

PALEOCENE COCCOSPHERES FROM DSDP LEG 39, SITE 356, SÃO PAULO PLATEAU, S ATLANTIC OCEAN

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Abstract: Numerous coccospheres representing the two extant families, Coccolithaceae and Prinsiaceae, were observed in 12 Paleocene (NP2 through NP6) samples from DSDP Site 356, and are briefly described (*Calcidiscus?* sp., *Chiasmolithus edentulus*, *Coccolithus pelagicus*, *Cruciplacolithus primus*, *Cruciplacolithus tenuis*, *Cruciplacolithus* sp., *Cyclagelosphaera alta*, *Ericsonia subpertusa*, *Ericsonia?* sp., *Futyania petalosa*, *Markalius* cf. *Markalius inversus*, *Prinsius dimorphosus*, *Sullivania consueta*, *Sullivania* sp., *Towieus eminens*, *Towieus pertusus*). Upper Maastrichtian (CC26) and lowermost Danian (NP1) sediments furnished only coccospheres of *Watznaueria barnesae*, whereas samples covering the zones from NP2 to NP6 exhibited an increased number of different species. The excellent state of preservation of coccoliths from samples 39-356-29-1, 83-85cm (NP2) and 39-356-21-2, 122-123cm (NP5) may be due to rapid deposition, possibly within fecal pellets, and minor diagenetic effects. We conclude that the presence of intact fossil coccospheres occurs if a sediment is rich in well-preserved coccoliths; their observation then depends on an adequate preparation method and the time spent with the scanning electron microscope.

Introduction

Fossil coccoliths are not usually found forming coccospheres but are distributed as single platelets on the slide prepared for investigation by light microscope (LM) or scanning electron microscope (SEM). Some fossil coccospheres are, however, occasionally found and illustrated. *Watznaueria barnesae*, numerous species of *Biscutum*, *Coccolithus pelagicus*, and various representatives of small- and medium-sized Prinsiaceae are the most common forms reported as coccospheres.

The intensive SEM study of the K/T boundary clays of Geulhemmerberg in The Netherlands (Mai et al., 1997) resulted in the illustration and description of more than 30 Maastrichtian and lowermost Danian coccosphere species, many of them well preserved.

While investigating the K/T boundary interval of DSDP Leg 39, Site 356 for calcareous dinoflagellate cysts, a well-preserved coccosphere of *Markalius* cf. *M. inversus* was found in sample 39-356-21-2, 122-123cm (NP5 of Martini, 1971). The subsequent discoveries of coccospheres of *Futyania petalosa* in sample 39-356-29-1, 83-85cm (NP2 of Martini, 1971) triggered a major effort to find additional coccospheres. Perch-Nielsen (1977) had only illustrated coccospheres of *Prinsius dimorphosus* from sample 39-356-28-3, 70 (NP3 of Martini, 1971).

Material and methods

The samples studied were collected from DSDP Leg 39 at Site 356 on the São Paulo Plateau in the South Atlantic at 28°17.22'S, 41°05.28'W, 950km offshore from Brazil at a water-depth of 3175m. The sediments mainly consist of pure nannofossil and foraminiferal chalks with varying amounts of clay. The ages of the 12 samples studied range from latest Maastrichtian CC25 to Late Paleocene NP6 (Perch-Nielsen, 1977). The samples were prepared following the method described by Mai et al. (1997), which is less destructive for coccospheres than the methods usually used. The total time for SEM analysis in search of coccospheres amounted to more than 500 hours.

The negatives referred to in the plate descriptions are stored in the Fachgebiet Historische Geologie/Paläontologie, Fachbereich 5, Bremen University.

Systematic palaeontology

The genera are arranged in alphabetical order.

Genus *Calcidiscus* Kamptner, 1950

Calcidiscus? sp.

Plate 1, Figure 1

The spherical coccosphere measures 21µm in diameter and consists of approximately 20 circular to elliptical coccoliths of equal size resembling those of the Neogene and Recent genus *Calcidiscus*. The coccoliths overlap considerably. The distal shields consist of approximately 38 elements and are larger than the proximal shields. The curved elements imbricate dextrally and leave only a small, conical central depression.

Genus *Chiasmolithus* Hay et al., 1966 emend. Varol, 1992

Chiasmolithus edentulus van Heck & Prins, 1987

Plate 1, Figures 2, 3, 6

The coccospheres are 12µm to 18µm in diameter, spherical to slightly ovoid and consist of ten to 16 elliptical, overlapping coccoliths of about equal size. Each coccolith is surrounded by five or six other coccoliths. The central cross is similar in all visible coccoliths of the coccospheres.

Genus *Coccolithus* Schwartz, 1894

Coccolithus pelagicus (Wallich, 1877) Schiller, 1930

Plate 1, Figures 4, 5

The coccospheres are 10µm to 18µm in diameter, spherical and resemble the modern coccospheres of the species. The number of coccoliths varies from nine to 14 in the spheres illustrated here, a number comparable to that of Recent coccospheres. The equally-sized coccoliths overlap considerably and each coccolith is surrounded by five other coccoliths.

Genus *Cruciplacolithus* Hay & Mohler in Hay et al. 1967

***Cruciplacolithus primus* Perch-Nielsen 1977**
Plate 2, Figures 1-3

The coccospheres are spherical to slightly ovoid with diameters of between 6µm and 16µm, and consist of ca. 12-18 coccoliths which show variation in overall size. Each coccolith is surrounded by five or six other coccoliths. The number of elements forming the rims of the coccoliths seems to be similar within coccoliths of the same coccosphere, and increases with the size of the coccolith.

