FLORISTIC STUDY OF ICE ALGAE IN THE SEA ICE OF A LAGOON, LAKE SAROMA, HOKKAIDO, JAPAN

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Abstract: Fifty-two taxa of microorganisms, including 20 taxa of diatoms, 7 of choanoflagellates, 5 of *Paraphysomonas*, and other 20 taxa, were determined from fixed and unfixed samples of the sea ice and lake water which were collected from a lagoon, Lake Saroma, Hokkaido in February 1979.

The diatom population was dominantly distributed both in the sea ice and lake water, and *Dunaliella* sp. *Gymnodinium* sp. and *Quadrichloris* sp. were relatively abundant in the sea ice. Forty-five taxa were found in the sea ice and 41 taxa of them were distributed in the bottom part.

Twenty-nine taxa of microorganisms were found with the optical microscope, whereas other 23 taxa were identified by the electron microscope.

Two taxa each of *Paraphysomonas*, *Chrysochromulina* and *Pinaciophora*, and 7 taxa of choanoflagellates are new to Japan.

1. Introduction

It is well known that high concentration of chlorophyll pigments is detected in the polar sea ice, where the so-called ice algae or ice biota are contained in the interstices between ice crystals. The previous investigators reported that the ice algal communities consist of diatom population (BRADFORD, 1979; HOENER, 1977; HOSHIAI, 1977, 1979).

In February 1979, the present author had an opportunity to survey the ice algae in the sea ice of a lagoon, Lake Saroma, in Hokkaido, participating in the ice biota research group of the National Institute of Polar Research, Tokyo.

Preliminary results of a floristic investigation which was carried out by both optical and electron microscopic observations are described in this paper.

2. Materials and Method

On February 21 and 22, 1979, seven ice cores were sampled with SIPRE ice auger and 4 bottles of lake water collected at the site about 100 meters off the pier of the Taetoko harbor on the coast of Lake Saroma which is connected with the Sea of Okhotsk. In addition, one ice block of about $10 \times 10 \times 10$ cm was collected at two offshore sites which were respectively 50 meters and 100 meters distant from the pier. The sea ice of the lake was 45 cm in thickness.

The ice cores were cut into 5 pieces according to the appearance. 25 pieces derived from 5 ice cores were fixed immediately with 10% glutaraldehyde solution

buffered at pH 7.8 (GA), and then with formalin after melted at room temperature. 10 pieces of other two ice cores were melted at room temperature and kept at 10°C without fixative and nutrients. Two bottles of water samples of 0.6 liter were collected from each of two layers of lake water; surface and 3 meters deep. The water sample in one bottle was fixed with 10% GA and later with formalin, and then, was concentrated to 10 m*l* after stationarily kept for one week. The other samples were concentrated to 10 m*l* by centrifuge at 3000 rpm for 10 minutes and then kept at 10°C without fixative and nutrients.

Five fixed samples of the sea ice (Core No. 12; 1–5 parts) and fixed two of the lake water, and 4 unfixed samples of sea ice and two of lake water were used in quantitative studies with the optical and the electron microscopes.

Quantitative results described in this paper were obtained by optic microscopical investigation of the fixed samples.

3. Results and Discussion

3.1. Distribution of species

From both the fixed and unfixed samples, 52 taxa, including 20 taxa of diatoms, 7 of choanoflagellates, 5 of *Paraphysomonas* and the other 20, including 5 kinds of scales presumably derived from unidentified 5 loricate organisms, were determined with the optical and the electron microscopes. 29 taxa among them were identified with the optical microscope, whereas, 23 were identified with the electron microscope (Table 1).

Among 52 taxa collected, 8 species were found in the lake water only, 24 in the sea ice only, and 20 in the both habitats. 41 taxa out of 44 taxa which were found in the sea ice were distributed in the bottom part. 28 taxa were found in three middle parts and 23 in the surface part (Table 2). 17 species of the diatoms, excluding three which were found only in the surface part of the sea ice, were widely distributed in all five parts of the sea ice and also in the lake water. On the other hand, almost all species of *Paraphysomonas* and choanoflagellates were distributed in the bottom part of the sea ice and in the lake water.

3.2. Vertical distribution of biomass

As for 29 taxa which were countable under the optical microscope, the biomass is shown by the number of cells of 29 taxa per milliliter of melted sea ice and of lake water.

The vertical distribution of total biomass is shown in Fig. 1 with the biomass of the prominent taxa. The total cell number in each layer of both the sea ice and lake water ranges from 40000 to 20. In the lake water, 60 were found in the three meters deep part and 20 in the surface part. In the sea ice, 40000 were counted in the bottom part, 200 in the surface part, and 400–500 in the middle three parts. In the

Table 1. Species collected from Lake Saroma in February 1979.

