Observations on the fossil resting spore morphogenus *Peripteropsis* gen. nov. of the marine diatom genus *Chaetoceros* (Bacillariophyceae) in the Norwegian Sea

**ITSUKI SUTO**

*Graduate School of Life and Environmental Sciences, Doctoral Program in Earth Evolution Sciences, University of Tsukuba, Tennoudai 1-1-1, Tsukuba, Ibaraki 305-8572, Japan*


The morphology and taxonomy of the fossil diatom resting spore morphogenus *Peripteropsis* gen. nov. from the lower Oligocene through middle Miocene sediments of Deep Sea Drilling Project Site 338 in the Norwegian Sea were examined. The new genus *Peripteropsis* is characterized by elongated processes on the shoulder or centre of its valves and contains four species including one new species and three new combinations: *P. tetracladia* sp. nov., *P. trinodis* comb. nov., *P. norwegica* comb. nov. and *P. tetracornusa* comb. nov. *Peripteropsis tetracladia*, the oldest species of the genus, arose in the early Oligocene in the stratigraphic records of the Norwegian Sea, and all *Peripteropsis* species including the last species, *P. tetracornusa*, became extinct by the earliest late Miocene. Some species are biostratigraphically useful in the Norwegian Sea and the North Pacific. Moreover, two similar species which may belong to *Peripteropsis*, ‘*Periptera* schraderi’ and ‘*Periptera* petiolata’, are also described.

**INTRODUCTION**

*Chaetoceros* Ehrenberg 1844 is one of the largest and most diverse of the marine planktonic diatom genera (Van-Landingham 1968; Rines & Hargraves 1988; Hasle & Syvertsen 1996). It plays an important role in marine primary production in nearshore upwelling regions and other coastal areas. Most species of the subgenus *Hyalochaete* Gran are known to form resting spores under various unfavourable conditions, such as nutrient depletion, darkness, and low temperature (e.g. Durbin 1978; Garrison 1981; Hargraves & French 1983; Kuwata & Takahashi 1990; Kuwata et al. 1993; Oku & Kamatani 1995, 1997, 1999; McQuoid & Hobson 1996). On the other hand, resting spores of the other subgenus *Phaeoceros* Gran are reported for only one species, *Chaetoceros eibenii* (Grunow) Meunier. The resting spores of *Chaetoceros* are differentiated from the weakly silicified vegetative frustules by possessing heavily silicified valves, and they occur frequently in nearshore sediments in association with other fossil diatom valves.

In previous studies, many fossil resting spore genera such as *Dictadia* Ehrenberg 1854, *Periptera* Ehrenberg 1854, *Syndendrion* Ehrenberg 1854, *Xanthiopyle* Ehrenberg 1854, *Liradiscus* Greville 1865 and *Monocladia* Suto 2003a have been described, and diatomists have realized that they may belong to the genus *Chaetoceros*. However, except for studies such as Gersonde (1980), Akiba (1986), Lee (1993) and Suto (2003a, b, 2004), the investigation of the taxonomy and biostratigraphy of fossil resting spores has been limited, because their weakly silicified vegetative valves are not usually preserved as fossils in sediments and the classification of resting spores was thought to be difficult or impossible.

Since *Periptera* was erected by Ehrenberg (1844, 1854), several species have been described (e.g. Abbott & Andrews 1979; Dzinoridze et al. 1979). Recently, Suto (2003b) described *Peripteropsis tetracornusa* from upper lower Miocene to Pleistocene sediments in the North Pacific Ocean and demonstrated its biostratigraphic utility. However, the name ‘*Periptera*’ is invalid because the angiosperm *Periptera* DC 1824 has priority over the diatom resting spore morphogenus ‘*Periptera*’. Therefore, the invalid fossil diatom resting spore morphogenus name ‘*Periptera*’ is renamed as *Peripteropsis* in this study.

Four *Peripteropsis* species, including one new species and three new combinations transferred to new genus from ‘*Periptera*’, are described herein from lower Oligocene to middle Miocene sediments at the Deep Sea Drilling Project (DSDP) Leg 38, Site 338 in the Norwegian Sea (Figs 1, 2) to clarify the systematic taxonomy of this genus, which might appear in the early Oligocene and expanding to the Atlantic and North Pacific.

