Sediment reworking into the Pleistocene Sawane Formation at Shichiba, Sado Island, Niigata, Japan: A view from dinoflagellate cyst assemblages

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Abstract

Organic-walled dinoflagellate cyst assemblages which consist of 30 species are reported from the Pleistocene Sawane Formation at Shichiba, Sado Island, Niigata Prefecture, central Japan. Considering the established age of the formation as well as the dinoflagellate cyst datum levels by previous studies, 9 species are judged to be reworked from older sediments, which means that the present assemblages are heavily altered by sediment reworking during their deposition. Such sort of alteration by reworking, frequently observed in some other Late Pliocene-Pleistocene microfossil records at several localities around the Japanese Islands, may be related to intensive land uplift due to the tectonic inversion since the Late Pliocene as well as to eustatic sea level fluctuations that intensified since the Middle Pleistocene.

Key words: dinoflagellate cysts, Pleistocene, reworking, Sado Island, Sawane Formation.

Introduction

A fossil assemblage can be altered significantly as a result of sediment reworking. In fine-grained sedimentary successions, effect from reworking may be serious enough for microfossil assemblages to mask out the *in situ* composition, and causes some difficulties in age determination or paleoenvironmental reconstruction. This paper aims to describe the fossil dinoflagellate cyst assemblages from the Pleistocene Sawane Formation at Shichiba in Sawada Town, a famous fossil locality in Sado Island, Niigata Prefecture, central Japan (Fig. 1), and to discuss the effect from sediment reworking on the assemblages.

The Sawane Formation (Utashiro, 1950; Research Group on Foraminifera in Niigata

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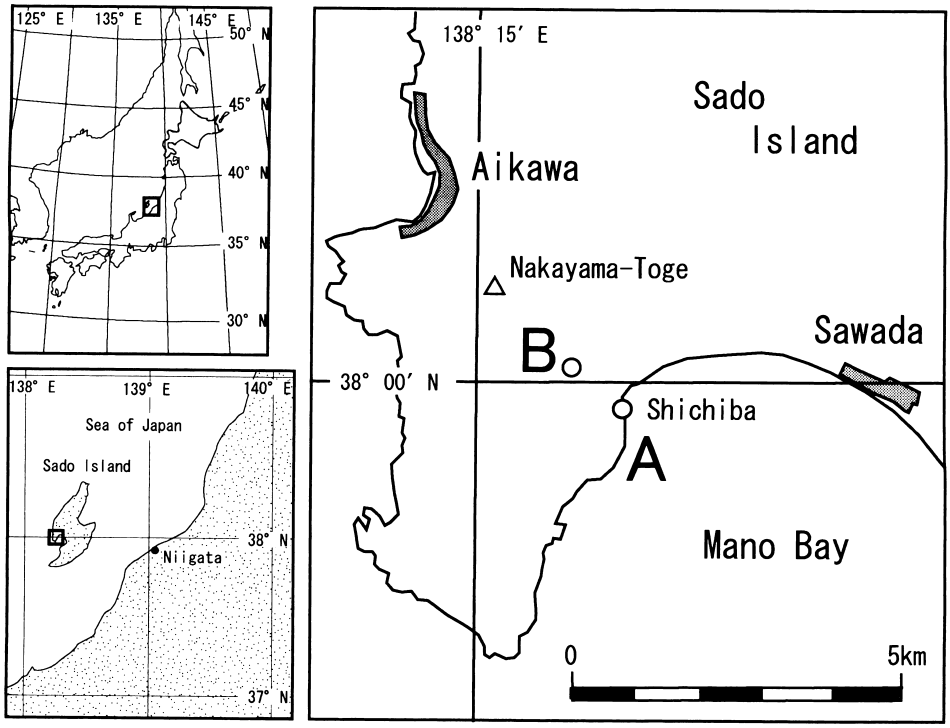

Fig. 1. Index map showing the fossil localities. A= sample locality of the present study; B= Akiba (1987)'s locality of the Kawachi Formation.

Prefecture, 1967; Shiraishi et al., 1999) is exposed in the southwestern part of Sado Island, located at the northwestern margin of the Neogene Niigata sedimentary basin. This unit represents a part of the final major marine transgression into the island today and is known for its diverse fossil assemblages including both mega- and microfossils (e.g., Yokoyama, 1926; Kobayashi et al., 1976). Okubo et al. (1995) concluded that the age of this formation is the Middle Pleistocene or younger on the basis of calcareous nannofossils and magnetostratigraphy. This paper follows the definition of the stratigraphic units by Shiraishi et al. (1999) who did not use the further subdivision of the Sawane Formation (i.e., Kaidate and Shichiba Formations).

