

11. PITHONELLOID CALCAREOUS DINOFLAGELLATES FROM THE UPPER CRETACEOUS AND CENOZOIC OF THE SOUTHEASTERN ATLANTIC OCEAN, DEEP SEA DRILLING PROJECT LEG 74¹

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ABSTRACT

Two new species, three new forms in open nomenclature and two previously known species of the genus *Pithonella* (sensu Bolli, 1974), attributed to the dinoflagellate family Peridiniaceae are described from Upper Cretaceous to lower Pleistocene sediments of the Walvis Ridge, southeastern Atlantic Ocean. It is the first time that pithonelloid calcareous dinoflagellates are described from sediment younger than early Paleocene.

INTRODUCTION

Many species of the incertae sedis family Calcisphaerulidae have been reported previously from various DSDP core sections (Bolli, 1974, Leg 27; 1978a, Leg 40; 1978b, Leg 44; 1980, Leg 50; Rögl, 1976, Leg 35; Pflaumann and Krasheninnikov, 1978, Leg 41). Most of them were included in the genus *Pithonella* following the system discussed in detail by Bolli (1974); only a few species were included in the genus *Bonetocardiella*.

Classification of *Pithonella* has been controversial for a long time (e.g., Masters and Scott, 1978). However, the dinoflagellate nature of these forms as described by Bolli (1974) was proved by Keupp (1979, 1980, 1981), who described a complete peridinoid cyst paratabulation on the inside wall surface of *P. patriciagreleyae* attributing the genus *Pithonella* to the dinoflagellate family Peridiniaceae. But there is still some uncertainty whether *Pithonella* sensu Bolli (1974) strictly corresponds to *Pithonella* Lorenz 1902 as emended by Bignot and Lezaud (1964). Scanning electron microscope (SEM) investigations of *Pithonella* sensu Bignot and Lezaud by Villain (1977) exhibit ultrastructural test patterns completely different from those known from *Pithonella* sensu Bolli.

Despite this controversy, all authors describing *Pithonella* from DSDP core material used the system introduced by Bolli (1974). Because of this and the fact that no topotypic material has been investigated specifically for this study, the genus *Pithonella* is still treated in the sense of Bolli (1974) in the present chapter.

The stratigraphic distribution of *Pithonella* in DSDP cores shows three distinctly different groups of species: (1) Rich and diverse assemblages occur from the Upper Jurassic through the Lower Cretaceous. (2) Rich but less diverse assemblages are present in the Upper Cretaceous from the Coniacian to the Maestrichtian (Bolli, 1974, 1978a, Pflaumann and Krasheninnikov, 1978). (3) Very

poor assemblages are restricted to the early Paleocene (Rögl, 1976, Bolli, 1978a). This indicates a continuous decrease of species diversity from Early Cretaceous to early Paleocene. To date no species of *Pithonella* from younger Cenozoic sediments have been described.

In pelagic sediments recovered during Leg 74 (Fig. 1) from the Walvis Ridge area of the southeastern Atlantic Ocean, specimens of *Pithonella* were found to be present in minor abundance in all core sections from the Upper Cretaceous to Recent. The main aim of this chapter is to show the stratigraphic range and nature of the species observed. Special emphasis is given to the species distribution around the Cretaceous/Tertiary boundary.

MATERIAL AND METHODS

The distribution of *Pithonella* species was investigated in samples from Holes 525A, 526, and 527. The last two holes were chosen in order to cover and compare different paleo-water-depths from shallow to deep. Holes 526 and 527 were drilled in modern water depths of 1054 and 4428 m, respectively. Cores from Hole 525A were sampled only around the Cretaceous/Tertiary boundary for comparison with corresponding sections of Hole 527.

Lithologically all samples represent pelagic foraminifer nannofossil ooze and chalk, respectively. Preservation is quite good, although slightly increasing modifications by diagenetic crystal overgrowth are observed with increasing core depth and age.

All samples were washed through a 40- μ m mesh sieve. The material < 40 μ m was fractionated by sedimentation analyses. The 6–40 μ m fractions were mounted on scanning electron microscope (SEM) stubs and coated twice with carbon and gold palladium for examination.

Samples containing *Pithonella* species are listed on Table 1. The relative abundance of each species refers to frequencies counted directly from the SEM screen and calculated per section across the SEM stub (10 mm in diameter). It is given as follows: F, few (5–15 specimens); R, rare (1–5 specimens); r, very rare (less than 1 whole specimen). Stratigraphic classification of the samples is according to the Initial Core Descriptions.

STRATIGRAPHIC DISTRIBUTION

Four species, *Pithonella krasheninnikovi*, *P. cylindrica*, and the newly described *P. globosa* and *P. sp. 1* occur in the late Maestrichtian (Table 2). Only two, *P. krasheninnikovi* and *P. globosa*, pass the Cretaceous/Tertiary boundary into the *G. eugubina* Zone of the early Danian, where they rapidly disappear.

¹ Moore, T. C., Jr., Rabinowitz, P. D., et al., *Init. Repts. DSDP, 74*: Washington (U.S. Govt. Printing Office).

