

AN EARLY CRETACEOUS DINOCYST ASSEMBLAGE FROM THE WEALDEN OF SOUTHERN ENGLAND

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ABSTRACT. A dinocyst assemblage from the Warlingham borehole, Surrey is described. One new species, *Australisphaera fragilis* is erected. The genus *Australisphaera* and the species *Taleisphaera hydra* and *Subtilisphaera terrula* are emended. In contrast with other known dinocyst assemblages from the 'non-marine' Wealden, the majority of the species discovered are known from truly marine sediments. The varying morphologies and fluctuating diversity of the dinocysts in the study samples allow a number of palaeoenvironmental conclusions to be drawn. These conclusions conflict with the observed distribution of low-salinity ostracods, which are now believed to be hydrodynamically controlled in their distribution. Evidence of a Boreal source for marine incursions into the Wealden basin during Weald Clay times is presented. The dinocyst assemblage is interpreted as being late Hauterivian in age.

INTRODUCTION

An important local requirement in Britain is for detailed time-correlation of the virtually non-marine Wealden succession of southern England with the traditional international stratigraphical scale of the marine Cretaceous of Europe. N. F. Hughes (1973, p. 186)

IN an attempt to accomplish the above time-correlation, material from four north-west European Lower Cretaceous localities is being studied. The results of the palynological investigation of one of these sequences are the subject of this paper.

The non-marine deposits of the Weald Clay of southern England have long been suspected to span the Hauterivian and Barremian stages of the Lower Cretaceous. This supposition was originally based on purely sedimentological grounds (e.g. Allen 1965). However, the lack of age-diagnostic marine megafossils in the thick Wealden succession has complicated attempts at detailed correlation with marine sediments of similar age in Europe, which have ammonite-based zonal systems. Limited corroboration of a Hauterivian to Barremian age for the Weald Clay has come from the ostracod zonation system devised by Anderson (1971, 1973). Unfortunately, this system has limited potential as only one species, *Orthonotacythere diglypta* (Triebel), is common to both the Wealden (Anderson *et al.* 1967, p. 191) and the marine Boreal Lower Cretaceous (Neale 1973, table 1).

Correlations of separate 'Wealden' successions in England based on sporomorphs (Hughes and Croxton 1973) have met with some success, but do not refer to truly marine sequences. Direct sporomorph correlation of Wealden strata with marine sequences (e.g. Speeton, Yorkshire) is only made possible by referring to an intermediate sequence of mixed facies (e.g. Lincolnshire) (Hughes 1958, 1973). Such detailed intermediate steps in the sporomorph correlation procedure have so far not been undertaken.

Attention has recently shifted to the dinocyst component of the palynoflora which, hitherto, has only been reported briefly (Batten 1973, 1982; Batten and Eaton 1980; Hughes 1975, 1980; Hughes and Moody-Stuart 1967). These microplankton assemblages, though of limited occurrence and restricted diversity (e.g. Batten and Eaton 1980; Hughes and Harding 1985), are potentially useful for performing detailed stratigraphic correlation.

SAMPLES AND METHODS

Twenty-six samples were studied, taken from a collection of unregistered samples given to Dr N. F. Hughes by the Geological Survey in 1959. These lie between 1391 ft (423.96 m) and 1513 ft 3 in. (461.22 m) in the Weald Clay succession of the Warlingham borehole, Surrey, drilled in 1956–1958 south of London (Worssam and Ivimey-Cook 1971). Of these samples 24 were of a greenish-grey silty mudstone (often reddened by oxidation), whilst WM 1418 ft 3–6 in. (432.26–432.34 m) and WM 1423 ft 2 in. (433.76 m), were of glauconitic sandstone. A more detailed account of the lithological sequence is given by Worssam and Ivimey-Cook (1971, pp. 22–23, 63–65).

All samples were treated with standard palynologic extraction techniques: dilute HCl, HF, hot HCl, conc. HNO₃ oxidation, dilute NH₄OH, ZnBr (S.G. = 2.0) heavy liquid separation. Some stored residues up to 25 years old have successfully been extracted from hardened glycerine jelly with hot water or HF, depending on their solidity. Residues are now stored in 50:50 glycerine/water solution.

Light microscope slides were made by standard Hydramount/Depex or polyvinyl alcohol/Depex methods. A count of 200 palynomorphs was made per slide, to determine the percentage of microplankton and sporomorphs present. One slide was examined for each sample studied. Samples found to contain dinocysts in slide observations were also examined using the scanning electron microscope (technique in Hughes *et al.* 1979). Stubs were sputter-coated with gold and observed on a Philips 501B scanning electron microscope. Micrographs were taken on 70 mm Ilford FP4 film.

All specimens and preparations are lodged in the Sedgwick Museum, Cambridge.

SYSTEMATIC SECTION

The following is a list of dinocysts encountered in the study samples. Those marked with an asterisk are discussed in the text, under one of three headings: Gonyaulacacean Group, Ceratiacean Group, or Peridiniacean Group. Dimensions are given as (x) y (z) measurements, x being smallest, z the largest, and y the average of observed values for the dimension under discussion. The number of specimens examined is given as v (w), v being the number of examples photographed and w the number of those specimens measured.

Marine palynomorphs

Acanthomorph acritarchs

**Australisphaera fragilis* sp. nov.

Cassiculosphaeridia magna Davey 1974.

**Cribroperidinium diaphane* (Cookson and Eisenack 1958) Stover and Evitt 1978

Ctenidodinium elegantulum (Millioud 1969) Below 1981.

**Cyclonephelium* spp.

**Gonyaulacysta* sp. A.

Gonyaulacysta sp. B.

Hystrihosphaerina schindewolfii Alberti 1961.

Kiokansium polyopes (Cookson and Eisenack 1962) Below 1982.

Muderongia simplex Alberti 1961.

**M. simplex* Alberti 1961 subsp. *microperforata* Davey 1982.

M. staurota Sarjeant 1966c.

**Oligosphaeridium complex* (White 1842) Davey 1982.

?*Oligosphaeridium* sp.

Pseudoceratium pelliiferum (Gocht 1957) Dörhöfer and Davies 1980 (Pl. 17 fig. 11).

