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A Cretaceous dinoflagellate cyst zonation for NE Greenland

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Abstract

A palynostratigraphic zonation is for the first time established for the entire Cretaceous succession in NE Greenland from Traill Ø in the south to Store Koldewey in the north (72–76.5° N). The zonation is based on samples from three cores and more than 100 outcrop sections. The zonation is calibrated to an updated ammonite zonation from the area and to palynozonations from the northern North Sea, Norwegian Sea and Barents Sea areas. The palynozonation is primarily based on dinoflagellate cyst and accessory pollen. The Cretaceous succession is divided into 15 palynozones: seven Lower Cretaceous zones and eight Upper Cretaceous zones. The two lowermost zones are new. The following five (Lower Cretaceous) zones have already been described. Two of the Upper Cretaceous zones are new. The zones have been subdivided into 20 subzones, 11 of which have been described previously and one of which has been revised/redefined. Nine subzones (Upper Cretaceous) are new. More than 100 stratigraphical events representing more than 70 stratigraphic levels have been recognized and presented in an event-stratigraphic scheme.

1. Introduction

Mesozoic sediments in East Greenland have been studied for almost 150 years. A detailed historical review of the expeditions in the area between 1870 and 1956 was given by Donovan (1957) and updated by Surlyk (1978a). Cretaceous biostratigraphy and the dating of the Cretaceous successions in East and NE Greenland (Fig. 1) were sparse until the 1990s, especially compared with the studies of the Jurassic strata in the same area. During the historic exploration of East and NE Greenland (e.g. Surlyk, 1978a), Cretaceous biostratigraphy of the sedimentary basins remained fragmentary and variably developed, partly because the majority of the succession is badly exposed and commonly severely intruded and covered by Palaeogene basalts providing poor recovery of fossils from the sedimentary successions. The most comprehensive biostratigraphy has been recorded in lowest Cretaceous strata with relatively good exposures, for example in the Wollaston Forland – Kuhn Ø region (e.g. Surlyk, 1978a; ‘Ø’ is Danish for island). The ammonite succession was documented by Maync (1949) and Donovan (1964); Surlyk (1978a) provided a middle Volgian (c. middle Tithonian) – Lower Cretaceous ammonite zonation and an Upper Jurassic – Lower Cretaceous Bucharia zonation was introduced by Surlyk & Zakharov (1982). The correlation to the Tithonian–Berriasian stages is based on Wimbledon (2017). In contrast, mid-Cretaceous biostratigraphic data were sparse and Upper Cretaceous data were almost missing, despite the large efforts invested in fieldwork over many years (e.g. Ravn, 1911; Koch, 1929a, b, 1935; Frebold, 1932a, b, 1934, 1935; Frebold & Noe-Nyegaard, 1938; Maync, 1949; Donovan, 1949, 1953, 1954, 1955, 1957, 1961, 1964, 1972a, b).

Nahr-Hansen (1993, 1994) introduced dinoflagellate cysts (dinocysts) as a stratigraphic tool in the Cretaceous successions of East and NE Greenland. Based on a comprehensive study of the Lower Cretaceous dinocyst flora, a detailed zonation of the upper Hauterivian? – Lower Cenomanian? was established. Thirty-seven sections and three shallow cores without macrofossils were dated on the basis of dinocysts throughout NE Greenland.

In more recent times, Alsen (2006) monographed an upper Ryazanian (c. upper Berriasian) – Hauterivian ammonite fauna in the Wollaston Forland region and later applied Upper Jurassic – Lower Cretaceous ammonite stratigraphy on the Rodryggen-1 core (Bojesen-Koefoed et al. 2014). Alsen & Mutterlose (2009) demonstrated the stratigraphic potential of Lower Cretaceous belemnites in this region. Recently, dinocysts (Nøhr-Hansen et al. 2018), foraminifers and nanofossils have been applied for stratigraphy on restricted intervals where calcareous tests are preserved (Pauly et al. 2012a, b; Rodryggen-1 core, Bojesen-Koefoed et al. 2014), Brorson Halvo-1 core (Bojesen-Koefoed et al. 2014), Store Koldewey study (Piasecki et al. 2012) and the Nanok-1 core (Bojesen-Koefoed et al. 2014).

During the petroleum geological studies in East and NE Greenland (2008–2011), Cretaceous biostratigraphic data have been collected from the whole region between Traill...
Ø (72° N) in the south to Store Koldewey (latitude, 76–76.5° N) in the north (Figs 2–5). It incorporates previous work in the area but has been centred around a recent intensive programme of fieldwork, including drilling of cored wells (Bojesen-Koefoed et al. 2014). In order to develop a better understanding of the onshore geology, the goal was to identify basin evolutionary trends and describe depositional systems that would be valuable in interpreting existing and future datasets offshore NE Greenland, particularly in the Danmarkshavn Basin (Fig. 1) at the northern limit of the onshore project. Palynomorphs, primarily dinocyst, recorded from more than 100 sections throughout the region, dated the sequence as late Tithonian – late Campanian or ?Early Maastrichtian. The dinocyst zonation of Nøhr-Hansen (1993) is expanded stratigraphically to now include the upper Tithonian – Valanginian strata in addition to the Cenomanian – Campanian or ?Lower Maastrichtian strata. Extensive collection of macrofossils has improved the calibration of dinocyst zonation with ammonite stratigraphy and higher precision has been achieved. The improved biostratigraphy has been used extensively to date the units of a revised and updated Cretaceous lithostratigraphy. This comprehensive revision is nearing completion (Geological Survey of Denmark and Greenland) but is presently unpublished; the lithostratigraphic framework utilized here (Fig. 6) is therefore provisional and hence informal. The informal units are in lower case in the text and in Figure 6.

North of the studied area, from Germania Land north of Store Koldewey, macrofossils from loose boulders of Aptian age have been reported by Ravn (1911) and Rosenkrantz (1934, p. 24), but no outcrops have been recorded. Reworked dinocysts of early Aptian and late Albian ages have been recorded as reworked in Plioce ne deposits at Ile de France (Fig. 1; unpublished data). Ammonites of late Volgian (c. late Tithonian) – early Valanginian and Early–middle Albian ages have been reported by Birkelund & Håkansson (1983) and Alsen (2018) from the Wandel Sea Basin in North Greenland (Fig. 1). Dinocysts from the same area indicate ages of middle Oxfordian – early Valanginian (Håkansson et al. 1981). Dinocysts of Early Albian age have also been recorded from the area by Århus (1991). Recently, Piasecki et al. (2018) described in situ Barremian and reworked Upper Cretaceous dinocyst assemblages from the Wandel Sea Basin (81° N), and Pedersen et al. (2018) described middle Albian – late Coniacian dinocysts, inoceramid and ammonite assemblages...
Fig. 2. Geological map of NE Greenland showing study area stretching from Traill Ø to Store Koldewey. Insert maps: a, Traill Ø and Geographical Society Ø (Fig. 3); b, Gauss Halve and Hold with Hope (Fig. 4); and c, Clavering Ø and Wollaston Forland (Fig. 5). BBF – Bordbjerg Fault; BEF – Blå Elv Fault; CF – Clavering Fault; DF – Dombjerg Fault; GF – Gisecki Fault; HBF – Hühnerbjerg Fault; HF – Hochstetter Fault; FDF – Fosdalen Fault; KUF – Kuhn Fault; LPF – Laplace Bjerg Fault; MDF – Månedal Fault; MG – Midter Gneisnæs; MBF – Mols Bjerge Fault; PDMF – Post-Devonian Main Fault; TLF – Thomsen Land Fault.

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from Kilen (Fig. 1; 81° N). From southern Jameson Land (Fig. 1), south of the studied area, the youngest Lower Cretaceous formation described is the Berriasian–lower Valanginian Hesteelv Formation (Surlyk et al. 1973; Fig. 1). According to C. Marcussen (pers. comm. 1991), seismic data from Scoresby Sund (Fig. 1), south of Jameson Land, indicate that the Jameson Land basin continues to the south beneath the lower Cenozoic basalts on the southern shore of the fjord. The Lower Cretaceous successions possibly attain a total thickness here of up to 500 m. On Milne Land (Fig. 1; 70° N), dinocysts indicating
middle Volgian (c. middle Tithonian) – late Ryazanian (c. late Berriasian – early Valanginian) ages have been reported by Piasecki (1979). Cretaceous dinocysts of Albian–Maastrichtian ages have been recorded by Nøhr-Hansen (2012) further south in the Kangerdlugssuaq area (Fig. 1; 68°N), and dinocysts of Albian age have been reported from reworked sandstones obtained offshore Tasilaq at Ocean Drilling Program (ODP) Site SEG80 during the transect EG65 (Fig. 1; Thy et al. 2007).
2. Geological setting

The NE Greenland margin and the conjugate margin on the Norwegian continental shelf were formed by periodic rifting since the late Palaeozoic Era (Surlyk, 1990). Extensional collapse and basin formation were initiated during the Devonian Period, following the culmination of the Caledonian Orogeny in Silurian and Devonian times as Laurentia (represented by Greenland and North America) collided with Baltica and Avalonia (Higgins & Leslie, 2008). A number of large, mostly
N–S- to NNE–SSW-trending, normal faults confine the post-Caledonian sedimentary basins in the area, broadly mimicking the Caledonian structural grain of the region (Fig. 2). Devonian and Carboniferous rifting resulted in the formation of deep basins filled by more than 8 km of non-marine deposits (Larsen et al. 2008). Subsequent rift episodes affected the area during Permain, Early–middle Triassic and Middle Jurassic – earliest Cretaceous times (Surlyk et al. 1981; Surlyk, 1990).
Stemmerik et al. 1993). Further North Atlantic extension during Late Cretaceous and Early Palaeogene times ultimately led to continental separation during the Early Eocene Epoch and Atlantic seafloor spreading to present. The pre-Eocene extensional basins of NE Greenland, onshore and offshore, are thus complemented by the offshore record of the conjugate Norwegian margin. This is particularly relevant to the Cretaceous period, when the NE Greenland margin represented the proximal portion of a symmetrical marine trough. The axial deep-water part of the rift basin is represented by the Voring and Møre basins and the terraced Norwegian margin, mirroring that of NE Greenland (Fig. 1).

The North Atlantic region experienced two major rift episodes during late Mesozoic – early Cenozoic times. Rifting related to widespread broadly E–W-aligned extension in the North Atlantic region, accompanying Central Atlantic spreading, began during late Bajocian times in NE Greenland (Doré et al. 1999). Middle–Late Jurassic extension in East Greenland resulted in broad, fault-controlled depocentres, propagating northwards from Jameson Land with time (Surylk, 2003); this phase of regional basin subsidence and expansion was accompanied by a eustatic sea-level rise and resulted in the accumulation of the world-renowned Kimmeridgian source rocks from the North Sea through the Greenland–Norway rift to the Barents Sea (Bojesen-Koefoed et al. 2018). During latest Jurassic – earliest Cretaceous times, extension culminated in the development of a rugged rift topography due to marked rotation of narrow fault blocks (10–25 km across) along broadly N–S-aligned faults (Vischer, 1943; Surylk, 1978a, 2003). This event and the resulting unconformity is an important feature throughout the North Atlantic rift and a key seismic marker on the Norwegian shelf (e.g. Tsikalas et al. 2005) and in the Danmarkshavn Basin (Hamann et al. 2005; Fig. 1). The second phase of rifting during Late Cretaceous – Early Palaeogene times heralded the eventual break-up and onset of sea-floor spreading at the Paleocene–Eocene boundary. The onset of rifting in the Campanian is typically linked to the initiation of sea-floor spreading in the Labrador Sea (Fig. 1), and is associated with a shift in the extension direction in the North Atlantic region from N–S to NE–SW (Doré et al. 1999).

In NE Greenland, this rift phase is poorly documented in the sedimentary record of onshore NE Greenland, from the Hauterivian–Barremian to the lowermost Campanian – Lower Maastrichtian strata, thus occupies the timespan between these two regional North Atlantic rift phases and can be broadly considered as ’postrift’, deposited during a time of relative tectonic quiescence (Færsø & Lien, 2002; Lien, 2005).

3. Material and methods

The studied material includes samples from the Nanok-1 (1517004, Fig. 4), Redryggen-1 (1517001, Fig. 5) and Store Koldewey-1 (1517002, Fig. 2) cores and numerous outcrop sections, as well as a restudy of several of the old samples originally described by Nøhr-Hansen (1993). The palynological zonation established below is based on the study of more than 1000 samples representing more than 100 sections throughout the area (Figs 2–5). The new established Upper Cretaceous zones follow the roman numerals system established for the Lower Cretaceous zones by Nøhr-Hansen (1993), whereas the two lowermost Cretaceous zones are named NEG Cr 1 and NEG Cr 2 (NE Greenland Cretaceous 1 and 2). The Heterosphaeridium difficile, Aquapollenites and Cerodinium diebeli intervals identified in West Greenland were originally not intended to be formal biostratigraphic zones (Nøhr-Hansen, 1996); they therefore do not preoccupy the names for the new Heterosphaeridium difficile (IX), Aquapollenites (XII) or Cerodinium diebeli (XIII) zones. The majority of the sections are named with the initial of the collector (all Geological Survey of Denmark and Greenland (GEUS) employees), often followed by section number, for example SP-15a (Stefan Piasceki section 15a, Fig. 2); with initial, section number and year, for example MBJ-049/2010 (Morton Bjørgøer, section 49, 2010, Fig. 2), JHOV -2/2009 (Jussi Hovikoski section 2, 2009, Fig. 4) and PAL-8/2011 (Peter Alsen, section 8, 2011, Fig. 4); or with initial, month, date, year of collection and section number, for example HNH 081610-4 (Henrik Nøhr-Hansen 16th of August 2010 section 4, Fig. 4) or LHN 080810-1 (Lars Henrik Nielsen 8th of August 2010 section 1, Fig. 4). The sections named HNH followed by a number (e.g. HNH 29–31; Fig. 3) refers to the sections described by Nøhr-Hansen (1993).