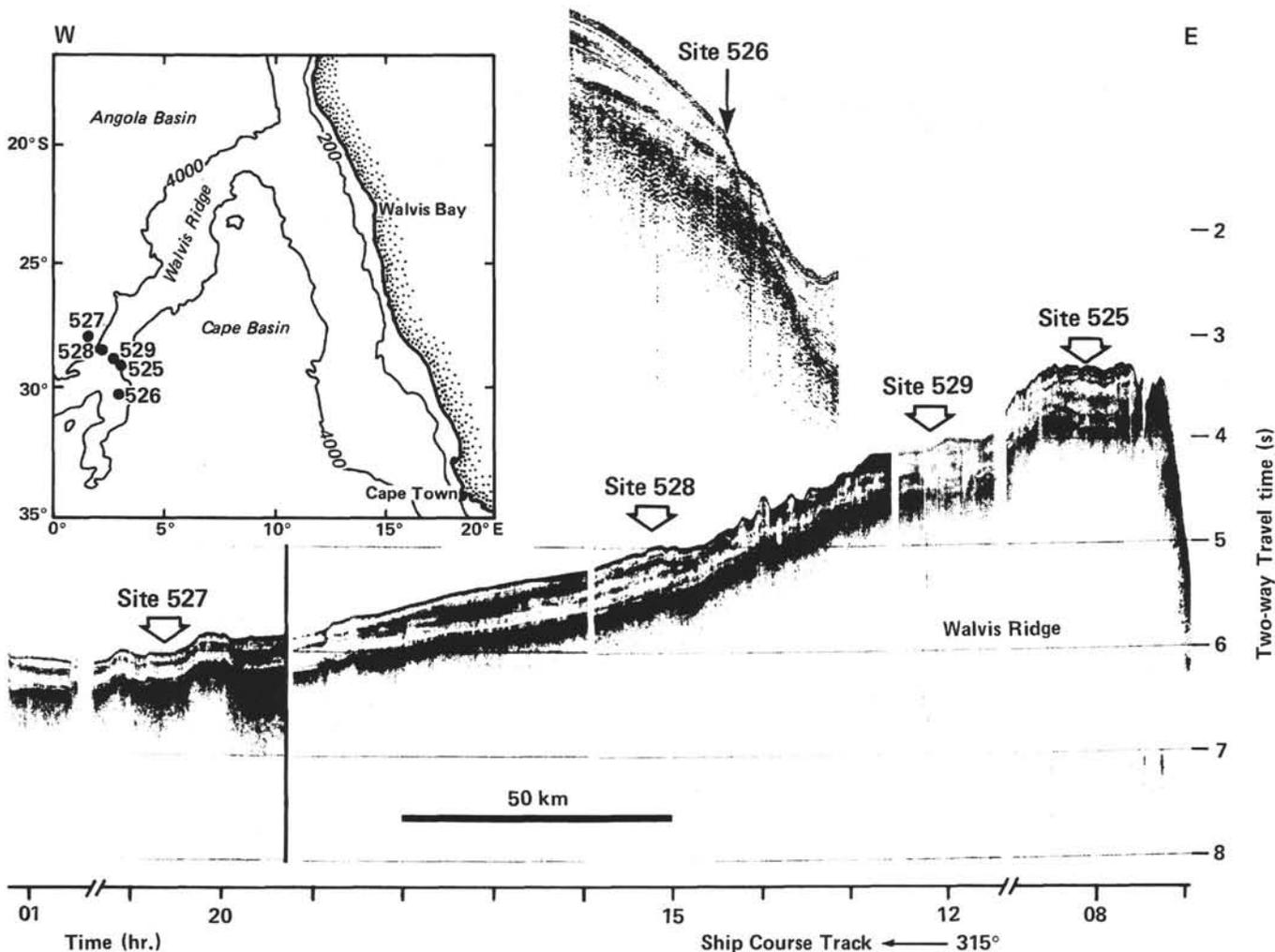


Figure 1. Index map showing geographic position and bathymetry of the Walvis Ridge and locations of Leg 74 Sites 525-529.

Three new species, *P. parva*, *P. sp. 2*, and *P. sp. 3*, are present in the Cenozoic. *P. parva* is a long-ranging species that appears in the early Danian (P1b-c, NP1) and continues at least into the early Pleistocene (NN19/20). It seems to be more frequent in the sediments from the shallow water of Hole 526 than in those from the deeper water of Hole 527. But the differences are not so great as to cause us to conclude that at the Walvis Ridge *Pithonella* has a clear preference for shallow water, as reported from the Cretaceous of other regions (e.g., Bein and Reiss, 1976). *P. sp. 2* and *P. sp. 3* occur only in very low numbers in Oligocene to (probably) Miocene sections.

MORPHOLOGICAL CRITERIA

Various morphological criteria have been used for taxonomic classification of pithonelloid calcareous dinoflagellates. Certain disagreements as to classification derive from the different methods used, such as light microscopy and scanning electron microscopy (SEM) or thin section examination and investigation of isolated specimens, respectively. However, the main difficulties arise from significantly different points of view with re-

spect to (1) primary species variability, (2) variability caused by ecological influences, and (3) secondary variability produced by diagenetic crystal overgrowth or partial dissolution.

Bolli (1974) used size and shape of the test or cyst, presence, size and shape of an aperture, number of layers forming the cyst wall, size, shape and arrangement of crystals in each layer, as well as inner and outer surface patterns as taxonomic features to describe 19 new species included in the genus *Pithonella*. He confined species variability within very narrow limits without discussing secondary diagenetic effects. This taxonomic system was used later in the same sense (Bolli, 1974) by Pflaumann and Krashennnikov (1978), Rögl (1976), and Bolli (1978a, 1978b, 1980).

Masters and Scott (1978) lay particular stress on diagenetic features. They interpret the multilayered cyst walls described by Wanner (1940), Vogler (1941), Bolli (1974), and Bein and Reiss (1976) to be "diagenetic sparry calcite that encrust the test wall, which may form upon either or both the external or internal surfaces of the wall." They also declare the number of layers to be of no taxonomic value. Though morphological modifi-

Table 1. Occurrence of *Pithonella* species in Leg 74 samples. For symbol explanation see text.

