Miocene Diatom Biostratigraphy of Onshore Sequences on the Pacific Side of Northeast Japan, with Reference to DSDP Hole 438A (Part 2)

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Miocene Diatom Biostratigraphy of Onshore Sequences on the Pacific Side of Northeast Japan, with Reference to DSDP Hole 438A (Part 2)

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ABSTRACT

The biostratigraphic distribution of Miocene diatoms in onshore sequences on the Pacific side of Northeast Japan has been investigated with reference to Hole 438A of the Deep Sea Drilling Project. Determination of stratigraphic ranges of diagnostic diatom species enables the establishment of datum levels that are most reliable for a long-distance correlation. Eleven diatom datums are proposed on the basis of the stratigraphic distribution pattern of several species belonging to the genus *Denticulopsis*. By employing these datums, a composite sequence of Miocene strata is divided biostratigraphically into eleven zones in upward sequence, as follows: The *Actinocyclus ingens* Zone, *Denticulopsis lauta* Interval-zone, *D. hyalina* Interval-zone, *D. hustedtii* Interval-zone, *D. nicobarica* Interval-zone, *D. praedimorpha* Range-zone, *Coscinodiscus yabei* Interval-zone, *D. dimorpha* Range-zone, *D. katayamae* Interval-zone, *Thalassionema schraderi* Interval-zone, and *D. kamtschatica* Zone.

Onshore sequences have precisely been correlated with DSDP Hole 438A by means of these datum levels and zones proposed herein. Detailed correlation of the proposed zones with those of previous authors leads to a systematic explanation of the diatom biostratigraphy in the northwestern Pacific.

CONTENTS

INTRODUCTION

This is a continuation of the work by Maruyama (1984) where the present author classified the genus *Denticulopsis* into six groups, and proposed a new taxonomic formulation of representative *Denticulopsis* species. The morphology of *D. praedimorpha* and *D. dimorpha* was also studied and three trends in the evolutionary development of this genus were elucidated. A new diatom species *D. katayamae* was described, which was found to be useful for establishing the Miocene biostratigraphy in the northwestern Pacific region.

DIATOM DATUM LEVELS AND ZONATION

Eleven datum levels and eleven diatom zones are proposed and discussed below. For the purpose of a long-range stratigraphic correlation, the present author prefers interval-zones and the first appearances of easily recognizable taxa

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wherever possible. Consequently, six first appearances, three last appearances, and one rapid decrease and one rapid increase in abundance are recognized as important paleontologic events suitable for the delineation of datum levels. The eleven diatom zones established comprise seven interval, two range, and two unspecified zones. The boundaries of these zones are all related to a datum level as is signified in the range chart of diagnostic taxa (Fig. 2). The general framework and names of the proposed zones are similar to those of the diatom zonations of Koizumi (1973a, 1975d), Barron (1980, 1981), and Akiba (1979, 1982a).

Datum levels

It is generally known that a taxon trends to increase its abundance gradually up to a climax and then decreases toward its extinction point. A study of stratigraphic variations in abundance of a given taxon throughout its geologic range would conceptually give an elliptical form terminated in two narrow spines as shown in Fig. 1. Those intervals represented by the lower and upper spines, where the taxon is rare but occurs continuously, are defined as the Emerging and Declining Intervals (EI, DI), respectively. The interval corresponding to the ellipse, where the taxon occurs abundantly, is called the Thriving Interval (TI). As the taxon vigorously thrives to reach its maximum development, this interval corresponds to what has been called the acme.

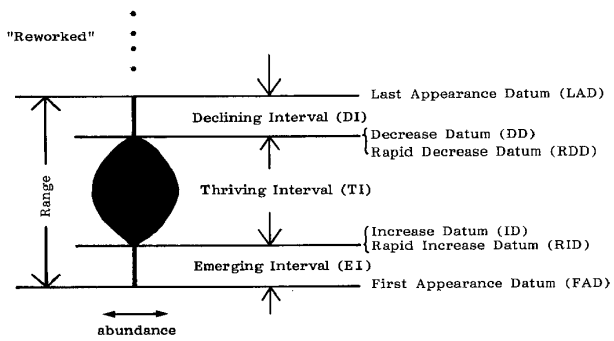


Fig. 1. Terminology of biohorizons explaining a mode of stratigraphic distribution of a diatom species.