Subtilisphaera perlucida (Alberti 1959b) Jain and Milleped 1973.

**S. terrula* (Davey 1974) Lentin and Williams 1976.

?*Surculosphaeridium* sp.

Spiniferites sp. (Pl. 17, fig. 4).

**Taleisphaera hydra* Duxbury 1979.

*Gonyaulacacean Group**Genus* CRIBROPERIDINIUM (Neale and Serjeant 1962) Helenes 1985*Cribroperidinium diaphane* (Cookson and Eisenack 1958) Stover and Evitt 1978

Plate 16, figs. 1 and 2

1958 *Gonyaulax diaphanis* Cookson and Eisenack, p. 36, pl. 3, figs. 13 and 14.1969 *Gonyaulacysta diaphanis* Sarjeant, p. 9.1978 *Cribroperidinium diaphane* Stover and Evitt, p. 150.1981 *Cribroperidinium diaphanis* Below, p. 37, pl. 8, figs. 10–12; pl. 13, fig. 6.*Dimensions.* Length (50) 63.2 (83) μm , breadth (40) 50.4 (66) μm , 215 (43) specimens.

Remarks. High resolution micrographs have enabled the following paraplate formula to be determined: 4', 6'', 6c, 6' ", 1" ", as, ra, rs, ls, ps, lp. This form exhibits a tremendous morphological variability, both in size and ornamentation. Attempts to subdivide the species complex have proved difficult. A continuous series of morphotypes from those with prominent apical horns and strong ornamentation to those with reduced horns and subdued ornamentation, complicates the procedure. The author believes that the specimens observed may form a continuous variation series between the limits of *C. diaphane* and *C. comptum* (Duxbury 1979) Lentin and Williams 1981.

Genus GONYAULACYSTA (Deflandre 1964) Stover and Evitt 1978*Gonyaulacysta* sp. A

Plate 17, fig. 6

Remarks. This is very rare in these samples; only four specimens were isolated from samples WM 1446 ft 6 in. (440.87 m) and WM 1421 ft 3 in. (433.18 m). It bears a strong resemblance to *G. helicoidea* (Eisenack and Cookson 1960) Sarjeant 1966b. However, there are prominent gonal extensions of the parasutural crests, reaching maximum development in the formation of a left antapical 'horn'. The cyst is cavate; the endocyst can clearly be seen in the archaeopyle region. A prominent sub-cylindrical, hollow, apical horn is another distinguishing feature.

Genus OLIGOSPHAERIDIUM (Davey and Williams 1966) Davey 1982*Oligosphaeridium complex* (White 1842) Davey 19821842 *Hystrichosphaeridium complex* White, p. 39, pl. 4, div. 3, fig. 11.1966 *Oligosphaeridium complex* Davey and Williams, pp. 71–74, pl. 7, figs. 1 and 2; pl. 10, fig. 3.*Dimensions.* Cyst diameter (less processes) (32) 38.3 (45) μm , cyst diameter (including processes) (62) 70.6 (82) μm , 9 (7) specimens.

Remarks. An uncommon form in these samples, with broad, stout processes, it is very similar to the examples illustrated by Thusu (1978, pl. 5, figs. 5–7). The processes are flared to buccinate distally, rarely showing perforations.

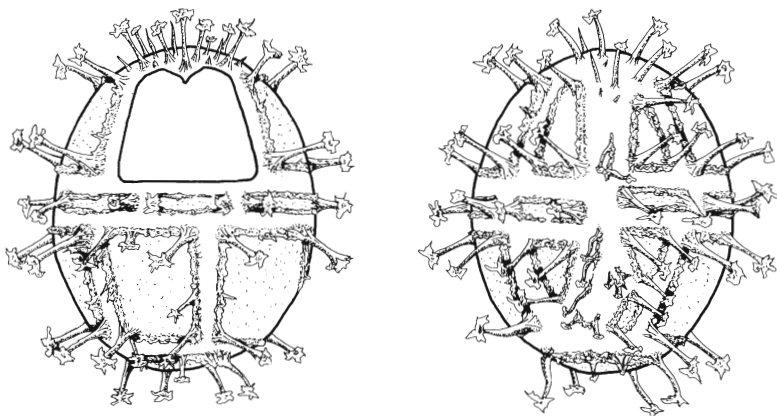
Genus TALEISPHAERA Duxbury 1979*Type species.* *Taleisphaera hydra* Duxbury 1979, p. 201, pl. 2, figs. 1, 4, 6, 7. Barremian, Speeton, UK.

Remarks. The most comparable genus is *Danea* Morgenroth 1968; however, the apical prominence, lack of processes, and a type P(3'') archaeopyle suffice to distinguish it from *Taleisphaera*. The author agrees with Duxbury (1983) that *Taleisphaera* and *Kiokansium* Stover and Evitt 1978 are not synonymous, as suggested by Below (1982). The latter genus lacks the penitabular septa which connect *all* the processes in the former (see Below 1982, fig. 3).

Taleisphaera hydra Duxbury 1979 emend.

Plate 16, figs. 3–5; text-fig. 1

Emended diagnosis. Shape: ellipsoidal to sub-spherical and sub-polygonal. Phragma: autophragm, 0.3 μm thick. Sculpture of coarse granulae. Low 'porous' penitabular septa formed by coalescing



TEXT-FIG. 1. Generalized reconstruction of *Taleisphaera hydra*, showing 2P archaeopyle. Left, dorsal view; right, ventral view. $\times 925$ approx.

of granulae, may fuse and become prolonged into (mainly gonal) short processes. Distally, processes are solid and secate, larger ones occasionally furcate. Paratabulation: gonyaulacacean tabulation indicated by penitabular septa on dorsal and ventral surfaces of cyst. Septa reduced in parasulcal region and tabulation indicated by solitary processes. Formula: ?4', 6'', 6c'', 1''', as, ra, rs, ls, ps. Archaeopyle: precingular, type 2P, plates 3'' and 4''. Operculum free. Paracingulum: indicated by fused granulae in the form of single transverse equatorial septa (with processes at either end of the septa). The septa can take the form of simulate 'process complexes' delineating rectangular fields within the paraplate area. Parasulcus: indicated by low penitabular septa and isolated processes.

