RECENT THECATE AND FOSSILIZED DINOFLAGELLATES OFF HACHINOHE COAST, NORTHEASTERN JAPAN

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With Text-figures 1–2 and Plates I–IV

Contents

Introduction

It has long been known that a few species of dinoflagellates such as *Ceratium hirundinella* produce cysts or resting spores at a certain stage of the life cycle (Huber and Nipkow, 1922 and 1923 in Sarjeant, 1974). The fact, on the other hand, that the dinoflagellates obtained from bottom sediments including hystrichospheres in a narrow sense are fossilized cyst forms is recently clarified by Evitt (1963) and others. On the bases of these knowledges, much has been added to the information on the occurrence and distribution of the dinoflagellate cysts in the Pleistocene and Recent sediments (Rossignol, 1962; Wall, 1967; Wall, Dale and Harada, 1973; Reid and Downie, 1973; Harland, 1973; Reid, 1974; Davey and Rogers, 1975).

For the northwestern Pacific, Boulouard and Delauze (1966) first reported on the occurrence of dinoflagellate cysts referred to the fossil genera *Leptodinium* and *Spiniferites* accompanied by some acritarchs, *Concentricystes* and other various palynomorphs from the Japan Trench off Sendai (4,500 m in depth) and off Boso Peninsula (9,200 m in depth). They were followed by Shimakura (1970) who preliminarily took the reports and found that Recent dinoflagellate assemblage in the sediments of the Sea of Japan was composed of many species of *Operculodinium* and *Spiniferites* with additional forms such as *Nematosphaeropsis labyrinthea*, *Peridinium* spp., and *Tuberculodinium vancampoae*. Then, Matsuoka and Nishida (1973) reported the occurrence of fossil dinoflagellate cysts such as *Leptodinium, Spiniferites, Hemicystodinium, Hystrichokolpoma* and *Tuberculodinium* from the Pliocene to Recent sediments off Kii Peninsula and off Shikoku, while Harada (1974, MS.) studied on the distribution of dinoflagellate cysts and acritarchs in Recent bottom sediments on the continental margins of the western North Pacific, mainly off Northeastern Japan.

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Some authors, though they are not many, have discussed on the relationship between motile thecate dinoflagellates (generally in the planktonic life phase) and fossilized cysts in the bottom sediments from the same sampling areas. Reid (1972, 1974) treated of the distribution of the thecate and cyst forms of dinoflagellates around the British Isles. Davey and Rogers (op. cit.) also discussed on this relationship in their study about palynomorphs from the Recent sediments off South Africa.

Around the northwestern Pacific, on the other hand, there has been till now no reports dealing with this problem. The present article is prepared to describe the dinoflagellate assemblages of both thecate forms in the surface water and fossilized cysts in the bottom sediments collected from the same locations off Hachinohe, northeast coast of Honshu Island of Japan. Furthermore, the remarkable differences in their components as observed between the thecate and the cyst assemblages are discussed, and finally are given the brief descriptions of several cyst forms mainly of the genus *Peridinium*.

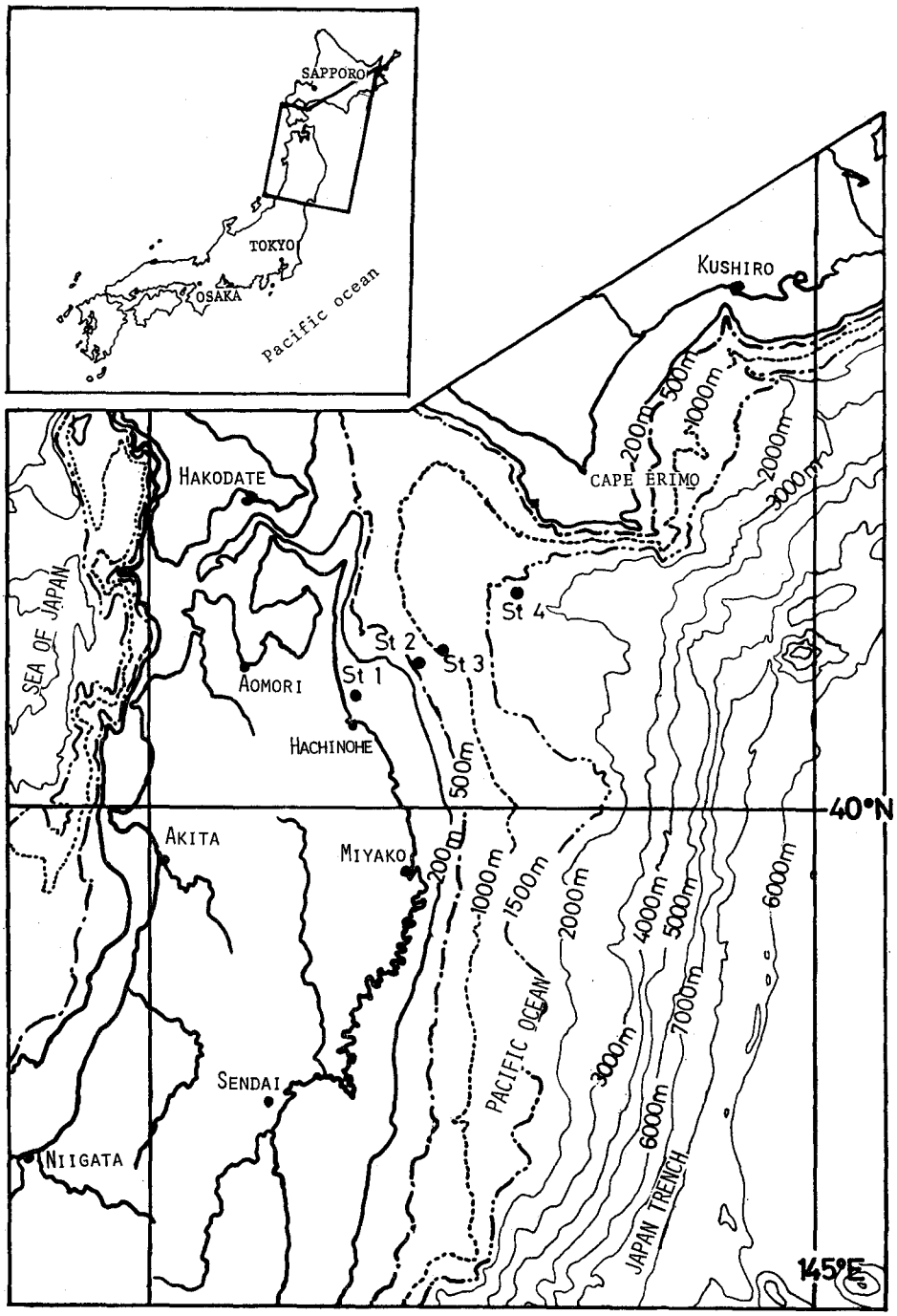
Methods of Sampling and Preparation

Both plankton net and dredged bottom samples were collected from off Hachinohe coast during the research cruise KT 73–5 made in May, 1973, by the MSV "Tansei Maru" of the Ocean Research Institute of the University of Tokyo. The plankton was sampled at the same stations as for the dredging by means of a plankton net (250 mesh) hauled up vertically from the depth of 50 m or 200 m. The collected plankton was fixed with dilute formalin solution in 250 cc polyethylene bottles, and preserved at room temperature. The water depth and surface water temperature at each station are given in Table 1.

Table 1. Sampling data off Hachinohe in Cruise KT73–5 (May, 1973).