Core/Section (interval in cm)	<i>P. krashennikovii</i> Bolli <i>P. cylindrica</i> Pflaumann <i>P. globosa</i> n. sp. <i>P. parva</i> n. sp. <i>P. sp. 1</i> <i>P. sp. 2</i> <i>P. sp. 3</i>	Age (from ICD)
Hole 525A		
38, CC		
39-4, 90-92	?	early Paleocene
39-7, 30-32		
40-2, 5-6	r	
40-2, 13-14		
40-2, 26-28		
40-3, 3-5	r r	late Maestrichtian
40-4, 30-32	R r	
40-5, 140-142	r r	
Hole 526		
1-2, 85-87		
2-1, 76-78	r	early Pliocene
3-1, 133-135	R	
5-1, 96-98	R	
6-1, 100-102	r	
7-1, 37-39	r	
9-1, 55-57	r	late Miocene
10-1, 139-141	R	
12-1, 55-57	R	
13-2, 94-96	?	
16-1, 64-66	r	middle Miocene
19-1, 80-82	r	
21-1, 95-97	r	
23-2, 105-107	r ?	early Miocene
26-2, 107-109	R	
29-1, 90-92	F r	
31-1, 96-98	R r	late Oligocene
38-2, 120-122	r r	
42-1, 58-60	r	late Eocene
44-3, 74-76	R	
Hole 527		
1-3, 38-40	r	early Pleistocene
4-1, 70-72	r	early Pliocene
6-3, 10-12	r	
8-3, 19-21	r	late Miocene
11-1, 40-42	r	
14-6, 15-17	r	early Oligocene
21-2, 40-42	r	early Eocene
23-1, 35-37	r	
24-3, 24-26	R	late Paleocene
25-2, 100-102	r	
27-2, 98-100	r	middle Paleocene
28-2, 108-110	r	
29-2, 46-48	r	
32-1, 25-26	R	
32-2, 28-30	R	early Paleocene
32-3, 28-30	r	
32-3, 148-150	r	
32-4, 37-39	R r	
32-4, 69-71	r r r	
32-4, 101-103	r	late Maestrichtian
32-4, 131-133	r	
33-1, 60-61	R r	
34-4, 8-10	R R	
35-3, 100-101	r r	
36-4, 49-50	r r r	late/middle Maestrichtian
37-1, 40-42	r	
38-4, 51-53	r	
42-2, 56-58	r	

Table 2. Stratigraphic ranges of *Pithonella* species in Upper Cretaceous and Cenozoic sediments based on SEM investigations (according to Pflaumann and Krashennikov, 1978, and this chapter).

Period	Epoch	<i>Pithonella krashennikovii</i> <i>P. cylindrica</i> <i>P. globosa</i> n. sp. <i>P. parva</i> n. sp. <i>P. sp. 1</i> <i>P. sp. 2</i> <i>P. sp. 3</i>
	Pleistocene	
	Pliocene	
	Miocene	
Tertiary	Oligocene	
	Eocene	
	Paleocene	
Upper Cretaceous	Maestrichtian	
	Campanian	
	Santonian	
	Coniacian	

cations caused by diagenetic crystal overgrowth are well known from micro- and nannofossils, the latter conclusion seems to be too sweeping.

Keupp (1981), describing Lower Cretaceous calcareous dinoflagellates, interprets wide variability in size and shape of the cysts, size and outline of aperture, number and thickness of wall layers, as well as size and habitus of layer-forming crystals to be the result mainly of ecological changes due to changing environmental parameters. He found crystal orientation to be the only feature not so influenced and as a consequence combined several morphotypes into a few superposed units. Furthermore, Keupp (1981) denied that diagenesis had affected the material studied by him.

In general the taxonomic criteria summarized in Bolli (1974) are used in the present investigation. However, variability of distinct features—for example, size and shape of the cysts—is considered within a wider framework. Diagenetic modifications of features—above all thickness of wall layers and size and shape of crystals—are noted and interpreted if possible.

TAXONOMY

That pithonelloid calcispheres are definitely calcareous dinoflagellate cysts has been proved with certainty by Keupp (1980). Being cysts, their systematic treatment is possible only by a morphotypic parataxonomy which at a higher level can be related by reflected paratabulation to an orthotaxonomy based on the thecate phase of the dinoflagellate life cycle.

**Family PERIDINIACEAE Lindemann,
Genus PITHONELLA Lorenz, 1902**

The genus *Pithonella* is used here in the sense of Bolli (1974), which differs considerably from that of Bignot and Lezaud (1964). It

represents resting cysts of peridinoid dinoflagellates (Keupp, 1979, 1980, 1981).

Diagnosis. The single-chambered cyst ranges from an elongated cylinder or ovoid to a sphere. Cyst size varies from 40 to 140 μm . Wall thickness varies greatly, is single- or multilayered, and consists of calcite crystals of different size, shape, and arrangement. Crystal orientation in the distal layer is either oblique or parallel to the cyst surface. An irregularly circular apertural opening may be present.

The known stratigraphic range is from Upper Jurassic to lower Pleistocene. Highest abundance and diversity are from the Lower and Upper Cretaceous.

Pithonella krasheninnikovi Bolli
(Plate 1, Figs. 1–8)

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

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

Description from SEM examination. The elongated ovoidal cyst ranges from 50–135 μm in length and 35–90 μm in width (Plate 1, Figs. 1–3). The width:length ratio is between 1:1.9 and 1:1.3. A circular aperture is present slightly asymmetrically at one pole. Its size varies from 15–35 μm in diameter.

The cyst wall consists of two layers. The outer layer measures 1.5–3 μm in thickness. The small, prismatic, blade-like crystals, about 2–4 μm in length and 0.5–1 μm in diameter, are arranged oblique to the surface externally revealing a somewhat porous surface pattern. The crystal habitus of the outer layer varies widely (Plate 1, Figs. 4–6) and is probably a diagenetic effect. In many cases the outer layer is partially or completely removed.

The inner layer, about 5 μm thick, consists of densely packed, heavy, rhombohedral crystals arranged with the long axis perpendicular to the surface, which gives a very characteristic surface pattern (Plate 1, Figs. 7–8). Increasing diagenesis can produce an even or smooth surface pattern.

Occurrence. Sections 525A-40-5 to 525A-39-4 and 527-42-2 to 527-32-2.

Age. Middle–late Maestrichtian to early Danian.