Dimensions. Length (less processes) (25) 34.8 (42) μm , breadth (less processes) (20) 29.2 (36) μm , processes 2–10 μm long, 52 (12) specimens.

Remarks. This species shows wide morphologic variation between forms with high penitabular septa to those with 'septata' consisting of rows of swollen granulae. In contrast with the specimens illustrated by Duxbury (1979) from Speeton, many of the specimens have broken processes, these being truncated level with the top of the septa. The delicate nature of the processes implies that they may not be prominent features on every specimen. All the examples encountered in this study lie at the

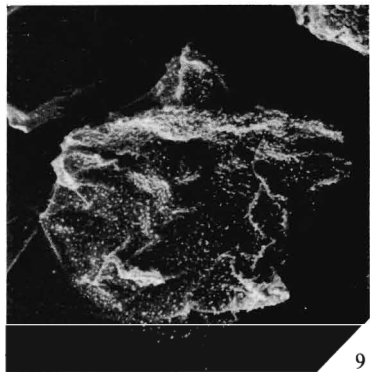
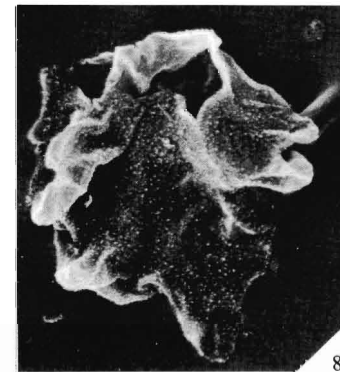
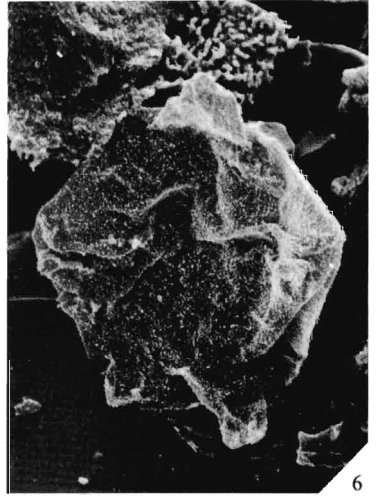
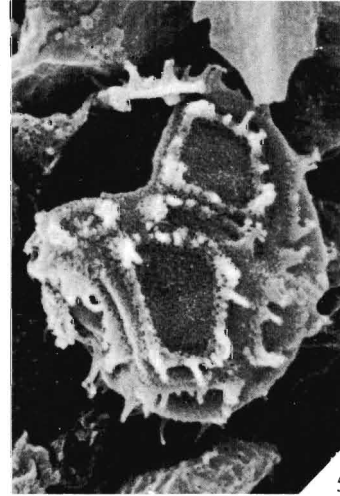
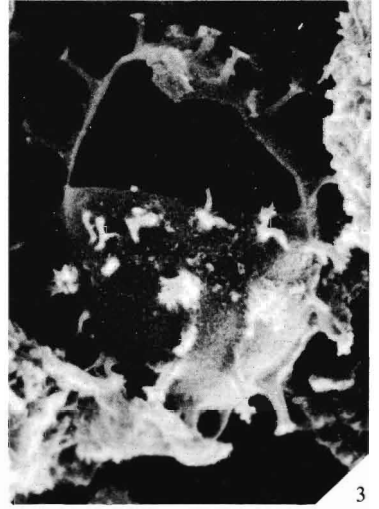
EXPLANATION OF PLATE 16

All magnifications $\times 800$ unless otherwise stated.

The following samples, residues, and SEM stubs were used in the preparation of this plate: WM 1424/2–3, residue V959, stub IC164 (fig. 1); WM 1423/2, residue Z143, stub IC173 (fig. 5); WM 1418/3–6, residue CH 139, stub IC183 (figs. 3 and 4); WM 1416/6–7, residue V962, stub IC109 (figs. 6 and 9); WM 1416/3, residue Y557, stub IC171 (figs. 2 and 8); WM 1407/5, residue V965, stub IC178 (fig. 7).

Grid references refer to the Cambridge Geology Grid (Hughes *et al.* 1979, p. 514).

Figs. 1 and 2 *Cribopteridinium diaphane*. 1, oblique dorsal view showing archaeopyle. Grid ref. 361/878. Film HSP 001/12. 2, Ventral view—detail of sulcal paratabulation. Grid ref. 249/816. Film HSP 001/22. $\times 1600$. Figs. 3–5. *Taleisphaera hydra*. 3, dorsal view showing 2P archaeopyle. Grid ref. 402/783. Film HSP 001/41. $\times 1600$. 4, incipient archaeopyle development, plate 3'' becoming detached. Grid ref. 323/723. Film HSP 001/38. $\times 7000$. 5, oblique dorsal view, specimen with very reduced processes. Grid ref. 229/744. Film HSP 001/05. $\times 1600$. Figs. 6–9. *Australisphaera fragilis* sp. nov. 6, holotype. Ventral view. Grid ref. 240/708. Film HSP 001/43. 7, ventral view showing archaeopyle and notched lateral horns. Grid ref. 217/793. Film HSP 001/04. 8, dorsal view, more pronounced horns. Grid ref. 380/725. Film HSP 001/25. 9, obliquely squashed specimen, ventral view. Grid ref. 328/778. Film HSP 001/54.



lower end of the size distribution detailed by Duxbury (1979). These cysts display all the features seen in Duxbury's (1979) illustrations.

Ceratiacean Group

Genus AUSTRALISPHAERA (Davey 1978) Duxbury 1983 emend.

Type species. *Australisphaera verrucosa* Davey 1978, pp. 892–893, pl. 2, figs. 1–5. Campanian–Maastrichtian offshore South Africa.

