Miocene Diatom Biostratigraphy of Onshore Sequences on the Pacific Side of Northeast Japan, with Reference to DSDP Hole 438A (Part 1)

著者	Maruyama Toshiaki
journal or publication title	The science reports of the Tohoku University. Second series, Geology = 東北大学理科報告. 地質学
volume	54
number	2
page range	141-A27
year	1984-03-30
URL	http://hdl.handle.net/10097/28848

Tohoku Univ., Sci. Rep., 2nd ser. (Geol.), v. 54, no. 2, p. 141-164, 6 figs., 8 tables, pls. 12-20, March 30, 1984

Miocene Diatom Biostratigraphy of Onshore Sequences on the Pacific Side of Northeast Japan, with Reference to DSDP Hole 438A (Part 1)*

Toshiaki Maruyama**

ABSTRACT

Taxonomic investigations of the genus *Denticulopsis* are attempted through observations aided by both optical and scanning electron microscopes. Species belonging to the genus *Denticulopsis* are classified into six groups on the basis of structure of the valve face and the presence or absence of secondary pseudosepta. A new taxonomic formulation is proposed in order to describe a diatom frustule and its components by taking representative *Denticulopsis* species. A comparative study of morphology of *D. praedimorpha* and *D. dimorpha* indicates that a structural difference of the connecting band provides the most easily recognizable character to differentiate these two species. Three trends in the morphological development of this genus are discussed. A new diatom species *Denticulopsis katayamae* is described and this species has been found to be useful for biostratigraphic studies of Miocene sequences of Northeast Japan.

CONTENTS

INTRODUCTION

Studies of diatom in the North Pacific region have progressed rapidly in recent years and have provided a powerful tool in establishing biostratigraphy of Neogene deposits (e.g. Schrader, 1973a; Koizumi, 1973a, 1975a, b, c, d, 1977a, 1980a; Burckle and Opdyke, 1977; Barron, 1980, 1981). For low latitudinal regions, diatom zonation proposed by Burckle (1972, 1977) has widely been accepted and for high latitudes that of Koizumi (1973a, 1975d, 1977a) has shown to be readily applicable. A correlation of several diatom events with paleomagnetic epochs has been attempted both in low (Burkle, 1972) and high latitudes (Donahue, 1970; Koizumi, 1975c, 1977b; Koizumi and Kanaya, 1976; Barron, 1980).

In the northwestern Pacific region, Koizumi (1975d, 1977a) has established a diatom zonal scheme for the Miocene to Quaternary interval. Independently, Akiba (1977a, 1979, 1982a, b, c) proposed his zonation on the basis of some new *Denticulopsis* species which were erected by himself. However, a correlation between these two zonations has shown to

---

* This work will be published in two parts. The first part largely contains taxonomic notes on the diatom genus *Denticulopsis*. A complete bibliography covering all the literatures referred to both in the first and second parts appears in the first part. The second part also in the *Science Reports* will include discussions on diatom biostratigraphy and correlation of Miocene sequences based on stratigraphically important diatom taxa.

** Department of Earth Sciences, College of General Education, Tohoku University, Sendai, 980 Japan.

be rather difficult because their zonations were initially established on the basis of a composite stratigraphic sequence.

The Japan Trench transect of the Deep Sea Drilling Project (Legs 56 and 57, 1977) has provided excellent reference sections for Miocene diatom biostratigraphy. Based on DSDP cores from Leg 57 Barron (1980) refined the diatom zonation of Koizumi (1973a, 1975d) for the Middle Miocene through Quaternary interval, and applied his refined zonation to Neogene sections in and off California (Barron, 1981 ; Keller and Barron, 1981 ; Poore *et al.*, 1981). Through works of these authors, Miocene diatom biostratigraphy is rapidly approaching to its completion for the North Pacific region.

The main purposes of this paper are :

1) Taxonomic evaluation of the genus *Denticulopsis* ;

2) Determination of the stratigraphic ranges of diatom species, paying a special attention to stratigraphic distribution of the genus *Denticulopsis* ;

3) Selection of diatom events useful for long-range correlation of Miocene sequences distributed on the Pacific side of northeast Honshu, Japan ;

4) Establishment of biostratigraphic zonation based on these events ;

5) Intra-regional correlation of the biostratigraphic sequences established for the Pacific side of northeast Japan ;

6) Correlation of the zones proposed by the present author with those of previous authors.

The present paper deals with Miocene sequences distributed in eight separate areas on the Pacific side of Northeast Honshu, Japan. These are : Sannohe, Ichinoseki, Sendai, Takahagi, Hitachi, Hitachiota, Nakaminato, and Usuitoge areas from north to south (Fig. 1), and the sequence recovered from DSDP Hole 438A during Leg 57 off Northeast Honshu, Japan. These areas are chosen because lithostratigraphy is well established and marine deposits yield diatoms nearly continuously.

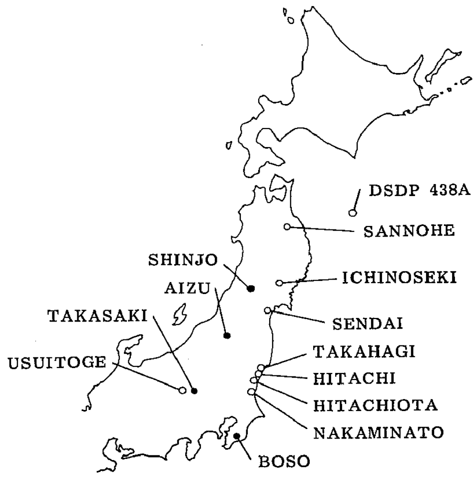


Fig. 1. Map showing the studied area. Open circles indicate discussed areas which yield plentiful diatoms. Black circles indicate undiscussed areas which yield poor diatoms.

In order to establish a correlation between Miocene marine deposits distributed on the Pacific side and those on the Japan Sea side, preliminary examinations were made by studying inland sedimentary basins of Shinjo (Sato, 1981MS), Aizu (Maruyama, unpublished data), and Takasaki (Takayanagi *et al.*, 1967). Marine deposits of these basins, however, yield diatom fossils so poorly that diatom biostratigraphy cannot be established (Fig. 1). Furthermore, a direct correlation of the diatom zones with calcareous microfossil zones was attempted by examining rock samples collected by Oda (1977) from the Boso Peninsula, but these samples yielded only rare and fragmental diatom specimens.

ACKNOWLEDGMENTS

The author expresses his deep appreciation to Professor Yokichi Takayanagi of the Institute of Geology and Peleontology, Faculty of Science, Tohoku University, for his critical reading of the manuscript and many helpful discussions. Deep appreciations are also expressed to Professor Kunihiro Ishizaki of the same institute for providing constructive criticism and helpful advice toward the manuscript.

The author is also much indebted to Dr. Taro Kanaya of Nikko Kanaya Hotel, Professor Jun Akutsu of Utsunomiya University, Dr. Itaru Koizumi of Osaka University, Mr. Fumio Akiba of the Japan Petroleum Exploration Company, Dr. John A. Barron of U.S. Geological Survey, Dr. Yoshihiro Tanimura of the National Science Museum, Tokyo, Mr. Yukio Yanagisawa of the Gelolgical Survey of Japan, and Professor Kankichi Sohma of Tohoku University for their helpful suggestions and valuable discussions concerning taxonomical and biostratigraphical problems. The author wishes to extend his thanks to Professor Tsunemasa Saito of Yamagata University for the improvement of the manuscript.

Sincere thanks are also extended to Professor Toyosaburo Sakai of Utsunomiya University, Professor Haruyuki Takahashi, Professor Kazuo Amano, both of Ibaraki University, Dr. Takaaki Fukudome of Akita University, Professor Michio Kato of Kanazawa University, and Mr. Hiroyuki Tanaka of the Gumma Prefectural Museum of History for providing important rock samples and geological information.

The author wishes to thank Professor Nobu Kitamura, Dr. Motoyoshi Oda, and Dr. Shiro Hasegawa, all of the Institute of Geology and Paleontology, Faculty of Science, Tohoku University for providing helpful suggestions and valuable discussions. Acknowledgments are due to Mr. Shohei Otomo of the same institute for his assistance in photographic works.

Core samples of the Deep Sea Drilling Project, Leg 57 Site 438 Hole 438A were made available for this study through the assistance of the U.S. National Science Foundation.

METHODS

Cleaning and preparation of slides

Samples (about 1.0 g each) from dried sediment cores and sedimentary rocks (about 5.0 g) from land exposures are placed in an oven for 12 hours at 60℃ of temperature. Then, those sediment samples are placed in a 200 ml beaker, and a 50 ml boiling hydrogen peroxide solution (H_2O_2, 15%) is added. The peroxide will disaggregate those sediment samples into small pieces and oxidize organic material. The peroxide-immersed sample is then boiled for about 20 minutes until all effervescence stops. A 10 ml hydrochloric acid solution (HCl, 10%) is then added to dissolve any carbonates present in the samples and boiling is resumed for about 20 minutes.

Upon cooling, the beaker is filled with distilled water. After 10 seconds, clastic grains and volcanic glass will settle on the bottom of the beaker. All the suspended matters will be separated for diatom analysis. The beaker containing the suspended matters is kept at room temperature for 3 hours. Water with an excess acid solution and suspended clay minerals is decanted off, and the residue is re-stirred with addition of distilled water. The procedure of stirring and decanting off suspended matters is repeated at least 10 times.

The sodium pyrophosphate method is not adopted in order to prevent smaller diatom valves from dissolution. The final residue is diluted with distilled water to make a 10 ml volume and stored in a plastic vial.

The vial is shaken carefully, and out

of the middle of the vial a few drops are taken by using a straw and they are diluted moderately with addition of distilled water in a test tube. Out of that split about 0.5 ml is obtained by the same straw, placed on a cover glass of 18×24 mm, and dried on a hot plate at 50℃. Three subsamples are prepared from each sample. After drying, three drops of Pleurax dissolved in methyl alcohol are added onto the cover glass, which is then heated for a few minutes at a temperature of 100℃. Finally, the cover glass is carefully mounted on a slide.

Identification and counting

Counts are made on each slide using a 100× oil immersion objective and a 15× eyepiece. This optical set allows a microscopical field measuring 150 μm in diameter. Some traverses are laid across the middle of the cover glass and every diatom valve retaining more than half of a valve is counted as a specimen. Specimens of such pennate diatoms as *Denticulopsis*, *Thalassionema* and *Thalassiothrix* are counted as one specimen when a complete valve or a set of two broken polar ends are found. No count was made on resting spores. All the diatom species encountered along an optical traverse are identified and counted until a total of 200 valves or more are identified.

Frequencies of various taxa in a given sample are plotted in the distribution charts. Estimates for diatom preservation are made by considering the degree of destruction and dissolution of valves, and are expressed as follows ; G for good, M for moderate, P for poor and DP for dissolved poor. Overall abundances are expressed by the number of traverses made to examine up to 200 specimens, or by such index letters as A (abundant; more than 100 specimens per traverse), C (common ; less than 100 specimens per traverse) and R (rare ; several specimens per traverse).

Inarticulated components of the frustules of *Denticulopsis praedimorpha* and *D. dimorpha* are separately counted and presented in Tables 3-8.

TAXONOMIC NOTES ON THE DIATOM GENUS *DENTICULOPSIS*

Six groups of *Denticulopsis*

Many species have been proposed since Simonsen and Kanaya (1961) made their taxonomic investigations of the genus *Denticula* and clarified biostratigraphic significance of several marine species assigned to this genus. Later Simonsen (1979) transferred marine planktonic species from that genus to his new genus *Denticulopsis*, in which he recognized 15 taxa. Since then, various workers proposed additional taxa for this genus.

Akiba (1977a, 1979) proposed, though invalidly, four species of *Denticulopsis*, namely *D. ikebei*, *D. kanayae*, *D. paranicobarica*, and *D. praedimorpha*. The last named species was recently validated by himself (Akiba, 1982b). Barron (1980) carefully distinguished *D.* cf. *kamtschatica* from *D. kamtschatica* s.s. in the material from DSDP Leg 57 off northeast Japan. Koizumi in Takayama *et al.* (1979) informally named *D. praelauta* for forms occurring before the first appearance of *D. lauta* in the Noto Peninsula, Japan. Barron (1980) and Akiba (Akiba *et al.*, 1982a, b) also paied attention to the same form which precedes *D. lauta* s.s. and called it *D.* cf *lauta* and *D.* sp. A, respectively.

In the present study, two forms *D. hustedtii* (elliptical form) and *D. nicobarica* var. 1, are found to be distinct from other known taxa. The former differs from *D. hustedtii* s.s. in the disparity of the ratio between length and width, and the latter is discriminated from *D. nico-*

Table 1. List of all taxa belonging to the genus *Denticulopsis*

SIMONSEN (1979)
1. *D. dimorpha*
2. *D. hustedtii*
3. *D. hustedtii* var. *ovata*
4. *D. hyalina*
5. *D. kamtschatica*
6. *D. lauta*
7. *D. lauta* var.*ovata*
8. *D. maccollumii*
9. *D. miocaenica*
10. *D. nicobarica*
11. *D. norvegica*
12. *D. punctata*
13. *D. punctata* f. *hustedtii*
14. *D. seminae*
15. *D. seminae* f. *fossilis*

AKIBA (1977a, 1979, 1982b)
16. *D. ikebei*
17. *D. kanayae*
18. *D. paranicobarica*
19. *D. praedimorpha*

MARUYAMA (this paper)
20. *D. katayamae* n. sp.
21. *D. hustedtii* (elliptical form)
22. *D. nicobarica* var. 1

23. *D. praelauta* Koizumi; Takayama *et al.*, 1979
23'. *D.* cf. *lauta* Barron, 1980
23". *D.* sp. A Akiba; Akiba *et al.*, 1982a, b

24. *D.* cf. *kamtschatica* Barron, 1980

barica s.s. by the presence of secondary pseudosepta. Furthermore, *D. katayamae* is newly proposed.

Thus, at present the genus *Denticulopsis* holds 24 taxa including 16 formally described, four invalidly proposed, one new and three taxa under consideration. These taxa are summarized in Table 1.

By considering the valve face characters and taking into account the absence or presence of secondary pseudosepta, the present author classifies 24 taxa of the genus *Denticulopsis* into six species groups (Table 2).

Short explanations for each of the groups are given below and the group name comes from the most typical taxon present.

1. *Denticulopsis katayamae* group: Represented by *D. katayamae* only, characterized by the hyaline valve face and the presence of secondary pseudosepta.
2. *Denticulopsis hyalina* group: Characterized by the hyaline valve face and the absence of secondary pseudosepta.
3. *Denticulopsis hustedtii* group: Characterized by the finely punctate valve face and the presence of secondary pseudosepta. *D. hustedtii* is the generotype (Simonsen, 1979).
4. *Denticulopsis lauta* group: Characterized by the finely punctate valve face and the absence of secondary pseudosepta.
5. *Denticulopsis punctata* forma *hustedtii* group: Characterized by the coarsely punctate valve face and the presence of secondary pseudosepta.
6. *Denticulopsis nicobarica* group: Characterized by the coarsely punctate valve face and the absence of secondary pseudosepta.

With regard to Table 2, some discussions will be helpful to clarify views expressed by previous authors.

Table 2. Classification of the genus *Denticulopsis*

valve face secondary pseudosepta	hyaline	punctate	
		finely	coarsely
present	*D. katayamae*	*D. hustedtii* *D. hustedtii* var. *ovata* *D. hustedtii* (elliptical form) *D. seminae* *D. seminae* f. *fossilis*	*D. punctata* f. *hustedtii* *D. nicobarica* var. 1
absent	*D. hyalina* *D. maccollumii*	*D. lauta* *D. lauta* var. *ovata* *D. miocaenica* *D. dimorpha* *D. praedimorpha* *D. praelauta* (*D.* cf. *lauta*, *D.* sp. A) *D. kamtschatica* *D.* cf. *kamtschatica*	*D. punctata* *D. nicobarica* *D. paranicobarica* *D. ikebei* *D. kanayae* *D. norvegica*

(1) Simonsen and Kanaya (1961) and Schrader (1973b) pointed out that, in some instances, *D. kamtschatica* develops short secondary pseudosepta. Since their claims have not been documented by later wokers, however, it seems reasonable to include *D. kamtschatica* into the *D. lauta* group.

(2) On the basis of descriptions made by McCollum (1975) and Schrader (1976), *D. maccollumii* is included in the *D. hyalina* group, though the present author has so far had no chance of making direct examination of the species.

Formulation of *Denticulopsis* morphologies

A diatom frustule consists basically of two thecae, an epitheca and a hypotheca. A theca is divided into two components, valve and cingulum. The combination of an epicingulum and a hypocingulum is known as a girdle. The relationship of these components can be expressed by the following formulas.

Diatom frustule
=epitheca+hypotheca
=(epivalve+epicingulum)
+(hypocingulum
+hypovalve) ....(1)
=epivalve+girdle+hypovalve

A frustule of the genus *Denticulopsis* is similarly formulated within the limits set forth by the present investigation aided by optical and scanning electron microscopes. Furthermore, it should be noted that a cingulum of *Denticulopsis* theca consists of a single connecting band (Simonsen, 1979; Akiba, 1982b). Consequently, the following equation can be derived from the above-mentioned equation (1).

Denticulopsis
=epivalve+epi-connecting band
+hypo-connecting band
+hypovalve..............(2)

It is impossible, however, to discriminate the epi-component from the hypo-component in practice, because each component usually occurs as a disarticulated specimen. Even if an articulated frustule is present in fossil assemblages, it is not possible to differentiate them with the aid of a light microscope. Therefore, a realistic equation will be written as follows (Figs. 2, 3).

Denticulopsis
=valve+connecting band
+connecting band+valve
=V+B+B+V ....(3)

If the forms of septum and connecting band and ornamentation on the thecal junction are emphasized during the modeling of a frustule, the equation (3) will be reformulated as follows.

Denticulopsis
=Vx+By /z/ By+Vx ......(4)

where x is the form of septum, y is the form of connecting band, and /z/ is ornamentation on the thecal junction.

