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Dinoflagellate Cysts Assemblage Found in the Surface Sediments of Lake Nakaumi, Western Japan

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Abstract: Dinoflagellate cysts occur extensively in the surface sediments of Lake Nakaumi, brackish-water lake in western Japan. The cyst assemblage is composed mainly of *Brigantedinium* spp., *Algidasphaeridium?* sp. aff. *minutum*, and other heterotrophic species. The assemblage is formed in a high productivity area, maintained by waters rich in dissolved nutrients from rivers. The change of the species composition in the lake is hardly observed. The species composition rate, however, indicates some differences in waters in the lake. The disparity is probably caused by an inflow of fresh water from some rivers around the lake, and may be directly influenced by salinity fluctuations.

Key words: brackish-water lake, dinoflagellate cyst, heterotrophic species, Lake Nakaumi, salinity

Introduction

Dinoflagellates are generally unicellular planktonic organisms that have two flagella. In waters, they are known as primary producers, occuping an important position with other phytoplankton such as diatom and silicoflagellate. Dinoflagellates are often reported in the news as the creature which causes red tides. However, the ecology of merely specific groups has been studied.

Some of dinoflagellates form dormancy cysts in their life cycles, and particular groups of them make peculiar cyst walls containing sporopollenin-like material. The cyst type is highly resistant to chemical and biological attacks, and they are consequently found in sediments as fossils.

Dinoflagellate cysts are widely distributed in modern marine sediments (*e.g.*, Wall *et al.* ,1977; Harland, 1982). The information of the cyst distribution around the Japanese Islands has rapidly been accumulated during this decade (*e.g.*, Matsuoka 1985a,b, 1987; Kobayashi and Yuki, 1991), and more than 31 genera and 70 species have been observed (Matsuoka *et al.*, 1989). The results show that the cyst assemblage around Japan is characterized by the regional differences of the composition and rate of the species.

In a coastal region, we can expect that dinoflagellates are largely influenced by the fluctuations of salinity and dissolved nutrients, supplied from terrestrial waters. There is ,however, not enough information in the region especially of a brackish-water lake where oligohaline and nutrient rich conditions exist (*e.g.*, Matsuoka, 1987), though the lake must offer important knowledge about the relationship between cyst distributions and the environments.

This paper reveals the assemblage of a dinoflagellate cyst in Lake Nakaumi, brackish-water lake, western Japan where the modern cyst assemblage has not been recorded, and also considers the environment under the cyst assemblage inhabits.

Samples and Environment

Samples were collected from Lake Nakaumi in February and June, 1993. The sampling sites are the fixed points for environmental observation of

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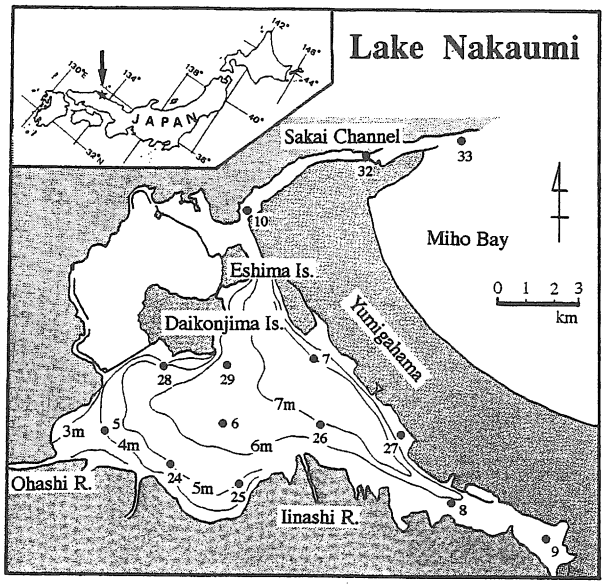

Fig.1. Location map showing sampling sites with bathymetry

Shimane Preferctural Fisheries Experimental Station. Eleven points (Nos. 5, 6, 7, 8, 9, 24, 25, 26, 27, 28, 29) are situated in the southern part of Daikonjima Island, and 3 points (Nos. 10, 32, 33) are in the Sakai Channel and Miho Bay (Fig. 1).