The characteristic features of the microfossil assemblages from the Sawane Formation include co-occurrences of various taxa from different origin that have calcareous or siliceous tests (Sawane Formation Collaborative Research Group, 1973; Uchio, 1974; Utashiro et al., 1977; Yamanoi, 1978; Watanabe, 1987). In addition, conspicuous occurrence of reworked specimens was pointed out in the diatom assemblages from the Upper Pliocene Kawachi Formation directly underlying the Sawane Formation (Fig. 1; Akiba, 1987). In other microfossil groups such kind of reworking have not been pointed out in the Kawachi and Sawane Formations.

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Studies on Neogene and Quaternary dinoflagellate cysts in and around Japan date back to the pioneering work by K. Matsuoka (e.g., Matsuoka, 1974, 1983; Matsuoka et al., 1987; Matsuoka and Bujak, 1988). Recently Obuse and Kurita (1999) and Kurita and Obuse (submitted) aimed to refine the Miocene-Pliocene biostratigraphic scheme by Matsuoka et al. (1987). Although the Pleistocene records of dinoflagellate cysts in Japan is still very few, Matsuoka (1983) reported a Pleistocene assemblage from the Sawane Formation, when he did not mention the effect of reworking on the assemblage.

Material

The present study uses two samples, #1 and #2, from the Sawane Formation at a coastal exposure at Shichiba (Fig. 1). Various mega- and microfossils were recorded from this exposure, being composed of sandy siltstone and sandstone beds at this locality (e.g., Kobayashi et al., 1976; Kobayashi and Nomura, 1992). The samples were collected from a horizon which corresponds to the horizon s-6 or s-5 in the lower part of Unit 5 of Okubo et al. (1995) who placed this particular outcrop above the base of the Matuyama Chron (0.79Ma or younger) on the basis of calcareous nannofossil biostratigraphy as well as magnetostratigraphy. Furthermore, this outcrop corresponds to the locality SDA-5 of Matsuoka (1983) who described dinoflagellate cyst assemblages for the first time in this area. Both samples are gray siltstone that contains foraminifera tests and molluscan shell fragments commonly.

Methods

The samples, weighed 10 g each, were treated with HCl and HF to eliminate carbonate and siliceous minerals. Organic substances were then concentrated in the aid of $ZnBr_2$ heavy liquid (S.G. = 2.0). The recovered organic residues were screened on a sieve with 20 μm openings. Parts of the remaining residues on the sieve were then oxidized by means of the Schulze's solution ($KClO_3$ + HNO_3+ H_2O) to eliminate humic acids. Both the unoxidized and oxidized residues from each sample were then mounted on slides with poly-vinyl-alchohol and polyester resin. As a result, two different slides were made from each sample.

The whole mounted residues on each slide were scanned by a Carl Zeiss Axioplan microscope at the magnification of 160x. Identification was conducted at the magnification of 600x using interference contrast. Each collective raw count of a given taxa in a sample was converted to relative abundance against the total count in the sample as follows; R (rare, less than 5%), C (common, 5 - 10%), A (abundant, 10 - 30%), VA (very abundant, 30% or over).

This study generally follows Williams et al. (1998) for generic allocation of the identified species. All the material discussed in this paper are housed in the palynological collection at the Department of Geology, Faculty of Science, Niigata University.

Dinoflagellate cyst assemblages

The results are shown in Table 1. Both samples yielded relatively small number of dinoflagellate cyst specimens (42-49 specimens per sample). Their preservation is moderate or slightly poor, as the deformation of specimen was frequent and slight corrosion of process ornaments was sometimes observed.

The species composition and diversity are similar to each other in the two samples. Among the 17-20 taxa recorded in each sample, most abundant is *Operculodinium centrocarpum*. The assemblages also mutually contain common to abundant *Achomosphaera callosa*, with relatively minor presence of *Spiniferites* species. *Brigantedinium* spp., which were rarely recorded from the both samples, are the only component in the assemblages that belongs to the family Protoperidiniaceae. Other recorded taxa include *Achomosphaera ramulifera*, *Achomosphaera spongiosa*, *Batiacasphaera* sp., *Diphyes latiusculum*, *Impagidinium* sp. cf. *I. patulum*, *Lingulodinium machaerophorum*, *Melitasphaeridium choanophorum*, *Nematosphaeropsis* sp. cf. *N. lemniscata*, *Operculodinium israelianum*, *Protoceratium reticulatum*, *Reticulatosphaera actinocoronata*, cf. "*Systematophora placacantha*" and *Tuberculodinium vancampoae*.

