

New dinocyst taxa from the Eocene of the North Sea

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ABSTRACT - Dinoflagellate cysts (dinocysts) are abundant in the Eocene of the North Sea and provide a high-resolution biostratigraphic zonation. Twelve species are erected to accommodate zonal markers that have not been previously described. These are *Areosphaeridium ebdonii*, *Areosphaeridium michoudii*, *Cerebrocysta magna*, *Diphyes brevispinum*, *Diphyes pseudofucusoides*, *Hystrichosphaeropsis costae*, *Hystrichostroglylon clausenii*, *Membranilarnacia compressa*, *Phthanoperidinium clithruidium*, *Phthanoperidinium distinctum*, *Phthanoperidinium powellii* and *Phthanoperidinium regalis*. *J. Micropalaeontol.* 13(2): 119–131, December 1994.

INTRODUCTION

Bujak & Mudge (1994) defined eight dinocyst zones and 23 subzones for the Eocene of the North Sea based on last occurrence or abundance events (Fig. 1), which were observed in more than 150 wells examined from Quadrant 3 in the north to Quadrants 21 and 22 in the south. Many of the zonal markers also occur in northwest European stratotypes and reference sections, permitting correlation with standard nannoplankton (NP) zonal assignments made for these sections, of significance because few Eocene NP index species occur in North Sea wells.

Mudge & Bujak (1994) defined five North Sea Eocene stratigraphic sequences and eight subsequences bounded by high gamma log peaks, based on the examination of over 750 released wells from Quadrant 3 to Quadrants 21 and 22. They demonstrated that each sequence and subsequence boundary consistently falls within the same dinocyst subzone, giving a high degree of confidence that these boundaries represent time lines.

Twelve dinocyst taxa used to define the zones and subzones erected by Bujak & Mudge (1994) have not been previously described, although some have been informally illustrated from northwest Germany, Belgium and Denmark. The purpose of this paper is to formally describe these taxa in order to provide the taxonomic framework needed for the North Sea Eocene dinocyst scheme proposed by Bujak & Mudge (1994).

MATERIAL

All of the illustrated material is from ditch cuttings, sidewall core or conventional core samples recovered from North Sea wells operated by various companies. Palynological slides containing the type material from the UK22/9-1, UK22/14-1 and UK22/16-1 wells are curated at the British Geological Survey, Keyworth. Palynological slides containing the type material from the UK15/13-2 and UK16/1a-1 wells are curated at BP Operating Company, Aberdeen. Palynological slides containing the type material from the UK21/28a-4, UK21/28a-5 and UK21/28a-6 wells are curated at Simon Petroleum Technology Limited, Llandudno. Palynological slides from all other wells were donated for curation at the Natural History Museum, London, by

Chevron UK Limited, Conoco (UK) Limited, Oryx UK Energy, Shell UK Exploration and Production, Sun International Exploration and Production, Total Oil Marine plc, and Unocal UK Limited.

SYSTEMATICS

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

Class **Dinophyceae** Pascher, 1914

Order Gonyaulacales Taylor, 1980

Family **Gonyaulacaceae** Lindemann, 1928

Genus **Areosphaeridium** Eaton, 1971

Remarks. Stover & Williams (in press) reviewed the morphology of species that had been assigned to *Areosphaeridium* and emended its diagnosis, placing particular emphasis on the number and distribution of processes on the hypocyst. They distinguished two groups of species previously assigned to *Areosphaeridium* based on the hypocystal paratabulation. The hypocyst on *Areosphaeridium diktyoplokus* (Klumpp) Eaton and *Areosphaeridium fenestratum* Bujak typically has seven processes on paraplates 5^{'''}, 1p and 1^{'''}, arranged in the standard sexiform pattern. Stover & Williams retained these species in *Areosphaeridium*, which has a confirmed stratigraphic range of late Ypresian to Priabonian, according to Stover & Williams (in press).

Stover & Williams (in press) erected the genus *Enneadocysta* to accommodate the second group of species, previously assigned to *Aereosphaeridium*, which have a partiform hypocystal configuration, with processes on paraplates 6^{'''}, 2^{'''} and 1ps. They designated *Enneadocysta pectiniformis* (Gerlach) Stover & Williams as the types species. *Enneadocysta* has a confirmed stratigraphic range of early Lutetian to Rupelian, according to Stover & Williams (in press).

Areosphaeridium ebdonii sp. nov.

(Plate 2, figs 8–9)

Derivation of name. Named after the palynologist Christopher Ebdon.

Diagnosis. Cysts skolochorate with subspherical bodies comprising an autophragm. Body typically with 17 intratabular processes, ten on the epicyst and seven on the

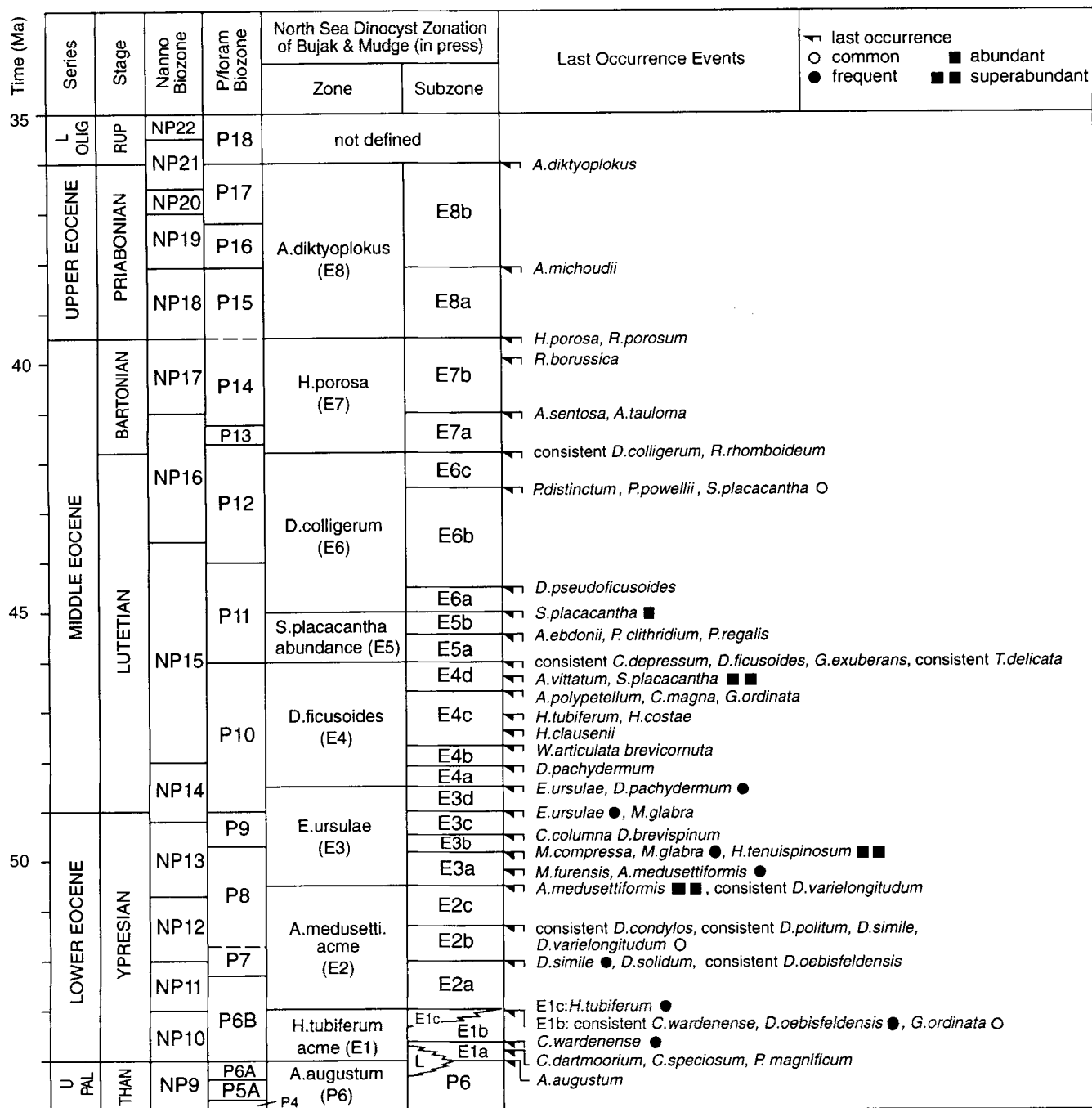


Fig. 1. The North Sea Eocene dinocyst zonation of Bujak & Mudge (1994)