Station	Latitude	Longitude	Water depth	Surface water temp.	Bottom sample	Net sample
St. 1	40°36.6′N	141°36.5′E	62 m	10.2°C	Dredge	50 m (vertical)
St. 2	40°49.5′N	142°02.0′E	550 m	9.2°C	Dredge	200 m (vertical)
St. 3	40°53.7′N	142°11.3′E	1010 m	9.4°C	Dredge	none
St. 4	41°12.8′N	142°45.5′E	1730 m	7.0°C	Dredge	200 m (vertical)

A large amount of phyto- and zooplankton was found from the surface samples. Among the former, diatoms especially *Coscinodiscus* spp. are very abundant and followed by dinoflagellates and silicoflagellates. In zooplankton samples are observed copepods, tintinnids and foraminifers in order of abundance. For removing larger organisms such as *Coscinodiscus* and copepods, the samples were sifted through a 100 mesh screen. In order to concentrate the dinoflagellates a smaller fraction was centrifuged and then mounted on a slide glass with glycerine jelly. The separation of cysts from the sediments was generally carried out according to Shimakura's method (1970). To avoid the destruction of some *Peridinium* cysts, especially those with single, thin and dark brownish wall, the samples were treated intentionally with



Text-fig. 1. Location of sampling stations together with bathymetric contours.

much more dilute alkali solutions. Finally, as in the same with plankton samples, palynomorphs were concentrated and mounted on a slide glass with glycerine jelly.

The observation was done under an optical microscope and occasionally under a scanning electron microscope.

More than 200 individuals of both plankton forms and cysts were counted at random just as in the case of a pollen analysis.

The figured specimens and a part of the original samples of the present study are deposited in the Laboratory of Palaeobotany, Osaka City University.

Observations

The thecate and fossilized dinoflagellates obtained from both plankton and sediment samples off Hachinohe Coast are listed in Tables 2 and 3.

Table 2. List of dinoflagellate cysts collected from the bottom sediments off Hachinohe, northeastern Japan

	St. 1	St. 2	St. 3	St. 4
Leptodinium sp.		*		*
Lingulodinium machaerophorum		*		*
Nematosphaeropsis labyrinthea				*
Operculodinium centrocarpum		*	*	*
Operculodinium islaerianum				*
Peridinium conicoides	*	*	*	*
Peridinium ? denticulatum	*			*
Peridinium sp. cf. *P. ? denticulatum*				*
Peridinium leonis		*		*
Peridinium oblongum		*	*	
Peridinium sp. aff. *P. oblongum*		*	*	
Peridinium sp. cf. *P. pentagonum*		*		*
Peridinium sp. cf. *P. punctulatum*		*		*
Peridinium sp. cf. *P. subinerme*		*	*	
Peridinium sp. (Cyst-form A)		*		*
Peridinium sp. (Cyst-form B)		*		*
Peridinium sp. (Cyst-form C)		*	*	
Peridinium sp. (Cyst-form D)				*
Peridinium spp.		*	*	*
Spiniferites bentori			*	*
Spiniferites bulloideus		*	*	
Spiniferites mirabilis		*	*	*
Spiniferites nodosus				*
Spiniferites ramosus		*		*
Spiniferites spp.		*	*	*
Tuberculodinium vancampoae		*		

* Present

Table 3. List of pelagic dinoflagellates collected from the surface plankton off Hachinohe, northeastern Japan

	St. 1	St. 2	St. 4
Ceratium articum	*	*	*
Ceratium bucephalum	*	*	
Ceratium fusus	*	*	
Ceratium kofoidii	*		
Ceratium spp.		*	*
Diplopsalis lenticula			*
Gonyaulax sp. indet.			*
Peridinium berve	*	*	*
Peridinium conicoides	*		*
Peridinium conicum	*	*	*
Peridinium crassipes	*	*	*
Peridinium depressum	*	*	*
Peridinium inflatum			*
Peridinium islandicum		*	*
Peridinium leonis	*		*
Peridinium pellucidum	*		*
Peridinium subinerme	*		
Peridinium thorianum	*	*	*
Peridinium wiesneri	*		*
Peridinium spp.	*	*	*
Dinophysis acuta	*		*
Dinophysis fortii	*	*	*
Dinophysis ovum	*		
Dinophysis sp. indet.	*	*	*
Phalacroma rotundata			*

* Present

The plankton and fossilized cyst assemblages observed at each station are as follows:

St. 1: The plankton assemblage consists mainly of common genera *Peridinium* and *Ceratium*. In the former group, *Peridinium depressum* is predominant and is followed by *P. thorianum* and *P. conicum*.

The fossilized cyst assemblage is very poor because the sediment sample is coarse and sandy. Only a few *Peridinium* cysts are obtained.

St. 2: The plankton assemblage is almost exclusively made up of *Peridinium depressum*. Small numbers of *Peridinium crassipes* and *Ceratium* spp. are also found. The occurrence of a warm water species, *P. crassipes*, is noteworthy.

The fossilized cyst assemblage is composed of several species of *Peridinium* cysts, *Spiniferites mirabilis*, *S. ramosus* and *Operculodinium centrocarpum*. It is noticeable that a few specimens of *Tuberculodinium vancampoae* which is the cyst form of the warm-water species, *Pyrophacus vancampoae* (Rossignol), were found.

St. 3: At this location a plankton sample was not available.

The fossilized cyst assemblage consists of a few *Peridinium* cysts, *Operculodinium centrocarpum* and *Spiniferites mirabilis*.

St. 4: Just as in the other plankton samples, *Peridinium depressum* and other *Peridinium* species make up more than 90 per cent of the plankton population. It is important that many individuals of *Peridinium conicoides* enveloping the cyst within are found together with some thecate specimens.

Operculodinium centrocarpum occupies more than 60 per cent of the present fossilized cyst population, and *Peridinium* group makes up 80 per cent of the remaining part. A pelagic cyst form with *Gonyaulax* type tabulation corresponding to the fossil genus *Leptodinium* was not found except for a few specimens from this sample.

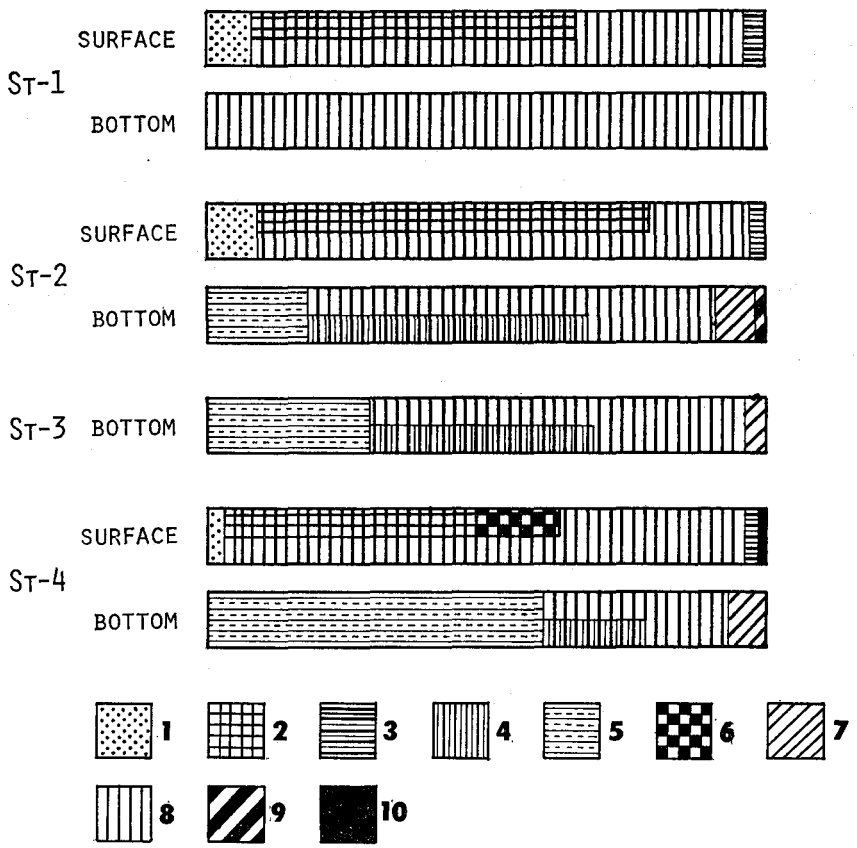
No cyst form of the genera *Ceratium* and *Dinophysis*, commonly occurring dinoflagellates in the surface plankton, was obtained from any present sediment sample. Generally speaking, the dinoflagellate assemblage of both plankton and sediment samples off Hachinohe Coast are characterized by a predominant occurrence of the genus *Peridinium*, but on the specific level there is a distinct difference between them.

