PERIDINIACEAN CYST GENUS *XANDARODINUM* IN THE MIOCENE KAMINOHAMA FORMATION IN THE WESTERN PART OF ZAO VOLCANO, YAMAGATA, NORTH JAPAN

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Abstract—Two species of the peridiniacean cyst genus *Xandarodinium* are reported from the Miocene Kaminohama Formation in Yamagata Prefecture, north Japan. The morphological differences among the dinoflagellate cyst genera *Sumatradinium*, *Trinovantedinium* and *Xandarodinium* are discussed. The relationship of *Xandarodinium variabile* with the modern cyst form of *Protoperidinium divaricatum* is also discussed.

Key words: Peridiniaceae, *Sumatradinium*, *Trinovantedinium*, *Xandarodinium*, dinoflagellate cyst, late Early Miocene, Zao Volcano, north Japan

INTRODUCTION

Since Shimakura (1960) first noticed Neogene dinoflagellate cysts in the Pliocene Nishiyama Formation of the Niigata district in Japan, Neogene to Quaternary dinoflagellates have been described from various localities in Japan by Matsuoka (1974, 1983) and Matsuoka et al. (1987). Most of these dinoflagellates are gonyaulacacean cysts, and only a few species of peridiniacean cysts have been known. Duffield and Stein (1986) suggested on the basis of the Fujiwara Group dinoflagellate cyst data given by Matsuoka (1974) that the Fujiwara sediments were deposited in coastal to shelf environments. Matsuoka et al. (1987) listed many peridiniacean cysts in Lower Miocene to Upper Pliocene sediments in the Nishiyama oil field, Niigata Prefecture and the Oga Peninsula, Akita Prefecture, north Japan.

Many modern peridiniacean cysts such as *Brigantedinium*, *Lejeuneecysta*, *Trinovantedinium*, *Selenopemphix*, *Xandarodinium*, and others have been recovered from pre-Pleistocene sediments (e.g., Bujak, 1984; Duffield and Stein, 1986; Powell, 1986a, b, c; Wrenn and Kokinos, 1986). However, as some of these genera were first described from Holocene sediments, *Brigantedinium*, *Trinovantedinium*, and *Xandarodinium* were excluded from a critical morphological analysis given by Stover and Evitt (1978) and Stover and Williams (1987). This has resulted in some taxonomic confusion, in particular between *Sumatradinium* and *Xandarodinium*.

This report is concerned with the description of two species of the cyst genus *Xandarodinium* which abundantly occurred together with other dinoflagellate cysts in the Lower Miocene Kaminohama Formation. A discussion is also given on the taxonomy of such related genera as *Sumatradinium* and *Trinovatedinium*.

MATERIAL

According to Saito (1985), the Kaminohama Formation is exposed in the Nidogawa (river) at the western foot of

![Fig. 1. Map of sampling location in Zao Volcano, Yamagata Prefecture.](image-url)
Zao Volcano (Fig. 1). This formation consists of a massive black mudstone containing abundant molluscan, crustacean, foraminifer and nanofossil in a good state of preservation. These rocks were used for the present study.

A late Early to early Middle Miocene age (Zone CN 4 of calcareous nanofossil) has been assigned to those rocks on the basis of the occurrence of Sphenolithus heteromorphus, Coccolithus eopelagicus, Discoaster deflandrei, Helicopentosphera carteri, Reticulofenestra gartneri and others (Okada, 1985).

**DINOFLAGELLATE CYST ASSEMBLAGE**

Dinoflagellate cysts, moderately well preserved, occur abundantly in those rocks. They include two major dinoflagellate cyst groups: cysts of the Gonyaulacaceae such as *Diphyes colligerum* (Deflandre and Cookson), *Diphyes latusculum* Matsuoka, *Lingulodinium machaerophorum* (Deflandre and Cookson), *Heteraulacacysta campanula* Drugg and Loeblich, *Spirotheres pseudofurcatus* (Klumpp), *Systematophora ancyrea* (Cookson and Eisenack), *Hystrochomphoropsis obscura* Habib, *Hystrochomphoropsis obscura* Deflandre and Cookson, *Tuberculodinium rossignolae* Drugg, *Dapsilidium* sp., *Distatodinium paradoxxum* (Brosius), and cysts of the Peridiniaceae such as *Capillitrella fuscata* Matsuoka and Bujak, *Lejeunecysta spp.*, *Xandarodinium variabile* Bujak, *X. sp.*, *Selenopemphix spp.*, and *Brigantedinium* sp.

