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Coccolithophorids of the North Pacific Central Gyre with notes on their vertical and seasonal distribution

ABSTRACT

Scanning electron micrographs supplement earlier observations on the living coccolithophorids of the North Pacific Central Gyre, and suggest that new forms may be present among the 44 taxa described. Vertical and seasonal distribution data obtained from 6 cruises during 1972–1974 confirm the existence of depth-dependent communities, particularly in the summer months. The populations become less structured in the winter months when some taxa, notably *Emiliania huxleyi*, expand their depth range, probably responding to a greater degree of mixing in the water mass.

INTRODUCTION

In the course of an inverted microscope study of the total range of microplankton in a 400-sq. mile area of the North Pacific Central Gyre in the region of 28°N, 155°W, the coccolithophorid data proved to be most useful in testing the hypothesis of seasonal stability of populations. It was therefore important to identify as many forms as possible, and the SEM (scanning electron microscope) was used to supplement light microscope analysis. The following illustrations and descriptions resulted from these studies. Illustrations are introduced which further clarify existing taxa and new forms are described, although too few specimens were encountered to allow formal establishment of new taxa.

The use of the TEM (transmission electron microscope) for morphological and taxonomic work in this group began in the 1950's, resulting in papers such as those by Deflandre and Fert (1954) and Halldal and Markali (1955), and has continued to the present with major contributions from Gaarder (1962), McIntyre and Bé (1967), Kamptner (1967), Gaarder (1970), Gaarder and Hasle (1971) and Okada and McIntyre (1977). The last 3 include some SEM micrographs, but the publications based mainly on SEM work are those of Martini and Müller (1972), Heimdal (1973), Borsetti and Cati (1972, 1976), Kling (1975) and Gaarder and Heimdal (1977). Earlier, coccolithophorid taxonomists depended on the light microscope and made surprisingly accurate observations, e.g. Lohmann (1902, 1912, 1913b), Schiller (1930), Kamptner (1927, 1941), and Lecal-Schlauder (1951).

The taxa illustrated and described herein were selected from a total of 53 named species and a group of unidentified forms found in the light microscope analysis of the gyre samples. Some previously well-described species were not included. Table 1 summarizes seasonal and depth distribution data for selected species derived from this analysis but does not include all the forms illustrated here, some of which were not recognized at lower magnifications. For further discussion of the total microplankton of the North Pacific Central Gyre refer to papers presently being prepared by Beers, Reid and E. Stewart and by Beers, Reid and G. Stewart.

Data records for 5 cruises are published as IMR Report 75–6 (Beers, Reid and Stewart, 1975) and 77–1 (Beers, Reid and Stewart, 1977). Cato 1 data were incomplete due to sample loss. These records have quantitative data on all microplankton taxa identified, including many of the coccolithophorids described in this paper and notes on name changes that have been made during the years spent on this study.

TABLE 1

Vertical and seasonal distribution of selected species based on numbers averaged over several stations for each cruise. Cruises arranged seasonally rather than chronologically.

CRUISE	DEPTH INTERVAL (m.)	Upper layer group												"Intermediate" group					Lower layer group								
		<i>Calyptrorpha oblonga</i>	<i>Discosphaera tubifera</i>	<i>U. irregularis</i>	<i>Rhabdosphaera stylifer/clavigera</i>	<i>Acanthoica acanthifera</i>	<i>Cyclodoccolithus leptoporus</i>	<i>Helicosphaera carteri</i>	<i>Periphyllophora mirabilis</i>	<i>Helladosphaera cornifera</i>	<i>Syracosphaera pulchra</i>	<i>S. pirus/pulchroides</i>	<i>Umbellosphaera tenuis</i>	<i>Emiliania huxleyi</i>	* <i>Halopappus</i> sp.	* <i>Michaelsarsia splendens</i>	<i>Calciolosolenia sinuosa</i>	<i>Anoplosolenia brasiliensis</i>	<i>Umbilicosphaera sibogae</i>	<i>Collothotus fragilis</i>	<i>Deutschlandia</i> spp.	<i>Thorosphaera flabellata</i>	<i>Ophiaster hydroideus</i>	<i>Anthosphaera oryza</i>	# <i>Florisphaera profunda</i> (lg.)	<i>Florisphaera profunda</i> (sm.)	<i>Thoracosphaera heimii</i>
SOUTH TOW 13 Jan.-Feb. 1973	0/20	4	17	1	12	4	4	3	1	60	7	4	7	907	3	18	2	2	3					7	2	6	
	40/60/80	2	19	5	10	2	9			100	6	4	6	1087	5	32	4	4					5	1	6		
	100/120	2	10		6	2	10	2		50	6	3	3	1276	5	22	3	5	6				No Data	14	6	6	
	140/160		10		2	2	3	1		40				628	3	8	2		5		5	20	12	22	30	5	
	180/200	5					1							10							8		5	3		2	
TASADAY 11 March 1974	0/20	20	43	11	9	2		3			4	7	74	289		4	1	2	1		4		2			8	
	40/60/80	16	68	18	13	3	3	3		120	3	8	100	359	3	5	1	1			3		3			8	
	100/120	3	27	6	8	3	3	3		110	2	2	37	947	5	25	6	4	3		1	8	18	11	20	10	
	140/160					3							3	787		4	3		3	3	44	3	20	51	80	8	
	180/200									10				160						2	5	35	1	14	35	10	5
DRAMAMINE II May 1974	0/20	19	77	7	17	5			7	80		11	55	20						2			5			9	
	40/60/80	11	32	4	36	6	1	5	9	440	5	16	120	70	8	7	2			5					2	12	
	100/120	11		2	13	2	5	5	2	40	2	3	37	760	6	24	10	10	9	18	22	13	68	49	42	5	
	140/160									30		3	3	130		1	2		3	7	18	62	5	75	68	399	6
	180/200													100					1	3	2	47	1	22	28	170	2
TASADAY 1 June 1973	0/20	18	55	2	1	51	1		11	191	1	23	23														
	40/60/80	25	12	9	5	16			20	507	11	45	45			4											
	100/120		9	3	2		1			44	8	3	28	213	2	16	4	4	3	2	5		4	7	6	6	
	140/160				6				1				6	38	2	3	7		6	19	33	25	6	55	28	3	
	180/200												1	7					5	6	16	18		16	8	No Data	4
CLIMAX VII Aug.-Sept. 1973	0/20	4	28	143	3	3			1	93	4	9	13							1		3				4	
	40/60/80	8	20	60	8	3	4	10	10	332	2	6	23	13		5	3	6		10		3				13	5
	100/120		12	29	4		1	4	2	93	4		24	66	3	9	12	13	4	8	52	33	21	27	12	306	3
	140/160												2	67		2	2			4	19	50	3	23	33	159	2
	180/200																			4	10		17	21	27		4

Numbers are coccospheres per 100 ml. Counts > 50 per 100 ml are underlined.

**Halopappus* sp. is probably equivalent to the form of *Halopappus adriaticus* in plate 5, figures 4-5, *Michaelsarsia splendens* to that in plate 5, figure 6.

**Helladosphaera cornifera* may include *H. aurisinae* (pl. 7, figs. 5-6).

†*Syracosphaera pirus/pulchroides* probably includes *S. hystrix* (pl. 5, figs. 7-8) and *S. pirus* (pl. 5, fig. 9).

#*Florisphaera profunda* (lg.) is probably *F. profunda* var. *elongata* (pl. 8, fig. 5).

METHOD

Samples were acquired during 6 cruises to the vicinity of 28°N, 155°W in the central North Pacific at various seasons: Cato Leg 1 (C1) in June, 1972—2 stations studied; South Tow Leg 13 (ST 13) in Jan.-Feb., 1973—4 stations; Tasaday Leg 1 (T1) in June, 1973—6 stations; Climax VII (CL VII) in Aug.-Sept., 1973—3 stations; Tasaday Leg 11 (T11) in March, 1974—4 stations, and Dramamine II (DII) in May, 1974—4 stations. On each cruise, water samples were collected with a 30-liter Niskin bottle at 20-m intervals through the upper 200 m of each station. These were fixed with 5% borate-buffered formalin and eventually combined to form composite samples representing the following depth intervals: 0/20 m, 40/60/80 m, 100/120 m, 140/160 m and 180/200 m. Taxonomic analysis was carried out on a phase-contrast, inverted microscope at either 250x or 625x magnification for the number of stations indicated above. Samples used in SEM photography were prepared by concentrating materials on a 0.22- μ m millipore filter. De-salting was carried out *in situ* by washing with water of decreasing salinity and finally with tap water. A vacuum dessicator was used for drying, after which the filter was mounted on an SEM stub with tape and coated with gold-palladium. (See table 1.)

DISTRIBUTION

Table 1 includes some of the more interesting species encountered in the course of the inverted microscope study. It shows numbers per 100 ml. Biomass estimates indicate a similar distribution (Data Records—Beers, Reid and Stewart, 1975, 1977).

When vertical distribution is considered, the data show 2 distinct groups of species especially in the May through September cruises. Some species are confined to the upper layers (0/20, 40/60/80 m) and some to the lower layers (140/160, 180/200 m). Between, the 100/120-m level seems to be inhabited by a diverse flora consisting of species from above and below, although generally the absolute numbers are less than at adjacent levels.

In the upper layers (0/20, 40/60/80 [100/120] m) the species with relatively high abundance are *Discosphaera tubifera* (Murray and Blackman) Ostenfeld, *Umbellosphaera tenuis* (Kamptner) Paasche and *Heladosphaera cornifera* (Schiller) Kamptner. Other species found in a similar position in the water column are *Calyptrorpha oblonga* Lohmann, *Umbellosphaera irregularis* Paasche, *Rhabdosphaera stylifer* Lohmann/*clavigera* Murray and Blackman, *Acanthoica acanthifera* Lohmann, *Syracosphaera pulchra* Lohmann and *S. pirus* Halldal and Markali/*pulchroides* Halldal and Markali. *Umbellosphaera irregularis* is clearly more

abundant in CL VII (Aug.-Sept.) and this agrees with the finding of Okada and Honjo (1973) and Honjo and Okada (1974) whose Central North Zone C on Traverse 4 is geographically equivalent to our stations and whose samples were collected in Aug./Oct.

In the lower layers ([100/120 m], 140/160, 180/200 m) there is a flora in which the predominant species include *Anthosphaera oryza* (Schlauder) Gaarder [= *quadricornu* (Schiller) Halldal and Markali], *Florisphaera profunda* Okada and Honjo, *Thorosphaera flabellata* Halldal and Markali, *Oolithotus fragilis* (Lohmann) Okada and McIntyre and probably *Deutschlandia* spp., although this was a difficult form to count with the light microscope, and data are less reliable.

Okada and Honjo (1973) found *Emiliania huxleyi* (Lohmann) Hay and Mohler to be a dominant species at the surface in Aug./Oct. in their more northerly Transitional Zone B but not in Central North Zone C which includes our study area. However our data show that, in the winter samples (ST 13 and T 11) this species is, in fact, also important in the latter zone probably responding to lower water temperatures. Our physical data showed a greater degree of mixing at this season. It is also evident that in the summer season when stratification occurs, the population of this species is generally found below 100/120 m, whereas in winter it is present throughout the water column studied. A similar distribution is seen for *Halopappus* sp./*Michaelsarsia splendens* Lohmann, *Calciosolenia sinuosa* Schlauder (= *C. murrayi* Gran) and *Anoplosolenia brasiliensis* (Lohmann) Deflandre, although numbers are much lower. The SEM micrographs of *E. huxleyi* from our samples (not reproduced here) indicate that it is similar to the "cold-water" variety of Okada and Honjo (1973, pl. 1, no. 3) and it is tempting to assume that the species just listed are also cooler water species. *Calciosolenia sinuosa* is interesting because it was also found associated with a group of dinoflagellates, in the nearshore waters off Southern California during an experiment conducted in March, 1976 (Reid et al., 1978). It was more common in the chlorophyll-maximum layer than at the surface.

Data on *Gephyrocapsa* spp. noted by Okada and Honjo as important in this area are probably not reliable in the present work due to the small size of the cells and the limitation of the inverted microscope technique. *Thoracosphaera heimii* (Lohmann) Kamptner is an enigmatic form whose classification as a coccolithophorid is open to doubt. It showed a uniform distribution seasonally and vertically in these data with the exception of lower numbers in late summer.

SYSTEMATIC DESCRIPTIONS

An alphabetical listing of families is used with the holococcolithophorid and unassigned genera at the end. The source of the samples used for the SEM photographs is given first, by cruise, station and depth interval [e.g., Tasaday 1(4) 140/160 m]. This is followed by a note on occurrence in other SEM samples and, where available, by additional information derived from the light microscope analysis on seasonal and/or vertical distribution in the study area.

The synonymies include references to works with photographs or drawings which can be usefully compared with those in this paper. For a more extensive index and bibliography refer to the publications of Loeblich and Tappan (1963, 1966, 1968, 1969, 1970a, 1970b, 1972 and 1973). Dimensions in the text are for the particular coccospheres or coccoliths illustrated by the micrographs in this paper.

Kingdom PLANTAE

Division CHRYSOPHYTA Pascher, 1914

Class HAPTOPHYCEAE Parke and Dixon, 1964

Order COCCOLITHOPHORALES Schiller, 1926

Family COCCOLITHACEAE Kamptner, 1928

Genus CRENALITHUS Roth, 1973

Crenalithus sessilis (Lohmann) Okada and McIntyre
Plate 1, figures 1–3

Pontosphaera sessilis LOHMANN, 1912, pp. 42–46, text-fig. 9; 1913a, pp. 360–362, text-fig. 16.

Coccolithus sessilis (Lohmann).—LECAL-SCHLAUDER, 1951, p. 298, pl. 13, fig. 1.

Crenalithus sessilis (Lohmann).—OKADA and MCINTYRE, 1977, p. 8, pl. 5, figs. 1–3.

Note: Brenneckella lorenzi Lohmann and *B. kohli* Lohmann were used by Lohmann to designate the "host" diatom in this association. (See Gaarder and Hasle, 1962). The diatom here was identified as *Thalassiosira cf. punctifera* by G. Fryxell.

Figure 1: Shows the relationship between *C. sessilis* and *T. cf. punctifera*. Coccospheres and free coccoliths are attached to the girdle area of the diatom.

Figure 2: Placoliths showing distal and proximal shields, crenelate edge and distal convexity of both shields. Distal shield $2.5 \times 2.1 \mu\text{m}$, proximal $1.5 \times 1.2 \mu\text{m}$. The central area has a pore through the placolith with an uneven margin in the distal shield.

Figure 3: Coccosphere shows overlapping placoliths; subspherical 6.8 to $7.3 \mu\text{m}$ along main axes.

South Tow 13(1) 140/160 m. Tasaday 11(4) 140/160 m.

Found at or below the 100/120 m level, always in association with the diatom. Usually from 1 to 4 diatom cells per 100 mls, and more common in the summer samples.

Genus GEPHYROCAPSA Kamptner, 1943

Gephyrocapsa crassipons Okada and McIntyre
Plate 1, figure 4

Gephyrocapsa crassipons OKADA and MCINTYRE, 1977, p. 10, pl. 2, figs. 5–6.

Spherical coccosphere $2.6 \mu\text{m}$ diameter. Coccoliths oval $1.6 \times 1.1 \mu\text{m}$, the central area reticulate with a thick collar consisting of many radial elements. The thick bridge formed by 2 halves arises at a low angle to the coccolith surface, and is markedly diagonal to the long axis of the coccolith.

South Tow 13(1) 100/120 m. Included in cf. *Gephyrocapsa* sp. in analysis, always at or above 140/160 m.

Gephyrocapsa ericsonii McIntyre and Bé
Plate 1, figure 5

Gephyrocapsa ericsonii MCINTYRE and BÉ, 1967, p. 571, pl. 10; pl. 12, fig. b.—OKADA and MCINTYRE, 1977, p. 10, pl. 2, fig. 9 (part).