Discussions

As shown in Table 3 and Text-fig. 2, each thecate assemblage is characterized by an abundant occurrence of *Peridinium depressum* and very rare occurrence or lack of *Gonyaulax* and *Protoceratium* groups. On the other hand, most cyst assemblages are made up of *Peridinium conicoides*, *P.* ? *denticulatum*, *P.* sp. cf. *P.* ? *denticulatum*, *P. oblongum* and *P.* sp. aff. *P. oblongum*. Furthermore, *Operculodinium centrocarpum*, a cyst form of the thecate species *Protoceratium reticulatum*, and *Spiniferites*, one of the typical cyst forms of thecate genus *Gonyaulax*, are relatively abundant in the cyst assemblages, although these dinoflagellates were not found from the present thecate assemblages.

The remarkable differences as observed between the living assemblage in the

water column, the biocoenosis, and the fossilized one in the bottom sediments, the thanatocoenosis, at relatively smaller areas have already been well documented and some possible explanations have been suggested for the differences in the case of other smaller planktonic organisms. As an example for calcareous planktonic foraminifers and coccolithophorids, the differences may result from the following factors: morphological characteristics such as fine spines of planktonic foraminifers, central



Text-fig. 2. Percentage frequency of thecate and fossilized dinoflagellates in surface plankton and bottom sediments.
1: *Ceratium* spp., 2: *Peridinium depressum*, 3: *Dinophysis* spp., 4: spherical cysts of *Peridinium* spp. such as *Peridinium conicoides*, *P.*? *denticulatum*, etc. 5: *Operculodinium centrocarpum*, 6: *Peridinium conicoides* (thecate form), 7: *Spiniferites* spp., 8: *Peridinium* spp. 9: *Tuberculodinium vancampoae*, 10: *Diplopsalis lenticula*.

bridge structures and arrangement of calcite crystal grains of coccolithophorids, and dissimilarity of CCD in each species (Roth and Berger, 1975).

In the case of the present dinoflagellate assemblages, the following factors may explain the differences. First, as the sampling of planktonic thecate dinoflagellates was carried out only once in a particular season, the obtained result may not necessarily represent the conclusive dinoflagellate assemblages throughout the year. The

fossilized cyst assemblages in the bottom sediments, on the other hand, seem to show a genaral aspect of cysts produced during the last many years. In addition, some of the cysts may have been transported from other area by ocean currents. Secondly, only certain members of thecate dinoflagellates produce the resting spores but others do not, and at present the cyst-theca relationship of modern dinoflagellates producing spores is not clarified sufficiently. According to the single cell excystment experiments carried out by Wall and Dale (1968, 1969, 1970 and 1971), the cyst-theca relationship of about six genera including ten species of modern dinoflagellates has been established. In Pleistocene sediments, many dinoflagellate cysts have been reported as hystrichospheres (Rossignol, 1964). Reid (op. cits.) discussed the discordant occurrence between planktonic thecate and fossilized cyst forms of modern dinoflagellates around the British Isles. And then he (1974) described many gonyaulacacean dinoflagellate cysts. Those thecate and motile forms, however, have been quite unknown. Furthermore, in such genera as *Ceratium,* with the exception of a few freshwater species, and *Dinophysis,* both universally distributed in world oceans, their resting spores have never been clarified.

According to Davey and Rogers (1975), off the southwest coast of South Africa, *Operculodinium centrocarpum* is associated with the warm-water Agulhas current, while *Spiniferites ramosus* is associated with the cold-water Benguela current. The same aspect of distrubution of these dinoflagellates was pointed out in the Atlantic region also by Williams (1970).

Around the Japanese Island, two major current systems are present; the warm-water Kuroshio and Tsushima currents on the one hand and the cold-water Oyashio current on the other. The present study area is under the influence of the Tsugaru current which is a branch of warm water divided from the Tsushima current and is streaming from the Sea of Japan through the Tsugaru Strait into the Pacific towards the southern district of Hokkaido and the northeastern district of Honshu. Therefore, the fact that *Operculodinium centrocarpum* occurred more abundantly than *Spiniferites ramosus* in the present bottom sediments is concordant with the previous works in the Atlantic and off South Africa.

The general life cycle of dinoflagellates is interpreted by Wall and Dale (op. cits.) as follows: in the favorable condition such as late spring to early summer, the life phase of *Gonyaulax,* for example, is planktonic with two flagella, many plates and platelets, and much food reserves are accumulated by active photosynthesis. When the environmental condition becomes unfavorable in autumn and winter, the thecate *Gonyaulax* bears a cyst and takes a benthonic life phase on the shallow sea bottom. Its fossilized hystrichospherid cysts such as *Spiniferites* and *Lingulodinium* do not morphologically resemble thecate and motile form at all, and are frequently collected from the bottom sediments in the coastal area. On the other hand, the fossil genus *Leptodinium* with *Gonyaulax* type tabulation is mostly obtained from the deep-sea bottom sediments in a pelagic area, and appears to lack a benthonic life phase. But life cycles of modern dinoflagellates have been poorly investigated in the natural state,

and only a few knowledges are available as to how the encystment cells with protoplasm behave in the water column.

The present findings of *Peridinium conicoides* at encystment stage covered with thecate wall in the surface plankton sample may throw some light on the understanding of the life cycle of the pelagic species. These encystment specimens were obtained from the plankton sample at St. 2 and St. 4, in which the specimens were relatively abundant. At St. 4 the depth is 1,740 m and its surface water temperature was 7°C. Undoubtedly the bottom floor must be aphotic, and its water temperature may be less than 4°C, possibly throughout seasons. If the encystment cells fall down into such unfavorable environments, it may be impossible for them to germinate and to retake a planktonic life phase. Judging from rare occurrence of these cysts enclosed with thecate wall in the surface plankton at St. 1 and St. 2, the encystment cells of *Peridinium conicoides* are not considered to have been drived from the photic zone near the coastal area. Therefore, it seems likely that the dinoflagellates with the planktonic life phase distributed in the pelagic zone may take a planktonic resting phase at an encystment stage.

Systematic Description

Division PYRRHOPHYTA Pascher, 1914

Class DINOPHYCEAE Fritsch, 1929

Order PERIDINIALES Haeckel, 1894

Family Peridiniaceae Ehrenberg, 1832

Genus Peridinium Ehrenberg, 1832

Peridinium conicoides Paulsen, 1905

Pl. II, figs 5–9.

