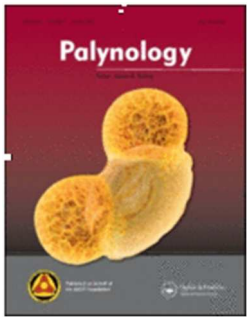

New Albian to Cenomanian ovoidinioid dinoflagellate cysts taxa from East Greenland, Barents Sea and U.K.

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New Albian to Cenomanian ovoidinioid dinoflagellate cysts taxa from East Greenland, Barents Sea and UK

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Abstract

High-resolution palyno-biostratigraphical studies of upper Albian to Lower Cenomanian successions from East Greenland, southwestern Barents Sea and southeastern United Kingdom have revealed new ovoidinioid dinoflagellate cysts taxa. This paper includes descriptions of the new genus *Sindridinium*, four new species: *Ovoidinium epelidosphaeroides* sp. nov, *Epelidosphaeridia manifesta* sp. nov, *Sindridinium borealis* gen. et sp. nov, *Sindridinium anaanae* gen. et sp. nov and the proposal of a new combination *Sindridinium? torulosa* comb. nov. (formerly *Canningia toulosa*). The diagnosis of *Epelidosphaeridia* is emended to account for the morphology of the new species *E. manifesta* described here, which demonstrate the peridiniacean affinities of the genus. Morphological gradations have been observed between *Epelidosphaeridia spinosa, E. manifesta* sp. nov. and *Ovoidinium epelidosphaeroides* sp. nov. suggesting close phylogenetic relationships that are also postulated between *Sindridinium? torulosa* comb. nov., *S. borealis* gen. et sp. nov. and *S.*

anaanae gen. et sp. nov. The short stratigraphic ranges recorded for the taxa described are correlated to other stratigraphic dinoflagellate cyst markers and ammonites of mid-Cretaceous age.

Keywords: Upper Albian, Lower Cenomanian, dinoflagellate cysts, new species, new genera, systematic.

1. Introduction

Ovoidinioid peridinioid dinoflagellate cysts ~~(archaeocysts)~~ of the genera *Epelidosphaeridia*, *Ovoidinium* and *Sindridinium* gen. nov. characterised by a tAtI archeopyle are in the rich late Albian to Early Cenomanian palynological assemblages from offshore wells in the Barents Sea, Norwegian Sea, northern North Sea, outcrop sections from North-East Greenland and borehole material from southeastern UK (Figure 1). All the species described and discussed here have short stratigraphic ranges and are useful marker fossils in the region. As some of these species are scarce or absent from sediments to the south of the study locations, their spacial distribution may help to delimit palaeogeographic suites during the Albian–Cenomanian transition. The present study was instigated ~~on~~ observations reported by Costa (1985) on Early and Late Cretaceous sections from the Barents Sea, Norwegian Sea and northern North Sea. One of the ovoid forms first reported by Costa (1985) became established as a particularly useful marker species for the Early Cenomanian due to its abundance and short stratigraphic range. Despite remaining formally undescribed, this species became well known ~~in the biostratigraphic industry for~~ over 30 years as "*Sidridinium borealis*". It has subsequently been informally recognised in the literature as the *Ovoidinium*? sp. 1 by Nøhr-Hansen (1993, 2012) and Radmacher et al. (2014) but is now formally described here.

2. Material

Numerous palynological slides from several offshore Norwegian mid-Cretaceous dark mudstone successions and chalk borehole material from southeastern UK were studied. The material includes slides from the Norwegian wells 7120/7-2; 7120/8-2, 7119/12-1, 7119/12-2 processed by consulting companies and by the Norwegian Petroleum Directorate (NPD), slides from Trunch Borehole, Norfolk UK from Evolution Applied Limited, Biostratigraphic consultants UK and numerous slides from onshore outcrop sections from Hold with Hope and Geographical Society Ø, North-East Greenland and Kangerlussuaq basins, South-East Greenland (Figure 1) processed by the former Geological Survey of Greenland (GGU) and by the Geological Survey of Denmark and Greenland (GEUS).

The illustrated specimens from the Norwegian wells are stored by the Norwegian Petroleum Directorate (NPD, Professor Olav Hanssens vei 10, 4003 Stavanger, Norway). The specimens from Trunch Borehole are stored by Evolution Applied Limited, Biostratigraphic consultants, Gloucestershire, GL7 3QQ UK. The type material and all the specimens from North-East Greenland marked with MGUH numbers are stored in the type collection of the Geological Museum of the University of Copenhagen (Øster Voldgade 5–7, DK-1350, Copenhagen K, Denmark).

3. Ovoidinioid peridinioid cysts genera with a tAtl archeopyles

Peridinioid dinocysts with combination archeopyles formed by all four apical and three anterior intercalary plates (tAtl) as in the subfamily Ovoidinioideae, are known from ?Hauterivian to Early Cenozoic (Fensome et al. 1993), whereas many published species (with this type of archeopyle) of the genera *Ascodinium*, *Epelidosphaeridia* and *Ovoidinium* seem to be further restricted to the Albian and Cenomanian.

Ascodinium, established by Cookson and Eisenack (1960) and emended by Helenes, 1983 includes circumcavate cysts with endophragm that is slightly thicker than the periphragm, with or without short apical and left antapical horns, a cingulum that is not or weakly indicated, a peridinioid

tabulation (when expressed), and an archeopyle of the type tAtI (1'–4' + 1a–3a) that is angular to rounded.

Ovoidinium was first decribed by Davey (1970) and emended by Lentin & Williams (1976). It encompasses bicavate peridinioid cysts with a relatively thick endophragm enveloped by a thinner periphragm, a tabulation not or only poorly expressed, a distinct cingulum, and an archeopyle type tAtI (1'–4' + 1a–3a) with a relatively wide margin that is commonly slightly angulose.

The narrow subcircular archeopyle outline and the continuous ambital pericoel that distinguish *Ascodinium* from the bicavate *Ovoidinium* (which in addition, has a wider and more angulose archeopyle margin), were taken by Helenes (1983) to be discriminatory only at the specific level. Helenes (1983) considered that the similarity in cyst type, relative thickness of the walls, shape of the endophragm, and archeopyle style justified the transference of all *Ovoidinium* species into *Ascodinium*, the former then becoming a junior synonym of the latter; however, Lentin & Williams (1989, p. 269) retained *Ovoidinium*.

Although overall morphology, archeopyle type and overlapping stratigraphic ranges indicate close affinities between *Ascodinium* and *Ovoidinium*, the differences between them are consistent with generic discriminations in fossil peridiniacean cysts. The similarities between the two genera suggest that they may have derived from a common ancestor, but morphological divergence appears to have taken place at an earlier stage in the evolution of this lineage. The morphological features distinguishing *Ascodinium* from *Ovoidinium* are clear and stable, readily permitting the assignment of a species to one or the other.

Epelidosphaeridia was erected by Davey (1969) to accommodate *Palaeoperidinium spinosum*, described by Cookson & Hughes (1964) from the upper Albian to Lower Cenomanian of SE England. *Epelidosphaeridia spinosa* has a pentagonal ambitus with very short apical and antapical horns, a dense cover of stout, atabular processes, a cingulum sometimes marked by aligned processes and an archeopyle located on the cysts apex. This species was originally described by Cookson & Hughes

(1964) as single-walled. From his observations of European and Canadian material, Davey (1969) concluded that *E. spinosa* was a double-walled cyst, although in the a modified description of the genus, Stover & Evitt (1978) restated the cyst was formed only by an autophragm. From the curved to nearly straight shape of the archeopyle's dorsal margin, and its more posterior position relative to the ventral margin, Stover & Evitt (1978) inferred a possible involvement of intercalary plates in archeopyle formation. However, due to its indistinct tabulation and uncertain archeopyle type, the affinities of *Epelidosphaeridia* remained uncertain.

3. Systematic palaeontology

Division **Dinoflagellata** (Bütschli 1885) Fensome et al. 1993

Class **Dinophyceae** Pascher 1914

Family **Peridiniaceae** Ehrenberg 1831

Subfamily **Ovoidinioideae** (Norris, 1978) Bujak &Davies, 1983.

Epelidosphaeridia Davey 1969, **emend.**

Type: *Epelidosphaeridia spinosa* (Cookson & Hughes) Davey 1969

The generic diagnosis of *Epelidosphaeridia* is here emended to include the following features:

- Peri- and endophragm in close contact throughout or forming pericoels on parts of the cyst, which then varies from cornucavate to bicavate.
- Tabulation of 4', 3a, 7", 5c, 5‴, 2⁗, Xs. Expression of the tabulation varies in different species and also on different specimens of a same species.
- Archeopyle type tAtI (1'–4' + 1a–3a)

Epelidosphaeridia spinosa Cookson & Hughes 1964 ex Davey 1969

Plate 1, Figures 4–6

1964 *Palaeoperidinium spinosum* Cookson & Hughes: p. 49, plate. 8, figures 6–8.

1969 *Epelidosphaeridia spinosa* (Cookson & Hughes) Davey: p. 143.

Description. This species includes small acavate cysts with reduced apical and left antapical horns and an absent or very reduced right antapical horn. The peri- and endophragm, are closely appressed throughout and undiscernable. The processes ~~consist of densely arranged, atabular short spines with blunt tips~~. The cingulum may be partially discernable through alignment of the processes along its margin; and when observable, is narrow and unindented.

The archeopyle is type (A) (1'–4' + 1a–3a) with wide, with a weakly angulose margin.

Distribution. Upper Albian to middle Cenomanian, North Western Europe, North Sea, Barents Sea, Greenland, USA, Arctic Canada.

lidosphaeridia manifesta **sp. nov.**

Plate 1, Figures 7–16

Derivation of name. Latin "manifestus" clear, expressed.

Holotype. Plate 1 Figure 7 GGU sample no. 487643-3 EF F52-4.

Type locality. Section HNH081410-4, East of Fosdalen, north Hold with Hope, North-East Greenland (73°52'N; 20°43'W).

Diagnosis. A cornucavate to bicavate species of *Epelidosphaeridia*. Short apical and left antapical horns; right antapical horn reduced or absent. Ornament of solid, very short, rod-like processes, mainly sutural in distribution; base of the processes sometimes coalescing into very lowsutural ridges. Tabulation formula of 4', 3a, 7'', 5c, 5''', 2''''. Cingulum relatively wide, faintly indented, tabulated. Archeopyle type tAtI, with a wide, weakly angulose margin. Operculum simple, free or adnate.

Description. Cysts dorsoventral compresed, with an asymmetrical peridinioid ambitus. Apical horn short, broadly triangular, distally blunt and occasionally bearing an apical pore. Left antapical horn short, acuminate. Right antapical horn usually absent but a lobe or a rod-like processe may occur in its place (e.g. Plate 1, Figure 15). Endocyst ambitus elliptical. The pericoels are commonly restricted to the horns' cavities, but wider apical and antapical pericoels and partial ambital pericoels may occur (e.g. Plate 1, Figure 14). Endophragm smooth. Periphragm also smooth, bearing a moderate number of solid, short processes, mainly sutural in distribution; a variable, but generally small number of intratabular process may also occur. The processes are stout, rod-like, and distally simple, with buccinate, oblate or occasional capitate endings. The expanded bases of the sutural processes may coalesce forming low, partial sutural ridges (e.g. Plate 1, Figure 7). A tabulation formula of 4', 3a, 7'', 5c, 5''', 2'''', Xs, is commonly expressed by the sutural ornament.

The cingulum is flanked by two low, continuous or broken ridges formed by the coalescing bases of the processes. It is moderately helicoid, only slightly indented and wide relative to the overall cyst diameter. The cingular surface also bears a few sutural processes or low ridges. The sulcus is shallow and wide on the hypocyst, becoming narrower and deeper on the epicyst; its surface is free of ornament.

The archeopyle type is tAtI (1'–4' + 1a–3a), with wide, somewhat angulose margins on which the precingular edge of the three intercalary plates may be distinct. The operculum is simple, free or adherent.

Dimensions.

Greenland specimens:

Holotype: Pericyst length 62 µm, breadth 55 µm; endocyst length 44 µm; apical horn 8 µm; antapical horns, left 7 µm, right, 3 µm; processes up to 3 µm.

Range: Pericyst length 57 (65) 76 µm, breadth 49 (56) 64 µm; endocyst lenght 42 (46) 52 µm; apical horn 5 (7) 10 µm; antapical horns, left 4 (7) 9 µm, right 2 (3) 3 µm; processes up to 4 µm (6 specimens).

Norwegian specimens:

Range: Pericyst length 64 (71) 83 µm, breadth 49 (59) 66 µm, endocyst lenght 48 (58) 64 µm, apical horn 4 (8) 12 µm, antapical horns left 5 (7) 9 µm, right 0 (2) 5 µm. Ornament up to 5 µm (11 specimens).

Distribution. *Epelidosphaeridia manifesta* sp. nov. has only been recorded from a narrow interval in the Lower Cenomanian, it has a FO and LO slightly older than the FO and LO of *Ovoidinun epelidosphaeroides* sp. nov.

Comparison. *Epelidosphaeridia manifesta* sp. nov. differs from *E. spinosa* in having wider, clearly developed pericoels; a smaller number of processes, most of which are sutural, and partially developed sutural ridges. *Epelidosphaeridia manifesta* sp. nov. resembles, and appears to grade morphologically into *Ovoidinium epelidosphaeroides* sp. nov. specimens with few sutural processes (e.g. Plate 2 Figures 13–16), from which it differs in its more reduced pericoel width, more numerous processes and in lacking a cingular flange. There appears to be a continuous morphological transition between *Epelidosphaeridia* sp. 1 of Nøhr-Hansen 1993, *E. spinosa*, *E. manifesta* sp. nov. and *Ovoidinium epelidosphaeroides* sp. nov.