Spherical coccosphere $3.5 \mu\text{m}$ diameter. Coccoliths oval $1.9 \times 1.4 \mu\text{m}$. The central area composed of about 23 radial elements, surrounded by a thick collar without obvious structure and spanned by a high, delicate bridge consisting of 2 parts, at a slight diagonal from the long axis of the coccolith.

Tasaday 11(4) 0/20 m. Also in T 11(1) 100/120 m. Included in cf. *Gephyrocapsa* sp. in analysis, always at or above 140/160 m.

Gephyrocapsa oceanica Kamptner
Plate 1, figure 6

Geophyrocapsa oceanica Kamptner.—HALLDAL and MARKALI, 1955, p. 18, pl. 24, figs. 1–2.—HASLE, 1960, pl. 2, figs. 3–5.—BARTOLINI, 1970, pl. 5, figs. 1–8.—GAARDER and HASLE, 1971, fig. 6d–f.—OKADA and MCINTYRE, 1977, pp. 10–11, pl. 3, fig. 5.

Single coccolith, oval about $5.5 \times 4.3 \mu\text{m}$. A large central area with fine radial elements; collar high and heavy consisting of many radiating connected elements which form a ridge on top of the collar on the distal side. From this, 2 large, heavy projections form the bridge set at approximately right angles to the long axis of the coccolith.

Tasaday 11(1) 0/20 m. Also in T11(4) 0/20 m. Whole cell not recognized in analysis.

Gephyrocapsa protohuxleyi McIntyre
Plate 1, figure 7

Gephyrocapsa protohuxleyi MCINTYRE, 1970, pp. 187–190, text-fig. 1a, b, d, f, g.—MÜLLER, 1972, p. 84, pl. 6, figs. 1–2.

Spherical coccosphere $5.7 \mu\text{m}$ diameter. Coccoliths oval $3.2 \times 2.6 \mu\text{m}$. The central area with about 22 radial elements, surrounded by a collar consisting of about 24 separate ribs similar to those of *Emiliania*

huxleyi. Two-part bridge, slender and fairly high at a slight angle from the long axis of the coccolith.

Tasaday 11(5) 100/120 m. Also in T 11(5) 0/20 m. Included in cf. *Gephyrocapsa* sp. in analysis, always at or above 140/160 m level.

Gephyrocapsa* cf. *protohuxleyi McIntyre
Plate 1, figure 8

cf. *Gephyrocapsa protohuxleyi* MCINTYRE, 1970, pp. 187–190, text-fig. 1a, b, d, f, g.

Spherical cell 3.0 μm diameter with oval coccoliths $1.5 \times 1.1 \mu\text{m}$. Large central area with reticulate structure giving a porous effect, surrounded by a collar formed by about 26–33 separate ribs similar to that of *E. huxleyi*. Bridge high and slender, of 2 parts, set at a slight angle from the long axis of the coccolith.

Tasaday 11(4) 0/20 m. Included in cf. *Gephyrocapsa* sp. in analysis, always at or above 140/160 m.

Genus OOLITHOTUS Reinhardt in Cohen and Reinhardt, 1968

Oolithotus fragilis (Lohmann) Okada and McIntyre
Plate 1, figure 9

Coccolithophora fragilis LOHMANN, 1912, pp. 49, 54, text-fig. 11.

Cyclococcolithus fragilis (Lohmann) Deflandre.—HASLE, 1960, pl. 3, figs. 3–7.

Cyclococcolithina fragilis (Lohmann) Wilcoxon var. A.—OKADA and HONJO, 1973, pl. 2, fig. 2.

Oolithotus fragilis (Lohmann).—OKADA and MCINTYRE, 1977, p. 11, pl. 4, fig. 3.

Single placolith from the proximal side showing asymmetry. Distal shield 7.5 μm diameter with about 17 straight radiating suture lines. Proximal shield diameter 4.5 μm , more than half that of the distal. No perforation through the shields.

Tasaday 11(5) 180/200 m. Not differentiated from *O. fragilis* subsp. *cavum* in analysis. Highest numbers below 100/120 m.

Oolithotus fragilis (Lohmann) OKADA and MCINTYRE subsp. *cavum* Okada and McIntyre
Plate 1, figure 10

Cyclococcolithus fragilis (Lohmann) Deflandre.—MCINTYRE and BÉ, 1967, p. 570, pl. 9, fig. c.

Discolithus antillarum Cohen.—MCINTYRE, BÉ and PREIKSTAS, 1967, pp. 7–8, pl. 1, fig. c.

Cyclococcolithina fragilis (Lohmann) Wilcoxon.—OKADA and HONJO, 1973, pl. 2, fig. 1.

Oolithotus fragilis (Lohmann) Okada and McIntyre subsp. *cavum* OKADA and MCINTYRE, 1977, pp. 11–12, pl. 4, figs. 4–5.

Coccoliths smaller than those of *O. fragilis*. Distal and proximal views of the placoliths showing asymmetry and perforation through the shields. Proximal shield diameter 2.6 μm , less than half that of the distal shield, which is 5.8 μm . Suture lines curved.

South Tow 13(1) 140/160 m. Not differentiated from *O. fragilis* in analysis. Highest numbers below 100/120 m.

Genus UMBILICOSPHAERA Lohmann, 1902

Umbilicosphaera sibogae (Weber-van Bosse) Gaarder
Plate 2, figures 1–2.

Umbilicosphaera mirabilis LOHMANN, 1902, pp. 139–140, pl. 5, figs. 66, 66a.—MCINTYRE and BÉ, 1967, pp. 571–572, pl. 11, fig. c.

Umbilicosphaera sibogae (Weber-van Bosse).—GAARDER, 1970, pp. 122–126, fig. 9c-d.—BORSETTI and CATI, 1976, pp. 223–224, pl. 18, figs. 3–4.—OKADA and MCINTYRE, 1977, p. 13, pl. 4, fig. 2.

Figure 1: Part of complete subspherical coccosphere of the larger form of this taxon (see pl. 2, figs. 3–4). Long axis about 22 μm , short axis about 15 μm . Approximately 50–100 overlapping placoliths.

Figure 2: Circular placolith with distal shield, 4 μm , smaller than proximal, 4.7 μm . Shows strongly convex distal, and flatter proximal shield. Distal shield with about 25 elements radiating in overlapping fashion from center; zig-zag pattern of sutures clear. Large central area with no hook structure.

Tasaday 11(1) 100/120 m, 140/160 m.

The 2 forms of this taxon were not separated in the analysis. Combination present at all stations in all cruises usually with highest numbers at 100/120 m and 140/160 m. Also in upper layers in ST 13, at 180/200 m in T 1 and D II and throughout the water column studied in T 11.

Umbilicosphaera sibogae (Weber-van Bosse) Gaarder var. *foliosa* (Kamptner) Okada and McIntyre
Plate 2, figures 3–4

Cycloplacolithus foliosus KAMPTNER, 1963, pp. 167–168, pl. 7, fig. 38.

Umbilicosphaera mirabilis Lohmann.—MCINTYRE and BÉ, 1967, pp. 571–572, pl. 12, fig. A.

Umbilicosphaera sibogae (Weber-van Bosse) Gaarder var. *foliosa* (Kamptner).—OKADA and MCINTYRE, 1977, pp. 13–14, pl. 4, fig. 1.

Figure 3: Spherical coccosphere showing small cell of this variety (13 μm diameter) and smaller number (approx. 20) of larger circular placoliths than in figures 1 and 2. Lateral view of placolith showing convexity of both shields; the diameter of the distal shield (5.5 μm) larger than that of the proximal (4.4 μm) shield. Hooklike structures in the central area.

Figure 4: Placoliths showing hooklike protrusions from base of inner margin of proximal shield into the central area.

About 30 elements radiating from the central area, with outer portion of suture line zig-zag.

Tasaday 11(1) 140/160 m. T 11(4) 100/120 m.

Note: The 2 forms not separated in the analysis. Combination present at all stations in all cruises usually with highest numbers at 100/120-m and 140/160-m levels. Also in upper layers in ST 13, at 180/200 m in T 1 and D II and throughout the water column studied in T 11.

Family DEUTSCHLANDIACEAE Kamptner, 1928
Genus DEUTSCHLANDIA Lohmann, 1912

Deutschlandia anthos Lohmann
Plate 2, figures 5–6

Deutschlandia anthos LOHMANN, 1912, p. 47, text-fig. 10.

Figure 5: Collapsed trimorphic coccosphere showing relative numbers of the 3 coccolith types: small oval inner discoliths, some with blunt spines and outer large, circular lepidoliths, mostly in proximal view.

Figure 6: Small coccoliths approximately $2.1 \times 1.2 \mu\text{m}$. Outer rim $0.4 \mu\text{m}$ high with no midwall structure, arising at a slight angle from the basal disc and made up of many oblique elements arranged in counter-clockwise fashion. The floor of the coccolith is dome-shaped and consists of about 28 radiating lamellae with a central, slightly thickened area, from which arises a short, blunt spine ($1.1 \mu\text{m}$ long) in some cases. The spine is apparently not forked.

The larger circular coccoliths 3.5 to $3.8 \mu\text{m}$ in diameter and $0.2 \mu\text{m}$ thick are distally slightly convex in the center and have radial oblique suture lines which give the edge an angular appearance. Pierced by a small hole in the center.

Tasaday 11(4) 180/200 m, T 11(5) 140/160 m.

Probably confused with *Florisphaera* sp. in light microscope counts but indications of main occurrence in the lower layers. Also called *Deutschlandia* sp. X and Coccolithophorid sp. P in data record (Beers, Reid and Stewart, 1975, 1977).

Family PONTOSPHAERACEAE Lemmermann, 1908
Genus DISCOLITHINA Loeblich and Tappan, 1963

Discolithina japonica Takayama
Plate 2, figures 7–9

Discolithina japonica TAKAYAMA, 1967, pp. 189–190, pl. 9; pl. 10, figs. 1, 2a–d.—BARTOLINI, 1970, p. 148, pl. 3, figs. 1–3.—OKADA and MCINTYRE, 1977, p. 15, pl. 6, fig. 3.

Figure 7: Coccosphere subspherical about $21 \mu\text{m}$ in the longest dimension with about 15 oval overlapping discoliths, slightly convex distally. (Coccoliths of *Emiliania huxleyi* attached).

Figure 8: Discoliths oval $7.6 \times 5 \mu\text{m}$ and $0.4 \mu\text{m}$ thick. Pitted structure of the distal surface and slight thickening of the edge to form a low rim is seen. The proximal surface apparently smooth and flat.

Figure 9: Lateral view of the discolith showing edge with fine spiral elements. Distal surface with fine pore structure in central area and smooth outside band lacking both pits and pores.

South Tow 13(2) 0/20 m. Not seen in samples analyzed so that distribution is uncertain, but probably rare.

Genus PONTOSPHAERA Lohmann, 1902

Pontosphaera cf. *variabilis* Halldal and Markali
Plate 3, figures 1–3

cf. *Pontosphaera variabilis* HALLDAL and MARKALI, 1955, p. 12, pl. 12, figs. 1–3.

cf. *Discolithus ribosus* KAMPTNER, 1967, p. 136, pl. 5, figs. 30–31; pl. 7, fig. 52.

cf. *Pontosphaera ribosa* (Kamptner) MARTINI and MÜLLER, 1972, p. 68, pl. 1, fig. 4.

cf. *Syracosphaeridae* DEFLANDRE and FERT, 1954, pl. 4, fig. 2.

Figure 1: Collapsed coccosphere with distal and proximal views of oval discoliths, $3.5 \times 2.5 \mu\text{m}$ (slightly larger than in Halldal and Markali, 1955). No obvious dimorphism.

Figure 2: Distal and lateral views of the discoliths showing about 32 lamellae radiating from a central thickened area which is not as distinct as suggested by Halldal and Markali, hence the uncertainty of this identification. The walls are thin and low ($0.5 \mu\text{m}$) slightly flaring with a serrated edge. Deep indentation at junction of wall and base, but no midwall structure.

Figure 3: Proximal view showing flat base with clearly defined central element from which lamellae radiate toward a smooth margin. Similar to illustration of *P. ribosa* in Martini and Müller, 1972 (= *Discolithus ribosus* Kamptner) and of unnamed form in Deflandre and Fert, 1954.

Tasaday 11(4) 100/120 m. Not distinguished in light microscope analysis.

Pontosphaera sp. T
Plate 3, figures 4–6

Figure 4: Part of a coccosphere showing simple discoliths $4 \times 3 \mu\text{m}$ similar to those in plate 3, figures 1–3. No obvious dimorphism.

Figure 5: Lateral view of discolith showing indentation between the wall and the base. High ($2 \mu\text{m}$), thin, slightly flaring walls with jagged edge and vertical creases but no midwall structure.

Figure 6: Proximal view showing flat base of discolith with 30–32 lamellae radiating from central barlike structure and smooth margin.

Tasaday 11(4) 100/120 m. Dramamine II(1) 140/160 m. Equivalent to *Syracosphaera* sp. T in light microscope counts. This was found mostly in 100/120 or

140/160 m samples from all cruises and is readily distinguished as a large (25–29 × 19–25 μm) heart-shaped cell with large cup-shaped coccoliths giving the coccosphere a scalloped appearance. The apical view is circular.

Genus SCYPHOSPHAERA Lohmann, 1902

Scyphosphaera apsteinii Lohmann f. *apsteinii* Gaarder
Plate 3, figure 7

Scyphosphaera apsteinii LOHMANN, 1902, p. 132, pl. 4, figs. 26–30.—BORSETTI and CATI, 1972, p. 399, pl. 41, fig. 3a–b; pl. 42, figs. 1–2.

Scyphosphaera apsteinii f. *apsteinii* GAARDER, 1970, pp. 119–121, figs. 4e–f, 6a, b.

Coccosphere showing dimorphism. The central body about 18 μm diameter covered by approximately 18 thin elliptical coccoliths 7 × 5.5 μm , the distal surface with a smooth border surrounding a central area covered with small pores and the edge slightly thickened to form a low rim, which flares out distally. Eight large vase-shaped lopadoliths arranged around the equator of the cell, 10 μm long × 13 μm at the widest point distally. Thick walls with weblike longitudinal and horizontal markings. The distal view shows a large pore, seen in the broken coccolith at the bottom of the picture to be part of a central cavity. Total cell diameter about 37 μm .

Tasaday 11(4) 40/60/80 m. Also in T 11(4) 140/160 and 180/200 m. Rarely seen in light microscope analysis.

Family RHABDOSPHAERACEAE Lemmermann in Brandt and Apstein, 1908

Genus ACANTHOICA Lohmann, 1903

Acanthoica acanthifera Lohmann
Plate 3, figures 8–9

Acanthoica acanthifera LOHMANN, 1913a, pp. 358–359, text-fig. 15b–c.—HALLDAL and MARKALI, 1955, p. 16, pl. 19, figs. 1–3.—BORSETTI and CATI, 1972, pp. 397–398, pl. 39, fig. 1a–b.

Figure 8: Collapsed coccosphere showing oval (overlapping?) cyrtoliths, 1.8 × 1.2 μm . Styliform cyrtoliths seen, the upper one showing a collar at the base and a pore on the proximal surface.

Figure 9: Proximal, distal and lateral views of oval, conical cyrtoliths, which are 2.1 × 1.9 μm in this specimen. The proximal side is smooth with a central pore which does not pierce the distal surface. The distal view shows about 30 radiating elements, not overlapping and surrounded by a smooth, slightly thickened margin. Central knob with a blunt end.

Tasaday 11(1) 100/120 m, 11(4) 140/160 m. Seen in all cruises mostly at 100/120 m and above, never at the lowest level.