Cyst-form

Chytroeisphaeridea simplica Wall, 1966; p. 308, text-figs. 7, 20.
Peridinium conicoides Paulsen: Wall and Dale, 1968; p. 277, pl. 2, figs. 29, 30.

Description:

The thecate specimens have a slightly tapering apical and two small hollow antapical horns, and are characterized by a sulcal region broadening posteriorly. The cyst enclosed in the thecate wall is dark brownish, mostly circular on lateral view and of thick wall. In the sediment samples collected from St. 1, St. 2, St. 3 and St. 4, these cyst forms are identified with *Peridinium conicoides* based on the structure of mid-dorsal, intercalary, trapezoidal archeopyle corresponding to plate 2a with two short and four long sides.

Dimension:

Thecate form; length 34–56μ, width 37–56μ.

Cyst form; length 30–40μ, width 34–46μ.

Remarks:

Several thecate forms enclosing resting spores were found together with other planktonic thecate dinoflagellates from St. 2 and St. 4. On the other hand, there are no specimens of thecate forms in the sample at St. 1.

The significance of finding these thecate forms enclosing the resting spores has been already discussed in detail (p. 357–358).

Peridinium? *denticulatum* Gran and Braarud, 1935

Pl. III, fig. 12.

Cyst-form

Peridinium ? denticulatum Gran and Braarud: Wall and Dale, 1968; p. 277, pl. 3, fig. 30.

Description:

The cyst is spherical, dark brown, and of smooth wall surface and has a hexagonal intercalary archeopyle expanded equatorially.

Dimension:

Cyst diameter 56μ–76μ, archeopyle 22$\mu \times$42μ on an average.

Remarks:

The present specimens are slightly larger than those previously described by Wall and Dale (1968); the average diameter is 68μ in the former and 56μ in the latter.

Peridinium sp. cf. *P.*? *denticulatum* Gran and Braarud, 1935

Pl. III, fig. 10

Cyst-form

Cf. *Peridinium ? denticulatum* Gran and Braarud: Wall and Dale, 1968; p. 277, pl. 3, fig. 30.

Description:

The cyst has spherical, dark brownish wall, and a hexagonal anterior intercalary archeopyle with two long and four short sides expanded equatorially.

Dimension:

Cyst diameter 37μ on an average.

Remarks:

The present specimens are closely similar to *Peridinium*? *denticulatum* shown by Wall and Dale (1968) in general shape and its characteristic archeopyle. The former specimens, however, are much smaller than the latter.

Peridinium leonis Pavillard, 1916

Pl. III, fig. 9

Cyst-form

Peridinium leonis Pavillard: Wall and Dale, 1968; p. 276, pl. 2, figs. 18–21, pl. 3, fig. 22.

Description:

The cyst is roundly peridinioid in outline and has brownish and smooth wall surface. The epitract is broadly conical in shape. The apex is minutely flattened. Its archeopyle is a single anterior intercalary type corresponding to plate 2a, and roundly pentagonal in shape. The hypotract is tapered toward antapex and has two asymmetrical antapical projections. The girdle region is represented by two parallel ridges well developed.

Dimension:

Cyst length 69μ–71μ, width 75μ–80μ, diameter of archeopyle 15μ–17μ×13μ–15μ.

Remarks:

The present specimens from the bottom sediments off Hachinohe are slightly larger than those reported by Wall and Dale (1968). Except for the cyst size, the morphological features, that is the pentagonal intercalary archeopyle, characteristic girdle zone reflected by two parallel ridges, and minutely flattened apex, coincide well with their descriptions.

Peridinium oblongum (Aurivillius) Paulsen, 1907

Pl. III, figs. 2, 3, Pl. IV, figs. 4, 5

Cyst-form

Peridinium sp. (Cyst-forms 1, 3, 4): Wall, 1966; p. 304–307, text-figs. 8, 9, 11, 13–15, 22.
Peridinium oblongum (Aurivillius) Paulsen: Wall and Dale, 1968; p. 272–273, pl. 1, figs. 22–29, pl. 3, figs. 9–11.
Peridinium oblongum (Aurivillius) Paulsen: Davey and Rogers, 1975; pl. 1, fig. 11.

Description:

The test is roundly pentagonal to subconical in shape, and has two distinctive antapical horns with subtriangular to hexagonal intercalary archeopyle corresponding to plate la or 2a.

Dimension:

Cyst length 62μ–73μ, width 61μ–73μ.

Remarks:

Wall and Dale (1968) divided the cyst forms of *Peridinium oblongum* into three types on the bases of variation in its apical and antapical regions and general shape. The specimen figured in Pl. III, fig. 2 is assigned to their second type, and another figured specimen (Pl. III, fig. 3) to their third type, respectively.

Peridinium sp. aff. *P. oblongum* (Aurivillius) Paulsen, 1907

Pl. III, fig. 4

Cyst-form

Cf. *Peridinium oblongum* (Aurivillius) Paulsen: Wall and Dale, 1968; p. 272–273, pl. 1, fig. 28.

Description:

The test is generally pentagonal in shape without apical and antapical horns and with dark brownish and smooth cyst wall. Its archeopyle is large, hexagonal and expanded equatorially in shape with some accessory archeopyle sutures.

Dimension:

Cyst length 63μ–75μ, width 60μ–70μ.

Remarks:

The present specimens are generally similar to the second type of *Peridinium oblongum* described by Wall and Dale (1968). The former, however, is distinguished from the latter in lacking obvious apical and antapical horns and having a large hexagonal intercalary archeopyle.

Peridinium sp. aff. *P. pentagonum* Gran, 1902

Pl. III, fig. 8

Cyst-form

Cf. *Peridinium* sp. cf. *P. pentagonum* Gran: Wall and Dale, 1968; p. 274–275, pl. 2, figs. 11, 12.

Description:

The cyst is pentagonal on dorso-ventral view and separated equally into epi- and hypotract by well defined girdle without remarkable displacement. The epitract with a short conical apical boss is subroundly triangular in shape. The hypotract has two short but prominent antapical horns and a shallow sulcal region. The colorless cyst wall is ornamented with numerous, short acuminate spines. Each plate boundary is reflected by linear arrangement of these spines.

Dimension:

Cyst length 73μ, width 77μ, length of spines ca. 3μ, antapical horn 4μ.

Remarks:

These specimens closely resemble *Peridinium* sp. cf. *P. pentagonum* described by Wall and Dale (1968), but the latter differs by possessing shorter and intratabular spines.

Peridinium sp. cf. *P. punctulatum* Paulsen, 1907

Pl. III, fig. 11

Cyst-form

Cf. *Peridinium punctulatum* Paulsen: Wall and Dale, 1968; p. 276, pl. 2, fig. 27, pl. 3, fig. 25.

Description:

The cyst is spherical, dark brown and with smooth wall surface. Its archeopyle is slightly deformedly hexagonal in shape with two short sides corresponding to the second anterior intercalary plate.

Dimension:

Cyst diameter 56μ–59μ, archeopyle 19$\mu \times$ 35μ on an average.

Remarks:

It is very difficult to distinguish the present species from other spherical single walled *Peridinium* cysts such as *Peridinium avellana, P. conicoides* and *P.* ? *denticulatum.* They are, however, different in cyst diameter, and provided each with characteristic intercalary archeopyle. Actually in the present work, these spherical cysts cannot be specifically identified.