***Cruciplacolithus tenuis* (Stradner, 1961) Hay & Mohler in Hay et al., 1967**
Plate 2, Figure 6

The coccosphere measures 19µm, it is spherical and consists of approximately 13 interlocking coccoliths of similar size. Each coccolith is surrounded by five other coccoliths. The central cross is clearly axially-aligned and all four arms bear terminal feet.

***Cruciplacolithus* sp.**
Plate 4, Figure 6

The subcircular coccoliths of this subspherical coccosphere feature a central structure consisting of a cross with a slightly rotated long axis. The coccosphere is constructed of approximately 14 coccoliths. Single coccoliths are surrounded by five or six others. It measures 11µm.

Genus *Cyclagelosphaera* Noël, 1965

***Cyclagelosphaera alta* Perch-Nielsen, 1979**
Plate 2, Figures 4, 5

The coccospheres are spherical and 11µm to 15µm in diameter. They consist of 12 coccoliths of equal size. Each coccolith is surrounded by five other coccoliths. The number of radial to tangential ridges forming the central cone varies on the coccosphere from a minimum of five to a maximum of seven. In the two coccospheres illustrated here, the central cone has a pentagonal to polygonal central depression.

Genus *Ericsonia* Black, 1964

The genus *Ericsonia* is here retained for the forms which feature a relatively narrow distal shield, although many authors include these within *Coccolithus*. The elements of the tube form a crown over the distal shield and are overlapping in a clockwise direction around a narrow central opening. In *Coccolithus*, the distal shield is wider and the elements of the tube-cycle are arranged more-or-less radially.

***Ericsonia subpertusa* Hay & Mohler, 1967**
Plate 3, Figure 4

The coccosphere is formed from only six subcircular

coccoliths of equal size. As each coccolith is surrounded by four coccoliths, the coccosphere is cube-shaped. It measures approximately 10µm. The illustrations of *E. subpertusa* in Perch-Nielsen (1977) and Mai et al. (1997) also show coccospheres with only six coccoliths. The coccosphere illustrated as *Ericsonia* cf. *E. subpertusa* in Perch-Nielsen (1971) from the Lower Eocene of Denmark, however, has approximately 12 coccoliths, each surrounded by five others.

***Ericsonia*? sp.**
Plate 3, Figure 5

The subspherical coccosphere consists of approximately 14 elliptical coccoliths, each of them surrounded by five others. The sphere measures 15µm in diameter, and the coccoliths are of equal size. The distal shields are relatively narrow and steep and the crown is formed by elements of the tube-cycle. The central opening is elliptical. The form shows features typical of *Ericsonia*, but the central-area elements seem to be arranged radially, as in *Coccolithus*, rather than imbricating, as in *E. subpertusa*.

Genus *Futyania* Varol, 1989

***Futyania petalosa* (Ellis & Lohman, 1973) Varol, 1989**
Plate 3, Figures 1-3

The coccospheres of *F. petalosa* are spherical, 10µm to 12µm in diameter, and consist of approximately 80 small, elliptical coccoliths. Most of them are surrounded by six others, sometimes by seven. The presence of the petaloid distal elements seems to depend on the state of preservation.

Genus *Markalius* Bramlette & Martini, 1964

***Markalius* cf. *M. inversus* (Deflandre in Deflandre & Fert, 1954) Bramlette & Martini, 1964**
Plate 3, Figures 6-9

The spherical coccospheres are constructed of approximately 12 more-or-less circular coccoliths of equal size. The coccospheres are 17µm to 19µm in diameter. Each coccolith is surrounded by five other coccoliths. The central areas of the coccoliths are formed by several layers of approximately radially-arranged, polygonal elements which do not reach the crown of the distal shield.

Genus *Prinsius* Hay & Mohler, 1967

***Prinsius dimorphosus* (Perch-Nielsen, 1969) Perch-Nielsen, 1977**
Plate 4, Figure 1

The coccosphere measures 10µm in diameter and is comparable with those illustrated in the existing literature. Each coccolith is surrounded by six other coccoliths, which are equal in size. The total number of coccoliths on the coccosphere is approximately 20.

Genus *Sullvania* Varol, 1992

Sullvania consueta (Bramlette & Sullivan, 1961)
Varol, 1992
Plate 4, Figure 2

This large coccosphere (21µm) is subspherical and consists of 16 coccoliths of equal size. Each coccolith is surrounded by either five or six other coccoliths. The form illustrated is characterised by a central diagonal cross with arms of approximately equal length. The crown of the coccolith is formed by the distal shield, a characteristic feature of the genus *Sullvania*. The structure of the arms is not clearly visible, but there seems to be no indication of parallel, longitudinal laths, as is typical of forms belonging to the genus *Chiasmolithus*.

Sullvania sp.
Plate 4, Figures 3-5

The coccospheres measure 11µm to 15µm. They are spherical and contain seven to 12 overlapping coccoliths of equal size. The central areas of the coccoliths are relatively small and spanned by a central diagonal cross. Each arm of the central structure connects to a foot that lines the central opening. Each coccolith is surrounded by five other coccoliths, both on coccospheres with only seven coccoliths and those with more than ten coccoliths.

Genus *Toweius* Hay & Mohler, 1967

Toweius eminens (Bramlette & Sullivan, 1961) Perch-Nielsen, 1971
Plate 5, Figure 1

As the illustrated coccosphere of 13µm in diameter is probably not completely preserved (some coccoliths missing?) the shape cannot be exactly determined. Each coccolith exhibits four central openings, characteristic of this species.

Toweius pertusus (Sullivan, 1965) Romein, 1979
Plate 5, Figures 2-5

The coccospheres here assigned to *T. pertusus* are from 6µm to 9µm in diameter and are subspherical. They consist of ten to 12 elliptical, interlocking coccoliths. Each coccolith is surrounded by four to five other coccoliths of about equal size.