Emended diagnosis. Shape: ceratioid. Rhomboidal with a blunt apical, two cingular and two unequally developed antapical horns (the left being longer). The apical and cingular horns are often poorly developed and only expresses as 'lobes'. Strong dorsoventral flattening. Phragma: very thin to moderate thickness (0.5–1.5 μm). Wall is two layered, consisting of an unornamented 'endocyst' and an ornamented pericyst of equal thicknesses. The two layers are closely adpressed throughout and can only be resolved clearly by electron microscopy. The non-tabular ornamentation varies from low, widely spaced verrucae to densely packed echinae or large tubercles. Paratabulation: indicated only by archaeopyle suture and paracingulum. Archaeopyle: apical, type (tA). Principal archaeopyle suture moderately zigzag; operculum free. Paracingulum: not always developed. When present, most noticeable in lateral regions; cingular horns appear notched. Parasulcus: rarely observed. Marked by an antapical arcuate depression.

Remarks. The genus is herein emended to include details of the apical structure of the cysts. Previously described species (Davey 1978; Duxbury 1983) had all lost their operculae. All the known species of the genus have been considered in this emendation. (The author has yet to receive details of Jain and Khowaja-Attequzzaman's (1984) work on this genus.) The presence of four or five horns (i.e. one or two antapical horns) in both this genus and in *Muderongia* (Cookson and Eisenack 1958) is very variable. It is believed to be an environmentally controlled feature and not generically significant. *Muderongia* is distinctly cavate, having a reduced endocyst in comparison to the pericyst, whereas in *Australisphaera* the 'endocyst' mimics the shape of the 'pericyst' completely.

Muderongia? digita (Duxbury 1983) may also belong to the genus *Australisphaera*. Further examination of the type material is needed before any reassignments are made.

Australisphaera fragilis sp. nov.

Plate 16, figs. 6–9; Plate 17, fig. 9; text-fig. 2

Etymology. Latin *fragilis*, easily broken, fragile. In reference to the very thin-walled phragma.

Holotype. Plate 16, fig. 6.

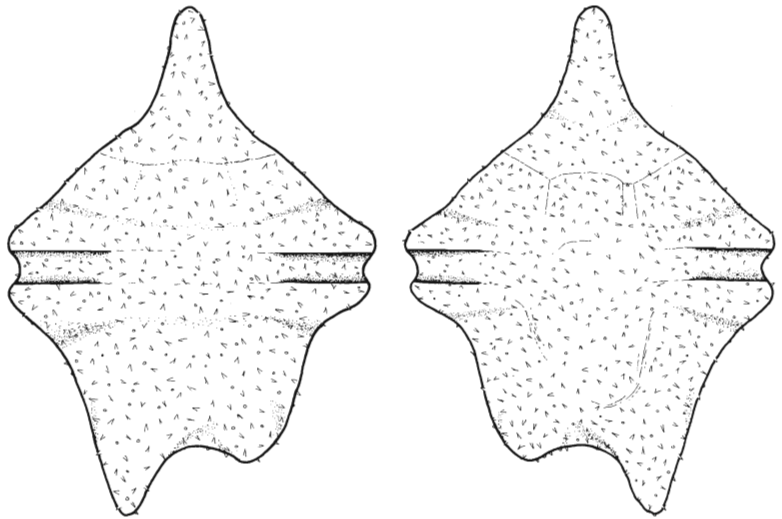
Type locality. Waringham borehole, Surrey, England. Sample WM 1416 ft 6–7 in. (431.73 m).

Diagnosis. Shape: regularly ceratioid. Horns developed to greater or lesser extent in apical (1 horn), cingular (2 horns), and antapical (1 or 2 horns) positions. Often only 'bulges' developed. Phragma: of two closely adpressed layers (see generic diagnosis). 0.5 μm thick, sculpture of short echinae 0.5 μm long or smaller granulae. Paratabulation: only visible as archaeopyle suture, rarely around paracingulum and parasulcus. Archaeopyle: apical, type (tA), operculum free. Paracingulum: well developed on cingular horns in which it forms a notched groove. Not expressed in mid-dorsal position. Parasulcus: occasionally an arcuate depression in mid-ventral position.

Dimensions. Length (less operculum) (40) 47.2 (55) μm , length (including operculum) (55) 60.8 (68) μm , breadth (45) 49.8 (60) μm , 56 (24) specimens.

Remarks. The extremely thin autophragm of this species means that specimens are rarely found in a good state of preservation. For every five torn or folded cysts there is only one well-preserved example. The apical horn is well developed when present; some specimens have long left antapical

TEXT-FIG. 2. Generalized reconstruction of *Australisphaera fragilis* sp. nov., showing main morphological features. Left, dorsal view; right, ventral view. $\times 1075$ approx.



horns. *A. fragilis* can be distinguished from the other species of *Australisphaera* by its evenly distributed ornamentation and much more regular ceratioid shape.

Genus CYCLONEPHELIUM (Deflandre and Cookson 1955) Stover and Evitt 1978
Cyclonephelium spp.

Plate 17, fig. 10

Remarks. Several hundred specimens of *Cyclonephelium*-type cysts have been photographed and, as with the other cysts described from these samples, much variation in morphology was observed. The small variation in ornament-type exhibited, its distribution, and the questionable significance of rounded/indented/lobate antapices, makes 'splitting' difficult. It may be that adherence to a morphological classification scheme is inappropriate in this case (Duxbury, pers. comm.).

Genus MUDERONGIA Cookson and Eisenack 1958
Muderongia simplex Alberti 1961 subsp. *microperforata* Davey 1982

Plate 17, figs. 3, 5, 8

Dimensions. Length (less operculum) (42) 57.7 (72) μm , length (including operculum) (72) 85.3 (98) μm , breadth (over circular horns) (56) 68.5 (93) μm , 60 (30) specimens.

Remarks. The degree of perforation of the pericyst is variable. Sometimes the perforation is restricted to the horns and pandasutural zones; in others, the whole pericyst may be perforate. The shape of the endocyst also varies from sub-circular to one in which lobes are developed which protrude into the pericystal horns. This form is quite easily recognized and distinct from *M. simplex* and it may ultimately warrant specific status.