Bacillariophyceae	Chrysophyceae
Amphiprora hyperborea	Craspedomonadophycidae*
Biddulphia cf. *pulchella*	°*Acanthoecopsis apoda*
Chaetoceros sp.	°*A. unguiculata*
Cocconeis placentula	°*Diaphanoeca grandis*
Coscinodiscus angusti-lineatus	°*D.* sp.
C. kützingi	°*Savillea micropora*
C. radiatus	°*Salpingoeca* sp.
Fragilaria striatura	°*Stephanoeca urnula*
F. spp. (2 taxa)	Dictyochales
Melosira juergensii	*Dictyocha* sp.
Navicula salinatum	Ochromonadales*
N. spp. (3 taxa)	*Paraphysomonas butcheri*
Pinnularia sp.	°*P.* cf. *cribosa*
Thalassiosira sp.	°*P. imperforata*
Chlorophyceae	°*P. sideriophora*
Chlamydomonas sp.	*P. vestita*
Dunaliella sp.	Prymnesiophyceae*
Quadrichloris sp.	°*Chrysochromulina birgeri*
Cryptophyceae	°*C.* sp.
Cryptomonas sp.	Prasinophyceae*
Dinophyceae	°*Pyramimonas* sp.
Gymnodinium sp.	Rhizopoda
Euglenophyceae	Heliozoa*
Anisonema sp.	°*Pinaciophora denticulata*
Astasia sp.	°*P. candelabrum*
Euglena sp.	Undescribed scales of 5 taxa*°

* Taxa found with the electron microscope.
° New to Japan.

bottom of the sea ice, the cell number was extraordinarily large and attained to 95% of the total cell number of a whole ice core.

As for the detailed distribution of the remarkable taxa, in the sea water, *Fragilaria striatura* was dominant in both the surface and three meters deep parts, whereas *Dunaliella* sp. was subdominant in the surface part and *Melosira juergensii* in the three maters deep part. The bottom part of the sea ice was dominated by *Nitzschia frigida* with subdominant *Fragilaria striatura* and two abundant species, *Dunaliella* sp. and *Gymnodinium* sp. In the part just above the bottom, *F. striatura* appeared as the dominant and *M. juergensii, Quadrichloris* sp. and *Gymnodinium* sp. were the subdominant species. In the middle part and the fourth part from the bottom, *M. juergensii* and *F. striatura* occurred as the dominant and the subdominant. The surface

Table 2. The distribution of species in the sea ice and the lake water of Lake Saroma in February 1979.

Taxa	No. of taxa	Sites: Water only	Ice only	Water & ice	Sea ice		
					Bottom	Middle	Surface
Cryptomonas	1		1			1	
Gymnodinium	1		1		1	1	1
Dictyocha	1		1		1	1	1
Centric diatoms	7	1	2	4	4	6	4
Pennate diatoms	13	1	3	9	11	12	11
Anisonema	1		1		1	1	1
Astasia	1		1		1		
Euglena	1		1		1	1	1
Chlamydomonas	1			1	1	1	1
Dunaliella	1			1	1	1	1
Quadrichloris	1			1	1	1	1
Pyramimonas	2		2		2	1	
Paraphysomonas	5	1	1	3	4		
Chrysochromulina	2		2		2	1	1
Choanoflagellates	7	3	3	1	5		
Pinaciophora	2	2					
Loricate organisms	5		5		5		
Total	52	8	24	20	41	28	23

Numerals show the number of taxa which found in each site.