The results of the present study is similar to those by Matsuoka (1983) from the same exposure and containing the following 12 species; *Melitasphaeridium choanophorum* (as "*M. aequabile*"), *Reticulatosphaera actinocoronata* (as "*R. stellata*"), *Impagidinium patulum*, *Lingulodinium machaerophorum*, *L. sadoense*, *Protoceratium reticulatum* (as "*Operculodinium centrocarpum*"), *Operculodinium crassum*, *O. israelianum*, *O. longispinigerum*, *Tectatodinium pellitum*, *Achomosphaera callosa*, *Nematosphaeropsis lemniscata* (as "*N. labyrinthea*") and *Tuberculodinium vancampoae*.

Discussion

1. Dinoflagellate cyst age of the samples

Obuse and Kurita (1999), in their study on the onshore sections in northern Japan, reported the first occurrence of *Protoceratium reticulatum*, an extant species, within the middle Lower Pliocene. A close estimate was subsequently confirmed by Kurita and Obuse (submitted) who studied Hole 1151A, ODP Leg 186, off the Sanriku Coast. Accordingly, on the basis of the occurrence of *P. reticulatum*, the age of the present samples is considered as middle Early Pliocene or younger. This does not oppose to the discussion by Okubo et al. (1995). The present dinoflagellate cyst data show no further constraints on the age.

2. Reworked dinoflagellate cysts

Obuse and Kurita (1999) and Kurita and Obuse (submitted) discussed the first and last occurrence datum levels of dinoflagellate cyst species in the Middle Miocene to Pliocene

Table 1. List of dinoflagellate cysts from the Sawane Formation at Shichiba, Sado Island. **: reworked taxa, *: probable reworked taxa, (v): taxon named based on Recent vegetative cells and the cyst-theca relationship confirmed by culture experiments. VA: very abundant, A: abundant, C: common, R: rare.

sample	#1	#2
total counts	42	49
Achomosphaera callosa Matsuoka, 1983	C	A
Achomosphaera ramulifera (Deflandre, 1937) Evitt, 1963	C	R
Achomosphaera sp. A		R
Achomosphaera spongiosa Matsuoka and Bujak, 1988 **		R
Batiacasphaera sp.	R	R
Brigantedinium simplex (Wall, 1965) ex Lentin and Williams, 1993	R	R
Brigantedinium sp. indet.	R	R
Diphyes latiusculum Matsuoka, 1974 **		R
Impagidinium sp. cf. *I. patulum* (Wall, 1967) Stover and Evitt, 1978 *		R
Lingulodinium machaerophorum (Deflandre and Cookson, 1955) Wall, 1967	R	
Melitasphaeridium choanophorum (Deflandre and Cookson, 1955) Harland and Hill, 1979 **		R
Nematosphaeropsis sp. cf. *N. lemniscata* Bujak, 1984		R
Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967 *	VA	VA
Operculodinium israelianum (Rossignol, 1962) Wall, 1967	R	
Protoceratium reticulatum (Claparede and Lachmann, 1859) Bütschli 1885 (v)	R	R
Reticulatosphaera actinocoronata (Benedeck, 1972) Bujak and Matsuoka, 1986		R
Spiniferites asperulus Matsuoka, 1983	R	
Spiniferites bulloideus (Deflandre and Cookson, 1955) Sarjeant, 1970	R	
Spiniferites sp. cf. *S. belerius* Reid, 1974		R
Spiniferites firmus Matsuoka, 1983 **		R
Spiniferites hexatypicus Matsuoka, 1983 **	R	
Spiniferites mirabilis (Rossignol, 1964) Sarjeant, 1970	R	
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854		R
Spiniferites sp. B		R
Spiniferites sp. indet.	C	
Spiniferites sp. (large, gonal)		R
Spiniferites sp. (round)	R	
Systematophora sp. **	R	
cf. *Systematophora placacantha* (Deflandre and Cookson, 1955) Davey et al., 1969 *	R	
Tuberculodinium vancampoae (Rossignol, 1962) Wall, 1967		R

interval within northern Japan. Considering the Middle Pleistocene or younger age of the Sawane Formation at Shichiba (Okubo et al., 1995), as well as the previous biostratigraphic scheme of dinoflagellate cysts, the taxa listed below, followed by the age of the last occurrence of each species, are judged to be of reworked origin.

Achomosphaera spongiosa	middle Late Miocene
Diphyes latiusculum	middle Middle Miocene
Melitasphaeridium choanophorum	middle Early Pliocene
Spiniferites firmus	middle Early Pliocene
Spiniferites hexatypicus	early Late Miocene
Systematophora spp.	early Late Miocene

In addition, as *Systematophora placacantha* and *Impagidinium patulum* have their last occurrences in the middle Middle Miocene and Early Pliocene, respectively, cf. "*Systematophora placacantha*" and *Impagidinium* sp. cf. *I. patulum*, both of which were recorded in the present study, are also probable reworked specimens.

