocephalites* sp. (*C. pompeckji* Zone) is reworked into the Cretaceous basal conglomerate. The ammonite data thus indicate that parts of the lower Pelion Formation are equivalent to the *C. apertum* – *P. koenigi* Chronozones, Lower Callovian, and parts of the lower Bernbjerg Formation are equivalent to the *A. glosense* Chronozone, Upper Oxfordian. A more detailed stratigraphical framework is provided by the more consistently occurring dinoflagellate cysts.

Dinoflagellate cysts

The dinoflagellate cyst data are described below in relation to five lithostratigraphic units, as presented by Vosgerau *et al.* (2004, this volume).

Pelion Formation, lower sandstone unit

The dinoflagellate cyst assemblages are of low to moderate diversity and density in the samples from this coarse-grained unit. The most diverse assemblages were recovered from the succession at Stensiö Plateau (Figs 2, 4, 5, Locality 3). Many of the species in this assemblage are known from strata in East Greenland older than the Early Callovian age indicated here by ammonites (Milner & Piasecki 1996). Three assemblages have been distinguished in this unit, based on a limited number of samples. A lower assemblage of poor diversity with frequent *Chytroeisphaeridia hyalina* and *Sentusidinium* sp. D (Fensome 1979) is followed by a middle assemblage of higher diversity with abundant

Sirmiodinium grossii, *Valensiella dictydia* and *Sentusidinium* spp. The third and uppermost assemblage, above the ammonite horizon of the *C. apertum* Zone, is moderately to highly diverse and contains abundant *Chytroeisphaeridia hyalina*, *Rhynchodiniopsis cladophora*, *R. cf. cladophora* and *Pareodinia pachyceras* (Fig. 5).

The corresponding succession at Steensby Bjerg (Figs 2, 6, Locality 1) contains a very poor dinoflagellate cyst assemblage and *Chytroeisphaeridia hyalina* is the only frequent species. However, also at this locality slightly more species appear in the uppermost strata of the unit, thus showing an upwards increase in diversity.

Correlation. The succession of species appearances up through the lower sandstone unit of the Pelion Formation in the Stensiö Plateau succession (Locality 3) does not yield any significant stratigraphic information. However, the abundance of *Chytroeisphaeridia hyalina* combined with the earliest appearance of *Fromea tornatilis*, *Pareodinia prolongata*, *Aldorfia aldorfensis* and *Kallosphaeridium* sp. in this unit are considered indicative of the *C. apertum* Chronozone based on comparison to the dinoflagellate records in Jameson Land and Store Koldewey (Milner & Piasecki 1996; Piasecki *et al.* 2004, this volume). This is also in accordance with the ammonite record in this succession.

The poor dinoflagellate assemblage from the 'lower sandstone unit' at Steensby Bjerg (Locality 1) does not provide clear correlation but contains some characteristic species, e.g. *Paraevansia brachybelis* which has its lowest record in the *C. apertum* Chronozone on Store Koldewey (Piasecki *et al.* 2004, this volume).

Several species that are restricted to the upper assemblage of the Stensiö Plateau succession are also limited to the topmost strata of the corresponding unit in the succession at Steensby Bjerg: *Aldorfia aldorfensis*, *Lithodinia planoseptata*, *Ctenidodinium thulium* and *Pareodinia prolongata*. However, other species from the upper assemblage in the Stensiö Plateau succession (*C. apertum* Chronozone at Locality 3) appear for the first time at a stratigraphically higher level in the Steensby Bjerg succession (Locality 1). This may reflect the restricted material and data from this unit in the Steensby Bjerg succession (Locality 1).

Age. The age of the 'lower sandstone unit' of the Pelion Formation is Early Callovian, equivalent to the *C. apertum* – *P. koenigi* Chronozones based on ammonites and dinoflagellate cysts.

Depositional environment. The presence of a low diverse assemblage with *Limbicysta bjaerkei* in the basal strata combined with significant, upwards increasing diversity indicate that deposition of this unit began in a marginal marine environment and changed to deposition in a fully marine environment. The preferred habitat of *L. bjaerkei* is non-marine (Bailey & Hogg 1995) but it also has been recorded in restricted marine dinoflagellate cyst assemblages, for example in the basal strata of the Payer Dal Formation in Hochstetter Forland (Piasecki & Stemmerik 2004, this volume). Here, *L. bjaerkei* occurs together with the marine fauna immediately above non-marine–brackish sediments.

Pelion Formation, Spath Plateau Member,
lower shale unit

The diversity and especially abundance of dinoflagellate cysts reach a maximum in the basal mudstone of the Spath Plateau Member. In the Stensiö Plateau succession (Locality 3), the composition of the assemblage is not significantly different from the highest assemblage in the unit below. However, in the Steensby Bjerg succession (Locality 1), several species appear stratigraphically delayed compared to the Stensiö Plateau succession and their appearance in this ‘lower shale unit’ produces a local, significant increase in the diversity (Fig. 6). *Chytroeisphaeridia hyalina* is very abundant at both localities together with frequent *Sirmiodinium grossii*, *Sentusidinium pelionense*, *Rhynchodiniopsis cladophora*, *R. cf. cladophora* and *Sentusidinium* sp. D (Fensome 1979).

Correlation. The ammonite biostratigraphy shows that the mudstone is within or above the *C. apertum* and the *P. koenigi* Chronozones at Localities 1 and 3, respectively. The dinoflagellate biostratigraphy suggests that this mudstone is of the same age at Localities 1 and 3, i.e. equivalent to the *P. koenigi* Chronozone, but the stratigraphic resolution does not exclude the possibility that the basal mudstone at Locality 3 may include strata from the *C. apertum* Chronozone. This is the stratigraphical lower limit based on ammonites (Fig. 4). It is possible that the mudstone is diachronous.

The ammonite found in sandstone at the lithostratigraphic transition to the basal mudstone of the Spath Plateau Member at Locality 1 (Fig. 4), is referred to the *Proplanulites koenigi* Zone. Most of the dinoflagellate species that appear just above the ammonite at this

locality, are reported to appear for the first time in or near the *C. apertum* Chronozone. The highest occurrence of *Paragonyaulacysta retiphragmata* is found at the same level in both successions (Localities 1, 3) and indicates the *P. koenigi* Chronozone based on its last occurrence in the Jameson Land Basin (Milner & Piasecki 1996). The highest occurrence of *Kallosphaeridium hypornatum* in Jameson Land is also in the *P. koenigi* Chronozone. *Pareodinia stegasta* appears in the basal mudstone as it does in a stratigraphically comparable transgressive shale unit on Store Koldevey (Piasecki *et al.* 2004, this volume). The lower boundary of the Spath Plateau Member is a major drowning surface overlain by mudstone both on Hold with Hope and on Store Koldevey (Piasecki *et al.* 2004, this volume; Vosgerau *et al.* 2004, this volume).

Age. The age of the ‘basal shale unit’ of the Spath Plateau Member is Early Callovian, equivalent to the *C. apertum* – *P. koenigi* Chronozones.

Depositional environment. The maximum diversity and density of dinoflagellate cysts in the Middle Jurassic succession occur in this unit and indicate deposition of shelf mudstone in a fully marine environment during flooding.

Pelion Formation, Spath Plateau Member,
upper sandstone unit

Samples are available only from the succession at Steensby Bjerg (Locality 1). The dinoflagellate assemblage is moderately rich and diverse. The bulk of the species are the same as in the shale below, but are combined with more species higher in the succession that typically appear in the Callovian. *Chytroeisphaeridia hyalina*, *Gonyaulacysta jurassica*, *Rhynchodiniopsis cladophora* and *Sentusidinium* spp. are most frequent. *Mendicodinium groenlandicum* appears in the lower part of the unit and *Tubotuberella eisenackii* and *Trichodinium scarburgense* appear higher in the unit.

Correlation. The overall Callovian dinoflagellate assemblage provides few stratigraphical markers. The unit is stratigraphically restricted downwards by the presence of Lower Callovian dinoflagellate cysts and ammonites (*P. koenigi* Chronozone) in the shale unit below. Records from the Jameson Land Basin indicate that *Mendicodinium groenlandicum* appears in the *K.*

0	10	20	30	40	50	Metres
1.00	2.25	21.00	28.00	37.00	45.00	Sample height
433865	433868	433869	444855	444857	444853	GGU sample no.
Middle Jurassic					Cretaceous	Age
Callovian						Stage
Pelion					Steensby Bjerg	Formation
						<ol style="list-style-type: none"> 1 <i>Tasmanites</i> spp. 2 <i>Valensiella dictydia</i> 3 <i>Solisphaeridium ankyleton</i> 4 <i>Leiofusa jurassica</i> 5 <i>Rhynchodiniopsis</i> cf. <i>regalis</i>? 6 <i>Sentusidinium</i> spp. 7 <i>Pareodinia halosa</i> 8 <i>Chytroeisphaeridia hyalina</i> 9 <i>Valensiella ovula</i> 10 <i>Sentusidinium</i> cf. <i>pelionense</i> 11 <i>Sentusidinium</i> sp. D (Fensome 1979) 12 <i>Fromea tomatilis</i> 13 <i>Atopodinium</i> spp. 14 <i>Valvaeodinium hanneae</i> 15 <i>Ctenodinium thulium</i> 16 <i>Nannoceratopsis plegas</i> var. <i>dictyornata</i> 17 <i>Paraevansia</i> spp. 18 <i>Sirmiodinium grossii</i> 19 <i>Lithodinia spongiosa</i> 20 <i>Cyclopsiella</i> spp. 21 <i>Rhynchodiniopsis cladophora</i> 22 <i>Tubotuberella</i> spp. 23 <i>Ambonosphaera calloviana</i> 24 <i>Lithodinia</i> spp. 25 <i>Valvaeodinium leneae</i> 26 <i>Sentusidinium pelionense</i> 27 <i>Paragonyaulacysta retiphragmata</i> 28 <i>Pareodinia</i> spp. 29 <i>Pterospermopsis</i> sp. A (Fensome 1979) 30 <i>Valensiella</i> spp.

Hold with Hope, Locality 3, Stensjö Plateau

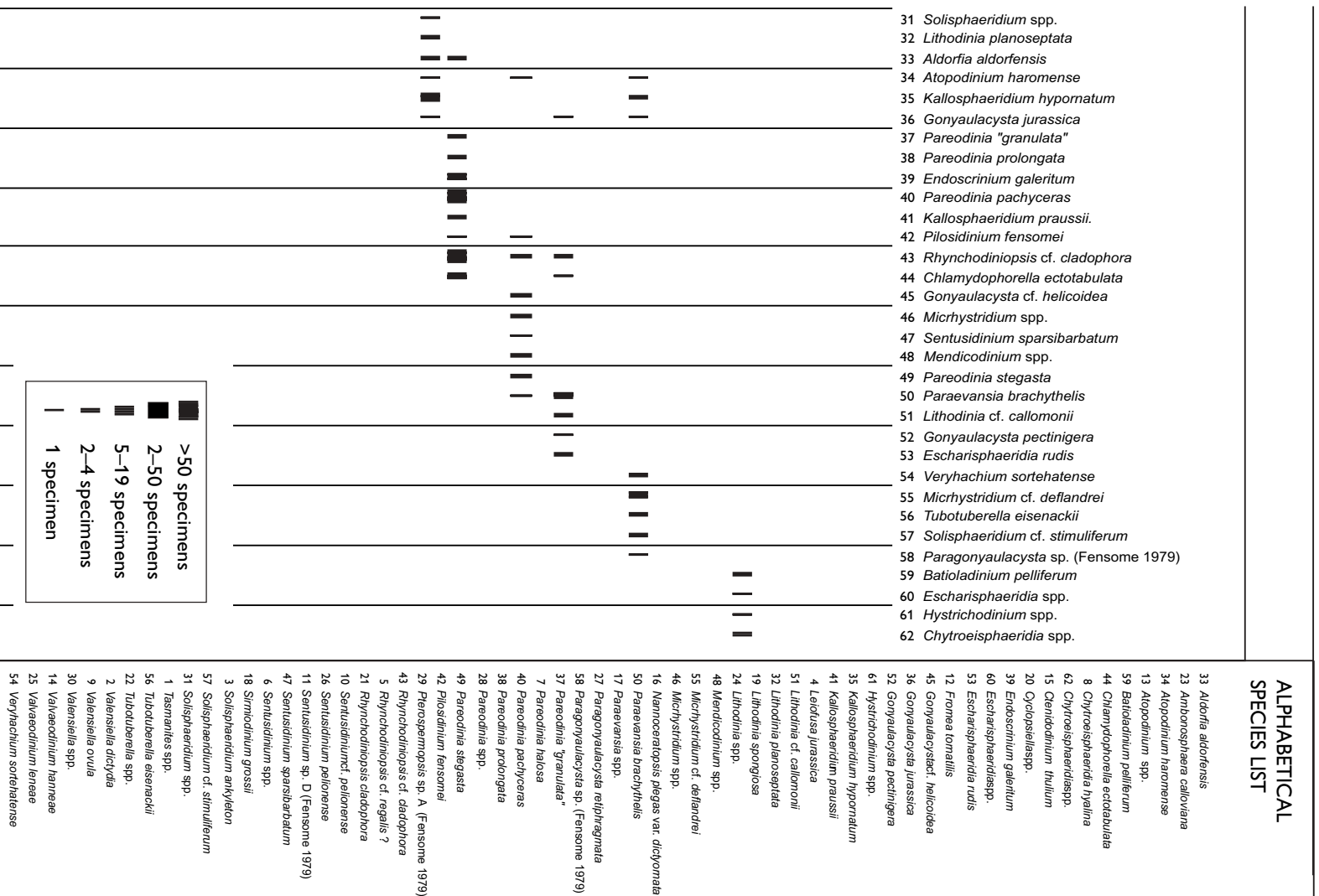
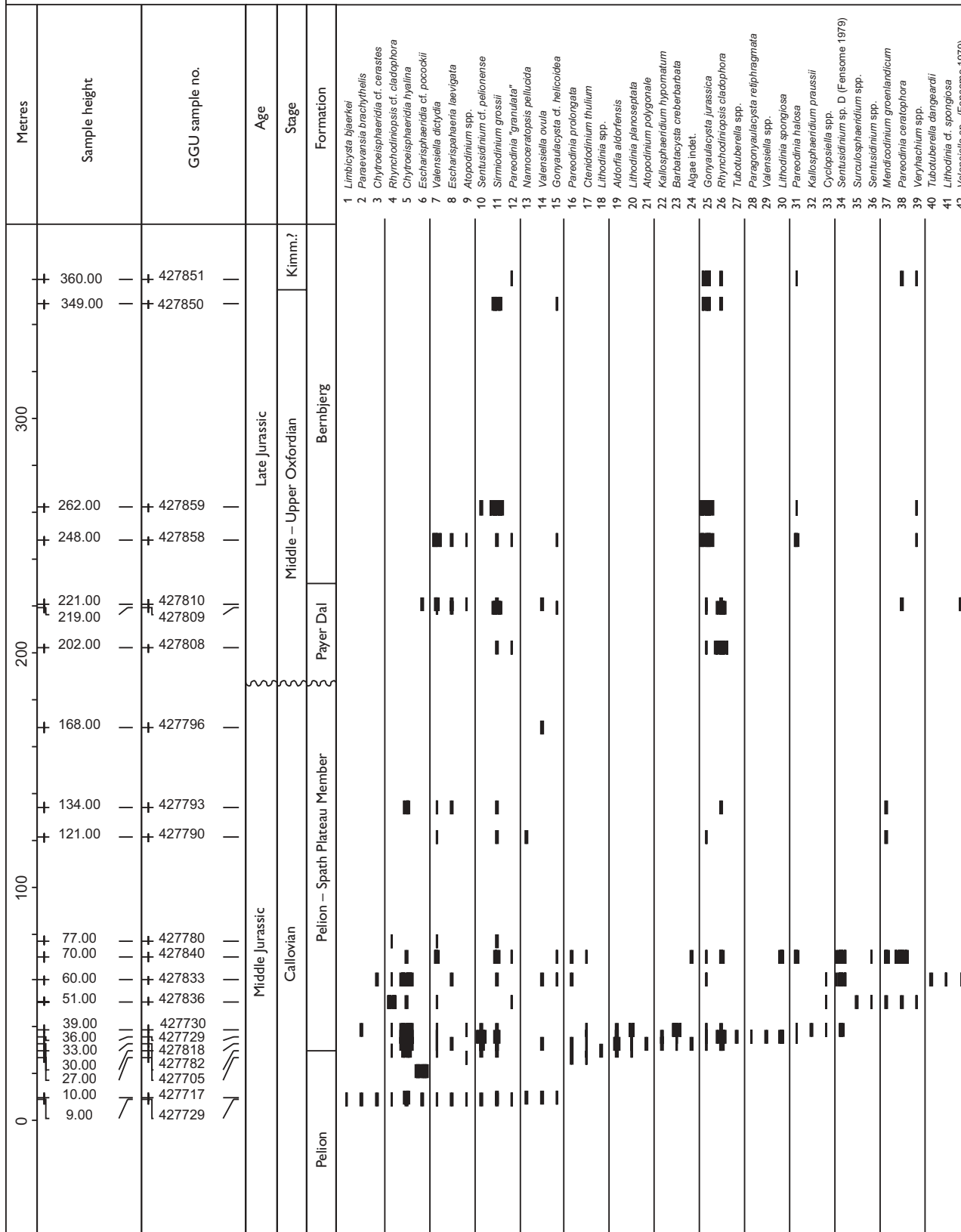
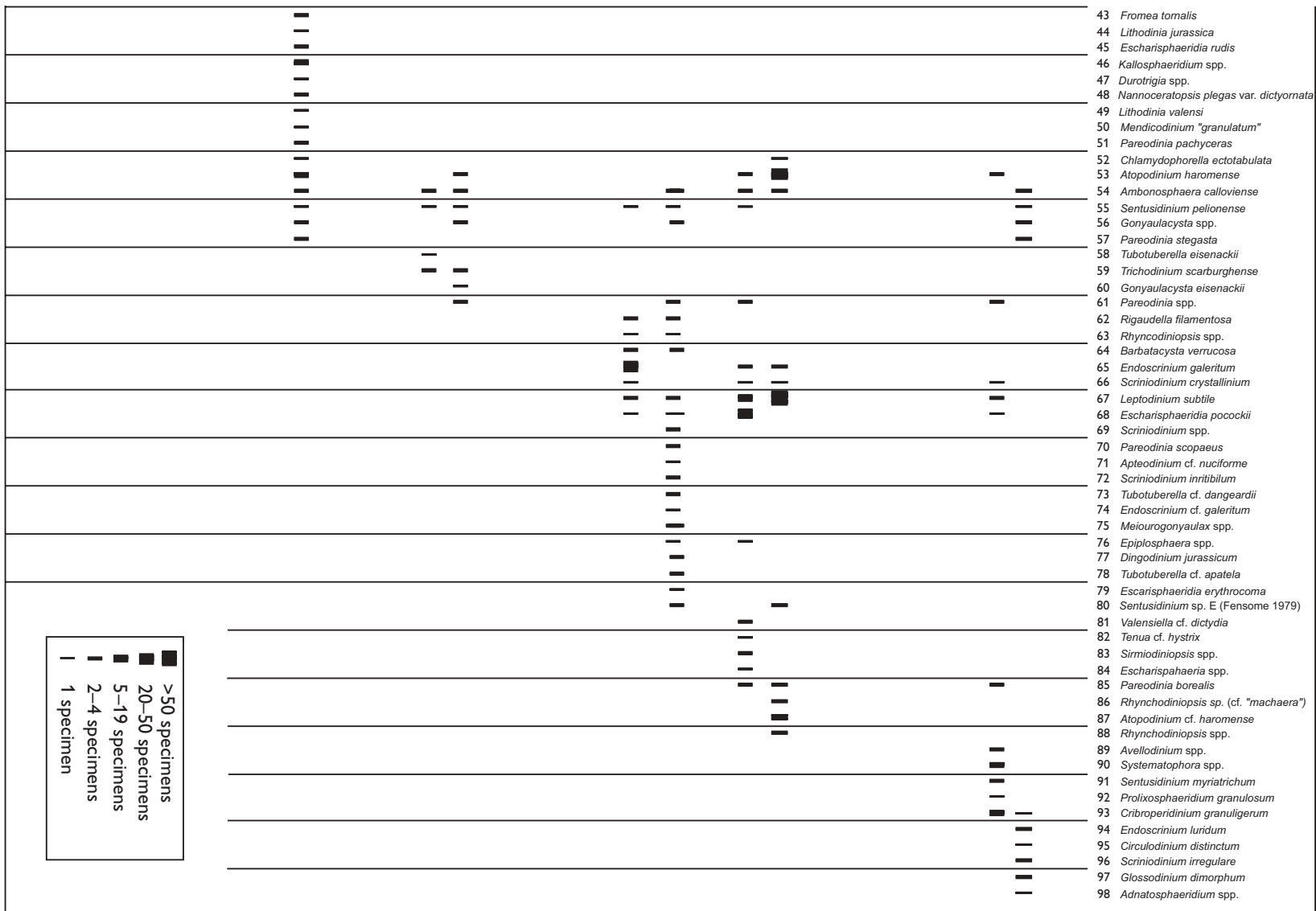


