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*. *Adnatospahaeridium* 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

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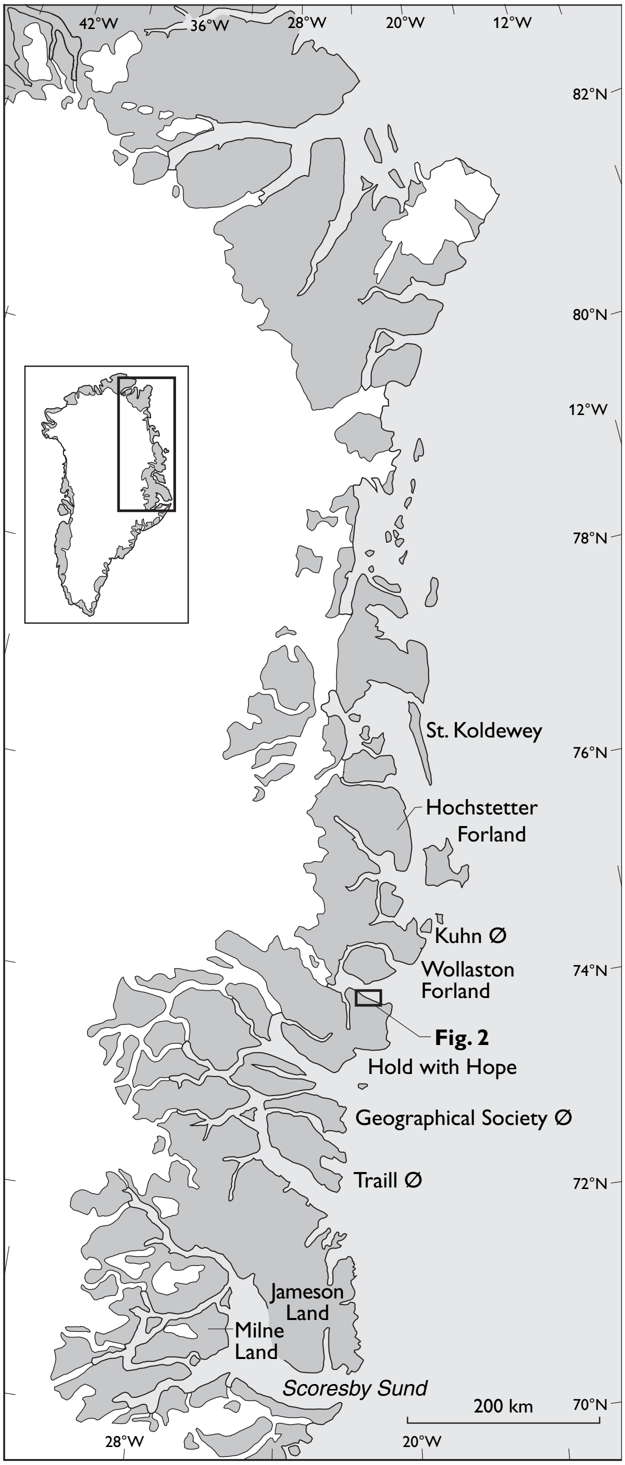

Fig. 1. Locality map of East Greenland and eastern North Greenland. The **white** region illustrates the permanent inland ice cap of Greenland, the **grey** areas are ice-free. Hold with Hope is located between 73°N and 74°N.

