Barker, P. F., Kennett, J. P., et al., 1990
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 113

33. DISTRIBUTION OF CALCAREOUS DINOFLAGELLATES AT THE CRETACEOUS-TERTIARY BOUNDARY OF QUEEN MAUD RISE, EASTERN WEDDELL SEA, ANTARCTICA (ODP LEG 113)[1]

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ABSTRACT

The distribution and stratigraphic ranges of upper Maestrichtian to Paleocene calcareous dinoflagellate species ("Calcispheres") which occurred in two Cretaceous/Tertiary (K/T) boundary sections (ODP Leg 113, Holes 689B and 690C) at Queen Maud Rise, eastern Weddell Sea, are described from semi-quantitative investigations with a scanning electron microscope (SEM).

Four new species of the genus *Orthopithonella* are described, namely *O. minuta, O. aspera, O. flora,* and *O. congruens*. A calcareous dinoflagellate mass occurrence, dominated by *Obliquipithonella operculata,* evolves above the K/T boundary in nannofossil Subzone CP1b. This mass occurrence, which accounts for 20%–30% of the total sediment, is present throughout the Danian.

The stratigraphic distribution of individual calcareous dinoflagellate taxa clearly shows a major change in species composition. Four species, *Obliquipithonella operculata, O. parva, Orthopithonella minuta,* and *O. flora* first occur in Subzone CP1a and CP1b. All taxa in the uppermost Maestrichtian (*Orthopithonella congruens, O. gustafsonii, Obliquipithonella krasheninnikovii,* and *Centosphaera barbata*) seem to become extinct at the base of nannofossil Subzone CP1a or immediately above the K/T boundary in Subzone CP1b. There is apparently no taxon continuing from the uppermost Maestrichtian to the upper Paleocene.

Our data of calcareous dinoflagellate evolution and distribution at ODP Site 690 suggest that the extinction of Cretaceous and the evolution of Cenozoic taxa at the Cretaceous/Tertiary transition were caused by one event, even though some of the Cretaceous taxa, such as *Orthopithonella gustafsonii*, became extinct gradually.

INTRODUCTION

During the last decade, numerous investigations of calcispheres, an important group of calcareous nannofossils and qualitatively significant contributors to Mesozoic and Cenozoic sediments, have greatly widened our knowledge of this systematically still very uncertain category. There are at least two distinctly different and stratigraphically restricted groups, the Mesozoic Calcisphaerulidae (calcispheres sensu strictu) and the Cenozoic thoracosphaerids. The dinoflagellate cyst nature of the calcispheres was first shown for the Cenozoic thoracosphaerids (Fütterer, 1976) by analogy to cultivated modern peridinoid species (Wall and Dale, 1968). Later this was shown for the Mesozoic Calcisphaerulidae by evidence of an incomplete peridinoid paratabulation on the external cyst wall of the Lower Cretaceous *Pithonella paratabulata* by Keupp (1980) which later (Keupp, 1981) was combined with *Orthopithonella ("Pithonella") gustafsonii* (Bolli, 1974).

The stratigraphic distribution of the Mesozoic Calcisphaerulidae shows rich and diverse assemblages in the Upper Jurassic through Lower Cretaceous (Bolli, 1974; Keupp, 1981; Keupp and Mutterlose, 1984) and rich but less diverse assemblages in the Upper Cretaceous (Bolli, 1978; Willems, 1988). To date, only very few species have been reported to occur in intervals younger than the Cretaceous/Tertiary boundary (Rögl, 1976; Fütterer, 1984). The Cenozoic thoracosphaerids seem to have appeared abruptly at the Cretaceous/Tertiary boundary. They flourished during the Paleogene, are present throughout the Cenozoic, and include many modern representatives among the peridinoid dinoflagellates.

It is not clear whether the rapid decrease in abundance and diversity of the Calcisphaerulidae at the Cretaceous/Tertiary boundary (Fütterer, 1976), resulted from the catastrophic change at that time or whether the increase in thoracospherids represented response by surviving forms to newly available niches.

During routine shipboard investigations while drilling on Queen Maud Rise in the eastern Weddell Sea (ODP Leg 113) it became clear that various Paleogene and Upper Cretaceous core sections contained well preserved calcispheres in significant abundance accounting for up to 30% of the total sediment. The main aim of this paper is to analyze and describe the distribution pattern of the calcareous dinoflagellates near the Cretaceous/Tertiary boundary, the nature and stratigraphic ranges of the species observed, and to contribute some data towards the assessment of the crisis which affected the flora and fauna of the earth at that time.

MATERIAL AND METHODS

The present study is based on core material recovered during ODP Leg 113 (Barker, Kennett, et al., 1988) at Sites 689 and 690 on Queen Maud Rise in the eastern Weddell Sea (Fig. 1). Maud Rise is an aseismic plateau some 800 km north of the Antarctic continent. It rises from the surrounding Weddell abyssal plain to a water depth of about 2000 m. Site 689 is located near the crest of Maud Rise in a water depth of 2080 m whereas Site 690 is located on the southwestern flank of Maud Rise in a water depth of 2914 m. Maud Rise is isolated by distance and topography from terrigenous sediment supply from the East Antarctic continent, except for ice-rafted and wind-blown material. Therefore, both drill sites yielded exclusively pelagic sediment sequences of biogenic origin ranging in age from the Late Cretaceous to the Pleistocene. Several brief sedimentary hiatuses or condensed sequences occur. The only major hiatus spans the middle to late Eocene at Site 690. Together both sites provide an almost complete stratigraphic sequence. The sedimentary sequences recovered consist of almost pure siliceous and calcare-

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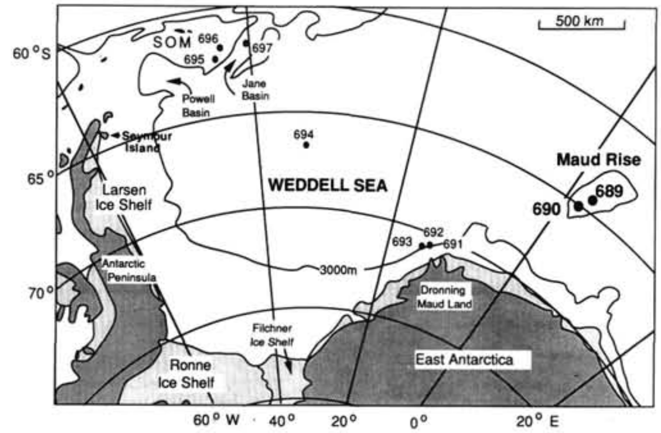

Figure 1. Location of Leg 113 Sites in the Weddell Sea. Sites 689 and 690 lie on the aseismic plateau of Queen Maud Rise in less than 3000 m water depth well above the present day CCD.

ous oozes in the upper section and mixed calcareous ooze/chalk in the lower part of the section with increasing quantities of terrigenous components downcore.

Deposition across the Cretaceous/Tertiary boundary most probably was continuous at Site 690, whereas at Site 689 nannofossil Subzone CP1a could not be delineated. The Cretaceous/Tertiary boundary at this site was found associated with a strongly bioturbated (by Zoophycos and other infauna) 40 cm interval of color change from predominantly white Maestrichtian to predominantly green Danian material.

The Cretaceous/Tertiary boundary at Site 690 is, similar as at Site 689, associated with a marked color change from pinkish white, intensely bioturbated upper Maestrichtian chalk into a darker very pale brown clay- and zeolite-rich Danian unit above. This brownish sequence is only about 80 cm thick and its color fades back again into a pinkish white.

The distribution of calcareous dinoflagellates was investigated in samples from Holes 689B, 690B, and 690C. All sampling was carried out aboard *JOIDES Resolution* following standard procedures. Generally one sample of 10 cm^3 per section was taken. Cores 113-689B-25X and 113-690C-15X, comprising the Cretaceous/Tertiary boundary sections, were sampled following a special plan (only 5 cm^3 samples and sharing paleomagnetic samples) to enable denser sample spacing.

Lithologically, the majority of the samples represent pelagic foraminifer-bearing nannofossil ooze or chalk. Preservation generally is quite good. Lithification of the Cretaceous/Tertiary boundary sequence at Site 690 (Core 113-690C-15X, 252.5–261.8 mbsf) is slightly less intensive than at Site 689 (Core 113-689B-25X, 226.6–236.3 mbsf). This may be expressed in morphological modification by diagenetic crystal growth in Site 689 specimens.

For the purpose of this study Hole 689B was sampled (see Fig. 4) from the upper Paleocene (CP7) at 218.41 mbsf (Sample 113-689B-24X-CC, 41–43 cm) to the upper Maestrichtian (*Nephrolithus frequens* Zone) at 235.2 mbsf (Sample 113-689B-25X-6, 30–32 cm). Hole 690C was sampled (see Fig. 5) from the Danian (CP1b) at 243.25 mbsf (Sample 113-690C-15X-1, 36–38 cm) to the upper Maestrichtian (*N. frequens* Zone) at 251.94 mbsf (Sample 113-690C-15X-7, 4–6 cm).

All samples were treated with H_2O_2, to promote rapid and complete disintegration, and washed through a 63 μm mesh sieve. The coarse fraction was tested for calcispheres using a light microscope. The material <6.3 μm was separated from the <63 μm fraction by hydraulic sedimentation. The 6.3–63 μm fractions were mounted on scanning electron microscope (SEM) stubs and sputtered twice with carbon and gold-palladium for examination.

The stubs were investigated for calcareous dinoflagellates with SEM (gun potential 10 kv). Identified specimens were counted directly from the SEM screen by examining a various number (up to 25) of sections across the SEM stub. This yielded a semi-quantitative abundance for each species. The relative abundance for each species refers to frequency counts normalized to one section across the SEM stub (Figs. 4, 5). It is given as follows: M = very abundant (>40 specimens); A = abundant (25-40 specimens); C = common (15–25 specimens); F = frequent (5–15 specimens); R = rare (1–5 specimens); r = very rare (less than 1 whole specimen); (r) = very rare and not definitely determined.

Stratigraphic classification of lithological sections and samples is mainly according to the shipboard nannofossil zonation (Barker, Kennett, et al., 1988); only few corrections were added (Pospichal and Wise, this volume, chapter 32).

DISTRIBUTION OF CALCAREOUS DINOFLAGELLATES

Calcareous dinoflagellates were found to occur in varying numbers throughout all carbonate bearing sections recovered at Sites 689 and 690. Absolute numbers and frequencies of calcispheres could be obtained from the sedimentological shipboard summary data based on light optical smear slide examinations (Barker, Kennett, et al., 1988). Even in view of the uncertainties of deriving absolute numbers from smear slide analyses it is evident from Figures 2 and 3 that calcispheres are present in lower frequencies (<5% of total sediment) during the Maestrichtian at both sites. Above the Cretaceous/Tertiary (K/T) boundary an increase in frequency is observed beginning in nannofossil Zone CP1b and culminating in an abundance equal to about 30%–35% of total sediment at Site 690 (Fig. 3).

This pattern, which is less evident in Hole 689B (Fig. 2) than in Hole 690C (Fig. 3), may be explained by stratigraphic hiatuses and by the difficulties in precisely delineating the K/T boundary in this hole. Firstly the boundary interval has been intensely bioturbated by Zoophycos and other infauna. This is indicated by greenish burrows (filled with Danian sediment) in a whitish Maestrichtian matrix detectable as low as Sample 113-689B-25X-5, 130 cm and by distinct whitish blebs (burrow fills of upper Maestrichtian sediment) in a greenish matrix of Danian sediment occurring as high as Sample 113-689B-25X-5, 55 cm. This bioturbation expands the boundary interval over a distance of about 80 cm which may more likely account for the "absence" of the Subzone CP1a than discontinuous sedimentation. Secondly the lower Paleocene sequence is rather incomplete. An apparent color change immediately below Sample 113-689B-25X-1, 5 cm, which was dated as late Paleocene (CP7), marks a major hiatus comprising Zones CP4–CP6 (Barker, Kennett, et al., 1988).

A more detailed picture can be derived from species analyses giving the relative abundance pattern of each species. There is an apparent change in calcareous dinoflagellate species composition at the K/T boundary (Figs. 4, 5). From 11 species investigated for this study, 5 species disappear rapidly at or near the boundary, while 6 species have their first appearance there. Two of these, *Obliquipithonella operculata* (Bramlette and Martini 1964) and *Orthopithonella minuta* n. sp. develop into mass occurrences.

