A late-winter (March 10, 2008) living radiolarian fauna in surface-subsurface waters of the Japan Sea off Tassha, Sado Island, central Japan

Toshiyuki KURIHARA* and Atsushi MATSUOKA**

Abstract

This paper documents a radiolarian fauna in late winter (March 10, 2008) within surface-subsurface waters (< 100 m depth) in the Japan Sea off Tassha, Sado City, Sado Island, Niigata Prefecture, central Japan. The sea-water temperature at the sampling site (38°05' N, 138°10' E) is near-constant down to 100 m depth (9.6-9.7 ℃), which probably represents the lowest water temperature throughout the year. This water body with a uniform temperature is considered to have formed by the development of a surface mixed layer influenced by the strong northwesterly winter monsoon on the Japan Sea. Eleven spumellarian and 14 nassellarian species were identified from 583 recovered skeletons. The faunal composition is characterized by the dominance of cold-water spumellarians (*Cyrtidosphaera reticulata* and *Larcopyle buetschlii*) and spicule-type nassellarians (*Neosemantis distephanus* and *Plectacantha cremastoplegma*) with minor amounts of a warm-water dweller (*Didymocyrtis tetrathalamus*). Based on accumulated knowledge of the radiolarian ecology of living species off Sado Island, these findings can be explained in terms of the low water temperature preferred by cold-water species, the opportunistic appearances of spicule-type nassellarians, and weak inflow of the Tsushima Warm Current during winter.

Key words: Japan Sea, plankton, Radiolaria, Sado Island, seasonal change, winter.

* Graduate School of Science and Technology, Niigata University, Niigata 950-2181, Japan
** Department of Geology, Faculty of Science, Niigata University, Niigata 950-2181, Japan
(Manuscript received 28 January, 2009; accepted 26 February, 2009)

Introduction

Marine organisms in the Japan Sea provide insight into ecosystem evolution and past and present environmental change within the sea (e.g., Nishimura, 1974; Amano, 2001). Planktonic organisms, including polycystine radiolarians, are important in this regard, and their horizontal and vertical distributions have been investigated by many researchers (e.g., Chiba and Saino, 2002; Itaki, 2003; Itaki et al., 2004, 2007; Kitamura and Kimoto, 2006).

The Japan Sea is a semi-enclosed marginal sea (maximum depth exceeding 3700 m) surrounded by the Japanese Islands, the Korean Peninsula, and the Eurasian Continent. The sea is connected to adjacent seas via the Tsushima, Tsugaru, Soya, and Tatar straits, and most of oceanic waters originates from the Tsushima Warm Current (TWC).

The faunal composition of living radiolarians in the Japan Sea is believed to be strongly dependent on the vertical water-mass structure of the Japan Sea Proper Water (JSPW) (Itaki, 2003, 2007) and the properties of inflowing TWC; information on the latter is available in our recent article (Kurihara et al., 2008).

Seasonal changes in radiolarian fauna in surface-subsurface waters off Tassha, Sado Island, Niigata Prefecture, central Japan (Fig. 1), have attracted much attention in recent years, as the seasonal temperature difference reaches 15 ℃ [see fig. 2 of Itaki et al. (2003b)]. Since the introductory study by Matsuoka et al. (2001), the second author of the present study (A. M.) and collaborators have investigated the nature of these seasonal changes (Matsuoka et al., 2002; Itaki et al., 2003; Kurihara et al., 2006, 2007) from a base at the Sado Marine Biological Station administered by the Faculty of Science, Niigata University, Japan. These studies have provided increasing information on living radiolarian faunas over the period from early summer (June) to autumn (September); however, the occurrence of hostile weather over the Japan Sea during the winter monsoon season has prevented us from obtaining plankton

