DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2006/23

Biostratigraphy zonation (palynology and macrofossil) for the Upper Cretaceous – Lower Palaeogene based on the sedimentary succession in Kangerlussuaq, southern East Greenland

Phase 1 report for the Sindri Group
March 2006

Nøhr-Hansen, H. & Larsen, M. (GEUS)
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MINISTRY OF THE ENVIRONMENT

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G E U S

Contents

Preface

This report forms the final deliverable of Phase 1 of the research project: “Biostratigraphy zonation (palynology and macrofossil) for the Upper Cretaceous – Lower Palaeogene based on the sedimentary succession in East Greenland” jointly conducted by the Geological Survey of Denmark and Greenland (GEUS) and CASP (Formerly Cambridge Arctic Shelf Programme). The project was initiated in February 2005 (phase 1 and 2) and will be concluded in January 2007 (Phase 3). It forms part of the Sindri programme: “Future Exploration Issues Programme of the Faroese Continental Shelf” (briefly referred to at the Sindri programme) established by the Faroese Ministry of Petroleum and financed by the partners of the Sindri Group.

The current licensees of the Sindri Group are: Agip Denmark BV, Amerada Hess (Faroes) Ltd., Anadarko Faroes Company, P/F Atlantic Petroleum, BP Amoco Exploration Faroes Ltd., British Gas International BV, DONG Føroyar P/F, Enterprise Oil Exploration Ltd., Føroya Kolvetni P/F, Petro-Canada Faroes GmbH, Phillips Petroleum Europe Exploration Ltd., Shell (UK) Ltd., and Statoil Færøyene AS.

Abstract

Data gathered in the ongoing Sindri stratigraphy project have shown that the Upper Cretaceous – Lower Palaeogene succession of the northern North Atlantic still presents problems for biostratigraphic correlation. The main reasons for the apparent correlation problems are the extensive erosion occurring at the K/T boundary at basin margins, poor preservation of palynomorphs due to intense heating by Palaeogene intrusions and extensive reworking of Upper Cretaceous strata. The project aims to investigate the correlation problems for the Cretaceous – Lower Palaeogene succession in the northern North Atlantic (West and East Greenland – Faroes – UK) based on biostratgraphic framework established in onshore sections. This is accomplished by analysis of a large number of mudstones and macrofossils from the Kangerlussuaq Basin. The results of the study are important for dating and correlation of the new wells drilled in Faroese waters and for predicting volcanic influence on basin evolution and reservoir properties in the Early Paleocene. Based on the new sampling of the Skiferbjerg succession and new material from the Watkins Fjord, Fairytale Valley and Sill City successions a revised palyno-stratigraphy has been proposed for the Upper Cretaceous – Lower Palaeogene succession in Kangerlussuag.

Based on the new sampling of the Skiferbjerg succession and new material from the Watkins Fjord, Fairytale Valley and Sill City successions a revised palyno-stratigraphy based on events is proposed for the Upper Cretaceous – Lower Palaeogene succession in Kangerlussuaq. The results are in good agreement with the collected macrofossils and indicate that strata of Turonian, Coniacian, and Maastrictian age are found in the basin. The Santonian, Campanian and the uppermost Maastrictian, however appears to be unrepresented and like most places around the Northern North Atlantic the K/T boundary is represented by a major unconformity.

The results of the study are important for dating and correlation of the new wells drilled in Faroese waters and West of Shetland and for predicting volcanic influence on basin evolution and reservoir properties in the early Paleocene

Introduction

Southern East Greenland provides a unique opportunity to study at outcrop the sedimentary basins associated with rifting and break-up of the North Atlantic. An ~1 km thick sub-basaltic sedimentary succession of Cretaceous to Palaeogene age is exposed in Kangerlussuaq (Fig. 1). The Sindri project ”Stratigraphy of the pre-basaltic sedimentary succession of the Kangerlussuaq Basin” concluded in 2005 established a sedimentological and stratigraphic framework for the basin, but also revealed the need for additional biostratigraphic data. In the original project a limited number of new palynological samples were prepared and interpreted. Experience gained from the stratigraphy project, however showed the need for analysing a much larger number of palynological samples to overcome problems of low recovery and thermal effects from intrusion. In areas away from major intrusions palynological work thus suggested the existence of Lower Paleocene strata, a fact that has otherwise been disputed in the literature. In addition a significant discrepancy between ages determined from macrofossils compared to dinoflagellate cysts/spores and pollen suggested extensive reworking of Upper Cretaceous strata or that a revision of the Upper Cretaceous – Lower Palaeogene biostratigraphic schemes is needed.

This project includes preparation of mudstone samples from the Upper Cretaceous – Lower Palaeogene succession in Kangerlussuaq (Fig. 2). The samples were collected specifically for the project in 2004 and originate from sections that are least affected by Palaeogene intrusions. The sample spacing was approximately 1 m, compared to previous material collected at 10 m spacing and thus allow for identification of subtle changes in flora assemblages across critical stage boundaries. The relative high number of samples processed and analysed in this study also increases the chance for recovering less thermally altered samples. In addition to the mudstone samples macrofossils were collected from the various sections. These comprise ammonites, bivalves (mainly inoceramids) and echinoids.

The palynological assemblages found in the Kangerlussuaq area are correlated with the existing stratigraphies for the North Atlantic including the West Greenland succession. Whenever possible, correlation with macrofossils (bivalves, ammonites) is made. In phase 3 of the project, spore and pollen data from the ongoing Phase 2 of this project by David Jolley will be integrated in the revised stratigraphy.

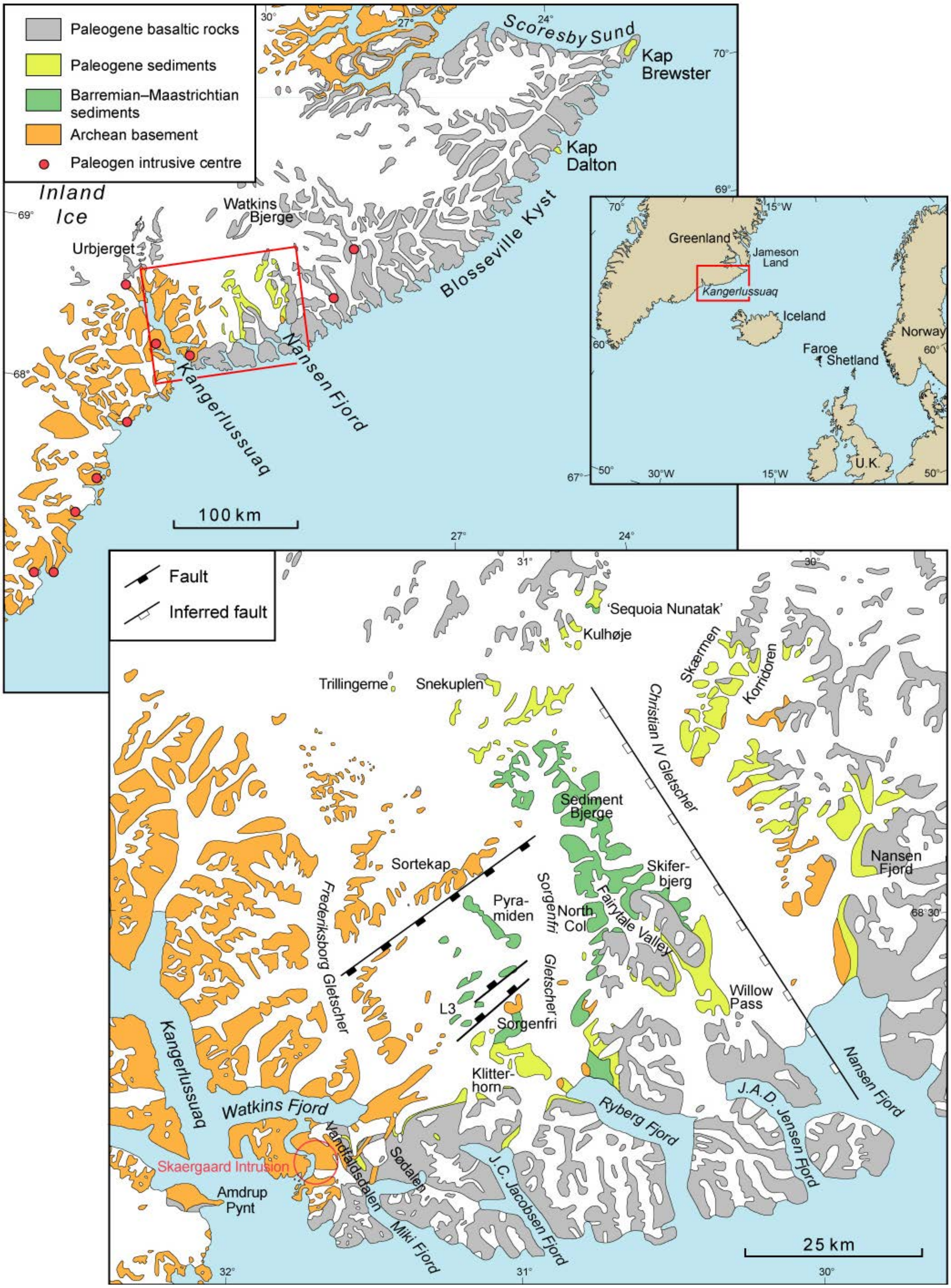


Figure 1. *Geological maps showing the distribution of the Cretaceous–Palaeogene sediments and the Palaeogene flood basalts of the southern East Greenland volcanic province.*

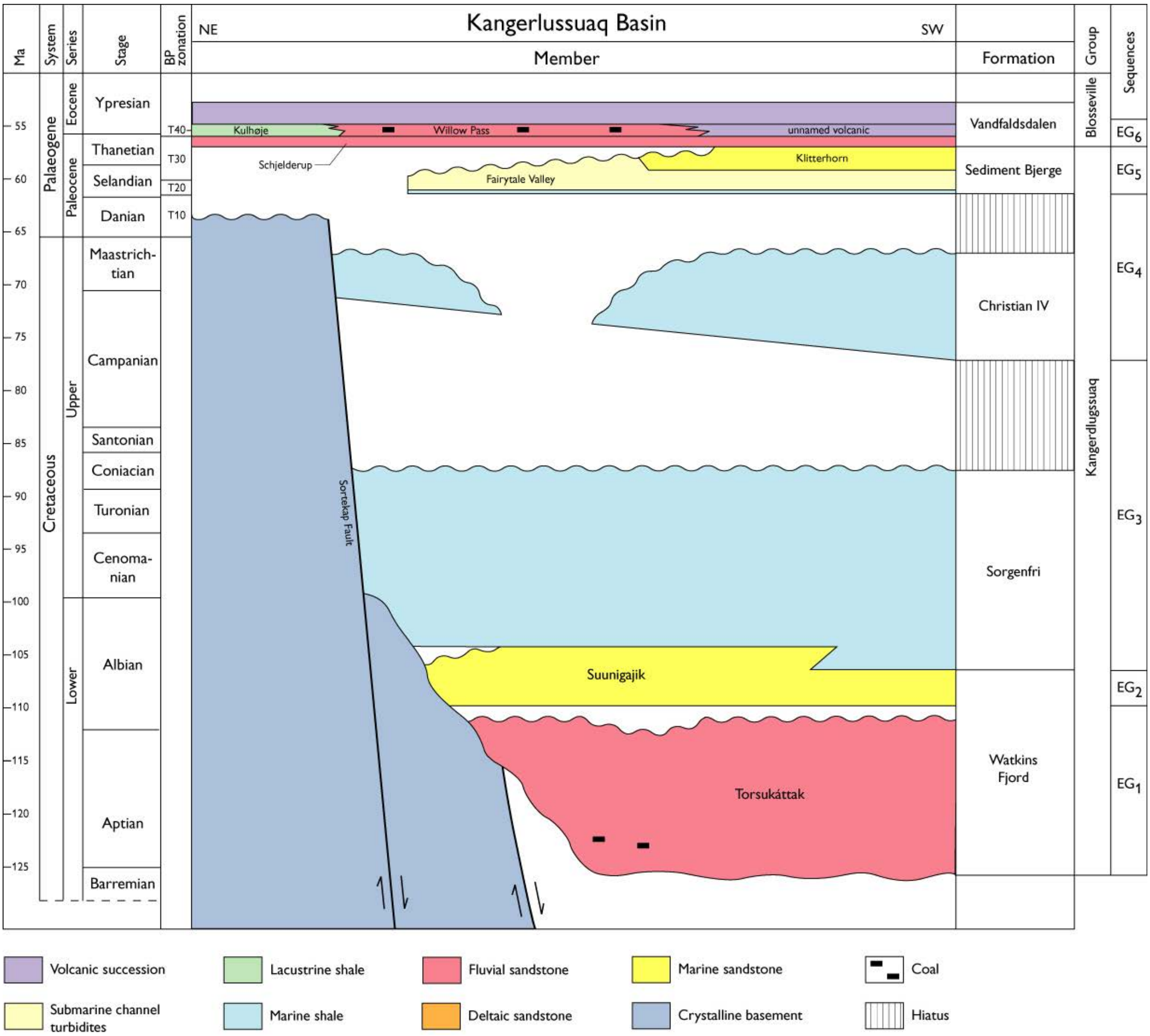


Figure 2. *Simplified stratigraphic scheme for the sedimentary succession in the Kangerlussuaq Basin with proposed new formations and members (Larsen et al. 2005). Time scale from Gradstein et al. 2004.*

Palynostratigraphy

By Henrik Nøhr-Hansen

Methods

Palynological preparation and studies of the samples were carried out at the Geological Survey of Denmark and Greenland (GEUS). Palynomorphs were extracted from 20 g of sediment from each sample by modified standard preparation techniques including treatment with hydrochloric (HCl) and hydrofluoric (HF) acids, sieving using a 20 μ nylon mesh and oxidation (3–10 minutes) with concentrated nitric acid (HNO_3). Finally, palynomorphs were separated from coal particles and woody material in most samples, using the separation method described by Hansen and Gudmundsson (1978) or by swirling. After each of the steps mentioned above the organic residues were mounted in a solid medium (Eukitt ®) or in glycerine gel. The palynological slides were studied with transmitted light using a Leitz Dialux 22 microscope (No. 512 742/057691). Dinoflagellate cysts, acritarchs and selected stratigraphically important spores and pollen species were recorded from the sieved, oxidised or gravity-separated slides. Approximately 100 specimens were counted whenever possible. Stratigraphically important dinoflagellate cysts and pollen are illustrated on plates 1–10; each illustration is marked with sample number, slide number, locality, stratigraphic height and image database number (laser-video-record number (LVR)).

The sample position and relative abundance of species referred to in the biostratigraphic section (below) are illustrated on range-charts of eight selected sections (Enclosures 1–8).

Material

The present stratigraphic study is based on the study of 142 samples representing 11 sections from the Kangerlugssuaq area collected between 1995 and 2004.

1) Skiferbjerg 2004 section, (equivalent to CASP W4245, W4246), 61 samples (collected at 1 m spacing). Marine deposits of Early to Late Maastrichtian age. Preservation poor to fair.

2) Skiferbjerg 2003 section, (equivalent to CASP W4245, W4246), 21 samples (collected at 10 m spacing). Marine deposits of Early to Late Maastrichtian age. Preservation poor to fair.

3) Sequoia West section, 8 samples. Marine deposits of late Early to early Late Maastrichtian age. Preservation fair.

4) Sequoia Nunatak section, (CASP W4235 composite including W4236, W4237, W4238), 6 samples. Marine deposits of early Late Maastrichtian age. Preservation fair.

5) Watkins Fjord 2003 section, (CASP W4259, W4260; W4291), 8 samples. Marine deposits of Cretaceous and Danian age. Preservation poor.

6) Watkins Fjord 2004 section, (CASP W4259, W4260; W4291), 8 samples. Marginal marine deposits of Early Cretaceous age and marine deposits of Danian age. Preservation poor.

7) Fairytale Valley section, (CASP W4220), 5 samples. Marine deposits of middle to late Selandian age. Preservation poor.

8) Sill City section, (CASP W4259, W4260; W4291), 17 samples. Marine deposits of Late Cretaceous and late Selandian age. Preservation poor.

9) North Col 2004 section, 3 samples. Organic material thermally overmature.

10) Rybjerg Fjord North 2004 section, 2 samples. Organic material thermally overmature.

11) Christian IV Col 2004 section, 3 samples. Organic material thermally overmature.

Palynostratigraphic results

Early to Late Maastrichtian

Skiferbjerg 2004

The Skiferbjerg 2004 succession represents 260 m of the Christian IV Formation (Fig. 3). The succession represents the same succession as Skiferbjerg 2003, however at the 2004 section samples were collected with 1 m spacing. The re-sampling of the succession was carried out in order to solve the biostratigraphical questions raised during the study of the Skiferbjerg 2003 (Larsen *et al.* 2005). The general state of preservation of the material is poor and it has often only been possible to identify the examined specimens to generic level. The Skiferbjerg 2003 succession was first questionably interpreted as spanning the Maastrichtian – Danian boundary, however based on the new material collected in 2004 it has been possible to refer the entire section to uppermost Cretaceous, and a palyno-

stratigraphy for the Maastrichtian has been established (Fig. 4). The stratigraphy is also illustrated on the enclosed rangechart for Skiferbjerg 2004 (Enclosure 1). The stratigraphy has been used for correlation with the Sequoia West and the Sequoia Nunatak sections.
The results of the study illustrate that most of the middle Maastrichtian is represented, whereas the uppermost Maastrichtian is missing.

Figure 3. *Type section of the Christian IV Formation along the western side of the glacier. Height of section c. 250 m.*

Well preserved ammonite, echinoderm and bivalve specimens are recorded scattered from both Skiferbjerg 2003 and 2004 and dated (see Kelly and Whitham below). The preservation of palynomorphs is fair to very poor, very poor in the lower and upper parts. The presence of the dinoflagellate cyst *Cerodinium diebelii* throughout most of the section (60–232 m) suggests an age not older than Early Maastrichtian and the presence of the pollen *Wodehouseia spinata* in the upper part (145–234 m) suggests a Late Maastrichtian age according to Nichols & Sweet (1993).

Based on these observations, the lower part (60–145 m) is correlated with the *Cerodinium diebelii* interval of Early Maastrichtian age and the upper part (145–236 m) is correlated with the *Wodehouseia spinata* interval of Late Maastrichtian age described from West Greenland (Nøhr-Hansen, 1996; Fig. 5).

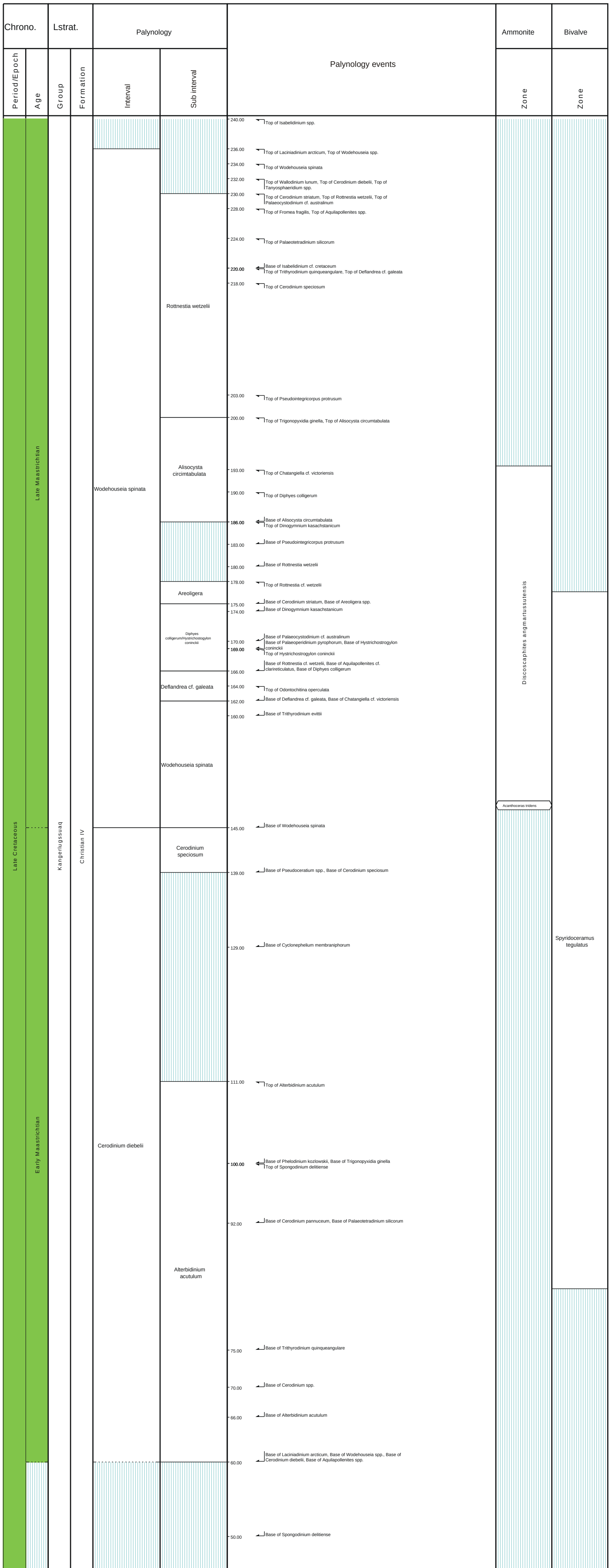
Cerodinium diebelii interval (60–145 m)

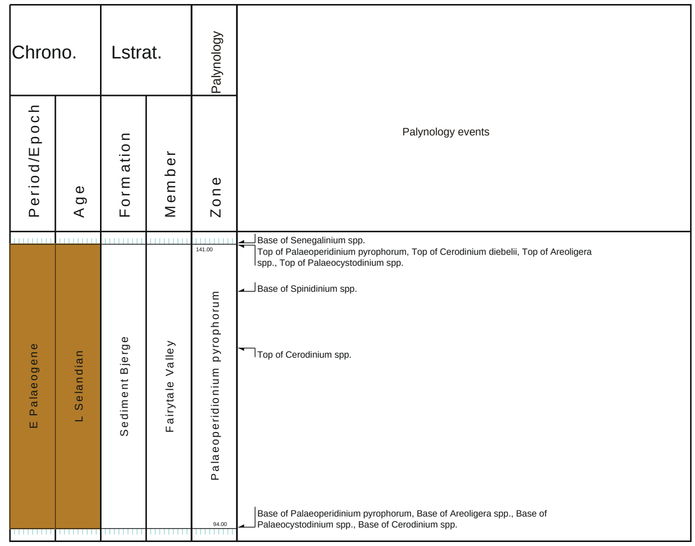
Definition. The Interval was defined as being from the First Occurrence (FO) of *Cerodinium diebelii* to immediately below the FO of the pollen species *Wodehouseia spinata* by Nøhr-Hansen (1996).

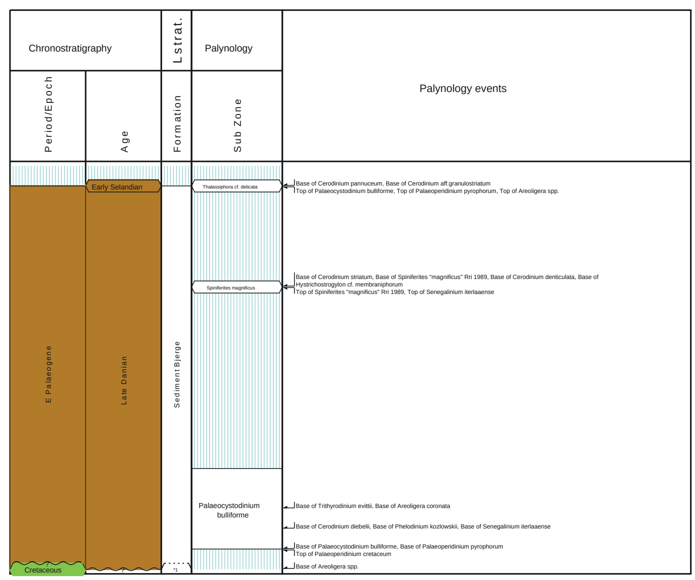
Discussion and correlation. The *Cerodinium diebelii* interval is dominated by *Hystrichosphaeridium tubiferum*, *Isabelidinium* spp., *Spiniferites* spp. and the pollen *Aquilapollenites* spp. is present throughout the interval. A single *Wodehouseia* sp. specimen has been recorded from the base (60 m). Schiøler and Wilson (2001) recorded the FO of *Cerodinium diebelii* from the uppermost Campanian from the proposed Campanian–Maastrichtian type locality at Tercis les Bains, France and Nicols and Sweet (1993) considered the FO of the genus *Wodehouseia* to mark the Campanian–Maastrichtiaan boundary. *Rhombodella paucispina* and *Bourkidinium* sp. occur in the lower part (66–75 m), reworked from Albian–Cenomanian strata.

The *Cerodinium diebelii* interval may be subdivided into two local palyno sub-intervals based on the first occurrences/ranges of characteristic species. The sub-intervals and their correlation to published stratigraphies are discussed below.