The palynology samples were processed by a methodology including treatment with hydrogen chloride (HCl), hydrogen fluoride (HF), oxidation with nitric acid (HNO₃), and heavy liquid separation. At each preparation step, a slide was inspected to follow the process closely. Finally, the organic residue was sieved on a 21 μm, occasionally on 30 μm, filter (to concentrate palynomorphs in samples, poor in dinocysts), swirled and was finally mounted on glass slides using a glycerine jelly medium. The dinocyst content was analysed using a normal light microscope. Approximately 100 identifiable dinocysts per sample were counted to perform a relative abundance analysis. Prasinophycean and freshwater algae and acritarchs in the slide were also counted in addition to the main dinocyst tally. Additional dinocyst species occurring outside the 100 counted specimens in the first slide or in other slides were recorded as present. The taxonomy used here follows that of Williams et al. (2017).

The stratigraphic results are illustrated in a stratigraphic event chart (Fig. 7a–d), timescale (Ma) from Ogg et al. 2016). Since all analysed material is from cores or outcrops, caving is not an issue. Reworked dinocyst taxa are recorded. The pore and pollen flora is not recorded systematically, but reworked and selected stratigraphic marker mio- and macrospores are recorded.

4. Stratigraphic methods

Based on the oldest or first occurrence (FO) and youngest or last occurrence (LO) of stratigraphically important dinocyst species (events), the studied succession has been calibrated to ammonite zones of the local Boreal ammonite zonation (Surylk, 1973, 1977, 1978a, b; Callomon & Birkelund, 1982; Birkelund et al. 1984; Birkelund & Callomon, 1985; Kelly & Whitham, 1999; Alsen, 2006). Adjusted or new calibrations of dinocyst events calibrated by the local ammonite stratigraphy have been established in this work. The ammonite biozonation correlates with ammonite chronozones and the succession is dated on the basis of these chronostratigraphic units. Ammonite zonations vary with geographically separate faunal provinces and these diverging zonations are not precisely correlated at many stratigraphic levels; however, stratigraphic schemes generally ignore this fact. Calibrating dinocyst events with ammonite zones in different faunal provinces, and then comparing these ammonite zones
**Fig. 7.** (a–d) Palynostratigraphic zonation and event stratigraphy (primarily based on dinocysts) for the upper Tithonian – Lower Maastrichtian stages in NE Greenland based on the study of three cores and more than 100 sections, of which 29 are selected as reference sections representing the studied Cretaceous succession. Timescale (Ma) from Ogg et al. (2016).

| Age (Ma) | Event | Zone | Subzone | Stratigraphic Range |
|----------|-------|------|---------|---------------------|
| 131.0    |       |      |         |                     |
| 131.5    |       |      |         |                     |
| 132.0    |       |      |         |                     |
| 132.5    |       |      |         |                     |
| 133.0    |       |      |         |                     |
| 133.5    |       |      |         |                     |
| 134.0    |       |      |         |                     |
| 134.5    |       |      |         |                     |
| 135.0    |       |      |         |                     |
| 135.5    |       |      |         |                     |
| 136.0    |       |      |         |                     |
| 136.5    |       |      |         |                     |
| 137.0    |       |      |         |                     |
| 137.5    |       |      |         |                     |
| 138.0    |       |      |         |                     |
| 138.5    |       |      |         |                     |
| 139.0    |       |      |         |                     |
| 139.5    |       |      |         |                     |
| 140.0    |       |      |         |                     |
| 140.5    |       |      |         |                     |
| 141.0    |       |      |         |                     |
| 141.5    |       |      |         |                     |
| 142.0    |       |      |         |                     |
| 142.5    |       |      |         |                     |
| 143.0    |       |      |         |                     |
| 143.5    |       |      |         |                     |
| 144.0    |       |      |         |                     |
| 144.5    |       |      |         |                     |
| 145.0    |       |      |         |                     |
| 145.5    |       |      |         |                     |
| 146.0    |       |      |         |                     |
| 146.5    |       |      |         |                     |
| 147.0    |       |      |         |                     |
| 147.5    |       |      |         |                     |
| 148.0    |       |      |         |                     |
| 148.5    |       |      |         |                     |
| 149.0    |       |      |         |                     |
| 149.5    |       |      |         |                     |
| 150.0    |       |      |         |                     |
| Age (Ma) | Subzone | Zone | Subzone | Stratigraphic Range |
|---------|---------|------|---------|--------------------|
| 108.0   | M Albian| Rhombodella pseudolinea (V) | Chichousadninium vestum (2) | 107.70 'Chichousadninium vestum, Lpsadninium cancellum, Odontoschoene singhi, \*Efiopsastra imperfectum' |
| 109.0   | Late Albian | Liptophycus spinulosus (1) | Chichousadninium vestum acuta | 109.20 'Chichousadninium vestum acuta' |
| 109.5   | E Albian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 110.0   | Stretoceras trilabiatum (1) | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 110.5   | | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 111.0   | N Albian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 111.5   | Early Lutecian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 112.0   | Late Lutecian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 112.5   | Early Danian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 113.0   | Danian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 113.5   | Middle Danian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 114.0   | Late Danian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 114.5   | | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 115.0   | Early Aptian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 115.5   | Late Aptian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |
| 116.0   | Early Aptian | Liptophycus spinulosus (1) | Chichousadninium vestum | 109.70 'Chichousadninium vestum' |

Fig. 7. (Continued).
### Cretaceous dinoflagellate cyst zonation, NE Greenland

| Age (Ma) | Zone | Subzone | Events |
|----------|------|---------|--------|
| 88.5     |      |          | • Odonotrichina rhodesi |
| 89.0     |      |          |        |
| 89.5     |      |          |        |
| 90.0     |      |          |        |
| 90.5     |      |          |        |
| 91.0     |      |          | • Actinocyclus arcticus, Odonotrichina rhodesi |
| 91.5     |      |          |        |
| 92.0     |      |          | • Aphidonion fucatum, Senarinusphaera rosettae |
| 92.5     |      |          |        |
| 93.0     | Odonotrichina rhodesi (3) |          |        |
| 93.5     |      |          | • Chetangela granulifera, Heterospherasium difforme |
| 94.0     | Cyclonephelium compositum E, membranophorum complex (VII) | • Skolithoza kekatto |
| 94.5     |      |          | • Cyclonephelium qingpoense, Converdinium membranophorum complex, Scolecocephalium longifrons, Rhombosphaera pusilla, Skolithoza kekatto, comm. |
| 95.0     |      |          | • Trisaccinum aff. rhomboideum, Nizorhysoma aff. nigra |
| 95.5     |      |          | • Haplopora aff. rimosae |
| 96.0     |      |          | • Haplopora aff. ramosae, Skolithoza comm. |
| 96.5     |      |          | • Skolithoza aff. ramosae, Skolithoza aff. ramosae, Axinellina aff. ramosae |
| 97.0     |      |          | • Axinellina aff. ramosae, Axinellina aff. ramosae |
| 97.5     |      |          | • Senarinusphaera aff. microreticulata, Spharidium beneficium comm. |
| 98.0     |      |          | • Odonotrichina epoikolophorides, Veinacea aff. plota |
| 98.5     |      |          | • Epononotrigon sp. 1, Shonkinia variens (senosenae) |
| 99.0     |      |          | • Epononotrigon sp. 1, Shonkinia variens (senosenae) |
| 99.5     |      |          | • Epononotrigon sp. 1, Shonkinia variens (senosenae) |
| 100.0    |      |          | • Epononotrigon sp. 1, Shonkinia variens (senosenae) |
| 100.5    |      |          | • Epononotrigon sp. 1, Shonkinia variens (senosenae) |

**Fig. 7.** (Continued)

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Fig. 7. (Continued).
across biogeographic boundaries to obtain a relevant age, is hazardous; however, this is the only possibility in some cases. The lowermost Cretaceous flora varies significantly in composition, diversity and abundance from sub-Boreal to Boreal and Arctic regions (e.g. Bideaux & Fisher, 1976; Bideaux, 1977; Lebedeva & Nikitenko, 1999; Riding et al. 1999; Smelror & Dypvik, 2005); consequently, the age of stratigraphic events may also vary. Examples are documented in this work based on the common ammonite and dinocyst stratigraphy presented here.

5. Ammonite zonation

Since the biostratigraphic review of Donovan (1957), the most important contribution to Cretaceous ammonite stratigraphy in NE Greenland has been on the Jurassic–Cretaceous boundary beds in Wollaston Forland and Kuhn Ø (Donovan, 1964; Suryl, 1974, 1978a), the lower Aptian beds from Hold with Hope (Kelly & Whitham, 1999) and the upper Berriasian – Hauterivian strata in Wollaston Forland (Alsen & Rawson, 2005; Alsen, 2006). Recent sampling has added data from levels and intervals previously not known to contain ammonites. The Berriasian (c. uppermost Volgian) –Hauterivian zones are mainly documented from the Lindemans Bugt Formation and Palnatokes Bjerg Formation in the Wollaston Forland area (Suryl, 1978a; Alsen, 2006; Fig. 6). The Hauterivian zone was only referred to as Simbirsikites beds by Alsen (2006) based on the first but poorly preserved finds of Simbirsikites, but further collection now allow the identification of the Simbirsikites (Spectoniceras) inversum Zone and the Simbirsikites decheni Zone (Fig. 8). The former documents that the deposition of the Rodryggen Member of the Palnatokes Bjerg Formation extended into the upper Hauterivian Stage is also reflected by the recently established belemnite and calcareous nannofossil stratigraphies (Alsen & Mutterlose, 2009; Pauly et al. 2012a). Finds of coccristatid heteromorphs at Store Koldeweys and Stratumbjerg, Wollaston Forland (Figs 2, 5) are the first ammonite evidence of the Barremian Stage. The assemblage has close affinity with assemblages described from northern Germany (Kakabdze & Hoedemaeker, 2010). The identified taxa indicate the presence of three zones that are adopted from the lower–upper Barremian boundary interval in northern Germany. However, sampling conditions did not allow a clear separation of the zones in Greenland. The zones are accordingly indicated as undifferentiated as Fissicossticraceras ferricosstatae – Paracrioceras elegans – Paracrioceras denckmanni zones (Fig. 8). Rare material from Store Koldeweys has shown the presence of the uppermost Barremian Paracycloloceras bidentatum Zone (Fig. 8), also adopted from NW Europe. Deshayesites in Greenland marks the base of the Aptian Stage. Occurrences are recorded from Kuhn Ø (Bogvad & Rosenkrantz, 1934), Hochstetter Forland (Suryl, 1978b) and Hold with Hope (Kelly & Whitham, 1999). Deshayesites are now also recorded from Store Koldeweys. Lower Aptian Deshayesitid zonation is partly adopted from the lowermost Aptian strata of NW Europe. It is overlain by strata with ammonites of the genus Tropacum that allows the adoption of the Tropacum bowerni Zone from NW Europe (Fig. 8). The remaining Cretaceous succession (Albian–Campanian) only contains rare and scattered ammonites (Donovan, 1957). The Albian Hoplites dentatus Zone is identified by the index species. The Cenomanian in places contains a rich Schloenbachia fauna, especially in Tværdal, Geographical Society Ø, where its marks the base of the Cenomanian Stage. Rare Schloenbachia occur in Lygnaelv, Hold with Hope, followed by a thick interval without ammonites. A few reports have been made on Turonian ammonites (Spath, 1946; Donovan, 1953, 1954) that have not been confirmed by new material. Revisions to the Scaphitid-bearing succession in the eastern Geographical Society Ø, yielded well–preserved Hoploscaphites ikorfatiensis, in addition to the reports of Hoploscaphites greenlandicus providing rare ammonite dated levels of middle and late Campanian, respectively. In summary, the Cretaceous ammonite succession and zonation remains incomplete and subject to improvements. In the present study, its main purpose is to provide calibration points between the Cretaceous succession in NW Europe (commonly well–dated by ammonites) and the locally established palyno–stratigraphy in NE Greenland.

6. Palynostratigraphic zonation

The Cretaceous succession is divided into 15 biozones and intervals and 20 subzones, and more than 100 stratigraphic events representing more than 70 stratigraphic levels have been recognized (Fig. 7a–d). Dinocysts and pollen markers are illustrated in Figures 9–15.

6.a. Zone: Gochteodinia villosa villosa (NEG Cr 1) new

Age: latest Tithonian – latest Berriasian, latest Jurassic – Early Cretaceous.

