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SILICEOUS CYSTS FROM KITA-NO-SETO STRAIT, NORTH OF SYOWA STATION, ANTARCTICA

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Abstract: Siliceous cysts of 29 different morphological shapes were observed in the sea ice and sea water at the Kita-no-seto Strait, north of Syowa Station, Antarctica. Twenty species of those were newly discovered in the Antarctic waters. Cysts collected were in the size range of 3 to 10 μm. They were tentatively classified into four groups based on their morphological characteristics; Sphaerica, Ovoidea, Hemisphaerica, and Tri/quadrihedra. Twelve cysts representative of each group and a cyst of *Paraphysomonas imperforata* confirmed newly were described.

Cysts appeared from March to May, and in December (summer to autumn season) and the species diversity was highest in December with 18 species. Among 29 species, 20 appeared in the sea ice, eight in both sea ice and sea water, and one in sea water only. Main habitat of them seemed to be the brine pockets or channels of the sea ice.

1. Introduction

Many species of siliceous cysts reported hitherto from many parts of the world by micropaleontologists have been put into the Chrysophyta (DEFLANDRE, 1933; TAPPAN, 1980). Several new types of minute siliceous cyst species were recently found in the Weddell Sea (SILVER *et al.*, 1980; MITCHELL and SILVER, 1982), the Gulf of Alaska (BOOTH *et al.*, 1980), and the western Pacific (NISHIDA, 1979), and these morphological characteristics were revealed by the scanning electron microscopy. At the same time, noticeable discussion about those cysts from the ecological or biosystematic viewpoint has been done by each of the above-cited authors.

From taxonomical and ecological researches of siliceous cysts and nanoplankton in the coastal region along Syowa Station, 29 species of cysts including 23 species which were newly found in the Antarctic waters, were observed in the sea ice and sea water. The present authors describe their general morphological features and scanning electron microscopical characteristics. Moreover, their vertical distribution and occurrence at the Kita-no-seto Strait are also mentioned.

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2. Materials and Methods

Sea water and sea ice core samples were collected at a sampling site on the fast ice at the Kita-no-seto Strait between East Ongul Island and Nesöya, north of Syowa Station (69°00'S, 35°39'E) (Fig. 1), from March to December, 1983. Maximum depth of water at this site was 13 m. The sea ice cores were taken monthly with a SIPRE ice auger, 9 cm in diameter. At the same time, the sea water samples were taken with a Kitahara water sampler from three layers, 0 (surface), 2 and 5 m, below the surface through the hole from which an ice core was removed. The water samples from 0, 2, 5, 8 and 11 m depths were also taken with a Van Dorn sampler near another sampling hole a few days before or after the ice core samplings. The sea ice thickness varied from 30 (May 14) to 120 cm (October 17) with the progress of season. Each core sample was divided into three portions; surface, middle and bottom. Each portion was melted at room temperature in the laboratory. Suspended materials in 200 m*l* out of the melted sea ice sample and the sea water samples were concentrated to 1.4 m*l* (sometimes 1.0 m*l*) with centrifuge at 3000 rpm for 10 min. One drop (*ca.* 0.02 m*l*) of the concentrated water sample was mounted on a cover slip (*ca.* 8 × 8 mm) for examination with a scanning electron microscope (SEM). The remainder was fixed with one drop of 25% glutaraldehyde for 10 min, then one drop of 1% OsO solution was added. After 5 min the fixed sample was washed twice with distilled water by centrifuge, then one drop of sample was mounted on one cover slip. The cover slip was desiccated at 45°C. Specimens on the cover slip was coated with Au. The SEM used to this study is JEOL JSM-T-100.