Fig. 5. Distribution chart of dinoflagellate cysts in the Jurassic succession at Locality 3, Stensjö Plateau, northern Hold with Hope. The first appearances of species are stratigraphically arranged. The Jurassic succession is overlain unconformably by Cretaceous strata of the Steensby Bjerg Formation (Kelly *et al.* 1998) – see sample at 45 m.

Hold with Hope, Locality 1, Steensby Bjerg





jason Chronozone and *Trichodinium scarburghense* appears in the *P. athleta* Chronozone (Milner & Piasecki 1996; Piasecki 1996).

Age. The age of the upper sandstone unit of the Spath Plateau Member, Pelion Formation, is therefore Early to Late Callovian, equivalent to the *P. koenigi*–*P. athleta* Chronozones (Fig. 4).

Depositional environment. The organic matter is dominated by terrestrial palynomorphs and debris. The proportion of brown and black lath-shaped woody material increases upwards until it completely dominates the organic content in the upper Pelion Formation. The upwards increase and dominance of woody material suggests deposition in the lower shoreface environment in front of a prograding shoreline.

Payer Dal Formation

The Payer Dal Formation was analysed from two localities at Steensby Bjerg, along the Sortelv (Locality 2)

and Gulelv (Locality 1) rivers (Figs 2, 4, 6, 7). The formation is characterised by frequent *Rigaudella aemula*, *Rhynchodiniopsis cladophora*, *Sirmiodinium grossii* and *Gonyaulacysta jurassica*. New, stratigraphically characteristic species appear in the lower part of the formation at Sortelv: *Wanaea digitata*, *Rigaudella aemula* and *Leptodinium subtile*. Higher in the formation at both localities further stratigraphically significant species appear: *Scriniodinium crystallinum*, *Endoscrinium galeritum*, *Chytroeisphaeridia chytrooides*, *Rhynchodiniopsis* sp., *Prolixosphaeridium granulosum* and *Dingodinium jurassicum*.

Correlation. The dinoflagellate assemblage represents a characteristic Lower to Middle Oxfordian assemblage with frequent *Rigaudella aemula*, *Scriniodinium crystallinum* and *Endoscrinium galeritum*, as known from the Jurassic succession elsewhere in East Greenland such as in Milne Land (Piasecki 1996). This Lower–Middle Oxfordian assemblage in Milne Land reaches close to the top of the Middle Oxfordian before gradual replacement by an Upper Oxfordian assemblage. *Wanaea* spp. occurs only to the top of the Lower

ALPHABETICAL SPECIES LIST

- | | | |
|--|--|---|
| 98 <i>Adnatosphaeridium</i> spp. | 60 <i>Gonyaulacysta eisenackii</i> | 86 <i>Rhynchodiniopsis</i> sp. (cf. "machaera") |
| 19 <i>Aldorfia aldorfensis</i> | 15 <i>Gonyaulacysta</i> cf. <i>helicoidea</i> | 26 <i>Rhynchodiniopsis cladophora</i> |
| 24 Algae indet. | 25 <i>Gonyaulacysta jurassica</i> | 88 <i>Rhynchodiniopsis</i> spp. |
| 54 <i>Ambonosphaera calloviense</i> | 56 <i>Gonyaulacysta</i> spp. | 63 <i>Rhynchodiniopsis</i> spp. |
| 71 <i>Apteodinium</i> cf. <i>nuciforme</i> | 22 <i>Kallosphaeridium hypornatum</i> | 62 <i>Rigaudella filamentosa</i> |
| 87 <i>Atopodinium</i> cf. <i>haromense</i> | 32 <i>Kallosphaeridium praussii</i> | 66 <i>Scriniodinium crystallinum</i> |
| 53 <i>Atopodinium haromense</i> | 46 <i>Kallosphaeridium</i> spp. | 72 <i>Scriniodinium irritabilum</i> |
| 21 <i>Atopodinium polygonale</i> | 67 <i>Leptodinium subtile</i> | 96 <i>Scriniodinium irregulare</i> |
| 9 <i>Atopodinium</i> spp. | 1 <i>Limbicysta bjaerkei</i> | 69 <i>Scriniodinium</i> spp. |
| 89 <i>Avellodinium</i> spp. | 41 <i>Lithodinia</i> cf. <i>spongiosa</i> | 10 <i>Sentusidinium</i> cf. <i>pelionense</i> |
| 23 <i>Barbatacysta creberbarbata</i> | 44 <i>Lithodinia jurassica</i> | 91 <i>Sentusidinium myriatrichum</i> |
| 64 <i>Barbatacysta verrucosa</i> | 20 <i>Lithodinia planoseptata</i> | 55 <i>Sentusidinium pelionense</i> |
| 52 <i>Chlamydophorella ectotabulata</i> | 30 <i>Lithodinia spongiosa</i> | 34 <i>Sentusidinium</i> sp. D (Fensome 1979) |
| 3 <i>Chytroeisphaeridia cerastes</i> | 18 <i>Lithodinia</i> spp. | 80 <i>Sentusidinium</i> sp. E (Fensome 1979) |
| 5 <i>Chytroeisphaeridia hyalina</i> | 49 <i>Lithodinia valensi</i> | 36 <i>Sentusidinium</i> spp. |
| 95 <i>Circulodinium distinctum</i> | 75 <i>Meiourogonyaulax</i> spp. | 83 <i>Sirmiodiniopsis</i> spp. |
| 93 <i>Cribroperidinium granuligerum</i> | 50 <i>Mendicodinium "granulatum"</i> | 11 <i>Sirmiodinium grossii</i> |
| 17 <i>Ctenidodinium thulium</i> | 37 <i>Mendicodinium groenlandicum</i> | 35 <i>Surculosphaeridium</i> spp. |
| 33 <i>Cyclopsiella</i> spp. | 48 <i>Nannoceratopsis plegas</i> var. <i>dictyornata</i> | 90 <i>Systematophora</i> spp. |
| 77 <i>Dingodinium jurassicum</i> | 13 <i>Nannoceratopsis pellucida</i> | 82 <i>Tenua</i> cf. <i>hystrix</i> |
| 47 <i>Durotrigia</i> spp. | 2 <i>Paraevansia brachythelis</i> | 59 <i>Trichodinium scarburghense</i> |
| 74 <i>Endoscrinium</i> cf. <i>galeritum</i> | 28 <i>Paragonyaulacysta retiphragmata</i> | 78 <i>Tubotuberella</i> cf. <i>apatela</i> |
| 65 <i>Endoscrinium galeritum</i> | 12 <i>Pareodinia "granulata"</i> | 73 <i>Tubotuberella</i> cf. <i>dangeardii</i> |
| 94 <i>Endoscrinium luridum</i> | 85 <i>Pareodinia borealis</i> | 40 <i>Tubotuberella dangeardii</i> |
| 76 <i>Epiplosphaera</i> spp. | 38 <i>Pareodinia ceratophora</i> | 58 <i>Tubotuberella eisenackii</i> |
| 79 <i>Escharisphaeridia erythrocoma</i> | 31 <i>Pareodinia halosa</i> | 27 <i>Tubotuberella</i> spp. |
| 8 <i>Escharisphaeria laevigata</i> | 51 <i>Pareodinia pachyceras</i> | 81 <i>Valensiella</i> cf. <i>dictydia</i> |
| 84 <i>Escharisphaeria</i> spp. | 16 <i>Pareodinia prolongata</i> | 7 <i>Valensiella dictydia</i> |
| 6 <i>Escharisphaeridia</i> cf. <i>pocockii</i> | 70 <i>Pareodinia scopaeus</i> | 14 <i>Valensiella ovula</i> |
| 68 <i>Escharisphaeridia pocockii</i> | 61 <i>Pareodinia</i> spp. | 42 <i>Valensiella</i> sp. (Fensome 1979) |
| 45 <i>Escharisphaeridia rudis</i> | 57 <i>Pareodinia stegasta</i> | 29 <i>Valensiella</i> spp. |
| 43 <i>Fromea tornalis</i> | 92 <i>Prolixosphaeridium granulosum</i> | 39 <i>Veryhachium</i> spp. |
| 97 <i>Glossodinium dimorphum</i> | 4 <i>Rhynchodiniopsis</i> cf. <i>cladophora</i> | |

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Fig. 6. Distribution chart of dinoflagellate cysts in the Jurassic succession at Locality 1, Steensby Bjerg, northern Hold with Hope. The first appearances of species are stratigraphically arranged. Alphabetical species list given above.

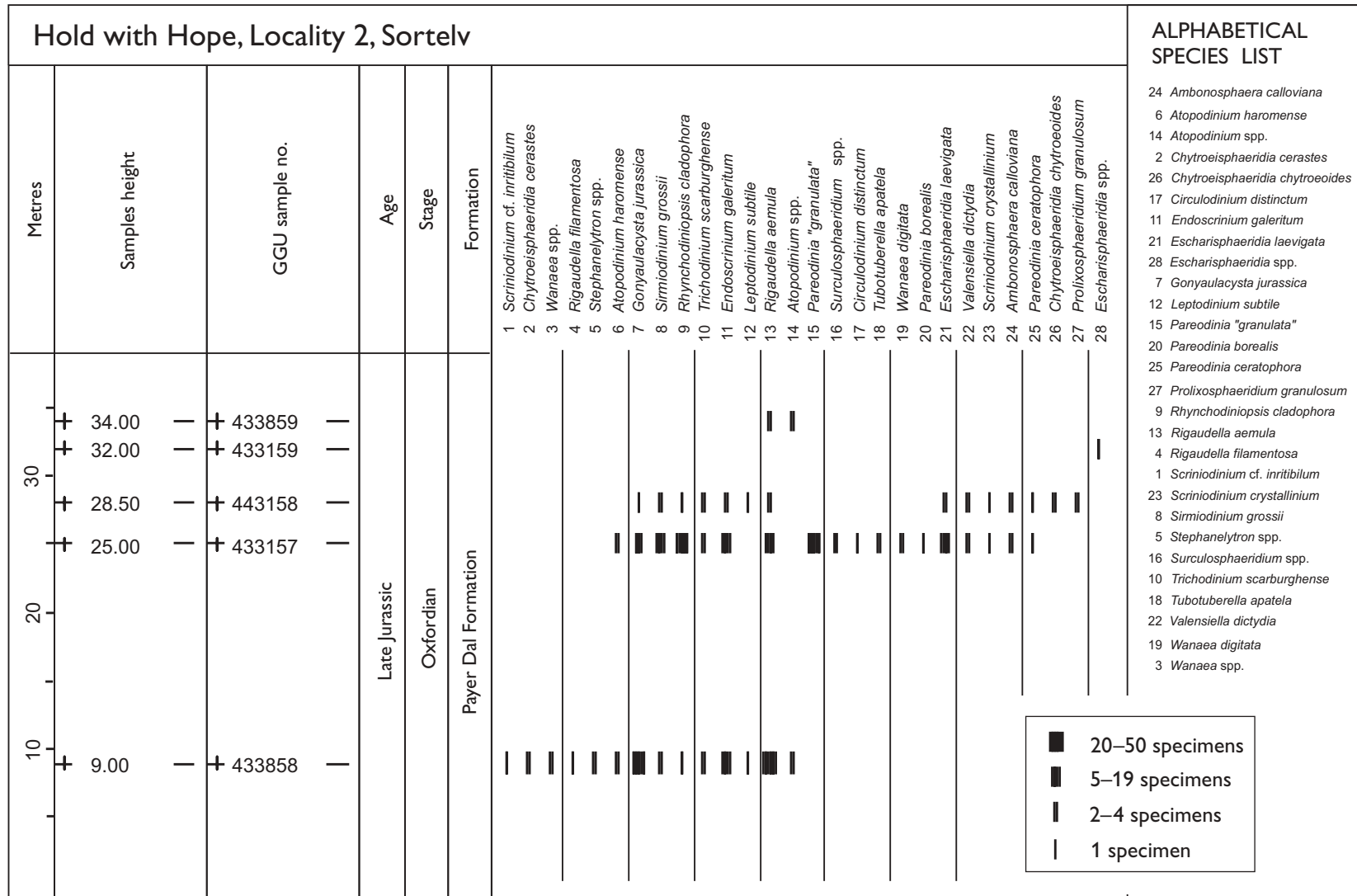


Fig. 7. Distribution chart of dinoflagellate cysts in the Jurassic succession at Locality 2, Sortelv, western Steensby Bjerg, Hold with Hope. The first appearance of species is stratigraphically arranged.