Definition: From the FO of Gochteodinia villosa villosa to the FO of Oligosphaeridium complex.

Comments: Gochteodinia villosa villosa appears in the Prachetaexec tenuicostatum – Pratetolla maynici ammonite zones in the Rodryggen-1 core (517001) Wollaston Forland (Fig. 5) near the Jurassic–Cretaceous boundary and in Perispichites Ravine, Kuhn Ø, section HNH 10 (Nohr-Hansen, 1993). The nominate species G. villosa villosa has a stratigraphic range in NE Greenland, spanning the entire zone. The range of the G. villosa villosa Zone is from near the Jurassic–Cretaceous boundary to the uppermost Berriasian (c. uppermost Ryazanian) in NE Greenland. The autonym subspecies G. villosa villosa is applied here to distinguish this zone from earlier G. villosa zones and to focus on the range of this subspecies in contrast to the ranges of other present or future subspecies. Gochteodinia villosa refers to the species in the following discussion.

Woollam & Riding (1983) defines the G. villosa Zone (Gv) in England based on Davey’s (1979) "Parecodinia dasyiforma" Zone. The definition of the zone is based on species that are not common in East Greenland (e.g. Ctenodinium panneum (now Dichadogyaulax? pannea) and C. culmula (now D? culmula)). However, the zone nearly coincides with the range of G. villosa. The FO of G. villosa is in the basal Paracrasspedites oppressus ammonite Zone (uppermost Tithonian) to the Peregrinus albium ammonite Zone (uppermost Berriasian), that is, a range very similar to that recorded in East Greenland. The range of G. villosa may extend into basal Valanginian (e.g. Costa & Davey, 1992), but may be reworked into higher strata.

On the Russian Platform, Riding et al. (1999) report the first appearance of rare G. villosa in the Kachpurites fulgens ammonite Zone (correlative to the Subcrasspedites primitivus ammonite Zone of NW Europe) and then again very near the Tithonian–Berriasian (Jurassic–Cretaceous) boundary. Riding et al. (1999) suggest a G. villosa Zone (RPJ17) defined from the FO of G. villosa to the FO of Batioladinium spp. in the basal upper
Ryazanian (c. upper Berriasian; *Ryazanensis*-Spasskensis ammonite Zone). The *G. villosa villosa* Zone does not correlate well with dinoflagellate zones in the corresponding successions on Svalbard, the Janusfjellet Formation, because *G. villosa villosa* is not recorded below the basal Valanginian, probably due to an impoverished Boreal dinocyst flora in the pre-Valanginian strata (Århus, 1988). Consequently, the local FO of *G. villosa villosa* coincides with the FO of *Oligosphaeridium complex* (Århus, 1988).

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**Fig. 8.** Cretaceous ammonite zonation of NE Greenland. Lower Cretaceous after Surlyk (1978a, Ryazanian approximately equivalent to Berriasian), Kelly & Whitham (1999, lower Aptian), Alsen (2006, Ryazanian – Hauterivian) and this work. Zones shaded in grey indicate intervals that are not present or not yet proven in NE Greenland. Zones younger than Early Cenomanian have not been observed in NE Greenland. Zones shaded in grey and with indices in white are zones referred to in correlation with the palynological zonations for the central North Sea area of Duxbury (2001) and Davey (2001). The indices are adopted from the (NW European) Boreal ammonite zonation (Gradstein et al. 2004) since most of the zones in NE Greenland have close affinity to that area. The two upper Volgian zones are approximately equivalent to the upper Tithonian zone (Wimbledon, 2017).

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| Upper Cenomanian | L |
|------------------|---|
| U                |  |
| M                |  |
| L                |  |
| U                |  |
| M                |  |
| L                |  |

| Lower Cretaceous |
|------------------|
| U                |
| M                |
| L                |

| Barremian        |
|------------------|
| U                |
| L                |

| Hauterivian      |
|------------------|
| U                |
| L                |

| Valanginian      |
|------------------|
| U                |
| L                |

| Berriasian       |
|------------------|
| U                |
| L                |

| Upper Jurassic   |
|------------------|
| U                |
| L                |

| Lower Jurassic   |
|------------------|
| U                |
| L                |

| Triassic         |
|------------------|
| U                |
| L                |

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Fig. 9. Dinocysts marker of latest Jurassic – Early Cretaceous age (late Tithonian, Berriasian, Valanginian and earliest Hauterivian). Picture reference number, locality, slide number and England Finder co-ordinates are listed for the specimens illustrated. Scale bars all 20 μm. (a) Gochtreadinia villosa subsp. villosa, 2324, Store Koldewey-1 core, S17002-66-7, Q37/1. (b) Isthmocystis distincta, 2332, Perisphinctes Ravine, Kuhn B, HNH 87-3, 342088-4, Q27. (c) Scrinodinium pharo, 2329, Redryggen-1 core, S17001-3-3, F35-4. (d) Palaeocysta palma subsp. palmula, 2328, Redryggen-1 core, S17001-3-2, J20/1. (e) Lagenarhytis delicatula, 2307, SP-4a Store Koldewey, S2201, D23/3. (f) Rotapheroza thule, 2288, Redryggen-1 core, S17001-7-7, X29/2. (g) Paragonyaulacysta? borealis, 2286, Redryggen-1 core, S17001-5-10, W27/1. (h) Paragonyaulacysta? borealis, 2287, Redryggen-1 core, S17001-304-2, M18/3. (i) Paragonyaulacysta capillosa, 2298, Hvideklaft Store Koldewey, S17649-3, J60/4. (j) Oligosphaeridium complex, 2331, Redryggen-1 core, S17001-330-2, W14/2. (k) Boreocysta isfjordica, 1411, PAL-5/2010 Store Koldewey, 495984-4, R29/3. (l) Apteodinium spongiosum, 2403, PAL-5/2010 Store Koldewey, 495988-5, W35/1. (m) Nelchinopsis kastromiensis, 2326, Store Koldewey-1 core, S17002-137-5, X70/3. (n) Endoscirinium hauterivianum, 1117, Store Koldewey-1 core, S17002-139-5, B39. (o) Endoscirinium hauterivianum, 1116, Store Koldewey-1 core, S17002-138-5, B60/3. (p) Muderongia australis, 2319, Store Koldewey-1 core, S17002-92-3, W27/4.
Fig. 10. Dinocysts marker of Early Cretaceous age (earliest Hauterivian, Barremian and Aptian). Picture reference number, locality, slide number and England Finder co-ordinates are listed for the specimens illustrated. Scale bars all 20 μm. (a) Oligospheridium umbraculum, 1111, Store Koldewey-1 core, S17002-82-4, N42-3. (b) Batioladinium longicornutum, 2334, HNH section 21 1993, 342239-4, M41/2. (c) Pseudoceratium anaphrissum, 2335, HNH section 16 1993, 351512-4, J40-3. (d) Muderonia simplex subsp. microperforata, 2316, Store Koldewey-1 core, S17002-79-6, P46. (e) Ödontochitina nuda, 2317, Store Koldewey-1 core, S17002-79-6, X42. (f) Oligospheridium abaculum, 1096, Store Koldewey-1 core, S17002-75-3, V47/3. (g) Pseudoceratium toveae, 2336, HNH section 17 1993, 342167-5, G49/2. (h) Pseudoceratium aff. iveri, 1098, Store Koldewey-1 core, S17002-75-3, K42/2. (i) Pseudoceratium retusum, 2337, HNH section 7 1993, 342087-10, H31-2. (j) Apteodinium granulatum, 2338, HNH section 7 1993, 342087-4, Y39-2. (k) Pseudoceratium distinctum, 2339, HNH section 7 1993, 342087-4, Y39-2. (l) Pseudoceratium distinctum, 2340, HNH section 34 1993, 324556-4, E45/3. (m) Circulodinium brevispinosum, 2341, HNH section 34 1993, 324556-4, E45/3.
Fig. 11. Dinocysts marker of Early Cretaceous age (late Aptian – middle Albian). Picture reference number, locality, slide number and England Finder co-ordinates are listed for the specimens illustrated. Scale bars all 20 μm. (a) Vesperopsis mayi, 2341, HNH section 13 1993, 351587-4, Q35/1. (b) Leptodinium cancellatum, 2342, HNH section 12 1993, 351589-4, N34/4. (c) Leptodinium cancellatum, 2343, HNH section 20 1993, 342176-4, P50/4. (d) Canningia reticulata, 2344, HNH section 37 1993, 351592-4, F26/4. (e) Nyktericysta vitrea, 2345, HNH section 17 1993, 342169-4, JS5/4. (f) Senonisphaera microreticulata, 2346, HNH section 17 1993, 342172-4, Q26/2. (g) Cauca parve, 2347, HNH section 30 1993, 342620-7, U20/3. (h) Hapsocysta? benteae, 2348, HNH section 30 1993, 342619-3, Q30/4. (i) Odontochitina singhi, 2349, HNH section 20 1993, 342183-4, N34/1. (j) Ovoidinium sp., 2350, HNH section 21 1993, 342240-7, D46/3. (k) Rhombodella paucispina, 2351, HNH section 20 1993, 342191-5, U30/2. (l) Leptodinium? hyalodermopse, 2352, HNH section 17 1993, 342167-4, R23/2. (m) Odontochitina longicornis, 2353, HNH section 34 1993, 342556-4, E33/3. (n) Chichauadinium vestitum, 2354, HNH section 20 1993, 342202-4, T23/3. (o) Litosphaeridium arundum, 2355, HNH section 23 1993, 351670-4, F34/3. (p) Leptodinium cancellatum, 2356, HNH section 20 1993, 342194-4, R25/1. (q) Rhombodella paucispina, 2357, HNH section 30 1993, 342615-3, S31/4. (r) Ovoidinium sp. 3, HNH section 20 1993, 342240-7, D46/3. (s) Ovoidinium shaftesburensese, 2358, HNH section 26

