Water temperature, salinity, algal-chlorophyll profiles and radiolarian fauna in the surface and subsurface waters in early June, off Tassha, Sado Island, central Japan

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Abstract

The profiles of water properties and vertical distribution of radiolarian faunas are documented from the surface to subsurface water shallower than 100 m deep in the Sea of Japan, off Tassha, Sado City, Sado Island, Niigata Prefecture, central Japan. The temperature from 64 m deep to the surface ranges from ca. 12.0° C to 18.0° C. Based on temperature gradient, the water mass can be subdivided into three layers. The surface layer shallower than 21 m has a high temperature gradient (2.0° C/10 m). This profile indicates that the water mass is in the intermediate condition between the winter to spring and summer seasons. The faunal compositions for three different depth intervals can be summarized as follows: (1) the fauna collected from ca. 90-63 m deep is characterized by the abundant occurrences of *Cyrtidosphaera reticulata* and plagiacanthid and lophophaenid nassellarians, associated with *Tetrapyle octacantha*, *Didymocyrtis tetrathalamus tetrathalamus*, and *Larcopyle butschlii*, (2) the faunas collected from ca. 63-36 m and 36-0 m deep are similar to those of the deeper fauna but their compositions are quite different; *T. octacantha* and *D. t. tetrathalamus* are relatively abundant instead of *C. reticulata*. For *C. reticulata* and *L. butschlii*, there is a close correlation between lowering temperature in the vertical profile and increasing numbers of individuals. This may be caused by their temperature tolerance ranges. In addition, species preferring warm water such as *D. t. tetrathalamus* comprise a large percentage of the shallower fauna than the deeper. Taken the temperature profile and faunal data together, we conclude that the faunal transition off Tassha is mediated by the influx of warm water dwellers of the Tsushima Warm Current into the surface layer of the water column during spring to summer.

Key words: algal chlorophyll, Radiolaria, Sado Island, salinity, Sea of Japan, seasonal faunal change, Tsushima Warm Current, water temperature.

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Introduction

Radiolaria is broadly distributed from coastal surface to pelagic abyssal water depths. A radiolarian fauna is often highly diverse, and its construction is controlled by various physical and chemical conditions of a water mass, such as temperature, sunlight, salinity, and nutrient content, etc., and surrounding biological factors involving the variously-scaled food web. Among these factors, water temperature is thought to be the primary physical factor affecting other physical, chemical, and biological conditions in the oceanic environment. However, very few studies attempting to directly clarify the temperature tolerance of Radiolaria by laboratory culture experiments have been demonstrated (Matsuoka and Anderson, 1992), because cultivating radiolarians is exceedingly difficult making it arduous to accumulate quantitative data on optimum temperatures and ranges of temperature tolerances for individual species. Therefore, in order to know the temperature effect for radiolarians, it is more practical to monitor changing faunal compositions arising from the temperature fluctuation. The surface water of the Sea of Japan has an obvious seasonal temperature gradient caused by the inflow of the subtropical Tsushima Warm Current from the East China Sea (Fig. 1). Thus, seasonal changes of radiolarian faunas in this ocean are expected to directly reflect the temperature effect, resulting from temperature tolerances of faunal constituents.

To assess seasonal change in faunal composition, the third author (A. M.) and his collaborators have been conducting radiolarian samplings at different seasons in the coastal area off Tassha, Sado Island (e.g., Matsuoka et al., 2001) over the past five years. In 2005, we introduced a conductivity-temperature-depth (CTD) sensor in order to easily obtain water properties corresponding to the water mass targeted at our radiolarian sites. This paper reports the vertical profile data on water properties and detailed radiolarian faunal compositions of different depth intervals. We also discuss the relationship between the vertical water property and radiolarian fauna and the seasonal transition process of the fauna.

Materials and methods

Measurements of water property and plankton sampling were carried out at a location (38° 05’N, 138° 10’E) approximately 6 km west of Tassha, Sado City, Sado Island, Niigata Prefecture, central Japan (Fig. 1). The measurement and sampling operations were conducted in the daytime of June 6, 2005 using the research boat “IBIS2000” of the Sado Marine Biological Station. We recorded data on temperature, salinity, density, and relative abundance of algal chlorophyll by introduction of a CTD sensor (Alec Electronics Co., Ltd. COMPACT-CTD). We recorded water temperature with a conventional digital thermometer.

Six plankton samples (606-6SD-1, 606-6SD-2, 606-6SD-3, 606-6SD-4, 606-6SD-5, and 606-6SD-6) were collected using a 100 μm opening net of the Marukawa type with a 0.3 m