Oxfordian in Milne Land, whereas *Leptodinium subtile* rarely occurs below the Middle Oxfordian and *Prolixosphaeridium granulosum* does not occur below the Upper Oxfordian. The Payer Dal Formation at Locality 1 is therefore considered Middle to Late Oxfordian in age, and the presence of *Wanaea digitata*, *Wanaea* sp. and *Trichodinium scharburgense* in the assemblage is due to reworking. In Milne Land, the appearance of *Leptodinium subtile* in the *C. tenuiserratum* Chronozone coincides with the gradual disappearance of *Rigaudella* spp., and the following appearances of *Dingodinium jurassicum* and *Prolixosphaeridium granulosum* in the *A. glosense* Chronozone. A corresponding sequence of events in the Steensby Bjerg succession indicates a Middle–Upper Oxfordian succession, *C. tenuiserratum* – *A. glosense* Chronozones. Consequently, a significant Late Callovian – earliest Middle Oxfordian hiatus occurs between the Pelion and Payer Dal Formations. However, several samples in the boundary interval (c. 30 m thick) were barren of dinoflagellate cysts and parts of the succession were therefore not dated. The dinoflagellate cysts, which are considered reworked, indicate that Lower Oxfordian sediments have been present in the region.

Age. The age of the Payer Dal Formation is Middle–Late Oxfordian, equivalent to the *C. tenuiserratum* – *A. glosense* Chronozones based on dinoflagellate cysts. Ammonites in the overlying Bernbjerg Formation support this age of the uppermost Payer Dal Formation as they indicate the *A. glosense* Chronozone.

Depositional environment. The organic matter is dominated by terrestrial palynomorphs and debris, and the proportion of brown and black lath-shaped woody material is high in the Payer Dal Formation. The organic content suggests deposition in a lower shore-face environment.

Bernbjerg Formation

The Bernbjerg Formation is represented by a few samples from the lower and upper parts of the formation at Steensby Bjerg (Locality 1). The Bernbjerg Formation contains abundant *Sirmiodinium grossii* and *Gonyaulacysta jurassica*. In the lower levels of the formation, the presence of abundant *Leptodinium subtile* is combined with the appearance of *Paragonaulacysta borealis*, *Rhynchodiniopsis* sp. and *Tenua* cf. *hystrix*. The assemblage is very similar to the as-

semblage in the upper Payer Dal Formation partly due to the continued presence of *Endoscrinium galeritum* and *Scriniodinium crystallinum*. The stratigraphically important *Taeniophora* sp. / *Adnatosphaeridium* sp. (informal name '*A. hartzii*' in: Piasecki 1980) appears in the uppermost sample from the formation.

Correlation. The continued presence of *Endoscrinium galeritum* and *Scriniodinium crystallinum* from the Payer Dal Formation below, and the absence of *Taeniophora* sp. / *Adnatosphaeridium* sp. ('*A. hartzii*') correlates with the lower Upper Oxfordian, *A. glosense* Chronozone, by comparison to dinoflagellate floras from Milne Land (Piasecki 1996). This is in accordance with abundant ammonites of the *Amoeboceras glosense* Zone in these strata, and with the absence of the uppermost Oxfordian dinoflagellate cyst species that appear above.

The upper part of the Bernbjerg Formation contains abundant *Gonyaulacysta jurassica* and *Sirmiodinium grossii* in combination with *Adnatosphaeridium* sp. ('*A. hartzii*'), *Cribroperidinium granuligerum*, *Scriniodinium irregulare*, *Glossodinium* cf. *dimorphum*, *Endoscrinium luridum* and *Prolixosphaeridium granulosum*. The composite dinoflagellate cyst flora indicates an Upper Oxfordian to lowermost Kimmeridgian succession, *A. serratum* – *P. baylei* Chronozones. The presence of *Avellodinium* spp. in the uppermost sample could indicate the lowermost Kimmeridgian *A. mutabilis* Chronozone, but this is not supported by any other stratigraphical diagnostic species such as *Perisseiasphaeridium pannosum* (Piasecki 1996; Piasecki & Stemmerik 2004, this volume).

Age. The age of the Bernbjerg Formation is Late Oxfordian – earliest Kimmeridgian, equivalent to the *A. glosense* – *P. baylei* Chronozones based on dinoflagellate cysts. Ammonites in the lower part of the Bernbjerg Formation indicate the *A. glosense* Chronozone and confirm the Late Oxfordian age for this part of the formation.

Depositional environment. The organic content is dominated by terrestrial sporomorphs and woody material but dinoflagellate cysts occur frequently. A depositional environment of lower shoreface to open shelf is interpreted on this basis.

Correlations

The Pelion Formation on northern Hold with Hope comprises two main units, a lower sandstone unit followed by mudstones and heterolithic sandstones of the Spath Plateau Member. The same overall pattern occurs in the Pelion Formation on Store Koldewey at Ravn Pynt (Piasecki *et al.* 2004, this volume). However, on Store Koldewey, the lower sandstone unit is older (Bathonian) than the lower sandstone unit on Hold with Hope. The mudstone and overlying sandstone on Store Koldewey are basically of the same Early Callovian age as the lowermost Spath Plateau Member on Hold with Hope (*C. apertum* – *P. koenigi* Chronozones). The marine flooding represented by deposition of this mudstone can be traced from Milne Land and Jameson Land in the south (P7 – third order sequence; Engkilde & Surlyk 2003) to Hold with Hope and Store Koldewey in the north.

The Payer Dal Formation is defined on Kuhn Ø where it comprises two units that are of Early–Middle Oxfordian age and early Late Oxfordian age (Alsgaard *et al.* 2003). On Hold with Hope, the exposure of the oldest part of the Payer Dal Formation at Sortelv (Fig. 2; Locality 2) is limited by a fault, and older strata may be present in the subsurface. However, no strata of Early Oxfordian age have been recorded here, and the age of the Payer Dal Formation on Hold with Hope is Middle–Late Oxfordian, partly corresponding to the upper part of this formation on Kuhn Ø.

Sedimentation of fine-grained sand and mudstone of the Bernbjerg Formation began in the *A. glosense* Chron on Hold with Hope as in Wollaston Forland to the north (Surlyk 1977).

Conclusions

The combined biostratigraphical dataset from ammonites and dinoflagellate cysts dates the stratigraphical range of the lithological units with a high degree of precision (Figs 3, 4). However, the extent of non-depositional or erosional hiatus in or between the units cannot be determined with the same certainty due to the limited number of productive samples. The 'basal sandstone unit' of the Pelion Formation ranges from the uppermost *C. apertum* Chronozone to the lower *P. koenigi* Chronozone (Figs 3, 4). The age is therefore Early Callovian. The dinoflagellate assemblages show no indication of a break in sedimentation so the succession is considered complete. The Spath Plateau

Member of the Pelion Formation comprises the *P. koenigi*, *K. jason* and *P. athleta* Chronozones (Fig. 3). The age is therefore Early to Late Callovian, but a part of the succession occurs above the highest productive sample and may therefore be younger.

A considerable hiatus is present between the Pelion Formation and the overlying Payer Dal Formation. However, the exact stratigraphical position of the unconformity and the extent of the hiatus cannot be determined precisely, because no productive samples were recovered from the boundary interval. The available data suggest a hiatus that comprises most of the Late Callovian, Early Oxfordian and earliest Middle Oxfordian. The Payer Dal Formation ranges from the *C. tenuiserratum* to the *A. glosense* Chronozones, and the age is consequently Middle to Late Oxfordian (Fig. 3). The dinoflagellate assemblages indicate no break in deposition at the boundary to the Bernbjerg Formation, and the *A. glosense* Chronozone is also identified in the basal Bernbjerg Formation on the basis of ammonites. The Jurassic succession and the Bernbjerg Formation are limited upwards by pre-Barremian, Cretaceous erosion, and the highest samples are referred to the *A. rosenkrantzi* – *P. baylei* Chronozones at the Oxfordian–Kimmeridgian boundary (Fig. 3). The age of the Bernbjerg Formation is thus Late Oxfordian, possibly earliest Kimmeridgian.

The Jurassic succession on northern Hold with Hope correlates well with the corresponding Jurassic successions towards the north and the south, but appears more fragmented compared to these successions. A Boreal Bathonian (Bajocian–Bathonian) succession has been deposited in this region, at least partly, but was removed by later erosion as indicated by the reworked ammonite of the *P. pompeckji* Zone. The previous presence of a Lower Oxfordian succession is similarly indicated by reworked dinoflagellate cysts. The magnitude of the hiatus below the Payer Dal Formation is Late Callovian – Middle Oxfordian.

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References

- Alsgaard, P.C., Felt, V.L., Vosgerau, H. & Surlyk, F. 2003: The Jurassic of Kuhn Ø, North-East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 865–892.
- Bailey, D. & Hogg, N.M. 1995: *Fentonia bjaerkei* gen. et comb. nov.; transfer from *Parvocysta* Bjaerke 1980. Journal of Micropalaeontology **14**(1), 58 pp.
- Callomon, J.H. 1993: The ammonite succession in the Middle Jurassic of East Greenland. Bulletin of the Geological Society of Denmark **40**, 83–113.
- Donovan, D.T. 1957: The Jurassic and Cretaceous systems in East Greenland. Meddelelser om Grønland **155**(4), 1–214.
- Engkilde, M. & Surlyk, F. 2003: Shallow marine syn-rift sedimentation: Middle Jurassic Pelion Formation, Jameson Land, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 813–863.
- Fensome, R.A. 1979: Dinoflagellate cysts and acritarchs from the Middle and Upper Jurassic of Jameson Land, East Greenland. Bulletin Grønlands Geologiske Undersøgelse **132**, 98 pp.
- Kelly, S.R.A., Whitham, A.G., Koraini, A.M. & Price, S.P. 1998: Lithostratigraphy of the Cretaceous (Barremian–Santonian) Hold with Hope Group, NE Greenland. Journal of the Geological Society (London) **155**(6), 993–1008.
- Larsen, M., Piasecki, S., Preuss, T., Seidler, L., Stemmerik, L., Therkelsen, J. & Vosgerau, H. 1997: Petroleum geological activities in East Greenland in 1997. Geology of Greenland Survey Bulletin **180**, 35–42.
- Milner, P.S. & Piasecki, S. 1996: Boreal Middle Jurassic dinoflagellate cyst stratigraphy of Jameson Land, East Greenland. In: Piasecki, S. *et al.* (eds): Formation of source and reservoir rocks in a sequence stratigraphic framework, Jameson Land, East Greenland. Energy research programme EFP-93, projects 1313/93-0010 and 0017. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1996/30**, Vol. I & II, 46 pp.
- Piasecki, S. 1980: Middle to Late Jurassic dinoflagellate cyst stratigraphy from Milne Land and Jameson Land (East Greenland) correlated with ammonite stratigraphy, 167 pp. Unpublished Ph.D. thesis, University of Copenhagen, Denmark.
- Piasecki, S. 1996: Boreal dinoflagellate cyst stratigraphy of Middle to Upper Jurassic sediments of Milne Land, East Greenland. In: Piasecki, S. *et al.* (eds): Formation of source and reservoir rocks in a sequence stratigraphic framework, Jameson Land, East Greenland. Energy Research Programme EFP-93, projects 1313/93-0010 and 0017. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1996/30**, Vol. I & II, 100 pp.
- Piasecki, S. & Stemmerik, L. 2004: Jurassic dinoflagellate cysts from Hochstetter Forland, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 89–97 (this volume).
- Piasecki, S., Callomon, J.H. & Stemmerik, L. 2004: Jurassic dinoflagellate cyst stratigraphy of Store Koldewey, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 99–112 (this volume).
- Poulsen, N.E., Gudmundsson, L., Hansen, J.M. & Husfelt, Y. 1990: Palynological preparation techniques, a new Maceration-tank-method and other modifications. Danmarks Geologiske Undersøgelse Serie C **10**, 22 pp.
- Price, S.P. & Whitham, A.G. 1997: Exhumed hydrocarbon traps in East Greenland: analogs for the Lower–Middle Jurassic play of Northwest Europe. American Association of Petroleum Geologists Bulletin **81**, 196–221.
- Stemmerik, L., Clausen, O.R., Korstgård, J., Larsen, M., Piasecki, S., Seidler, L., Surlyk, F. & Therkelsen, J. 1997: Petroleum geological investigations in East Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. Geology of Greenland Survey Bulletin **176**, 29–38.
- Surlyk, F. 1977: Stratigraphy, tectonics and palaeogeography of the Jurassic sediments of the areas north of Kong Oscars Fjord, East Greenland. Bulletin Grønlands Geologiske Undersøgelse **123**, 56 pp.
- Surlyk, F. 1978: Mesozoic geology and palaeogeography of Hochstetter Forland, East Greenland. Bulletin of the Geological Society of Denmark **27**, 73–87.
- Surlyk, F., Clemmensen, L.B. & Larsen, H.C. 1981: Post-Palaeozoic evolution of the East Greenland continental margin. In: Kerr, J.W. & Fergusson, A.J. (eds): Geology of the North Atlantic borderlands. Canadian Society of Petroleum Geologists Memoir **7**, 611–645.
- Vischer, A. 1943: Die postdevonische Tektonik von Ostgrønland zwischen 74° und 75°N. Br. Kuhn Ø, Wollaston Forland, Clavering Ø und angrenzende Gebiete. Meddelelser om Grønland **133**(1), 195 pp.
- Vosgerau, H., Larsen, M., Piasecki, S. & Therkelsen, J. 2004: A new Middle–Upper Jurassic succession on Hold with Hope, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 51–71 (this volume).

Jurassic dinoflagellate cysts from Hochstetter Forland, North-East Greenland

Stefan Piasecki and Lars Stemmerik

Three sections in Hochstetter Forland, North-East Greenland, referred to the Jurassic Payer Dal and Bernbjerg Formations, have been analysed for dinoflagellate cysts. The dinoflagellate cysts, new finds of ammonites and previously recorded marine faunas form the basis for improved dating of the succession. The basal strata of the Payer Dal Formation at Kulhus is here dated as Late Callovian, *Peltoceras athleta* Chronozone, based on the presence of relatively abundant *Limbicysta bjaerkei*, *Mendicodinium groenlandicum*, *Rhychoniopsis cladophora* and *Tubotuberella dangeardii* in an otherwise poor Upper Callovian dinoflagellate assemblage. Ammonites have not been recorded from these strata. The upper Payer Dal Formation at Agnetesøelven is dated as Late Oxfordian, *Amoeboceras glosense* – *Amoeboceras serratum* Chronozones, based on the presence of *Sciniodinium crystallinum*, together with *Cribooperidinium granuligera* and *Stephanelytron* sp. The age is in accordance with ammonites present in the uppermost part of the formation at Søndre Muslingeberg. New ammonites in the Bernbjerg Formation at Agnetesøelven together with dinoflagellate cysts indicate an earliest Kimmeridgian age, *Rasenia cymodoce* and *Aulacostephanoides mutabilis* Chronozones.

The Upper Callovian dinoflagellate cysts from Hochstetter Forland belong to a local brackish to marginal marine assemblage, which only allows a fairly broad correlation to coeval assemblages in central East Greenland. In contrast, the Oxfordian and Kimmeridgian assemblages are fully marine and can be correlated from Milne Land in central East Greenland via Hochstetter Forland to Peary Land in eastern North Greenland.

Keywords: ammonites, Boreal, dinoflagellate cysts, Hochstetter Forland, Jurassic, North-East Greenland

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The northernmost onshore Jurassic outcrops in East Greenland occur in Hochstetter Forland and, some 60–80 km farther north, on Store Koldeway (Fig. 1); the stratigraphy of the latter area is described in an accompanying paper (Piasecki *et al.* 2004a, this volume). The Hochstetter Forland peninsula is dominated by flat lowlands dissected by small streams; outcrops of pre-Quaternary sediments are restricted to stream cuts and low coastal cliffs scattered throughout the region (Fig. 1). However, at Søndre Muslingeberg to the south, Caledonian basement and Middle–Upper Jurassic sandstones and coals are faulted and reach up to approximately 400 m above sea level. Caledonian basement

and Jurassic sediments also crop out in northern Hochstetter Forland, east of Agnetesø, and the meanders of Agnetesøelven (the river from Agnetesø to the coast) erode into marine Jurassic sediments deposited on basement rocks (Fig. 1).