The taxonomic change is quite pronounced in Hole 689B (Fig. 4). However, it has to be considered that hiatuses may occur in the lithological section and that the K/T boundary interval has been extended and blurred by bioturbation, as described above. As a consequence, it has not yet been possible to verify

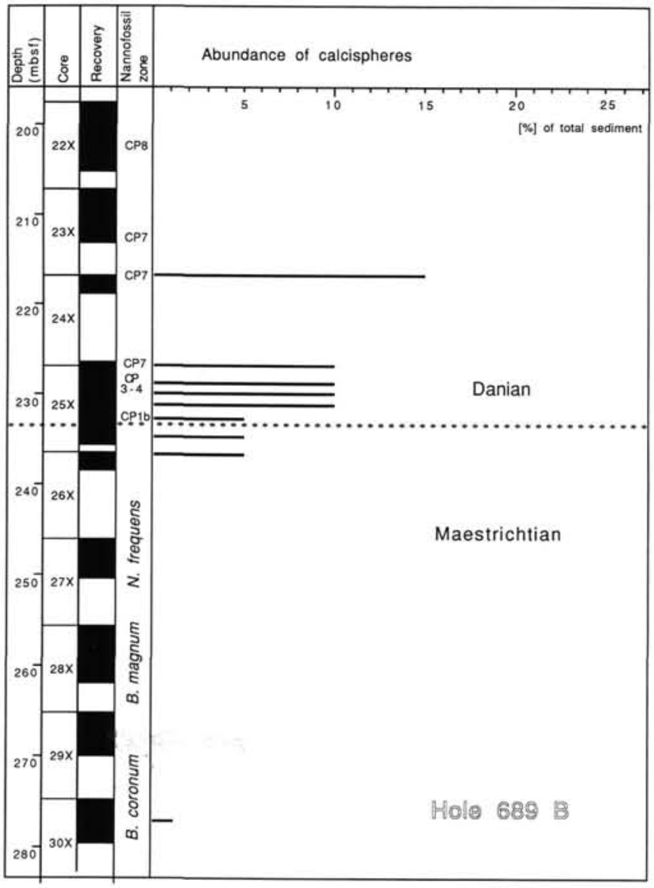

Figure 2. Abundance of calcareous dinoflagellates at the Cretaceous/Tertiary (K/T) boundary of Hole 689B, Queen Maud Rise, eastern Weddell Sea. Data are from shipboard smear-slide analyses. The K/T boundary is indicated by line of asterisks. The nannofossil zonation is presented as discussed in Barker, Kennett, et al. (1988).

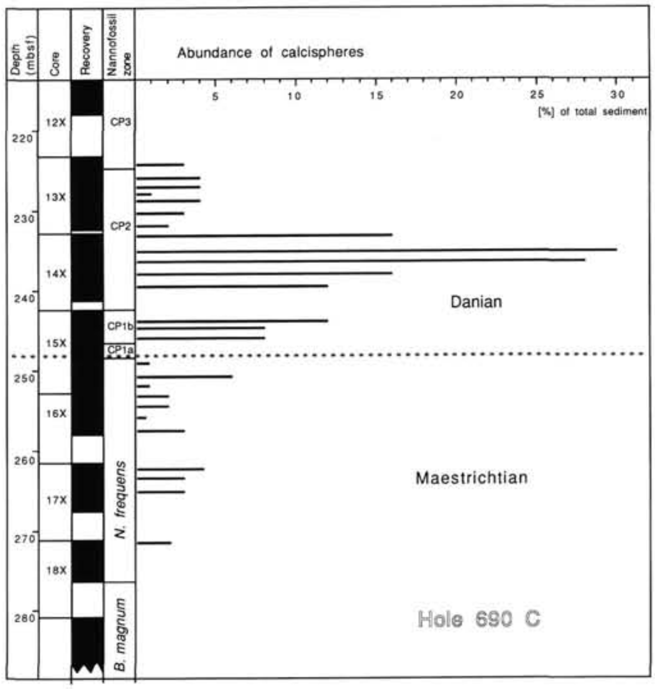

Figure 3. Abundance of calcareous dinoflagellates at the Cretaceous/Tertiary (K/T) boundary of Hole 690C, Queen Maud Rise, eastern Weddell Sea. Data are from shipboard smearslide analyses. The K/T boundary is indicated by line of asterisks. The nannofossil zonation is presented as discussed in Barker, Kennett, et al. (1988).

whether the Danian sequence directly above the K/T boundary is continuous or not. Anyway, the boundary section is not very extended. Secondly, a major hiatus (CP4–CP6) occurs directly above Sample 113-689B-25X-1, 30–31 cm.

Thus, the interval from 226.55 mbsf to 235.5 mbsf examined in Hole 689B (Fig. 4) spans the time period from the late Maestrichtian *Nephrolithus frequens* Zone (Sample 113-689B-26X-6, 30–32 cm) to the late Paleocene Zone CP7 (Sample 113-689B-24X-CC, 41–43 cm) including a possible hiatus (CP1a) directly following the K/T boundary and a major hiatus comprising the Zones CP6–CP4 between Samples 113-689B-25X-1, 30–31 cm and 113-689B-24X-CC, 41–43 cm.

The K/T boundary in Hole 690C is reasonably well defined. It was first placed, by cursory shipboard study, between 48 and 50 cm in Section 113-690C-15X-4 (at 247.9 mbsf) very near to a prominent color change of white upper Maestrichtian (*Nephrolithus frequens* Zone) ooze below and a pale brown clay-rich Danian unit above (Barker, Kennett, et al., 1988). Based on more thorough shore-based studies the K/T boundary finally was placed in Section 113-690C-15X-4 within a thin boundary zone or interval between 41 and 41.5 cm (247.81 mbsf; Pospichal and Wise, this volume, chapter 32). Sediments of the boundary section are intensely bioturbated which is clearly shown by the differently colored burrow fills. Nevertheless, the boundary sequence at this site is continuous and considerably expanded. This is indicated because it was possible to delineate a definite CP1a Subzone. The interval from 243.26 mbsf to 251.95 mbsf examined in Hole 690C (Fig. 5) for this study covers the time span from the late Maestrichtian *Nephrolithus frequens* Zone (Sample 113-690C-15X-7, 4–6 cm) to the Danian CP1b Subzone (Sample 113-690C-15X-1, 36–38 cm). This suggested that, for the purpose of this study, Hole 690C would yield the more reliable results.

The species distribution pattern of Figure 5 shows the first "new" or Tertiary calcareous dinoflagellate taxon (*Orthopithonella aspera*) to occur in the upper Maestrichtian Sample 113-690C-15X-5, 20–22 cm, the next (*Obliquipithonella operculata*) in Sample 113-690C-15X-4, 55–56 cm very near the boundary and finally *Orthopithonella minuta* and *Obliquipithonella parva* in the Danian Sample 113-690C-15X-3, 26–28 cm. The Cretaceous taxa *Orthopithonella congruens* and *Obliquipithonella krasheninnikovii* show their last occurrence in the Danian Sample 113-690C-15X-4, 12–13 cm, immediately above the K/T boundary. *Centosphaera barbata* has its last appearance only a little higher, in Sample 113-690C-15X-3, 26–28 cm, and *Orthopithonella gustafsonii* seems to disappear with Sample 113-690C-15X-1, 36–38 cm, still within the Danian CP1b Subzone.

There is a relatively wide transition zone (at least 1.6 m) of disappearing Cretaceous and newly appearing Tertiary calcareous dinoflagellate taxa in Hole 690C between Samples 113-690C-15X-5, 20–22 cm and 113-690C-15X-4, 12–13 cm. This transitional record seems to be too extended to be simply explained by mixing and redistribution of a distinct sediment layer through bioturbation. Because of the color change from whitish Maestrichtian to brownish Danian sediments, color may serve as a guide to visually estimate the interval mixed by bioturbation in Core 113-690C-15X, which seems to span some 60–70 cm only. Present data do not allow a definite interpretation as to whether we have in Hole 690C a gradual extinction/evolution of Cretaceous and Tertiary taxa respectively, or an instantaneous

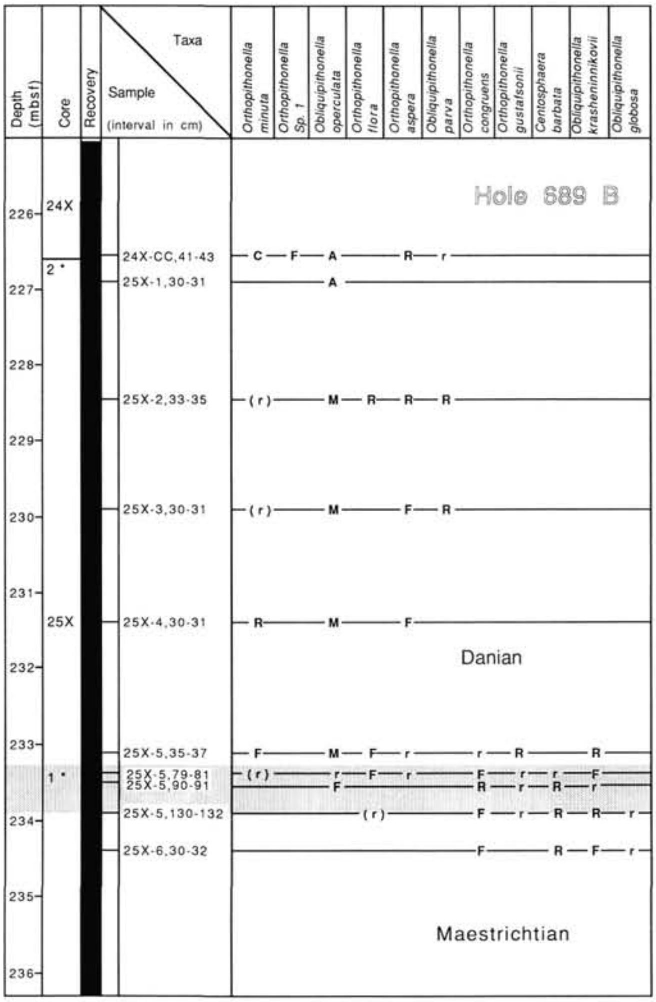

Figure 4. Relative abundance of calcareous dinoflagellate species at the Cretaceous/Tertiary boundary of Hole 689B: hatched = strongly bioturbated K/T boundary interval; 1* = probable hiatus comprising Danian Subzone CP1a; 2* = major hiatus comprising Lower Paleocene Zones CP4–CP6. M = very abundant, A = abundant, C = common, F = frequent, R = rare, r = very rare, (r) = very rare and systematically uncertain.

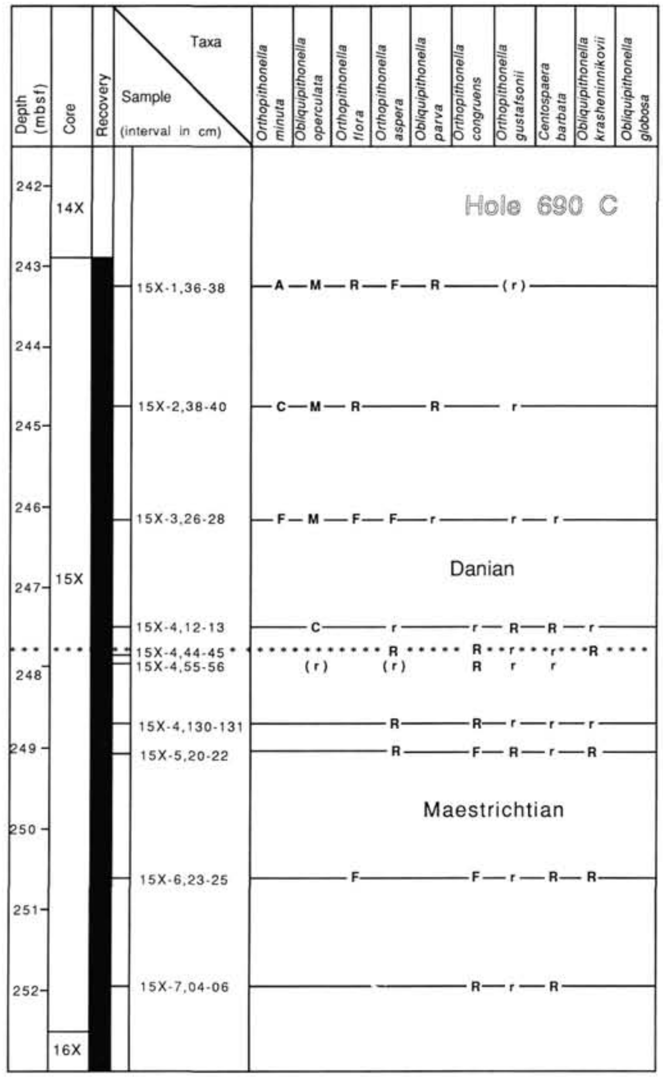

Figure 5. Relative abundance of calcareous dinoflagellate species at the Cretaceous/Tertiary boundary of Hole 690C; K/T boundary as discussed in Barker, Kennett, et al. (1988) marked by asterisks. M = very abundant, A = abundant, C = common, F = frequent, R = rare, r = very rare, (r) = very rare and systematically uncertain.

extinction event with gradual evolution over a longer interval additionally extended by bioturbation. The latter scenario, however, is expected to be the more likely one. Proposed quantitative analysis of calcareous nannofossils across the boundary interval may better explain existing uncertainties.

