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New calcareous dinoflagellates from the Palaeogene of the South Atlantic Ocean (DSDP Site 357, Rio Grande Rise)

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ABSTRACT – The new calcareous dinoflagellate taxa *Bitorus truncus* n.sp., *Calcigonellum ansatum* n.sp. and *Fuettererella fungiforma* n.sp. are formally described on the basis of Eocene and Oligocene samples from DSDP Site 357 (western South Atlantic Ocean). *J. Micropalaeontol.* **18**(1): 89–95, June 1999.

INTRODUCTION

Calcareous dinoflagellates occur in significant quantities in many Mesozoic and Cenozoic marine sediments. However, for two main reasons the organisms have generally been overlooked in the past. As a result of their average size of 20–25 μm, they appear to be too small for foraminiferal studies and too large to be included in nannoplankton studies. Furthermore, they are dissolved during the preparation process for studies on organic-walled dinoflagellates.

Most information on fossil calcareous dinoflagellates focuses on Cretaceous material; few data on Palaeogene representatives are available. As a result of the interest in the Cretaceous/Tertiary (K/T) boundary, the majority of studies on Palaeogene calcareous dinoflagellates deal with Palaeocene taxa exclusively (e.g. Fütterer, 1990; Kienel, 1994; Willems, 1996). Eocene and Oligocene forms have been subject to only a few studies (e.g. Weiler, 1990; Kohring, 1993; Keupp & Kohring, 1994), and Fütterer (1977, 1984) alone has examined more extended time intervals, covering the entire Cenozoic.

This study concentrates on the description of new taxa in the Palaeogene of DSDP Site 357. It forms part of an extensive evaluation of the latest Cretaceous to early Neogene calcareous dinoflagellate associations within two mid-latitude DSDP cores of the South Atlantic Ocean: Sites 356 and 357 (Hildebrand-Habel *et al.*, in press; Hildebrand-Habel & Willems, in press). The investigations focus particularly on the Palaeogene. This interval is exceptionally interesting, as it not only includes the recovery following the K/T boundary, but also represents an intermediate stage between the warm Cretaceous and the colder Late Tertiary climates. It is marked by a general decline in temperature and shows significant palaeoceanographic changes (Miller *et al.*, 1987; Crowley & North, 1991; Berger & Wefer, 1996).

The associations of calcareous dinoflagellates and the morphology of the tests are influenced by external factors (e.g. nutrients, insolation, temperature, salinity), and the organisms thus represent sensitive tools for palaeoreconstructions (e.g. Zonneveld *et al.*, in press). By describing the three new species, the present study gives additional information about the poorly known Palaeogene assemblages of the South Atlantic Ocean. The systematic inventory may provide the background for subsequent analyses of the palaeoenvironmental signal of individual calcareous dinoflagellate taxa, as shown in Zonneveld *et al.* (in press).

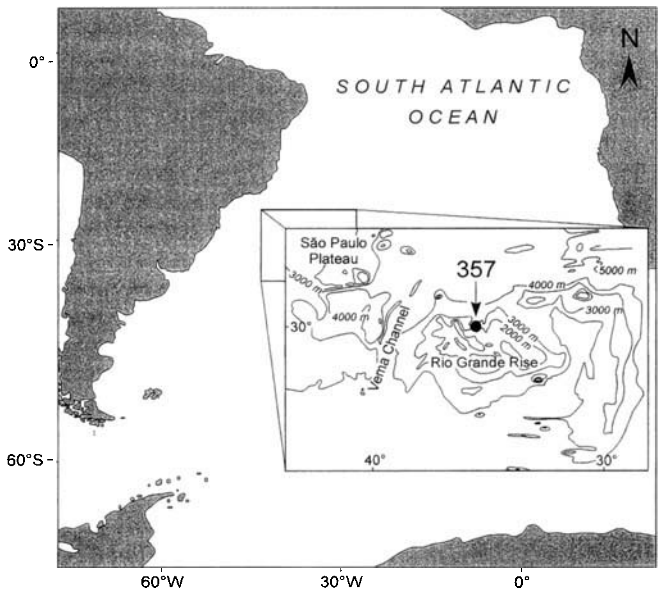


Fig. 1. Geographical location of DSDP Site 357 on the Rio Grande Rise. Bathymetry according to Shipboard Scientific Party (1977).