Figure 4. *Palynostratigraphy and marker events from the three Kangerlussuaq area key sections: Skiferbjerg 2004, Watkins Fjord 2003 and Fairytale Valley. Ammmonite and bivalve Zones from Kelly and Whitham.*


Chrono.
Lstrat.
Palynology
Palynology events
Ammonite
Bivalve
Period/Epoch
Age
Group
Formation
Interval
Sub interval
Zone
Zone
Late Cretaceous
Late Maastrichtian
Early Maastrichtian
Kangerlugssuaq
Christian IV
Wodehouseia spinata
Cerodinium diebelii
Rottnestia wetzelii
Alisocysta circimtabulata
Areoligera
Diphyes colligerum/Hystrichostogylon coninckii
Deflandrea cf. galeata
Wodehouseia spinata
Cerodinium speciosum
Alterbidinium acutulum
Discoscaphites angmartussutensis
Acanthoceras tridens
Spyridoceramus tegulatus
240.00 Top of Isabelidinium spp.
236.00 Top of Laciniadinium arcticum, Top of Wodehouseia spp.
234.00 Top of Wodehouseia spinata
232.00 Top of Wallodinium lunum, Top of Cerodinium diebelii, Top of Tanyosphaeridium spp.
230.00 Top of Cerodinium striatum, Top of Rottnestia wetzelii, Top of Palaeocystodinium cf. australinum
228.00 Top of Fromea fragilis, Top of Aquilapollenites spp.
224.00 Top of Palaeotetradinium silicorum
220.00 Base of Isabelidinium cf. cretaceum
Top of Trithyrodinium quinqueangulare, Top of Deflandrea cf. galeata
218.00 Top of Cerodinium speciosum
203.00 Top of Pseudointegricorpus protrusum
200.00 Top of Trigonopyxidia ginella, Top of Alisocysta circumtabulata
193.00 Top of Chatangiella cf. victoriensis
190.00 Top of Diphyes colligerum
186.00 Base of Alisocysta circumtabulata
Top of Dinogymnium kasachstanicum
183.00 Base of Pseudointegricorpus protrusum
180.00 Base of Rottnestia wetzelii
178.00 Top of Rottnestia cf. wetzelii
175.00 Base of Cerodinium striatum, Base of Areoligera spp.
174.00 Base of Dinogymnium kasachstanicum
170.00 Base of Palaeocystodinium cf. australinum
169.00 Base of Palaeoperidinium pyrophorum, Base of Hystrichostrogylon coninckii
Top of Hystrichostrogylon coninckii
166.00 Base of Rottnestia cf. wetzelii, Base of Aquilapollenites cf. clarireticulatus, Base of Diphyes colligerum
164.00 Top of Odontochitina operculata
162.00 Base of Deflandrea cf. galeata, Base of Chatangiella cf. victoriensis
160.00 Base of Trithyrodinium evittii
145.00 Base of Wodehouseia spinata
139.00 Base of Pseudoceratium spp., Base of Cerodinium speciosum
129.00 Base of Cyclonephelium membraniphorum
111.00 Top of Alterbidinium acutulum
100.00 Base of Phelodinium kozlowskii, Base of Trigonopyxidia ginella
Top of Spongodinium delitiense
92.00 Base of Cerodinium pannuceum, Base of Palaeotetradinium silicorum
75.00 Base of Trithyrodinium quinqueangulare
70.00 Base of Cerodinium spp.
66.00 Base of Alterbidinium acutulum
60.00 Base of Laciniadinium arcticum, Base of Wodehouseia spp., Base of Cerodinium diebelii, Base of Aquilapollenites spp.
50.00 Base of Spongodinium delitiense


Chrono.
Lstrat.
Palynology
Palynology events
Period/Epoch
Age
Formation
Member
Zone
E Palaeogene
L Selandian
Sediment Bjerge
Fairytale Valley
Palaeoperidinium pyrophorum
141.00
94.00
Base of Senegalinium spp.
Top of Palaeoperidinium pyrophorum, Top of Cerodinium diebelii, Top of Areoligera spp., Top of Palaeocystodinium spp.
Base of Spinidinium spp.
Top of Cerodinium spp.
Base of Palaeoperidinium pyrophorum, Base of Areoligera spp., Base of Palaeocystodinium spp., Base of Cerodinium spp.


Chronostratigraphy
Lstrat.
Palynology
Palynology events
Period/Epoch
Age
Formation
Sub Zone
E Palaeogene
Late Danian
Early Selandian
Cretaceous
Sediment Bjerge
Thalassiphora cf. delicata
Spiniferites magnificus
Palaeocystodinium bulliforme
Base of Cerodinium pannuceum, Base of Cerodinium aff.granulostriatum
Top of Palaeocystodinium bulliforme, Top of Palaeoperidinium pyrophorum, Top of Areoligera spp.
Base of Cerodinium striatum, Base of Spiniferites "magnificus" Rri 1989, Base of Cerodinium denticulata, Base of Hystrichostrogylon cf. membraniphorum
Top of Spiniferites "magnificus" Rri 1989, Top of Senegalinium iterlaaense
Base of Trithyrodinium evittii, Base of Areoligera coronata
Base of Cerodinium diebelii, Base of Phelodinium kozlowskii, Base of Senegalinium iterlaaense
Base of Palaeocystodinium bulliforme, Base of Palaeoperidinium pyrophorum
Top of Palaeoperidinium cretaceum
Base of Areoligera spp.

***Alterbidinium acutulum* sub-interval (60–111 m)**

Definition. The sub-interval is defined by the FO of *Cerodinium diebelii* to the Last Occurrence (LO) of consistent *Alterbidinium acutulum.*

Discussion and correlation. The presence of *Cerodinium diebelii* and consistent *Alterbidinium acutulum* suggests correlation with the *Alterbidinium acutulum* Interval Subzone (Fig. 2) of Schiøler and Wilson (1993). Schiøler and Wilson (1993) recorded the last occurrence of *Alterbidinium acutulum* from their *Alterbidinium acutulum* Interval Subzone of late Early Maastrichtian age. However, later Schøiler *et al.* (1997) recorded a few *Alterbidinium acutulum* together with *Isabelidinium cooksoniae* from their *Isabelidinium cooksoniae* Interval Zone, of early Late Maastrichtian age from the Maastrichtian type section in the Netherlands.

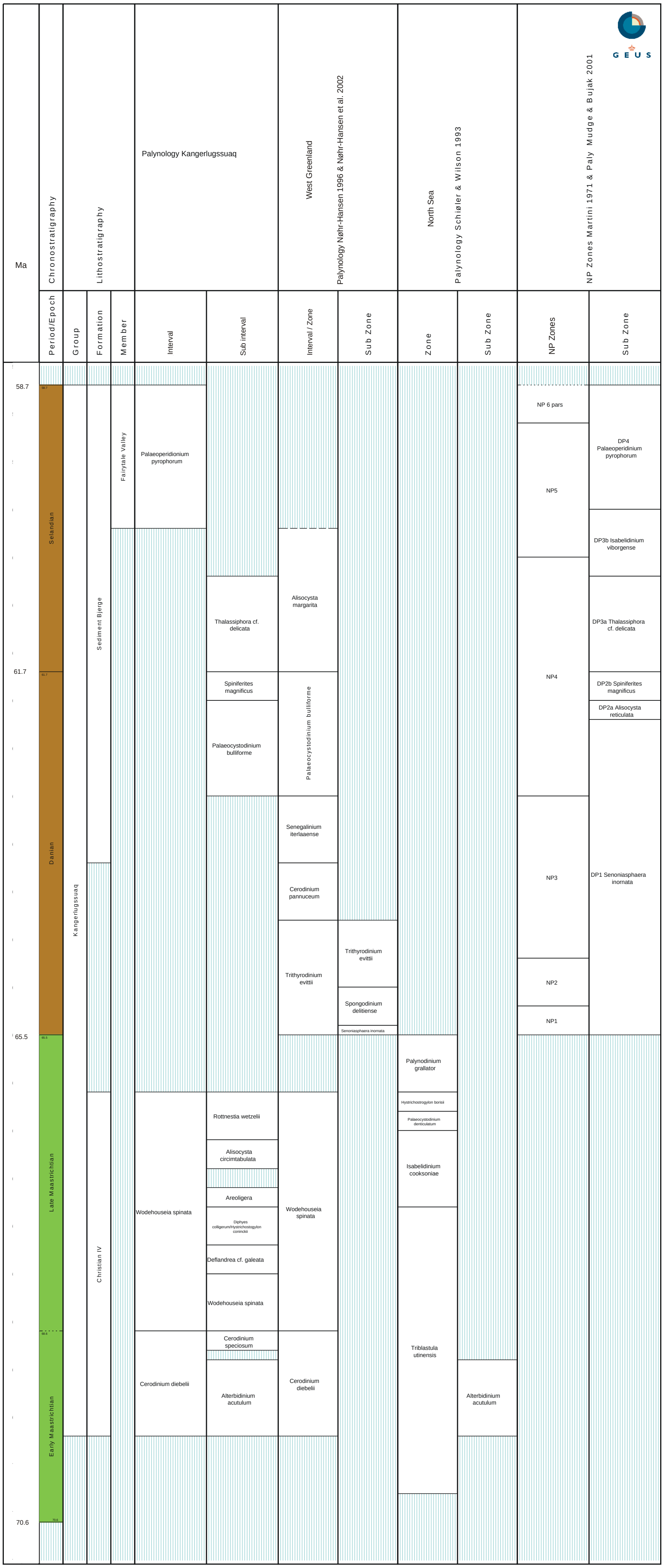
Isabelidinium spp. predominates in the upper part (85–92 m) of the *Alterbidinium acutulum* sub-interval and *Cerodinium pannuceum* and *Palaeotetradinium silicorum* both have their FO at 92 m.

***Cerodinium speciosum* sub-interval (139–145 m)**

Definition. The sub-interval is defined as being from the FO of *Cerodinium speciosum* to immediately below the FO of the pollen species *Wodehouseia spinata.*

Discussion and correlation. Trithyrodinium quinqueangulare is relative common within and *Cerodinium speciosum* has its FO at the base of the *Cerodinium speciosum* interval. May (1980) recognised rare specimens of *Cerodinium speciosum* from the Lower Maastrichtian in New Jersey, U.S.A.

Figure 5*. Correlation of the palynostratigraphy of the Kangerlussuaq area with published palyno and nanno zonations from West Greenland and the North Sea. Time scale from Gradstein et al. (2004).*



Ma
Chronostratigraphy
Lithostratigraphy
Palynology Kangerlugssuaq
West Greenland
Palynology Nøhr-Hansen 1996 & Nøhr-Hansen et al. 2002
North Sea
Palynology Schiøler & Wilson 1993
NP Zones Martini 1971 & Paly Mudge & Bujak 2001
Period/Epoch
Group
Formation
Member
Interval
Sub interval
Interval / Zone
Sub Zone
Zone
Sub Zone
NP Zones
Sub Zone
58.7
61.7
65.5
70.6
Selandian
Danian
Late Maastrichtian
Early Maastrichtian
Kangerlugssuaq
Sediment Bjerge
Christian IV
Fairytale Valley
Palaeoperidinium pyrophorum
Wodehouseia spinata
Cerodinium diebelii
Thalassiphora cf. delicata
Spiniferites magnificus
Palaeocystodinium bulliforme
Rottnestia wetzelii
Alisocysta circimtabulata
Areoligera
Deflandrea cf. galeata
Wodehouseia spinata
Cerodinium speciosum
Alterbidinium acutulum
Alisocysta margarita
Palaeocystodinium bulliforme
Senegalinium iterlaaense
Cerodinium pannuceum
Trithyrodinium evittii
Wodehouseia spinata
Cerodinium diebelii
Trithyrodinium evittii
Spongodinium delitiense
Senoniasphaera inornata
Palynodinium grallator
Isabelidinium cooksoniae
Triblastula utinensis
Alterbidinium acutulum
NP 6 pars
NP5
NP4
NP3
NP2
NP1
DP4 Palaeoperidinium pyrophorum
DP3b Isabelidinium viborgense
DP3a Thalassiphora cf. delicata
DP2b Spiniferites magnificus
DP2a Alisocysta reticulata
DP1 Senoniasphaera inornata

***Wodehouseia spinata* interval (145–236 m)**

Definition. The interval was defined as being from the FO of the pollen species *Wodehouseia spinata* to it's LO by Nøhr-Hansen (1996).

Discussion and correlation. The FO of *Wodehouseia spinata* is here regarded as a marker for the basal Upper Maastrichtian. The exact age correlation of the FO of *Wodehouseia spinata* is discussed below. The *Wodehouseia spinata* interval is dominated by *Hystrichosphaeridium tubiferum*, *Isabelidinium* spp. and *Spiniferites* spp., *Circulodinium distinctum* and *Oligosphaeridium* spp. are common in the lower part, whereas *Rhombodella paucispina*, reworked from Albian–Cenomanian strata, is present in the middle of the interval. The FO of *Wodehouseia spinata*, *Rottnestia* cf. *wetzelii, Hystrichostrogylon coninckii* together with the first common occurrence of *Areoligera* spp. in a rather narrow interval within the *Wodehouseia spinata* interval is useful for correlation of the studied sections, and may be important in tracing the Lower/Upper Mastrichtian boundary outside the studied area. The co-occurrence with reworked material of Albian–Cenomanian age may be of local importance.

The Upper Maastrichtian *Wodehouseia spinata* interval may be subdivided into six local palyno sub-intervals based on the first occurrences/ranges of characteristic species. The sub-intervals and their correlation to published stratigraphies are discussed below.

***Wodehouseia spinata* sub-interval (145–162 m)**

Definition. The base of the *Wodehouseia spinata* sub-interval is defined by the FO of *Wodehouseia spinata* (145 m). The FO of *Chatangiella* cf. *victoriensis* occur in the upper part (162 m).

***Deflandrea* cf. *galeata* sub-interval (162–166 m)**

Definition. The base of the *Deflandrea* cf. *galeata* sub-interval is characterised by the FO of *Deflandrea* cf. *galeata*.

Discussion and correlation. Schiøler *et al.* (1997) reported *Deflandrea galeata* from the entire Upper Maastrichtian of the Type Maastrichtian section in Netherlands. Kirsch (1991) defined the basis of his middle Maastrichtian *Deflandrea galeata* Subzone from Germany by the FO of *Deflandrea galeata* and *Cerodinium speciosum*.

***Diphyes colligerum-Hystrichostrogylon coninckii* sub-interval (166–175 m)**

Definition. The base of the *Diphyes colligerum-Hystrichostrogylon coninckii* sub-interval is characterised by the FO of *Diphyes colligerum*, *Hystrichostrogylon coninckii* and *Rottnestia* cf. *wetzelii*.

Discussion and correlation. May (1980) and Brinkhuis and Zachariasse (1988) recorded the first occurrence of *Diphyes colligerum* in the Upper Maastrichtian. Firth (1987) recognised the FO of *Diphyes colligerum* at the base of the high abundance of *Areoligera* cysts from the lowermost part of the Upper Maastrichtian in Maryland, U.S.A. Kirsch (1991) recorded the FO of *Diphyes colligerum* just above his middle Maastrichtian *Deflandrea galeata* Subzone from Germany. Heilmann-Clausen in Thomsen and Heilmann-Clausen (1984) described *Hystrichostrogylon coninckii* from the Danian in Denmark and mentioned that the species also ranges down into the Upper Maastrichtian. Schiøler *et al.* (1997) reported *Rottnestia wetzelii* from the lowermost Upper Maastrichtian from the Maastrichtian type section in Netherlands, where it co-occurs with *Triblastula utinensis*.
The present interval may correlate with the upper part of the *Triblastula utinensis* Range Zone (Schiøler and Wilson, 1993; Fig. 2) suggesting an early Late Maastrichtian age. The *Diphyes colligerum-Hystrichostrogylon coninckii* sub-interval can be correlated with similar intervals recorded from the Skiferbjerg 2003, Sequoia Nunatak and Sequoia West sections.

***Areoligera* sub-interval (175–178 m)**

Definition. The base of the thin *Areoligera* sub-interval is characterised by the first common occurrence of *Areoligera* spp. and the FO of *Cerodinium striatum*.

Discussion and correlation. Firth (1987, 1993) recognised the FO of *Cerodinium dartmoorium* together with high abundance of *Areoligera* cysts from the Lower – Upper Maastrichtian boundary in Maryland, U.S.A. He suggested that the abundance might reflect a level of maximum transgression in the middle of the Maastrichtian. Schiøler and Wilson (1993) also recorded common *Areoligera* sp. from the Lower Maastrichtian in the North Sea and Schiøler *et al.* (1997) reported *Areoligera coronata* from the lower part of Upper Maastrichtian in Netherlands. The *Areoligera* sub-interval can be correlated with similar narrow intervals described from the Skiferbjerg 2003, Sequoia West and possibly from the Sequoia Nunatak sections.

***Alisocysta circumtabulata* sub-interval (186–200 m)**

Definition. The base of *Alisocysta circumtabulata* sub-interval is characterised by the FO of the index species *Alisocysta circumtabulata*.

Discussion and correlation. Allisocysta circumtabulata first occurs in the lowermost Upper Maastrichtian in the Maastrichtian type section in the Netherlands (Schøiler *et al.* 1997). Marheineche (1992) recorded the first occurrence of *Allisocysta circumtabulata* from the uppermost lower Maastrichtian in Germany.

***Rottnestia wetzelii* sub-interval (200–230 m)**

Definition. The top of the *Rottnestia wetzelii* sub-interval is characterised by the LO of *Rottnestia wetzelii*.

Discussion and correlation. The LO of *Trithyrodinium quinqueangulare* occur in the upper part of the sub-interval. Both *Rottnestia wetzelii* and *Trithyrodinium quinqueangulare* have their LO just below the FO of the uppermost Maastrichtian marker *Palynodinium grallator* in the Maastrichtian type section in the Netherlands (Schøiler *et al.* 1997).

Barren interval (240–260 m)

The uppermost part of the succession (240–260 m) just below the basalt is barren of palynomorphs or only contains corroded and thermally degraded specimens of the genus *Isabelidinium*. However, the ammonite *Diplomoceras cylindraceum* continues to occur from this level as seen from fallen specimens The presence of the dinoflagellate cyst species discussed above and the absence of markers of latest Maastrichtian age (e.g. *Palynodinium grallator*) indicate that the uppermost Maastrichtian is missing in the Skiferbjerg 2004 section.

Skiferbjerg 2003

The Skiferbjerg 2003 succession represents 260 m of the Christian IV Formation. The succession from the Skiferbjerg 2003 locality (Enclosure 2) yields ammonite fragments throughout and an echinoderm specimen from the base (see Kelly and Whitham below). Four of the studied samples (GEUS 455641, 160 m; 455645, 175 m; 455646, 180 m and 455649, 190 m) are specimens of the ammonite *Diplomoceras cylindraceum*, a species which ranges throughout the Maastrichtian and into the uppermost Campanian. The preservation of palynomorphs is poor to very poor, especially in the upper part. Based on the restudy of the section, the lower part (35–155 m) is correlated with the Lower Maastrichtian *Cerodinium diebelii* interval and the upper part (125–240 m) is correlated with the Upper Maastrichtian *Wodehouseia spinata* interval, both these intervals were described from West Greenland (Nøhr-Hansen, 1996; Fig. 4).

***Alterbidinium acutulum* sub-interval (35–115 m)**

Discussion and correlation. The presence of *Cerodinium diebelii*, a few *Odontochitina operculata* and consistent *Alterbidinium acutulum* in the lowermost part (35–115 m) suggests an age not older than Early Maastrichtian probably correlating with the *Alterbidinium acutulum* Interval Subzone of Schiøler and Wilson (1993) and the *Alterbidinium acutulum* sub-interval described from Skiferbjerg 2004.

***Diphyes colligerum-Hystrichostrogylon coninckii* sub-interval (125 m)**

Discussion and correlation. The sample at 125 m is characterised and by the FO of *Wodehouseia spinata*, *Cerodinium pannuceum*, *Cerodinium speciosum*, *Diphyes colligerum*, *Fibradinium annetorpense*, *Hystrichosphaeropsis quasicribrata*, *Hystrichostrogylon coninckii* and by abundant *Spiniferites* spp. suggesting a Late Maastrichtian age. The sample may correlate with *Diphyes colligerum-Hystrichostrogylon coninckii* sub-interval described from Skiferbjerg 2004. Reworked material of Albian–Cenomanian age is present like in the Skiferbjerg 2004, Sequoia Nunatak and Sequoia West sections.

***Areoligera* sub-interval (135 m)**

Discussion and correlation. The sample at 135 m is characterised by the first common occurrence of *Areoligera* spp. and is correlated with the *Areoligera* sub-interval described from Skiferbjerg 2004.

Upper part of the *Wodehouseia spinata* interval (145–215 m)

Discussion and correlation. The upper part of the section (145–215 m) is characterised by abundant *Isabelidinium* spp. and *Spiniferites* spp., common *Cerodinium diebelii*, and *Trithyrodinium evittii* together with *Isabelidinium cooksoniae*, *Cerodinium striatum* and the pollen *Aquilapollenites* spp. and *Wodehouseia spinata*. It has not been possible to recognise the *Alisocysta circumtabulata* sub-interval described from Skiferbjerg 2004 and only a single specimen of *Rottnestia wetzelii* has been recorded from 175 m. The presence of *Wodehouseia spinata* at 165–195 m, strongly suggest a Late Maastrichtian age, correlating with the upper part of the *Wodehouseia spinata* interval. The presence of a few poor *Cerodinium striatum* specimens and the increase in numbers of *Trithyrodinium evittii* was first interpreted to indicate an early Danian, earliest Paleocene age. However, Aurisano (1989) has reported *Cerodinium striatum* from Lower to middle Maastrichtian in U.S.A. and *Trithyrodinium evittii* do occur in the uppermost Cretaceous in lower latitudes (Nøhr-Hansen & Dam, 1999).

The uppermost studied sample (240 m) yields few poorly preserved palynomorphs, upon which dating is questionable.

Like in the Skiferbjerg 2003 and in the two Sequoia sections, described below, the marker species for the upper part of the Skiferbjerg 2003 section, suggests an early Late Maastrichtian age.

The lower part of section Skiferbjerg 2003/W4245 was earlier suggested to be Campanian (Larsen et al., 2005, pp. 30, 62) based on identification of an ammonite as *Rhaeboceras*, and associated palynoflora representing the *I. cooksoniae* interval. However, the ammonite is now identified by Jim Kennedy as an Lower Maastrichtian *Acanthoscaphites tridens*. Thus we now have no primary evidence for the Campanian Stage in the Kangerlussuaq Basin.

Sequoia West

The Sequoia West succession represents 94 m of the Christian IV Formation unconformably overlain by the Vandfaldsdalen Formation. Based on the present observations, the lower part of the Christian IV Formation from the Sequoia West section (1428–1480 m; Enclosure 3) is correlated with the *Cerodinium diebelii* interval of Early Maastrichtian age and the upper part (1482–1506 m) correlated with the *Wodehouseia spinata* interval of Late Maastrichtian age.

***Alterbidinium acutulum* sub-interval (1428–1480 m)**

Discussion and correlation. The lower part of the Sequoia West section (1428–1480 m) has been dated as late Early Maastrichtian probably the *Alterbidinium acutulum* Interval Subzone of Schiøler and Wilson (1993) and the *Alterbidinium acutulum* sub-interval described from Skiferbjerg 2004. The dating is based on the absence of the Late Maastrichtian pollen marker *Wodehouseia spinata* and the absence of *Odontochitina* species, which in northern latitudes have their last occurrence in the lowermost Maastrichtian according to Williams *et al.* (2004). The presence of *Aquillapollenites* spp. indicates a Campanian to Maastrichtian age and the presence of *Cerodinium diebelii* indicates a post middle Campanian age.

***Wodehouseia spinata* interval (1482–1506 m)**

Discussion and correlation. The upper part (1482–1506 m) of the section contains almost the same palyno assemblage as recorded from the upperpart of the two Skiferbjerg sections and from the Sequoia Nunatak section. *Alterbidinium acutulum, Cerodinium diebelii, C. pannuceum, Isabelidinium* spp. *Laciniadinium arcticum, Aquillapollenites* spp. and *Wodehouseia spinata* occur through most of the upper part, which has been correlated to the *Wodehouseia spinata* interval.

***Triblastula utinensis/Diphyes colligerum-Hystrichostrogylon coninckii* sub-interval (1482–1489 m)**

Discussion and correlation. Triblastula utinensis has been recorded from a thin interval (1482–1489 m) which possible correlate with the *Diphyes colligerum-Hystrichostrogylon coninckii* sub-interval described from the Skiferbjerg 2004 section. Schiøler and Wilson (1993) recorded the range of *Triblastula utinensis* from their *Triblastula utinensis* Range Zone of middle Early to early Late Maastrichtian age, in the Danish North Sea.

***Areoligera* sub-interval (1489 m)**

Discussion and correlation. The FO of *Areoligera* spp. was recorded from 1489 m suggesting a correlation with the *Areoligera* sub-interval described above.

***Alisocysta circumtabulata* sub-interval (1494–1506 m)**

Discussion and correlation. The FO of *Allisocysta circumtabulata*, *Cerodinium pannuceum*, *Diphyes colligerum* and *Fibradinium annetorpense* has been recorded from the upper part (1494–1506 m) suggesting a correlation to the *Alisocysta circumtabulata* sub-interval at Skiferbjerg 2004. Reworked material in the upper part is represented by specimens of Albian–Cenomanian and Santonian age.

The presence of the species discussed above and the absence of markers of latest Maastrichtian age date the upper part of the Sequoia West section as early Late Maastrichtian. The presence of the ammonite *Discoscaphites angmartussutensis* collected from float at c1480 m, also constrains a Late Maastrichtian age (Kennedy et al., 1999), probably from the lower part of the substage.

Sequoia Nunatak

The Sequoia West succession (Enclosure 4) represents 80 m of the Christian IV Formation unconformably overlain by the Vandfaldsdalen Formation. Based on the present observations is the studied part (40 m) of the Christian IV Formation from the Sequoia West section correlated with the Upper Maastrichtian *Wodehouseia spinata* interval. The palynomorph assemblage from the lower part is dominated by marker species of early Late Maastrichtian age (e.g. *Alterbidinium acutulum, Cerodinium diebelii, Cerodinium pannuceum, Diphyes colligerum, Hystrichostrogylon coninckii, Isabelidinium cooksoniae, Laciniadinium arcticum, Rottnestia wetzelii* together with a few pollen specimens, e.g. *Aquillapollenites* spp. and *Wodehouseia spinata*). Reworked material is represented by specimens of Albian–Cenomanian age (*Rhombodella paucispinosa*) and of Campanian age (*Isabelidinium micoarmum*). The succession yields scaphitid ammonite fragments in the lower part, which were first recorded by Nørgaard-Pedersen (1991).