Genus ANTHOSPHAERA Kamptner, 1936

Anthosphaera oryza (Schlauder) Gaarder
Plate 3, figure 10; plate 4, figure 1

Aligrosphaera oryza SCHLAUDER, 1945, p. 23, pl. 5, fig. 19. *Anthosphaera oryza* (Schlauder).—GAARDER in Gaarder and Hasle, 1971, pp. 523, 529, text-fig. 4a–e.

Anthosphaera quadricornu (Schiller).—BORSETTI and CATI, 1972, p. 403, pl. 48, fig. 1.

Anthosphaera robusta (Lohmann).—BORSETTI and CATI, 1972, p. 403, pl. 48, fig. 2.

Figure 10: Coccosphere (diameter 13 μm) showing a row of "equatorial" coccoliths projecting at right angles to the others, numerous body coccoliths, and three stomatal coccoliths. The equatorial and body coccoliths consist of an oval basal plate, about 2.2 μm in the longest dimension, and normal to this, an appendix about 2.4 μm high with a clear apical invagination parallel to the long axis of its distal surface. There is also a small central pore. The stomatal coccoliths lack these features and are larger.

Plate 4, figure 1: Stomatal coccoliths (right) showing basal plate and flat oval appendix 4.6 μm long × 2.7 μm at the broadest point.

Tasaday 11(1) 140/160 m. South Tow 13(1) 100/120 m. Also at T 11(4) 140/160 m. Occurs in all cruises at all stations mostly below 100/120 m. Low numbers in upper levels in ST 13. Called *Anthosphaera quadricornu* Schiller or cf. *Calyptrorpha depressa* Schiller in the data record.

Genus RHABDOSPHAERA Haeckel, 1894

Rhabdosphaera longistylis Schiller
Plate 4, figures 2–3

Rhabdosphaera longistylis SCHILLER, 1925, p. 40, pl. 4, fig. 40.—NORRIS, 1971, p. 902, text-fig. 4.—BORSETTI and CATI, 1972, p. 409, pl. 55, fig. 1.—OKADA and MCINTYRE, 1977, p. 17, pl. 5, fig. 6.

Figure 2: Dimorphic coccosphere with large number of spines projecting from some cyrtoliths. Body approximately 6 μm , spines about 12 μm .

Figure 3: Simple cyrtoliths oval 1.6 × 1.2 μm with smooth marginal rim and slightly convex central area from which (overlapping?) elements radiate on the distal side. The proximal side at upper right with no central pore.

Helatoform cyrtoliths smaller and more nearly circular, about 1.2 μm diameter. Proximal side with a central pore. On lower left, lateral view showing swollen area at the base of the spine.

Tasaday 11(1) 0/20 m. (4) 100/120 m. Mostly in upper levels but probably difficult to distinguish on the light microscope due to breakage of the spines. In ST 13, D II and CL VII only.

Genus UMBELLOSPHAERA Paasche, 1955

Umbellosphaera irregularis Paasche

Plate 4, figures 4–5

Umbellosphaera irregularis PAASCHE in Markali and Paasche, 1955, p. 97, pls. 3–6.—MCINTYRE and BÉ, 1967, p. 567, pl. 2, figs. a–c.—OKADA, 1970, pl. 1, fig. 8.

Figure 4: Collapsed coccosphere showing macro- and micrococcoliths in distal and proximal views. Macrococcoliths have a flaring, funnel-shaped structure projecting distally from a basal disc. The disc is subcircular about 1.6–2.0 μm diameter with a thickened margin; the funnel is delicate and smooth with about 18 radial elements, approximately 5.4 μm at the widest part and with a slightly uneven edge. The micrococcoliths are elliptical with a proximal disc 1.4 \times 1.0 μm , similar to that of the macrococcoliths, and distally with a shallow funnel with about 20 radiating elements, and a slightly serrated rim, 3.5 \times 2.4 μm . Larger macrococcoliths in proximal view at the top.

Figure 5: Larger macrococcoliths 7–8 μm diameter at the rim of the funnel, showing the proximal disc. Micrococcolith, about 4 μm in this specimen, just visible.

Tasaday 11(4) 40/60/80, 100/120 m. Also in T 11(4) 0/20 m. Present in all cruises at almost all stations at 0/20 and 40/60/80 m, less frequently at 100/120 m and rarely below.

Umbellosphaera tenuis (Kamptner) Paasche

Plate 4, figures 6–7

Coccolithus tenuis KAMPTNER, 1937, pp. 311–312, pl. 17, figs. 41–42.

Umbellosphaera tenuis (Kamptner).—PAASCHE in Markali and Paasche, 1955, p. 96, pls. 1–2.—MCINTYRE and BÉ, 1967, pp. 566–567, pl. 3.—NORRIS, 1971, pp. 900–902, text-fig. 3.—BORSETTI and CATI, 1972, pp. 406–407, pl. 53, fig. 3; pl. 54, figs. 1–2.

Figure 6: Coccosphere subspherical 9.2 μm diameter. Macrococcoliths almost circular, longest axis 5.9 μm . Micrococcolith just visible at right center.

Figure 7: Collapsed coccosphere showing macrococcoliths, 7.2 μm diameter, with basal disc, 1.7 μm diameter, similar to that of *U. irregularis*. Distal part of the coccolith umbrella-shaped, convex distally to fit the shape of the cell and so produce a more compact appearance than does *U. irregularis* in the light microscope. Coccoliths have coarse irregular radial furrows on the distal surface but the lower surface is similar to that of *U. irregularis*. Micrococcoliths have a flatter structure as seen in lateral view and a basal disc, 1.5 μm diameter, similar to that of the macrococcoliths. The distal surface, 3.8 μm diameter, has coarse furrows as above. All coccoliths have a large central pore which does not penetrate the basal disc.

Tasaday 11(5) 0/20, 40/60/80 m. Present at almost all stations in all cruises from 0 to 120 m, and less frequently at lower depths; with a more extended vertical distribution than *U. irregularis*.

Family SYRACOSPHAERACEAE Lemmermann, 1908

Genus ALISPHAERA Heimdal, 1973

Alisphaera unicornis Okada and McIntyre

Plate 4, figures 8–11

Alisphaera unicornis OKADA and MCINTYRE, 1977, p. 18, pl. 6, figs. 7–8.

Figure 8: Collapsed coccosphere (12 μm diameter) showing large number of coccoliths. Regular arrangement not apparent in this preparation.

Figure 9: Caneolith-like coccoliths in distal and lateral views showing high, straight-walled tube with elliptical cross-section 2.2 \times 0.9 μm at the proximal end and distally having a lip about 0.1 μm wide.

Walls with diagonal markings on the outside; inside about 16 nodules regularly arranged around the rim of the coccolith and continuing to the basal disc as a series of ridges lining the coccolith. On one side, parallel to the long axis, an asymmetrical triangular spine projects beyond the distal margin. The spine is 0.8 μm long and its base is equivalent to 2 rim nodules—about 0.4 μm .

PLATE 1
Scale bar = 3 μm

- 1–3 *Crenolithus sessilis* (Lohmann) Okada and McIntyre
- 4 *Gephyrocapsa crassipons* Okada and McIntyre
- 5 *Gephyrocapsa ericsonii* McIntyre and Bé
- 6 *Gephyrocapsa oceanica* Kamptner

- 7 *Gephyrocapsa protohuxleyi* McIntyre
- 8 *Gephyrocapsa* cf. *protohuxleyi* McIntyre
- 9 *Oolithotus fragilis* (Lohmann) Okada and McIntyre
- 10 *Oolithotus fragilis* subsp. *cavum* Okada and McIntyre

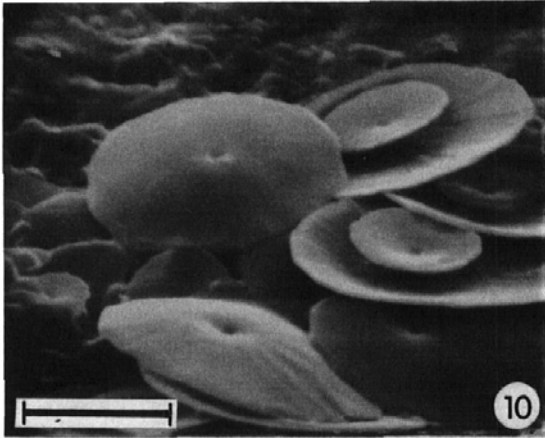
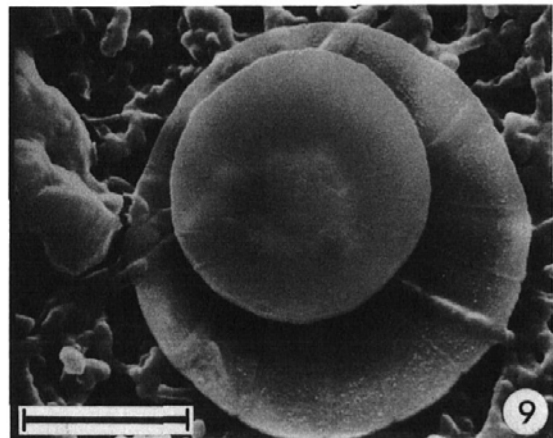
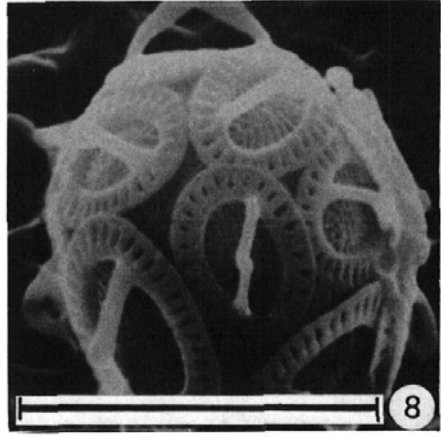
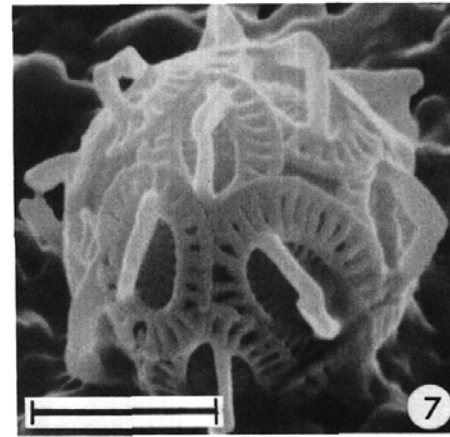
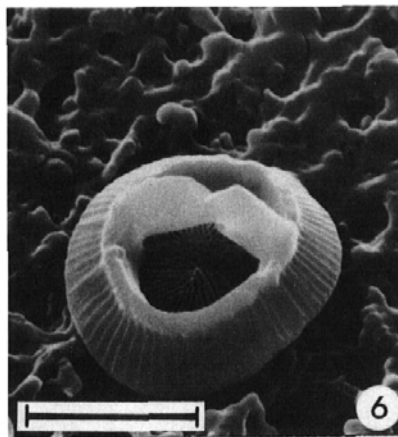
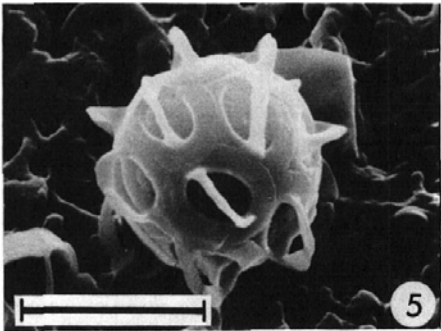
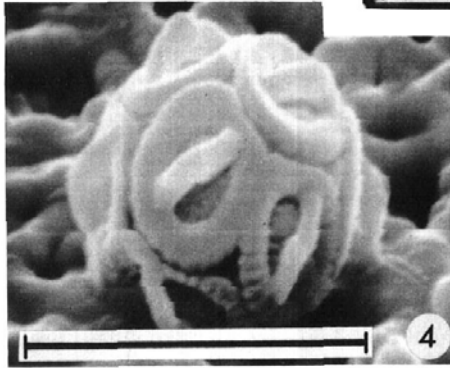
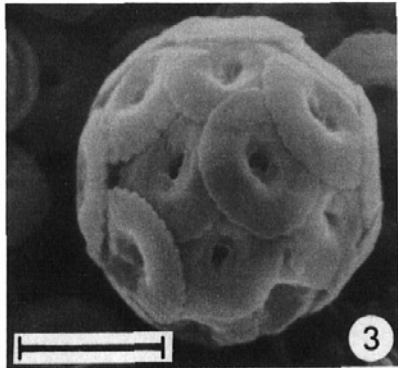
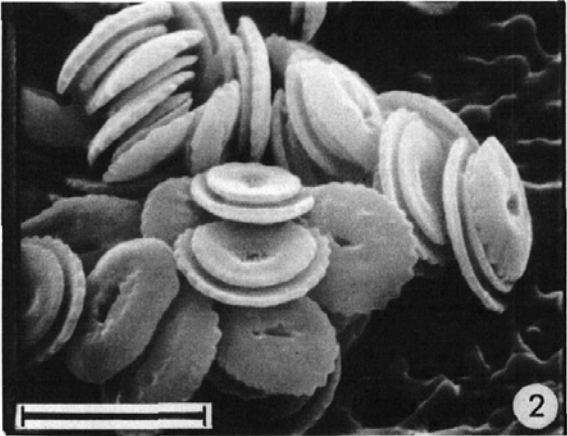
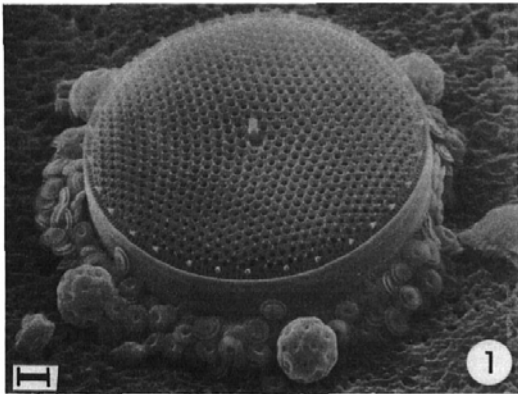


Figure 10: Lateral and proximal views of coccoliths showing flat, narrow-elliptical basal disc. Slit noted by Okada and McIntyre (1977) not visible.

Figure 11: Detail of coccoliths in lateral, proximal and inside views.

Tasaday 11(4) 100/120 m. Not recognized in light microscope analysis.

Genus *CORONOSPHAERA* Gaarder, 1977

Coronosphaera maxima (Halldal and Markali) Gaarder
Plate 5, figures 1–3

Syracosphaera maxima HALLDAL and MARKALI, 1955, p. 11, pls. 8–9.—BORSETTI and CATI, 1976, p. 216, pl. 14, figs. 18–20.—OKADA and MCINTYRE, 1977, p. 23, pl. 10, fig. 7.
Coronosphaera maxima (Halldal and Markali) GAARDER in Gaarder and Heimdal, 1977, p. 62, pl. 5, figs. 33–34.

Figure 1: Collapsed coccosphere showing large number of body coccoliths and 7 stomatal coccoliths at the bottom of the picture. (Complete coccospheres from 34 to 53 μ m diameter in sample analysis and usually spherical.)

Figures 2 and 3: Body coccoliths elliptical about $5 \times 3.3 \mu$ m. Wall is fairly thin, 1μ m high, with slight distal widening, and consists of about 40 lamellae arranged diagonally and forming a serrated distal rim. No midwall rim present. Central area has thickening in the form of a figure 8 and a large number of fine radiating lamellae. Stomatal coccoliths are narrower and smaller ($4 \times 2 \mu$ m) with a pointed central rod (2.7μ m long) which is bent in some cases.

Dramamine II(1) 140/160 m. In analysis found only rarely in D II 100/120 and 140/160 m and in T 11 140/160 m.