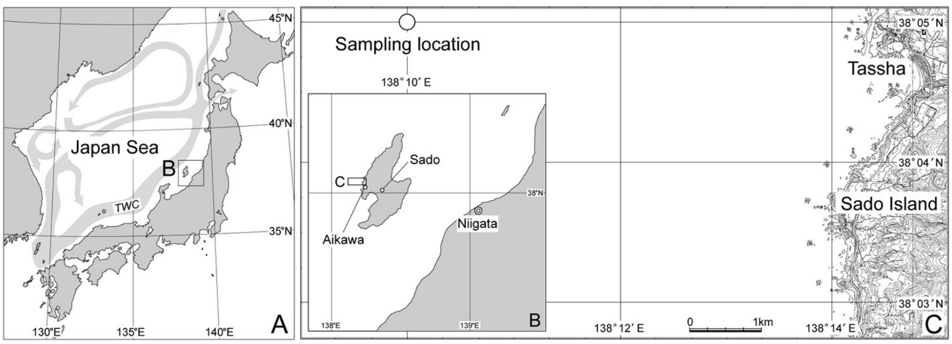

Fig. 1. Index map showing the location of the sampling site. Topographic data are sourced from the 1:25,000 "Aikawa" map sheet published by the Geographical Survey Institute of Japan.

samples at this time of year using our research vessel (*IBIS2000* of the Sado Marine Biological Station).

In March of 2008 we started a new project involving year-round plankton sampling off Tassha, Sado Island. The aim is to provide information not only regarding the radiolarian faunal composition during the winter season but also regarding the process of the seasonal faunal transitions in the Japan Sea. Herein, we describe the radiolarian fauna sampled on March 10, 2008. The characteristics of the faunal composition are also briefly discussed.

Materials and methods

Plankton sampling was conducted on March 10, 2008 at 38°05' N, 138°10' E, approximately 6 km west of Tassha, Sado Island, central Japan (Fig. 1). A single plankton sample (310-9SD-1) was collected from 0-100 m depth without closing the net, using a Marukawa-type 10 µm opening net with a mouth diameter of 0.3 m. For depths between 100 m and the surface, sea-water temperature was measured using a conventional digital thermometer. These operations were carried out by the vessel *Iwayuri*. The measurements of sea-water temperature for 0-100 m depth by the digital thermometer were also conducted on April to December, 2008, along with the plankton samplings.

For sample 310-9SD-1, siliceous residues were obtained after treatment involving the acid dissolution (ca. 50% sulfuric acid) of organic matter and washing in a sieve (46 µm opening). The residues were then mounted on a glass slide using Canada balsam for observation under a transmitted light microscope. Digital photomicrographs of radiolarian skeletons (Figs. 2–4) were taken using a Nikon Coolscope.

Results and implications of faunal characteristics

Table 1 lists the sea-water temperature of the water mass from the surface to 100 m depth, as measured on March 10, 2008. For comparison, temperature data for other months (April to December of 2008) are also listed. The temperature is near-constant (around 9.6-9.7 ℃) at every measurement depth. This finding is related to the development of a surface mixed layer under the influence of a strong, cold northwesterly wind that blows off the Asian Continent in winter. According to Itaki et al. (2003b), the lowest sea-surface temperature around Sado Island was recorded during March (around 10 ℃). Although temperatures were not measured during January or February, it is likely that the temperature measured on March 10 represents the lowest temperature during 2008.

Eleven spumellarian and 14 nassellarian species were identified from sample 310-9SD-1, including *Acanthosphaera circopora* Popofsky, *Cyrtidosphaera reticulata* Haeckel, *Dictyocoryne* sp., *Didymocyrtis tetrathalamus* (Haeckel), *Larcopyle buetschlii* Dreyer,

Table 1. Sea-water temperatures of the water mass measured from 100 m depth to the surface from March to December, 2008 at the sampling location off Tassha, Sado Island.

Depth (m)	Sea-water temperature (°C)								
	2008/3/10	2008/4/16	2008/5/28	2008/6/16	2008/7/15	2008/9/9	2008/10/14	2008/11/13	2008/12/4
0	9.7	12.4	14.7	15.3	23.4	25.3	21.4	19.4	17.3
10	9.7	11.3	13.6	15.0	22.8	25.3	21.3	19.4	17.3
20	9.7	11.0	12.0	15.1	19.6	24.6	21.2	19.4	17.2
30	9.7	10.9	10.6	14.0	17.4	22.4	21.1	19.4	17.2
40	9.7	10.5	10.6	13.4	15.9	20.5	21.1	19.4	17.2
50	9.7	10.4	10.5	12.6	15.6	19.2	19.9	19.3	17.2
60	9.6	10.4	9.8	10.9	14.8	18.1	17.3	19.1	17.1
70	9.6	10.4	9.0	9.7	14.1	16.7	16.5	18.9	17.0
80	9.6	10.2	8.6	8.6	13.5	15.4	16.0	18.6	17.0
90	9.6	9.9	8.4	8.5	13.0	14.8	15.1	18.3	17.0
100	9.6	9.5	8.4	8.4	12.4	14.1	14.3	17.1	17.0