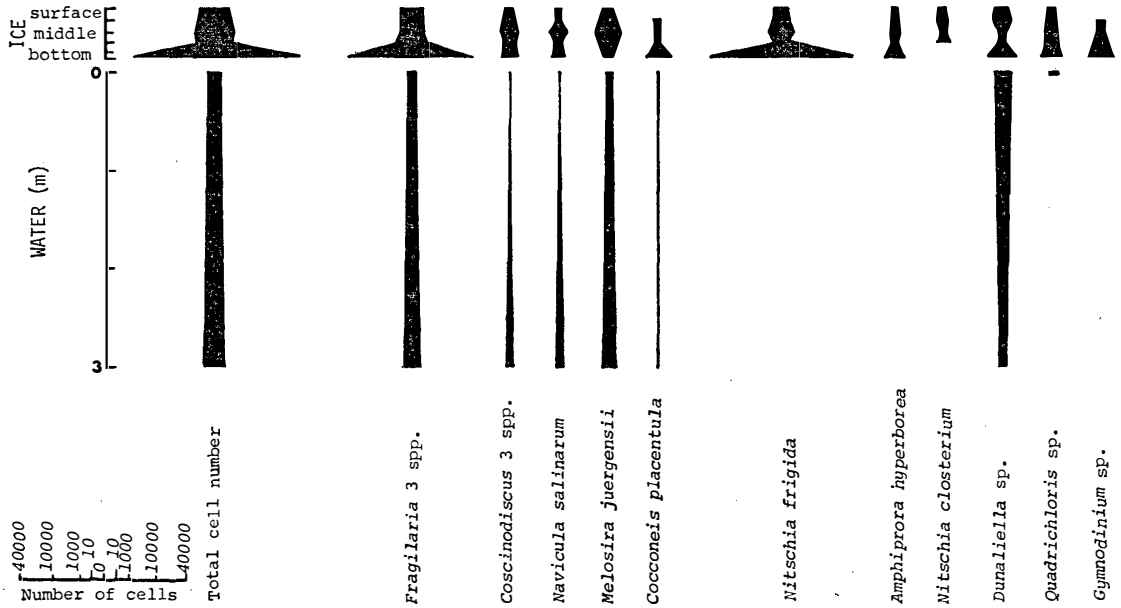

Fig. 1. The vertical distribution of total biomass of 29 microorganisms and the biomass of the prominent components in Lake Saroma in February 1979.

part was occupied by dominant *F. striatura*, and subdominant *Dunaliella* sp. and *Nitzschia frigida*.

The biomass of the diatoms was extraordinarily large in the bottom of the sea ice, and was dominant in the other parts of sea ice and also in the lake water. It is obvious, therefore, that the diatoms are dominant components in the sea ice biota of this lake in winter as already described by the previous investigators. However, *Dunaliella* sp. was found relative abundant in both habitats, and *Gymnodinium* sp. and *Quadrichloris* sp. were abundant in the sea ice. Moreover, 23 taxa of microorganisms which were uncountable under an optical microscope and came to about 44% of the total species number were detected from the sea ice and the lake water by means of the electron microscope. It seems that these microorganisms play an important ecological role in the sea ice biotic community. At present, however, taxonomical investigations as well as ecological studies of them are quite insufficient. Further detailed investigations are needed.

3.3. Taxonomical description of species

The above-mentioned results seem to indicate the importance of the sea ice as one of the habitats of microorganisms. Therefore, electron microscopical investigations of microorganisms of the sea ice and the lake water were carried out and 23 microorganisms were detected. Seven species of choanoflagellates, 3 of *Paraphysomonas*, 2 of marine heliozoans, *Chrysochromulina birgeri*, and 8 unidentified taxa are new occurrence in Japan.

Brief descriptions of 13 remarkable taxa are given based on electron micrographs as shown in Plates I-IV.

Chrysophyceae

Ochromonadales

Genus *Paraphysomonas*

Paraphysomonas butcheri PENNICK et CLARKE (1972)

Cells spherical, 2.5 μm in diameter or ellipsoidal, 2.5×2 μm, with two unequal flagella and covered with two types of scales; plate scale and crown one. This species was found only once from a fresh water pond in Japan but is a cosmopolitan (TAKAHASHI, 1978).

Paraphysomonas imperforata LUCAS (1967)

Cells spherical, 1.7–4.3 μm in diameter, with two unequal flagella; long pleuronematic one, 10–19 μm long, and short simple one, 2.8–3.5 μm long, and covered with one type of scale; disc with spine. Its occurrence is new to Japan. Previously recorded from England, Norway and Denmark (LUCAS, 1967; LEADBEATER, 1972b; THOMSEN, 1975).

Cysts of the above two species were first found and illustrated in Figs. 3 and 4 in Plate I.

Paraphysomonas cf. *cribosa* LUCAS (1968)

Several plate scales built of rod were found in the sea ice and the lake water. It is new to Japan. Previously recorded from England, Norway and Denmark (LUCAS, 1968; LEADBEATER, 1972b; THOMSEN, 1975).

Paraphysomonas sideriophora THOMSEN (1975)

Several flat-iron like body-scales were found in the surface of lake water. It is new to Japan. Previously recorded from Denmark only (THOMSEN, 1975).

Paraphysomonas vestita (STOKES) DE SAEDELEER (1929)

Several scales were found in the bottom of the sea ice. This species is a cosmopolitan and is widely distributed also in fresh waters of Japan (TAKAHASHI, 1978).

All five species of *Paraphysomonas* mentioned above are the first record from the saline or brackish waters of Japan.

Craspedomonadophycidae

Acanthoecopsis apoda LEADBEATER (1972)

Lorica is formed by 16 longitudinal costae which converge at the bottom of the posterior chamber and are free-ended at the anterior end, 14.6 μm long. Two transverse costal rings encircle the anterior chamber and one costal ring the posterior one. This species is new to Japan. Previously recorded from Norway (LEADBEATER, 1972a).