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Fig. 12. Dinocysts marker of Early–Late Cretaceous age (middle Albian – earliest Cenomanian). Picture reference number, locality, slide number and England Finder co-ordinates are listed for the specimens illustrated. Scale bars all 20 μm. (a) Ellipsoidictyum imperfectum, 2363, HNH section 21 1993, 342240-4, W20/1. (b) Subtilisphaera kalaallitii, 1484, HNH section 30 1993, 522066-4, U66/2. (c) Wigginsiella grandstandica, 2364, HNH section 29 1993, 324599-4, X24/3. (d) Dino sp. 1 HNH 1993, 2371, HNH section 31 1993, 324623-4, C18/4. (e) Circulodinium sp. 1 HNH 1993, 2370, HNH section 30 1993, 324619-3, H53/4. (f) Epeilidosphaeridia sp. 1 HNH 1993, JHOV 2/2009, 518602-7, R45/1. (g) Sindriniun? torulosa, 1560, HNH section 30 1993, 324608-8, W21/4. (h) Odontochitina ancales, 2367, HNH section 36 1993, 324092-7, K55/2. (i) Endoceratium exquisitum, 1221, HNH 081410-4, 487620-3, T17-4. (j) Endoceratium exquisitum, 1519, PAL3-2011, 522085-4, X45/3. (k) Endoceratium exquisitum, 2382, HNH 081009-4, 475197-3, W39/2. (l) Epeilidosphaeridia spinosa, 2373, HNH section 39 1993, 335321-4, X34/4. (m) Dinopterygium alatum, 2368, HNH section 30 1993, 324613-8, N42/3. (n) Sindriniun borealis, 1463, PAL3-2011, 522076-4, U53/1. (p) Senonisphaera aff. microreticulata, 1218, HNH 081410-4, 487640-3, D42/2. (q) Senonisphaera aff. microreticulata, 1203, HNH 081410-4, 487633-3, P46/4.
Fig. 13. Dinocysts marker of Late Cretaceous age (earliest Cenomanian – late Cenomanian). Picture reference number, locality, slide number and England Finder co-ordinates are listed for the specimens illustrated. Scale bars all 20 μm. (a) Epeidiosphaeridia manifesta, 1206, HNH 081410-4, 487643-3, F52/4. (b) Oovidinium epeidiosphaeroides, 1507, PAL3-2011, 522082-3, Y27/1. (c) Ovoidinium epeidiosphaeroides, 1516, PAL3-2011, 522084-5, K33/3. (d) Xenascus aff. plotei, 1551, HNH 081410-4, 487620-3, B27/4. (e) Sindridinium anaanae, 1464, HNH 081410-4, 487631-3, O28/2. (f) Palaeohystrichophora infusoriae, 2374, HNH section 30 1993, 324613-8, OS1/3. (g) Ginginodinium aff. evittii, 2376, HNH 081009-1, 475185-2, C27. (h) Ginginodinium aff. evittii, 2377, HNH 081009-1, 475185-2, W48/2. (i) Endoceratium ludbrookiae, 2383, HNH 081009-2, 475195-2, Q41/4. (j) Endoceratium ludbrookiae, 2384, HNH 081009-2, 475195-3, G35/3. (k) Isabelidinium acuminatum, 0098, Nanok-1 core, 517004-136-5, S20/1. (l) Isabelidinium magnum, 2387, HNH 080209-4, 475175-2, Y32. (m) Isabelidinium magnus, 2386, HNH 080209-4, 475175-2, O20/2. (n) Thriodyrodinium aff. rhomboidum, 2378, HNH 080110-4, 475435-6, Y3/3. (o) Thriodyrodinium suspectum, 2380, Knudshoved locality 5, 433504-4, J37/1. (p) Nyktericyusta aff. tripente, 2381, HNH 081009-2, 475197-2, X36/2. (q) Surculosphaeridium longifurcatum, 2390, HNH 080209-4, 475179-2, K22/3.
Fig. 14. Dinocysts marker of Late Cretaceous age (late Cenomanian–middle Coniacian). Picture reference number, locality, slide number and England Finder co-ordinates are listed for the specimens illustrated. Scale bars all 20 μm. (a) Cyclonephelium compactum-Cauveridinium membraniphorum complex, 118, Nanok-1 core, S17004-116-6, B42/2. (b) Cyclonephelium compactum-Cauveridinium membraniphorum complex, 97, Nanok-1 core, S17004-136-5, T48/2. (c) Cyclonephelium compactum-Cauveridinium membraniphorum complex, 110, Nanok-1 core, S17004-117-7, W71/2. (d) Heterosphaeridium difficile, 116, Nanok-1 core, S17004-166-6, N58/4. (e) Heterosphaeridium difficile, 115, Nanok-1 core, S17004-166-6, G41/1. (f) Heterosphaeridium difficile, 115, Nanok-1 core, S17004-316-9, H53/1. (g) Chatangiella granulifera, 2379, Nanok-1 core, S17004-110-7, L59/2. (h) Raphidodinium fucatum, 2397, Nanok-1 core, S17004-113-3, F23/2. (i) Senonisphaera rotundata, 1705, Nanok-1 core, S17004-101-5, M59/1. (j) Senonisphaera rotundata, 1707, Nanok-1 core, S17004-317-5, B28/4. (k) Laciniaodinium arcticum, 2300, 470105-2, HNH081508-1, M18/2. (l) Odontochitina rhakodes, 1767, Nanok-1 core, S17004-106-6, Y63/3. (m) Xenascus gochti, 124, Nanok-1 core, S17004-101-5, Y52/4. (n) Stephodinium coronatum, 126, Nanok-1 core, S17004-317-3, W31/4. (o) "Chatangiella spinosa", 134, Nanok-1 core, S17004-311-10, M38/2. (p) "Chatangiella spinosa", 130, Nanok-1 core, S17004-315-9, B40/1.
Fig. 15. Dinocysts marker of Late Cretaceous age (late Coniacian – Early Maastrichtian). Picture reference number, locality, slide number and England Finder co-ordinates are listed for the specimens illustrated. Scale bars all 20 μm. (a) Spinidinium echinoideum, 132, Nanok-1 core, 517004-314-9, T23/4. (b) Spinidinium echinoideum, 129, Nanok-1 core, 517004-317-3, F34/2. (c) Trithyrodinium vermiculatum, 2394, HNH 0100209-4, 475134-2, S44/3. (d) Odontochitina panifera, 2391, Knudshoved locality 5, 433898-4, W20/2. (e) Alterbidinium ioinnidesii, 2395, HNH 0100209-3, 475113-8, V36/4. (f) Aquilapollenites sp., 136, Nanok-1 core, 517004-81-2, T47/2. (g) Aquilapollenites sp., 135, Nanok-1 core, 517004-313-4, G48. (h) Aqualapollenites sp., 2270, HNH081508-2, 470107-5, V15/2. (i) Chatangia bondarenkoi, 2296, PAL-6/2011, 529719-6, V11/3. (j) Azonia faborea, 2400, Knudshoved locality 5, 700802-4, V12/3. (k) Azonia faborea, 2401, Knudshoved locality 5, 700802-4, K24/3. (l) Isabelidinium magnum, 2297, PAL-6/2011, 529716-4, T38/4. (m) Cerodinium diebelii, 2238, HNH081508-2, 470102-5, B17/2. (n) Alterbidinium biaperturum, 2241, HNH081508-2, 470102-4, J31/2. (o) Alterbidinium biaperturum, 2239, HNH081508-2, 470102-3, N40/3. (p) Wodehousea gracile, 2272, HNH081508-2, 470107-5, V25/1. (q) Wodehousea gracile, 2243, HNH081508-2, 470102-6, Q18/2. (r) Wodehousea gracile, 2234, HNH081508-2, 470102-1, X4/2. (s) Wodehousea gracile, 2269, HNH081508-2, 470106-2, G42/2. (t) Spongodinium delitense, 2247, HNH081508-2, 470104-3, C30. (u) Phelodinium kozlowskii, 2244, HNH081508-2, 470102-6, W20. (v) Hystrichosphaeridium sp. 3 McIntyre 1974, 2268, HNH081508-2, 470106-4, X48. (w) Hystrichosphaeridium sp. 3 McIntyre 1974, 2266, HNH081508-2, 470106-4, V39/2.
Similarly, Boreal Volgan–Ryazanian (c. upper Berriasian) dinocyst assemblages without *G. villosa villosa* are reported from cores in the Barents Sea (Árhus et al. 1990).

*Gochtodinia villosa* occurs in the subboreal regions of NW Europe and the Russian Platform as well as the Boreal East Greenland apparently with similar FOs based on correlation of local ammonite zonations. The last occurrence of *G. villosa* is not well constrained; the upper boundary of the *G. villosa villosa* Zone is therefore selected at the widespread and distinct FO of *O. complex*. The *G. villosa villosa* Zone (NEG Cr 1) is a robust dinocyst biozone of the lowermost Cretaceous deposits in the North Atlantic region. However, *G. villosa villosa* is rare or absent in the high Boreal regions of Canada, North Greenland, the Barents Sea and northern Siberia (Davies, 1983; Árhus, 1988; Árhus et al. 1990; Smelror et al. 1998; Pestchevitskaya, 2007a, b; Nikitenko et al. 2008).

*Stratigraphic events: Isthmocystis distincta* has FO contemporaneous with *G. villosa villosa*. The FO of *Lagenorhyhitis delicatula, Palaeacysta palmula and Phoberocysta neocomica* and the LO of *Rotosphaeropsis thule* occur in or above the *Hectoroceras kochi* ammonite Zone (near the lower–upper Berriasian boundary) in the Rodrygg-1 core, Wollaston Forland (Fig. 5). *Gochtodinia villosa villosa, Paragonyaulacysta borealis* and *P. capillosa* have their stratigraphic LO in the upper part of the *G. villosa villosa* Zone, upper Berriasian in the Rodrygg-1 core, even though they are reported to continue into lower Valanginian successions in Canada, Svalbard, the Barents Sea, Siberia and Arctic Russia (e.g. Davies, 1983; Árhus, 1988; Pestchevitskaya, 2007a, b; Nikitenko et al. 2008).

6.b. Zone: *Oligosphaeridium complex* (NEG Cr 2) new

*Age*: latest Ryazanian (c. latest Berriasian) – earliest Hauterivian, Early Cretaceous.

*Definition*: From the FO of *Oligosphaeridium complex* to the FO of *Batioladinium longicornutum*.

*Comments*: Oligosphaeridium complex appears (FO) in the *Peregurinis albidum* ammonite Zone, uppermost Berriasian (or lower Valanginian according to Gradstein et al. 2012; in SP-04a, SP-15a Koldewey, Fig. 2) and is abundant in the lower Valanginian deposits (e.g. Rodrygg-1 core (S17001) Wollaston Forland, Fig. 5; PAL05/2010, Koldewey, Fig. 2). In NW Europe, Costa & Davey (1992) and Duxbury (2001) suggest that the FO of *Oligosphaeridium complex* occurs in the lowermost Valanginian strata.

*Stratigraphic events: The FO of abundant Oligosphaeridium complex* is followed by the FO of *Apteodinium spongiosum, Boreocysta isjfordica and Nelchinopsis kostromiensis* in the lower part of this zone (PAL05/2010, Koldewey, Fig. 2) and by the FO of *Endoscrinium hauterivianum* and *Muderongia australis* in the uppermost part of the zone (Store Koldewey-1 core (S17002), Fig. 2). Duxbury (2001) mentioned that *Endoscrinium hauterivianum* is essentially a lower Hauterivian form that can range into the upper Hauterivian Stage.

6.c. Zone: *Batioladinium longicornutum* (I) of Nørh-Hansen (1993) redefined

*Age*: early Hauterivian – latest Barremian.

*Definition*: From the FO to the LO of *Batioladinium longicornutum*.

*Comments*: Nørh-Hansen’s (1993) original definition of the lower boundary of the zone is here redefined from the FO of *Muderongia australis* to the slightly younger FO of *Batioladinium longicornutum*, which seems to be a more reliable marker. The zone was subdivided into the three subzones by Nørh-Hansen (1993): *Nelchinopsis kostromiensis* (1) redefined, *Pseudoceratium anaphrissum* (2) and *Pseudoceratium toveae* (3).

Detailed studies of a core and numerous sections from Store Koldewey have enabled a refinement of the dinoflagellate stratigraphy of the *Batioladinium longicornutum* (I) Zone, Nørh-Hansen (1993).

Correlations: The FO of *B. longicornutum* correlates with the middle part of the lowermost Hauterivian *Endomoceras amblygonium* ammonite Zone according to Davey’s (2001; Fig. 8) dinocyst correlation with lower Hauterivian ammonite stratigraphy at Speeton, east England. *B. longicornutum* has its LO in the upper Barremian Stage (Nørh-Hansen, 1993).

6.d. Subzone: *Nelchinopsis kostromiensis* (1) of Nørh-Hansen (1993) redefined

*Age*: early–late Hauterivian.

*Definition*: From FO of *Batioladinium longicornutum* to the LO of *Nelchinopsis kostromiensis*.

*Comments*: Nørh-Hansen’s (1993) original definition of the lower boundary of the zone is redefined from the FO of *Muderongia australis* to the slightly younger FO of *Batioladinium longicornutum*, which seems to be a more reliable marker.

*Stratigraphic events: The FO of *B. longicornutum* at the base and LO of *Endoscrinium hauterivianum* in the middle part of the subzone. Other stratigraphic markers are the FO of *Pseudoceratium anaphrissum* and the LO of *Apteodinium spongiosum, Muderongia australis* and *Stanfordella ordocava* in the upper part of the subzone. The distinct species *Oligosphaeridium umbraculum* has been recorded from the lowermost part of the present subzone.

Correlations: The FO of *B. longicornutum* correlates with the middle part of the lowermost Hauterivian *Endomoceras amblygonium* ammonite Zone according to Davey’s (2001) dinocyst correlation with lower Hauterivian ammonite stratigraphy at Speeton, east England. The LO of *Endoscrinium hauterivianum* in the present subzone may correlate with the LO of the species in the lowermost part of the upper Hauterivian LKP16.1 Zone (Duxbury, 2001), which is approximately equivalent to the *Simbirskites* (*Milanowskia*) *spectenensis* ammonite Zone (Fig. 8). Originally *O. umbraculum* was described from the lower Hauterivian Stage (Duxbury, 2001). *Nelchinopsis kostromiensis* and *Phoberocysta neocomica* are common in the *Nelchinopsis kostromiensis* Subzone, which is well-represented in the Store Koldewey-1 core (S17002, Fig. 2). Recently, the subzone has been recorded from Genetic Sequence 1 (approximately equivalent to parts of the Knurr and Klippfisk formations) Loppa High, southwestern Barents Sea (Fig. 6) by Marin et al. (2018).

6.e. Subzone: *Pseudoceratium anaphrissum* (2) of Nørh-Hansen (1993)

*Age*: early Barremian.

*Definition*: From the LO of *Nelchinopsis kostromiensis* to the LO of *Pseudoceratium anaphrissum*.

*Stratigraphic events: Hystrichosphaeridium arborispinum, Muderongia simplex subsp. microperforata, Oligosphaeridium asterigerum and Pseudoceratium anaphrissum* are often common to abundant within the subzone. *Muderongia simplex* subsp. *microperforata* has its FO in the lower part whereas *Oligosphaeridium...
Cretaceous dinoflagellate cyst zonation, NE Greenland

abaculum, Odontochitina nuda, Pseudoceratium aff. iveri and P. toveae have FO in the upper part of the subzone.

Correlation: The LO of Nelchinopsis kostromiensis correlates with the uppermost Haueritian Simbirskitina variabilis ammonite Zone (Gradstein et al. 2004). Previously, the Simbirskitina variabilis Zone was thought to represent the lowermost Barremian Stage (Kemper et al. 1981). Recently, the subzone has been recorded from the Kurikjéllet and Helvetiafjéllet formations on Spitsbergen and from Genetic Sequence 1 (approximately equivalent to the Knurr Formation) Barents Shelf by Grundvåg et al. (2017), and from Genetic Sequence 1 (approximately equivalent to parts of the Knurr and Klippfjåk formations) Loppa High, southwestern Barents Sea (Fig. 6) by Marin et al. (2018).

6.f. Subzone: Pseudoceratium toveae (3) of Nøhr-Hansen (1993)

Age: late Barremian.