Table 2. List of radiolarian species and standing stocks of radiolarian shells obtained from sample 310-9SD-1.

Spumellarian species	#shells	Nassellarian species	#shells
Acanthosphaera circopora Popofsky	45	*Botryopyle cribosa* (Popofsky) group	5
Cyrtidosphaera reticulata Haeckel	99	*Ceratocyrtis histricosa* (Jørgensen)	10
Dictyocoryne sp.	2	*Lipmanella* sp.	3
Didymocyrtis tetrathalamus (Haeckel)	3	*Lithomelissa setosa* Jørgensen	6
Larcopyle buetschlii Dreyer	75	*Lophophaena* sp.	8
Plegmosphaera pachypila Haeckel	2	*Neosemantis distephanus* Popofsky	145
Spongotrochus glacialis Popofsky	3	*Peridium spinipes* Haeckel	10
Stylochlamydium aff. *venustum* (Bailey)	1	*Peridium* sp.	10
Stylodictya sp.	1	*Peromelissa phalacra* Haeckel	1
Tetrapyle octacantha Müller	7	*Plectacantha cremastoplegma* Nigrini	46
Actinommidae gen. et sp. indet.	2	*Plectacantha* sp.	47
other spumellarians	15	*Pseudodictyophimus gracilipes* (Bailey)	14
Total numbers of spumellarian shells	255	*Pterocorys* sp.	2
		Zygocircus productus (Hertwig)	1
		other nassellarians	20
		Total numbers of nassellarian shells	328
Total numbers of radiolarian shells	583		

Plegmosphaera pachypila Haeckel, *Spongotrochus glacialis* Popofsky, *Stylochlamydium* aff. *venustum* (Bailey), *Stylodictya* sp., *Tetrapyle octacantha* Müller, Actinommidae gen. et sp. indet., *Botryopyle cribosa* (Popofsky) group, *Ceratocyrtis histricosa* (Jørgensen), *Lipmanella* sp., *Lithomelissa setosa* Jørgensen, *Lophophaena* sp., *Neosemantis distephanus* Popofsky, *Peridium spinipes* Haeckel, *Peridium* sp., *Peromelissa phalacra* Haeckel,