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

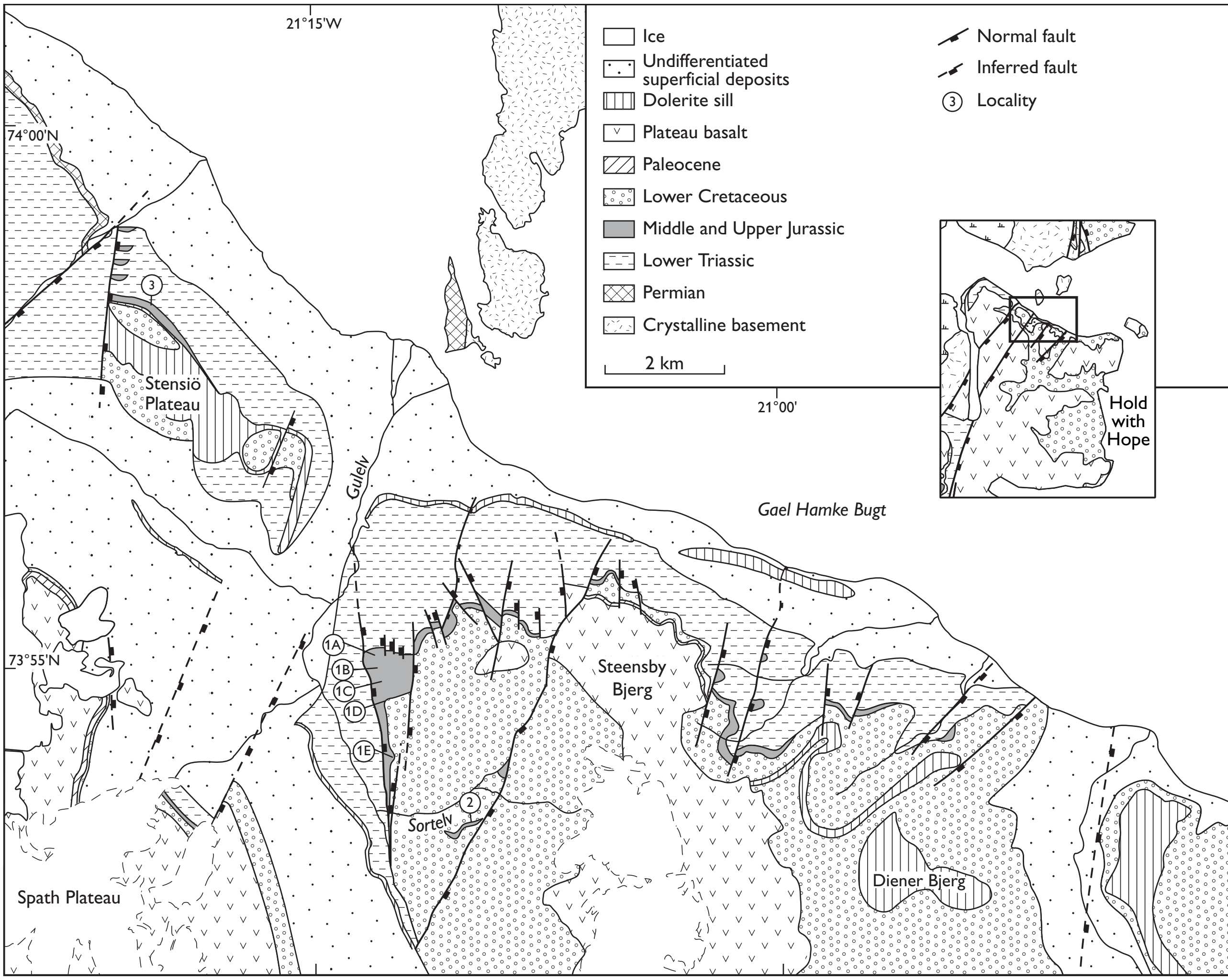

Fig. 2. Geological map of the northern Hold with Hope which illustrates the distribution of the studied Jurassic succession. Localities 1, 2 and 3 are marked; the succession at Locality 1 has been compiled from a number of short laterally correlated sections (**1A–1E**).