Definition: From the LO of Pseudoceratium anaphrissum to the LO of Batioladinium longicornutum.

Stratigraphic events: An acme of Pseudoceratium toveae occurs in this subzone. The species Pseudoceratium aff. iveri has its LO within the lower part and Pseudoceratium iveri has its FO in the upper part of the subzone. Pseudoceratium aff. iveri is common in the northern part of Store Koldewey, where it occurs in the major part of the Store Koldewey-1 core (517002, Fig. 2). The middle part of the subzone is well represented on Store Koldewey, for example at PAL-6/2010 (Fig. 2), between Ravn Pynt and Tryakkjåkt where it can be calibrated with ammonites of the Fissicostataricas fissicostatum – Paracrioceras denckmanni zones (Fig. 8) and in the Midter Gneisnes area (MBJ-049, 053/2010, Fig. 2), where it is further characterized by the presence of brackish to marginal marine dinocysts (Vesperopsis longicornis and Hurllandia rugata), the zygospore Tetrangulare concisum and the colonial algae Scenedesmus.

Correlations: Pseudoceratium aff. iveri has previously been recorded as Pseudoceratium anaphrissum in the lower part of the Pseudoceratium toveae (3) Subzone at Rodroygen and Stratumbjerg, Wollaston Forland (sections 16, 21, Nøhr-Hansen, 1993, Fig. 5).

The species P. iveri was previously recorded only from the upper part of the Pseudoceratium toveae (3) Subzone e.g. at Stratum Bjerg, Wollaston Forland (section 21, Nøhr-Hansen, 1993; Fig. 5) and from the Diener Bjerg area (PAL-9/2009, Fig. 4), northern Hold with Hope (Nøhr-Hansen, 1993). In the present study the species is also recorded from the lowermost part of the overlying Odontochitina nuda (II) Zone (previously the Pseudoceratium nudum Zone of Nøhr-Hansen, 1993) from the Stenssío Plateau Member of the Steensby Bjerg Formation (Figs 6, 7) at Stenssío Plateau (HNH 081310-1, Fig. 4), northern part of Hold with Hope. The record of the ammonite Prodesaysesites sp. by Kelly & Whitham (1999) at Stenssío Plateau dates the Stenssío Plateau Member as earliest Aaptian Prodesaysesites fissicosatus Zone, and confirms that P. iveri range into the lowermost part of the lower Aaptian Odontochitina nuda (II) Zone. The zone has previously been recorded from the south Sabine section, Melville Island, Arctic Canada (Nøhr-Hansen & McIntyre, 1998). The subzone has recently been recorded from the Kap Rigsdagen beds, Valdern Gluckstad Land in North Greenland (Fig. 1) by Piasiecki et al. (2018) and from the upper part of the Genetic Sequence 1 (approximately equivalent to the middle part of the Kolje Formation) from Loppa High, southwestern Barents Sea by Marin et al. (2018; Fig. 6), and from the lower part of the Genetic Sequence 2 (approximately equivalent to the upper part of the Kolje Formation) from Barents Shelf and the north-central Barents Sea by Grundvåg et al. (2017) and Kairanov et al. (2018), respectively.

6.g. Zone: Odontochitina nuda (II) (previously Pseudoceratium nudum Zone of Nøhr-Hansen, 1993)

Age: early Aiptian.

Definition: From the LO of Batioladinium longicornutum to the LO of Odontochitina nuda.

Comments: Dinocysts characterizing the Odontochitina nuda (II) Zone from the Midter Gneisnes area, Store Koldewey (MBJ-049, –53/2010, Fig. 2) have been recorded from a concretion with the ammonite Deshayesites (Prodesaysesites) cf. bodei, suggesting the Prodesaysesites bodei Subzone of the Prodesaysesites fissicosatus Zone is of earliest Aiptian age (Fig. 8).

Stratigraphic events: Pseudoceratium aff. iveri and Pseudoceratium toveae both have their FO in the lower part, the FO of Pseudoceratium retusum is in the middle part and the LO of Odontochitina nuda (II) Zone and Exiguisphaera plectrili are in the top of the zone. Subtilisphaera percula and Vesperopsis longicornis are common within the zone and Protorhizopodinium clavulus is present.

Correlations: The presence of Protoellipsoidinium clavulus seems to be a good lower Aiptian marker in NE Greenland. It occurs in the Gulvel Member of the Steensby Formation at Diener Bjerg and in the laterally equivalent Rodelv Member of the Stratumbjerg Bjerg Formation (Fig. 6) at Steensby Bjerg (East) in the northern part of Hold with Hope. Previously, it was recorded only from the lower part of the Odontochitina nuda (II) Zone at Aucellabjerget, Wollaston Forland (Nøhr-Hansen, 1993; section 17, Fig. 5). The zone has previously been recorded from the Mesa Creek section, Ellesmere Island, Arctic Canada (Nøhr-Hansen & McIntyre, 1998; Fig. 1). Recently, the zone has been recorded from the Carolinefjellet Formation (Fig. 6), Spitsbergen by Grundvåg et al. (2017), and questionably from Genetic Sequence 2 (approximately equivalent to the upper Kolje Formation – lower Kolmule Formation) on the Barents Shelf by Grundvåg et al. (2017), southwestern Barents Sea by Marin et al. (2017), the Loppa High, southwestern Barents Sea by Marin et al. (2018) and possibly from Genetic Sequence 3 (approximately equivalent to the lower Kolmule Formation) north central Barents Sea by Kairanov et al. (2018).

6.h. Zone: Circulodinium brevispinosum (III) of Nøhr-Hansen (1993)

Age: early Aiptian to Early Albian.

Definition: From the LO of Odontochitina nuda to the LO of Circulodinium brevispinosum.

Comments: The zone was subdivided into four subzones by Nøhr-Hansen (1993): Vesperopsis longicornis (1), Vesperopsis mayri (2), Senoniaisphaera microreticulata (3) and Leptodinium? hyalodermopse (4). Detailed studies of two sections through the Rodelv Member from Diener Bjerg (PAL-9/2009 , Fig. 4) and Steensby Bjerg (East) (LHN 080810-2, Fig. 4) in the northern part of Hold with Hope have refined the dinoflagellate stratigraphy of the Circulodinium brevispinosum (III) Zone (see below).

Correlations. The zone has previously been recorded from the Mesa Creek section and the Rollrock River section, Ellesmere Island and the Junction Diapir section, Axel Heiberg Island, Arctic Canada (Nøhr-Hansen & McIntyre, 1998; Fig. 1).
Recently, the zone has been recorded from the genetic sequences 2–3/74 (approximately equivalent to the Kolmule Formation; Fig. 6) Loppa High, southwestern Barents Sea by Marin et al. (2018).

6.i. Subzone: Vesperopsis longicornis (1) of Nøhr-Hansen 1993

Age: late early – early late Aptian. This revised age assignment differs slightly from the late early Aptian age of Nøhr-Hansen (1993).

Definition: From the LO of Odontochitina nuda to the FO Vesperopsis mayi.

Stratigraphic events: FO of Odontochitina nuda to the FO Vesperopsis mayi.

Correlations: The common occurrence of Apteodinium granulatum and Apteodinium distinctum in the middle part of the zone, common Apteodinium granulatum in the middle and upper part and FO of Pseudoceratium distinctum in the middle and upper part, respectively. Vesperopsis longicornis is common to abundant throughout the subzone.

Correlations: The common occurrence of Apteodinium granulatum and the FO of P. distinctum (Rodelv Member sample 518674 from Diener Bjerg, PAL-9/2009, Fig. 4) in the middle part of the zone may correlate with the dinocyst zones LKP27.2 or LKP28 of Duxbury (2001), which he tentatively correlates with the upper part of the Tropaeum bowerbanki ammonite Zone (uppermost lower Aptian) and the lowermost Epicheloniceras martinoaides ammonite Zone (lower upper Aptian; Fig. 8); respectively. A Tropaeum bowerbanki Zone ammonite has also been recorded from the V. longicornis Subzone in the Rodelv Member at Diener Bjerg (section PAL-7/2009). The LO of P. distinctum in the middle part of the subzone correlates with dinocyst LKP30 Zone of Duxbury (2001), tentatively correlated with the Parahoplitites notfieldensis ammonite Zone (middle upper Aptian; Fig. 8). The subzone has recently been recorded from Genetic Sequence 2 (approximately equivalent to the lower Kolmule Formation) on the Barents Shelf and from the southwestern Barents Sea by Grundvåg et al. (2017) and Marin et al. (2017), respectively.

6.j. Subzone: Vesperopsis mayi (2) of Nøhr-Hansen 1993

Age: late Aptian. The age is revised and differs slightly from the latest early Aptian – late Aptian? age of Nøhr-Hansen (1993), a consequence of the redating of the older Vesperopsis longicornis (1) Subzone.

Definition: From the FO of Vesperopsis mayi to the FO of Senoniasphaera microreticulata.

Stratigraphic events: FO of Vesperopsis mayi at the base and FO of Liptodinium cancellatum in the lower part of the subzone, whereas the FO of Canningia reticulata and the FO of Nyktericysta vitrea occur in the upper part.

Correlations: Duxbury (2001) reported the FO of consistent L. cancellatum from his LKP32.2 Subzone, tentatively correlated with the middle part of the Leymeriella tardefurcata ammonite Zone (of earliest Albian age; Fig. 8), but mentions that the species can occur sporadically in his older, late Aptian LKP31 Zone. The study of 22 samples from the Vitskøl Elv section, Peary Land (Fig. 2) date the lower part of the section to possibly early–late Aptian, based on the presence of Vesperopsis mayi and Circulodinium brevispinosum indicating the presence of the Vesperopsis mayi Subzone (unpublished data). Recently, the subzone has been recorded from the middle part of Genetic Sequence 2 (approximately equivalent to the Kolmule Formation) in the southwestern Barents Sea by Marin et al. (2017).

6.k. Subzone: Senoniasphaera microreticulata (3) of Nøhr-Hansen 1993

Age: late Aptian – Early Albian.

Definition: From the FO to the LO of Senoniasphaera microreticulata.

Stratigraphic events: FO of Cauca parva is in the lower part of the subzone, whereas the FO of Hapsocysta? benteae occurs in the upper part of the subzone.

Correlations: The study of 22 samples from the Vitskøl Elv section, Peary Land (Fig. 2) dates the upper part as late Aptian – Early Albian based on the FO of Senoniasphaera microreticulata indicating the presence of the Senoniasphaera microreticulata Subzone (unpublished data).

6.1. Subzone: Leptodinium? hyalodermopse (4) of Nøhr-Hansen 1993

Age: Early Albian.

Definition: From the FO of Senoniasphaera microreticulata to the FO of Circulodinium brevispinosum.

Correlations: FO of Aptea polymorpha and Odontochitina singhii occur in the middle part of the subzone, whereas the FO of Circulodinium brevispinosum, Leptodinium hyalodermopse and Vesperopsis longicornis occur at the top of the subzone.

Correlations: Duxbury (2001) recorded the FO of Odontochitina singhii from the base of his Lower Albian dinocyst LKP33 Subzone, tentatively correlated with the upper part of the Leymeriella tardefurcata ammonite Zone (of Early Albian age; Fig. 8).

6.m. Zone: Rhombodella paucispina (IV) of Nøhr-Hansen 1993

Age: middle Albian.

Definition: From the FO of Circulodinium brevispinosum to the FO of Subtilisphaera kalaallittii.

Comments: The zone was subdivided into the two subzones by Nøhr-Hansen (1993): Litosphaeridium arundum (1) and Chichaouadinium vestitum (2). Studies of a section through the Rodelv Member from east Steensby Bjerg (LHN 080810-2, Fig. 4), northern part of Hold with Hope, have refined the dinocyst stratigraphy of the lower part of the Rhombodella paucispina (IV) Zone.

Correlations: The zone has previously been recorded from the Mesa Creek section, Ellesmere Island and the Junction Diapir section, Axel Heiberg Island, Arctic Canada (Nøhr-Hansen & McIntyre, 1998; Fig. 1). The Rhombodella paucispina (IV) Zone has been recorded from the Alban succession in Kangerlussuaq southern, East Greenland (Nøhr-Hansen, 2012; Fig. 1). The zone has recently been recorded from the lower part of Genetic Sequence 4 (approximately equivalent to the Kolmule Formation) from the Loppa High, southwestern Barents Sea by Marin et al. (2018).

6.n. Subzone: Litosphaeridium arundum (1) of Nøhr-Hansen 1993

Age: middle Albian.

Definition: From the FO of Circulodinium brevispinosum to the FO of common specimens of Chichaouadinium vestitum.

Correlations: FO of Chichaouadinium vestitum, Litosphaeridium arundum, Pseudoceratium expolitum and Rhombodella paucispina at the base of the subzone followed by
the FO of Batioladinium shaftesburiense in the middle part; Oovidinium sp. 3 Nøhr-Hansen (1993) is also present.