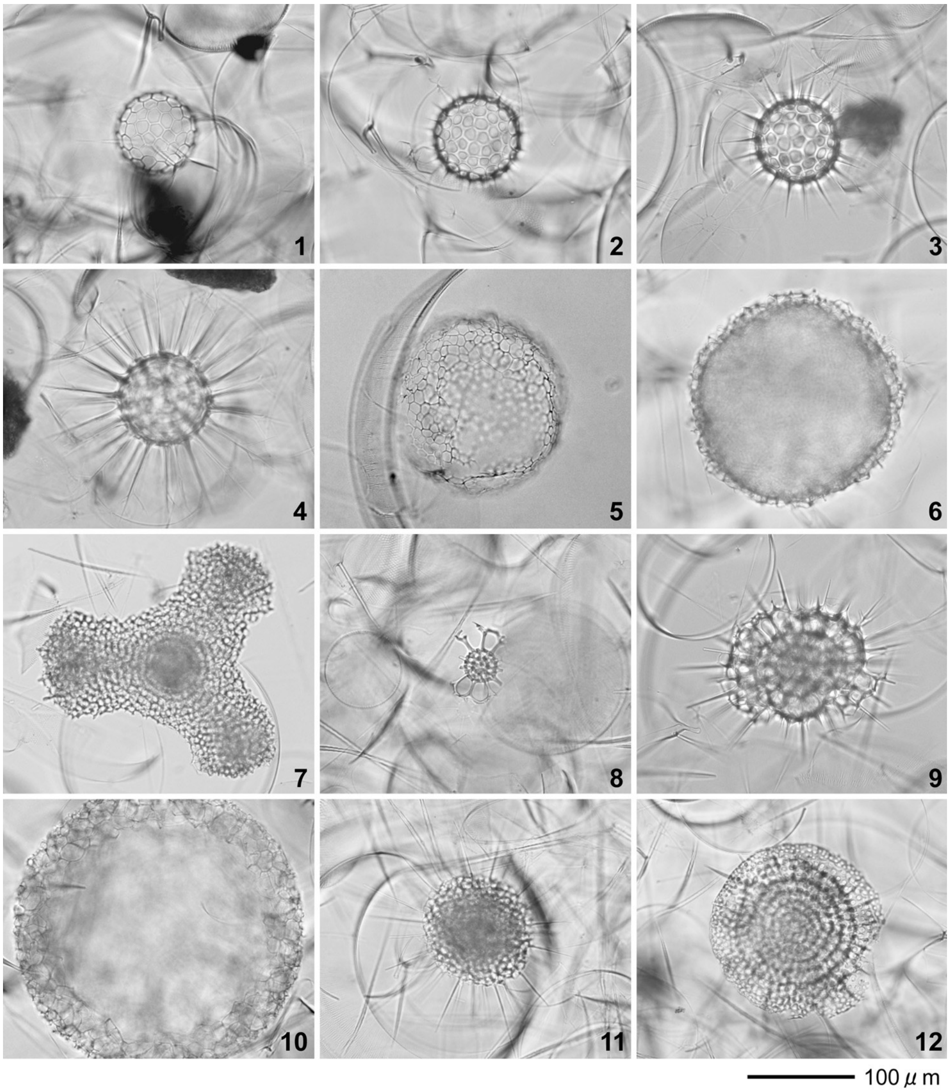

Fig. 2. Photomicrographs (transmitted light) of radiolarian skeletons from sample 310-9SD-1. 1-4: *Acanthosphaera circopora* Popofsky, 5, 6: *Cyrtidosphaera reticulata* Haeckel, 7: *Dictyocoryne* sp., 8: *Didymocyrtis tetrathalamus* (Haeckel), 9: *Larcopyle buetschlii* Dreyer, 10: *Plegmosphaera pachypila* Haeckel, 11: *Spongotrochus glacialis* Popofsky, 12: *Stylochlamydium* aff. *venustum* (Bailey).

Plectacantha cremastoplegma Nigrini, *Plectacantha* sp., *Pseudodictyophimus gracilipes* (Bailey), *Pterocorys* sp., and *Zygocircus productus* (Hertwig). Table 2 lists the radiolarian species and numbers of skeletons counted from all residues obtained from the sample. Figures 2-4 show photomicrographs of radiolarian skeletons. The standing stock of radiolarian shells per 1 m^3 of sea water in the sample was calculated to be 82.5 shells/m^3.

Based on the number of skeletons listed in Table 2, the fauna of sample 310-9SD-1 is characterized as follows: (1) two species considered to be cold-water dwellers (*Cyrtidosphaera reticulata* and *Larcopyle buetschlii*) are dominant, making up approximately 30% of the fauna; (2) *Neosemantis distephanus* and *Plectacantha cremastoplegma*, which have a spicular skeleton, make up approximately 44% and 14%, respectively, of the nassellarian component; and (3) small amounts of a warm-water dweller are found.

Regarding (1), the dominance of *Cyrtidosphaera reticulata* and *Larcopyle buetschlii* has been described previously in the fauna collected during June of 2001 and 2005 (water mass shallower than 100 m depth) at the same sampling location as that of the present study (Matsuoka et al., 2002; Kurihara et al., 2006). In contrast, at the same location and depth these species were absent in the September fauna of 2000, 2001, and 2005 (Matsuoka et al., 2001; Kurihara and Matsuoka, 2005; Kurihara et al., 2007). According to Itaki (2003), the adult forms of *L. buetschlii* are abundant in the water mass between 1000 and 200 m depth in the northeastern Japan Sea, whereas juvenile forms occur in waters shallower than 200 m.