Thierstein and Okada (1979) describe the distribution of nannofossils across the K/T boundary in DSDP Site 384 in the North Atlantic. There the transition from 100% Cretaceous taxa to 100% Tertiary taxa occurs over an interval of 90–100 cm. From detailed analyses, they assume a complete nannofossil record at Site 384, which is most likely the result of an instantaneous extinction of the Cretaceous nannoflora, masked in the sedimentary record by benthic mixing and lateral reworking.

At Site 738 on the southern Kerguelen Plateau, drilled during ODP Leg 119, a continuous Cretaceous/Tertiary boundary section was recovered lying within a laminated claystone interval of about 15 cm thickness (Barron, Larsen, et al., in press). This laminated boundary interval shows a gradual replacement of the Cretaceous nannofossil taxa by early Tertiary taxa which cannot be explained by bioturbation processes, but must be truly gradual or due to lateral redistribution of older Cretaceous material. Similarly, smearing of the fossil record by bioturbation and lateral sediment supply may account for the ambiguities observed in the Cretaceous/Tertiary boundary section of Hole 690C.

SYSTEMATIC PALEONTOLOGY

Calcareous dinoflagellates were first described by Deflandre (1947) from Miocene sediments and included within the peridinoid family Calciodinellidae. The dinoflagellate cyst nature of these organisms was proved by incubation experiments of isolated specimens from modern marine sediments by Wall and Dale (1968). By analogy of skeletal ultrastructure and architecture (reflected tabulation) the Cenozoic subfamily Thoracosphaeroideae was included later (Fütterer, 1976). Unfortunately the type-species of this group *Thoracosphaera heimii* (Lohmann) Kamptner 1920, proved to represent a vegetative cell, not a cyst, and had to be classified within the new order Thoracosphaerales Tangen, (Tangen et al., 1982). *Thoracosphaera* species other than *T. heimii* are known only by their calcareous shells which are interpreted to represent resting cysts. Consequently, these species should be referred to a taxon outside the new order Thoracosphaerales Tangen. By skeleton ultrastructure, aperture size, and outline resembling the archeopyle of the calciodinelloids most of the thoracosphaerid species should probably be allocated to the family Calciodinellaceae of the Peridiniales.

The tight relationship of the genus *Pithonella* Lorenz 1901 (*sensu* Bolli 1974) of the *incertae sedis* family Calcisphaerulidae to thoracosphaerid calcareous dinoflagellates was emphasized by Fütterer (1976). The calcareous dinoflagellate cyst nature of at least certain species of the collective genus *Pithonella* Lorenz 1901 was proved by Keupp (1980).

On the basis of orientation of the morphological long axis of the skeletal crystallites of the cyst wall relative to the cyst's surface, Keupp and Mutterlose (1984) split the systematically chaotic collective genus *Pithonella* Lorenz 1901 (*sensu* Bolli, 1974) into three units, the old genus *Pithonella* Lorenz 1901 (*sensu* Villain, 1977) and the new genera *Orthopithonella* Keupp and *Obliquipithonella* Keupp. Later these systematic categories were raised into the rank of subfamilies (Keupp, 1987) of the family Calciodinellaceae Deflandre as follows:

— Orthopithonelloideae Keupp 1987, comprising dinoflagellate cysts showing single-layered or double-layered calcareous cyst walls. Crystals of the distal layer strictly radially orientated.

— Obliquipithonelloideae Keupp 1987, comprising dinoflagellate cysts showing single-layered to triple-layered calcareous cyst walls. Crystals of each layer show irregular, oblique, or tangential orientation.

— Pithonelloideae Keupp 1987, comprising dinoflagellate cysts showing single-layered to double-layered calcareous cyst walls. Crystals of the distal layer show regular oblique orientation. Due to their arrangement in regular rows a parquet-like surface pattern is formed.

An excellent summary of existing calcareous dinoflagellate taxa on the species and/or genus level was recently compiled by Lentin and Williams (1985). The present study deals only with taxa of the Orthopithonelloideae and Obliquipithonelloideae.

Asterisks in synonymous lists below mark citations of holotypes.

Class DINOPHYCEAE Fritsch 1929

Order PERIDINIALES Haeckel 1894

Suborder PERIDINIINEAE Fott 1959 (*sensu* Bujak and Davies 1983)

Family CALCIODINELLACEAE Deflandre 1947 (*sensu* Bujak and Davies 1983)

Subfamily ORTHOPITHONELLOIDEAE Keupp 1987

Diagnosis. Calcareous dinoflagellate cysts with single or double-layered cyst wall. Morphological orientation of calcite crystals of the outer wall layer is strictly radial. The inner wall layer may exhibit radial crystal orientation (genus *Orthopithonella* Keupp 1984) or oblique crystal orientation (genus *Tetramerosphaera* Willems 1985).

Genus *Orthopithonella* Keupp 1984

Diagnosis. Mostly circular sometimes slightly ovoid calcareous cysts showing predominantly single-layered cyst walls. Crystal orientation is always perpendicular to the cyst's surface. Slight paratabulation may occur.

Orthopithonella minuta n. sp.
(Pl. 1, Figs. 3–9)

Thoracosphaera sp. 2. Perch-Nielsen, 1971, p. 1–76, pl. 50, figs. 2, 3, 7.
Thoracosphaera sp. Martini, 1976, DSDP 33: p. 392, pl. 3, fig. 12.
Thoracosphaera sp. 5. Fütterer, 1977, DSDP 41: p. 717, pl. 8, figs. 9, 12.
Thoracosphaera? sp. 1. Perch-Nielsen, 1979, p. 115–135, pl. 3, fig. 21.

Diagnosis. Small spherical calcareous dinoflagellate cyst showing a medium-sized circular apical archeopyle. The single-layered wall consists of stubby stem-like crystals which are strictly radially orientated. The distal surface is characterized by a densely packed pattern of tiny, irregularly orientated rhombohedral crystals.

Description from SEM examinations. The cyst of *O. minuta* is predominantly spherical; slightly ovoid specimens may occur rarely. Its diameter ranges from 14 to 26 μm (Fig. 6) with a predominance of sizes smaller than 20 μm. Larger specimens up to 40 μm in diameter may occur occasionally. The size of the circular, sometimes slightly serrated archeopyle is between 8 and 12 μm, comprising one-third to less than a half of the cyst's diameter. An operculum has not been observed.

The cyst wall is single layered and generally one to 2.5 μm in thickness. The skeletal ultrastructure is composed of tiny compact, radially orientated, elongated crystals which terminate distally in three-sided, dominantly pointed or rarely, slightly flattened rhombohedrons. Skeletal crystals show proximally a rather even habit (Pl. 1, Fig. 8). Distal surfaces generally show clean and well developed crystal faces which give the cysts a characteristically fresh and diagenetically unaffected habit even if the surrounding sediment exhibits strong diagenetic alteration by crystal overgrowth.

There is no indication of a reflected tabulation either on the distal or on the proximal cyst surface. Likewise, the outline of the archeopyle does not show any indicative paratabulation pattern.

Remarks. The skeletal ultrastructure of *O. minuta* is very similar to that of "*Thoracosphaera*" *tuberosa* Kamptner from which it differs only by smaller cyst size, smaller skeletal crystallites, and smaller size and circular outline of the archeopyle.

Orthopithonella gustafsonii (Bolli 1974) at first glance shows strong similarities (Pl. 4, Figs. 4, 5, 8, 9) to *O. minuta*. Significant differences, however, are larger cyst size, thicker wall, smaller size, and ultrastructural details of skeletal crystallites of *O. gustafsonii*.

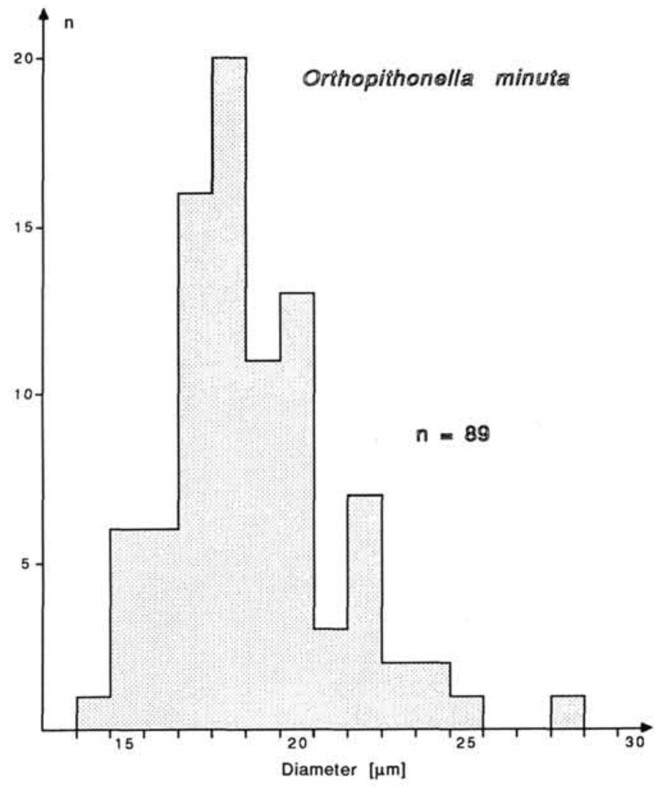

Figure 6. Distribution of cyst sizes of *Orthopithonella minuta* n.sp. n = number of specimens.

Holotype. AWI SEM No. 470-471/88, stub No. 113-3/8. Pl. 1, Figs. 4, 5. The diameter of the spherical cyst is 22.2 μm; width of archeopyle is 12.5 μm; thickness of the wall is 2.5 μm.

Type-locality and stratum typicum. Queen Maud Rise, eastern Weddell Sea, ODP Leg 113, Sample 113-689B-20H-3, 70-72 cm, lower/middle Eocene (CP12-CP13).

Derivatio nominis. minuta (Latin) = tiny; for its skeletal composition of tiny three-sided pyramid-shaped crystals.

Age and range of species. In sediments of Sites 689 and 690 at Queen Maud Rise *O. minuta* occurs first at the Cretaceous/Tertiary boundary. It is present at Site 689 up to the early Oligocene (CP17; Sample 113-689B-12H-1, 72-74 cm). At Site 690 it was observed up to the middle Eocene (CP14, Sample 113-690B-12H-3, 60-62 cm).

On Sierra Leone Rise (eastern North Atlantic) *O. minuta* is present from the late Paleocene to Oligocene (Fütterer, 1977). In sediments of the Walvis Ridge in the South Atlantic (DSDP Site 526) this species was observed from the late Eocene (NP18/19) to the middle Miocene (NN9, Fütterer, unpubl. data). In the central Pacific it is reported to occur from early to late Eocene (NP13-NP19/20; Martini, 1976). At Danish land sections it was described from near the K/T boundary (Perch-Nielsen, 1979) and from the Eocene (Perch-Nielsen, 1971).

Altogether, documentation of the stratigraphic range of *O. minuta* as shown, is rather complete. Its first occurrence is directly at or at least very close to the K/T boundary (ODP Sites 689 and 690); its decreasing abundance through the early Miocene and finally its last occurrence in the middle Miocene (NN9) is evident from DSDP Site 526 (Fütterer, unpubl. data).