The sediment characters of the sampling sites are shown in Table 1. The samples were taken with an Ekman-Birge Sampler or a Smith-McIntire Grab Sampler, and the uppermost part of sediment (ca. 2 cm in depth) was taken for cyst analysis.

Lake Nakaumi, an oligohaline to polyhaline lake, covers an area of approximately 97km^2 ; the greatest depth is 8.4 m in the eastern part of the lake, but the western part is shallower (5.4 m on average). The eastern part of the lake along Yumigahama has a northwest-southeast trending trough (Fig. 1). Fig. 2 shows the salinity level at each station in summer (Augst 10, 1992) and in winter (February 4, 1993). The results indicate that salinity in the lake has almost the same level except for a few sations in the northern part of the lake, but some stations distributed around the mouth of a river such as Ohashi River show a rather lower level. Surface salinity in summer was reported generally 5-10‰(Tokuoka *et al.*, 1990) but Ohtake *et al.* (1981) observed 15-20‰ on average during 5 years (1974-1978). The maximum salinity level is approximately 25‰ and the minimum observed value is approximately 5‰ during 15 years (1966-1980) (Ohtake *et al.*, 1982). The surface water temperature in the lake fluctuates between 3℃ (winter) and 29℃ (summer) (Ohtake *et al.*, 1981).

Lake Nakaumi is a typical brackish-water lake, and its water mass forms a double-layered structure, the saline water mass invading under the fresh-water mass. This fact brings about a decline of dissolved oxygen level at the lake bottom (Tokuoka *et al.*, 1990), especially in summer.

Methods

The sample processing used was the palynological technique by Matsuoka *et al.* (1989). The sediments were taken into a teflon beaker, and then washed with distilled water to remove salt. The material was rinsed out with distilled water. Then 5 % hydrochloric acid was added to the material to remove calcium carbonate fragments originating mainly from the outer shell of some organisms. Fluoric acid was further added to the remnants to remove silicate particles after washing the remnants with distilled water. The organic remnants repeatedly washed out were sieved through a 150 μ m-opening screen to remove large-sized non-cyst residue, and were then sieved through a 20 μ m-opening screen to trap cysts on the sieve. The residue on the sieve was subjected to microscopic cyst analysis.

The dinoflagellate cysts were counted and

Table 1. Sediment characters of each site (described by K. Seto)

Characters / Station No.	5	6	7	8	9	10	24
Depth	4.5m	6.7m	6.5m	15.1m	3.6m	8m	5.5m
Sediment grain size	silt	silt	silty sand	silt	silt	medium - coarse sand	silt
Sediment color	yellowish brown	yellowish brown	yellowish brown	dark brown	grayish brown balckish gray	gray	yellowish gray grayish black
Organisms or their evidence in the sediments	tube	pellet *Raeta pulchella* (mollusca)	-	-	tube	tube shell fragments	*Corbicula japonica* (mollusca)
Characters / Station No.	**25**	**26**	**27**	**28**	**29**	**32**	**33**
Depth	5.7m	-	1.7m	5m	7.4m	9.8m	14m
Sediment grain size	silt	silt	medium sand	silt	silt	coarse sand	silt
Sediment color	yellowish gray grayish black	yellowish brown bluish black	brown light brown	yellowish brown bluish black	yellowish brown grayish black	yellowish brown bluish gray	yellowish brown
Organisms or their evidence in the sediments	tube	tube *Raeta pulchella* (mollusca)	*Tapes japonica* (mollusca)	tube	tube *Raeta pulchella* (mollusca)	-	tube