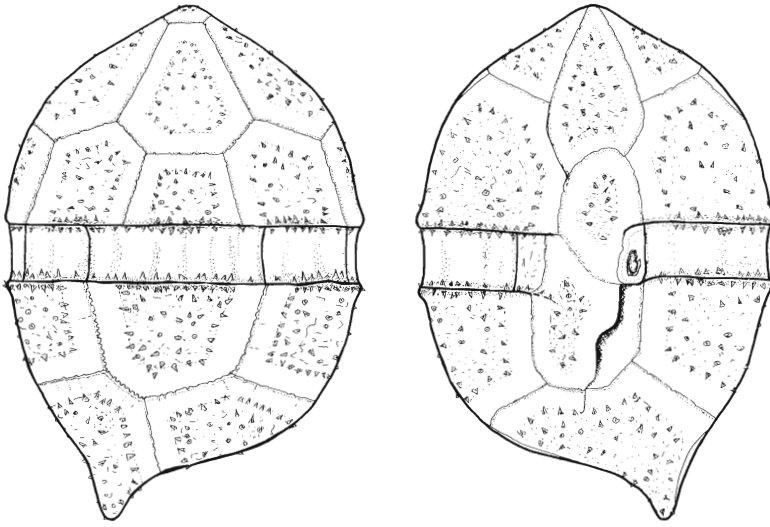
Peridiniacean Group

Genus SUBTILISPHAERA (Jain and Millepied 1973) Lentin and Williams 1976
Subtilisphaera terrula (Davey 1974) Lentin and Williams 1976 emend.

Plate 17, figs. 1, 2, 7; text-fig. 3

1974 *Deflandrea terrula* Davey, p. 65, pl. 8, figs. 4 and 5.

1976 *Subtilisphaera? terrula* Lentin and Williams, p. 119.



TEXT-FIG. 3. Generalized reconstruction of *Subtilisphaera terrula*, showing details of paratabulation. Left, dorsal view; right, ventral view. $\times 1075$ approx.

Emended diagnosis. Shape: ambitus ovoidal to sub-circular to peridinioid. Apex rounded or developed into a single short, broad apical horn. Antapex bears an eccentrically located horn on the left side, often poorly developed. Epipericyst and hypopericyst equidimensional. Moderate dorsoventral compression. Endocyst ovoidal to ellipsoidal, in contact with pericyst only in dorsal and ventral positions. Ambital pericoel. Phragma: periphragm $0.5 \mu\text{m}$ thick. Ultra-structure (discernible on more poorly preserved examples whose surface is slightly corroded) comprises interwoven fibrils of sporopollenin (Pl. 2, fig. 2). Surface sculpture units of granulae or low echinae appear to be swollen fibrillar endings. Sculpture is penitabular and laevigate pandasutural zones are usually present. Endophragm $0.5 \mu\text{m}$ thick, laevigate. Paratabulation: excellent preservation has enabled a pericystal paratabulation formula of $4', 3a, 7'', 7c, 5''', 2''''$, as, rs, ps to be determined.

EXPLANATION OF PLATE 17

All magnifications $\times 800$ unless otherwise stated.

The following samples, residues, and SEM stubs were used in the preparation of this plate: WM 1421/3, residue Z145, stub IC172 (figs. 2 and 6); WM 1418/3-6, residue CH139, stub IC183 (figs. 1 and 10); WM 1416/6-7, residue V962, stub IC109 (figs. 3-5, 8, 9); WM 1416/3, residue Y557, stub IC171 (figs. 7 and 11).

Grid references refer to the Cambridge Geology Grid (Hughes *et al.* 1979, p. 514).

Figs. 1, 2, 7. *Subtilisphaera terrula*. 1, dorsal view illustrating paratabulation. Grid ref. 189/763. Film HSF 117/26. 2, detail of paraplate ultrastructure at $5''$ /rs paraplate boundary. Grid ref. 326/717. Film HSP 001/26. $\times 7000$. 7, ventral view with parasulcal tabulation visible. Grid ref. 206/744. Film HSP 001/55.

Figs. 3, 5, 8. *Muderongia simplex microporata*. 3, ventral view showing parasulcal depression. Grid ref. 237/734. Film HSP 001/46. 5, archaeopyle in ventral view showing parasulcal notch and nature of two wall layers. Grid ref. 203/793. Film HSP 001/53. $\times 1600$. 8, dorsal view of complete specimen. Grid ref. 273/725. Film HSP 001/50.

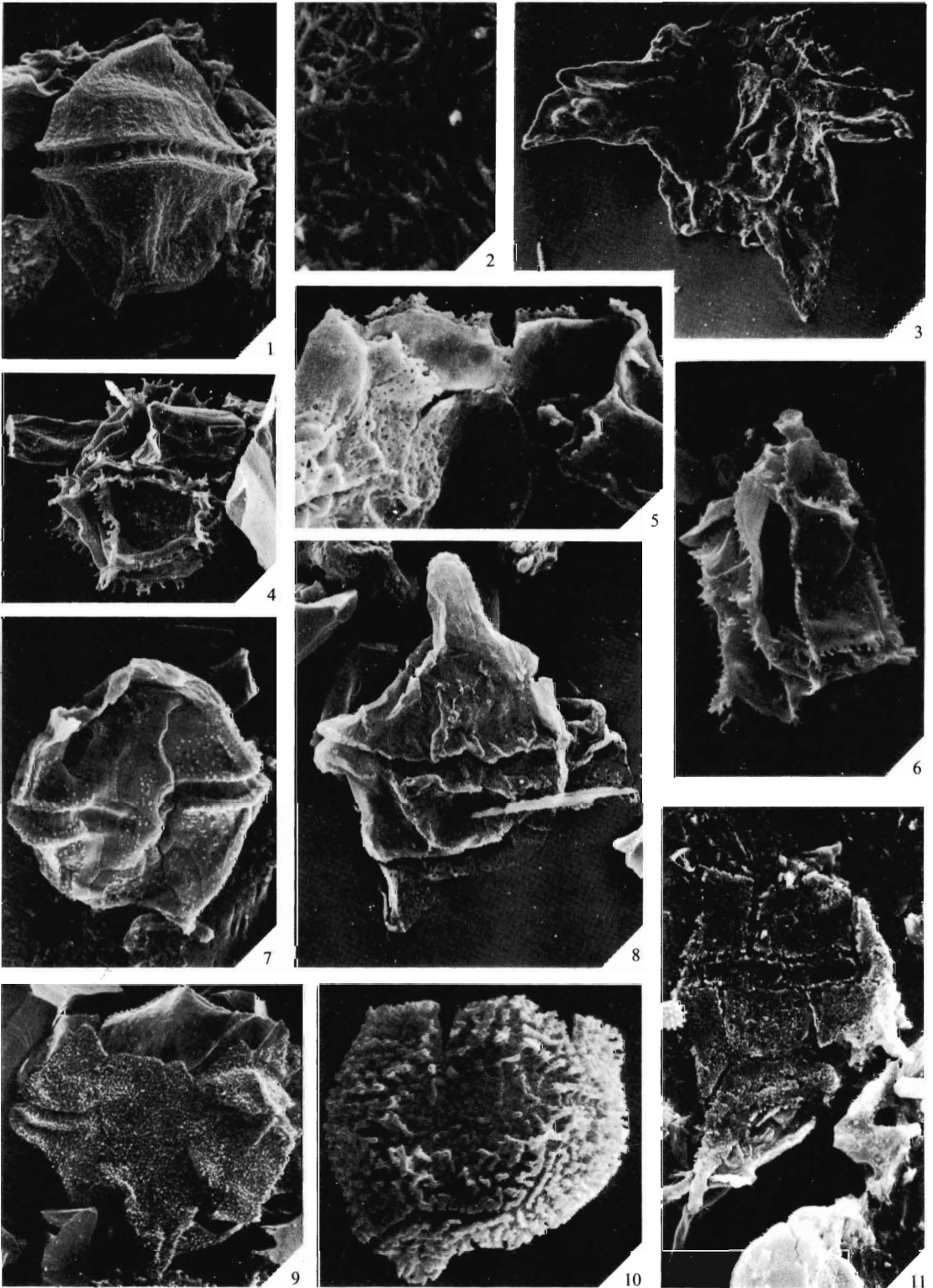
Fig. 4. *Spiniferites* sp. Grid ref. 294/749. Film HSF 001/52.