hypocyst; areas between process bases smooth, or indistinctly ornamented, or finely and irregularly granulate. Processes less than 15 μm in length. Process stems solid, with proximal fibrous ends expanded slightly and merging smoothly with the autophragm surface. Process stems expanded distally into vasiform or infundibular, fenestrate to reticulate process platforms with irregular to circular outlines. On some specimens the vasiform or infundibular distal terminations have irregular or entire margins. The

processes reflect a paratabulation of 4', 6", 0c, 5"', 1p, 1''', 0s, with the hypocystal paratabulation following the standard sexiform pattern. Paracingulum typically expressed by the absence of processes, but one or two narrow paracingular processes may be present. Parasulcal processes absent although a medial parasutural notch is frequently discernible. Archeopyle apical; operculum tetraplacoid, contiguous.

Type locality and stratum. Locality: North Sea, UK22/14-1

well. Stratum: section at 8020 ft, Early Eocene (Ypresian).

Holotype. UK22/14-1, 8020 ft (ditch cuttings), England Finder coordinates D44/4, illustrated in Plate 2, figs 8–9, curated at the British Geological Survey, Keyworth, slide number MPK 9725.

Paratype. UK22/14-1, 8020 ft (ditch cuttings), England Finder coordinates U49/3, curated at the British Geological Survey, Keyworth, slide number MPK 9726.

Dimensions. Central body length (without operculum) 47–53 μm , breadth 40–48 μm , maximum process length 10–12 μm .

Observed stratigraphic range. North Sea dinocyst zones: E3c to E5a of Bujak & Mudge (1994) (Early to Middle Eocene: Ypresian to Lutetian).

Remarks. *A. ebdonii* is distinguished from other species of *Areosphaeridium* by its short processes.

Areosphaeridium michoudii sp. nov.

(Plate 1, figs 1–3)

Derivation of name. Named after the palynologist Daniel Michoux.

Diagnosis. Cysts skolochorate with subspherical bodies comprising an autophragm. Central body diameter typically greater than 50 μm . Body typically with 17 intratabular processes, ten on the epicyst and seven on the hypocyst; areas between process bases smooth, or indistinctly ornamented, or finely and irregularly granulate. Process stems solid, with proximal fibrous ends expanded slightly and merging smoothly with the autophragm surface. Process stems expanded distally, and forming recurved or straight distal bifurcations. The distal margin of the bifurcations are digitate or bear completely or partially developed fenestrations which are restricted to a band lying along the bifurcations. The processes reflect a paratabulation of 4', 6", 0c, 5"', 1p, 1''', 0s, with the hypocystal paratabulation following the standard sexiform pattern. Paracingulum typically expressed by the absence of processes. Parasulcal processes absent although a medial parasutural notch is frequently discernible. Archeopyle apical; operculum tetraplacoid, contiguous.

Type locality and stratum. Locality: North Sea, UK21/28b-7 well. Stratum: section at 3900 ft, Middle Eocene (Lutetian).

Holotype. UK21/28b-7, 3900 ft (ditch cuttings), England Finder coordinates X17/0, illustrated in Plate 1, figs 1–2, curated at The Natural History Museum, London, slide number FD 513(1).

Paratypes. UK21/28b-7, 3900 ft (ditch cuttings), England Finder coordinates V30/3, curated at The Natural History Museum, London, slide number FD 513(3); UK16/16b-4, 6040 ft (ditch cuttings), England Finder coordinates U39/3, curated at The Natural History Museum, London, slide number FD 524(1).

Dimensions. Central body length (without operculum) 50–58 μm , breadth 56–63 μm , maximum process length 35–40 μm .

Observed stratigraphic range. North Sea dinocyst zones: E2a to E8a of Bujak & Mudge (1994) (Early to Late Eocene: Ypresian to Priabonian).

Remarks. *A. michoudii* is distinguished from all other species of *Areosphaeridium* by its distally bifid processes which lack fenestrate or reticulate process platforms. The process terminations on *A. michoudii* are similar to those on several species of *Enneadocysta*, including *E. arcuata* (Eaton) Stover & Williams and *E. multicornuta* (Eaton) Stover & Williams which are common in the North Sea. *A. michoudii* differs from all species of *Enneadocysta* in having a sexiform hypocystal paratabulation reflected by a processes on paraplates 5"', 1p and 1'''. Species of *Enneadocysta* have a partiform hypocystal paratabulation reflected by processes on paraplates 6", 2''' and ps.

Genus *Cerebrocysta* Bujak in Bujak *et al.*, 1980

Cerebrocysta magna sp. nov.

(Plate 2, figs 10–11)

Derivation of name. Latin, *magnus*, large, with reference to the large cyst size.

Diagnosis. Autocyst spherical to ovoidal, without apical, antapical or other projections, except for an apparently random ornament of low crests which give the cyst a cerebral appearance. The crests occasionally suggest a paratabular arrangement. Cyst diameter always exceeding 40 μm . Archeopyle formed by the loss of precingular paraplate 3".

Type locality and stratum. Locality: North Sea, UK21/28a-5 well. Stratum: section at 4619 ft, Middle Eocene (Lutetian).

Holotype. UK21/28a-5, 4619 ft (conventional core), England Finder coordinates V38/2, illustrated in Plate 2, fig. 10, curated at Simon Petroleum Technology Limited, Llandudno.

Paratypes. UK16/17-3, 6830 ft (ditch cuttings), England Finder coordinates N47/0, curated at The Natural History Museum, London, slide number FD 514(1); UK16/26-2, 7030 ft (ditch cuttings), England Finder coordinates F27/3, illustrated in Plate 2, fig. 11, curated at The Natural History Museum, London, slide number FD 515(1).

Dimensions. Cyst length 49–59 μm , breadth 46–63 μm .

Observed stratigraphic range. North Sea dinocyst zones: E2c to E4c of Bujak & Mudge (1994) (Early to Middle Eocene: Ypresian to Lutetian).

Remarks. The genus *Cerebrocysta* was erected by Bujak (1980) for specimens present in the Barton Beds of the Hampshire Basin, with the type species, *C. bartonensis* Bujak, having a cyst diameter ranging from 24–28 μm (Plate 2, fig. 12). *C. bartonensis* is persistently present in fairly low numbers in the North Sea where it has its highest occurrence in Bartonian Subzone E7a of Bujak & Mudge (1994). *C. magna* is identical to *C. bartonensis* in all respects except for its larger size, and there is no indication that the two species intergrade. *C. magna* has a more restricted stratigraphic range in the North Sea, having its highest occurrence at the top of Lutetian Subzone E4c of Bujak & Mudge (1994).

Genus *Diphyes* Cookson, 1965

Diphyes brevispinum sp. nov.