Some representative species of the genus *Denticulopsis* are expressed by using this equation (4) as follows:

D. katayamae
=Vt+Boo /s/ Boo+Vt
D. hustedtii
=Vt+Boo /s/ Boo+Vt
D. hyalina
=Vt+Boo /s/ Boo+Vt

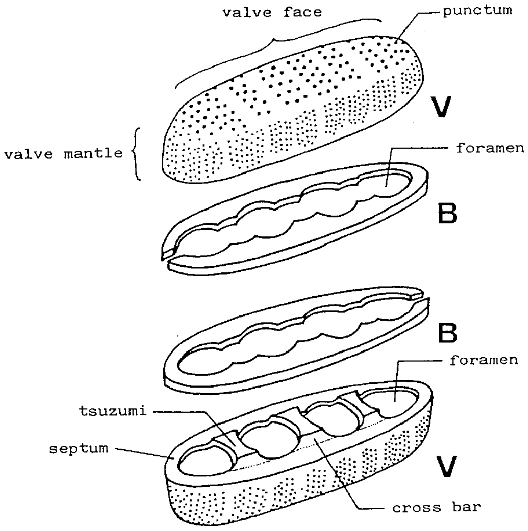


Fig. 2. Schematic drawing of components of *Denticulopsis* frustule.
V: valve, B: connecting band.

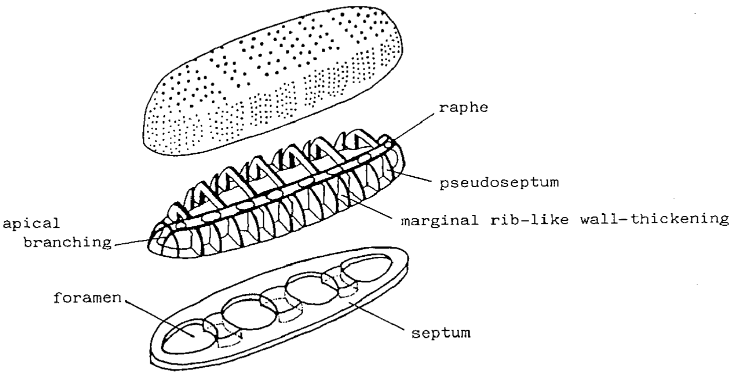


Fig. 3. Schematic drawing of valve of *Denticulopsis*.

D. lauta
=Vt+Boo /s/ Boo+Vt
D. nicobarica
=Vt+Boo /s/ Boo+Vt
D. praedimorpha (isovalvate)
=DVt+DBco /s/ DBco+DVt
(general case)
=DVt+DBco /w/ DBco+DVt
(very rare case)
D. praedimorpha (heterovalvate)
=DVt+DBco /d/ SB+SVs
D. dimorpha (isovalvate)
=DVn+DBcc /s/ DBcc+DVn
D. dimorpha (heterovalvate)
=DVn+DBcc /d/ SB+SVs

where the type of valve (V) is expressed as follows:

Vt: valve with a septum bearing tsuzumis*
Vs: valve with a septum bearing no tsuzumis
Vn: valve without a septum
DV: deeper valve of deeper theca
SV: shallower valve of shallower theca

where the form of connecting band (B) is expressed as follows:

Boo: open connecting band with open foramina
Bco: closed connecting band with open foramina
Bcc: closed connecting band with closed foramina
DB: deeper connecting band of deeper theca
SB: shallower connecting band of shallower theca

where ornamentation on thecal junction (/ /) is expressed as follows:

/s/: solid line
/d/: dotted line
/w/: wavy line

However, the *D. nicobarica* and *D. punctata* var. *hustedtii* groups are not examined in detail in this study. A review of the formulas thus obtained will lead to the following conclusions:

(1) *D. katayamae*, *D. hustedtii*, *D. hyalina*, *D. lauta*, and *D. nicobarica* produce isovalvate frustules only. The structure of these frustules is basically the same in all of these species (Fig. 4).

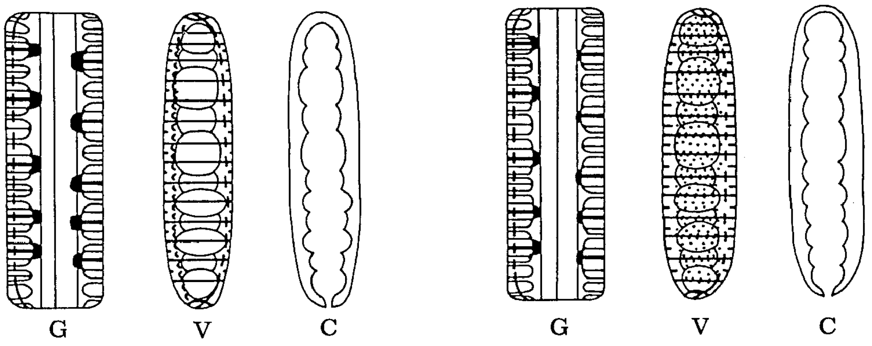
(2) *D. praedimorpha* and *D. dimorpha* produce both isovalvate and heterovalvate frustules from deeper thecae and shallower thecae (Figs. 4, 5). The deeper thecae of these two species have a very similar appearance, but differ structurally as discussed in the next paragraph. The structure of their shallower thecae is also presumed to be the same in these two species, though the structure of the shallower connecting bands has yet to be examined in detail.

Comparative morphology of *D. praedimorpha* and *D. dimorpha*

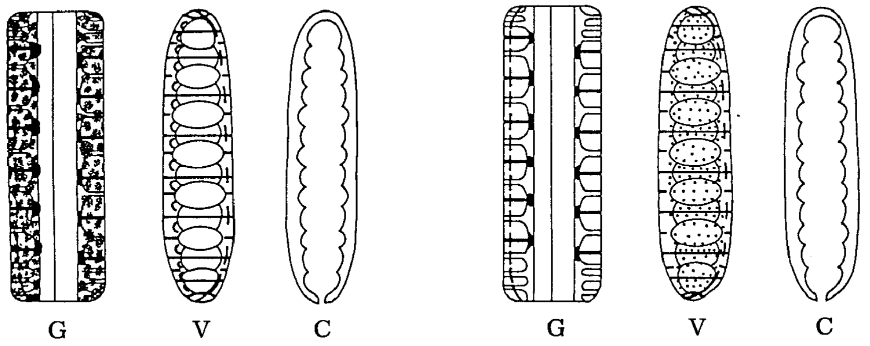
The purpose of this paragraph is to

---

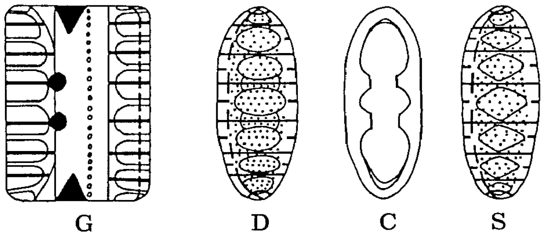
* See definition given on p. 150.



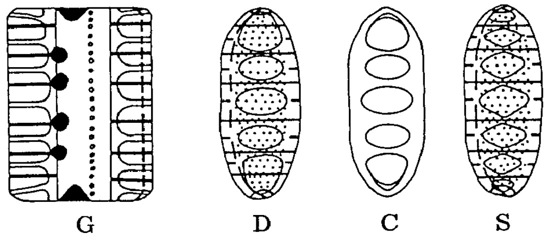
D. *katayamae* D. *hustedtii*



D. *hyalina* D. *lauta*



D. *praedimorpha*



D. *dimorpha*

Fig. 4. Schematic drawing of some *Denticulopsis* species. G ; frustule in girdle view. V ; valve bearing septum in valve view. C ; connecting band in valve view. D ; deeper valve bearing septum in valve view. S ; shallower valve bearing septum in valve view.

describe in detail comparative morphology between *D. praedimorpha* and *D. dimorpha*. These two species had been identified as *D. lauta* until Schrader (1973a, b) proposed a new species *D. dimorpha*. Recently, Akiba (1979, 1982b) separated *D. praedimorpha* from *D. dimorpha* by emphasizing a stratigraphic significance of his species. Koizumi (1982) pointed out that the taxonomic definition of these two species is vague, although they are very important

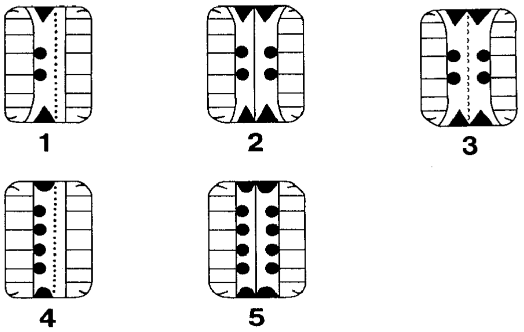


Fig. 5. Variations in frustules of *D. praedimorpha* and *D. dimorpha*.

1, 2, 3. *Denticulopsis praedimorpha*
- 1, heterovalvate frustule with dotted thecal junction.
- 2, isovalvate frustule with straight thecal junction.
- 3, isovalvate frustule with wavy thecal junction.

4, 5. *Denticulopsis dimorpha*
- 4, heterovalvate frustule with dotted thecal junction.
- 5, isovalvate frustule with straight thecal junction.

speces for establishing diatom biostratigraphy in the North Pacific.

(1) Valve

a. Valve face : No clear distinction is present between *D. praedimorpha* and *D. dimorpha*. Transapical striae are finely punctate. Puncta seem to arrange in quincunx in light microscope (LM) observations. Scanning electron microscope (SEM) observations show that the puncta are irregularly dispersed on the valve face, but they tend to arrange in transapical rows. There is no regularity in the arrangement of transapical rows. The valve face is hyaline on every pseudoseptum.

b. Valve mantle : No clear distinction is present between these two species. The valve mantle is a meshwork consisting of very fine puncta. Puncta are closely packed between pseudosepta. The surface of pseudoseptum and valve mantle on the valvar suture side is hyaline and smooth.

c. Edge of valve face/valve mantle : Edge is hyaline and smooth in these two species.

d. Pseudoseptum : The primary pseudosepta are present, but the secondary pseudosepta are absent in these two species. An apical pseudoseptum located between the apex and primary pseudoseptum on the most apical side, is distinguished herein for the first time. The apical pseudosepta appear to traverse the apical foramen of the connecting band, when the deeper theca is examined with an optical microscope in a valve view position. It should be pointed out that the deeper valve of *D. praedimorpha* has two apical pseudosepta at each apex, although Akiba (1982b) regarded them to be the secondary pseudosepta. The secondary pseudosepta as used in this work denote those between the two primary pseudosepta. The deeper theca of *D. dimorpha* has an apical pseudoseptum at each apex. The shallower valves of both *D. praedimorpha* and *D. dimorpha* generally have no apical pseudoseptum. The presence of apical pseudosepta is confirmed in *D. hustedtii*, *D. katayamae*, *D. hyalina*, and *D. lauta* as well.

e. Marginal rib-like wall-thickening : These two species have a marginal rib-like wall-thickening between the pseudosepta of the deeper and shallower valves. Marginal ribs are easily distinguishable in LM observations, but are puzzled during SEM observations because of the hindrance by a septum in inner valve view.

f. Raphe : The raphe is present beneath the valve wall, along the valve face edge both in *D. praedimorpha* and *D. dimorpha*. The raphe is easily distinguishable in LM observations, but is hardly visible in SEM observations due to the presence of septum in inner valve view. The structure of raphe could not be determined precisely in this study. The raphe branches out at each apex. The branching-out part of the raphe is named apical branching in the present paper. The presence of the apical branching is confirmed in *D. hustedtii*, *D. katayamae*, *D. hyalina*, and *D. lauta* as well (Fig. 3).

(2) Septum

It is difficult in LM observations to grasp structural details of septum. From SEM observations of the inner valve view, however, it is concluded that there is a clear-cut distinction between the septa of these two species in regard to the presence or absence of tsuzumi, a new term for diatom morphology.

Tsuzumi (pl. tsuzumis) : A siliceous process with a smooth surface is well visible on the cross bar in inner valve view SEM observations (Fig 2). The function of the tsuzumis is to couple the septum to a connecting band. An outline of tsuzumi in valve view is similar to a bow tie or a hourglass. In LM observations, a tsuzumi would appear in silhouette in valve view in the form of a bow tie. The spacing of tsuzumis corresponds to that of primary pseudosepta in all the species belonging to the genus *Denticulopsis*. The term tsuzumi is adopted from the outline of a hand-drum, traditional percussion instrument in Japan.

a. Septum of *D. lauta* : The tsuzumis occur on all the cross bars. Subelliptical foramina are bound by two cross bars. A frustule of *D. lauta* has two septa having an identical form. Such species as *D. katayamae*, *D. hustedtii*, *D. hyalina*, and *D. nicobarica* all possess two septa having the same structure.

b. Septum of *D. praedimorpha* : Both deeper and shallower thecae have septa of a peculiar outline. The tsuzumis are present on a septum of the deeper valve. If two tsuzumis are present on both sides of a central foramen, cross bars having no tsuzumis will appear directly opposite to apical pseudosepta. When a septum develops more than four tsuzumis, such a septum would hold cross bars always bearing tsuzumis. Therefore, apical pseudosepta seem to traverse apical foramina. A septum of the shallower valve possesses cross bars and subelliptical foramina, but bears no tsuzumis.

c. Septum of *D. dimorpha* : The deeper theca of *D. dimorpha* develops no septum, although the possession of the septum is one of the most characteristic feature of the genus *Denticulopsis*. The shallower valve has a septum bearing no tsuzumis as was the case of the shallower valve of *D. praedimorpha*. Accordingly, there is no morphological basis to distinguish the shallower valve of *D. dimorpha* from that of *D. praedimorpha*.

(3) Connecting band

The connecting bands of *D. lauta*, *D. praedimorpha* and *D. dimorpha* are easily distinguished by their distinct morphological characteristics.

a. Connecting band of *D. lauta* : The connecting band is weakly silicified and open at one end. Cross bars or teeth-like extensions are not present, so that foramina are connected to form one open space (Fig. 4). These features are common to the connecting bands of *D. katayamae*, *D. hustedtii*, and *D. hyalina*.

b. Connecting band of *D. praedimorpha* : The connecting band of the deeper theca is closed, strongly silicified, thick and well developed. Some pairs of the teeth-like extensions (Akiba, 1982b) are present in a transapical direction. The arrangement of these pairs corresponds to that of the tsuzumis. At both apices, inner protuberances are present and show up well as triangular silhouettes in the girdle view of LM observations. Elliptical foramina are connected with each other. Apical foramina are bigger than other more-centrally located foramina. The margin of the connecting band which face another connecting band is either flat or pleated. This character has an important bearing upon the appearance of thecal junction in transmitted light. The morphology of the connecting band of the shallower theca has not been studied in detail. According to Akiba (1982b), the connecting band of the shallower theca is open with a row of distinct puncta along its margin facing another connecting band.

c. Connecting band of *D. dimorpha* : The connecting band of the deeper theca is closed, heavily silicified, thick and well developed. Some cross bars are present in a transapical direction, and their arrangement correponds to that of the primary pseudosepta. At both apices, inner protuberances are present, well seen as semicircular silhouettes in the girdle view of LM observations. Elliptical foramina are closed between cross bars (Fig. 4). Two apical foramina are present. The margin of the connecting band facing another connecting band is either flat or wavy. This character has an important bearing upon the appearance of thecal junction in transmitted light. The connecting band of shallower theca is not morphologically studied in detail. Taking all the results of LM observations into consideration, the connecting band of the shallower theca appears to have the same structure as that of *D. praedimorpha*.

(4) Spots along valvar suture in girdle view.

In the deeper theca of both *D. praedimorpha* and *D. dimorpha*, some black spots are visible along the valvar suture in girdle view (Figs. 4, 5). In *D. praedimorpha*, the spot is actually a silhouette formed by the combination of both a tsuzumi and a pair of teeth-like extensions of the connecting band. On the other hand, in *D. dimorpha*, one black spot is a silhouette of one cross bar of the connecting band, because the septum is not present in the deeper valve.

In some cases, smaller spots are visible further out of a row of the black spots. In *D. praedimorpha*, this smaller spot is a silhouette of both a rudimentary tsuzumi and a undergrown teeth-like extension. In *D. dimorpha*, this smaller spot is a silhouette of a rudimentary cross bar of the connecting band.

Some black spots are also visible along the valvar suture in the girdle view in *D. hustedtii*, *D. katayamae*, *D. hyalina*, and *D. lauta* (Fig. 4). These are silhouettes of both the connecting bands and tsuzumis.

Variations in the deeper thecae of *D. praedimorpha* and *D. dimorpha*

This paragraph intends to establish variations in the structure of the deeper thecae of both *D. praedimorpha* and *D. dimorpha* and to investigate their stratigraphic distributions in DSDP Hole 438A and the Sannohe area.

1. Successive variations

Considering all the characters observed by using a light microscope, it is clear that the deeper thecae and their elements can be arranged according to the number of intervals between pseudosepta and the number of foramina in the connecting bands excluding apical foramina.

(1) General cases

The deeper theca and its components can be expressed by the following terms.

Bm-type : connecting band bears m foramina in the valve view except for apical foramina.

Gm-type : deeper theca possesses Bm-type connecting band as seen in girdle view.

Vn-type : valve develops n intervals between pseudosepta in the valve view. In *D. dimorpha*, n is the number of all the intervals present between primary pseudosepta. In *D. praedimorpha*, n is the total number of intervals present between all the pseudosepta.

Both m and n are natural number.

The relation of these terms can be expressed in the following equation :

$$\mathrm{G}m=\mathrm{V}n+\mathrm{B}m$$

In *D. praedimorpha*, the relation between m and n is generally written as,

$$n=m+4$$

and in some cases (e.g. Pl. 19, fig. 9), as

$$n=m+2$$

In *D. dimorpha*, this relation is

$$n=m$$

(2) Particular cases

If the rudimentary cross bars or rudimentary teeth-like extensions are present in the deeper connecting band, the deeper theca and connecting band can expressed as follows, although the valve as seen in valve view can be written by the Vn-type equation.

Bma-type : connecting band develops m foramina and a rudimentary cross bar, or one or two rudimentary teeth-like extensions at either apex (e.g. Pl. 18, figs. 9, 15, 16).