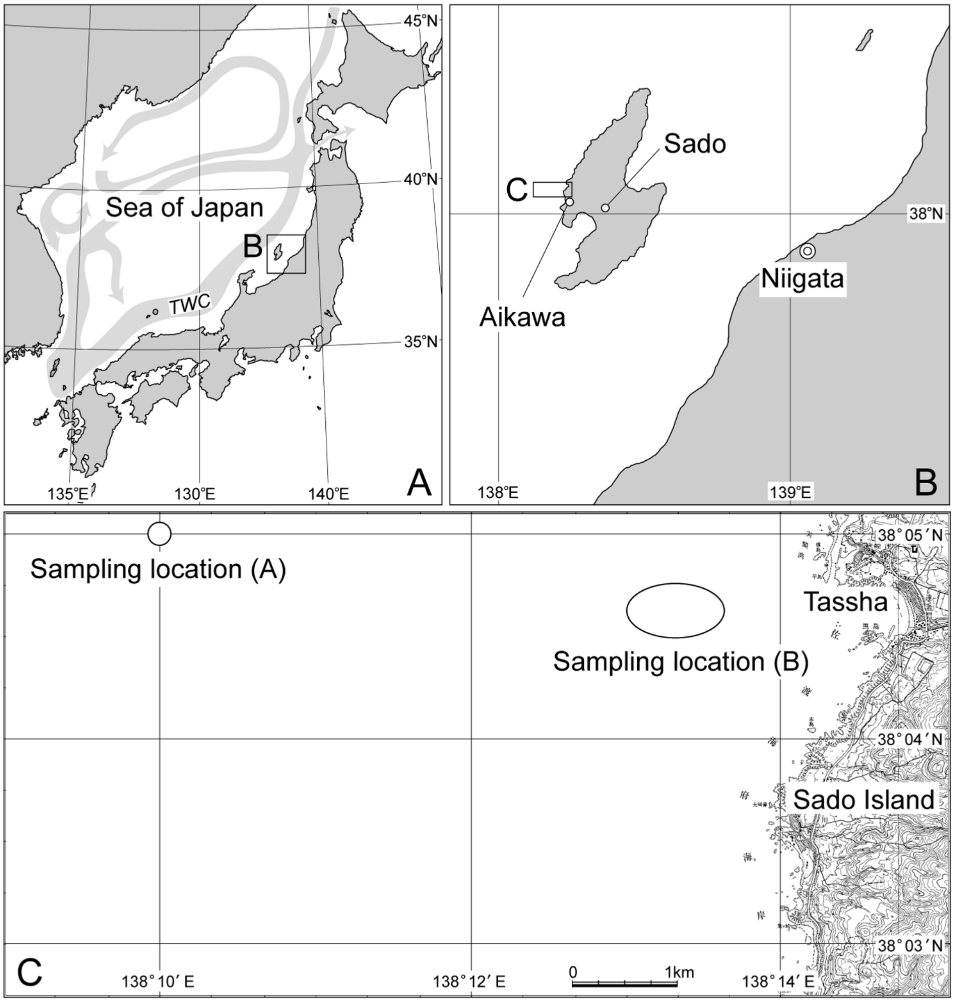

Fig. 1. Index map showing the sampling locations. The topography is from the 1:25,000 scale "Aikawa" map sheet published by the Geographical Survey Institute of Japan. Main surface currents of the Sea of Japan are after Senjyu (1999). TWC: Tsushima Warm Current. The sampling location (A) corresponds to the study areas of Matsuoka et al. (2002), Itaki et al. (2003), and Kurihara and Matsuoka (2004, 2005). The sampling location (B) corresponds to the study area of Matsuoka et al. (2001).

diameter mouth. To obtain radiolarian faunal data at every ca. 30 m interval of water from approximately 100 m deep to the surface, we attempted to sample from a water depth between 100 m and 70 m (606-6SD-1) and between 70 m and 40 m (606-6SD-2) by closing the net with a messenger. Sample 606-6SD-3 was collected from between 40 m and the surface without closing the net. Other samples were taken from 100 m deep to the surface without closing the net for the total faunal composition (606-6SD-4) and observation of living specimens (606-6SD-5 and 606-6SD-6). In the sampling processes for 606-6SD-5 and 606-6SD-6, we collected healthy plankton only from the bottle of the plankton net to avoid collecting damaged specimens by the rubbing of the net. Based on the dip angle of the plankton net (65°), actual sampling depth of each interval can be calculated as approximately 90 % of the above-set depth.

Living radiolarians were picked from a small aliquot of samples 606-6SD-5 and 606-6SD-6 and transferred into another dish using a Pasteur pipette with a binocular microscope. Living specimens were observed by an inverted microscope (Nikon Eclipse TE300-DEF) and captured by a CCD camera (Fujix Digital Camera HC-300Z). All observed specimens were picked by a Pasteur pipette and placed in ca. 50 % sulfuric acid for a day to eliminate the organic matter from radiolarian specimens. Following this, radiolarian skeletons were mounted on stubs and observed by scanning electron microscope (SEM, JEOL JSM-5600). Plankton samples (606-6SD-1, 606-6SD-2, 606-6SD-3 and 606-6SD-4) were also placed in ca. 50 % sulfuric acid. The residues were collected on a 46 μm opening sieve and rinsed in water. Following this process, the residues were kept in an aqueous ethanol solution, and then mounted in Canada balsam. Microscopic images of radiolarian skeletons were taken by a digital transmitted light microscope (Keyence VH-7000).

Vertical profile of water property

In measuring water property, we obtained a vertical profile data at every 1 m depth on water from 64 m deep to the surface by using the CTD sensor with a rope 120 m long. Profiles of selected water properties (temperature, salinity, density, and relative abundance of algal chlorophyll) at the sampling site are presented in Fig. 2. The vertical profile of the relative abundance of algal chlorophyll was prepared from output signal values measured as fluorescence intensity.

Temperature: The temperature of the water mass from 64 m deep to the surface in the sampling site ranges from ca. 12.0° C to 18.0° C. Based on the characteristics of the temperature gradients, the water mass can be subdivided into three layers (Fig. 2). The lower layer is the water mass from 64 m to 58 m deep and has a low temperature gradient of 0.5° C/10 m. The middle layer is recognized in the water mass between 58 m and 21 m deep and has a low temperature gradient of ca. 0.4° C/10 m. The bottom 4 m interval of the middle layer (58 m to 54 m deep), however, has a high temperature gradient of ca. 1.6° C/10 m. The temperature gradients of the lower and middle layers are similar, but can be distinguished from the high temperature gradient part. This part is also important in terms of the relationship to the relative abundance peak of algal chlorophyll. The upper layer recognized in the water mass from 21 m to the surface is characterized by a high temperature gradient of ca. 2.0° C/10 m.