(Plate 2, figs 4–6)

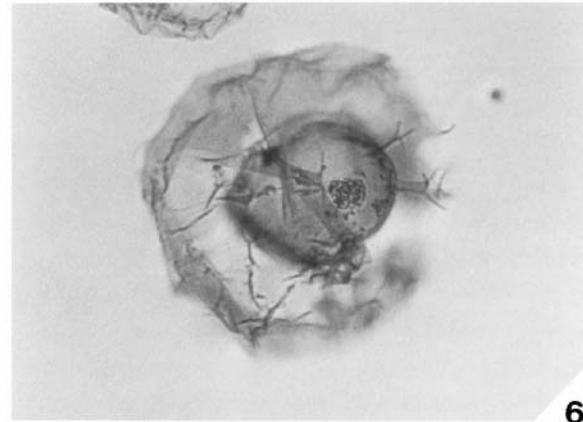
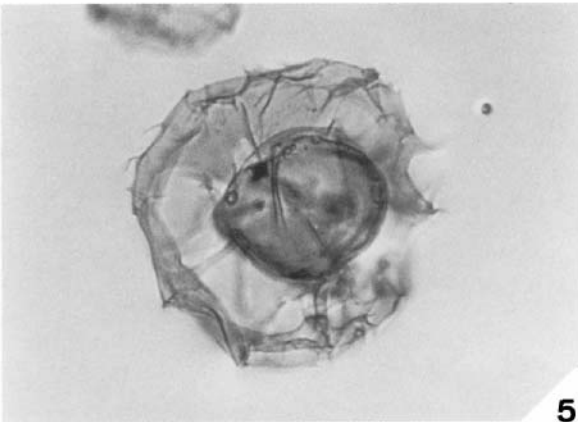
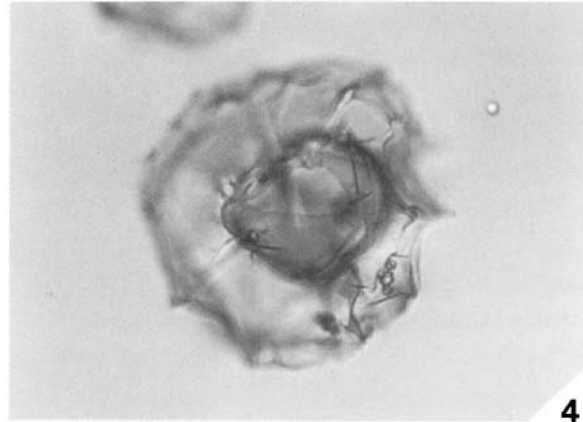
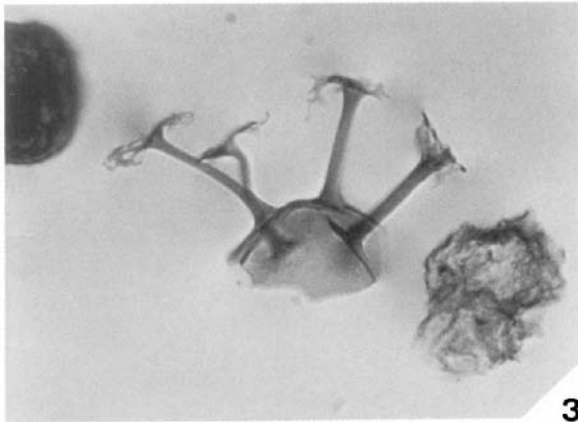
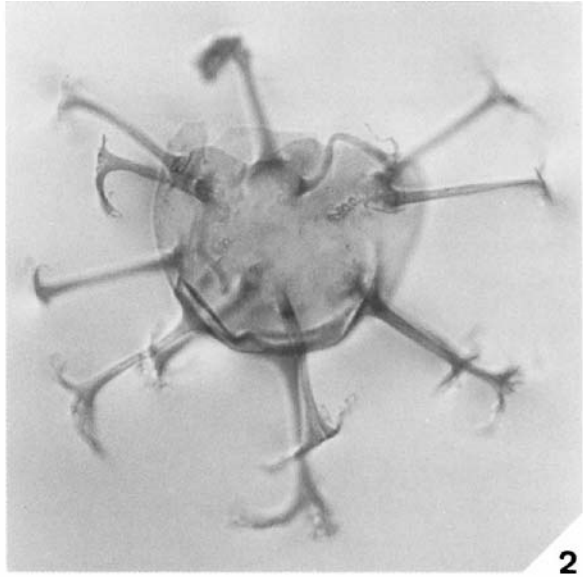
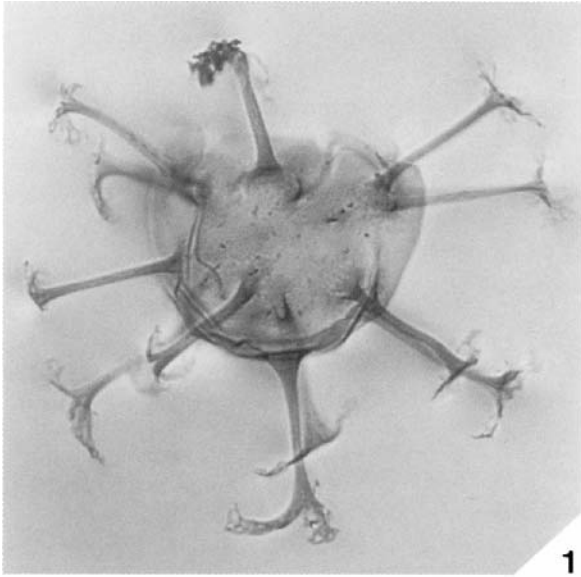


Plate 1

Derivation of name. Latin, *brevis*, short, plus *spina*, thorn, with reference to the short processes.

Diagnosis. Cyst subspherical, skolochorate and biphragmal, endophragm and periphragm adpressed except beneath the processes. Periphragm smooth to chaggrinate, forming numerous nontabular processes. Processes other than the antapical process less than $5\ \mu\text{m}$ in length, tubular, tapering from broader circular bases to narrow, open or closed terminations. Antapical process large, inflated, ovoidal to subspherical, with a closed circular base, and a constricted distal opening. Archeopyle apical; operculum tetraplacoid, contiguous.

Type locality and stratum. Locality: North Sea, UK21/28a-4 well. Stratum: section at 4580 ft, Early Eocene (Ypresian).

Holotype. UK21/28a-4, 4580 ft (sidewall core), England Finder coordinates R46/3, illustrated in Plate 2, figs 4–5, curated at Simon Petroleum Technology Ltd, Llandudno.

Paratypes. UK21/28a-4, 4567 ft (sidewall core), England Finder coordinates K38/0, illustrated in Plate 2, fig. 6, curated at Simon Petroleum Technology Limited, Llandudno; UK21/28a-4, 4567 ft (sidewall core), England Finder coordinates M47/3, curated at Simon Petroleum Technology Limited, Llandudno.

Dimensions. Central body length (without operculum) $22\text{--}28\ \mu\text{m}$, breadth $27\text{--}31\ \mu\text{m}$, antapical process length $17\text{--}20\ \mu\text{m}$, breadth $15\text{--}25\ \mu\text{m}$, maximum process length (excluding the antapical process) $2.5\text{--}4\ \mu\text{m}$.

Observed stratigraphic range. North Sea dinocyst zones: E3a to E3b of Bujak & Mudge (1994) (Early Eocene: Ypresian).

Remarks. *D. brevispinum* is intermediate in morphology between *D. ficusoides* Islam and *Duosphaeridium nudum* (Cookson) Loeblich & Loeblich. *D. nudum* does not possess processes except for the large antapical process, whereas *D. ficusoides* has processes that typically vary in length between $11\text{--}15\ \mu\text{m}$. *D. brevispinum* has a more restricted North Sea stratigraphic range than *D. ficusoides* which ranges up into Lutetian Subzone E4d of Bujak & Mudge (1994). *D. nudum* is rare in North Sea wells (Bujak, pers. obs.), and has approximately the same stratigraphic range as *D. brevispinum*.

Diphyes pseudoficusoides sp. nov.

(Plate 2, figs 2–3)

Derivation of name. Greek, *pseudos*, false, plus *ficusoides*, with reference to the similarity to, but distinction from *Diphyes ficusoides*.

Diagnosis. Cyst subspherical, skolochorate and biphragmal, endophragm and periphragm adpressed except beneath the processes. Periphragm smooth to chaggrinate, forming numerous nontabular processes. Processes greater than $10\ \mu\text{m}$ in length; processes other than the antapical process tubular, tapering from broad circular bases to narrow necks before ending in expanded, distally aculeate or entire terminations. Antapical process expanded, having a maximum breadth of between $10\ \mu\text{m}$ and $15\ \mu\text{m}$, and tapering distally to a constricted termination that is typically open. Archeopyle apical; operculum tetraplacoid, contiguous.