Bama-type : connecting band develops m foramina and a rudimentary cross bar, or one or two rudimentary teeth-like extensions at each of the apices (e.g. Pl. 18, figs. 22, 23, 24).

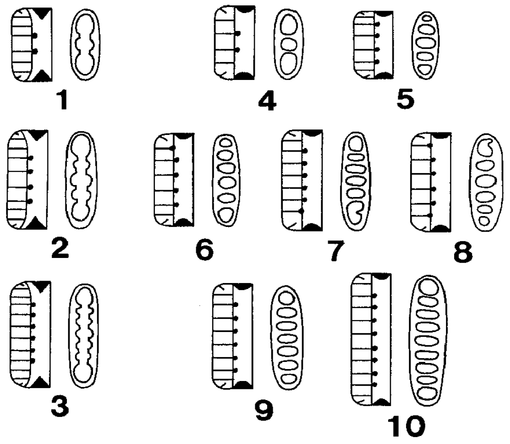
Gma-type : deeper theca possesses Bma-type connecting band as seen in girdle view.

Gama-type : deeper theca possesses Bama-type connecting band as seen in girdle view.

For a precise modeling of the deeper theca of *D. praedimorpha*, the structure of septum must be clarified and expressed by similar terms to those used for other components. However, further studies are required to elucidate combinations of all the components.

2. Combination of the deeper valve and deeper connecting band

Results of observations during the course of this study, as described above, are summarized in Fig. 6. In every sketch of Fig. 6, the deeper theca as seen in girdle view is drawn to the left, and the deeper connecting band as seen in valve view to the right. Combinations of the deeper valve and deeper connecting band can be seen in each sketch. A few examples will be given to provide a better understanding.



	LEFT	RIGHT	
	a deeper theca in girdle view	a connecting band in valve view	species
1	G1-type	B1-type	*D. praedimorpha*
2	G3-type	B3-type	
3	G5-type	B5-type	
4	G1-type	B1-type	*D. dimorpha*
5	G3-type	B3-type	
6	G3a-type	B3a-type	
7	G4a-type	B4a-type	
8	Ga3a-type	Ba3a-type	
9	G5-type	B5-type	
10	G7-type	B7-type	

Fig. 6. Variations in the deeper thecae of *D. praedimorpha* and *D. dimorpha*.

Sketch 2 in Fig. 6 : The deeper theca of *D. praedimorpha* as seen in girdle view has four black spots along the valvar suture (left-hand side). From this character, it is judged that this specimen has four tsuzumis in its septum, seven intervals between pseudosepta, and contains a connecting band bearing three foramina except for apical foramina (right-hand side). Therefore, this deeper theca as seen in girdle view is named G3-type, and the deeper connecting bands B3-type. The deeper theca as observed in valve view is named V7-type.

Sketch 5 in Fig. 6 : The deeper theca of *D. dimorpha* as seen in girdle view has four black spots along the valvar suture (left-hand side). From this character, it is judged that this specimen has four primary pseudosepta and one apical pseudoseptum at each apex, and contains connecting band bearing three foramina excluding apical foramina (right-hand side). Therefore, this deeper theca as seen in girdle view is called G3-type, and the deeper connecting band B3-type. The deeper theca as observed in valve view is called V3-type.

Sketch 6 in Fig. 6 : The deeper theca of *D. dimorpha* as seen in girdle view has four black spots and a smaller spot along the valvar suture (left-hand side). From this character, it is judged that this specimen has four primary pseudosepta and one rudimentary pseudoseptum, and contains connecting band bearing four cross bars and one weakly silicified cross bar (right-hand side). Therefore, this deeper theca as seen in girdle view is named G3a-type, and the deeper connecting band B3a-type. The deeper theca as observed in valve view is named V4-type.

Sketch 8 in Fig. 6 : The deeper theca of *D. dimorpha* as seen in girdle view has four black spots and two smaller spots along the valvar suture (left-hand side). From this character, it is judged that this specimen has four primary pseudosepta and two rudimentary pseudosepta, and contains connecting band bearing four cross bars and two rudimentary cross bars (right-hand side). Therefore, this deeper theca as seen in girdle view is called Ga3a-type, and the deeper connecting band Ba3a-type. The deeper theca as observed in valve view is called V5-type.

3. Stratigraphic distribution of variations

The stratigraphic distribution of each variation type of *D. praedimorpha* are examined in DSDP Hole 438A (Table 3) and the Kawaguchi section in the Sannohe area (Table 4). The same variation in *D. dimorpha* are studied in DSDP Hole 438A (Table 5), and the Shitazaki section (Table 6) and the Yachizawa section (Table 7), both in the Sannohe area.

As a matter of fact, it is a time-consuming task to distinguish a deeper valve from a shallower valve in valve view. Therefore, both the deeper and shallower valves are counted in making no distinction and expressed as the same term of

Table 3. Biostratigraphic distribution of *Denticulopsis praedimorpha* in DSDP Hole 438A, core 66 through core 62

CORE		66	65	65	65	64	64	64	62
		1	5	3	1	5	3	1	1
INTERVAL		118	18	100	54	30	10	10	20
		122	21	103	56	32	14	14	24
Denticulopsis praedimorpha	Akiba								
Connecting band	B1	40	6	40	73	79	87		
	B1a			5	5	10	3		
	B3	4	4	64	53	15	26		2
	B3a			7	1	1			
	B5	1	2	12	1	1	1		
	B fragment	17		58	66	43	35		
	total	62	12	186	199	149	152		2
Girdle view	G1	19	6	38	36	24	37		
	G1a			2	4	2			
	G3	7	1	70	18	5	5		
	G3a			2					
	G5		1	3	3				
	G7			2					
	G fragment	1	1	10	20	5	7		
	total	27	9	127	81	36	49		
Valve view	V3	59	6	47	28	16	14	1	
	V4	1		7	1				
	V5	13	5	97	52	32	26		
	V7		1	17	1	3	2		
	V8			1					
	V fragment	37	4	117	59	36	40		2
	total	110	16	286	141	87	82	1	2
TOTAL		199	37	599	421	272	283	1	4

Table 4. Biostratigraphic distribution of *Denticulopsis praedimorpha* in the Kawaguchi section, Sannohe area

FORMATION		TOMESAKI FORMATION									
MEMBER		JUMONJI SANDSTONE MEMBER									
SAMPLE		KWG 3	KWG 4	KWG 5	KWG 6	KWG 7	KWG 8	KWG 9	KWG 10	KWG 11	KWG 12
Denticulopsis praedimorpha	Akiba										
Connecting band	B1		1	1		5			15	7	
	B3				3	5	9	7	4		
	B4						1				
	B fragment		1		2	1		1	6	1	
Girdle view	G1							10	31		
	G1a		1			2					
	G3		1					1			
	G3a							1	1		1
	G4							4	2		
	G5			1							
	G fragment							4	3	1	2
Valve view	V2							1	1		
	V3	2	2	2	4	8	12	13	13	5	
	V5	1	2			4		6	12	2	
	V7			1				11	2	2	
	V fragment			4	5	4	2	38	20	4	
TOTAL		3	8	9	14	29	24	97	110	22	3

Table 5. Biostratigraphic distribution of *Denticulopsis dimorpha* in DSDP Hole 438A, core 59 through core 56

C O R E		59	59	59	58	57	57	56	56	56
		5	4	1	1	3	2	6	3	1
I N T E R V A L		17	17	17	16	31	31	20	20	20
		21	21	21	20	35	35	24	24	24
Denticulopsis dimorpha (Schrader) Simonsen										
Connecting band	B1	3			1	2	7	3		
	B1a	1					4	2	2	
	B2a	1								
	B3	10	3	3	7	12	20	17	16	1
	B3a	3	3	2		1	3	10	2	
	Ba3a	1								
	B4a	1				2	8	23	1	
	B5	10	4	7	13	7				
	B5a				2	1	1	2		
	B6			1	1			3		
	B6a						1			
	B7	3			3	1	4	4		
	B7a							1		
	B8						1			
	B fragment	9	12	12	20	27	36	55	15	
	total	42	22	25	47	53	85	120	36	1
Girdle view	G1	2		1			3	1		
	G1a							2		
	G3	3		2		5		7	3	
	G3a			1		3		1	1	
	G4						1			
	G4a							1		
	G5	6	3	2	4	7	4	5		
	G5a						1	2		
	G7						3			
	G7a		1							
	G9	2								
	G fragment	2	3	3	3		6	8	2	
	total	15	7	9	7	15	18	27	6	
Valve view	V3	1	2		2	3	4	5	2	1
	V4	1								
	V5	8	8	1	5	3	3	5	2	
	V6	2	1	1						
	V7	4	1	4	2	1	1	7		
	V9				1					
	V fragment	4	4	7	16	10	13	26	4	2
	total	20	16	13	26	17	21	43	8	3
T O T A L		77	45	47	80	85	124	190	50	4

Table 6. Biostratigraphic distribution of *Denticulopsis dimorpha* in the Shitazaki section, Sannohe area

F O R M A T I O N		SHITAZAKI FORMATION								
M E M B E R		KAMIME	SHITAZAKI SILTSTONE MEM.							
S A M P L E		STZ 17	STZ 18	STZ 19	STZ 20	STZ 21	STZ 22	STZ 23	STZ 24	STZ 25
Denticulopsis dimorpha (Schrader) Simonsen										
Connecting band	B1	3	5	4	2	4			3	1
	B1a		3	1		4	2	1	3	
	B a1a		1		1					
	B2a					1				
	B3	10	17	8		10	2	9	10	5
	B3a	1	4			2	2		1	2
	B4a		1					1		
	B5	8	11	4		1	4		1	1
	B5a		1							
	B6			1						
	B6a			1						
	B a6a								1	
	B7	1	3	5			2			
	B7a		1							
	B fragment	16	33	39	5	27	26	9	29	29
Girdle view	G1		2	2			2		2	2
	G1a								1	
	G3	1	3	4		2	2	2	5	2
	G3a							1		
	G4a	1								
	G5		10	10	1			3	4	3
	G5a			2						
	G6a			1						
	G7		5	2						
	G8		1							
	G fragment	1	11	5	7	5	3		4	8
Valve view	V3	1	4	1	1	1	2	3	11	
	V5		5	2	3	1	1	1	3	2
	V7		3	4		1				
	V8			1					1	
	V9		1							
	V fragment	1	51	31	8	9	16	7	13	13
T O T A L		44	176	128	28	68	64	37	92	68

KAMIME : Kamimetoki Sandstone Member

V*n*-type. Their stratigraphic distributions are constructed on the basis of observations of the connecting bands as seen in valve view and the deeper thecae as seen in girdle view.

The stratigraphic distribution of reworked specimens of *D. praedimorpha* and *D. dimorpha* is investigated in DSDP Hole 438A (Table 8). It also constitutes a work which takes long time

Table 7. Biostratigraphic distribution of *Denticulopsis dimorpha* in the Yachizawa section, Sannohe area

FORMATION		SHITAZAKI FORMATION												
MEMBER		KA	SHITAZAKI SILTSTONE MEMBER											
SAMPLE		YAC 14	YAC 13	YAC 12	YAC 11	YAC 10	YAC 9	YAC 8	YAC 7	YAC 6	YAC 5	YAC 4	YAC 3	YAC 2
Denticulopsis dimorpha (Schrader) Simonsen														
Connecting band	B1		4	1	1	4	1	1	1	2		1		
	B1a			1	1			1		2				
	B a1a			1										
	B3	6	7	11	4	11	16	17	9	10		6		
	B3a		1	3			2	1		1				
	B a3a		1				1	1						
	B5	5	4	3		4		4	1	7	1	4		
	B5a						1							
	B6a	1			1									
	B7	1		1	1									
	B9		3					1						
	B fragment	25	13	9	7	10	17	22	20	19	8	21		
Girdle view	G1	2	5	2			4	2	1	4		1		
	G2		1											
	G3	3	8	11	3	11	13	7	7	11		5	1	
	G3a		2											
	G5	1	5		1	6	8	2	3	2		1		
	G6	2												
	G7	2								1		1		
	G9						1							
	G fragment	5	6	8	6	4	7	3	1	3		1		1
Valve view	V1					1			1	1				
	V3	1	6	1		1	5	2	3	2		2		
	V5		3			1	2	2	2	2				
	V7	1												
	V9	1	1											
	V fragment	15	16	14	3	6	16	10	5	21		3	1	
TOTAL		71	86	66	28	59	94	76	54	88	9	46	2	1

KA : Kamimetoki Sandstone Member

to distinguish a deeper valve of *D. praedimorpha* from that of *D. dimorpha* in valve view. Furthermore, it is impossible to discriminate a shallower valve of *D. praedimorpha* from that of *D. dimorpha*, because they have the same structure. Therefore, all the valves of both *D. praedimorpha* and *D. dimorpha* as seen in valve view are counted without making any distinction and they are expressed as the same term of Vn-type.

The following conclusions can be drawn from Tables 3-8 :

1) In *D. praedimorpha* and *D. dimorpha*, connecting bands tend to keep basically odd numbers of foramina except for apical foramina ($m=1, 3, 5, 7, 9$).

2) As an inevitable consequence of 1), the deeper thecae of both *D. praedimorpha* and *D. dimorpha* basically tend to contain connecting bands which possess odd numbers of foramina.

3) *D. praedimorpha* tends to produce

Table 8. Biostratigraphic distribution of reworked specimens of *Denticulopsis praedimorpha* and *D. dimorpha* in DSDP Hole 438A, core 55 through core 41

CORE		55	54	53	52	52	52	51	51	51	50	50	50	49	49	48	48	48	47	47	47	46	46	45	45	45	44	44	43	43	43	42	42	42	41
		1	1	1	4	3	1	6	4	1	6	3	1	6	3	6	3	1	6	4	1	6	3	6	6	1	6	3	6	3	1	6	4	1	6
INTERVAL		70	110	77	36	36	36	16	16	16	20	20	20	10	10	26	46	14	4	110	10	14	18	30	5	54	10	10	82	30	59	16	50	14	10
		74	114	81	38	38	38	20	20	20	24	24	24	14	14	30	50	18	8	114	14	18	22	34	9	58	14	14	86	34	63	20	54	18	14
Denticulopsis praedimorpha Akiba																																			
Connecting band	B1					1		1						1	1	2		1						2		1	1			1	1			1	
	B3					1				1				2																					
	B5																		1																
	total					2		1		1				3	1	2		1	1					2		1	1			1	1			1	
Girdle view	G1				1									1	1			1				1					1								
	G3																	1			1			1		1									
	G fragment									1									1																
	total				1					1				1	1			2	1		1	1		1		1	1								
Denticulopsis praedimorpha Akiba AND / OR *Denticulopsis dimorpha* (Schrader) Simonsen																																			
Valve view	V3			1				2	2		1	2	2	5					2	1		1				1			2	1	1				
	V5	1				3		1					1	1	1		2				1	1		2	3	1		1	1		1	1		1	
	V7							1											1			1								1				1	
	V fragment	1	1		1			1		1	2		1							2			1					1	2						
	total	2	1	1	1	3		5	2	1	3	2	4	6	1		2		3	3	1	3	1	2	3	2		2	5	2	2	1		1	
Denticulopsis dimorpha (Schrader) Simonsen																																			
Connecting band	B3												1	1																					
	B3a				1																														
	total				1								1	1																					
Girdle view	G1		1				1					2	1																						
	G3	1																																	1
	G5																																1		
	G fragment									1																									
	total	1	1				1			1		2	1																				1		1

the G1-type and G3-type deeper thecae more abundantly than those of other types throughout the *D. praedimorpha* Range-zone.

4) In the stratigraphic distribution of the connecting bands of *D. praedimorpha*, the B1-type and B3-type are more abundant than those belonging to other types. This tendency is in good agreement with 3).

5) *D. dimorpha* tends to produce G3-type and G5-type deeper thecae more abundantly than those of other types throughout the *D. dimorpha* Range-zone.

6) In the stratigraphic distribution of the connecting bands of *D. dimorpha*, the B3-type and B5-type are produced more abundantly. This tendency agrees well with 5).

7) The deeper thecae and connecting bands of reworked specimens of these two species are very rare and occur discontinuously in the Upper Miocene sequence of DSDP Hole 438A.

8) The deeper thecae and valves showing a valve view of reworked specimens of these two species occur continuously but are very rare in the Upper Miocene interval of DSDP Hole 438A.

Evolutionary trends

Since Schrader (1973b) discussed three evolutionary trends radiating from *Denticulopsis lauta*, the evolution of the genus *Denticulopsis* has received little attention.

As a possible ancestor of the genus *Denticulopsis*, two different taxa have so far been suggested : They are a species of the genus *Nitzschia* according to Schrader (1973b) and a species belonging to the section *Fragilariopsis* of *Nitzschia* according to Simonsen (1979). Schrader (1973b) assumed the genus *Denticulopsis* to have evolved from an unknown ancester at early Miocene time.

The oldest species of *Denticulopsis* is also difficult to designate at present time. Although *Denticulopsis lauta* and *D. norwegica* are the oldest known species, the presence of its forerunners has only lately been noted by Akiba (1977a) under the name of *D. kanayae* and *D. ikebei*. Furthermore, as a direct precursor of *D. lauta*, the following have been suggested : *D. praelauta* by Koizumi (Takayama *et al*., 1979), *D.* cf. *lauta* by Barron (1980), and *D.* sp. A by Akiba (Akiba *et al*., 1982a, b). All of them are characterized by the lack or underdevelopment of the marginal ribs. In the foregoing lines, evolutionary trends followed by species of the genus *Denticulopsis* will be discussed by taking *D. lauta* as the starting point.

Evidence provided during the present study leads to the formulation of three hypotheses as follows : (1) evolutionary trend toward acquiring secondary pseudosepta, (2) evolutionary trend toward acquiring hyaline valve face, and (3) evolutionary trend toward loosing tsuzumis.