These data regarding the center of the distribution suggest that in the central Japan Sea adults of *Larcopyle buetschlii* and probably also *Cyrtidosphaera reticulata* survive in deeper waters below 100 m depth during the warm seasons. The reappearance of these species at depths shallower than 100 m during winter occurs in response to a shallowing and mixing of the deep water mass caused in turn by the strong development of a surface mixed layer.

Ceratocyrtis histricosa and *Pseudodictyophimus gracilipes* are relatively abundant among the nassellarians. Itaki (2003) reported the common occurrence of living *C. histricosa* at 40-500 m depth with 0.5-4.0 ℃ (Itaki et al., 2003a) in the northeastern Japan Sea. In the Chukchi and Beaufort seas, western Arctic, *C. histricosa* and *P. gracilipes* are common species at depths of 300-500 m (0.5-1.0 ℃) and 0-300 m (-1.5-0.5 ℃), respectively (Itaki et al., 2003a). On this basis, it is possible that these species are also adapted to winter conditions in the Japan Sea as cold-water dwellers.

Point (2) is considered to be related to the blooming of spicule-type nassellarians without a chambered shell (e.g., species belonging to the genera *Pseudocubus* and *Plectacantha*). A similar phenomenon was observed in the faunas of June 6 and September 28, 2005 (Kurihara et al., 2006, 2007). In the fauna of June 2005, *Plectacantha trichoides* Jørgensen and *Plectacantha oikiskos* (Jørgensen) made up approximately 50% of the fauna obtained from ca. 90-63 m depth. In the case of September 2005, *Pseudocubus obeliscus* Haeckel and *Pseudocubus octostylus* Haeckel [= *Pseudocubus* sp. A of Kurihara et al. (2007)] made up approximately 70% of the fauna from ca. 35-0 m depth. Among these species, the feeding activity of *P. obeliscus* has been reported by Matsuoka (2007); the feeding strategy of this species is considered to be of advantage in collecting microflagellates and bacteria. Kurihara et al. (2006, 2007) proposed that the dominant occurrences of *Plectacantha* and *Pseudocubus* species during June and September 2005 were linked to the bacterial decomposition of algal remains and subsequent proliferation of microbial communities as the prey of radiolarians,