Several datum levels are defined on the basis of the distribution pattern of species as mentioned above. The first appearance datum level (FAD) is defined as the base of the Emerging Interval. The increase datum level (ID) is defined as the boundary between the Emerging and Thriving Intervals. When a taxon rapidly increases its abundance across this level, it is called the rapid increase datum level (RID). The decrease datum level (DI) is defined as the boundary between the Thriving and Declining Intervals. If a taxon rapidly decreases its abundance across this level, it is named the rapid decrease datum level (RDD). The last appearance datum level (LAD) is defined as the top of the Declining Interval.

Specimens which occur very rarely and very sparsely above the Declining Interval are regarded as reworked specimens.

Figure 2 summarizes the datum levels and diatom zones discussed below, with stratigraphic ranges of diagnostic taxa.

1. The first appearance datum level of *Denticulopsis lauta* (FAD of *D. lauta*)

Definition: The level of the first appearance of *Denticulopsis lauta*.

Holotype locality: The Kadonosawa section, between samples KDN-5 and KDN-6, the middle part of the Shikonai Siltstone Member, Kadonosawa Formation, Shiratorigawa Group; a cliff near the confluence of the Shiratori River and its branch, under the bridge on a road between Tate and Shikonai, 3,250 m E of Kitafukuoka railroad station, Ninohe City, Iwate Prefecture (see Fig. 6).