Epelidosphaeridia sp. 1 Nøhr-Hansen 1993.

Plate 1, Figures 1–3

1993 *Epelidosphaeridia* sp. 1; Nøhr-Hansen, p. 66, plate 8, figures 11– 12.

Comments. *Epelidosphaeridia* sp. 1 Nøhr-Hansen 1993 closely resembles *Epelidosphaeridia spinosa* in size and shape, but differs from it by only having only a weakly developed cingulum and by its slightly shorter spines. The available material is considered too small to establish a new species.

Distribution. *Epelidosphaeridia* sp. 1 Nøhr-Hansen 1993 has a FO in the middle part of upper Albian, below the FO of *Epelidosphaeridia spinosa* and a LO in Lower Cenomanian.

Genus ***Ovoidinium*** Davey 1970

Type: ***Ovoidinium verrucosum*** (Cookson & Hughes) Davey 1970

***Ovoidinium epelidosphaeroides* sp. nov.**

Plater 2, Figures 1– 16; Plate 7, Figures 10–12

1993 *Ovoidinium* sp. 2; Nøhr-Hansen, p. 92, plate 16, figures 5–8.

Derivation of name. "epelidosphaeroides" refers to the morphological resemblance of this species to *Epelidosphaeridia*.

Holotype. Plate 2, Figure 1 GGU sample no. 522081-4 EF Z21-2.

Type locality. Section 30 of Nøhr-Hansen 1993 and GEUS PAL-3/2011, Tværdal, Geographical Society Ø, North-East Greenland (72°58'N; 23°02'E).

Diagnosis. A bicavate to circumcavate species of *Ovoidinium* with a pentagonal ambital outline, a short apical horn and one or two reduced antapical horns, of which the right is commonly vestigial. Cingulum marked on the dorsal face by a flange. Sulcus indicated by low ridges. Periphragm smooth (Plate 2, Figures 1–12) or bearing a few short, solid, sutural processes with a simple or buccinate tip.

Tabulation not or only poorly expressed. Archeopyle tAtI (1'–4' + 1a–3a), with a wide, angulose dorsal margin (Plate 2, Figures 2, 11; Plate 7, Figur 11), and a gently curved ventral margin that is more anteriorly located than the dorsal margin.

Description. Small to medium-sized, dorsoventrally compressed bicavate cysts. The pericyst ambitus is subpentagonal, slightly asymmetrical. The epicyst ambitus is triangular, terminating in a short apical horn distally blunt and occasionally bearing an apical pore. The hypocyst, commonly larger than the epicyst, is trapezoidal with a slanted antapex. The left antapical horn is broad, distally acuminate and may be reduced; the right antapical horn is reduced or absent. The endocyst ambitus is circular to elliptical. Peri- and endophragm are in contact along the central portions of the cyst but separate anteriorly and posteriorly to form pericoels of variable width. Periphragm hyaline, smooth or with faint longitudinal striations. The periphragm may bear a small number of solid, rod-like, 1–3 µm long, sutural processes with a simple, buccinate or capitate tip, and sometimes also partially developed low, sutural ridges (Plate 2, Figures 13–16; Plate 7, Figur 10). The endophragm is smooth.

The cingulum is marked on the dorsal side by a prominent flange, formed by a fold on the periphragm. A double row of sparse processes distributed along incomplete sutural ridges are often observable on the cyst's ventral face. The sulcus, flanked by distally smooth or denticulate ridges is broad and shallow, and occupies most of the ventral face (Plate 2, Figure 1; Plate 9, Figure 10).

Archeopyle type tAtI (1'–4' + 1a–3a) with wide margins. The precingular edge of the three intercalary plates forms a distinct indentation on the archeopyle's dorsal margin. The archeopyle's ventral margin is straight or gently curved, and lies closer to the apex than its dorsal margin. The operculum is simple, free or adherent.

Tabulation partially expressed by the cingulum, the archeopyle margins and the distribution of the ornament when present. A nodular inclusions which may correspond to an epiphalus, often occur on the inner side of the endocyst (e.g. Plate 2, Figures 1, 3, 13).

Dimensions.

Greenland specimens:

Holotype: Pericyst length 74 µm, breadth 66 µm; endocyst, 51 µm x 51 µm; apical horn 7 µm; antapical horns, left. 8 µm, right, 2 µm.

Range: Pericyst length 71 (73) 80 µm, breadth 59 (62) 68 µm; endocyst, 48 (53) 68 µm x 51 (55) 60 µm; apical horn 7 (9) 10 µm; antapical horns, left. 5 (9) 13 µm, right, 0 (2) 3 µm; when present processes up to 3 µm (7 specimens).

Norwegian Specimens:

Range: Pericyst length 73 (77) 87 µm, breadth 57 (65) 71 µm; endocyst, 46 (57) 66 µm x 57 (64) 71 µm; apical horn 5 (7) 12 µm; antapical horns, left. 3 (10) 16 µm, right, 0 (4) 7 µm; when processes up to 5 µm (15 specimens).

Comparisons. The pentagonal ambital outline, the cingular flange and the presence of processes and partially developed sutural ridges, distinguish *O. epelidosphaeroides* sp. nov. from all other *Ovoidinium* species. The ambital outline of this species resembles that of *Yalkalpodinium scutum* Morgan 1980, but the archeopyle of the latter has been interpreted as a type tA and its tabulation as gonyaulacoid. *Ovoidinium epelidosphaeroides* sp. nov. resembles ~~*Epelidosphaeridia* ,~~in the wide, faintly angular archeopyle margins and in the shape of the short processes when these occur. It differs in having well defined, wide pericoels, a cingular flange, and only a small number of processes.

Distribution. The species was first reported from Troms and Hammerfest basins offshore north-west Norway (Costa 1985) and later described as *Ovoidinium*? sp. 2 by Nøhr-Hansen (1993) from North-East Greenland.

Age. FO and LO in the Early Cenomanian. A latest late Albian to ?Early Cenomanian age was tentatively given by Nøhr-Hansen (1993).

Sindridinium gen. nov.

Type species. *Sindridinium borealis* gen. et sp. nov.

Derivation of name. Sindri, from the Norse (North Germanic language) sindr: ("spark") is the name of both a dwarf, and of the hall where the souls of the virtuous will dwell after Ragnarök. The informal name "*Sidridinium*" often used in consulting biostratigraphic reports is incorrectly spelled.

Diagnosis. Small dinocysts represented by two-layered dorsoventrally compressed forms with an oval to subcircular ambital outline, and absent or vestigial horns. The endo- and periphragm may be entirely tightly adpressed or separated posteriorly, forming a narrow antapical pericoel. Periphragm thin, smooth or ornamented by nontabular grana, verrucae or tubercles. The endophragm is thinner than the periphragm and presumably smooth. Cingulum and sulcus are indistinct or, rarely suggested by folds, grana or verrucae on the periphragm.

Archeopyle located on the apex, presumably of type tAtI (1'–4' + 1a–3a) but reduced. Relatively narrow archeopyle margins of which the dorsal is straight to subrectangular or rarely slightly angulose, and lies closer to the antapex than the gently curved ventral margin. Operculum simple, free or adnate.

Discussion. The cavate and non cavate forms share sufficient morphological features to leave no doubt as to their congenecity. Due to the lack of a clear tabulation and its relatively smooth margins, the identity of the archeopyle in *Sindridinium* gen nov. remains somewhat problematic. Our interpretation of a tAtI archeaeopyle is based on:

- the smooth to weakly angulose (not zig-zag) margins, devoid of accessory sutures;
- more posterior position of the dorsal margin relative to the ventral margin, and its straight to slightly indented shape;
- absence of an offset sulcal notch on the ventral margin of the archeopyle, which suggests the involvement of intercalary plates;

- the relatively narrow margin has a subtriangular, symmetrical ventral side and a weakly polygonal to subrectangular dorsal side, suggesting the presence of a series of reduced intercalary plates.

If the interpretation of the archeopyle is correct, then this is of a same type as in *Ovoidinium*. The presence of the non cavate forms, the absence of apical and antapical horns (i.e. not cornucavate), the absence of a clear cingulum on the pericyst and the narrower, less angulose archeopyle margins, distinguish *Sindridinium* gen nov. from *Ovoidinium.* Narrower, subcircular archeopyle margins and a poorly defined cingulum are known within the range of variability of *Ovoidinium*, suggesting that the two genera may be closely related.

***Sindridinium borealis* gen. et sp. nov.**

Plate 3, Figures 1–16; Plate 4, Figures 1–12; Plate 5 Figures 1–9

1993 *Ovoidinium*? sp. 1; Nøhr-Hansen, p. 91, plate. 24, figures. 5–6, 11,14.

2014 *Ovoidinium*? sp. 1; Radmacher et. al**.**, p 116; plate 2, figures g, h.

Derivation of name. "*Boreas"* Greek North.

Holotype. Plate 3, Figure 1 GGU sample no. 522076-4 EF U53-1.

Type locality. Section 30 of Nøhr-Hansen 1993 and GEUS PAL-3 2011, Tværdal, Geographical Society Ø, North-East Greenland (72°58'N; 23°02'W).

Description. Double-walled dinocysts with oval to slightly elongate ambital outline. The endo- and pericystphragm are entirely tightly compressed and only recognised at the archeopyle margins (e.g. Plate 3, Figures 7, 15; Plate 5 Figure 3), horns absent. Endophragm thin (<1 µm), perihragm normally thicker (>1 µm), smooth (e.g. Plate 3, Figures 1, 11; Plate 5 Figures 1, 6) or bearing scattered non-tabular grana, verrucae or tubercles; the density of the ornament varies on different individuals. Tabulation not expressed. Cingulum and sulcus are occasionally indistinct or, rarely, suggested by folds, grana, verrucae or tubercles on the periphragm (e.g. Plate 3, Figure 2; Plate 5 Figure 3). On

some specimens, the periphragm has been affected by microbiological activity (Plate 5, Figure 4). One or two large nodular inclusions and a variable number of smaller ones, which may correspond to an omphalus, occasional occur on the inner side of the endocyst (e.g. Plate 3, Figures 1, 4, 16).

Archeopyle type tAtI. The archeopyle margins are weakly angulose and relatively narrow. Its dorsal margin, when well preserved, is straight to subrectangular or rarely slightly angulose, and lies closer to the antapex than the slightly narrower, curved ventral margin. A conspicuous v-shaped notch appears on many of the southeast UK specimens (Plate 4, Figures 5, 8, 11) and on some of the specimens from the Norwegian/Greenland seas (Plate 3, Figures 8, 16; Plate 5, Figure 4). A possible tabulation pattern may be recognized on a single specimen (Plate 4, Figure 10); however no plate-boundary marks have been recognised on the specimens studied by scanning electon microscope (SEM; Plate 5). A small separation between peri- and endophragm may be observable along the archeopyle margins. The operculum is free or adnate (Plates 3–5).

Dimensions.

Greenland specimens:

Holotype: Pericyst length 63 µm, breadth 52 µm, width of archeopyle 21 µm.

Range: Cysts with operculum in situ: length 50(64) 86 µm x breath 40 (53) 77 µm, width of archeopyle 19 (23) 35 µm (15 specimens). Cysts without operculum: Lenght 47 (60) 73 µm x breath 48 (55) 62 µm, width of archeopyle 17 (22) 31 µm (15 specimens).

Norwegian specimens:

Range: Length 47 (54) 66 µm x breath 45 (52) 52 µm (14 specimens).

UK specimens:

Range: Length 39(49.3)58 µm x breath 31(42.8)54 µm (30 specimens).

Distribution. The species was first reported from Troms and Hammerfest basins offshore north-west Norway (Costa 1985) and later described as *Ovoidinium*? sp. 1 from North-East Greenland (Nøhr-

Hansen 1993). Recently *Ovoidinium*? sp. 1 has been recorded from the Troms and Hammerfest basins offshore north-west Norway (Radmacher 2014) and from the Trunch Borehole, Norfolk southeastern UK

Stratigraphic range. Resampling and restudy of the approximately 415 m thick succession in Tværdal on Geographical Society Ø (section 30 of Nøhr-Hansen 1993, Pal-3/2011, Figure. 2) have revealed a horizon with an assemblage of the ammonite *Schloenbachia varians* from 349 m indicating an earliest Cenomanian age (*Mantelliceras mantelli - dixoni* ammonite Zones, undivided). The ammonite level corresponds to the lower part of the *S. borealis* gen. et sp. nov. acme, whereas the FO of *S.borealis* gen. et sp. nov. occur at a lower level, presumably of latest Albian age (Figures 2, 5). The ammonite correlated age obtained from North-East Greenland correspond to the observations from the Ferriby Chalk Formation in the Trunch Borehole, Norfolk southeastern UK where *S. borealis* gen. et sp. nov. first occur from the *Mantelliceras mantellii* Zone (questionably above the Lower Cenomanian $\delta^{13}C$ Event I and below the $\delta^{13}C$ Virgatus Beds Event of Jarvis et al. 2006) to the *Mantelliceras dixoni* Zone (LO immediately below the middle Cenomanian I Event; Lower Cenomanian) in the Trunch borehole (Figure 6). Radmacher et. al. (2014) reported a late Abian age.