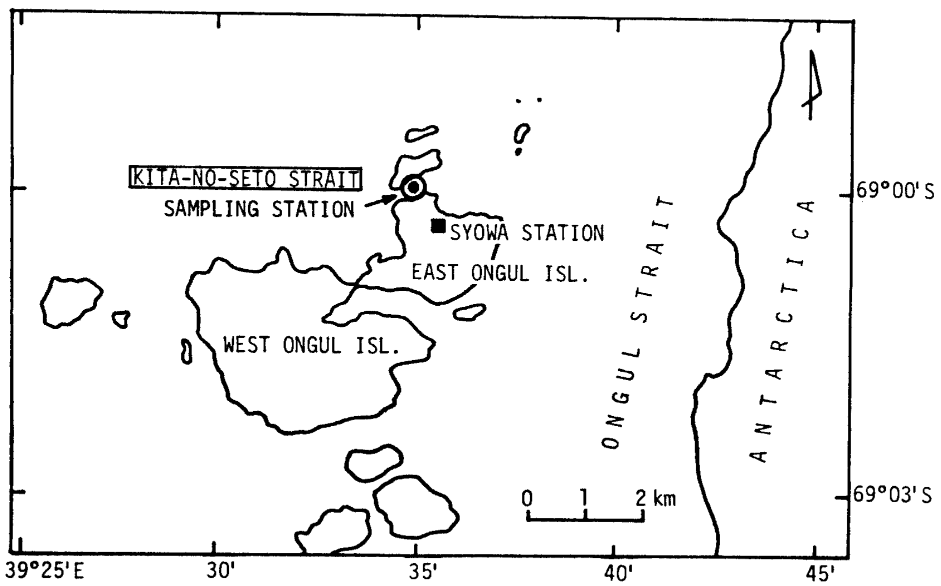

Fig. 1. Map showing sampling site in the Kita-no-seto Strait, north of Syowa Station, Antarctica.

3. Results

3.1. Morphology of cysts

Twenty-nine cysts having different morphological shapes collected from the Kita-no-seto Strait were tentatively classified into four groups based on the general morphological characteristics; namely, 11 of them as Group I, Sphaerica; two as Group II, Ovoidea; four as Group III, Hemisphaerica; and 12 as Group IV, Tri/quadrihedra. The morphological description of 12 species of cysts and a cyst of *Paraphysomonas imperforata* are given in this paper. On the other 16 species of cysts, further studies are required.

Group I. Cyst Sphaerica

Cyst body sphaerical or ellipsoidal, 5–10 μm in diameter, with one pore and the collar complex surrounding the pore (SANDGREN and CARNEY, 1983). Body surface smooth or ornamented with papillae, spikes, vermiformic ribs, or reticulate structure.

1) Cyst 1A (Plate 1, Figs. 1–3)

Cyst body ellipsoidal, but spherical in upper/under views, 6–10×5–7 μm, with one pore, 0.3 μm in diameter, and the collar complex composed of a low collar, 0.3 μm high and 2.0–2.2 μm in outside diameter, and ornamented with irregular meshes made of thick ribs, *ca.* 0.4 μm thick and max. 0.4 μm high. Cyst wall *ca.* 0.5 μm thick excluding ribs of meshes. The inner side is smooth with the inner opening of pore which is surrounded by a slightly thickened and wide collar (Fig. 3). A plug with swollen head inserted in the pore. The mesh structure of the immature cyst is poorly developed. This was recorded from the Weddell Sea (MITCHELL and SILVER, 1982). It is very similar to siliceous cysts, *Archaeomonas areolata* DEFLANDRE (1933) and *Cysta reticulata* NYGAARD (1956).

2) Cyst 1B (Plate 1, Figs. 4–6)

Cyst body slightly ellipsoidal, 7.8–9.5×7.1–8.9 μm, with one pore without annulus, *ca.* 0.2 μm in diameter, surrounded by slightly raised collar, and ornamented with a number of spines terminating into abruptly thickened and flat end, 1.3–1.6 μm long. A spine shaft is constructed of several hollow tubules, which are closely bound at their shafts and seem to become loose at the apex. The cyst with slender and slightly taper spines seems to be immature (Fig. 6). The mature cyst was recorded from the Weddell Sea as *Litheusphaerella spectabilis* DEFLANDRE (1932) (MITCHELL and SILVER, 1982).

Group II. Cyst Ovoidea

Cyst body ob-ovoidal, with one pore surrounded with a collar having a minute triangular crack and an annulus, ornamented with acattered papillae or hexagonal meshes.

1) Cyst 2A (Plate 2, Figs. 7, 8)

Cyst ob-ovoidal, 4×3 μm, with one pore, 0.25 μm in diameter, surrounded by a wide annulus and a raised collar having a minute triangular crack, 1.4 μm outside diameter and 0.3 μm high, and ornamented with scattered papillae, 0.1 μm across. It was newly found in the Antarctic waters.

Group III. Cyst Hemisphaerica

Cyst spheroid with a flat bottom, 3–5.4 μm across. Cyst wall smooth and ornamented with a wing structure surrounding the equator or several long spines radiating from the equator or cordiform like wings or papillae, and with one large circular bottom plate at the flat bottom.