The Jurassic stratigraphy of the Hochstetter Forland area is based on records of marine faunas including ammonites from several isolated exposures (Ravn 1911; Surlyk 1978). The lowermost deposits consist of the non-marine to marginal marine Muslingeberg Formation, which is undated owing to the absence of marine fossils. The overlying sands of the Payer Dal Formation contain Upper Oxfordian ammonites in the upper

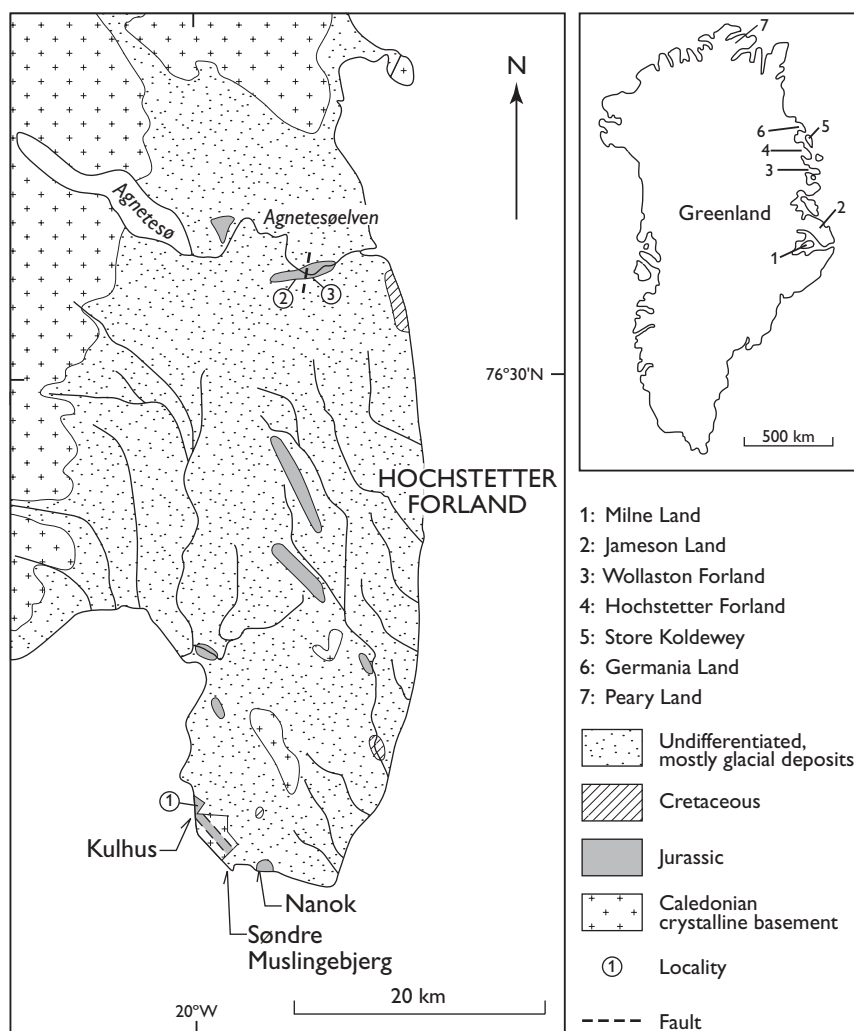


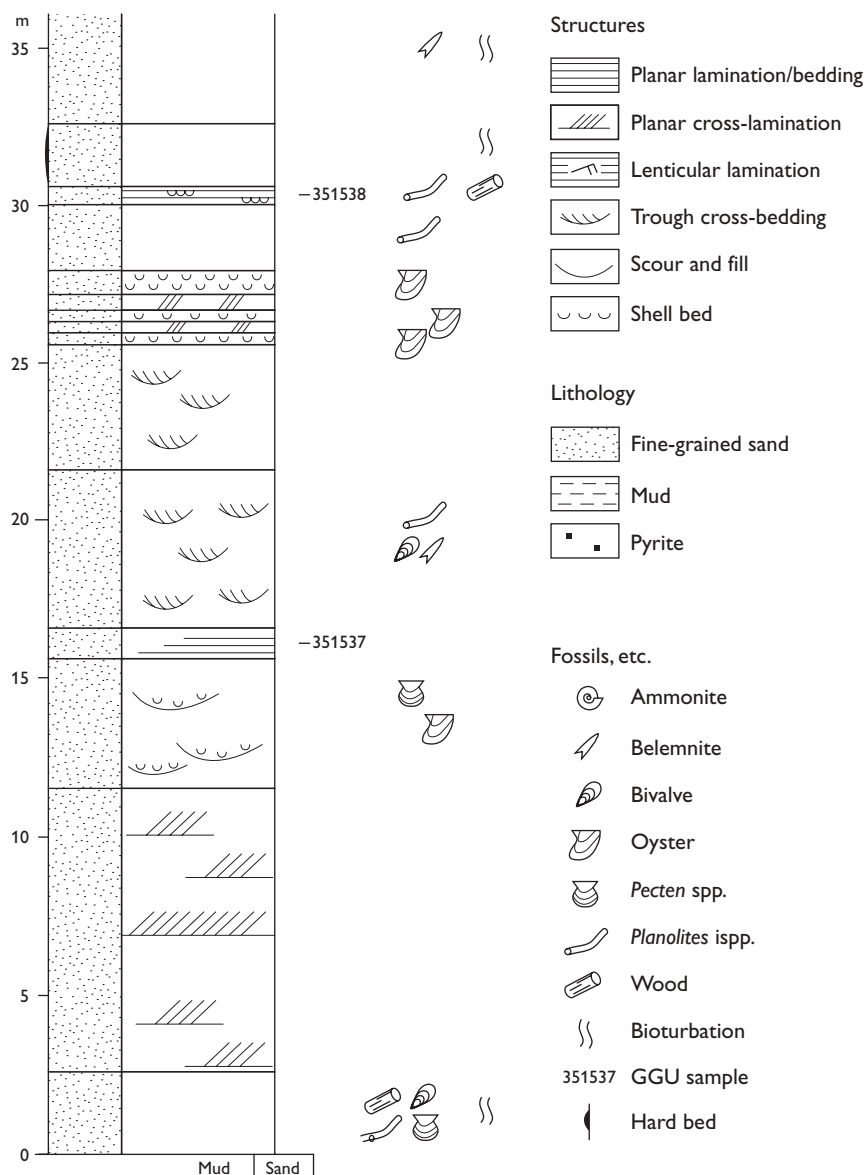
Fig. 1. Simplified sketch map of Hochstetter Forland illustrating the Jurassic outcrops and the sampled localities. The map is modified from Surlyk (1978, fig. 1).

part, and are followed by mudstones of the Bernbjerg Formation that yield Upper Oxfordian – Lower Kimmeridgian ammonites (Surlyk 1978). The outcrops at Kulhus and Agnetesøelven expose the main part of the Jurassic succession in Hochstetter Forland. These localities were visited during fieldwork in 1987 in order to collect material for palynological analysis with the aim of refining the stratigraphy. The present paper describes for the first time the dinoflagellate cyst floras from these northern outcrops close to the transition to the Boreal dinoflagellate cyst province, for example in Peary Land (Håkansson *et al.* 1981) and on Svalbard (Århus 1988).

Material

At Kulhus (Fig. 1; Locality 1), on the south coast of Hochstetter Forland west of Søndre Muslingeberg, sand and coal seams were sampled during a ground stop on helicopter reconnaissance in 1987. Only one sample (GGU 351570) contains dinoflagellate cysts. Two closely situated localities at Agnetesøelven were spotted from the air and visited during a short ground stop. The westernmost sandstone outcrop (Locality 2) was measured and two fine-grained samples with at least some potential for palynology were collected from two horizons (Fig. 2). Eastwards and down-river, the sandstone-dominated succession was seen to be faulted against a succession of laminated mudstones (Locality 3), and this was closely sampled for palynology (Fig. 3). Only a few, well-preserved dinoflagellate cysts were recovered from the sand succession at Locality 2. By

Fig. 2. Sedimentological log of the upper Payer Dal Formation at Agnetesøelven (Locality 2) showing the positions of analysed samples.



contrast dinoflagellate cysts are abundant but poorly preserved in the mudstones at Locality 3. Ammonites are abundant in the lower, pyritic, part of the mudstone succession and in loose concretionary beds at the base of the cliff. These ammonites provide independent stratigraphical control of the dinoflagellate cyst assemblages.

All of the samples from the three localities on Hochstetter Forland were prepared by traditional palynological methods and analysed for their content of dinoflagellate cysts.

Geology

The Jurassic succession on Hochstetter Forland is divided into the Muslingebjerg, Payer Dal and Bernbjerg Formations of the Vardekløft Group. The marine sandstones of the Payer Dal Formation were previously included in the Pelion Member of the Vardekløft Formation (*sensu* Surlyk 1978); the Pelion Member is now raised to formation status (Surlyk 2003, fig. 5).

Kulhus (Locality 1)

The low coastal cliff at Kulhus, south-west Hochstetter Forland (Fig. 1, Locality 1), comprises 3–4 main coal

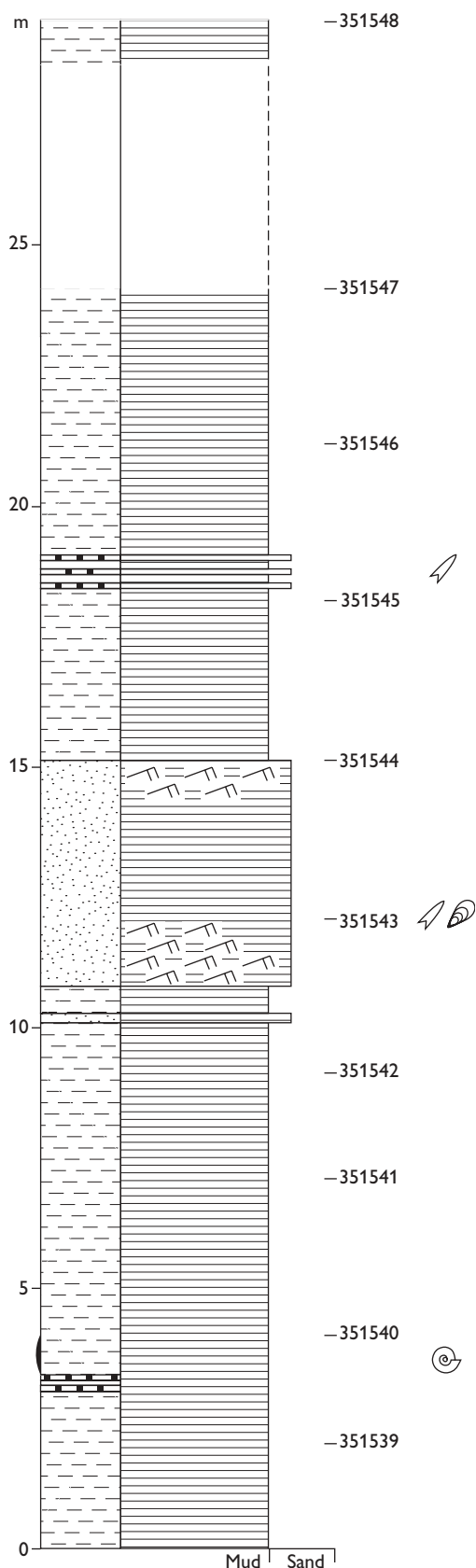


Fig. 3. Sedimentological log of the Bernbjerg Formation at Agnetesøelven (Locality 3) showing the positions of analysed samples. For legend, see Fig. 2.

seams interbedded with black carbonaceous shales and light-coloured sandstones of the Muslingebjerg Formation (Clemmensen & Surlyk 1976). No marine fossils have been recorded from the formation but the high sulphur content of the coals and shales suggests a marine depositional environment (Petersen *et al.* 1998). The Jurassic succession at Kulhus extends up the western flank of Søndre Muslingebjerg where the stratigraphically highest strata contain Upper Oxfordian ammonites referable to the *Amoeboceras glosense* and/or *A. serratum* Zones (Ravn 1911; Sykes & Surlyk 1976).

Coals and shales of the Muslingebjerg Formation have been prepared palynologically without finding any microscopic marine fossils. At Kulhus, the first dinoflagellate cysts appear in the basal mudstone bed of the overlying Payer Dal Formation, immediately above the highest coal seam, at the same level as the earliest marine faunas. Restricted assemblages of sporomorphs from the underlying coals indicate an overall Jurassic age.

Agnetesøelven (Localities 2 and 3)

Fine-grained sandstone, with abundant marine fossils, is exposed at Locality 2 and referred to the Payer Dal Formation (Figs 1, 2). Shell beds of *Pecten* spp., oysters, other bivalves and serpulids occur throughout the succession and are commonly concentrated in scour fills. Belemnites are present, but no ammonites were recovered during the short visit. Woody material and small logs are also common. The sandstone is intensely bioturbated and many sedimentary structures are obliterated although cross-bedding or lamination is recognisable in most beds. *Planolites* ispp. is common at certain horizons.

The shale succession exposed at Locality 3 is referred to the Bernbjerg Formation. It consists of laminated, dark mudstones alternating with lenticular-bedded, fine-grained, grey sandstones (Fig. 3). Ammonites and bivalves are abundant in a concretionary bed low in the section and belemnites and bivalves occur scattered higher in the succession. The concretionary beds are washed out from the lowermost succession and lie at the foot of the cliff. They contain accretions of ammonites in several stacked laminae together with abundant *Buchia* sp. Abundant male and female individuals occur together in the ammonite assemblages (J.H.

LITHOSTRATIGRAPHY	BIOSTRATIGRAPHY	CHRONOSTRATIGRAPHY	
FORMATION	AMMONITE ZONE	AGE BASED ON DINOFLAGELLATE CYSTS	CHRONOZONES
Bernbjerg	<i>A. mutabilis</i> <i>R. cymodoce</i>	Early Kimmeridgian	<i>A. mutabilis</i> <i>R. cymodoce</i>
Payer Dal	<i>A. glosense</i> – <i>A. serratum</i> —	Late Oxfordian Late Callovian	<i>A. glosense</i> – <i>A. serratum</i> <i>P. athleta</i>
Muslingebjerg	No marine fossils	(Callovian?)	pre- <i>P. athleta</i>

Fig. 4. Summary of the Jurassic stratigraphy of Hochstetter Forland.

Callomon, personal communication 1999). The assemblage is equivalent to ammonite Fauna 15 from Milne Land in the lower *Rasenia cymodoce* Zone, Lower Kimmeridgian (Fig. 4; Birkelund & Callomon 1985; J.H. Callomon, personal communication 1999). Lower Kimmeridgian ammonites have been reported previously from sandstones at the locality of Nanok in southern Hochstetter Forland (Frebald 1932). Ammonites of the lowermost Kimmeridgian *Rasenia cymodoce* and *Aulacostephanoides mutabilis* Zones, have been collected from mudstones of the Bernbjerg Formation in Hochstetter Forland (Frebald 1932; Surlyk 1978).

Stratigraphy

Basal Payer Dal Formation (Locality 1)

Dinoflagellate cysts. An unusual and relatively poor assemblage of dinoflagellate cysts was recorded immediately above the lithological transition from the barren Muslingeelv Formation to the fossiliferous Payer Dal Formation (Fig. 5). *Limbicysta bjaerkei*, *Pilosidinium fensomei* and *Pareodinia halosa* dominate the assemblage, in association with *Gonyaulacysta jurassica*, *Nannoceratopsis* sp., *Occisucysta* sp., *Pareodinia* sp., *Solisphaeridium* sp., *Tubotuberella* cf. *dangeardii* and *Tubotuberella* cf. *egemenii*. Single specimens of *Atopodinium baromense*, *Mendicodinium groenlandicum* and *Rhynchodiniopsis cladophora* were recorded.

Age. Stratigraphically diagnostic species are few in

this assemblage. In East Greenland, *Limbicysta bjaerkei* has not been recorded stratigraphically higher than the basal Boreal Middle Jurassic in the *Cranoccephalites borealis* Chronozone in Jameson Land (Milner & Piasecki 1996). However, a stratigraphical range of Middle Callovian and possibly into lowermost Upper Callovian has been reported from both the Subboreal and Arctic regions (Smelror 1987, 1993). In Jameson Land, *M. groenlandicum* appears no lower than the *Kosmoceras jason* Chronozone (mid-Callovian) and distinct *Rhynchodiniopsis cladophora* and *Tubotuberella dangeardii* appear in the basal Upper Callovian in the *Peltoceras athleta* Chronozone (Milner & Piasecki 1996). In conclusion, the sparse data indicate an age equivalent to the earliest Late Callovian, *P. athleta* Chronozone (Fig. 4). An Early Callovian age previously indicated for this unit (Petersen *et al.* 1998) was based on a sample that was subsequently found to be from another section and locality.

Depositional environment. The dinoflagellate cyst assemblage is dominated by three species (Fig. 5). *Limbicysta bjaerkei* is possibly an acritarch because no clear archaeopyle has been documented. The assemblage differs markedly from normal marine assemblages described from time equivalent strata in Milne Land (Piasecki 1996). Bailey & Hogg (1995) reported abundant *L. bjaerkei* in otherwise non-marine assemblages. This may indicate that the associated, frequent species, *Pilosidinium fensomei* and *Pareodinia halosa*, may have had similar environmental preferences. The abundance of *L. bjaerkei* – together with the restricted

assemblage – is taken as evidence for estuarine, brackish depositional environments during the initial transgression of Hochstetter Forland.

Upper Payer Dal Formation (Locality 2)

Dinoflagellate cysts. Dinoflagellate cysts are relatively sparse in these sediments. However, the diversity is moderately good and the preservation is fine. *Ambonosphaera calloviense* is the only dinoflagellate species represented by more than one or two specimens in the assemblage (Fig. 5). *Ambonosphaera calloviense*, *Sirmiodinium grossii* and *Sentusidinium* sp. are the only species common to both samples.