MATERIAL

The study is based on core material recovered during DSDP Leg 39 (Shipboard Scientific Party, 1977) at Site 357 (30°00.25′S, 35°33.59′W) in the western South Atlantic Ocean (Fig. 1). The site was drilled in a water depth of 2086 m on the northern flank of the Rio Grande Rise. The cored section of 796.5 m mainly consists of pelagic, biogenic carbonates. Terrigenous components occur only sporadically and in insignificant quantities; siliceous organisms are important only in the lower to middle Eocene interval.

Inferred hiatuses occur in the Campanian, at the K/T boundary, the Palaeocene/Eocene boundary, the Eocene/Oligocene boundary, and in the middle Miocene and Plio-Pleistocene (Shipboard Scientific Party, 1977).

A complete evaluation of the early Maastrichtian to early Miocene calcareous dinoflagellate assemblages of Site 357 is currently in preparation (Hildebrand-Habel & Willems, in press). The present study concentrates on the introduction of new species occurring in this time interval. Samples of Site 357 which contain new species are listed in Table 1.

METHODS

The samples were processed as described by Willems (1996). They were treated with saturated Glauber's salt solution

Table 1. Samples of DSDP core 39-357 containing the described new species of calcareous dinoflagellates. Nannoplankton zonation according to Martini (1971).

Sample (depth, cm)	Stratigraphy	New species
16-2 (75–76)	Late Oligocene (NP 25)	*Fuettererella fungiforma*
20-2 (79–80)	Late Eocene (NP19)	*Bitorus truncus*
		Calcigonellum ansatum
21-3 (88–89)	Middle Eocene (NP 16)	*Fuettererella fungiforma*

($Na_2SO_4 \cdot 10H_2O$) and repeatedly frozen and defrosted to disintegrate the material. Afterwards, the samples were washed through a 20 μm sieve and the residual fraction dried at 70°C. The specimens were then picked using a binocular microscope at a magnification of ×256 and stuck on scanning electron microscopy (SEM) stubs covered with adhesive stickers. The stubs were coated with gold and the morphotypes examined using a CamScan-44-SEM. Subsequently, some specimens were broken with a scalpel to allow examination of the wall structure.

To investigate the crystallographic orientation of the wall-forming crystallites, several specimens of *Calcigonellum ansatum* n.sp. and *Fuettererella fungiforma* n.sp. were additionally prepared as described by Janofske (1996). They were mounted on the gelatinous surface of a transparent piece of developed photographic film by wetting with water; they were then coated with gold and examined using the scanning electron microscope. The film strip was then embedded in low viscosity resin and cut into 3 μm thin sections using a rotation microtome. After embedding in Canada balsam, these thin sections were examined using a Zeiss Axioplan light microscope. Only the examination in polarized light enabled the exact determination of the crystallographic orientation of the wall-forming calcite crystals.

The original material is stored in the Division of Historical Geology and Palaeontology of the University of Bremen.

SYSTEMATIC PALAEONTOLOGY

Remarks. The suprageneric classification of calcareous dinoflagellates follows Fensome *et al.* (1993). These workers proposed a single subfamily Calciodinelloideae for dinoflagellate taxa with peridiniacean tabulation and a calcareous layer. Fensome *et al.* (1993) considered wall structures to be of unproved value in identifying phylogenetic relationships. On the contrary, Keupp (1987) and Kohring (1993) established a systematic concept of four subfamilies of calcareous dinoflagellate cysts based on the crystallographic orientation of the wall-forming calcite crystals. These subfamilies are directly related to wall types after Young *et al.* (1997). Recent studies (Janofske, 1996; Montresor *et al.*, 1997) proved the crystallographic orientation of calcite crystals to be species-specific, thus characterizing phylogenetic groupings. As a systematic revision of calcareous dinoflagellates, discussing all relevant morphological features, is currently in preparation (Janofske, pers. comm.), we continue using the classification according to Fensome *et al.* (1993).