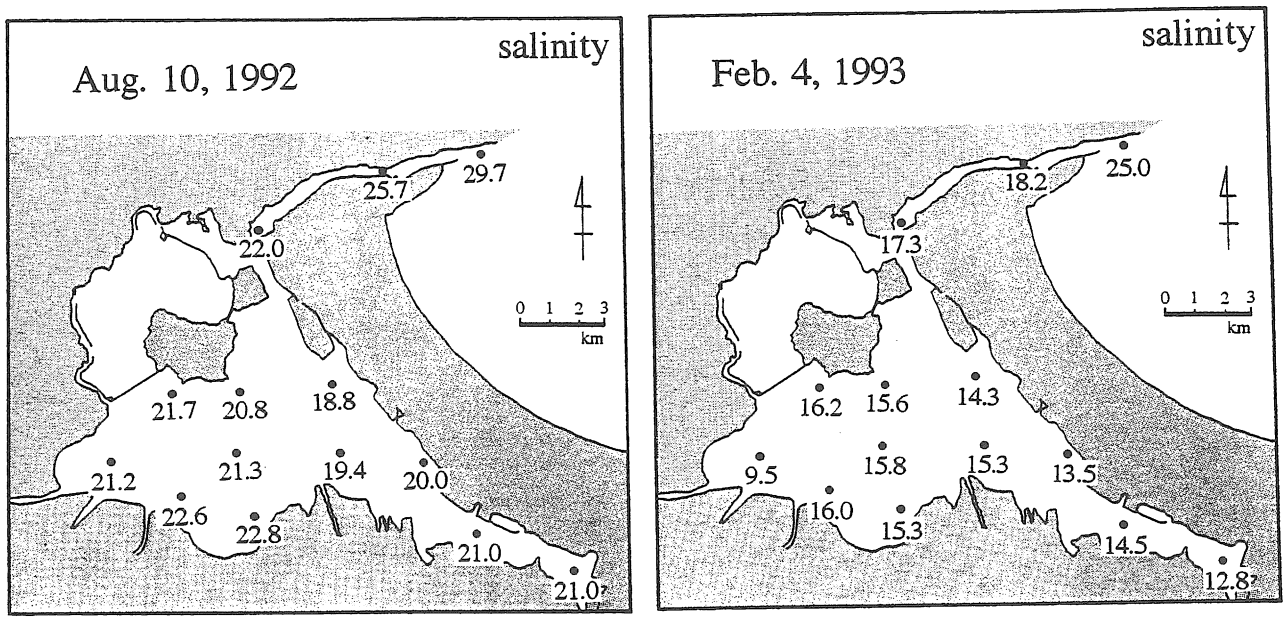

Fig.2. Salinity of Lake Nakaumi in summer and winter

identified under a light microscope up to more than 200 specimens per sample. We also counted the total dinoflagellate cysts number per 1 cc sediments at each station.

The method of this sample procedure brings about the disappearance of calcareous and silicate cysts because this procedure uses hydrochloric and hydrofluoric acids.

We follow the cyst taxonomical opinion of Matsuoka (1985a, 1987) in this paper.

Results

Table 2 shows the list of dinoflagellate cysts in surface sediments of Lake Nakaumi. The assemblage is characterized by the dominance of protoperidiniacean cysts, especially *Brigantedinium* spp. Many kinds of small spherical brown cysts having many spines also exist, and the cysts have hardly been known in Japan.

In Gonyaulacoid cysts, *Spiniferites delicatus* dominates in this group; they vary in their morphological features, especially crest development, and thus some of them may be identified as *S. bulloideus* according to their petaloid process morphology. *Operculodinium centrocarpum* has many small cysts (ca. 30 μ m) in this region.

Brigantedinium cysts are overwhelmingly abundant in Peridinioid cysts. This group is classified by their archeopyle shapes, since the form of this cysts is a simple sphere with no ornaments. The morphological character causes difficulty in identifying the group when the archeopyle is not positioned in a good direction under a microscope, and is invisible on a cyst in spite of a good specimen. For the above reason, unidentified *Brigantedinium* cysts are increased. This species may also include *Dubridinium* spp. when observed from polar directions.

Selenopemphix quanta and *Lejeunecysta concreta* of Peridinioid cysts are also stably counted.