According to Matsuoka *et al.* (1987), the co-occurrence of *Diphyes latusculum*, *Heteraulacacysta campanula*, *Spirotheres pseudofurcatus*, *Systematophora ancyrea*, *Hystrochomphoropsis obscura*, and *Capillitrella fuscata* indicates that the dinoflagellate cyst assemblage of this sample leads to assignment to the *Diphyes latusculum* Zone of latest Early Miocene to early Middle Miocene age. This age indication is in agreement with that given by the previously mentioned nanofossils.

**SYSTEMATIC DESCRIPTION**

**Taxonomic notes of Xandarodinium and related peridiniacean fossil genera Sumatradinium and Trinovantedinium**

There are many cyst genera of the Peridiniaceae in modern surface and Neogene to Quaternary sediments. Among these, three genera, *Sumatradinium*, *Trinovantedinium* and *Xandarodinium*, are quite similar to each other, because they are all characterized by an autophagium or two strongly adpressed layers, a single anterior intercalary archeopyle, dorso-ventral compression and spinose ornamentation on the surface.

**Taxonomic review**

*Sumatradinium* (Fig. 2A): Drugg (1970) first described *Xenocodinium hispidum* from the Middle Miocene of Sumatra as being subcircular in outline, dorso-ventrally compressed and ornamented with non-parasutural, non-tabular short processes. Later, Lentin and Williams (1976) erected a new genus, *Sumatradinium*, based on this species and transferred it to the new genus. At present, several forms including *. hispidum* and anonymous

![Diagramatic illustrations of three peridiniacean cyst genera (A-C) and two species of Xandarodinium (C-E). A. Sumatradinium hispidum (Drugg) Lentin and Williams; showing intercalary archeopyle (after Drugg, 1970, fig. 12, holotype). B. Trinovantedinium capitatum Reid; showing intercalary archeopyle and paracystogulum (after Reid, 1977, pl. 1, fig. 8, holotype). C. Xandarodinium xanthum Reid; cyst filled with protoplasm (after Reid, 1977, pl. 3, fig. 29, paratype). E. Xandarodinium variabile Bujak; showing intercalary archeopyle (after Bujak, 1984, pl. 4, fig. 8).](image-url)
species of this genus are illustrated from the Neogene without descriptions (e.g., Duffield and Stein, 1986; Edwards, 1986; LeNoir and Hart, 1986; Powell, 1986b; Wrenn and Kokinos, 1986). No species of *Sumatradinium* has yet been reported from modern surface sediments.

*Trinovatedinium* (Fig. 2B): Reid (1977) erected this genus on the basis of a Holocene cyst, *Trinovatedinium capitatum* Reid, obtained from the British Isles. In Reid’s diagnosis, *Trinovatedinium* is characterized by a pentagonal cyst body with conspicuous one apical and two antapical horns. Later Harland (1977) and Bujak (1984) emended the genus to be an acapsulate pentagonal cyst with conspicuous apical and antapical horns and ornamented with sutural and intratubular spines. Cysts without spines were transferred to *Lejeuneocysta* or *Quinquecuspis* (Harland, 1977; Bujak, 1984).

It has been proved that *Trinovatedinium capitatum* is a cyst form of *Protoperidinium pentagonum* (Gran) Balech on the basis of an incubation experiment (Wall and Dale, 1968). Edwards (1986) reported the oldest occurrence of this cyst in the Early Miocene Marks Head Formation in South Carolina, U.S.A.

Bujak (1984) described another species, *T. boreale*, from the Upper Eocene of the northern North Pacific, and Matsuoka and Bujak (1988) also recorded this species from the Upper Eocene—Lower Oligocene of the Bering Sea. This species is characterized by poorly-developed antapical horns and paracingulum.