(1) Evolutionary trend to acquire secondary pseudosepta

Denticulopsis hustedtii is regarded as a descendant of *D. lauta* and is the first species which has positively been shown to possess secondary pseudosepta among the genus *Denticulopsis*. Other basic morphological characteristics including its finely structured surface are kept unchanged from that of *D. lauta*. Compared with a single marginal rib-like wall-thickening between two adjoining primary pseudosepta of *D. lauta*, *D. hustedtii* develops a marginal rib-like wall-thickening between two adjoining psedosepta. Although the spacing of primary pseudosepta is very regular in *D. lauta*, individual specimens of *D. hustedtii* vary their spacing of primary pseudosepta in proportion to the number of secondary pseudosepta appearing in between. This tendency is equally reflected in the spacing of foramina on the septa as well as on the connecting bands.

It is surmised that this evolutionary trend is accompanied by an appended tendency to develop a finer valve face structure leading finally to *D. seminae.*

(2) Evolutionary trend to acquire hyaline valve face

The stratigraphic distribution patterns show clearly that taxa with the hyaline valve face first appear in the middle of the Thriving Interval in each ancestor and then flourish for a short interval. For instance, *D. hyalina* split from *D. lauta* during early Middle Miocene time when *D. lauta* reached its maximum flourishment. *D. katayamae* evolved from *D. hustedtii* during early Late Miocene time when *D. hustedtii* reached its maximum prosperity.

Three kinds of features are noticed in this evolutionary trend. The first one is areolation consisting of sexangular large puncta arranged irregularly on the whole mantle. This feature is recognized only in *D. hyalina* among all the *Denticulopsis* taxa. The second feature is areolation consisting of puncta arranged in a line along the valve face edge. In *D. hyalina*, large puncta are arranged in a line (Pl. 13, fig. 10), while in *D. katayamae* clusters of small puncta are arranged in a line (Pl.12, figs. 2, 3). Such a feature is considered to be a third feature reflected on outer valve surface. The third feature is the most important character of a taxon bearing the hyaline valve face, and is only discernible with the use of an electron microscope. They are large puncta arranged in a line along the edge of the inner valve face (e.g. Pl. 12, figs. 1b, 6), that correspond to small puncta on the outer valve surface. It is, however, not certain as to whether these puncta are directly connected with each other through the siliceous cell wall.

(3) Evolutionary trend of loosing tsuzumis

It might be stated that *D. lauta*, *D.praedimorpha*, and *D. dimorpha* lie on a single evolutionary lineage, though the points of divergence from *D. lauta* to *D. praedimorpha* and from *D. praedimorpha* to *D. dimorpha* have not been detected yet. *D. lauta* produces only a isovalvate frustule from two similar thecae with tsuzumis. *D. praedimorpha* and *D. dimorpha* make either isovalvate frustule consisting of two deeper thecae or heterovalvate one consisting of a deeper theca and a shallower theca. The deeper valve of *D. praedimorpha* has a septum with tsuzumis, but the shallower valve has a flat septum without tsuzumis. The deeper valve of *D. dimorpha*, however, looses a septum, although the shallower valve has a flat septum without tsuzumis like that of *D. praedimorpha.*

The tendency to loose tsuzumis finally reaches the loss of septum in a valve, and is positively reflected in the morphological change of the connecting band. The connecting band of the deeper theca of *D. praedimorpha* is closed and has teeth-like extensions, whereas that of *D. dimorpha* is closed and has cross bars which appear to have evolved from the teeth-like extensions of *D. praedimorpha.* A connecting band of the shallower theca of these two species is rarely found and needs further study (Akiba, 1982b).

Schrader (1973b) pointed out the evolutionary trend of building up coarser valve structures. It still remains to be ascertained as to whether *D. lauta* is an ancestor of *D. nicobarica*, although the first appearance of *D. nicobarica* is not precisely timed in this study. The evolutionary tendency of such taxa as *D. nicobarica* and *D. punctata*, which have a coarser valve face structure, is regarded to be important in the phylogeny of the genus *Denticulopsis.* Owing to insufficient data available for these species, the present author wishes to introduce a new character which has recently been observed by Yanagisawa (1982, personal communication). This is a siliceous cross in a punctum of *D. nicobarica* (Pl. 15, fig. 13b) and appears to be much worthy of further investigation.

Systematic description of *Denticulopsis katayamae* n. sp.

Class : Bacillariophyceae
Order : Pennales
Suborder : Raphidineae
Family : Nitzschiaceae Grunow 1860
Genus *Denticulopsis* Simonsen 1979
Denticulopsis katayamae sp. nov.
Pl. 12, figs. 1a-b, 2-6 ; Pl. 17, figs. 1-23

Probable synonym : *Denticula hyalina* var. *hustedtii* Schrader 1973b, p. 418, pl. 1, figs. 9, 21.

Description : Isovalvate frustule consisting of two thecae and a theca made of valve, septum, and connecting band. Strongly silicified valve, weakly convex, linear-elliptical outline with bluntly rounded apices, 7-37 μm long, 4-7 μm wide in valve view, depth of frustule 8-10 μm in girdle view, depth of valve 3-3.5 μm. Valve face hyaline, in some specimens sparsely punctate. Clusters of puncta arranged in a line along the valve face edge, visible as a brilliant line of large puncta when focused under a light microscope observation. Puncta probably penetrating valve wall, visible on inner valve wall by SEM observation, as a large punctum between primary pseudosepta, arranged linearly along the margin of inner valve face. Primary pseudosepta number 2-4, mostly 3, in a distance 10 μm. Secondary pseudosepta present, 1 or 2, rarely 3-4, between primary pseudosepta. One or two apical pseudosepta located at each apex. Between each pseudosepta, marginal rib-like wall-thickening is present on both mantle sides, its visibility varying case by case. Raphe marginal, at the valve face edge, branching out at both apices, well visible on inner wall of valve in SEM observations, when septum is removed. Septum with tsuzumis, closed on both ends, spacing and number of tsuzumis controlled by those of primary pseudosepta. Shape of a tsuzumi in inner valve view resembles those of a bow tie and of a hourglass. Between tsuzumis, foramina are present. Shape of a foramen, traverse elliptical, oval, or sub-hexagonal. Marginal siliceous wall of septum, parallel to valvar plane, 1 μm wide. Connecting band open on one end, with smooth wall, without areolation, both apical sides of a foramen open, foramina connected with each other.

Remarks : This species differs from the typical *D. hyalina* by having the secondary pseudosepta, and from *D. hustedtii* in having its heavily silicified and hyaline valve face.

Holotype : IGPS coll. (Institute of Geology and Paleontology Collection, Tohoku University, Sendai) no. 98255 (Pl. 17, fig. 2).

Type locality : A branch of the Mabechi River, on the border between Iwate and Aomori Prefectures, 250 m W of Kamasawa, Ninohe City, Iwate Prefecture. Sample STZ-30 in the Shitazaki section, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe Group.

Stratigraphic range : From the middle part of the *D. dimorpha* Range-zone to the top of the *D. katayamae* Interval-zone, middle Upper Miocene.

Other occurrence : In the middle Upper Miocene of DSDP Hole 438A (off Northeast Japan ; lat. 40° 37.79′N, long. 143° 14.15′E).

Measurements (in μ*m)*: At the top of p. 159.

Discussion : Some comments are given on the relationship between *D. hyalina* var. *hustedtii* Schrader 1973b and *D. katayamae*. (1) The original description of *D. hyalina* var. *hustedtii* states that the valve mantle is coarsely punctate with 8-9 rounded pores in 10 μm. The valve mantle of *D. katayamae*, however, is not coarsely punctate, but is made of a meshwork of small rounded pores as in *D. hustedtii*, *D. lauta*, *D. praedimorpha*, and *D. dimorpha*. (2) In specimens illustrated in Plate 6, figs. 9, 21 of Schrader (1973b), the secondary

Figure number in Plate 17	length	width	Number of primary pseudosepta	Number of primary pseudosepta per 10 μm	
1	28	7	6	2–3	
2	28	5	6	2–3	Holopype
3	20	5	5	3	
4	20	6	4	3	
5	22	6	4	3	
6	18	6	4	3	
7	27	6	7	3–4	
8	28	6	7	3–4	
9	31	6	8	3	
10	31	6	7	3	
11	33	7	7	3	
12	35	6	8	3	
13	37	6	6	2	
14	14	6	3	3	
15	11	5	3	3	
16	15	4	3	3	
17	18	5	3	2	
18	18	4	4	3	
19	22	5	5	3	
20	22	6	5	3	
21	24	5	5	3	
22	24	6	4	2	
23	23	6	6	4	
maximum	37	7	8	4	
minimum	11	4	3	2	
average	23.9	5.7	5.2	3	

pseudosepta are invisible. The author regards these specimens to be *D. hyalina* s.s. (3) In a sketch given in Text-figure 4, he draws the secondary pseudopepta. (4) *D. hyalina* var. *hustedtii* first occurs immediately after the last appearance of *D. dimorpha* and disappears subsequent to a rapid decrease of *D. hustedtii*, which is shown in Table 3 of Schrader (1974). This 1974 paper of Schrader dealt with the materials from Experimental Mohole Site off Guadalupe, and the range of *D. hyalina* var. *hustedtii* is not entirely identical with that of *D. katayamae* as determined in DSDP Hole 438A. The range of Schrader's variety seems to correspond to the upper half of the range of *D. katayamae*. Judging from all sources of information presented by Schrader (1973b, 1974), it should be concluded that the sketch in Text-figure 4 and the species description with the exception of valve mantle are identical with the concept of *D. katayamae*. The present author considers that *D. hyalina* var. *hustedtii* should be re-examined in detail.

The species is named after the late Mr. Toshio Katayama, the present author's classmate who studied the Sannohe area, the provenance of the holotype specimen, for his master's thesis.

REFERENCES

Akiba, F., 1977a, *Denticula kanayae* n. sp. in the *Denticula kanayae* Zone, a biostratigraphically significant diatom. *Bull. Tech. Lab. JAPEX*, v. 20, nos. 3-4, p. 126-146, 4 figs., 4 tabs., 2 pls. (*in* Japanese).

————, 1977b, Neogene biostratigraphy of the Ninohe area, Iwate Prefecture. *Japan. Assoc. Petrol. Tech., Jour.*, v. 42, no. 4, p. 275. (*in* Japanese).

————, 1979, The morphologies of *Denticula dimorpha* and its related species, and the Neogene diatom biostratigraphy of Japan. *Bull. Tech. Lab. JAPEX*, v. 22, no. 3, p. 148-188, 19 figs., 3 tabs., 3 pls. (*in* Japanese).

————, 1982a, Reconsideration of the *Coscinodiscus marginatus* Zone -taxonomy and biostratigraphic significance of *Thalassionema schraderi*-. *ibid.*, v. 24, nos. 3-4, p. 206-223, 6 figs., 2 tabs., 1 pl. (*in* Japanese ; original title translated).

————, 1982b, Late Quaternary diatom biostratigraphy of the Bellingshausen Sea, Antarctic Ocean. *Rep. Tech. Research Center. J.N.O.C.*, no. 16, p. 31-74, 4 figs., 2 tabs., 11 pls.

————, 1982c, Taxonomy and biostratigraphic significance of a new diatom, *Thalassionema schraderi*. *Bacillaria*, v. 5, p. 43-61, 5 figs., 1 pl.

————, 1983, Revised Neogene diatom zonation of the middle- and high-latitude North Pacific. *Marine Sciences Monthly*, v. 15, no. 12, p. 717-724, 4 figs. (*in* Japanese ; original title translated).

————, Hoshi, K., and Ichinoseki, T., 1982a, Litho- and biostratigraphy of the Miocene Atsunai Group distributed in the southwestern part of the Kushiro coal field, Eastern Hokkaido. *Bull. Tech. Lab., JAPEX*, v. 25, no. 1, p. 13-52, 11 figs., 15 tabs. (*in* Japanese with English abstract).

————, Yanagisawa, Y., and Ishii, T., 1982b, Neogene diatom biostratigraphy of the Matsushima area and its environs, Miyagi Prefecture, Northeast Japan. *Bull. Geol. Surv. Japan*, v. 33, no. 5, p. 215-239, 9 figs., 5 tabs., 3 pls. (*in* Japanese with English abstract).

Akima Collaborative Research Group, 1971, The Neogene System in the northern part of Annaka City, Gunma Prefecture. *Earth Science*, v. 25, no. 5, p. 219-226, 8 figs., 1 tab. (*in* Japanese with English abstract).

————, 1975, Geology in the Aima-gawa Valley along the Karasu-gawa River, Gunma Prefecture, Central Japan. *Earth Science*, v. 29, no. 4, p. 166-176, 6 figs., 2 tabs., 1 pl. (*in* Japanese with English abstract).

————, 1976, Geology of the eastern part of the River Kirizumi, Gunma Prefecture, Central Japan. *Geol. Soc. Japan, Mem.*, no. 13, p. 261-267, 5 figs., 1 tab. (*in* Japanese with English abstract).

Barron, J.A., 1973, Late Miocene-Early Pliocene paleotemperatures for California from marine diatom evidence. *Palaeogeog., Palaeoclimatol., Palaeoecol.*, v. 14, p. 277-291, 4 figs., 2 tabs., 3 pls.

————, 1976, Revised Miocene and Pliocene diadiatom biostratigraphy of Upper Newport Bay, Newport Beach, California. *Mar. Micropaleont.*, v. 1, p. 27-63, 7 figs., 5 tabs., 3 pls.

————, 1980, Lower Miocene to Quaternary diatom biostratigraphy of Leg 57, off Northeastern Japan, Deep Sea Drilling Project. *In* Scientific Party, *Init. Repts. DSDP*, v. 56-57, pt. 2, p. 641-685, 11 figs., 14 tabs., 6 pls., U.S. Govt. Printing Office, Washington.

————, 1981, Late Cenozoic diatom biostratigraphy and paleoceanography of the middle-latitude eastern North Pacific, Deep Sea Drilling Project Leg 63. *In* Yearts, R.S., Haq, B.U., *et al.*, *Init. Repts. DSDP*, v. 63, p. 507-538, 8 figs., 7 tabs., 7 pls., U.S. Govt. Printing Office, Washington.

————, Harper, H.E. Jr., Keller, G., Reynolds, R.A., Sakai, T., Shaffer, B.L., and Thompson, P.R., 1980, Biostratigraphic summary of the Japan Trench Transect, Legs 56 and 57, Deep Sea Drilling Project. *In* Scientific Party, *Init. Repts. DSDP*, v. 56-57, pt. 2, p. 505-520, 12 figs., 1 tab., U.S. Govt. Printing Office, Washington.

————, and Keller, G., 1983, Paleotemperature oscillations in the Middle and Late Miocene of the northeastern Pacific. *Micropal.*, v. 29, no. 2, p. 150-181, 12 figs., 9 tabs., 3 pls.

Burckle, L.H., 1972, Late Cenozoic planktonic diatom zones from the eastern equatorial Pacific. *In* Simonsen, R., Ed., First Symposium on Recent and Fossil Marine Diatoms. *Nova Hedwigia*, no. 39, p. 217-246, 4 figs., 1 tab., 3 pls.

————, 1977, Pliocene and Pleistocene diatom datum levels from the equatorial Pacific. *Quaternary Research*, v. 7, p. 330-340, 4 figs., 1 tab.

———, and Opdyke, N., 1977, Late Neogene diatom correlations in the circum-Pacific. *In* Saito, T., and Ujiié, H., Eds., *1-CPNS, Tokyo 1976, Proc.*, p. 255-284, 15 figs., 1 tab., Kaiyo Shuppan, Tokyo.

Chiji, M., and Konda, I., 1978, Planktonic foraminiferal biostratigraphy of the Tomioka Group and the Nishiyatsushiro and Shizukawa Groups, Central Japan, with some considerations on the Kaburan Stage, Middle Miocene. *In* Huzita, K., *et al.*, Eds., *Cenozoic Geology of Japan, Prof. N. Ikebe Mem. Vol.*, p. 73-92, 6 figs., 4 tabs., 2 pls. (*in* Japanese with English abstract).

———, and ———, 1981a, Tomioka area, Gunma Prefecture. *In* Tsuchi, R., Ed., *Fundamental data on Japanese Neogene bio- and chronostratigraphy -Supplement-*, p. 9-10, 2 figs. (*in* Japanese with English captions).

———, and ———, 1982b, Tomioka area. *In* Tsuchi, R., Ed., *Neogene of Japan -its biostratigraphy and chronology-*, p. 50-52, 2 figs.

Chinzei, K., 1958, Pliocene stratigraphy of the northern end of the Kitakami Mountains, Northeast Japan. *Geol. Soc. Japan, Jour.*, v. 64, no. 757, p. 526-536, 5 figs., 2 tabs. (*in* Japanese with English abstract).

———, 1966, Younger Tertiary geology of the Mabechi River valley, northeast Honshu, Japan. *Univ. Tokyo Fac. Sci., Jour.*, sec. 2, v. 16, no. 1, p. 161-208, 24 figs., 2 tabs.

———, 1981, Kadonosawa Area. *In* Tsuchi, R., Ed., *Neogene of Japan -its biostratigraphy and chronology-*, p. 57-61, 2 figs.

Donahue, J.G., 1970, Pleistocene diatoms as climatic indicators in North Pacific sediments. *In* Hays, J.D., Ed., *Geological investigations of the North Pacific. Geol. Soc. Amer. Mem.*, no. 126, p. 121-138, 6 figs., 1 tab., 3 pls.

Fukudome, T., 1974MS, Neogene microbiostratigraphy of the southern margin of the Abukuma Massif. Tohoku Univ., Inst. Geol. Pal., Master's Thesis. (*in* Japanese; original title translated).

Hanzawa, S., Hatai, K., Iwai, J., Kitamura, N., and Shibata, T., 1953, The geology of Sendai and its environs. *Tohoku Univ., Sci. Rep., 2nd Ser. (Geol.)*, v. 25, p. 1-50, 15 tabs., 2 maps.

Hayakawa, N., Funayama, Y., Saito, K., and Kitamura, N., 1954, Geology of the Neogene System of the area distributed from the western flank of the Kitakami Plateau to the backbone ranges. *Tohoku Min. Soc., Jour.*, no. 10, p. 1-97, 19 figs., 3 tabs. (*in* Japanese).

Honma, M., and Fujita, Y., 1979, On the collapse basin of Late Miocene in the western part of Gunma Prefecture, Japan-the geological study of the Upper Miocene Series around Goriniwa-. *Geol. Soc. Japan, Mem.*, p. 87-96, 7 figs., 1 tab. (*in* Japanese with English abstract).