The presence of the species discussed above and the absence of latest Maastrichtian markers suggest an early Late Maastrichtian age for the lower part of the Sequoia Nunatak section. The lowermost sample (1520 m) may be correlated with the *Diphyes colligerum-Hystrichostrogylon coninckii* sub-interval described from Skiferbjerg 2004. Whereas the three next samples (1525–1550 m) may be correlated to the *Alisocysta circumtabulata* sub-interval described from Skiferbjerg 2004, based on the FO of *Alisocysta circumtabulata* at 1525 m. The uppermost sample (1558 m) yields very few thermally over mature dinoflagellate cysts upon which dating are questionable.

Discussion of the discrepancies between the palynological and macrofossil dating of the Maastrichtian succession.

The subdivision of the Maastrichtian into an early and late substage is still an unsolved problem (Ogg *et al.* 2004; in Gradstein *et al*. 2004). Based on the presence of the bivalve *Spyridoceramus tegulatus* from 83.2–176.6 m Kelly and Whitham (see later) suggest an Early Maastrichtian age up to at least 176,6 m, approximately 30 m above the first palynological Upper Maastrichtian marker.

The present palynological study follows Nichols and Sweet (1993) who in the Western Interior Basin recorded the FO of *Wodehouseia spinata* at the base of Upper Maastrichtian. Nichols and Sweet (1993) mentioned that the lowest occurrence of *Wodehouseia spinata* in the central part of the basin occur in the ammonite *Hoploscaphites* aff. *H*. *nicolleti* Zone in Montata and in the equivalent *Sphenodiscus* Zone in Wyoming, whereas it in the southern part of the basin (in Colorado) ranges as low as strata just above the *Sphenodiscus* Zone or possibly as low as the underlying ammonite *Baculites clinolobatus* Zone. Ogg *et al.* (2004; in Gradstein *et al*. 2004) mention that the lowest occurrence of the ammonite *Hoploscaphites birkelundi* (formerly *Hoploscaphites* aff. *H*. *nicolleti*) is an informal marker for the base of the Upper Maastrichtian in the Western Interior. Ogg *et al.*(2004 fig 19.1; in Gradstein *et al*. 2004) illustrated the *Baculites clinolobatus* Zone just below the informal Lower/Upper Maastrichtian boundary, indicating that the possible occurrence of *Wodehouseia spinata* in the ammonite *Baculites clinolobatus* Zone in Western Interior may represent a FO of latest Early Maastrichtian age.

Srivastava (1970) originally erected the *Wodehouseia spinata* Zone for the Upper Maastrichtian in Alberta, Canada and subdivided the zone into three subzones, however Catuneanu and Sweet (1999) erected an fourth subzone in the lowermost part of the *Wodehouseia spinata* Zone and suggested a latest early Maastrichtian age for the new Subzone A. The Subzone A was recognised by the presence and co-occurrence of *Wodehouseia spinata* and *Scollardia trapaformis*, the general absence of other taxa typical of early Late Maastrichtian age and a reverse polarity chron (30r).

Therefore, the lower part of the *Wodehouseia spinata* interval (the *Wodehouseia spinata* sub-interval 145–166 m) from Skiferbjerg 2004 may be of latest Early Maastrichtian age however it has tentatively been dated as Late Maastrichtian based on the presence of *Wodehouseia spinata* and by the general absence of spores and pollen, especially the lower Maastrichtian marker *Scollardia trapaformis.* The *Deflandrea* cf. *galeata* sub-interval (162–166 m) could bee of latest Early Maastrichtian age, Kirsch (1991) recorded the FO of *Deflandrea galeata* from the middle Maastrichtian however the overlying *Diphyes colligerum-Hystrichostrogylon coninckii* sub-interval (166–175 m) strongly suggest an Late Maastrichtian age based the several upper Maastrichtian marker species.

Lower Palaeogene (Danian – lower Selandian)

Watkins Fjord

Two sections from Watkins Fjord have been studied; Watkins Fjord 2003 and Watkins Fjord 2004 (Fig. 6, Enclosure 5, 6).

Watkins Fjord 2003

The Watkins Fjord 2003 section (Enclosure 5) represents 60 m of the Lower Cretaceous Sorgenfri Formation, approximately 11 m of the Upper Cretaceous Christian IV Formation and 29 m of the Palaeogene Sediment Bjerge Formation. The preservation of the palynomorphs is very poor due to thermal heating. The Paleocene marine deposits rest unconformably on the middle Cretaceous Christian IV Formation and indicate the presence of a hiatus spanning the Upper Cretaceous and the lower Danian (lowermost Paleocene). It has not been possible to date the Cretaceous succession. The palyno-stratigraphy for the Palaeogene from the Watkins Fjord 2003 succession is illustrated in Figure 4.

***Palaeocystodinium bulliforme* Zone (86–91 m)**

Definition. The *Palaeocystodinium bulliforme* Zone was defined as being from the FO of *Palaeocystodinium bulliforme* to immediately below the FO of *Alisocysta margarita* by Nøhr-Hansen *et al.* (2002).

Discussion and correlation. The presence of *Palaeocystodinium bulliforme* and *Senegalinium iterlaaense* in the lower part (86–91 m) of the Paleocene succession indicate a late Danian age, correlating with the *Palaeocystodinium bulliforme* Zone described Nuussuaq, West Greenland by Nøhr-Hansen *et al.* (2002; Fig. 5), who also correlated the zone with the lower and middle part of nannoplankton zone NP4 of Martini (1971).

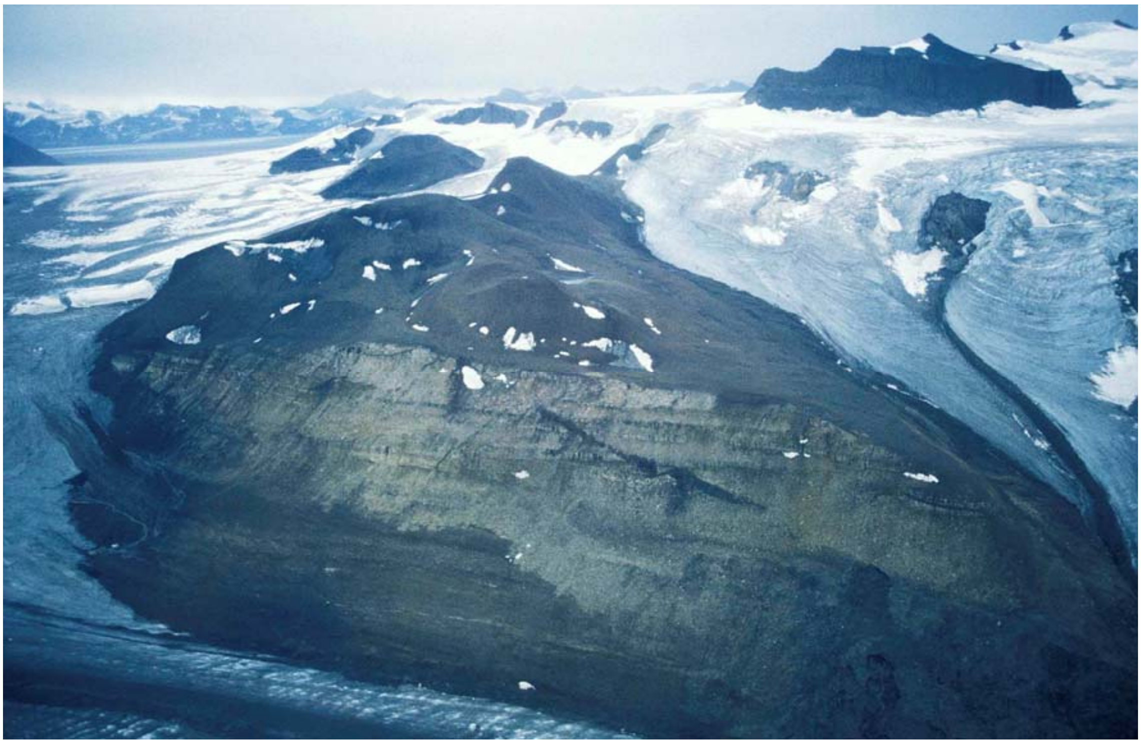


Figure 6. *The sedimentary succession at the Watkins Fjord locality comprises sandstones of the Lower Cretaceous Watkins Fjord Formation overlain by a mudstone dominated succession of the Upper Cretaceous – Paleocene, Sorgenfri, Christian IV and Sediment Bjerg formations. The samples analysed were collected along the ridge in the cental left part of the photo. Photo looking northeast. Light grey sandstone succession is approximately 150 m thick.*

***Spiniferites magnificus* Subzone (100 m)**

Definition. Mudge and Bujak (1996) defined the top of the *Spiniferites magnificus* Subzone (DP2b) by the last occurrence of *Spiniferites magnificus.*

Discussion and correlation. The sample from 100 m is dated as latest Danian (dinoflagellate cyst *Spiniferites magnificus* Subzone DP2b of Mudge and Bujak, 1996) based on the presence of *Cerodinium striatum, Palaeocystodinium bulliforme* and *Spiniferites magnificus.* The top of the uppermost Danian *Spiniferites magnificus* Subzone (DP2b; Fig. 5) was defined by the last occurrence of *Spiniferites magnificus* in the lower part of the Maureen Formation by Mudge and Bujak (1996), who mentioned that *Spiniferites magnificus* not has been recorded outside the North Sea. Mangerud *et al.* (1999) defined the top of their Lower Paleocene (Danian) Grane A Biozone by the last occurrence of the *Spiniferites magnificus* and *Alisocysta reticulata* in the middle of the Våle Formation offshore Norway.

Thalassiphora cf. *delicata* Subzone (105 m)

Definition. Mudge and Bujak (1996) defined the top of the *Thalassiphora* cf. *delicata* Subzone (DP3a) by the LO of *Thalassiphora* cf. *delicata* and the base above the LO of *Spiniferites magnificus.*

Discussion and correlation. The uppermost sample from 105 m is dated as possible earliest Selandian (lower part of dinoflagellate cyst *Thalassiphora* cf. *delicata* Subzone DP3a of Mudge and Bujak, 1996; Fig. 5) based on the presence of *Cerodinium striatum, Palaeocystodinium bulliforme*, common *Areoligera* spp. and common *Palaeoperidinium pyrophorum*. Mangerud *et al.* (1999) divided their Grane B Biozone of early Late Paleocene age into four subzones, the top of the oldest was defined by the by the last occurrence of common *Palaeocystodinium bulliforme* in the upper half of the Våle Formation offshore Norway. The subzone correlates with the lower part of the *Thalassiphora* cf. *delicata* Subzone DP3a of Mudge and Bujak (1996). Mudge and Bujak (1996) mentioned in their description of subzone DP3a that *Palaeoperidinium pyrophorum* dominate in the subzone.

This last common occurrence of *Palaeocystodinium bulliforme* is a useful regional North Sea event according to Mangerud *et al.* (1999). *Palaeocystodinium bulliforme* is quite common onshore Nuussuaq, West Greenland where it range from the *Palaeocystodinium bulliforme* Zone (mid to upper Danian) and into the *Alisocysta margarita* Zone (upper Danian/lower Selandian, Nøhr-Hansen *et al.*, 2002). *Palaeocystodinium bulliforme* has also been recorded onshore at Kap Brewster, East Greenland where it co-occur together with *Thalassiphora delicata* and *Alisocysta margarita* suggesting deposits of late Danian/early Selandian age (Nøhr-Hansen and Piasecki, 2002). Reworked specimens of Late Cretaceous age are recorded from the Watkins Fjord 2003 section.

The late Danian to earliest Selandian age suggested here for the Watkins Fjord 2003 section correlates with the top of sequence T10 or lowermost T20 of Ebdon *et al*. (1995), according to Mudge and Bujak (2001).

Watkins Fjord 2004

The Watkins Fjord 2004 section (Enclosure 6) represents 10 m of the Lower Cretaceous Sorgenfri Formation, approximately 22 m of the Upper Cretaceous Christian IV Formation and by 29 m of the Palaeogene Sediment Bjerge Formation. The preservation of the palynomorphs is very poor due to thermal heating.

Quantouendinium dictyophhorum Interval (70 m)

Discussion and correlation. The lowermost sample at 70 m from the Sorgenfri Formation is dated as Albian–Cenomanian based on the presence of *Quantouendinium dictyophhorum* and the spore *Rugubivesciculites rugusus*. Recently Nøhr-Hansen (2005) recorded the two species from brackish water deposits of Albian–Cenomanian age from Disko, West Greenland.

Late Cretaceous interval (80–102 m)

The interval at 80–102 m from the Christian V formation only contains few dinoflagellate cysts. The interval has been dated Late Cretaceous based on the presence of the genus *Isabelidinium*, which has its FO in the Upper Cenomanian.

Palaeocystodinium bulliforme Zone (102–105 m)

The Paleocene marine deposits rest unconformably on the middle Cretaceous Christian IV Formation and indicate as recorded from the Watkins Fjord 2003 section the presence of a hiatus spanning the Upper Cretaceous and the lower Danian (lowermost Paleocene). The presence of *Palaeocystodinium bulliforme* indicate a late Danian age, correlating with the *Palaeocystodinium bulliforme* Zone described Nuussuaq, West Greenland by Nøhr-Hansen *et al.* (2002).

Lower Palaeogene, Selandian

Fairytale Valley

The Fairytale Valley section represents 47 m of the Palaeogene Sediment Bjerge Formation (Enclosure 7). The palyno-stratigraphy for this succession is illustrated in Figure 4.
The upper prebasaltic successions at Fairytale Valley contain very pooly preserved, thermally altered, low diversity and low density palynoassemblages. However the presence of *Palaeoperidinium pyrophorum* in the section indicates an age no younger than latest Selandian (the *Palaeoperidinium pyrophorum* Zone DP4 of Mudge and Bujak 1996; 2001; Fig. 5). *Areoligera* spp. and *Palaeoperidinium pyrophorum* are common in the lower successions at Fairytale Valley (94 m) and present in the upper succession, where a distinct *Spinidinium* sp. and a distinct *Suttilisphaera* sp. have their first occurrence at 141 m. The dating of the section suggests correlation with NP5 and with the top of sequence T20 or lower part T30 of Ebdon *et al*. (1995).

Sill City

The Sill City section represents 82 m of the Upper Cretaceous Sorgenfri Formation and 14 m of the Palaeogene Sediment Bjerge Formation (Enclosure 8).
The lower part (25–30 m) of the section is dated as Middle Turonian to Early Santonian based on the presence of *Hystrichodinium voigtii*, *Raphidodinium fucatum* and *Xiphophoridium alatum*. Costa and Davey (1992) reported the FO of *Raphidodinium fucatum* from the Middle Turonian and the LO of *Xiphophoridium alatum* from the Lower Santonian.

The Upper Cretaceous Sorgenfri Formation is unconformably overlain by the Lower Palaeogene Sediment Bjerge Formation, which contain very poor preserved thermally altered low diverse and low density palynoassemblages. However, the occurrence of *Palaeoperidinium pyrophorum* and of the genus *Areoligera* at 87–90 m indicate an age no younger than latest Selandian (the *Palaeoperidinium pyrophorum* Zone DP4 of Mudge and Bujak 1996; 2001).The dating of the section suggest correlating with the Fairytale Valley section.

North Col 2004, Rybjerg Fjord North 2004 and Christian IV Col 2004

All samples from the three sections North Col 2004, Rybjerg Fjord North 2004 and Christian IV Col 2004 contain nothing but coalified organic matter and no palynomorphs have been recorded. The sections are thermal over mature.

Conclusion from palynological analysis

- Based on the close spaced new sampling of the Skiferbjerg succession and new material from the Watkins Fjord, Fairytale Valley and Sill City successions a revised palynostratigraphy has been proposed for the Upper Cretaceous – Lower Palaeogene succession in Kangerlussuag.
- The Upper Cretaceous Christian IV Formation has been dated as Early to Late Maastrichtian, and divided into two palyno-intervals. The lower *Cerodinium diebelii* interval represents the Lower Maastrichtian and the upper *Wodehouseia spinata* interval represents the Upper Maastrichtian, however the uppermost part of the Maastrichtian has not been recorded from the Kangerlussuag area. Based on first and last occurrences of stratigraphic marker species, the two intervals has been divided into two and six subintervals respectively (Fig. 4).
- The Sediment Bjerge Formation has been dated as late Danian to late Selandian. Four palyno intervals have been recorded from the formation (Fig. 4).
- The results indicate a hiatus spanning the uppermost Maastrichtian and the lower Danian, 2–3 million years (Fig. 5).

Macrofaunal biostratigraphic observations

By Simon R.A. Kelly and Andrew G. Whitham
With contributions by Bill Braham, F. John Gregory, J. Jagt and W. Jim Kennedy.

Introduction

Key sites in the Kangerlussuaq Basin were selected on the basis of their value for understanding the Late Cretaceous, Cenomanian to Maastrichtian, biostratigraphy of the wider region. The macrofossil ranges are given in the stratabugs charts together with data on dinoflagellates (Bill Braham data) and microfossils.

The report covers the stratigraphic interval covered by the Sorgenfri Formation, the Christian IV Formation, and the Sediment Bjerge Formation (Fig. 2). The Sorgenfri Formation has been formally used since its introduction by Soper (1976). The Christian IV and Sediment Bjerge formations are provisional terms, not yet formally published, but introduced in draft form by Larsen *et al.* (2005).

Macrofossils from the following sections are included:

Locality name	***Section number***
Fairytale Valley	(not included – no macrofauna)
Sequoia Nunatak	W4232b
Sequoia Nunatak	W4235 composite (including W4236, W4237, W4238)
Skiferbjerg Old	W4245
Skiferbjerg New	MIL/AGW 2004 section
Sediment Bjerge	W4293
Sill City	W4268 composite (including W4271-W4272)
Watkins Fjord	W4260 (=K7586), K7585, K7587, K7595, K7597(=W4320) (composite Turonian-Maastrichtian)

Sequoia Nunatak W4232b

Introduction. This section exposes the top of the Christian IV Formation, and a complete section through the Schelderup and Kulhøje members of the Vandfaldsdalen Formation. This is the site from which Nørgaard Pedersen (1991) first reported scaphitid ammonites. The data is incorporated from CASP Report MPS2.

Macropalaeontology. No macrofauna was obtained *in situ* in the Christian IV Formation, but loose material from the base of the section includes specifically indeterminate ammonite and inoceramid bivalves, gastropods and terebratulid brachiopods, which indicates no more than a Cretaceous age. Only indeterminate gastropods were found *in situ* in the Schelderup Member.

Biostratigraphic conclusions. The macrofauna does not contribute significantly to the dating of Locality W4232b.

Sequoia Nunatak W4235 composite

Introduction. The W4235 composite section includes data from localities W4236, W4237 & W4238. This is Michael Larsen's 'Sequoia Nunatak' locality. This section exposes the top of the Christian IV Formation, and a complete section through the Schelderup and Kulhøje members of the Vandfaldsdalen Formation. The data from CASP Report MPS2 is modified to fit the Larsen section thicknesses.

Macropalaeontology. The macrofaunas are marked as caved, but represent float collected from limited horizons which have not travelled downslope by any great distances. The lowest and highest confirmed Maastrichtian by macrofaunas are at 10 m and at 55 m with records of the ammonite, *Diplomoceras cylindraceum,* but these do not subdivide the stage. The single record of *Discoscaphites angmartussutensis* at 50 m is significant and may represent the Late Maastrichtian. Macrofauna was not obtained from higher levels in the section.

Biostratigraphic conclusions. The exposure of the Christian IV Formation at this site lies entirely within the Maastrichtian stage. The 0–20 m interval belongs to the Early Maastrichtian *C. diebelii* interval. The occurrence of *Discoscaphites angmartussutensis* may indicate the presence of the Late Maastrichtian at 50 m, but absence of further precision from the dinoflagellate data make this unconfirmed.

Skiferbjerg 2004

Introduction. Skiferbjerg is the proposed type locality of the Christian IV Formation by Larsen *et al.* (2005). The sills at the base and the top of the section obscure contacts with the adjacent units.

Macropalaeontology. Although *Diplomoceras cylindraceum* is widely distributed in the section, mostly as loose specimens, it does occur *in situ* between 143 m and close to the basalt sill where it comes from material fallen the baked margin of the sill at 278 m. One particularly large specimen, with a straight shaft of 0.5 m length with complete crozier, was collected at 193 m *in situ*. Other macrofauna is restricted to a small number of horizons. The ammonites *Acanthoscaphites tridens* and *Discoscaphites angmartussutensis* occur together with *Pachydiscus* sp. and *Anagaudryceras* sp. and the bivalve *Spyridoceramus tegulatus* at 148 m. *S. tegulatus* ranges from 93.2–176.62 m. At 193.5 m was also obtained *Anagaudryceras politissimum* and the highest *Discoscaphites angmartussutensis.* Other ammonites include *Saghalinites wrighti* at 176.6 m.
Other fauna includes the nautiloid *Eutrephoceras* sp. at 148 m. Scattered loose echinoid remains indicate the presence of a variety of forms including the spatangoids, holasterids, hemiasterids, cardiasterids and phymosomatids (J. Jagt determination).

Biostratigraphic conclusions. The widespread *Diplomoceras cylindraceum* gives a potential range of latest Campanian to latest Maastrichtian, but in the absence of any other Campanian indicators, an unspecified Maastrichtian age is indicated, right up to the baked margin of the upper sill. *Acanthoscaphites tridens* was collected loose in the lower part of the section only, and *in situ* at 148 m indicating an Early Maastrichtian age (Niebuhr 1993). At 148 m it overlaps in range with *Discoscaphites angmartusssutensis*. *D. angmartussutensis* ranges up to 193.5 m which may indicate the earliest part of the Late Maastrichtian (Kennedy *et al.* 1999) but possibly ranges into the end of the Early Maastrichtian because of its association with *A. tridens*.

The range of the inoceramid bivalve *Spyridoceramus tegulatus* from 90.21 m up to 176.6 m in the Skiferbjerg sectrion indicates an Early Maastrichtian age in comparison to European dates (e.g. Dhondt 1983). The forms represented show varying degrees of radial ornament which is typical of the mid-range of the species which becomes smoother in the upper and lower parts of its range according to I. Walaszczyk (pers. comm. 2004). Thus on the basis of inoceramids, the range of *S. tegulatus* in this section indicates the mid-Early Maastrichtian. This supports the Early Maastrichtian date for *Acanthoscaphites tridens*, but also suggests that the range of *Discoscaphites angmartussutensis* (at least in part) is also of late Early Maastrichtian age.

Watkins Fjord N, K7585 composite.

Introduction. This locality links together a number of short sections including, K7585, K7586 =(W4260), K7587, K7595, K7597(=W4320), which together with the underlying type locality of the Watkins Fjord Formation give one of the most complete and accessible Cretaceous successions of the Kangerlussuaq Basin.This locality exposes the upper part of the Sorgenfri Formation and the Christian IV Formation, although the quality of exposure is not always good and the unconformity between them has not been precisely pinpointed. The section is capped by the clearly exposed unconformity at the base of the Fairytale Valley Member of the Sediment Bjerge Formation. Despite much of the collection of macrofauna being from float (marked as ‘caved’), the assemblages are age diagnostic. The stratigraphic height difference between the material from 1043 m and that from around 1010 m is likely to be approximate as they have about 800 m horizontal separation.

Macropalaeontology. At K7585, above the sill *Inoceramus lamarcki* (also occurring down to the base of the section) and *Actinocamax* cf. *manitobensis* are common. Although poorly preserved ammonite fragments were obtained, they were only identifiable as *Neophylloceras* sp. and *Puzosia* sp., and were not of biostratigraphic value.

Macrofaunal assemblages including *Diplomoceras cylindraceum* and other ammonites, were found at K7588 and K7595, but these were loose and it is not clear from where they were derived, but never-the-less they indicate a broad Maastrichtian age.
Locality K7586 consists of float from around the 1010 m level. *Diplomoceras cylindraceum* is common, often with serpulids attached to the body chamber interiors, with *Anagaudryceras politissimum*, *Discoscaphites angmartussutensis*, *Neophylloceras groenlandicum* and a number of echinoids including spatangoid, conularid, holasterid and phymosomatid forms. At K7597, around 1043 m, *Diplomoceras cylindraceum* is again common often containing serpulids, together with *Hoploscaphites*, *Anagaudryceras politissimum* and a particularly well-preserved external mould of a teleost fish jaw.

Biostratigraphic conclusions. The *Inoceramus lamarcki/Actinocamax* cf. *manitobensis* assemblage at K7585 is of late MiddleTuronian age or possibly just into the earliest Late Turonian. The overall aspect of the ammonites at K7586 and K7597 is clearly Maastrichtian. The presence of *Discoscaphites angmartussutensis* in the former may indicate the Late Maastrichtian, and the *Spyridoceramus tegulatus* may indicate either the mid-Early or latest Early Maastrichtian.

Sediment Bjerge W4293

Introduction. This section provides a clear succession from the Albian to the Maastrichtian, including the Watkins Fjord/Sorgenfri Formation contact and the Sorgenfri/Christian IV Formation transition.

Macropalaeontology. An ammonite *Anahoplites* sp. of the *planus* group (17.5 m), provides a good *Euhoplites lautus* Zone indicator, Middle Albian, and gives good correlation with the same horizon at Sandridge and Watkins Fjord in the upper part of the Watkins Fjord Formation, Suunigajik Member, thus constraining the age of the base of the Sorgenfri Formation. The overlying Sorgenfri and Christan IV formations at this site did not provide macrofauna.

Palynology. (BB Data) Recognition of the *W. grandstandica* (V1) Subzone (44.5 m) indicates the top of the Watkins Fjord Formation is of potential latest Albian – earliest Cenomanian age. The lowest subzone identified in the section within the Sorgenfri Formations itself is the *O. ancala* (V2) Subzone (54.0–69.0 m), which is of Early Cenomanian age. The *I. cooksoniae* interval (90–105m) indicates the presence of the Late Campanian. The *C. diebelii* interval (112.0–126.5 m) indicates the presence of the Early Maastrichtian.

