964. INITIAL VALVES OF THE MIOCENE EXTINCT DIATOM GENUS *DENTICULOPSIS* SIMONSEN*

YUKIO YANAGISAWA

Geological Survey of Japan, 1–1–3 Higashi, Tsukuba, Ibaraki, 305

Abstract. Morphologic and stratigraphic study of the Miocene fossil diatom genera *Katahiraia* Komura and *Yoshidaia* Komura reveals that they are the initial valves of the genus *Denticulopsis* Simonsen. They have almost the same morphology and stratigraphic range as the corresponding vegetative valves of *Denticulopsis*, but differ in having a rounded valve shape in cross section and a central raphe. Probable vegetative *Denticulopsis* species are suggested for each of *Katahiraia* and *Yoshidaia* species on the basis of morphology and stratigraphic ranges.

Key words. Miocene marine diatom, *Denticulopsis*, *Katahiraia*, *Yoshidaia*, initial valve, auxospore.

Introduction

*Denticulopsis* is an extinct marine diatom genus which was erected by Simonsen (1979) and later emended by Akiba and Yanagisawa (1986). It is one of the most important diatom groups in the Miocene diatom biostratigraphy in the middle- to high-latitude North Pacific, because it includes a number of short-lived species which serve as remarkable biostratigraphic markers (e.g. Maruyama, 1984b; Koizumi, 1985; Barron, 1985; Akiba, 1986; Bodén, 1992).

Modern taxonomic study of the genus *Denticulopsis* began in 1961, when Simonsen and Kanaya (1961) made the first taxonomic synthesis of this species group, demonstrating its stratigraphic utility in the Neogene sediments of California and Japan. During the past three decades, systematic study of this genus has been greatly improved by many successive works (Schrader, 1973a, b, 1976; Simonsen, 1979; Maruyama, 1984a, Akiba and Yanagisawa, 1986; Tanimura, 1989; Harwood and Maruyama, 1992). Recently, a detailed taxonomic synthesis has been made on this genus by Yanagisawa and Akiba (1990), who presented its most probable evolutionary lineages based on both scanning electron microscopy (SEM) and biostratigraphic analysis.

However, there still remain some problems concerning the taxonomy of *Denticulopsis*. One of these is its taxonomic relationship with the genera *Katahiraia* and *Yoshidaia*, both of which were erected by Komura (1976) from Neogene sediments of Hokkaido, Japan. The two genera are very similar in morphology to *Denticulopsis* except that they have a rounded valve shape in cross section and a central raphe, in contrast to the flat valve face and a marginal raphe of *Denticulopsis*. Because of this morphologic similarity, Yanagisawa and Akiba (1990) suggested that *Katahiraia* and *Yoshidaia* species may be the initial valves of *Denticulopsis*, but they failed to present substantial evidence to support it.

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In the course of my continued study, diatom frustules consisting of a Katahiraia-type epivalve and a Denticulopsis-type hypovalve were occasionally found. This is an additional evidence to strongly suggest that Katahiraia is the initial valve of Denticulopsis. In this paper, the morphology of initial valves of some Denticulopsis species are described and the life cycle of this genus is suggested in relation to the initial valve formation.

Materials and methods

Samples used in this study are listed in Table 1. Sample JOB 557A was collected by the present author. Samples JDS 5801 and 6-9 were offered by Fumio Akiba and Itaru Koizumi, respectively. Samples of DSDP Hole 438A were those studied by Akiba et al. (1982), Maruyama (1984b), Akiba (1986) and Yanagisawa and Akiba (1990). In this study, I examined slides of some selected samples of DSDP Hole 71 which were studied by Barron (1983).

The samples were processed and prepared by a standard method. Light microscopy was carried out at a magnification of 1000X. The stratigraphic distribution of Katahiraia and Yoshidaia was examined in DSDP Hole 438A.

Results and observation

Selected specimens of Katahiraia and Yoshidaia species found in this study are illustrated in Figures 1 and 2, with their related Denticulopsis species. In this study the following six species are identified: Katahiraia oblonga Komura, K. pauperata Komura, K. aspera Komura, Yoshidaia divergens Komura, Y. constricta Komura and Y. loculata Komura.

The stratigraphic occurrences of the Katahiraia and Yoshidaia species in the DSDP Hole 438A are shown in Figure 3.