Salinity: The salinity ranges from 34.237 ‰ to 34.485 ‰ in the water mass between 64 m

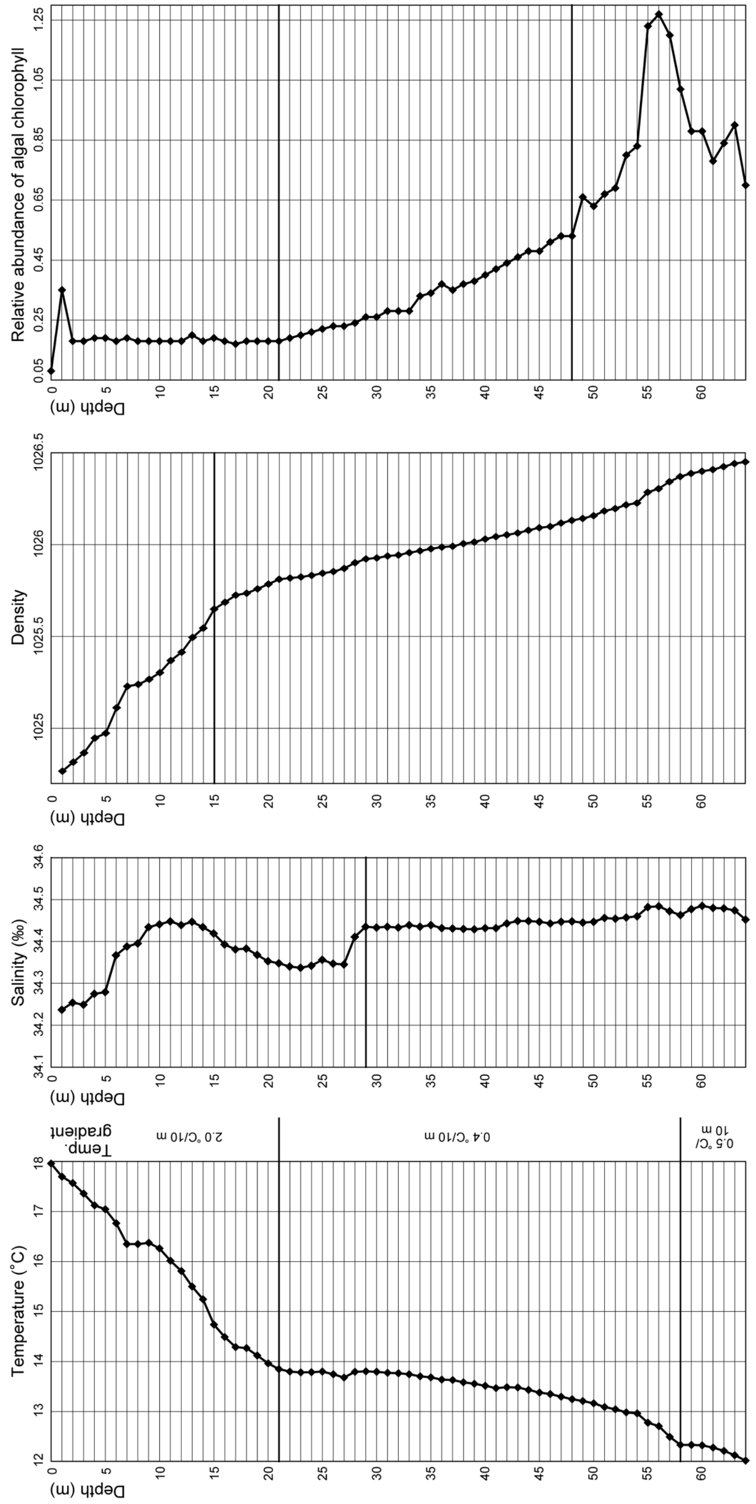

Fig. 2. Vertical profiles of temperature, salinity, density, and relative abundance of algal chlorophyll at sampling location (A) off Tassha, Sado Island.

and 1 m deep. The salinity fluctuation shows different characteristics in the lower (64 m to 29 m deep) and upper (29 m to 1 m deep) parts (Fig. 2). The salinity of the lower part is almost constant between 34.429 ‰ and 34.485 ‰ while the water mass in the bottom 10 m interval (64 m to 54 m deep) has a slightly high fluctuation. In contrast, the salinity of the upper part fluctuates widely from 34.237 ‰ to 34.448 ‰. In addition, the vertical profile suggests that low salinity waters probably originated from land water flow into waters shallower than 10 m deep and between 29 m and 14 m deep.

Density: The density of the water mass between 64 m and 1 m deep ranges from 1024.8 to 1026.5. The gradient differs between the water masses deeper and shallower than 15 m deep; the water mass from 64 m to 15 m deep has a low gradient, and the water mass from 15 m to 1m deep has a high gradient (Fig. 2). These gradients basically correspond to reduced water temperature.

Relative abundance of algal chlorophyll: The vertical profile of the relative abundance of algal chlorophyll fluctuates with respect to each depth interval (Fig. 2). In the water mass from 64 m to 48 m deep, the relative abundance of algal chlorophyll fluctuates widely with every 1 m depth and reaches a peak at 56 m deep. The relative abundance is generally low in the water mass between 48 m and 21 m deep and drops gently with shallowing depth. In the water mass shallower than 21 m, the relative abundance is low and almost constant.

Radiolarian faunas

Twenty-five species of solitary radiolarians from 159 shells were identified. The solitary radiolarian shells per 1 m^3 of sea water in samples 606-6SD-1, 606-6SD-2, and 606-6SD-3 are 49.8 shells/m^3, 17.8 shells/m^3, and 11.8 shells/m^3, respectively. Several isolated spicules of colonial Radiolaria (*Sphaerozoum* sp.) were also observed. Radiolarian species in each sample are listed in Table 1; transmitted light microscopic images of almost all faunal constituents are illustrated on Plates 1 to 3. The faunal composition for each depth interval is presented in Fig. 3.

The radiolarian fauna in sample 606-6SD-1 collected from water of ca. 90-63 m deep consists of 21 species belonging to nine spumellarian and 12 nassellarian genera. *Cyrtidosphaera reticulata* Haeckel, shown in Fig. 4, is the most abundant spumellarian and totals 14.7 % of the fauna. The next most dominant group includes *Didymocyrtis tetrathalamus tetrathalamus* (Haeckel), *Larcopyle butschlii* Dreyer, and *Tetrapyle octacantha* Müller, which comprise 4.2 %, 4.2 %, and 3.2 % of the fauna, respectively. The following five spumellarian species are minor and only one specimen of each was obtained: *Dictyocoryne truncatum* (Ehrenberg), *Spongodiscus* sp. A, *Spongodiscus* sp. B, *Styptosphaera spongiacea* Haeckel, and ?*Spongosphaera streptacantha* Haeckel. The nassellarian species composition is characterized by the dominance (approximately 50 % of the fauna) of two species of the genus *Plectacantha*; *Plectacantha trichoides* Jørgensen and *P. oikiskos* (Jørgensen). The next most abundant species are *Pseudocubus obeliscus* Haeckel, *Pseudodictyophimus gracilipes*

Table 1. List of all solitary radiolarian species obtained from samples 606-6SD-1, 606-6SD-2, and 606-6SD-3.