In Gymnodinioid cysts, *Gyrodinium instriatum* is abundant and stably observed at each station in the lake. *Polykrikos schwartzii* and *Poly.* sp. cf. *kofoidii* are also invariably identified, but they are not so many than *Gym. instriatum*. *Algidasphaeridium*? sp. aff. *minutum* is invariably observed 10-20 % of the cyst assemblage in the lake. Station No. 5 has especially a high occupation rate, 28 %. This species resembles *A.*? *minutum*, but differs from the latter in having smaller spine density on the cyst and a small-size shell.

All unidentified species belong to the group of small spherical brown cysts with many spines. This cyst group is concentrated at stations Nos. 24, 25, and 26, but their quantity is small.

The distribution character of the cysts in Lake Nakaumi exists in widely observed *Brigantedinium* spp., *Algidasphaeridium*? sp. aff. *minutum*, *Polykrikos* spp., and *Gyrodinium instriatum*.

Discussion

The cyst assemblage of Lake Nakaumi resembles that of Lake Kamo (Sado Island), off-Honjo, and off-Oga (Matsuoka, 1985b) which has been reported around Japan. Namely, the main components of this assemblage are *Brigantedinium* spp. and *?Maltispinula minuta* (*Algida sphaeridium*? sp. aff. *minutum* in this paper). In particular, when the above-mentioned characters of the assemblage

Table 2. List of dinoflagellate cysts of Lake Nakaumi

Species / Station No.	5	6	7	8	9	10	24	25	26	27	28	29	32	33
Gonyaulacoid Lineage														
Spiniferites bulloideus	2	6	2	1		5	1	6				1		10
S. delicatus	11	24	18	11	14	1	18	8	13					
S. sp. cf. *delicatus*	1	9	3	6	4	1		4	5					1
S. hyperacanthus	1	2	3	1	5				1					
S. mirabilis		2	3			2	2	1						5
S. sp. cf. *mirabilis*				4	1									
S. pachydermus									1					
S. spp.	8	13	7	6	5	7	9	7	13		1	1		2
Operculodinium israelianum		1				2								
O. centrocarpum	3			2	2	1		1	1			3		
O. crassum	1													
Lingulodinium machaerophorum	6	2	4	5		1	1		1					
Tuberculodinioid Lineage														
Tuberculodinium vancampoae		6	5	6	7		7	1	6					
Peridinioid Lineage														
Brigantedinium simplex		1			1	1			1					2
B. majusculum														2
B. sp. cf. *majusculum*	1													
B. irregurale		1	1				1	1						
B. cariacoense						1								
B. asymmetricum							1	1	1					
B. spp.	48	37	48	63	35	48	29	45	38		20	38		57
Selenopemphix quanta	11	11	19	10	2	3	20	9	9		2			2
Lejeunecysta concreta	6	12	8	10	11	7	13	13	10		1	1		2
Votadinium carvum	3	5	4	2		1		1	2		2			6
V. spinosum	2		1	1	4	1	2	2	2		6	6		2
Trinovantedinium capitatum		1				1								2
Trino. pallidifulvum		2		1			1	1	1					
Trino. type A		1					2	1						
Trino. type B												1		
Stelladinium reidii		1	1		1			1				1		1
Dubridinium caperatum		1				3								
D. sp. indet.														
*Protoperidinium lattisinum**							1							
*Proto. divaricatum**		3	1	5	5		1	1						
*Proto.** spp.	5			1		1	4	2	1		2	6		5
Gymnodinioid Lineage														
*Polykrikos schwartzii**	3	15	6	10	7	4	12	12	17			1		1
P. sp. cf. *kofoidii**	4	7	2	7	7	1	10	9	10			1		
*Gyrodinium instriatum**	13	15	19	17	67	22	19	19	19	1				
Algidasphaeridium? sp. aff. *minutum*	56	18	43	31	28	12	29	31	31		1	3		2
Lineage indet.														
Type A	2	2	1	1				4	1		1	1		
Type B	1						4	4	1		2	3		
Type C	8	3	4	3			2	4	4					
Type D		2		2			4	10	7		1			1
Type B (Matsuoka 1987)	4						8	2						
Type C (Matsuoka 1987)									5			1		
Total count	200	203	203	204	206	126	200	201	201	1	39	68	0	103
Total number / 1cc	1350	950	1875	725	2100	950	2325	1125	1925	25	725#	950#	0	1075#

* motile form-based name
# Tatal number / 1g dry weight

adds the yielding feature of *Polykrikos* spp., the resemblance of the assemblage to that of Lake Kamo becomes clear.