Fig. 6. *Gonyaulacysta* sp. A. Two wall layers clearly seen in region of archaeopyle; note left antapical 'horn'. Grid ref. 235/892. Film HSP 001/31.

Fig. 9. *Australisphaera fragilis* sp. nov. Oblique ventral view, archaeopyle and paracingulum clearly shown. Grid ref. 270/730. Film HSP 001/48.

Fig. 10. *Cyclonephelium* sp. Dorsal view showing paratabulation. Grid ref. 350/712. Film HSP 001/39.

Fig. 11. *Pseudoceratium pelliferum*. Showing paratabulation. Grid ref. 180/845. Film HSP 001/20.



HARDING, Cretaceous dinocysts

Paraplate margins are crenellated on the margins overlapping adjacent plates (crenellations indicate direction of plate imbrication). Endocyst paratabulation indeterminate. Archaeopyle: no clear archaeopyle seen (see Remarks). Paracingulum: very prominent, generally $4\mu\text{m}$ wide shallow groove exhibiting transverse corrugations. Laevorotatory, displaced by its own width. Anterior and posterior margins of paracingulum often exhibit a raised 'lip' ornamented with a single row of sharp echinae (up to $0.7\mu\text{m}$ tall). Parasulcus: broad (up to $10\mu\text{m}$) and extending well on to the epipericyst. Contains what appears to be a platelet bearing 'flagellar markings' at the beginning of the paracingulum.

Dimensions. Length pericyst (40) 51.6 (60) μm , breadth pericyst (36) 42.1 (51) μm , 110 (50) specimens.

Remarks. These specimens exhibit the following features which comply with the generic emendation of Lentini and Williams (1976): lack of right antapical horn; a clearly defined ovoidal pericyst; an endocyst whose only contacts with the pericyst are in dorsal and ventral areas; apical, antapical, and ambital pericoels. On the basis of light microscopy they state paratabulation to be indeterminate (Lentini and Williams 1976, p. 118). Traces of tabulation in this genus have been reported (Davey 1974; Duxbury 1983). However, using the superior resolution of the electron microscope, a tabulation formula is presented herein. It should be possible to construct paraplate formulae for the other members of this genus using this technique. Thus the concept of the genus should be expanded to include paratabulate forms.

Amongst several hundred examples logged, not one clear archaeopyle structure has been observed in this species. Similar difficulties were experienced by Davey (1974, p. 65, as *Deflandrea*) and by Jain and Millepied (1973, p. 27) discussing *S. senegalensis* and by Duxbury (1983, p. 67) discussing *S. perlucida*. Intercalary plates are always intact, the only breakages being apical fractures across paraplates (i.e. not along parasutures). The possibility suggested by Duxbury (1983) that the archaeopyle is formed by the loss of paraplate 3' needs further investigation.

PALAEOENVIRONMENT

The samples investigated fall into three of Anderson's (1971) Wealden ostracod zones (lower *Cypridea clavata* Zone, *C. tuberculata* Zone, upper *C. dorsispinata* Zone). Within these zones Anderson recognized alternations of C-phase ostracod assemblages (predominantly *Cypridea* spp.), with those of S-phase assemblages (other genera). These faunas have been interpreted as less saline and more saline phases respectively, in an overall reduced salinity environment.

Environmental interpretations can also be made from the lithologies present. The study section can be divided into an upper and lower part each characterized by the subsidiary beds they contain. In the lower part (1515–1430 ft (461.75–435.84 m)) of the section the mudstones are accompanied by over a dozen thin 'Paludina' (= *Viviparus*) limestones, deposited in a low salinity environment. The upper part (1430–1400 ft (435.84–426.70 m)) contains pebble bands, ironstones, and glauconitic sandstone horizons (with *Cassiope*, *Ostrea*, *Filosina*, and forams), generally held to indicate more brackish conditions.

Within the upper part of the sequence there are two distinct horizons representing increased salinity pulses ('marine incursions'), recognized by their macrofaunas. One lies between 1444 ft 9 in. (440.34 m) and 1448 ft (441.33 m), the other, the 'mid-Weald Clay brackish-marine band' of Anderson and Casey (1957), between 1416 ft 10 in. (431.83 m) and 1423 ft 8 in. (433.91 m). Above 1414 ft (430.97 m) the presence of *Unio* again shows a return to freshwater conditions. (All data detailed in Worssam and Ivimey-Cook 1971, pp. 22–23, 63–65).