Orthopithonella aspera n. sp.
(Pl. 5, Figs. 1-3)

Diagnosis. Relatively large, spherical, double-layered dinoflagellate cyst showing a circular archeopyle. Subhedral crystallites of both layers of the cyst wall are arranged strictly perpendicular to the surface.

Description from SEM examinations. The cyst of *O. aspera* is strictly spherical and ranges in size between 42 and 58 μm. The circular archeopyle is 19-26 μm in diameter corresponding to 40%-45% of the cyst's size.

The cyst wall is double layered and 12-16 μm in thickness. Crystallites of both layers are radially orientated. Crystallites of the outer layer are generally smaller than of the proximal layer. The former are 5-8 μm in length and 1.2-3 μm in width, the latter are 7-9 μm in length and 1.4-4.5 μm in width. The distal surface of the cyst shows an irregular arrangement of euhedral to subhedral, relatively coarse crystallites forming a rough surface pattern.

Remarks. This species differs from *O. flora* n. sp. by slightly larger cyst size, by its double-layered wall and by its crystallite ultrastructure and architecture.

Some principal ultrastructural similarities to *Orthopithonella ("Thoracosphaera") deflandrei* may exist. However, the latter shows a distinctly smaller cyst size, much smaller skeletal crystallites and most significantly, a much smaller and perfectly circular archeopyle.

Holotype. AWI SEM No. 2760-2761/88, stub No. 113-8/8; Pl. 5, Figs. 1, 2; Diameter of the spherical cyst is 48 μm; the width of the circular archeopyle is 21.4 μm.

Type-locality and stratum typicum. Queen Maud Rise, eastern Weddell Sea, ODP Leg 113, Sample 113-690C-15X-1, 36-38 cm, Danian, Subzone CP1b.

Derivation nominis. aspera (Latin) = rough, uneven; for its ultrastructurally rough surface pattern.

Age and range of species. On Queen Maud Rise *O. aspera* is present in Hole 689B from the poorly defined Maestrichtian/Danian boundary interval (Sample 113-689B-25X-5, 130-132 cm) to the late Paleocene Zone CP7 (Sample 113-689B-24X-CC, 41-43 cm). In Hole 690C it occurs from the uppermost Maestrichtian *Nephrolithus frequens* Zone to the late Danian Subzone CP1b (Sample 113-690C-15X-1, 36-38 cm). Its definite extinction datum needs further investigation.

Orthopithonella flora n. sp.
(Pl. 3, Figs. 1-7)

Thoracosphaera sp. 6. Fütterer 1977, p. 717, pl. 3, figs. 9, 12.

Diagnosis. Strictly spherical calcareous dinoflagellate cyst. Cyst wall single-layered. Morphological crystal orientation is perpendicular to the surface. Crystal arrangement shows a grid-shaped distal surface pattern.

Description from SEM examinations. The cyst of *O. flora* is strictly spherical and between 40 and 52 μm in diameter. An archeopyle has not been observed. The single-layered wall is to be recognized in broken specimens only.

The cyst wall reaches 7-10 μm in thickness and is composed of very irregularly formed prismatic crystals of variable length. At the proximal surface crystals are 0.5-1 μm in diameter and 1-2 μm in length. Toward their distal termination some of them coalesce to become as thick as 4 μm (Pl. 3, Fig. 7) which is interpreted to represent diagenetic crystal alteration.

On the distal surface skeletal crystallites terminate in generally small (0.2-0.4 μm in size), pointed rhombohedrons showing plain crystal faces (if diagenetically unaltered). Crystals are arranged in an indistinct circular pattern around a central depression (like petals in a blossom) which occasionally appears as a pseudo-pore. This crystal arrangement produces a striking reticular ultrastructural surface pattern.

Remarks. *O. flora* may be easily confused with *"Thoracosphaera" albatrosiana*. Both species show a very similar ultrastructure. The latter, however, shows a remarkably more regular crystal arrangement and true pores as well as a distinctly smaller cyst size. In addition, it shows a large irregularly shaped archeopyle and a corresponding polygonal operculum.

Holotype. AWI SEM No. 2712-2713/88, stub No. 113-8/10; Pl. 3, Figs. 1, 3. Diameter of the spherical cyst is 41.7 μm. Presence and size of archeopyle as well as wall thickness could not be identified.

Type locality and stratum typicum. Queen Maud Rise, eastern Weddell Sea, ODP Leg 113, Sample 113-690C-15X-3, 26-28 cm, Danian Subzone CP1b.

Derivatio nominis. flora (Latin) = blossom; because of crystal arrangement on the cyst surface.

Age and range of species. In sediments from Queen Maud Rise *O. flora* occurs in Hole 689B from the Cretaceous/Tertiary boundary zone (Sample 113-689B-25X-5, 130-132 cm) through the early Paleocene (Sample 113-689B-25X-2, 33-35 cm). In Hole 690C it is present from the late Maestrichtian *Nephrolithus frequens* Zone (Sample 113-690C-15X-6, 23-25 cm) to the Danian Subzone CP1b (Sample 113-690C-15X-1, 36-38 cm).

In the North Atlantic (Sierra Leone Rise) *O. flora* occurs in DSDP Hole 366A in the early Oligocene.

Orthopithonella gustafsonii (Bolli 1974) Keupp and Mutterlose 1984
(Pl. 4, Figs. 4, 5, 8-10)

**Pithonella gustafsoni* n. sp. Bolli 1974, p. 854, pl. 3, fig. 9-12; pl. 12, figs. 9-11; pl. 13, figs. 1, 2; pl. 22, fig. 3.

Pithonella sp. B. Bolli 1974, p. 857, pl. 7, figs. 6-8; pl. 20, fig. 9; pl. 24, fig. 3.

Pithonella gustafsoni Bolli 1974. Keupp 1977, p. 62, pl. 21, figs. 1-3, non fig. 4.

Orthopithonella gustafsoni (Bolli 1974). Keupp and Mutterlose 1984, p. 158-159, pl. 20, figs. 1-11.

Original diagnosis as given by Bolli (1974). Test spherical, formed by one layer of approximately 4 μm thickness. Outer surface consists of subrounded to angular, fairly regularly sized, crystals of 1-2 μm, arranged in a tight, cobblestone-like pattern. Crystals elongate in cross section, slightly conical with long axis in radial orientation. Wall thickness equals length of crystals. Inner surface similar to outer, but crystal ends more angular, slightly smaller and with faces better developed. Circular aperture fairly small, regular.

In contrast to his original description of a circular archeopyle, which is consistent with the figured holotype, Bolli (1974, pl. 12, figs. 7, 8, 12) figures some paratypes showing polygonal archeopyles. It is doubted here that both morphotypes belong to the same taxon.

Similarly, Keupp's (1981) classification comprises two morphotypical groups of specimens within *O. gustafsonii*: (1) specimens which are consistent with the original diagnosis showing a circular aperture or archeopyle; (2) specimens which show patterns of reflected tabulation and a polygonal, in outline very variable, archeopyle. The latter group had been formerly described as *Pithonella paratabulata* Keupp 1980.

Intensity and completeness of paratabulation of calcareous dinoflagellate cysts generally do vary in a wide range within a certain species.

Therefore paratabulation may be used only as a secondary systematic feature on the species level. The type, size and outline of the archeopyle, however, provides important information about the tabulation of the theca represented by the dinoflagellate cyst, and many cysts, morphologically similar in other respects, are distinguished by different archeopyles (Evitt, 1967). In particular, a circular as opposed to a polygonal archeopyle must be regarded as a significant systematic feature for distinguishing taxa on the genus and/or species level.

Therefore *Orthopithonella gustafsonii* (Bolli 1974) in this paper is treated according to the original description as given by Bolli (1974) not comprising *O. paratabulata* (showing a polygonal archeopyle) as mentioned by Keupp (1981) and Willems (1988). The list of synonymy is restricted to descriptions definitely fitting into this category.

Description from SEM examination. The cyst is strictly spherical. It shows a wide variety in size (22–38 μm) but cysts of 30–35 μm in diameter are most abundant (Fig. 7). The small, distinctly circular archeopyle is 9–14 μm in width comprising about one-third (30%–38%) of the cyst's diameter.

The cyst wall is single-layered, 2.5–4 μm in thickness and composed of densely packed, elongated stem-shaped crystals which, depending on preservation, may show a three-radiate cross section (Pl. 4, Fig. 10). Distal terminations of the crystals show small, euhedral to subhedral rhombohedrons and plain crystal faces which gives the distal cyst surface a fresh, compact appearance.

Remarks. There is some morphological resemblance to *O. minuta* from which it differs by width and outline of the archeopyle, by larger cyst size and thicker wall as well as by ultrastructural details in size and arrangement of cyst forming crystals.

Cyst size of *O. gustafsonii* given in the literature varies widely. Bolli (1974) indicated 50 μm for the holotype (Lower Cretaceous), Keupp (1977, 1981) mentioned 20–35 μm (Upper Jurassic) and 35–50 μm (Lower Cretaceous) respectively, and Keupp and Mutterlose (1984) quoted 30–40 μm (Lower Cretaceous). Willems (1988), in a detailed study of Upper Cretaceous chalk, mentioned a range of 45–85 μm with a predominance of 60–75 μm. From these data and the detailed discussion given by Willems (1988) it is argued that several species are lumped together. This is in part because of morphologically convergent forms and diverging taxonomic ideas but mainly because of diagenetically caused secondary alterations by crystal growth.

Age and range of species. At Queen Maud Rise in Hole 689B *O. gustafsonii* is present but very rare in the uppermost Maestrichtian to lowermost Danian (Sample 113-689B-25X-5, 130–132 cm to Sample 113-689B-25X-5, 35–37 cm). In Hole 690C it is present from the late Maestrichtian *Nephrolithus frequens* Zone (Sample 113-690C-15X-7, 4–6 cm) to the Danian Subzone CP1b (Sample 113-690C-15X-1, 36–38 cm).

The oldest occurrence of *O. gustafsonii* reported is from the uppermost Jurassic (Malm zeta 1 to zeta 3) of Solnhofen (southwest Germany; Keupp, 1977). In the D-beds of Speeton (England) it is present in the upper Berriasian (Keupp and Mutterlose, 1984). In the eastern Indian Ocean this species occurs from upper Aptian to upper Albian and from the Coniacian to the Santonian (Bolli, 1974). In the Upper Cretaceous chalk sections of Northern Germany it is present from the Coniacian to lowermost Campanian (Willems, 1988).

Orthopithonella congruens n. sp.
(Pl. 4, Figs. 1–3, 6–7)

Diagnosis. Spherical calcareous dinoflagellate cyst showing a small circular archeopyle. The single-layered wall is formed by very regularly shaped, elongated, rhombohedral crystals, orientated perpendicular to the cyst's surface. The distal cyst surface is characterized by a regular pattern of calcitic rhombohedrons.

Description from SEM examinations. The cyst of *O. congruens* is strictly spherical. It varies in size from 26 to 42 μm but is dominantly about 30 μm in diameter (Fig. 8). The small, circular archeopyle is between 8 and 14 μm in width comprising about 35%–45% of the cyst diameter. An operculum has not been observed. The single-layered wall is composed of very regularly shaped and sized elongated rhombohedric crystals (Pl. 4, Fig. 7) which are 2.6–4 μm in length and 1–2 μm in width. Wall thickness equals the length of the crystals. Crystal arrangement of the cyst wall is very regular which results in a corresponding regular pattern on the cyst's surface. The distal surface is composed of a regular pattern of equally sized, very pronounced, euhedral calcite rhombohedrons showing plain crystal faces.

Remarks. *O. congruens* shows some general similarities to *O. gustafsonii* but differs significantly from it by crystal size and extremely regular crystal arrangement.

Holotype. AWI SEM No. 0930-0931/88, stub No. 113-6/4; Pl. 4, Fig. 6. The diameter of the spherical cyst is 26.5 μm; width of the archeopyle is 11.5 μm; thickness of the wall or crystallite length is 2.9 μm.

Type-locality and stratum typicum. Queen Maud Rise, eastern Weddell Sea, ODP Leg 113, Sample 113-690C-15X-5, 20–22 cm; late Maestrichtian *Nephrolithus frequens* Zone.