Genus *HALOPAPPUS* Lohmann, 1912

Halopappus adriaticus Schiller
Plate 5, figures 4–6

Halopappus adriaticus SCHILLER, 1914, p. 10, pl. 2, fig. 29; 1930, pp. 231–232, text-fig. 115a, b.—GAARDER and HASLE, 1971, p. 533, text-fig. 5c-d.
Michaelsarsia sp.? BORSETTI and CATI, 1976, pp. 216–218, pl. 15, figs. 1–8.

Figure 4: Pear-shaped coccosphere about 12μ m long and 9μ m at widest part. Body coccoliths in distal and lateral view, arranged in about six parallel rows around the cell with long axis parallel to that of the cell. Discoid, flat basal coccoliths and several long spine coccoliths with 2 of the 3 segments visible, each showing 2 elongate elements fused at the ends, about 6μ m long. See figure 6 for terminal tapering segment.

Figure 5: Detail of 4 types of coccolith. Body coccoliths are oval caneloliths, $2.2 \times 1.4 \mu$ m. Central area made up of 22–26 clearly defined radiating elements connected to an elongate, thickened ridge. Distal shield fairly narrow flaring out from the central area to form a sharp edge. Deep indentation at junction with basal plate seen in the lateral view. Small rhomboidal buccal coccoliths visible in center of the photograph, about 1.4μ m long \times 0.6μ m wide and having a central knob. Discoid basal coccoliths about 3μ m in diameter. Thin platelike structures with a central aperture and composed of thin, irregularly concentric, superimposed lamellae. Proximal segment of one spine coccolith showing 2 elongate elements.

Figure 6: Spherical coccosphere approximately 14.5μ m diameter. Body coccoliths in 6 rows with long axis normal to equator of cell. Coccoliths similar to those above; rhomboid coccoliths not visible, complete spine coccoliths clearly seen.

Tasaday 11(1) 100/120 m 140/160 m, (4) 100/120 m, (5) 0/20 m.

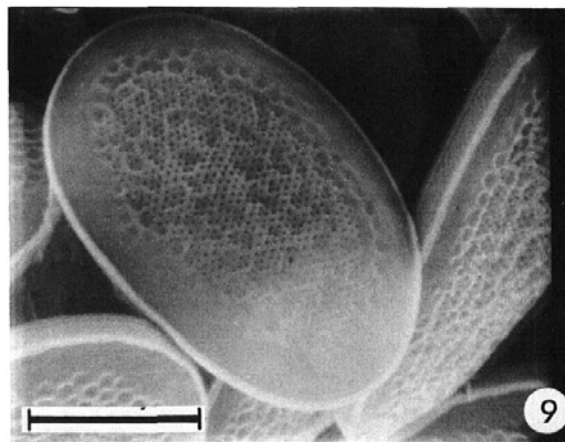
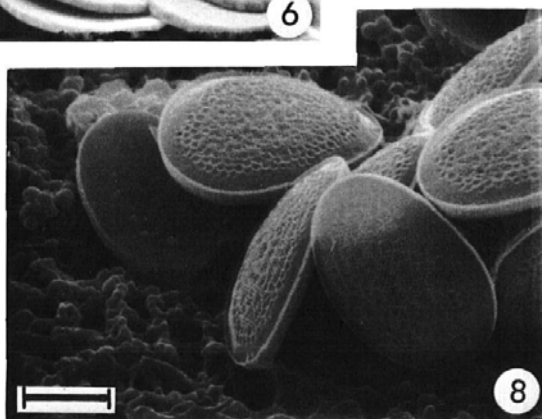
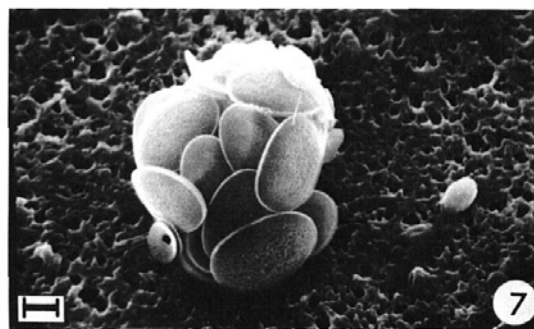
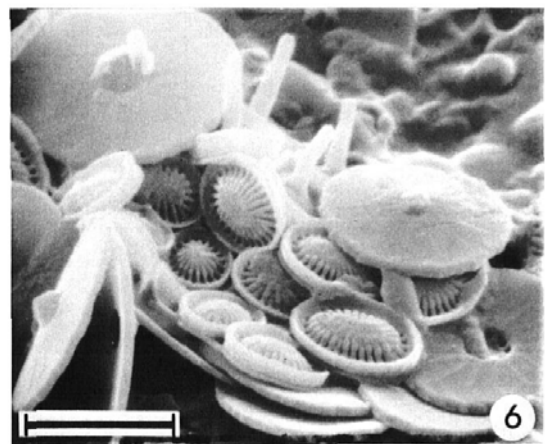
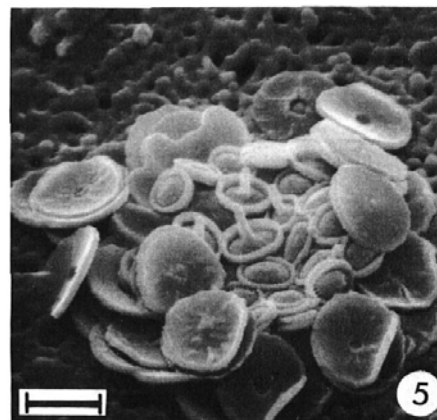
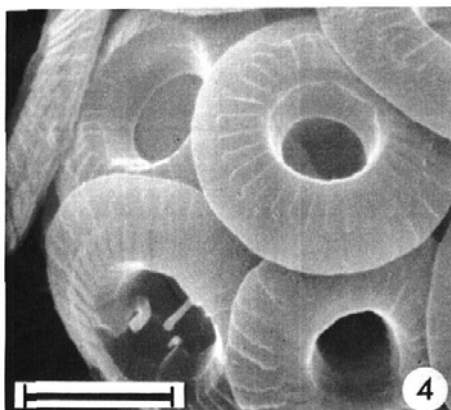
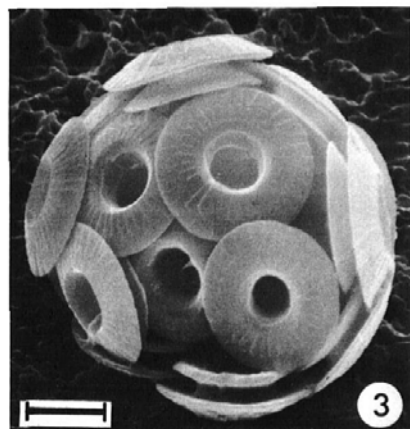
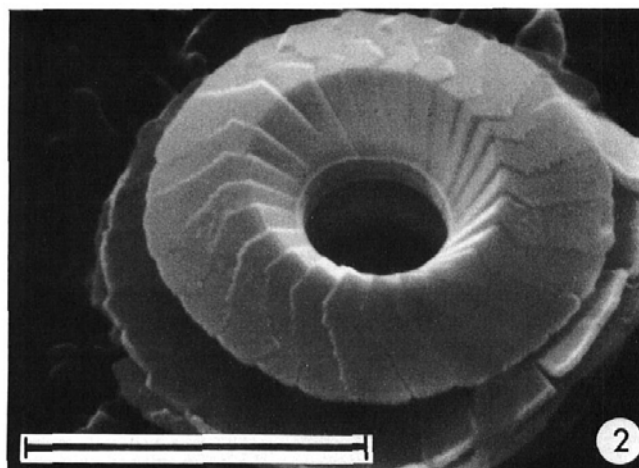
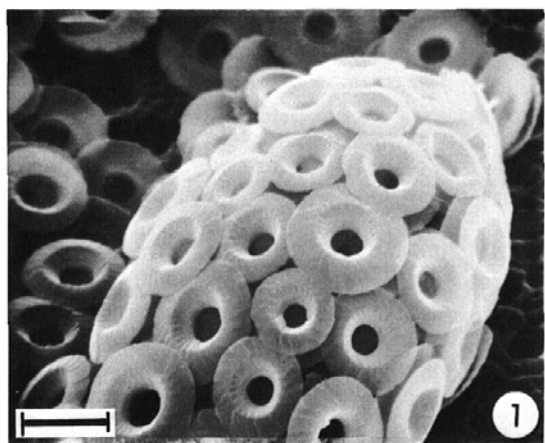
In the analysis the spherical form was called *Michaelsarsia splendens/elegans* and the pear-shaped form, *Halopappus* sp. They had a similar distribution occurring in all cruises at all depths except 180/200 m and predominantly at the 100/120 m level. More important in the upper levels in ST 13.

Genus *SYRACOSPHAERA* Lohmann, 1902

Syracosphaera histrica Kamptner
Plate 5, figures 7–8

PLATE 2
Scale bar = 3μ m

- | | |
|---|---|
| 1–2 <i>Umbilicosphaera sibogae</i> (Weber-van Bosse)
Gaarder | Gaarder var. <i>foliosa</i> (Kamptner) Okada and McIntyre |
| 3–4 <i>Umbilicosphaera sibogae</i> (Weber-van Bosse) | 5–6 <i>Deutschlandia anthos</i> Lohmann |
| | 7–9 <i>Discolithina japonica</i> Takayama |



Syracosphaera histrica KAMPTNER, 1941, pp. 84, 104, pl. 6, figs. 65–68.—GAARDER and HEIMDAL, 1977, pp. 55–56, pl. 2, figs. 9–15.

Syracosphaera nodosa (Kamptner).—OKADA and HONJO, 1970, p. 21, pl. 1, figs. 1–2.

Syracosphaera aff. *pirus* Halldal and Markali.—BORSETTI and CATI, 1972, p. 400, pl. 44, fig. 3a–b; p. 401, pl. 47, fig. 1.

Figure 7: Collapsed ccccosphere showing dithecatism, outer and inner surfaces of both endothelial and exothelial layers, lateral view of endothelial layer and stomatal coccoliths with spines. Exothelial coccoliths ovoid $3.0 \times 2.0 \mu\text{m}$ slightly arched with about 25 lamellae meeting at the center line. Narrow rim probably smooth and without beaded structure on the wall. Endothelial caneoliths ($3.3 \times 2 \mu\text{m}$) with slightly convex floor consisting of about 30 lamellae meeting in the center to form a knob of varying height. In the stomatal coccoliths this becomes a rod with a toothed end. Lateral view shows beaded structure of the wall.

Figure 8: Endothelial caneoliths showing beaded wall and toothed stomatal rods.

Tasaday 11(5) 40/60/80 m, 100/120 m. Not distinguished in light microscope counts. Probably confused with *Syracosphaera pirus/pulchroides*, which occurred mainly in and above the 100/120-m level on all cruises.

Syracosphaera pirus Halldal and Markali

Plate 5, figure 9

Syracosphaera pirus HALLDAL and MARKALI, 1955, pp. 11–12, pl. 10.—GAARDER and HEIMDAL, 1977, pp. 56–58, pl. 3, figs. 16–20.

Endothelial caneoliths showing twisted structure. Ovoid, $2.5 \times 1.1 \mu\text{m}$ with obvious mid-wall rim which is complete in this species. The distal rim is fairly broad ($0.2 \mu\text{m}$) and flat, forming an overhanging ledge seen in lateral view. The floor of the caneolith consists of about 29 lamellae meeting to form a short central spine, which is not forked. On the proximal side there is a small pore beneath the spine. Partially obscured exothelial coccolith at the center. (*Umbilicosphaera tenuis* macrococcolith at left.)

Tasaday 11(4) 100/120 m. Not distinguished in light microscope analysis, probably included in *Syracosphaera pirus/pulchroides* which occurred mainly in and above 100/120-m level on all cruises.

Syracosphaera pulchra Lohmann

Plate 6, figures 1–4

Syracosphaera pulchra LOHMANN, 1902, p. 134, pl. 4, figs. 33, 36–37.—KAMPTNER, 1941, pp. 85–86, pl. 7, figs. 77–78; pl. 8, figs. 79–84.—HALLDAL and MARKALI, 1955, p. 12, pl. 11.—BORSETTI and CATI, 1972, p. 402, pl. 46, fig. 2a–b.—MÜLLER, 1972, p. 92, pl. 5, figs. 1–4.—GAARDER and HEIMDAL, 1977, p. 55, pl. 1, figs. 1–8.

Figures 1 and 2: Exothelial coccolith, proximal side (fig. 1) and distal side (fig. 2). Coccoliths oval $4.5 \times 3.5 \mu\text{m}$. Distal view shows 3 rings of lamellae forming a high dome-shaped coccolith which is invaginated at the top to produce the rod seen in figure 1. The rod is flattened laterally and its tip is forked. The junctions of the ends of the lamellae are thickened in some cases. The margin of the coccolith is separated from the dome by a deep trough seen in figure 2.

Figures 3 and 4: Endothelial coccoliths in distal view, one from stomatal region about $5.4 \times 3 \mu\text{m}$. Lamellar structure of caneolith floor and wall visible, with slight thickening along central line. Complete mid-wall rim present. Distal edge has a wide rim with a crimped margin. Figure 4 shows lamellar structure of stomatal rod and the forked tip.

Tasaday 1(1) 40/60/80 m. Tasaday 11(1) 0/20, 100/120; (4) 0/20 m. Found on all cruises at the 40/60/80 and 100/120-m levels and rarely below the 140/160-m level. Common at 0/20 m during winter cruises (ST 13, T 11) only.

Family THORACOSPHAERACEAE Schiller, 1930

Genus THORACOSPHAERA Kamptner, 1927

Thoracosphaera heimii (Lohmann) Kamptner

Plate 6, figures 5–6

Syracosphaera heimi LOHMANN, 1920, p. 117, fig. 29.

Thoracosphaera pelagica (Lohmann) KAMPTNER, 1927, p. 180, fig. 6.