Sample number	606-6SD-1	606-6SD-2	606-6SD-3
Rope release length	100-70 m	70-40 m	40-0 m
Sampling depth	ca. 90-63 m	ca. 63-36 m	ca. 36-0 m
	Number of skeleton (%)		
SPUMELLARIA			
Cyrtidosphaera reticulata Haeckel	14 (14.7%)	1 (2.9%)	1 (3.3%)
Tetrapyle octacantha Müller	3 (3.2%)	6 (17.6%)	4 (13.3%)
Didymocyrtis tetrathalamus tetrathalamus (Haeckel)	4 (4.2%)	1 (2.9%)	4 (13.3%)
Larcopyle butschlii Dreyer	4 (4.2%)	1 (2.9%)	0 (0%)
Dictyocoryne truncatum (Ehrenberg)	1 (1.1%)	1 (2.9%)	0 (0%)
Spongodiscus sp. A	1 (1.1%)	0 (0%)	0 (0%)
Spongodiscus sp. B	1 (1.1%)	0 (0%)	0 (0%)
Styptosphaera spongiacea Haeckel	1 (1.1%)	0 (0%)	1 (3.3%)
Euchitonia elegans (Ehrenberg)	0 (0%)	0 (0%)	1 (3.3%)
?*Spongosphaera streptacantha* Haeckel	1 (1.1%)	0 (0%)	0 (0%)
NASSELLARIA			
Plectacantha trichoides Jørgensen	37 (38.9%)	7 (20.6%)	5 (16.7%)
Plectacantha oikiskos (Jørgensen)	10 (10.5%)	4 (11.8%)	3 (10%)
Pseudocubus obeliscus Haeckel	4 (4.2%)	3 (8.8%)	2 (6.7%)
Pseudocubus sp. A	1 (1.1%)	0 (0%)	0 (0%)
Pseudodictyophimus gracilipes (Bailey)	3 (3.2%)	2 (5.9%)	1 (3.3%)
Neosemantis distephanus Popofsky	2 (2.1%)	0 (0%)	0 (0%)
Phormacantha hystrix (Jørgensen)	1 (1.1%)	0 (0%)	2 (6.7%)
Zigocircus productus (Hertwig)	1 (1.1%)	1 (2.9%)	0 (0%)
Peridium spinipes Haeckel	0 (0%)	1 (2.9%)	0 (0%)
Lophophaena aff. *witjazii* (Petrushevskaya)	0 (0%)	1 (2.9%)	0 (0%)
Lophospyris sp.	3 (3.2%)	4 (11.8%)	6 (20%)
Plagiacantha sp.	0 (0%)	1 (2.9%)	0 (0%)
Amphiplecta sp.	1 (1.1%)	0 (0%)	0 (0%)
Acanthodesmia sp.	1 (1.1%)	0 (0%)	0 (0%)
Acanthodesmia? sp.	1 (1.1%)	0 (0%)	0 (0%)
Total	95 (100.5%)	34 (99.7%)	30 (99.9%)

(Bailey), and *Lophospyris* sp. The former species and each of the latter two consist of 4.2 % and 3.2 % of the fauna, respectively. The other nine nassellarian species, totaling 8.7 % of the fauna, include *Pseudocubus* sp. A, *Neosemantis distephanus* Popofsky, *Phormacantha hystrix* (Jørgensen), *Zigocircus productus* (Hertwig), *Amphiplecta* sp., *Acanthodesmia* sp., and *Acanthodesmia*? sp.

In sample 606-6SD-2, collected from water of ca. 63-36 m deep, only 10 specimens belonging to five spumellarian species were obtained. The fauna includes *Cyrtidosphaera reticulata*, *Tetrapyle octacantha*, *Didymocyrtis tetrathalamus tetrathalamus*, *Larcopyle butschlii*, and *Dictyocoryne truncatum*. *Tetrapyle octacantha* is the most abundant constituent occupying 17 % of the fauna; only one specimen each of the other species was recovered. Nine nassellarian species were identified in the fauna, including: *Plectacantha trichoides*, *Plectacantha oikiskos*, *Pseudocubus obeliscus*, *Pseudodictyophimus gracilipes*, *Zigocircus productus*, *Pe-*