Age. Despite the paucity of dinoflagellate cysts, the co-occurrence of *Sciniodinium crystallinum*, *Cribrerodinium granuligera* and *Stephanelytron* sp. indicates a Late Oxfordian age i.e. *Amoeboceras glosense* to *Amoeboceras serratum* Chronozones, by comparison to Hold with Hope and Milne Land further to the south (Piasecki 1996; Piasecki *et al.* 2004a, b, this volume; Figs 1, 4). None of the other dinoflagellate cysts are inconsistent with this age, which is also in accordance with the age indicated by ammonites from the uppermost Payer Dal Formation at Søndre Muslingebjerg (Ravn 1911; Sykes & Surlyk 1976). However, the dinoflagellate cyst assemblage is too restricted to allow a more precise correlation.

Depositional environment. The low abundance combined with the moderate diversity of dinoflagellate cysts indicates near-shore marine deposition in a high-energy environment. The sandy sediments with a rich benthic fauna, partly *in situ* and partly reworked into shell beds, support this interpretation.

Bernbjerg Formation (Locality 3)

Dinoflagellate cysts. Dinoflagellate cysts are abundant and relatively diverse, but their preservation is poor. The composition of the assemblages varies significantly through the relatively short section (Fig. 5). Extremely abundant *Sirmiodinium grossii* characterises the lower part of the section and is gradually replaced by abundant *Gonyaulacysta jurassica sensu lato* in the upper part. Five other species appear in succession with distinct and characteristic maxima through the succession (Fig. 5). Abundant *Nummus* sp. occurs together

with the maximum numbers of *Escharisphaeridium pocockii* in the lower part of the succession. This is followed closely by a maximum abundance of *Cribrerodinium granuligera*, then by a maximum of *Perisseiasphaeridium pannosum* (together with *Gonyaulacysta jurassica sensu lato*) and finally by maximum abundance of *Occisucysta* cf. *monobeuriskos* in the uppermost sample.

A comparable succession of dinoflagellate cyst assemblages has been recorded across the boundary of the Payer Dal and Bernbjerg Formations at Kløft II on Store Koldewey (Piasecki *et al.* 2004a, this volume). At this locality, a maximum of *G. jurassica sensu lato* is followed by abundant *P. pannosum* and *Occisucysta* cf. *monobeuriskos*, similar to that recorded from the upper part of the section at Agnetesøelven (Locality 3). Assemblages dominated by *Nummus* sp., *E. pocockii* and *C. granuligera* were not recorded at Store Koldewey, but these species are present. In contrast, the stratigraphically significant *Paragonyaulacysta capillosa* is abundant at Store Koldewey, whereas it is rare in the succession at Agnetesøelven.

Age. The succession cannot be older than Early Kimmeridgian based on the ammonite fauna in the basal strata, which is indicative of the lower *Rasenia cymodoce* Zone. This is in accordance with the dinoflagellate cyst assemblage of abundant *Sirmiodinium grossii* and frequent *Gonyaulacysta jurassica*, *Adnatosphaeridium* sp. and *Paragonyaulacysta capillosa*. To the south, on Milne Land, *P. capillosa* first appears in the *R. cymodoce* Chronozone and is followed by *Perisseiasphaeridium pannosum* in the succeeding *Aulacostephanoides mutabilis* Chronozone (Piasecki 1996). At Agnetesøelven, the appearance of *P. pannosum* higher in the succession accordingly indicates an age equivalent to the *A. mutabilis* Chronozone for this part of the succession (Fig. 4). Dinoflagellate cysts indicative of younger Jurassic strata were not recorded.

Lower Kimmeridgian ammonites have previously been recorded from the Bernbjerg Formation on Hochstetter Forland. An ammonite fauna referable to the *A. mutabilis* Zone has been recovered from the Nanok and Agnetesøelven regions (Frebold 1932; Surlyk 1978).

Depositional environment. The dinoflagellate cysts are strongly degraded. They are physically broken, and angular imprints of crystals and deep circular imprints of spherical pyrite framboids obscure the sculpture and structure of their walls. Together with the undisturbed lamination of the sediments, this indicates deposition

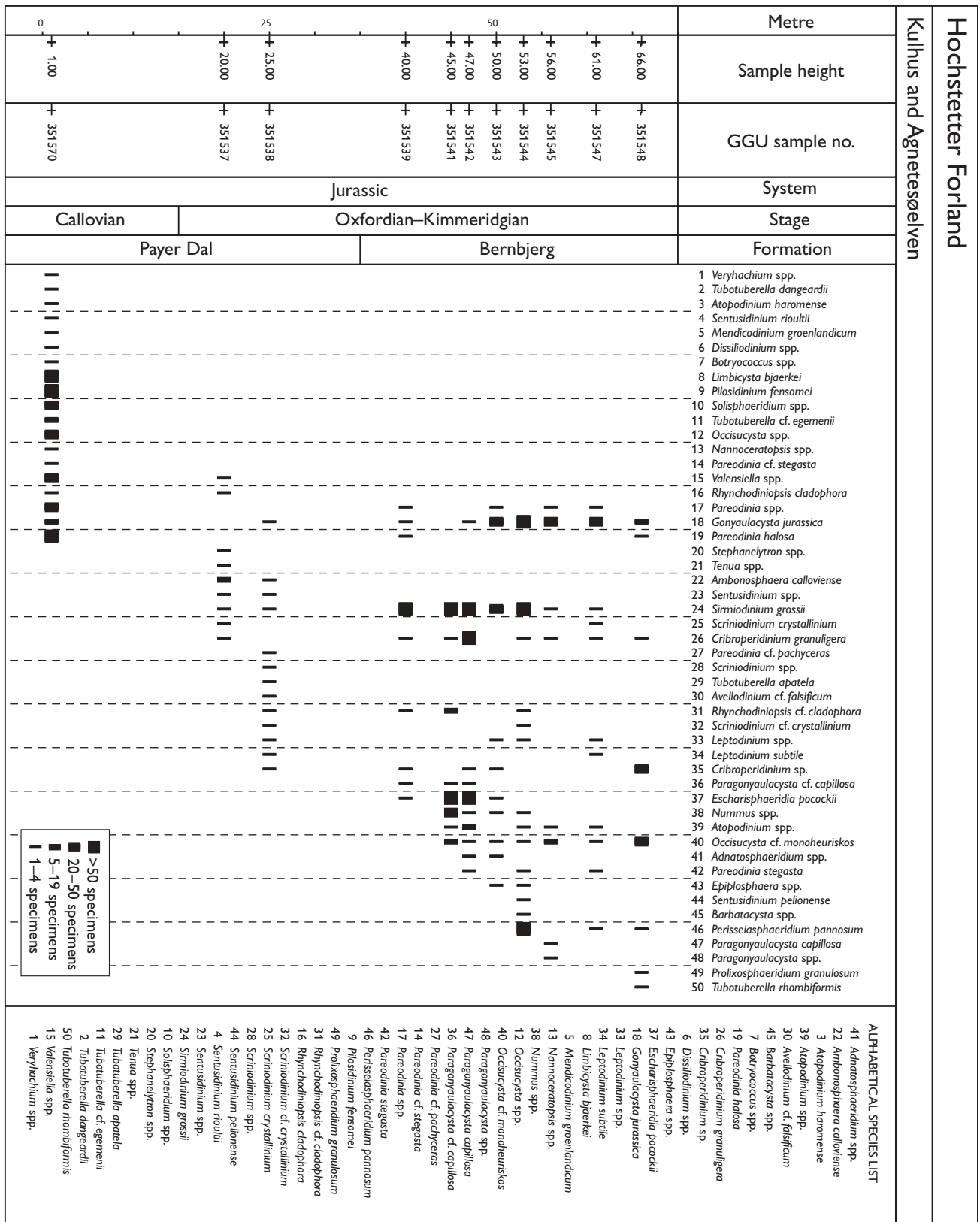


Fig. 5. Stratigraphical distribution chart of dinoflagellate cysts in samples from all three localities. The sample heights indicated are largely arbitrary, although the three localities are arranged in stratigraphic order. Sample at 1 m is from Locality 1, samples at 20 m and 25 m are from Locality 2 (arbitrary spacing, see Fig. 2 for correct locations) and samples at 40–66 m are from Locality 3 (spacings approximately to scale, see Fig. 3 for precise locations). The recorded species are arranged by their first stratigraphical appearance.

below wave base in a low-oxygenated environment. Lenticular laminae with small-scale ripples, however, show that the bottom water was not completely stagnant and that the sea floor was periodically swept by weak bottom currents.

Correlation

Studies of the Jurassic ammonite and dinoflagellate cyst stratigraphy in East Greenland, combined with sedimentological studies and sequence stratigraphical interpretations, contribute towards an integrated model in which units can be identified by their content of dinoflagellate cysts. The present study of the dinoflagellate cyst assemblages on Hochstetter Forland contributes basic data to this complex study.

The assemblage dominated by *Limbicysta bjaerkei* in the basal Payer Dal Formation at Kulhus has not been recorded anywhere else in East Greenland. This assemblage comprises the first marine fossils to have been deposited above the coal-bearing floodplain environment of the Muslingebjerg Formation. The dinoflagellate cyst assemblage records deposition in a marginal marine to brackish environment. The overlying sandstones are interpreted as tidal facies followed by shoreface facies (Petersen *et al.* 1998), reflecting a rise in relative sea level. This assemblage thus characterises marginal marine environments at the feather-edge of the Jurassic depositional basin during a major drowning event (Alsgaard *et al.* 2003).

The poor dinoflagellate cyst assemblage in the upper Payer Dal Formation is not representative of this stratigraphic interval, compared to the assemblages recorded from other localities in East Greenland. However, it is associated with a stratigraphic unit equivalent to the *A. glosense* and *A. serratum* Chronozones that previously has been identified throughout East Greenland, i.e. in Milne Land, Jameson Land and Hold with Hope (Engkilde 1994; Piasecki 1996; Vosgerau *et al.* 2004, this volume).

The dinoflagellate cyst assemblage from the Bernbjerg Formation at Agnetesølvén is known from Milne Land in the south to Store Koldewey in the north, and a similar assemblage occurs in the Ladegårdsåen Formation in Peary Land, North Greenland (Fig. 1; Piasecki 1966; Piasecki *et al.* 2004a, this volume). The dinoflagellate cyst assemblage correlates with the *R. cymodoce* and *A. mutabilis* Chronozones. It is associated with a major Kimmeridgian flooding event which allowed more permanent shelf anoxia to spread to

shallow shelf areas of East Greenland (Milne Land, Wollaston Forland, Hold with Hope, Store Koldewey) and North Greenland (Peary Land). Maximum flooding occurred in the *A. mutabilis* to *A. eudoxus* Chrons.

Conclusions

New ammonite data confirm and refine earlier age determinations of the Jurassic succession on Hochstetter Forland. The age of the upper Payer Dal Formation in Hochstetter Forland is confirmed as Late Oxfordian, and the age of the Bernbjerg Formation is confirmed as earliest Kimmeridgian.

The dinoflagellate cyst stratigraphy from the three localities is fragmentary. The assemblage from the lower Payer Dal Formation at Kulhus has not been reported from any other section in East Greenland; it is important because it represents marginal marine conditions associated with a major flooding event of earliest Late Callovian age, *P. athleta* Chronozone (Fig. 4). This limits the age of the Muslingeelv Formation upwards. The assemblage in the upper Payer Dal Formation is restricted, but supports the previously recorded Late Oxfordian age, corresponding to the *A. glosense* and/or *A. serratum* Chronozones. The third assemblage is well known from East Greenland and dates the Bernbjerg Formation at Agnetesølvén to the earliest Kimmeridgian, *R. cymodoce* and *A. mutabilis* Chronozones (Fig. 4). This assemblage is associated with a major transgressive event characterised by extensive shelf anoxia in East Greenland.

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References

- Alsgaard, P.C., Felt, V.L., Vosgerau, H. & Surlyk, F. 2003: The Jurassic of Kuhn Ø, North-East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 865–892.
- Århus, N. 1988: Palynostratigraphy of some Bathonian–Hautevirian sections in the Arctic, with emphasis on the Janusfjellet Formation type section, Spitsbergen. Institutt for Kontinentalsokkelundersøkelser (IKU) Report **23.1252.11/01/88**, 139 pp.
- Bailey, D.A. & Hogg, N.M. 1995: *Fentonia bjaerkei* gen. et comb. nov.; transfer from *Parvocysta* Bjaerke 1980. Journal of Micro-palaeontology **14**, 58 pp.
- Birkelund, T. & Callomon, J.H. 1985: The Kimmeridgian ammonite faunas of Milne Land, central East Greenland. Bulletin Grønlands Geologiske Undersøgelse **153**, 56 pp.
- Clemmensen, L.B. & Surlyk, F. 1976: Upper Jurassic coal-bearing shoreline deposits, Hochstetter Forland, East Greenland. Sedimentary Geology **15**, 193–211.
- Engkilde, M. 1994: The Middle Jurassic Vardekløft Formation, East Greenland: depositional environments and sequence stratigraphy of shallow marine sandstones deposited in a low-gradient epeiric seaway, 1–207. Unpublished Ph.D. thesis, University of Copenhagen, Denmark.
- Frebold, H. 1932: Geologie der Jurakohlen des nördlichen Ostgrønland. Meddelelser om Grønland **84**(5), 62 pp.
- Håkansson, E., Birkelund, T., Piasecki, S. & Zakharov, V. 1981: Jurassic–Cretaceous of the extreme Arctic (Peary Land, North Greenland). Bulletin of the Geological Society of Denmark **30**, 11–42.
- Milner, P.S. & Piasecki, S. 1996: Boreal Middle Jurassic dinoflagellate cyst stratigraphy of Jameson Land, East Greenland. In: Piasecki, S. *et al.* (eds): Formation of source and reservoir rocks in a sequence stratigraphic framework, Jameson Land, East Greenland. Energy research programme EFP-93, projects 1313/93-0010 and 0017. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1996/30**, Vol. I and II, 46 pp.
- Petersen, H.I., Bojesen-Koefoed, J., Nytoft, H.P., Surlyk, F., Therkelsen, J. & Vosgerau, H. 1998: Relative sea-level changes recorded by paralic liptinite-enriched coal facies cycles, Middle Jurassic Muslingebjerg Formation, Hochstetter Forland, Northeast Greenland. International Journal of Coal Geology **36**, 1–30.
- Piasecki, S. 1996: Boreal dinoflagellate cyst stratigraphy of Middle to Upper Jurassic sediments of Milne Land, East Greenland. In: Piasecki, S. *et al.* (eds): Formation of source and reservoir rocks in a sequence stratigraphic framework, Jameson Land, East Greenland. Energy research programme EFP-93, projects 1313/93-0010 and 0017. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1996/30**, Vol. I and II, 100 pp.
- Piasecki, S., Callomon, J.H. & Stemmerik, L. 2004a: Jurassic dinoflagellate cysts from Store Koldewey, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 99–112 (this volume).
- Piasecki, S., Larsen, M., Therkelsen, J. & Vosgerau, H. 2004b: Jurassic dinoflagellate cyst stratigraphy of Hold with Hope, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 73–88 (this volume).
- Ravn, J.P.J. 1911: On Jurassic and Cretaceous fossils from North-East Greenland. Meddelelser om Grønland **45**(10), 437–500.
- Smelror, M. 1987: Bathonian and Callovian (Middle Jurassic) dinoflagellate cysts and acritarchs from Franz Josef Land, Arctic Soviet. Polar Research **5**, 221–238.
- Smelror, M. 1993: Biogeography of Bathonian to Oxfordian (Jurassic) dinoflagellates: Arctic, NW Europe and circum-Mediterranean regions. Palaeogeography, Palaeoclimatology, Palaeoecology **102**, 121–160.
- Surlyk, F. 1978: Mesozoic geology and palaeogeography of Hochstetter Forland, East Greenland. Bulletin of the Geological Society of Denmark **27**, 73–87.
- Surlyk, F. 2003: The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 659–722.
- Sykes, R.M. & Surlyk, F. 1976: A revised ammonite zonation of the Boreal Oxfordian and its application in North-East Greenland. Lethaia **9**, 421–436.
- Vosgerau, H., Larsen, M., Piasecki, S. & Therkelsen, J. 2004: A new Middle–Upper Jurassic succession on Hold with Hope, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 51–71 (this volume).