**MATERIAL AND METHODS**

In this study, 80 samples of a section of middle Eocene through middle Miocene sediments from DSDP Leg 38, Site 338 (67°47.11′N, 05°23.26′E; water depth 400.8 m) were examined (Fig. 1). The diatom biostratigraphy of this site was reported in detail by Schrader & Fenner (1976) and Dzinoridze et al. (1978). Most samples investigated in this study include well preserved and abundant resting spore assemblages. The preparation and counting methods of resting spores

RESULTS

Peripteropsis species were moderately well preserved in the studied material. The cell/valve counts and stratigraphic distribution of each species are shown in Figs 3, 4 and Table 1. The stratigraphic ranges and ages are described relative to the Neogene north Pacific Diatom Zone (NPD) code of Akiba (1986) and Yanagisawa & Akiba (1998) in the Miocene and the diatom zones of Schrader & Fenner (1976) in the Oligocene and Eocene. The morphogenus name Peripteropsis is used for the fossil resting spores according to Articles 3.3 and 3.4 of the International Code of Botanical Nomenclature (Greuter et al. 2000).

Genus Peripteropsis gen. nov.

GENERIC TYPE: Peripteropsis tetracornusa sp. nov.

DESCRIPTION: Frustule heterovalvate. In girdle view epivalve hyaline and flat to slightly convex, mantle distinct. Epivalve face possesses some elongated processes at the shoulder or the centre of the valve. Mantle of epivalve hyaline and smooth. Hypovalve, hyaline, convex. Mantle of hypovalve with a single ring of puncta at its base. In valve view, valve outline broadly elliptical to subcircular.

REMARKS: This paper describes the taxonomy and stratigraphic occurrence of four species (Fig. 2); Peripteropsis tetracornusa comb. nov., P. tetracladia sp. nov., P. trinodis comb. nov. Moreover, 'Periptera' petiolata Andrews and 'Periptera' schraderi which may belong to Peripteropsis are also described. The description of P. tetracornusa has been presented in detail as the invalid species 'Periptera' tetracornusa in Suto (2003b).

ETYMOLOGY: The Latin tetracornusa means 'four horns'.

Key to species

(1a) Processes at the shoulder of valve ................. 2
(1b) Processes at the centre of valve ................. 4
(2a) Processes with branching processes ............ 3
(2b) Processes without branching processes ....... P. tetracornusa comb. nov.

(3a) Processes three, slender ........... P. trinodis comb. nov.
(3b) Processes four, tricornate ....... P. tetracladia sp. nov.
(3c) Processes numerous, thin and wide .............. P. norwegica comb. nov.
(4a) Central processes with two tricornate ones at the shoulder of epivalve ........ 'Periptera' schraderi
(4b) Central process on hypovalve .... 'Periptera' petiolata

Peripteropsis tetracornusa (Suto) Suto comb. nov.

Fig. 2A


TYPE LOCALITY: DSDP Hole 438A-73-5, 9–11 cm, the northwestern Pacific.

SIMILAR TAXA: Peripteropsis tetracornusa is very similar to P. tetracladia because it has four tricornate processes but is distinguished by lacking branched processes. This species differs from P. trinodis, 'Periptera' schraderi and 'Periptera' petiolata by possessing no central processes.

STRATIGRAPHIC OCCURRENCE: The species occurs from the early middle Miocene Zone NPD 3A to the upper part of the late middle Miocene Zone NPD 5C (see fig. 2 in Suto 2003b) in the North Pacific Ocean. At DSDP Site 338, rare occurrences of this species are recognized in the middle Miocene (Fig. 3).

ETYMOLOGY: The Latin tetracornusa means 'four horns'.

Peripteropsis trinodis (Hanna) Suto comb. nov.

Fig. 2B

SYNONYM: Dicladia trinodis Hanna (1927, p. 112, pl. 18, figs 4, 5); Barron & Mahood (1993, p. 38, pl. 3, fig. 10).


TYPE LOCALITY: Location 995 (California Academy of Science), Section 19, T. 18 S., R. 15 E., M.D.M., Fresno County, California, lower Miocene (Hanna 1927).