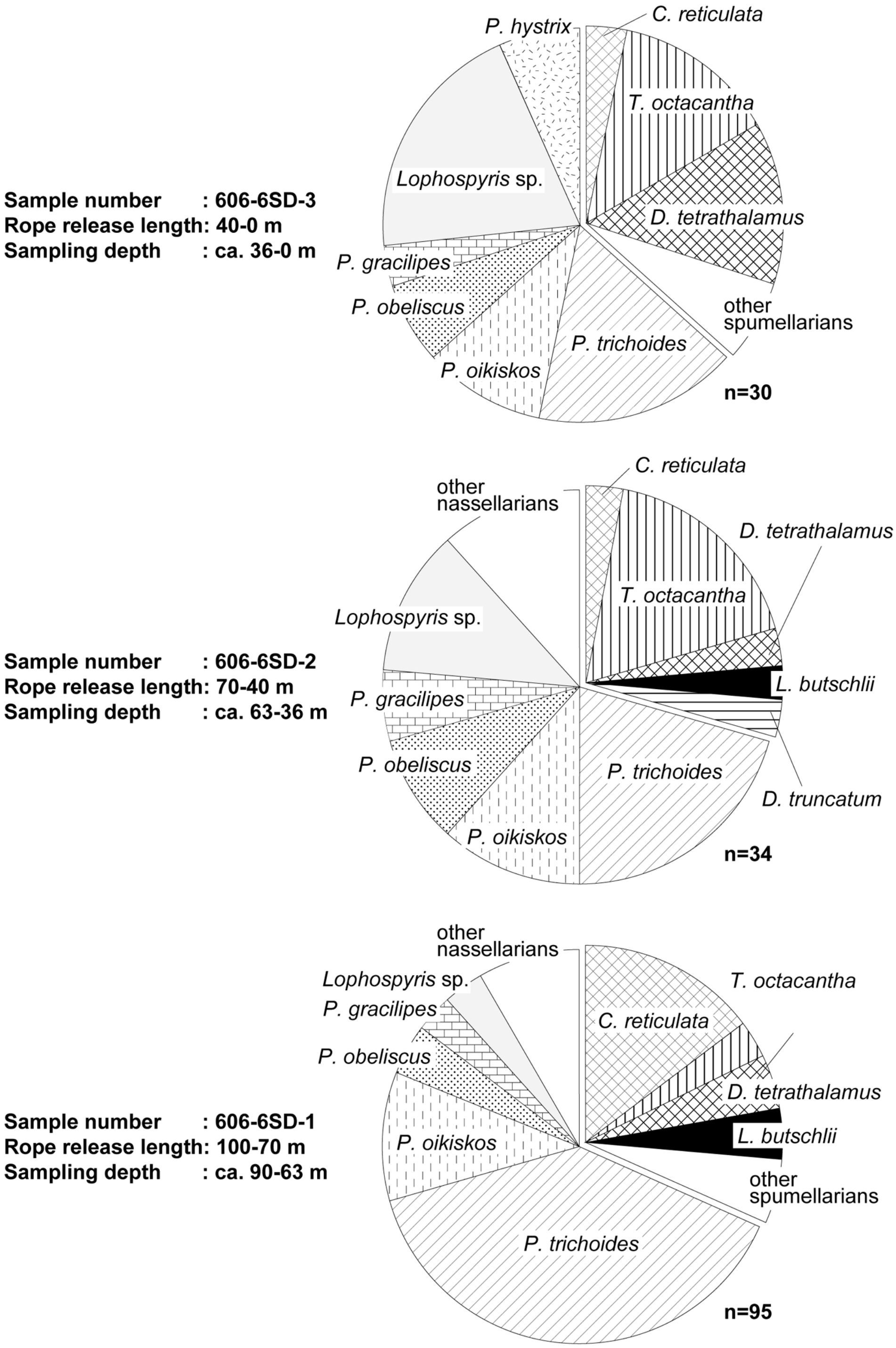

Fig. 3. Radiolarian faunal compositions at three different depth intervals.

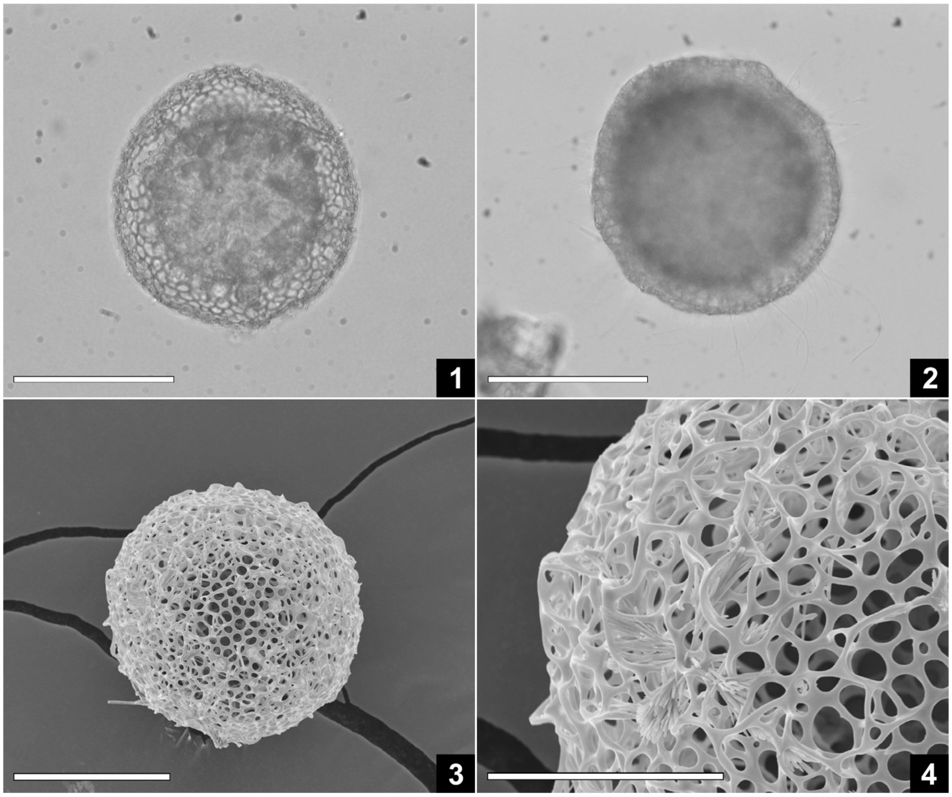

Fig. 4. Transmitted light microscopic and SEM images showing living specimens and a skeleton of *Cyrtidosphaera reticulata* Haeckel. 1 and 2: Transmitted light microscopic images of living specimens; scale bars equal 100 µm. 3: SEM image of the external appearance of the skeleton; scale bar equals 100 µm. 4: SEM image of high magnification view of the skeleton; scale bar equals 50 µm.

ridium spinipes Haeckel, *Lophophaena* aff. *witjazii* (Petrushevskaya), *Lophospyris* sp., and *Plagiacantha* sp. The nassellarian composition of this fauna is similar as a whole to that of sample 606-6SD-1 in terms of the dominance of *P. trichoides* and *P. oikiskos* (over 30 % of the fauna).