Biostratigraphic conclusions. The only date for the Sorgenfri Formation at locality W4293 is Early Cenomanian, *O. ancala* Subzone (V2). The unconfomity at this site with the overlying Christian IV Formation is a mud on mud contact and was identified in the field at Turonian, Coniacian and Santonian strata were not recognised, and the next dated interval, the *I. cooksoniae* interval, lies within the lower part of the Christian IV Formation. The upper part of the Christian IV Formation exposed in this section is of *C. diebelii* interval, of Early Maastrichtian age. There remains a substantial undated 21 m interval from 69–90 m, from which samples are available for study.

Sill City W4268 composite

Introduction. This composite section includes localities W4271–W4272 and provides an important succession through the Sorgenfri Formation, where the Christian IV Formation is cut out and the Sorgenfri Formation is unconformably overlain by the Fairytale Valley Member of the Sediment Bjerge Formation. However, Maastrichtian macrofauna is well represented in the reworked concretions of the Christian IV Formation near the top of the section in the upper part of the Fairytale Valley Member.

Macropalaeontology. *In situ* specimens of the bivalve *Inoceramus lamarcki* and the belemnite *Actinocamax* cf. *manitobensis* indicate the presence of the Turonian in the upper part of the Sorgenfri Formation in Locality W4271. Macrofauna was not obtained in the lower formation.
The macrofauna from the reworked nodules of the Christian IV Formation at Locality W4268 includes *Diplomoceras cylindraceum*, *Jeletzkytes* sp., *Scaphites* sp., and pachydiscid ammonites; the nautiloid *Eutrephoceras* sp.; echinoids: *Echinocorys* sp., cardiasterid and spatangoid; the bivalve *Lucina* sp., gastropods, crustacean, annelid and trace fossils.

Biostratigraphic conclusions. The only dating for upper part of the Sorgenfri Formation at locality W4271 is from the *Inoceramus lamarcki* and the belemnite *Actinocamax* cf. *manitobensis* which indicate a latest Middle to earliest Late Turonian age. The reworked ammonites of the Christian IV Formation in the Fairytale Valley Member indicate a broad Maastrichtian age.

Macrofaunal biostratigraphy

Cenomanian

Although in the sections under the present brief no Cenomanian ammonites were obtained. In adjacent sites they have proved important, especially W4225 where *Schloenbachia varians* occurs in close association with *Phylloceras (Hypophylloceras lombardensis, Gaudryceras (G.) cassisianum, G. (Mesogaudryceras) leptonema*, a large tetragonitid gen. et sp. nov., *Parapuzosia (Austeniceras) austeni* (Kelly in Larsen at al. 2005). This fauna is at present being described by W.J. Kennedy and S.R.A. Kelly. The *Schloenbachia* indicates the presence of the *Mantelliceras saxbyi* subzone of the *M. mantelli* Zone, Early Cenomanian and occurs in association with dinoflagellates of the *Ovoidinium* sp. 1 (V3) Subzone. While the genus *Mantelliceras* itself does not occur in Greenland, *Schloenbachia* is the next best indicator, suggesting the potential use of the *S. varians* Zone, now obsolete in NW Europe. Also present at this level is the bivalve *Inoceramus crippsi,* a further Early Cenomanian indicator.

Turonian

Kelly (in Larsen *et al.* 2005) stated the inoceramid bivalve, *Inoceramus lamarcki* gp., and the belemnite, *Actinocamax* cf. *manitobensis*, were the characteristic macrofauna of the Late Turonian in the Kangerlussuaq region. However this statement should be modified because the European range of *I. lamarcki* is given by Walazczyk (1992) as appearing in the latest Middle Turonian, and extending into the earliest Late Turonian. The *I. lamarcki* zone starts with the appearance of *I. lamarcki* and finishes with the appearance of next zone of *I. costellatus* and is strictly of latest Middle Turonian age. In Europe *I. lamarcki* then continues *alongside I. costellatus* in the earliest Late Turonian. In Greenland *I. costellatus* has not been recognised, therefore the Greenland range of *I. lamarcki* should now be given as latest Middle Turonian to earliest Late Turonian. Belemnites were first described from Pyramiden by Swinnerton (1943) as Senonian, and later described by Christensen and Hoch (1983) as *Actinocamax* cf. *manitobensis*, of Middle Turonian age. *I. lamarcki* and *A.* cf. *manitobensis* were collected at localities K7585 and W4268 confirming the presence of the Turonian, close to the Middle – Late Turonian boundary.

Coniacian–Campanian

Macrofauna significant of the Coniacian–Campanian interval were not identified from this or from previous studies in the Kangerlussuaq.

Maastrichtian

The Kangerlussuaq region is the only area of eastern Greenland where Maastrichtian faunas are known. Although there are a number of ammonites present in the Maastrichtian of the Kangerlussuaq, at least 9 genera occur (Kelly in Larsen *et al*. 2005). A full systematic description of the Campanian–Maastrichtian ammonites from eastern Greenland is currently being prepared for publication by W.J. Kennedy with S.R.A. Kelly. There is a problem with the subdivision of the Maastrichtian into an Early and Late substage and there is not agreement yet as to where precisely it should be drawn (reviewed in Ogg *et al.* 2004; in Gradstein *et al.* 2004).

Only one ammonite species is common in Kangerlussuaq, *Diplomoceras cylindraceum* (Defrance). This globally distributed species, which ranges throughout the whole of the Maastrichtian stage is also known to occur in the latest Campanian (Machalski 1996). However, all the Kangerlussuaq records of *D. cylindraceum* appear so far to be of Maastrichtian age only. Scaphitid ammonites provide the most useful biostratigraphic data and occur as sexual dimorphs. The lowest species is *Acanthoscaphites tridens* (Kner) which occurs at several localities including W4245. This species is characteristic of the Early Maastrichtian of NW Europe. Niebuhr (2003) recognised it from the *Belemnella obtusa* to *B. sumensis* zones in north Germany and Kennedy and Summesburger (1987) indicated that the type material, from the Ukraine, comes from the earlier *B. lanceolata* to *B. pseudobtusa* zones. A second species from Kangerlussuaq is *Discoscaphites angmartussutensis* (Birkelund), which was originally described from the Maastrichtian of West Greenland (Birkelund, 1965). Birkelund (1965) equated the dating of *D. angmartussutensis* to the *Discoscaphites* occurrences of the Western Interior of North America, i.e. the *Hoploscaphites* aff. *nicolletti*, *H. nicolletti* and *H. nebrascensis* Zones which Hancock (1995) placed in the later part of the Early Maastrichtian, but which Gradstein *et al.* (2004), as the *Hoploscaphites birkelundi, H. nicolletti* and *Jeletzkytes nebraskensis* zones, placed as the lower zones of the loosely defined Late Maastrichtian. Kennedy *et al.* (1999) demonstrated that Birkelund's (1965) original *D. angmartussutensis* material was in association with dinoflagellates of the *C. diebelii* interval. The highest West Greenland occurrences of *D*. aff *angmartussutensis* occur in association with the *Wodehouseia spinata* pollen interval. *Acanthoscaphites tridens* is probably equated with the *Cerodinium diebelii* dinoflagellate interval and *Discoscaphites angmartussutensis* with the *W. spinata* interval. However, the precise relationship between the ammonite and the dinoflagellate zonal schemes needs further elucidation because it is not established whether these zones are co-eval or whether there are overlaps. The constraints placed by the Early Maastrichtian inoceramid bivalve, *Spyridoceramus tegulatus*, suggest that the lower part of the *W. spinata* interval may be of Early Maastrichtian age (see discussion by Nøhr-Hansen, above).

Conclusions from macrofossils

- The dating of the Turonian *Inoceramus lamarcki-Actinocamax* cf. *manitobensis* association in the Kangerlussuaq Basin is now more accurately understood.
- The Coniacian and Campanian stages are unrepresented by biostratigraphically significant macrofauna in the Kangerlussuaq area.
- The occurrence of heteromorph ammonite *Diplomoceras cylindraceum* is the most commonly found macrofossil in the upper part of the Christian IV Formation and is a ready field indicator for the Maastrichtian Stage in Greenland. Although known to range down into the latest Campanian, this stage is not recognised in the Kangerlussuaq Basin.
- The ammonite *Acanthoscaphites tridens,* the bivalve *Spyridoceramus tegulatus* and the dinocyst *Cerodinium diebelii* interval are strong indicators for the Early Maastrichtian.
- The precise relationship between the concurrence/overlap of *Discoscaphites angmartussutensis* and the *Wodehouseia spinata* interval are unclear. They may indicate the late part of the Early Maastrichtian. Further work on the biostratigraphic significance of these taxa would be beneficial.

Summary and conclusions

The combined biostratigraphic studies of the Upper Cretaceous – Early Palaeogene strata have greatly improved the understanding of the palynological and macrofossil ranges. The main results are:

- The Turonian is well documented by *Inoceramus lamarcki*.
- The Santonian and Campanian have not been documented in the Kangerlussuaq Basin.
- The Maastrichtian is documented by co-occurence of *Diplomoceras cylindraceum* and dinoflagellates. The dinoflagellates and pollen allow subdivision into a lower; *Cerodinium diebelii* interval and upper; *Wodehouseia spinata* interval.
- The uppermost Maastrichtian appears to be unrepresented in the basin and the K/T boundary is everywhere represented by an unconformity. (See also discussion in Larsen *et al*. 2005).
- The oldest rocks overlying the K/T unconformity are of late Danian – late Selandian age as indicated by *Palaeoperidinium pyrophorum*.
- The K/T unconformity has a minimum range of 2–3 million years and spans the uppermost Maastrichtian to the lower Danian. However erosion extends down to the Turonian in the Sill City section.
- Association of *Spyridoceramus tegulatus* with the earliest part of the *Wodehouseia spinata* interval may indicate a latest Early Maastrichtian age.

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Appendix 1, Palynological plates

SINDRI PLATE 1

Fig. 1 *Alterbidinium acutulum* Skiferbjerg 2004 W4245, 493848-8, 80m, 29.9-7.8, LVR 29501

Fig. 2 *Alterbidinium acutulum* Skiferbjerg 2004 W4245, 493848-8, 80m, 40.5-2.2, LVR 29502

Fig. 3 *Cerodinium diebelii* Skiferbjerg 2004 W4245, 493829-4, 60m 50.1-4.8, LVR 29503

Fig. 4 *Cerodinium diebelii* Skiferbjerg 2004 W4245, 493829-5, 60m 33.0-11.2 LVR 29504

Fig. 5 *Wodehouseia* sp. Skiferbjerg 2004 W4245, 493829-4, 60m 46.7-15.8, LVR 29505

Fig. 6 *Aquilapollenites* sp. Skiferbjerg 2004 W4245, 493829-7, 60m 28.1-5.2, LVR 29506

Fig. 7 *Rhombodella paucispina* Skiferbjerg 2004 W4245, 493829-7, 60m 24.0-15.7, LVR 29507

Fig. 8 *Coronifera oceanica* Skiferbjerg 2004 W4245, 493829-7, 60m 52.2-4.7, LVR 29508

Fig. 9 *Rugubivesciculites rugosus* Skiferbjerg 2004 W4245, 493834-4, 66m 17.6-9.1, LVR 29509

Fig. 10 *Aquilapollenites* sp. Skiferbjerg 2004 W4245, 493838-7, 70m 39.6-11.3, LVR 29510

Fig. 11 *Isabelidinium* sp. Skiferbjerg 2004 W4245, 493838-9, 70m 34.0-10.3, LVR 29511

Fig. 12 *Isabelidinium* sp. Skiferbjerg 2004 W4245, 493838-9, 70m 41.6-9.1, LVR 29513

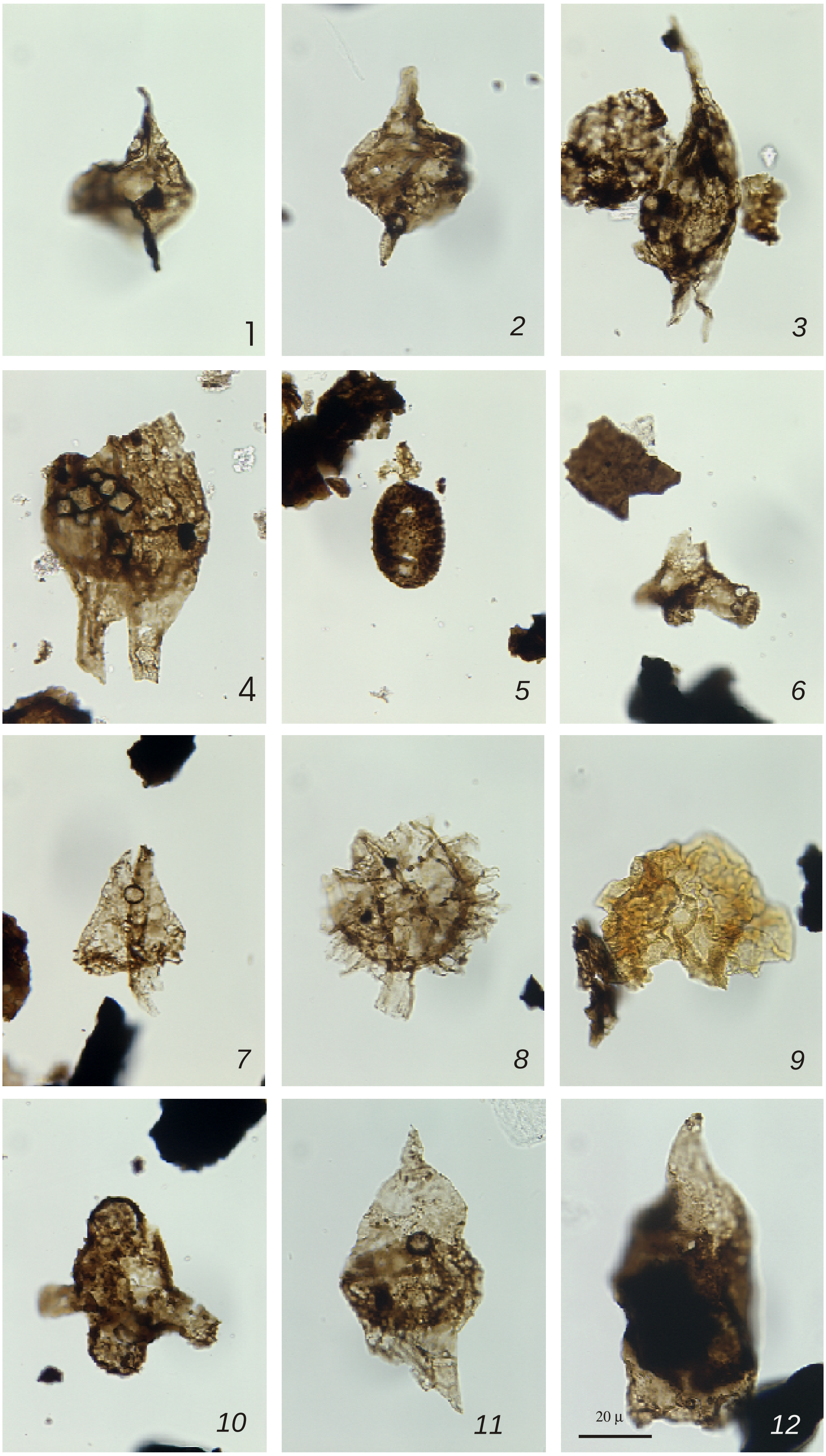


Plate 1

SINDRI PLATE 2

Fig. 1 *Heterosphaeridium heteracanthum* Skiferbjerg 2004 W4245, 493838-9, 70m, 33.6-24.7, LVR 29515

Fig. 2 *Laciniadinium arcticum* Skiferbjerg 2004 W4245, 493843-3, 75m, 37.4-12.9, LVR 29516

Fig. 3 *Bourkidinium* sp. Skiferbjerg 2004 W4245, 493843-3, 75m, 39.1-15.0, LVR 29517

Fig. 4 *Odontochitina operculata* Skiferbjerg 2004 W4245, 493859-7, 90m, 41.5-11.7, LVR 29518

Fig. 5 *Palaeocystodinium australinum* Skiferbjerg 2004 W4245, 493859-9 90m, 42.2-21.3, LVR 29519

Figs. 6– 7 *Cerodinium pannuceum* Skiferbjerg 2004 W4245, 493863-9 92m, 19.9-20.8, LVR 29520–21

Fig. 8 *Palaeocystodinium australinum* Skiferbjerg 2004 W4245, 493869-9 100m, 20.9-16.4, LVR 29522

Fig. 9 *Alterbidinium acutulum* Skiferbjerg 2004 W4245, 493869-10 100m, 19.8-5.6, LVR 29523

Fig. 10 *Wallodinium lunum* Skiferbjerg 2004 W4245, 493869-10 100m, 16.6-21.0, LVR 295243

Figs. 11–12 *Trithyrodinium ?evittii* Skiferbjerg 2004 W4245, 493894-4 139m, 25.8-20.7, LVR 29525–26

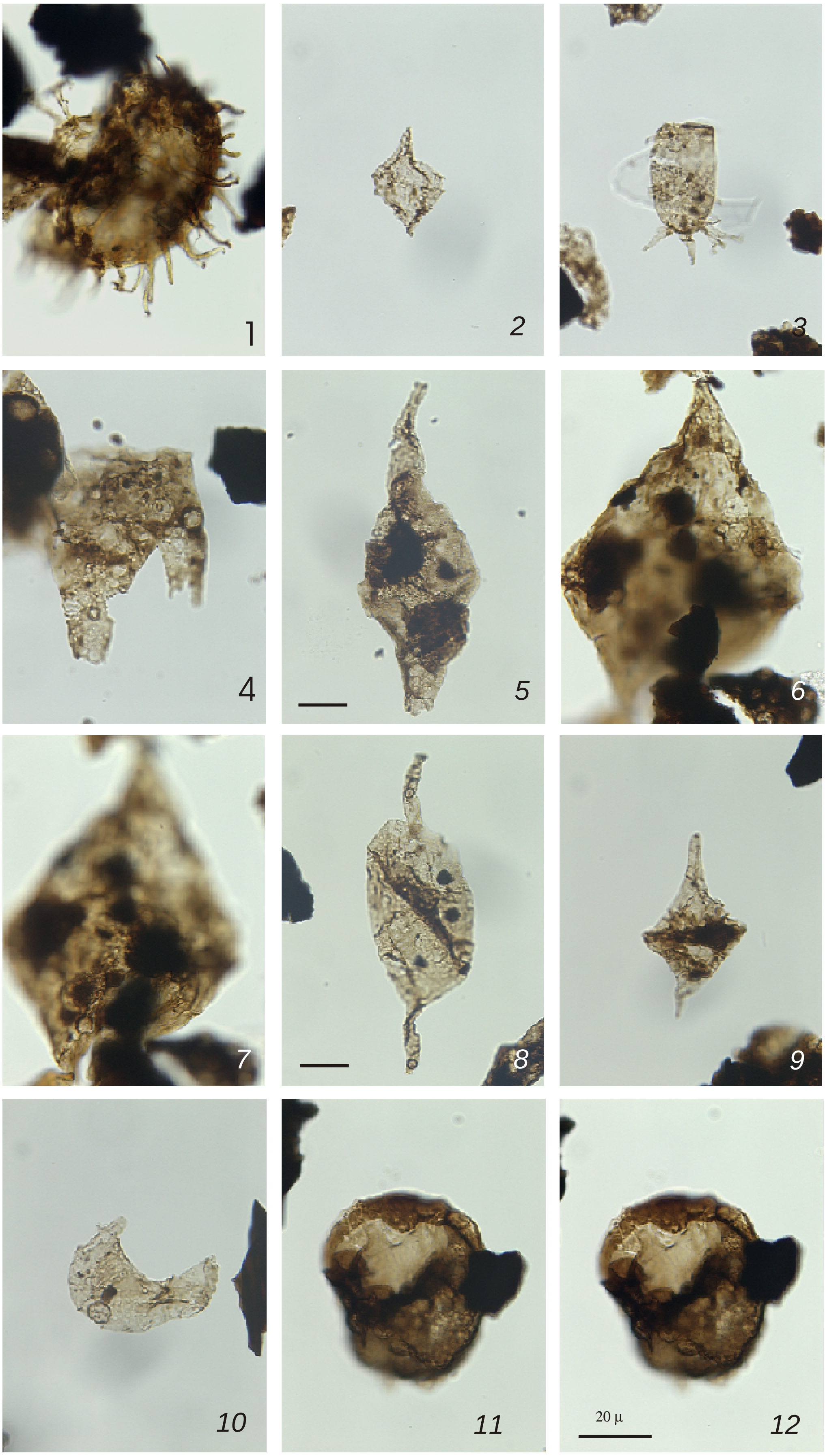


Plate 2

SINDRI PLATE 3

Fig. 1 *Hystrichosphaeridium tubiferum* Skiferbjerg 2004 W4245, 493894-5, 139m, 33.1-8.5, LVR 29527

Fig. 2 *Trithyrodinium quinqueangulare* Skiferbjerg 2004 W4245, 493894-5, 139m, 36.6-4.1, LVR 29528

Figs. 3–4 *Trithyrodinium quinqueangulare* Skiferbjerg 2004 W4245, 493894-5, 139m, 38.6-21.3, LVR 29529–30

Fig. 5 *Cerodinium speciosum* Skiferbjerg 2004 W4245, 493894-5, 139m, 16.0-4.3 LVR 29531

Fig. 6 *Wodehouseia spinata* Skiferbjerg 2004 W4245, 493704-3, 145m 52.3-3.7, LVR 29533

Fig. 7 *Tanyosphaeridium* sp. Skiferbjerg 2004 W4245, 493719-9, 160m 26.7-11.4, LVR 29536

Fig. 8 *Cerodinium speciosum* Skiferbjerg 2004 W4245, 493704-3, 145m, 49.3-7.6 LVR 29535

Fig. 9 *Isabelidinium* sp. Skiferbjerg 2004 W4245, 493720-6, 162m 23.5-8.9, LVR 29537

Fig. 10 *Isabelidinium* sp. Skiferbjerg 2004 W4245, 493721-6, 164m 17.4-10.5, LVR 29538

Fig. 11 *Aquilapollenites* cf. *clarireticulatum* Skiferbjerg 2004 W4245, 493822-7, 166m, 19.6-13.7, LVR 29539

Fig. 12 *Phelodinium kozlowskii* Skiferbjerg 2004 W4245, 493822-7, 166m 28.7-21.0, LVR 29541

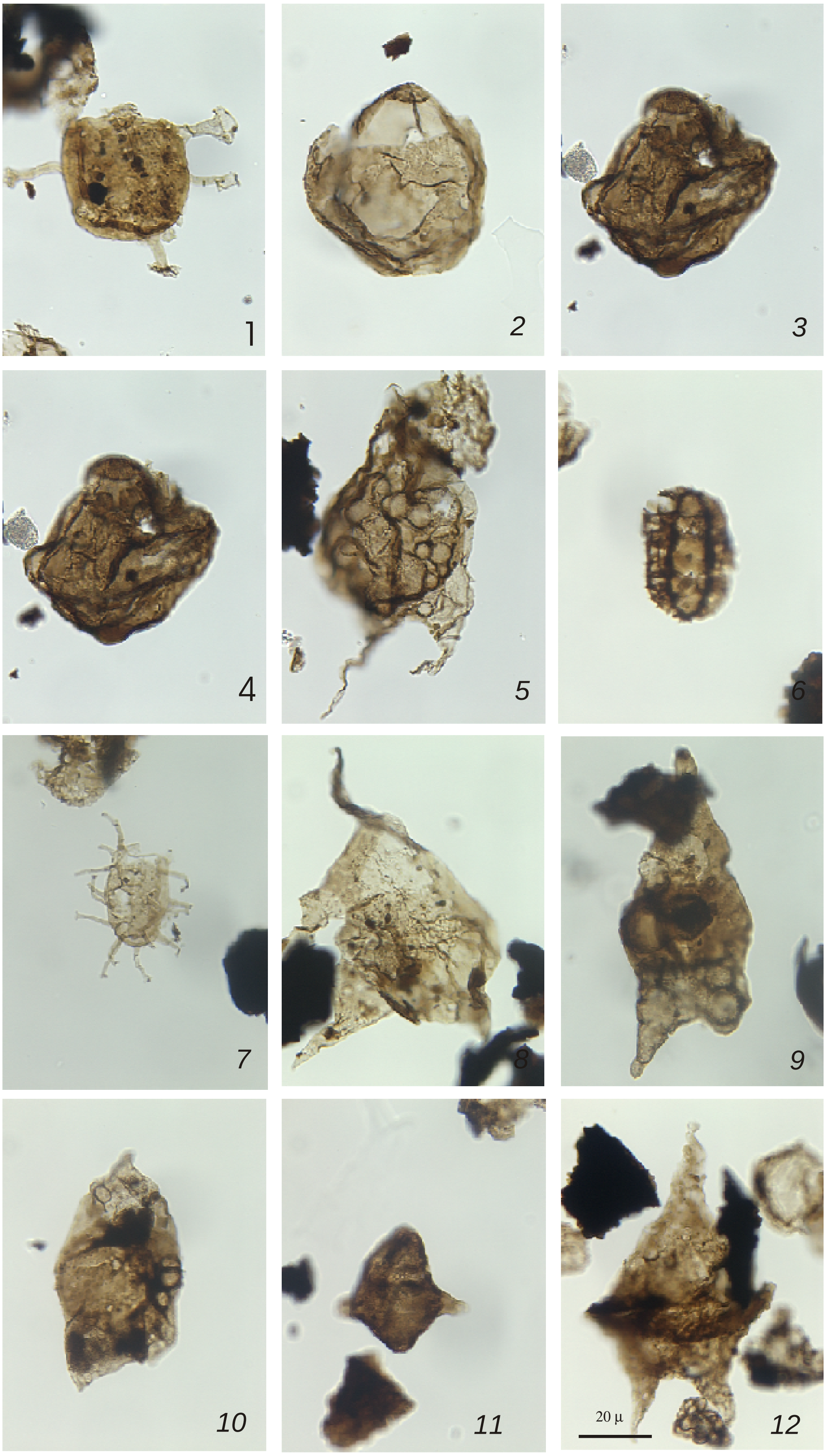


Plate 3

SINDRI PLATE 4

Figs. 1–2 *Triblastula utinensis* Sequoia West, 406748-3, 1482m, 17.9-8.3, LVR 29593–95