Results

Presence of coccospheres:

We suggest that the finding of intact coccospheres (other than *Watznaueria barnesae*) depends mainly on the following conditions:

- The sediment investigated must be rich in coccoliths.
- The coccoliths must be well-preserved.
- The preparation method must be non-destructive for coccospheres, which means no mechanical cracking of

treatment (Mai et al., 1997). Coccospheres can also be studied by direct observation of rock surfaces (e.g. Bown, 1993, and others).

- The time for SEM analysis must be greatly increased compared to the normal time spent looking for dispersed coccoliths.

In the lower part of the section studied, the coccosphere assemblages are dominated by relatively poorly preserved *Watznaueria barnesae*, not illustrated here, both in the uppermost Cretaceous (CC26) and in the lowermost Tertiary (NP1) samples (see Appendix).

The coccospheres from sample 39-356-29-1, 83-85cm (NP 2) are, like the dispersed coccoliths in this sample, very well-preserved and include *Coccolithus pelagicus*, *Futyania petalosa* and *Prinsius dimorphosus*. In the interval representing NP3 and NP4, only relatively poorly-preserved coccospheres of *C. pelagicus* and *Cruci-placolithus primus* were encountered. The sample richest in coccospheres (39-356-21-2, 122-123cm) belongs to the upper part of NP5 and yielded 13 species represented by well-preserved coccospheres. In the samples above this, only coccospheres of *C. pelagicus* were found.

Coccosphere morphology:

An attempt was made to determine the number of coccoliths surrounding each coccolith in the various species. The preliminary results indicate that many species tend to have five surrounding coccoliths, so that the resulting shapes are pentagonal dodecahedra. Some others usually have six, in some the number varies, and some forms seem to have only four coccoliths surrounding each coccolith. The latter leads to a more-or-less cubic coccosphere, as observed in *Ericsonia subpertusa*.

It may or may not be a coincidence that *Markalius* cf. *M. inversus* and *Cyclagelosphaera alta*, both forming a pentagonal dodecahedron-like structure, belong to genera that survived the K/T boundary event(s). Also,

(C) = Coccolithaceae (P) = Prinsiaceae			NUMBER OF COCCOLITHS PER SPHERE	NUMBER OF SURROUNDING COCCOLITHS
(FAMILY) SPECIES	SHAPE OF COCCOSPHERE			
(C) <i>Calcidiscus</i> ? sp.	spherical		20	5-6
(C) <i>Ch. edentulus</i>	spherical		10-16	5-6
(C) <i>C. pelagicus</i>	spherical		9-14	5
(C) <i>Cr. primus</i>	spherical to ovoid		12-18	5-6
(C) <i>Cr. tenuis</i>	spherical		13	5
(C) <i>Cruci-placolithus</i> sp.	spherical		14	5-6
(C?) <i>Cy. alta</i>	pentagonal dodecahedron		12	5
(C) <i>E. subpertusa</i>	cubic		6	4
(C) <i>Ericsonia</i> sp.	ovoid		14	5
(P) <i>F. petalosa</i>	spherical		80	6-7
(C?) <i>M. cf. M. inversus</i>	pentagonal dodecahedron		12	5
(P) <i>P. dimorphosus</i>	spherical		20	5
(C) <i>S. consueta</i>	spherical		16	5-6
(C) <i>Sullvania</i> sp.	spherical		7-12	5
(P) <i>T. eminens</i>	spherical to cubic?		≥6	≥3
(P) <i>T. pertusus</i>	spherical to cubic?		10-12	4-5

Table 1: Shape of coccospheres, number of coccoliths, and number

Braarudosphaera and *Goniolithus*, two other survivors of the K/T boundary event(s), form pentagonal dodecahedra, but this is due to the pentagonal outlines of single coccoliths.

As in Recent coccolithophorid species, the number of coccoliths varies on fossil coccospheres. While some species, like *Markalius* cf. *M. inversus* and *Cyclagelosphaera alta*, show a constant number of coccoliths on the sphere, others include a certain variation of numbers, like *Futyania petalosa* (Table 1).

Conclusions

We conclude that more coccospheres might be found than are commonly reported if the suggestions set out above are followed. The fact that even the 500 hours spent on the SEM did not result in the discovery of something similar to coccospheres of the systematically ambiguous fasciculiths, sphenoliths or helioliths does not necessarily indicate that there are no coccospheres of these taxa, but maybe due to their shape, they do not build preservable coccospheres (not interlocking).

Species which occur as coccospheres belong to only two families, the Coccolithaceae and the Prinsiaceae. They have living representatives and dominate calcareous nannoplankton assemblages of the upper photic zone. In the present day the Prinsiaceae are represented by *Emiliana huxleyi* and species of *Gephyrocapsa*.

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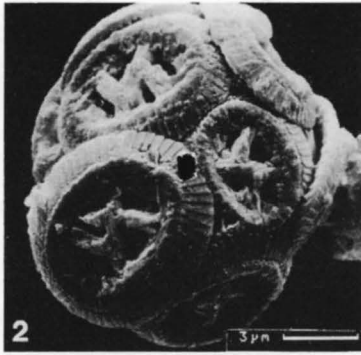
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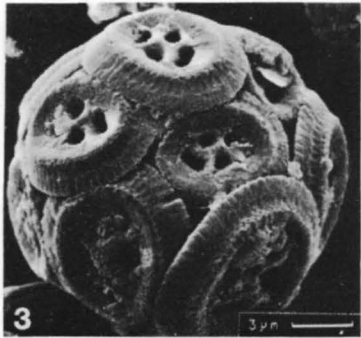
Appendix: Investigated samples