Remarks. Sporadically occurring single-layer specimens show very large rhombohedral crystals (Plate 1, Fig. 9) and are interpreted as extreme types of isolated inner layers. This type is provisionally included with *P. krasheninnikovi*. Compared with the specimens described by Bolli (1974), these are less oblong than ventricose.

Pithonella cylindrica Pflaumann and Krasheninnikov

**Pithonella cylindrica* n. sp. Pflaumann and Krasheninnikov, 1978, p. 822, pl. 5, figs. 1–4.

Description from SEM examination. The cyst shows an elongated cylindrical outline, subspherical at each pole, where an irregular circular aperture is situated slightly asymmetrically. The cyst wall is two-layered and shows ultrastructural patterns identical to those of *P. krasheninnikovi*.

Occurrence. Sections 525A-40-5 to 525A-40-3 and 527-36-4 to 527-33-1.

Age. Middle to late Maestrichtian.

Remarks. This species is distinguishable from *P. krasheninnikovi* by its cylindrical outline only.

Pithonella globosa n. sp.
(Plate 2, Figs. 1–9)

Description from SEM examination. Cyst strictly spherical, ranging from 84–132 μm in diameter (Plate 2, Figs. 1, 4, 7). The wall is two-layered and 9–15 μm thick. The inner wall, about 6–9 μm thick, consists of heavy sparry crystals (Plate 2, Fig. 6) oriented perpendicular to the surface, where the euheudral rhombohedral crystals reveal a very characteristic surface pattern (Plate 2, Fig. 8).

The outer layer, about 3–6 μm thick, consists of smaller rhombohedral prisms or blades, 1–2 μm in diameter, oriented slightly oblique to the surface (Plate 2, Figs. 5–6). Crystal arrangements on the distal surface create a porous or reticulated surface pattern.

An irregularly rimmed aperture (25–40 μm in diameter, which is about 25–35% of the cyst diameter) is present on many specimens but may be absent.

Remarks. The reticulated pattern of the distal surface of the outer layer resembles *Thoracosphaera albatrosiana*, but its internal ultrastructural crystal arrangement is completely different. The sparry crystal habitus of the inner layer is most probably a diagenetic effect of crystal growth, judging by the nanofossils incorporated into the growing crystals (Plate 2, Fig. 3).

Holotype. Diameter 102 μm , aperture 25 μm ; inner wall thickness about 6 μm , outer wall thickness about 3 μm ; Plate 2, Figs. 1–3; SEM photograph Nos. 91621–91623, film No. 2622/51–55; SEM stub No. 126/3; depository: Geol.-Paläont. Institut, University Kiel.

Type locality and stratum typicum. DSDP Leg 74, Hole 527, Sample 527-34-4, 8–10 cm, Walvis Ridge, Southeast Atlantic Ocean. Late Maestrichtian nanofossil mudstone.

Derivatio nominis. *globosus* (Latin) = spherical.

Age and range of species. *P. globosa* is present rare to very rare from late–middle Maestrichtian (*L. quadratus/A. mayaroensis*; Sample 527-36-4, 49–50 cm) to early Danian (*G. eugubina*; Sample 527-34-4, 37–39 cm).

Pithonella parva n. sp.

(Plate 3, Figs. 1–10; Plate 4, Figs. 8–9)

Description from SEM examination. Cyst slightly ovoid to spherical, ranging from 37–67 μm in length and 35–53 μm in diameter (Plate 3, Figs. 1–3). Width to length ratio in ovoid specimens is up to 1:1.26 (Fig. 2). The wall is two-layered and 2–6 μm thick. The inner wall seen in “young,” diagenetically unaltered specimens (Plate 3, Fig. 8) is less than 1 μm thick and is composed of small granular to slightly prismatic crystals oriented subparallel or oblique to the surface. With increasing age and diagenetic overgrowth the crystals thicken (Plate 3, Fig. 3), as does the inner layer (Plate 3, Fig. 9), which finally can exceed the outer layer in thickness (Plate 3, Fig. 10). Crystal orientation of the inner layer reveals a very characteristic distal surface pattern which is to be seen after removal of the outer layer (Plate 3, Fig. 7; Plate 4, Figs. 8–9). The outer layer is about 2–4 μm thick. It is composed of plate-shaped rhombohedral crystals of approximately 1–2 μm in width, 2–4 μm in length, and 0.3–0.8 μm in thickness transposed toward each other and interpenetrating (Plate 3, Figs. 5, 9). The long axis of the crystals is oriented more or less perpendicular to the surface. The ultrastructure of the outer layer crystals is composed of minute granular crystallites (Plate 3, Fig. 4) which fuse with increasing diagenesis, producing smooth crystal faces and the characteristic distal surface pat-

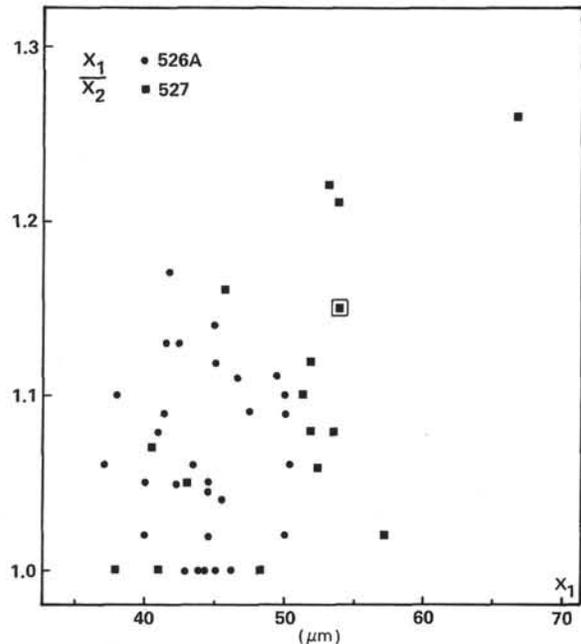


Figure 2. Variation of size and shape of *Pithonella parva* n. sp. from Holes 526A and 527 as function of diameter (X_1) and length (X_2). Framed square = holotype.

tern (Plate 3, Figs. 4–6). A circular, irregularly rimmed aperture, 15–20 μm in diameter (which is 35–40% of the cyst diameter), may be present at one pole.