Ishizaki, K., and Takayanagi, Y., 1981, Sendai area. *In* Tsuchi, R., Ed., *Neogene of Japan -its biostratigraphy and chronology-*, p. 53-56, 2 figs.

Katayama, T., 1980MS, Neogene stratigraphy of the Mabechi River area on the borders of Aomori and Iwate Prefectures. Tohoku Univ., Inst. Geol. Pal., Master's Thesis. (*in* Japanese; original title translated).

Kato, M., 1980, Planktonic foraminiferal biostratigraphy of the Takaku and Taga Groups in the Joban Coal Field, Northeast Honshu, Japan. *Tohoku Univ., Sci. Rep., 2nd Ser. (Geol.)*, v. 50, nos. 1-2, p. 35-95, 26 figs., 10 tabs., 2 pls.

Keller, G., and Barron, J.A., 1981, Integrated planktic foraminiferal and diatom biochronology for the Northeast Pacific and Monterey Formation. *In* Garrison, R.E., *et al.*, Eds., *The Monterey Formation and related siliceous rocks of California*, p. 43-54, 6 figs., 1 tab., Spec. Pub., S.E.P.M., Los Angeles.

Kinoshita, H., 1948MS, Geology of Mizusawa Town and its environs, Iwate Prefecture. Tohoku Univ., Inst. Geol. Pal., Graduation Thesis. (*in* Japanese; original title translated).

Kitamura, N., 1981, Neogene. *In* Onuki, Y., Kitamura, N., and Nakagawa, H., Eds., Explanatory text of the geological map of Kitakami Valley, scale 1 : 200,000, p. 225-277, Hase Geological Survey, Sendai. (*in* Japanese; original title translated).

Koizumi, I., 1973a, The stratigraphic ranges of marine planktonic diatoms and diatom biostratigraphy in Japan. *Geol. Soc. Japan, Mem.*, no. 8, p. 35-44, 4 figs.

———, 1973b, Marine diatom flora of the Pliocene Tatsunokuchi Formation in Miyagi Prefecture. *Trans. Proc. Palaeont. Soc. Japan, N.S.*, no. 79, p. 126-136, 4 figs., 2 tabs., 1 pl.

———, 1975a, Neogene diatoms from the western margin of the Pacific Ocean, Leg 31, Deep Sea Drilling Project. *In* Karig, D.E., Ingle, J.C., Jr., *et al.*, *Init. Repts. DSDP*, v. 31, p. 779-819, 9 figs., 10 tabs., 5 pls., U.S. Govt. Printing Office, Washington.

———, 1975b, Neogene diatoms from the Northwestern Pacific Ocean, Deep Sea Drilling Project. *In* Larson, R.L., Moberly, R., *et al.*, *Init. Repts. DSDP*, v. 32, p. 865-889, 5 figs., 5 tabs., 4 pls., U.S. Govt. Printing Office, Washington.

———, 1975c, Diatom events in Late Cenozoic deep-sea sequences in the North Pacific. *Geol.*

Soc. Japan, Jour., v. 81, no. 9, p. 567-578, 4 figs., 1 pl.

————, 1975d, Late Cenozoic diatom biostratigraphy in the circum-North Pacific region. *ibid.*, v. 81, no. 10, p. 611-627, 5 figs., 2 pls.

————, 1977a, Diatom biostratigraphy in the North Pacific region. *In* Saito, T., and Ujiié, H., Eds., *1-CPNS*, *Tokyo 1976*, *Proc.*, p. 235-253, 14 figs., 4 tabs., Kaiyo Shuppan, Tokyo.

————, 1977b, Micro-biostratigraphy and magnetostratigraphy of deep-sea sediments. *Quaternary Research*, v. 16, no. 3, p. 117-128, 7 figs. (*in* Japanese with English abstract).

————, 1979a, Kadonosawa-Sannohe area. *In* Tsuchi, R., Ed., *Fundamental data on Japanese Neogene bio- and chronostratigraphy*, p. 53-55, 3 figs. (*in* Japanese with English captions).

————, 1979b, An example of microbiostratigraphy on sea and land sections. *Earth Monthly, Tokyo*, v. 1, no. 3, p. 226-229, 3 figs. (*in* Japanese; original title translated).

————, 1980a, Neogene diatoms from the Emperor Seamount chain, Leg 55, Deep Sea Drilling Project. *In* Jackson, E.D., Koizumi, I., *et al.*, *Init. Repts. DSDP*, v. 55, p. 387-407, 4 figs., 5 tabs., 3 pls., U.S. Govt. Printing Office, Washington.

————, 1980b, Geohistory based on ocean bottom sediments (UP Earth Science). 108 p., *Tokyo Univ. Press*, Tokyo. (*in* Japanese; original title translated).

————, 1981a, Paleoceanography of Early-Middle Miocene in Japan by means of diatom fossils. *Fossil* (*Kaseki*), no. 30, p. 87-100, 9 figs. (*in* Japanese).

————, 1981b, Joban area (1) Takahagi. *In* Tsuchi, R., Ed., *Fundamental data on Japanese Neogene bio- and chronostratigraphy -Supplement-*, p. 18-19, 2 figs. (*in* Japanese with English captions).

————, 1982, Distribution and sedimentary environment of the marine diatomaceous deposits of Japan and its environs. *Earth Monthly, Tokyo*, v. 4, no. 8, p. 485-491, 10 figs. (*in* Japanese; original title translated).

————, and Kanaya, T., 1976, Late Cenozoic marine diatom sequence from the Choshi district, Pacific coast, Central Japan. *In* Takayanagi, Y., and Saito, T., Eds., *Progress in micropaleontology*, p. 144-159, 5 figs., 2 tabs., 1 pl., Spec. Pub., Micropal. Press, New York.

————, Barron, J.A., and Harper, H.E., Jr., 1980, Diatom correlation of Legs 56 and 57 with onshore sequences in Japan. *In* Scientific Party, *Init. Repts. DSDP*, v. 56-57, pt. 2, p. 687-693, 5 figs., U.S. Govt. Printing Office, Washington.

Konda, I., 1980, Benthonic foraminifera biostratigraphy of the standard areas of Middle Miocene in the Pacific side province, Central Japan. *Kyoto Univ. Fac. Sci. Geol. Min., Mem.*, v. 47, no. 1, p. 1-42, 18 figs., 5 pls.

Maruyama, T., 1980MS, Neogene stratigraphy of the southern hilly area, Ichinoseki City. Tohoku Univ., Inst. Geol. Pal., Master's Thesis. (*in* Japanese; original title translated).

————, 1981a, Sendai area. *In* Tsuchi, R., Ed., *Fundamental data on Japanese Neogene bio- and chronostratigraphy -Supplement-*, p. 28-29, 2 figs. (*in* Japanese with English captions).

————, 1981b, Ichinoseki area, Iwate Prefecture. *ibid.*, p. 32-33, 2 figs. (*in* Japanese with English captions).

————, 1982MS, Diatom biostratigraphy of the Shiratorigawa and Sannohe Groups. *Geol. Soc. Japan, Abstract, 89th Annual Meeting*, p. 155. (*in* Japanese; original title translated).

Matsumaru, K., 1967, Geology of the Tomioka Area, Gunma Prefecture, with a note on "*Lepidocyclina*" from the Abuta Limestone Member. *Tohoku Univ., Sci. Rep., 2nd Ser.* (*Geol.*), v. 39, no. 2, p. 113-147, 31 figs., 7 tabs., 2 pls.

————, 1977, Neogene stratigraphy of the northern to northeastern marginal areas of the Kwanto mountainland, Central Japan. *Geol. Soc. Japan, Jour.*, v. 83, no. 4, p. 213-225, 6 figs., 3 tabs. (*in* Japanese with English abstract).

Matsuno, K., 1948MS, Geology of Ichinoseki region, Iwate Prefecture. Tohoku Univ., Inst. Geol. Pal., Graduation Thesis. (*in* Japanese; original title translated).

————, 1967, Geology of the Wakayanagi district. Quadrangle series, scale 1 : 50,000, Akita (6) No. 69, *Geol. Surv. Japan*, 24 p. 8 figs., 1 tab., 6 pls., 1 map. (*in* Japanese with English abstract).

McCollum, D.W., 1975, Diatom stratigraphy of the Southern Ocean. *In* Hayes, D.E., Frakes, L.A., *et al.*, *Init. Repts. DSDP*, v. 28, p. 515-571, 12 figs., 2 tabs., 16 pls., U.S. Govt. Printing Office, Washington.

Mitsui, S., Ouchi, K., Endo, S., and Hasegawa, Y., 1973, Stratigraphy and geological age of the Taga Group in the Joban Coal-field of Fukushima and Ibaraki Prefectures. *Kochi Univ., Res. Rep.*, v. 22, Nat. Sci., no. 4, p. 103-124, 16 figs., 2 tabs.

Motojuku Green-tuff Research Group, 1968, Double depression structure discovered in the green-tuff (Miocene) beds of the Motojuku district, Gumma Prefecture, and its significance. *Earth Science*, v. 22, no. 1, p. 32-36, 1 fig., 1 tab. (*in*

Japanese with English abstract).

Nomura, S., and Akima Collaborative Research Group, 1981, Geology of the northwest margin of Kanto Plain, Central Japan. *Geol. Soc. Japan, Mem.*, no. 20, p. 161-167, 1 fig., 1 tab. (*in* Japanese with English abstract).

Oda, M., 1977, Planktonic foraminiferal biostratigraphy of the Late Cenozoic sedimentary sequence, Central Honshu, Japan. *Tohoku Univ., Sci. Rep., 2nd Ser.* (*Geol.*), v. 48, nos. 1-2, p. 1-72, 21 figs., 3 tabs., 10 pls.

————, and Sakai, T., 1977, Microbiostratigraphy of the lower to middle part of the Hatatate Formation, Sendai, Japan. *In* Takayasu, T., *et al.*, Eds., *Prof. Huzioka Mem. Vol.*, p. 441-456, 6 figs., 4 tabs., 4 pls. (*in* Japanese with English abstract).

————, and ————, 1979, Sendai area. *In* Tsuchi, R., Ed., *Fundamental data on Japanese Neogene bio- and chronostratigraphy*, p. 46-47, 2 figs. (*in* Japanese with English captions).

Onodera, S., 1956, A new occurrence of *Desmostylus* from Ichinoseki City, Iwate Prefecture. *Geol. Soc. Japan, Jour.*, v. 62, no. 735, p. 721-722, 2 figs. (*in* Japanese).

————, 1957, A new occurrence of *Desmostylus* from Ichinoseki City, Iwate Prefecture, with reference to the geology of the locality. *Geol. Soc. Japan, Jour.*, v. 63, no. 739, p. 238-253, 7 figs., 5 tabs., 6 pls. (*in* Japanese with English abstract).

Otuka, Y., 1934, Tertiary structures of the northeastern end of the Kitakami Mountainland, Iwate Prefecture, Japan. *Imp. Univ. Tokyo, Earthquake Res. Inst., Bull.*, v. 12, pt. 3, p. 566-638, 9 figs, 6 tabs, 5 pls.

Poore, R.Z., McDougall, K., Barron, J.A., Brabb, E.E., and Kling, S.A., 1981, Microfossil biostratigraphy and biochronology of the type Relizian and Luisian Stages of California. *In* Garrison, R.E., *et al.*, Eds., *The Monterey Formation and related siliceous rocks of California*, p. 15-41, 9 figs., 3 tabs., 4 pls., Spec. Pub., S.E.P.M., Los Angeles.

Samata, T., 1976, Tertiary planktonic foraminifera biostratigraphy in the Mabechi River region, northern end of the Kitakami Massif, northeast Honshu. *Geol. Soc. Japan, Jour.*, v. 82, no. 12, p. 783-793, 3 figs., 3 tabs., 1 pl. (*in* Japanese with English abstract).

Sasaki, I., 1955MS, Geology of the border area between Miyagi and Iwate Prefectures. Tohoku Univ., Inst. Geol. Pal., Graduation Thesis. (*in* Japanese; original title translated).

Sato, H., 1981MS, Neogene and Quaternary stratigraphy of the western flank of the Shinjo Basin and the Dewa Hilly Land. Tohoku Univ., Inst. Geol. Pal., Master's Thesis. (*in* Japanese; original title translated).

Schrader, H.-J., 1973a, Cenozoic diatoms from the northeast Pacific, Leg 18. *In* Kulm, L.D., von Huene, R., *et al.*, *Init. Repts. DSDP*, v. 18, p. 673-797, 36 figs., 8 tabs., 26 pls., U.S. Govt. Printing Office, Washington.

————, 1973b, Stratigraphic distribution of marine species of the diatom *Denticula* in Neogene North Pacific sediments. *Micropal.*, v. 19, no. 4, p. 417-430, 4 figs., 1 tab., 1 pl.

————, 1974, Revised diatom stratigraphy of the Experimental Mohole Drilling, Guadalupe site. *Proc. Calif. Acad. Sci. 4th ser.*, v. 39, p. 517-562, 6 figs., 4 tabs., 6 charts.

————, 1976, Cenozoic planktonic diatom biostratigraphy and taxonomy. *In* Talwani, M., Udintsev, G., *et al.*, *Init. Repts. DSDP*, v. 35, p. 605-671, 14 figs., 12 tabs., 15 pls., U.S. Govt. Printing Office, Washington.

Simonsen, R., 1979, The diatom system: Ideas on phylogeny. *Bacillaria*, v. 2, p. 9-71, 3 figs., 3 appendixes.

————, and Kanaya, T., 1961, Notes on the marine species of the diatom genus *Denticula* Kütz. *Int. Revue ges. Hydrobiol.*, v. 46, no. 4, p. 498-513, 1 fig., 2 tabs., 1 pl., 2 index-maps.

Takayama, T., Koizumi, I., and Maiya, S., 1979, Northern Noto Peninsula -Ukai River area-. *In* Tsuchi, R., Ed., *Fundamental data on Japanese Neogene bio- and chronostratigraphy*, p. 95-96, 2 figs. (*in* Japanese with English captions).

Takayanagi, Y., Takayama, T., Sakai, T., Oda, M., and Kitazato, H., 1976, Microbiostratigraphy of some Middle Miocene sequences in northern Japan. *In* Takayanagi, Y., and Saito, T., Eds., *Progress in micropaleontology*, p. 356-381, 7 figs., 6 tabs., 4 pls., Spec. Pub., Micropal. Press, New York.

————, Sakai, T., Oda, M., Takayama, T., Oriyama, J., and Kaneko, M., 1978, Problems relating to the Kaburan Stage. *In* Huzita, K., *et al.*, Eds., *Cenozoic geology of Japan, Prof. N. Ikebe Mem. Vol.*, p. 93-112, 9 figs. (*in* Japanese with English abstract).

————, Hasegawa, S., Oda, M., and Maruyama, T., 1982, Tertiary microfossils from the eastern province, Hokkaido. *In* Tanai, T., Ed., *Problems of the Neogene System in Hokkaido*, p. 33-48, 3 figs., 6 tabs. (*in* Japanese; original title translated).

Tanaka, H., Nakajima, K., and Yoshida, T., 1982MS, Neogene diatom fossils from the western part of Gunma Prefecture. *Geol. Soc. Japan, Ab-*

stract, 89th Annual Meeting, p. 169. (*in* Japanese; original title translated).

————, Nakajima, K., Kaneko, M., and Yoshida, T., 1983, Miocene diatom flora and radiolarian fauna at southern Usui Pass area, Gumma Prefecture, Central Japan. *Earth Science*, v. 37, no. 6, p. 349-360, 5 figs., 2 tabs., 3 pls. (*in* Japanese with English abstract).

Tsumaki, T., 1970MS, Geology and geologic structure of Hiraizumi Town, Iwate Prefecture. Tohoku Univ., Inst. Geol. Pal., Graduation Thesis. (*in* Japanese; original title translated).

Ueda, M., 1978MS, Geology of the eastern part of Mt. Kurikoma, Ichinoseki City, Iwate Prefecture. Tohoku Univ., Inst. Geol. Pal., Graduation Thesis. (*in* Japanese; original title translated).

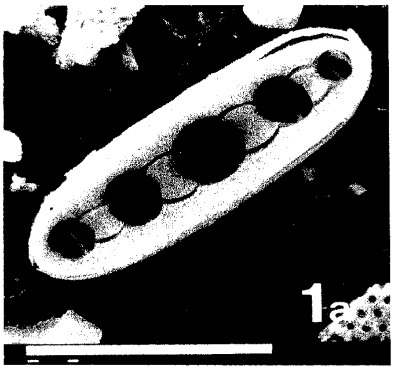
Umeda, H., 1979MS, Geology of the western part of Ichinoseki City, Iwate Prefecture. Tohoku Univ., Inst. Geol. Pal., Graduation Thesis. (*in* Japanese; original title translated).

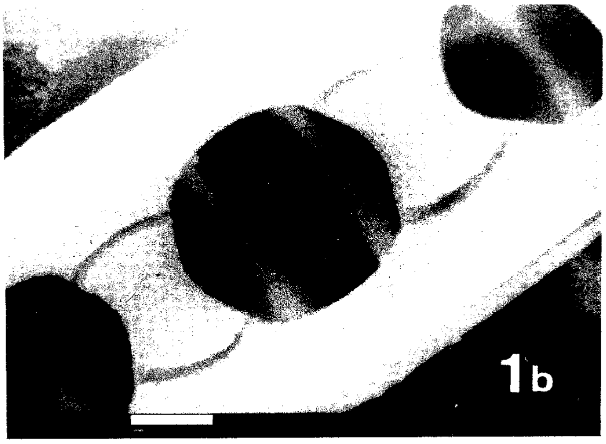
Yamamoto, S., 1941MS, Geology of the Ichinoseki area, Iwate Prefecture. Tohoku Imp. Univ., Inst. Geol. Pal., Graduation Thesis. (*in* Japanese; original title translated).