Fig. 3 *Hystrichosphaeridium quasicribrata* Skiferbjerg 2003, 455633-4, 125m, 25.2-21.0, LVR 29642

Fig. 4 *Rottnestica* cf. *wetzelii* Sequoia Nunatak, 406765-3, 1505m, 53.9-19.7, LVR 29596

Fig. 5 *Rottnestica* cf. *wetzelii* Skiferbjerg 2004 W4245, 493722-7, 166m, 24.3-12.6, LVR 29542

Fig. 6 *Hystrichostrogylon coninckii* Sequoia Nunatak, 406765-4, 1505m, 39.8-21.1, LVR 29640

Fig. 7 *Hystrichostrogylon coninckii* Skiferbjerg 2003, 455633-4, 125m, 38.2-19.50, LVR 29643

Fig. 8 *Cerodinium pannuceum* Sequoia Nunatak, 406769-7, 1510m, 36.3-24.8, LVR 29597

Fig. 9 *Hystrichosphaeridium tubiferum* Skiferbjerg 2004 W4245, 493723-6, 167m, 40.6-21.4, LVR 29543

Fig. 10 *Rhombodella paucispina* Skiferbjerg 2004 W4245, 493724-6, 169m 20.7-18.9, LVR 29545

Fig. 11 *Deflandrea* cf. *galeata* Skiferbjerg 2004 W4245, 493726-9, 170m 36.0-14.9, LVR 29546

Fig. 12 *Cerodinium speciosum* Skiferbjerg 2004 W4245, 493726-8, 170m 40.3-21.5, LVR 29547

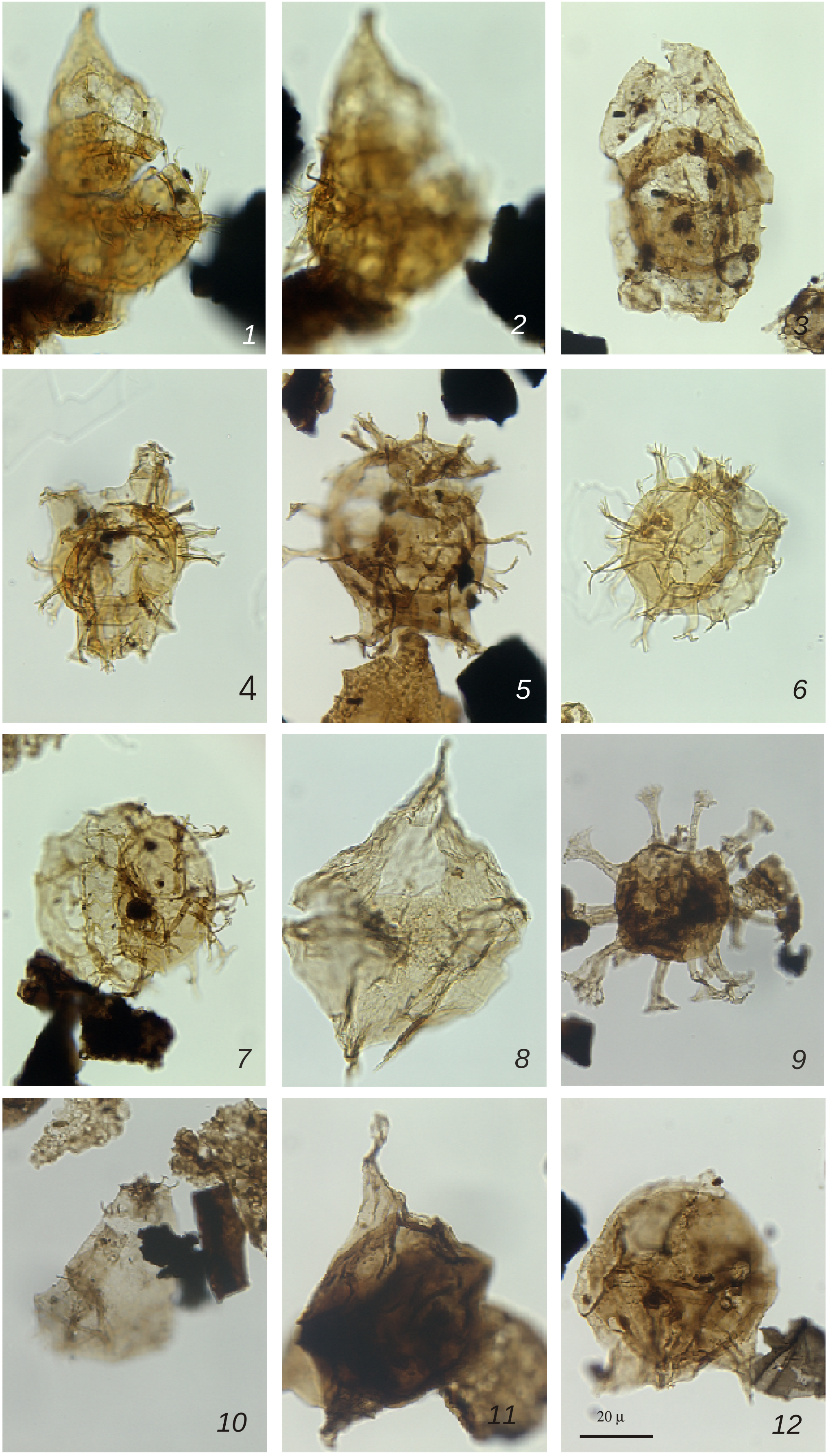


Plate 4

SINDRI PLATE 5

Fig. 1 *Cerodinium speciosum* Skiferbjerg 2004 W4245, 493726-10 170m 50.6-14.7, LVR 29548

Fig. 2 *Cerodinium speciosum* Skiferbjerg 2004 W4245, 493726-10 170m 34.9-15.2, LVR 29549

Fig. 3 *Palaeocystodinium* cf. *australinum* Skiferbjerg 2004 W4245, 493726-10 170m 50.5-13.1, LVR 29550

Fig. 4 *Isabelidinium* sp. Skiferbjerg 2004 W4245, 493727-6 171m 22.7-19.3, LVR 29551

Fig. 5 *Heterosphaeridium heteracanthum* Skiferbjerg 2004 W4245, 493727-6 171m 42.6-12.0, LVR 29552

Fig. 6 *Cerodinium diebelii* Skiferbjerg 2004 W4245, 493730-6 174m 40.9-23.3, LVR 29553

Fig. 7 *Dinogymnium* cf. *kasachstanicum* Skiferbjerg 2004 W4245, 493730-6 174m 40.9-23.3, LVR 29553

Fig. 8 *Cerodinium speciosum* Skiferbjerg 2004 W4245, 493731-6 175m 36.0-18.8, LVR 29555

Fig. 9 *Areoligera* sp. Skiferbjerg 2004 W4245, 493731-6 175m 47.7-5.7, LVR 29556

Fig. 10 *Areoligera* sp. Skiferbjerg 2004 W4245, 493731-6 175m 47.7-5.7, LVR 29557

Fig. 11*Cerodinium striata* Skiferbjerg 2004 W4245, 493731-7 175m 20.2-8.4, LVR 29558

Fig. 12 *Cerodinium diebelii* Skiferbjerg 2004 W4245, 493731-7 175m 20.8-24.5, LVR 29559

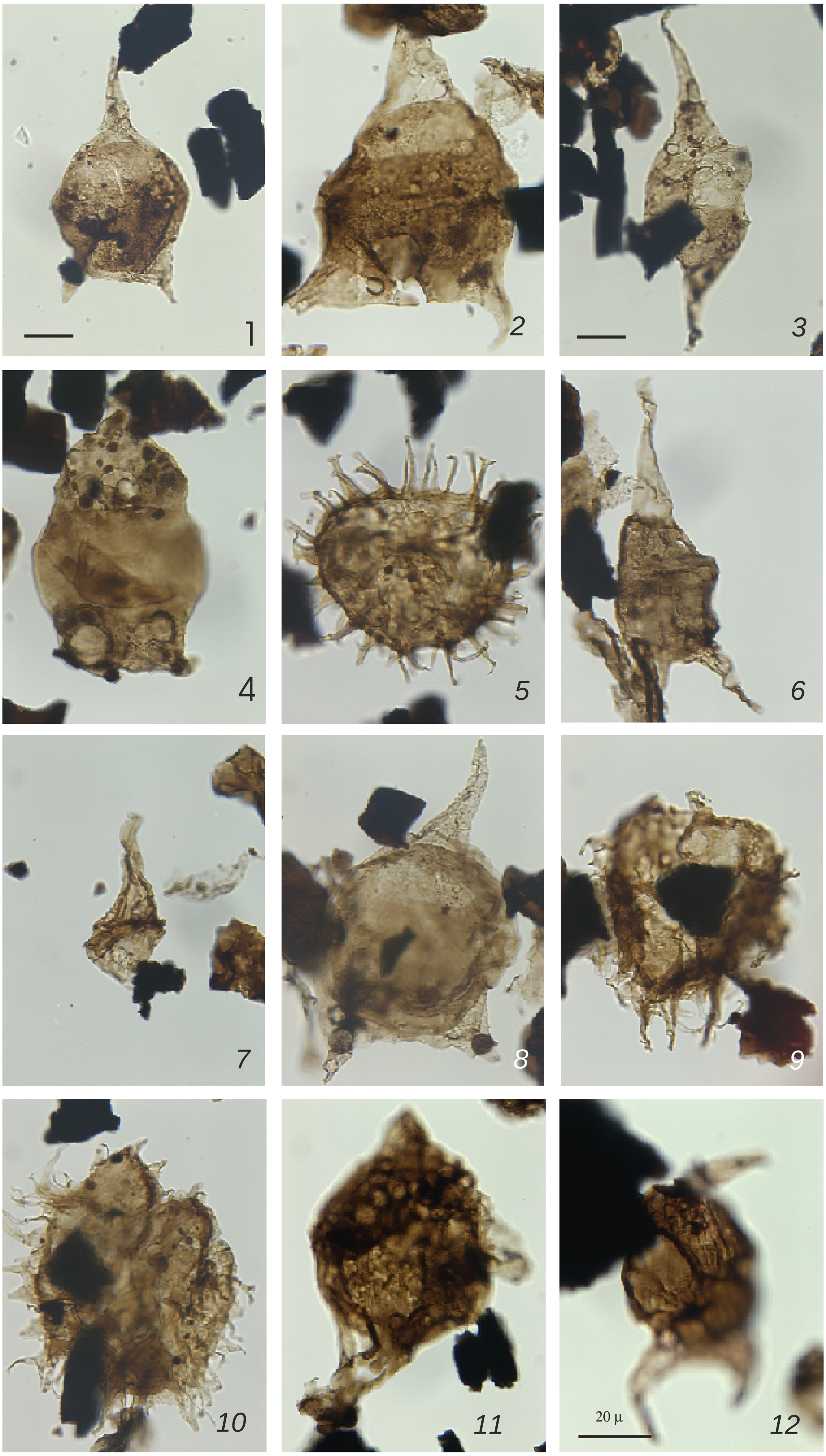


Plate 5

SINDRI PLATE 6

Fig. 1 *Areoligera* sp. Skiferbjerg 2004 W4245, 493732-7 176m 19.6-21.7, LVR 29560

Fig. 2 *Areoligera* sp. Skiferbjerg 2004 W4245, 493732-7 176m 29.4-7.0, LVR 29561

Fig. 3 *Areoligera* sp. Skiferbjerg 2004 W4245, 493732-5 176m 29.8-15.3, LVR 29562

Fig. 4 *Trithyrodinium quinqueangulare* Skiferbjerg 2004 W4245, 493733-6 177m 20.5-14.2, LVR 29563

Fig. 5 *Areoligera* sp. Skiferbjerg 2004 W4245, 493734-7 178m 30.8-18.9, LVR 29564

Fig. 6 *Palaeocystodinium australinum* Skiferbjerg 2004 W4245, 493734-6 178m 40.5-10.9, LVR 29565

Fig. 7 *Cerodinium striatum* Skiferbjerg 2004 W4245, 493735-9 180m 32.9-19.7, LVR 29566

Fig. 8 *Cerodinium striatum* Skiferbjerg 2004 W4245, 493735-10 180m 49.2-20.6, LVR 29567

Fig. 9 *Diphyes colligerum* Skiferbjerg 2004 W4245, 493735-10 180m 21.0-23.7, LVR 29568

Fig. 10 *Cerodinium striatum* Skiferbjerg 2004 W4245, 493744-7 190m 46.9-12.3, LVR 29569

Fig. 11 *Diphyes colligerum* Skiferbjerg 2004 W4245, 493744-7 190m 16.3-20.5, LVR 29570

Fig. 12 *Palaeocystodinium* cf. *australinum* Skiferbjerg 2004 W4245, 493744-9 190m 32.2-9.2, LVR 29571

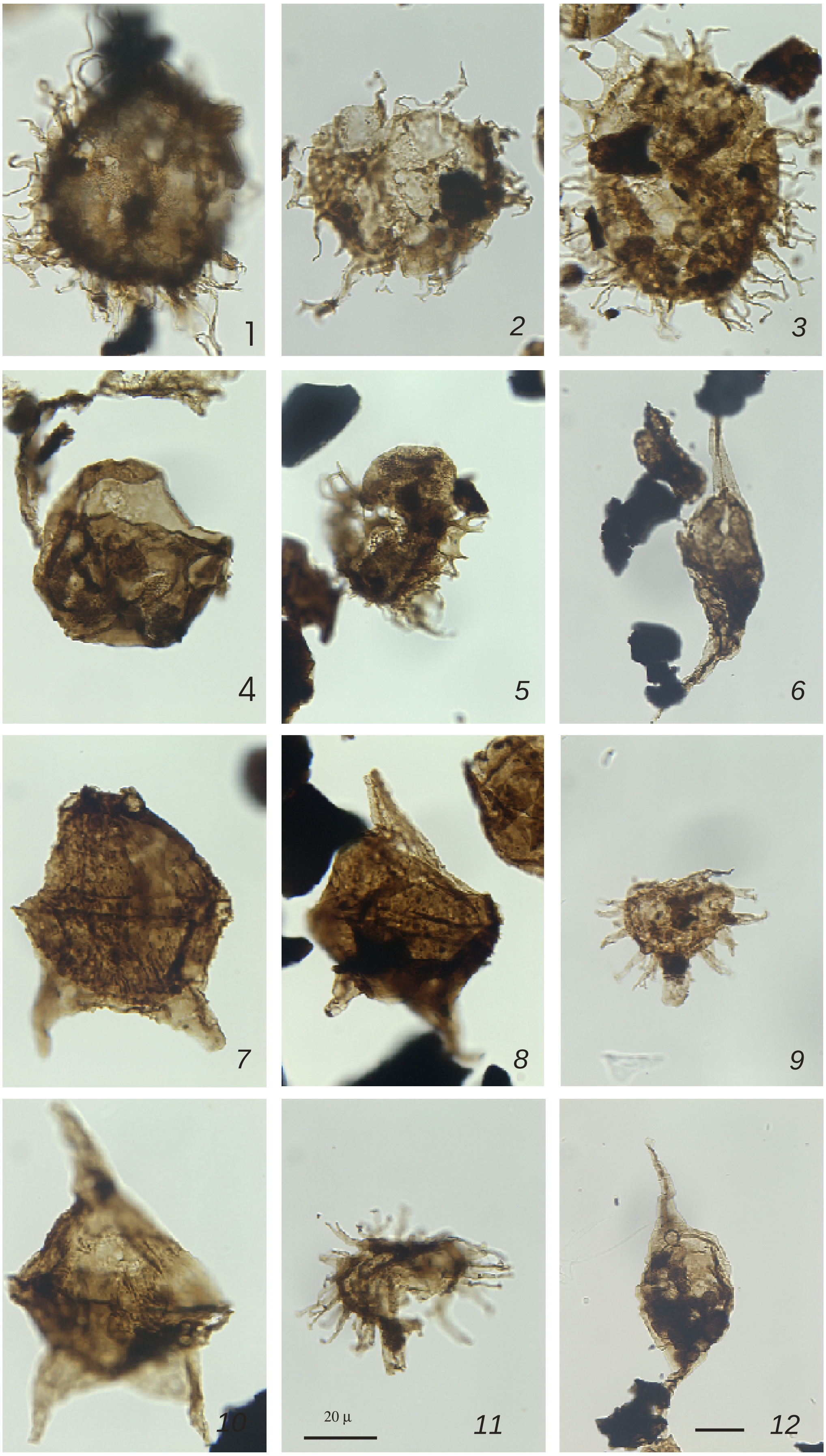


Plate 6

SINDRI PLATE 7

Fig. 1 *Palaeocystodinium* cf. *australinum* Skiferbjerg 2004 W4245, 493744-9 190m 54.1-24.1, LVR 29572

Fig. 2 *Deflandrea* cf. *galeata* Skiferbjerg 2004 W4245, 493744-10 190m 32.1-16.8, LVR 29573

Fig. 3 *Alisocysta circumtabulata* Sequoia West, 406752-4 1500m 20.7-7.2, LVR 29645

Fig. 4 *Cerodinium pannuceum* Skiferbjerg 2004 W4245, 493761-7 207m 23.1-18.0, LVR 29577

Fig. 5 *Isabelidinium* sp.*reoligera* sp. Skiferbjerg 2004 W4245, 493761-5 207m 53.4-24.2, LVR 295778

Figs 6–8 *Fibradinium annetorpense* Sequoia Nunatak, 406772-4 1550m 35.2-20.9, LVR 29647–49

Fig. 9 *Fibradinium annetorpense* SequoiaWest, 406752-3 1500m 40.1-9.5, LVR 29646

Fig. 10 *Rottnestia wetzelii* Skiferbjerg 2004 W4245, 493768-6 214m 24.5-17.1, LVR 29579

Figs 11–12 *Rottnestia wetzelii* Skiferbjerg 2004 W4245, 493772-6 218m 19.1-16.2, LVR 29581–82

Fig. 13 *Rottnestia wetzelii* Skiferbjerg 2004 W4245, 493772-6 218m 29.0-24.5, LVR 29584

Fig. 14 *Rottnestia wetzelii* Skiferbjerg 2004 W4245, 493772-7 218m 24.9-23.1, LVR 29585

Fig. 15 *Rottnestia wetzelii* Skiferbjerg 2004 W4245, 493772-6 218m 25.4-25.2, LVR 29583

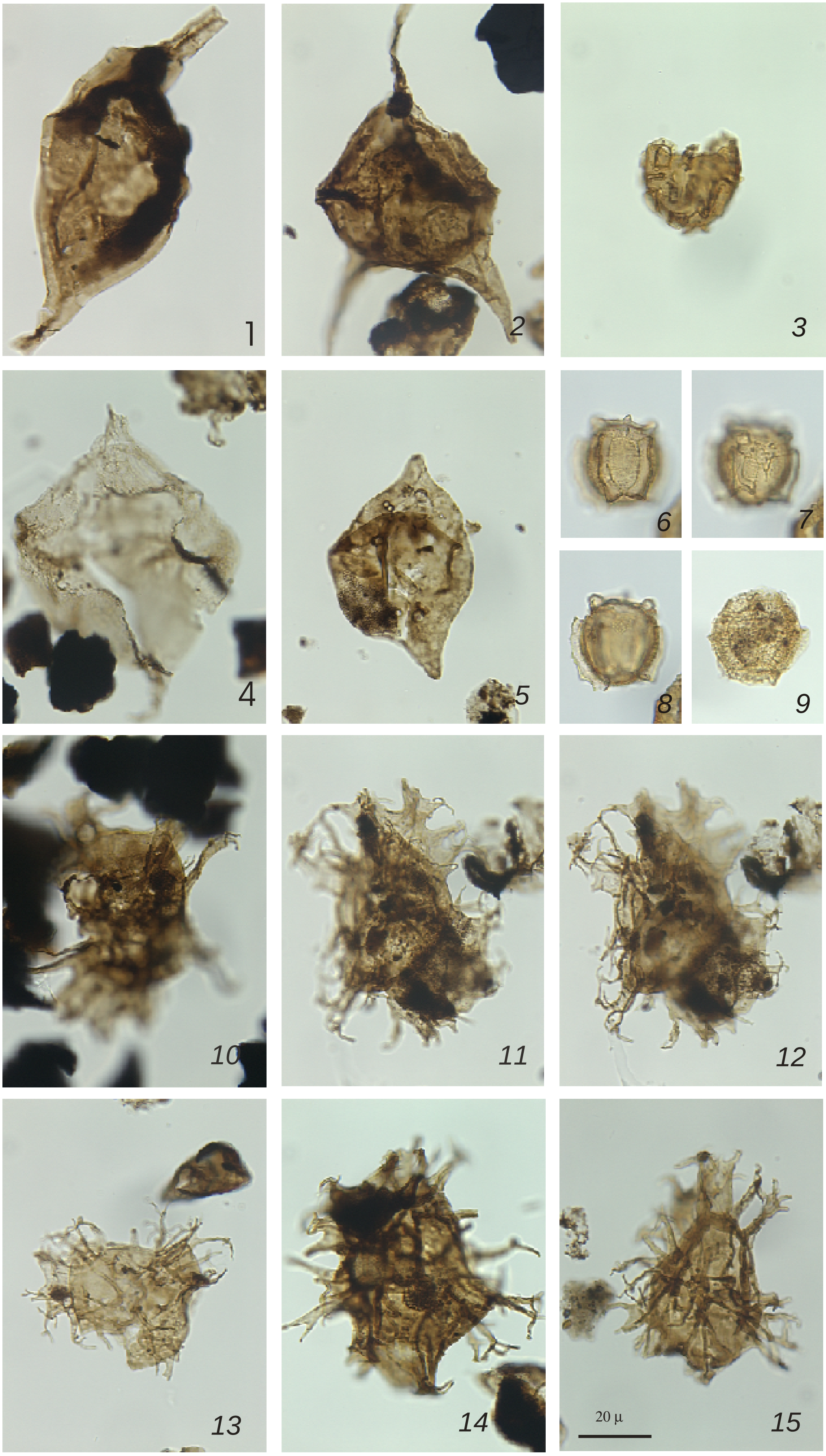


Plate 7

SINDRI PLATE 8

Figs 1–2 *Rottnestia wetzelii* Skiferbjerg 2004 W4245, 493772-7 218m 27.2-20.3, LVR 29586–87

Fig. 3 *Impagidinium* sp. Skiferbjerg 2004 W4245, 493772-7 218m 32.1-5.6, LVR 29589

Fig. 4 *Rottnestia wetzelii* Skiferbjerg 2004 W4245, 493772-7 218m 35.6-12.8, LVR 29590

Fig. 5 *Rottnestia wetzelii* Skiferbjerg 2004 W4245, 493770-7 216m 41.4-6.4, LVR 29591

Fig. 6 *Cerodinium* aff. *kangiliense* Watkins Fjord 2003, 483066-4 88m 46.6-16.3, LVR 29599

Figs 7–8 *Areoligera coronata* Watkins Fjord 2003, 483067-5 89m 20.3-22.2, LVR 29600–01

Fig. 9 *Areoligera coronata* Watkins Fjord 2003, 483067-5 89m 22.0-5.6, LVR 29602

Fig. 10 *Spiniferites magnificus* Watkins Fjord 2003, 413269-1 100m 30.1-10.3, LVR 29603

Fig. 11 *Senegalinium iterlaaense* Watkins Fjord 2003, 413269-1 100m 53.7-9.9, LVR 29604

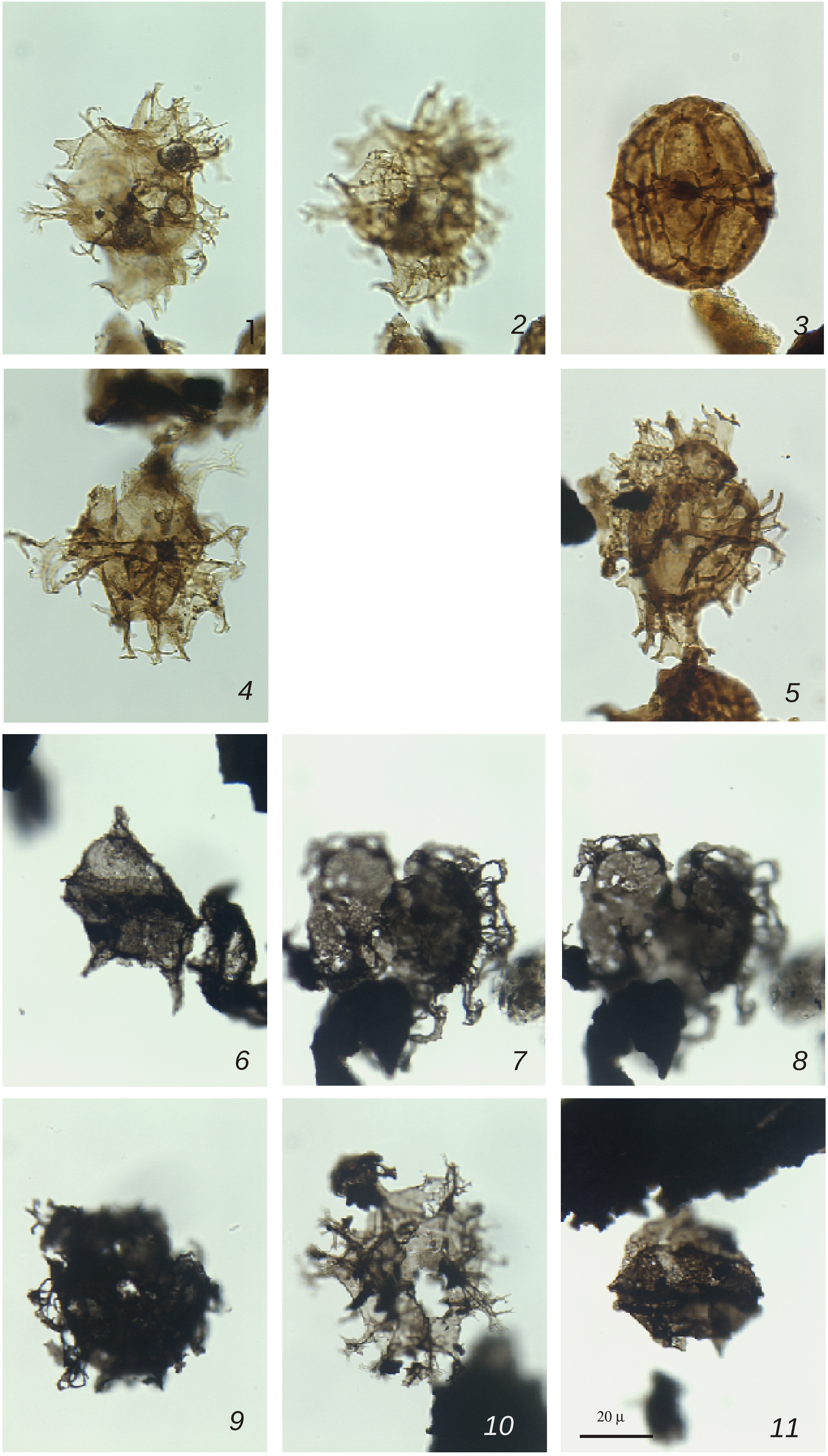


Plate 8

SINDRI–PLATE 9

Fig. 1 *Cerodinium diebelii* Watkins Fjord 2003, 413269-4 100m 27.7-18.5, LVR 29606