Dinoflagellates are generally considered algae, but only half the organisms are photosynthesis type creatures, and the other half has other nutrition types including heterotrophism (Taylor, 1987). Many of them, in particular, are heterotrophic gaining food by ingestion of organisms such as diatom and phytoflagellates (Gains and Taylor, 1984; Jacobson and Anderson, 1986).

The assemblage of Lake Nakaumi reported in this paper is greatly characterized by the high-percentage heterotrophic species such as *Brigantedinium* spp. (Fig. 3). The *Brigantedinium*-rich assemblage was recognized to increase with going north over the Tsushima Warm Current (Matsuoka, 1985b). In addition, the assemblage was recorded even in the north of the Pacific side in Japan. The fact led to the relationship between a cold current and the *Brigantedinium*-rich assemblage (Matsuoka, 1976). Matsuoka (1987) re-examined the distribution of the protoperidiniacean-dominated cyst (including *Brigantedinium* spp.) assemblage based on the report of Bujak (1984), which pointed out a close relation between protoperidiniacean cysts and high-productivity areas of diatoms along upwelling regions. Consequently, he indicated that the protoperidiniacean-dominated cyst assemblage suggested the two-typed high primary production in both upwelling and other eutrophic regions (*e.g.* land waters). Harland (1988) also pointed out that heterotrophic dinoflagellates were distributed in rather less stable condition than that of autotrophics. The cyst assemblage of Lake Nakaumi belongs to the

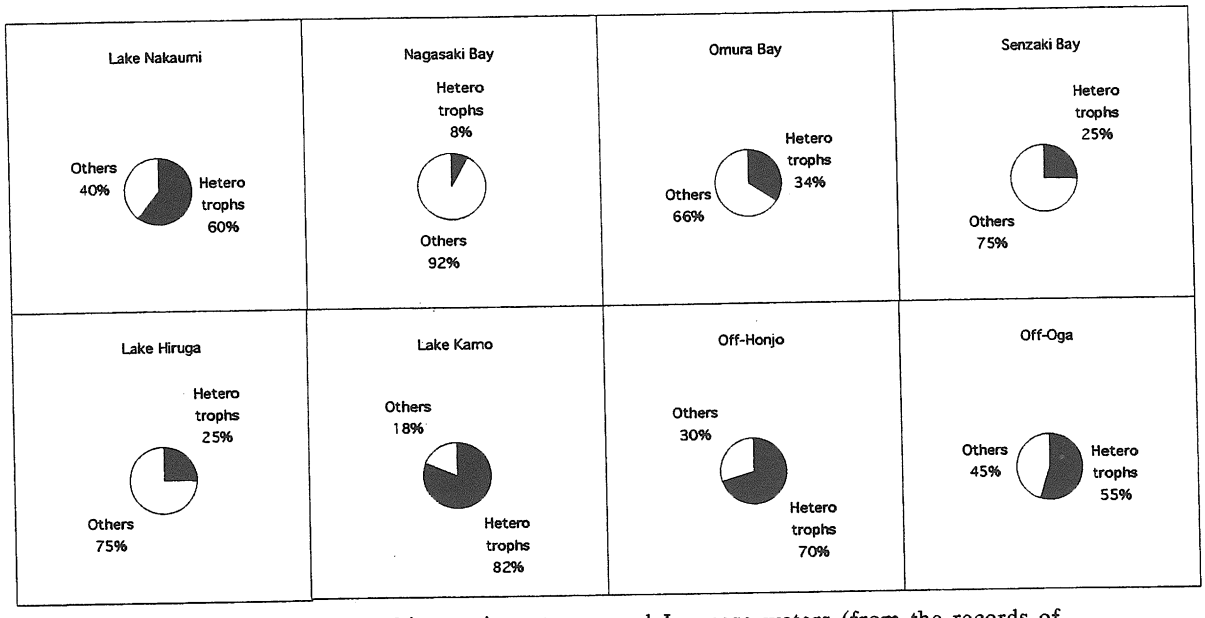

Fig.3. Heterotrophic species rates around Japanese waters (from the records of Matsuoka(1985a) except the data of Lake Nakaumi)

planktivorous type-assemblage, maintained by phytoplankton proliferating by use of nutrients from terrestrial waters.