The radiolarian fauna in sample 606-6SD-3, recovered from waters between 36 m deep to the surface, contains five spumellarian and six nassellarian species. Spumellarian species are *Cyrtidosphaera reticulata*, *Tetrapyle octacantha*, *Didymocyrtis tetrathalamus tetrathalamus*, *Styptosphaera spongiacea*, and *Euchitonia elegans* (Ehrenberg). *Tetrapyle octacantha* and *D. t. tetrathalamus* are abundant and total more than 20 % of the fauna, the others are generally minor. Six nassellarian species are included: *Plectacantha trichoides*, *Plectacantha oikiskos*, *Pseudocubus obeliscus*, *Pseudodictyophimus gracilipes*, *Phormacantha hystrix*, and *Lophospyris* sp. Two species of *Plectacantha,* which are the most dominate nassellarian species in samples 606-6SD-1 and 606-6SD-2, are common in this sample, but they do not dominate the fauna. *Lophospyris* sp. is the most abundant species comprising 20 % of the fauna.

Discussions

1. Relationship between the vertical profiles of water properties and radiolarian fauna

The CTD sensor allowed us to record the vertical profiles of water properties from 64 m deep to the surface (Fig. 2). The radiolarian faunas in three samples of different depth intervals (606-6SD-1, 606-6SD-2, 606-6SD-3) differ slightly in the spumellarian species composition between the deeper sample (606-6SD-1) and shallower two samples (606-6SD-2, 606-6SD-3). In sample 606-6SD-1, *Cyrtidosphaera reticulata* and *Larcopyle butschlii* are abundant compared to the shallower two samples (Fig. 3). These taxa were reported in the late June, 2001 and late May, 2002 faunas off Tassha by Matsuoka et al. (2002) and Itaki et al. (2003), but have not yet been found in the early September, 2000 and late September, 2001 faunas (Matsuoka et al., 2001; Kurihara and Matsuoka, 2005). Itaki et al. (2000) reported that *L. butschlii* is the most abundant component in the 40-160 m interval in the water column of the Sea of Japan off western Hokkaido. Itaki et al. (2000) also reported that mature forms of *L. butschlii* were recovered from water as deep as 1000 m. Furthermore, Matsuoka et al. (2002) suggested that *C. reticulata* is a deep-water dweller. Taken together, there is a close correlation between lowering temperature in the vertical profile (Fig. 2) and increasing numbers of *C. reticulata* and *L. butschlii*, which can be explained in relation to their temperature tolerance ranges. In addition, although the number of individuals is small, *Tetrapyle octacantha* and *Didymocyrtis tetrathalamus tetrathalamus* are relatively abundant in samples 606-6SD-2 and 606-6SD-3 compared to sample 606-6SD-1 (Fig. 3). Matsuoka et al. (2001) reported that these taxa are abundant in the early autumn fauna and are also common in the Kuroshio Warm Current. In conclusion, the vertical change of faunal compositions in several spumellarian species depends on reduced water temperature with increasing depth.

The nassellarian faunal constituents in each of the three samples are similar but the standing stocks of two *Plectacantha* species (*P. trichoides* and *P. oikiskos*) are quite different. As mentioned above, in sample 606-6SD-1, *P. trichoides* and *P. oikiskos* are highly dominant and comprise about 50 % of the fauna (Fig. 3). The cause of this phenomenon is not well known yet, but we suggest that the peak relative abundance of algae exists in the vicinity of the sampling interval of 606-6SD-1 (Fig. 2). A likely explanation is that the increasing number of these nassellarian taxa is linked to proliferation of microbial communities as the prey of radiolarians, which may be controlled by high algal density and bacterial decomposition.

2. Seasonal faunal change process during the transition period from spring to summer

Seasonal faunal data have been reported from the surface water off Tassha, Sado Island in late May, 2002 (Itaki et al., 2003), late June, 2001 (Matsuoka et al., 2002), early September, 2000 (Matsuoka et al., 2001), and late September, 2001 (Kurihara and Matsuoka, 2005). Although the sampling location and depth are not same for these studies, the faunal characteristics from spring to autumn (May to September) can be roughly summarized as follows; (1) the late May to late June faunas are characterized by the abundant occurrence of *Larcopyle butschlii*, *Cyrtidosphaera reticulata*, *Spongotrochus glacialis* Popofsky, and *Lithomellisa setosa* Jørgensen (Matsuoka et al., 2002; Itaki et al., 2003); and (2) the September fauna is composed mainly of *Didymocyrtis tetrathalamus tetrathalamus*, *Tetrapyle octacantha*, *Larcospina quadrangular* Haeckel, *Spongosphaera streptacantha*, and plagiacanthid and lophophaenid nassellarians such as *Pseudocubus obeliscus* (Matsuoka et al., 2001; Kurihara and Matsuoka, 2005). In addition, although the faunal details of July and August have not yet been published, Kurihara and Matsuoka (2004) obtained many *S. streptacantha* individuals from plankton samples collected in July 22 and August 18, 2003.

Radiolarian faunal characteristics of the present study correspond well to those of the late May to late June faunas mentioned above, especially the late June fauna. To help understand the faunal transition process, it is necessary to consider the relationships between the seasonal temperature structure of the surface water in the Sea of Japan and the faunal assemblages. The mean surface water temperature in the winter season is ca. 10° C (Sado Marine Biological Station, Niigata University, 2001), and the water forms a well-mixed layer into the deeper part. In the summer season, by contrast, the surface to subsurface waters are well stratified and a homogeneous temperature layer (ca. 27° C) is formed from the surface to 20-30 m deep (Matsuoka et al., 2001). The temperature profile of the present study indicates the presence of a high temperature gradient layer from the surface to 21 m deep (Fig. 2). This is regarded as being in the intermediate condition between the winter (or spring) and summer seasons and allows the Tsushima Warm Current to move northward keeping water temperature warm around Sado Island. As mentioned above, some spumellarian species such as *Larcopyle butschlii*, *Cyrtidosphaera reticulata*, and *Didymocyrtis tetrathalamus tetrathalamus* have different vertical distributions in our samples; *L. butschlii* and *C. reticulata* prefer cold, deeper water, whereas *D. t. tetrathalamus* likes warm, shallower water. It is important for the survival of the latter group whether the Tsushima Warm Current reaches Sado Island keeping water temperature warm or not. Consequently, it is highly probable that the faunal transition off Tassha is mediated by the influx of warm water dwellers of the Tsushima Warm Current into the surface layer of the water column during spring to summer.