Fig. 2 *Palaeocystodinium bulliforme* Watkins Fjord 2003, 413269-2 100m 29.8-22.5, LVR 29607

Fig. 3 *Palaeocystodinium bulliforme* Watkins Fjord 2003, 413269-2 100m 35.9-16.3, LVR 29608

Fig. 4 *Cerodinium striatum* Watkins Fjord 2003, 413269-1 100m 50.2-13.8, LVR 29609

Fig. 5 *Cerodinium denticulata* Watkins Fjord 2003, 413269-1 100m 32.2-21.8, LVR 29610

Fig. 6 *Palaeocystodinium bulliforme* Watkins Fjord 2003, 413269-4 100m 29.0-11.0, LVR 29611

Figs 7–8 *Areoligera* sp.Watkins Fjord 2003, 413271-4 105m 44.1-14.5, LVR 29612–13

Fig. 9 *Areoligera* sp.Watkins Fjord 2003, 413271-4 105m 36.2-10.5, LVR 29614

Fig. 10 *Palaeoperidinium pyrophorum* Watkins Fjord 2003, 413271-4 105m 36.0-10.0, LVR 29616

Fig. 11 *Areoligera* sp.Watkins Fjord 2003, 413271-2 105m 36.0-9.9, LVR 29618

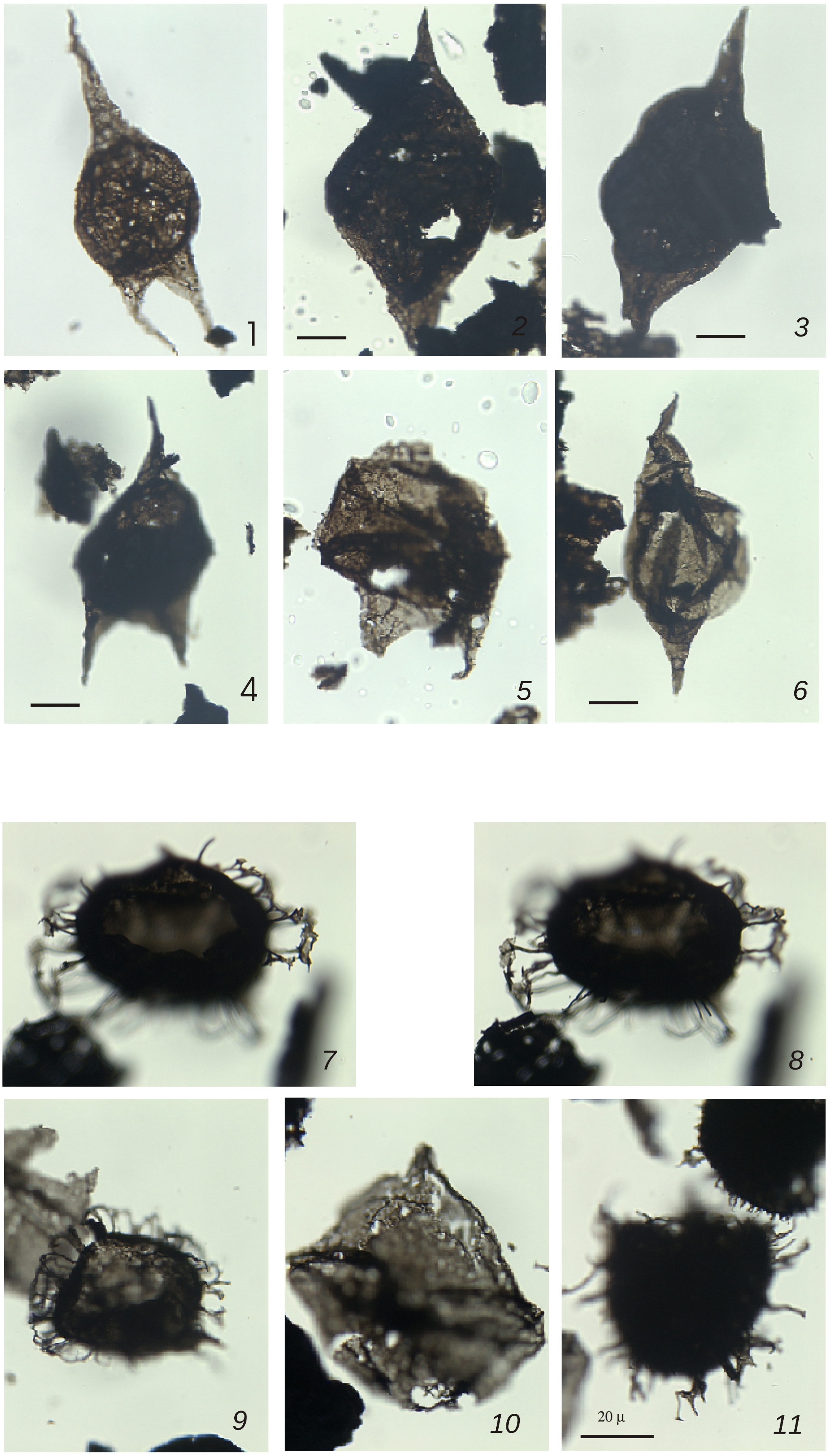


Plate 9

SINDRI PLATE 10

Fig. 1 *Hystrichodinium voigtii* Sill City, 483055-3 30m 27.0-15.0, LVR 29619

Fig. 2 *Raphidodinium fucatum* Sill City, 483055-4 30m 21.0-9.6, LVR 29620

Fig. 3 *Palaeoperidinium cretaceum* Sill City, 483055-5 30m 43.7-11.2, LVR 29621

Fig. 4 *Palaeohystrichophora infusorioides* Sill City, 483055-5 30m 22.4-12.7, LVR 29622

Fig. 5 *Palaeoperidinium pyrophorum* Sill City, 483233-1 87m 19.1-14.0, LVR 29623

Fig. 6 *Palaeoperidinium pyrophorum* Sill City, 483233-3 87m 29.6-4.2, LVR 29624

Fig. 7 *Areoligera* sp. Sill City, 483234-5 88m 50.6-12.4, LVR 29625

Fig. 8 *Palaeoperidinium pyrophorum* Sill City, 483236-4 90m 20.0-3.1, LVR 29626

Fig. 9 *Surculosphaeridium longifurcatum*Watkins Fjord 2003, 483064-3 86m 16.3-15.2, LVR 29627

Fig. 10 *Senegalinium* sp. Fairytale Valley, 413144-8 141m 35.1-20.5, LVR 29628

Fig. 11 *Senegalinium* sp. Fairytale Valley, 413144-6 141m 40.2-5.5, LVR 29631

Fig. 12 *Spinidinium ?ovale* Fairytale Valley, 413144-3 141m 28.1-20.2, LVR 29630

Fig. 13 Dino sp. Fairytale Valley, 413144-7 141m 45.1-4.2, LVR 29629

Fig. 14 *Senegalinium* sp. Fairytale Valley, 413144-3 141m 46.3-19.1, LVR 29633

Fig. 15 *Senegalinium* sp. Fairytale Valley, 413144-5 141m 44.6-5.0, LVR 29632

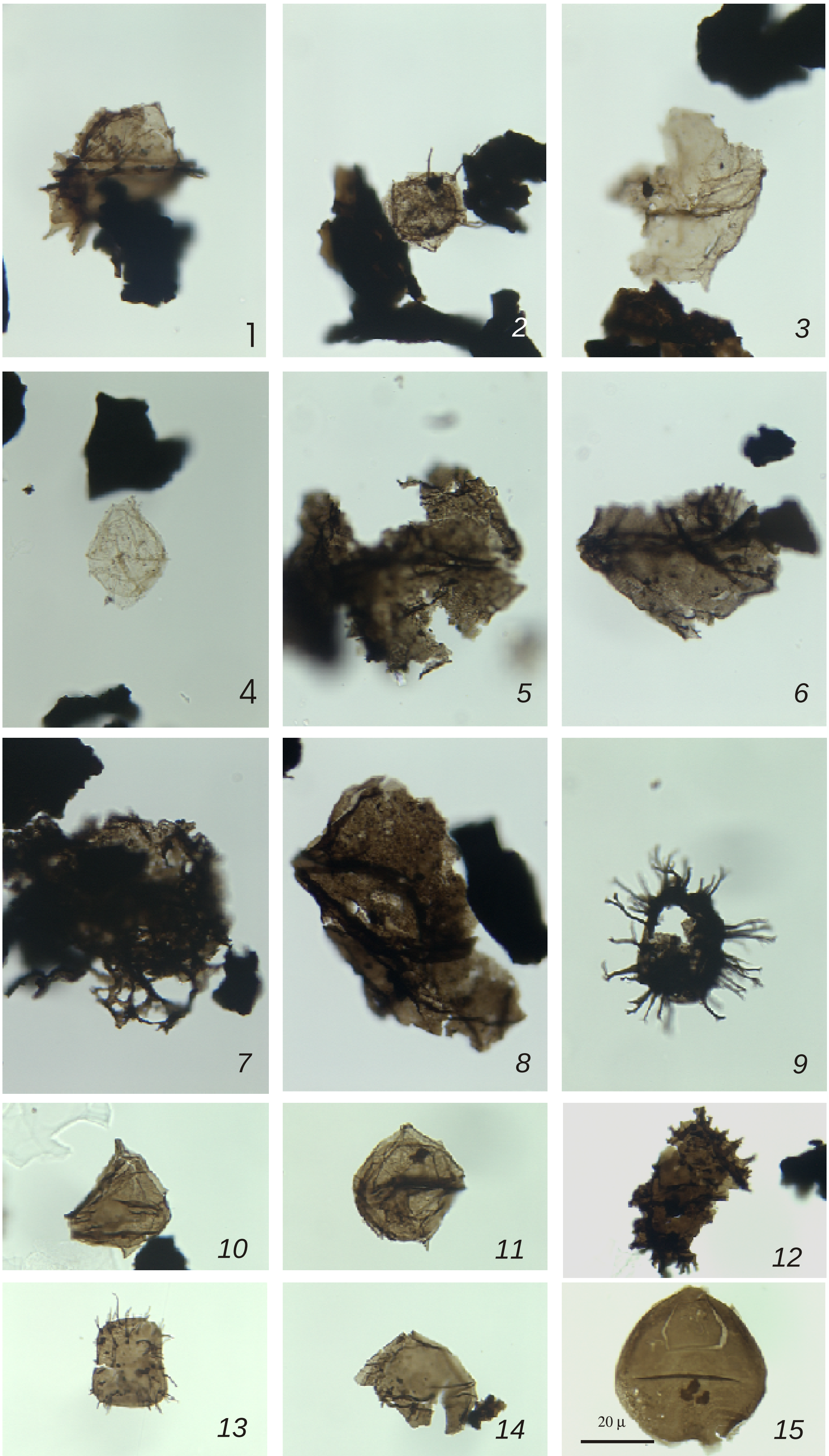


Plate 10

Stratabugs charts GEUS

Section : Skiferbjerg 2004

Interval : 265m - 0m

Scale : 1:500

Chart date : 08 March 2006

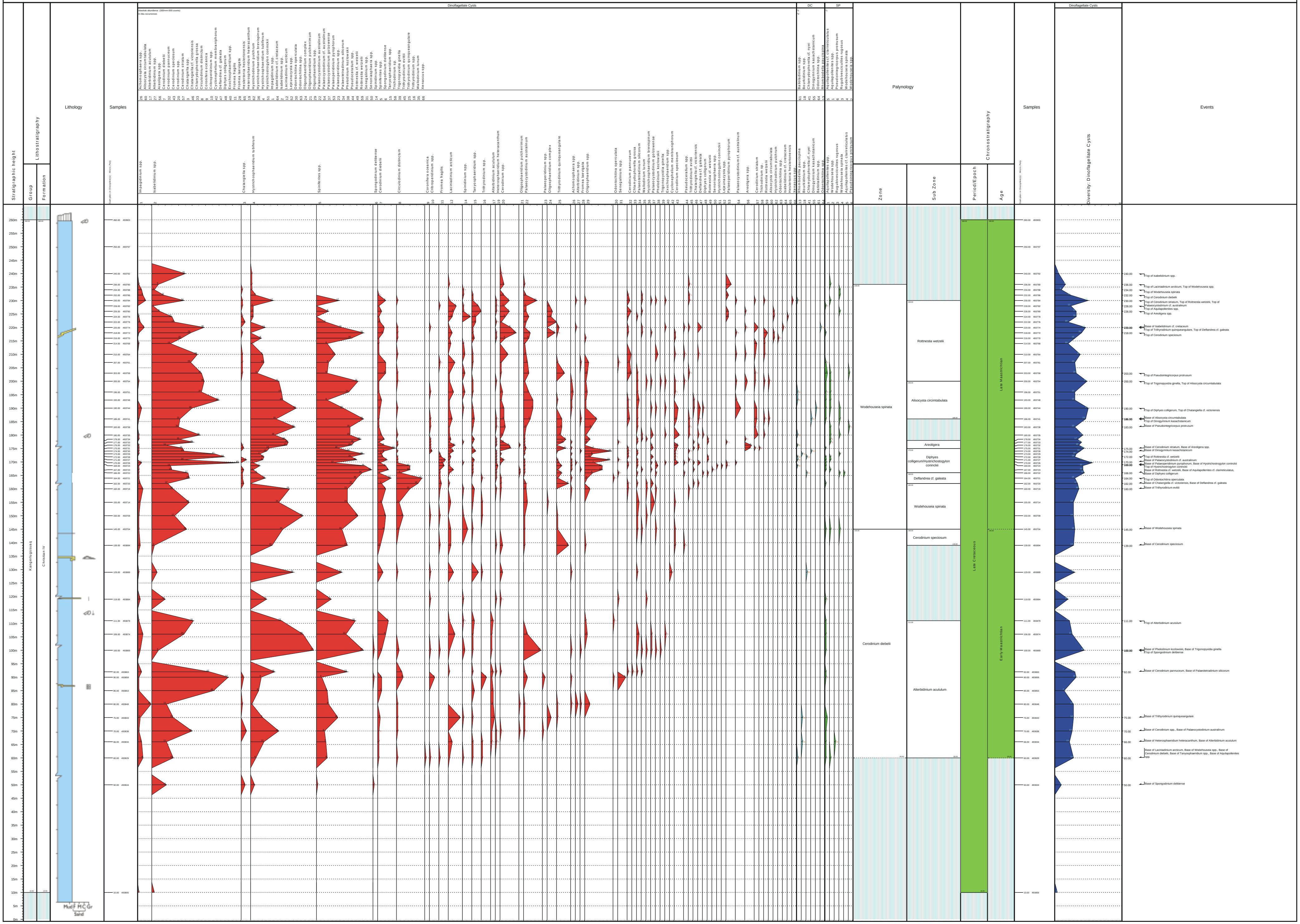
Skiferbjerg 2004

GEUS

Sindri Report January 2006

IGD Boundary Key
- Possible
- Probable
- Confident
- Unconformable
- ?Unconformable
- Fault
- ?Fault

Text Keys
*1 Absolute abundance (300mm=300 counts)
*2 Reworked,Caved occurrences



Section : Skiferbjerg 2003

Interval : 265m - 15m

Scale : 1:1000

Chart date : 08 March 2006

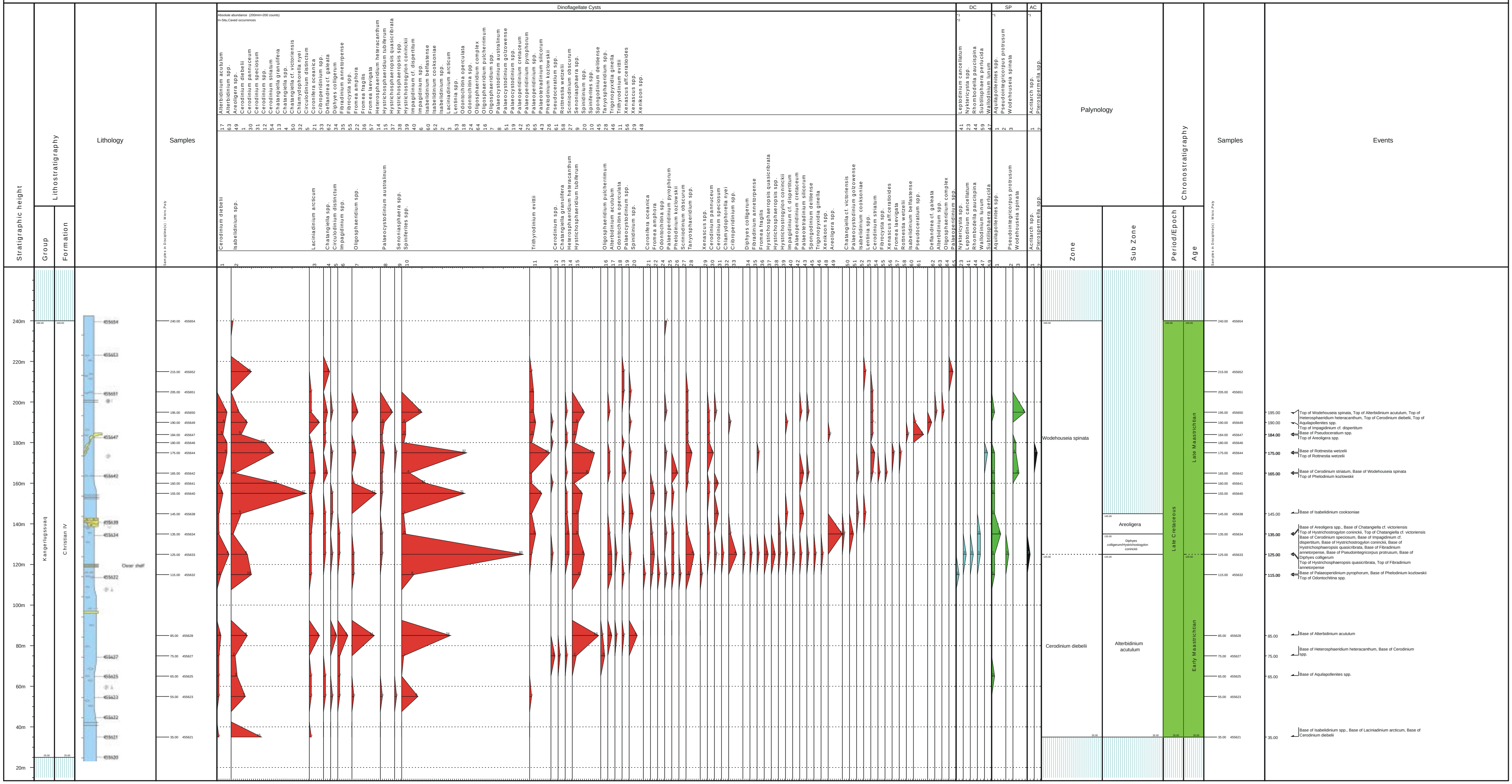
Skiferbjerg 2003

GEUS

Sindri Report January 2006

IGD Boundary Key
- Possible
- Probable
- Confident
- Unconformable
- ?Unconformable
- Fault
- ?Fault