Type locality and stratum. Locality: North Sea, UK15/30-4 well. Stratum: section at 5760 ft, Middle Eocene (Lutetian).

Holotype. UK15/30-4, 5760 ft (ditch cuttings), England Finder coordinates L54/1, illustrated in Plate 2, fig. 3, curated at The Natural History Museum, London, slide number FD 526(1).

Paratypes. UK15/30-2, 6080 ft (ditch cuttings), England Finder coordinates L47/2, illustrated in Plate 2, fig. 2, curated at The Natural History Museum, London, slide number FD 525(1); UK22/14-1, 7780 ft (ditch cuttings), England Finder coordinates H39/0, curated at the British Geological Survey, Keyworth, slide number MPK 9718.

Dimensions. Central body length (without operculum) $29\text{--}34\ \mu\text{m}$, breadth $27\text{--}40\ \mu\text{m}$, antapical process length $13\text{--}21\ \mu\text{m}$, breadth $10\text{--}15\ \mu\text{m}$, maximum process length (excluding the antapical process) $12\text{--}17\ \mu\text{m}$.

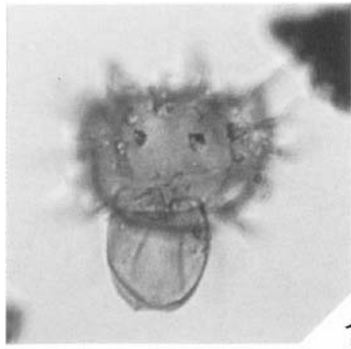
Observed stratigraphic range. North Sea dinocyst zones: E2b to E6a of Bujak & Mudge (1994) (Early to Middle Eocene: Ypresian to Lutetian).

Remarks. *D. pseudoficusoides* is distinguished from other species of *Diphyes* by its antapical process, which is intermediate in morphology between that on *D. colligerum* and *D. ficusoides*. The antapical process on *D. colligerum* typically varies in breadth between $6\text{--}8\ \mu\text{m}$, whereas that on *D. ficusoides* varies in breadth between $18\text{--}28\ \mu\text{m}$.

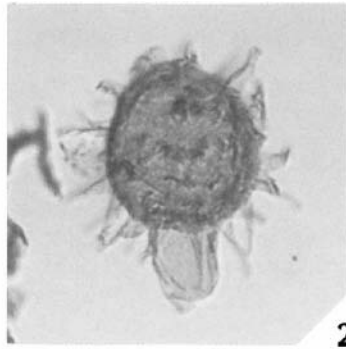
D. colligerum, *D. pseudoficusoides* and *D. ficusoides* have different stratigraphic ranges in the North Sea, where their last occurrences are zonal markers within the Eocene (Bujak & Mudge, 1994). *D. colligerum* has a last consistent occurrence at the top of Subzone E6c of Bujak & Mudge (1994), near the Lutetian–Bartonian boundary, but ranges up sporadically in the North Sea into the late Priabonian. *D. pseudoficusoides* has its last occurrence at the top of Lutetian Subzone E6a of Bujak & Mudge (1994), and *D. ficusoides* has its last occurrence at the top of Lutetian

Explanation of Plate 1

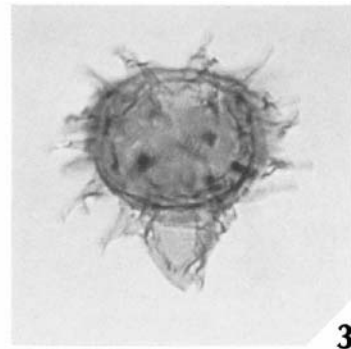
Magnification bar represents $20\ \mu\text{m}$ for all specimens. **Figs 1–3.** *Areosphaeridium michoudii* sp. nov. **Figs 1–2.** Holotype. UK21/28b-7, 3900 ft, showing the sexiform hypocystal process arrangement: fig. 1, lower dorsal surface; fig. 2, upper ventral surface. **Fig. 3.** Isolated operculum. UK21/28b-7, 3900 ft. **Figs 4–6.** *Hystrihostrogylon clausenii* sp. nov. Holotype. UK21/28b-7, 3900 ft: fig. 4, lower dorsal surface, showing the archeopyle formed by the loss of two precingular paraplates; fig. 5, optical section, showing the claustrum developed on the left cingular–postcingular side of the periphragm; fig. 6, upper ventral surface.



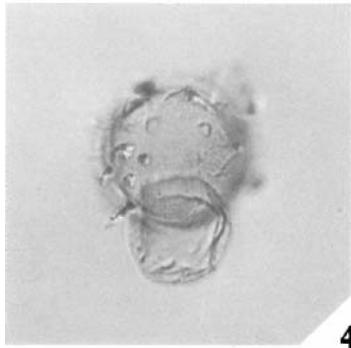
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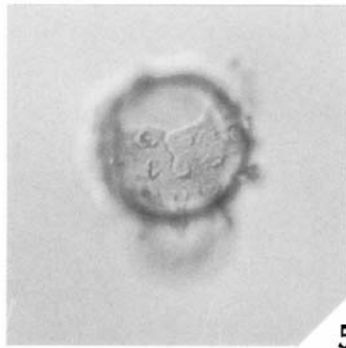
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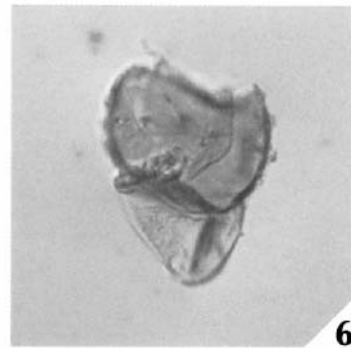
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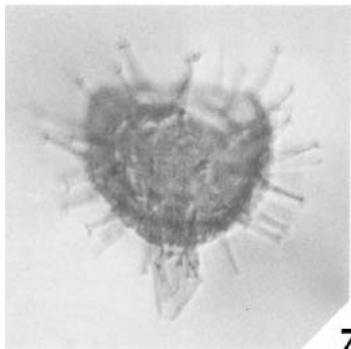
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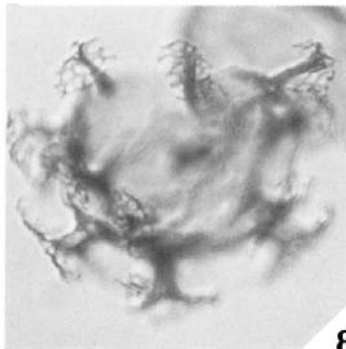
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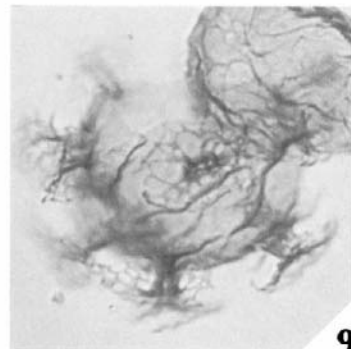
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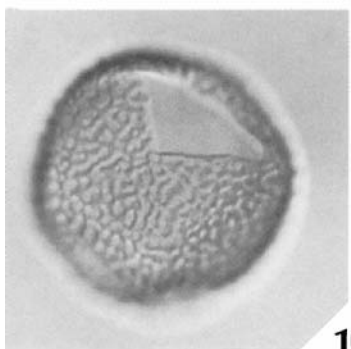
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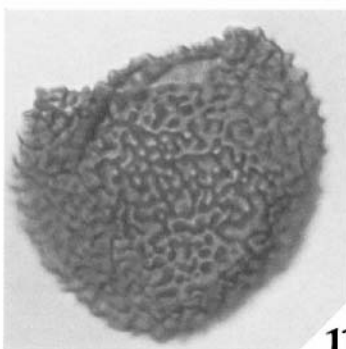
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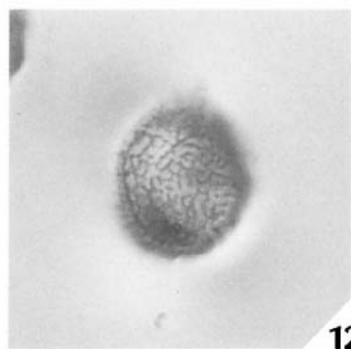
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Plate 2

Subzone E4d of Bujak & Mudge (1994). *D. ficusoides* and *D. pseudoficusoides* have their first North Sea occurrences in the early Ypresian, whereas *D. colligerum* ranges down in the Palaeocene in the North Sea Basin.