Peridinium sp. cf. *P. subinerme* Paulsen, 1904

Pl. III, fig. 1.

Cyst-form

Cf. *Peridinium subinerme* Paulsen: Wall and Dale, 1968; p. 276, pl. 2, figs. 22–24, pl. 3, fig. 23.

Description:

The test is light brown with medium striation from girdle to polar regions. In polar view, the cyst are cordiform, and dorsal area is much depressed. So the cyst is strongly compressed vertically, the lateral outline is scarcely observed. The epitract may be flat conical shape with concave side line and have small obscure apical projection. The hypotract may somtimes have one or two very small projections. The girdle region is reflected by clear deep furrow and its margin is flange-like and minutely denticulated around the dorsal area. Its relatively large archeopyle in the mid-dorsal surface is roundly hexagonal in shape and may be corresponding to the second anterior intercalary plate.

Dimension:

Cyst diameter; right to left 55μ–83μ, ventral to dorsal 54μ–74μ, archeopyle 22μ–29$\mu \times$ 28μ–30μ.

Remarks:

The present specimens are closely similar to the cyst form of *Peridinium subinerme* in general shape and in archeopyle type. The former, however, are distinct from the latter in possessing the striated wall surface, denticulated margin of the girdle on the dorsal side and stronger depression in the apical to antapical direction. Moreover, the former are larger than the latter in cyst diameter.

Peridinium sp. (Cyst-form A)

Pl. III, fig. 7

Description:

The dorso-ventral view is roundly pentagonal in shape. The wall surface is characterized by irregular wrinkles, and dark brown in color. In the apical region, the present specimens are provided with a broad but small projection. Two asymmetrical

antapical projections are observed, and relatively narrow and shallow longitudinal furrow is developed in the sulcal region. Its archeopyle may be an intercalary type corresponding to the plate 2a, and trapezoidal in shape.

Dimension:

Cyst length 57μ–77μ, width 60μ–75μ.

Remarks:

The present specimens resemble the cyst of *Peridinium claudicans* in the general outline of the dorso-ventral view and in the shape of archeopyle. According to Wall and Dale (1968), however, *Peridinium claudicans* produces a cyst covered with numerous short point-like spines. Also, the cyst of *P. oblongum* is distinguished from the present specimens in having smooth and thin wall and a deep antapical sulcus.

Peridinium sp. (Cyst-form B)

Pl. III, fig. 5.

Description:

The test with an inner capsule is a peridinioid shape with a truncated epitract. The outer wall is light brown, thin and of smooth surface; the inner capsule is dark brown in color. The outer body has two short asymmetrical antapical projections and relatively deep sulcus. Its archeopyle may be a large one and of combination type composed of apical and anterior intercalary plates. The upper part of the inner capsule is subspherical, but the lower part has two roundish projections such as those of the outer body. Also, there is a narrow sulcus in the lower part of the capsule. The opening of the inner capsule is not clear.

Dimension:

Outer wall; length 52μ, width 56μ. Inner capsule; length 45μ, width 49μ.

Remarks:

Only a single specimen has been obtained from the bottom sediment at St. 4. This specimen is characterized by having an inner capsule. Modern *Peridinium* cysts possessing an inner capsule such as observed in fossil genera *Deflandrea* and *Wetzeliella* have been reported by Eisenack and Fries (1965), Evitt and Wall (1968), and Wall and Dale (1968). Those cysts are produced by freshwater species, *Peridinium limbatum* and *P. wisconsinense*. Their inner capsule is spherical to subspherical in shape and lacks a sulcus in the antapical region. The present specimen is noteworthy in having the inner capsule with a narrow sulcus.

? *Peridinium* sp. (Cyst-form C)

Pl. III, fig. 13.

Description:

This specimen is a half pentagonal cyst ornamented with numerous and relatively

long acuminate spines, and provided with two asymmetrical projections in the hypotract.

Dimension:

Cyst length 56μ, width 50μ, antapical projection ca. 10μ, length of spine ca. 12μ.

Remarks:

According to its general shape and two asymmetrical projections, the present cyst seems to belong to a species of *Peridinium*.

Peridinium sp. (Cyst-form D)

Pl. III, fig. 6.

Description:

The specimens with smooth, dark brown and single layered wall are roughly pentagonal in shape. The trapezoidal hypotract has a moderately deep ventral sulcus and the epitract has the trapezoidal archeopyle reflected by the second anterior intercalary plate in mid-dorsal position. They have an obvious ridged girdle zone.

Dimension:

Cyst length 45μ–63μ, width 49μ–65μ, archeopyle 19μ–24$\mu \times$ 15μ–19μ.

Remarks:

The present specimens represent a general resemblance to the cyst form of *Peridinium* sp. 1 described by Wall and Dale (1968), but differ from the latter in the shape of the archeopyle and the epitract.

Family Protoceratacеae Lindemann, 1928

Cyst-genus Operculodinium Wall, 1967

Operculodinium centrocarpum (Deflandre and Cookson) Wall, 1967

Pl. II, fig. 10

Hystrichosphaeridium centrocarpum Deflandre and Cookson, 1955: p. 272–273, pl. 8, figs. 3, 4.
Baltisphaeridium centrocarpum (Defl. and Cook.) Downie and Sarjeant: Brosius, 1963; p. 44, pl. 6, fig. 6, text-fig. 8a, b.
Protoceratium reticulatum Claparede and Lachmann: Evitt and Davidson, 1964; p. 5, pl. 1, fig. 12.
Operculodinium centrocarpum (Defl. and Cook.) Wall, 1967: p. 111, pl. 16, figs. 1, 2, 5.
Operculodinium centrocarpum (Defl. and Cook.) Wall: Harland, 1973; p. 236–239, pl. II, figs. 4, 7–16, pl. III, figs. 1–6, pl. IV, figs. 1, 2.

Description:

Operculodinium centrocarpum, the cyst form of *Protoceratium reticulatum*, has a spherical body covered with numerous nontabular capitate processes. Its archeopyle is of a precingular type.

Dimension:

Cyst diameter 24μ–35$\mu \times$ 26μ–39μ, length of processes 4μ on an average.

Remarks:

This species makes up 20 per cent to 60 per cent of the thanatocoenosis population of the bottom sediments at St. 2 and St. 4. But none was sampled at St. 1. In the surface plankton at St. 4, a few specimens of *Operculodinium centrocarpum* enclosing the protoplasts with dark brown thick wall are found. These specimens are smaller than the excystment forms with the precingular archeopyle taken from the bottom sediments.

Family Pyrophacaceae Lindemann, 1928

Cyst-genus Tuberculodinium Wall, 1967

Tuberculodinium vancampoae (Rossignol) Wall, 1967

=*Pyrophacus vancampoae* (Rossignol) Wall and Dale, 1971

Pl. II, fig. 11

Pterospermopsis ? van campoae Rossignol, 1962: p. 134, pl. 2, fig. 1.
Tuberculodinium vancampoae (Rossignol) Wall, 1967: p. 114–115, pl. 16, figs. 15, 16.
Pyrophacus vancampoae (Rossignol) Wall and Dale, 1971: p. 234–235, figs. 19–25.

Description:

The discoidal cyst is composed of two wall layers. The inner wall of ca. 1.5μ in thickness makes up the central body with smooth and brown surface. There are short, stout and hollow tuberculate processes which support the thin fragile outer wall. These processes have an open distal end of the trampet shape. Its archeopyle is a peculiar type corresponding to a few posterior antapical plates (Wall and Dale, 1971).