Text Keys
- *1 Absolute abundance (300mm=200 counts)
- *2 Reworked occurrences



Enclosure 2

Section : Sequoia West

Interval : 1526m - 1408m

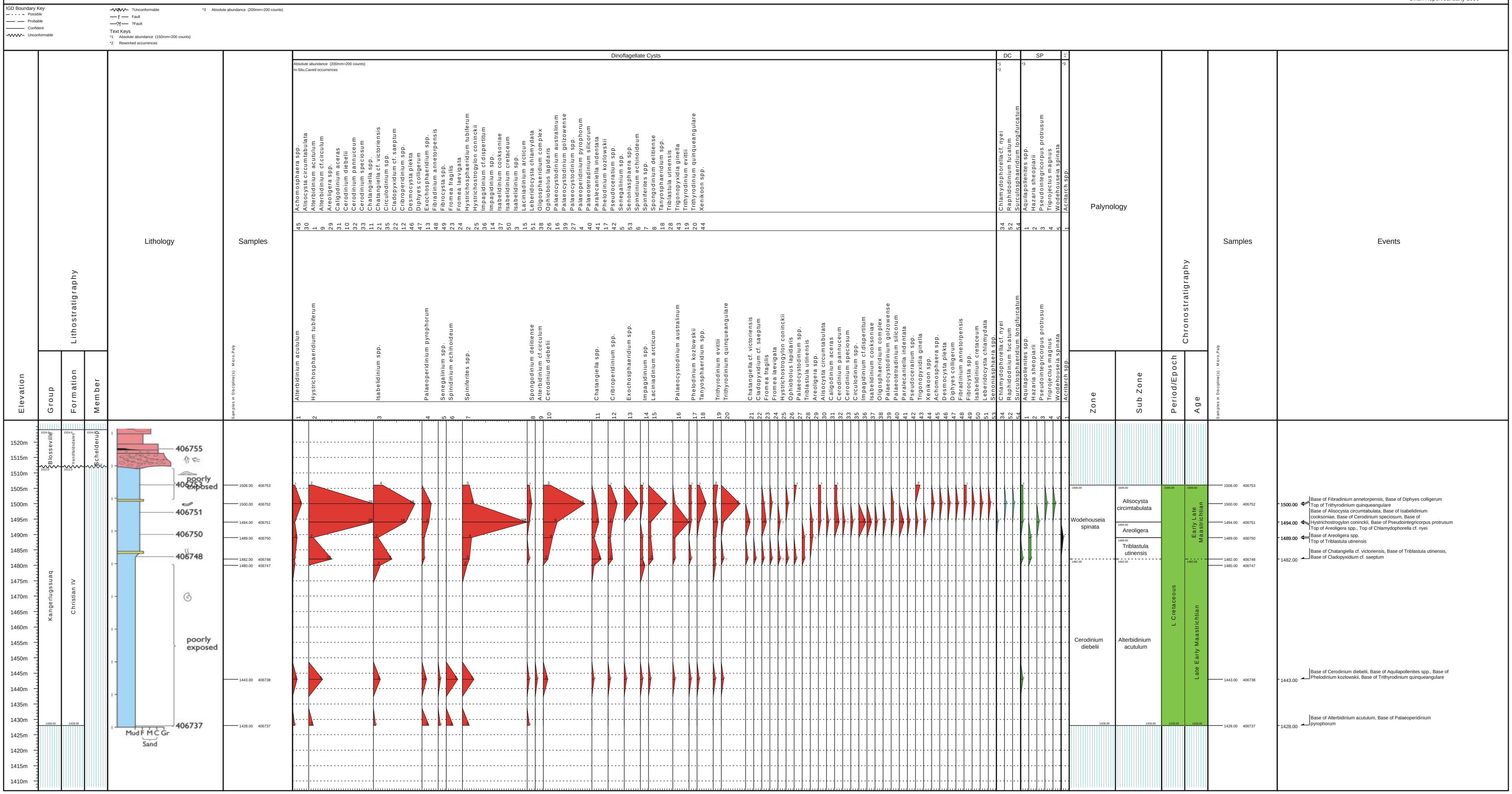
Scale : 1:750

Chart date : 09 February 2006

Sequoia West

GEUS

Sindri Report January 2006



Enclosure 3

Section : Sequoia Nunatak

Interval : 1578m - 1500m

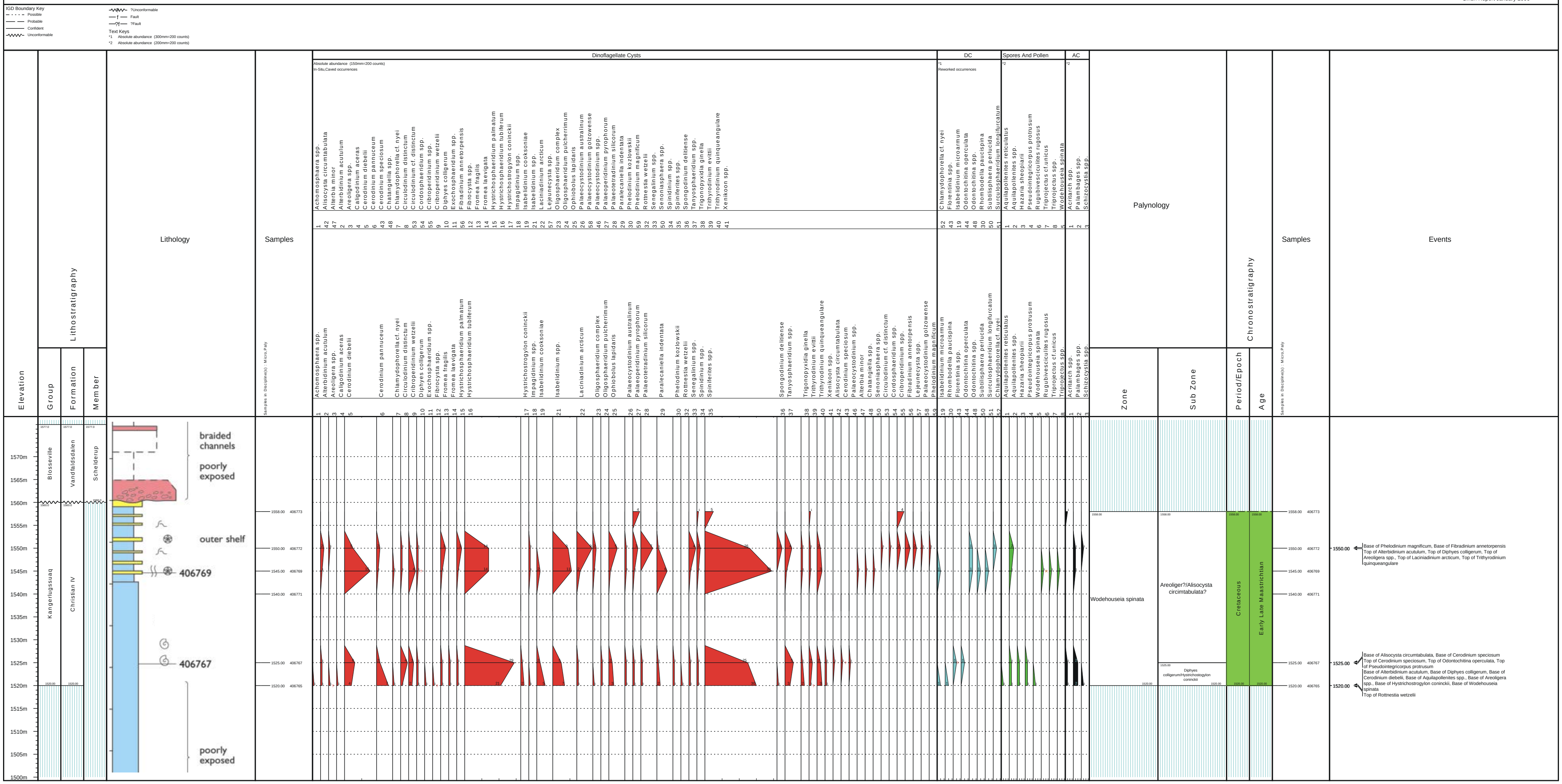
Scale : 1:500

Chart date : 08 February 2006

Sequoia Nunatak

GEUS

Sindri Report January 2006



Enclosure 4

Section : Watkins Fjord 2003

Interval : 110m - 60m

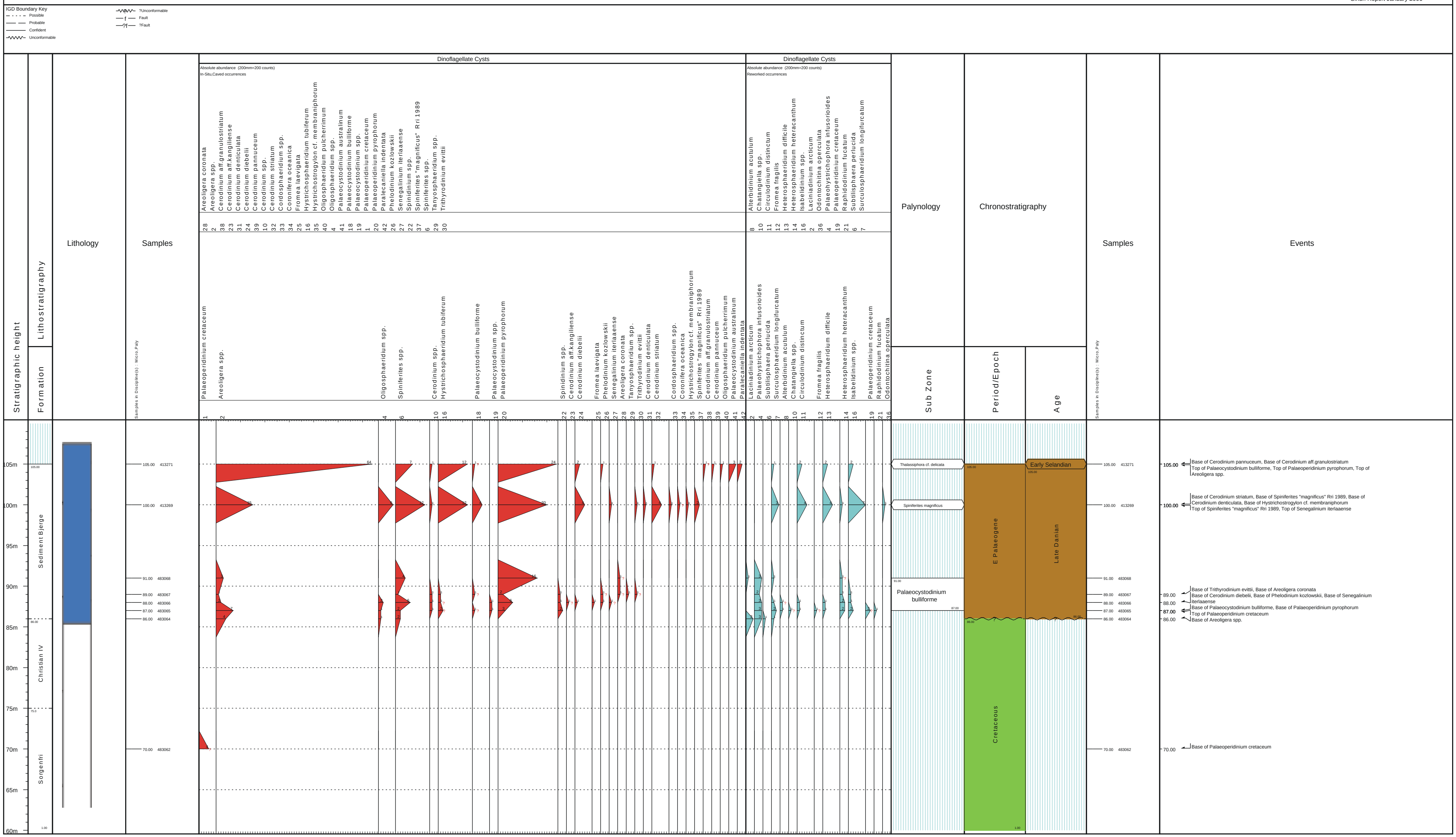
Scale : 1:300

Chart date : 27 February 2006

Watkins Fjord 2003

GEUS

Sindri Report January 2006



Enclosure 5

Section : Watkins Fjord 2004

Interval : 125m - 60m

Scale : 1:750

Chart date : 27 February 2006

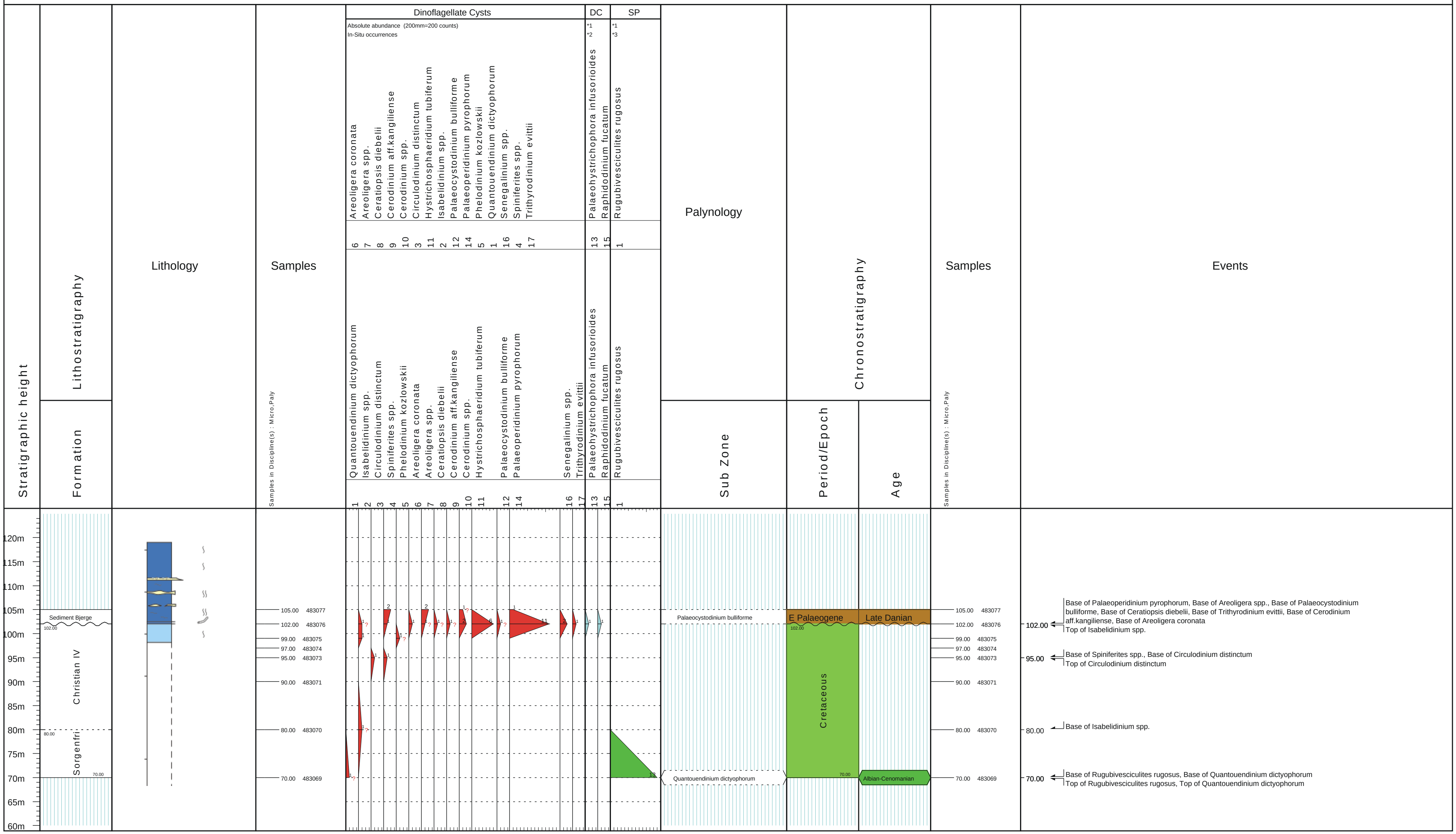
Watkins Fjord 2004

GEUS

Sindri Report January 2006

IGD Boundary Key
- Possible
- Probable
- Confident
- Unconformable
- ?Unconformable
- Fault
- ?Fault

Text Keys
- *1 Absolute abundance (200mm=200 counts)
- *2 Reworked occurrences
- *3 In-Situ,Reworked occurrences



Section : Fairytale Valley

Interval : 150m - 90m

Scale : 1:500

Chart date : 27 February 2006

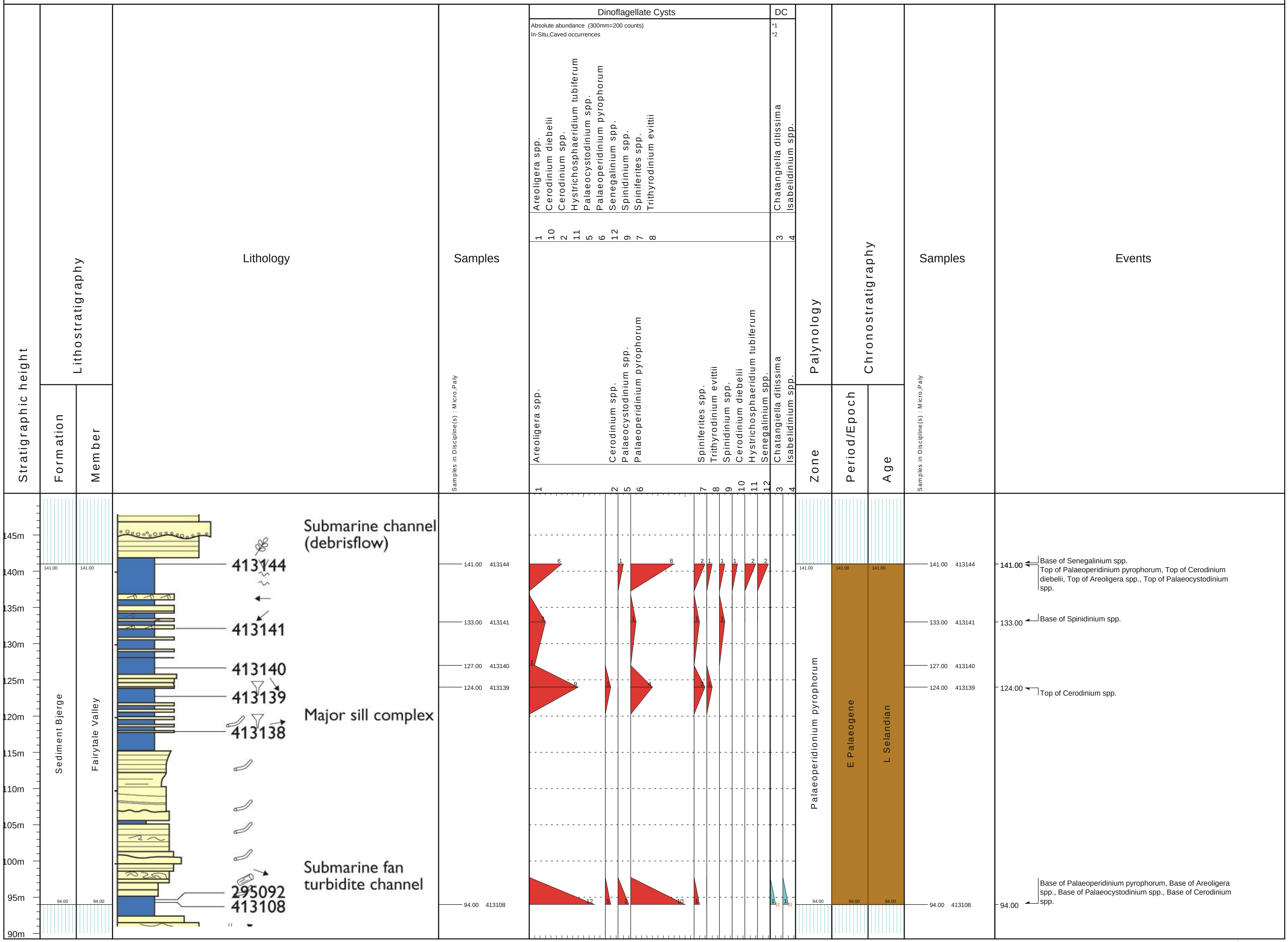
Fairytale Valley

GEUS

Sindri Report January 2006

IGD Boundary Key
- Possible
- Probable
- Confident
- Unconformable
- ?Unconformable
- Fault
- ?Fault

Text Keys
*1 Absolute abundance (300mm=200 counts)
*2 Reworked,Caved occurrences



Section : Sill City

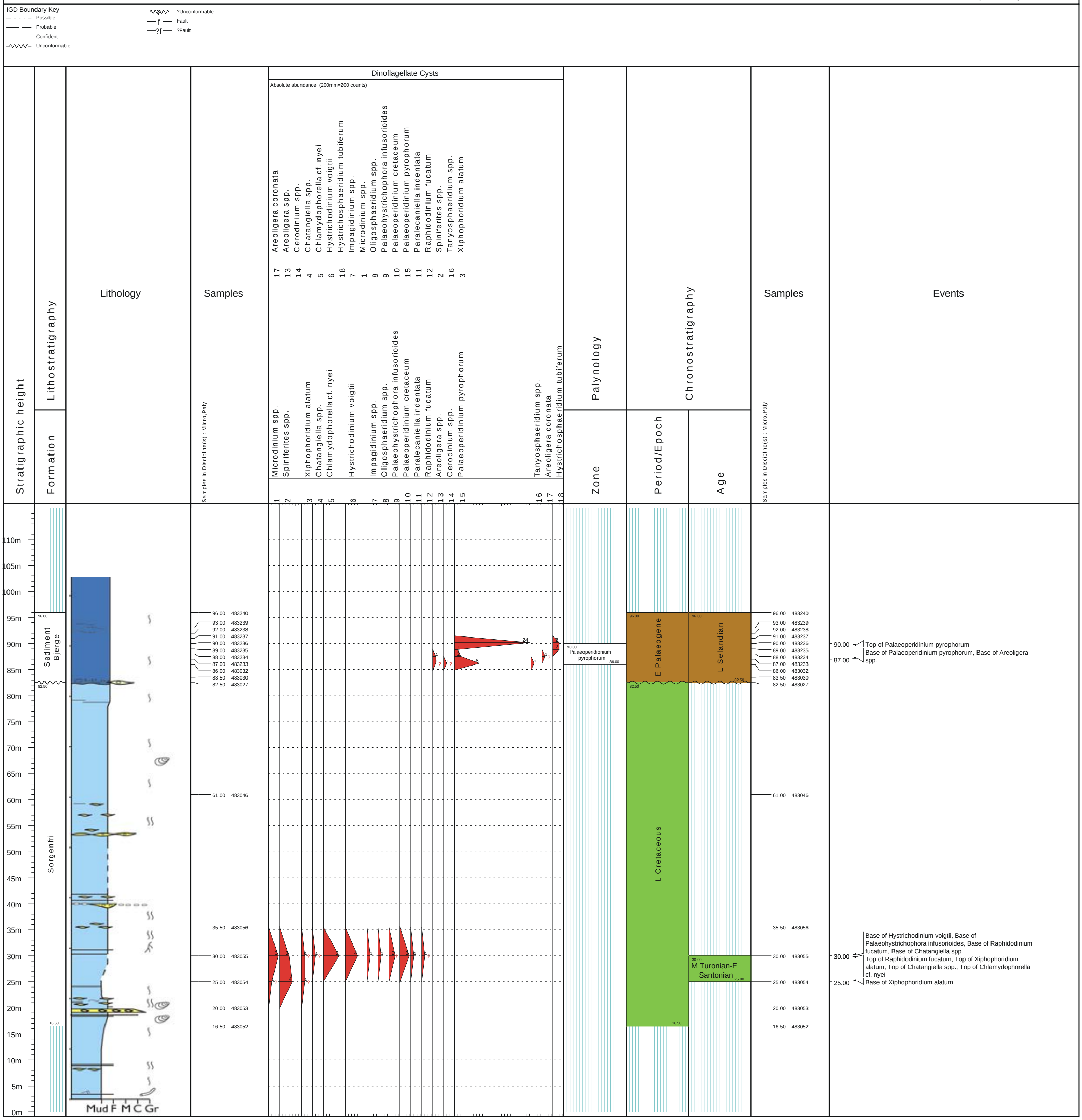
Interval : 116m - 0m

Scale : 1:600

Chart date : 27 February 2006

Sill City

Sinderi Report January 2006



Appendix 2, Macrofossils plates

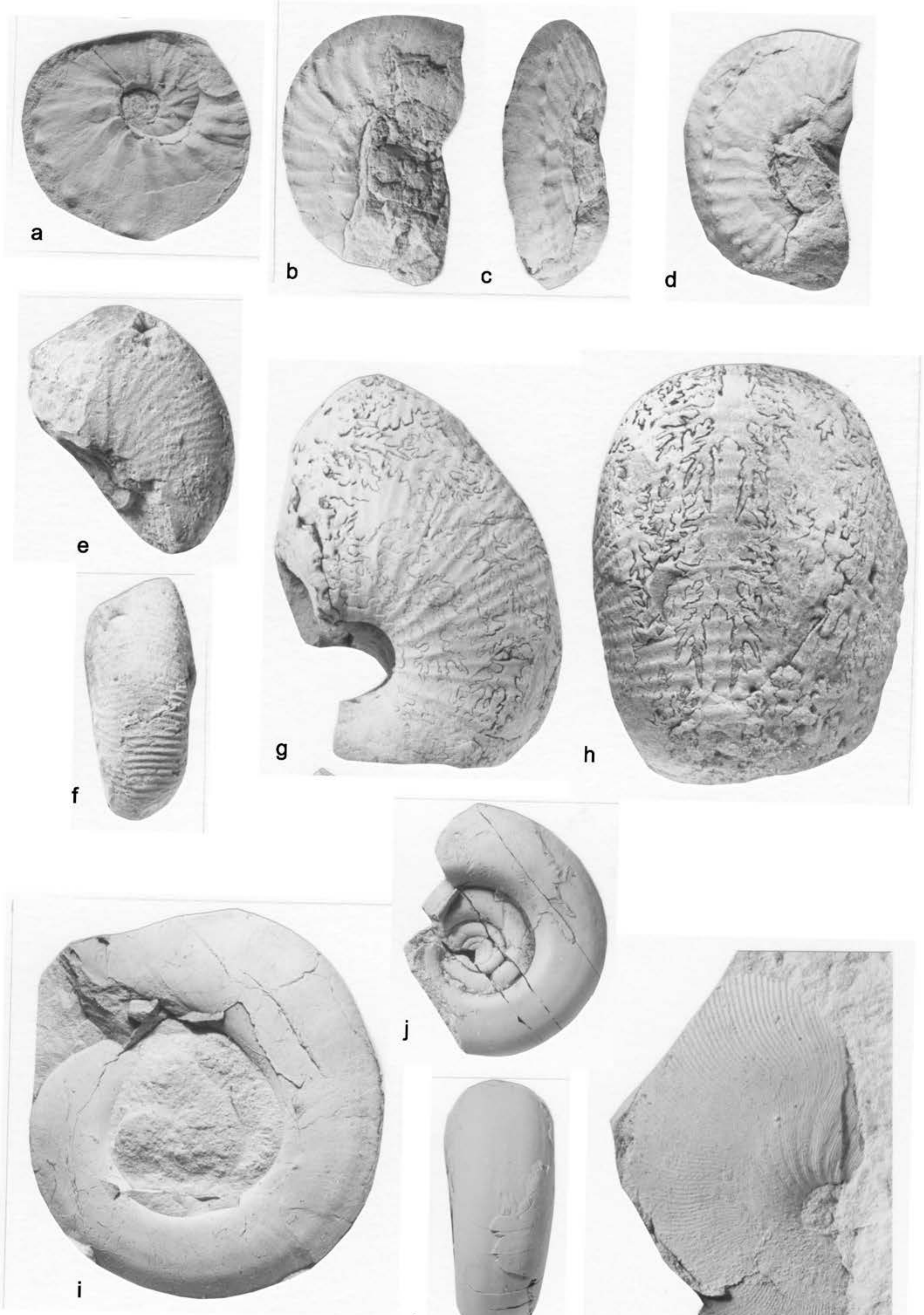
SINDRI PLATE 11. Ammonites:

a-d, *Discoscaphites angmartussutensis* Birkelund, **a-c,** CASP K10337, locality W4237, Sequoia Nunatak; **d,** latex cast, CASP K11299, locality K7512, Sedimentary Mountains.

e-h, *Acanthoscaphites* (*Acanthoscaphites*) *tridens* (Kner), **e**,**f**, internal mould, CASP K10572b, locality W4245**,** Skiferbjerg; **g,h**, K10133, locality 4222, North Coll;

i,k, *Saghalinites wrighti* Birkelund, **i**, CASP K10136; CASP K10135, locality W2222, North Coll; **j,k,** CASP K11151; locality W4297, NW Pyramiden;

l, *Neophylloceras groenlandicum* Birkelund, latex cast of flank, CASP K10766; locality W4260, Watkins Fjord; all from Christian IV Formation, Kangerlussuaq region, Maastrichtian, all x 1, except l, x 2. Photographs by W.J. Kennedy, Oxford University.


a
b
c
d
e
f
g
h
i
j
k
l

SINDRI PLATE 12. Ammonites:

Acanthoscaphites (*Acanthoscaphites*) *tridens* (Kner), composite photograph, based on external mould (left and central portions) and reversed internal mould (right portion), CASP K11296; Christian IV Formation, locality K7521, Sedimentary Mountains, Kangerlussuaq, Maastrichtian, x 1. Photographs by W.J. Kennedy, Oxford University.