Genus *Hystrichosphaeropsis* Deflandre, 1935

Hystrichosphaeropsis costae sp. nov.

(Plate 3, figs 1–4)

1989 *Hystrichosphaeropsis* sp. 1 Heilmann-Clausen & Costa: 467, pl. 17, figs 1–4, 6–8.

1993 *Hystrichosphaeropsis* sp. Heilmann-Clausen: 98, text-figs 5C–D.

Derivation of name. Named after the palynologist Lucy Costa.

Diagnosis. A species of *Hystrichosphaeropsis* with a weakly developed apical horn, and without antapical horns but with a well-developed antapical pericoel. Endophragm and periphragm smooth to chagriniate. Low, perforate or unperforate parasutural crests variably and incompletely developed, and typically absent from the paracingular region. Low, simple or bifid gonial processes may be present on the paracingulum. A claustrum is sometimes present near the antapex in the postcingular periphragm. Archeopyle precingular, formed by the loss of paraplate 3".

Type locality and stratum. Locality: North Sea, UK22/14-1 well. Stratum: section at 8020 ft, Early Eocene (Ypresian).

Holotype. UK22/14-1, 8020 ft (ditch cuttings), England Finder coordinates P36/2, illustrated in Plate 3, figs 1–3, curated at the British Geological Survey, Keyworth, slide number MPK 9719.

Paratypes. UK22/14-1, 8020 ft (ditch cuttings), England Finder coordinates L50/1, illustrated in Plate 3, fig. 4; UK22/14-1, 8020 ft (ditch cuttings), England Finder coordinates R64/3; UK22/14-1, 8020 ft (ditch cuttings), England Finder coordinates M35/2; UK22/14-1, 8020 ft (ditch cuttings), England Finder coordinates J47/4. All paratypes curated at the British Geological Survey, Keyworth, slide numbers MPK 9720 to 9723.

Dimensions. Pericyst length 56–75 μm , breadth 40–55 μm , endocyst length 32–49 μm , breadth 36–51 μm , maximum process length 3–5 μm .

Observed stratigraphic range. North Sea dinocyst zones: E3a to E4c of Bujak & Mudge (1994) (Early to Middle Eocene: Ypresian to Lutetian).

Remarks. *H. costae* is distinguished from *Rottnestia borussica* (Eisenack) in possessing poorly developed

parasutural crests, and in having processes that are absent or restricted to the paracingular region and which are much shorter than those on *R. borussica* (typical process length on *R. borussica* is greater than 10 μm). *H. costae* differs from *Hystrichosphaeropsis? rectangularis* Bujak in having less well-developed parasutural crests.

H. costae is considered to be conspecific with *Hystrichosphaeropsis* sp. 1, which Heilmann-Clausen & Costa (1989) described from the Wursterheide research well, northwest Germany, within the Glinde Formation, assigned to NP14 in their table 1. This informal species was also described from both the German Wursterheide research well and the Hinge section in Denmark as *Hystrichosphaeropsis* sp. by Heilmann-Clausen (1993). Heilmann-Clausen documented a morphological series from *R. borussica* to *Hystrichosphaeropsis* sp. and suggested that *Hystrichosphaeropsis* sp. was descended from *R. borussica*.

Genus *Hystrichostrogylon* Agelopoulos, 1964

Hystrichostrogylon clausenii sp. nov.

(Plate 1, figs 4–6)

1989 *Hystrichostrogylon* sp. 1 Heilmann-Clausen & Costa: 468, pl. 18, figs 5, 6, 8, 9.

Derivation of name. Named after the palynologist Claus Heilmann-Clausen.

Diagnosis. Endocyst smooth with a circular outline. Periphragm smooth to chagriniate, compressed dorso-ventrally, forming a high membrane surrounding the ambital periphery of the cyst, except in the mid-dorsal and mid-ventral regions where the periphragm and endophragm are in contact. Trifurcate and occasional bifurcate processes extend a short distance above the periphragm, except on the right lateral side of the cyst where the height of the periphragm is reduced and the length of the processes extending beyond the membrane is increased. A claustrum is typically developed on the left cingular-postcingular side of the periphragm. Archeopyle precingular, formed by the loss of paraplate 3" and sometimes also paraplates 2" and/or 4".

Type locality and stratum. Locality: North Sea, UK21/28b-7 well. Stratum: section at 3900 ft, Middle Eocene (Lutetian).

Holotype. UK21/28b-7, 3900 ft (ditch cuttings), England Finder coordinates G23/0, illustrated in Plate 1, figs 4–6, curated at The Natural History Museum, London, slide number FD 513(2).

Paratype. UK21/28a-6, 4320 ft (ditch cuttings), England

Explanation of Plate 2

Magnification bar represents 20 μm for all specimens. **Fig. 1.** *Diphyes ficusoides* Islam. Holotype shown for comparison with *Diphyes pseudoficusoides* and *Diphyes brevispinum*. **Figs 2–3.** *Diphyes pseudoficusoides* sp. nov.: fig. 2, paratype. UK15/30-2, 6080 ft; fig. 3, holotype. UK15/30-4, 5760 ft. **Figs 4–6.** *Diphyes brevispinum* sp. nov.: figs 4–5 Holotype. UK21/28a-4, 4580 ft; fig. 4, lower, oblique antapical view; fig. 5, upper, oblique apical view; fig. 6, paratype. UK21/28a-4, 4567 ft. **Fig. 7.** *Diphyes colligerum* (Deflandre & Cookson) Cookson. UK21/28b-7, 3676 ft. Shown for comparison with *Diphyes pseudoficusoides*. **Figs 8–9.** *Areosphaeridium ebdonii* sp. nov. Holotype. UK22/14-1, 8020 ft: fig. 8, lower surface; fig. 9, upper surface. **Figs 10–11.** *Cerebrocysta magna* sp. nov.: fig. 10, holotype, lower dorsal surface. UK21/28a-5, 4619 ft, fig. 11, paratype, upper surface. UK16/26-2, 7030 ft. **Fig. 12.** *Cerebrocysta bartonensis* Bujak. UK21/28b-7, 3960 ft. Shown for comparison with *Cerebrocysta magna*.