Dimension:

Over all diameter of cyst 90μ–116μ, diameter of central body 63μ–82μ, length of processes 27μ–34μ.

Remarks:

Wall and Dale (1971) carried out a minute single cell incubation experiment with *Pyrophacus horologicum, P. steinii* and *P. vancampoae* (motile and thecate form of *Tuberculodinium vancampoae*). As one of the results, it is clarified that only *Pyrophacus vancampoae* among them has a characteristic hystrichosphaerid cyst. In the present area, a few specimens of *Tuberculodinium vancampoae* were obtained.

Family Gonyaulacaceae Lindemann, 1928

Cyst-genus Spiniferites Mantell, 1850 emend. Sarjeant, 1970

Spiniferites bulloideus (Deflandre and Cookson) Reid and Downie, 1973

Pl. II, fig. 12

Hystrichosphaera bulloidea Deflandre and Cookson, 1955: p. 264, pl. 5, figs. 3, 4.
Spiniferites bulloideus (Defl. and Cook.) Reid and Downie, 1973, p. 316.

Spiniferites ramosus (Ehrenberg) Loeblich and Loeblich, 1966

Pl. II, fig. 13

Hystrichosphaera ramosa (Ehr.) O. Wetzel: Davey and Williams, 1966; p. 32, pl. 1, figs. 1, 6, text-fig. 8.
Hystrichosphaera furcata (Ehr.) O. Wetzel: Wall, 1967; p. 99–100, pl. 14, figs. 1, 2, text-fig. 2.
Spiniferites ramosus (Ehr.) Loeblich and Loeblich, 1966: p. 56–57

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EXPLANATION OF PLATES I–IV

PLATE I

Fig. 1. *Peridinium wiesneri* Schiller, ×560, Loc. St. 4.
Fig. 2. *Peridinium conicum* (Gran) Ostenfeld & Schmidt, ×560, Loc. St. 4.
Fig. 3. *Peridinium leonis* Pavillard, ×560, Loc. St. 1.
Fig. 4. *Peridinium pellucidum* (Berg) Schutt, ×560, Loc. St. 1.
Fig. 5. *Peridinium subinerme* Paulsen, ×560, Loc. St. 1.
Fig. 6. *Peridinium breve* Paulsen, ×560, Loc. St. 4.
Fig. 7. *Peridinium thorianum* Paulsen, ×560, Loc. St. 4.
Fig. 8. *Peridinium crassipes* Kofoid, ×560, Loc. St. 2.
Fig. 9. *Peridinium depressum* Bailey, ×560, Loc. St. 1.
Fig. 10. *Peridinium* sp. indet., ×560, Loc. St. 1.
Fig. 11. *Peridinium inflatum* Okamura, ×560, Loc. St. 1.
Fig. 12. *Peridinium islandicum* Paulsen, ×560, Loc. St. 2.

All specimens collected from surface water.

PLATE II

Fig. 1. *Ceratium arcticum* (Ehrenberg) Cleve, ×300, Loc. St. 2.
Fig. 2. *Dinophysis acuta* Ehrenberg, ×560, Loc. St. 4.
Fig. 3. *Dinophysis fortii* Pavillard, ×560, Loc. St. 1.
Fig. 4. *Dinophysis* sp. indet., ×560, Loc. St. 4.
Figs. 5–9. *Peridinium conicoides* Paulsen, encystment cell covered with thecate plates: 5 & 6; same specimen, ×560, Loc. St. 4: 7; ×560, Loc. St. 4: 8; ×560, Loc. St. 4: 9; ×560, Loc. St. 4.
Fig. 10. *Operculodinium centrocarpum* (Deflandre & Cookson) Wall=cyst form of *Protoceratium reticulatum* (Claparede & Lachmann) Butschli, ×560, Loc. St. 2; encystment stage.
Fig. 11. *Tuberculodinium vancampoae* (Rossignol) Wall=cyst form of *Pyrophacus vancampoae* (Rossignol) Wall & Dale, ×380, Loc. St. 2.
Fig. 12. *Spiniferites bulloideus* (Deflandre & Cookson) Reid & Davey=one of cyst forms of *Gonyaulax scrippsae* Kofoid, ×560, Loc. St. 2.
Fig. 13. *Spiniferites ramosus* (Ehrenberg) Loeblich & Loeblich=one of cyst forms of *Gonyaulax spinifera* (Claparede & Lachmann) Diesing, ×560, Loc. St. 2.

Specimens of figs. 1–9 collected from surface plankton.
Specimens of figs. 10–13 taken from bottom sediments.

PLATE III

Fig. 1. *Peridinium* sp. cf. *P. subinerme* Paulsen, ×560, Loc. St. 2.
Figs. 2 & 3. *Peridinium oblongum* (Aurivillius) Paulsen, ×560, 2; Loc. St. 2, 3; Loc. St. 4.
Fig. 4. *Peridinium* sp. aff. *P. oblongum* (Aurivellius) Paulsen, ×560, Loc. St. 2.
Fig. 5. *Peridinium* sp. (Cyst-form B), ×560, Loc. St. 4.
Fig. 6. *Peridinium* sp. (Cyst-form D), ×560, Loc. St. 4.
Fig. 7. *Peridinium* sp. (Cyst-form A), ×560, Loc. St. 4.
Fig. 8. *Peridinium* sp. aff. *P. pentagonum* Gran, ×560, Loc. St. 4.
Fig. 9. *Peridinium leonis* Pavillard, ×560, Loc. St. 2.
Fig. 10. *Peridinium* sp. cf. *P. ? denticulatum* Gran & Braarud, ×560, Loc. St. 4.
Fig. 11. *Peridinium* sp. cf. *P. punctulatum* Paulsen, ×560 Loc. St. 4.
Fig. 12. *Peridinium ? denticulatum* Gran & Braarud, ×560, Loc. St. 2.
Fig. 13. *? Peridinium* sp. (Cyst-form C), ×560, Loc. St. 4.

All specimens taken from bottom sediments.