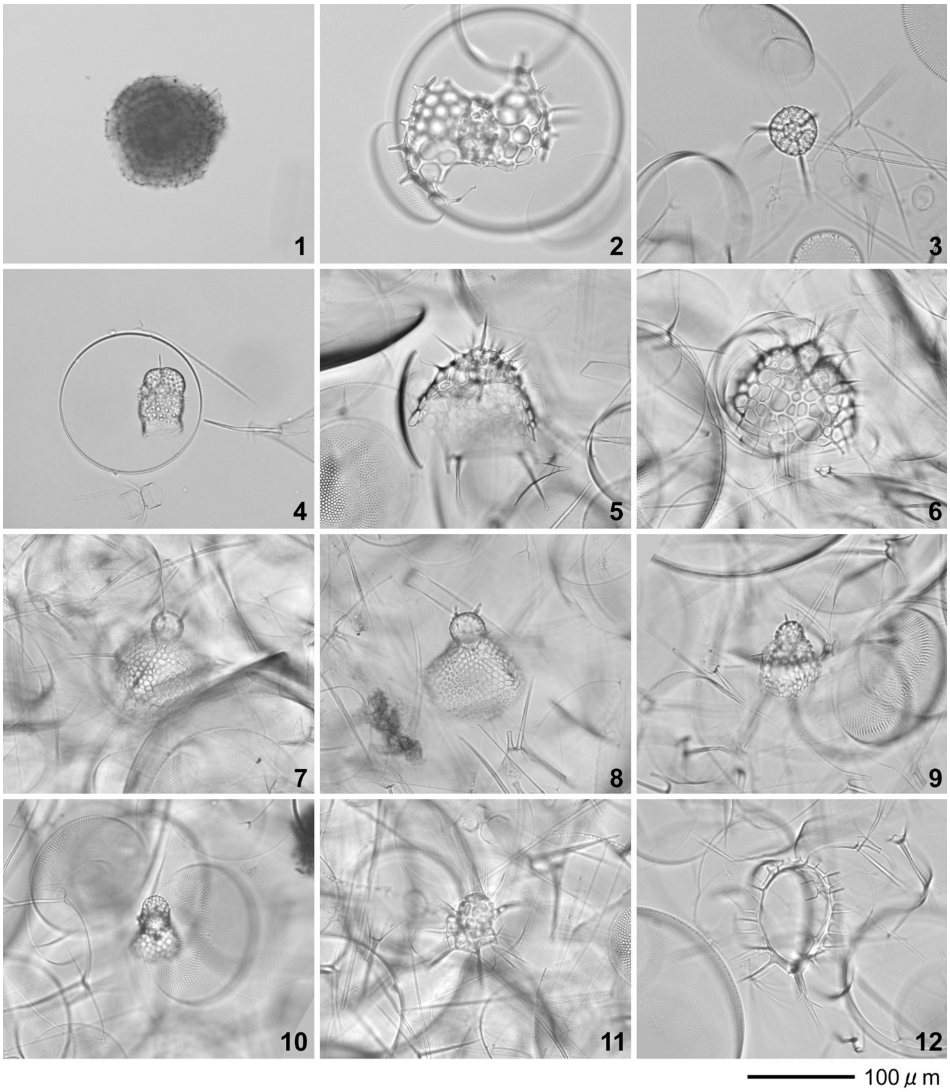

Fig. 3. Photomicrographs (transmitted light) of radiolarian skeletons from sample 310-9SD-1. 1: *Stylodictya* sp., 2: *Tetrapyle octacantha* Müller, 3: Actinommidae gen. et sp. indet., 4: *Botryopyle cribosa* (Popofsky) group, 5, 6: *Ceratocyrtis histricosa* (Jørgensen), 7, 8: *Lipmanella* sp., 9: *Lithomelissa setosa* Jørgensen, 10, 11: *Lophophaena* sp., 12: *Neosemantis distephanus* Popofsky.

because the sampling intervals corresponded to the peak abundance of algal chlorophylls.

Although we possess no clear evidence in determining the cause of the blooming of spicule-type nassellarians, these nassellarians (including *Neosemantis distephanus* and *Plectacantha cremastoplegma* in the present study) are considered opportunistic species adapted to a certain constrained environment, as indicated by their mode of occurrence. At