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References

Itaki, T., Domitsu, H. and Oba, M., 2000, Vertical distribution of living radiolarians in the northeastern Japan Sea, off western Hokkaido (Preliminary report). Comprehensive study on environmental changes in the western Hokkaido coastal area and study on evaluation of marine active faults. *Preliminary reports on researches in the 1999 fiscal year, Geol. Surv. Japan*, 204-211. (in Japanese)

Itaki, T., Matsuoka, A., Yoshida, K., Machidori S., Shinzawa, M. and Todo, T., 2003, Late spring radiolarian fauna in the surface water off Tassha Aikawa Town, Sado, central Japan. *Sci. Rep., Niigata Univ., Ser. E (Geol.)*, no. 18, 41-51.

Kurihara, T. and Matsuoka, A., 2004, Shell structure and morphologic variation in *Spongosphaera streptacantha* Haeckel (Spumellaria, Radiolaria). *Sci. Rep., Niigata Univ., Ser. E (Geol.)*, no. 19, 35-48.

Kurihara, T. and Matsuoka, A., 2005, Shell variability of *Pseudocubus obeliscus* Haeckel in the early autumn radiolarian fauna off Tassha, Sado Island, central Japan. *Sci. Rep., Niigata Univ., Ser. E (Geol.)*, no. 20, 29-45.

Matsuoka, A. and Anderson, O. R., 1992, Experimental and observational studies of radiolarian physiological ecology: 5. Temperature and salinity tolerance of *Dictyocoryne truncatum*. *Marine Micropaleontol.*, **19**, 299-313.

Matsuoka, A., Shinzawa, M., Yoshida, K., Machidori S., Kurita, H. and Todo, T., 2002, Early summer radiolarian fauna in surface waters off Tassha, Aikawa Town, Sado Island, central Japan. *Sci. Rep., Niigata Univ., Ser. E (Geol.)*, no. 17, 17-25.

Matsuoka, A., Yoshida, K., Hasegawa, S., Shinzawa, M., Tamura, K., Sakumoto, T., Yabe, H., Niikawa, I. and Tateishi, M., 2001, Temperature profile and radiolarian fauna in surface waters off Tassha, Aikawa Town, Sado Island, central Japan. *Sci. Rep., Niigata Univ., Ser. E (Geol.)*, no. 16, 83-93.

Sado Marine Biological Station, Niigata University, 2001, Hydrographic data taken at three locals in the vicinity of the Sado Marine Biological Station during the year 2000. *Annual activity reports of the Sado Marine Biological Station, Niigata Univ.*, no. 31, 19-22.

Senjyu, T., 1999, The Japan Sea Intermediate Water; its characteristics and circulation. *Jour. Oceanography*, **55**, 111-122.

Plate 1

Transmitted light microscopic images of radiolarian skeletons from sea water off Tassha, Sado Island. The scale bar of each figure equals 100 µm.

1. *Plectacantha trichoides* Jørgensen
2. *Plectacantha oikiskos* (Jørgensen)
3. *Pseudocubus obeliscus* Haeckel
4. *Pseudocubus* sp. A
5. *Amphiplecta* ? sp.
6. *Pseudodictyophimus gracilipes* (Bailey)
7. *Phormacantha hystrix* (Jørgensen)
8. *Peridium spinipes* Haeckel

Plate 2

Transmitted light microscopic images of radiolarian skeletons from sea water off Tassha, Sado Island. The scale bar on each figure equals 100 µm.

1. *Lophophaena capito* Ehrenberg
2. *Neosemantis distephanus* Popofsky
3. *Zigocircus productus* (Hertwig)
4. *Acanthodesmia* sp.
5. *Lophospyris* sp.
6. *Cyrtidosphaera reticulata* Haeckel
7. *Tetrapyle octacantha* Müller
8. *Larcopyle butschlii* Dreyer

Plate 3

Transmitted light microscopic images of radiolarian skeletons from sea water off Tassha, Sado Island. The scale bar on each figure equals 100 µm.

1. *Didymocyrtis tetrathalamus tetrathalamus* (Haeckel)
2. ?*Spongosphaera streptacantha* Haeckel
3. *Styptosphaera spongiacea* Haeckel
4. *Spongodiscus* sp. A
5. *Spongodiscus* sp. B
6. *Dictyocoryne truncatum* (Ehrenberg)
7. *Euchitonia elegans* (Ehrenberg)
8. *Sphaerozoum* sp.