**Correlations:** The presence of the informal species Oovidinium sp. 3 Nøhr-Hansen (1993) seems to be a useful lower middle Albian marker in NE Greenland. It occurs in Rodelv Member at eastern Steensby Bjerg in the northern part of Holm with Hope, and was originally recorded from the lower part of the Litosphaeridium arundum (1) Subzone at Straumtbjerg, Wollaston Forland and at Kontaktravine, Clavering Ø (Nøhr-Hansen, 1993; section 21, 22, Fig. 5). Duxbury (2001) recorded the FO of L. arundum from the base of his lower Albian dinocyst subzone LKP33 Subzone.

### 6.a. Subzone: Chichaouadinium vestibum (2) of Nøhr-Hansen (1993)

**Age:** middle Albian.

**Definition:** From the FO of the acme of Chichaouadinium vestibum to the FO of Subtilisphaera kalaallitii.

**Stratigraphic events:** LO of Aptea polymorpha, Chichaouadinium vestibum, Ellipsidictyum imperfectum, Leptodinium cancellatum and Odontochitina singhi occurs at the top of the subzone.

**Correlations:** Duxbury (2001) recorded an increase in abundance of E. imperfectum in the top of his dinocyst LKP34 Subzone upper middle Albian tentatively correlated with the Euhoplites latus ammonite Zone and the LO of O. singhi in the dinocyst LKP35.1 Subzone, lowermost upper Albian, Mortonioceras isfaltum ammonite Zone (Fig. 8). The subzone has recently been recorded from the upper part of Carolinelfjellet Formation on Spitsbergen by Grundvåg et al. (2017) and from the older part of the Kangoq Rgy Member, Galadriel Fjeld Formation at Kilen, eastern North Greenland (Hovikoski et al. 2018; Pedersen et al. 2018; Fig. 1).

### 6.p. Zone: Subtilisphaera kalaallitii (V) of Nøhr-Hansen (1993) redefined

**Age:** late Albian – middle Cenomanian.

**Definition:** From the FO of Subtilisphaera kalaallitii to the FO of Endoceratium ladbrokeae.

**Comments:** Originally the top of the zone was defined at the LO of Epelidosphaeridia spinosa (Nøhr-Hansen, 1993); in the present study this is changed to the slightly higher FO of Endoceratium ladbrokeae, which seems to be a more reliable marker.

The original zone was subdivided into four subzones by Nøhr-Hansen (1993): Wigginsiella grandstandica (1), Odontochitina ancala (2), Oovidinium sp. 1 (3) and Epelidosphaeridia spinosa (4). The redefined Subtilisphaera kalaallitii Zone is subdivided into the following five subzones: Wigginsiella grandstandica (1), Odontochitina ancala (2), Sindridinium borealis (3) new, Epelidosphaeridia manifesta (4) new and Sindridinium annaanae (5) new.

**Correlations:** The zone has previously been recorded from the Junction Diapir section, Axel Heiberg Island, Arctic Canada (Nøhr-Hansen & McIntyre, 1998; Fig. 1). Recently, the Subtilisphaera kalaallitii (V) Zone Nøhr-Hansen (1993) was recorded from the Albian–Cenomanian Sorgenfri Formation in Kangervalussuaq, southern East Greenland (Nøhr-Hansen, 2012; Fig. 6). The middle part of the Subtilisphaera kalaallitii Zone was reported from the Kolmule Formation in the southwestern Barents Sea and from the Langebarn Formation in the Norwegian Sea (Fig. 6) by Radmacher et al. (2014) and by Radmacher et al. (2015), respectively. Recently, the lower part of the subzone has been unquestionably recorded from Genetic Sequence 4 (approximately equivalent to the Kolmule Formation) from the Loppa High, southwestern Barents Sea by Marin et al. (2018).

### 6.q. Subzone: Wigginsiella grandstandica (1) of Nøhr-Hansen (1993)

**Age:** early late Albian.

**Definition:** From the FO of Wigginsiella grandstandica to the FO of Odontochitina ancala.

**Stratigraphic events:** FO of Subtilisphaera kalaallitii, Wigginsiella grandstandica and Circulodinium sp. 1 Nøhr-Hansen (1993) at the base of the subzone. Subtilisphaera kalaallitii and Rhombodella paucispina are common to dominant within the present subzone. The informal species Dinoflagellate cyst 1 Nøhr-Hansen (1993) is present in a narrow interval within the lower part of the present subzone, and seems to be a good lowermost upper Albian marker in NE Greenland.

**Correlations:** Dinoflagellate cyst 1 Nøhr-Hansen (1993) was originally recorded from the lower part of the Wigginsiella grandstandica (1) Subzone at Tverdal, Geographical Society Ø (Nøhr-Hansen, 1993; section 30, p. 162, Fig. 3). It also occurs together with W. grandstandica in the lower part of Fosdalen Formation (Fig. 6) at Diener Bjerg, northern Hold with Hope (PAL-9/2009, Fig. 4) and in a more than 500 m thick, E-dipping succession in the river valley (HNN 080910-1, Fig. 4) of western Lyngaelv, southern Hold with Hope. Recently, the subzone has been recorded from the older part of the Kangoq Rgy Member, Galadriel Fjeld Formation at Kilen, eastern North Greenland (Hovikoski et al. 2018; Pedersen et al. 2018; Fig. 1).

### 6.r. Subzone: Odontochitina ancala (2) of Nøhr-Hansen (1993)

**Age:** middle–late Albian.

**Definition:** From the FO of Odontochitina ancala to the FO of Sindridinium borealis.

**Comments:** The Odontochitina ancala (2) Subzone is represented by a more than 200-m-thick succession at Svinhuvud Bjerg (section 37, Nøhr-Hansen, 1993; Fig. 3) on Trállí Ø and less than 82-m-thick in Tverdal, Geographical Society Ø (section 30, Nøhr-Hansen, 1993; Fig. 3). Nøhr-Hansen (1993, section 28; Fig. 4) dated two samples to middle–late Albian at the eastern mouth of Lyngaelv, southern Hold with Hope. The succession was referred to the Odontochitina ancala (2) Subzone Nøhr-Hansen (1993) despite the lack of the zonal index species. Analyses of samples from this locality (HNN 080610-182, Fig. 4) confirmed the presence of Odontochitina ancala, together with the Lower Cenomanian zonal marker Sindridinium annaanae.

The Early Cenomanian age correlates with a latest Albian – Cenomanian age based on the recovery of Inoceramus dunveganensis McLean and the annelid Ditruga almost at the same site (CAS Loc. W. 3141; Kelly et al. 1998). The ammonite Schloenbachia ventiosa Stiefer of probable Early Cenomanian age occurs further inland at Lyngaelv (Kelly et al. 1998; CASP Loc. K.7359). Kelly et al. (1998) therefore regarded the Odontochitina ancala (2) Subzone of Nøhr-Hansen (1993) as Cenomanian. However, palynological studies of two successions from this locality refer these successions to the new Epelidosphaeridia manifesta (4) Subzone of Early–middle Cenomanian age (see below).

**Stratigraphic events:** The FO of Epelidosphaeridia sp. 1 Nøhr-Hansen (1993), Odontochitina ancala and Sindridinium? torn/media at the base of the subzone and LO of Circulodinium

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sp. 1 Nøhr-Hansen (1993) in the lower part of the subzone. The FO of *Endoceratium exquisitum* in the middle of the subzone seems to be a good stratigraphic marker; the species was wrongly reported and illustrated as *Endoceratium detritmanniae* by Nøhr-Hansen et al. (2018, pl. 9, figs 1–6). *Circulodinium* sp. 1 Nøhr-Hansen (1993), *Subtilisphaera kalaallitii* and *Rhombodella paucispira* are common to dominant in this subzone.

**Correlations:** The Odontochitina ancala (2) Subzone was recently recorded from thin (less than 10 cm) mudstone layers within an approximately 5-m-thick sandy section and the approximately 40-m-thick overlying mudstone section situated at the northern part of Snertadl, Hold with Hope (HNH081210-6, Fig. 4). The section contains a low-diversity assemblage, including the brackish water form *Nykterictys dictyophora* (former *Quantoenuedinium dictyophorum* according to Fensome et al. 2016) previously recorded from the Odontochitina ancala Subzone at Svinhufvud Bjerge, Trall Ø (section 36, 37, Nøhr-Hansen, 1993; Figs 2, 3) as *Vesperosis aff. V. fragilis*. Recently, the subzone has been recorded from the younger part of the Kangooq Ryg Member, Galadriel Fjeld Formation at Kilin, eastern North Greenland (Hovikoski et al. 2018; Pedersen et al. 2018).

### 6.5. Subzone: Sindridinium borealis (3) new

**Age:** latest Albian – Early Cenomanian.

**Definition:** From the FO of *Sindridinium borealis* to the FO of *Epelidosphaeridia manifesta*.

**Comments:** The *Sindridinium borealis* (3) Subzone corresponds to the lower part of the former *Ovoidinium* sp. 1 Subzone of Nøhr-Hansen (1993). Two morphologically almost similar forms of *Ovoidinium* sp. 1 Nøhr-Hansen (1993) (non-cavate and hypocavate forms) were earlier assumed to occur together; however, Nøhr-Hansen et al. (2018) recorded that *S. borealis* (the non-cavate form) has no or little overlap with the younger *Sindridinium anaanae* (the hypocavate form). The base of the up to 130-m-thick *Sindridinium borealis* (3) Subzone is recognized in four sections on Hold with Hope (Snertadl, JHOV-2/2009, east of Fosdalen HNH081410-4 and western Lygaerv HNH 089010-1, HNH080610-3, Fig. 4) and from the Tvaerdal section, Geographical Society Ø (section 30 of Nøhr-Hansen 1993; PAL-3/2011, Nøhr-Hansen et al. 2018).

**Stratigraphic events:** FO of *Epelidosphaeridia spinosa*, *Dinapertugyrum alatum* and *Sindridinium borealis* at the base of the subzone. LO of *Epelidosphaeridia* sp. 1 Nøhr-Hansen (1993), FO of *Senonisphaera aff. microreticulata* and FO of common *S. borealis* in the upper part of the subzone. *Subtilisphaera kalaallitii* and *Rhombodella paucispira* are common to dominant within the present subzone. The brackish to marginal marine indicator, the acritarch *Limbicysta*, is recorded from the upper part of the subzone at Lygaerv, HNH080610-3.

**Correlations:** The *Ovoidinium* sp. 1 (3) Subzone Nøhr-Hansen (1993) was recorded from the Albian Sorgenfrei Formation in Kangerlussuaq, southern East Greenland (Nøhr-Hansen, 2012; Figs 1, 6). An acme of *S. borealis* was reported from the Komule Formation in the southwestern Barents Sea (Radmacher et al. 2014; Figs 1, 6). *Sindridinium borealis* also occurs in the Lower Cenomanian at Norfolk, onshore eastern England and in the Lower Cenomanian Komule Formation in Troms and Hammerfest basins, Barents Sea (Nøhr-Hansen et al. 2018; Fig. 1).

### 6.t. Subzone: Epelidosphaeridia manifesta (4) new

**Age:** Early Cenomanian.

**Definition:** From the FO of *Epelidosphaeridia manifesta* to the FO of *Sindridinium anaanae*.

**Comments:** The *Epelidosphaeridia manifesta* (4) Subzone correlates with the middle part of the *Ovoidinium* sp. 1 Subzone of Nøhr-Hansen (1993). The subzone is represented by more than 100 m at Tvaerdal, Geographical Society Ø (section 30, Nøhr-Hansen, 1993; Fig. 3). Resampling and restudy of the approximately 415-m-thick succession in Tvaerdal on Geographical Society Ø (section 30 of Nøhr-Hansen, 1993; Pal-3/2011, Fig. 4) have yielded a rich assemblage of the ammonite *Schloenbachia varians* from 349 m, that is, a level in the upper part of the *Epelidosphaeridia manifesta* (4) Subzone indicating an earliest Cenomanian age (*Mantellliceris mantelli* – *M. dixoni* ammonite zones (undivided), Fig. 8; Nøhr-Hansen et al. 2018).

The subzone is also recorded from a more than 200-m-thick succession (HNH 081410-4, Fig. 4) in the hanging wall east of the Fosdalen Fault, east of Fosdalen, northern Hold with Hope.

The *Epelidosphaeridia manifesta* (4) Subzone has also been recorded in the uppermost part of an E-dipping succession along Lygnaerv (HNH 080610-3, Fig. 4), southern Hold with Hope. Here the ammonite *Schloenbachia* sp. is collected very close to Kelly et al.’s (1998) inland locality at Lygnaerv (CASP Loc. K.7359), where they found the ammonite *Schloenbachia ventiosa* that was probably of Early Cenomanian age. These records of *Schloenbachia* ammonites within the *Epelidosphaeridia manifesta* (4) Subzone both at Lygnaerv and in Tvaerdal provide an important palynostratigraphic means of placing the Albian–Cenomanian boundary in NE Greenland, and confirm that the boundary is in the *Sindridinium borealis* (3) Subzone and not in the underlying *Odontochitina ancala* (2) Subzone of Nøhr-Hansen (1993) as suggested by Kelly et al. (1998).