Furthermore, abundant to dominant occurrence of *Operculodinium centrocarpum* has been observed frequently in the Middle Miocene sediments in the previous studies, and it has never been observed in Late Miocene and Pliocene sections. The very abundant occurrence of *O. centrocarpum* in the present material of Middle Pleistocene age thus suggests that the species is also of reworked origin in the present samples.

As a result, out of the 30 species recorded from the two samples, 9 taxa are judged to represent reworking or probable reworking. The other 21 taxa, except *Protoceratium reticulatum*, are all long-ranging species that may be found anywhere in the Miocene- Pleistocene interval. These indicate that the dinoflagellate cyst assemblages from the Sawane Formation at Shichiba are effected substantially by reworked specimens.

3. Comparison with other microfossil assemblages from the Sawane Formation

Sediment reworking in the Late Pliocene–Pleistocene sediments in Sado Island and its effect on microfossil assemblages were discussed by Akiba (1987) who described diatom assemblages from the Kawachi Formation, directly underlying the Sawane Formation, at the Nakayama-Toge section, 1.3km northwest of the Shichiba locality. He concluded that the major part of the assemblages are reworked from the Nakayama Formation that is dated as middle Late Miocene to Early Pliocene by means of diatom biostratigraphy. Akiba (1987) further noted that the absence of considerable effect of reworking in the foraminifera and other calcareous microfossils from the same or close localities of the formation. Based on the evidence, Akiba (1987) mentioned that the remarkable reworking observed in the diatom assemblages from the Kawachi Formation, as well as the absence of reworking in the foraminifera and other calcareous microfossils, is due to the diatom-rich microbiofacies of the diatomaceous Nakayama Formation that should have supplied sedimentary particles during the deposition of the Kawachi Formation.

The results of the present study on the Sawane Formation shows the effect of reworking on the dinoflagellate cyst assemblages is as significant as seen in the diatom assemblages from the Kawachi Formation. This suggests high potential of reworking not only in the Upper Pliocene but also in the Pleistocene in this area.

4. Implications of reworking to geologic settings

In addition to the case of Sado Island, recent studies on diatom biostratigraphy revealed significant effects from reworking in the Pleistocene and possible Pleistocene sediments at several localities in Hokkaido and southern Sakhalin, which altered the assemblages *in situ* and obscured the presence of index species of the depositional age (Akiba, 1999; Akiba et al., 2000). In contrast, the effect of reworking in the Neogene sediments of Early Pliocene or older seems, in most cases, not to be prominent as in the Late Pliocene-Pleistocene.

The background for these disturbance common in Late Pliocene-Pleistocene micropaleontological records should relate to the tectonic setting. During the Late Pliocene and Pleistocene, the Northeast Japan arc experienced severe compressional tectonics that occurred in the later stage of prominent tectonic inversion (Amano and Sato, 1989; Sato, 1994). In central Hokkaido, probably as well as in southern Sakhalin, similar tectonic history that postulates compressional or transpressional tectonics since the Pliocene is proposed (e.g., Kurita and Yokoi, 2000). These settings resulted in notable uplift of the land area, which should have accelerated the erosional potential on land and clastic supply into the basins. This tectonic background can affect paleontological records as alteration of assemblages during the deposition by reworked specimens. The case of the diatom and dinoflagellate cyst assemblages from the Kawachi and Sawane Formations as well as the case in the diatom assemblages from Hokkaido and Sakhalin are well explained in this context.

On the other hand, glacial cycles and eustatic sea level fluctuations are known to have intensified markedly since the Middle Pleistocene (e.g., Shackleton and Opdyke, 1973). When considered the age of the Shichiba outcrop, the reworking may be regarded as a result of a lowered sea level, which also should have increased the erosional potential on land, at any of those intervals of eustatic lowstand since the Middle Pleistocene.

In summary, this paper has reported notable sediment reworking in the Pleistocene Sawane Formation that resulted in the heavy alteration of dinoflagellate cyst assemblages, similarly as described in the diatom assemblages from the underlying Kawachi Formation in the previous study. This reworking may be due to either intensive tectonic uplift of land areas since the Late Pliocene or high magnitude of eustatic sea level fluctuations since the Middle Pleistocene, or both. Similar settings may occur in the Upper Pliocene-Pleistocene sedimentation in neritic paleoenvironments in Northeast Japan and Hokkaido where tectonic deformation was prominent during the age.