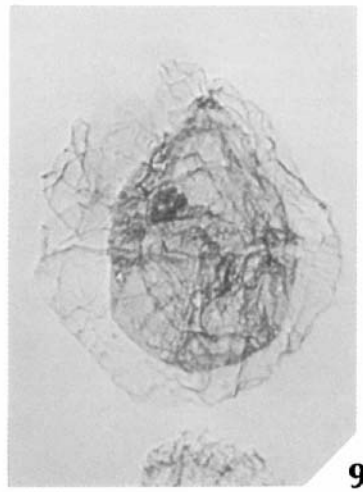
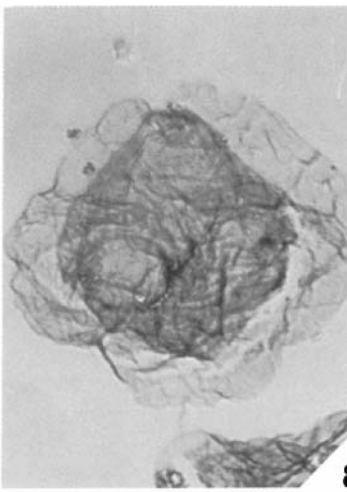
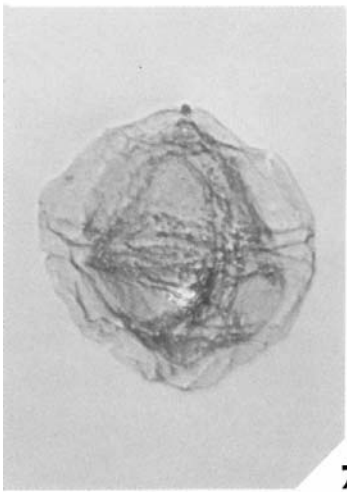
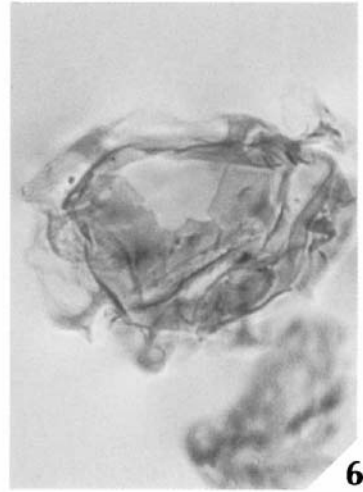
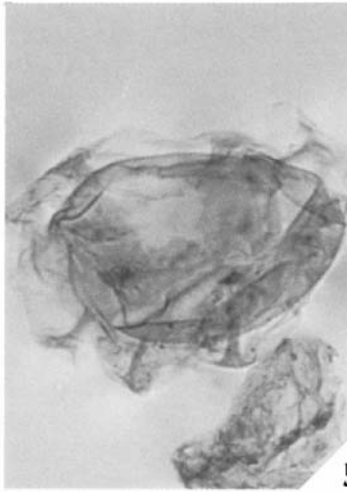
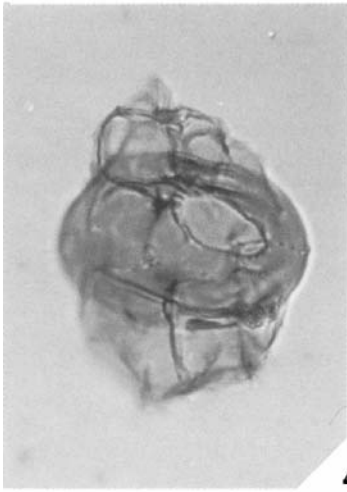
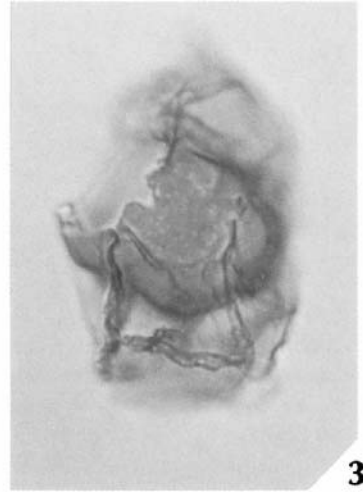
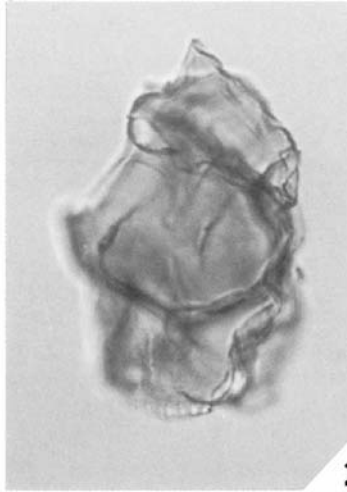
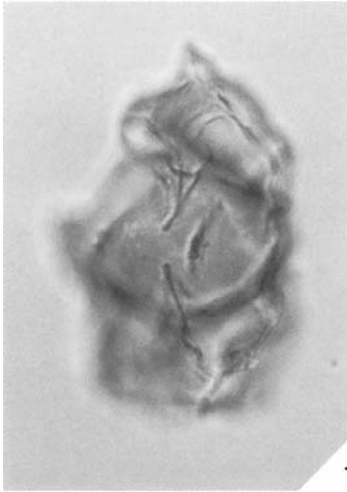


Plate 3

Finder coordinates Q32/3, curated at Simon Petroleum Technology Limited, Llandudno.

Dimensions. Pericyst length 63–73 μm , breadth 63–75 μm , endocyst length 32–41 μm , breadth 31–40 μm .

Observed stratigraphic range. North Sea dinocyst zones: E3c to E4c of Bujak & Mudge (1994) (Early to Middle Eocene; Ypresian to Lutetian).

Remarks. *H. clausenii* is considered to be conspecific with *Hystrichostrogydon* sp. 1, which Heilmann-Clausen & Costa (1989) described from the Wursterheide research well, northwest Germany, within the Glinde Formation, assigned to NP14 in their table 1.

Genus *Membranilarnacia* Eisenack, 1963

Membranilarnacia compressa sp. nov.

(Plate 3, figs 5–6)

1975 *Membranilarnacia* sp. A De Coninck 1975: 94, pl. 16, figs 17–19; pl. 17, fig 1.

1989 *Membranilarnacia* sp. A Heilmann-Clausen & Costa 1989: pl. 11, figs 4, 8, 9.

Derivation of name. Latin, *compressus*, compressed, with reference to the compressed nature of the cyst resulting from the short processes.

Diagnosis. Endocyst subspherical to ovoidal; periphragm smooth to chagriniate, in contact with the endophragm except beneath the processes. Processes intratabular, solid or hollow, proximally and distally expanded, less than 15 μm in length. Processes supporting a continuous, smooth, entire, or occasionally perforate ectophragm. Paratabulation gonyaulacoid, delimited formula 4', 6'', 0c, 5''', 1p, 1''', 0s. Archeopyle apical; tetraplacoid and contiguous.

Type locality and stratum. Locality: North Sea, UK21/28b-7 well. Stratum: section at 3960 ft, Early Eocene (Ypresian).

Holotype. UK21/28b-7, 3960 ft, (ditch cuttings) England Finder coordinates M34/4, illustrated in Plate 3, figs 5–6, curated at The Natural History Museum, London, slide number FD 516(1).

Paratype. UK21/28b-7, 3960 ft, (ditch cuttings) England Finder coordinates N23/2, curated at The Natural History Museum, London, slide number FD 516(2).

Dimensions. Central body length (without operculum) 37–50 μm , breadth 36–52 μm , maximum process length 6–11 μm .

Observed stratigraphic range. North Sea dinocyst zones: E2a to E3a of Bujak & Mudge (1994) (Early Eocene; Ypresian).

Remarks. The ectophragm on *M. compressa* is generally entire, but rare specimens have been observed in the

North Sea with a perforate ectophragm. These have the same stratigraphic range as specimens with an entire ectophragm, and they are included in *M. compressa*.

M. compressa has shorter processes than those on *Membranilarnacia glabra* Agelopoulos, which are typically 15–21 μm in length. *M. glabra* last occurs in the North Sea at the top of Ypresian Subzone E3c of Bujak & Mudge (1994), whereas *M. compressa* last occurs at the top of Ypresian Subzone E3a of Bujak & Mudge (1994). Species of *Eatonicysta* Stover & Evitt differ from *M. compressa* in possessing an ectophragm that is reticulate, fenestrate or irregularly net-like.

M. compressa is considered to be conspecific with *Membranilarnacia* sp. A, which De Coninck (1975) illustrated from the Argile de Merelbeke in the Kallo borehole, Belgium, assigned to NP13 by Verbeek (1988). Heilmann-Clausen & Costa (1989) also recorded *Membranilarnacia* sp. A *sensu* De Coninck (1975) from the Ypresian Heiligen-Hafen Formation of the Wursterheide research well, northwest Germany, between sections assigned to NP12 and NP14.

Family **Deflandraceae** Eisenack, 1954

Genus *Phthanoperidinium* Drugg & Loeblich, 1967

Remarks. Islam (1982) emended the diagnosis of *Phthanoperidinium* to include three major types of archeopyle: (1) intercalary archeopyles involving paraplate 2a; (2) combination precingular-intercalary archeopyles involving paraplates 4'' and 2a; (3) combination precingular-intercalary archeopyles involving paraplates 2–4'' and 1–3a.