PLATE 3

Scale bar = $3 \mu\text{m}$

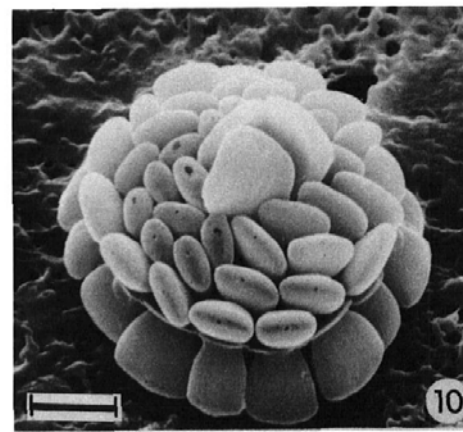
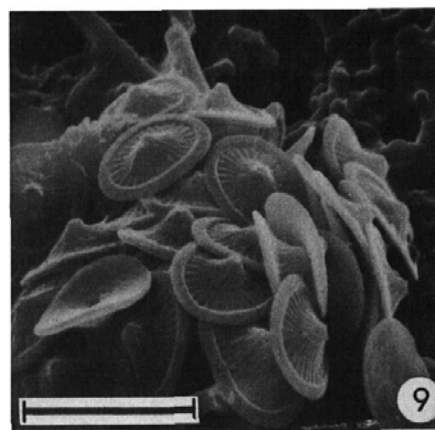
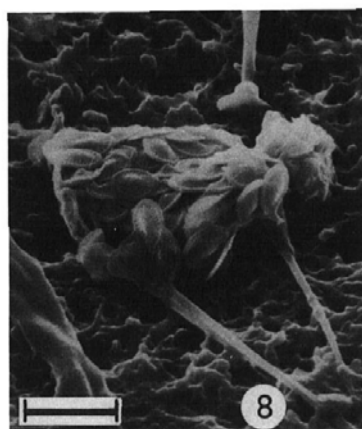
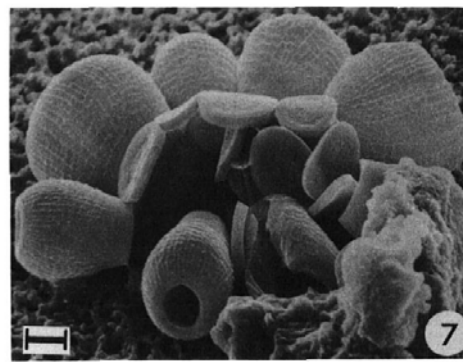
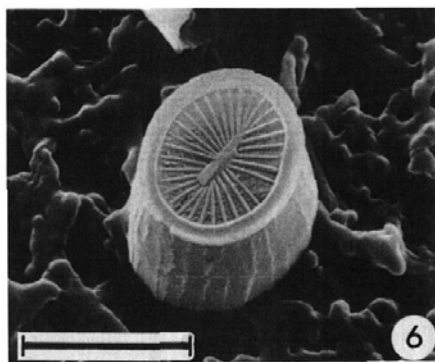
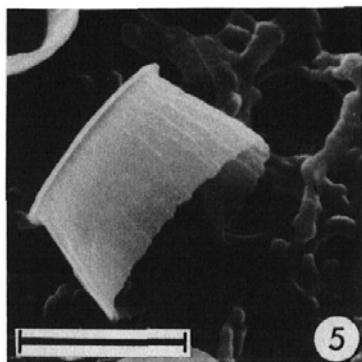
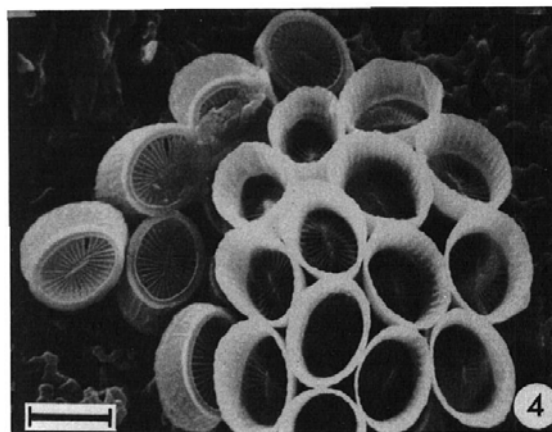
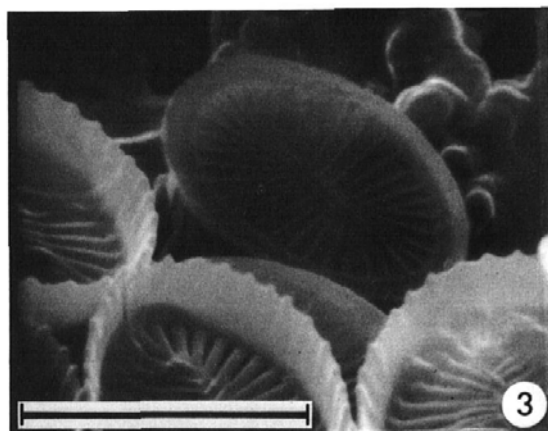
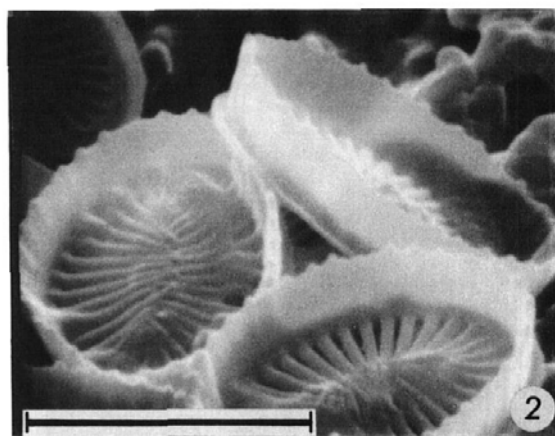
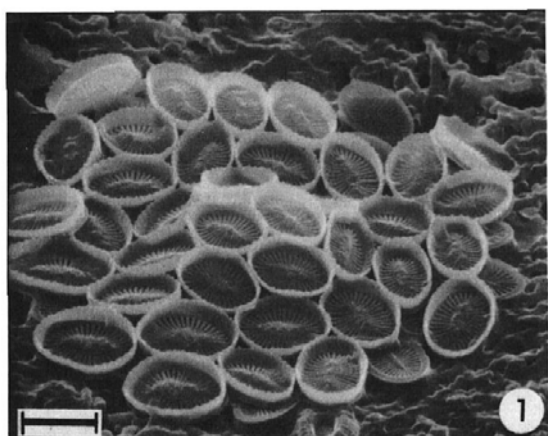
1–3 *Pontosphaera* cf. *variabilis*

4–6 *Pontosphaera* sp. T

7 *Scyphosphaera apsteinii* Lohmann f. *apsteinii*

8–9 *Acanthoica acanthifera* Lohmann

10 *Anthosphaera oryza* (Schlauder) Gaarder



Thoracosphaera heimi (Lohmann) KAMPTNER, 1941, p. 118; 1967, pp. 154–157, pl. 11, figs. 78–79, text-fig. 24.
Thoracosphaera heimii (Lohmann) Kamptner.—BORSETTI and CATI, 1972, p. 410, pl. 42, fig. 1a-b.

Figure 5: Spherical cell, 12 μm diameter, with a small stomatal opening. Coccoliths contiguous on all sides. The surface has a rugose appearance with small pores at intervals.

Figure 6: Cell 12.6 μm diameter showing individual donut-shaped coccoliths 1.0 μm in diameter with 0.3 μm pores. Indications of a very narrow space between adjacent coccoliths. May be more closely related to *T. albatrosiana* Kamptner (1967).

Tasaday 11(4) 0/20 m. Widespread species found at all stations at all depths on all cruises.

Family CALYPTROSPHAERACEAE Boudreaux and Hay, 1969
 Genus CALYPTROSPHAERA Lohmann, 1902

Calyptrorphaera catillifera (Kamptner) Gaarder
 Plate 6, figures 7–8

Syracosphaera catillifera KAMPTNER, 1937, p. 301, pl. 14, figs. 10–11.

Syracolithus catilliferus (Kamptner).—BORSETTI and CATI, 1972, pp. 398–399, pl. 40, fig. 2b.

Calyptrorphaera catillifera (Kamptner).—GAARDER, 1962, pp. 36–38, pl. 1, fig. a-b.—MÜLLER, 1972, p. 93, pl. 1, figs. 17–18.—BORSETTI and CATI, 1976, p. 210, pl. 12, fig. 2.—OKADA and MCINTYRE, 1977, p. 28, pl. 11, figs. 3–5.

Figures 7 and 8: Collapsed coccosphere showing calyptroliths in proximal, distal and lateral views, 3.5 \times 2.5 μm . The distal surface of the coccolith is flat and the proximal is shaped to fit the cell; walls slightly angled. The central spines on the distal surface of all coccoliths are either short rods or triangular projections, longer than those shown in Borsetti and Cati (1972). Holococcolith crystal structure evident.

Tasaday 11(5) 40/60/80 m. Not identified in light microscope analysis.

Calyptrorphaera oblonga Lohmann
 Plate 6, figures 9–10; plate 7, figure 1

Calyptrorphaera oblonga LOHMANN, 1902, p. 135, pl. 5, figs. 43–46.—HALLDAL and MARKALI, 1955, p. 8, pl. 1, figs. 1–3.—GAARDER and HASLE, 1971, fig. 5a, b.—OKADA and MCINTYRE, 1977, p. 28, pl. 13, fig. 10.

Figure 9: Complete cell 10 \times 8.6 μm with about 40–50 similar calyptroliths (2.2 \times 1.8 μm) having convex distal surfaces. Threadlike connections between coccoliths visible. An unusually small cell; more commonly in the 20 μm range or even larger. (Coccolith of *E. huxleyi* attached.)

Figure 10 and plate 7, figure 1: Proximal, distal and lateral views of slightly angular, oval coccoliths, showing similar crystalline structure of walls and dome and thin basal plate (broken) attached to a clearly defined proximal rim. Dimensions in figure 10, 2.4 \times 1.8 μm and 1.5 μm high; specimen in plate 7, figure 1, 1.9 \times 1.5 \times 1.3 μm high.

Tasaday 11(1) 0/20 m; (4) 0/20 m; (5) 0/20 m. Occurred at all stations on all cruises at 0/20 m and almost all at 40/60/80 m. Present at 100/120 m at a few stations on all cruises except Climax VII and never at 180/200 m.

Calyptrorphaera pirus Kamptner
 Plate 7, figures 2–3

Calyptrorphaera pirus KAMPTNER, 1937, p. 304, pl. 16, figs. 21–23.—KAMPTNER, 1941, pp. 78, 98, pl. 2, figs. 17–19.—THRONDSSEN, 1972, pp. 53–54, text-figs. 2–9.—BORSETTI and CATI, 1976, p. 211, pl. 13, figs. 1–3.—OKADA and MCINTYRE, 1977, pl. 12, fig. 2.

Figures 2 and 3: Body calyptroliths in proximal, lateral and distal view. Coccoliths oval, 2.3 \times 2.1 \times 2 μm high. Coccolith does not show thin areas in dome-shaped cap as in Throndsen (1972) but a ring of about 10 perforations at the junction of the cap and the basal collar is clearly seen in figure 2. The collar is deep (1.2 μm) and slopes outward distally. It consists of 3 bands, the proximal one connected to a smooth basal plate. In lateral view it obscures the row of perforations.

Tasaday 1(2) 40/60/80 m; T 11(4) 0/20 m. Not recognized in light microscope analysis.

***Calyptrorphaera* sp.?**
 Plate 7, figure 4

cf. *Calyptrorphaera catillifera* (Kamptner) GAARDER, 1962, pp. 36–38, pl. 1, figs. a-b.—OKADA and MCINTYRE, 1977, p. 28, pl. 11, figs. 3–5.

cf. *Sphaerocalyptra gracillima* (Kamptner) Throndsen.—KLING, 1975, p. 6, pl. 3, figs. 9–10.

PLATE 4

Scale bar = 3 μm

- 1 *Anthosphaera oryza* (Schlauder) Gaarder
- 2–3 *Rhabdosphaera longistylis* Schiller
- 4–5 *Umbellosphaera irregularis* Paasche

- 6–7 *Umbellosphaera tenuis* (Kamptner) Paasche
- 8–11 *Alisphaera unicornis* Okada and McIntyre

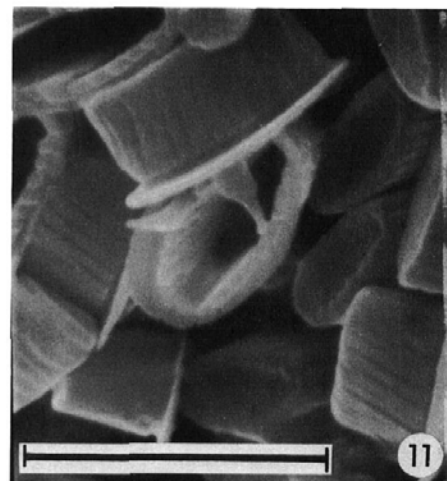
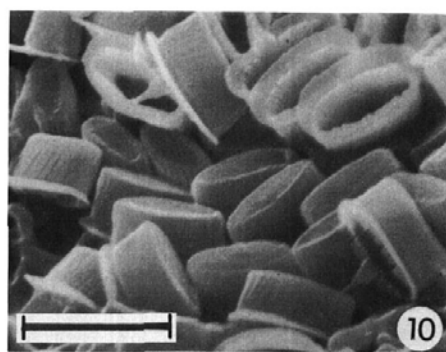
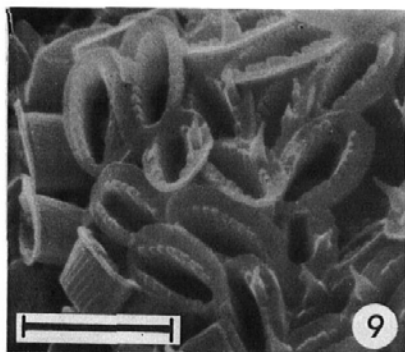
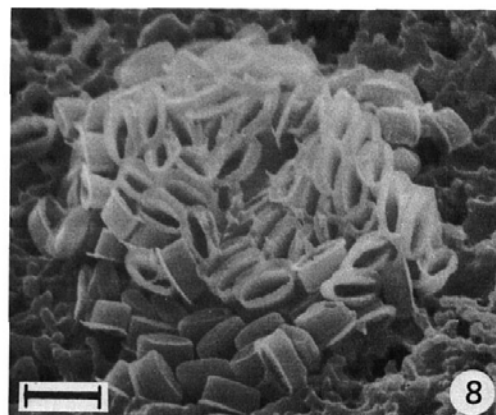
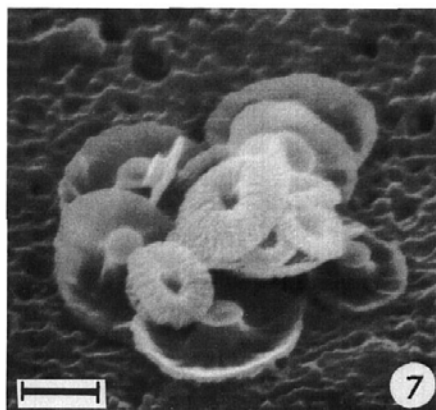
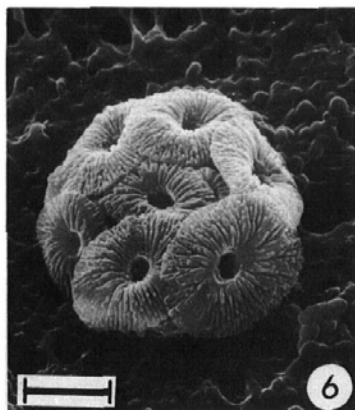
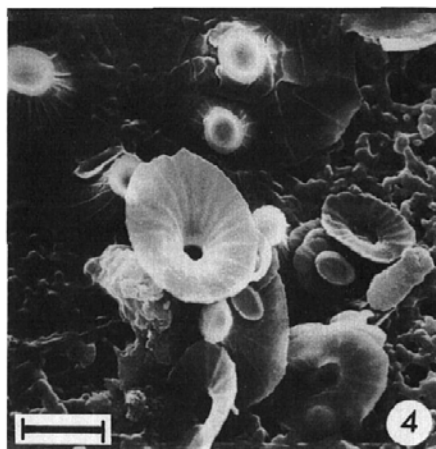
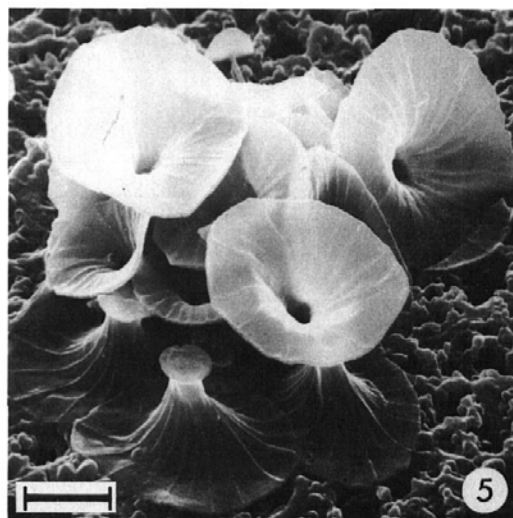
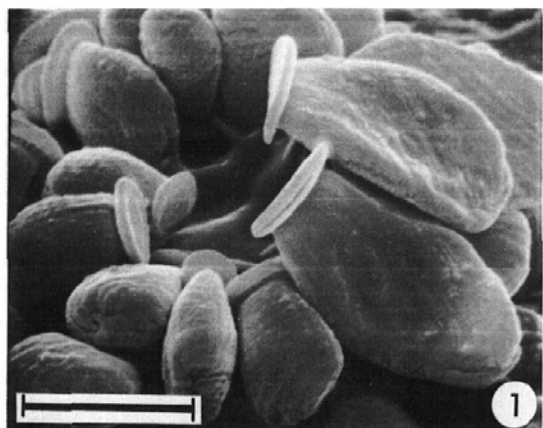


Figure 4: Coccosphere with no obvious dimorphism. Coccoliths oval $2.5 \times 1.8 \mu\text{m}$ and $0.6 \mu\text{m}$ high excluding the knob. Lateral view shows proximal curvature to match shape of cell and almost vertical wall. Distal view shows uneven thickening across the long axis of the coccolith with two peaks in some cases. This is similar to the illustration of *Calyptrorphaera catillifera* (Kamptner) Gaarder in Okada and McIntyre 1977, figure 5. Other illustrations of this species show a more pointed knob, hence the questionable identification. See also plate 6, figures 7–8 above.