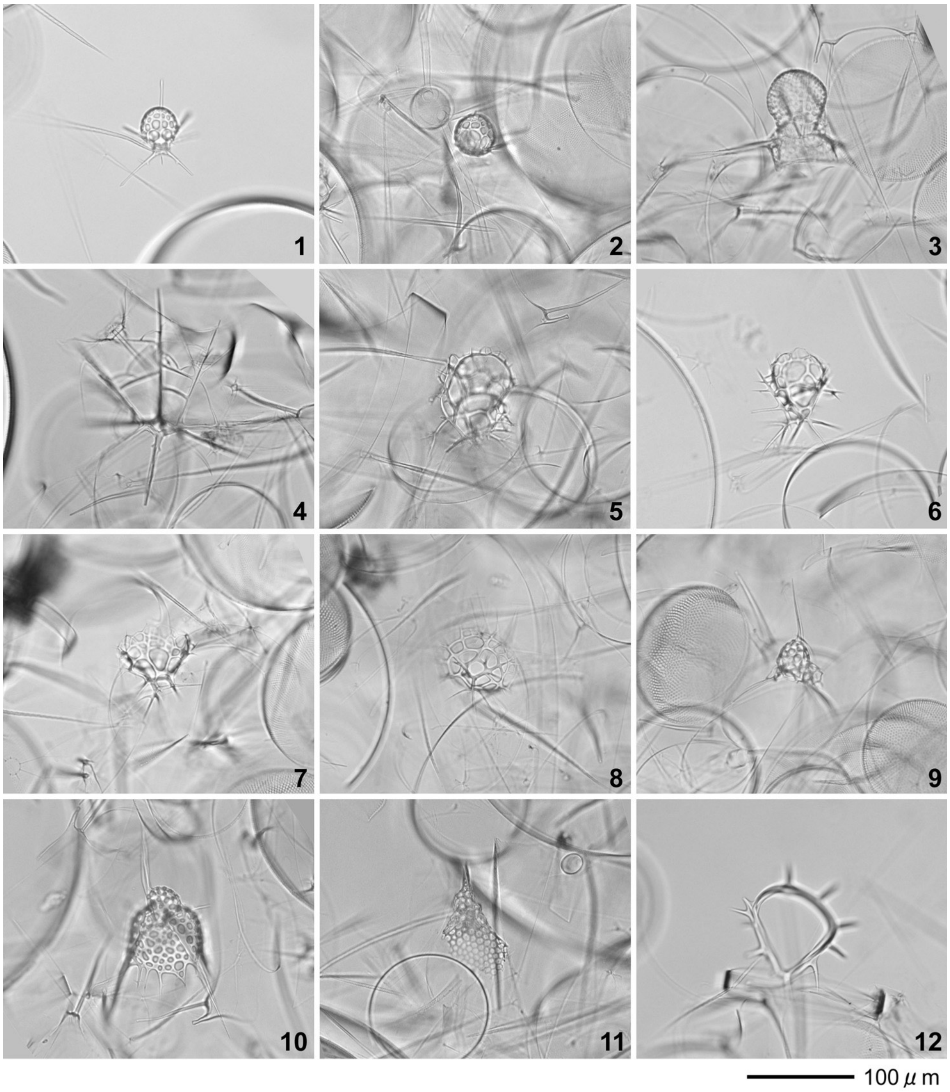

Fig. 4. Photomicrographs (transmitted light) of radiolarian skeletons from sample 310-9SD-1. 1: *Peridium spinipes* Haeckel, 2: *Peridium* sp., 3: *Peromelissa phalacra* Haeckel, 4: *Plectacantha cremastoplegma* Nigrini, 5-8: *Plectacantha* sp., 9, 10: *Pseudodictyophimus gracilipes* (Bailey), 11: *Pterocorys* sp., 12: *Zygocircus productus* (Hertwig).

least, although further study is required to ensure the repeatability of the results, the blooming of each spicule-type nassellarian species is possibly seasonal, being strongly affected by the temperature tolerance of each species.

With regard to (3), *Didymocyrtis tetrathalamus* can be considered a warm-water species, as it commonly occurs in the low-latitude regions of the Pacific (Nigrini, 1970; Lombari and

Boden, 1985). In terms of the occurrences of warm-water species in the Japan Sea, we previously suggested that inflow of the TWC strongly influenced the formation of a fauna including warm-water species during a mid-temperature season (early June) off Sado Island (Kurihara et al., 2008). Although the flow force of the TWC generally weakens during winter (Japan Meteorological Agency, available online), this warm-water species (*D. tetrathalamus*) can be considered an inflowed species transported by the TWC.

For other faunal constituents, *Acanthosphaera circopora* is abundant, making up 17.6% of spumellarian components. The dominant occurrence of this species has previously been detected from the September fauna at ca. 77-54 m depth (ca. 17-18 ℃) at the same location in 2005 [= *Acanthosphaera actinota* (Haeckel) of Kurihara et al. (2007)]. The wide range in temperature tolerated by this species makes it difficult to judge whether it is a warm-water species, but its ecologic characteristics are undoubtedly important as a major faunal component in the Japan Sea.

In conclusion, the March fauna, representing the winter (coldest) radiolarian fauna in surface-subsurface waters off Sado Island, is dominated by cold-water-dwelling spumellarians and opportunistic nassellarians, with minor warm-water species. In future work, additional sampling during early winter and spring is required to reveal the process of faunal transition throughout an entire year.

Acknowledgments

We thank Prof. M. Nozaki of the Sado Marine Biological Station, Faculty of Science, Niigata University, for the use of facilities at the station throughout our study. We would also like to thank Mr. Y. Kobayashi of Minshuku Iwayuri for carrying out plankton sampling, Mr. T. Shimotani for his assistance, and Dr. T. Itaki for his valuable comments on the identification of radiolarian species. We gratefully acknowledge Dr. H. Kurita for reviewing the manuscript.