Matsuoka (1987) described one modern cyst of this genus, *T. pallidifulvum*, from surface sediments in Hokkaido of north Japan. This species is characterized by a pentagonal outline in dorso-ventral view, two small antapical horns, and a brownish pigmented cyst wall.

*Xandarodinium* (Fig. 2C–2E): This is one of the modern peridiniacean genera and was first erected by Reid (1977) on the basis of a Holocene *Xandarodinium xanthum* Reid with the following characters: elliptical outline in dorso-ventral view, autonomphagm only, dorso-ventrally compressed body, hollow and partly tubular processes with closed distal extremities and proximal base opening to the internal cavity, and an intercalary archeopyle.

The thecal affinity of this cyst was suggested by Reid (1977) with *Protoperidinium minutum* (Kofoid) Balech, but another possibility, i.e. *Protoperidinium divaricatum* (Meunier) Parke and Dodge, was realized on the basis of an incubation experiment by Matsuoka et al. (1982).


The morphological characters are summarized as follows:

1. *Sumatradinium, Trinovatedinium* and *Xandarodinium* have the following characters in common: 1. dorso-ventral compression, 2. autonomphagm only, 3. single intercalary archeopyle and 4. spinose ornaments covering the cyst surface.

2. They are differentiated by: 1. outline in dorso-ventral view, 2. development of apical and antapical horns and 3. distribution pattern of spinose ornaments.

*Trinovatedinium* differs from those two genera in possessing a pentagonal outline with well-developed apical and/or antapical horns, and penitabular and/or parasutural arrangement of short spines. *Xandarodinium* is more closely comparable to *Sumatradinium* than *Trinovatedinium* and possibly a synonym of *Sumatradinium*. But I would prefer to keep these two genera independent at present, because the former differs from the latter in bearing apical and antapical processes with more complex morphology.

Class Dinophyceae Pascher, 1914
Order Peridiniales Taylor, 1980
Family Protopteridiniaceae Bujak and Davies, 1983
Cyst-genus *Xandarodinium* Reid, 1977

Type species: *Xandarodinium xanthum* Reid, 1977

*Xandarodinium variabile* Bujak, 1984

Figs. 1–4, 10.

*Xandarodinium variabile* Bujak, 1984, p. 194–195, pl. 4, figs. 7–10, text-fig. 3; Matsuoka and Bujak, 1988, p. 89–90, pl. 17, fig. 5.

Discussion.—The present specimens are very similar to the population of *X. variabile* in the Bering Sea and northern North Pacific, described by Bujak (1984) and Matsuoka and Bujak (1988).

Cysts of *Protoperidinium divaricatum* observed by Matsuoka et al. (1982) appear to be intermediate in...
Figs. 3-6, 13. *Xandarodinium variabile* Bujak; Loc. Kaminoyama Formation, Nido Gawa in Zao Volcano in Yamagata Prefecture, north Japan; 3a–3c, different focus levels in dorso-ventral view (Specimen ZA-11P9); 3b, larger apical processes, 3c, larger antapical process; 4a, ventral surface; 4b, dorsal surface showing intercalary archeopyle, 4c, optical cross section of dorso-ventral view in phase contrast (Specimen ZA-9P2); 5a–5b, different focus levels in dorso-ventral view, 5b, showing cluster of apical processes (Specimen Za-5R1); 6a–6b, different focus levels in dorso-ventral view (Specimen ZA-11P4); 7a–7b, different focus levels in dorso-ventral view, showing parasulcal depression in hypocyst (Specimen ZA-11P7); 13a–13b, different focus levels in dorso-ventral view, showing a short apical boss and two slightly larger antapical processes (Specimen ZA-5P2).
Figs. 8-12. *Prostoperidinium divaricatum* (Meunier) Parke and Dodge, Loc. surface sediments of Omura Bay in Nagasaki Prefecture, west Japan; 8, cyst form in dorsal surface, showing intercalary archeopyle and paracingulum (Specimen KOP-5A1); 9, cyst form in optical cross section in dorso-ventral view (Specimen KOP-5A2); 10, cyst form in optical cross section in polar view, showing dorso-ventral depression (Specimen KOP-5A3); 11, thecate form in ventral surface (Specimen KOP-20); 12, thecate form in optical cross section of dorso-ventral view, showing two conspicuous antapical horns (Specimen KOP-21).