SIMILAR TAXA: This species is differentiated from other Peripteropsis species by the three slender post-like scarcely dichotomous branching processes.

STRATIGRAPHIC OCCURRENCE: This species was not noted in this study. It is reported from the early Oligocene glacial sediments of Prydz Bay, East Antarctica (Barron & Mahood 1993), and lower Miocene deposits of the Kreyenhagen Shale, California (Hanna 1927).

ETYMOLOGY: The Latin trinodis means 'three knots'.

REMARKS: Hanna (1927) placed this species in the genus Dicladia, but the species should not be included in Dicladia because it does not possess two conical elevations with dichotomous branching processes at its tips on the epivalve (see Suto 2003a). This species is characterized by the three slender post-like processes and its flat epivalve and belongs to the genus Peripteropsis. Frustule not observed by Hanna (1927) or Barron & Mahood (1993).

Peripteropsis tetracladia sp. nov.

Figs 2C, 5–28, 50

SYNONYM: Periptera tetracladia Ehrenberg (1854, pl. 18, fig. 9); Van Heurck (1885, fig. 8 nec figs 7, 9); Proshchina-Lavrenko &
Fig. 2. Sketches of girdle views of species of *Peripteropsis* which indicate the following morphological characters: (a) pervalvar axis; (b) apical axis; (c) tricornate process; (d) slender post-like scarcely dichotomous branching process; (e) tricornate dichotomous branching process; (f) spiny process; (g) thin and wide dichotomous branching process; (h) slender central process; (i) prominent central process; (j) mantle; (k) a single ring of puncta; (l) epivalve; (m) hypovalve. All sketches were made using LM except for *Peripteropsis trinodis*, which is drawn after illustrations in Barron & Mahood (1993), *P. jouseae* after Dzinoridze et al. (1979, fig. 164), and *’Periptera’ petiolata* after LM illustrations in Abbott & Andrews (1979).

**Description**: Frustule heterovalvate, apical axis 16.0–26.5 μm, transapical axis 6.5–13.0 μm, pervalvar axis 5.5–9.5 μm. Valve narrowly to broadly elliptical in valve view. Epivalve hyaline, slightly convex in the centre, with four, sometimes several, numbers (see Figs 13, 14), tricornate processes, and with valve mantle. Tricornate processes hyaline, with dichotomous branching processes at their tips, curved near their apices. Hypovalve hyaline, high. Hypovalve hyaline, flat, with two strong spines at the apices. Mantle of hypovalve hyaline, high, with a single ring of puncta along the edge of the mantle.

**Holotype**: Slide MPC-03759. Micropaleontology Collection (MPC), the National Science Museum, Tokyo. England Finder P36-4N, illustrated in Figs 5, 6.

**Type Locality**: DSDP Site 338-17-3, 110–111 cm, the Norwegian Sea.

**Similar taxa**: This species is differentiated from *P. tetracornusa* and *P. trinodis* by its processes with triangular cross-sectional and dichotomous branching processes at its tips. This species is very similar to *P. norwegica* because it possesses dichotomous branching processes at the edge of the valve, but it is identified by the four tricornate processes on its epivalve. This species differs from *’Periptera’ schraderi* and *’P.’ petiolata* by lacking central processes.

**Stratigraphic occurrence**: This species is recognized only at DSDP Site 338 and occurs rarely but continuously from the early Oligocene to the middle Miocene.

**Etymology**: The Latin *tetracladia* means ‘four branches’.

Sheshukova-Poretzkaya (1949, p. 207, pl. 98, fig. 11a nec fig. 11b); Dzinoridze et al. (1978, pl. 17, fig. 8); Dzinoridze et al. (1979, p. 62, fig. 162); Schrader & Schuette (1981, p. 1192, figs 9–11 nec figs 9–12); *Dicladia elliptica* Schrader & Fenner (1976, p. 979, pl. 6, fig. 16); *Periptera* sp. 1 of Schrader & Fenner (1976, pl. 39, fig. 7); *Periptera* sp. 2 of Dzinoridze et al. (1978, pl. 17, fig. 11); *’Periptera’ schraderi* Jousé in Dzinoridze et al. (1979, fig. 163 nec fig. 164).
**Peripteropsis tetracladia** was formerly known as *Periptera tetracladia* erected by Ehrenberg (1844, 1854). However, the name ‘*Periptera*’ for diatom resting spore is invalid because the angiosperm *Periptera* DC 1824 has priority over the diatom resting spore morphogenus *Periptera*. Therefore, *Peripteropsis tetracladia* is invalid in both genus and species names, and the species are renamed as new species belonging to new genus *Peripteropsis*.