Derivatio nominis. congruens (Latin) = identical, because of cyst pattern composed of identically-sized crystals.

Age and range of species. At Queen Maud Rise *O. congruens* occurs in Hole 689B from late Maestrichtian *Nephrolithus frequens* Zone (Sample 113-689B-25X-6, 30–32 cm) through the Maestrichtian/Danian boundary zone, (Sample 113-689B-25X-5, 35–37 cm). In Hole 690C it is present from the late Maestrichtian *Nephrolithus frequens* Zone to the lowermost Danian Subzone CP1a (Sample 113-690C-15X-4, 12–14 cm).

At the Walvis Ridge (South Atlantic) this species is present in the late Maestrichtian and K/T boundary sequence (Sample DSDP-74-527-36-4, 49–50 cm, middle/late Maestrichtian, through Sample DSDP-74-527-32-4, 69–71 cm directly below the K/T boundary (Fütterer, unpubl. data).

Orthopithonella sp. 1
(Pl. 1, Figs. 1, 2)

Description. Cysts are strictly spherical and 22–28 μm in size. A large circular archeopyle 12.5–15 μm in diameter is present. The single

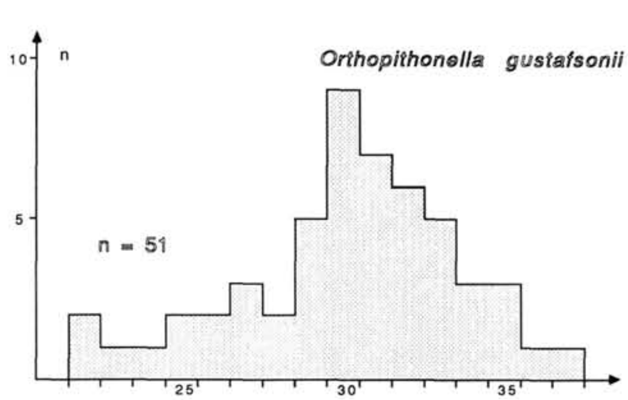

Figure 7. Distribution of cyst sizes of *Orthopithonella gustafsonii* (Bolli 1974). n = number of specimens.

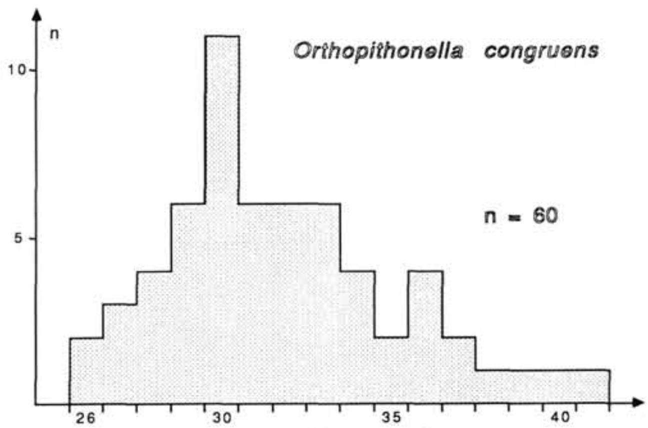

Figure 8. Distribution of cyst sizes of *Orthopithonella congruens* n.sp. n = number of specimens.

layered cyst wall is formed by very solid, rhombohedral crystallites orientated such that they terminate distally in polygonal irregular pyramids resulting in a somewhat spinous distal surface pattern. From crystallite ultrastructure it is clearly discernable that this crystal morphology is strongly dependent on secondary growth (Pl. 1, Fig. 2).

This cyst type resembles *O. minuta* to some degree but shows a distinctly different ultrastructure which, though clearly diagenetic in origin, could not be derived from *O. minuta*. It is regarded to represent a separate species. Because the data base is too small in abundance and range, it is still treated in open nomenclature.

Occurrence. Queen Maud Rise, eastern Weddell Sea, rare to very rare in the late Paleocene (CP7–CP8) of Hole 689B (Samples 113-689B-24X-1, 51–53 cm through 113-689B-23X-3, 70–72 cm).

Subfamily OBLIQUIPITHONELLOIDEAE Keupp 1987

Original diagnosis. Dinoflagellate cysts with single to triple-layered walls. Each composed of ± irregularly arranged, obliquely to tangentially orientated crystallites.

This diagnosis was supplemented and confirmed by Willems (1988). He defined the X-shaped growth of the irregular, obliquely orientated crystals of the distal layer of the cyst wall (cross beam structure) as the characteristic feature for the whole subfamily.

Genus *Obliquipithonella* Keupp 1984

Type-species. *Obliquipithonella multistrata* (Pflaumann and Krasheninnikov).

Original diagnosis. Cysts without external reflected tabulation, frequently showing double-layered cyst walls. Distal wall layer composed of obliquely orientated block-shaped to elongated calcite rhombohedrons.

Remarks. The large variability of the taxa, many of which are treated as morphotypes (Keupp, 1987), which comprise this genus, precludes the introduction of many detailed systematic features on a generic level.

Obliquipithonella krasheninnikovii (Bolli 1974) nov. comb.
Basionym. *Pithonella krasheninnikovi* Bolli 1974, p. 856, pl. 24, figs. 1, 2. (Pl. 2, Figs. 7, 8)

**Pithonella krasheninnikovi* n. sp. Bolli 1974, DSDP 27: p. 856, pl. 7, figs. 1–5; pl. 18, figs. 10–12; pl. 19, figs. 1–12; pl. 20, fig. 1–4; pl. 24, fig. 1–2.

Pithonella krasheninnikovi Bolli. Pflaumann and Krasheninnikov 1978, DSDP 41: p. 822, pl. 4, figs. 1–6.

Pithonella krasheninnikovi Bolli. Bolli 1978, DSDP 40: p. 821–822, pl. 3, figs. 1–12.

Pithonella krasheninnikovi Bolli. Krasheninnikov and Basov 1983, DSDP 71: p. 984, pl. 9, figs. 1–9; pl. 10, figs. 1–5.

Pithonella krasheninnikovi Bolli. Fütterer 1984, DSDP 74: p. 536, pl. 1, figs. 1–8.

Description from SEM examinations. The cyst is distinctly elongated to ovoidal and 45–120 μm in length. Width/length ratio is between 1:1.3 to 1:2. It may show a small apical to slightly asymmetrically circular aperture of 15–35 μm in diameter; an operculum has not been observed. The cyst wall is double-layered. The outer layer consists of elongated small, to some extent plate-shaped, irregularly arranged calcite crystals, the long axis obliquely orientated relative to the cyst's surface. Crystal arrangement produces a porous lattice-like surface pattern. Crystal size varies, 1–4 μm in length and 0.5–1 μm in diameter. Thickness of the outer layer varies considerably between 0.5 and 4.3 μm. It may be absent completely (Pl. 2, Fig. 8), or partially due to diagenetic crystal growth (of inner layer), dissolution or mechanical abrasion during sample preparation.

The inner layer consists of densely packed, massive, variably sized crystals showing well developed rhombohedral crystal faces on the distal surface. The thickness of the inner layer generally is 5–7 μm but layers as thick as 15 μm may occur.

Willems (1988, p. 437), listing all species of the genus *Orthopithonella*, mentions this species as systematically belonging, as a nov. comb., to the genus *Orthopithonella* Keupp 1984. The crystal orientation of the outer cyst wall is without doubt oblique to the cyst surface (see also Keupp, 1981) and thus assigns this species to the genus *Obliquipithonella* Keupp 1984.

Age and range of species. At Queen Maud Rise *O. krasheninnikovii* is present from the late Maestrichtian to the lowermost Danian (Samples 113-689B-25X-5, 35–37 cm; 113-690-15X-4, 12–13 cm). Because of stratigraphic uncertainties it is presently not possible to decide whether this species crosses the K/T boundary or becomes extinct directly at it.

In the South Atlantic this species is described from late/middle Maestrichtian to earliest Danian (Walvis Ridge; Fütterer, 1984), from the Campanian to early Maestrichtian (Falkland Plateau; Krasheninnikov and Basov, 1983), in the North Atlantic from Campanian to early Maestrichtian (Pflaumann and Krasheninnikov, 1978) and in the Indian Ocean from the Coniacian to Santonian (Bolli, 1974).

In summary, the stratigraphic range of *O. krasheninnikovii* as described so far is restricted to the Upper Cretaceous (Coniacian to Maestrichtian) becoming extinct directly at or immediately beyond the Cretaceous/Tertiary boundary.

Obliquipithonella operculata (Bramlette and Martini, 1964) nov. comb.
Basionym. *Thoracosphaera operculata* Bramlette and Martini 1964, p.305–306, pl. 5, figs. 3–7.
Pl. 2, Figs. 1–6)

**Thoracosphaera operculata* n. sp. Bramlette and Martini 1964, p. 305–306, pl. 5, figs. 3–7.

Thoracosphaera sp. Perch-Nielsen 1970, p. 51–68, pl. 2 fig. 13, 14.

Thoracosphaera sp. 3. Perch-Nielsen 1971, p. 1–76, pl. 50, fig. 1.

Thoracosphaera operculata Bramlette and Martini 1964. Perch-Nielsen 1972, p. 1023, pl. 8, fig. 1.

Thoracosphaera sp. cf. *T. operculata* Bramlette and Martini 1964. Edwards 1973, p. 655–657, pl. 15, figs. 5, 6.

Thoracosphaera atlantica n. sp. Haq and Lohmann 1976, p. 183, pl. 3, figs. 11, 12.

Thoracosphaera operculata Bramlette and Martini. Jafar 1977, p. 108–110, fig. 2, 1a–1d, fig. 3, 4a–4d.

Thoracosphaera operculata Bramlette and Martini 1964. Gazdzicka 1978, p. 335–375, pl. 41, figs. 2, 4.

Thoracosphaera operculata Bramlette and Martini 1964. Perch-Nielsen 1979, p. 115–135, pl. 3, fig. 22.

Thoracosphaera operculata Bramlette and Martini. Jafar 1979, p. 9–11, pl. 1, figs. 1–4, 6, 8, 9, non fig. 7.

Thoracosphaera operculata Bramlette and Martini. Okada and Thierstein 1979, p. 516–517, pl. 8, figs. 8a–b, pl. 19, figs. 11.

Thoracosphaera saxea Stradner. Okada and Thierstein 1979, pl. 19, fig. 12.

Thoracosphaera operculata Bramlette and Martini. Haq and Aubry 1981, p. 279–280, pl. 3, figs. 10, 11.

Original description (from light optical investigations, Bramlette and Martini, 1964). The spherical shell normally has a buccal opening, and a distinct operculum which covers the opening in some specimens but in others it is usually detached and isolated. The wall pattern is irregular, and the component calcite units, seen best under crossed nicols, are small and have different orientation in adjacent units. Around the buccal opening, a distinct border, with fine radial elements curving near the outer margin, is conspicuous under crossed nicols. The operculum shows the same structural character at its rim. Crystals surround a central part with a structure like that comprising most of the sphere. The diameter of the sphere is 16–24 μm, and the operculum 6–10 μm.

Remarks. The distinct border zone around the opening (archeopyle) is considered the most indicative feature for this species. Under crossed nicols it shows a bright zone which is also visible along the rim of operculum.

Description from SEM examinations. The cyst of *O. operculata* is spherical and 14–28 μm in diameter (Fig. 9). Slightly larger specimens may occur. The cyst wall is single-layered, 1.2–2 μm in thickness, composed of obliquely orientated, very small, granular to plate-shape euhedral crystals. On the distal surface the minute plate-like crystals are organized in a grid-shaped pattern (Pl. 2, Fig. 5), which erroneously has been interpreted as pore pattern (Haq and Lohmann, 1976; Jafar, 1979).

The cyst shows a small circular archeopyle of 7–12 μm in diameter which equals roughly 40% of the cyst's diameter. Rarely, kidney-shaped archeopyles occur. A circular operculum is frequently attached (Pl. 2, Fig. 2), showing identical ultrastructure to the cyst. The archeopyle always shows a collar-like rim of equally oriented crystals (Pl. 2, Fig. 3). A corresponding pattern is present on the operculum.

Remarks. There are abundant Upper Cretaceous specimens which show a large, circular to slightly serrated, unrimmed archeopyle. These are similar to the Danian specimen illustrated by Jafar (1979, pl. 1, fig.