In the following, the results of observation on some Katahiraia and Yoshidaia species are described. Terminology generally follows Yanagisawa and Akiba (1990) who discussed the basic terminology of Denticulopsis using several schematic drawings.

According to the original description of Komura (1976), both of the genera Katahiraia and Yoshidaia are characterized by central canal raphe, but the two genera can be differentiated by perforation on valve surface; Katahiraia has double-layered perforation composed of outer finely and regularly perforated wall and inner coarse and irregular areolation, whereas Yoshidaia has single-layered fine perforation with regularly arranged puncta.

<table>
<thead>
<tr>
<th>Samples and cores</th>
<th>Area</th>
<th>Latitude and longitude</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>JOB 557A</td>
<td>Joban Coalfield</td>
<td>36°47.37’ N, 140°44.38’ E</td>
<td>Isohara Formation</td>
</tr>
<tr>
<td>JDS 5801</td>
<td>Kushiro Coalfield</td>
<td>41°15.00’ N, 141°19.66’ E</td>
<td>Chokubetsu F.</td>
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<tr>
<td>Sample 6-9</td>
<td>Shimokita Peninsula</td>
<td>40°37.79’ N, 143°14.15’ E</td>
<td>Gamanosawa F.</td>
</tr>
<tr>
<td>DSDP Hole 438A</td>
<td>Northwest Pacific</td>
<td>04°28.28’ N, 140°18.91’ W</td>
<td></td>
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<tr>
<td>DSDP Hole 71</td>
<td>Eastern equatorial Pacific</td>
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*Katahiraia oblonga* Komura (Figure 1–3), and *Katahiraia pauperata* Komura (Figure 1–2)

*Katahiraia oblonga* Komura (1976, p. 386–387, text-fig. 6, pl. 41, fig. 6) and *K. pauperata* Komura (1976, p. 387–388, text-fig. 7, pl. 41, fig. 7) have a thickly silicified linear valve with rounded apices (Figures 1–2, 1–3). Primary pseudosepta and marginal ribs are present, but secondary pseudosepta are absent. Valve shape in cross section is rounded so that the valve face and mantle can not be separated. The whole valve surface is perforated with double-layered punctuation composed of outer fine perforation and inner coarse areolation. A raphe runs along the apical axis or somewhat subcentrally with each portula between each two primary pseudosepta.

These two species share a set of common morphological features mentioned above, and they are differentiated only by their slightly different valve outline; *K. oblonga* has a
broader and shorter valve, and *K. pauperata* has a more slender and longer valve. However, this difference is not clear enough to separate the two species distinctly. Consequently, they might be treated as a single taxon of *Katahiraia*. *Katahiraia* sp. (Komura, 1976, p. 388, text-fig. 8, pl. 40, fig. 13) may also be included in this taxon because of its intimate similarity to *K. oblonga* and *K. pauperata*.

Except for the central raphe and rounded cross section of valve, a number of morphologic characteristics of *K. oblonga* and *K. pauperata*, including the linear valve outline, thickly silicified valve, absence of secondary pseudosepta and double-layered perforation, are common to *Denticulopsis hyalina* (Schrader) Simonsen (Figure 1–5, 1–6), and also to *D. praehyalina* Tanimura and *D. tanimurae* Yanagisawa et Akiba.

In samples JOB-557A from the Isohara Formation and DSDP Hole 438A, 68–1, 30–34 cm, I have found heterovalvate frustules consisting of a *Katahiraia*-type epivalve.
which has rounded valve face and apices, and a flat-faced *Denticulopsis*-type hypovalve (Figures 1–1, 1–4).

At the DSDP Hole 438A, both *K. oblonga* and *K. pauperata* are found, though extremely rare, in 9 samples, all of which fall within NPD 4B (the *Denticulopsis hyalina* Zone) of Akiba (1986) (Figure 3). Their stratigraphic range is seemingly coincident with the interval where *D. hyalina*, *D. praehyalina* and *D. tanimurae* occur abundantly (Figure 3).

*Katahiraiia aspera* Komura (Figure 1–8)

*Katahiraiia aspera* Komura (1976, p. 385, text–fig. 5, pl. 41, figs. 1–4) is typified by its broad and oval valve outline (Figure 1–8). Other morphological features are almost the same as those of *K. oblonga* and *K. pauperata* described above. Detailed SEM observation of this species was carried out by Yanagisawa and Akiba (1990, pl. 10, figs. 3–3). This form exhibits close affinity to *Denticulopsis miocenica* (Schrader) Simonsen (Figure 1–7) in having an oval valve shape and a thickly silicified valve, but it differs by the possession of a central raphe, rounded valve face and double-layered perforation on the whole valve surface. *Katahiraiia aspera* is generally larger than *D. miocenica* (Yanagisawa and Akiba, 1990, fig. 19).