Division **Dinoflagellata** (Bütschli, 1885) Fensome *et al.*, 1993
Subdivision **Dinokaryota** Fensome *et al.*, 1993
Class **Dinophyceae** Pascher, 1914
Subclass **Peridiniphycidae** Fensome *et al.*, 1993
Order **Peridiniales** Haeckel, 1894
Suborder **Peridiniineae** Autonym
Family **Peridiniaceae** Ehrenberg, 1831
Subfamily **Calciodinelloideae** Fensome *et al.*, 1993

Genus *Bitorus* Keupp, 1992

Original diagnosis (Keupp, 1992: 500) 'The bicarinate orthopithonelloid cysts have a single-layered calcareous wall. The two prominent circular bulges are equivalent to the precingular and postcingular plates. The apical, conelike operculum (= archaeopyle of exhausted cysts) includes the apical paraplates 2′–4″.'

Bitorus truncus n.sp.
(Plate 1, figs 1–7)

Derivation of name. Truncus (Latin) = torso. With reference to the shape of the cyst, which resembles a torso.

Diagnosis. A species of *Bitorus* with two cingulum-parallel arranged rings of intratabular lobes: seven precingular and five postcingular. Wide depressions reflect the cingulum and sulcus. The single-layered wall consists of crystallites with radially oriented long axes.

Holotype. Cyst 116/36, SEM micrographs 116/6/3-6, 116/7/1-6, 130/7/2-6, 131/1/1-5, 136/4/4-5, 136/5/1-5 (Plate 1, figs 2–6).

Type locality. Rio Grande Rise, western South Atlantic, DSDP Leg 39, Site 357.

Type stratum. Late Eocene zone NP19; sample 39-357-20-2, 79–80 cm.