PLATE IV

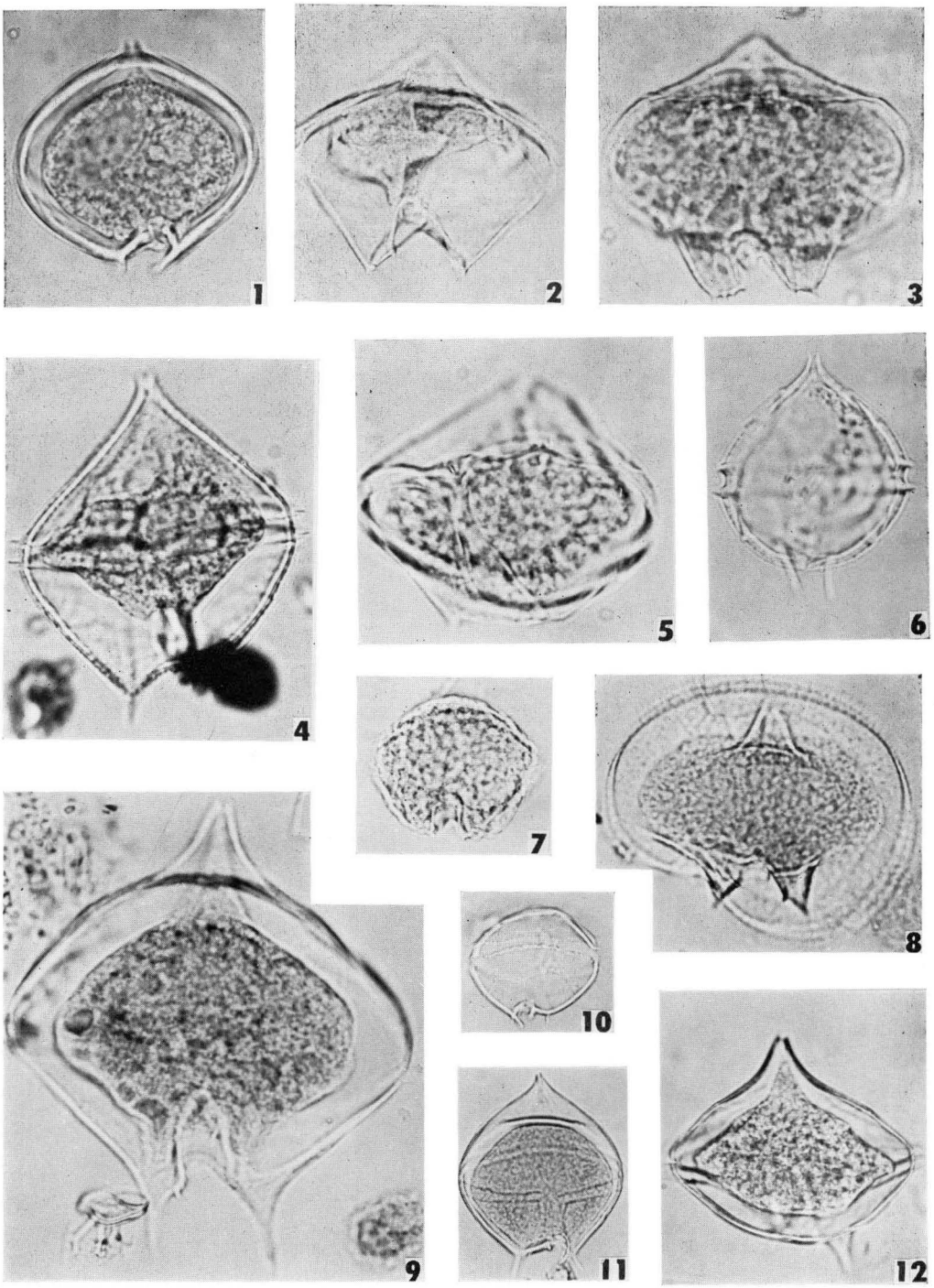
Figs. 1–3. *Peridinium depressum* Bailey, Loc. St. 1. 1; obliquer ventral view, ×550, 2; enlargement of Plate 1'', ×2300, 3; apical view, ×410.

Figs. 4–5. *Peridinium oblongum* (Aurivillius) Paulsen (Cyst form), Loc. St. 4, dorsal view, reflected girdle shown by slight depression of wall, ×670, 5. enlargement of archeopyle, accessory archeopyle sutures. ×2700

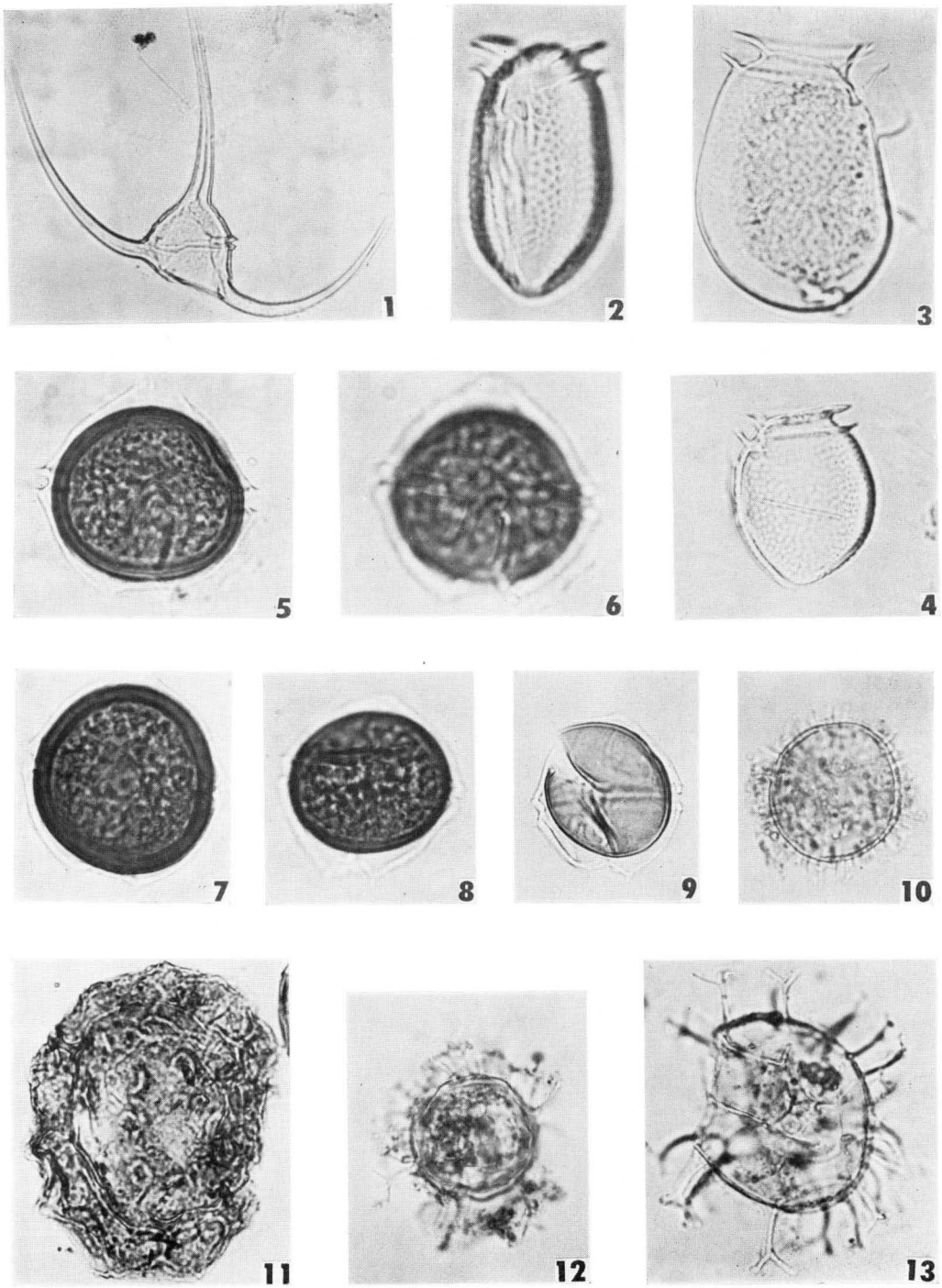
Fig. 6. *Ceratium bucephalum* (Cleve) Cleve, Loc. St. 1, ×380.

Fig. 7. *Peridinium leonis* Pavillard, Loc. St. 1, ×630.

All figures by scanning electron microscope.