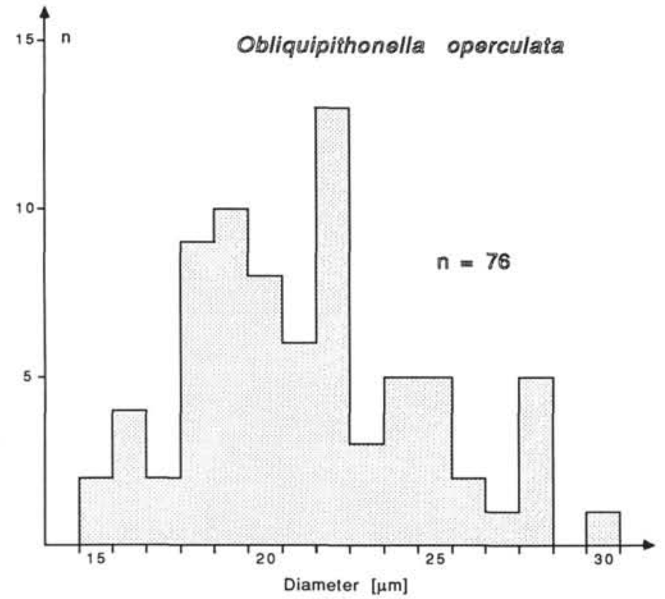

Figure 9. Distribution of cyst sizes of *Obliquipithonella operculata* (Bramlette and Martini 1964). n = number of specimens.

7) which does not belong to *O. operculata.* The cyst ultrastructure resembles the one described as *Thoracosphaera* sp. from the Campanian/Maestrichtian (Wise and Wind, 1977).

Age and range of species. At Queen Maud Rise *O. operculata* occurs in Hole 689B from the K/T boundary zone (Fig. 4) to the late Paleocene Zone CP8 (Sample 113-689B-23X-1, 70–71 cm). In Hole 690C it first appears exactly at or slightly above the K/T boundary (Fig. 5) and occurs through the Danian to the late Paleocene. Its precise extinction datum in the late Paleocene to early Eocene needs further investigation.

In the North Atlantic *O. operculata* occurs in the Paleocene or more precisely from the lowermost Paleocene (*Cruciplacolithus tenuis* Zone, Perch-Nielsen, 1972) to the middle Paleocene (*Fasciculithus tympaniformis* Zone; Okada and Thierstein, 1979).

In its original description (Bramlette and Martini, 1964) it is reported to occur commonly in the type Danian, and in equivalents in southwestern France, Tunisia, and Alabama (Clayton Formation), and less commonly in late Paleocene (Thanetian) strata of the Lodo Formation in California. Only rare specimens are mentioned from the Maestrichtian. It is assumed that those specimens belong to a morphologically similar but systematically different Upper Cretaceous morphotype described as *Thoracosphaera* sp. (Wise and Wind, 1977) rather than to *O. operculata.* Therefore it is assumed that *O. operculata, sensu strictu* is restricted to the Paleocene, having its first appearance exactly at the Cretaceous/Tertiary boundary. Its extinction datum needs further study but seems to occur somewhere in the middle to late Paleocene.

Obliquipithonella globosa (Fütterer 1984) nov. comb.
Basionym. *Pithonella globosa* Fütterer 1984, p. 536, pl. 2, fig. 1–9.

**Pithonella globosa* n. sp. Fütterer 1984, p. 536, pl. 2, fig. 1–9.

Remarks. Specimens occurring very rarely in the uppermost Maestrichtian of Hole 689B (Sample 113-689B-25X-5, 30–32 cm and 113-689B-25X-5, 130–132 cm) compare well with the middle Maestrichtian to Danian forms described from the South Atlantic. The spherical, double-layered cyst shows radial crystal orientation within the inner layer of the cyst wall. The outer layer of the cyst wall shows the oblique crystal orientation by which this species is defined to systematically belong to the genus *Obliquipithonella,* not to *Orthopithonella* as mentioned in Lentin and Williams (1985).

Obliquipithonella parva (Fütterer 1984) nov. comb.
Basionym. *Pithonella parva* Fütterer 1984, p. 536–537, pl. 3, Fig. 1–10; pl. 4, figs. 8–9.

**Pithonella parva* n. sp. Fütterer 1984, p. 536–537, pl. 3, figs. 1–10; pl. 4, figs. 8–9.

Remarks. Cyst specimens occurring at Queen Maud Rise sites are predominantly spherical and between 43–58 μm in diameter. They show all major features originally described. Thickness of the wall generally is rather small and varies considerably. The outer layer of the double-layered wall is composed of elongated, blade-shaped, euhedral to subhedral rhombohedral crystals, the long axes of which are predominantly obliquely orientated. The inner layer, generally thinner than the outer layer, is composed of irregularly to obliquely orientated compact rhombohedral crystals.

Occurrence. At Queen Maud Rise *O. parva* occurs in Hole 689B from the early Paleocene Zone CP3–CP4 (Sample 113-689B-25X-3, 30–31 cm) to the late Paleocene Zone CP7 (Sample 113-689B-24X-CC, 41–43 cm). In Hole 690C it is present in the Danian Subzone CP1b (Sample 113-690C-15X-3, 26–28 cm through Sample 113-690C-15X-1, 36–38 cm).

Genus *Centosphaera* Wind and Wise 1977.

Original Diagnosis. Large calcareous spheres constructed of hourglass-shaped blocks arranged in patchwork pattern. The sphere is ringed with one or more keels composed of needle-like crystals.

Centosphaera barbata Wind and Wise 1977
(Pl. 5, Figs. 4–9)

**Centosphaera barbata* n. sp. Wind and Wise in Wise and Wind 1977, p. 299, pl. 25, figs. 1–6, pl. 26. figs. 1–3, pl. 27, figs. 1–7.

Description. The cyst is spherical to slightly ovoid or laterally compressed and shows a variably complete pattern of keels circulating it. The cyst body is 18–25 μm in diameter; ovoid cysts show a length/width ratio of less than 1.15. The cyst wall is single-layered composed of regularly, tangentially orientated prismatic or slightly hour-glass-shaped crystals, 0.8–1.5 μm in width and 2–3 μm, rarely up to 4 μm, in length. Crystal arrangement on the distal surface causes a rather regular inlaid-pattern.

One or two parallel keels (Pl. 5, Fig. 8) of large, compact, subidiomorphic, irregularly blade-shaped crystals may circle the sphere. A wide variety of totally unkeeled, partially keeled and completely keeled specimens occurs (see Pl. 5, Figs. 4–9).

A circular to slightly oval archeopyle, 8–12 μm in diameter, can be observed in most specimens. Only rarely, an operculum is seen in place (Pl. 5, Fig. 6) showing the wall crystals forming a circular rim around the archeopyle. Where the keel pattern is complete a definite orientation of the cyst with respect to keel pattern and archeopyle is possible. The latter is positioned apically embedded between the keels (Pl. 5, Fig. 9).

Remarks. Specimens described here, at first glance, differ considerably from the original description by their crystallite ultrastructure. In the original description the keels are composed of needle-like crystals and the proximal surface of the cyst is lined with seemingly dendritic crystals. None of those features is to be observed among the specimens examined for this study. The main ultrastructural differences—coarser and massive crystals—are interpreted to represent simply diagenetic modifications by secondary crystal growth. This assumption is strongly supported by a figured paratype (Wise and Wind, 1977, pl. 26, figs. 1, 3) which shows a keel in an initial stage of recrystallization to form blade-like crystals.

The wide variety in keel morphology and completeness of its distribution is considered to represent an intraspecific property rather than the relationship to different species.

Age and range of species. At Queen Maud Rise *C. barbata* is present in Hole 689B from late Maestrichtian *Nephrolithus frequens* Zone (Sample 113-689B-25X-6, 30–32 cm) to the Danian CP1b Subzone (Sample 113-689B-25X-5, 35–37 cm). There is an uncertain isolated occurrence (Sample 113-689B-22X-3, 70–72 cm) in the late Paleocene to early Eocene (CP12–CP13) which might have been caused by contamination. In Hole 690C it is present from the Maestrichtian *Nephrolithus frequens* Zone (Sample 113-690C-15X-7, 6–7 cm) to the lowermost Danian Subzone CP1a (Sample 113-690C-15X-3, 26–28 cm).

In the South Atlantic (Falkland Plateau, DSDP Hole 327A) this species occurs throughout the Maestrichtian (Wise and Wind, 1977).

CONCLUSIONS

The semi-quantitative investigation of calcareous dinoflagellates of the two Cretaceous/Tertiary (K/T) boundary sections of Hole 689B, which is not continuous but probably comprises several hiatuses, and of Hole 690C showing a continuous and rather extended boundary succession, demonstrates a remarkable change in abundance and species distribution.

— A calcareous dinoflagellate mass occurrence evolved immediately above the K/T boundary (Danian CP1a) and flourished throughout the Danian into the higher Paleocene. This assemblage is dominated by only two species, predominantly *Obliquipithonella operculata* and to a lesser extent by *Orthopithonella minuta*. Five species account for up to 20%-30% of the total sediment.

— The complete Cretaceous calcareous dinoflagellate assemblage became extinct directly at or immediately above the K/T boundary (Danian CP1b). Subsequently a totally new Cenozoic assemblage evolved which forms the Danian mass occurrence.

— Cretaceous taxa that became extinct are *Orthopithonella gustafsonii, O. congruens, Obliquipithonella krasheninnikovii, O. globosa,* and *Centosphaera barbata.*

Cenozoic taxa which newly appear are *Obliquipithonella operculata, O. parva, Orthopithonella minuta, O. flora,* and *O. aspera.*

— Our data of calcareous dinoflagellate evolution and distribution at ODP Site 690 suggest that the extinction of Cretaceous and the evolution of Cenozoic taxa at the Cretaceous/Tertiary transition were caused by one event, even though some of the Cretaceous taxa such as *Orthopithonella gustafsonii* became extinct gradually.

ACKNOWLEDGMENTS

Review of this paper and many valuable suggestions for its improvement by H. Bolli, H. Keupp, H. R. Thierstein, S. W. Wise, Jr., and an anonymous colleague are gratefully acknowledged. K. Kerry kindly improved the English of the final manuscript. This research, as well as participation in ODP Leg 113, was kindly supported by the Deutsche Forschungsgemeinschaft (DFG). This is Alfred Wegener Institute for Polar and Marine Research Contribution No. 206.

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Date of initial receipt: 9 March 1989
Date of acceptance: 25 July 1989
Ms 113B-157