Brigantedinium spp. being characteristic of the assemblage of Lake Nakaumi is widely dominant throughout the lake, especially at stations Nos. 10, 28, 29, and 33. The reason is that the four stations are situated in Miho Bay, Sakai Channel, and the north of the lake where the stations are affected by open sea water. Namely, the species is presumed to be fond of higher salinity conditions than other species in the brackish-water lake.

Gyrodinium instriatum is also stably contained in the surface sediments in Lake Nakaumi; this species has not been recorded in a large quantity in sediments. The cyst has been thought to have a weak autophragm surrounded by geratinous material. In Lake Hamana, however, motile cell-like cysts of this species missing gelatinous material was reported. It is inferred that this cyst type is closely related with an anoxic condition at the bottom of the lake, which characterize a brackish-water lake (Kojima and Kobayashi, 1992). From of this point of view, the wide distribution of this cyst type indicates a large extent of low-oxygen content water in the bottom of Lake Nakaumi. The peculiar abundance of the cyst at station No.9 is explained by the fact that the station exists in an extremely low oxygen condition, situated in an inlet with a bad water circulation (Nomura and Seto, 1992). The absence of this cyst type at Nos. 28 and 29 located in the south of Daikonjima Island is probably influenced by using dry samples. The sample of No. 33 in Miho Bay did not record the fragile cyst. But even if we took a wet sample at the station, we would not recognize the cyst because of the existence of dissolved-oxygen rich water.

Algidasphaeridium? sp. aff. *minutum* is also extensively distributed in the lake like as *Brigantedinium* spp. and *Gyrodinium instriatum.* The cyst existing at the station No. 5 near the mouth of the Ohashi River with a high occupation rate, may be fond of a low-salinity environment contrary to *Brigantedinium* spp. *A.? minutum* has been recognized as an indicator species of cool or cold-water conditions (Harland *et al.*, 1980; Bujak, 1984; Dale, 1985). The results of Matsuoka (1985b) and this paper indicate that *Algidasphaeridium*? cysts in the two papers is fond of a high-productivity condition. The fact and the general character of dinoflagellates (mentioned below in this chapter) suggest that *Algidasphaeridium*? cysts may be heterotrophic species, although their nutritional type is presently unknown.

Polykrikos cysts deposit the same aspects in the lake, also. Especially high percentage, more than 10 %, was recorded at Nos. 6, 24, 25, and 26. The stations are located in the south of the lake, and are thought to be strongly affected by fresh water from the Ohashi River and Iinashi River principally. Omura Bay (in western Japan) having a closed environment with a weak relation to an open sea through a narrow channel has the same *Porikrikos*-rich assemblage (Kobayashi *et al.*, 1986), and we consequently recognized the assemblage as a peculiar type being formed by terrestrial waters, especially a low-salinity environment.

The cyst number per unit volume in Lake Nakaumi is from 725 to 2325, and it is almost the same as the level of other bay area in Japan (Matsuoka, 1985a, 1987).

In high-productivity area, phytoplankton reproduces in a great volume using rich nutrient salt. In case of autotrophic dinoflagellates, their reproduc-

tion rate is nothing but half the diatom's rate (Banse 1982), and hence they cannot multiply their volume. From this fact, it may be inferred that the condition leads to the abundance of heterotrophic species.

The cyst assemblage in Lake Nakaumi has not shown a large-scale fluctuation. But some species of the assemblage may be influenced by salinity, especially those in the south of the lake being affected by an inflow of rivers.