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References

Akiba, F., 1987, Neogene diatom biostratigraphy of the Nakayama-Toge section, Sado Island, Japan, and its relation to the Funakawa Floral Change Plane of Yamanoi (1978). *Publ. Sado Museum*, no. 9, 85-101. (in Japanese)

Akiba, F., 1999, *Neodenticula seminae* and *Proboscia curvirostris* (diatoms) from the Yuchi Formation of the Tenpoku area, northwestern Hokkaido, and their biostratigraphic implications. *Jour. Geol. Soc. Japan*, **105**, 733-736. (in Japanese)

Akiba, F., Hiramatsu, C., Tsoy, I.B., Ogasawara, K. and Amano, K., 2000, Diatom biostratigraphy and geologic age of the Maruyama and Kurasi Formations, southern Sakhalin, and their correlation to the Neogene of the Tenpoku area, Hokkaido. *Jour. Geog.*, **109**, 203-217. (in Japanese)

Amano, K. and Sato, H., 1989, Neogene tectonics of the central part of Northeast Honshu Arc. *Mem. Geol. Soc. Japan*, no. 32, 81-96. (in Japanese)

Kobayashi, I. and Nomura, M., 1992, Pliocene–Early Pleistocene molluscan fauna and paleoenvironment – Niigata sedimentary basin in the eastern marginal region of the Paleo-Sea of Japan. *Mem. Geol. Soc. Japan*, no. 37, 163-173.

Kobayashi, I., Watanabe, T., Takeda, Y. and Hirai, A., 1976, Molluscan fossils from the Pliocene Sawane Formation, Sado Island, Niigata Prefecture. *Pub. Sado Museum*, no. 4, 207-213. (in Japanese)

Kurita, H. and Obuse, A., submitted, Preliminary dinoflagellate cyst biostratigraphy of middle Miocene - lowermost Pliocene section of Hole 1151A, ODP Leg 186, off Sanriku Coast, northern Japan. *Sci. Res., Proc. ODP, Leg 186.*

Kurita, H. and Yokoi, S., 2000, Cenozoic tectonic settings and a current exploration concept in southern central Hokkaido, northern Japan. *Jour. Japanese Assoc. Petrol. Techn.*, **65**, 58-70. (in Japanese)

Matsuoka, K., 1974, Some plant microfossils from the Miocene Fujiwara Group, Nara, central Japan. *Trans. Proc. Palaeont. Soc. Japan, N. S.*, no. 94, 319-340.

Matsuoka, K., 1983, Late Cenozoic dinoflagellates and acritarchs in the Niigata District, central Japan. *Palaeontographica, Abt. B*, **187**, 89-154.

Matsuoka, K. and Bujak, J.P., 1988, Cenozoic dinoflagellate cysts from the Navarin Basin, Norton Sound and St. George Basin, Bering Sea. *Bull. Fac. Lib. Arts, Nagasaki Univ., Nat. Sci.*, **29**, 1-147.

Matsuoka, K., Bujak, J.P., and Shimazaki, T., 1987, Late Cenozoic dinoflagellate cyst biostratigraphy from the west coast of northern Japan. *Micropaleontology*, **33**, 214-229.

Obuse A., and Kurita, H., 1999, Neogene dinoflagellate cyst biostratigraphy in northern Japan. *Abstracts 1999 Ann. Mtg. Palaeont. Soc. Japan*, 95. (in Japanese)

Okubo, R., Oda, H., Takayama, T. and Kitamura, A., 1995, Paleomagnetic polarity and calcareous nannofossil biostratigraphy of the Pleistocene Sawane Formation on Sado Island, Niigata Prefecture, central Japan. *Jour. Geol. Soc. Japan*, **101**, 443-450. (in Japanese)

Research Group on Foraminifera in Niigata Prefecture, 1967, A preliminary report on foraminiferal assemblages from the Sawane area, Sado Island. *Commem. Vol. Prof. Y. Hiramatsu*, 113-119.

Sato, H., 1994, The relationship between late Cenozoic tectonic events and stress field and basin development in northeast Japan. *Jour. Geophys. Res.*, **99**, 22261-22274.

Sawane Formation Collaborative Research Group, 1973, A biostratigraphic study on the so-called Sawane Formation in Sado Island. *Bull. Takada Division, Niigata Univ.*, no. 18, 187-208. (in Japanese)

Shackleton, N.J. and Opdyke, N.D., 1973, Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: Oxygen isotope temperatures and ice volumes on a 10^5 year and 10^6 year scale. *Quaternary Res.*, **3**, 39-55.