Komura (1976) presented several girdle views of *K. aspera* (Komura, 1976, text–fig. 5, figs. 7, 8; pl. 41, fig. 5), but these specimens might probably be large forms of *Denticulopsis hyalina* because they have flat valve faces.

Although it does not occur in DSDP Hole 438A, rare specimens of *K. aspera* are rarely found in the upper part of NPD 4B (the *D. hyalina* Zone) in several onland sections of Japan. The sample JDS 5801 collected from the Chokubetsu Formation of Kushiro Coalfield in eastern Hokkaido is one of these samples which contain abundant *K. aspera* as well as *D. miocenica*.

*Yoshidaia divergens* Komura (Figures 2–6, 2–8, 2–9), and *Y. constricta* Komura (Figure 2–7)

*Yoshidaia divergens* Komura (1976, p. 389–390, text–fig. 9, pl. 40, figs. 6–8) and *Y. constricta* Komura (1976, p. 390–391, text–fig. 10, pl. 40, figs. 9, 10, pl. 41, fig. 8) are linear in valve outline with rounded apices and a central or subcentral raphe (Figure 2–6, 2–7). They have primary pseudosepta and marginal ribs, but lack secondary pseudosepta. The valve surface is rounded in cross section and therefore the valve face and mantle can not be distinguished (Yanagisawa and Akiba, 1990, pl. 9, figs. 10, 11). The valve surface is covered with fine perforation without reduction of puncta. The frustule of *Y. divergens* possesses some girdle bands quite similar to those of *Denticulopsis* (Yanagisawa and Akiba, 1990, pl. 9, fig. 10).

According to Komura (1976), *Y. divergens* and *Y. constricta* are separated mainly by their valve outline, but this difference is not significant enough and they may be safely interpreted as intraspecific variations. The valve of *Y. divergens* or *Y. constricta* is most similar to *Denticulopsis lauta* (Bailey) Simonsen (Figure 2–5) and *D. ichikawae* Yanagisawa et Akiba in all aspects except that it has the central raphe and convex valve face.

In DSDP Hole 438A, *Yoshidaia divergens* was detected in three samples within NPD 4A (the *Denticulopsis lauta* Zone), where *D. lauta* and *D. ichikawae* occur abundantly (Figure 3). *Yoshidaia constricta* was found in sample 6–9 from the Gamanosawa Formation in Shimokita Peninsula (Figure 2–7), a sample containing a diatom assemblage correlative with NPD 4A.

*Yoshidaia loculata* Komura (Figures 2–1, 2–4)

*Yoshidaia loculata* Komura (1976, p. 391, text–fig. 11, pl. 40, fig. 11, pl. 41, fig. 9) is linear in outline with rounded apices. The raphe is located in the valve center (Figure 2–1), almost straight but slightly curved near the apex (Figure 2–4). Primary pseudosepta, secondary pseudosepta and marginal ribs are
present. The valve shape in cross section is strongly convex without distinction between the valve face and mantle. The whole valve surface is perforated with fine puncta without reduction of puncta.

_Yoshidaia? densicostata_ Komura (Komura, 1976, p. 392–393, text-fig. 12, pl. 40, fig. 12) is very similar in morphology to _Y. loculata_, and the two species may constitute the same taxonomic unit.

_Yoshidaia loculata_ resembles _Y. divergens_ in having linear valve outline and fine perforation but is distinguished by the presence of secondary pseudosepta. It also exhibits obvious affinities to _Denticulopsis simonsenii_ Yanagisawa et Akiba (Figures 2–2, 2–3) and _D. vulgaris_ (Okuno) Yanagisawa et Akiba with its linear outline, fine perforation and the presence of secondary pseudosepta. The _Yoshidaia loculata_ valve is usually larger than those of _D. simonsenii_ and _D. vulgaris_ (Yanagisawa and Akiba, 1990, fig. 20).

In DSDP Hole 438A, _Y. loculata_ is recognized in 10 samples ranging from the base of NPD 5A (the _Crucidenticula nicobarica_ Zone) to lower part of NPD 6A (the _Denticulopsis katayamae_ Zone) (Figure 3). This interval approximates the stratigraphic interval where _D. simonsenii_ and _D. vulgaris_ occur most abundantly.