1) Cyst 3A (Plate 2, Figs. 9, 10)

Cyst body spheroid with a flat bottom, 4.1 μm across and 3.0–3.5 μm high, and with a narrow wing surrounding the equator, 0.25 μm wide. It was newly found in the Antarctic waters.

2) Cyst 3B (Plate 2, Figs. 11, 12)

Cyst body spheroid with a flat bottom, 5.4 μm across and 3.9 μm high, smooth, with an undulate-edged wing structure surrounding the equator, max. 1.3 μm wide, radiating two to five long taper spines from the edge, 10 to 20 μm long, and with a circular bottom plate, 1.8 μm in diameter. Some of cysts with one or three spikes on the upper half of cyst body. It was newly found in the Antarctic waters.

3) Cyst 3C (Plate 3, Fig. 13)

Cyst body spheroid with a flat bottom, *ca.* 4.8 μm across, and ornamented with 10 to 14 cordiformic projections, 1.2 μm wide at the base, 1.0 μm high and *ca.* 0.15 μm thick. Some of the projections are slightly concaved. It was newly found in the Antarctic waters.

4) Cyst 3D (Plate 3, Fig. 14)

Cyst body spheroid with a flat bottom, 5.0–5.2 μm across and 5.0–5.1 μm high excluding wings, and ornamented with round-edged wing structures, *ca.* 0.7 μm high and 0.6–2.9 μm wide. The bottom pore large, *ca.* 3.2 μm in diameter, encircled with a wide annulus with acute edge, 0.6 μm wide (Fig. 14, right side). It was newly found in the Antarctic waters.

Group IV. Cyst Tri/quadrihedra

Cyst body composed of eight component plates in general; circular shield and ventral plates, triradiate plates, and girdle plates as described by BOOTH *et al.* (1981). Each plate smooth, or with papillae, radiate slits, spines, or wing-like projections. BOOTH *et al.* (1981) classified nine forms obtained from the Gulf of Alaska into two groups based on the number of component plates of the cyst. However, at this stage of the present work, cysts of this group were tentatively defined by the number of shield and ventral plates, because SEM examination on the component plates of cysts is not completed.

1) Cyst 4A (Plate 3, Figs. 17, 18)

Cyst body spheroid, 6.8–7.2 μm across excluding wing-like projections of up to 1.8 μm long, composed of three circular plates; one ventral and two shield plates, *ca.* 4.0 μm across and *ca.* 1.3 μm high, and probably two triradiate plates; and with several longitudinal ribs between an upper circular rib and a rim of the circular shield plate. The wing-like projections linguiform, and radiated from the center and the upper circular rib of the shield plate, and from the edge of triradiate plate. It was recorded from the Weddlell Sea by SILVER *et al.* (1980, Fig. 1-E).

2) Cyst 4B (Plate 4, Figs. 19–21)

Cyst body spheroid, 6.5–8.0 μm across excluding spines, composed of three circular shield plates, *ca.* 4 μm across, with long and tubular dichotomous spines, radiating from the center and the upper circular rib of the shield plate and from the edge of triradiate plate, 10–20 μm long including spine bases of 1–2.5 μm long. Cysts with only spine bases as shown in Fig. 19 were also found. In such cysts, some of spine bases terminate in T-form tip (Fig. 19, indicated by arrowhead; SILVER *et al.*, 1980, Fig. 1-C). It was recorded from the Weddell Sea (SILVER *et al.*, 1980).

3) Cyst 4C (Plate 4, Figs. 22, 23)

Cyst body spheroid, 7 μm across, composed of three circular shield plates with two to three wing structures, *ca.* 5 μm in diameter, and of two triradiate plates with winged edge, *ca.* 0.4 μm high. It was newly found in the Antarctic waters.

4) Cyst IX. BOOTH *et al.* (1981) (Plate 3, Fig. 15)

Cyst body spheroid, *ca.* 3 μm in diameter, with four shield plates and four triradiate plates. Plates with densely packed papillae and each with a central spike. It was recorded from the Gulf of Alaska (BOOTH *et al.*, 1980, Figs. 1–4, 7, 9; 1981, Cyst IX), and from the western Pacific (NISHIDA, 1979).

5) Cyst 4E (Plate 3, Fig. 16)

Cyst body spheroid, *ca.* 2.4 μm in diameter, with four shield plates and four triradiate plates. Plates with radiate slits, and each with a central spike. It was recorded from the Weddell Sea (SILVER *et al.*, 1980, Figs. 1-A and B).