Shiraishi, T., Hasegawa, Y. and Niikawa, I., 1999, The geology of Sado Island. Explanation text to the 1:50,000 geological map. Basic Research on Land Characteristics and Use "Washizaki, Aikawa, Ryoutsu, Kawarada, Akadomari and Ogi", Bureau of Land Development and Niigata Prefecture, 85p. (in Japanese)

Uchio, T., 1974, Tertiary nannoplankton stratigraphy of Sado Island, Niigata Prefecture, and a proposal of the *Braarudosphaera bigelowii-Coccolithus pelagicus* Zone for the Pliocene of Japanese Oil Field of Japan Sea side. *Bull. Geol. Surv. Japan*, no. 250-1, 235-254. (in Japanese)

Utashiro, T., 1950, On the stratigraphy of the Sawane-Aikawa area, Osado, Sado Island. *Jour. Geol. Soc. Japan*, **56**, 302-303. (in Japanese)

Utashiro, T., Kuroda, K., Kobayashi, T., Nishikawa, M., Hasegawa, Y., Harada, T. and Watanabe, H., 1977, Tertiary stratigraphy and fossil diatom assemblages from the Sawada area, Sado-Gun, Niigata Prefecture. *Publ. Sado Museum*, no. 7, 45-62. (in Japanese)

Watanabe, K., 1987, Tertiary foraminifera and radiolaria fossils from Sado Island, central Japan. *Publ. Sado Museum*, no. 9, 127-156. (in Japanese)

Williams, G.L., Lentin, J.K. and Fensome, R.A., 1998, *The Lentin and Williams index of fossil dinoflagellates 1998 edition*. American Association of Stratigraphic Palynologists Contributions Series, no. 34, 817p.

Yamanoi, T., 1978, Neogene pollen stratigraphy at the Nakayama-Toge, Sado Island. *Jour. Japanese Assoc. Petrol. Techn.*, **43**, 119-127. (in Japanese)

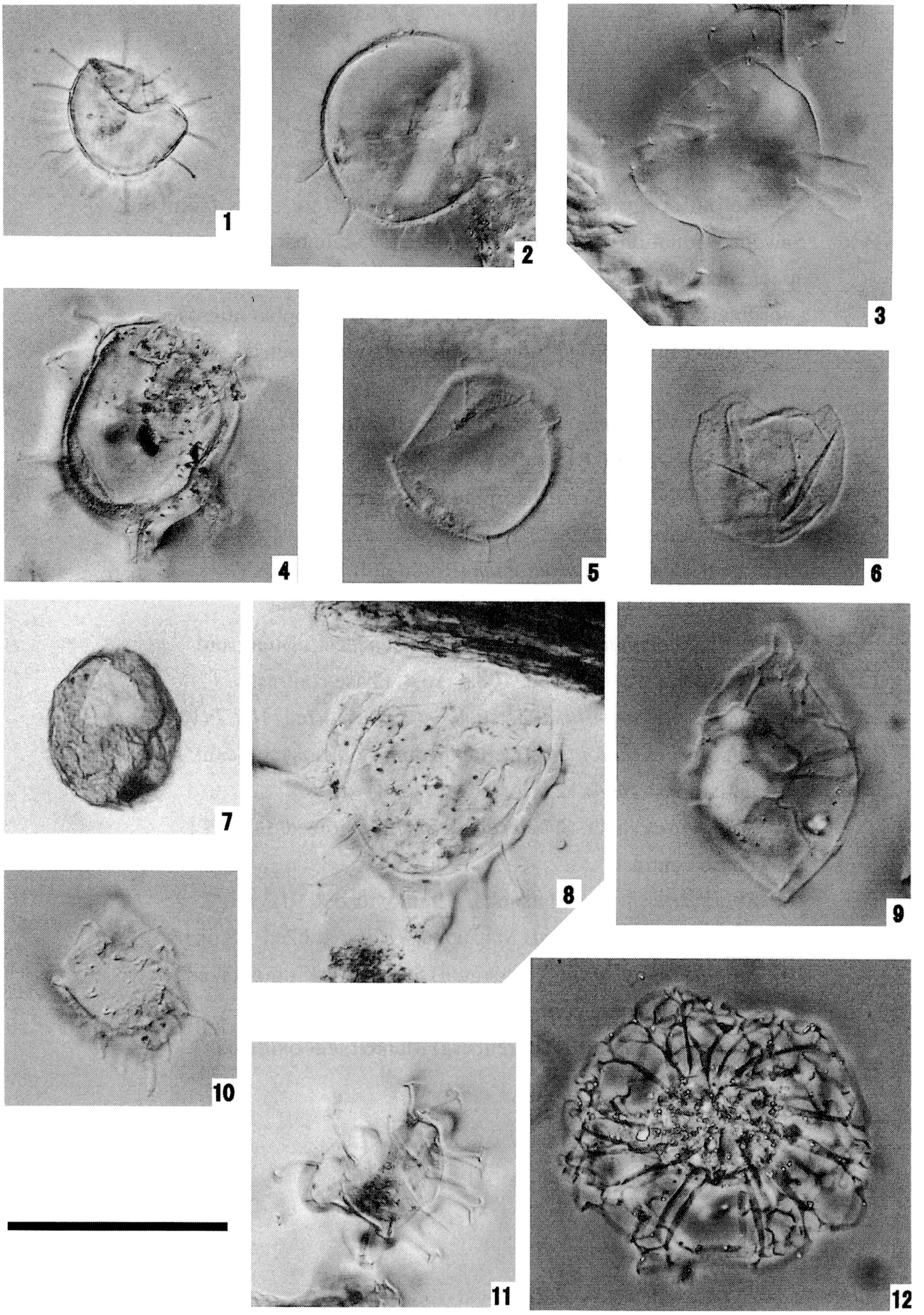
Yokoyama, M., 1926, Fossil shells from Sado. *Jour. Fac. Sci., Imp. Univ. Tokyo, sec. II*, **1**, 249-312.