**Discussion**

The genera _Katahiraia_, _Yoshidaia_ and _Denticulopsis_ are morphologically very similar to each other, sharing a set of common morphological features including linear or linear-elliptical valve outline, rounded apices, valve interior chambered by a number of transapical pseudosepta, the presence of marginal ribs, the structure of the basal ridge, two types of perforation pattern on the valve surface, the presence of a canal raphe system and so on. Morphologic differences among _Katahiraia_, _Yoshidaia_ and _Denticulopsis_ include only the convexity of the valve surface and the location of the raphe; the valves of _Katahiraia_ and _Yoshidaia_ have a convex valve surface and a central raphe, while _Denticulopsis_ possesses a flat valve face and a marginal raphe (Figure 4). No other distinct differences exist between the two.

The morphologic and stratigraphic features of _Katahiraia_ and _Yoshidaia_ are summarized as follows: (1) The valve surface is rounded in cross section so that the valve face and mantle can not be differentiated. (2) The raphe runs along the valve center in contrast to the marginal raphe of _Denticulopsis_. (3) Each species of _Katahiraia_ and _Yoshidaia_ has its corresponding _Denticulopsis_ species which have almost the same morphologic features except for the rounded valve surface and the central raphe. (4) The valve surface is covered with the same type of perforation as that of the mantle of the corresponding _Denticulopsis_ species. (5) _Katahiraia_ and _Yoshidaia_ species are relatively larger in size than the corresponding _Denticulopsis_ species. (6) The occurrence of _Katahiraia-Yoshidaia_ species is always extremely scarce. (7) The stratigraphic ranges of these forms are roughly coincident with the ranges of the corresponding _Denticulopsis_ species.

These morphologic resemblances and stratigraphic coincidences between _Katahiraia-Yoshidaia_ and _Denticulopsis_ species clearly indicate that they are different products of the same genotypes. This is also confirmed by the presence of “Janus cells”, i.e. the frustules with an epivalve of _Katahiraia_-type and a hypovalve of _Denticulopsis_-type.

There may be three cases where a single
diatom genotype produces different morphotypes in its life cycle: (1) resting spores, (2) environmental modification, and (3) auxospore and initial valves. Among the three cases, the resting spores may be excluded, because most of the raphid diatoms such as *Denticulopsis* do not form resting spores (Round *et al.*, 1990).

The second possibility, environmental modification, occurs where morphology is modified in response to change in various environmental factors such as temperature, salinity and silicate availability. For example, Fryxell (1991) reported that *Eucampia antarctica* produces two different seasonal morphotypes; winter and summer forms, in response to seasonal changes in oceanographic factors. If *Katahiraia* and *Yoshidaia* are such a case, they might be found fairly commonly in conjunction with the occurrence of *Denticulopsis* species. However, they are always extremely rare and hence it seems very unlikely that *Katahiraia* and *Yoshidaia* species are the environmental morphotypes of *Denticulopsis*.

The remaining third possibility, auxospores and initial valves, seems to best agree with *Katahiraia* and *Yoshidaia*, as will be discussed in detail in the following section.

The formation of the auxospore and initial cells takes place during the life cycle of diatoms (e.g. Round *et al.*, 1990). The presumed life cycle of pennate diatoms is summarized in Figure 5. After a phase of vegetative multiplication, during which the cell size has greatly decreased, pennate diatoms undergo a meiosis and sexual reproduction to form a zygote (Figure 5, A). This is followed by auxospore formation (B) and bipolar expansion of the auxospore (C-D). As the auxospore expands, a number of transverse perizonial silica bands are deposited around the surface of the auxospore (D-E). After the expansion is completed, the cell size is restored and the first theca of new generation, namely the initial epivalve and hypovalve are laid down immediately under the perizonial bands (E). As the shape of the auxospore is circular in cross section, the initial cell, which is moulded directly by the auxospore, has also a rounded cross section without distinction between the valve face and valve mantle. The perizonial bands gradually break open to reveal the initial cell (F-G). After that, the first cell division of the initial cell takes place to form two new normal vegetative hypovalves which contact each other back to back so that they have flat valve faces (H). The vegetative multiplication continues to make a long colony chain of cells (I-K).