Cyst of *Paraphysomonas imperforata* LUCAS (1967) (Plate 4, Fig. 24)

Cyst body ellipsoidal, but spaerical in front view, 5.5–6.0 μm across and 5.0–5.5 μm long, smooth, with the collar complex composed of a low collar, 1.1 μm in outside diameter, 0.8 μm in inside diameter, and 0.4 μm high. The cyst and mother cell were found newly in the Antarctic waters.

This is the first description of the cyst of this species.

3.2. Occurrence of cysts (Table 1)

Cysts were observed from March to May, in August, September, November and December 1983. The diversity of cyst species was highest in December with 18 species. Almost all cysts which appeared in August and September were empty, lacking the plug or shield Plate. The seasonal differences in species composition was also observed. Main components in March and April were species of Group I, and those in December were species of Groups I and IV.

Table 1. Number of species of cysts found at Kita-no-seto Strait, 1983.

Group of cyst	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Number of spp. found through 1983
I	10	8	2				2		1	7	11
II	1									2	2
III	3	3	1						1	1	4
IV		1	3			3	4		1	8	12
Total	14	12	6			3	6		3	18	29

3.3. *Virtical distribution of cysts (Table 2)*

The vertical distribution of 29 species of cysts in the sea ice and sea water at the Kita-no-seto Strait is shown in Table 2. Twenty out of 29 species of cysts appeared in the sea ice only, eight in both sea ice and sea water, and one species in water column only. This fact seems to support a hypothesis that the principal habitat of cysts as well as mother micro-organisms which reproduce cysts is the brine pockets or channels of the sea ice.

Table 2. Vertical distribution of number of cyst species in the sea ice and sea water at Kita-no-seto Strait, 1983.

	Mar.				Apr.				May				June				July				Aug.				Sep.				Oct.				Nov.				Dec.			
Cyst group	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Ice surface	5				5				1		1	2												3	2			4									3	1	0	3
Ice middle	7	1	1		6		3		1			2													1												5	1		3
Ice bottom	8	1	2		7		1					1																							1		4	1	1	4
Water (depth) 0 m					3			1	1			1																												
Water (depth) 2																																								
Water (depth) 5																																	1							
Water (depth) 8																																				1				
Water (depth) 11																																								
No. of spp.	14				12				6				0				0				3				6				0				3				18			

4. Discussion

In addition to several species of fossil siliceous cysts recorded hitherto, several new types of minute cysts species were recently found in the sea water and sea ice in the Weddell Sea (SILVER *et al.*, 1980; MITCHELL and SILVER, 1982), the Gulf of Alaska (BOOTH *et al.*, 1980), and the western Pacific (NISHIDA, 1979). By the present study, 29 cyst species were mainly found in the sea ice at the Kita-no-seto Strait, and 20 of them were newly found in the Antarctic waters. This fact proved that many species of siliceous cysts are distributed in the sea ice in the Antarctic waters more than in other parts of the world.

About 200 species of fossil cysts belonging to the Chrysophyceae have been recorded from marine and freshwater regions in many parts of the world (STARMACH 1985; DEFLANDRE, 1932, 1933, 1938; ANDRIEU, 1936; NYGAARD, 1956; BOURRELLY, 1957, 1968; DEFLANDRE and D.-RIGAUD, 1970). Those morphological characteristics are not yet revealed because of their minute sizes for a light microscopical examination. Therefore, SEM re-investigations on them are urgently required (CORNELL, 1972; GRITTEN, 1977; BOOTH *et al.*, 1980, 1981; CRONBERG, 1980; SILVER *et al.*, 1980; TAPPAN, 1980; TAKAHASHI, 1981; SANDGREN and CARNEY, 1983).

Reproduction of cysts in chrysomonads is done at certain stage in their life cycles (BOURRELLY, 1957, 1968; SANDGREN, 1980a, b, 1981). BOOTH *et al.* (1980) assumed that some of the spheroid cysts may be reproduced by choanoflagellates. The present results suggested that reproduction of cysts is made mainly in the brine pockets or channels of sea ice from summer to autumn seasons. In those seasons, about 10 species of choanoflagellates, some of silicoflagellates and *Paraphysomonas*, and many species of diatoms occurred in the sea ice and sea water. The present authors found cysts of *Paraphysomonas imperforata* which were just produced by mother cells, but the relation between other cysts and their mother organisms was not clarified. It is also one of the most essential subjects from the biosystematic viewpoint to clarify the relation mentioned above, as is pointed out by SANDGREN and CARNEY (1983), and so further studies including the culture methods are necessary.