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-

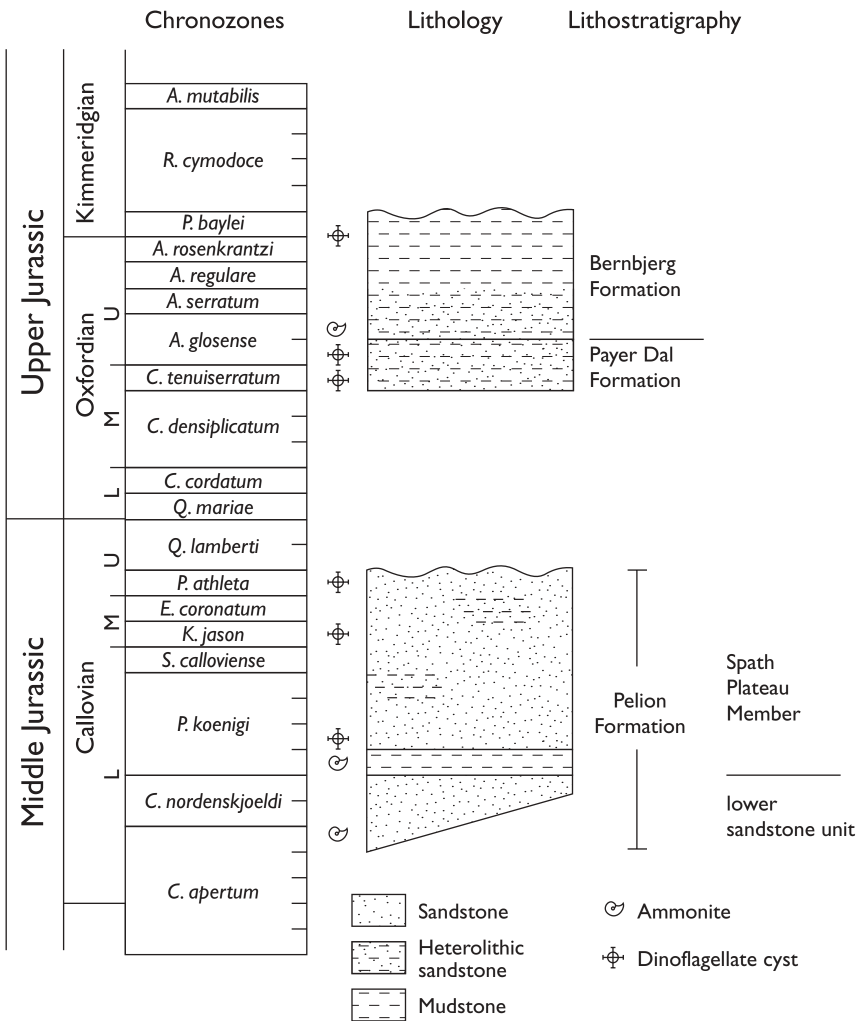

Fig. 3. Schematic correlation of the Jurassic succession on northern Hold with Hope. The lithostratigraphical units are correlated with the Middle to Upper Jurassic chronozonation on the basis of ammonites and dinoflagellate cysts. Points of correlation to chronozones are indicated by ammonite or dinoflagellate 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 (HNO_3) 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 stratigraphy (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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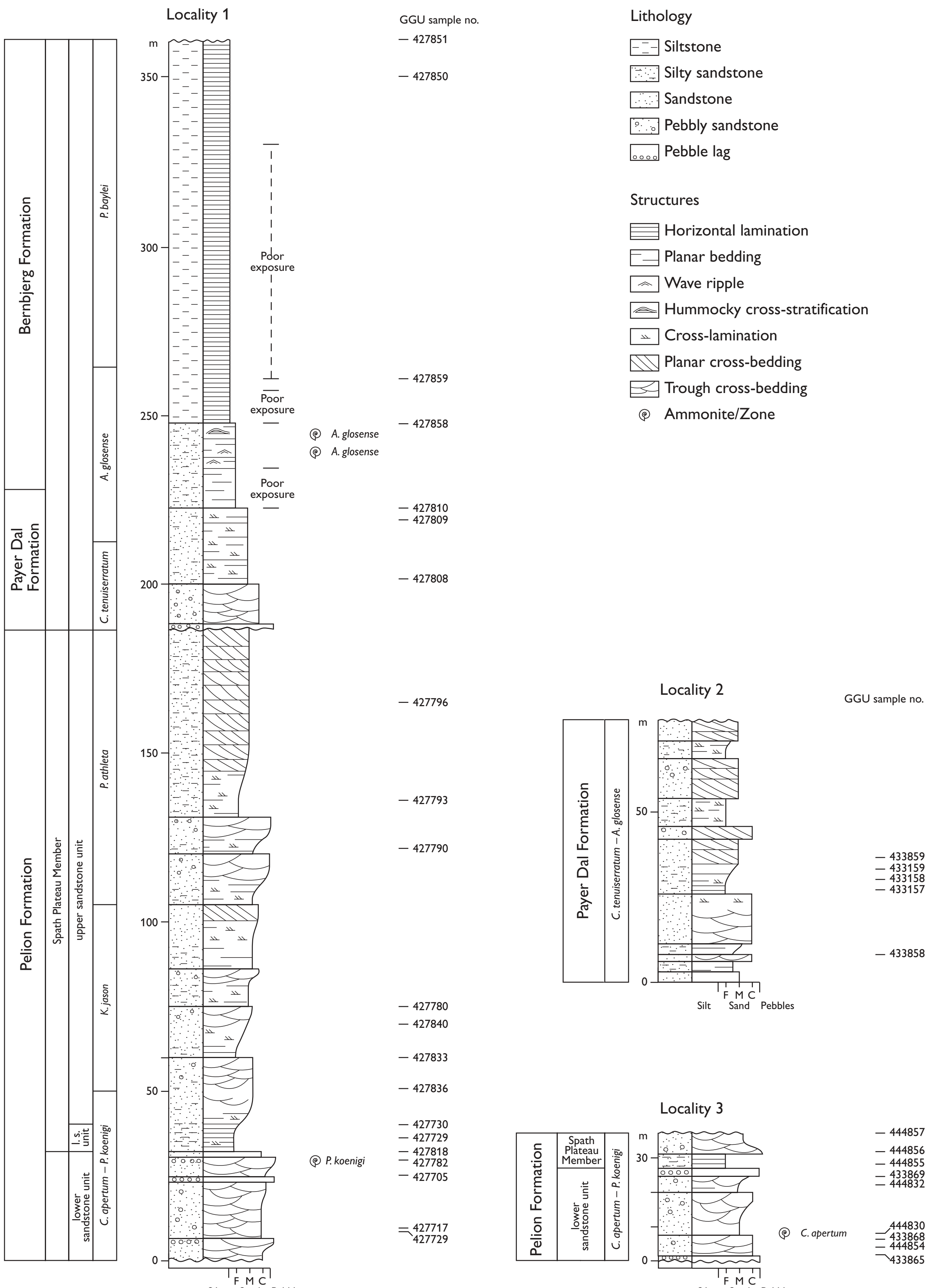
Fig. 4. Simplified sedimentological logs of the Jurassic succession from Localities 1, 2 and 3 on northern Hold with Hope. The formal and informal lithostratigraphic units are indicated together with the ammonite horizons; **l.s.**, lower shale.