Jurassic dinoflagellate cyst stratigraphy of Store Koldewey, North-East Greenland

Stefan Piasecki, John H. Callomon and Lars Stemmerik

The Jurassic of Store Koldewey comprises a Middle Jurassic succession towards the south and an Upper Jurassic succession towards the north. Both successions onlap crystalline basement and coarse sediments dominate. Three main lithostratigraphical units are recognised: the Pelion Formation, including the Spath Plateau Member, the Payer Dal Formation and the Bernbjerg Formation. Rich marine macrofaunas include Boreal ammonites and the successions are dated as Late Bathonian – Early Callovian and Late Oxfordian – Early Kimmeridgian on the basis of new collections combined with material in earlier collections. Fine-grained horizons and units have been analysed for dinoflagellate cysts and the stratigraphy of the diverse and well-preserved flora has been integrated with the Boreal ammonite stratigraphy. The dinoflagellate floras correlate with contemporaneous floras from Milne Land, Jameson Land and Hold with Hope farther to the south in East Greenland, and with Peary Land in North Greenland and Svalbard towards the north. The Middle Jurassic flora shows local variations in East Greenland whereas the Upper Jurassic flora gradually changes northwards in East Greenland. A Boreal flora occurs in Peary Land and Svalbard. The characteristic and stratigraphically important species *Perisseiasphaeridium pannosum* and *Oligosphaeridium patulum* have their northernmost occurrence on Store Koldewey, whereas *Taeniophora iunctispina* and *Adnatosphaeridium* sp. extend as far north as Peary Land. Assemblages of dinoflagellate cysts are used to characterise significant regional flooding events and extensive sequence stratigraphic units.

Keywords: ammonites, Boreal, dinoflagellate cysts, Jurassic, North-East Greenland, Store Koldewey

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Jurassic sediments are well exposed in the East Greenland Basin from Milne Land (70°N) in the south to Hochstetter Forland (75°N) in the north. Yet farther to the north, Jurassic sediments are restricted to isolated outliers (Ravn 1911; Stemmerik & Piasecki 1990) until the more extensive outcrops of Jurassic deposits in the Wandel Sea Basin in eastern North Greenland are reached (81°N–83°N; Fig. 1). The geographical gap between the Jurassic outcrops of the Wandel Sea Basin (Peary Land) and the well-studied ones of the East Greenland Basin corresponds to the zone covering the transition from the strictly Boreal dinoflagellate cyst flora of Peary Land to the Subboreal hybrid flora of

East Greenland. Accordingly, dinoflagellate data from Store Koldewey are important since they improve correlation between these two floral provinces. The Jurassic exposures on the island of Store Koldewey are also stratigraphically important because they provide the nearest accessible record in guiding the evaluation of the hydrocarbon potential of the extensive offshore shelf areas in the northern region.

The Mesozoic of Store Koldewey was first described by Ravn (1911) and Koch (1929) on the basis of data collected by members of 'Danmarks Expeditionen' in 1906–1908. Store Koldewey was then not visited by geologists until the summer of 1989, when several field-

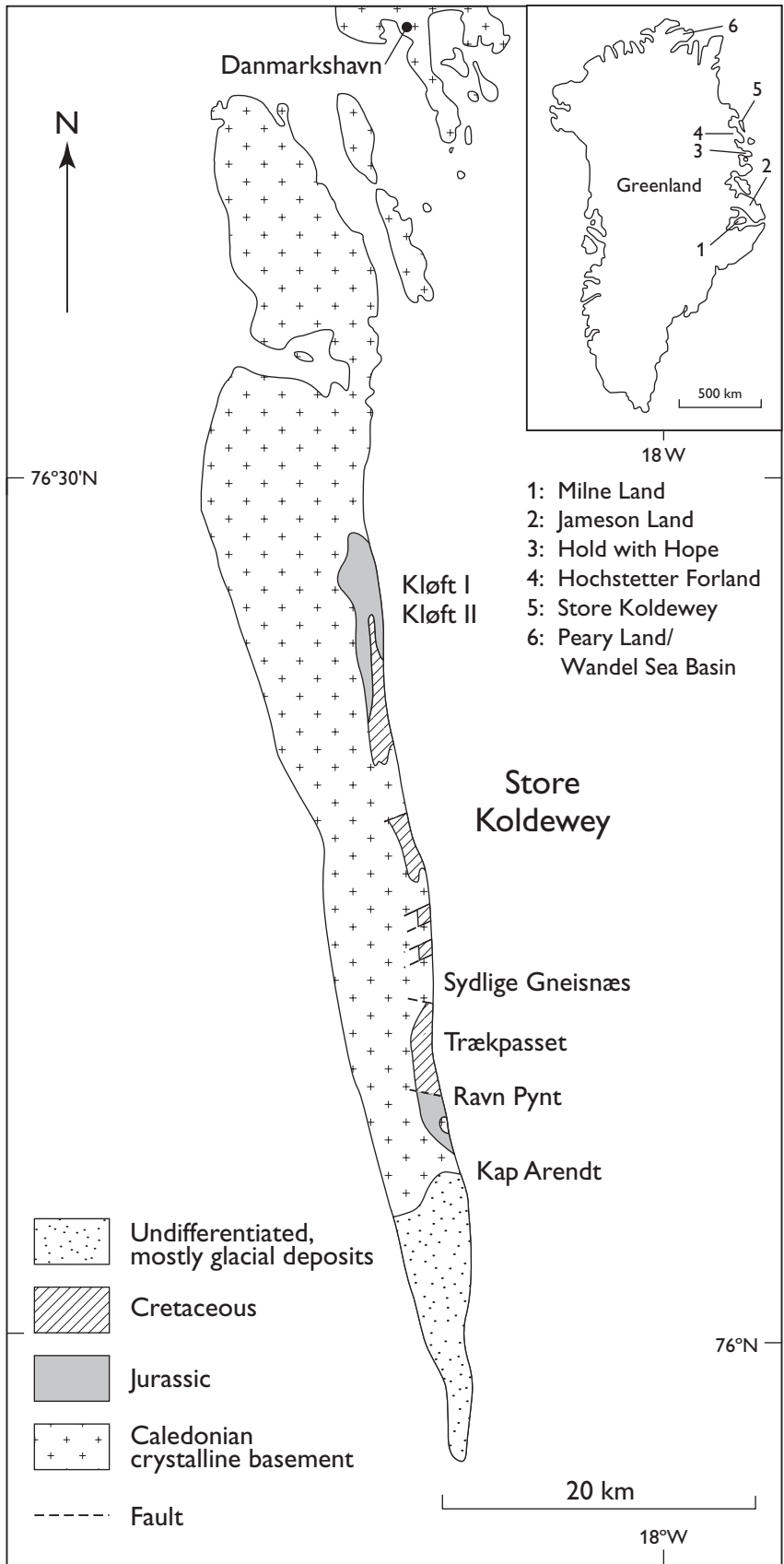


Fig. 1. Simplified geological map of Store Koldewey.

parties from the Geological Survey of Greenland (GGU; since 1995 part of the Geological Survey of Denmark and Greenland) studied the geology of the island as part of regional mapping projects (Stemmerik & Piasecki 1990; Henriksen 1997). Other areas mapped as Palaeozoic and Mesozoic sediments by Haller (1983) were also visited at the same time but most of these appeared to be glacial deposits (Stemmerik & Piasecki 1990). However, some new, very small outcrops of Jurassic sediments were found, protected from erosion on the downthrown side of basement faults (Piasecki *et al.* 1994).

Geological setting

The elongated shape of Store Koldewey reflects a north–south-oriented crystalline basement ridge. Mesozoic sediments are exposed only in low coastal cliffs along the east side of the island (Fig. 1). They include four distinct stratigraphic units (I–IV) that are preserved in small structural basins separated by basement highs (Fig. 1). The lithology is generally of mud to fine-grained sand grade and the units are highly fossiliferous. The stratigraphic units are of Middle Jurassic (I), Late Jurassic (II) and Early Cretaceous ages (III–IV). The southernmost outcrop at Ravn Pynt consists of a Middle Jurassic succession more than 60 m thick, the Trækpasset Formation (Koch 1929; Figs 1, 2). Upper Jurassic sediments crop out in two gullies, Kløft I and Kløft II, in the northern part of the island (Fig. 1). The sediments in the first (northern) of these gullies have been referred to the Kløft I Formation (Koch 1929) based on the description by Ravn (1911) of material collected by members of the ‘Danmarks Ekspeditionen’ in 1906–1908. Ravn (1911) proposed a Callovian age for the Trækpasset Formation and a ‘Sequanian’ (Kimmeridgian) age for the Kløft I Formation based on ammonites. The sandstone of the Kløft I Formation was later found in the Kløft II locality to be overlain with a sharp boundary by grey laminated mudstones of the Bernbjerg Formation (Piasecki *et al.* 1994).

Samples and methods

The palynological samples were prepared by standard preparation methods including treatment with hydrochloric and hydrofluoric acids, oxidation and filtration with 20 micron mesh. The stratigraphical position of the Middle Jurassic samples is marked on the sedi-

mentological log from Ravn Pynt (Fig. 2). This succession is well dated by ammonites and the recorded occurrences and distributions of dinoflagellate cysts are mainly used to improve the precision of Middle Jurassic dinoflagellate cyst stratigraphy in East Greenland. This has involved new palynological analyses of ammonite-dated samples from Jameson Land for confirmation of the new stratigraphical results from Store Koldewey. These new data are not published yet, but are referred to in this paper. The new ammonite records are not yet published in detail but are utilised in this paper.

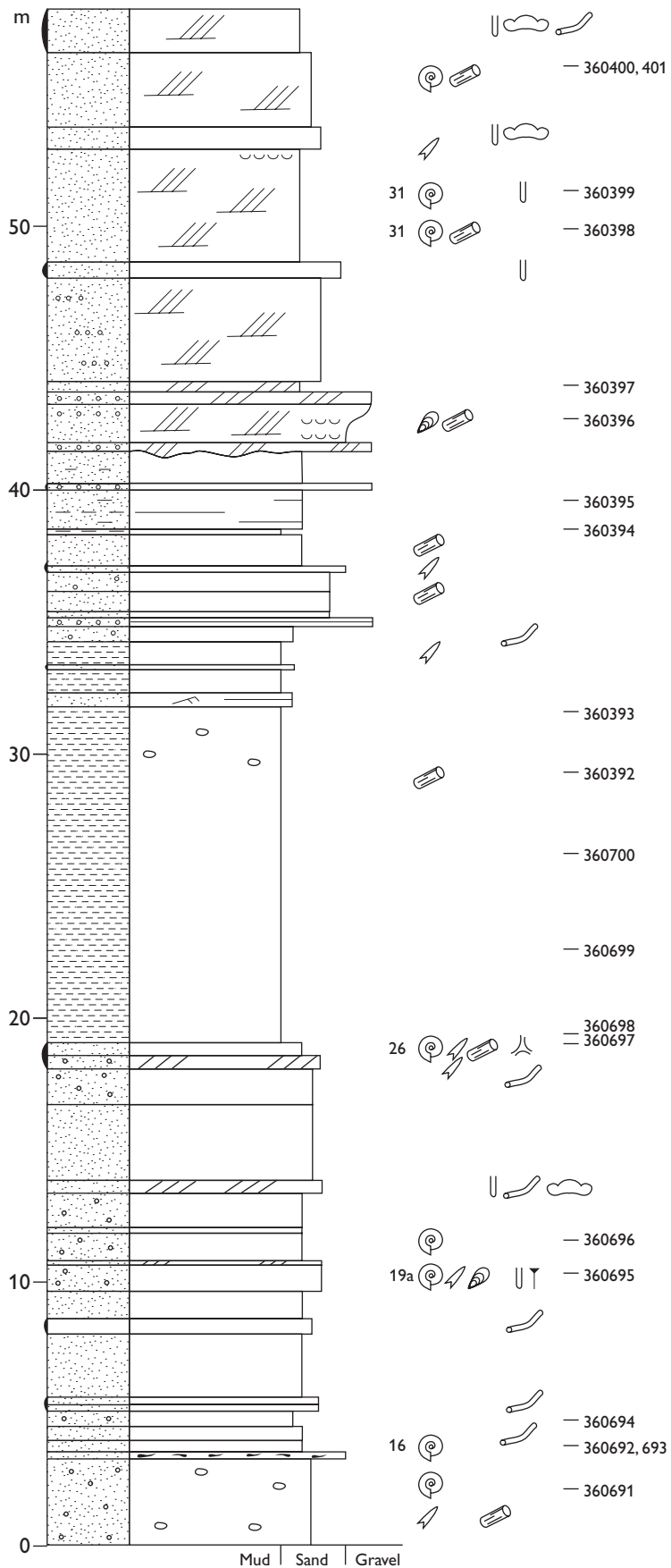
The position of the Upper Jurassic samples is marked on the sedimentological log from Kløft II (see Fig. 5). The record of dinoflagellate cysts is then used to date the regionally recorded transition from shallow marine sandstone to the shale of the Bernbjerg Formation. The dinoflagellate assemblages are correlated with older ammonite data, but the samples were not themselves directly associated with ammonites. A number of new species have been described and defined separately (Piasecki 2001).

Middle Jurassic

Lithostratigraphy

The Middle Jurassic succession on Store Koldewey, the Trækpasset Formation of Koch (1929), is a lateral equivalent in part of the geographically widespread Pelion Formation, and as there is little reason to maintain a separate stratigraphy for Store Koldewey, it is herewith re-assigned to the Pelion Formation. The upper part of the exposed succession is of Early to Middle Callovian age and biostratigraphically equivalent to the new Spath Plateau Member on Hold with Hope (Vosgerau *et al.* 2004, this volume) where the same two ammonite zones are recorded. This part of the Store Koldewey succession provides dinoflagellate cyst data from an interval that is not so well documented in Jameson Land (Milner & Piasecki 1996).

Ammonites and dinoflagellate cysts in the succession at Ravn Pynt may indicate a depositional break between the Bathonian and the Callovian parts of the Pelion Formation (Figs 3, 4). The basal Callovian comprises the only significant mudstone in this succession. This shift in depositional facies is associated with the appearance of Callovian ammonites and several of the uppermost Bathonian ammonite zones are not recorded beneath the facies shift. The absence of these zones



Lithology

- Sand
- Sand with gravel
- Mud

Structure

- Lamination
- Lenticular lamination
- Planar cross-bedding
- Shell bed
- Clay clasts
- Calcareous concretions
- Hardened bed

Fossils

- Thalassinoides* isp.
- Curvolithos* isp.
- Monocraterion* isp.
- Diplocraterion* isp.
- Planolites* isp.
- 16 Boreal ammonite fauna horizon
- Belemnite
- Bivalve
- Pinna* sp.
- Wood
- Serpulid
- Oyster
- 360691 GGU sample numbers

Fig. 2. Sedimentological log of the exposed Middle Jurassic succession at Ravn Pynt. Levels of the analysed palynological samples are indicated.

may indicate a hiatus in the sedimentary succession or simply no preservation of fauna and flora in that specific part of the section. Some of the absent ammonite faunas, however, have been collected just south of Ravn Pynt on Store Koldewey.

Ammonites

The Jurassic succession contains abundant ammonites in well-separated faunal horizons and the stratification is generally preserved despite some solifluction. The sedimentological succession was studied in a ravine at Ravn Pynt and four ammonite horizons were collected here *in situ* and directly correlated with the fine-grained palynological samples (Fig. 2). These ammonites represent the *Arcticoceras ishmae* Zone (horizon 16), the *Arcticoceras cranocephaloide* Zone (horizon 19a including topotypes of *Kepplerites tychonis* Ravn), the *Cadoceras apertum* Zone (horizon 26) and the *Proplanulites koenigi* Zone (horizon 31) of the standard Boreal ammonite biostratigraphy of Jameson Land (Calomon 1993). The age of the succession is then mid-Bathonian to Callovian based on the ammonite faunas.

Dinoflagellate cysts

The organic matter in the Middle Jurassic succession is dominated by black and brown woody material. The abundance of dinoflagellate cysts is generally low but the diversity is fair (65 recorded species, including a few acritarchs). The assemblages are dominated by proximate cysts accompanied by few cavate cysts but are basically barren of chorate cysts. Specimens from the *Pareodinia/Paraevansia/Evansia* and the *Escharisphaeridium/Sentusidinium* groups are the most abundant cysts. Successive species appear regularly upwards in the succession but the highest number of appearances is in GGU sample 360698 at 19.60 m (Fig. 4) at the base of a 13 m thick fine-grained interval (Fig. 2). This may reflect a hiatus in the succession below the sample and/or a shift to a more open marine depositional environment.