Explanation of Plate 1

Photomicrographs of selected dinoflagellate cysts from the Sawane Formation at Shichiba, Sado Island. Scale bar = 50 μm. Each species name followed by Sample ID, residue type and X-Y stage coordinates at a Carl Zeiss 45-35-02 stage for Axioplan microscope. Taken under interference contrast unless otherwise noted.

1. *Protoceratium reticulatum* (Claparede and Lachmann) Bütschli. #2/ oxidized/ 101.8x3.9. Phase contrast.
2. *Achomosphaera callosa* Matsuoka. #2/ oxidized/ 101.8x11.2.
3. *Achomosphaera ramulifera* (Deflandre) Evitt. #2/ oxidized/ 96.9x5.1.
4. *Achomosphaera* sp. A. #2/ unoxidized/ 79.3x10.5.
5. *Achomosphaera spongiosa* Matsuoka and Bujak. #2/ oxidized/ 92.2x12.0.
6. *Batiacasphaera* sp. #1/ oxidized/ 101.1x10.5.
7. *Brigantedinium simplex* (Wall) ex Lentin and Williams. #1/ unoxidized/ 90.7x9.5.
8. *Diphyes latiusculum* Matsuoka. #2/ unoxidized/ 87.8x15.8.
9. *Impagidinium* sp. cf. *I. patulum* (Wall) Stover and Evitt. #2/ oxidized/ 94.3x11.9.
10. *Lingulodinium machaerophorum* (Deflandre and Cookson) Wall. #1/ unoxidized/ 86.1x6.1.
11. *Melitasphaeridium choanophorum* (Deflandre and Cookson) Harland and Hill. #2/ unoxidized/ 99.3x12.5.
12. *Nematosphaeropsis* sp. cf. *N. lemniscata* Bujak. #2/ unoxidized/ 104.5x19.0. Phase contrast.