Plate 12

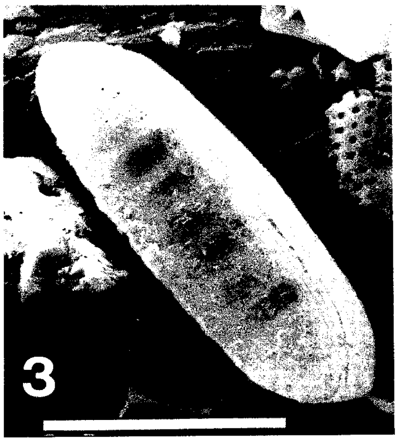
All figures scanning electron micrographs
Scale bars represent 10 μm in Figs. 1a, 2-8, 9a, and 1 μm in Figs. 1b, 9b.

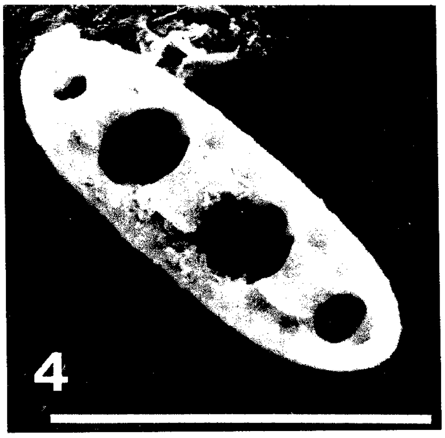
Figs. 1a-b, 2-6. *Denticulopsis katayamae* Maruyama n. sp.
  Sample DSDP Hole 438A 54-1 (110-114).
  1a-b. Inner view of a theca.
  2. Outer valve view.
  3. Oblique outer view of a theca.
  4-6. Inner view of a valve.
Figs. 7-8, 9a-b. *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen
  Sample AY-21, Kokubu Formation, Hitachi area.
  7, 9a-b. Inner view of a valve.
  8. Inner view of a theca.


1a

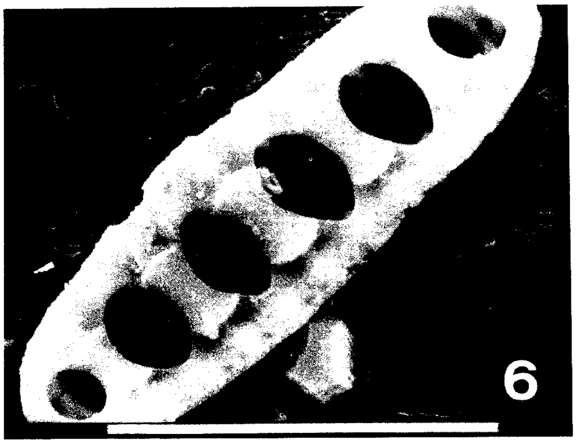

1b


2

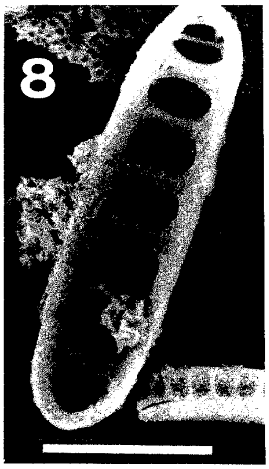

3


4


5


6

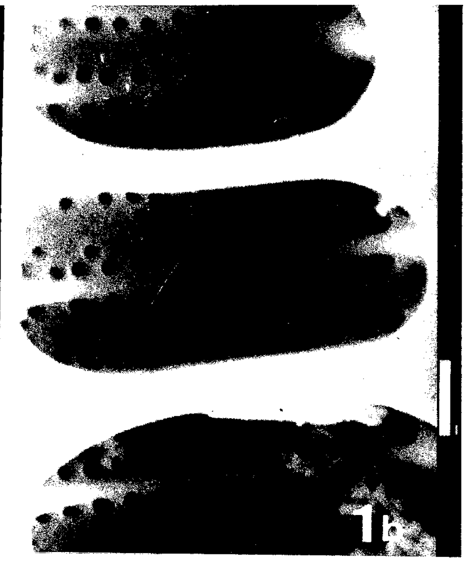

7


8

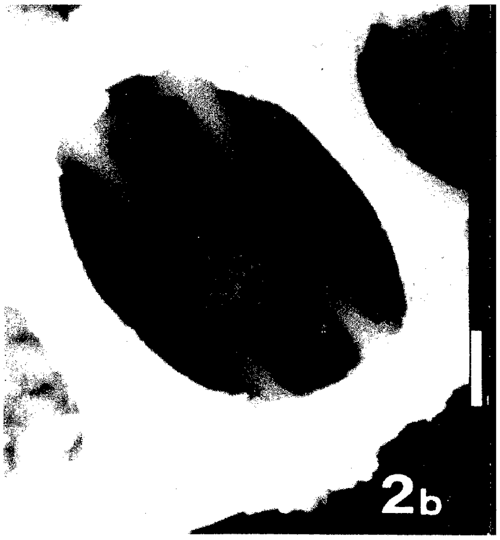

9b


9a


1a

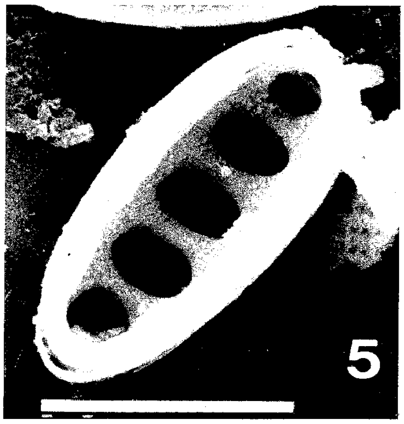

1b

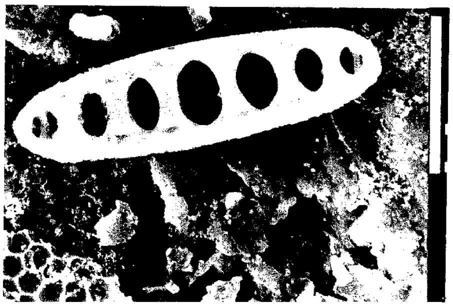

2a


2b

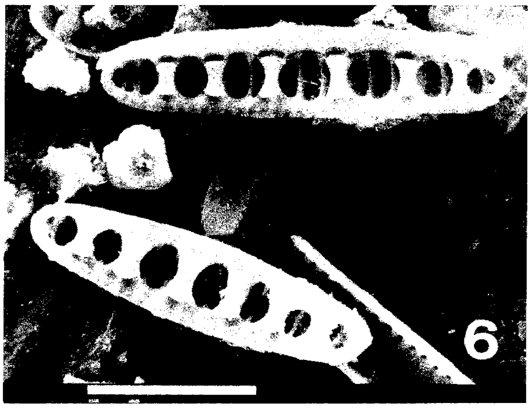

3

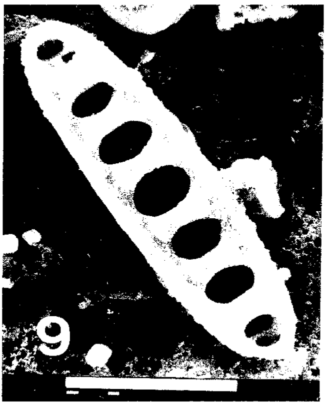

4


5




8


6


9

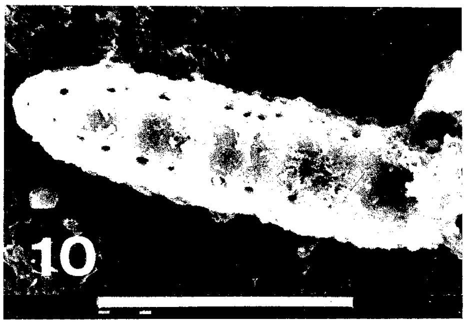

10

Plate 13

All figures scanning electron micrographs
Scale bars represent 10 μm in Figs. 1a, 2a, 3-10, and 1 μm in Figs. 1b, 2b.

Figs. 1a-b, 2a-b, 3. *Denticulopsis hustedtii* (elliptical form)
Sample AY-21, Kokubu Formation, Hitachi area.
1a-b. Inner view of a valve.
2a-b. Inner view of a theca.
3. Oblique inner view of a valve.

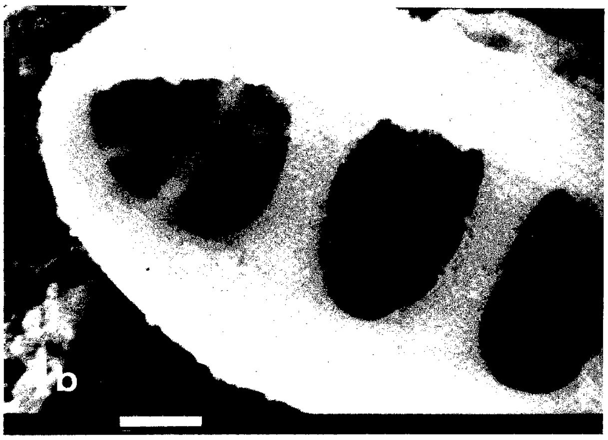
Figs. 4-6. *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen
Sample AY-21, Kokubu Formation, Hitachi area.
4. Inner view of a theca.
5. Inner view of a theca with another connecting band.
6. Inner view of a valve (lower specimen), inner view of a valve with destroyed connecting band (upper specimen).

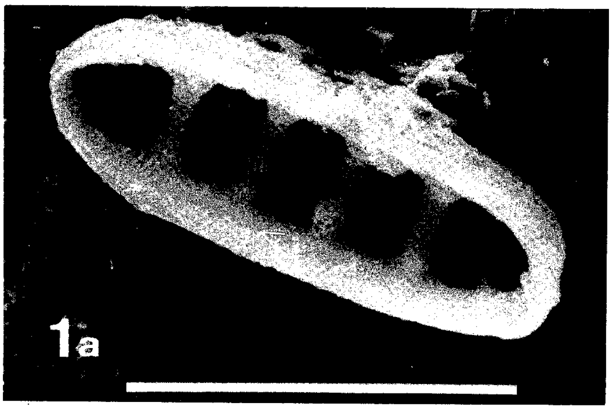
Figs. 7-10. *Denticulopsis hyalina* (Schrader) Simonsen
Sample DSDP Hole 438A 68-1 (30-34).
7-9. Inner view of a valve.
10. Valve view.

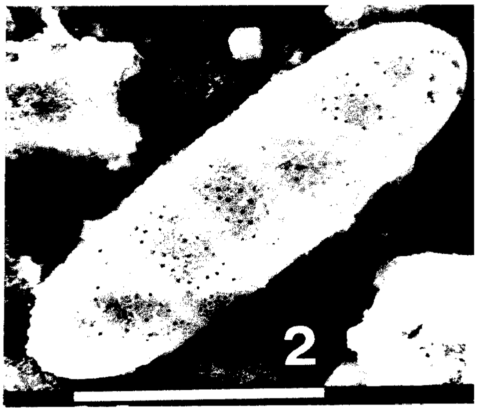
Plate 14

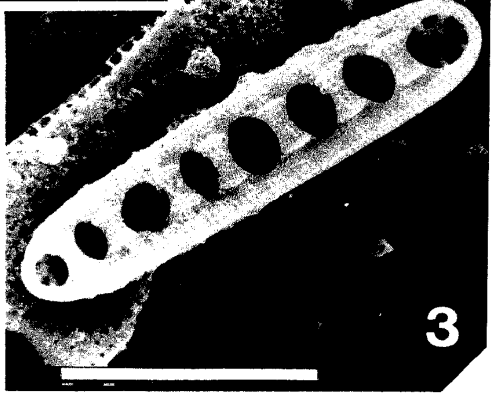
All figures scanning electron micrographs
Scale bars represent 10 μm in Figs. 1a, 2–7, 8a, and 1 μm in Figs. 1b, 8b.

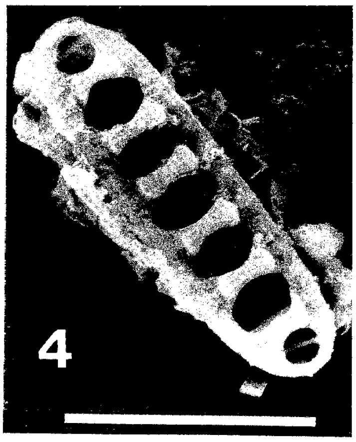
Figs. 1a–b, 2–7, 8a–b. *Denticulopsis lauta* (Bailey) Simonsen
1a–b. Oblique inner view of a theca, sample ZIR-23, Genjigawa Formation, Hitachiota area.
2. Valve view, sample DSDP Hole 438A 71-3 (7–11).
3–7, 8a–b. Inner view of a valve, sample ZIR-23, Genjigawa Formation, Hitachiota area.