Acanthoecopsis unguiculata THOMSEN (1973)

Lorica is composed of a posterior cell chamber which is composed of longitudinal costae and transversal and more or less obliquely oriented costae, and an anterior chamber which is formed by about 14 free end of the longitudinal curved costae. It is new to Japan. Previously recorded from Denmark and Norway (THOMSEN, 1973, 1977; THRONDSEN, 1974).

Diaphanoeca grandis ELLIS (1930)

Lorica is composed of 11 to 12 longitudinal costae which are free-ended at the anterior end and converge at the posterior one, and three transverse costal rings; one double costal ring encircles at neck and two single ones at basal portion in Japanese specimens. It is new to Japan, but recorded from many countries (ELLIS, 1930; LEADBEATER, 1972a; THOMSEN, 1973; THRONDSEN, 1974).

Stephanoeca urnula THOMSEN (1973)

Lorica is composed of a small posterior chamber and an anterior one. It is a highly complicated construction, 12 μm long and 9 μm wide. This species is new to Japan. Previously recorded from Denmark only (THOMSEN, 1973).

Savillea micropora (NORRIS) LEADBEATER (1974)

Lorica is formed by 12–14 longitudinal costae and a certain number of transverse ones, 5–8 μm long and 5.5–7 μm wide, and is composed of expanded anterior chamber and a small posterior chamber. This species is new to Japan. Previously recorded from U.S.A. and England (NORRIS, 1965; LEADBEATER, 1975).

Prymnesiophyceae

Prymnesiales

Genus *Chrysochromulina*

Chrysochromulina birgeri HÄLLFORS et NIEMI (1974)

Many dissociated scales were found in the bottom of the sea ice and three meters deep of the lake water. Scale surface shows a pattern of radial ridges arrnaged in quadrant. The large scale possesses two horn-like projections which are connected by a narrow bridge across the scale center. This species is new to Japan. Previously recorded from Finland (the entrance of the Gulf of Finland) (HÄLLFORS and THOMSEN, 1979).

Rhizopoda

Heliozoa

Genus *Pinaciophora*

Pinaciophora denticulata THOMSEN (1978)

syn. *Potamodiscus kalbei* GERLOFF (1968)

Plate scales and spine scales were found in three meters deep water of the lake. Plate scales are circular to oval, with large perforations, minute pores closely arranged, and intercalary materials. Spine scales are tubular, with minute spines at distal end and the basal plate. This species is new to Japan. Previously recorded from Germany, Peru and Denmark (GAARDER *et al.*, 1976; THOMSEN, 1978).

Pinaciophora candelabrum THOMSEN (1978)

Several spine scales were found in the bottom of the sea ice. Spine scales consist of a tubular shaft with a flattened bifurcate tip and a complicate basket-like base. It is new to Japan. Previously recorded from a type locality in Denmark (THOMSEN, 1978).

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References

BRADFORD, J.M. (1978): Sea ice organisms and their importance to the Antarctic ecosystem (Review). N. Z. Antarct. Rec., **1**(2), 43–50.

ELLIS, W.N. (1929): Recent researches on the Choanoflagellata (Craspedomonadines) (fresh-water

and marine) with description of new genera and species. Ann. Soc. R. Zool. Belg., **60**, 49–88, Pls. 2.

GAARDER, K.R., FRYXELL, G.A. and HASLE, G.R. (1976): *Potamodiscus kalbei* GERLOFF, an organism with siliceous scales. Arch. Protistenkd., **118**, 346–351.

HÖLLFORS, G. and THOMSEN, H. (1979): Further observations on *Chrysochromulina birgeri* (Prymnesiophyceae) from the Tvärminne archipelago, SW coast of Finland. Acta Bot. Fenn., **110**, 41–46.

HORNER, R.A. (1977): History and recent advances in the study of ice biota. Polar Ocean, ed. by M.J. DUNBAR. Calgary, Arctic Inst. North Am., 269–284.

HOSHIAI, T. (1977): Seasonal change of ice communities in the ice near Syowa Station, Antarctica. Polar Ocean, ed. by M.J. DUNBER. Calgary, Arctic Inst. North Am., 307–317.

HOSHIAI, T. (1979): Kaihyô to seibutsu-gun (Note on the ecology of ice biota). Engan Kaiyô Kenkyû Nôto (Bull. Coastal Oceanogr.), **17**, 25–32.

LEADBEATER, B.S.C. (1972a): Fine structural observations on some marine choanoflagellates from the coast of Norway. J. Mar. Biol. Assoc. U.K., **52**, 67–79.

LEADBEATER, B.S.C. (1972b): *Paraphysomonas cylicophora* sp. nov., a marine species from the Coast of Norway. Norw. J. Bot., **19**, 179–185.