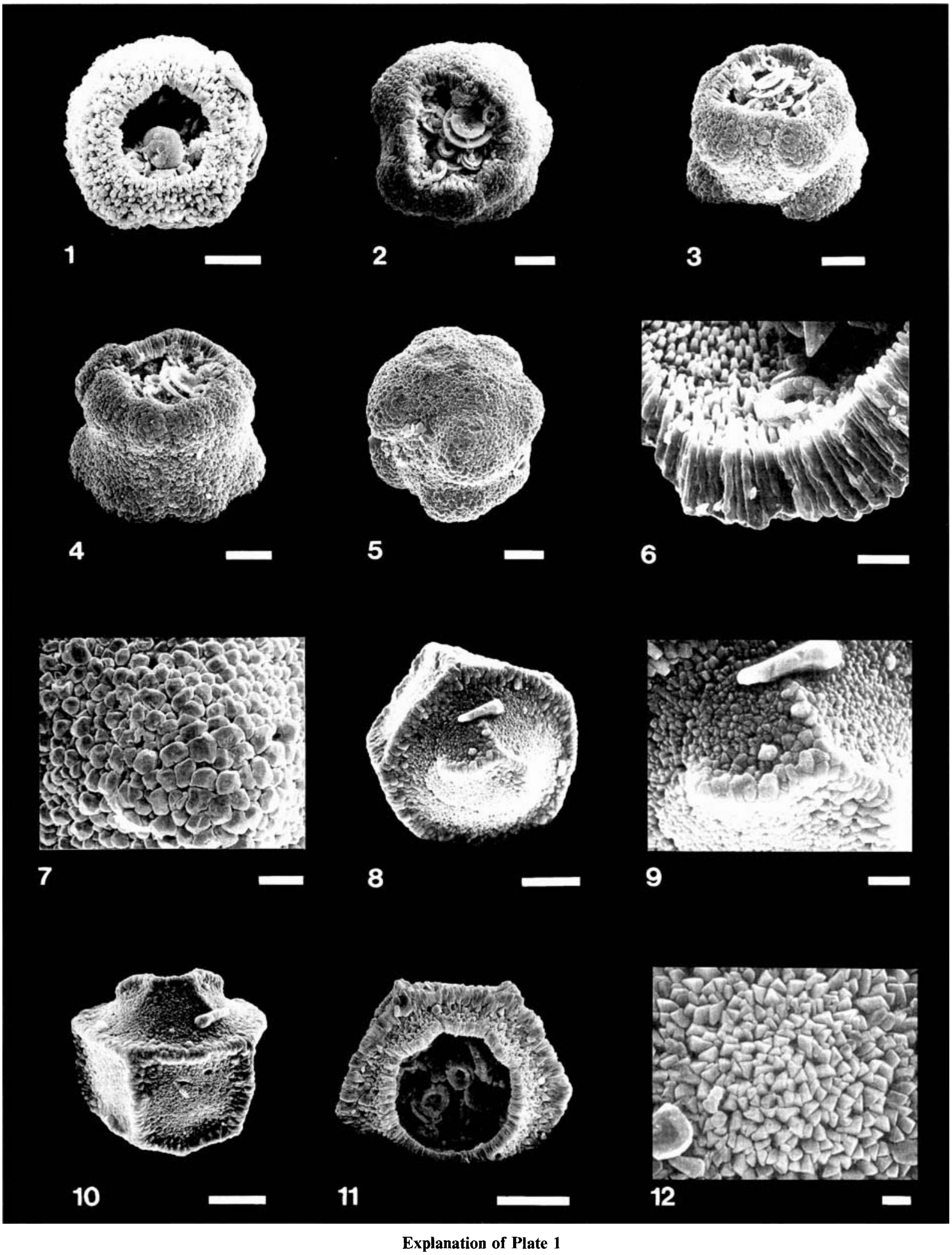
Paratypes. Cyst 116/17, SEM micrographs 115/1/1-5, 115/2/1-5, 128/6/5-6, 128/7/1-5, 129/1/1-4, 136/1/3-5 (Plate 1, fig. 1); cyst 116/35, SEM micrographs 116/4/1-6, 116/5/1-6, 130/5/3-6, 130/6/1-6, 130/7/1, 136/3/5, 136/6/1-3 (Plate 1, fig. 7).

Repository. Collection of the Division of Historical Geology and Palaeontology, Department of Geosciences, Bremen University, Germany.

Description. Bicarinate calcareous dinoflagellates with an incomplete reflection of precingular and postcingular plate equivalents. The apical face is subcircular and possesses a subcircular archaeopyle (Plate 1, fig. 1), possibly formed by the release of the paraplates 2′–4′. Seven intratabular lobes, arranged in a ring framing the apical face, reflect the precingular plates (Plate 1, figs 2–4). Paraplate 1′ is not reflected by a lobe, instead an intercalated depression transits to the sulcus. The intersection of the depressions of sulcus and cingulum results in a wide, ventral plane (Plate 1, fig. 3). A ring of five intratabular lobes represents the postcingular paraplates (Plate 1, fig. 5). The only slightly convex antapical face shows no plate equivalent. The lobes may be indistinct; however, the ventral lobes always remain prominent.