References

Amano, K., 2001, Pliocene molluscan fauna of Japan Sea borderland and the paleoceanographic conditions. *Biol. Sci. (Tokyo)*, **53**, 178-184. (in Japanese)

Chiba, S. and Saino, T., 2002, Interdecadal change in the upper water column environment and spring diatom community structure in the Japan Sea: an early summer hypothesis. *Marine Ecology Progress Series*, **231**, 23-35.

Itaki, T., 2003, Depth-related radiolarian assemblage in the water column and surface sediments of the Japan Sea. *Marine Micropaleontol.*, **47**, 253-270.

Itaki, T., 2007, Historical changes of deep-sea radiolarians in the Japan Sea during the last 640 kyrs. *Fossils*, no. 82, 43-51. (in Japanese with English abstract)

Itaki, T., Ikehara, K., Motoyama, I. and Hasegawa, S., 2004, Abrupt ventilation changes in a marginal sea of the NW Pacific over the last 30 kyr: Evidence from deep-dwelling Radiolaria in the Japan Sea. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **208**, 263-278.

Itaki, T., Ito, M., Narita, H., Ahagon, N. and Sakai, H., 2003a, Depth distribution of radiolarians from the Chukchi and Beaufort Seas, western Arctic. *Deep-Sea Res. I*, **50**, 1507-1522.

Itaki, T., Komatsu, N. and Motoyama, I., 2007, Orbital- and millennial-scale changes of radiolarian assemblages during the last 220 kyrs in the Japan Sea. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **247**, 115-130.

Itaki, T., Matsuoka, A., Yoshida, K., Machidori, S., Shinzawa, M. and Todo, T., 2003b, 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.

Japan Meteorological Agency, available online, The ocean currents of the Japan Sea. http://www.data.kishou.go.jp/kaiyou/db/maizuru/knowledge/kairyu.html. (in Japanese)

Kitamura, A. and Kimoto, K., 2006, History of the inflow of the warm Tsushima Current into the Sea of Japan between 3.5 and 0.8 Ma. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **236**, 355-366.

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.

Kurihara, T., Shimotani, T. and Matsuoka, A., 2006, Water temperature, salinity, algal-chlorophyll profiles and radiolarian fauna in the surface and subsurface waters in early June, off Tassha, Sado Island, central Japan. *Sci. Rep., Niigata Univ., Ser. E (Geol.)*, no. 21, 31-46.

Kurihara, T., Uchida, K., Shimotani, T. and Matsuoka, A., 2007, Radiolarian faunas and water properties in surface and subsurface waters of the Japan Sea in September 2005, off Tassha, Sado Island, central Japan. *Sci. Rep., Niigata Univ., Ser. E (Geol.)*, no. 22, 43-56.

Kurihara, T., Uchida, K., Shimotani, T. and Matsuoka, A., 2008, Radiolarian faunal characteristics in surface-subsurface waters of the Japan Sea off Tassha, Sado Island, central Japan in June 2007: inflowing radiolarians on the Tsushima Warm Current. *Sci. Rep., Niigata Univ., Ser. E (Geol.)*, no. 23, 65-74.

Lombari, G. and Boden, G., 1985, Modern radiolarian global distributions. *Cushman Found. Foraminiferal Res., Spec. Pub.*, vol. 16A, 3-125.

Matsuoka, A., 2007, Living radiolarian feeding mechanisms: new light on past marine ecosystems. *Swiss J. Geosci.*, **100**, 273-279.

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.

Nigrini, C., 1970, Radiolarian assemblages in the North Pacific and their application to a study of Quaternary sediments in core V20-130. *In* Hays, J.D., ed., *Geological Investigations of the North Pacific*. Geol. Soc. America, Memoir, vol. 126, 139-183.

Nishimura, S., 1974, *Origin and History of the Japan Sea: an approach from biogeographic standpoint*. Tsukiji Shokan, Tokyo, 274 p. (in Japanese)