LEADBEATER, B.S.C. (1975): A microscopical study of the marine Choanoflagellate *Savillea micropora* (NORRIS) comb. nov., and preliminary observations on lorica development in *S. micropora* and *Stephanoeca diplocostata* ELLIS. Protoplasma, **83**, 111–129.

LUCAS, I.A.N. (1967): Two new marine species of *Paraphysomonas*. J. Mar. Biol. Assoc. U.K., **47**, 329–334.

LUCAS, I.A.N. (1968): A new member of the Chrysophyceae, bearing polymorphic scales. J. Mar. Biol. Assoc. U.K., **48**, 437–441.

NORRIS, R.E. (1965): Neustonic marine Craspedomonadales (Choanoflagellates) from Washington and California. J. Protozool., **12**, 589–602.

TAKAHASHI, E. (1978): Electron Microscopical Studies of the Synuraceae (Chrysophyceae) in Japan—Taxonomy and Ecology. Tokyo, Tokai Univ. Press, vi+194p.

THOMSEN, H.A. (1973): Studies on marine choanoflagellates I. Silicified choanoflagellates of the icefjord (Denmark). Ophelia, **12**, 1–26.

THOMSEN, H.A. (1975): An ultrastructural survey of the chrysophycean genus *Paraphysomonas* under natural conditions. Br. Phycol. J., **10**, 113–117.

THOMSEN, H.A. (1977): Studies on marine choanoflagellates III. An electron microscopical survey of the genus *Acanthoecopsis*. Arch. Protistenkd., **119**, 86–99.

THOMSEN, H.A. (1978): On the identity between the heliozoan *Pinaciophora fluviatilis* and *Potamodiscus kalbei;* with the description of eight new *Pinaciophora* species. Protistologica, **14**, 359–373.

THRONDSEN, J. (1974): Planktonic choanoflagellates from North Atlantic waters. Sarsia, **56**, 95–122.

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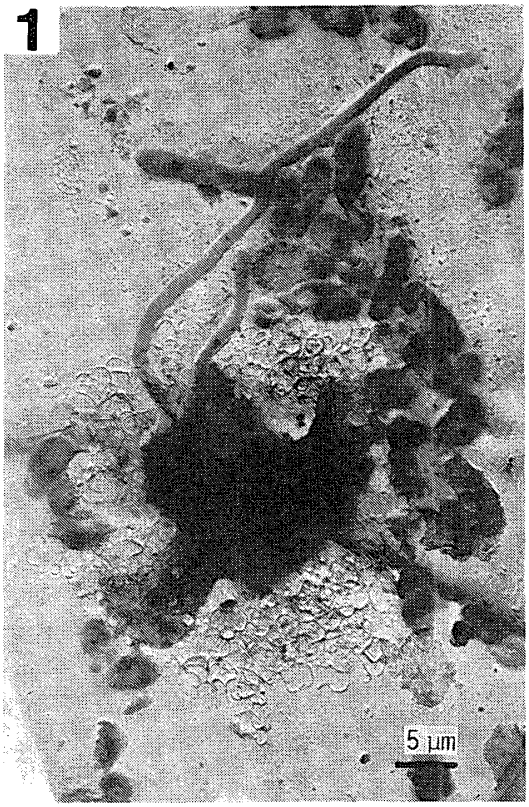
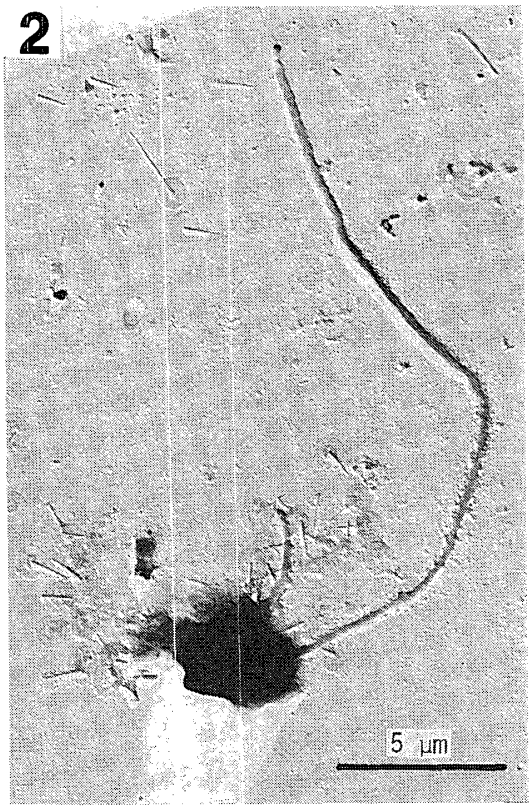
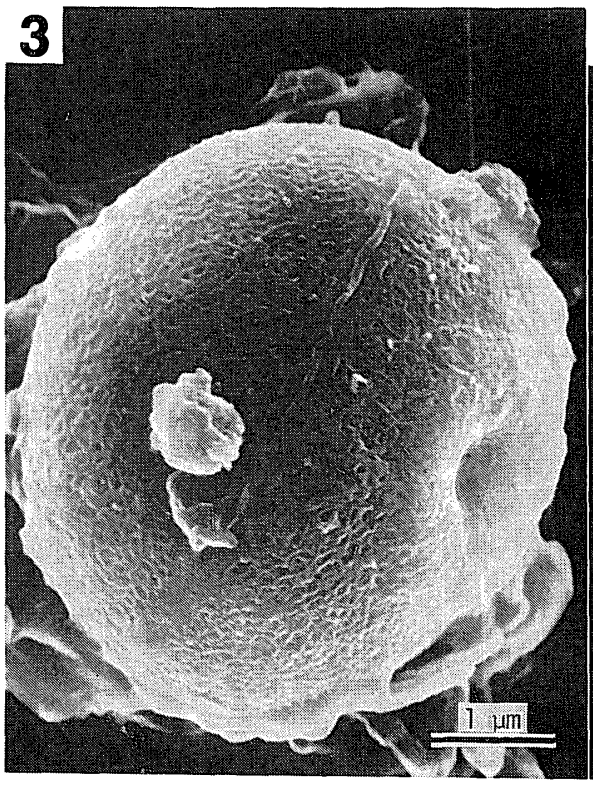
Plate I