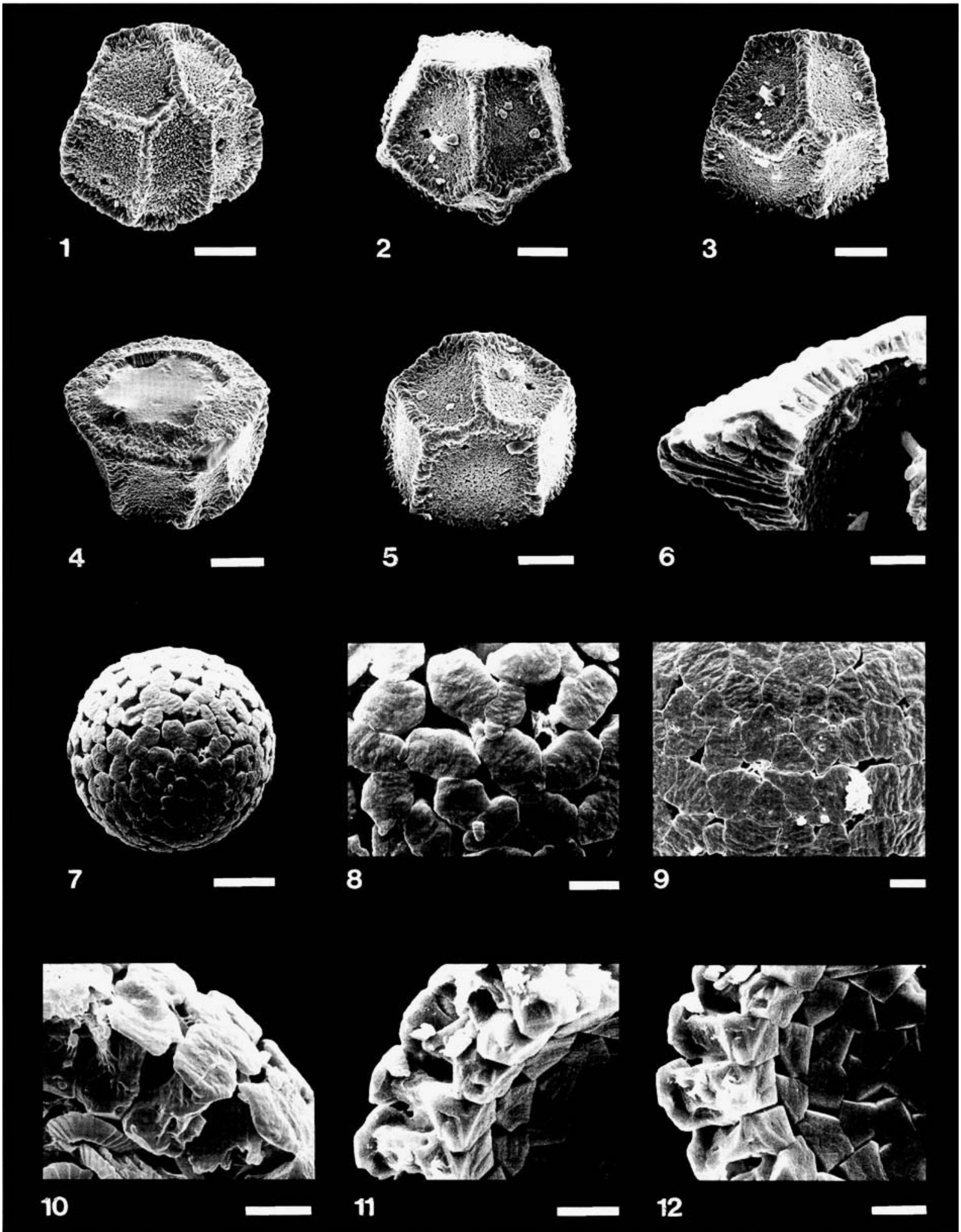
The single-layered wall is composed of slim crystallites (Plate 1, fig. 6). The long axes of the crystallites are radially oriented, although the orientations of the crystallographic *c*-axes remain unproved.

Dimensions. Holotype: length 44 μm, width 43 μm, archaeopyle 19.9 μm, thickness of wall 6.0 μm. Other specimens: length 35–36 μm, width 35–37 μm, archaeopyle 15.5–16.5 μm, thickness of wall 5.5–5.9 μm.