Tasaday 11(1) 140/160 m. Not recognized in light microscope analysis.

Genus HELLADOSPHERA Kamptner, 1936

Helladosphaera aurisinae Kamptner
Plate 7, figures 5–6

Helladosphaera aurisinae KAMPTNER, 1941, p. 91, pl. 11, figs. 121–124.—GAARDER, 1962, pp. 44–46, pl. 8, figs. a–d; pl. 9, figs. a–c.—BORSETTI and CATI, 1972, p. 403, pl. 49, fig. 1a–b.—OKADA and MCINTYRE, 1977, p. 28, pl. 13, fig. 7.

Figures 5 and 6: Complete cell collapsed, approximately $10 \mu\text{m}$ wide. Dimorphism clearly seen; the stomatal coccoliths (zygolites) showing pointed, bladelike distal extensions ($2.7 \times 1.3 \mu\text{m}$, blade $1.5 \mu\text{m}$) made up of regular crystalline elements. Body coccoliths ($2.2 \times 1.3 \mu\text{m}$) in distal, proximal and lateral views. Proximally a smooth basal plate is present. Distally, there are 3 low bridges across the narrow dimension of the coccolith, the middle one thickened by an extra row of crystals. Lateral view of the wall ($0.7 \mu\text{m}$ high) shows some coccoliths with pores at intervals (fig. 5, upper right and center left).

Tasaday 11(4) 100/120 m. Not identified in light microscope analysis. Possibly confused with *H. cornifera* which usually occurred at and above the 100/120-m level.

Helladosphaera cornifera (Schiller) Kamptner
Plate 7, figures 7–9

Syracosphaera cornifera SCHILLER, 1913, pp. 602–603, pl. 2, fig. 13.

Helladosphaera cornifera (Schiller).—KAMPTNER, 1941, p. 91, pl. 11, figs. 121–124.—BORSETTI and CATI, 1972, p. 404, pl. 49, fig. 2a–b.—OKADA and MCINTYRE, 1977, p. 28, pl. 13, figs. 4–5.

Figure 7: Coccosphere showing dimorphism, $6 \mu\text{m}$ long \times $6 \mu\text{m}$ at widest region near mouth (coccolith of *Umbellosphaera tenuis* also present).

Figure 8: Collapsed coccosphere showing stomatal coccoliths (zygolites) and body coccoliths in lateral, distal and proximal views. Body coccoliths oval, $1.5 \times 0.9 \mu\text{m}$, consisting proximally of a narrow band $0.4 \mu\text{m}$ high and distally of a low, bridge about $0.7 \mu\text{m}$ high, across the narrow dimension. Stomatal coccoliths oval with concave curvature proximally, the rim angled outward from the basal plate to a widest dimension of $1.5 \mu\text{m}$. The distal bridge across the narrow dimension is higher than in the body coccoliths, about $1.2 \mu\text{m}$ from the base and is flattened along the axis of the bridge to form a pointed leaflike structure.

Figure 9: Detail of coccoliths, body (left) and stomatal (right) showing regular papillae-like protuberances formed by crystals, 4 rows of which form the proximal ring of the coccolith.

Tasaday 11(1) 0/20 m, 40/60/80 m. Difficult to recognize in routine analysis due to small size. Seen in 40/60/80-m samples, to a lesser degree in 0/20-m samples and never found at 180/200 m. Numbers much lower in the winter cruises (ST 13, T 11).

Genus ZYGOSPHERA Kamptner, 1936

Zygosphaera divergens Halldal and Markali
Plate 7, figure 10

Zygosphaera divergens HALLDAL and MARKALI, 1955, p. 8, pl. 2.—BORSETTI and CATI, 1976, p. 223, pl. 18, fig. 1.—OKADA and MCINTYRE, 1977, p. 36, pl. 12, fig. 1a–b. Unidentified holococcolithophore "a".—KLING, 1975, p. 10, pl. 3, figs. 7–8.

Figure 10: Collapsed coccosphere (about $5\text{--}7 \mu\text{m}$ diameter); stomatal coccoliths not visible. Calyptroliths are oval $1.2 \times 0.8 \mu\text{m}$ and $0.7 \mu\text{m}$ high. They consist of a marginal rim formed by a narrow band of crystals, from which a symmetric conical peak arises distally. Proximal side (lower left) apparently flat.

Cato 1(4) 40 m. Tasaday 1(2) 40/60/80 m. Not identified in light microscope analysis.

Zygosphaera hellenica Kamptner
Plate 8, figures 1–2

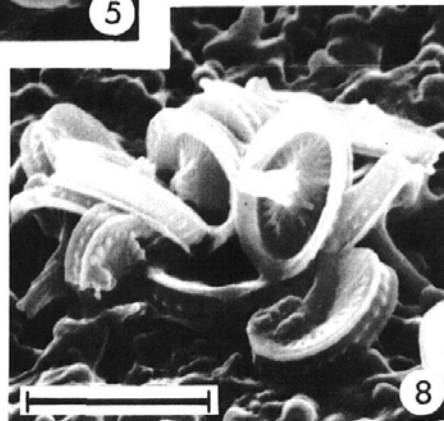
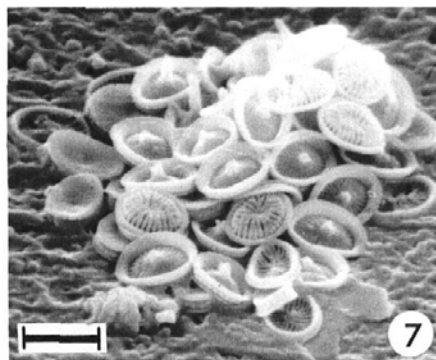
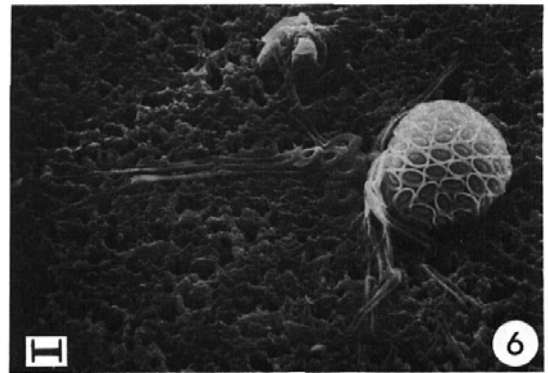
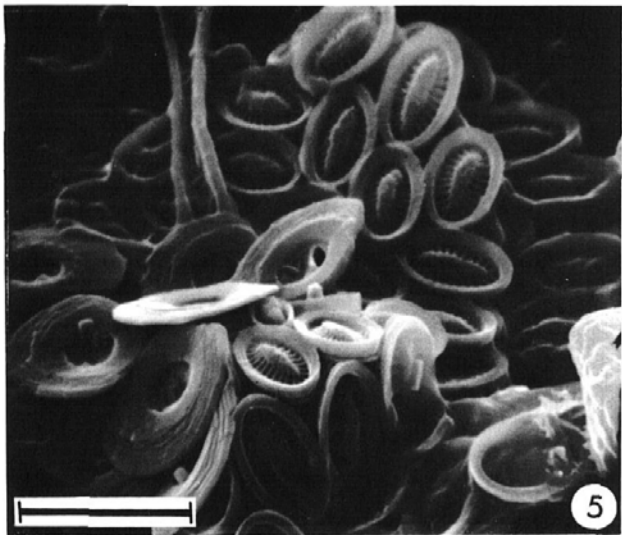
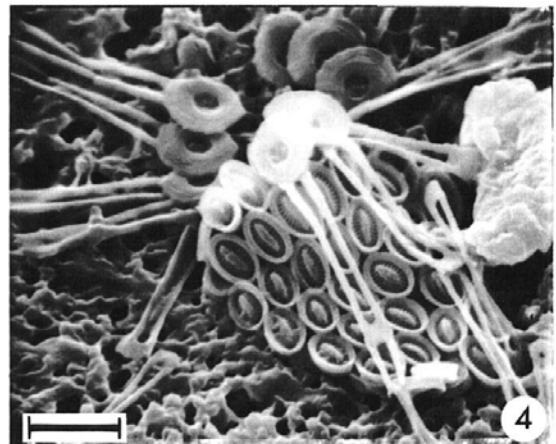
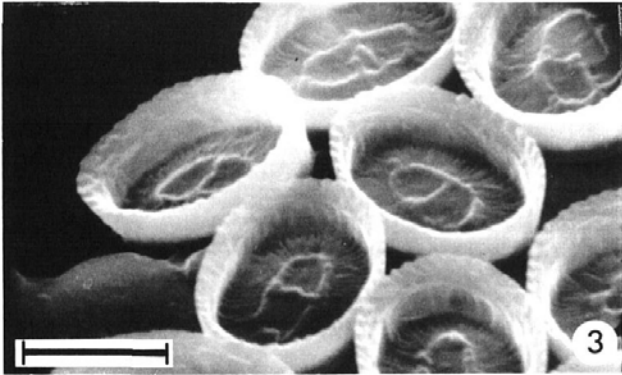
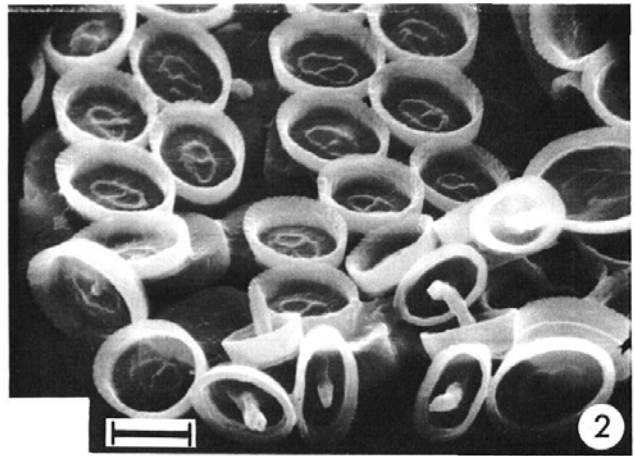
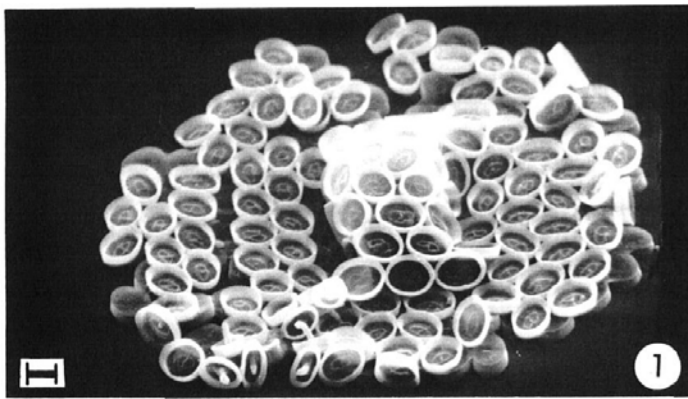
PLATE 5
Scale bar = $3 \mu\text{m}$

1–3 *Coronosphaera maxima* (Halldal and Markali)
Gaarder

4–6 *Halopappus adriaticus* Schiller

7–8 *Syracosphaera histrica* Kamptner

9 *Syracosphaera pirus* Halldal and Markali



Zygospaera hellenica KAMPTNER, 1937, p. 306, pl. 16, figs. 27–29.

Figure 1: Collapsed coccosphere about 10 μm diameter (smaller than in Kamptner). Stomatal coccoliths not visible (except possibly partially hidden conical structure at upper left.) Body coccoliths oval and flat, $2.2 \times 1.4 \mu\text{m}$. The base consists of concentric rows of crystals and is 0.5 μm thick. In lateral view (middle right) a small knob barely projects beyond the base. The knob is centrally placed, short and blunt.

Figure 2: A lateral view, in which a row of holes is visible near the proximal side. This is a possible generic character (Gaarder, personal communication).

Tasaday 1(2) 40/60/80 m. Not identified in light microscope analysis.

Family: Not determined

Genus FLORISPHAERA Okada and Honjo, 1973

Florisphaera profunda Okada and Honjo

Plate 8, figures 3–4

Florisphaera profunda var. A.—OKADA and HONJO, 1973, pp. 373–374, pl. 2, figs. 4–5.

Florisphaera profunda Okada and Honjo.—BORSETTI and CATI, 1976, p. 225, pl. 18, figs. 5–6.—OKADA and MCINTYRE, 1977, p. 36.

Coccolithophorid sp. 1.—THRONSEN, 1972, p. 59, text-figs. 29–32.

Figures 3 and 4: Coccosphere (5.7 μm diameter) from bottom showing thin overlapping flat coccoliths. The sides of the quadrangular coccoliths slope slightly inward toward base and are about 2.1 μm long; the ends are roughly parallel, about 1.2 μm wide. The lower edge is angled at the corners, one side having a small protuberance. The upper edge has 2 blunt projections giving it a wavy appearance. The coccolith is thicker at the basal end (0.2 μm).

Tasaday 11(1) 140/160 m. South Tow 13(1) 100/120 m. In analysis probably confused with *Deutschlandia* sp. due to small size, but most common at and below 100/120 m.

Florisphaera profunda Okada and Honjo var. *elongata* Okada and McIntyre
Plate 8, figure 5

Florisphaera profunda var. B.—OKADA and HONJO, 1973, pp. 373–374, pl. 1, fig. 6; pl. 2, fig. 6.

Florisphaera profunda Okada and Honjo var. *elongata* OKADA and MCINTYRE, 1977, p. 36.—BORSETTI and CATI, 1976, p. 225, pl. 18, fig. 7.

Figure 5: Coccosphere from bottom, subspherical about 12 μm in diameter (N.B. magnification half that of figs. 3 and 4.) Coccoliths overlapping like tiles from the base, forming a rosette when spread open in top view. Coccoliths with slightly sloping sides 5.6 μm long and 2.4 μm at widest point distally. The base is at right angles to the sides except for 1 corner which is angled and has a small protuberance at the side. The distal end has a low biased peak formed by 2 straight edges intersecting at an oblique angle.

Tasaday 11(4) 100/120 m, 140/160 m. Rarely found above 100/120-m level, but present below in most of the stations.

Florisphaera sp. R

Plate 8, figures 6–7

Figure 6: Inside (top) view of the coccosphere of a small form (6 μm diameter) differing from *F. profunda* (figs. 3 and 4) in having shell-like overlapping coccoliths. Coccoliths are about 2.3 μm at widest point and have a scalloped outer edge. Several fairly prominent ridges run from edge to base of the coccolith on the outside and the inside is smooth. Threadlike structures seen between the coccoliths.

Figure 7: Outside, lateral view of coccosphere showing overlapping coccoliths which have depressions at the bottom (proximal) edge.

Tasaday 11(4) 100/120 m. Only specimens seen. Probably included with *F. profunda* or *Deutschlandia anthos* in light microscope analysis.