Fig. 1. *Paraphysomonas butcheri;* a cell and scales.
Fig. 2. *Paraphysomonas imperforata;* a cell and scales.
Fig. 3. Cyst of *Paraphysomonas butcheri* (SEM).
Fig. 4. Cyst of *Paraphysomonas imperforata* (SEM).

Plate I







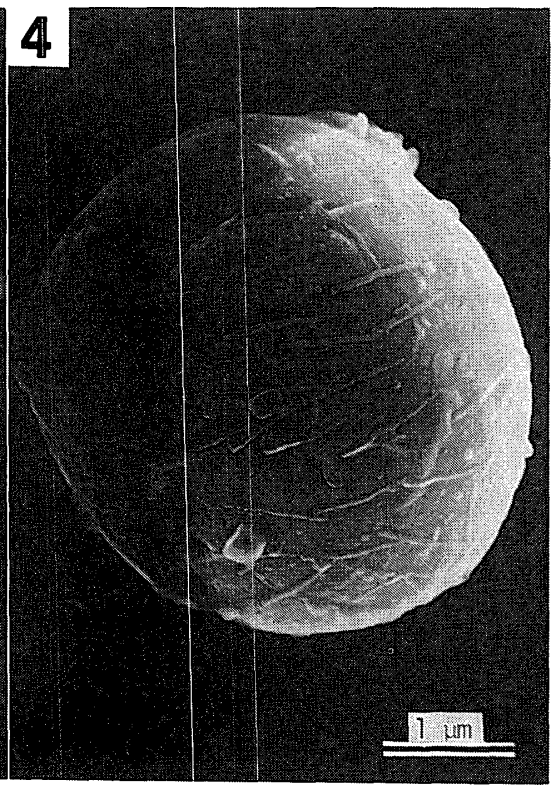


Plate II

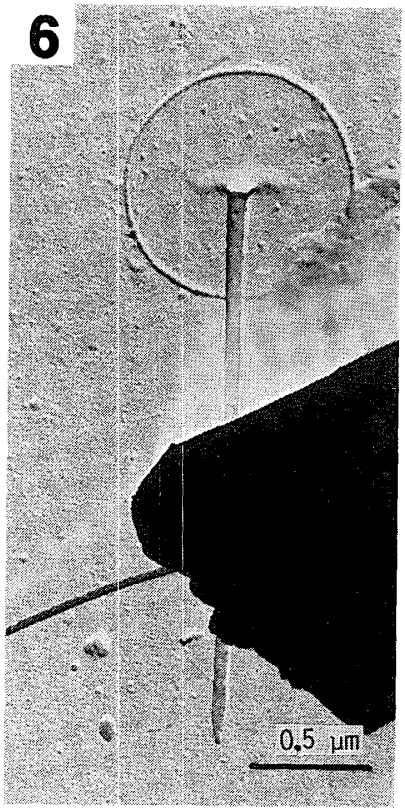
Fig. 5. A flat-iron like body-scale of *Paraphysomonas sideriophora* (upper one) and two plate scales of *P.* cf. *cribosa* (under two).