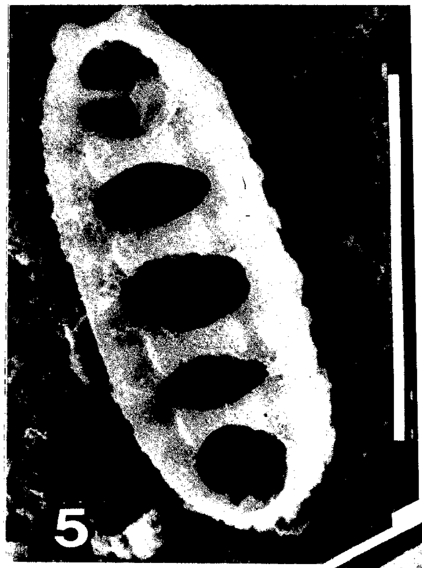

1b

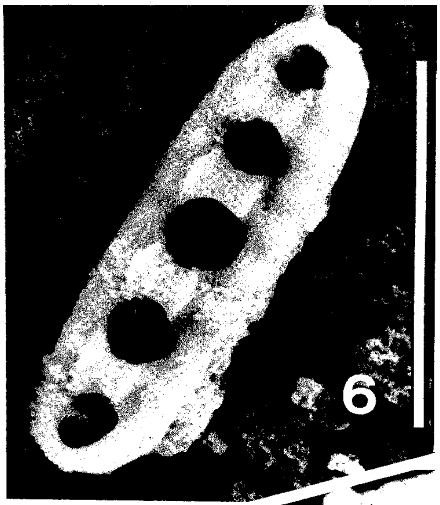

1a

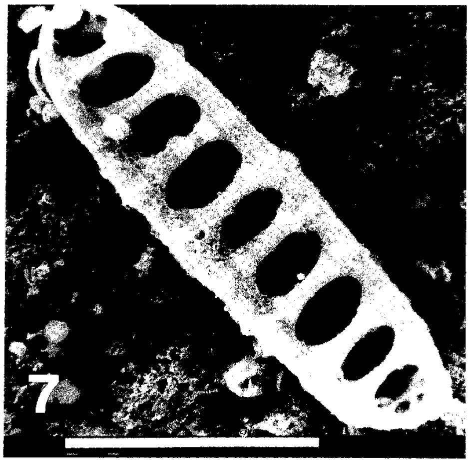

2

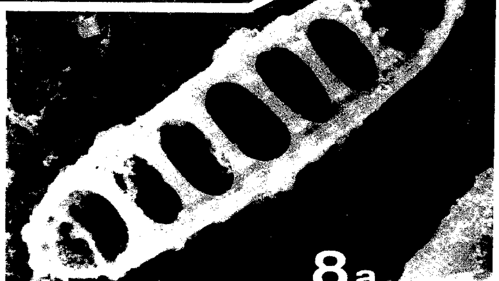

3


4

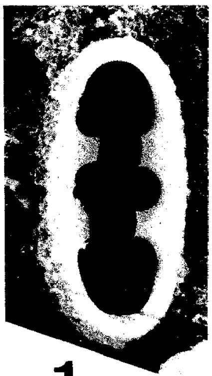

5


6

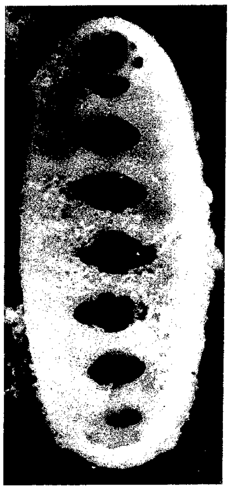

7

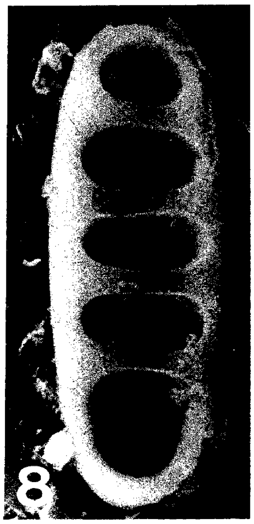

8a

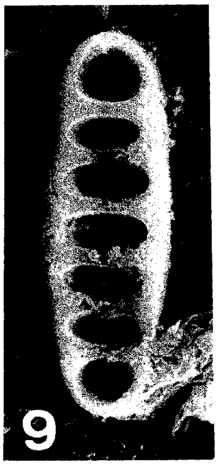

8b

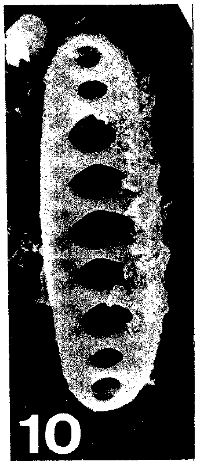

1

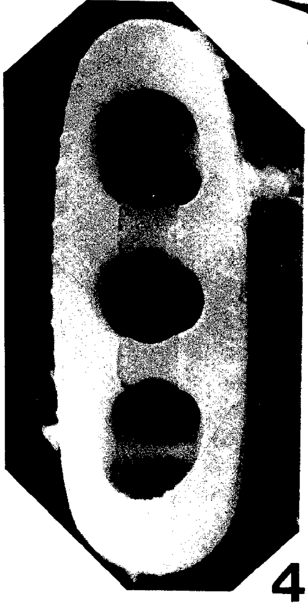

2

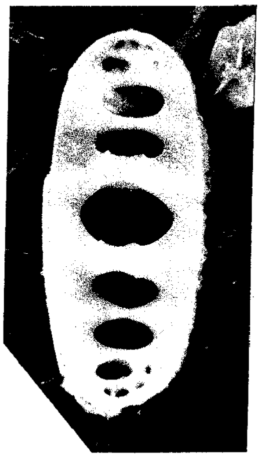

3

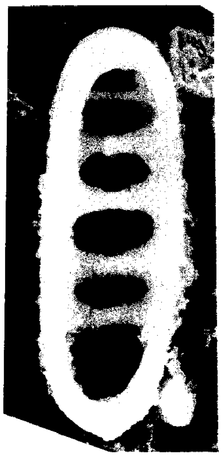


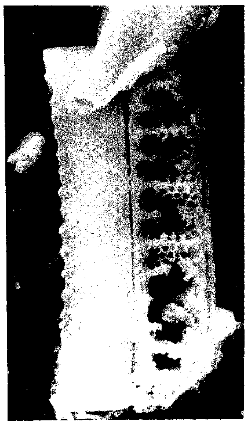


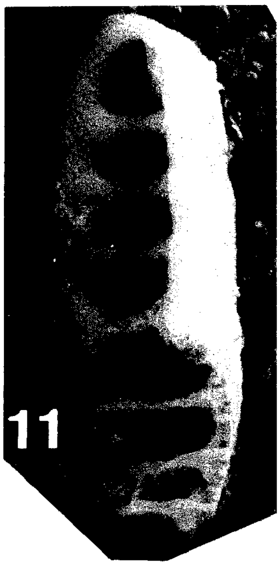


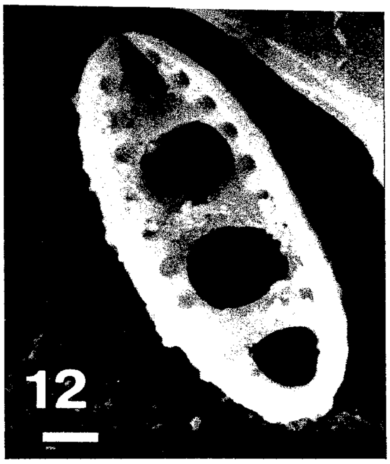

4

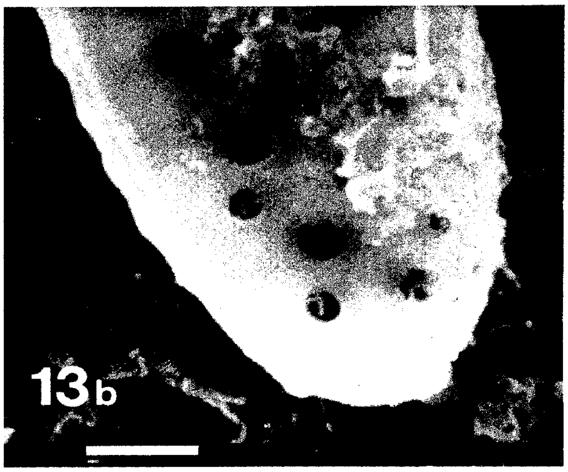

5


6


7







A

B

Plate 15

All figures scanning electron micrographs
Black scale bar A represents 10 μm in Figs. 1-3, 5-7, 9-10.
Black scale bar B represents 10 μm in Figs. 4, 8, 11.
White scale bars represent 1 μm in Figs. 12,13b, and 10 μm in Fig. 13a.

Figs. 1-7. *Denticulopsis praedimorpha* Akiba
Sample DSDP Hole 438A 65-1 (54-56).
1. Connecting band, B1-type.
2. Connecting band, B3-type.
3. Inner view of a shallower valve, V5-type.
4. Inner view of a deeper theca, B1+V3-type.
5. Inner view of a deeper valve, V5 (G1a)-type.
6. Inner view of a deeper theca, B3+V5-type.
7. Girdle view of a deeper theca.

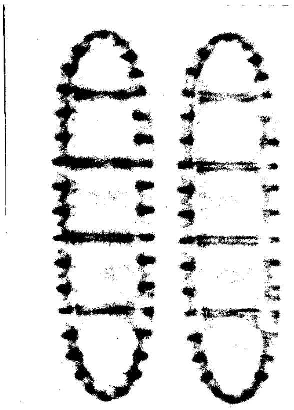
Figs. 8-11. *Denticulopsis dimorpha* (Schrader) Simonsen
Sample DSDP Hole 438A 59-1 (17-21).
8. Connecting band, B3-type.
9. Connecting band, B5-type.
10. Inner view of a shallower valve, V5-type.
11. Oblique inner view of a destroyed deeper theca, B5+V5-type.

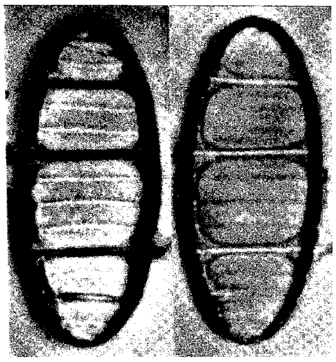
Figs. 12, 13a-b. *Denticulopsis nicobarica* (Grunow) Simonsen
Sample IWS-10, Shimokurosawa Formation, Ichinoseki area.
12. Inner view of a theca.
13a-b. Valve view.

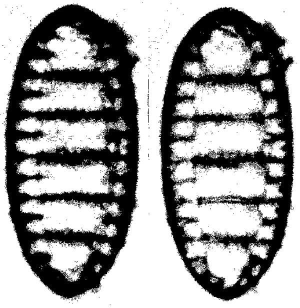
Plate 16

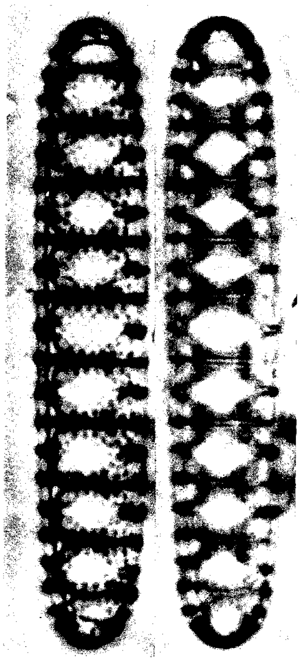
All figures transmitted photomicrographs
Scale bar represents 20 μm

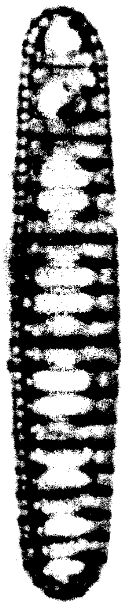
Figs. 1-3. *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen
  1. Sample IWN-1, Shimokurosawa Formation, Ichinoseki area.
  2-3. Sample AY-23, Kokubu Formation, Hitachi area.
Figs. 4, 5. *Denticulopsis hustedtii* (elliptical form)
  4. Sample AY-21, Kokubu Formation, Hitachi area.
  5. Sample DSDP Hole 438A 62-1 (20-24).
Fig. 6 *Denticulopsis punctata* (Schrader) Simonsen
  Sample TAH-6, Shimotezuna Formation, Takahagi area.
Figs. 7, 8. *Denticulopsis hyalina* (Schrader) Simonsen
  7. Sample KT-1, Katsuta Formation, Nakaminato area.
  8. Sample DSDP Hole 438A 71-3 (7-11).
Figs. 9, 10. *Denticulopsis lauta* (Bailey) Simonsen
  9. Sample TAH-9, Shimotezuna Formation, Takahagi area.
  10. Sample B-6, Tomioka Group, Usuitoge area.
Fig. 11. *Denticulopsis nicobarica* (Grunow) Simonsen
  Sample IWS-3, Shimokurosawa Formation, Ichinoseki area.
Fig. 12. *Denticulopsis nicobarica* var. 1
  Sample KT-1, Katsuta Formation, Nakaminato area.
Fig. 13. *Denticulopsis norvegica* (Schrader) Simonsen
  Sample B-6, Tomioka Group, Usuitoge area.

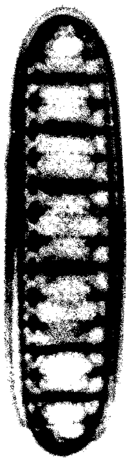

1

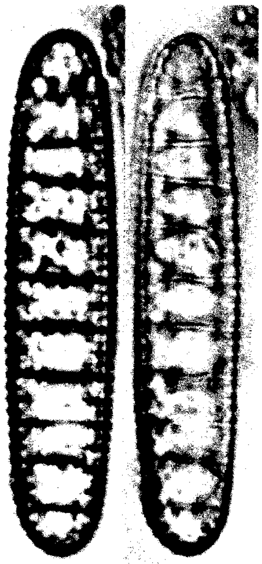

4

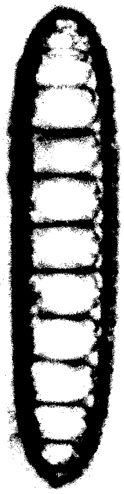

5

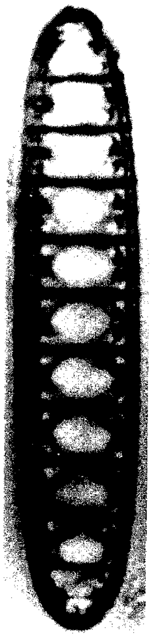

9

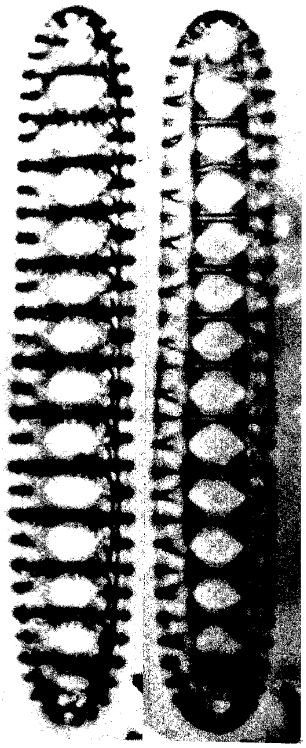

2

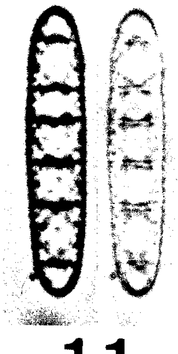

3

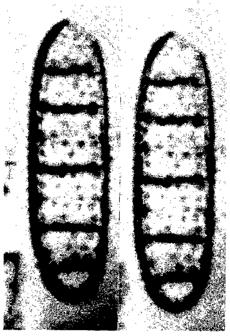

6

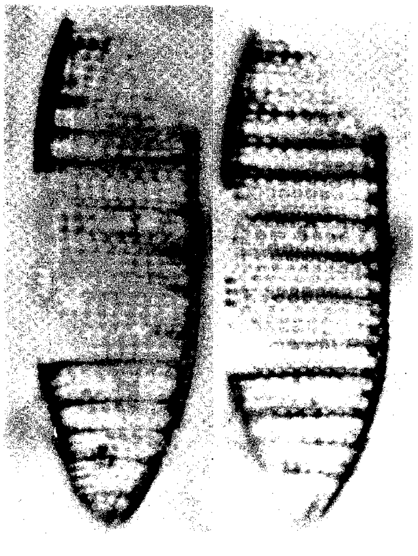

7

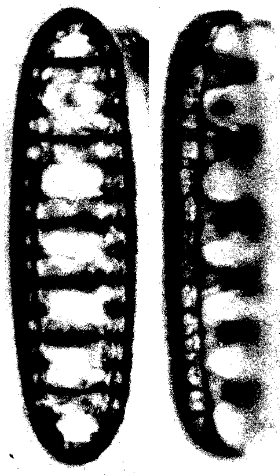

8

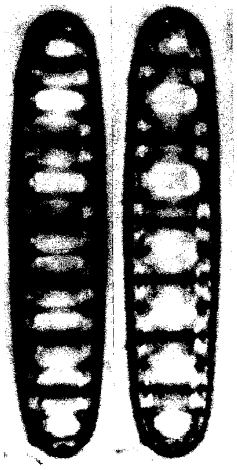

10

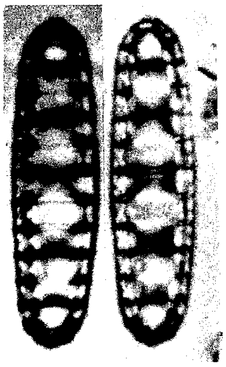

11

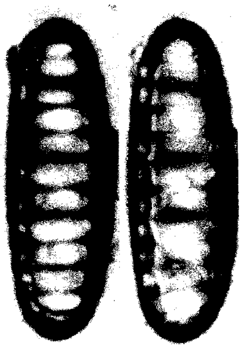

12

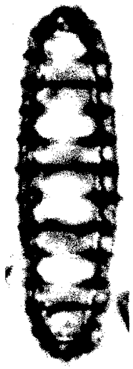

13

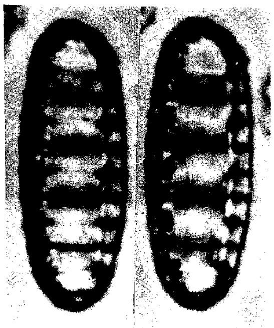

1

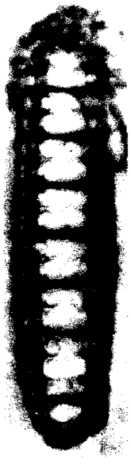

2

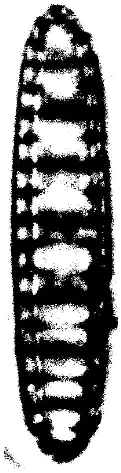

3

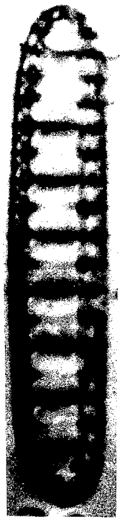

4

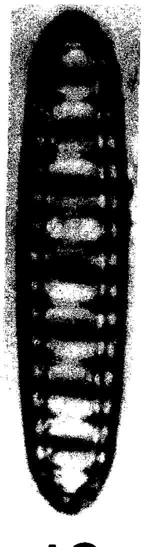

5

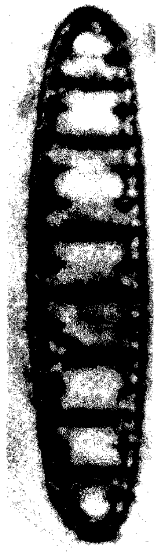

6

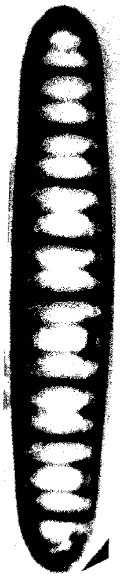

7


8

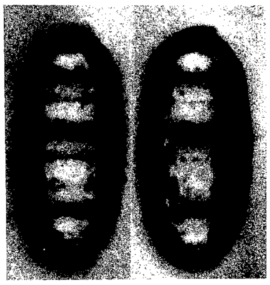

9

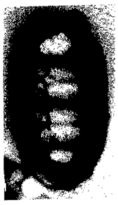

10

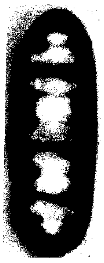

11

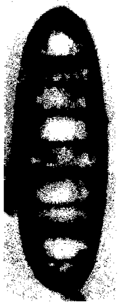

12

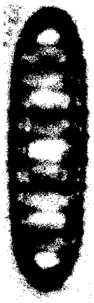

13


14

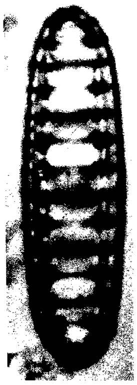

15

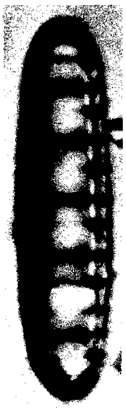

16

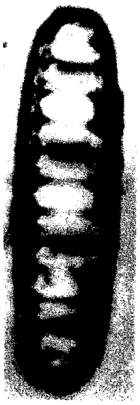

17


18


19


20


21


22

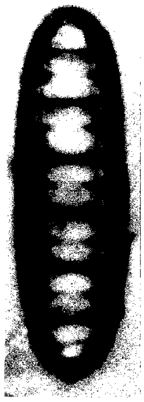

23

Plate 17

All figures transmitted photomicrographs
Scale bar represents 20 μm

Figs. 1–23. *Denticulopsis katayamae* Maruyama n. sp.

1. Valve view and oblique girdle view, sample DSDP Hole 438A 55-3 (70–74).

2–23. Valve view.

2. Holotype, IGPS 98255, sample STZ-30, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
3. Sample YAC-3, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
4. Sample YAC-13, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.

5, 7–9, 12, 15, 18–19. Sample DSDP Hole 438A 54-1 (110–114).

6. Sample YAC-8, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
10. Sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
11. Sample YAC-5, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
13. Sample YAC-11, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
14. Sample DSDP Hole 438A 57-2 (31–35).
16. Sample STZ-26, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
17. Sample DSDP Hole 438A 58-1 (16–20).
20. Sample YAC-14, Kamimetoki Sandstone Member, Shitazaki Formation, Sannohe area.

21–22. Sample STZ-24, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.

23. Sample YAC-12, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.

Plate 18

All figures transmitted photomicrographs
Scale bar represents 20 μm

Figs. 1-11. *Denticulopsis praedimorpha* Akiba
Deeper connecting band in valve view.

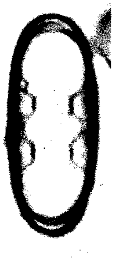
1. B1-type, sample IWN-1, Shimokurosawa Formation, Ichinoseki area.
2. B1a-type, sample IWN-3, Shimokurosawa Formation, Ichinoseki area.
3. B3-type, sample IWN-1, Shimokurosawa Formation, Ichinoseki area.
4. B3-type, sample IWN-5, Shimokurosawa Formation, Ichinoseki area.

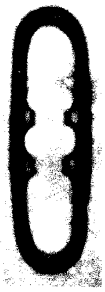
5, 9. B3a-type, sample KWG-10, Jumonji Sandstone Member, Tomesaki Formation, Sannohe area.
6, 7. B3-type, sample DSDP Hole 438A 64-3 (10-14).
8. B3-type, sample KWG-11, Jumonji Sandstone Member, Tomesaki Formation, Sannohe area.
10. B5-type, sample IWN-3, Shimokurosawa Formation, Ichinoseki area.
11. Ba3a-type, sample IWN-3, Shimokurosawa Formation, Ichinoseki area.