Locality 1
GGU sample no.
Bernbjerg Formation
Payer Dal Formation
Pelion Formation
Spath Plateau Member
upper sandstone unit
l. s. unit
lower sandstone unit
P. baylei
A. glosense
C. tenuiserratum
P. athleta
K. jason
C. apertum – P. koenigi
m
350
300
250
200
150
100
50
0
Poor exposure
Poor exposure
Poor exposure
A. glosense
A. glosense
P. koenigi
427851
427850
427859
427858
427810
427809
427808
427796
427793
427790
427780
427840
427833
427836
427730
427729
427818
427782
427705
427717
427729
F M C
Silt
Sand
Pebbles
Lithology
Siltstone
Silty sandstone
Sandstone
Pebbly sandstone
Pebble lag
Structures
Horizontal lamination
Planar bedding
Wave ripple
Hummocky cross-stratification
Cross-lamination
Planar cross-bedding
Trough cross-bedding
Ammonite/Zone
Locality 2
GGU sample no.
Payer Dal Formation
C. tenuiserratum – A. glosense
m
50
0
433859
433159
433158
433157
433858
F M C
Silt
Sand
Pebbles
Locality 3
Pelion Formation
Spath Plateau Member
lower sandstone unit
C. apertum – P. koenigi
m
30
0
C. apertum
444857
444856
444855
433869
444832
444830
433868
444854
433865
F M C
Silt
Sand
Pebbles

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 brachythelis* 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). *Chytroeispharidia 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 Koldewey (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 Koldewey (Piacecki *et al.* 2004, this volume; Vosgerau *et al.* 2004, this volume).

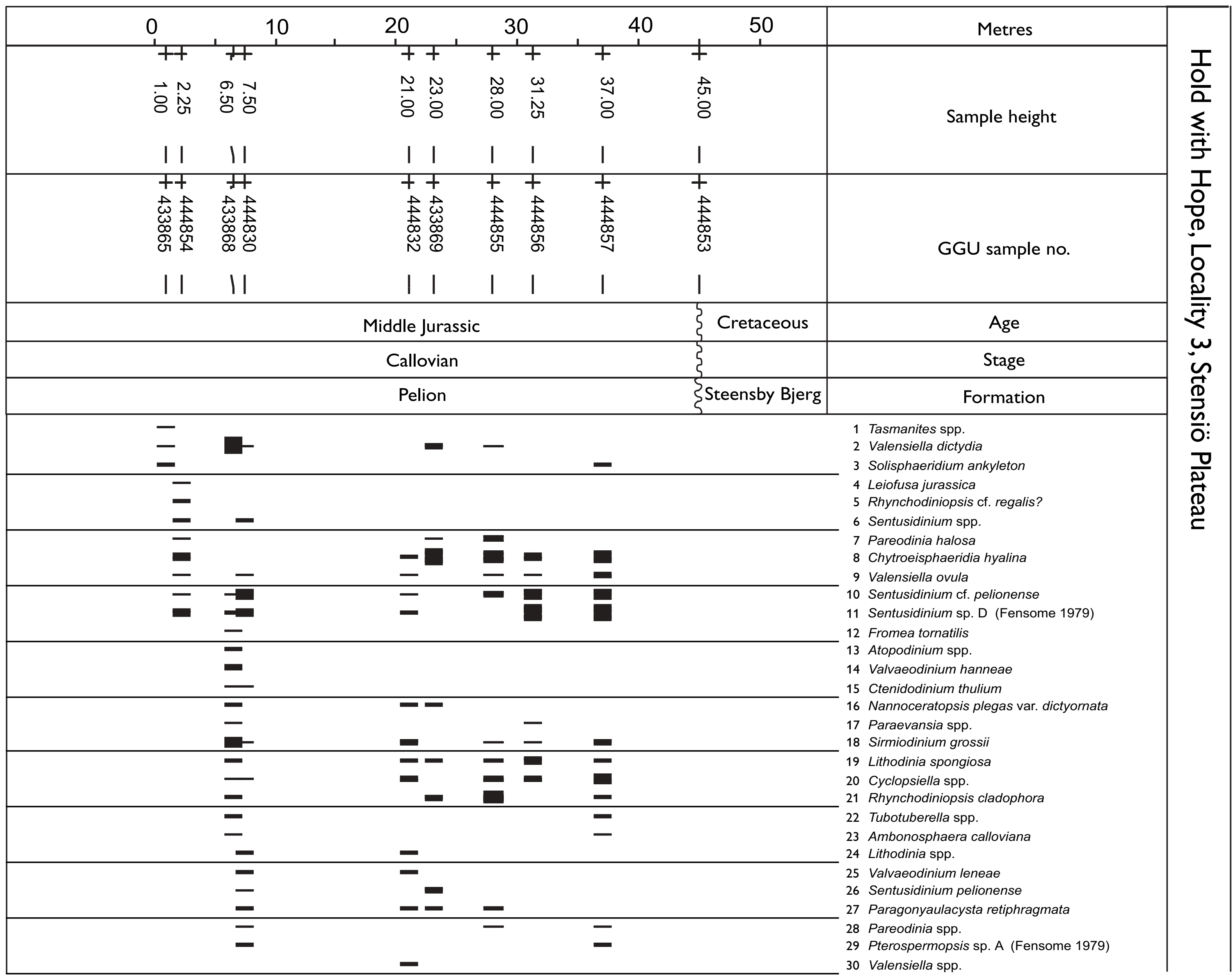
Age. The age of the 'basal shale unit' of the Spath Plateau Member is Early Callovian, equivalent to the *C. apertum* – *P. koenigi* Chronozones.