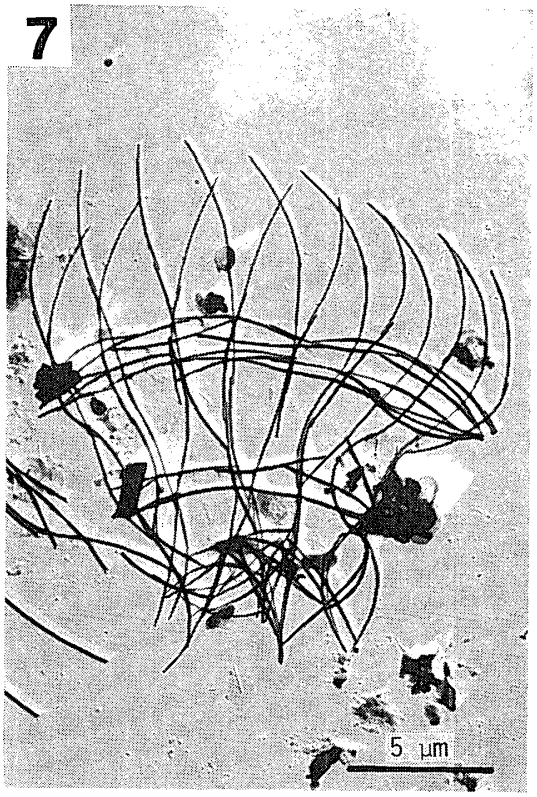
Fig. 6. A scale of *Paraphysomonas vestita.*

Fig. 7. *Acanthoecopsis apoda;* an intact lorica.

Fig. 8. *Acanthoecopsis unguiculata;* an intact lorica.

Plate II





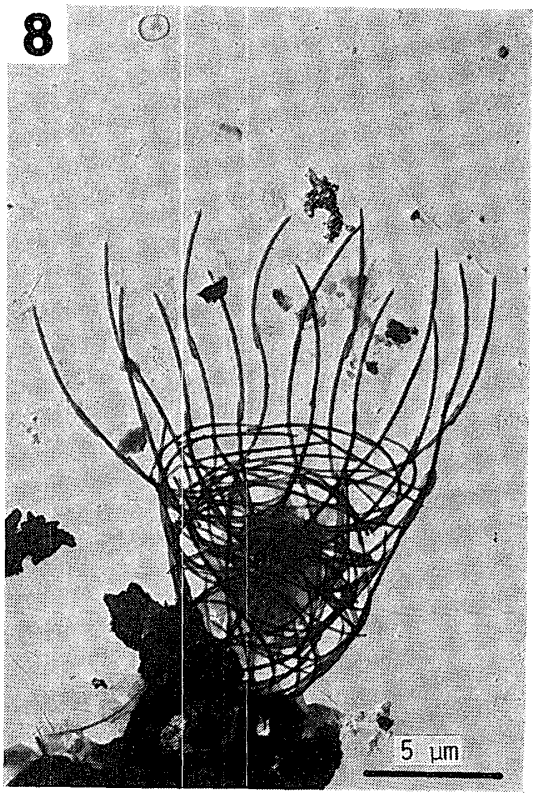
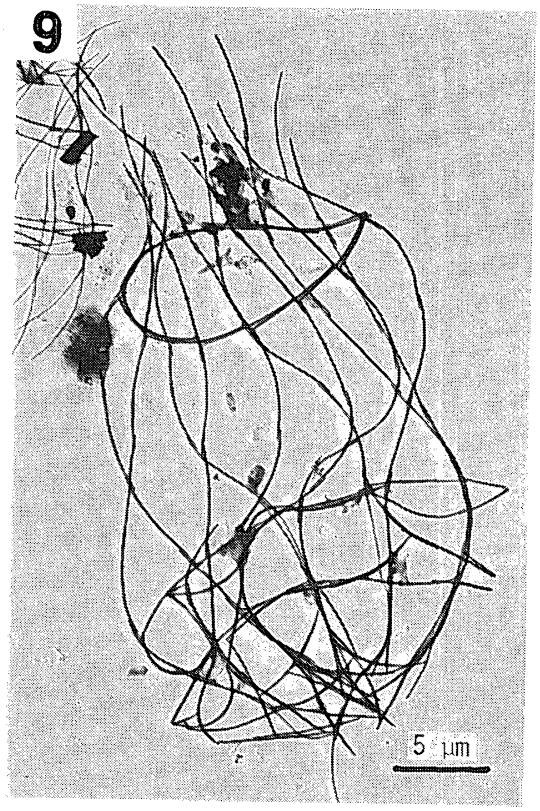