Comparisons. *Sindridinium borealis* gen. et sp. nov. differs from *Fromea amphora* which has a circular margin to its apical pylome, and equatorial folds. The nodular inclusions occasionally observed in the location of an omphalus in *Sindridinium* gen. nov. never seem to occur in *Fromea amphora*. *Hexagonifera glabra*, from the Senonian of Australia (Cookson & Eisenack 1961), somewhat resembles *S. borealis* gen. et sp. nov. but its archeopyle is type I (2a). Isolated endocysts of *Leberidocysta* may resemble *S. borealis*, but *Leberidocysta* possesses a clear tA archeopyle with a well-marked offset sulcal notch. *S. borealis* gen. et sp. nov. differs from *S. anaanae* gen. et sp. nov. by being non cavate.

***dridinium anaanae* gen. et sp. nov.**

Plate 6, Figures 1–16; Plate 7, Figures 1–9

1993 *Ovoidinium*? sp. 1; Nøhr-Hansen, p. 91, plate. 24, figures. 7–10, 12, 13.

2012 *Ovoidinium* sp. 1; Nøhr-Hansen, plate. 1, figures. 14, 15.

Derivation of name. Greenlandic “anaana” for mother.

Holotype. Plate 5, Figure 1 GGU sample no. 518602-7 EF M32-1.

Type locality. Section JHOV-2/2009, Snertadal, north Hold with Hope, North-East Greenland (73°52.122'N; 20°37.993' W).

Description. Double-walled hypocavate cysts, dorsoventral compression moderate. Pericyst ambitus slightly elongate, endocyst ambitus oval to subcircular. Periphragm and endophragm are in close contact over apical and central portions of the cyst, separating posteriorly to form a narrow hypocystal pericoel. The pericyst’s antapex is rounded (e.g. Plate 6, Figure 11) to weakly lobate (e.g. Plate 5, Figure 1). Apical horn absent or vestigial, cyst apex rounded or slightly angulose. Endophragm thin (<1 µm), periphragm normally thicker (>1 µm), smooth or bearing scattered non-tabular grana, verrucae or disc-like tubercles; the density of the ornament varies on different individuals from almost none (e.g. Plate 7, Figures 3, 4) to almost cover the entire periphragm (e.g. Plate 7, Figures 8, 9). In poorly preserved specimens where the periphragm (and pericoel) may be absent, the shape of the endocyst can be used to distinguish the subcircular *S. anaanae* gen. et sp. nov. from the ovoid to elongate *S. borealis* gen. et sp. nov. (Plate 6, Figure 12). On some specimens, the periphragm has been affected by microbiological activity (Plate 6, Figures 12, 13). One or two large nodular inclusions and a variable number of smaller ones, which may correspond to an omphalus, occasionally occur on the inner side of the endocyst (e.g. Plate 6, Figures 13, 15). Tabulation not expressed. Cingulum and sulcus absent, although occasionally the periphragm may be folded in their place. Archeopyle type tAtI. The archeopyle margins are weakly angulose and relatively narrow. Its dorsal margin, when well preserved, is straight to subrectangular or rarely

slightly angulose and lies closer to the antapex than the slightly narrower, curved ventral margin. A small separation between peri- and endophragm may be observable along the archeopyle margins. The operculum is free or adherent.

Specimens with a lobate antapex tend to have a more pointed apex/operculum (Plate 6, Figures 1–4), whereas the more seldom hypocystal elongate/egg-shaped specimens have a more rounded apex (Plate 6, Figures 8, 9) as on *S. borealis* gen. et sp. nov.

Dimensions.

Greenland specimens:

Holotype: Pericyst length 63 µm x breath 55 µm, length endocyst 54 µm, width of archeopyle 33 µm.

Range: Cysts with operculum in situ: Pericyst length 53 (62) 68 µm x breath 44 (53) 56 µm; length endocyst 48 (54) 60 µm, width of archeopyle 26 (28) 31 µm (11 specimens).

Cysts without operculum: Pericyst 44 (54) 58 µm x breath 44 (52) 58 µm; length endocyst 39 (46) 50 µm, width of archeopyle 25 (30) 35 µm (11 specimens).

Norwegian specimens:

Range: Pericyst 52 (58) 69 µm x breath 47 (54) 59 µm; endocyst 43 (50) 59 µm (14 specimens).

Distribution. The species was first reported from Troms and Hammerfest basins offshore north-west Norway (Costa 1985) and later described as *Ovoidinium*? sp. 1 from North-East Greenland (Nøhr-Hansen 1993). Recently *Ovoidinium*? sp. 1 has been recorded from the Kangerlussuaq Basin, southern East Greenland (Nøhr-Hansen 2012). The present study strongly indicate that the *Sindridinium borealis* gen. et sp. nov. and *S. anaanae* gen. et sp. nov. are stratigraphical separated in on shore samples East Greenland and offshore Norwegian sidewall cores, whereas the forms co-occurring in offshore Norwegian cutting samples may represent caving. *Sindridinium borealis* gen. et sp. nov. seems to be older maybe precursor for *S. anaanae* gen. et sp. nov. *Sindridinium anaanae*

gen. et sp. nov. has it FO just above the last common occurrence of the *S. borealis* gen. et sp. nov. at the east of Fosdalen section Hold with Hope (Figures 3, 5). *Sindridinium anaanae* gen. et sp. nov. was not recorded in the Trunch Borehole in the five productive samples above the LO of *S. borealis* gen. et sp. nov. Unfortunantly, due to a conspicuous barren interval that extends from the upper middle Cenomanian to the upper Turonian section, it is not known if the species exists in the area. Additional, studies are required to test the southern limit of *S. anaanae* gen. et sp. nov.

Age. A late Albian to ?Early Cenomanian age has been reported by Nøhr-Hansen (1993, 2012), The present study indicates a FO in the Lower Cenomanian, the uppermost limit of the species range is not believed to have been observed but most likely occurs in the Lower Cenomanian.

Comparisons. The closest described forms are *Ovoidinium implanum, O. scabrosum* and *O. verrucosum* ssp. *ostium*, but these are normally represented by double-walled cysts with an apical horn and apical pericoel, usually have a distinct cingulum and a wider archeopyle margin on which the outline of the intercalary plates is better defined.

***Sindridinium? torulosa* comb. nov.**

Plate 8, Figures 1–16

1973 *Canningia torulosa* Davey & Verdier, p. 180, 183, plate 1, figures 2, 5, 8.

1980 *Batiacasphaera torulosa* Dörhöfer & Davies p. 41.

1981 *Ovoidinium torulosum* Below, p. 124.

1981 *Canningia torulosa* Lentin & Williams p. 34.

1985 *Canningia torulosa* Lentin & Williams p. 44.

Below (1981) transferred (after his emendation of the genus *Canningia*) *Canningia torulosa* to *Ovoidinium? torulosum*, whereas Lentin & Williams (1981, 1985) retained the species in *Canningia*.

The species is herein questionably transferred to the new genus *Sindridinium* based on its apical archeopyle, circular or subcircular outline devoid of horns, a smooth to lightly granular wall with a numbers of irregularly distributed low tubercles, partly mirroring a tabulation.

Sindridinium? torulosa com. nov. is distinguished from *S. borealis* gen. et sp. nov. by its tubercules aligned at the cingulum, sulcal areas as well as intratabular and by having a wider slightly angulose archeopyle, and from *S. anaaae* gen. et sp. nov. by not being hypocavate.

Sindridinium? torulosa nov. comb. has a late Albian FO in Norwegian/Greenland Sea. Davey & Verdier (1973) gave a late Albian – Early Cenomanian age range for the species in France.

Dimensions.

Greenland specimens:

Cyts with operculum in situ: length 47 (57) 64 µm x breath 46 (55) 60 µm, width of archeopyle 25 (29) 33 µm (12 specimens).

Cysts without operculum: Lenght 47 (53) 64 µm x breath 48 (54) 59 µm, width of archeopyle 28 (32) 36 µm (5 specimens).

Norwegian specimens:

Cyts with operculum in situ: length 52 (54) 58,5 µm x breath 49 (52) 54 µm, width of archeopyle 31 (34) 36 µm (3 specimens).

Cysts without operculum: Lenght 47 (49) 54 µm x breath 49 (52) 54 µm, width of archeopyle 21 (35) 39 µm (5 specimens).

4. Biostratigraphy

The ages of the new species are based on their occurrence and co-occurrence with other stratigraphic marker species in the studied samples from onshore North-East Greenland, sidewall cores from Norwegian offshore wells (Plate 9, Figures 1–20) and from the $\delta^{13}C$ calibrated Trunch

borehole, Norfolk UK In the sections from Tværdal and east of Fosdalen the dinocyst assemblage is dominated by *Rhombodella paucispina* together with common *Subtilisphaera kalaalliti. Sindridinium borealis* gen. et sp. nov. becomes common in the upper part of Tværdal section (Figure 2) and in the lower part of the east of Fosdalen section (Figure 3). *Sindridinium borealis* gen. et sp. nov. dominates the dinocyst assemblage in the same stratigraphic interval in the Barents Sea well 7102/7-2 (Figures 4, 5). *Sindridinium anaanae* gen. et sp. nov. first occurs in the upper part of the east of Fosdalen section and in the nearby Snertadal section, whereas this form is very rare in a narrow interval in the Barents Sea well.

The lowermost part of the Tværdal section is dated as late Albian based on the presence of *Odontochitina ancala* and LO of *Wigginsiella grandstandica* (Figure 2, 5) and a side wall core (SWC) from the lowermost studied part of well 7102/7-2 is dated middle Albian based on the LO of *Leptodinium cancellatum.* This is followed by the FO of *Sindridinium? torulosa* comb. nov.*,* *Epelidosphaeridia* sp. 1 Nøhr-Hansen 1993, *Palaeohystrichophora infusorioides, P. palaeoinfusa* and *Endoceratium dettmanniae* (Plate 9, Figures 1–6) in both the lower part of the Tværdal section and the Barents sea well 7102/7-2 (Figure 5) indicating a latest Albian age (Davey & Verdier 1973; Costa & Davey 1992; Fensome et al. 2009). The presence of the pollen *Rugubivesiculites multisaccus* (Plate 9, Figure 8) in the lower part of the Tværdal section (Figures 2, 5) may indicate that this Lower Cenomanian marker (Singh 1983; Zippi & Bajc 1990, Pedersen & Nøhr-Hansen 2014) could have a late Albian FO in North East Greenland.

The FO of *Sindridinium borealis* gen. et sp. nov. is dated as latest Albian based on the co-occurrence with the FO of *Epelidosphaeridia spinosa* and *Dinopterygium alatum* in the lower part of the Tværdal section (Figures 2, 5), whereas data from the Trunch borehole, Norfolk UK indicate an Early Cenomanian FO. *Sindridinium borealis* gen. et sp. nov. is rare in its lower range but become common to abundant in its upper range together with the FO of *Senoniasphaera* aff. *microreticulata* (Figure 4; Plate 9, Figures 9–14).

The acme of *Sindridinium borealis* gen. et sp. nov is dated as Early Cenomanian (*Mantelliceras mantelli - dixoni* ammonite Zones, undivided) based on the co-occurrence with the ammonite *Schloenbachia varians* in the Tværdal section (Figures 2, 5). In the Trunch borehole, no ammonites were recovered from the core. The limits of the Lower Cenomanian ammonite zones are based in lithological correlations to ammonite calibrated sections, and by the distribution of *Inoceramus* and *Orbirhynchia* (see Wood et al., 1994). However, the acme of *S. borealis* gen. et sp. nov. clearly occurs in the Early Cenomanian, below the mid-Cenomanian $\delta^{13}C$ isotope event I of Jarvis et al. (2006) and above the upper Albian Carstone. The $\delta^{13}C$ calibration to the GTS 2016 (recalibrated here from Jarvis et al. 2006) suggests an age range of increased abundance of *S. borealis* gen. et sp. nov. of 97.7–96.8 Ma, with the acme at 97.4 Ma, all within the *Mantelliceras dixoni* Zone.

Within the upper range of *Sindridinium borealis* gen. et sp. nov. do *Epelidosphaeridia manifesta* sp. nov. have its FO followed by the FO of *Ovoidinium epelidosphaeroides* sp. nov.. The three species all seems to have their LO immediately before the FO of *Sindridinium anaanae* gen. et sp. nov.(Figure 5). The LO of *S. anaanae* gen. et sp. nov. has not been recorded onshore; however, the relative abundance of the species is very low at the top of east of Fosdalen section, which indicates a LO possibly latest Early Cenomanian or maybe early middle Cenomanian due to its occurrence after the LO of *Odontochitina ancala,* after the LO of *Xenascus* aff. *plotei* (Figure 5; Plate 9, Figures 15–20) and before the FO of *Trithyrodinium suspectum* and *Isabelidinium magnum* in the Barents Sea well 7120/7-2 (Figures 4, 5).

5. Geographical distribution

The known geographical distribution of the new species described here has until now been restricted to the high boreal areas. The presence of *Sindridinium borealis* gen. et sp. nov. from the southern boreal locality at Norfolk extends the southern limit of at least that species. The inception of *S. borealis* gen. et sp. nov. in the late Albian to the north and the subsequent appearance in the

Early Cenomanian to the south in Norfolk, may be due to the migration of the species under Late Cretaceous climatic cooling. The new species *Epelidosphaeridia manifesta* sp. nov.*, Ovoidinium epelidosphaeroides* sp. nov. and *Sindridinium anaanae* gen. et sp. nov. have, to the authors knowledge, only been recorded from the northern boreal Norwegian/Greenland seas.

Acknowledgements

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References.

Below R. 1981. Dinoflagellaten-Zysten aus dem oberen Hauterive bis unteren Cenoman Süd-West-Marokkos. Palaeontographica, Abteilung B 176:1–145.