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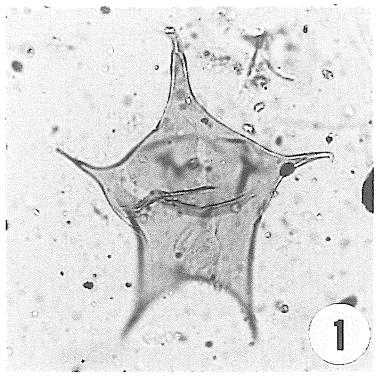
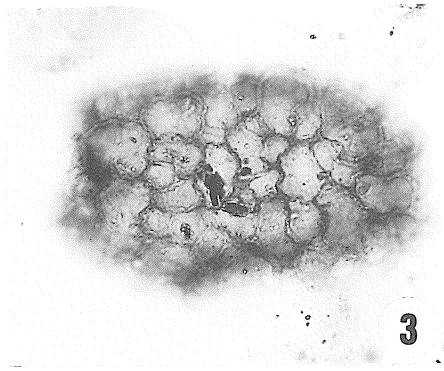
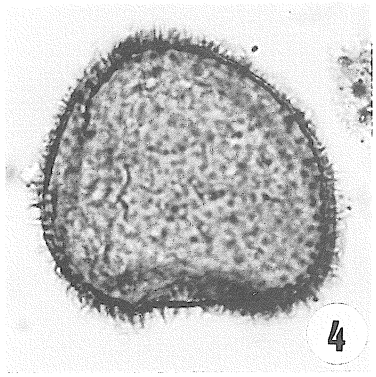
Plate 1. Dinoflagellate cysts of Lake Nakaumi

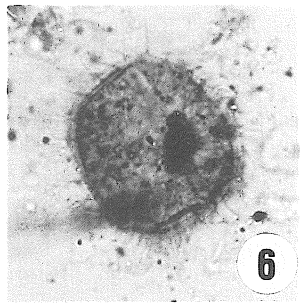
1.*Stelladinium reidii* Bradford, 2.*Lejeunecysta concreta* (Reid) Matsuoka, 3. *Polykrikos schwartzii* Butschli*, 4.*Votadinium spinosum* Reid, 5.*Brigantedinium irregrale* Matsuoka, 6. *Algidasphaeridium*? sp. aff. *minutum* (Harland and Reid) Matsuoka et Bujak, 7. *Algidasphaeridium*? sp. aff. *minutum* (Harland and Reid) Matsuoka et Bujak, 8. aggregation of *Gyrodinium instriatum* Freudenthal et Lee*, 9. *Gyrodinium instriatum* Freudenthal et Lee*

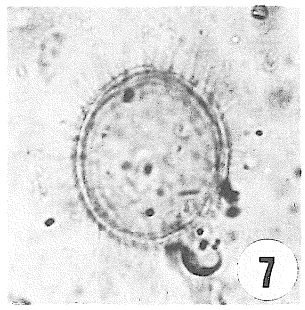
*:motile cell-based name, Scale=20 μ m

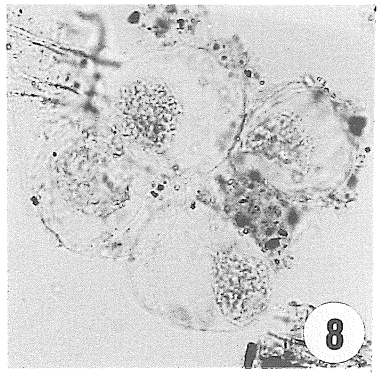


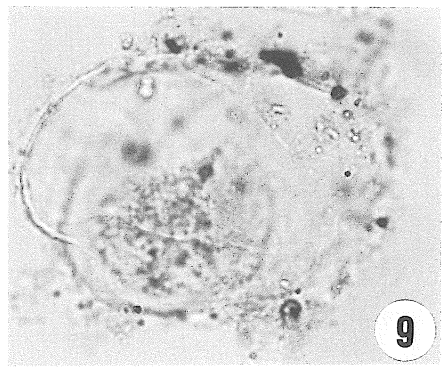












1-3
4-7.9
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