**Stratigraphic events:** FO of *Epelidosphaeridia manifesta* and *Ovoidinium epelidosphaeroides* in the lower part of the subzone, both species are previously observed from the Lower Cenomanian Kolmule Formation in Troms and Hammerfest basins, Barents Sea (Nøhr-Hansen et al. 2018). The LO of *E. manifesta* occur in the middle of the subzone, whereas the FO of *Xenucass aff. platei* and the LO of *O. epelidosphaeroides*, *Senonisphaera aff. microreticulata* and common *Sindridinium borealis* occur in the uppermost part of the Subzone. *Sindridinium borealis*, *Subtilisphaera kalaallitii* and *Rhombodella paucispira* are common to dominant within the present subzone. The brackish to marginal marine indicator, the acritarch *Limbicysta* and the zygospore *Tetrangularis conspicuum* are recorded from the subzone east of Fosdalen (HNH081410-4) and the Tvaerdal sections (section 30 of Nøhr-Hansen 1993 and GEUS, PAL-3/2011).

### 6.u. Subzone: Sindridinium anaanae (5) new

**Age:** Early – ?middle Cenomanian.

**Definition:** From the FO of *Sindridinium anaanae* to the FO of *Endoceratium ludbrookei*.

**Comments:** The *Sindridinium anaanae* (5) Subzone correlates with the upper part of the *Ovoidinium* sp. 1 Subzone of Nøhr-Hansen (1993). The subzone is represented by a total thickness of more than 190 m in three sections at the hanging wall east of the Fosdalen fault, east of Fosdalen, northern Hold with Hope.
6.v. Zone: Endoceratium ludbrookiae (VI) new

Age: Middle Cenomanian (pars).
Definition: From the FO of Endoceratium ludbrookiae to the FO of Isabelidinium magnun.
Comments: The Endoceratium ludbrookiae (VI) Zone has been recorded from three small sections: one 3-m- and two 25-m-thick successions south of Knudshoved at the east coast of Hold with Hope (HNN 081009-4, HNN 081009-2 and HNN 081009-1; Fig. 4). The incoming of E. ludbrookiae has not been observed in a continuous exposed section; in the Knudshoved sections the species occurs from the base of the exposures.

Stratigraphic events: FO of Endoceratium ludbrookiae, Ginginodinium aff. evitti and Palaeostrichophora infusorioroides together with the LO (or reworked specimens) of Endoceratium exquisitum at the base of the zone. Dorocyclus litotes, Hapscyctta? benteae and Rhombodella paucispina are present and Subtilisphaera kalaalliti is abundant within this new zone.

Correlations: Endoceratium ludbrookiae has an upper Albion—upper Cenomanian range according to Helby et al. (1987) and a middle Lower—end upper Cenomanian range according to BioStrat (2018). The presence of G. aff. evitti may indicate an age not younger than Early Cenomanian according to Singh (1983); however, the absence of Epelidophora spinosa and Isabelidinium magnun may suggest a middle Cenomanian age. Based on the FO of Palaeostrichophora infusorioroides, this new E. ludbrookiae Zone may correlate with the lower part of the Cenomanian Palaeostrichophora infusorioroides—P. palaeoinfusa Interval Zone established from the intra-Early to intra-late Cenomanian part of the Kveite Formation from the southwestern Barents Sea by Radmacher et al. (2014; Figs 1, 6) and later reported from the Langebarn and Blålange formations from the Norwegian Sea by Radmacher et al. (2015; Figs 1, 6). Recently, the FO of Endoceratium ludbrookiae has been recorded from the younger part of the Kangog Ryg Member, Galadriel Fjeld Formation at Kilen, eastern North Greenland (Fig. 1), suggesting the presence of the subzone (Hovikoski et al. 2018; Pedersen et al. 2018).

6.w. Zone: Isabelidinium magnun (VII) new

Age: Middle–late Cenomanian.
Definition: From the FO of Isabelidinium magnun to the FO of Cyclonephelium compactum—Cauveridinium membraniphorum complex.
Comments: The Isabelidinium magnun (VII) Zone is recorded from two 15-m-thick successions (HNN080710-3 and HNN080710-4; Fig. 4) south of Knudshoved, and in the lowermost 5 m of the Nanok-1 core (517004) at the east coast of Hold with Hope.

Stratigraphic events: FO of Isabelidinium magnun, Isabelidinium acuminatum, Isabelidinium spp., Trithyrodinium aff. rhomboideum and Trithyrodinium suspectum at the base of the zone. LO of Hapscyctta? benteae is in the lower part and LO of Rhombodella paucispina and T. aff. rhomboideum are in the uppermost part of the zone. Subtilisphaera kalaalliti is abundant in the lower part and common in the upper part of the zone. Palaeostrichophora infusorioroides is common in the middle part of the zone and Isabelidinium spp. is common throughout the new zone.

Correlations: The FO of I. magnun suggests a late Cenomanian age (Costa & Davey, 1992) and the FO of T. suspectum suggests a middle–late Cenomanian age (Costa & Davey, 1992; Williams et al. 2004). Trithyrodinium rhomboideum is described from the middle Cenomanian Stage of Alberta, Canada (Singh, 1983). The FO of Isabelidinium magnun and Trithyrodinium suspectum have recently been recorded from the older part of the Solverbek Formation at Kilen, eastern North Greenland (Fig. 1), suggesting the presence of the subzone (Hovikoski et al. 2018; Pedersen et al. 2018).
Radmacher et al. (2015; Figs 1, 6). *Subtilisphaera kalaalliti* becomes extinct in the uppermost part of their *Palaehystrichophora* *infusorioidea* – *P. palaeoinfusa* Interval Zone from the Norwegian Sea according to Radmacher et al. (2015). The last consistent occurrence of *S. kalaalliti* within the new *C. compactum* – *C. membraniphorum* complex Zone may indicate that its upper boundary is slightly younger than the *Palaehystrichophora* *infusorioidea* and *P. palaeoinfusa* Interval Zone of Radmacher et al. (2014). Recently, the FO of *Cauveridinium membraniphorum* has been recorded from the older part of the Solverbæk Formation at Kilén, eastern North Greenland, suggesting the presence of the subzone (Hovikoski et al. 2018; Pedersen et al. 2018; Fig. 1).

### 6.y. Zone: Heterosphaeridium difficile (IX) new

**Age:** Early Turonian – ?middle Coniacian.

**Definition:** From the FO of *Heterosphaeridium difficile* to the FO of the undefined species informally named “Chatangiella spinosa” in industrial reports.

**Comments:** The *Heterosphaeridium difficile* (IX) Zone has been recorded from a 27-m-thick succession (HNN080209-4) and represented by 28 m in Fosdalen formation in the Nanøk-1 core (517004) south of Knudshoved at the east coast of Hold with Hope (Fig. 4). The zone is subdivided into four new subzones: *Chatangiella granulifera* (1), *Senoniasphaera rotundata* (2), *Odontochitina rhakodes* (3) and *Xenusicus gochiti* (4). The *Heterosphaeridium difficile* (IX) Zone differs from the informal *Heterosphaeridium difficile* interval of Coniacian – Early Santonian age described by Nøhr-Hansen (1996) from West Greenland, which was defined from the LO of *Arvalidinium scheii* to the LO of *Heterosphaeridium difficile*.

**Correlations:** Parts of the informal *Heterosphaeridium difficile* interval of Nøhr-Hansen (1996) were recently recorded from the Turonian–Coniacian succession in the Sorgenfri Formation at Kangerlussuag, southern East Greenland (Nøhr-Hansen, 2012; Figs 1, 6) and from the Turonian – ?intra-early Coniacian part of the Kveite Formation in the southwestern Barents Sea (Radmacher et al. 2014) and from the Turonian – ?intra-early Coniacian part of the Blålange and Kvitno formations in the Norwegian Sea (Radmacher et al. 2015; Figs 1, 6). Recently, the FO of *Heterosphaeridium difficile* has been recorded from the older part of the Solverbæk Formation at Kilén, eastern North Greenland, suggesting the presence of the subzone (Hovikoski et al. 2018; Pedersen et al. 2018; Fig. 1).

### 6.z. Subzone: Chatangiella granulifera (1) new

**Age:** Early Turonian.

**Definition:** From the FO of *Chatangiella granulifera* to the FO of *Senoniasphaera rotundata*.

**Comments:** The *Chatangiella granulifera* (1) Subzone has been recorded from a 4-m-thick Fosdalen formation succession (HNN080209-4) south of Knudshoved and is represented by 6 m in the Nanøk-1 core (517004) at the east coast of Hold with Hope (Fig. 4).

**Stratigraphic events:** The FO of *Chatangiella granulifera* and *Heterosphaeridium difficile* at the base of the subzone.

**Correlations:** Both *C. granulifera* and *H. difficile* have their FO at the base of the Turonian Stage according to Costa & Davey (1992), Pearce et al. (2003), Williams et al. (2004) and BioStrat (2018) suggest an age not older than Early Turonian for the FO of *H. difficile*. Dodsworth (2000) recorded the FO of rare *H. difficile* from the Lower Turonian bed 95, 1.2 m above the global boundary stratotype section and point (GSSP) at the type section at Pueblo, Colorado, USA. Eldrett et al. (2015) recently dated the FO of *H. difficile* to middle Turonian (92.28 ma) from Texas, USA, based on astronomical calibration. An Early Turonian age for the FO of *H. difficile* is tentatively used in the present paper. Bell & Sellnes (1997) suggested an Early-middle Cenomanian FO age for *H. difficile* based on its co-occurrence with members of the *Endocreatia dittmanniaceae* – *E. ludbrookiae* plexus, offshore Norway. However, *E. ludbrookiae* has in the present study been recorded in assemblages together with *H. difficile* and the Turonian – middle Coniacian marker species *Odontochitina rhakodes* and *Xenusicus gochiti* from Nanøk-1 core (517004) at the east coast of Hold with Hope, and together with *H. difficile* and *O. rhakodes* from the middle – upper part of the Solverbæk Formation at Kilén, eastern North Greenland (Hovikoski et al. 2018; Pedersen et al. 2018; Fig. 1), suggesting either reworking or a Coniacian LO for *E. ludbrookiae*. Olde et al. (2015) mention (based on Bell & Sellnes, 1997; Bloch et al. 1999) the FO of *H. difficile* in the Cenomanian Stage in the high northern latitudes, suggests that *H. difficile* is a cold-water-tolerant species that migrated southwards with the predominant Late Cretaceous cooling; however, Lenniger et al. (2014, unpublished data) recorded its FO in the Lower Turonian Stage from Axel Heiberg Island, Artic Canada and from the Baffin Bay area.

### 6.aa. Subzone: Senoniasphaera rotundata (2) new

**Age:** middle Turonian.

**Definition:** From the FO of *Senoniasphaera rotundata* to the FO of *Odontochitina rhakodes*.

**Comments:** The *Senoniasphaera rotundata* (2) Subzone has been recorded from a 6-m-thick Fosdalen formation succession (HNN080209-4) south of Knudshoved, and is represented by 3 m in the Nanøk-1 core (517004) at the east coast of Hold with Hope (Fig. 4).

**Stratigraphic events:** The FO of *Senoniasphaera rotundata* and *Raphidodinium fucatum* at the base of the subzone. *Sarcaloxaphidion longifurcatum* are common in the subzone.

**Correlations:** *Senoniasphaera rotundata* has a FO in the ?upper Turonian – lower Coniacian stages according to Costa & Davey (1992). However, an FO in the middle Turonian Stage and a first common occurrence in the uppermost Turonian Stage was reported by Pearce et al. (2003). The FO of *R. fucatum* in the middle Turonian Stage is described by Costa & Davey (1992) and was also recorded from the North Sea area, Norwegian Sea and West Greenland by Radmacher et al. (2015), Pedersen & Nøhr-Hansen (2014) and Nøhr-Hansen et al. (2016), respectively; an upper Coniacian FO was reported by Nøhr-Hansen (2012) from the Sorgenfri Formation at Kangerlussuag, southern East Greenland.

### 6.ab. Subzone: Odontochitina rhakodes (3) new

**Age:** ?middle Turonian – ?early Coniacian. The suggested age is tentative, based on the ages of the subzones below and above.

**Definition:** From the FO of *Odontochitina rhakodes* to the FO of *Xenusicus gochiti*.

**Comments:** The *Odontochitina rhakodes* (3) Subzone has been recorded from a 12-m-thick Fosdalen formation succession (HNN080209-4) south of Knudshoved, and represented by 4 m in the Nanøk-1 core (517004) at the east coast of Hold with Hope (Fig. 4).
Stratigraphic events: FO of *Lacinidiunum arcticum* and *Odontochitina rhakodes* at the base of the subzone and LO of *O. rhakodes* at the top of the subzone. *Palaeohystrichophora infusorioides* and *Spiniferites* spp. and *Scuruliphaedrium longifurcatum* are common in the subzone.

Correlations: A Lower Turonian LO for *O. rhakodes* was reported by Fensome et al. (2008). The FO of *Lacinidiunum arcticum* was recorded as most likely in the lower Coniacian Stage from West Greenland by Nehr-Hansen (1996), whereas a Turonian FO was reported from Europe by Stover et al. (1996). Recently, the FO of *Odontochitina rhakodes* has been recorded from the Solverbek Formation at Kilen, eastern North Greenland, suggesting the presence of the subzone (Hovikoski et al. 2018; Pedersen et al. 2018; Fig. 1).