If the auxospore and the initial cells of the fossil diatom *Denticulopsis* were formed, then they may be present in the fossil record. The perizonial bands of auxospore, however, are too delicate to remain as fossils, because they might be easily dissolved. In contrast, the initial valves, silicified as thickly as the normal vegetative valves, may be found in the fossil record although they will be very rare. Williams (1990) pointed out that fossil initial valves will be readily recognized by their distinctive morphological modifications, in combination with their large size and shape, and he has succeeded in identifying fossil initial valve of *Tetracyclus* from non-marine diatomaceous deposits. Mayama and Kobayashi (1991) have also recognized a fossil initial valve which is presumed to be produced by *Eunotia arcus*, applying the

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**Figure 5.** Inferred life cycle of *Denticulopsis*. **A.** Sexual reproduction. **B.** Auxospore formation. **C-E.** Bipolar expansion and formation of perizonium (p: primary transverse perizonial band, t: transverse perizonial band). **F.** Detachment of perizonial bands after the initial cell formation under the auxospore casing. **G.** Initial cell composed of an initial epivalve (left) and an initial hypovalve (right). The two initial valves are noted as 1. **H.** First cell division of initial cell to form two new normal vegetative (noted as 2). **I.** Second cell division. New valves formed in this cell division are noted as 3. **K.** Chain of relatively small frustules after multiple cell divisions.
Initial valves of Denticulopsis
criteria used for identifying initial valves in living populations.

According to Round et al. (1990) and other basic studies (e.g. Geitler, 1932, 1969, 1970; Ehrlich et al., 1982; Mann, 1982, 1984a, 1984b; Mann and Stickle, 1989; Mayama and Kobayashi, 1991), the initial valves are structured with a slightly modified morphology compared with the normal vegetative valves because, as they are produced beneath the auxospore wall, they are not subjected to the same constraints as the normal vegetative valves.

The modified morphologic features of the initial valves are as follows: (a) The initial valves form much more rounded morphologies than the valve shape of vegetative cells because they are moulded directly by the auxospore casing which originally has a strongly arched section. This rounded morphology is the most diagnostic feature of the initial valves in pennate diatoms (e.g. Mann, 1984b, Mayama and Kobayashi, 1991) and also in centric diatoms (e.g. Round, 1982). (b) In some raphid diatoms, the raphe of the initial valves is slightly different in location and morphology from that of the normal valves. Mann (1984b) reported that the initial epivalve of Rhóicosphénia curvata has much shorter and unequal raphe slits compared with vegetative valves. Mayama and Kobayashi (1991) noted a slightly shifted raphe slit of the initial valve in Eunotia arcus. (c) The perforation pattern of the initial valves is somewhat modified from that of the vegetative valves. Mayama and Kobayashi (1991) described slight modification of the perforation pattern on the initial valves of Eunotia arcus. (d) The initial valves often have a rather simple structure. (e) The initial valves are larger than any other vegetative valves because the size reduction by cell division starts from the initial cells.

These morphologic characteristics can be used as good criteria to distinguish the initial valves from the vegetative valves in both living and fossil assemblages, and they are in excellent agreement with the features of the Katahiraia and Yoshaidaia species.

The rounded valve surface of Katahiraia and Yoshaidaia agrees well with the most general feature of the initial valves. The central raphe of Katahiraia and Yoshaidaia can be explained as one of the structural modifications of the initial valves. The raphe on normal vegetative valve of Denticulopsis is located along the boundary between the valve face and the valve mantle. In the case of an initial valve, however, there is no constraint on the location of the raphe because the initial valve is rounded in cross section so that the valve face and mantle can not be distinguished. This may explain partly the reasons why the raphe of the initial valve is located in the valve center.

The perforation pattern on the valve surface of Katahiraia and Yoshaidaia can be also interpreted as one of modified morphology of the initial valves. Furthermore, the relatively large size of Katahiraia and Yoshaidaia species well coincides with the general morphologic nature of the initial valves. The extremely rare findings of Katahiraia and Yoshaidaia species are reasonably understood if these species are the initial valves.

The frustule composed of a Katahiraia-type epivalve and a Denticulopsis-type hypovalve (Figures 1-1, 1-4) can be considered to be a terminal cell of a colony chain, a heterovalvate cell consisting of an initial valve and a vegetative normal valve (Figures 5-H, 5-I).