Cookson IC, Eisenack A. 1960.Microplankton from Australian Cretaceous sediments. Micropaleontology 6:1–18.

Cookson IC, Eisenack A. 1961. Upper Cretaceous microplankton from the Belfast No. 4 Bore, south-western Victoria. Proceedings of the Royal Society of Victoria 74:69–76.

Cookson IC, Hughes NF. 1964. Microplankton from the Cambridge Greensand (mid-Cretaceous). Palaeontology 7:37–59.

Costa LI. 1985. The *Ascodinium* plexus in the latest Albian to earliest Cenomanian offshore Arctic Norway. In: Third International Conference on Modern and Fossil Dinoflagellates, Egham, August, 1985, Abstracts, unnumbered page.

Costa LI, Davey RJ. 1992. Dinoflagellate cysts of the Cretaceous System. In Powell, A J, editor. A Stratigraphic Index of Dinoflagellate Cyst, 99–154, British Micropalaeontological Society Series, London: Chapman & Hall.

Davey RJ. 1969. Non-calcareous microplankton from the Cenomanian of England, northern France and North America, part I. British Museum (Natural History) Geology, Bulletin 17:103–180.

Davey RJ. 1970. Non-calcareous microplankton from the Cenomanian of England, northern France and North America, part II. British Museum (Natural History) Geology, Bulletin 18:333–397.

Davey RJ, Verdier JP. 1973. An investigation of microplankton assemblages from latest Albian (Vraconian) sediments. Revista Espanola de Micropoleontologia 5:173-212.

Fensome RA, Williams GL, MacRae RA. 2009. Late Cretaceous and Cenozoic fossil dinoflagellates and other palynomorphs from the Scotian Margin, offshore Eastern Canada. J. Syst. Palaeontol. 7:1–79.

Fensome RA, Taylor FJR, Norris G, Sarjeant WAS, Wharton DI, Williams GL. 1993. A classification of fossil and living dinoflagellates. Micropaleontology Press Special Paper7:351 p.

Helenes J. 1983. Evaluation of Jurassic-Cretaceous dinoflagellates in the Ascodinium-Ovoidinium complex. Micropaleontology 29:255–266.

Jarvis I, Gale A S, Jenkyns HC, Pearce MA. 2006. Secular variation in Late Cretaceous carbon isotopes and sea‐level change: Evidence from a new d13C carbonate reference curve for the Cenomanian–Campanian (99.6–70.6 Ma), Geol. Mag. 143:561–608, doi:10.1017/S0016756806002421.

Lentin JK, Williams GL. 1976. A monograph of fossil peridinioid dinoflagellate cysts. Bedford Institute of Oceanography, Report Series BI-R-75-16:237 p.

Lentin JK, Williams GL. 1981. Fossil dinoflagellates: index to genera and species, 1981 edition. Bedford Institute of Oceanography, Report Series BI-R-81-12:345 p.

Lentin JK, Williams GL. 1985. Fossil dinoflagellates: index to genera and species, 1985 edition. Canadian Technical Report of Hydrography and Ocean Sciences 60:451 p.

Lentin JK, Williams GL. 1989. Fossil dinoflagellates: index to genera and species, 1989 edition. American Association of Stratigraphic Palynologists, Contributions Series 20:473 p.

Morgan R. 1980. Palynostratigraphy of the Australian early and middle Cretaceous. Geological Survey of New South Wales, Palaeontology Memoir 18:1–153.

Nøhr-Hansen H. 1993. Dinoflagellate cyst stratigraphy of the Barremian to Albian Lower Cretaceous, north-east Greenland. Bulletin Grønlands Geologiske Undersøgelse 166:171 p.

Nøhr-Hansen H. 2012. Palynostratigraphy of the Cretaceous – lower Palaeogene sedimentary succession in the Kangerlussuaq Basin, southern East Greenland. Review of Palaeobotany and Palynology 178:59–90.

Ogg JG, Ogg GM, Gradstein FM, 2016. A Concise Geologic Time Scale Elsevier, 234 p. http://dx.doi.org/10.1016/B978-0-444-59467-9.00001-7

Pedersen GK, Nøhr-Hansen H. 2014. Sedimentary successions and palynoevent stratigraphy from the non-marine Lower Cretaceous to the marine Upper Cretaceous of the Nuussuaq Basin, West Greenland. Bulletin of Canadian Petroleum Geology 62:216–244.

Radmacher W, Tyszka J, Mangerud G, Pearce MA. 2014. Dinoflagellate cyst biostratigraphy of the Upper Albian to Lower Maastrichtian in the southwestern Barents Sea. Marine and Petroleum Geology 57:109–121.

Singh C. 1983. Cenomanian microfloras of the Peace River area, northwestern Alberta: Alberta Research Council, Bulletin 44:322 p.

Stover LE, Evitt WR. 1978. Analyses of pre-Pleistocene organic-walled dinoflagellates. Stanford University Publications, Geological Sciences 15:300 p.

Wood CJ, Morter AA, Gallois RW. 1994. Appendix 1. Upper Cretaceous stratigraphy of the Trunch borehole. TG23SE8. *In:* (Arthurton RS, Booth SJ, Morigi AN, Abbott MAW, Wood CJ, eds) *Geology of the Country around Great Yarmouth*. Memoir for 1:50,000 Sheet 162 (England and Wales) with an Appendix on the Truch Borehole by Wood and Morter. H.M.S.O., London, 105–110 pp.

Zippi PA, Bajc AF. 1990. Note: Recognition of a Cretaceous Outlier in Northwestern Ontario. Journal: Canadian Journal of Earth Sciences 27:306–311.

Figure Captions.

Figure 1. Location map of the studied sections.

Figure 2. Range-chart of selected dinoflagellate cysts from the more than 400 m thick dark greý mudstone succession at Tværdal, Geographical Society Ø, North-East Greenland; (section 30 of Nøhr-Hansen 1993 and GEUS, PAL-3/2011; 72°58'N; 23°02'W).

Figure 3. Range-chart of selected dinoflagellate cysts from the more than 500 m thick dark greý mudstone succession east of Fosdalen, Hold with Hope, North-East Greenland (GEUS section, HNH081410-01; 73°52'N; 20°43'W).

Figure 4. Range-chart of selected dinoflagellate cysts from the Albian to Turonian interval (depth 1000–1500m) in well 7120/7-2. Snøhvit, Barets Sea, offshore Norway (71° 19' 11.49'' N; 20° 19' 44.31'' W).

Figure 5. Correlation of the Tværdal and east of Fosdalen sections with the well 7120/7-2, based on events of old and new marker species.

Figure 6.The stratigraphic distribution of *Sindridinium borealis* gen. et sp. nov. in the Trunch borehole (Norfolk, southeast UK, 52°51'34'' N; 01°24'19'' E) and its correlation to the $\delta^{13}C$ isotope curve of Jarvis et al. (2006). As no ammonites were recovered from the Lower Cenomanian section, the limits of the ammonite zones are based in lithological correlations to ammonite calibrated sections, and by the distribution of *Inoceramus* and *Orbirhynchia* (see Wood et al., 1994). However, the acme of *S. borealis* gen. et sp. nov. clearly occurs in the Early Cenomanian, below the mid-Cenomanian $\delta^{13}C$ isotope event I of Jarvis et al. (2006) and above the late Albian Carstone. The $\delta^{13}C$ calibration to the GTS 2016 (recalibrated here from Jarvis et al. 2006) suggests an age range of increased abundance of *S. borealis* gen. et sp. nov of 97.7–96.8 Ma, with the acme at 97.4 Ma, all within the *Mantelliceras dixoni* Zone.

Plate 1. Figures 1–16. *Epelidosphaeridia* sp. 1 Nøhr.-Hansen 1993.

Sample number; England Finder coordinates; picture reference number and locality are listed for the specimens illustrated.

Figure 1. 518602-7, R45-1, Section JHOV-2/2009, Snertadal, north Hold with Hope, North-East Greenland.

Figure 2. 487645-3, W39-3, 1224, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 3. 487648-2, S49-1, 1226, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figures 4–6 *Epelidosphaeridia spinosa*

Figure 4. 1251m DC, N25-4, 1140, Well 7120/7-2 Offshore Norwey.

Figure 5. 1185m SWC, G47-2, 1162, Well 7120/7-2 Offshore Norway.

Figure 6. 1269m DC, G30-1, 1127, Well 7120/7-2 Offshore Norway.

Figures 7–16 *Epelidosphaeridia manifesta* gen. et sp. nov.

Figure 7. Holotype 487643-3, F52-4, 1206, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 8. 487645-3, N34-4, 1223, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 9. 1420-30m DC b, P30-1, 1186, Well 7119/12-1 Offshore Norway.

Figure 10. 1160m DC, E39-4, 1163, Well 7120/7-2 Offshore Norway.

Figure 11. 522074-4 U34-1, 1461, Section PAL-3/2011, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 12. 487643-3, U42-3, 1207, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 13. 1302–05m DC, H43, 1119, Well 7120/7-2 offshore Norway.

Figure 14. 1150m DC00 a, G43-1, 1174, Well 7120/7-2 offshore Norway.

Figure 15. 1150m DC00 a, S34-4, 1170, Well 7120/7-2 offshore Norway.

Figure 16. 1302–05m DC, J40-2, 1120, Well 7120/7-2 offshore Norway.

Plate 2. Figures 1–16. *Ovoidinium epelidosphaeroides* sp. nov.

Sample number; England Finder coordinates; picture reference number and locality are listed for the specimens illustrated.

Figure 1. Holotype, 522081-4, Z21-2, 1502, Section PAL-3/2011, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 2. 422081-4, K35-2, 1505, Section PAL-3/2011, Tværdal Geographical Society Ø, North-East Greenland.

Figure 3. 422082-3, Y27-1, 1507, Section PAL-3/2011, Tværdal Geographical Society Ø, North-East Greenland.

Figure 4. 422082-4, O42-3, 1512, Section PAL-3/2011, Tværdal Geographical Society Ø, North-East Greenland.

Figure 5. 487634-3, S16-4, 1460, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 6. 487633-3, M45-3, 1200, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 7. 487633-4, S29-2, 1202, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 8. 422082-4, O42-3, 1510, Section PAL-3/2011, Tværdal Geographical Society Ø, North-East Greenland.

Figure 9. 1169m DC00 a, G34-2, 1169, Well 7120/7-2 offshore Norway.

Figure 10. 1010m DC00 b, S46-1, 1197, Well 7120/8-2 offshore Norway.

Figure 11. 1150m DC00 a, G55-3, 1178, Well 7120/7-2 offshore Norway.

Figure 12. 1150m DC00 a, F49-3, 1176, Well 7120/7-2 offshore Norway.

Figure 13. 422082-4, R42-4, 1513, Section PAL-3/2011, Tværdal Geographical Society Ø, North-East Greenland.

Figure 14. 487637-3, L46-3, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 15. 1150m 1218 SWC, H29-2, 1166, Well 7120/7-2 offshore Norway.

Figure 16. 422084-5, K33-3, 1516, Section PAL-3 2011, Tværdal Geographical Society Ø, North-East Greenland.

Plate 3. Figures 1–16. *Sindridinium borealis* gen. et sp. nov.

Sample number; England Finder coordinates; picture reference number and locality are listed for the specimens illustrated.

Figure 1. Holotype, 522076-4 U53-1, 1463, Section PAL-3/2011, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 2. 487643-3, J45-4, 1212, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 3. 487643-4, M18-2, 1455, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 4. 487643-4, T41-3, 1456, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 5. 518602-7, 41,73-11,45, Section JHOV-2/2009, Snertadal, north Hold with Hope, North-East Greenland.

Figure 6. 487648-3, V35-4, 1227, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 7. 487645-4, F33-3, 1458, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 8. 487645-4, O31-3, 1457, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 9. 522076-4 W53-4, 1462, Section PAL-/ 2011, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 10. 1420–30m DC b, E32-3, 1187, Well 7119/12-1 offshore Norway.

Figure 11. 1272–75m, P35-1, 1122, Well 7120/7-2 offshore Norway.

Figure 12. 1420–30m DC b, R33-4, 1190, Well 7119/12-1 offshore Norway.

Figure 13. 1152,5m SWC, C44-1, 1161, Well 7120/7-2 offshore Norway.

Figure 14. 1257–60m, E42-2, 1137, Well 7120/7-2 offshore Norway.

Figure 15. 1420–30m DC b, Q33-1, 1188, Well 7119/12-1 offshore Norway.

Figure 16. 1420–30m DC b, V27-1, 1185, Well 7119/12-1 offshore Norway.

Plate 4. Figures 1–12. *Sindridinium borealis* gen. et sp. nov. from the Trunch borehole, Norfolk, southeast UK. The scale bar represents 10 μm.

Figures 1–6. 507.8–507.9 m, showing a specimen with an attached operculum, and an omphalos in the internal cavity.

Figure 7. 507.8–507.9 m, showing a more elongate specimen, presumably compressed.

Figure 8. 507.8–507.9 m, showing a specimen with a detached operculum. The arrow points to a conspicuous v-shaped notch that appears on many specimens.

Figures 9–10, 507.8–507.9 m.

Figure 11. 507.8–507.9 m, same specimen as Figure 10 but illustrated with a possible tabulation pattern.

Figure 12. 507.8–507.9 m, showing a specimen with a detached operculum. The arrow points to a conspicuous v-shaped notch that appears on many of the specimens from the Trunch borehole.

Plate 5. Figures 1–6, 8–9. *Sindridinium borealis* gen. et sp. nov. SEM pictures. Scale bars 10 μm.

Figures 1–6, 8–9, 522082, Section PAL-3/2011, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 7, 522079, Section PAL-3/2011, Tværdal, Geographical Society Ø, North-East Greenland. Scale bar 10 μm.