Remarks. Variations in thickness of the inner and outer layer of the cyst wall are interpreted as being the result of diagenetic crystal overgrowth. Primarily the inner layer is only weakly calcified and separated from the outer calcified layer by a (probably) organic wall or membrane. After decomposition of the organic wall a cavity develops (Plate 3, Fig. 8) which is filled by the diagenetically growing inner layer. Similar variations in intensity of primary calcification in Lower Cretaceous *Pithonella* were observed by Keupp (1981) and interpreted as being the result of environmental effects.

P. parva shows similarities in crystal shape of the outer layer to *P. cylindrica* and *P. krasheninnikovi*. The crystals of the latter two species, however, are slightly wider. *P. parva* differs from both mainly by cyst shape and by size and pattern of the distal surface of the inner layer.

Holotype. Length 54 μm , diameter 47 μm ; thickness of inner wall layer 3.5 μm , outer layer 1.3 μm ; aperture 19 μm but secondarily enlarged; Plate 3, Figures 3, 6, 10; SEM photograph Nos. 89062–89064; film No. 2551/54–58; SEM stub No. 116/10; depository: Geol.-Paläont. Institut, University Kiel.

Type locality and stratum typicum. DSDP Leg 74, Hole 527, Sample 527-25-2, 100–102 cm, Walvis Ridge, Southeast Atlantic Ocean. Late Paleocene (NP9) alternation of nannofossil ooze and chalk.

Age and range of species. *P. parva* is frequent to very rare from the early Paleocene (Danian, P1-b-c, NP1) to the early Pleistocene (N22, NN19).

Pithonella sp. 1
(Plate 4, Fig. 10)

Description. Cyst strictly spherical, 30–40 μm in diameter, showing a small circular aperture 8–12 μm in width. The cyst wall is thin (< 5 μm) and two-layered. The outer layer is composed of small elongated, rhombohedral crystals arranged slightly oblique to the test surface. Crystals on the surface (0.5–1 μm in width) show smooth faces and tend to fuse, especially in the form of epitaxial overgrowth of large euhedral crystals.

Remarks. This species is extremely small. The surface pattern is unique, but its principal pattern resembles that of *P. krasheninnikovi* and *P. cylindrica*. This species is given in open nomenclature because only a few specimens have been found and the details of the wall structure are not precisely known.

Occurrence. DSDP Leg 74, very rare in Samples 527-32-4, 131–133 cm and 527-32-4, 69–71 cm; late Maestrichtian.

Pithonella sp. 2
(Plate 4, Figs. 5–7)

Description. Cyst spherical and about 40 μm in diameter. Cyst wall two-layered and about 3 μm thick (Plate 4, Fig. 6). Outer layer consists of small, irregular, rhombohedral crystals (0.2–0.5 μm wide, about 1–1.5 μm in length) with the long axis arranged perpendicular to the surface. The distal surface therefore reveals a granular pattern, each granule showing smooth rhombohedral crystal faces (Plate 4, Fig. 7). The inner layer is approximately as thick as the outer layer but composed of somewhat coarser crystals (Plate 4, Fig. 6). An aperture has not yet been observed.

Remarks. This species resembles *Thoracosphaera deflandrei* in surface pattern, but differs clearly in its two-layered cyst wall. It is given in open nomenclature because (1) the wall structure is not clear in all its details, (2) size and shape of an aperture as a major feature have not been observed, and (3) too few specimens have been found to evaluate the range of size and morphology.

Occurrence. DSDP Leg 74, very rare in Samples 526A-29-1, 90–92 cm, early Miocene (NN1, N4), and Sample 526A-38-2, 120–122 cm, late Oligocene (NP23, P18–19).

Pithonella sp. 3
(Plate 4, Figs. 1–4)

Description. Cyst spherical and about 45 μm in diameter. Cyst wall is three-layered (about 8 μm thick) and shows small granular crystals

(up to 1 μm in diameter) composing the proximal layer (Plate 4, Figs. 3–4). The outer layer is formed by irregular-sized plate-like crystals which are arranged obliquely to the distal surface (Plate 4, Fig. 2). The middle layer is composed of irregular-shaped crystals, about 3 μm in length and about 1 μm in width, arranged perpendicular to the proximal and outer layer.

Remarks. The middle layer, grown from the proximal and outer layer respectively into a primarily open space between both layers, seems to be of diagenetic origin. Only one specimen was observed.

Occurrence. DSDP Leg 74, one specimen in Sample 526A-31-1, 96–98 cm, late Oligocene (NP25, N4).