Explanation of Plate 1

New Palaeogene calcareous dinoflagellates from DSDP Site 357. **figs 1–7.** *Bitorus truncus* n.sp., core 39-357-20-2, 79–80 cm. **fig. 1.** Paratype, cyst 116/17, apical view. Scale bar = 10 μm. **figs 2–6.** Holotype, cyst 116/36. **fig. 2.** Apical view. Scale bar = 10 μm. **fig. 3.** Ventral–apical view. Scale bar = 10 μm. **fig. 4.** Dorsal–apical view. Scale bar = 10 μm. **fig. 5.** Ventral-antapical view. Scale bar = 10 μm. **fig. 6.** Cross-section of wall. Scale bar = 3 μm. **fig. 7.** Paratype, cyst 116/35, distal surface. Scale bar = 3 μm. **figs 8–12.** *Calcigonellum ansatum* n.sp., core 39-357-20-2, 79–80 cm. **figs 8–10.** Holotype, cyst d/2. **fig. 8.** Apical view. Scale bar = 10 μm. **fig. 9.** Distal surface. Scale bar = 3 μm. **fig. 10.** Dorsal view. Scale bar = 10 μm. **figs 11–12.** Paratype, cyst 116/23. **fig. 11.** Apical view. Scale bar = 10 μm. **fig. 12.** Distal surface. Scale bar = 3 μm.



Explanation of Plate 2

New Palaeogene calcareous dinoflagellates from DSDP Site 357. **figs 1–6.** *Calcigonellum ansatum* n.sp., core 39-357-20-2, 79–80 cm. **fig. 1.** Paratype, cyst 116/33, antapical–ventral view. Scale bar = 10 μm. **figs 2–6.** Paratype, cyst 116/15. **fig. 2.** Antapical view. Scale bar = 10 μm. **fig. 3.** Antapical–ventral view. Scale bar = 10 μm. **fig. 4.** Apical–ventral view. Scale bar = 10 μm. **fig. 5.** Antapical–dorsal view. Scale bar = 10 μm. **fig. 6.** Cross-section of wall. Scale bar = 3 μm. **figs 7–12.** *Fuettererella fungiforma* n.sp. **figs 7–8.** Holotype, cyst 113/76, core 39-357-21-3, 88–89 cm. **fig. 7.** Lateral view. Scale bar = 10 μm. **fig. 8.** Distal surface. Scale bar = 3 μm. **fig. 9.** Paratype, cyst 121/99, core 39-357-16-2, 75–76 cm, distal surface. Scale bar = 3 μm. **fig. 10.** Paratype, cyst 114/14, core 39-357-21-3, 88–89 cm, cross-section of wall. Scale bar = 1 μm. **figs 11–12.** Paratype, cyst 113/38, core 39-357-21-3, 88–89 cm. **fig. 11.** Cross-section of wall. Scale bar = 3 μm. **fig. 12.** Proximal surface. Scale bar = 3 μm.

Comparison. *Bitorus truncus* differs from the two other species of *Bitorus*, *B. turbiformis* Keupp, 1992 and *B. bulbjergensis* Kienel, 1994, in possessing intratabular lobes reflecting the precingular and postcingular paraplate equivalents.

Occurrence. Rare in the late Eocene of the Rio Grande Rise, sample 39-357-20-2, 79–80 cm.

Genus *Calcigonellum* Deflandre, 1948; emend. Keupp, 1984; emend. Keupp & Versteegh, 1989

Emended diagnosis (translated from Keupp & Versteegh, 1989: 211) 'Dinoflagellate cysts with a single-layered, radial-fibrous calcareous wall. The parasutural paratabulation is characterised by large, prismatic areas constructed by fused pre- and postcingular homologues. The large, apical archaeopyle at least integrates the homologues of the apical and intercalary plates.'

Calcigonellum ansatum n.sp.
(Plate 1, figs 8–12; Plate 2, figs 1–6; Fig. 2)

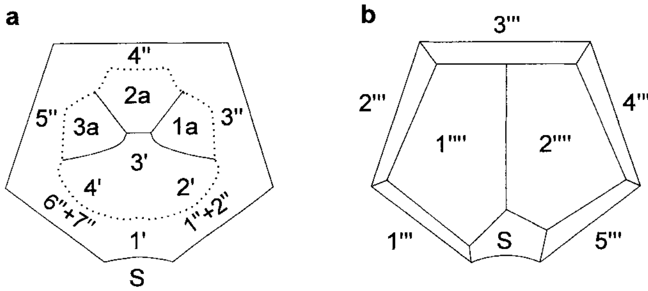


Fig. 2. Schematic diagram of the orthoperidinioid paratabulation of *Calcigonellum ansatum* n.sp. (a) Apical view; archaeopyle suture dotted. (b) Antapical view.