Phthanoperidinium clithridium sp. nov.

(Plate 4, figs 1–3)

Derivation of name. Greek, *kleithridion*, small key-hole, with reference to the shape of the archeopyle.

Diagnosis. Pericyst ovoidal with one small apical horn and one or two unequal antapical horns, the right always being strongly reduced. Endocyst ovoidal, and in contact with the periphragm except sometimes beneath the apical and antapical horns. Periphragm chagriniate to granulate with or without extremely low parasutural crests. When present these partially delimit a paratabulation of 4', 3a, 7'', xc, 5''', 2'''. An archeopyle is always formed by the loss of paraplates 2a and 4''.

Type locality and stratum. Locality: North Sea, UK16/16b-4 well. Stratum: section at 5900 ft, Middle Eocene (Lutetian).

Holotype. UK16/16b-4, 5900 ft (ditch cuttings), England Finder coordinates K36/4, illustrated in Plate 4, figs 1–2,

Explanation of Plate 3

Magnification bar represents 20 μm for all specimens. **Figs 1–4:** *Hystrichosphaeropsis costae* sp. nov. **Figs 1–3.** Holotype. UK22/14-1, 8020 ft; fig. 1, lower surface; fig. 2, optical section; fig. 3, upper surface. **Fig. 4.** Paratype. UK22/14-1, 8020 ft. **Figs 5–6.** *Membranilarnacia compressa* sp. nov. Holotype. UK21/28b-7, 3960 ft; fig. 5, lower surface; fig. 6, upper surface. **Figs 7–9.** *Phthanoperidinium powellii* sp. nov.: fig. 7, paratype. UK16/16b-4, 5200 ft; figs 8, holotype. UK16/26-2, 6280 ft; fig. 9, paratype. UK16/17-2A, 6010 ft.

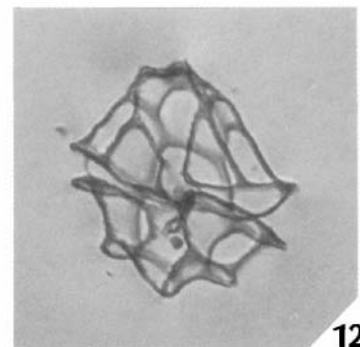
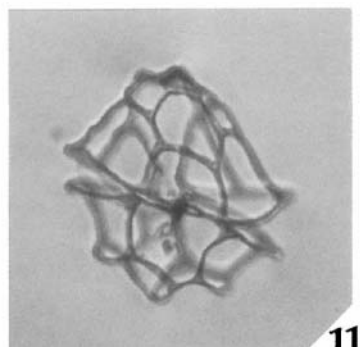
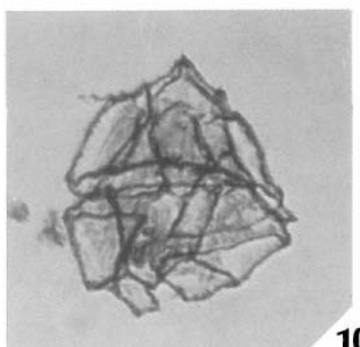
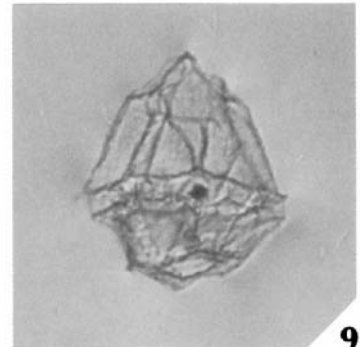
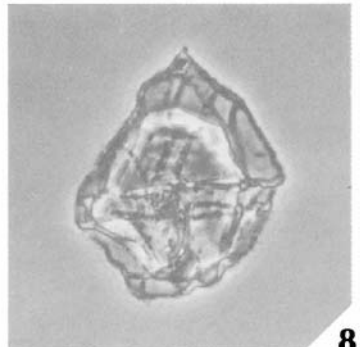
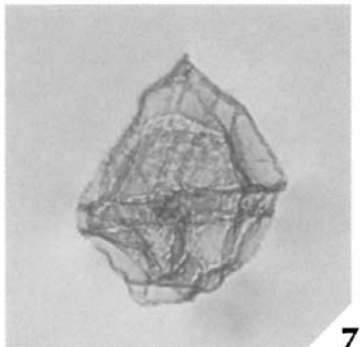
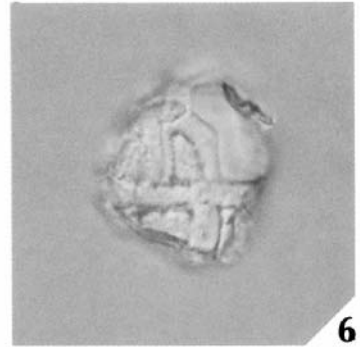
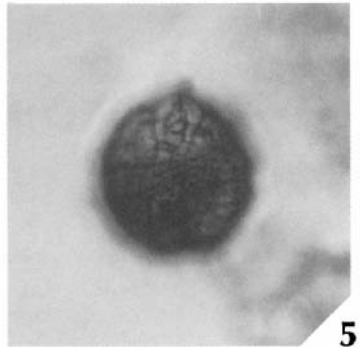
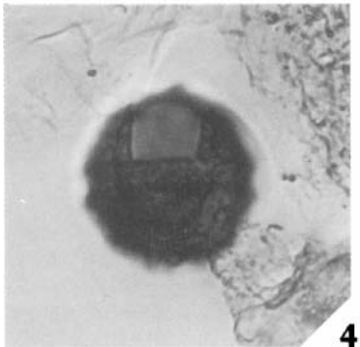
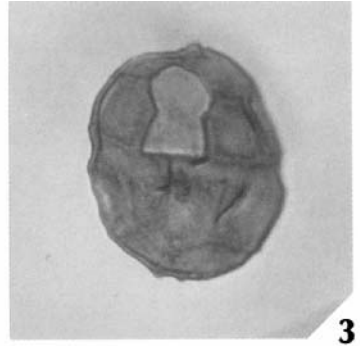
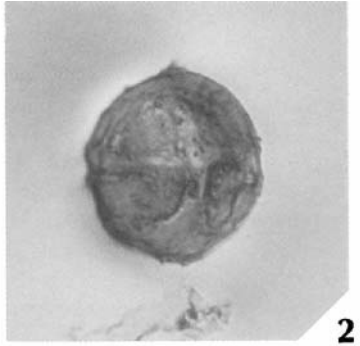
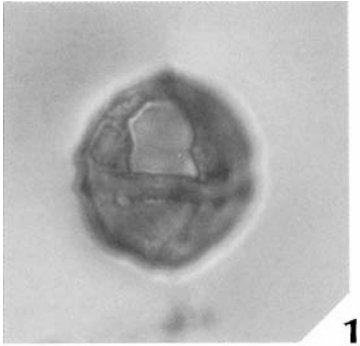


Plate 4

curated at The Natural History Museum, London, slide number FD 518(1).

Paratypes. UK16/16b-4, 5900 ft (ditch cuttings), England Finder coordinates P35/2, illustrated in Plate 4, fig. 3, curated at The Natural History Museum, London, slide number FD 518(2); UK16/16b-4, 6040 ft (ditch cuttings), England Finder coordinates P41/0, curated at The Natural History Museum, London, slide number FD 525(1).

Dimensions. Pericyst length 32–44 μm , breadth 27–40 μm , apical horn length less than 2 μm .

Observed stratigraphic range. North Sea dinocyst zones: E4c to E5a of Bujak & Mudge (1994) (Middle Eocene: Lutetian).

Remarks. *P. clithridium* is distinguished from all other species of *Phthanoperidinium* except *P. regalis* by the formation of an archeopyle involving the loss of paraplates 2a and 4". The mode of archeopyle formation is identical in *P. clithridium* and *P. regalis* which differ in their ornament. *P. clithridium* does not possess the penitabular ornament present on *P. regalis* and has less well-defined parasutural ornament. Rare specimens intergrade between these taxa, but the majority of specimens comprise distinct morphological populations, which have different palaeogeographic distributions in the North Sea (Bujak, pers. obs.). *P. clithridium* has not been recorded outside the North Sea region.