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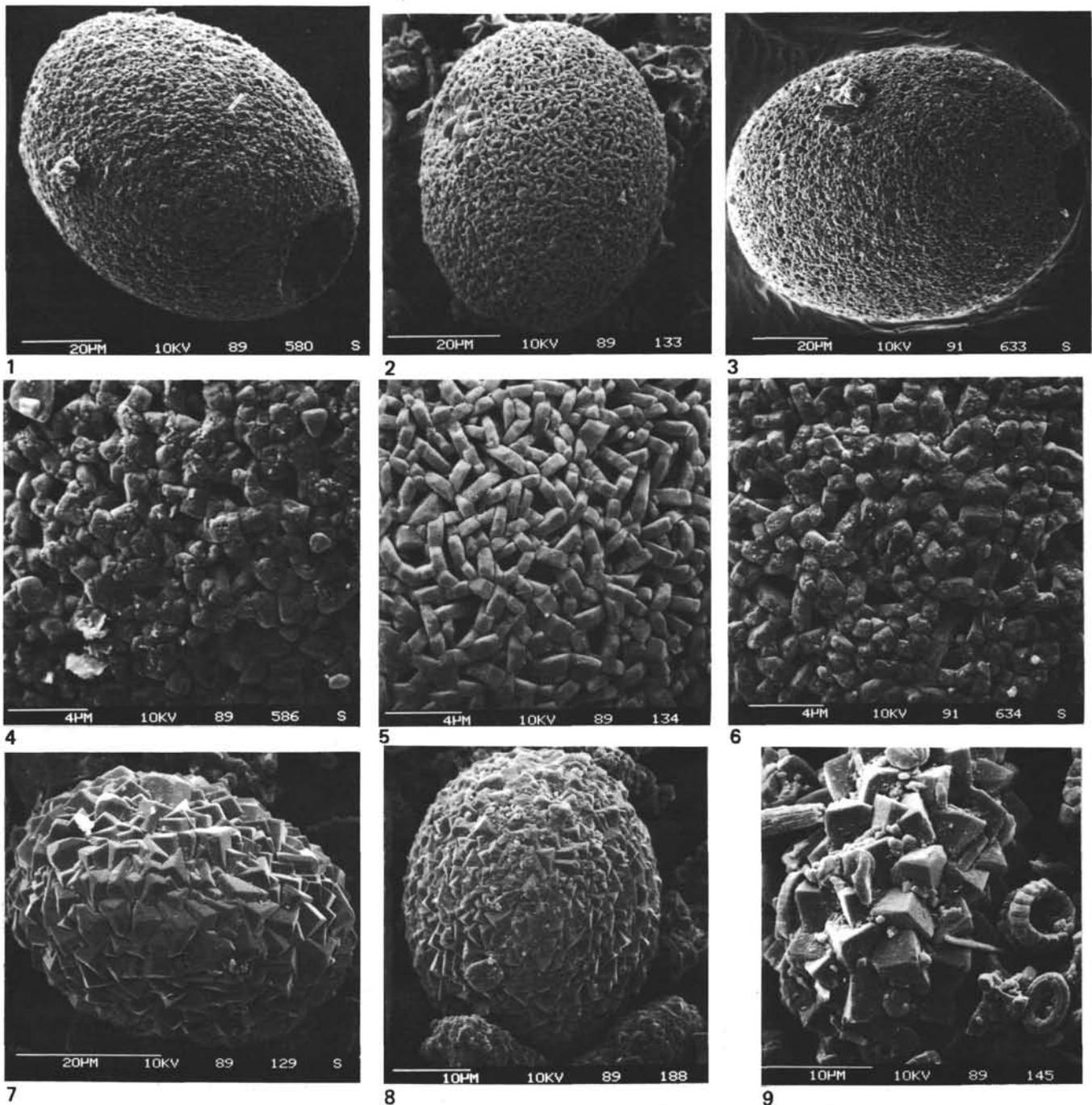


Plate 1. Middle Maestrichtian to early Danian *Pithonella krasheninnikovi* Bolli. 1,4. *P. krasheninnikovi*, Sample 527-32-4, 37-39 cm; early Danian (*G. eugubina* Zone). 2,5. *P. krasheninnikovi*, Sample 527-33-1, 60-61 cm; late Maestrichtian (*Micula mura*). 3,6. *P. krasheninnikovi*, Sample 527-34-4, 8-10 cm; late Maestrichtian (*M. mura*/*L. quadratus*). Note variability in crystal habitus of distal surface of outer layer in Figures 4-6. 7. *P. krasheninnikovi*, outer layer completely removed; Sample 527-33-1, 60-61 cm; late Maestrichtian (*M. mura*). 8. *P. krasheninnikovi*, outer layer completely removed, Sample 527-38-4, 51-53 cm; middle Maestrichtian. 9. *P. cf. krasheninnikovi* showing extremely large crystals of the inner layer, Sample 527-33-1, 60-61 cm; late Maestrichtian (*M. mura*).