Plate 6. Figures 1–16. *Sindridinium anaanae* gen. et sp. nov.

Sample number; England Finder coordinates; picture reference number and locality are listed for the specimens illustrated.

Figure 1. Holotype, 518602-7, M32-1,Section JHOV-2/2009, Snertadal, north Hold with Hope, North-East Greenland.

Figure 2. , 518604-8, D47, 1233,Section JHOV-2/2009, Snertadal, north Hold with Hope, North-East Greenland.

Figure 3. 487631-3, O28-2, 1464, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 4. 487631-3, N24-4, 1471, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 5. 518604-9, V31-2, 1235,Section JHOV-2/2009, Snertadal, north Hold with Hope, North-East Greenland.

Figure 6. 487631-3, M50-1, 1476, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 7. 487631-3, M51-1, 1467, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 8. 487631-3, Y22-2, 1469, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 9. 487631-3, X41-1, 1474, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 10. 487631-4, H30-3, 1898, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

730 Figure 11. 487631-3, M52-1, 1478, Section HNH081410-4, east of Fosdalen, north Hold with Hope,

731 North-East Greenland.

732 Figure 12. 518610-8, L43-3, 1532,Section JHOV-2/2009, Snertadal, north Hold with Hope, North-East

733 Greenland.

734 Figure 13. 1160m DC, P30-4, 1165, Well 7120/7-2 offshore Norway.

735 Figure 14. 1010m DC00 b, H41-2, 1199, Well 7120/8-2 offshore Norway.

736 Figure 15. 1010m DC00 b, D33-3, 1196, Well 7120/8-2 offshore Norway.

737 Figure 16. 1010m DC00 b, G29-3, 1195, Well 7120/8-2 offshore Norway.

738 Plate 7. Figures 1–9. *Sindridinium anaanae* gen. et sp. nov. SEM pictures. 48763, Section

739 HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland. Scale bars 10 μm.

740 Figures 10–12. *Ovoidinium epelidosphaeroides* sp. nov. SEM pictures, 522082, Section PAL-3/2011,

741 Tværdal, Geographical Society Ø, North-East Greenland. Scale bars 10 μm.

Plate 8. Figures 1–16. *Sindridinium*? *torulosa* comb. nov.

Sample number; England Finder coordinates; picture reference number and locality are listed for the specimens illustrated.

Figure 1. 324608-8, W21-4, 1560, Section SP 1986, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 2. 324611-4, O48-4, 1573, Section SP 1986, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 3. 324611-7, Y19-3, 1571, Section SP 1986, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 4. 522059-5, U26-4, 1568, Section SP 1986, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 5. 324611-7, P48-1, 1570, Section SP 1986, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 6. 324608-7, N43-2, 1558, Section SP 1986, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 7. 324610-4, O24-2, 1564, Section SP 1986, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 8. 324612-4, N54-1, 1575, Section SP 1986, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 9. 1247,5m SWC, L47-3, 1152, Well 7120/7-2 offshore Norway.

Figure 10. 1247,5m SWC, D42-1, 1146, Well 7120/7-2 offshore Norway.

Figure 11. 1247,5m SWC, K47-1, 1151, Well 7120/7-2 offshore Norway.

764 Figure 12. 1247,5m SWC, L44-2, 1149, Well 7120/7-2 offshore Norway.

765 Figure 13. 1247,5m SWC, G44-3, 1147, Well 7120/7-2 offshore Norway.

766 Figure 14. 1247,5m SWC, P46-2, 1153, Well 7120/7-2 offshore Norway.

767 Figure 15. 1247,5m SWC, P42-1, 1145, Well 7120/7-2 offshore Norway.

768 Figure 16. 1247,5m SWC, E45-3, 1150, Well 7120/7-2 offshore Norway.

Plate 9. Scale bar 20μm for Figures 1–14 is placed at Figure 14.

Sample number; England Finder coordinates; picture reference number and locality are listed for the specimens illustrated.

Figures 1–6. *Endoceratium dettmanniae.*

Figure 1. 1251m DC b, U35-2, 1144, Well 7120/7-2 Offshore Norway.

Figure 2. 1260m DC b, K42-3, 1136, Well 7120/7-2 Offshore Norway.

Figure 3. 1260m DC b, B35-3, 1135, Well 7120/7-2 Offshore Norway.

Figure 4. 487620-3, T17-4, 1221, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 5. 522085-4, X45-3, 1519, Section PAL 3-2011, Tværdal, Geographical Society Ø, North-East Greenland.

Figure 6. 1260m DC a, S38-3, 1133, Well 7120/7-2 offshore Norway.

Figure 7. *Nyktericysta arachnion,* 487627-4, V24-2, 1557, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 8. *Rugubivesiculites multisaccus* 52266-4, 1483, Section PAL 3-2011, Tværdal, Geographical Society Ø, North-East Greenland.

Figures 9–14. *Senoniasphaera* aff. *microreticulata.*

Figure 9. 1420–30m DC b, D49-3, 1194, Well 7119/12-1 offshore Norway.

Figure 10. 1272–75m, R47-4, 1124, Well 7120/7-2 offshore Norway.

Figure 11. 487633-3, J49-1, 1205, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 12. 487633-3, 1203, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 13. 1218m SWC, T42-2, 1159, Well 7120/7-2 offshore Norway.

Figure 14. 1218m SWC, W40-2, 1155, Well 7120/7-2 offshore Norway.

Figures 15–18. *Xenascus* aff. *plotei* Individual scale bars 20 μm.

Figure 15. 487623-4, W43-1, 1554, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 16. 487620-3, B27-4, 1551, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 17. 487625-3, O42-3, 1556, Section HNH081410-4, east of Fosdalen, north Hold with Hope, North-East Greenland.

Figure 18. 518602-8, V43-2, 1544, Section JHOV-2/2009, Snertadal, north Hold with Hope, North-East Greenland.

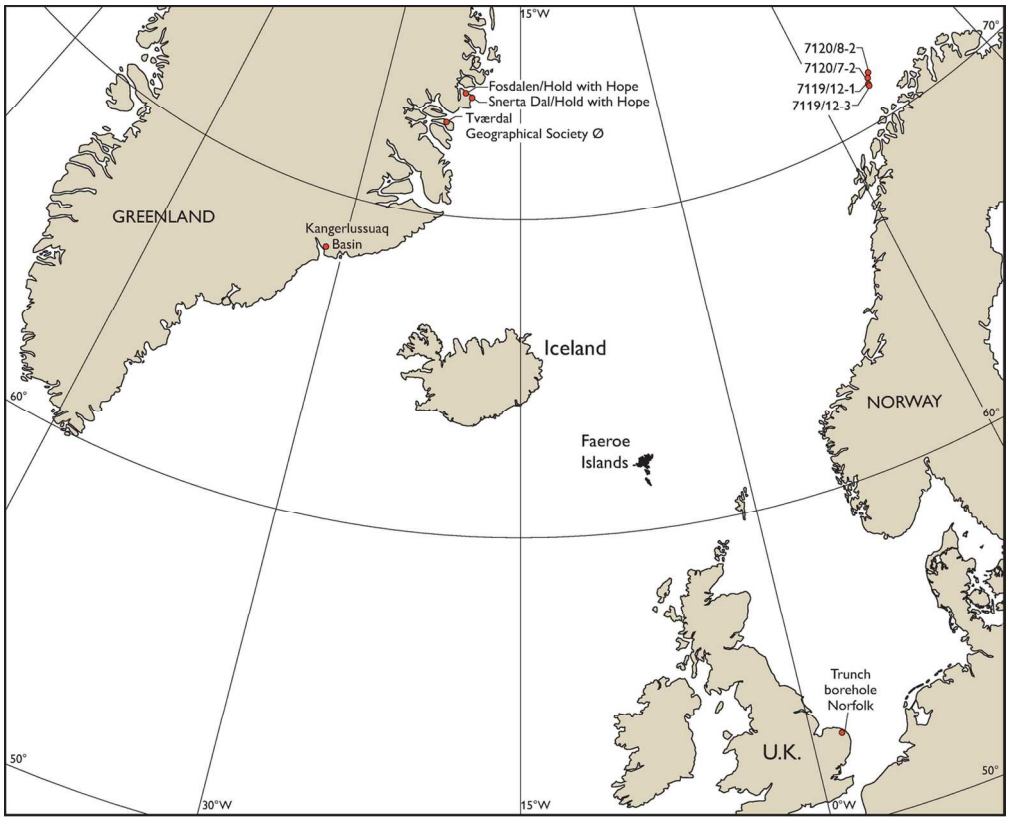


Figure 1. Location map of the studied sections.

129x104mm (300 x 300 DPI)

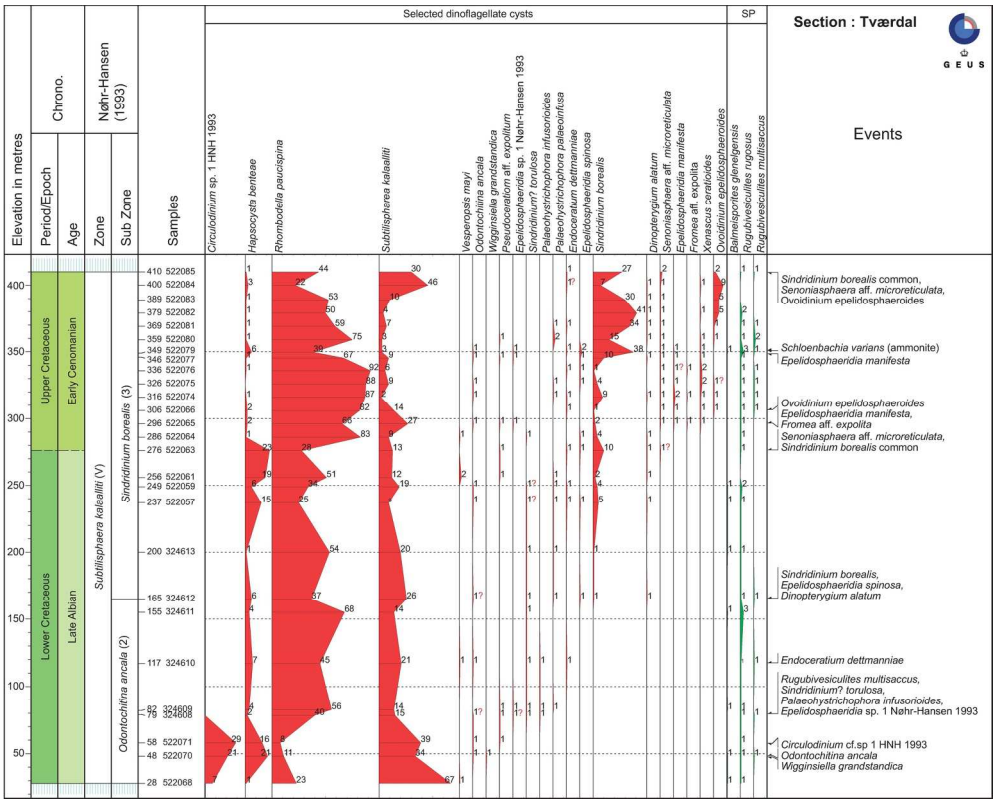


Figure 2. Range-chart of slected dinoflagellate cysts from the more than 400 m thick dark greý mudstone succession at Tværdal, Geographical Scociety Ø, North-East Greenland; (section 30 of Nøhr-Hansen 1993 and GEUS, PAL-3/2011; 72o58'N; 23o02'W).

190x150mm (300 x 300 DPI)

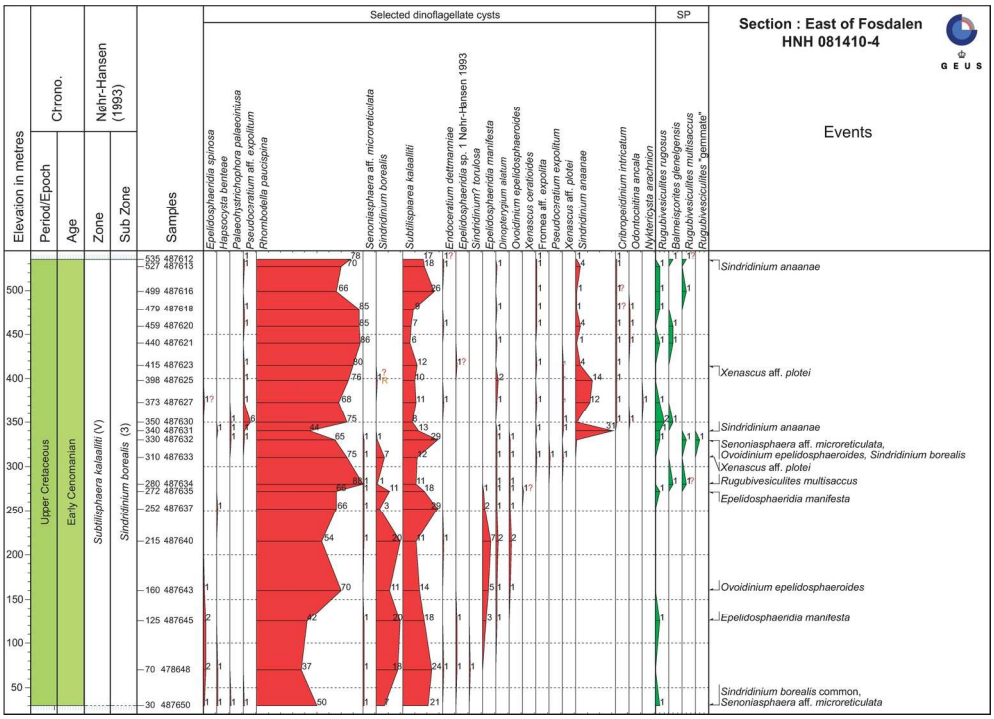


Figure 3. Range-chart of selected dinoflagellate cysts from the more than 500 m thick dark greý mudstone succession east of Fosdalen, Hold with Hope, North-East Greenland (GEUS section, HNH081410-01; 73o52'N; 20o43'W).