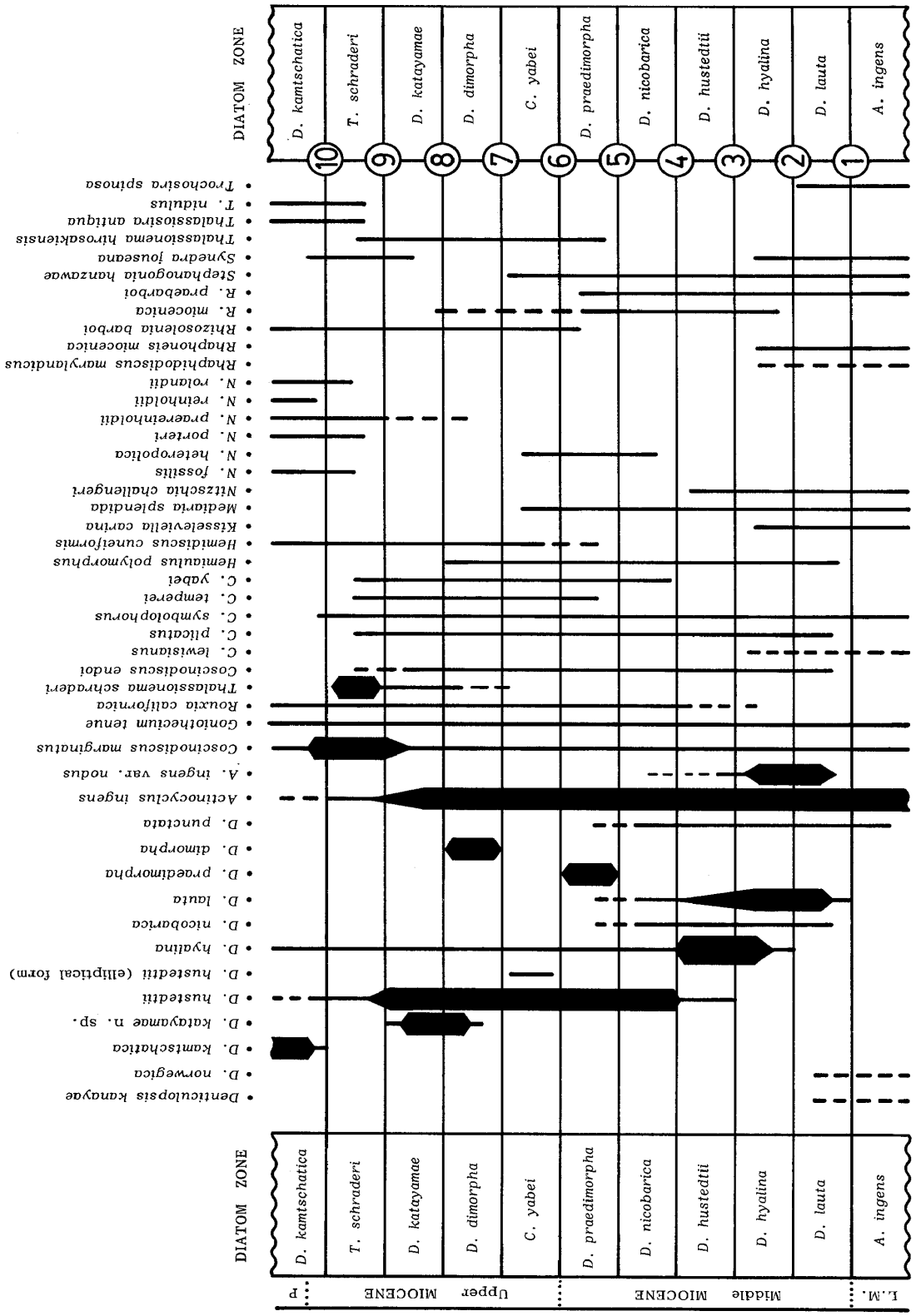


Fig. 2. Diatom zones proposed in this study with biostratigraphic ranges of selected diatoms.

2. The first appearance datum level of *Denticulopsis hyalina* (FAD of *D. hyalina*)

Definition: The level of the first appearance of *Denticulopsis hyalina*.

Holotype locality: The Takahagi section, between samples TAH-7 and TAH-8, the lower part of the Shimotezuna Formation; a roadside cliff along a descending road leading from Daitakahagi to Sugiuchi, 2 km NW of Takahagi railroad station, Takahagi City, Ibaraki Prefecture (see Fig. 17).

Paratype locality: The Sawadasawa section, between samples SAW-6 and SAW-7A, the middle part of the Jumonji Sandstone Member, Tomesaki Formation, Sannohe Group; a roadside cliff between Sawada and Yanagisawa, 2,500 m SW of Kintaichi railroad station, Ninohe City, Iwate Prefecture (see Fig. 6).

3. The first appearance datum level of *Denticulopsis hustedtii* (FAD of *D. hustedtii*)

Definition: The level of the first appearance of *Denticulopsis hustedtii*.

Holotype locality: The Nakaminato section, between samples KT-3 and KT-4, the middle part of the Katsuta Formation; a cliff at the foot of a hill near Takai, 3,850 m NW of the mouth of the Naka River, Nakaminato City, Ibaraki Prefecture (see Fig. 23).

Paratype locality: DSDP Hole 438A, between core 68, section 4, 68–72 cm and core 68, section 1, 30–34 cm, off Northeast Honshu (see Fig. 3).

4. The rapid decrease datum level of *Denticulopsis hyalina* (RDD of *D. hyalina*)

Definition: The level of a rapid decrease of *Denticulopsis hyalina*.

Holotype locality: The Nakaminato section, between samples KT-8 and KT-10, the upper part of the Katsuta Formation; a cliff at the foot of a hill near Takai, 4,850 m NW of the mouth of the Naka River, Nakaminato City, Ibaraki Prefecture (see Fig. 23).

Paratype localities: The Takahagi section, between samples TAH-9 and TAH-10, the lower part of the Shimotezuna Formation; a cutting along a road descending from Daitakahagi to Sugiuchi, 1,900 m NW of Takahagi railroad station, Takahagi City, Ibaraki Prefecture (see Fig. 17): DSDP Hole 438A, between core 67, section 1, 27–32 cm and core 66, section 1, 118–122 cm, off Northeast Honshu (see Fig. 3).

Remarks: *Denticulopsis hyalina* decreases in abundance from 40–60% to a few percent across this datum.

5. The rapid increase datum level of *Denticulopsis hustedtii* (RID of *D. hustedtii*)

Definition: The level of a rapid increase of *Denticulopsis hustedtii*.

Holotype locality: The Nakaminato section, between samples KT-8 and KT-10, the upper part of the Katsuta Formation; a cliff at the foot of a hill near Takai, 4,850 m NW of the mouth of the Naka River, Nakaminato City, Ibaraki Prefecture (see Fig. 23).