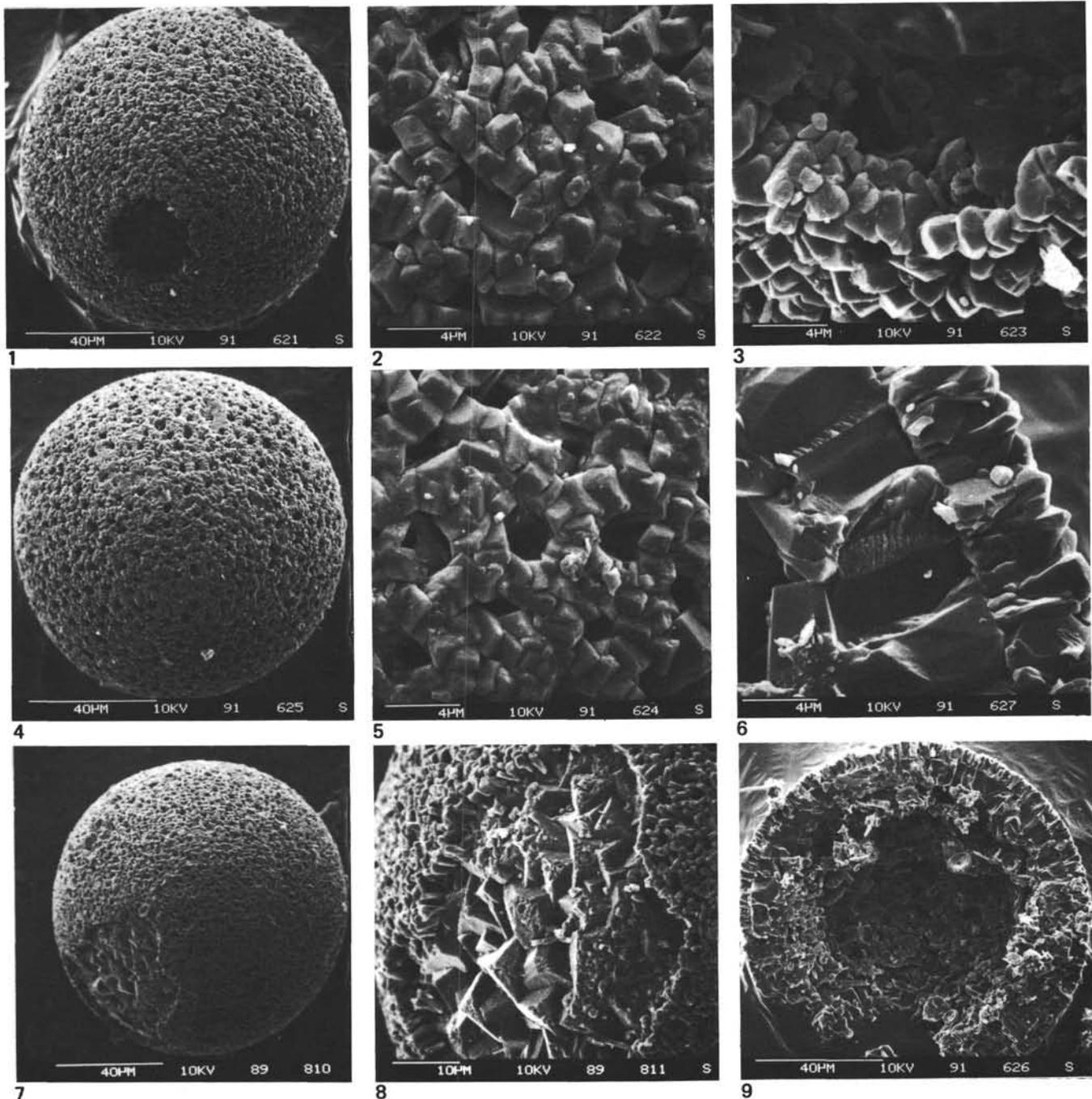


Plate 2. Middle Maestrichtian to early Danian *Pithonella globosa* n. sp., Sample 527-34-4, 8-10 cm. 1-3. Holotype showing the small circular archaeopyle (1), ultrastructural details of outer layer distal surface (2), and two-layered test wall (3). 4-5. Paratype showing details of outer layer distal surface. 6,9. Paratype artificially broken revealing details of two-layered test wall. 7-8. Paratype with partially removed outer layer showing densely packed large crystals of inner layer distal surface.