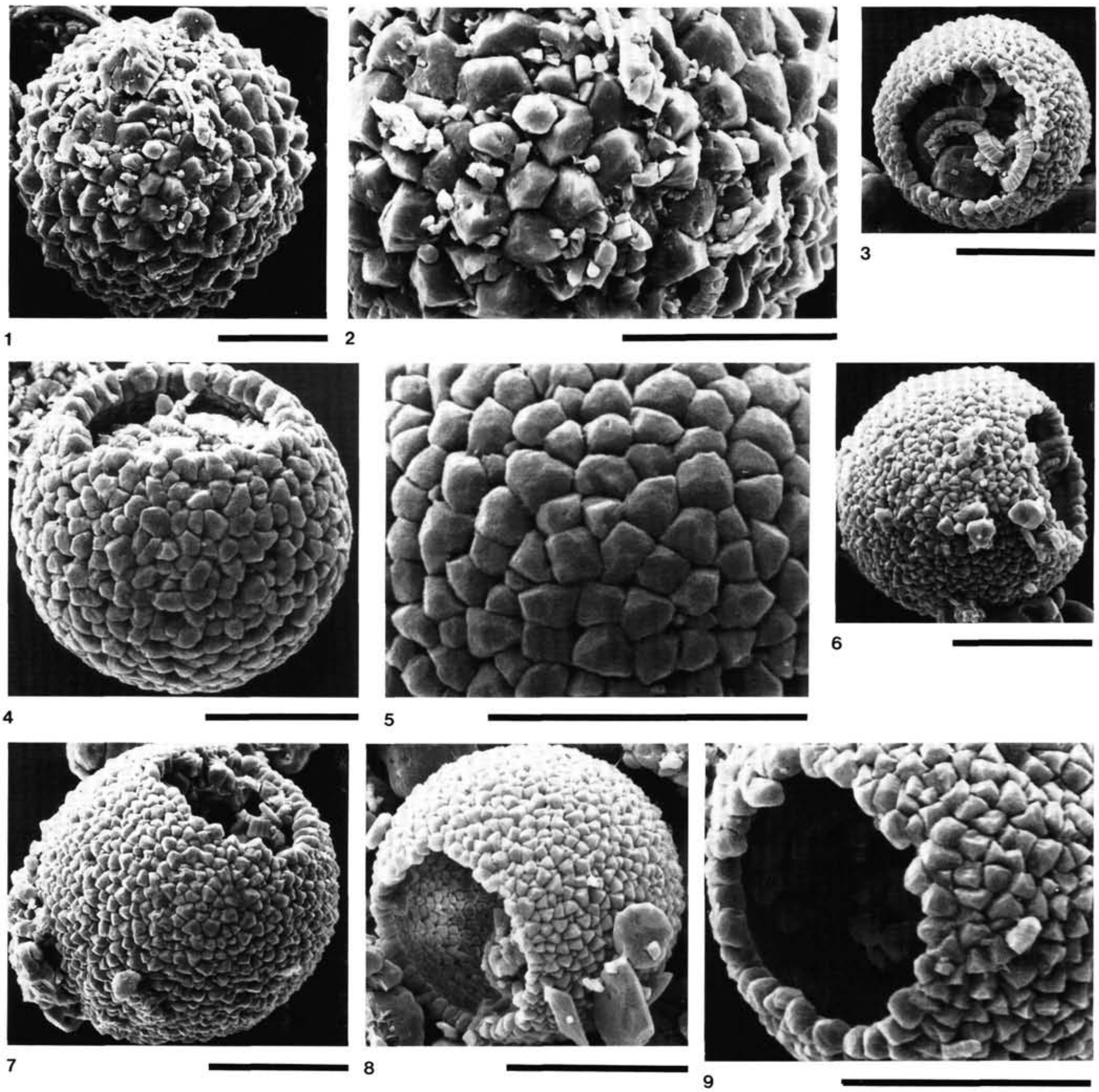

Plate 1. SEM photomicrographs of calcareous dinoflagellates; bar = 10 μm. **1.** *Orthopithonella* sp. 1 (No. 2095/88), Sample 113-689B-24X-1, 51–53 cm, late Paleocene (CP7). **2.** Same specimen as Fig. 1; close-up of distal surface ultrastructure, note the diagenetic growth pattern of skeletal crystallites. **3–9.** *Orthopithonella minuta* n.sp., (3) Paratype (No. 2390/88), apical view, Sample 113-689B-18H-1, 70–72 cm, middle Eocene (CP14a); (4–5) Holotype (No. 0470/88, 0471/88) showing details of distal surface crystallite pattern, Sample 113-689B-20H-3, 70–72 cm, early/middle Eocene (CP12–CP13); (6–7) Paratypes (No. 2388/88, 2393/88) showing irregularly shaped archeopyle; both specimens from Sample 113-689B-18H-1, 70–72 cm, middle Eocene (CP14a); (8) Paratype (No. 0941/88) showing details of distal and proximal wall surfaces; note the fresh outline of the euhedral skeletal crystallites compared to strongly recrystallized detrital particles attached, Sample 113-689B-18H-1, 70–72 cm, middle Eocene (CP14a); (9) Paratype (No. 0679/88) showing crystallite ultrastructure of the single-layered cyst wall, Sample 113-689B-20H-1, 70–72 cm, early/middle Eocene (CP12–CP13).

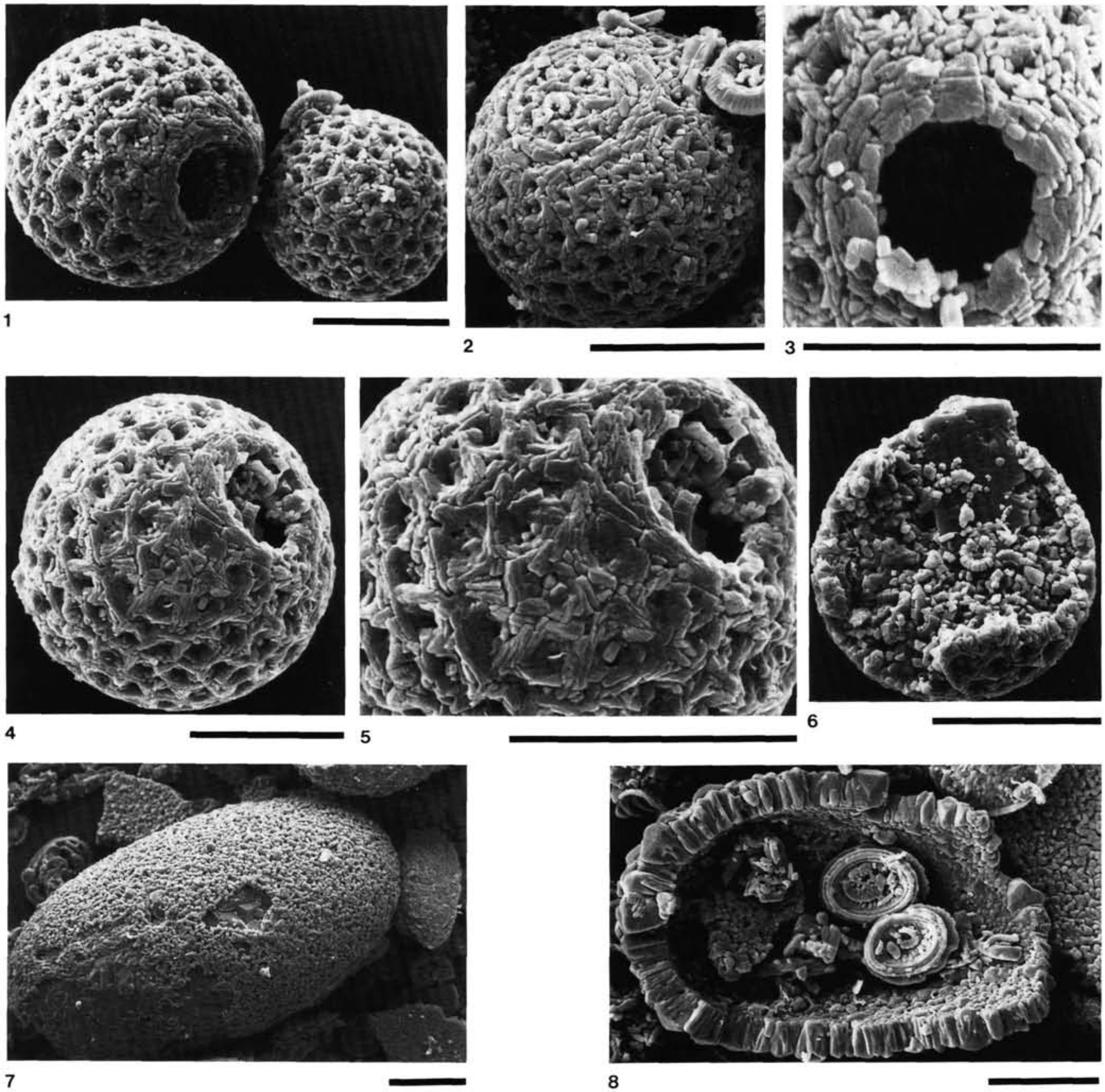

Plate 2. SEM photomicrographs of calcareous dinoflagellates; bar = 10 μm. **1-6.** *Obliquipithonella operculata,* (1) Cysts (No. 2154/88) showing variability of cyst size, Sample 113-689B-25X-3, 30-31 cm, late Paleocene (CP3-CP4); (2) Cyst (No. 2898/88) with operculum attached *in situ,* Sample 113-689B-25X-5, 35-37 cm, Danian (CP1); (3) Cyst (No. 0612/88) showing ultrastructural crystal arrangement at the archeopyle, Sample 113-689B-25X-3, 30-31 cm, late Paleocene (CP3-CP4); (4-5) Cyst (No. 0607/88, 0608/88) showing details of crystallite arrangement, Sample 113-689B-25X-1, 30-31 cm, late Paleocene (CP7); (6) Broken cyst (No. 2155/88) showing details of cyst wall architecture, note the large diagenetically formed calcite crystal penetrating the cyst wall without effecting its ultrastructure, Sample 113-689B-25X-3, 30-31 cm, late Paleocene (CP3-CP4). **7.** *Obliquipithonella krasheninnikovii* (No. 2801/88) with partially removed outer layer showing densely packed massive crystals of inner layer distal surface, Sample 113-689B-25X-6, 30-32 cm, late Maestrichtian (*Nephrolithus frequens* Zone). **8.** *O. krasheninnikovii* (No. 2808/88), cross section showing strong diagenetic crystal growth of inner layer, Sample 113-689B-25X-6, 30-32 cm, late Maestrichtian (*N. frequens* Zone).

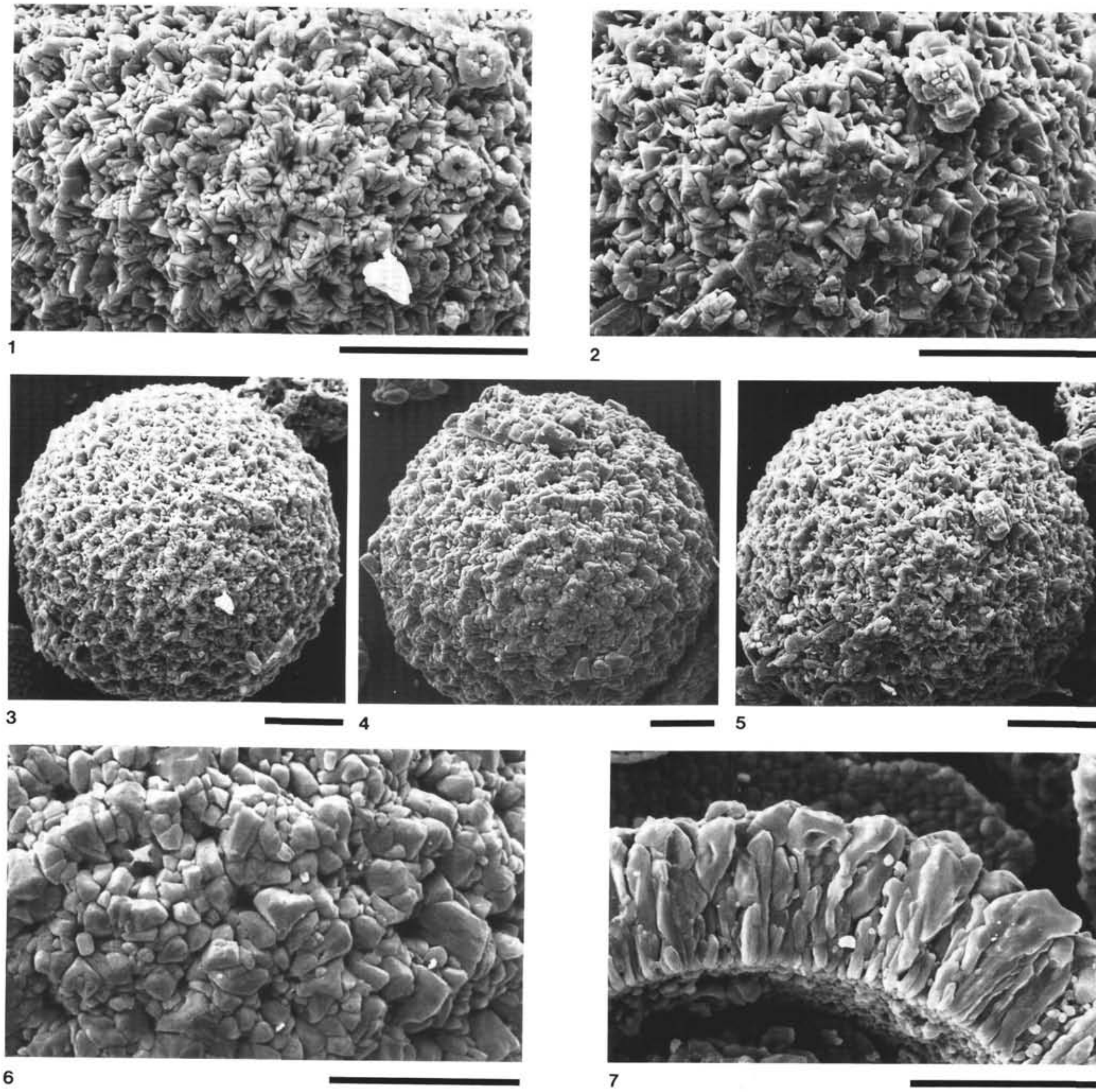

Plate 3. SEM photomicrographs of late Maestrichtian to Paleocene *Orthopithonella flora* n. sp.; bar = 10 μm. **1, 3.** Holotype (No. 2712-2713/88), Sample 113-690C-15X-3, 26–28 cm, Danian (CP1a). **2, 5.** Paratype (No. 2697-2698/88), showing cyst with small and fresh crystals on distal surface, Sample 113-690C-15X-3, 26–28 cm, Danian (CP1a). **4, 6.** Paratype (No. 2933-2934/88), showing relatively coarse diagenetically altered ultrastructure, Sample 113-689B-25X-5, 79–81 cm, lowermost? Danian. **7.** Paratype (No. 2879/88), showing details of one-layered cyst wall, radial crystal orientation and increasing diagenetic crystal growth toward the distal surface, Sample 113-689B-25X-5, 35–37 cm, lowermost? Danian.