How do the previously described dinocysts fit into this framework? Previous literature suggests that in general, pre-Tertiary dinocysts were confined to marine environments, which their presence may be taken to indicate (see Batten and Eaton 1980). Recently, research has begun to show an early Cretaceous invasion of low salinity water bodies by cyst-forming dinoflagellates (Batten 1982; Hughes and Harding 1985).

Although the recovery of dinocysts from samples WM 1509 and WM 1500/1–3 was not sufficient

to draw any firm conclusions the cysts may have been associated with a minor pulse of increased salinity, culminating in the 'Cyrena' (= *Filosina*) limestone at 1487 ft (453.22 m). However, the dinocyst assemblages recovered from the samples above 1456 ft 5 in. (443.90 m) indicate an environment of fluctuating salinity levels. The species diversity of the dinocyst flora shows a strong correlation with the two brackish-marine horizons. The eight samples from the level of these horizons all contain twice as many species of dinocyst as the remaining samples (see text-fig. 4). Microplankton percentages reach a peak value of 66% of the total palynomorph assemblage in the lower of these two bands (sample WM 1446/6). The greater the dinocyst diversity the higher the inferred palaeosalinity.

It has been stated that many species of Wealden dinocysts are unknown in marine sediments of a similar age (Batten 1982; Batten and Eaton 1980; Hughes and Harding 1985). In these assemblages the species identified, excluding *A. fragilis* sp. nov., are known from truly marine rocks. However, the distributions of *M. simplex microperforata* and *S. terrula* are known to be related to environments where salinity levels were reduced (Davey, pers. comm.; Batten 1982). Thus, the species found in these samples appear to have been tolerant of a wide range of salinities.

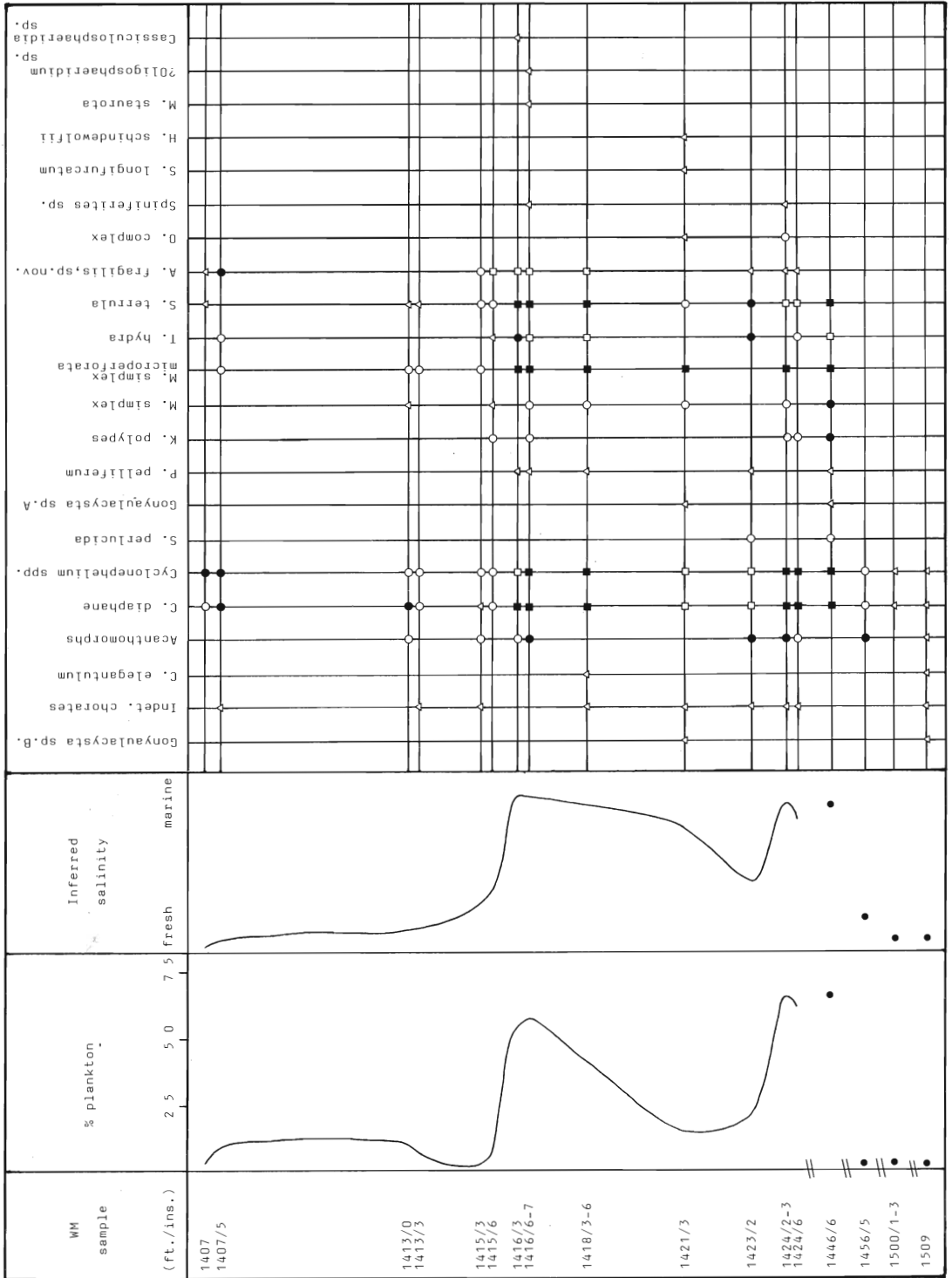
The described species all show a wide range of morphologic variation, both in horn development and ornamentation. Most of the dinocysts appear to be at the minimum of their known size ranges. In the case of *Cribroperidinium diaphane*, examples with pronounced horn development and ornamentation correlate with the high planktonic diversity, increased salinity phases. This may be related to the more stable 'marine' environment in which the dinocysts were able to develop more fully.