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 scarburghense* 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.*



Hold with Hope, Locality 3, Stensiö Plateau

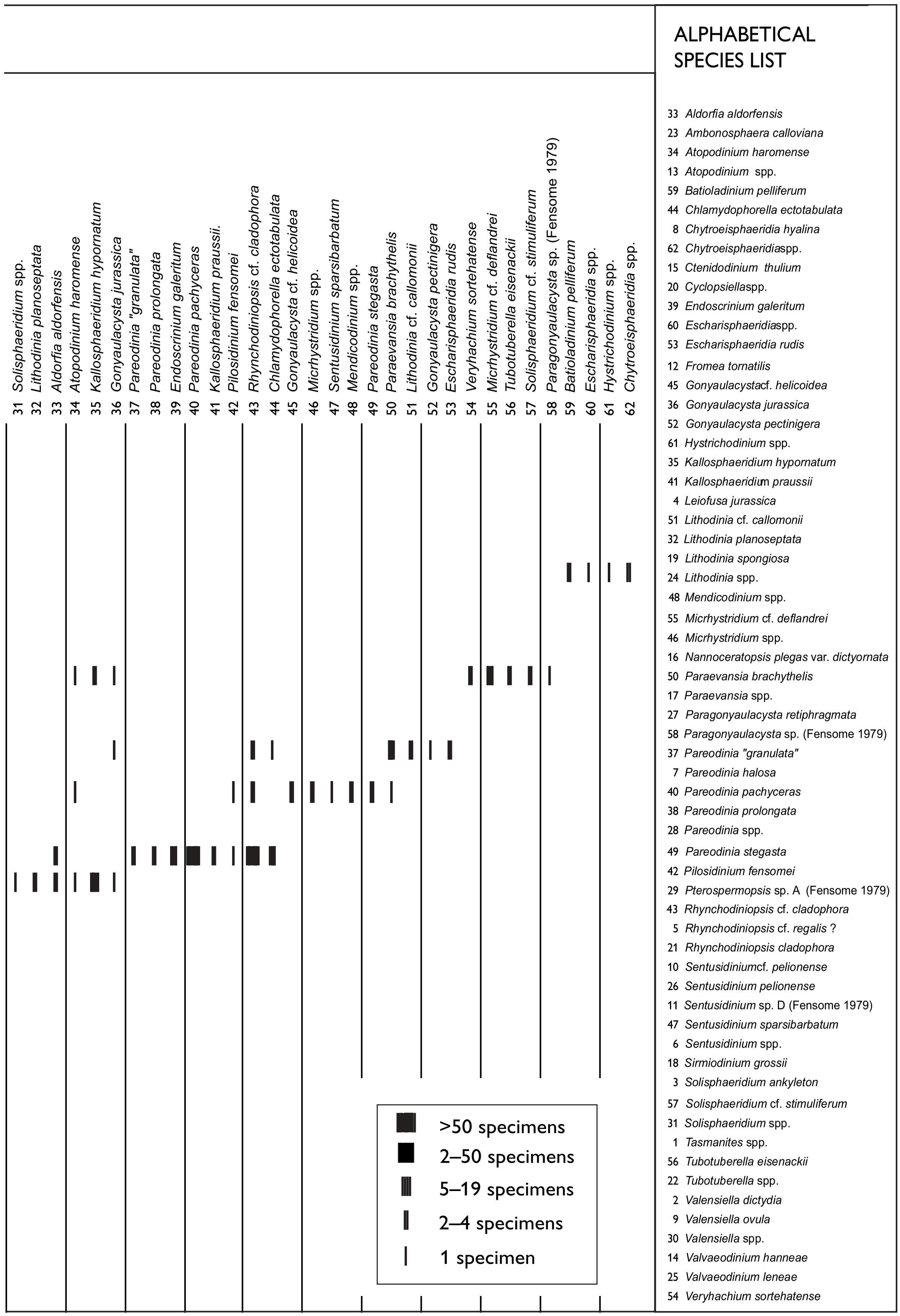
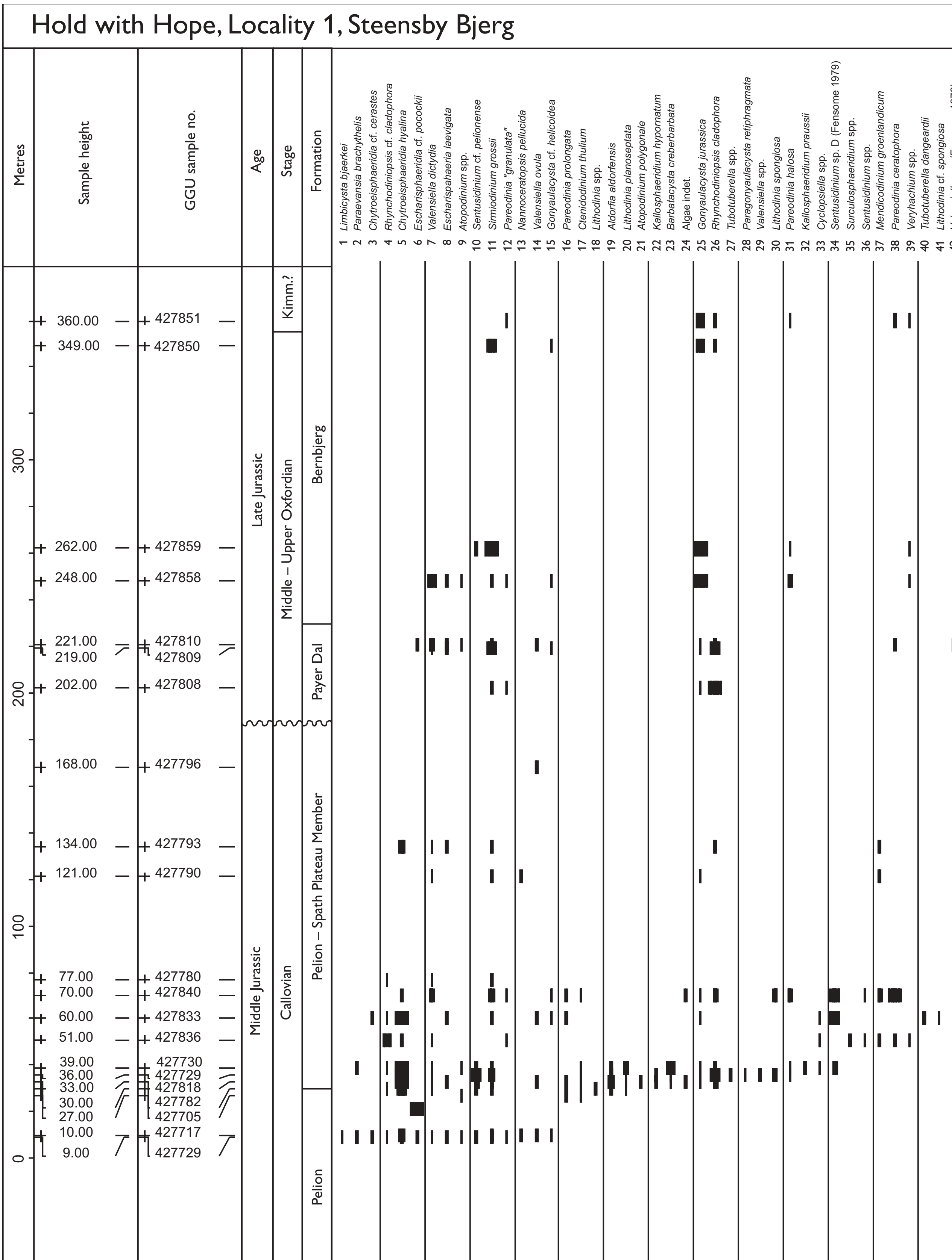
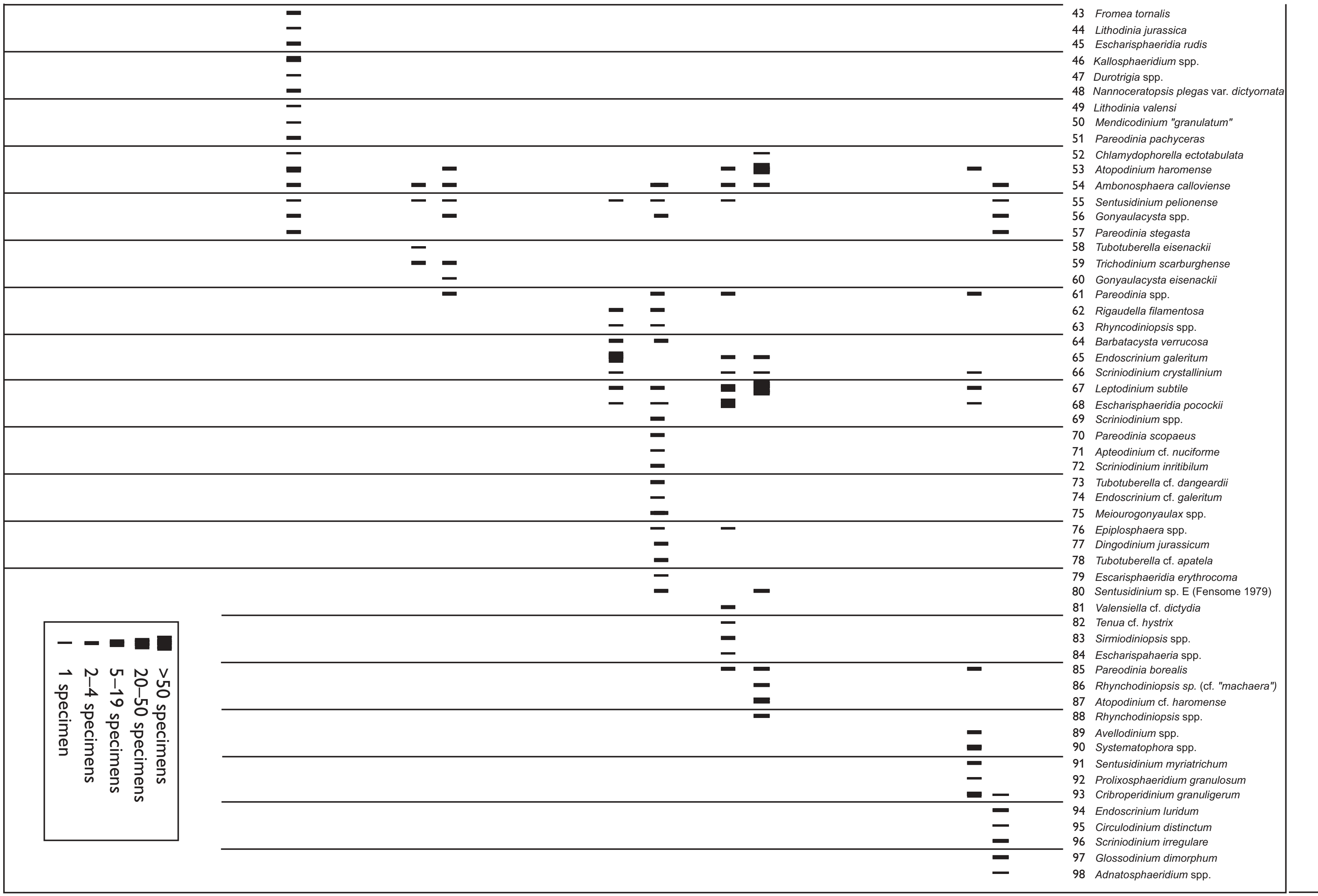