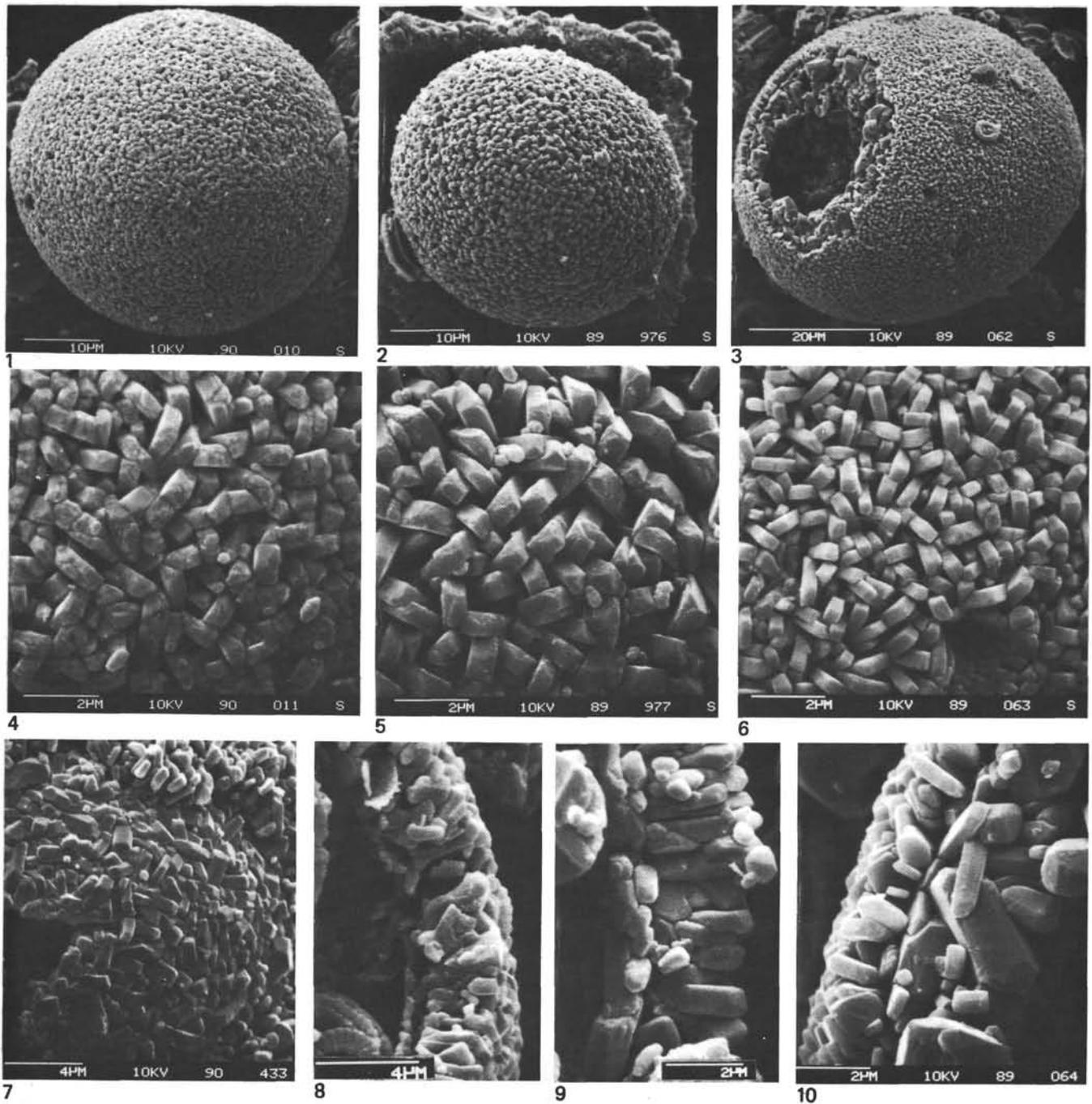


Plate 3. Late Paleocene to late Miocene *Pittonella parva* n. sp.. 1,4. Paratype of subspherical shape showing outer layer crystals composed of granular subunits, Sample 526A-12-1, 55–57 cm; late Miocene (NN10). 2,5. Paratype, very small cyst showing relatively large crystals, Sample 526A-10-1, 139–141 cm; late Miocene (NN10). 3,6,10. Holotype showing ovoid cyst type with small crystals on distal surface (6) and two-layered test wall showing progressive diagenesis, Sample 527-25-2, 100–102 cm; late Paleocene (NP9). 7. Paratype, distal surface of inner layer, Sample 526A-29-1, 90–92 cm; early Miocene (NN1). 8. Paratype, two-layered cyst wall showing early stage of diagenesis with thin inner and thick outer layer, Sample 526A-16-1, 64–66 cm; middle Miocene (NN7). 9. Paratype, two-layered cyst wall showing progressive stage of diagenesis by thickening of inner wall, Sample 526A-23-1, 105–107 cm; early Miocene (NN1).

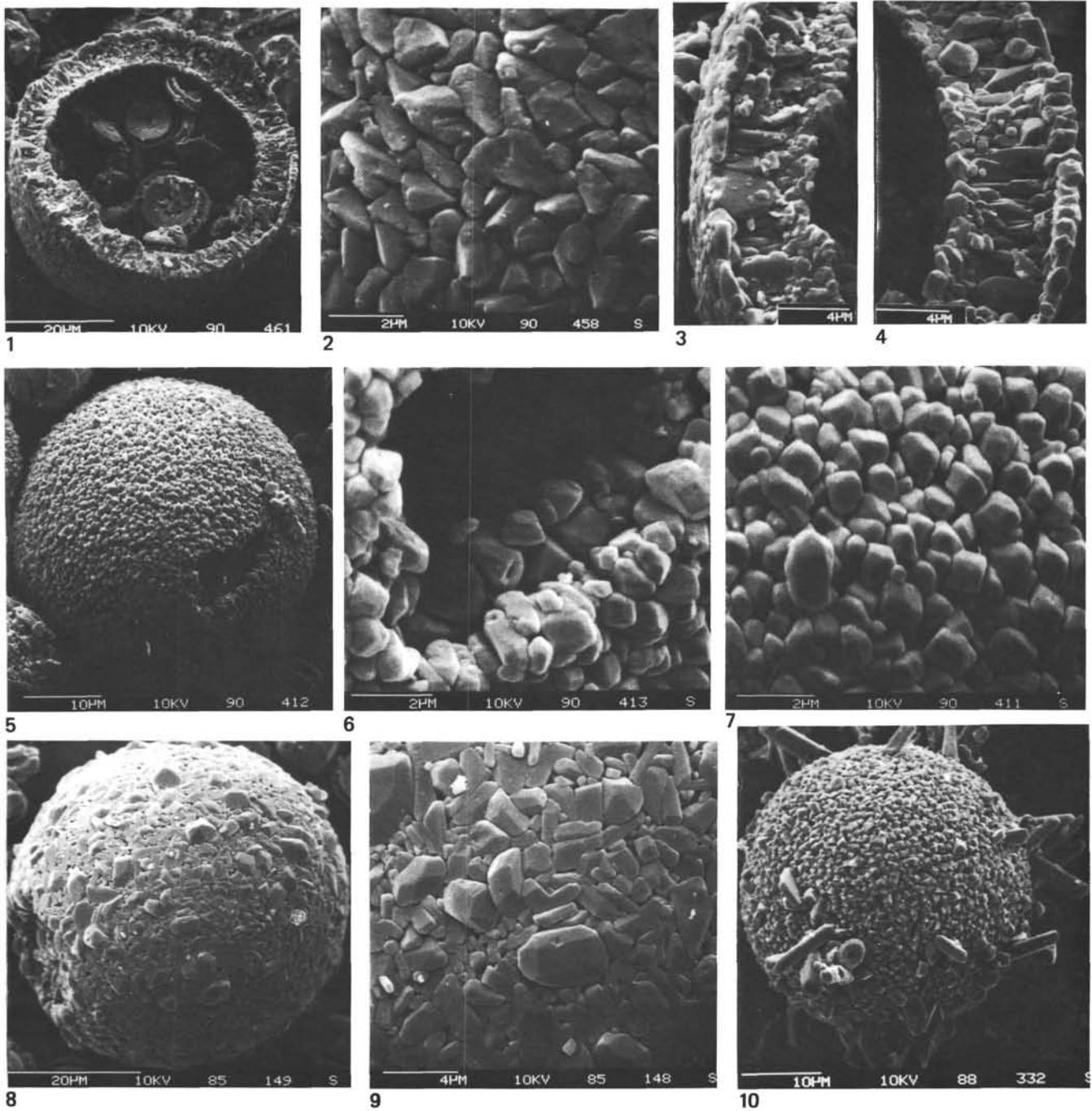


Plate 4. 1-4. *Pithonella* sp. 3, spherical cyst type showing three-layered wall, Sample 526A-31-1, 96-98 cm; late Oligocene (NP25). 5-7. *Pithonella* sp. 2, spherical cyst type showing two-layered wall, Sample 526A-29-1, 90-92 cm; early Miocene (NN1). 8-9. *Pithonella parva* n. sp. showing distal surface of inner layer, outer layer completely removed, Sample 527-23-1, 35-37 cm; late Paleocene (NP9). 10. *Pithonella* sp. 1, spherical cyst type showing extremely small crystals and characteristic diagenetic crystal overgrowth, Sample 527-32-4, 69-71 cm; late Maestrichtian (*Micula mura*).