Phthanoperidinium distinctum sp. nov.

(Plate 4, figs 7–12)

Derivation of name. Latin, *distinctus*, distinct, with reference to the distinctive morphology of the cyst.

Diagnosis. Pericyst subpolygonal peridinioid, with a small but distinct apical horn, without antapical horns or with a poorly developed left antapical horn. Endocyst ovoidal, thin and often corroded, sometimes absent due to preservation, exhibiting birefringence under phase contrast illumination. Periphragm thin and chaggrinate, forming low but thick and robust parasutural crests that are distally smooth and delimit a paratabulation of 4', 3a, 7", 6c, 5"', 2'''. Penitabular areas of the periphragm between the parasutural crests may be absent due to corrosion. Archeopyle formed by the loss of paraplate 2a.

Type locality and stratum. Locality: North Sea, UK16/16b-4 well. Stratum: section at 5624 ft, Middle Eocene (Lutetian).

Holotype. UK16/16b-4, 5624 ft (sidewall core), England Finder coordinates K24/3, illustrated in Plate 4, figs 7–8, curated at The Natural History Museum, London, slide number FD 519(1).

Paratypes. UK21/28a-5, 4460 ft (ditch cuttings), England Finder coordinates E39/2, illustrated in Plate 4, fig. 9, curated at Simon Petroleum Technology Limited, Llandudno; UK21/28b-7, 3740 ft (ditch cuttings), England Finder coordinates N35/2, curated at The Natural History Museum, London, slide number FD 520(1).

Dimensions. Pericyst length 37–50 μm , breadth 38–46 μm , apical horn length less than 2 μm .

Observed stratigraphic range. North Sea dinocyst zones: E6a to E6b of Bujak & Mudge (1994) (Middle Eocene: Lutetian).

Remarks. *P. distinctum* is characterized by its peridinioid shape, thin birefringent endocyst that may be corroded or absent, and the low but robust smooth parasutural crests. The periphragm between the crests is thin and may be absent, so that all that remains of the cyst in these extreme cases is a paratabular network of crests (Plate 4, figs 11–12).

Phthanoperidinium powellii sp. nov.

(Plate 3, figs 7–9)

Derivation of name. Named after the palynologist A.J. Powell.

Diagnosis. Endocyst compressed dorso-ventrally, with an oval ambitus and one small conical apical horn; antapical horns absent or very poorly developed. Endophragm relatively thick, ovoidal and chaggrinate to granulate. Pericyst ovoidal, sometimes with a small, solid apical horn. Periphragm thin and smooth to chaggrinate, separated from the endocyst by a wide pericoel. Paratabulation indistinct or absent, sometimes poorly delimited by extremely low and indistinct parasutural crests on the periphragm. Paracingulum circular to weakly helicoidal, delimited by low crests. Parasulcus narrow and poorly defined. Archeopyle typically formed by the loss of paraplate 2a, or by the loss of paraplates 1a to 3a on rare specimens.

Type locality and stratum. Locality: North Sea, UK16/26-2 well. Stratum: section at 6280 ft, Middle Eocene (Lutetian).

Holotype. UK16/26-2, 6280 ft (ditch cuttings), England Finder coordinates P34/1, illustrated in Plate 3, fig. 8, curated at The Natural History Museum, London, slide number FD 521(1).

Paratypes. UK16/16b-4, 5200 ft (ditch cuttings), England Finder coordinates N28/0, illustrated in Plate 3, fig. 7, curated at The Natural History Museum, London, slide number FD 522(1); UK16/17-2A, 6010 ft, England Finder coordinates U36/3, illustrated in Plate 3, fig. 9, curated at The Natural History Museum, London, slide number FD 523(1).

Explanation of Plate 4

Magnification bar represents 20 μm for all specimens. **Figs 1–3.** *Phthanoperidinium clithridium* sp. nov. **Figs 1–2.** Holotype. UK16/16b-4, 5900 ft: fig. 1, lower dorsal surface showing the archeopyle formed by the loss of paraplates 4" and 2a; fig. 2, upper ventral surface. **Fig. 3.** Paratype. UK16/16b-4, 5900 ft. **Figs 4–6.** *Phthanoperidinium regalis* sp. nov. **Figs 4–5.** Holotype. UK16/16b-4, 6040 ft: fig. 4, upper dorsal surface; fig. 5, optical section. **Fig. 6.** Paratype. 16/16a-3, 1689 m. **Figs 7–12.** *Phthanoperidinium distinctum* sp. nov. **Figs 7–8.** Holotype. UK16/16b-4, 5624 ft: fig. 8, phase contrast illumination showing the birefringent endocyst. **Fig. 9.** Paratype. UK21/28a-5, 4460 ft. **Fig. 10.** UK22/16-1, 8100 ft. Specimen with a corroded endophragm. **Figs 11–12.** UK21/28a-4, 4190 ft. Specimen without endophragm, and with the periphragm removed between the paratabular crests: fig. 11, lower dorsal surface; fig. 12, upper ventral surface.

Dimensions. Pericyst length 56–65 μm , breadth 51–65 μm , endocyst length 43–51 μm , breadth 34–44 μm , maximum pericoel height 7.5–14 μm , apical horn length on endocyst 3–5 μm .

Observed stratigraphic range. North Sea dinocyst zones: E6a to E6b of Bujak & Mudge (1994) (Middle Eocene: Lutetian).

Remarks. *P. powelli* is distinguished from all other species of *Phthanoperidinium* by the presence of a large pericoel.

Phthanoperidinium regalis sp. nov.

(Plate 4, figs 4–6)

Derivation of name. Latin, *regale*, royal.

Diagnosis. Pericyst ovoidal with one small apical horn and one or two unequal antapical horns, the right always being strongly reduced. An endocyst is rarely visible, but is sometimes present beneath the apical horn. Periphragm chagriniate to granulate with parasutural rows of granulae, short spines, or low, irregular crests. These delimit a paratabulation of 4', 3a, 7", 6c, 5"', 2'''. Strongly developed penitabular rows or zones of similar ornament lie 1–3 μm inside the parasutures, except adjacent to the paracingulum where the parasutural and penitabular ornament merges. Archeopyle always formed by the loss of paraplates 2a and 4''.

Type locality and stratum. Locality: North Sea, UK16/16b-4 well. Stratum: section at 6040 ft, Middle Eocene (Lutetian).

Holotype. UK16/16b-4, 6040 ft (ditch cuttings), England Finder coordinates K26/4, illustrated in Plate 4, figs 4–5, curated at The Natural History Museum, London, slide number FD 525(2).

Paratype. UK16/16a-3, 1689 m (sidewall core), England Finder coordinates P37/1, illustrated in Plate 4, fig. 6, curated at BP Operating Company, Aberdeen.

Dimensions. Pericyst length 37–46 μm , breadth 33–37 μm , apical horn length 2–3 μm .

Observed stratigraphic range. North Sea dinocyst zones: E4c to E5a of Bujak & Mudge (1994) (Middle Eocene: Lutetian).

Remarks. *P. regalis* is identical to *P. geminatum* Bujak in all respects except for the mode of archeopyle formation which comprises the loss of paraplate 2a in *P. geminatum*, and the loss of paraplates 2a and 4'' in *P. regalis*. The stratigraphic ranges of the two taxa are also distinct. *P. regalis* has its last North Sea occurrence in Lutetian Subzone E5a of Bujak & Mudge (1994), whereas *P. geminatum* ranges up into the Bartonian.

The mode of archeopyle formation is identical in *P. regalis* and *P. clithridium* which differ in their ornament. *P. clithridium* does not possess the penitabular ornament present on *P. regalis* and has less well-defined parasutural crests. Rare specimens intergrade between these taxa, but the majority of specimens assigned to the two taxa comprise populations with distinct palaeogeographic distributions in the North Sea (Bujak, pers. obs.). *P. regalis* has not been recorded outside the North Sea region.

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