Fig. 5. Distribution chart of dinoflagellate cysts in the Jurassic succession at Locality 3, Stensiö Plateau, northern Hold with Hope. The first appearances of species are stratigraphically arranged. The Jurassic succession is overlain unconformably by Cretaceous strata of the Steensby Bjerg Formation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


Hold with Hope, Locality 1, Steensby Bjerg
Metres
Sample height
GGU sample no.
Age
Stage
Formation
0
100
200
300
360.00
349.00
262.00
248.00
221.00
219.00
202.00
168.00
134.00
121.00
77.00
70.00
60.00
51.00
39.00
36.00
33.00
30.00
27.00
10.00
9.00
427851
427850
427859
427858
427810
427809
427808
427796
427793
427790
427780
427840
427833
427836
427730
427729
427818
427782
427705
427717
427729
Late Jurassic
Middle Jurassic
Kimm.?
Middle – Upper Oxfordian
Callovian
Bernbjerg
Payer Dal
Pelion – Spath Plateau Member
Pelion
1 Limbicysta bjaerkei
2 Paraevansia brachythelis
3 Chytroeisphaeridia cf. cerastes
4 Rhynchodiniopsis cf. cladophora
5 Chytroeisphaeridia hyalina
6 Escharisphaeridia cf. pocockii
7 Valensiella dictydia
8 Escharispahaeria laevigata
9 Atopodinium spp.
10 Sentusidinium cf. pelionense
11 Sirmiodinium grossii
12 Pareodinia "granulata"
13 Nannoceratopsis pellucida
14 Valensiella ovula
15 Gonyaulacysta cf. helicoidea
16 Pareodinia prolongata
17 Ctenidodinium thulium
18 Lithodinia spp.
19 Aldorfia aldorfensis
20 Lithodinia planoseptata
21 Atopodinium polygonale
22 Kallosphaeridium hypornatum
23 Barbatacysta creberbarbata
24 Algae indet.
25 Gonyaulacysta jurassica
26 Rhynchodiniopsis cladophora
27 Tubotuberella spp.
28 Paragonyaulacysta retiphragmata
29 Valensiella spp.
30 Lithodinia spongiosa
31 Pareodinia halosa
32 Kallosphaeridium praussii
33 Cyclopsiella spp.
34 Sentusidinium sp. D (Fensome 1979)
35 Surculosphaeridium spp.
36 Sentusidinium spp.
37 Mendicodinium groenlandicum
38 Pareodinia ceratophora
39 Veryhachium spp.
40 Tubotuberella dangeardii
41 Lithodinia cf. spongiosa
42 Valensiella sp. (Fensome 1979)


43 Fromea tornalis
44 Lithodinia jurassica
45 Escharisphaeridia rudis
46 Kallosphaeridium spp.
47 Durotrigia spp.
48 Nannoceratopsis plegas var. dictyornata
49 Lithodinia valensi
50 Mendicodinium "granulatum"
51 Pareodinia pachyceras
52 Chlamydophorella ectotabulata
53 Atopodinium haromense
54 Ambonosphaera calloviense
55 Sentusidinium pelionense
56 Gonyaulacysta spp.
57 Pareodinia stegasta
58 Tubotuberella eisenackii
59 Trichodinium scarburghense
60 Gonyaulacysta eisenackii
61 Pareodinia spp.
62 Rigaudella filamentosa
63 Rhyncodiniopsis spp.
64 Barbatacysta verrucosa
65 Endoscrinium galeritum
66 Scriniodinium crystallinium
67 Leptodinium subtile
68 Escharisphaeridia pocockii
69 Scriniodinium spp.
70 Pareodinia scopaeus
71 Apteodinium cf. nuciforme
72 Scriniodinium inritibilum
73 Tubotuberella cf. dangeardii
74 Endoscrinium cf. galeritum
75 Meiourogonyaulax spp.
76 Epiplosphaera spp.
77 Dingodinium jurassicum
78 Tubotuberella cf. apatela
79 Escarisphaeridia erythrocoma
80 Sentusidinium sp. E (Fensome 1979)
81 Valensiella cf. dictydia
82 Tenua cf. hystrix
83 Sirmiodiniopsis spp.
84 Escharispahaeria spp.
85 Pareodinia borealis
86 Rhynchodiniopsis sp. (cf. "machaera")
87 Atopodinium cf. haromense
88 Rhynchodiniopsis spp.
89 Avellodinium spp.
90 Systematophora spp.
91 Sentusidinium myriatrichum
92 Prolixosphaeridium granulosum
93 Cribroperidinium granuligerum
94 Endoscrinium luridum
95 Circulodinium distinctum
96 Scriniodinium irregulare
97 Glossodinium dimorphum
98 Adnatosphaeridium spp.
>50 specimens
20–50 specimens
5–19 specimens
2–4 specimens
1 specimen

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 chytroeides*, *Rhynchodiniopsis* sp., *Prolixosphaeridium granulosum* and *Dingodinium jurassicum*.