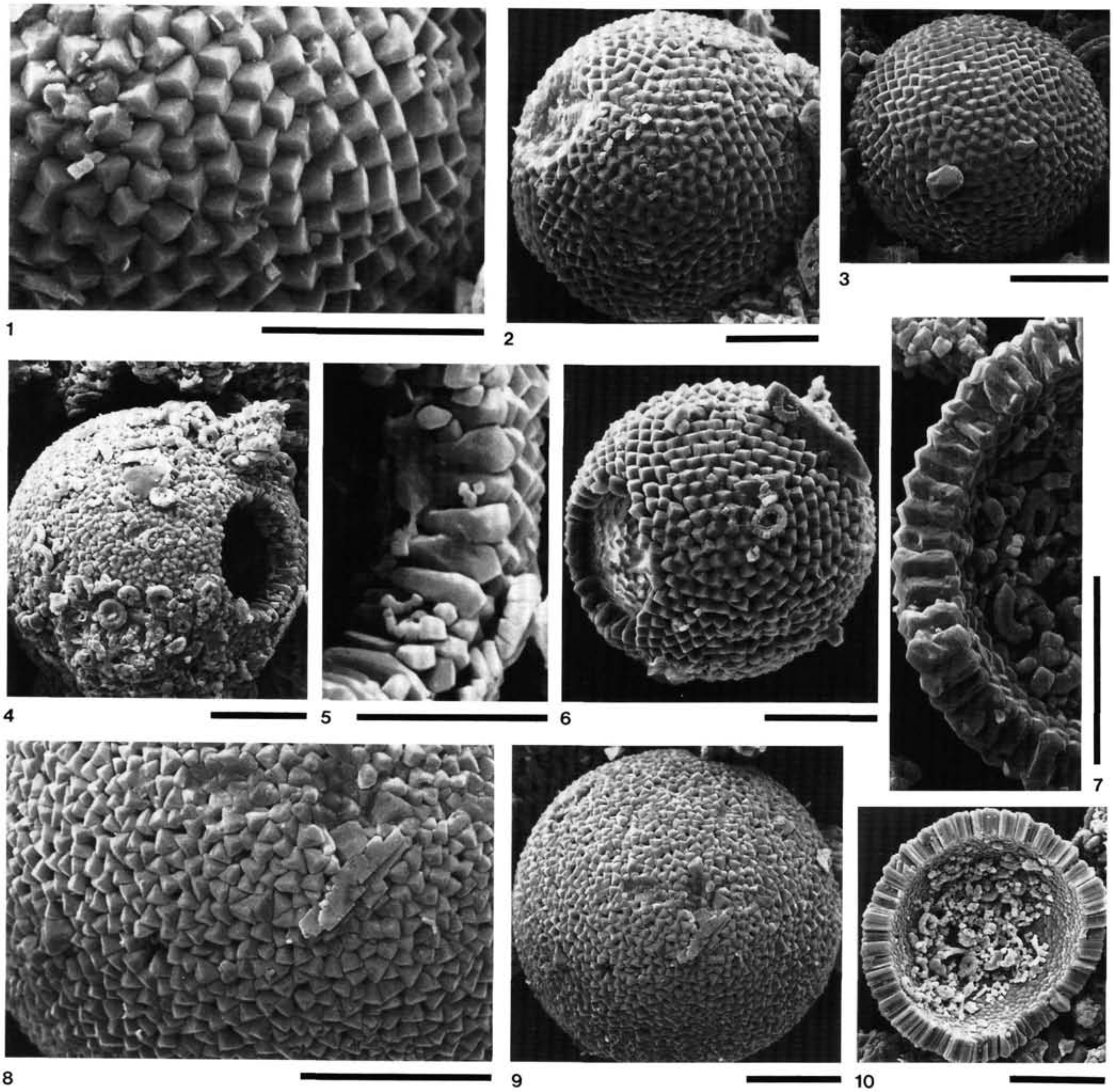

Plate 4. SEM photomicrographs of calcareous dinoflagellates; bar = 10 μm, for Fig. 5 = 5 μm. **1-3, 6-7.** *Orthopithonella congruens* n.sp.; (1-2) Paratype (No. 2216-2217/88), showing regular orientation and acute crystal outline, Sample 113-690C-15X-6, 23-25 cm, late Maestrichtian (*Nephrolithus frequens* Zone); (3) Small specimen, paratype (No. 2812/88), Sample 113-689B-25X-6, 30-32 cm, late Maestrichtian (*N. frequens* Zone); (6) Holotype (No. 0930/88) showing a small circular archeopyle and one-layered cyst wall, Sample 113-690C-15X-5, 20-22 cm, late Maestrichtian (*N. frequens* Zone); (7) Paratype (No. 2841/88), showing crystal arrangement in cyst wall, Sample 113-689B-25X-5, 130-132 cm, late Maestrichtian (*N. frequens* Zone). **4-5, 8-10.** *Orthopithonella gustafsonii* (Bolli 1974), (4) Cyst (No. 2721/88), showing small, spherical archeopyle, Sample 113-690C-15X-3, 26-28 cm, Danian Subzone CP1b; (5) Same specimen as Fig. 4 (No. 2719/88), showing crystal arrangement of the cyst wall; (8, 9) Cyst (No. 2925-2926/88), showing ultrastructure of distal cyst wall, Sample 113-689B-25X-5, 35-37 cm, late Maestrichtian (*Nephrolithus frequens* Zone); (10) Broken cyst (No. 2887/88), showing orientation of skeletal crystallites, Sample 113-689B-25X-5, 79-81 cm, lowermost? Danian.

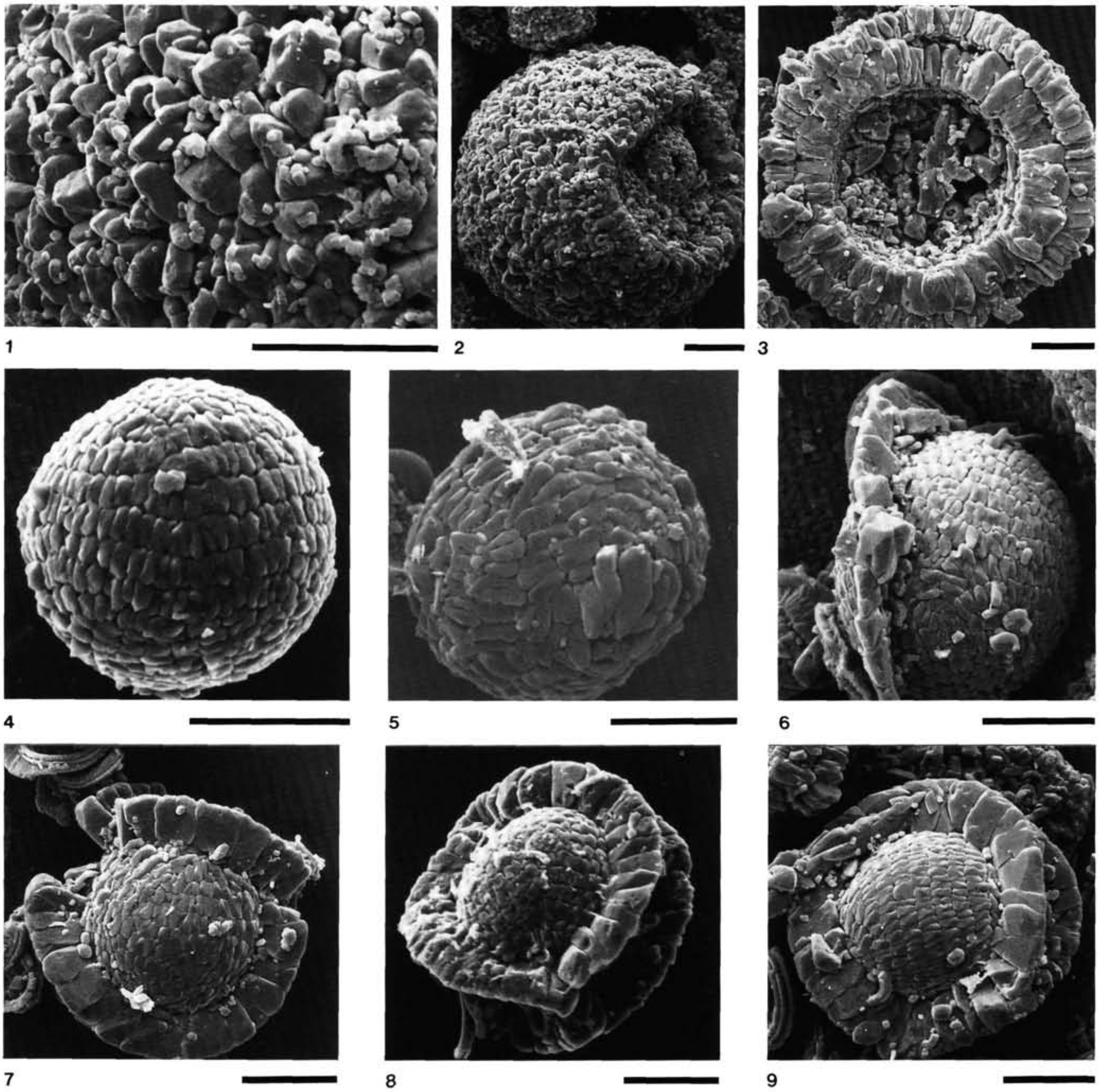

Plate 5. SEM photomicrographs of calcareous dinoflagellates; bar = 10 μm. **1, 2.** *Orthopithonella aspera* n.sp., holotype, showing circular archeopyle and irregular crystallite arrangement on a rough outer layer distal surface, Sample 113-690C-15X-1, 36–38 cm, Danian (CP1b). **3.** *Orthopithonella aspera* n.sp., Paratype, showing two-layered cyst wall and radial orientation of sturdy crystals in inner and outer layer, Sample 113-689B-25X-5, 79–81 cm, late Maestrichtian/Danian. **4–9.** *Centosphaera barbata* Wind and Wise 1977 showing various stages of preservation and increasing reflected tabulation. (4) Well preserved cyst lacking any ornamentation, Sample 113-690C-15X-6, 23–25 cm, late Maestrichtian; (5) Cyst (No. 0933/88) showing strong secondary crystallite overgrowth, Sample 113-689B-25X-5, 79–81 cm, late Maestrichtian; (6) Slightly ovoid cyst (No. 2915/88), apical view, showing attached ovoid operculum and rather incomplete tabulation pattern, Sample 113-689B-25X-6, 30–32 cm, late Maestrichtian; (7) Spherical cyst (No. 2844/88) showing strongly recrystallized tabulation ridges, Sample 113-689B-25X-5, 130–132 cm, late Maestrichtian; (8) Spherical cyst (No. 0929/88) in anteapical view, showing well developed set of strongly recrystallized tabulation ridges, Sample 113-690C-15X-5, 20–22 cm, late Maestrichtian; (9) Spherical cyst (No. 2832/88), lateral view (apex right), with well developed tabulation ridges, Sample 113-689B-25X-6, 30–32 cm, late Maestrichtian.