Paratype locality: DSDP Hole 438A, between core 67, section 1, 27–32 cm and core 66, section 1, 118–122 cm, off Northeast Honshu (see Fig. 3).

Remarks: *Denticulopsis hustedtii* increases in abundance from several percent to more than 10% across this datum.

6. The first appearance datum level of *Denticulopsis praedimorpha* (FAD of *D. praedimorpha*)

Definition: The level of the first appearance of *Denticulopsis praedimorpha*. The FAD of this species is defined by the first appearance of deeper theca in girdle view and/or deeper connecting band so as to avoid confusion with *D. lauta* s.s.

Holotype locality: The Iwaigawa sec-

tion, between samples SHA-5 and SHA-4, the middle "main part" of the Shimokurosawa Formation; the right bank of the Iwai River, under the bridge on Tohoku Express Way, Ichinoseki City, Iwate Prefecture (see Fig. 13).

Paratype localities: The Takahagi section, between samples TAH-13 and TAH-14, the upper part of the Shimotezuna Formation; a roadside cliff, 1,400 m NW of Takahagi railroad station, Takahagi City, Ibaraki Prefecture (see Fig. 17): The Kawaguchi section, between samples KWG-1 and KWG-3, the Jumonji Sandstone Member, Tomesaki Formation, Sannohe Group; a cliff on the right bank of the Kaisho River, 250 m S of Kawaguchi, Ninohe City, Iwate Prefecture (see Fig. 6).

7. The last appearance datum level of *Denticulopsis praedimorpha* (LAD of *D. praedimorpha*)

Definition: The level of the last appearance of *Denticulopsis praedimorpha*. Defined by the upper limit of the Declining Interval of specimens having deeper theca in girdle view and/or deeper connecting band.

Holotype locality: The Kawaguchi section, between samples KWG-12 and KWG-13, near the top of the Jumonji Sandstone Member, Tomesaki Formation, Sannohe Group; a cliff on the right bank of the Kaisho River, 250 m S of Kawaguchi, Ninohe City, Iwate Prefecture (see Fig. 6).

Paratype localities: The Ayukawa section, between samples AY-9 and AY-11, the Kokubu Formation; a riverside cliff under the bridge between Ayukawa and Nakanarisawa, 900 m W of the mouth of the Ayu River, Hitachi City, Ibaraki Prefecture (see Fig. 19): The Sawadasawa section, between samples SAW-12 and SAW-13, near the boundary between the Jumonji Sandstone and Numanokubo Diatomaceous Mudstone Members, Tomesaki Formation, Sannohe Group; a roadside cutting between Sawada and Yanagisawa, 2,750 m SW of Kintaichi railroad station, Ninohe City, Iwate Prefecture (see Fig. 6).

8. The first appearance datum level of *Denticulopsis dimorpha* (FAD of *D. dimorpha*)

Definition: The level of the first appearance of *Denticulopsis dimorpha*. Defined by the first appearance of specimens having deeper theca in girdle view and/or deeper connecting band, which distinguishes *D. dimorpha* from *D. lauta* and *D. praedimorpha*.

Holotype locality: The Shitazaki section, between samples STZ-16 and STZ-17, the Kamimetoki Sandstone Member, Shitazaki Formation, Sannohe Group; the right bank of the Mabechi River, under the bridge between Shitazaki and Kamasawa, 250 m SW of Seigan Bridge, Ninohe City, Iwate Prefecture (see Fig. 6).

Paratype localities: The Yachizawa section, between samples YAC-15 and YAC-14, the Kamimetoki Sandstone Member, Shitazaki Formation, Sannohe Group; a riverside cliff along a branch of the Kaisho River, 1,750 m S of Shimokaisho, Ninohe City, Iwate Prefecture (see Fig. 6): DSDP Hole 438A, between core 60, section 1, 34–38 cm and core 59, section 5, 17–21 cm, off Northeast Honshu (see Fig. 3).

9. The last appearance datum level of *Denticulopsis dimorpha* (LAD of *D. dimorpha*)

Definition: The level of the last appearance of *Denticulopsis dimorpha*. Defined by the upper limit of the Declining Interval of specimens having deeper theca in girdle view and/or deeper connecting band.