Derivation of name. Ansatus (Latin) = provided with handles. With reference to the handle-like structure of ridges on the operculum.

Diagnosis. A species of *Calcigonellum* with reduced paratabulation pattern in the roof-shaped epitract. The operculum features a handle-like structure of ridges. The antapex is slightly asymmetrical.

Holotype. Cyst d/2, SEM micrographs Ds/d/3/4-5, Ds/d/4/1-5, Ds/d/5/1-5, Ds/d/6/1-4 (Plate 1, figs 8–10).

Type locality. Rio Grande Rise, western South Atlantic, DSDP Leg 39, Site 357.

Type stratum. Late Eocene zone NP19; sample 39-357-20-2, 79–80 cm.

Paratypes. Cyst 116/23, SEM micrographs 114/6/4-5, 114/7/1-5, 115/3/1-5, 115/4/1, 129/5/6, 129/6/1-6, 129/7/1-2, 136/2/2-5, 136/2/1-2 (Plate 1, figs 11–12); cyst 116/33, SEM micrographs 115/7/6, 116/1/1-4, 116/2/1-3, 116/3/1-4, 130/2/2-5, 103/3/1-4, 130/4/1-3, 136/2/3-4 (Plate 2, fig. 1); cyst 116/15, SEM micrographs 113/1/4-6, 113/2/1-5, 113/3/1-4, 128/2/3-6, 128/3/1-4, 128/4/1-3, 135/7/6, 136/1/1-2 (Plate 2, figs 2–6).

Repository. Collection of the Division of Historical Geology and Palaeontology, Department of Geosciences, Bremen University, Germany.

Description. The apical face of this holotabulate cyst has a pentagonal shape (Plate 1, fig. 8). Handle-like arranged ridges are situated on the operculum, separating the three intercalary plates 1a–3a from each other, and from the fused apical plates 2′–4′ (Plate 1, figs 8–10; Fig. 2). The ridges thus cause a roof-shaped epicyst (Plate 1, fig. 10). Plates 1′, and 1″–7″ are not distinguished. The hypocyst shows five large, postcingular plates 1‴–5‴ (Plate 2, figs 2–5). The sulcus is 9.2–10.7 μm wide and always shows a homogeneous width in a single specimen (Plate 2, figs 1, 3 and 4). The antapex exhibits two large 1⁗ and 2⁗ plates (Plate 2, figs 2, 3 and 5). Characteristically, the ridge separating sulcus and plate 1⁗ is longer than the ridge separating sulcus and 2⁗, inducing a slightly asymmetrical arrangement (Plate 2, figs 2 and 3). The average length/width ratio of the cysts is around 1.0.

The single-layered wall consists of stemmed crystallites. Distal elongation of several rows of crystals constitutes the ridges (Plate 2, fig. 6). The crystallographic *c*-axes are tangentially oriented; however, the long axes are of radial orientation; this corresponds to the tangential wall type after Young *et al.* (1997).

Dimensions. Holotype: length 33 μm, width 42 μm, archaeopyle 23.1 μm, minimal thickness of wall 1.7 μm, maximum thickness of wall 7.8 μm. Other specimens: length 24–35 μm, width 28–34 μm, archaeopyle 17.5–22.5 μm, minimal thickness of wall 2.0–2.5 μm, maximum thickness of wall 4.7–7.5 μm.

Comparison. The elongation of crystal-rows stresses the close affinity of *Calcigonellum ansatum* to the other two species of *Calcigonellum*, i.e. *C. infula* Deflandre, 1948 and *C. granulata* Kohring, 1993. The species show different expressions of the peridinoid paratabulation pattern, however. Additionally, the shape of the *Calcigonellum* species vary. The cysts of *C. infula* are notably elongated, whereas the cysts of *C. granulata* are almost spherical.