*Dicladia elliptica* Schrader & Fenner (1976, p. 979, pl. 6, fig. 16) and *Periptera* sp. 2 of Dzinoridze et al. (1978, pl. 17, fig. 11) are identified as *Peripteropsis tetracladia* by the four dichotomous branching processes. The type specimens of *Periptera schraderi* in Dzinoridze et al. (1978, p. 61, fig. 163 nec fig. 164) belong to *Peripteropsis tetracladia* because they possess broken tricornate processes on the epivalve; therefore *Periptera schraderi* is a synonym. *Peripteropsis tetracladia sensu* Van Heurck (1880–1885, figs 7, 9), Proshchka-Lavrenko & Sheshukova-Poretzkaya (1949, p. 127,

Figs 5, 6. Holotype (Slide MPC-03759). DSDP Site 338-17-3, 110–111 cm.
Figs 7–10. DSDP Site 338-17-1, 100–101 cm.
Figs 11, 12. DSDP Site 338-15-4, 100–101 cm.
Peripertera norwegica (Schrader) Suto comb. nov.

Figs 2D, 29–40, 51, 52

BASIONYM: Dicladia norvegica Schrader in Schrader & Fenner (1976, p. 979, pl. 6, figs 13, 14)

SYNONYM: Periperta tetrocladida sensu Van Heurck (1885, figs 7, 9 nec fig. 8); Proschkina-Lavrenko & Shushkovova-Poretzkaya (1949, p. 127, pl. 98, fig. 12); Baldauf & Barron (1987, p. 7, pl. 4, figs 4, 5); Suto (1976, p. 992, pl. 39, figs 5, 6; Schrader & Fenner 1976, p. 248, pl. 5, fig. 2), HajoÅs (1986, p. 4, figs 1, 2, pl. 49, figs 9–12), Baldauf & Barron (1987, p. 7, pl. 4, figs 4, 5), Homann (1991, p. 132, pl. 57, figs 1–3) and Lee (1993, p. 43, pl. 1, figs 22, 23) do not belong to Peripertopsis tetrocladida because they lack dichotomous branching processes. These species were not observed in this study, and therefore it is not clear whether or not they belong to the genus Peripertera.

DESCRIPTION: Frustule heterovalvate, apical axis 6.5–26.5 μm, perivalvar axis 7.0–15.0 μm. Valve narrowly to broadly elliptical in valve view. Epivalve hyaline, slightly convex in the centre, with numerous (6–12) thin and wide processes, with valve mantle. The thin and wide processes hyaline, flatness around the margin of the epivalve, with dichotomous branching processes at their tips, curved near their apices. Epivalve mantle hyaline, high. Hypovalve hyaline, vaulted with one hump. Mantle of hypovalve hyaline, high, with a single ring of puncta at its base.

HOLOTYPE: Dicladia norvegica sensu Schrader in Schrader & Fenner (1976, p. 979, pl. 6, figs 13, 14).

TYPE LOCALITY: DSDP Site 338-10-2, 55–56 cm, the Norwegian Sea (Schrader & Fenner 1976).

SIMILAR TAXA: This species is distinguished from other Peripertopsis species by the thin and wide dichotomous, branching processes around the margin of the epivalve.

STRATIGRAPHIC OCCURRENCE: The sporadic and rare occurrences of this species are recognized in the upper Oligocene, but this species occurs abundantly and continuously in the lower Miocene through to the upper middle Miocene sediments at DSDP Site 338.

ETYMOLOGY: The Latin norvegica means ‘Norway’.