Since the Middle Jurassic succession is dated in detail by ammonites, the distribution of the dinoflagellate cysts can be used to increase the precision of their ranges in the Boreal Jurassic as previously recorded in other regions in East Greenland (Jameson Land and Hold with Hope). *Sirmiodinium grossii*, *Gonyaulacysta pectinigera*, *Paragonyaulacysta retiphragmata* and

Chytroeisphaeridia hyalina are the stratigraphically important species that occur throughout the investigated succession. *S. grossii* appears in the *Arctocephalites arcticus* Chronozone in Milne Land (Larsen *et al.* 2003) and becomes more frequent from approximately the *Arctocephalites cranocephaloide* Chronozone and upwards to the *Cadoceras apertum* Chronozone (Milner & Piasecki 1996). This increase in abundance of *S. grossii* is not observed here because no samples were collected from this part of the section. In Milne Land, *G. pectinigera* is recorded as becoming abundant from the *A. cranocephaloide* Chronozone upwards into the *C. apertum* Chronozone but again, this increase in abundance is not represented in the present section. In Jameson Land, *P. retiphragmata* has its earliest appearance in the *A. cranocephaloide* Chronozone but at Store Koldewey it clearly appears already in the *Arcticoceras ishmae* Chronozone. *C. hyalina* appeared earliest in the *Cadoceras calyx* Chronozone in Jameson Land (Milner & Piasecki 1996). The present material, in combination with new data from Jameson Land, show that *C. hyalina* is present already in the *A. ishmae* Chronozone and becomes abundant from the *C. apertum* Zone. *Aldorfia aldorfensis* appears in the *A. cranocephaloide* Chronozone precisely where it is expected from its range in Jameson Land (Milner & Piasecki 1996). The morphologically variable species *Ctenidodinium thulium* is recorded throughout the succession, having a much more extensive range than that recorded elsewhere in East Greenland. Towards the south, in Milne Land, it is restricted to the interval above the *A. cranocephaloide* Chronozone and below the *Paltoceras athleta* Chronozone (Larsen *et al.* 2003). This upper range is confirmed in these northern regions by data from Hold with Hope where it is recorded in strata just below the *P. athleta* Chronozone (Piasecki *et al.* 2004, this volume).

Many of the less frequent species seem to occur in a rather random way that makes their presence and especially their absence less stratigraphically useful. *Crussolia perireticulata* is a good example of this. In Milne Land, it occurs in the Bathonian *A. arcticus* Chronozone and again higher in the Callovian part of the succession (Larsen *et al.* 2003). In Jameson Land, it appears one ammonite zone higher than in Milne Land, the Bathonian *Arctocephalites greenlandicus* Chronozone and is then not recorded again until it reappears in the basal Callovian, top *C. apertum* Chronozone. There are no records of this species from the Bathonian or the Callovian of Store Koldewey and Hold with Hope. This could indicate a southern affinity of this

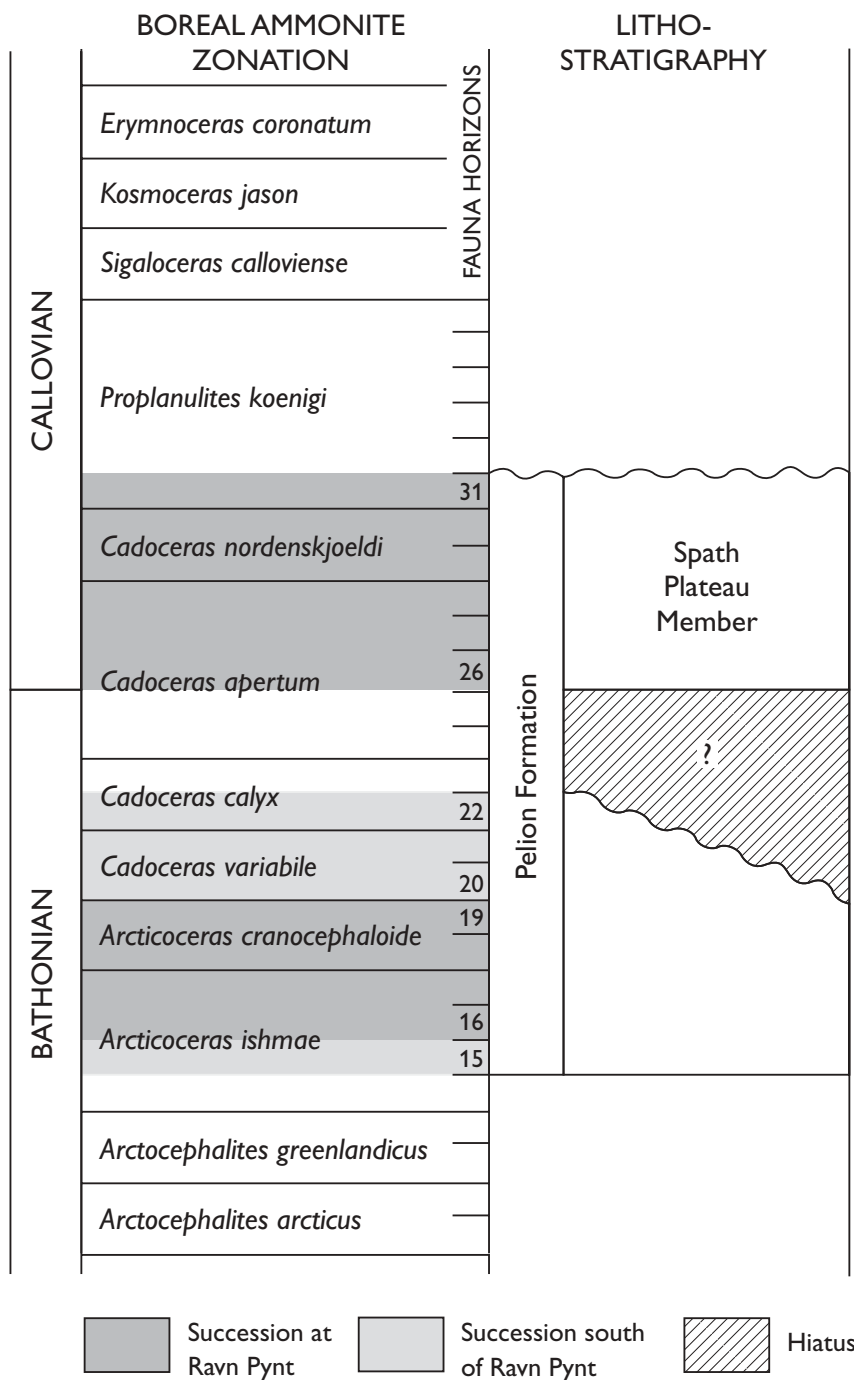


Fig. 3. Schematic stratigraphical classification of the Middle Jurassic succession on Store Koldewey.

species as the depositional settings of these localities are comparable overall. However, a Callovian range is reported from the present Arctic regions of the Sverdrup Basin and Svalbard (Smelror 1993).

Some exceptionally early occurrences of *Ambonosphaera calloviana* and *Gonyaulacysta helicoidea* in the *A. ishmae* Chronozone and of *Pareodinia stegasta* and *Paraevansia brachybelis* in the *C. apertum* Chronozone are recorded in the present succession.

The dinoflagellate cysts in the Middle Jurassic succession are divided into an Upper Bathonian and a Lower Callovian dinoflagellate cyst assemblage. The boundary is placed at 19.2 m, above which level a significant number of new species appear (Figs 2, 4). Most species in the Upper Bathonian assemblage also occur in the Lower Callovian assemblage and the composition of the Bathonian assemblage varies significantly between the few samples studied. The younger,

Store Koldewey

Ravn Pynt

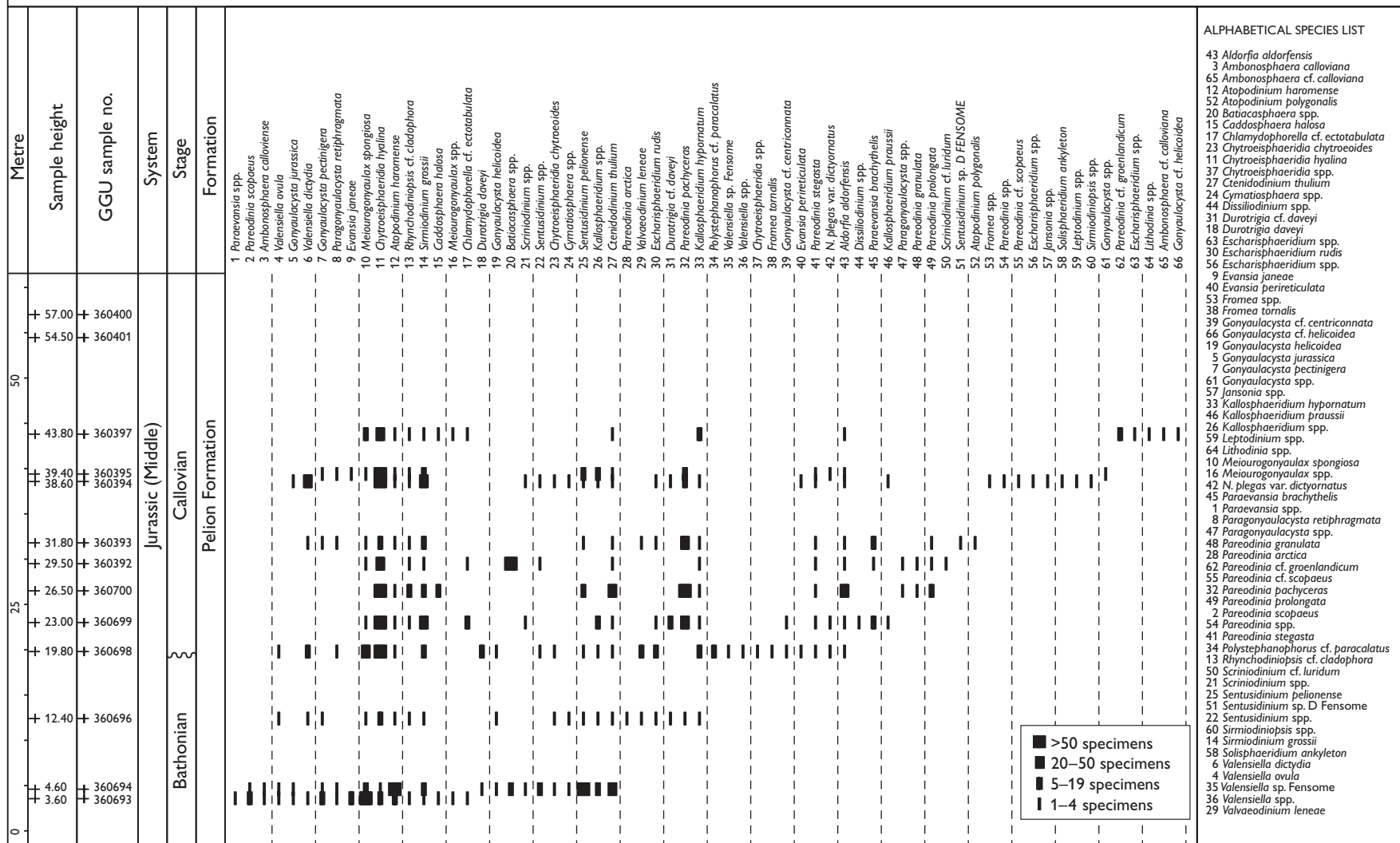


Fig. 4. Distribution chart of the dinoflagellate cysts in the Middle Jurassic succession at Ravn Pynt on Store Koldewey.

Lower Callovian assemblage is characterised by abundant *Chytroeisphaeridia hyalina* and *Pareodinia pachyceras*, together with many species not present below e.g. *Pareodinia stegasta*, *Aldorfia aldorfiense* and *Paraevansia brachythelis*.

Middle Jurassic correlation

The dinoflagellate cyst assemblage of the lower part of the succession (Bathonian) correlates with assemblages of the *A. arcticus* – *A. cranocephaloide* Chronozones from both Milne Land (Assemblages 2 and 3 in: Larsen *et al.* 2003) and Jameson Land (Milner & Piasecki 1996) in central East Greenland. The assemblages from the Charcot Bugt Formation in Milne Land are very poor, both in diversity and density, but have stratigraphically significant species such as *S. grossii*, *C. hyalina*, *Kallosphaeridium hypornatum* and *Evansia janaeae* in common with the present assemblage. In the same stratigraphical interval in the Fossilbjerget Formation of Jameson Land, new species appear for the first time in abundance and have many species in common with the assemblage from Store Koldewey. Differences in occurrence and first appearances of significant species between the two areas are discussed above.

The dinoflagellate cyst assemblage of the higher part of the succession (Lower Callovian) on Store Koldewey also correlates well with assemblages from the Charcot Bugt Formation in Milne Land, whereas the contemporaneous assemblages from the Fossilbjerget Formation in Jameson Land are poor and not so well documented. In contrast, dinoflagellate cyst assemblages from the Pelion Formation, Spath Plateau Member, on Hold with Hope (Piasecki *et al.* 2004, this volume) correlate well with assemblages from Store Koldewey. The assemblages in the Charcot Bugt Formation (Assemblages 4 and 5 in: Larsen *et al.* 2003) are not precisely dated but are not older than the *A. cranocephaloide* Chronozone (Bathonian) and not younger than the *Erymnoceras coronatum* Chronozone (top Middle Callovian).

Discussion

The correlation of the Pelion Formation on Store Koldewey with the Charcot Bugt, the Fossilbjerget and the Pelion Formations in southern parts of the Jurassic East Greenland basin complex shows that time-equivalent

sedimentary successions exist regionally in different lithostratigraphical units. The Middle Jurassic dinoflagellate assemblages vary with depositional environments but the overall characters can be recognised and correlated over long distances.

The main problem is the interdependence of deposition of relatively fine-grained sediments and preservation of dinoflagellate cysts, giving relatively few horizons with rich assemblages in the generally coarse-grained Middle Jurassic successions, i.e. the Pelion and Charcot Bugt Formations.

Upper Jurassic

Lithostratigraphy

The Upper Jurassic succession on Store Koldewey was defined as the Kløft I Formation (Koch 1929). Its lower sandstone-dominated part is equivalent to the recently defined Payer Dal Formation (Alsgaard *et al.* 2003) from Hold with Hope, Kuhn Ø and Hochstetter Forland further to the south, and the overlying mudstones are equivalent to the geographically extensive Bernbjerg Formation (Fig. 5). For convenience and simplification of the lithostratigraphy, the Kløft I Formation is not used here and the succession is referred to the Payer Dal and Bernbjerg Formations (Fig. 5).

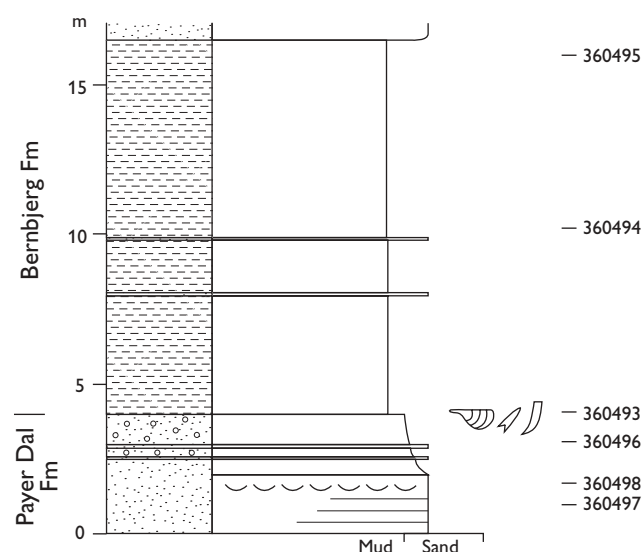


Fig. 5. Sedimentological log of the exposed Upper Jurassic succession at Kløft II with the levels of analysed samples marked. For legend, see Fig. 2.

Fig. 6. Schematic stratigraphical classification of the Upper Jurassic succession on Store Koldewey.

	Chronostratigraphy Chronozones	Lithostratigraphy Formations
Kimmeridgian	<i>Aulacostephanoides mutabilis</i>	Bernbjerg
	<i>Rasenia cymodoce</i>	
	<i>Pictonia baylei</i>	
<i>Amoeboceras rosenkrantzi</i>	Payer Dal	
<i>Amoeboceras regulare</i>		
<i>Amoeboceras serratum</i>		
<i>Amoeboceras glosense</i>		
Oxfordian		

Based on ammonites
 Based on dinoflagellate cysts

Ammonites

The old ammonite collections from the Kløft I Formation (Payer Dal Formation) described by Ravn (1911) were recently correlated more precisely with the British ammonite succession, confirming a Late Oxfordian to Early Kimmeridgian age, equivalent to the *Amoeboceras serratum*, *A. rosenkrantzi* and *Aulacostephanoides mutabilis* Zones (Fig. 6; Sykes & Surlyk 1976; Sykes & Callomon 1979). New ammonite finds indicate a similar age. These ammonites are not precisely located but most probably came from the sandstones referred here to the Payer Dal Formation. The samples analysed for dinoflagellate cysts are from the top of this formation and from the overlying Bernbjerg Formation (Fig. 6).

Dinoflagellate cysts

The organic content of the Upper Jurassic samples is dominated by brown and black woody material and the abundance and diversity of the dinoflagellate cyst floras are low. The richest samples are from the base of the Bernbjerg Formation, probably representing a flooding event. The dinoflagellate cysts are better preserved in the Payer Dal Formation than in the Bernbjerg Formation. The composition of the dinoflagellate cyst flora is clearly in favour of proximate cysts, with a minority of chorate specimens and species.