Plate 1

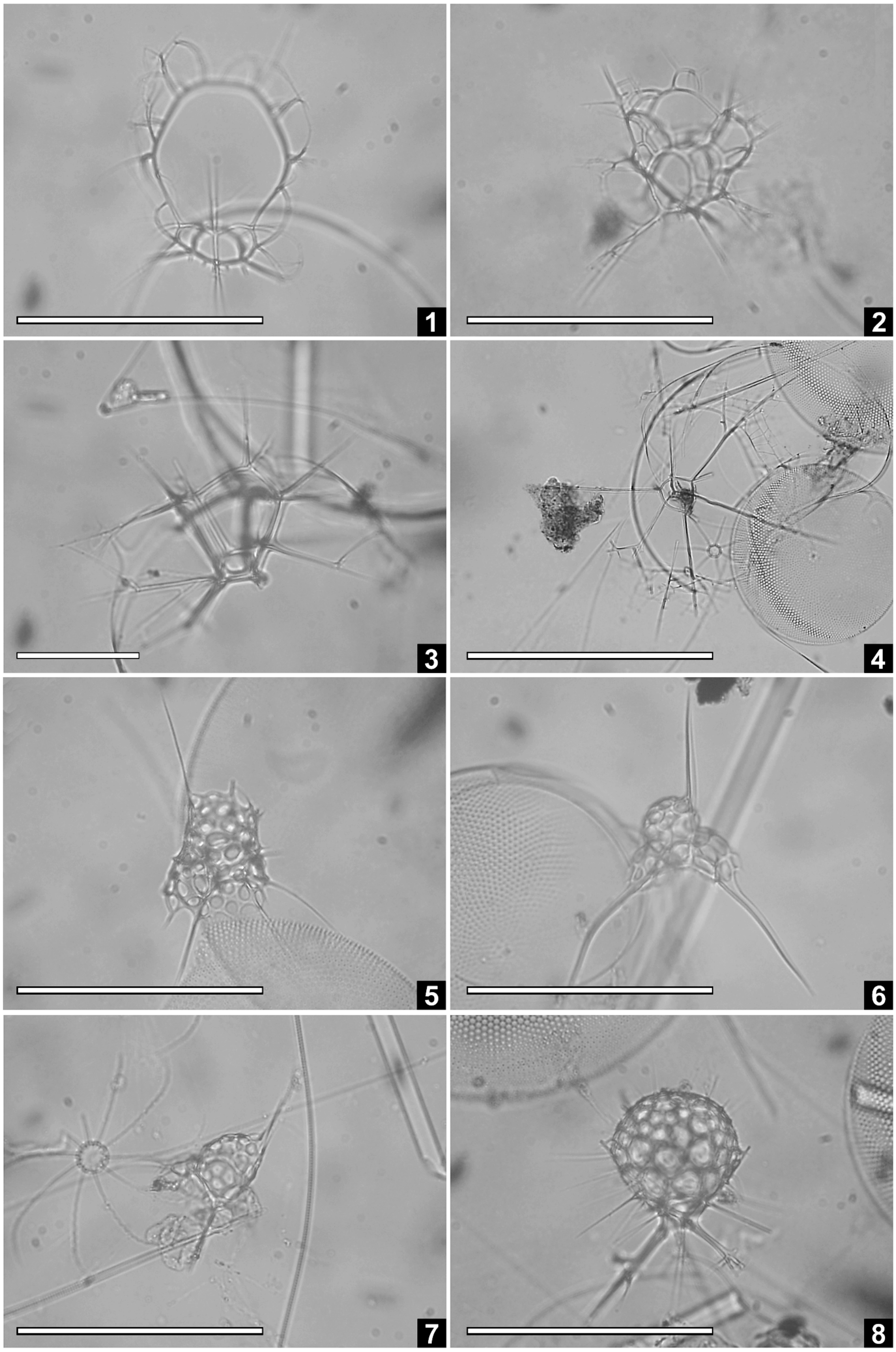

Plate 2

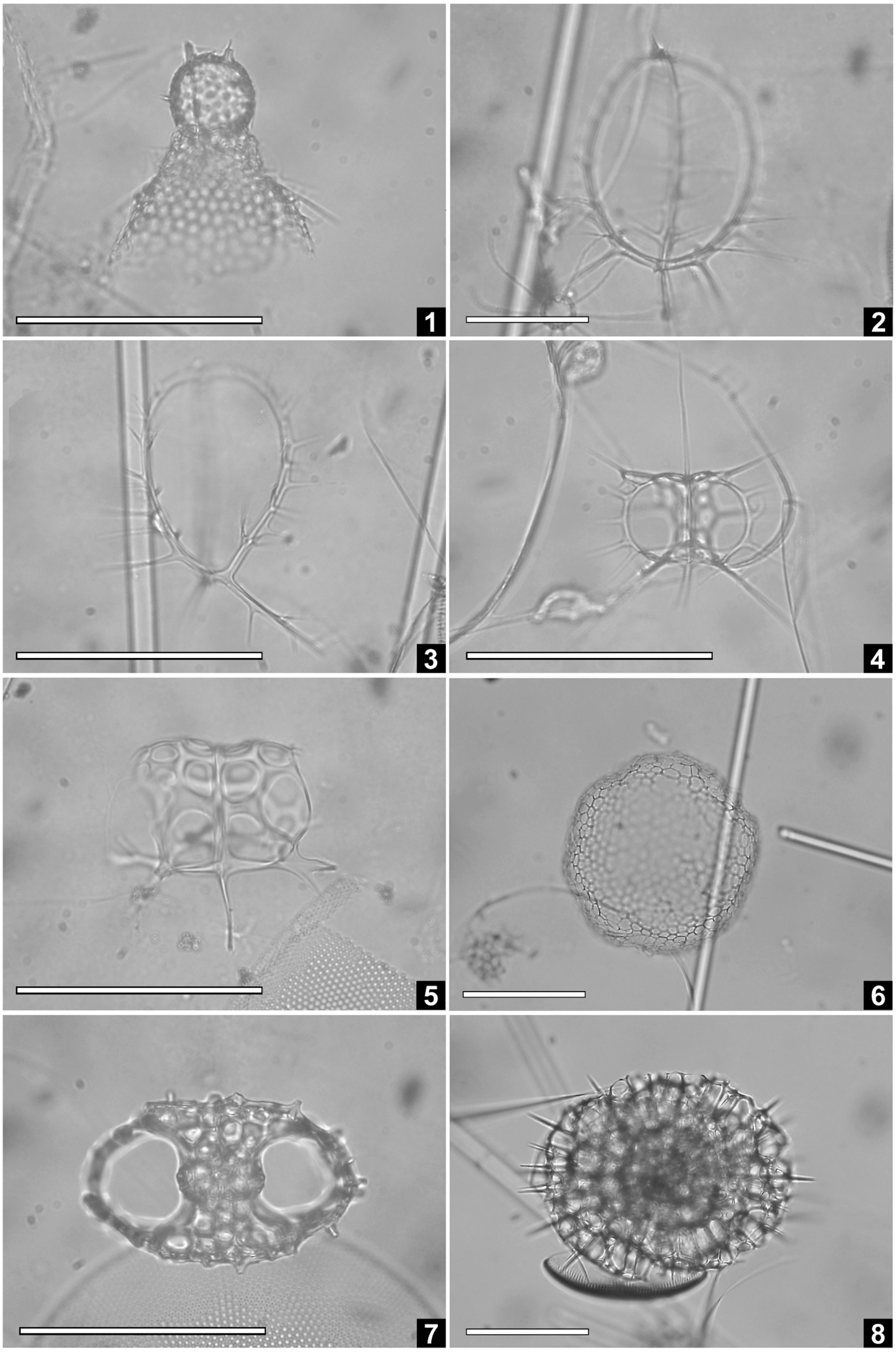

Plate 3