Figs. 14-15. *Xandarodinium* sp., Loc. Kaminoyama Formation, Nido Gawa in Zao Volcano in Yamagata Prefecture, north Japan; 14a-14b, different focus levels in dorso-ventral view, showing parasulcal depression (Specimen ZA-11P8); 15a-15b, different focus levels, orientation unknown (Specimen ZA-22P3).

Scale bar: 10 μm.
morphology between *X. xanthum* and *X. variabile*, but may be closer to the latter, even if a large number of specimens have broad spines (Matsuoka et al., 1982; pl. 1, figs. 2, 6). However, *Protoperidinium divaricatum* has also been recorded as a thecate form around the British Isles (Dodge, 1982). For this observation, the following interpretations are possible:

1) More than one thecate species which are indistinguishable from *Protoperidinium divaricatum* may be present. These species may be distinguishable on the cyst morphology only. In this case, *X. xanthum* and *X. variabile* might represent a biological species rather than a cyst species.

2) One biological species (*Protoperidinium divaricatum*) might be present, but its cyst morphology varies geographically and stratigraphically. For example, *X. xanthum* is distributed in the temperate, middle-latitude zone of the North Atlantic (Reid, 1977; Harland, 1977), while *X. variabile* is known in the subarctic Bering Sea and northern Pacific in the Late Miocene to Early Pleistocene (Bujak, 1984; Matsuoka and Bujak, 1988) and a recent intermediate population is reported from the warm temperate region in west Japan (Matsuoka et al., 1982). However, since paleoceanographic conditions around north Japan were estimated to have been subtropical to warm temperate in the latest Early Miocene (Chinzei, 1978), this species range from subtropical to subarctic zones. Therefore, *X. variabile* did not distinctly show morphological variations during the late Early Miocene to Early Pleistocene and over subtropical to subarctic zones. At present, I retain *X. xanthum* and *X. variabile* as separate species.

**Measurement.**—Cyst length 36-42 μm, width 32-41 μm, length of processes up to 7.5 μm. Number of specimens observed: 10.

**Occurrence.**—Kaminoyama Formation, Yamagata Prefecture.

**Repository.**—Palynological collection of Department of Geology, Nagasaki University.

*Xandarodinium* sp.

Figs. 11-12.

**Description.**—Cyst is of brown pigmentation, strongly compressed dorso-ventrally, and shows an irregular outline resulting from various shapes of processes. Cyst wall consists of smooth autophagom alone except for processes. Processes are extremely variable in shape and number. Some of them are large and short, cylindrical to buccinate, with smooth and entire distal ends, some are irregularly dentate distally, and others are short and acuminate. Large processes are generally restricted within major paraplate areas, but they do not correctly represent the paraplate distribution. Small and acuminate processes are distributed between two large process clusters, and probably represent paracircular and parasulcral regions. The archeopyle is not clear, but presumably of single intercalary type.

**Measurements.**—Cyst length 32-35 μm, width 32-36 μm, length of large processes up to 7 μm, width of large processes ca. 4 μm, length of small processes ca. 4 μm. Number of specimens observed: 5.

**Remarks.**—The specimens occurring from the Kaminoyama Formation are poorly preserved, however, two types of processes are observed. So far, two cyst species belonging to *Xandarodinium* have been described: *X. xanthum* Reid and *X. variabile* Bujak. The present species is closer to *X. xanthum* in having large and wide processes. But the former differs from the latter in possessing two types of processes: large and wide type, and small and simple type, which represent the paracingulum and parasulcus and probably major paraplate boundaries. This species is also different from *X. variabile* in bearing much larger and wider processes and being elliptical in shape.

**Occurrence.**—Kaminoyama Formation, Yamagata Prefecture.

**Repository.**—Kaminoyama Formation, Yamagata Prefecture.

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