REMARKS: Dicladia norvegica Schrader in Schrader & Fenner (1976) belongs to the genus Peripertera because it does not possess elevations or domes on its epivalve and has numerous thin and wide processes around the margin of the epivalve. This species has been included with the invalid species Periperta tetrocladida because it possesses two tricornate processes on the valve shoulder and may belong to 'Periperta' schraderi. Therefore, Periperta schraderi Jouse in Dzinoridze et al. (1979, fig. 164), the other type figure of P. schraderi, must be renamed because it possesses two slender central processes. However, it is not determined whether or not this species belongs to Peripertopsis in this study.

In this study, this type species has not occurred, but very similar species are recognized ('Periperta' schraderi; Figs 41, 42, 49). The specimen in Figs 41, 42 possesses one central slender process, and one in Fig. 49 lacks central slender process, but each specimen possesses two tricornate processes on the valve shoulder and may belong to 'Periperta' schraderi.

‘Periperta’ petiolata Andrews in Abbott & Andrews

Figs 2F, 43–48

SAME SPECIES: Periperta sp. (Chaetoceros? sp.) I of HajoÅs 1968, p. 137, pl. 38, fig. 8; Periperta sp. (Chaetoceros? sp.) VII of HajoÅs 1968, p. 138, pl. 38, fig. 14; Periperta petiolata Andrews in Abbott & Andrews 1979, p. 248, pl. 4, figs 30–34, pl. 8, fig. 1; Periperta sp. of Lee 1993, p. 43, pl. 1, fig. 14, pl. 3, fig. 7.

DESCRIPTION: Frustule heterovalvate, apical axis 45–70 μm, transapical axis 12.0–18.5 μm, perivalvar axis 15–30 μm. Valve narrowly elliptical to elongate rectangular in valve view. Epivalve hyaline, slightly convex, sometimes slightly concave in central area, with distinct mantle, which is hyaline and high. Hypovalve hyaline, with a central prominent process 8–10 μm in height, with a sheath surrounding the hypovalve margin. A prominent process flange is present (Fig. 47) around the margin and its top is flat at the centre. Mantle of hypovalve hyaline, high, with a single ring of puncta at its base.

TYPE LOCALITY: USGS diatom locality 6459, Dawson’s Landing, South Carolina.
Table 1. Occurrence of Peripteropsis species at DSDP Site 338.

<table>
<thead>
<tr>
<th>Diatom zones</th>
<th>NPD</th>
<th>Core Section, Interval (cm)</th>
<th>Leg 39 Site 338</th>
<th>Depth (m)</th>
<th>Preservation</th>
<th>Peripteropsis</th>
<th>Peripteropsis</th>
<th>Peripteropsis</th>
<th>Peripteropsis</th>
<th>Peripteropsis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>zonata</td>
<td>tetracladia</td>
<td>norwegica</td>
<td>teitracladia</td>
<td>norwegica</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denticulodiscus pseudodentatus 5B</td>
<td>8-1</td>
<td>140-141</td>
<td>77.40</td>
<td>G</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8-2</td>
<td>48-49</td>
<td>77.98</td>
<td>A</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8-3</td>
<td>99-100</td>
<td>78.49</td>
<td>G</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. micrantha 5A</td>
<td>8-5-6</td>
<td>10-14</td>
<td>79.16</td>
<td>G</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denticulodiscus sydowii 4B</td>
<td>8-4</td>
<td>80-81</td>
<td>79.96</td>
<td>G</td>
<td>A</td>
<td>1</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8-5-6</td>
<td>10-14</td>
<td>79.80</td>
<td>G</td>
<td>A</td>
<td>1</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8-4-6</td>
<td>80-81</td>
<td>80.60</td>
<td>G</td>
<td>A</td>
<td>1</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8-4-5</td>
<td>80-81</td>
<td>81.30</td>
<td>G</td>
<td>A</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8-4-4</td>
<td>80-81</td>
<td>80.00</td>
<td>G</td>
<td>A</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9-1</td>
<td>140-149</td>
<td>86.98</td>
<td>G</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9-2</td>
<td>140-149</td>
<td>85.88</td>
<td>G</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9-3</td>
<td>140-149</td>
<td>85.88</td>
<td>G</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SIMILAR TAXA: This species is characterized by its prominent central process on the hypovalve.

STRATIGRAPHIC OCCURRENCE: This species occurs rarely and sporadically, only at DSDP Site 338 from the earliest early Miocene through early middle Miocene.