Genus HAYASTER Bukry, 1973

Hayaster perplexus (Bramlette and Riedel) Bukry

Plate 8, figure 8

Discoaster perplexus BRAMLETTE and RIEDEL, 1954, p. 400, pl. 39, fig. 9.—KAMPTNER, 1967, p. 179, pl. 23, figs. 118–119. *Hayaster perplexus* (Bramlette and Riedel).—BUKRY, 1973, p. 308.—OKADA and MCINTYRE, 1977, p. 38, pl. 5, figs. 4–5.

Figure 8: Proximal side of placoliths showing large umbrella-shaped distal plate with 10 radiating sutures and angular outline (6–7.4 μm diameter). Proximal plate small (1.4–2.0 μm) with scalloped edges and slightly depressed central area, symmetrical with respect to the distal plate. Some coccoliths have a tubular projection from the small plate. Small placoliths not seen.

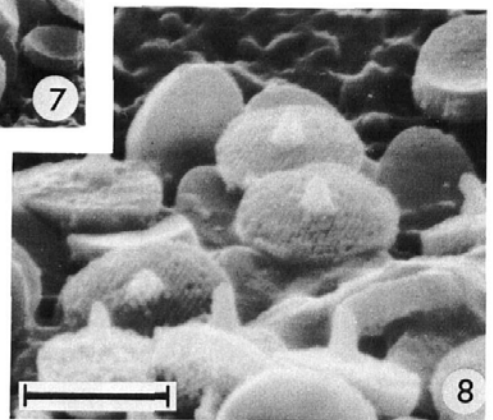
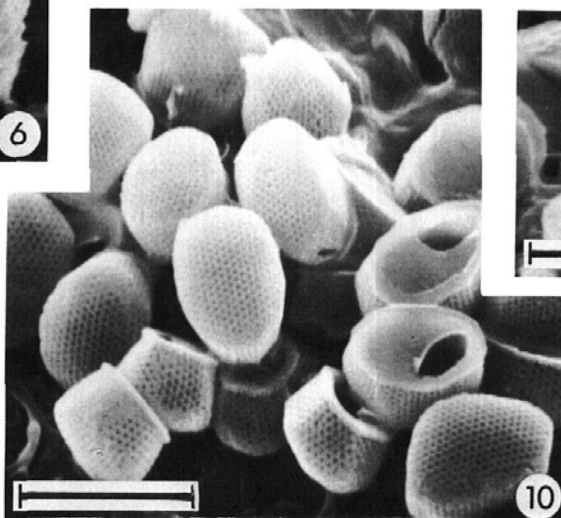
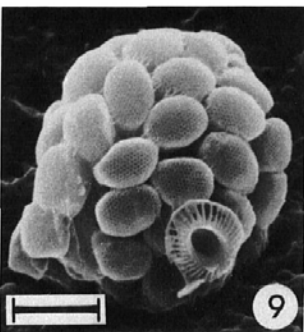
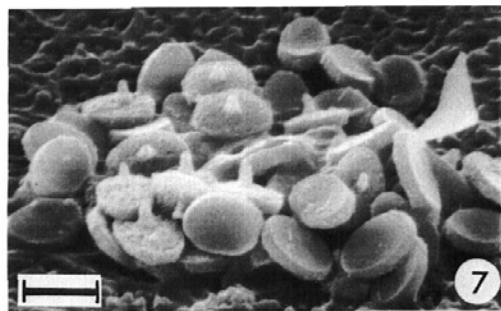
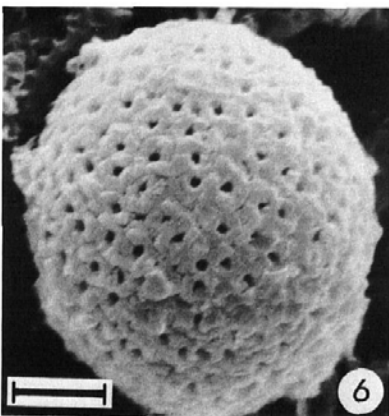
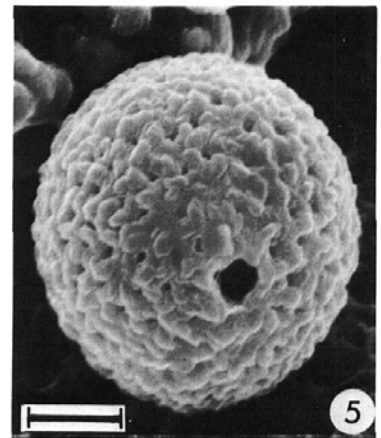
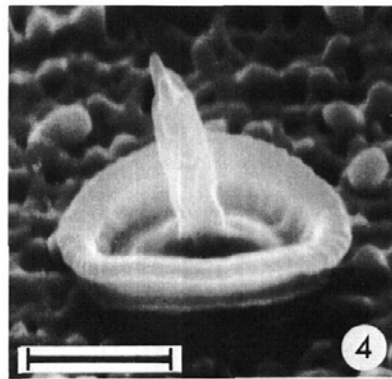
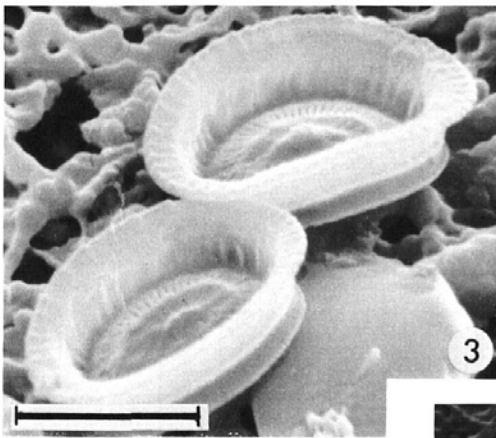
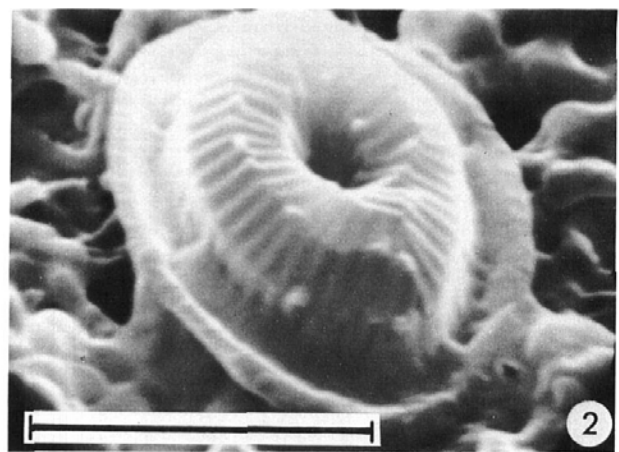
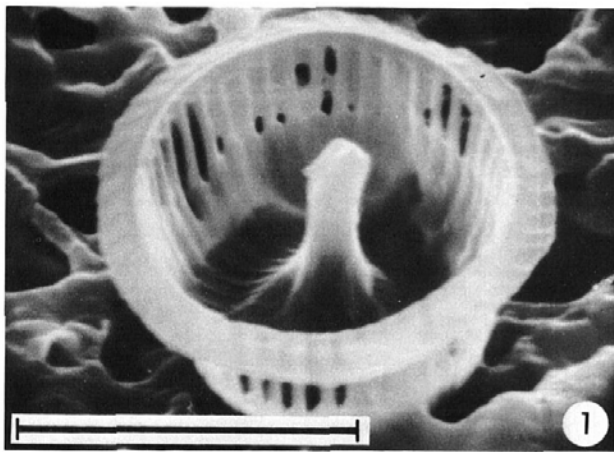
PLATE 6
Scale bar = 3 μm

1–4 *Syracosphaera pulchra* Lohmann

5–6 *Thoracosphaera heimii* (Lohmann) Kamptner

7–8 *Calyptrosphaera catillifera* (Kamptner) Gaarder

9–10 *Calyptrosphaera oblonga* Lohmann



Tasaday 11(4) 100/120 m. Also seen at T 11(4) 140/160 m. Not recognized in light microscope analysis.

Genus THOROSPHAERA Ostenfeld, 1910

Thorosphaera flabellata Halldal and Markali
Plate 8, figures 9–11; plate 9, figures 1–2

Thorosphaera elegans OSTENFELD, 1910, pp. 397–400, text-figs. 1–5.

Scyphosphaera (*Thorosphaera*) *elegans* (Ostenfeld).—DEFLANDRE, 1942, p. 136, figs. 1, 9.

Thorosphaera flabellata HALLDAL and MARKALI, 1955, p. 19, pl. 26.—OKADA and HONJO, 1973, pl. 2, fig. 3.

Figure 9: Coccosphere from top about 9.6 μm diameter showing lopadoliths arranged in compact fashion, not around the equator as in most illustrations. Open distal ends of flattened tubes visible.

Figure 10: Partially collapsed coccosphere (about 10 μm diameter) from bottom showing oval lepidoliths and elongate tubular lopadoliths with closed proximal ends.

Figure 11: Lepidoliths showing simple flat elliptical form ($1.5 \times 1.0 \mu\text{m} \times 0.1 \mu\text{m}$ high). Proximal side without any obvious structure; distal side with a transverse furrow from which the 2 halves are inclined slightly upward.

Plate 9, figures 1 and 2: Lopadoliths, approximately 6 μm long \times 2 μm wide, showing flattened tubular structure. The broad side of the tube has a flat ridge with tiny irregular spinelike projections along the edges. Distal end of the coccolith is toothed, 2 large teeth coinciding with the flat ridges and 2 small ones at each side. Figure 2 shows this clearly at the center and also shows closed, elliptical, proximal end at bottom right. (N.B. Ostenfeld's estimate of the lopadolith length as 40 μm must be an error as it does not match his illustration).

Tasaday 11(4) 140/160 m. South Tow 13(1) 140/160 m. Seen at 140/160 m. and 180/200 m. levels at almost all stations on all cruises, occasionally at 100/120 m (e.g. CL VII) and 40/60/80 m. but never at 0/20 m.

Thorosphaera sp. L

Plate 9, figures 3–4

Figures 3 and 4: Single specimen of form probably assignable to *Thorosphaera*. Lopadoliths and small, oval lepidoliths present. Lepidoliths oval, $1.1 \times 0.7 \times 0.3 \mu\text{m}$ high, with probable proximal view showing slightly thickened edge and with no transverse furrow visible in this preparation. Lateral view at middle left figure 4. Lopadoliths spinelike, fewer (18), much longer (20 μm) and slenderer than in *T. flabellata*. Figure 4 shows broken spine at center left with hollow structure and vertical wall elements. Spine has a flat ridge running longitudinally but no tiny spines as in *T. flabellata* and the proximal end is closed.

Tasaday 11(1) 140/160 m. Not recognized in light microscope analysis.

Unidentified sp. 1

Plate 9, figures 5–7

Figure 5: Coccosphere occurring fairly often in this horseshoe-shaped form. This cell is 50 μm long \times 30 μm wide at the stomatal end, but varies from 36 to 62 μm long and 19 to 43 μm wide in the samples. Stomatal coccoliths bottom left and body coccoliths probably of 2 forms, elliptical "lamina" type and sub-circular type with a delicate floor, missing in some cases.

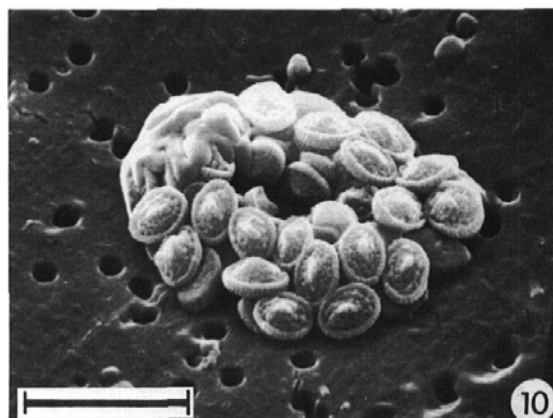
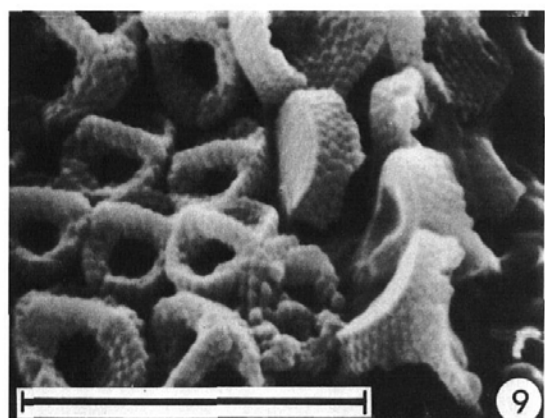
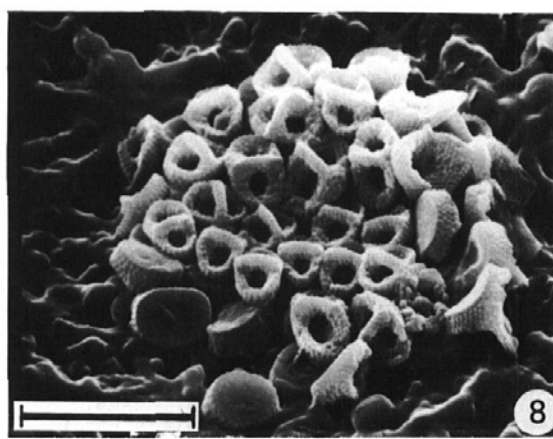
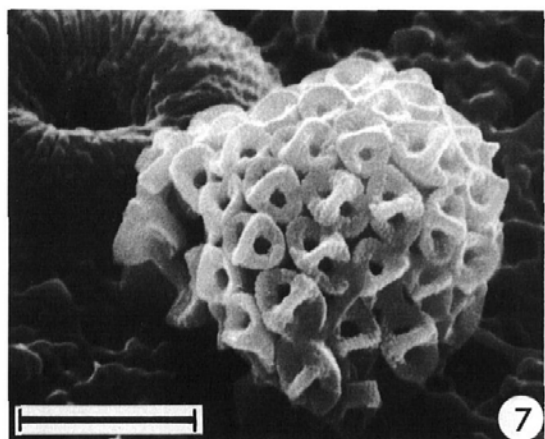
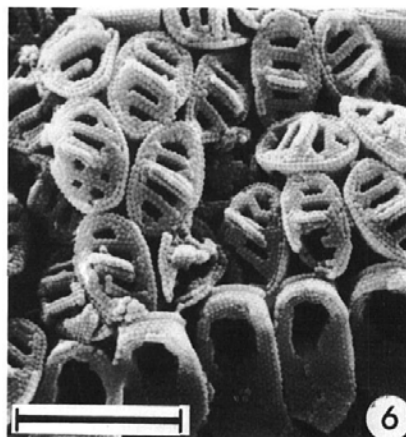
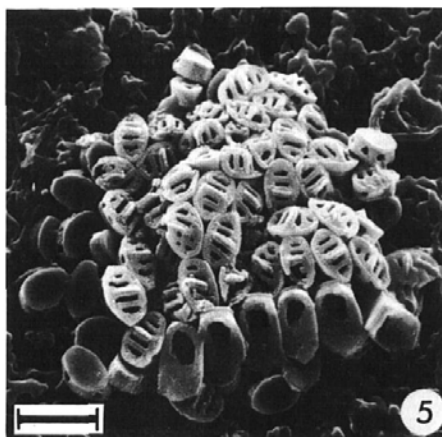
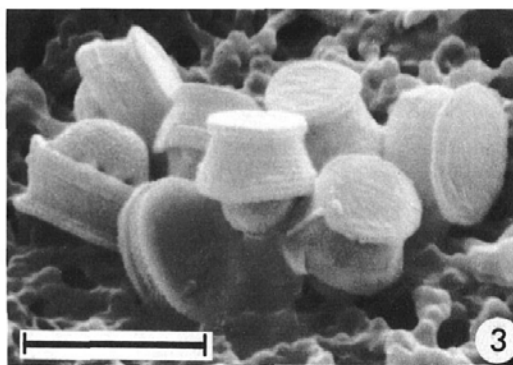
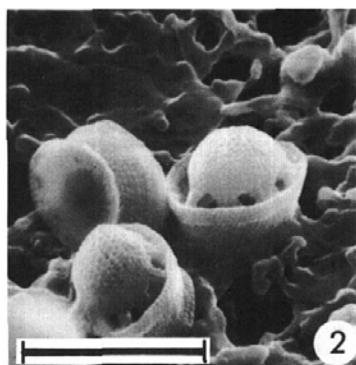
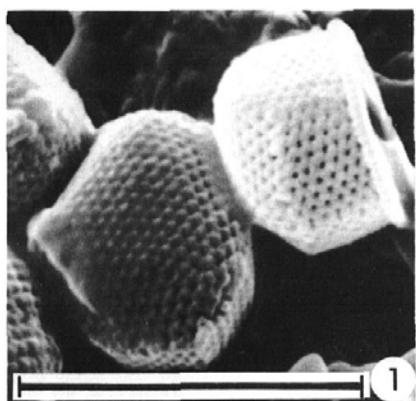
Figures 6 and 7: Stomatal end of the cell. Body coccoliths $3.3 \times 2.2 \times 0.8 \mu\text{m}$ high are caneloliths, with radiating elements arising from a low central ridge and a thin serrated wall without a midwall rim. Some body coccoliths appear to be almost circular hoops ($3.7 \times 3.1 \times 0.8 \mu\text{m}$) with similar wall to that above and indications of a thin floor. These could be part of an exothecal layer. The stomatal coccoliths are oval ($3.1 \times 2.0 \times 0.9 \mu\text{m}$) with a wall slightly angled outward and a long blunt rod (2.6 μm), made up of vertical elements, arising from the floor.