170x120mm (300 x 300 DPI)

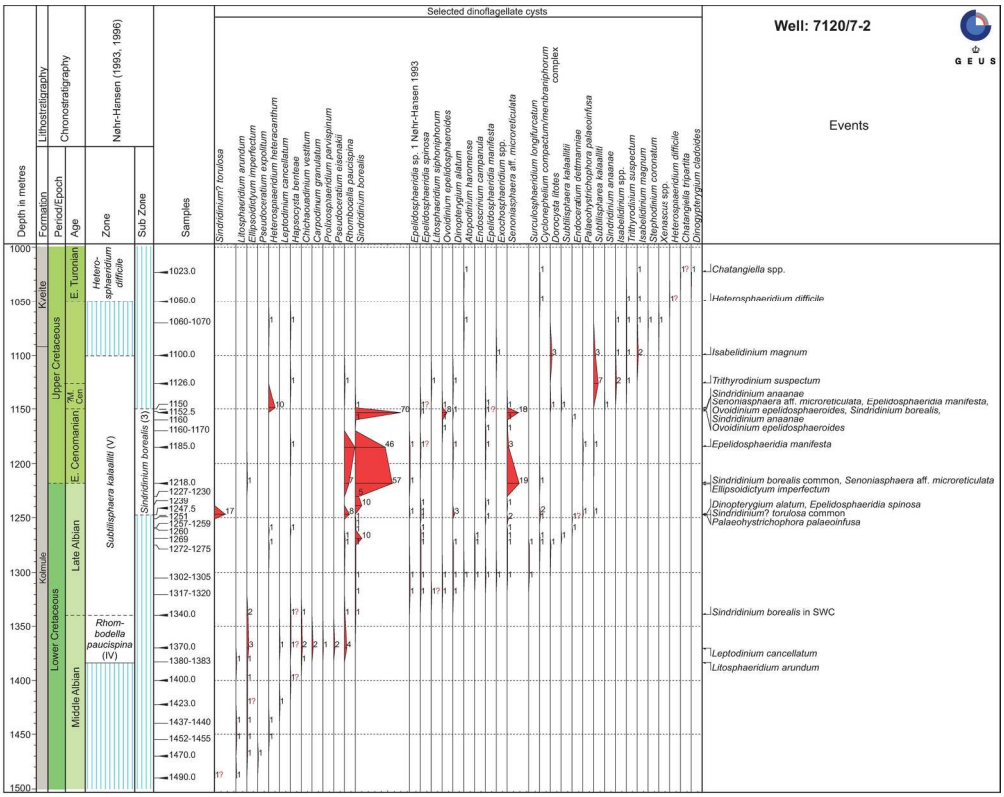


Figure 4. Range-chart of slected dinoflagellate cysts from the Albian to Turonian interval (depth 1000–1500m) in well 7120/7-2. Snøhvit, Barets Sea, offshore Norwey (71° 19' 11.49'' N; 20° 19' 44.31'' W).

190x149mm (300 x 300 DPI)

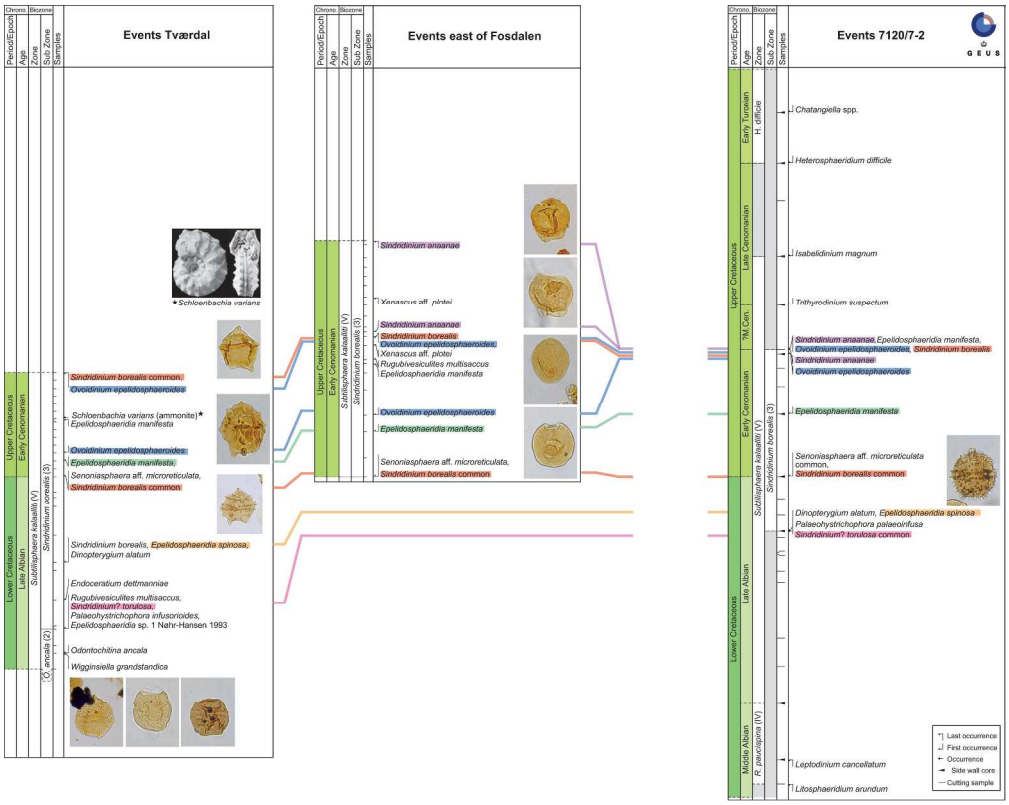


Figure 5. Corellation of the Tværdal and east of Fosdalen sections with the well 7120/7-2, based on events of old and new index species.

240x191mm (300 x 300 DPI)

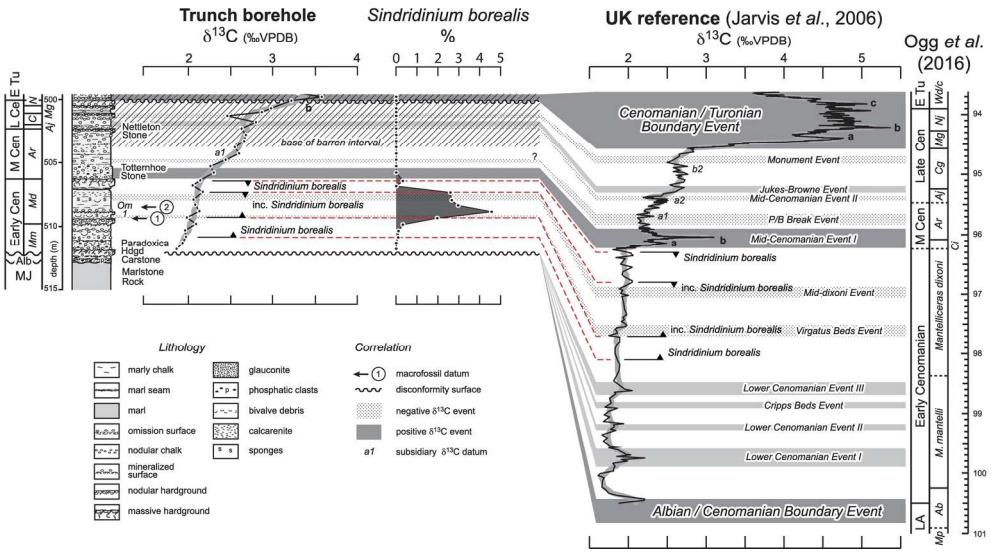
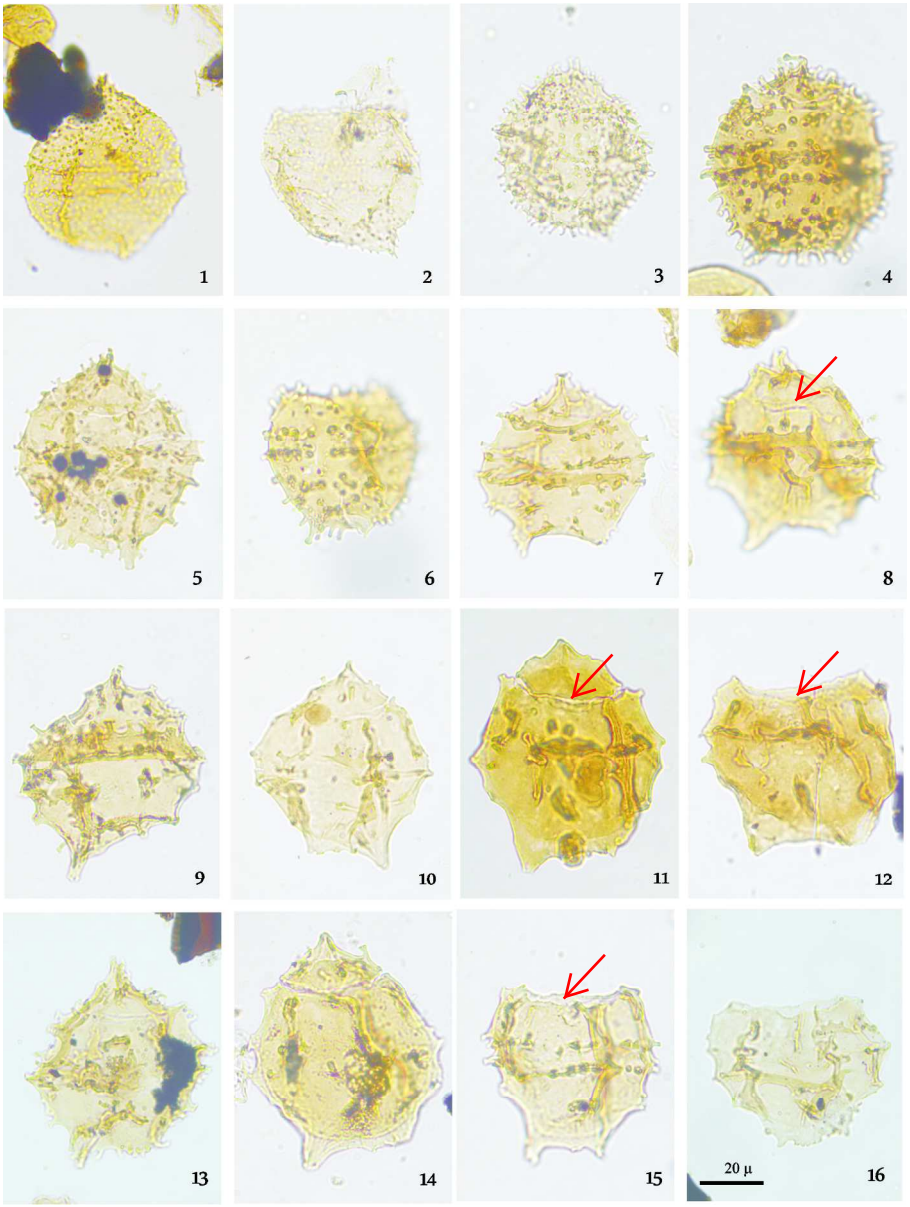


Figure 6.The stratigraphic distribution of Sindridinium borealis gen. et sp. nov. in the Trunch borehole (Norfolk, southeast UK, 52°51'34'' N; 01°24'19'' E) and its correlation to the δ13C isotope curve of Jarvis et al. (2006). As no ammonites were recovered from the Lower Cenomanian section, the limits of the ammonite zones are based in lithological correlations to ammonite calibrated sections, and by the distribution of Inocermus and Orbirhynchia (see Wood et al., 1994). However, the acme of S. borealis gen. et sp. nov. clearly occurs in the Early Cenomanian, below the mid-Cenomanian δ13C isotope event I of Jarvis et al. (2006) and above the late Albian Carstone. The δ13C calibration to the GTS 2016 (recalibrated here from Jarvis et al. 2006) suggests an age range of increased abundance of S. borealis gen. et sp. nov of 97.7–96.8 Ma, with the acme at 97.4 Ma, all within the Mantelliceras dixoni Zone.