LEG	SITE	CORE	cm INTERVAL	STRATIGRAPHY	COCCOSPHERES
39	356	17-4	75-77	NP6	<i>C. pelagicus</i>
39	356	18-3	130-133	NP5	<i>C. pelagicus</i>
39	356	19-2	74-75	NP5	<i>C. pelagicus</i>
39	356	21-2	122-123	NP5	Most of taxa described
39	356	22-4	77-78	NP5	<i>C. pelagicus</i> , <i>C. primus</i>
39	356	24-2	77-78	NP5	<i>C. pelagicus</i> , <i>C. primus</i>
39	356	25-4	60-62	NP4	<i>C. pelagicus</i> , <i>C. primus</i>
39	356	26-5	77-78	NP4	<i>C. pelagicus</i> , <i>C. primus</i>
39	356	27-6	75-76	NP3	<i>C. pelagicus</i> , <i>C. primus</i>
39	356	29-1	83-85	NP2	<i>F. petalosa</i> , <i>C. pelagicus</i> , <i>P. dimorphosus</i>
39	356	29-2	131-133	NP1	<i>W. barnesae</i>
39	356	29-3	106-108	CC26	<i>W. barnesae</i>

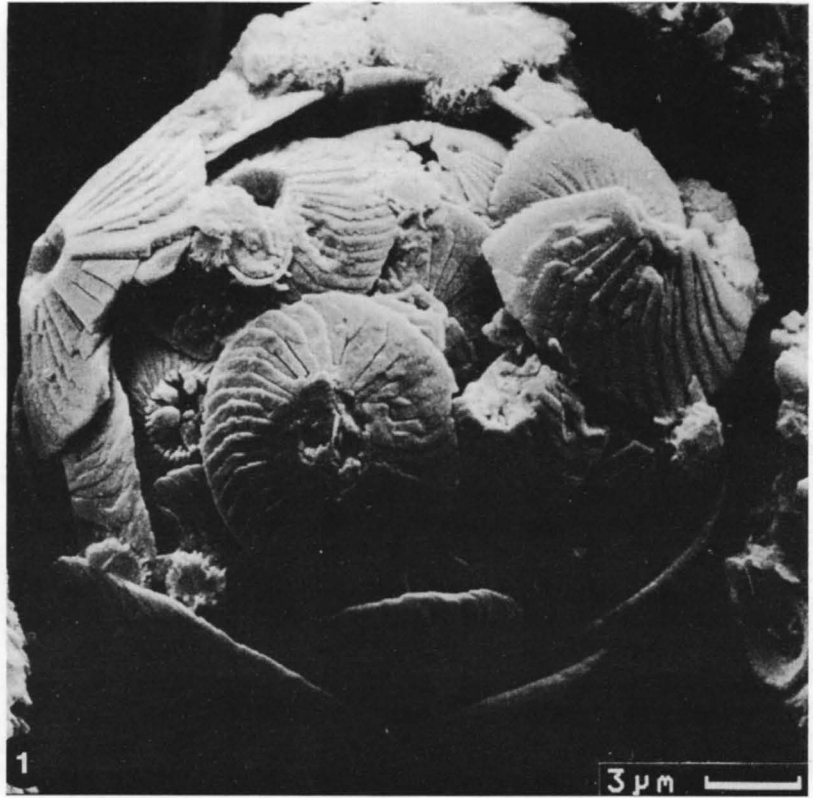
PLATE 1



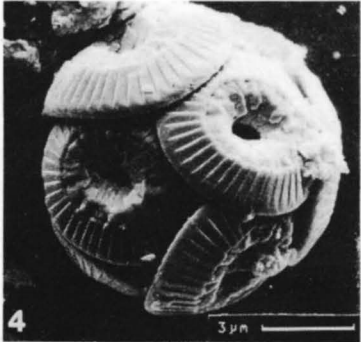
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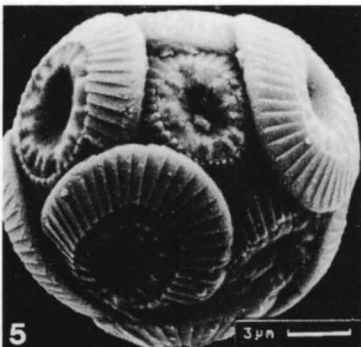
Chiasmolithus edentulus



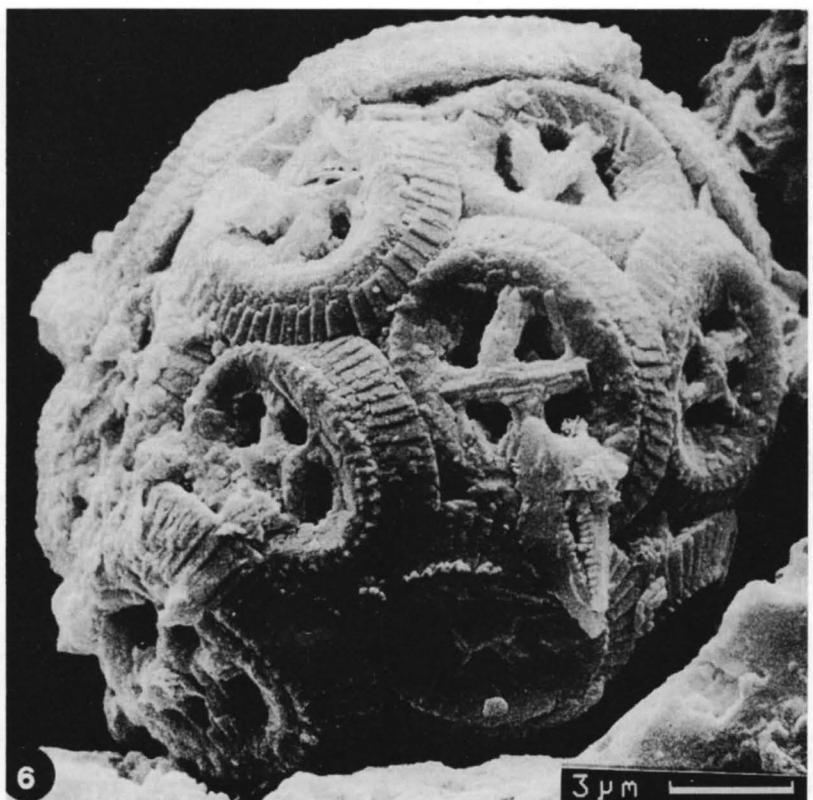
Calcidiscus? sp.