Plate 1

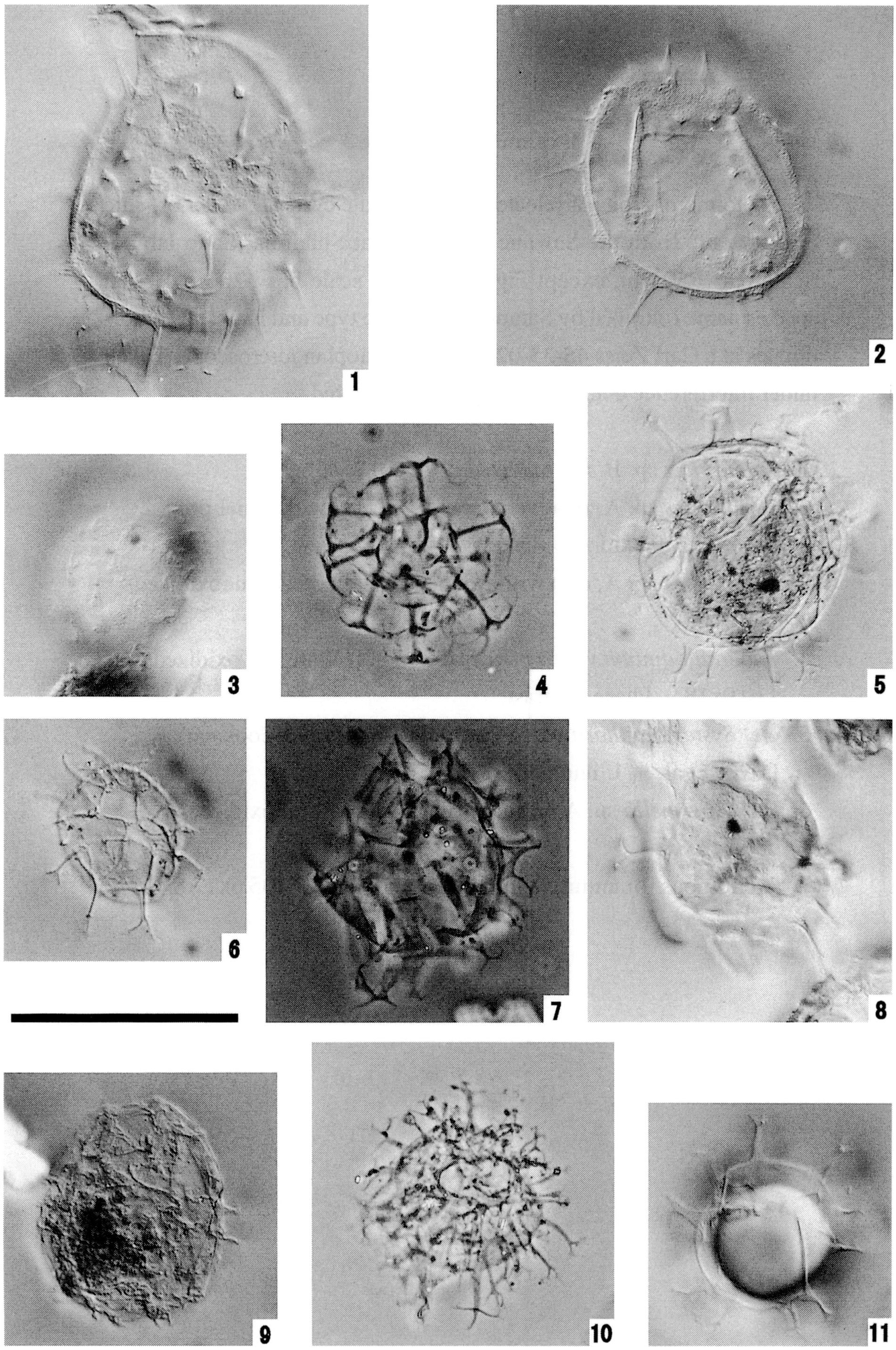


Explanation of Plate 2

Photomicrographs of selected dinoflagellate cysts from the Sawane Formation at Shichiba, Sado Island. Scale bar = 50 μm. Each species name followed by Sample ID, residue type and X-Y stage coordinates at a Carl Zeiss 45-35-02 stage for Axioplan microscope. Taken under interference contrast unless otherwise noted.

1. *Operculodinium centrocarpum* (Deflandre and Cookson) Wall. #2/ oxidized/ 96.8x5.1.
2. *Operculodinium centrocarpum* (Deflandre and Cookson) Wall. #1/ oxidized/ 102.9x23.3.
3. *Operculodinium israelianum* (Rossignol) Wall. #1/ unoxidized/ 103.8x8.9.
4. *Reticulatosphaera actinocoronata* (Benedeck) Bujak and Matsuoka. #2/ oxidized/ 108.5x16.4. Phase contrast.
5. *Spiniferites asperulus* Matsuoka. #1/ unoxidized/ 101.7x12.0.
6. *Spiniferites bulloideus* (Deflandre and Cookson) Sarjeant. #1/ unoxidized/ 88.4x12.0.
7. *Spiniferites* sp. cf. *S. belerius* Reid. #2/ oxidized/ 94.0x5.1. Phase contrast.
8. *Spiniferites firmus* Matsuoka. #2/ unoxidized/ 91.3x16.7.
9. *Spiniferites hexatypicus* Matsuoka. #1/ unoxidized/ 88.6x16.7.
10. *Spiniferites mirabilis* (Rossignol) Sarjeant. #1/ unoxidized/ 91.5x19.1. Phase contrast.
11. *Spiniferites ramosus* (Ehrenberg) Mantell. #2/ oxidized/ 92.3x16.0.

Plate 2



Explanation of Plate 3

Photomicrographs of selected dinoflagellate cysts and other organic microfossils from the Sawane Formation at Shichiba, Sado Island. Scale bar = 50 μm, except Figure 6 where scale bar= 200μm. Each species name followed by Sample ID, residue type and X-Y stage coordinates at a Carl Zeiss 45-35-02 stage for Axioplan microscope. Taken under interference contrast unless otherwise noted.

1. *Spiniferites* sp. B. #2/ oxidized/ 94.2x10.2.
2. *Spiniferites* sp. A, relatively large-sized cyst with gonal processes. #2 unoxidized/ 86.2x11.3.
3. *Spiniferites* sp. A, cyst with Rounded cyst body. #1/ unoxidized 105.3x7.0.
4. *Tuberculodinium vancampoae* (Rossignol) Wall. #2/ oxidized/ 110.9x18.9. Phase contrast.
5. cf. "*Systematophora placacantha* (Deflandre and Cookson) Davey et al." #1/ unoxidized/ 100.3x11.4.
6. *Pterospermella* sp. A prasinophycean alga. #1/ unoxidized/ 98.6x16.6.
7. A chitinous foraminifera lining. #1/ unoxidized/ 105.6x17.8.

Plate 3