SINDRI PLATE 13. Ammonites:

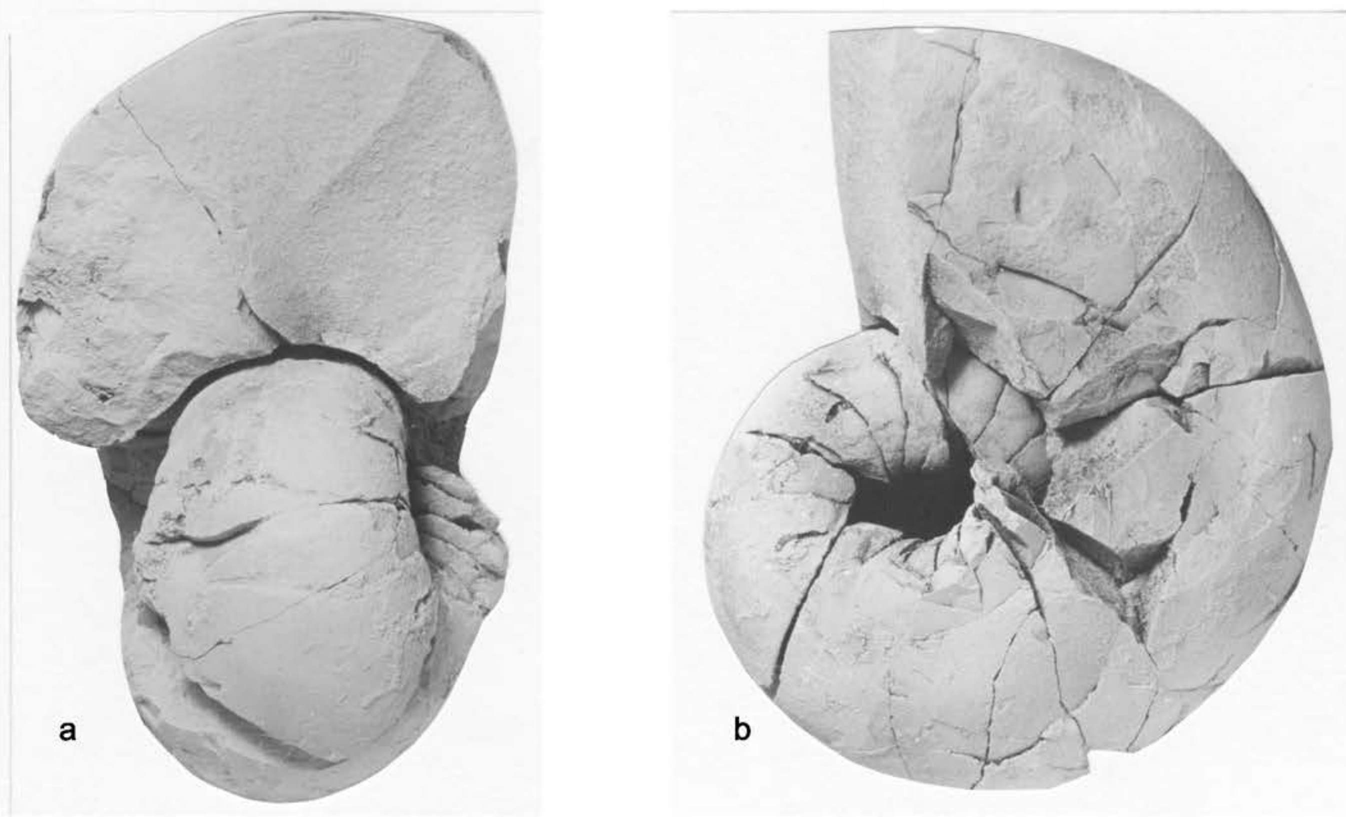
a, *Baculites* sp. latex cast of flank, CASP K10223; Christian IV Formation, locality W4229, Pyramiden, NW ridge.

b,c, *Diplomoceras cylindraceum* (Defrance), **b** silicone rubber cast of flank, CASP K11291, locality K7512, Sedimentary Mountains; c internal mould of part of body chamber, CASP W4797 locality W4320, Watkins Fjord; all from Kangerlussuaq region, Maastrichtian, x 1. Photographs by W.J. Kennedy, Oxford University.


a
b
c

SINDRI PLATE 14. Nautiloid:

a, b, *Eutrephoceras* sp. Internal mould, **a**, anterior, **b**, flank, CASP K10610. Christian IV Formation, locality W4245, Skiferbjerg, Kangerlussuaq, Maastrichtian, x 1. Photographs by W.J. Kennedy, Oxford University.



Stratabugs charts CASP

Section : W4232b

Operator : CASP
Lat/Long : 68°53' 16.00"N 30°43' 44.00"W
Interval : 180m - -5m — Kangerlussuaq, E. Greenland
Scale : 1:500 — Sequoia Nunatak
Chart date: 23 January 2006 — CASP 2000 MPS2; BB & SRAK data; CASP 2002 BIO 1

W4232b

CASP

Sindri Report January 2006

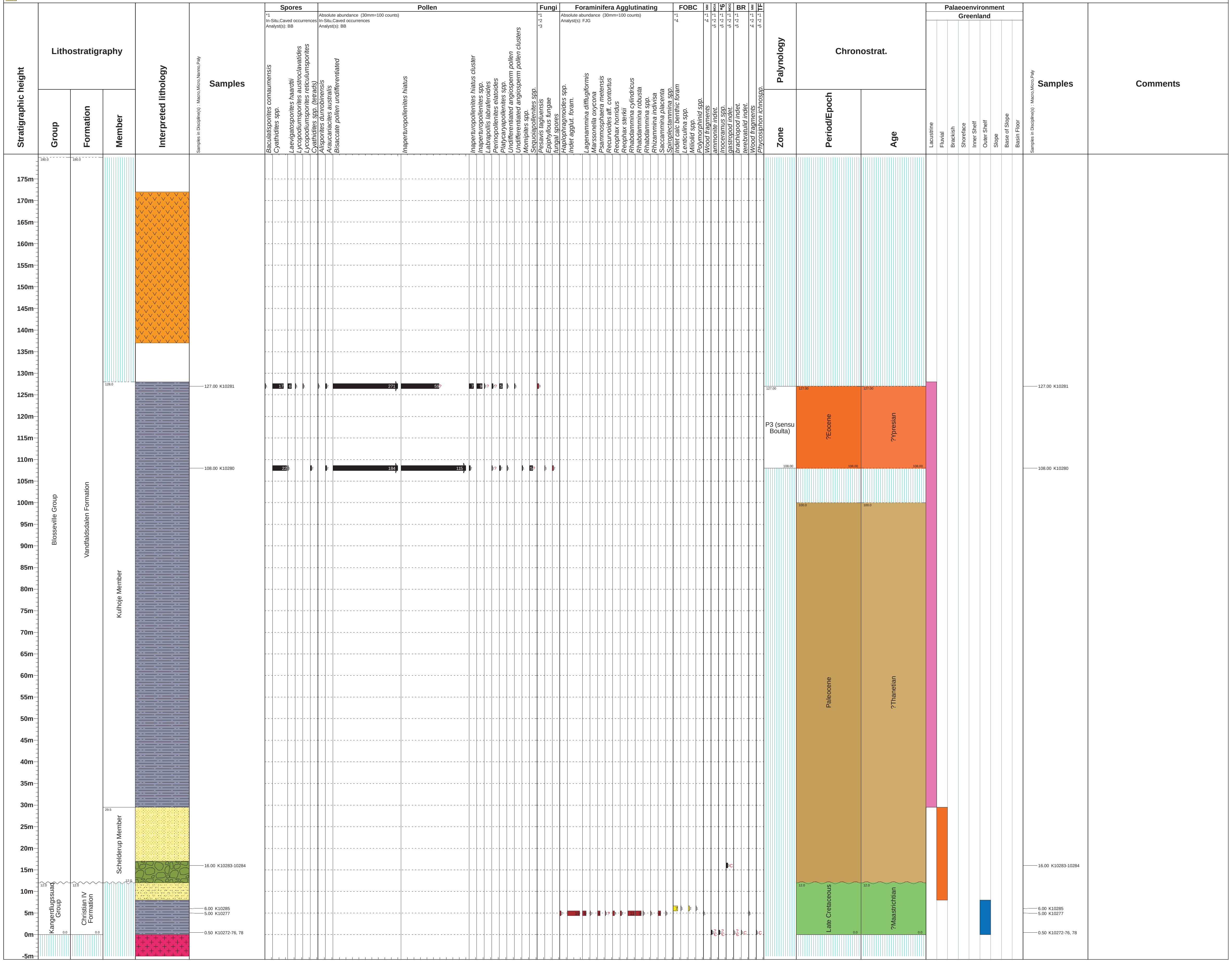
Base Lithology
- sandy mudstone
- sandstone (fine - medium)
- sandstone (coarse)
- silty sandstone
- conglomerate
- volcaniclastic
- intrusive igneous

Lithology Stringers

IGD Boundary Key
- Possible
- Probable
- Confident
- Unconformable
- ?Unconformable

f Fault
?f ?Fault

Text Keys
- *1 Absolute abundance (30mm=100 counts)
- *2 In-Situ,Caved occurrences
- *3 Analyst(s): BB
- *4 Analyst(s): FJG
- *5 Analyst(s): SRAK
- *6 MOBV



Section : W4235 composite

Operator : CASP
Lat/Long : 68°52' 90.00"N 30°42' 0.00"E
Interval : 140m - -5m — **Greenland**
Scale : 1:500 — **Sequoia Nunatak W**
Chart date: 19 January 2006 — **SRAK FNB 1998**

W4235 composite

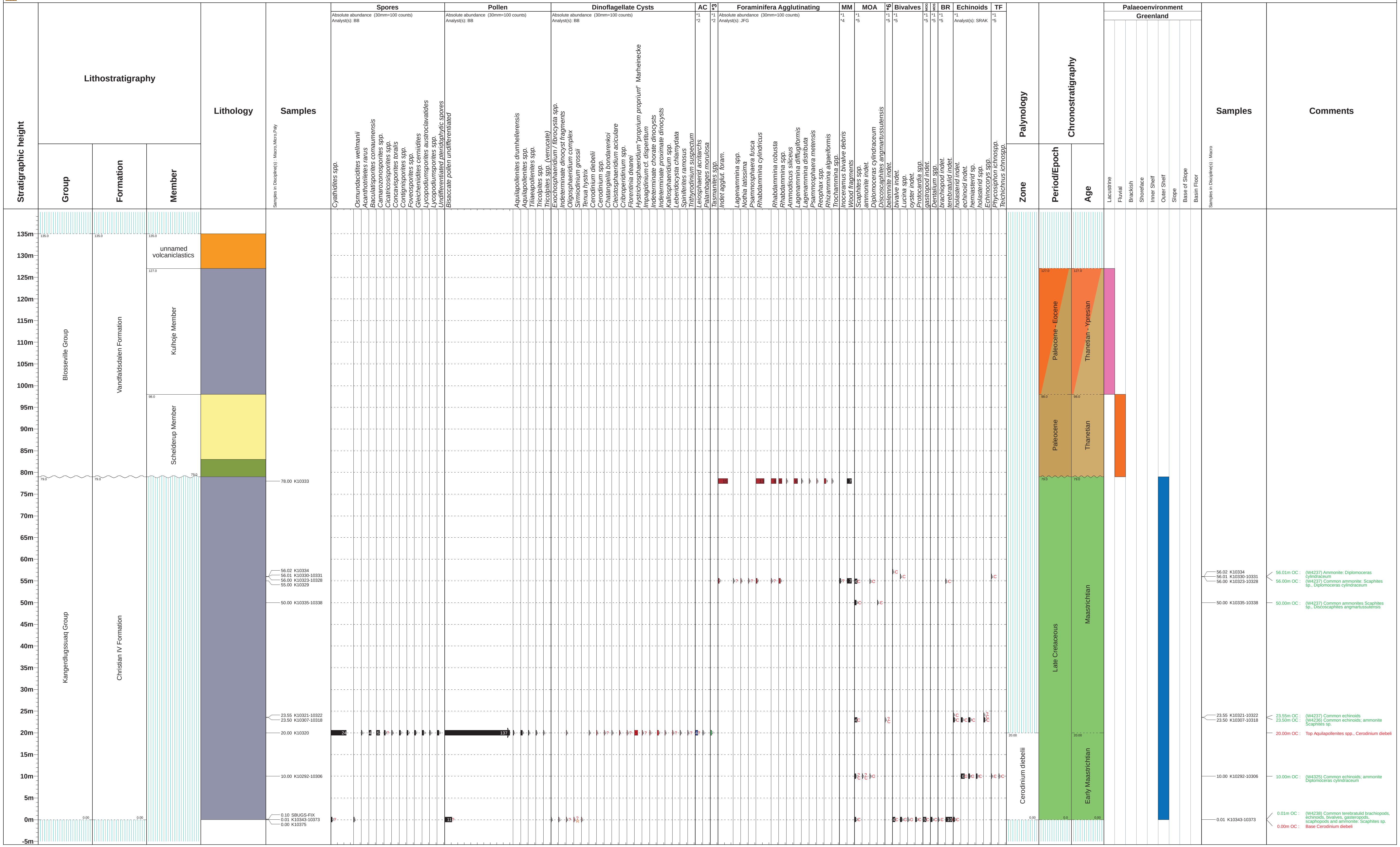
CASP

SINDRI Report January 2006

Base Lithology
- sandy mudstone
- sandstone (fine - medium)
- conglomerate
- volcaniclastic

IGD Boundary Key
- Possible
- Probable
- Confident
- Unconformable
- ?Unconformable
- Fault
- ?Fault

Text Keys
- *1 Absolute abundance (30mm=100 counts)
- *2 Analyst(s): BB
- *3 ALPR
- *4 Analyst(s): JFG
- *5 Analyst(s): SRAK
- *6 MOBM



Section : W4245

Operator : CASP
Lat/Long : 68°35' 19.00"N 30°38' 1.00"W
Interval : 260m - -20m — Kangerlussuaq, East Greenland
Scale : 1:300 — Sedimentary Mountains, E
Chart date: 03 March 2006 — Field 1999 2004; CASP EGP MPS 2; CASP BIO1

W4245

Sindri Report January 2006

Base Lithology
- sandy mudstone
- sandstone (fine - medium)
- intrusive igneous

IGD Boundary Key
- Possible
- Probable
- Confident
- Unconformable
- ?Unconformable
- Fault
- ?Fault

Text Keys
- *1 Absolute abundance (30mm=100 counts)
- *2 In-Situ,Caved occurrences
- *3 Analyst(s): BB
- *4 Microforaminiferal test linings "fragments/chambers"
- *5 Hystrichosphaeridium "proprium proprium" Marheinecke
- *6 Hystrichosphaeridium "proprium brevispinum" Marheinecke
- *7 Analyst(s): FJG
- *8 Reworked occurrences
- *9 ALPR
- *10 In-Situ occurrences
- *11 Analyst(s): SRAK

Section : W4293

Operator : CASP

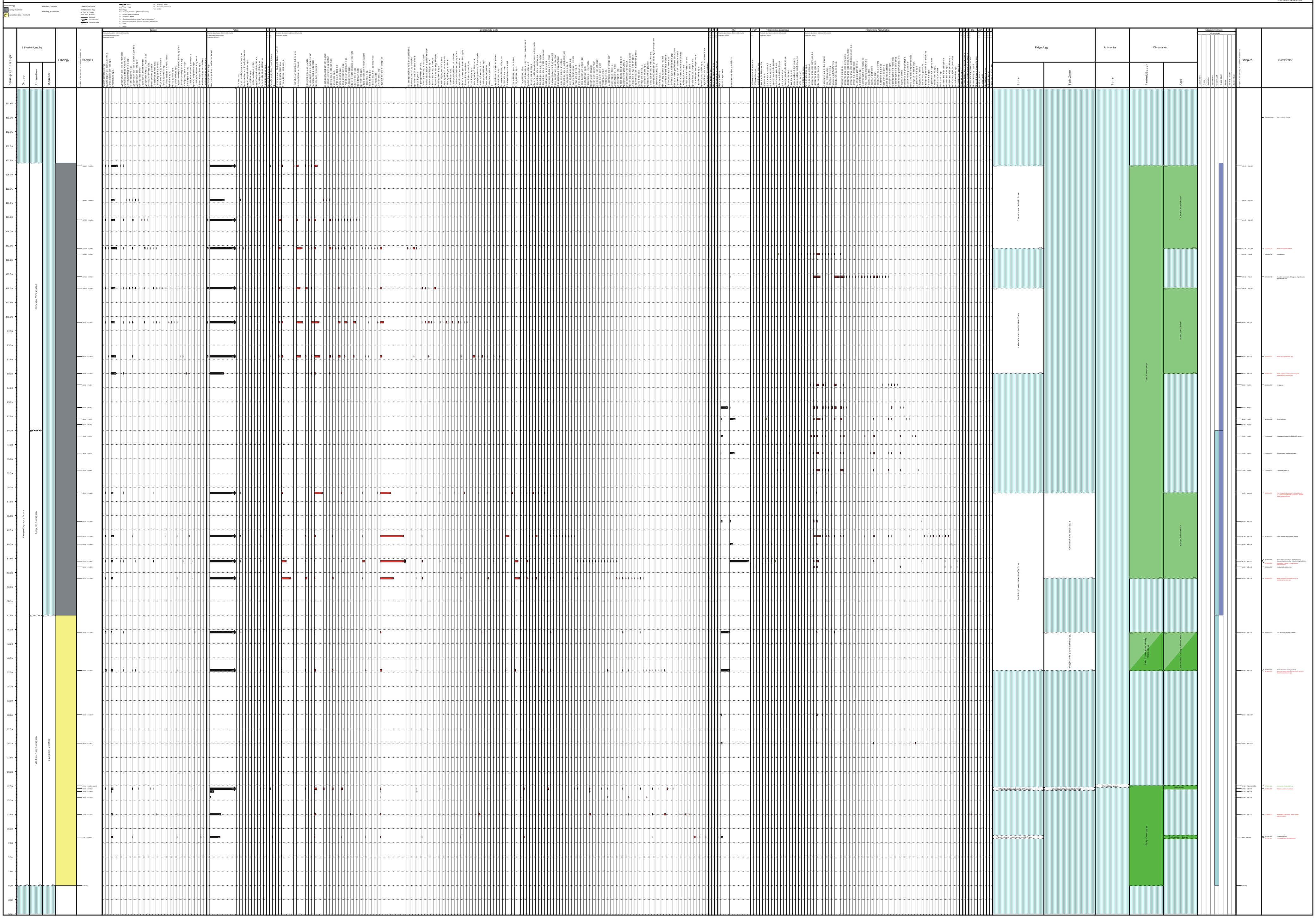
Lat/Long : 68°37' 13.00"N 30°51' 42.00"W

Interval : 140m - -5m — Kangerlussuaq, E. Greenland

Scale : 1:150 — Sedimentary Mountains, NW

Chart date : 19 January 2006 — CASP 2000 MPS2; BB, FJG data, SRAK data; CASP BIO 1

W4293

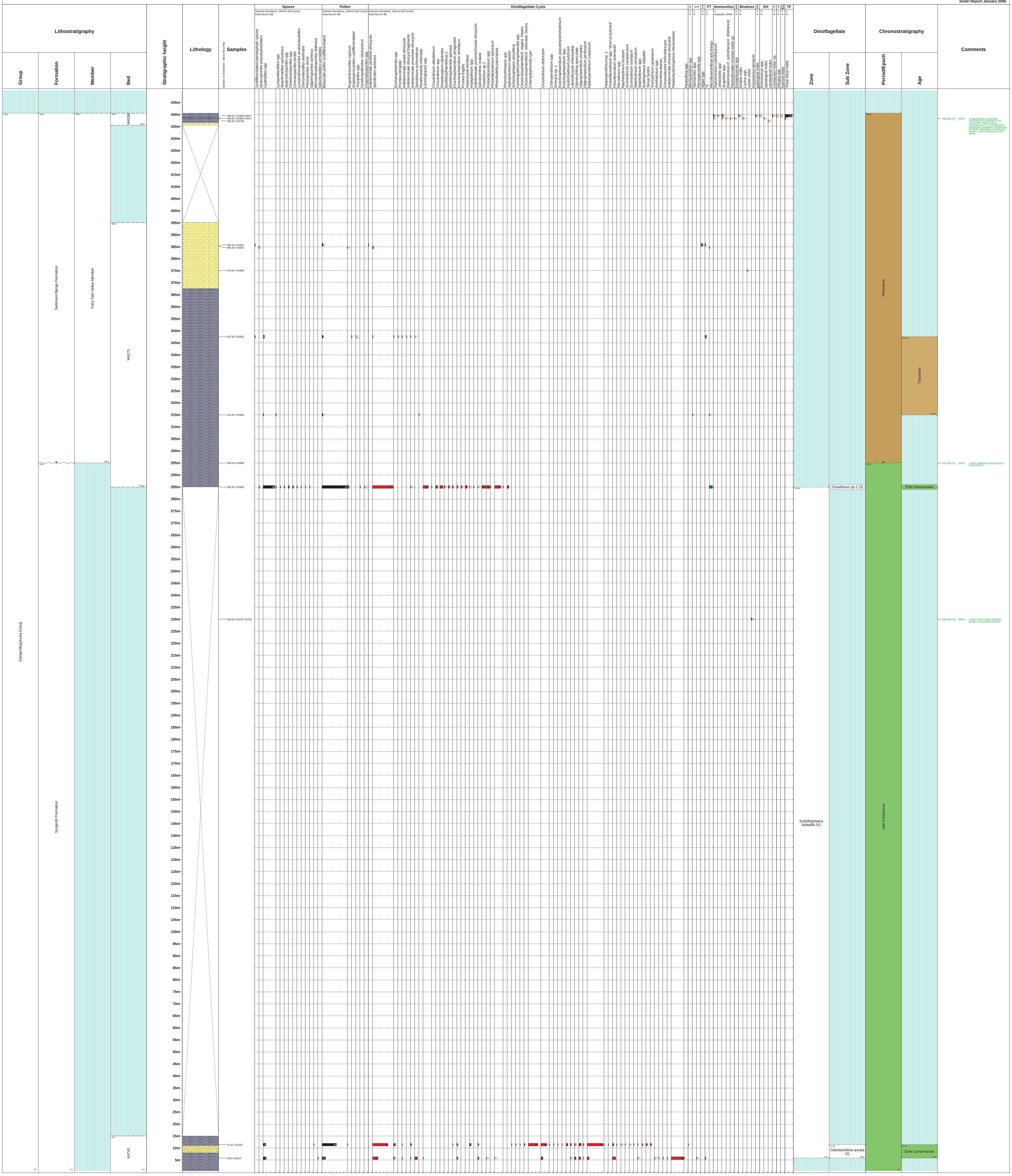


Section : W4268 composite

Operator : CASP
Lat/Long : 68° 0' 0.00"N 31° 0' 0.00"E
Interval : 450m - 0m Kangerlussuaq
Scale : 1:500 Sill Sity
Chart date: 24 January 2006 SRAK, BB, AGW CASP Report MPS 2

W4268 composite

Sindri Report January 2006



Section : K7585 composite

Operator : CASP
Lat/Long : 68°24' 81.00"N 31°11' 43.00"E
Interval : 1060m - 885m — Kangerlussuaq
Scale : 1:500 — Watkins Fjord N
Chart date : 19 January 2006 — SRAK 2004 FNB

K7585 composite

Sindri Report January 2006

Base Lithology
- sandy mudstone
- intrusive igneous

Lithology Qualifiers

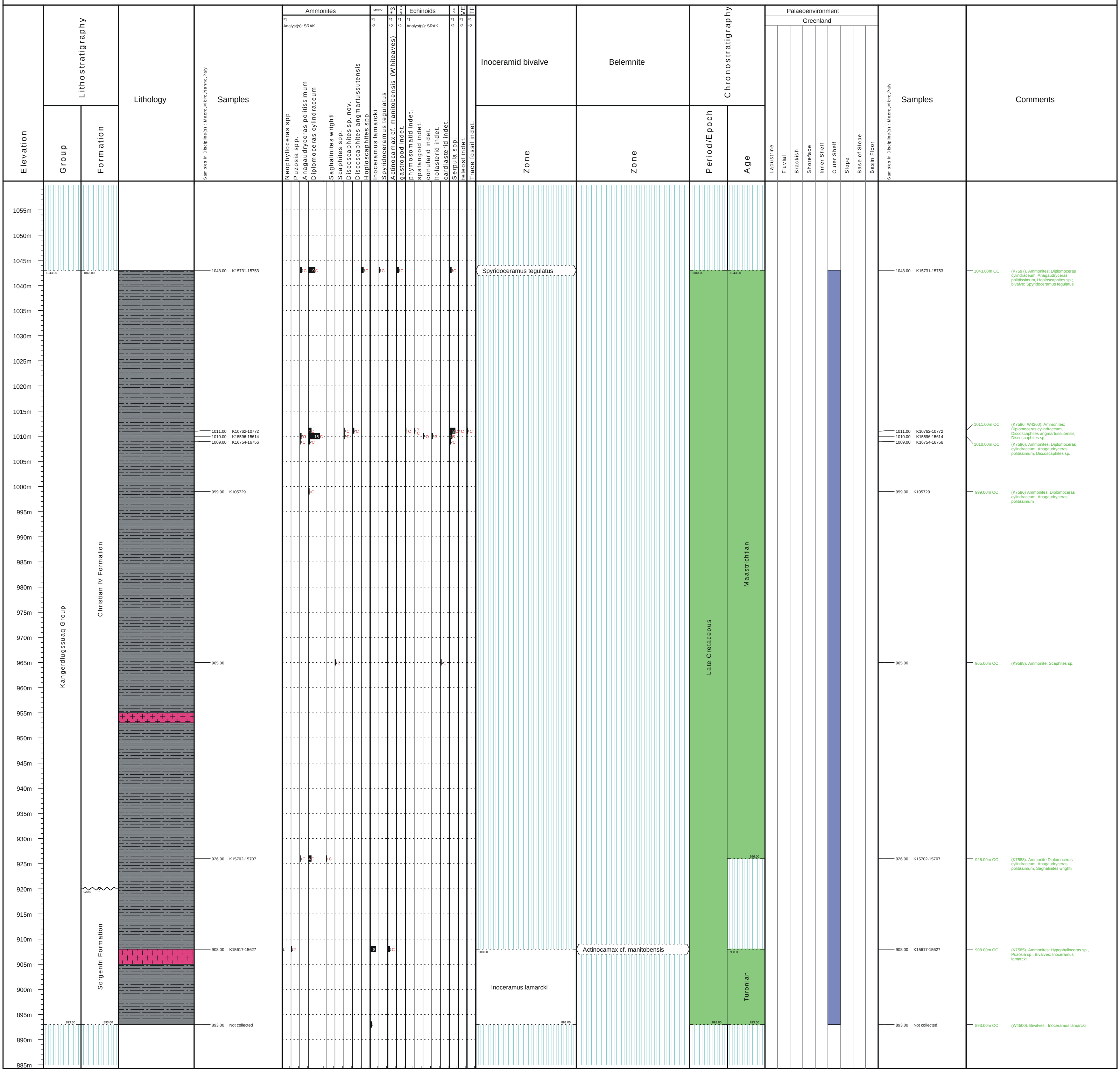
Lithology Accessories

Lithology Stringers

IGD Boundary Key
- Possible
- Probable
- Confident
- Unconformable
- ?Unconformable

— f — Fault
—?f— ?Fault

Text Keys
*1 Absolute abundance (30mm=100 counts)
*2 Analyst(s): SRAK
*3 MOBM



Appendix 3

Correlation chart showing the main sedimentary sections in the Kangerlussuaq Basin