The characteristics of the microplankton population correlate directly with results derived from fossil bivalve data, though the dinocysts indicate a longer lived pulse of increased overall salinity. This contrasts with the lack of correlation with ostracod microfaunas (Hughes 1980; Hughes and Harding 1985). This is especially noticeable with the two C-phase ostracod assemblages of the Capel and Ewhurst cycles of Anderson (1971, p. 127), 1413–1414 ft (430.66–430.97 m) and 1418–1424 ft (432.19–434.01 m) respectively. The occurrence of non-marine ostracods with higher salinity indicators (dinocysts) casts doubt on the interpretation of the C-phase ostracod assemblages (Allen *et al.* 1973, p. 619; Kilenyi and Allen 1968, p. 158). MacDougall and Prentice (1964), citing Jones (1959), believe many of the ostracod assemblages to be hydrodynamically controlled in their distribution and not to represent biocoenoses. Many of the ostracod assemblages examined by the author consist of virtually monospecific, unidirectionally orientated accumulations, often of only left or right valves of similar instars. Transportation of ostracod valves has also been remarked upon by Kilenyi and Allen (1968). It now seems unwise to accept a 'non-marine' (or low salinity) palaeoenvironmental interpretation of horizons containing C-phase faunas. These faunas may have had a non-marine provenance but are not indicative of conditions prevalent at the site of deposition of the transported faunas.

The presence of large numbers of *Taleisphaera hydra* in several samples is interesting as this species has only been found previously in the Barremian of Speeton, Yorkshire (Duxbury 1979). (The specimens described by Below (1982) are not believed to be synonymous—see Systematic Section.) This provides evidence for the postulated northerly connection between the non-marine Weald basin and the Boreal ocean (Kaye 1966; Worssam and Ivimey-Cook 1971). It also supports Allen's (1975) hypothesis that the Weald Clay of Warlingham was deposited near the mouth of the corridor admitting Boreal sea-water into the Wealden Basin via East Anglia.

STRATIGRAPHY

The presence of 'floods' of microplankton (especially sample WM 1446/6), the excellent preservation, and the lack of any obviously reworked specimens (see Batten 1982) all point to the fact that these dinocyst floras are preserved *in situ*. For this report the dinocyst zonal scheme erected by Davey (1979, 1982) has been utilized. The presence of *S. terrula* in the samples implies that the stratigraphic age must be late Hauterivian or younger (*S. terrula* Zone or later). A further refinement is possible, placing these assemblages in the lower part of the



TEXT-FIG. 4. Inferred palaeosalinity levels and stratigraphic distribution of the microplankton species encountered. (Note breaks in vertical scale. Samples WM 1394/1, 1397, 1403, 1468, 1488/7, 1492/4, 1495/2, 1506/3, 1510/4, 1512/8, 1513/3 did not yield any microplankton). Numbers encountered: ▲ = < 5; ○ = 5-10; ◻ = 10-20; ● = 20-50; ■ = > 50.

TABLE 1. The dinocyst zonation scheme used in this work (from Davey 1982)

Age		Boreal Ammonite Zones	Dinocyst Zonation	
			Subzones	Zones
Barremian	late	<i>bidentatum</i>	<i>Palaeoperidinium cretaceum</i>	<i>Odontochitina operculata</i>
	mid	<i>rude-fissicostatum</i>	<i>Aptea anaphrissa</i>	
	early	<i>rarocinctum</i>	<i>Cassiculosphaeridia magna</i>	
		<i>variabilis</i>	<i>Nexosispinum vetusculum</i>	
Hauterivian	late	<i>marginatus</i>	<i>Canningia cf. reticulata</i>	<i>Subtilisphaera terrula</i>
		<i>gottschei</i>		
		<i>speetonensis</i>	<i>Batiodinium longicornutum</i>	<i>Discorsia nanna</i>
	early	<i>inversum</i>		
		<i>regale</i>		
		<i>noricum</i>		
		<i>amblygonium</i>		

Canningia cf. reticulata subzone due to the presence of *M. simplex* which is absent from the upper part of this Subzone (Davey 1979, p. 73). The other forms encountered all have ranges consistent with such an assignment. *M. simplex microperforata*, although mainly considered characteristic of the Ryazanian-Valanginian (Davey 1982), was also recorded from the Hauterivian (op. cit., fig. 3) and from the early Barremian of offshore Holland (Davey, pers. comm.). *T. hydra* is believed to first appear in the early Barremian (Duxbury, pers. comm.), although the author has observed it in the Hauterivian of Speeton. Thus it seems feasible to assign a latest Hauterivian age to the studied samples, equated with the *gottschei* and *marginatus* Boreal ammonite Zones (see Table 1).

CONCLUSIONS

The relatively high salinity pulses recorded by the dinocyst floras are believed to be latest Hauterivian in age. The dinocyst floras are present upwards in the borehole as far as sample WM 1403, after which no microplankton are found until the unusual forms described by Hughes and Harding (1985) at 1298 ft (395.61 m). Thus, the Hauterivian/Barremian boundary lies somewhere in the intervening 100 ft (30.49 m) of the borehole. The implication of this is that the Hauterivian/Barremian boundary should be placed *above* Topley's Bed 5 (which lies between 1400 ft (426.70 m) and 1424 ft (434.01 m)—Topley 1875, p. 105) not *below* this bed as stated by Worssam (1978, table 1, p. 7).

Dinocysts are absent from the 100 ft (395.61 m) of Weald Clay above 1403 ft (427.61 m) due to the Barremian marine regression restoring 'non-marine' conditions to the Weald Basin for a time. The late Hauterivian 'marine' incursion represented in these samples follows evidence from other sources of a general Hauterivian marine transgression (e.g. Kemper 1973), but does not correlate well with the mid-Hauterivian transgression reported by Rawson and Riley (1982) in the North Sea

area. Possibly this Wealden event was independent of Boreal conditions and related to the structural breakdown of 'coastal barriers' to the north, in East Anglia (Allen 1981, p. 389).

The attribution of a late Hauterivian age to these samples is of great importance for early angiosperm evolution. Semi-tectate columellate pollen grains have been extracted from several of the study samples (they comprise 4 % of the palynomorph flora in sample WM 1415/3). Previously these angiosperm microfossils were believed to be of early Barremian age (e.g. Hughes *et al.* 1979). An earlier age of late Hauterivian now seems likely, making these fossils the oldest record of angiosperms yet known.

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