Plate III

Fig. 9. *Diaphanoeca grandis;* an intact lorica.
Fig. 10. *Stephanoeca urnula;* a intact cell.
Fig. 11. *Savillea micropora;* an intact cell.
Fig. 12. *S. micropora;* three loricae.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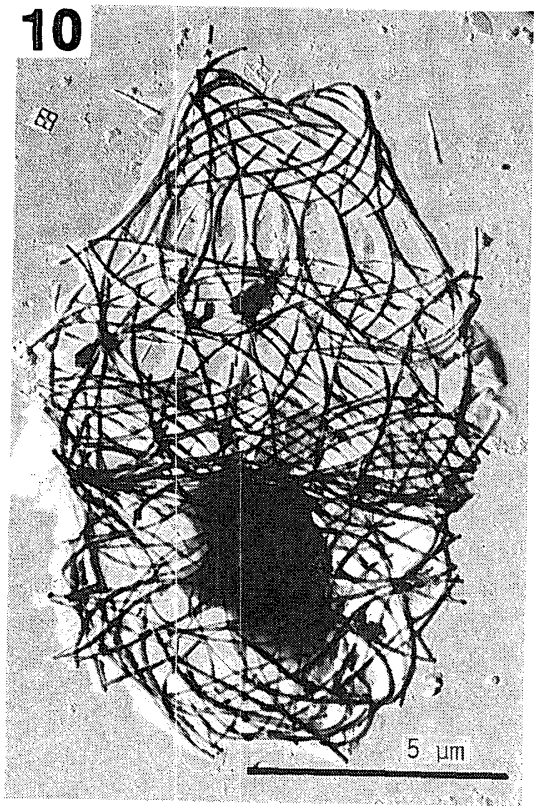
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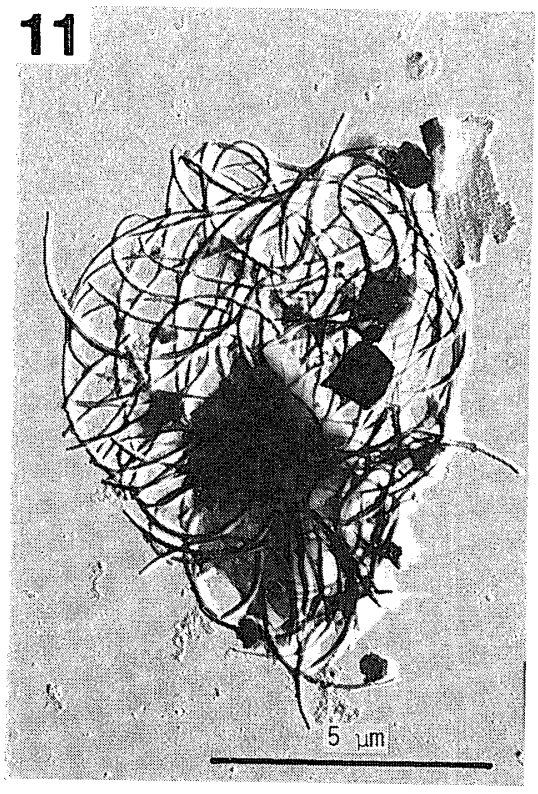
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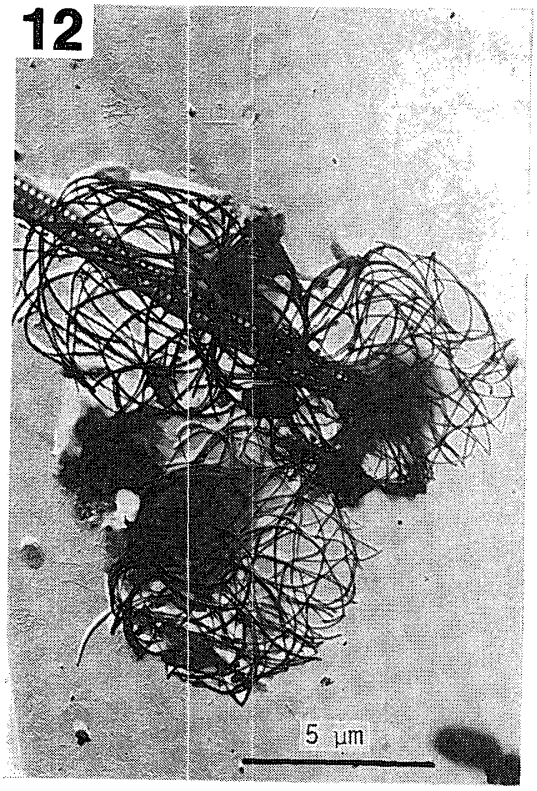
12
5 µm

Plate IV

Fig. 13. *Chrysochromulina birgeri;* scales.

Fig. 14. *Pinaciophora denticulata;* two plate scales and three spine scales.

Fig. 15. *Pinaciophora candelabrum;* a spine scale.

Plate IV