Coccolithus pelagicus



Coccolithus pelagicus



Chiasmolithus edentulus

PLATE 1: Fig. 1: *Calcidiscus?* sp.. Sample 39-356-21-2, 122-123cm (NP5); Neg.# 867/32. Figs 2, 3, 6: *Chiasmolithus edentulus*. Sample 39-356-21-2, 122-123cm (NP5); 2: Neg.# 867/32; 3: Neg.# 867/4; 6: Neg.# 867/17. Figs 4, 5: *Coccolithus pelagicus*. Sample 39-356-21-2, 122-123cm (NP5); 4: Neg.# 854/12; 5: Neg.# 854/24.

PLATE 2

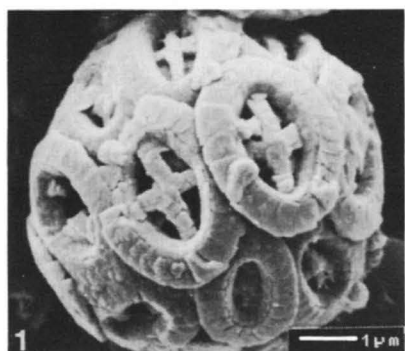
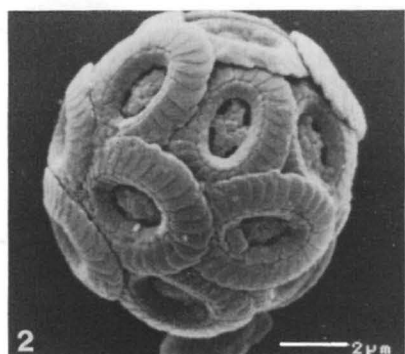
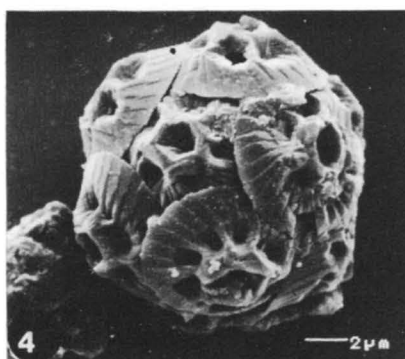
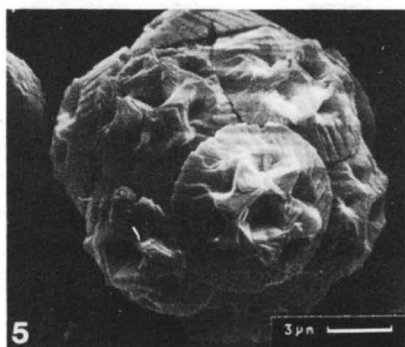
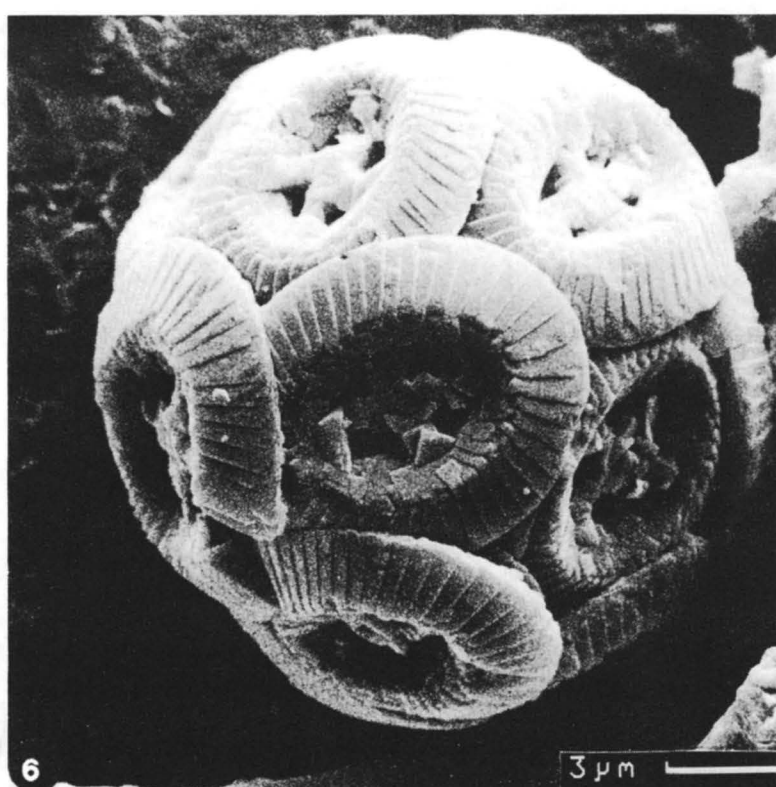
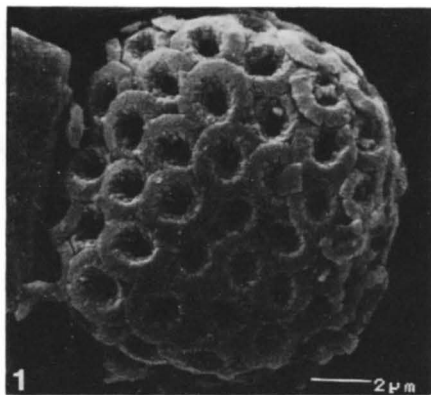
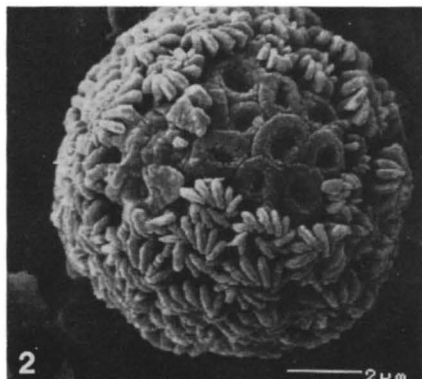
*Cruciplacolithus primus**Cruciplacolithus primus**Cruciplacolithus primus**Cyclagelosphaera alta**Cyclagelosphaera alta**Cruciplacolithus tenuis*