Occurrence. Rare in the late Eocene of the Rio Grande Rise, sample 39-357-20-2, 79–80 cm.

Genus *Fuettererella* Kohring, 1993

Original diagnosis. (Kohring, 1993: 88) 'Calcareous dinoflagellate cyst with a pseudoorthopithonelloid outer wall, however wall crystals with the c-axis parallel to the cysts surface.'

Fuettererella fungiforma n.sp.
(Plate 2, figs 7–12)

Derivation of name. Fungus (Latin) = mushroom; forma (Latin) = form. With reference to mushroom-shaped crystals.

Diagnosis. Atabulate, strictly spherical calcareous dinoflagellate cysts. The single-layered wall consists of mushroom-shaped crystals with tangentially oriented *c*-axes. Crystal-tops widen and flatten, forming a distal surface of thin, undulated plates.

Holotype. Cyst 113/76, SEM micrographs 175/4/5, 175/5/1-2, 204/3/4-5, 204/4/1 (Plate 2, figs 7–8).

Type locality. Rio Grande Rise, western South Atlantic, DSDP Leg 39, Site 357.

Type stratum. Middle Eocene zone NP16; sample 39-357-21-3, 88–89 cm.

Paratypes. Cyst 121/99, SEM micrographs 208/7/3-5, 209/1/1-3 (Plate 2, fig. 9); cyst 114/4, SEM micrographs 176/6/2-4, 176/7/1-2, 204/5/3-5, (Plate 2, fig. 10); cyst 113/38, SEM micrographs

173/3/5, 173/4/1-3, 210/6/5, 210/7/1-5, 211/1/1, (Plate 2, figs 11 and 12).

Repository. Collection of the Division of Historical Geology and Palaeontology, Department of Geosciences, Bremen University, Germany.

Description. The spherical cysts show no paratabulation pattern (Plate 2, fig. 7). The thick calcareous wall is single-layered and consists of mushroom-shaped crystals (Plate 2, figs 10 and 11). Under the light microscope in crossed nicols and with gypsum plate, thin sections exhibit clear interference colours and have a positive optic sign. The species is thus assigned to the tangential wall type after Young *et al.* (1997). Each individual crystal is proximally based on a solid, polygonal plate with distinct edges (Plate 2, figs 11 and 12). The crystals taper distally and continue as relatively slim stems until they widen again and constitute flat, distal plates (Plate 2, fig. 10). These undulated plates may be oval-shaped (Plate 2, figs 7 and 8) or polygonal, and commonly fuse, producing a homogenous surface (Plate 2, fig. 9). In the studied material, no archaeopyle has been observed.

Dimensions. Holotype: length 36.5 μm, width 36.5 μm, thickness of wall 5.2 μm. Other specimens: length 31.5–43.5 μm, width 31.6–43.5 μm, thickness of wall 4.9–5.7 μm.

Comparison. Common to all species of *Fuettererella* is the tangential orientation of the crystallographic *c*-axes; however, the orientation of the morphological long axes is perpendicular to the cysts' surface. *F. fungiforma* differs from the other species of *Fuettererella*, i.e. *F. conforma* Kohring, 1993, *F. tesserula* (Fütterer, 1977) Kohring, 1993, and *F. elliptica* Kohring, 1993, in the unique shape of the crystals, which do not show distinct crystal faces.

Occurrence. Common in the middle Eocene NP19 and rare in the late Oligocene NP25 of the Rio Grande Rise (samples 39-357-21-3, 88–89 cm, and 39-357-16-2, 75–76 cm).

SUMMARY

From the Eocene and Oligocene of DSDP Site 357, three new species of calcareous dinoflagellates are described. We thereby add information to the poorly known Palaeogene calcareous dinoflagellate assemblages of the western South Atlantic Ocean. By using both scanning electron and polarized light microscopy, tangential wall types have been proved for *Calcigonellum ansatum* n.sp. and *Fuettererella fungiforma* n.sp. The crystallographic orientations of the *c*-axes within *Bitorus truncus*, however, remain unverified.

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