ETYMOLOGY: The Latin petiolata means ‘leafstalk’.

REMARKS: It is not clear whether or not this species belongs to the genus Peripteropsis because it lacks elongated processes on the epivalve. The prominent central process on the hypovalve characterizes this species, but other Peripteropsis species lack processes on their hypovalve. This species may belong to another genus.

Chaetoceros sp. in Harwood (1986, pl. 3, fig. 1) is similar to this species because it possesses a central prominent process on the valve, but it may not belong to Peripteropsis because it connected by slender setae which Peripteropsis species lack. This species may belong to another genus.

DISCUSSION

The morphology, taxonomy and biostratigraphy of the fossil resting spore morphogenus Peripteropsis formerly known as ‘Periptera’ are described in this paper. The genus Peripteropsis is characterized by elongated processes at the valve shoulder. Of the four species in this genus, Peripteropsis tetracladia and P. norwegica are similar to the fossil resting spore genera Monocladia, Dicladia and Syndendrium in possessing dichotomous branching processes on their valves (Suto 2003a), suggesting a close phylogenetic relationship between the four genera. However, Peripteropsis is clearly distinguished by the possession of processes on the valve margin, which are lacking in the other three genera. In addition, Peripteropsis differs from Monocladia, Dicladia and Syndendrium by having a relatively flat valve face in contrast to the strongly domed valve faces of the other three genera. Among the morphogeneata of Chaetoceros, no others have such processes on the valve margin, and therefore Peripteropsis is distinct and is clearly characterized by the presence of marginal processes.

The genus Peripteropsis appeared in the early Oligocene and became extinct in the early late Miocene (Fig. 3) in the Norwegian Sea at Site 338. The oldest species P. tetracladia arose in the early Oligocene in the stratigraphic records of the Norwegian Sea and disappeared in the early middle Miocene (Fig. 4). In the late Oligocene, P. norwegica appeared and increased upward in abundance through the early Miocene to middle Miocene (Fig. 3). The last species P. tetracornus appeared in the earliest middle Miocene and became extinct in the earliest late Miocene. ‘Periptera’ petiolata occurs through the early Miocene to the earliest middle Miocene. ‘Periptera’ schraderi (see Figs 41, 42, 49) rarely occurs in the early middle Miocene, but its stratigraphic range is not well known because of its rare abundance.


Figs 29, 30. DSDP Site 338-12-2, 40–41 cm.
Figs 31–34, 39, 40. DSDP Site 338-10-2, 80–81 cm.
Figs 35, 36. DSDP Site 338-15-4, 100–101 cm.
Figs 37, 38. DSDP Site 338-15-1, 30–31 cm.

1 Numbers indicate individuals encountered during counts of 100 resting spore valves; + indicates epivalves encountered after the count; blank indicates absence of any taxa. Diatom zones and NPD codes in the Oligocene after Yanagisawa & Akiba (1998), and diatom zones in the Miocene after Schrader & Fenner (1976). Preservation: G, good. Abundance: A, abundant; C, common; R, rare. T, total number of resting spore valves counted.
Suto: Fossil diatom resting spore *Peripteropsis* in the Norwegian Sea

Figs 41, 42. ‘Periptera’ schraderi? DSDP Site 338-8-2, 48–49 cm.
Figs 43–48. ‘Periptera’ petiolata.
Figs 43, 44. DSDP Site 338-14-2, 20–21 cm.
Figs 45, 46. DSDP Site 338-11-4, 70–71 cm.
Figs 47, 48. DSDP Site 338-11-4, 148–149 cm.
Fig. 49. DSDP Site 338-11-4, 148–149 cm.
Fig. 50. Peripteropsis tetracodium. DSDP Site 338-15-2, 100–101 cm.
Figs 51, 52. Peripteropsis norwegica. DSDP Site 338-15-2, 100–101 cm.
Homann (1991) described *Periptera tetracladia* (p. 132, pl. 57, figs 1–3) and *Periptera* sp. (pl. 57, fig. 4) from the Fur Formation, Denmark, in the late Paleocene and early Eocene. These species possess elongated processes at the valve shoulder, but they do not belong to any *Peripteropsis* species described in this study because these are characterized by their central processes, not on the valve shoulder. These taxa occurred from the Paleocene and Eocene deposits; therefore they may be the oldest *Peripteropsis* species. Moreover, Harwood & Gersonde (1990) reported many resting spores, except for *Peripteropsis*, from the lower Cretaceous sediments in the eastern Weddell Sea, east Antarctica.