K. MATSUOKA: *Recent Thecate and Fossilized Dinoflagellates*



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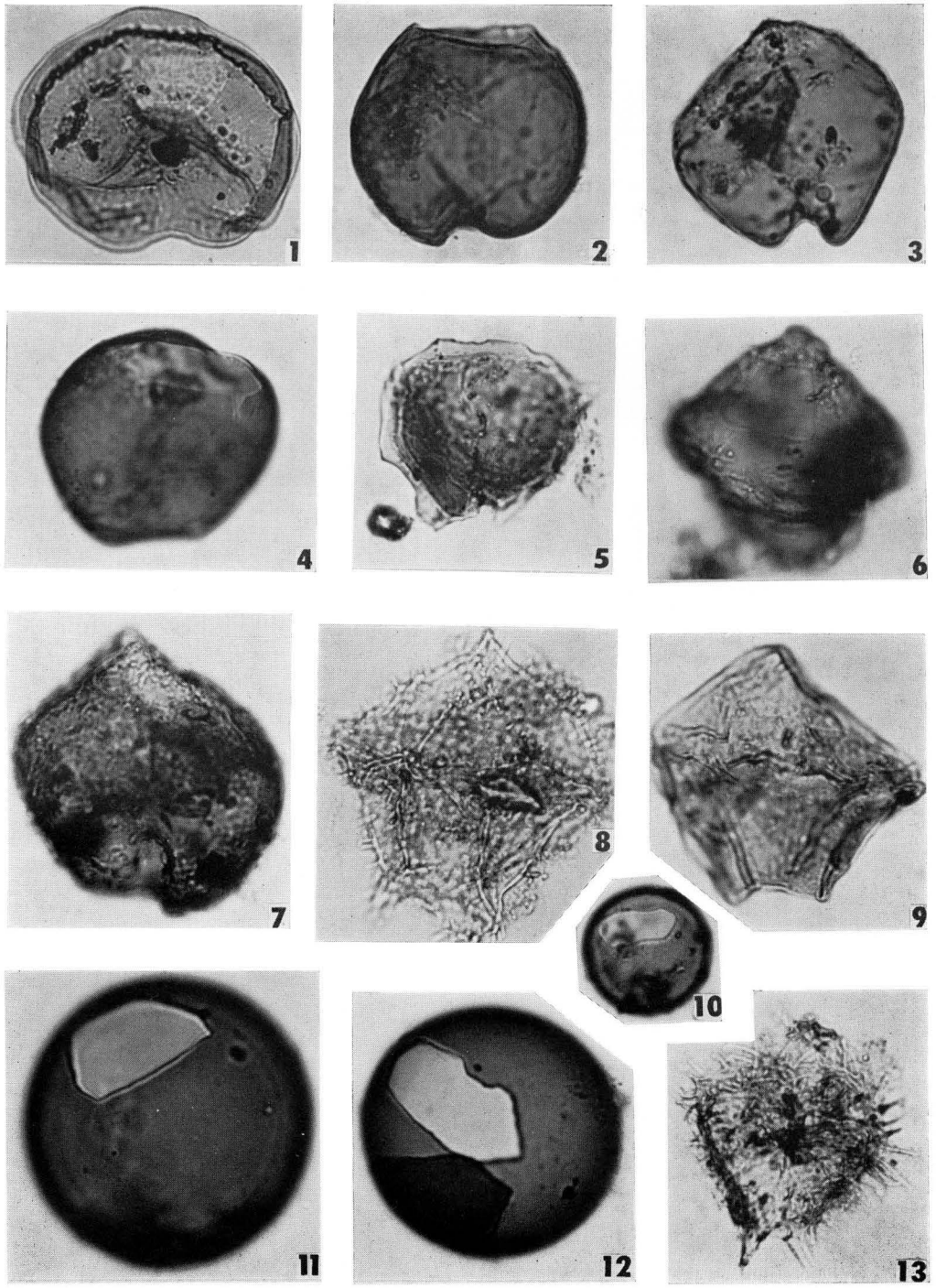

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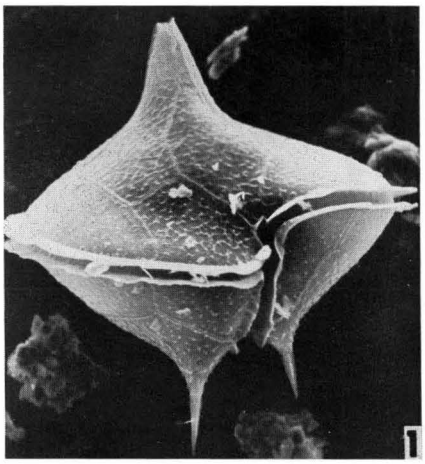

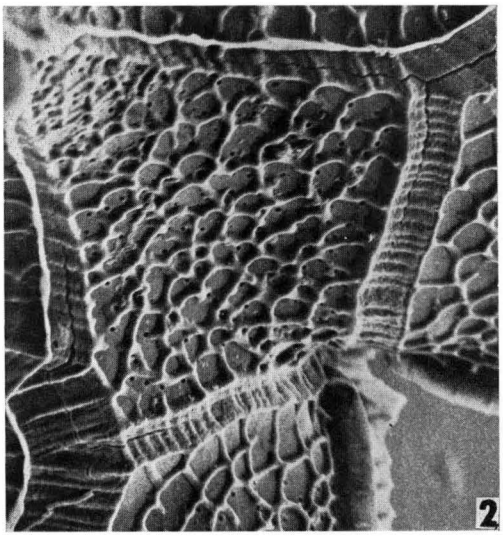

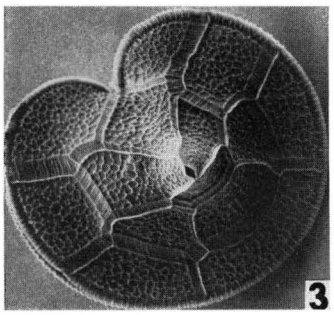

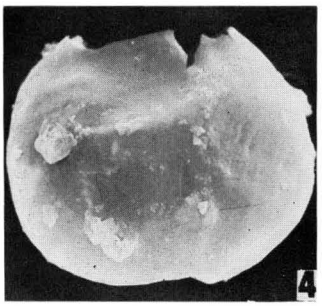

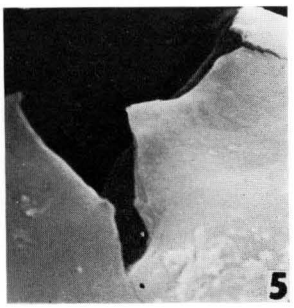

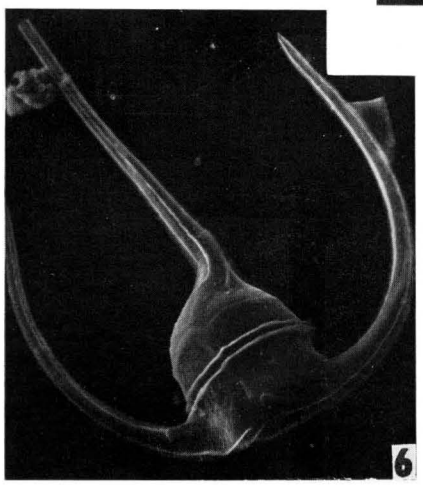

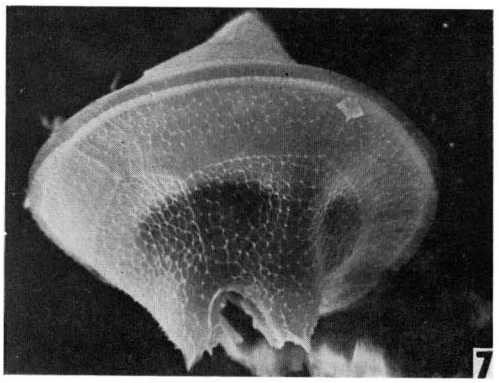

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