Moreover, the present results that the principal habitat of those cysts as well as their mother organisms is the brine pockets or channels of the sea ice support also MITCHELL and SILVER' opinion that several cysts of Archaeomanads may be useful as indicators of ice conditions for marine environments.

Acknowledgments

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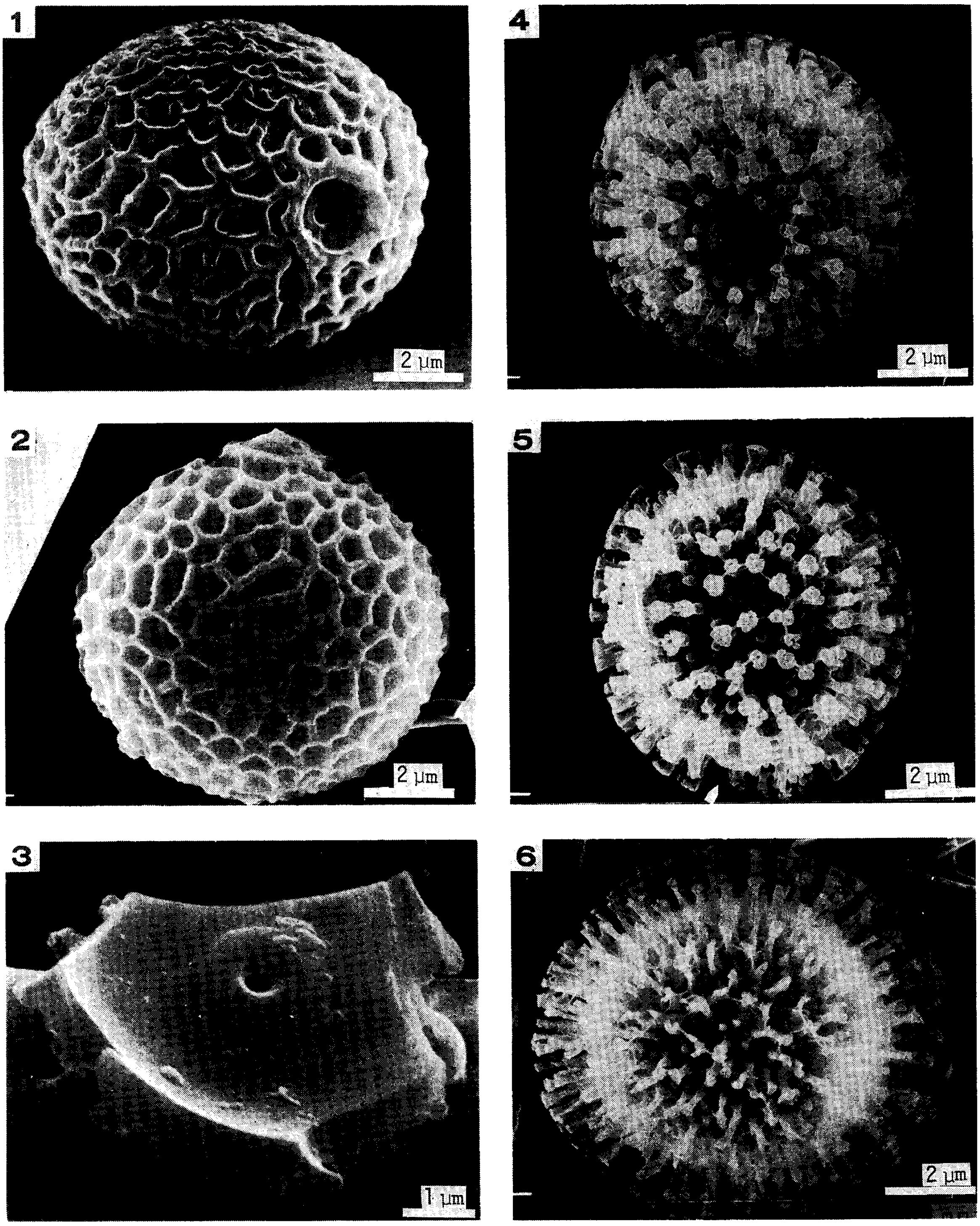
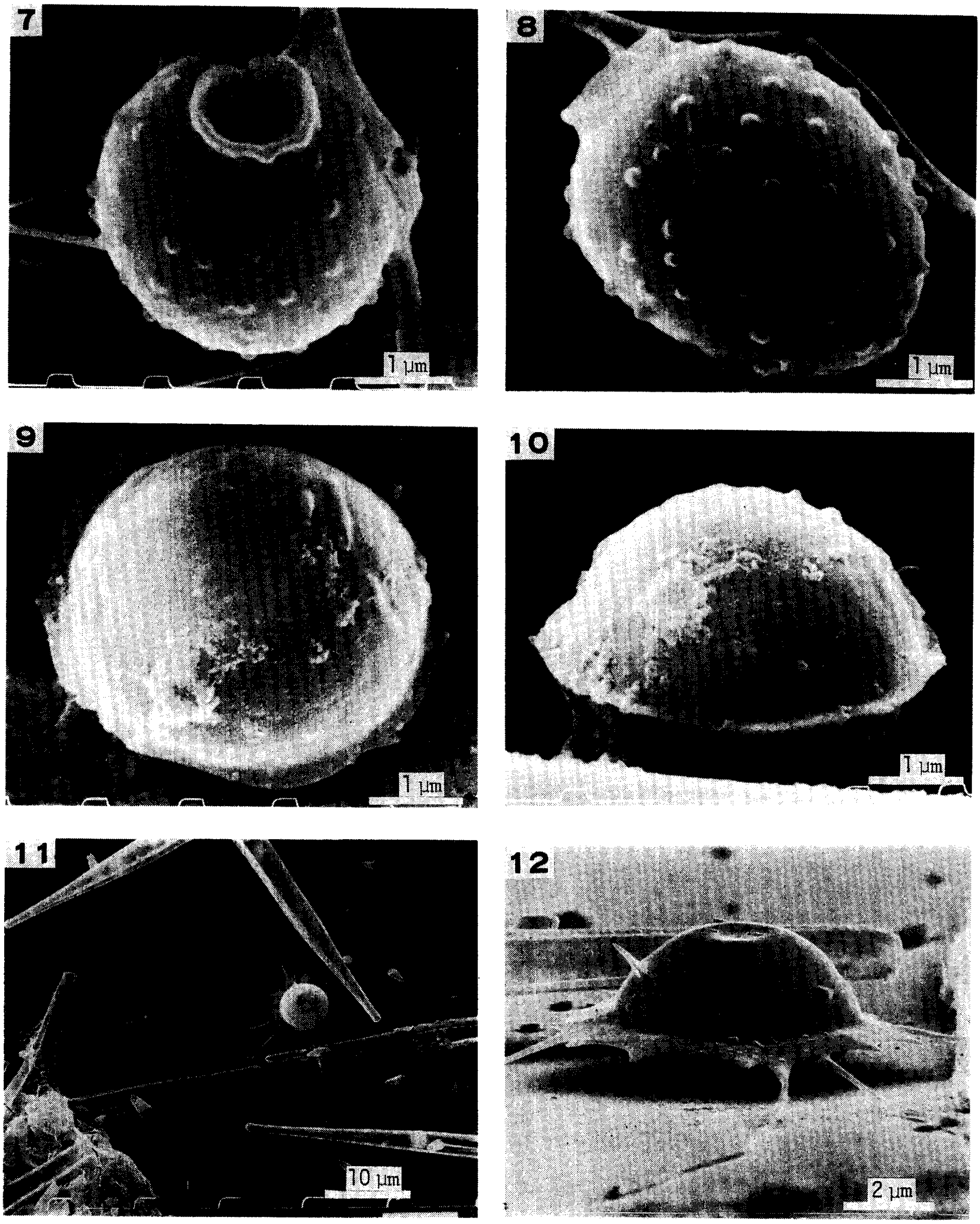
Plate 1