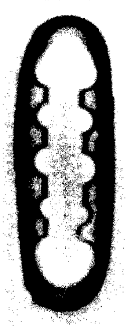
Figs. 12-34. *Denticulopsis dimorpha* (Schrader) Simonsen
Deeper connecting band in valve view.

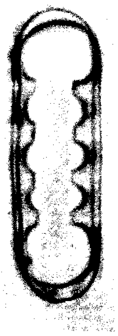
12. B1-type, sample STZ-25, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
13. B3-type, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
14. B3-type, sample DSDP Hole 438A 59-5 (17-21).

15, 19. B3a-type, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
16. B3a-type, sample STZ-23, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
17, 18. B4-type, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
20. B3a-type, sample STZ-24, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
21. B3a-type, sample DSDP Hole 438A 59-5 (17-21).
22. Ba3a-type, sample STZ-23, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
23. Ba3a-type, sample STZ-25, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
24. Ba3a-type, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
25, 26. B5-type, sample STZ-23, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
27. B5-type, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
28. B5-type, sample STZ-25, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
29. B5-type, sample STZ-23, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
30. B5-type, sample DSDP Hole 438A 59-5 (17-21).
31. B7-type, sample DSDP Hole 438A 59-5 (17-21).
32. B7-type, sample DSDP Hole 438A 59-1 (17-21).
33. B7-type, sample DSDP Hole 438A 57-3 (31-35).
34. B7-type, sample STZ-22, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.


1

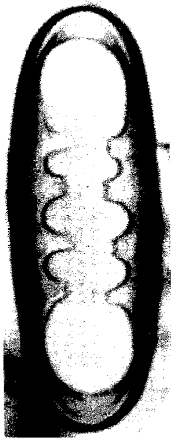

2

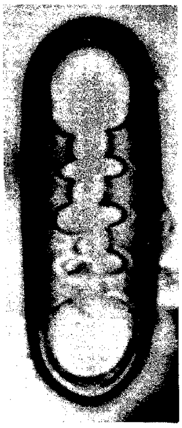

3

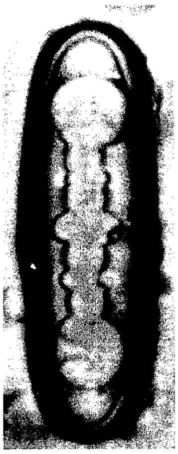

4

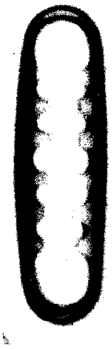

5

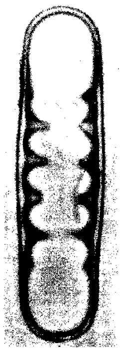

6

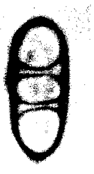

7

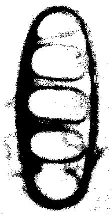

8

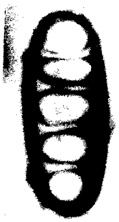

9

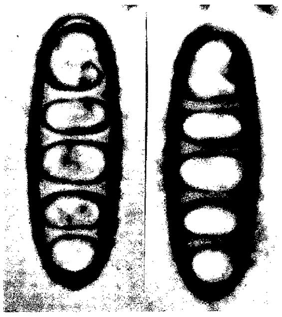

10

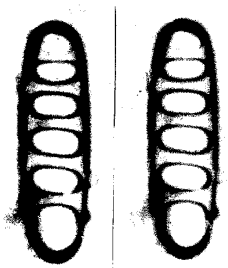

11

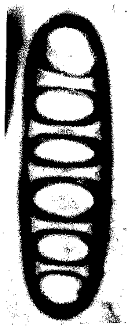

12

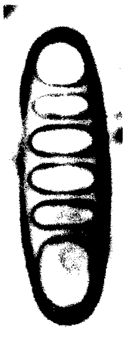

13


14

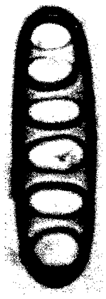

15

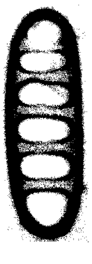

16

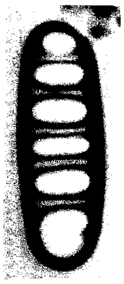

17

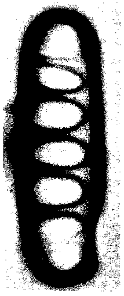

18

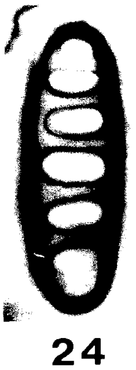

19

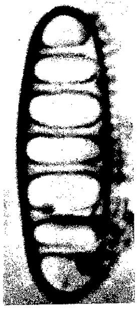

20

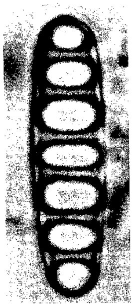

21

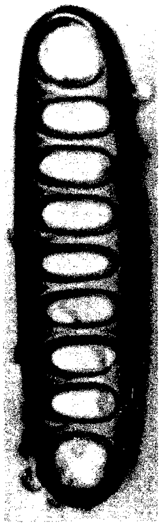

22

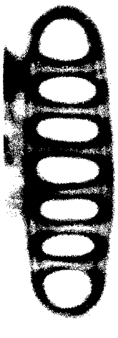

23

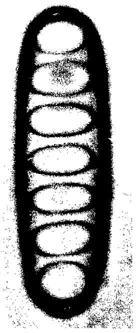

24


25

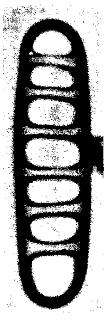

26

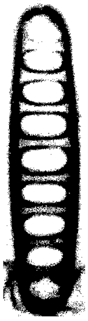

34

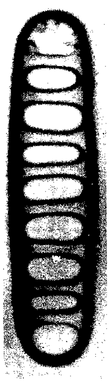

27

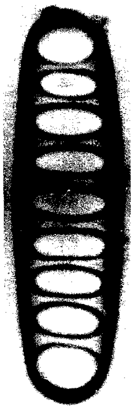

28

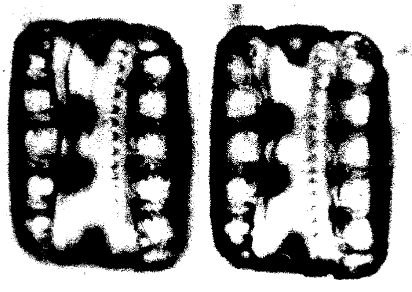

29

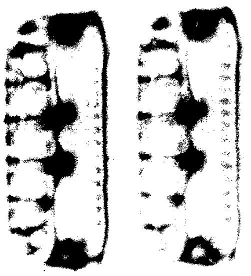

30

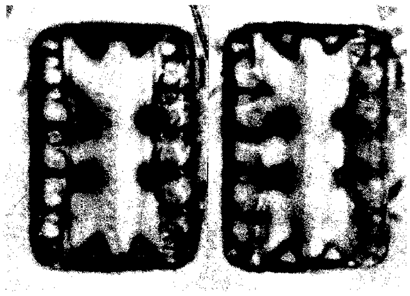

31

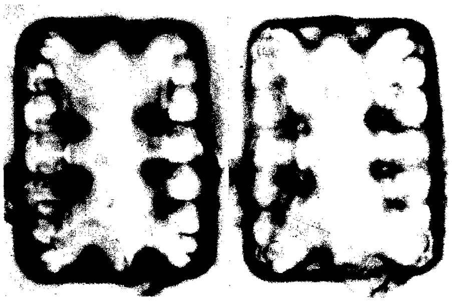

32

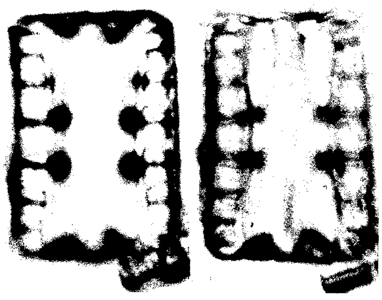

33

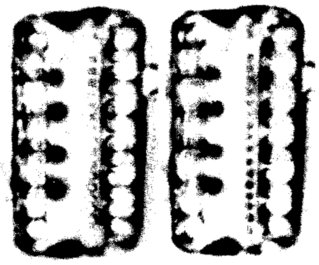

1


2

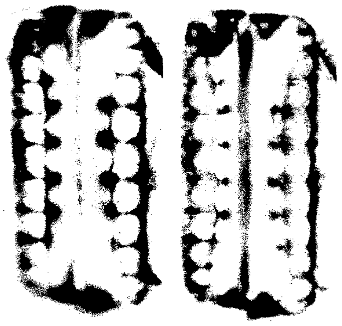

3

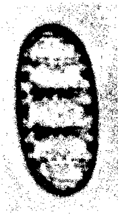

4

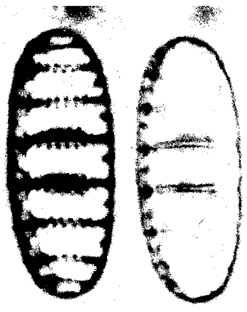

5

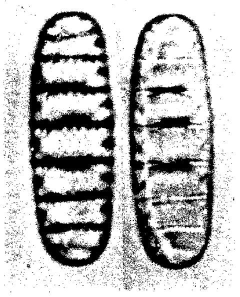

6

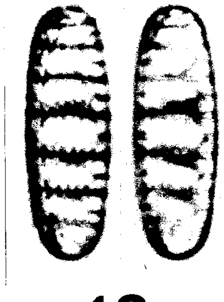

7

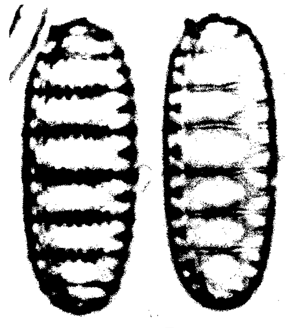

8

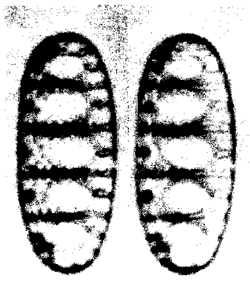

9


10


11


12


13


14

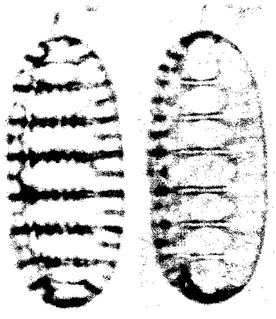

15

Plate 19

All figures transmitted photomicrographs
Scale bar represents 20 μm

Figs. 1-15. *Denticulopsis praedimorpha* Akiba

1. G1-type deeper theca+shallower theca, dotted thecal junction, sample IWN-14, Shimokurosawa Formation, Ichinoseki area.
2. G1-type deeper theca+shallower connecting band, dotted thecal junction, sample IWN-3, Shimokurosawa Formation, Ichinoseki area.
3. G1-type deeper theca+G1-type deeper theca, wavy thecal junction, sample IWN-14, Shimokurosawa Formation, Ichinoseki area.
4. G1-type deeper theca+G1-type deeper theca, probably straight thecal junction, sample IWN-11, Shimokurosawa Formation, Ichinoseki area.
5. G1-type deeper theca+G1-type deeper theca, straight thecal junction, sample IWN-14, Shimokurosawa Formation, Ichinoseki area.
6. G3-type deeper theca+shallower theca, dotted thecal junction, sample IWN-7, Shimokurosawa Formation, Ichinoseki area.
7. G3-type deeper theca+shallower theca, dotted thecal junction, sample IWN-5, Shimokurosawa Formation, Ichinoseki area.
8. G3a-type deeper theca+G3a-type deeper theca, straight thecal junction, sample IWN-1, Shimokurosawa Formation, Ichinoseki area.
9. V3 (=B1=G1)-type deeper valve, sample IWN-9, Shimokurosawa Formation, Ichinoseki area.
10. V5 (=B1=G1)-type deeper valve, sample IWN-3, Shimokurosawa Formation, Ichinoseki area.
11. V6 (=B1a=G1a)-type deeper valve, sample IWN-3, Shimokurosawa Formation, Ichinoseki area.
12. V5 (=B1a=G1a)-type deeper valve, sample IWN-1, Shimokurosawa Formation, Ichinoseki area.
13. V5 (=B3a=G3a)-type deeper valve, sample IWN-3, Shimokurosawa Formation, Ichinoseki area.
14. V3-type, probably shallower valve, sample IWN-17, Shimokurosawa Formation, Ichinoseki area.
15. V5-type shallower valve, sample IWN-3, Shimokurosawa Formation, Ichinoseki area.

Plate 20

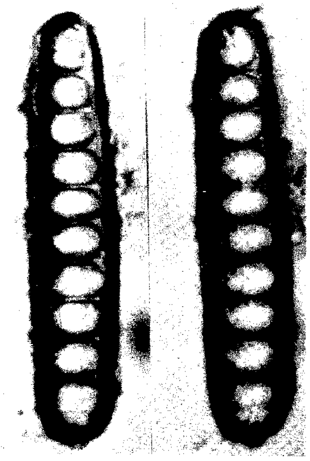
All figures transmitted photomicrographs
Scale bar represents 20 μm

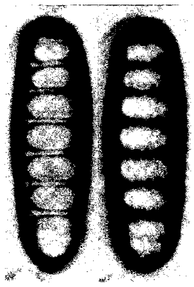
Figs. 1-18. *Denticulopsis dimorpha* (Schrader) Simonsen

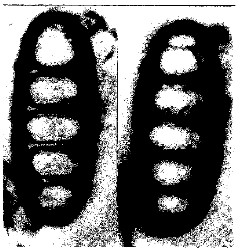
1. V8 (=B8=G8)-type deeper theca, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
2. V5 (=B5=G5)-type deeper theca, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
3. V3 (=B3=G3)-type deeper theca, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
4. V8-type shallower valve, sample STZ-22, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.

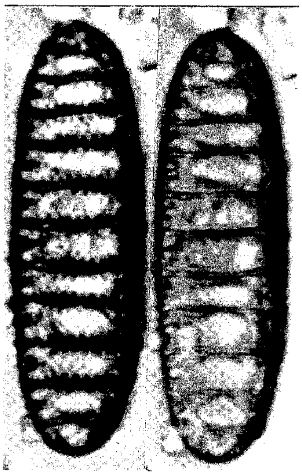
5, 6. Ga1a-type deeper theca, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.

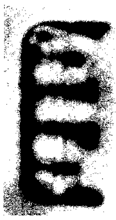
7. B1-type deeper connecting band+B1a-type deeper connecting band, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
8. Ba1a-type deeper connecting band+shallower theca, dotted thecal junction, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
9. G3-type deeper theca+B3-type deeper connecting band, straight thecal junction, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
10. G3-type deeper theca, sample DSDP Hole 438A 59-5 (17-21).
11. G3a-type deeper theca, sample DSDP Hole 438A 59-5 (17-21).
12. G3a-type deeper theca, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
13. G6-type deeper theca+B6-type deeper connecting band, straight thecal junction, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
14. Ga5a-type deeper theca, sample DSDP Hole 438A 57-2 (31-35).
15. G5-type deeper theca, sample DSDP Hole 438A 58-1 (16-20).
16. B9 (8a)-type deeper connecting band, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
17. Ga7a-type deeper theca, dotted thecal junction, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
18. G11-type deeper theca+shallower theca, dotted thecal junction, sample YAC-6, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.

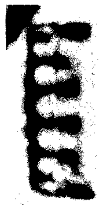

1


2


3

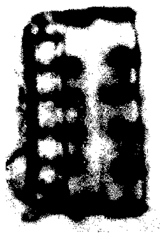

4

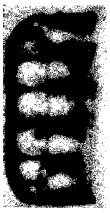

5

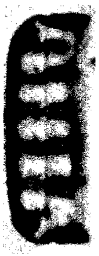

6

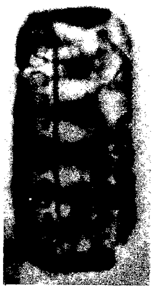

7

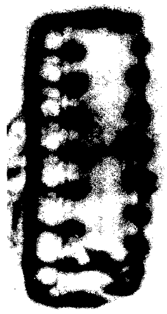

8

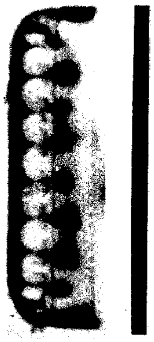

9

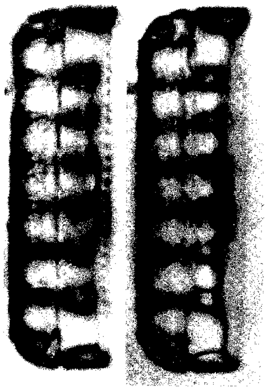

10

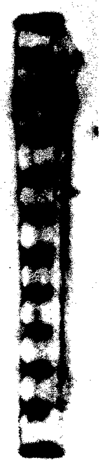

11

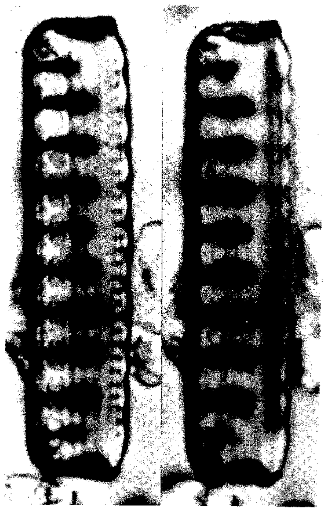

12

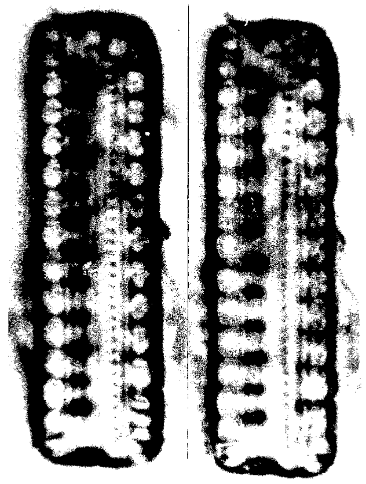

13


14


15


16


17


18