PLATE 2: Figs 1-3: *Cruciplacolithus primus*. Sample 39-356-21-2, 122-123cm (NP5); 1: Neg.# 854/7; 2: Neg.# 854/32; 3: Neg.# 854/14. Figs 4, 5: *Cyclagelosphaera alta*. Sample 39-356-21-2, 122-123cm (NP5); 4: Neg.# 853/27; 5: Neg.# 853/8. Fig. 6: *Cruciplacolithus tenuis*. Sample 39-356-21-2, 122-123cm (NP5); Neg.# 854/28

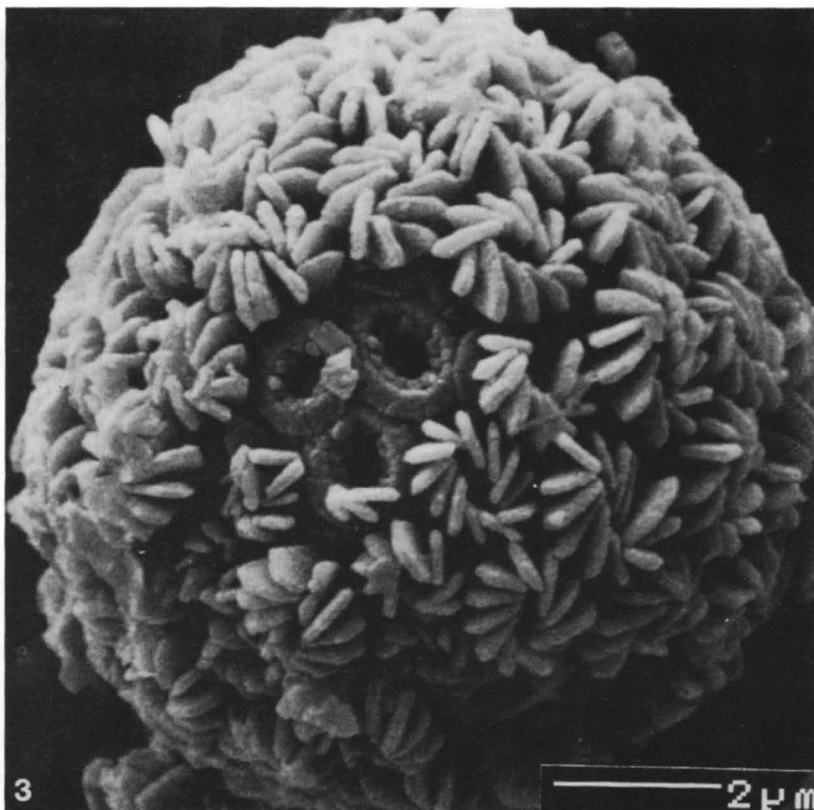
PLATE 3



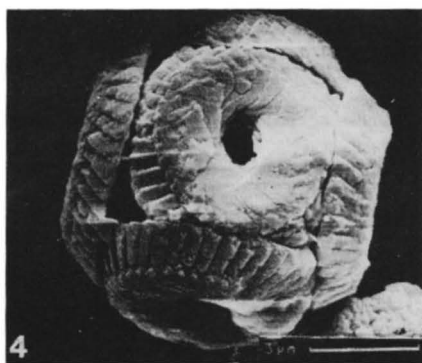
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2
Futyania petalosa



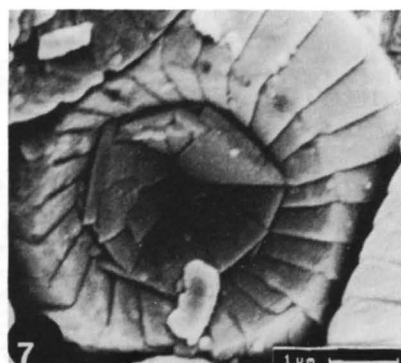
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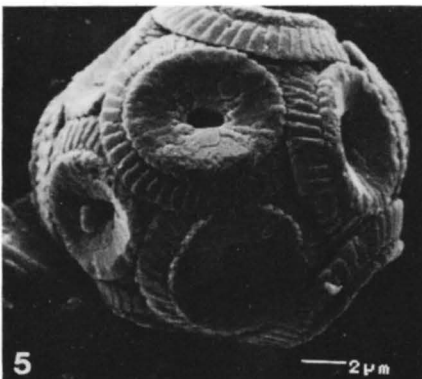
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6
Markalius cf. M. inversus