The Upper Jurassic succession comprises two assemblages, which intermingle at the transition from Payer Dal to Bernbjerg Formation (Fig. 7). The lower assemblage is characterised by *Gonyaulacysta dualis*, *Adnatosphaeridium* sp. (*A. bartzi* in: Piasecki 1980), *Taeniophora iunctispina*, *Ambonosphaera calloviana* and *Paragonyaulacysta capillosa*. This assemblage is well known from Oxfordian/Kimmeridgian strata in Milne Land in East Greenland (Piasecki 1980; Piasecki 1996), Hochstetter Forland (Piasecki & Stemmerik 2004, this volume) and in Peary Land, North Greenland (Håkansson *et al.* 1981; Piasecki 1994).

The upper assemblage is characterised by *Paragonyaulacysta capillosa*, *Occisucysta* sp., *Perisseiasphaeridium pannosum*, *Rhynchodiniopsis* sp. and *Rhynchodiniopsis* cf. *pennata*. This assemblage is known from Kimmeridgian strata in Milne Land with a slightly different frequency of the species involved (Piasecki 1996), and from Peary Land, North Greenland (Piasecki 1994) and Svalbard (Århus 1988).

The earliest *Paragonyaulacysta capillosa* on Milne Land appears in the basal Kimmeridgian, *Rasenia cymodoce* Chronozone, shortly before the earliest *Perisseiasphaeridium pannosum* and *Avellodinium* cf. *falsificum* at the base of the *A. mutabilis* Chronozone. These two events are recorded within an assemblage of abundant *Adnatosphaeridium* sp. (*A. bartzi* in: Piasecki 1980), *Taeniophora iunctispina*, *Gonyaulacysta jurassica/dualis* and *Ambonosphaera calloviana* that dominates from the Late Oxfordian (*A. rosenkrantzi*

Chronozone) to the earliest Kimmeridgian (*Pictonia baylei* and *R. cymodoce* Chronozones). A similar order of appearances occurs in the Upper Jurassic succession of Store Koldewey and the presence of *Occisucysta* sp. in these strata also supports a stratigraphical level equivalent to the *R. cymodoce* Chronozone by comparison with the assemblages from Milne Land.

P. pannosum becomes abundant in Milne Land in the *A. mutabilis* Chronozone and dominates the dinoflagellate assemblages throughout the *A. eudoxus* Zone until *Oligosphaeridium patulum* becomes the totally dominant species in the *A. autissiodorensis* Chronozone. The assemblage on Store Koldewey contains *Perisseiasphaeridium pannosum* most abundantly at the transition between the two formations and *Oligosphaeridium patulum* follows rapidly at the base of Bernbjerg Formation. None of the two species are abundant at higher levels in the Bernbjerg Formation at Kløft II.

Upper Jurassic correlation

The Upper Jurassic dinoflagellate cyst assemblages on Store Koldewey closely resemble the Boreal assemblages from the Jurassic Ladegårdsåsen Formation of Peary Land (Piasecki 1994), and to some degree also the assemblage in the Janusfjellet Formation, Svalbard (Århus 1988). However, the restricted ammonite faunas in these two formations do not allow precise dating of the dinoflagellate assemblages on Peary Land and Svalbard. The most significant difference between these assemblages is the presence of *P. pannosum* and *O. patulum* only at Store Koldewey. *Adnatosphaeridium* sp. and *Taeniophora iunctispina* occur as far north as Peary Land but are not reported from Svalbard.

The stratigraphically highest occurrence of *Gonyaulacysta dualis*, *Atopodinium baromense*, *Occisucysta* sp. in Peary Land, in an assemblage with abundant *Escharisphaeridium pocockii*, *Rhynchodiniopsis* sp., *Taeniophora iunctispina* and *Adnatosphaeridium* sp. is associated with the appearance of *Paragonyaulacysta capillosa* and *Cribroperidinium perforans*. This assemblage and associated stratigraphic events in Peary Land are directly comparable with the dinoflagellate cyst assemblage at the transition from the Payer Dal Formation to the Bernbjerg Formation on Store Koldewey. The age of this assemblage is interpreted to be Early Kimmeridgian (*R. cymodoce*–*A. mutabilis* Chronozones).

A comparable event has not been recorded in the

Kimmeridgian of Svalbard (Janusfjellet Formation) where only *Paragonyaulacysta capillosa* seems to have stratigraphical potential, with a consistently relative short range (Århus 1988). There, *P. capillosa* appears after a poor to barren interval in the Upper Oxfordian to lowermost Kimmeridgian, above a poor ammonite record of *Rasenia* sp. and at a level where bioturbated mudstones are followed by laminated mudstones, just as on Store Koldewey and in Milne Land. The appearance of *P. capillosa* and its associated assemblage may therefore reflect a relative sea-level rise. The presence of *P. capillosa* and its associated dinoflagellate cyst assemblage may be used as a general indication of the stratigraphical level from the *R. cymodoce* Chronozone into the *A. mutabilis* (*A. eudoxus*?) Chronozone. The few other associated species in the Janusfjellet section are the stratigraphically long-ranging species *Paragonyaulacysta borealis*, *Lanterna saturnalis* and *Trubertella apatela*, the typical Borealis Assemblage (Brideaux & Fisher 1976) which also occurs in East and North Greenland.

The dinoflagellate cyst assemblages in Peary Land and Svalbard provide no clear upper stratigraphical limits, except for the disappearance of *P. capillosa*. *P. capillosa* occurs commonly up to the *A. autissiodorensis* Chronozone (top Kimmeridgian) in Milne Land but is also recorded scattered throughout the Volgian. The successions at Store Koldewey, Peary Land and Svalbard within the range of abundant *P. capillosa* are therefore considered to be of Kimmeridgian (pre-Volgian) age.

Discussion

Despite the similarity in composition and abundance of specific species in the geographically widespread assemblages described above, there are also clear differences reflecting the latitudinal distance between the compared localities. The Upper Jurassic dinoflagellate cyst assemblage on Store Koldewey is a mixture of species with Subboreal or Boreal preference but with a clear affinity to the Boreal region. *P. pannosum* and *O. patulum* are abundant and long-ranging in Northwest Europe, they are abundant with a more restricted stratigraphical range in East Greenland, and they appear in low numbers with a limited stratigraphical range in Store Koldewey. This is probably close to the northern limit of these species as they do not appear farther to the north in Peary Land (Piasecki 1994) and Svalbard (Århus 1988). On Store Koldewey, the occurrence of these species so far north is associated with the most

significant relative sea-level rise recorded in the Upper Jurassic of East Greenland, in the *R. cymodoce* to *A. mutabilis* (*A. eudoxus*) Chronozones of the Kimmeridgian.

Sequence stratigraphic implications

Studies of the Jurassic ammonite and dinoflagellate cyst stratigraphy integrated with sedimentological studies and sequence stratigraphical interpretations in East Greenland lead towards an integrated genetic model in which the units can be identified by their content of dinoflagellate cysts. The present study of the dinoflagellate cyst assemblages on Store Koldewey contributes to the study of this complex problem.

The Middle Jurassic succession deposited directly on crystalline basement on Store Koldewey correlates with contemporaneous and stratigraphically similar successions from the lower part of the Fossilbjerget Formation in Jameson Land (P5 and P6 third-order sequences of Engkilde & Surlyk 2003), the Charcot Bugt Formation in Milne Land (Larsen *et al.* 2003) and the Pelion Formation at Hold with Hope (Vosgerau *et al.* 2004, this volume). Both in Milne Land and on Hold with Hope, the Middle Jurassic successions represent the earliest evidence of the Jurassic transgression of the margins of the sedimentary basins. The ammonite fauna from the *A. ishmae* Chronozone is among the most widespread faunas in the Arctic (Callomon 1993) and marks the considerable extent of this circum-Arctic second-order marine transgression represented also in most areas of East Greenland. The third-order depositional sequence P5 in Jameson Land is limited by sequence boundaries located in the *A. ishmae* and *C. calyx* Chronozones, respectively (Engkilde & Surlyk 2003). The P6 depositional sequence is confined to the *C. apertum*, *C. nordenskjoldi* and basal *P. koenigi* Chronozones. Stratigraphically, P5 and P6 correspond to the two sedimentological units identified in the Middle Jurassic of Store Koldewey and their content of dinoflagellate cysts correlates as well.

In Milne Land, the Charcot Bugt Formation also contains ammonites from the *A. ishmae* and the *A. cranecephaloide* Zones (Larsen *et al.* 2003). The associated dinoflagellate cyst assemblages correlate well with assemblages from the corresponding lower Pelion succession on Store Koldewey. Dinoflagellate cysts from the higher Pelion Formation, the Spath Plateau Member, at Store Koldewey (*C. apertum* Chronozone to the basal *P. koenigi* Chronozone) correlate with those

from Assemblage 4 from the Charcot Bugt Formation.

On Hold with Hope, the Pelion Formation comprises two sedimentological units: a lower sandstone unit followed by the Spath Plateau Member (Vosgerau *et al.* 2004, this volume). Ammonites indicating the *C. apertum* Zone and the *P. koenigi* Zone occur in the basal strata of Spath Plateau Member. Dinoflagellate cyst assemblages equivalent to the assemblages from the corresponding Spath Plateau Member on Store Koldewey have been recorded in this succession (Piasecki *et al.* 2004, this volume).

Thus, two distinct dinoflagellate cyst assemblages of Bathonian and Callovian age characterise the two sedimentological units that have been identified as third-order depositional sequences and are found to be extensively distributed throughout East Greenland.

As already mentioned above, the Upper Jurassic succession on Store Koldewey, consisting of the Payer Dal and Bernbjerg Formations, correlates excellently with contemporaneous successions from eastern Peary Land and Svalbard in the north to Milne Land in the south. The overall transgressive trend from the Upper Oxfordian to maximum flooding in the Kimmeridgian is represented by sedimentary deposits throughout East and North Greenland that can be correlated in detail on the basis of both ammonites and dinoflagellate cysts. A succession of distinct dinoflagellate cyst assemblages characterises the stepwise progress of relative sea-level rise and can be recognised throughout the sedimentary basins of East Greenland.

Conclusion

The Jurassic succession of Store Koldewey is divided into the Pelion, Payer Dal and Bernbjerg Formations. Abundant Boreal ammonites date the succession in detail and associated floras of dinoflagellate cyst provide supplementary data. The Pelion Formation is dated as Late Bathonian – Early Callovian, in the Middle Jurassic, and the Payer Dal and Bernbjerg Formations are dated as Late Oxfordian – Early Kimmeridgian in the Late Jurassic.

The Middle Jurassic succession consists of a Bathonian and a Callovian part. They can be correlated with contemporaneous sedimentary successions on Hold with Hope, in Jameson Land and in Milne Land to the south, where corresponding dinoflagellate cyst assemblages have been recorded. Ranges of individual dinoflagellate species are given in relation to the Boreal ammonite stratigraphy.

The Upper Jurassic succession is correlated with corresponding successions in Hochstetter Forland, Hold with Hope and Milne Land to the south and with those of Peary Land, North Greenland, and Svalbard to the north. Passing northwards from East Greenland via North Greenland to Svalbard, the Upper Jurassic dinoflagellate cyst floras show a transition from dominantly Subboreal species in central East Greenland to a distinct Boreal flora in Svalbard. The stratigraphic ranges of many species and their abundance decrease towards the north. In contrast, species with Boreal affinity range southwards to Milne Land. The assemblages in Store Koldewey are transitional in composition.

The sedimentological units of Store Koldewey are placed in the sequence stratigraphic framework developed for the Jurassic in East Greenland, and the associated dinoflagellate cyst assemblages are used to characterise and to identify these sequence stratigraphic elements.

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References

- Alsgaard, P.C., Felt, V.L., Vosgerau, H. & Surlyk, F. 2003: The Jurassic of Kuhn Ø, North-East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 865–892.
- Århus, N. 1988: Palynostratigraphy of some Bathonian–Haute-rievian sections in the Arctic, with emphasis on the Janusfjellet Formation type section, Spitsbergen. Institutt for Kontinentalsokkelundersøkelser (IKU) Report **23.1252.11/01/88**, 139 pp.
- Brideaux, W.W. & Fisher, M.J. 1976: Upper Jurassic – Lower Cretaceous dinoflagellate assemblages from Arctic Canada. Geological Survey of Canada Bulletin **259**, 1–53.
- Callomon, J.H. 1993: The ammonite succession in the Middle Jurassic of East Greenland. Bulletin of the Geological Society of Denmark **40**, 83–113.
- Engkilde, M. & Surlyk, F. 2003: Shallow marine syn-rift sedimentation: Middle Jurassic Pelion Formation, Jameson Land, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 813–863.
- Håkansson, E., Birkelund, T., Piasecki, S. & Zakharov, V. 1981: Jurassic–Cretaceous of the extreme Arctic (Peary Land, North Greenland). Bulletin of the Geological Society of Denmark **30**, 11–42.
- Haller, J. 1983: Geological map of Northeast Greenland 75°–82°N Lat. Meddelelser om Grønland **200**(5), 22 pp.
- Henriksen, N. 1997: Geological map of Greenland 1:500 000, Sheet 10, Dove Bugt. Copenhagen: Geological Survey of Denmark and Greenland.
- Koch, L. 1929: Stratigraphy of Greenland, 124 pp. Dr. Scient thesis, University of Copenhagen, Denmark.
- Larsen, M., Piasecki, S. & Surlyk, F. 2003: Stratigraphy and sedimentology of a basement-onlapping shallow marine sandstone succession, the Charcot Bugt Formation, Middle–Upper Jurassic, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 893–930.
- Milner, P.S. & Piasecki, S. 1996: Boreal Middle Jurassic dinoflagellate cyst stratigraphy of Jameson Land, East Greenland. In: Piasecki, S. *et al.* (eds): Formation of source and reservoir rocks in a sequence stratigraphic framework, Jameson Land, East Greenland. Energy research programme EFP-93, projects 1313/93-0010 and 0017. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1996/30**, Vol. I and II, 46 pp.
- Piasecki, S. 1980: Middle to Late Jurassic dinoflagellate cyst stratigraphy from Milne Land (East Greenland) correlated with ammonite stratigraphy, 167 pp. Unpublished Ph.D. thesis, University of Copenhagen, Denmark.
- Piasecki, S. 1994: Biostratigraphy of the Jurassic – Lower Cretaceous Ladegårdsåen Formation, Peary Land. In: Håkansson, E. (ed.): Wandel Sea Basin: Basin Analysis. EFP-91, Project No. 0012, 1–14.
- Piasecki, S. 1996: Boreal dinoflagellate cyst stratigraphy of Middle to Upper Jurassic sediments of Milne Land, East Greenland. In: Piasecki, S. *et al.* (eds): Formation of source and reservoir rocks in a sequence stratigraphic framework, Jameson Land, East Greenland. Energy research programme EFP-93, Projects 1313/93-0010 and 0017. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1996/30**, Vol. I and II, 100 pp.
- Piasecki, S. 2001: Three new Middle Jurassic dinoflagellate cysts of East Greenland. Neues Jahrbuch für Geologie und Paläontologie. Abhandlungen **219**(1–2), 15–31.
- Piasecki, S. & Stemmerik, L. 2004: Jurassic dinoflagellate cysts from Hochstetter Forland, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 89–97 (this volume).
- Piasecki, S., Stemmerik, L., Friderichsen, J.D. & Higgins, A.K. 1994: Stratigraphy of the post-Caledonian sediments in the Germania Land area, North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 183–190.
- Piasecki, S., Larsen, M., Therkelsen, J. & Vosgerau, H. 2004: Jurassic dinoflagellate cyst stratigraphy of Hold with Hope,

- North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 73–88 (this volume).
- Ravn, J.P.J. 1911: On Jurassic and Cretaceous fossils from North-East Greenland. Meddelelser om Grønland **45**(10), 437–500.
- Smelror, M. 1993: Biogeography of Bathonian to Oxfordian (Jurassic) dinoflagellates: Arctic, NW Europe and circum-Mediterranean regions. Palaeogeography, Palaeoclimatology, Palaeoecology **102**, 121–160.
- Stemmerik, L. & Piasecki, S. 1990: Post-Caledonian sediments in North-East Greenland between 76° and 78°30'N. Rapport Grønlands Geologiske Undersøgelse **148**, 123–126.
- Sykes, R.M. & Callomon, J.H. 1979: The *Amoeboceras* zonation of the Boreal Upper Oxfordian. Palaeontology **22**(4), 839–903.
- Sykes, R.M. & Surlyk, F. 1976: A revised ammonite zonation of the Boreal Oxfordian and its application in North-East Greenland. Lethaia **9**, 421–436.
- Vosgerau, H., Larsen, M., Piasecki, S., Therkelsen, J. & Surlyk, F. 2004: A new Middle–Upper Jurassic succession on Hold with Hope, North-East Greenland. In: Stemmerik, L. & Stouge, S. (eds): The Jurassic of North-East Greenland. Geological Survey of Denmark and Greenland Bulletin **5**, 51–71 (this volume).

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