171x104mm (300 x 300 DPI)



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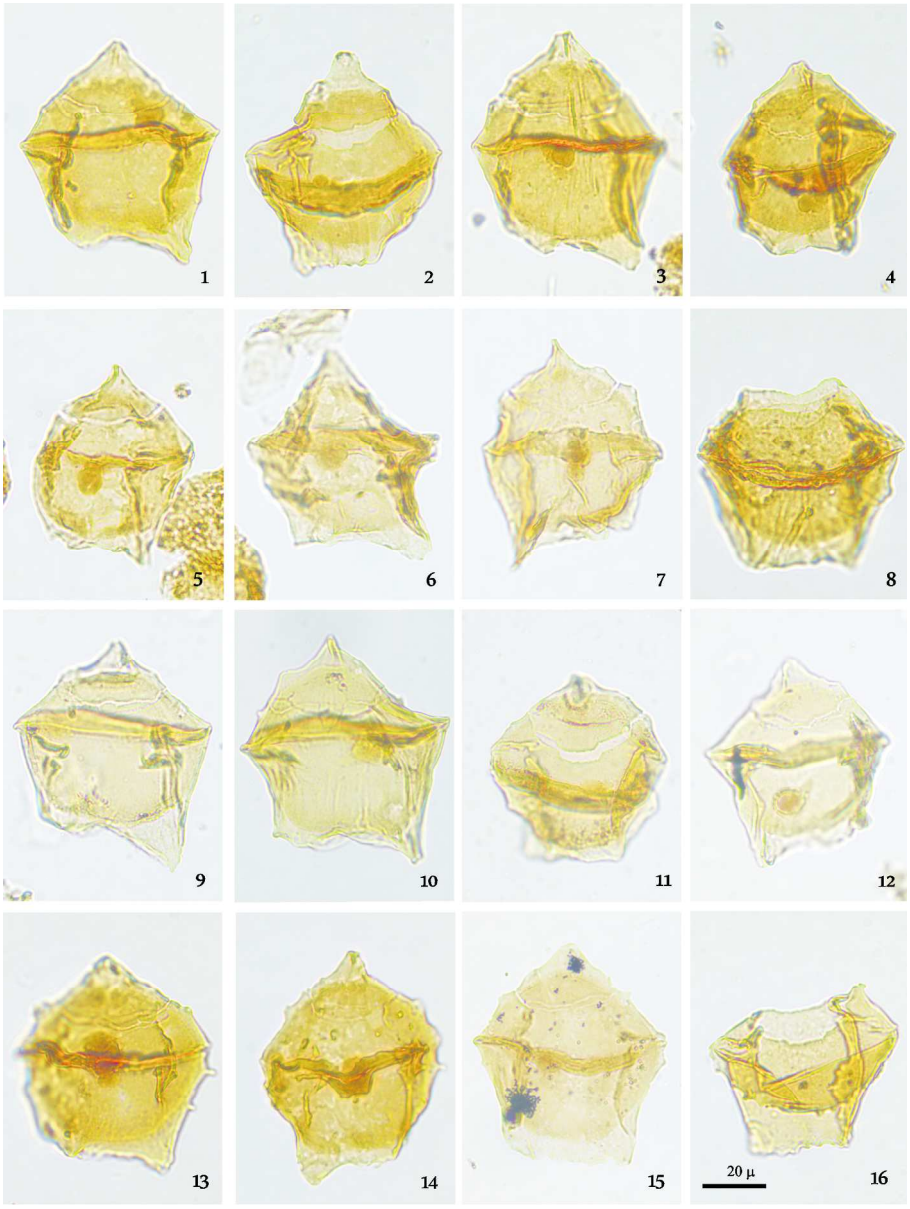

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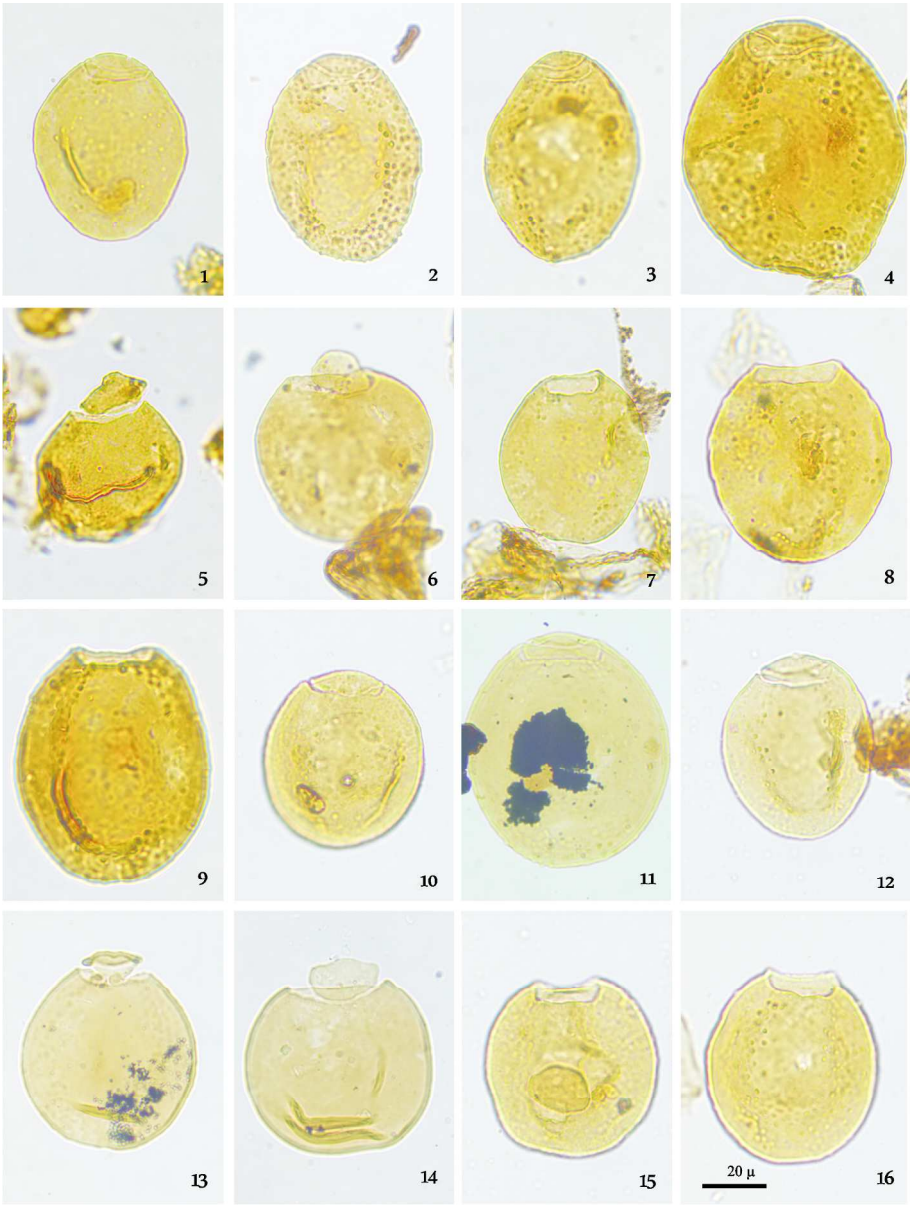

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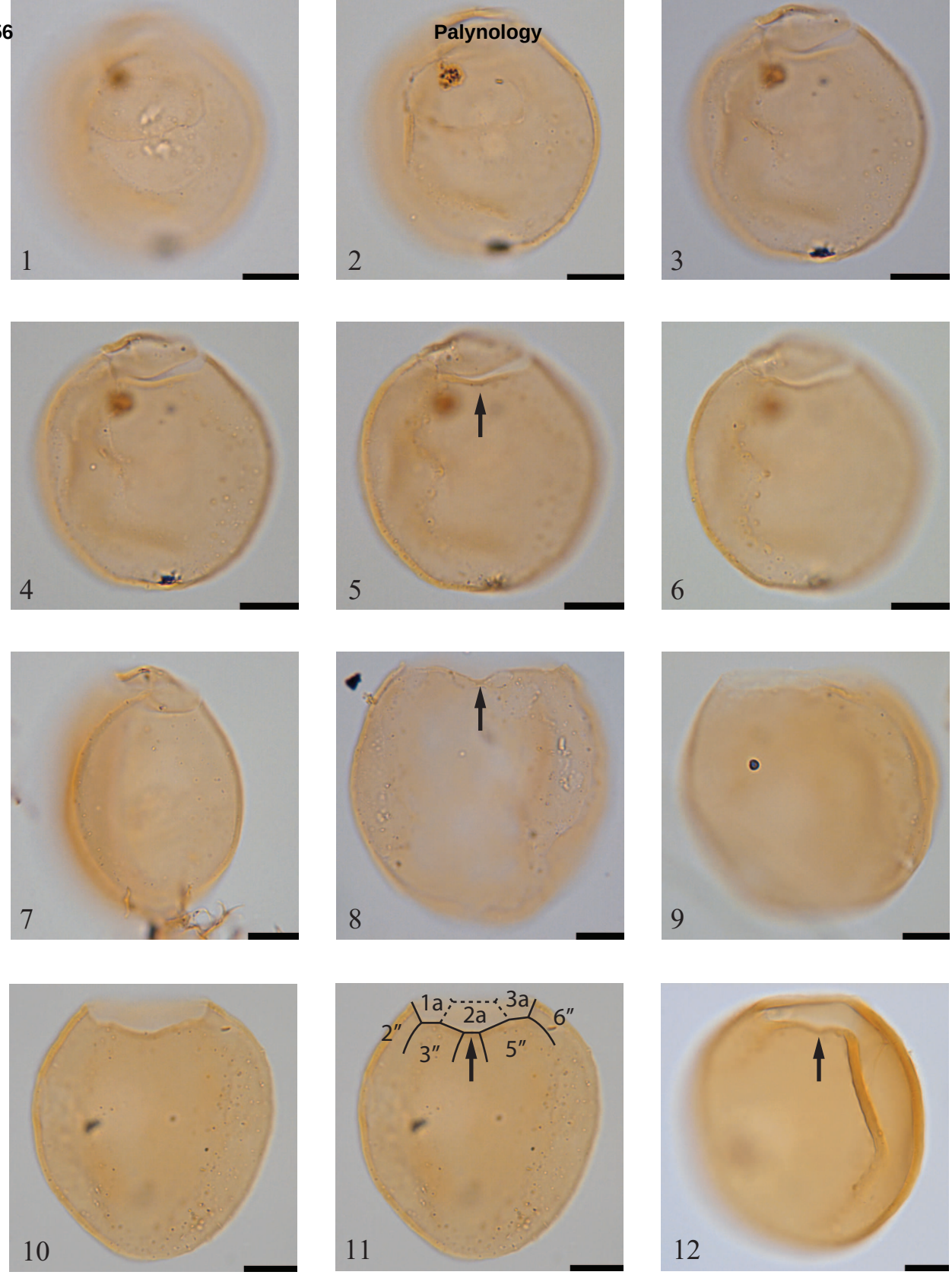
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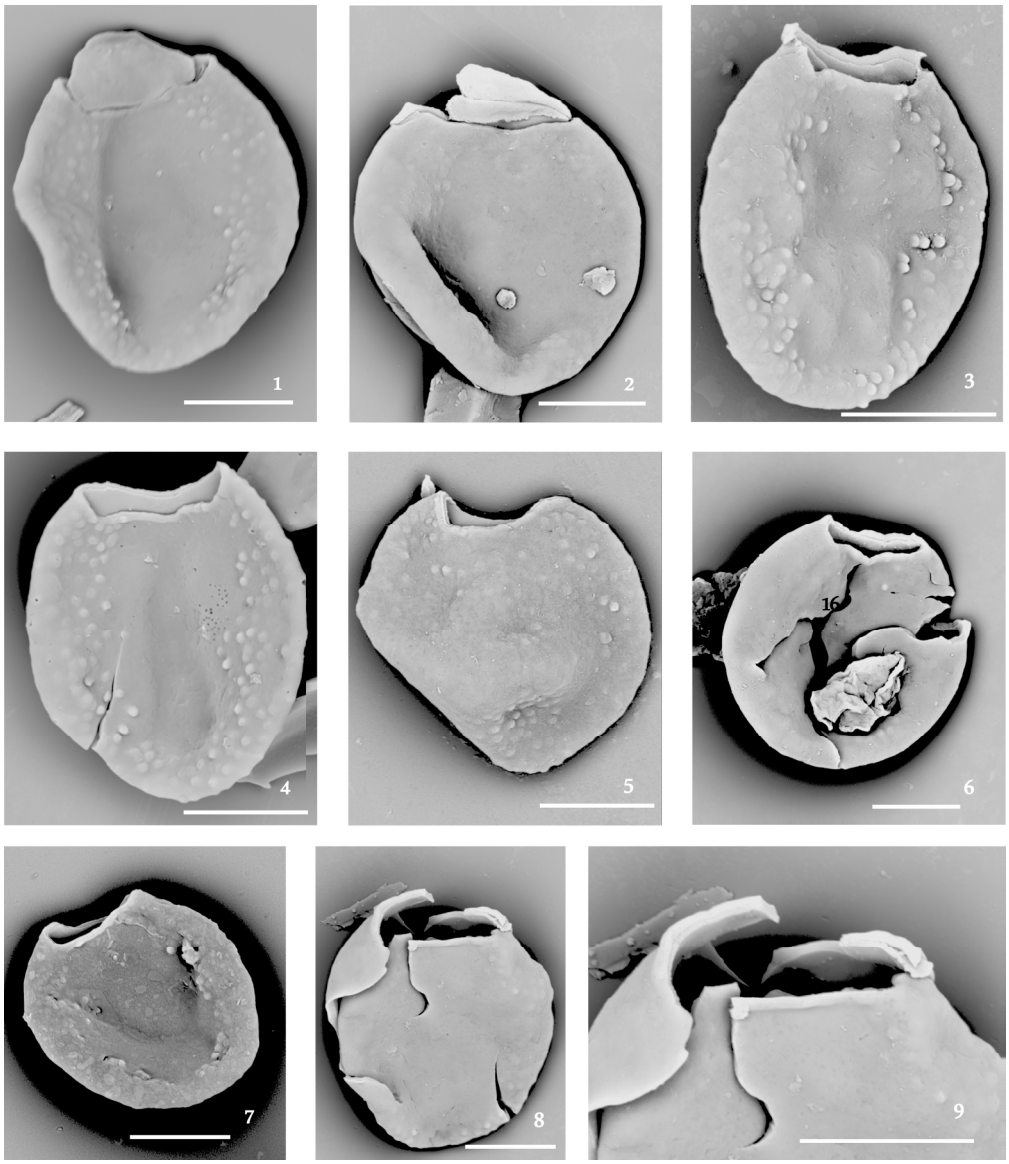