7
Markalius cf. M. inversus



5
Ericsonia? sp.



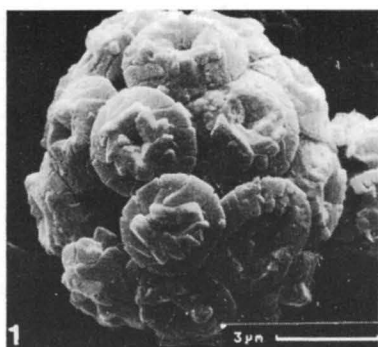
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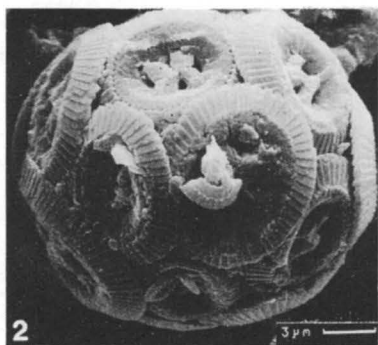
9
Markalius inversus

PLATE 3: Figs 1-3: *Futyania petalosa*. Sample 39-356-29-1, 83-85cm (NP2); 1: Neg.# 854/16; 2: Neg.# 854/9; 3: Neg.# 854/24. **Fig. 4: *Ericsonia subpertusa*.** Sample 39-356-21-2, 122-123cm (NP5); Neg.# 853/2. **Fig. 5: *Ericsonia? sp.*** Sample 39-356-21-2, 122-123cm (NP5); Neg.# 853/3. **Figs 6-9: *Markalius cf. M. inversus*.** Sample 39-356-21-2, 122-123cm (NP5); 6: Neg.# 853/5; 7: Neg.# 853/6; 8: Neg.# 853/12; 9: Neg.# 853/13.

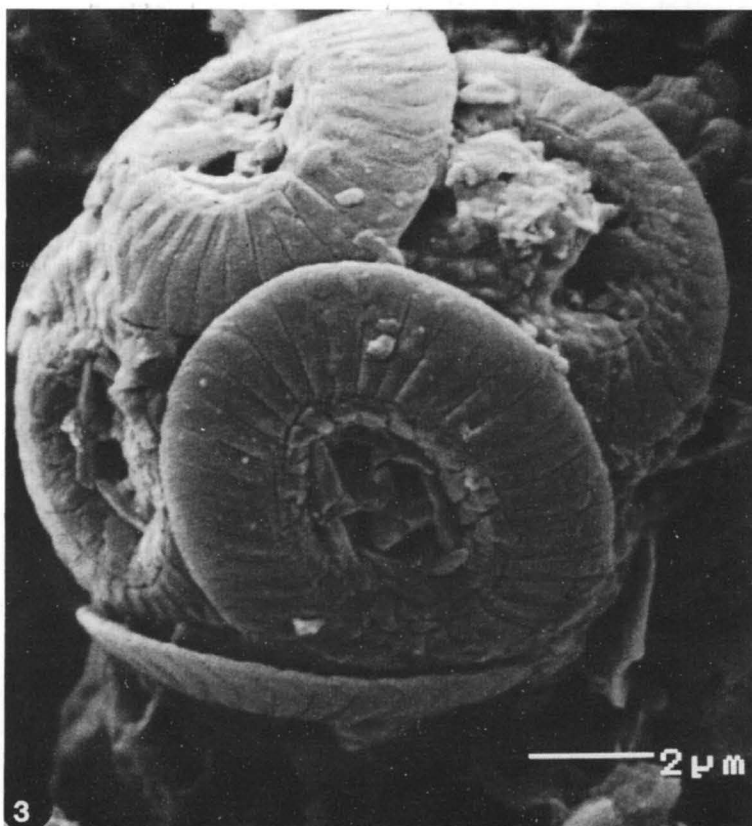
PLATE 4



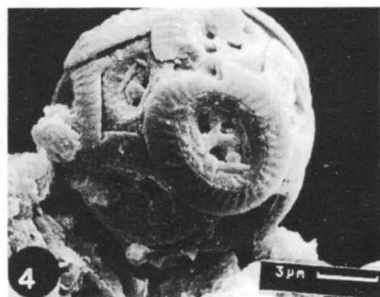
1
Prinsius dimorphosus



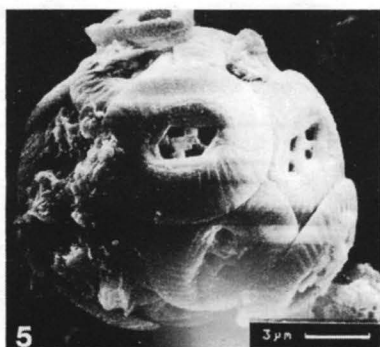
2
Sullivania consueta



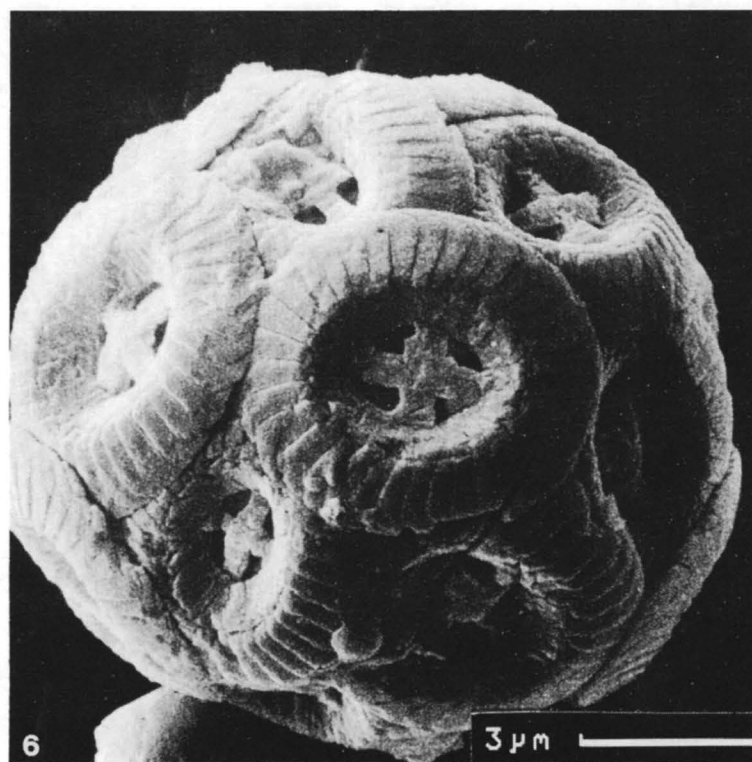
3
Sullivania sp.