This form does not clearly belong to the genus *Syracosphaera* as defined by Gaarder and Heimdal (1977). The body coccoliths resemble those of *Discolithus ribosus* Kamptner (1967, pl. 5, figs. 30–31) (= *Syra-*

PLATE 7
Scale bar = 3 μm

- 1 *Calyptrorphaera oblonga* Lohmann
- 2–3 *Calyptrorphaera pirus* Kamptner
- 4 *Calyptrorphaera* sp. ?

- 5–6 *Helladosphaera aurisinae* Kamptner
- 7–9 *Helladosphaera cornifera* (Schiller) Kamptner
- 10 *Zygosphaera divergens* Halldal and Markali



cosphaera lamina Lecal-Schlauder) also illustrated in Borsetti and Cati, 1976 (pl. 14, figs. 15–17) but that species has no stomatal spines. It is receiving further study.

Tasaday 1(3) 180/200 m. Tasaday 11(5) 180/200 m. Occurs in lower levels, never above the 100/120 m. depth and only in the T 11, D II and T1 cruises.

Unidentified sp. 2
Plate 9, figures 8–9

Figures 8 and 9: Coccosphere $5.2 \times 4.5 \mu\text{m}$ with large oval coccoliths 1.6×1.0 and $0.4 \mu\text{m}$ high. Stomatal coccoliths present: similar to body coccoliths except for short, blunt rod about $0.6 \mu\text{m}$ long. No obvious exothecal layer. No mid-wall rim, but on the inside the wall appears to be double. Placement in the genus *Coronosphaera* established by Gaarder and Heimdal (1977) is tentatively suggested pending further study.

Tasaday 11(5) 0/20 m. Not identified in analysis.

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PLATE 8 Scale bar = $3 \mu\text{m}$

1–2 *Zygosphaera hellenica* Kamptner

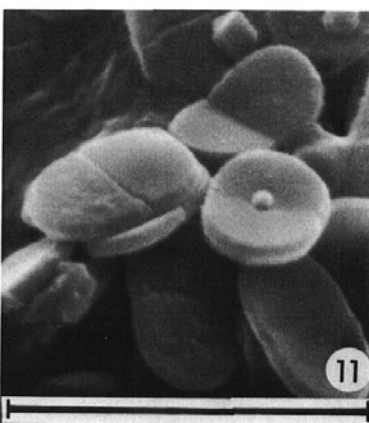
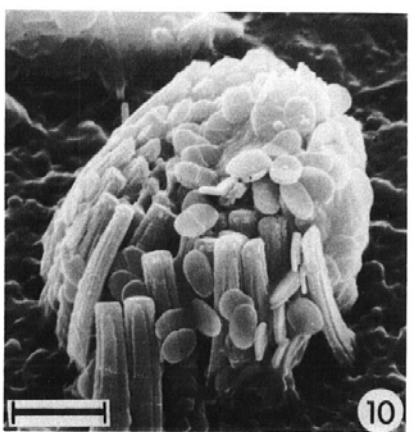
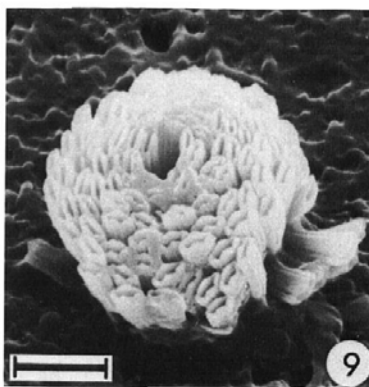
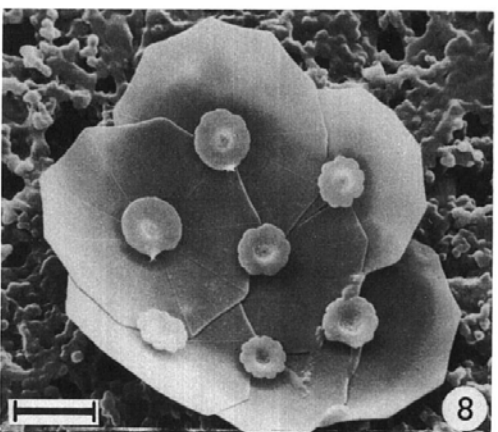
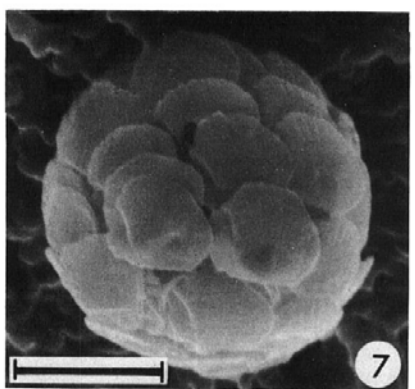
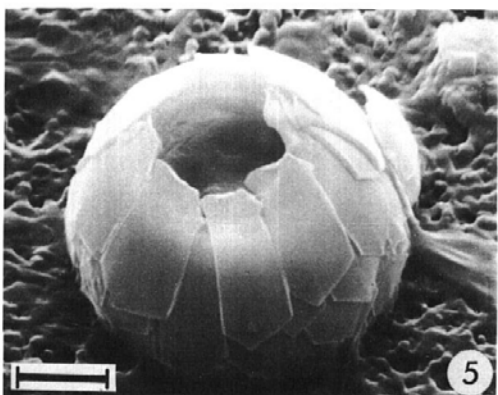
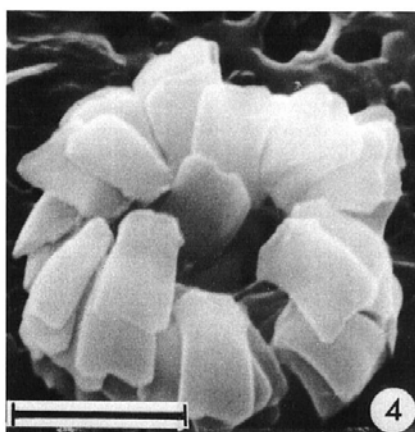
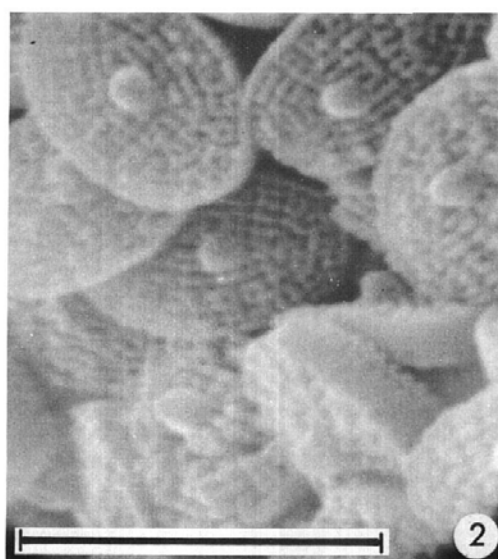
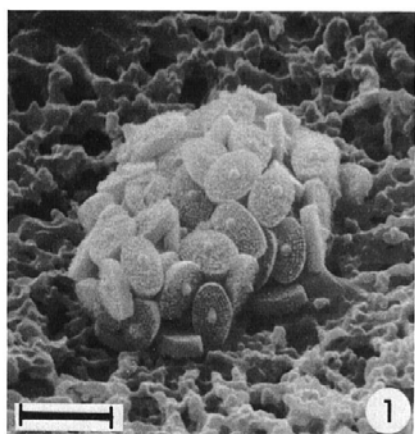
3–4 *Florisphaera profunda* Okada and Honjo

5 *Florisphaera profunda* var. *elongata* Okada and McIntyre

6–7 *Florisphaera* sp. R

8 *Hayaster perplexus* (Bramlette and Riedel) Bukry

9–11 *Thorosphaera flabellata* Halldal and Markali

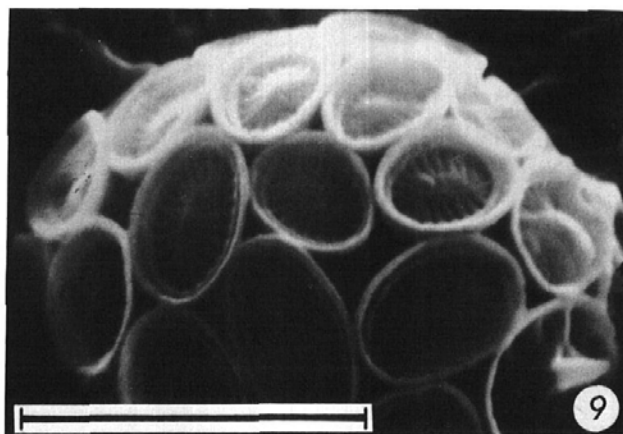
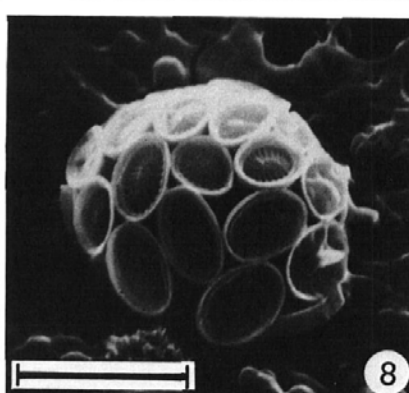
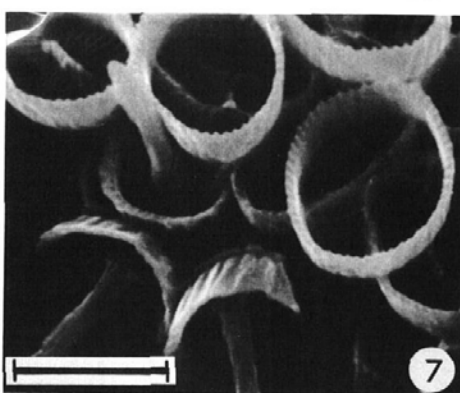
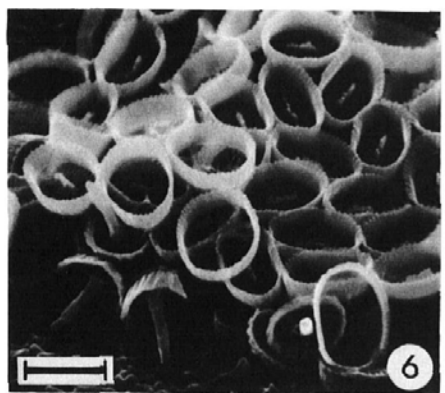
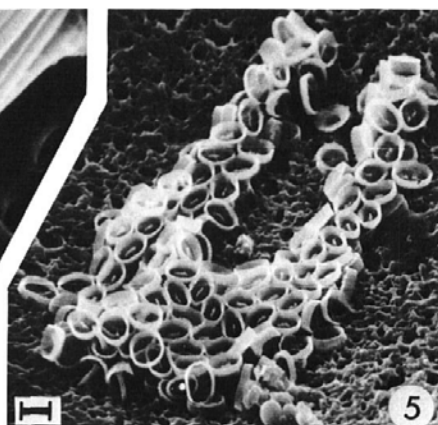
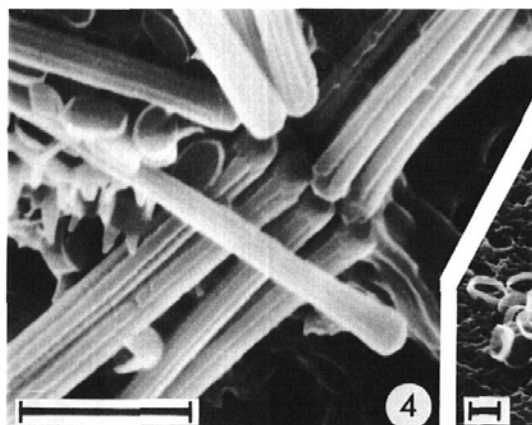
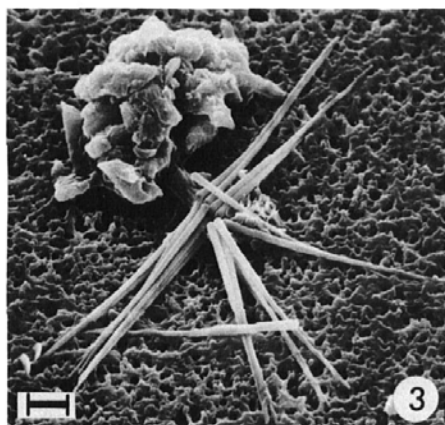
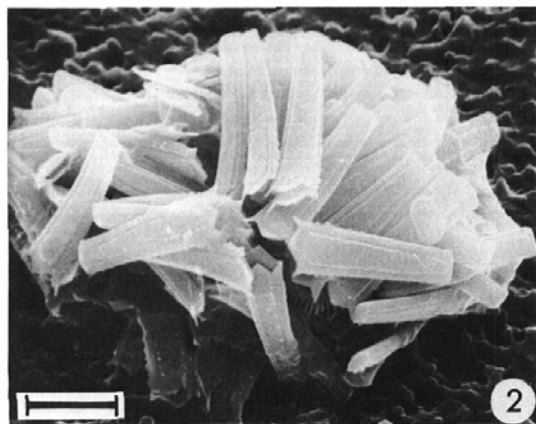
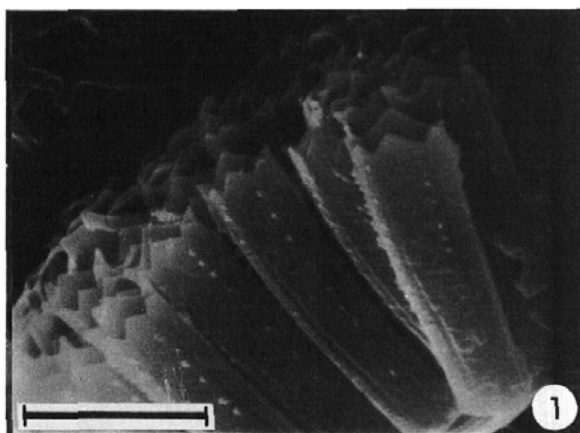


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PLATE 9
Scale bar = 3 μ m

1-2 *Thorosphaera flabellata* Halldal and Markali
3-4 *Thorosphaera* sp. L

5-7 Unidentified sp. 1
8-9 Unidentified sp. 2



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