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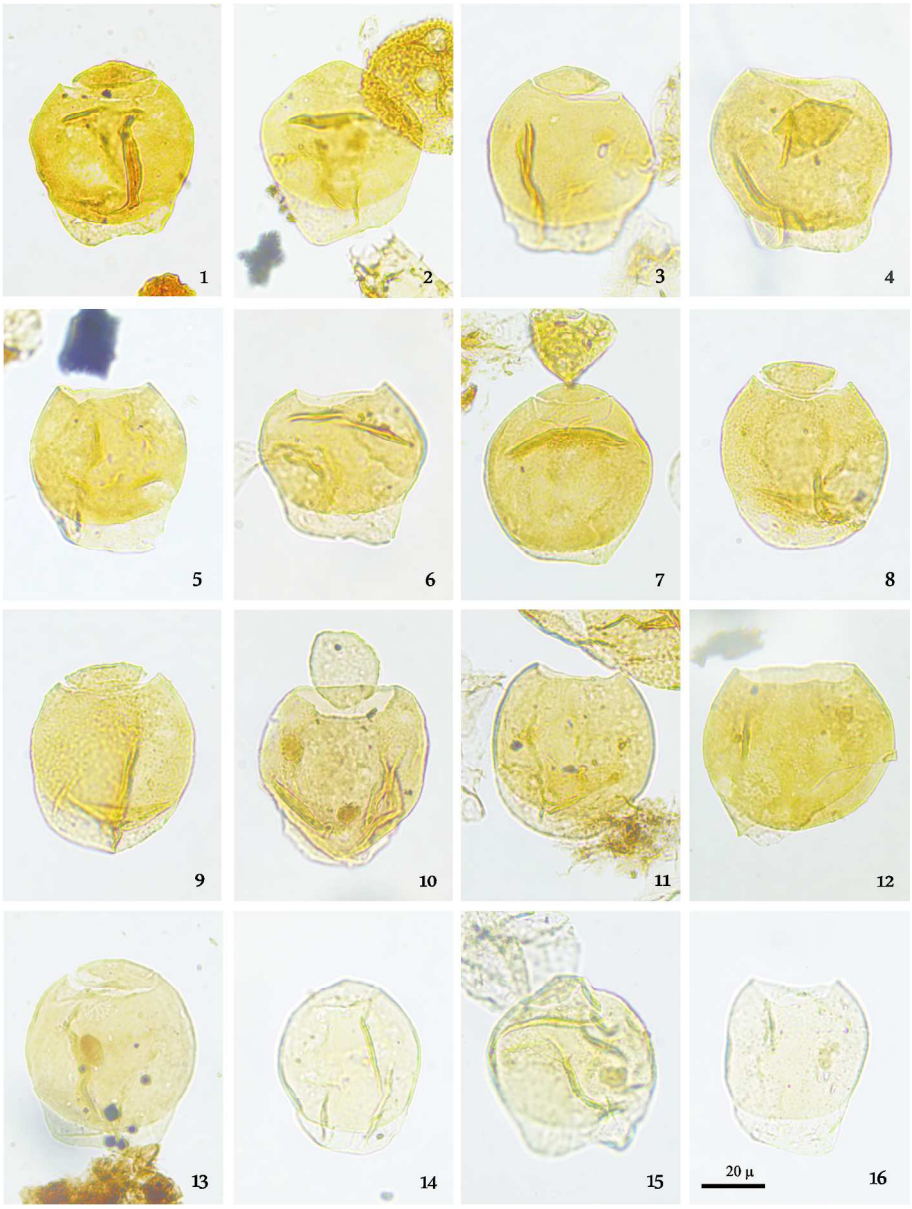

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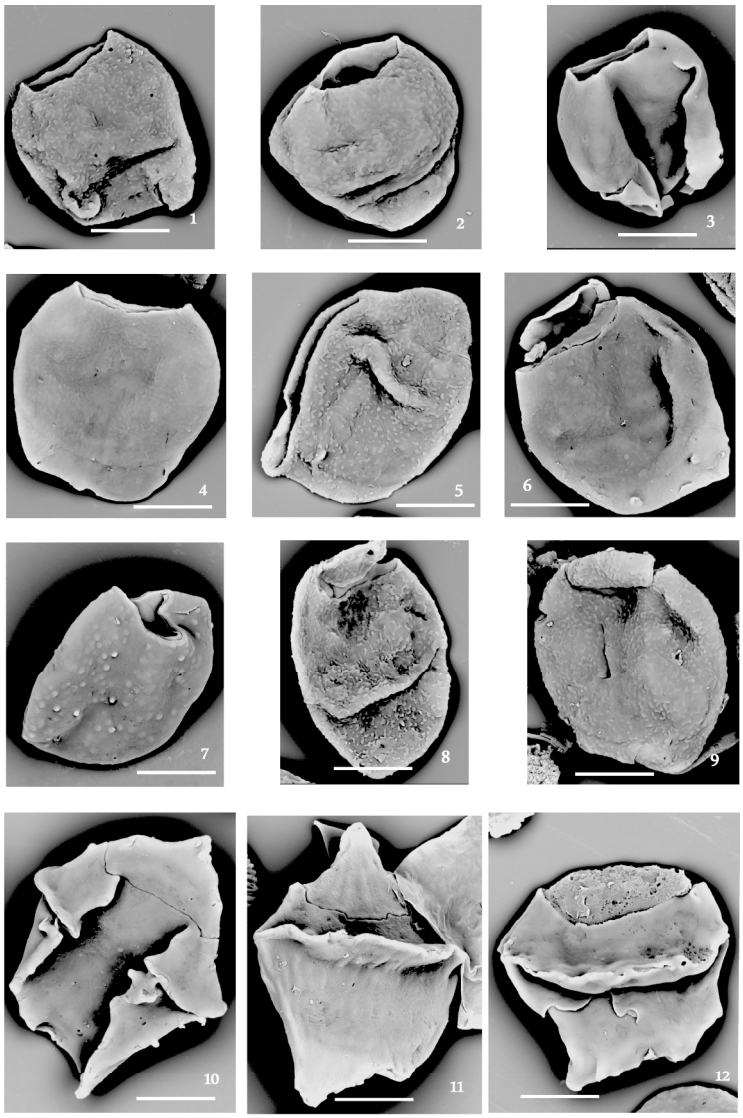
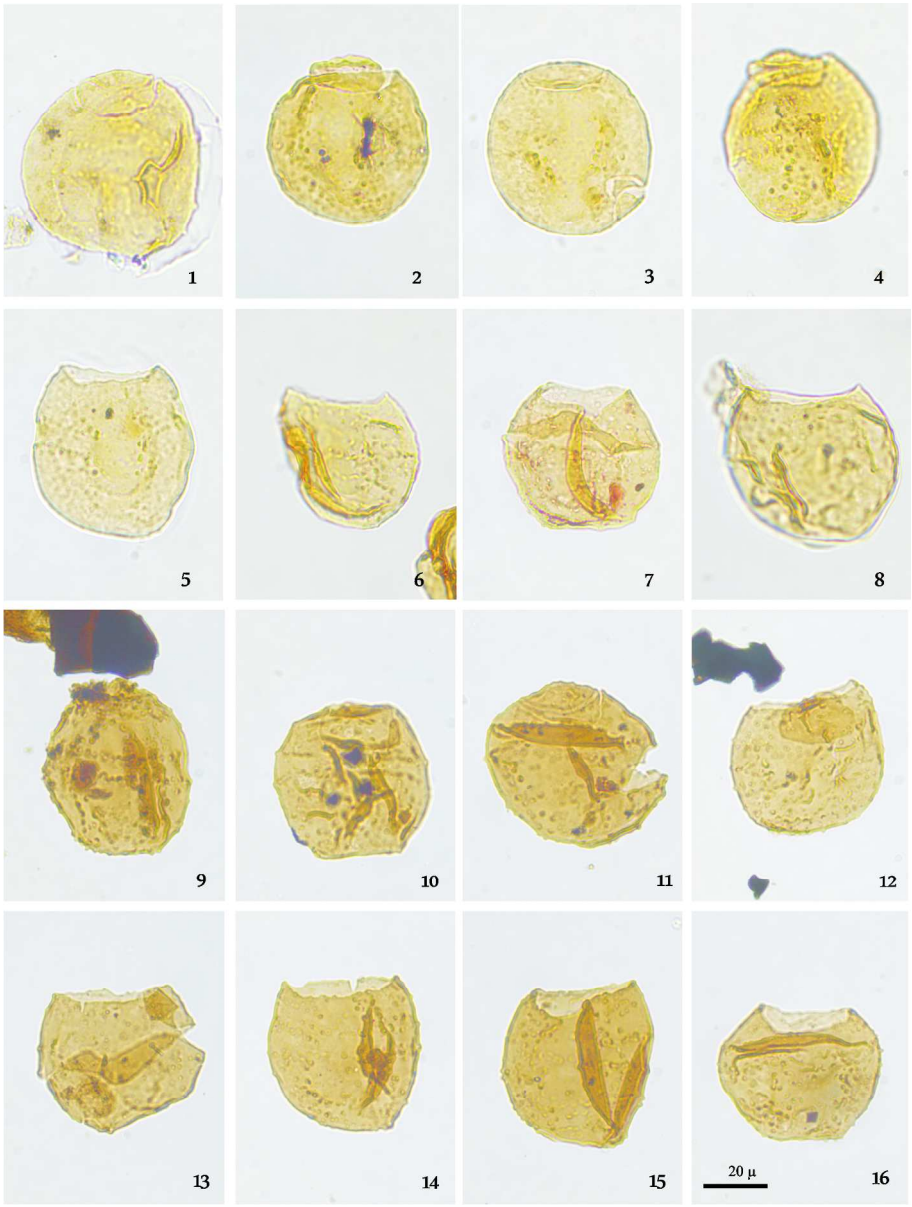


276x416mm (300 x 300 DPI)



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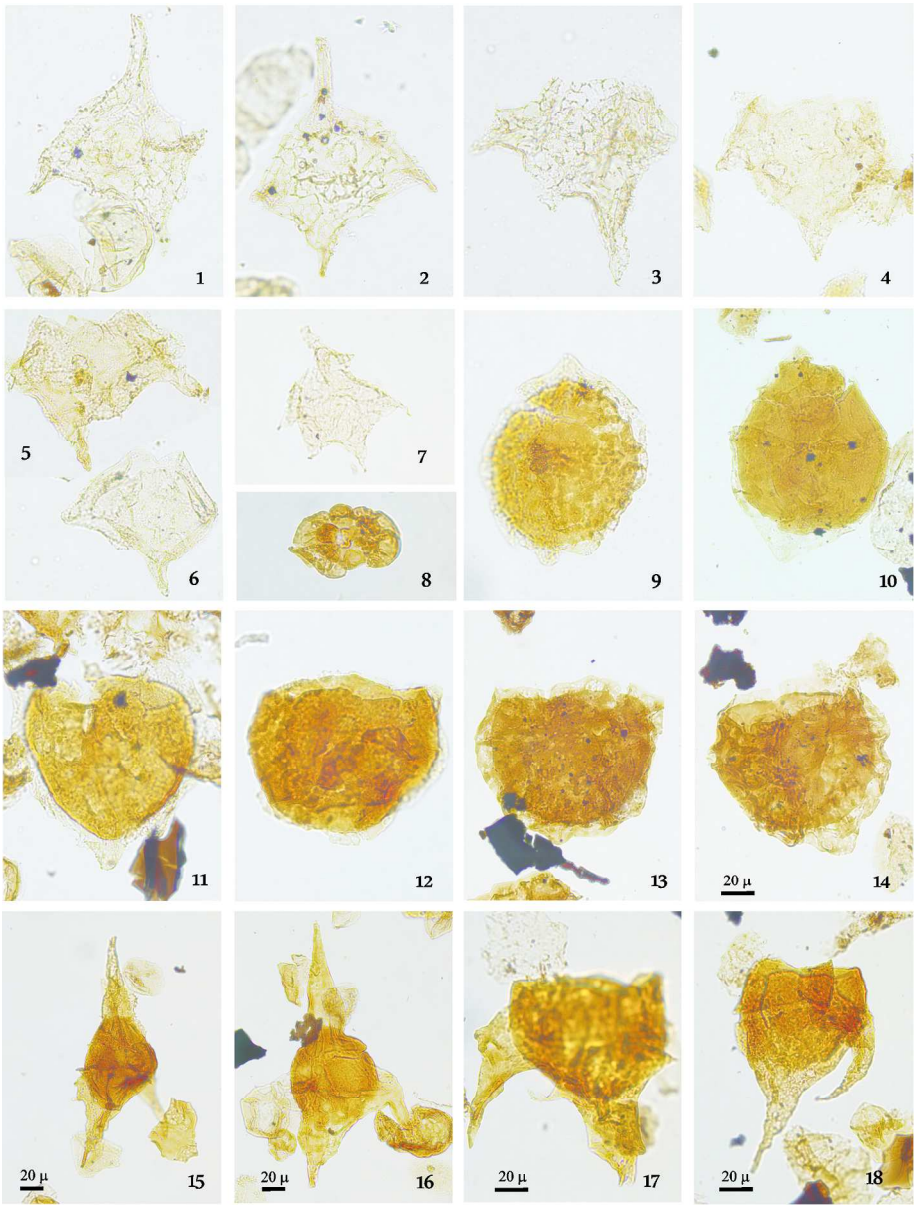

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