6.ad. Zone: “Chatangiella spinoa” (X) new

Age: middle Coniacian – middle Santonian.

Definition: From the FO of “Chatangiella spinoa” (informal name for an undefined species used in biostratigraphic reports within petroleum exploration drilling) to the FO of *Alterbidinium ioannidesii*.

Comments: The “Chatangiella spinoa” (X) Zone has been recorded from the lowermost 14.5 m of the Østersletten formation (including the Nanok Member, which forms the basal 2.5 m of the formation; Fig. 6) in the exposed section (HNN080209-4) south of Knudshoved, and from the lower 6 m of the Østersletten formation in the Nanok-1 core (517004, Fig. 4).

Stratigraphic events: FO of “Chatangiella spinoa”, *Spinidinium echnioideum* and *Trithyrodiunum vermiculatum* at the base of this zone. LO of *Senoniastra phaerot rotundata* in the lower part and LO of *Isabelidinium magnum* and FO of *Odontochitina porifera* in the middle part of the zone. *Palaeohystrichophora infusorioides* and *S. echnioideum* are common in the subzone.

Correlations: The informal “C. spinoa” is assumed to have a middle Coniacian – middle Santonian range in the Norwegian Sea according to BioStrat (2018). *Trithyrodiunum vermiculatum* was recorded from the middle Coniacian strata by Schieler (1992). The FO of *O. porifera* may support a Santonian age. *O. porifera* has a Lower Santonian – lower Campanian range in Australia according to Helby et al. (1987), whereas Fensome et al. (2008) and Fensome et al. (2016) recorded an LO of *O. porifera* in the upper Santonian deposits in the Scotian Margin and Labrador Sea, respectively. The zone may correlate with the lower part of the ?intra-early Coniacian – late Santonian *Dinopterygium alatum* Interval Zone in the Kveite Formation in the southwestern Barents Sea (Radmacher et al. 2014). Radmacher et al. (2015) reported abundant occurrence of *T. vermiculatum*, and abundant occurrences of “C. spinoa” at the base of the *D. alatum* Interval Zone from the Kvittos and Nise Formations from the Norwegian Sea (Figs 1, 6).

6.ae. Zone: *Alterbidinium ioannidesii* (XI) new

Age: late Santonian.

Definition: From the FO of *Alterbidinium ioannidesii* to the FO of *Aquilapollenites* spp.

Comments: The *Alterbidinium ioannidesii* (XI) Zone is recorded from the 26-m-thick succession representing the middle and upper part of the Østersletten formation at locality 5 south of Knudshoved and represented by 32 m in the Nanok-1 core (517004) at the east coast of Hold with Hope (Fig. 4), from a 20-m-thick succession at northeastern Hold with Hope (HNN081610-1, Fig. 4), from an approximately 100-m-thick succession on southern Jackson Ø (HNN081610-2, 3, Fig. 4) and from the upper 23 m of the 80-m-thick Kista Ø formation type section (Pal-5/2011, Figs 3, 6) eastern Månedal, Trail Ø.

Stratigraphic events: FO of *Alterbidinium ioannidesii* at the base of this zone and LO of “Chatangiella spinoa” and *Heterosphaeridium difficile* in the middle part of this zone.

Correlations: A. ioannidesii has a stratigraphical range from the upper Santonian – middle-lower Campanian strata in the Norwegian Sea (Pearce, 2010). “Chatangiella spinoa” has a top Early Santonian LO according to BioStrat (2018), whereas other consultants mention a middle Santonian LO. The LO of
H. difficile indicates an age no younger than late Santonian. *Heterosphaeridium difficile* is often very abundant in Coniacian – Lower Santonian deposits in the North Sea, but isolated specimens are recorded from the upper Santonian onshore England (Prince et al. 1999).

### 6.af. Zone: *Aquilapollenites* (XII) new

**Age:** early–late Campanian.

**Definition:** From the FO of the pollen genus *Aquilapollenites* to the FO *Cerodinium diebelii*.

**Comments:** The lower part of the zone is subdivided into two new subzones: *Aquilapollenites* (1) and *Isabelidinium microarmum* (2). The *Aquilapollenites* Zone (XII) differs from the lower–middle Campanian informal *Aquilapollenites* interval of Nøhr-Hansen (1996) by defining the upper boundary at the FO of *Cerodinium diebelii* instead at the LO of *Isabelidinium microarmum*. The upper boundary of the *Aquilapollenites* Zone has not been recognized in a continuous exposed succession in NE Greenland.

The *Aquilapollenites* Zone has been recorded from a 12-m-thick succession (locality 5) representing the uppermost 5 m of the Østersletten formation and the lowermost 7 m of the Knudshoved formation (Fig. 6) south of Knudshoved (east coast of Hold with Hope, Fig. 4); it is represented by 37 m in the nearby Nanok-1 core (517004) and from three sections at Geographical Society Ø, namely, a 65-m- and 20-m-thick succession at Hundeklemmen (PAL-6/2011, PAL-7/2011, Fig. 3) and a 45-m-thick succession west of Leitch Bjerg (PAL-8/2011, Fig. 3).

### 6.ah. Subzone *Isabelidinium microarmum* (2) new

**Age:** early–middle Campanian.

**Definition:** From the FO to the LO of *Isabelidinium microarmum*.

**Comments:** The lower part of the *Isabelidinium microarmum* Subzone is recorded in the uppermost part of the Knudshoved formation in the Nanok-1 core (517004) at the east coast of Hold with Hope (Fig. 4) and in three sections at Geographical Society Ø, namely, a 65-m- and a 20-m-thick succession at Hundeklemmen (PAL-6/2011, PAL-7/2011, Fig. 3) and a 45-m-thick succession west of Leitch Bjerg (PAL-8/2011, Fig. 3). The outgrowing of *I. microarmum* has not been observed in a continuous exposed section; the species occurs at the top of the studied exposures in NE Greenland.

**Stratigraphic events:** FO and LO of *Isabelidinium microarmum*, presence of *Alterbidinium ioannidesii*.

**Correlations:** The presence of *Alterbidinium ioannidesii* throughout the Knudshoved formation at Geographical Society Ø suggests an age not younger than early Campanian according to Pearce (2010), who recorded a range up to the middle–lower Campanian in the Norwegian Sea and a range from the lower part of the echinoid *Offoster pillula* Zone (low lower Campanian) to the lower part of the belemnite *Gonioteutus quadrata* Zone (middle lower Campanian) at Norfolk, United Kingdom (Fig. 1). The present record of *A. ioannidesii* below and above the ammonite *Scaphites ikorhensis* in the Hundeklemmen section, Geographical Society Ø (PAL-7/2011, Fig. 3) may indicate an extent of the range of *A. ioannidesii* into the upper middle Campanian *Bostryhocheras polyplom* ammonite Zone (according to Kaplan et al. 2005, p. 152). The FO of *I. microarmum* at the base of the zone (uppermost part of the Nanok-1 core: 517004, at Knudshoved), and the presence of the species in all the three sections at Geographical Society Ø, may suggest that these sections are younger than the type locality of the Knudshoved formation (locality 5). *Isabelidinium microarmum* was described from the lower Campanian – Maastrichtian in northwestern Canada by McIntyre (1975), and recorded from the lower–middle Campanian Stage in West Greenland (Nøhr-Hansen, 1996) and from the lower Campanian Stage in northern Siberia (Lebedeva, 2006). In a palynological zonation scheme of the northern North Sea and Norwegian Sea, BioStrat (2018) shows a lower middle Campanian LO for *A. ioannidesii* and *I. microarmum*. The new subzone may correlate with the intra-Campanian *Hystrichosphaeridium dawlingii* – *Heterosphaeridium* spp. Interval Zone from Nise Formation in the Norwegian Sea (Radmacher et al. 2015; Figs 1, 6).
6.1.2. Zone: Cerodinium diebelii (XIII) new

Age: Late Campanian – Early Maastrichtian.

Definition: From the FO of Cerodinium diebelii to the FO of the pollen Wodehouseia spinata.

Comments: The Cerodinium diebelii Zone has been recorded from a 25-m-thick succession on the south side of Haredal, Wollaston Forland (HNH081508-4, Fig. 3), and the lowermost part of the zone may be represented in an 80-m-thick succession east of Jacksontoppen, Jackson Ø (HNH081610-4, Fig. 4). The presence of C. diebelii has not been observed in a continuous exposed section, and the species occurs from the base of the exposures in NE Greenland. The FO of the pollen Wodehouseia spinata has not been observed in the studied section.

Stratigraphic events: FO of Cerodinium diebelii in the Jackson Ø section. All palynomorphs from this 80-m-thick succession are thermally overmature (thermal alteration index, TAI 3 to 4 – ). C. diebelii, Hystrochorea biapertura and A. biapertura are present throughout and A. biapertura is common in the upper part of the Haredal section.

Correlations: McIntyre (1974, 1975) recorded an Early Maastrichtian FO age for C. diebelii in the Northwest Territories of Canada and a late Campanian – Early Maastrichtian age for W. gracile, his Hystrochorea biapertura sp. and Deflandrea biapertura (now Alterbidinium biaperturatum, according to Fensome et al. 2016). BioStrat (2018) recorded the FO of Hystrochorea biapertura sp. 3 McIntyre (1974) and the first common occurrences of A. biaperturatum and C. diebelii from the Early Maastrichtian Age in the northern North Sea and in the Norwegian Sea. A late Campanian FO for W. gracile is recorded in southern Alberta, Canada (Braman, 2018). The Cerodinium diebelii Zone (XII) differs slightly from the Early Maastrichtian informal Cerodinium diebelii interval of Nohr-Hansen (1996) by its content of Wodehouseia species, and the questionable extension into the latest Campanian Age. The informal C. diebelii interval of Nohr-Hansen (1996) was also reported by Radmacher et al. (2014) from the Lower Maastrichtian part of the Kveite Formation in the Barents Sea. The present zone partly correlates with the interpreted Lower Maastrichtian Cerodinium diebelii interval recorded from southern East Greenland (Nohr-Hansen, 2012). The Haredal section has previously been referred to an early to middle Campanian age based on the presence of the dinocysts Alterbidinium ioannidesi (one specimen only) and C. diebelii (Nohr-Hansen et al. 2011). Re-examinations of the palynological material from Haredal revealed the presence of the pollen Wodehouseia gracile in all six studied samples, whereas the presence of one specimen of the Santonian – middle Campanian marker species A. ioannidesi in the uppermost sample is considered as reworked.

Discussion of the late Campanian and/or Early Maastrichtian age. Schiøler & Wilson (2001) recorded the FO of C. diebelii, followed by a younger LO of the genus Odontochitina, within the uppermost Campanian in the Campanian–Maastrichtian stratotype at Tercis les Bains, France. The absence of the pollen genus Wodehouseia and the co-occurrence of C. diebelii and O. operculata may suggest a late Campanian age for the Jackson Ø section. Likewise, the FO A. biaperturatum and W. gracile in the lower part of the Haredal may also indicate a late Campanian age, whereas the common occurrence of A. biaperturatum and the FO of Hystrochorea biapertura sp. 3 McIntyre (1974) (= Rigaudella apenninica according to M. Pearce, pers. comm. 2019) may advocate for an Early Maastrichtian age for the upper part of the Haredal section.

7. Upper Maastrichtian

Records of late Maastrichtian palynomorphs in NE Greenland have been restricted to reworked material deposited in Palaeogene successions from Langsiden, Hold with Hope and Haredal, Wollaston Forland (Nohr-Hansen et al. 2011; Fig. 5). The late Maastrichtian pollen marker species Wodehouseia spinata has not been observed in situ in NE Greenland, but is reported from upper Maastrichtian successions in southern East Greenland (Nohr-Hansen, 2012) and in central West Greenland (Nohr-Hansen, 1996; Pedersen & Nohr-Hansen, 2014).

8. Conclusion

The palynostratigraphic zonation presented here is the first to cover the entire Cretaceous succession in East and NE Greenland. The zonation is correlated with other areas from where stratigraphic data are available.

The biostratigraphy is primarily based on dinocysts, which are present in all sections with marine deposits except when the sediments are severely thermally affected (e.g. by intrusions or subsidence).

The Cretaceous succession is divided into 15 palynozones. Six zones are subdivided into 20 subzones. More than 100 palynostratigraphic events representing more than 70 stratigraphic levels are recorded. The average age of zones is approximately 5 ma. Two new zones are erected in the lowermost Cretaceous successions, and the stratigraphy for the remaining Lower Cretaceous is based on the zonation by Nohr-Hansen (1993) in an updated and revised version. Eight Upper Cretaceous palynozones are all new. Several of these Upper Cretaceous stratigraphic units are also recognized in the Kangerlussuaq area, SW Greenland by Nohr-Hansen (2012). The Upper Cretaceous zonation partly correlates with the informal intervals identified from central West Greenland (Nohr-Hansen, 1996) and with the zonations from the Barents and Norwegian seas (Radmacher et al. 2014, 2015).

Dinocyst stratigraphy is the principal means of biostratigraphic dating of the Cretaceous deposits in NE Greenland. Cretaceous ammonite stratigraphy is incomplete in the area due to the occurrence of barren intervals. When ammonites are present, they are used for calibration of the palynostratigraphic units.

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