Figs. 1–3. *Cyst 1A. An oblique front view of cyst (Fig. 1), an upper/under view of intact cyst with a low collar and a swollen plug head (Fig. 2) and a fragment of cyst wall (Fig. 3).*

Figs. 4–6. *Cyst 1B. A front view of cyst (Fig. 4), an upper/side view of the same cyst shows and ellipsoidal cyst body with a raised collar (indicated by arrowhead) (Fig. 5) and a side view of an immature cyst with slender spines (Fig. 6).*



Figs. 7 and 8. *Cyst 2A. An oblique front view of cyst (Fig. 7) and an upper/side view shows ob-ovoidal body form (Fig. 8).*

Figs. 9 and 10. *Cyst 3A. An upper view of cyst (Fig. 9) and an oblique side view of the same cyst (Fig. 10).*

Figs. 11 and 12. *Cyst 3B. An upper view of intact cyst (Fig. 11) and a side view of cyst (Fig. 12).*

Plate 3

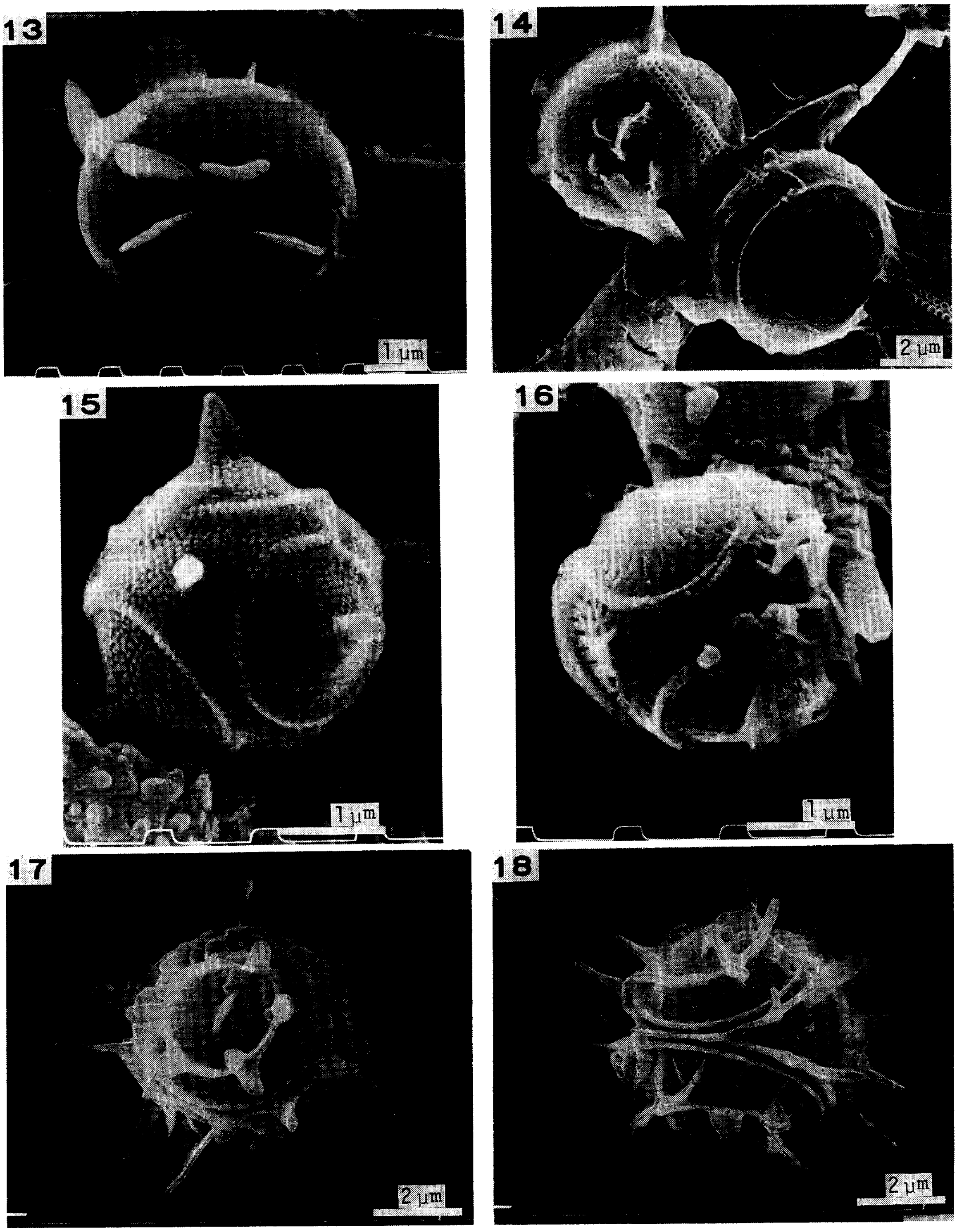


Fig. 13. *Cyst 3C. An upper view of cyst.*

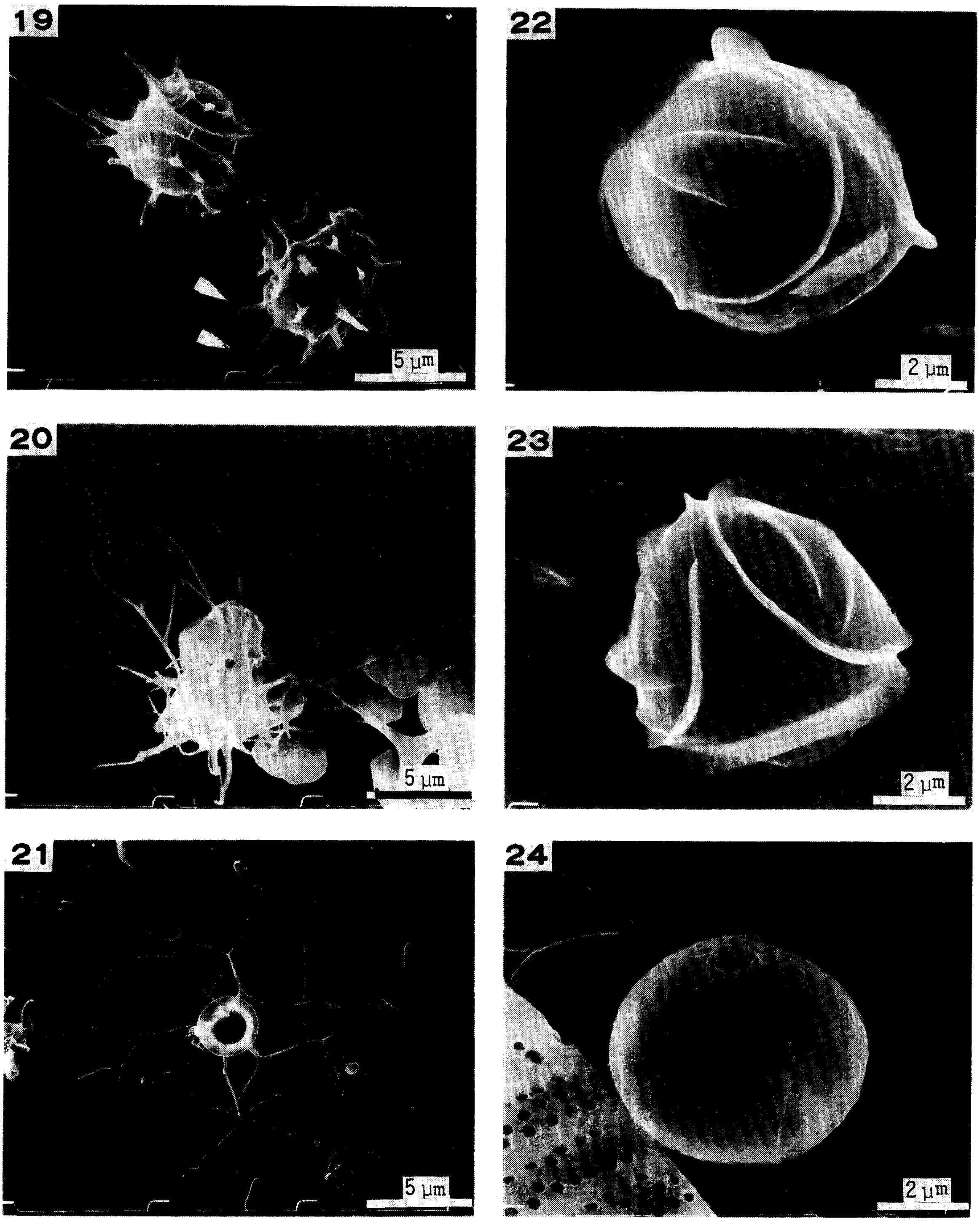
Fig. 14. *Cyst 3D. Upper (left) and under (right) views of cysts. The bottom plate is removed from cyst (right side).*

Fig. 15. *Cyst IX (Cyst 4D). Three shield plates and a triradiate plate are shown.*

Fig. 16. *Cyst 4E. Three shield plates and two triradiate plates with radiate slits (striae) are shown.*

Fig. 17. and 18. *Cyst 4A. An upper view of cyst (Fig. 17) and the other side view of the same cyst (Fig. 18).*

Plate 4



Figs. 19–21. Cyst 4B. Under (left) and oblique upper (right) view of cysts with spine base terminating in T-form tip (indicated by arrowhead) (Fig. 19), an intact cyst (Fig. 20) and an inner side of a shield plate (Fig. 21).

Fig. 22 and 23. Cyst 4C. A circular shield plate of cyst (Fig. 22) and the other side view of the same cyst (Fig. 23).

Fig. 24. Cyst of Paraphysomonas imperforata *Lucas (1967), an oblique upper view of ellipsoidal cyst.*