In summary, the forms described as Katahiraia and Yoshaidaia species by Komura (1976) seem best considered as the initial valves of Denticulopsis species on the basis of morphology and stratigraphic data. However, other possibilities cannot not be precluded, because it is impossible, as Denticulopsis species are all extinct, to culture them and make them produce auxospores and initial cells.

Probable normal vegetative Denticulopsis
Initial valves

Katahiraia oblonga
K. pauperata

Denticulopsis hyalina
D. praehyalina
D. tanimuriae

Vegetative valves

Katahiraia aspera

Denticulopsis miocenica

Yoshidaia divergens
Y. constricta

Denticulopsis lauta
D. ichikawae

Yoshidaia loculata
Y. ? densicostata

Denticulopsis simonsenii
D. vulgaris

Figure 6. Relationship between the species of Katahiraia, Yoshidaia and Denticulopsis.

species corresponding to Katahiraia and Yoshidaia species are listed in Figure 6.

Katahiraia oblonga, K. pauperata or Katahiraia sp. may be the initial valve of Denticulopsis hyalina, D. praehyalina or D. tanimuriae, because all of them share the same morphologic features as well as nearly the same stratigraphic ranges. Similarly, K. aspera must be the initial valve of D. miocenica. Yoshidaia divergens or Y. constricta may be the initial valve of Denticulopsis lauta or D. ichikawae. They are all characterized by linear valve outline, single-layered perforation and the absence of secondary pseudosepta. Yoshidaia loculata or probably Y. ? densicostata may be the initial valve of Denticulopsis simonsenii or D. vulgaris.

In this study, I determined the initial valves corresponding to the eight Denticulopsis species listed in Figure 6, but those of the other Denticulopsis species including D. praedimorpha, D. dimorpha, D. ovata, D. praekatayamae and D. katayamae have not been encountered. This is probably due to extremely rare occurrence of the initial valves, and if so, they will be found through further thorough examination.

Since it is strongly suggested that the genera Katahiraia and Yoshidaia are the initial valves of Denticulopsis, the three genera should be taxonomically united to a single genus. The generic erection of the genus Katahiraia Komura (1976) predates Yoshidaia by Komura (1976) and Denticulopsis by Simonsen (1979), and therefore the epithet Katahiraia has priority under ICBN (Greuter et al., 1988). Thus, all Denticulopsis species should be transferred to the genus Katahiraia, but it is impossible to do this at present, because a one-to-one correspondence between Denticulopsis and Katahiraia-Yoshidaia species is unknown at the present except for the relationship between K. aspera and D. miocenica (Figure 6). For example, we are now aware that K. oblonga is probably the
initial valve of either *D. hyalina*, *D. prae-hyalina* or *D. tanimurae*. However, we cannot determine which species is the vegetative valve of *K. oblonga* because the initial valves of the three *Denticulopsis* species are presumed to have the same morphology. Detailed investigation of the type materials of *Katahiraia* and *Yoshidaia* species is required for the establishment of a one-to-one correspondence between these species, but I have not yet examined these materials. In this paper, therefore, the generic name *Denticulopsis* Simonsen is tentatively retained.

**Conclusion**

A combination of morphologic observation and stratigraphic study of the Miocene fossil diatom genera *Katahiraia* Komura and *Yoshidaia* Komura strongly suggests that they are the initial valves of the genus *Denticulopsis* Simonsen. These forms possess nearly the same morphology and stratigraphic ranges as the corresponding normal vegetative valves of *Denticulopsis*, but they differ in having the rounded valve face and the central raphe.

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**References**


964. Initial valves of Denticulopsis


Yukio Yanagisawa

Joban 常磐, Kushiro 鎷路, Shimokita 下北, Isohara 磯原, Chokubetsu 直別, Gamanosawa 藤野沢。

中新世絶滅珪藻 Denticulopsis 属の初生蓋殻: Katahiraia 属および Yoshidaia 属として記載された中新世の珪藻化石について，形態学的及び層序学的な研究を行った。その結果，これらは，Denticulopsis 属の初生蓋殻である可能性が高いことがわかった。この 2 つの属は，Denticulopsis 属に形態が非常に似ているが，蓋殻表面に丸みを帯びていること，縦溝が蓋殻の中央にあることによって，Denticulopsis 属とは区別される。こうした特徴は，珪藻類の初生蓋殻に見られる一般的な特徴によく合致する。また，Katahiraia 属および Yoshidaia 属の種の層序学的産出範囲は，対応する Denticulopsis 属の種のそれとよく一致する。

柳沢幸夫