4
Sullivania sp.



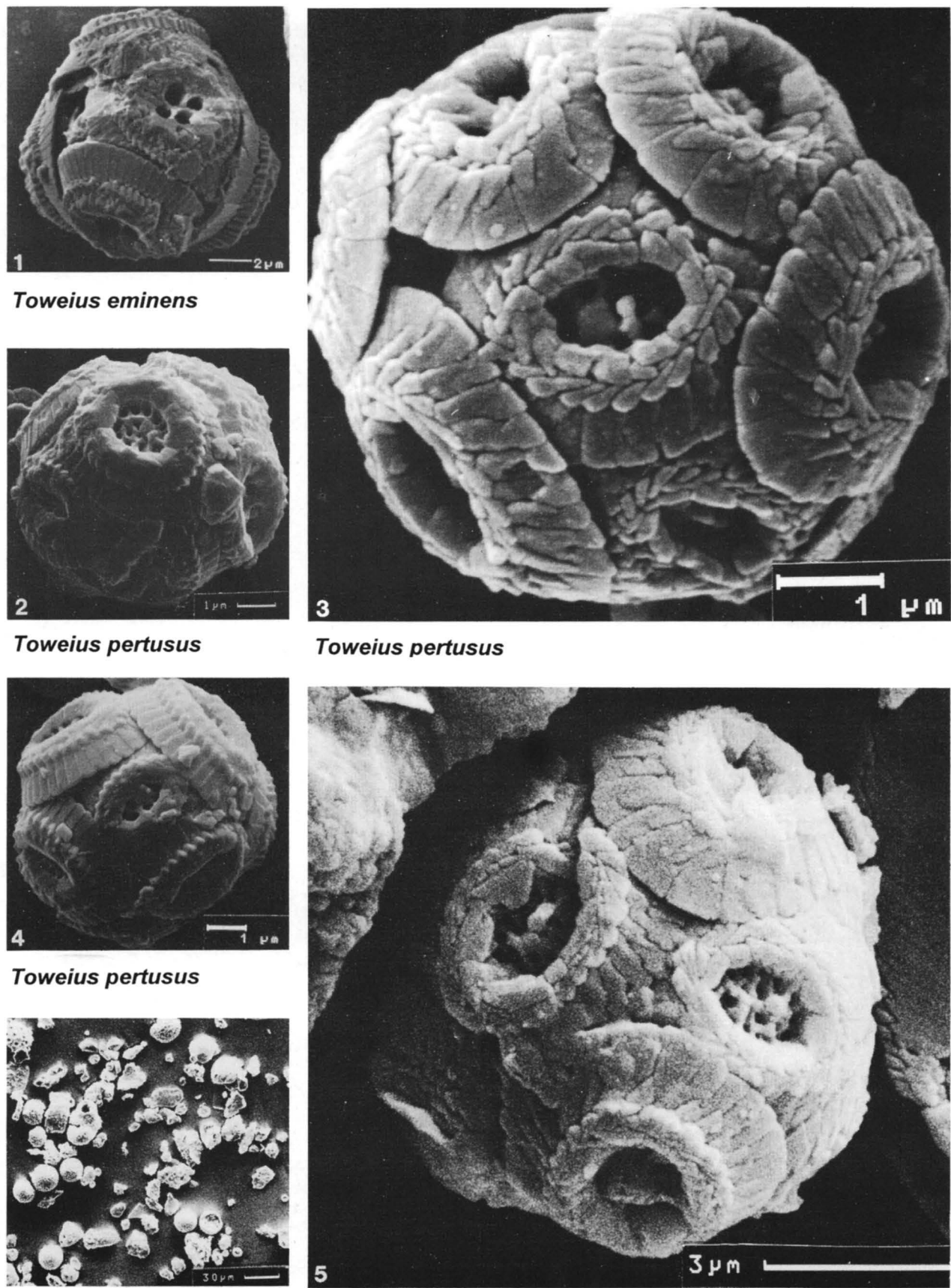
5
Sullivania sp.



6
Cruciplacolithus sp.

PLATE 4: Fig. 1: *Prinsius dimorphosus*. Sample 39-356-29-1, 83-85cm (NP2); Neg.# 854/3. Fig. 2: *Sullivania consueta*. Sample 39-356-21-2, 122-123cm (NP5); Neg.# 854/5. Figs 3-5: *Sullivania* sp.. Sample 39-356-21-2, 122-123cm (NP5); 3: Neg.# 854/28; 4: Neg.# 854/24; 5: Neg.# 854/19. Fig. 6: *Cruciplacolithus* sp.. Sample 39-356-21-2, 122-123cm (NP5); Neg.# 854/4.

PLATE 5



Sediment (NP5) *Toweius pertusus*

PLATE 5: Fig. 1: *Toweius eminens*. Sample 39-356-29-1, 83-85cm (NP2); Neg.# 853/19. Figs 2-5: *Toweius pertusus*. Sample 39-356-21-2, 122-123cm (NP5); 2: Neg.# 853/22; 3: Neg.# 853/20; 4: Neg.# 853/9; 5: Neg.# 853/16. Unnumbered: Sediment of NP5 at low magnification.