Each *Peripteropsis* species has its own geographic distribution pattern. *Peripteropsis tetracornus* occurs abundantly in the northwest and northeast Pacific (Suto 2003b) and is also encountered in the Norwegian Sea, although its abundance there is scarce (Table 1). Thus, *P. tetracornus* is probably a cosmopolitan species mainly distributed in the Pacific. *Peripteropsis tetracladia* and *P. norwegica* have been noted only in the North Atlantic, and therefore they may be endemic to this ocean, although available geographic distributional data are very limited at present.

Some species of *Peripteropsis* are biostratigraphically useful in the Norwegian Sea and the North Pacific. Suto (2003b) indicated that the last occurrence of *Peripteropsis tetracornus* (c. 10.3 million years before present) may be a distinct biohorizon and useful for identifying the upper part of the Zone NPD 5C in the North Pacific. *Peripteropsis tetracladia* occurs continuously in the interval from the bottom of the late early Oligocene *Pseudodimerogramma filiformis* Zone through the early middle Miocene Zone NPD 4A, and therefore the species is useful for identifying this interval.

Many detailed descriptions of extant *Chaetoceros* vegetative cells have been published in previous works (e.g. Cupp 1943; Rines & Hargraves 1988; Hasle & Syvertsen 1996). On the other hand, our knowledge on morphologies of their resting spores is limited, mainly because it is difficult to observe in detail in valve view in the case of extant resting spores in their frustule of vegetative cells. Therefore, more detailed studies about extant and fossil resting spores morphology are needed. When the morphologies and combinations between resting spores and vegetative cells are clarified, we can identify the same species of fossil resting spores and extant vegetative cells.

The significant role of *Chaetoceros* in marine primary production and ecology has been known for a very long time (e.g. McQuoid & Hobson 1996; Itakura 2000). The abundance changes of fossil resting spores must be effected by changes in nutrient conditions and/or water-column stratification. Therefore the fossil resting spores abundance changes may indicate the past fluctuations and be used as a paleoecological tool. However, the past ecological influences to resting spores have been neglected because the taxonomies of fossil resting spores are not completed and their ecological information is scant.

It is significant to classify correctly other fossil resting spores in all upwelling regions and several ages and to investigate how old the genus *Chaetoceros* is, in order to understand past productivity and to know the age when circumstances changed to suit initiation and ensuing evolution of this genus. Therefore the establishment of a reliable taxonomy for all fossil resting spores will allow us to detect additional paleoceanographic signals recorded in the fossil resting spore assemblages in upwelling regions.

ACKNOWLEDGEMENTS

I am especially grateful to Yukio Yanagisawa (Geological Survey of Japan/AIST), who provided numerous helpful suggestions and reviewed the manuscript carefully. I wish to thank Fumio Akiba (Diatom Minilab Akiba Ltd.) for invaluable discussions and his careful review of the manuscript. I am grateful to Richard W. Jordan (Yamagata University) who has reviewed and edited the manuscript. I am grateful to two reviewers and an associate editor, Dr Takeo Horiguchi, who have reviewed and edited my manuscript. I am also grateful to Shigeaki Mayama (Tokyo Gakugei University) who gave helpful suggestions and allowed me to copy some classic papers. I wish also to thank Kenshiro Ogasawara (University of Tsukuba) and my colleagues for their helpful advice and encouragement. This research used samples provided by the Ocean Drilling Program (ODP). ODP is sponsored by the U.S. National Science Foundation (NSF) and participating countries under the management of the Joint Oceanographic Institutions (JOI), Inc.

REFERENCES


EHRENBERG C.G. 1844 (1845). Über zwei neue Lager von Gebirgsmassen aus Infusorien als Meeresabsatz in Nord-Amerika und eine Vergleichung derselben mit den organismen Kreidegebilden in Eu-