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

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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.

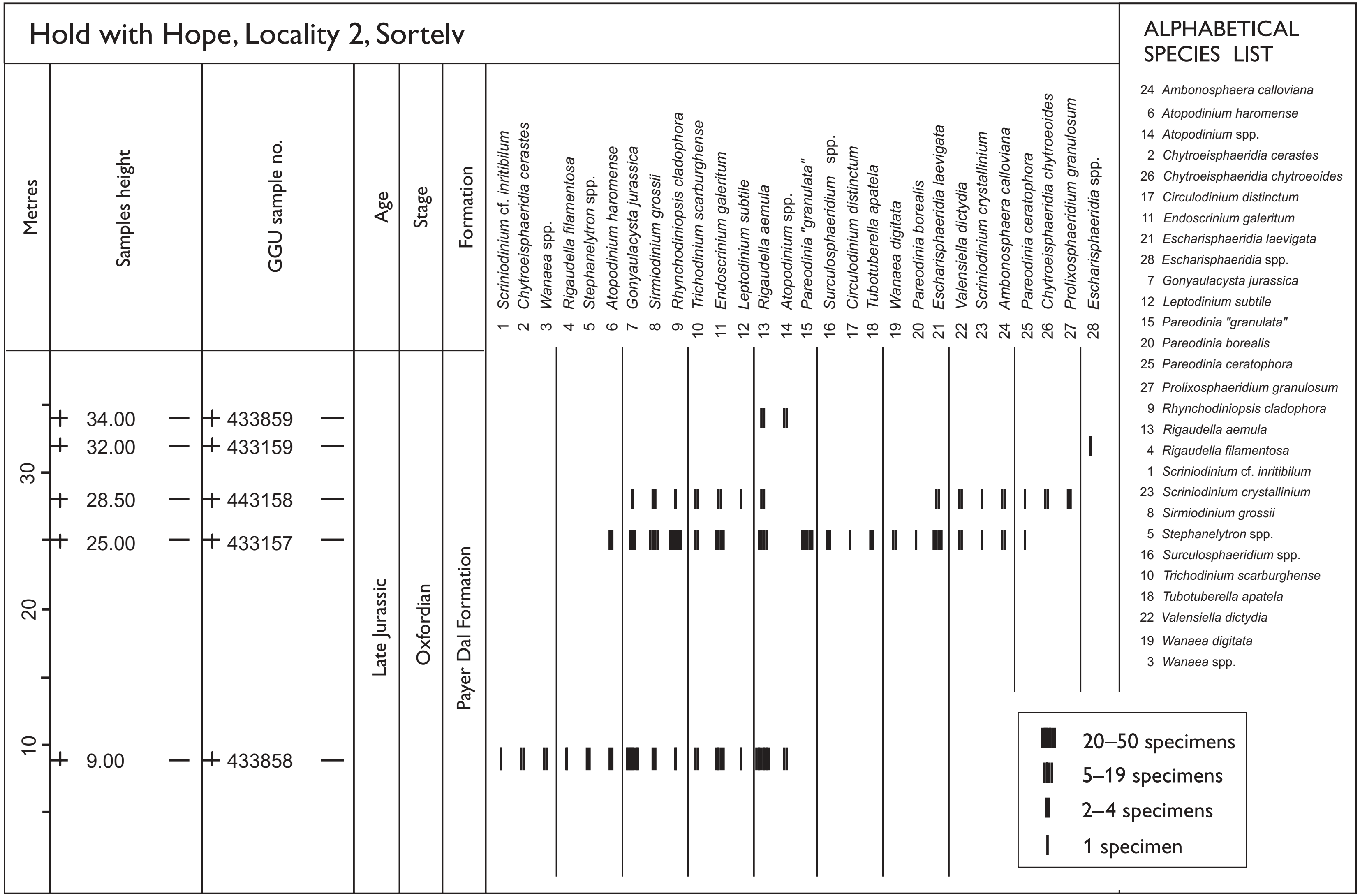

Fig. 7. Distribution chart of dinoflagellate cysts in the Jurassic succession at Locality 2, Sortelv, western Steensby Bjerg, Hold with Hope. The first appearance of species is stratigraphically arranged.

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 scharburghense* 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 shoreface 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 *Paragonyaulacysta borealis*, *Rhynchodiniopsis* sp. and *Tenua* cf. *hystrix*. The assemblage is very similar to the assemblage 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. / *Adnathosphaeridium* 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*, *Sciniodinium 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 sporomophs 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 hiati 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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