Holotype locality: The Shitazaki section, between samples STZ-27 and STZ-28, the Shitazaki Siltstone Member, Shitazaki Formation, Sannohe Group; a

cliff on the left bank of the Mabechi River, near the border between Iwate and Aomori Prefectures, 500 m NW of Kamasawa, Ninohe City, Iwate Prefecture (see Fig. 6).

Paratype localities: The Yachizawa section, between samples YAC-2 and YAC-1, the Shitazaki Siltstone Member, Shitazaki Formation, Sannohe Group; a riverside cliff along a branch of the Kaisho River, 750 m S of Shimokaisho, Ninohe City, Iwate Prefecture (see Fig. 6): DSDP Hole 438A, between core 56, section 1, 20–24 cm and core 55, section 3, 70–74 cm, off Northeast Honshu (see Fig. 3).

10. The last appearance datum level of *Denticulopsis katayamae* (LAD of *D. katayamae*)

Definition: The level of the last appearance of *Denticulopsis katayamae*.

Holotype locality: The Shitazaki section, between samples STZ-34 and STZ-35, the Shitazaki Siltstone Member, Shitazaki Formation, Sannohe Group; a riverside cliff along a branch of the Mabechi River, near the border between Iwate and Aomori Prefectures, 500 m W of Kamasawa, Ninohe City, Iwate Prefecture (see Fig. 6).

Paratype localities: The Kosakazawa section, between samples KOS-4 and KOS-5, the Shitazaki Siltstone Member, Shitazaki Formation, Sannohe Group; a riverside cliff along a branch of the Kaisho River, 500 m N of Shimokaisho, Ninohe City, Iwate Prefecture (see Fig. 6): DSDP Hole 438A, between core 49, section 6, 10–14 cm and core 49, section 3, 10–14 cm, off Northeast Honshu (see Fig. 3).

11. The first appearance datum level of *Denticulopsis kamtschatica* (FAD of *D. kamtschatica*)

Definition: The level of the first appearance of *Denticulopsis kamtschatica*.

Holotype locality: DSDP Hole 438A, between core 42, section 6, 16–20 cm and core 42, section 4, 50–54 cm, off Northeast Honshu (see Fig. 3).

Zonation

1. *Actinocyclus ingens* Zone

Definition: The base is not defined, the top is the FAD of *D. lauta* s.s.

Age: Early Miocene.

Important characteristics: This zone is characterized by the occurrence of abundant *A. ingens*, common *Kisseleviella carina* and rare *Denticulopsis norwegica*.

Geographic distribution: This zone is recognized in the lower part of the Kadonosawa Formation, sample KDN-3 to KDN-5, Kadonosawa section, Sannohe area (see Fig. 7).

Correlation: This zone is approximately coeval with the *Actinocyclus ingens* Zone of Akiba (Akiba *et al.*, 1982a, b), Barron (1980) and Koizumi (1980b) (see Fig. 28).

2. *Denticulopsis lauta* Interval-zone

Definition: The interval from the FAD of *D. lauta* to the FAD of *D. hyalina*.

Age: Middle Miocene.

Important characteristics: The lower part of this zone is characterized by the presence of an abundant to common *Kisseleviella carina* and rare *D. lauta*. The upper part is characterized by abundant occurrences of *D. lauta*.

Geographic distribution: This zone is recognized in the following sections: The upper part of the Kadonosawa Formation and the basal part of the Suenomatsuyama Formation, sample KDN-6 to KDN-15, Kadonosawa section, Sannohe area (see Fig. 7); the basal part of the Shimotezuna Formation, sample TAH-4 to TAH-7, Takahagi section, Takahagi area (see Fig. 18); the lower part of the Genjigawa Formation, sample ZIR-18 to ZIR-39, Zuiryuzawa section,

Hitachiota area (see Fig. 22); the Tomioka Group, sample B-6 to B-1, Usuitoge section, Usuitoge area (see Fig. 26).

Correlation: This zone is correlated with the Subzone *a* of the *D. lauta* Zone of Barron (1980) and the Subzone B of the *D. lauta* Zone of Akiba *et al.* (1982b), and approximately corresponds to the lower part of the *D. lauta* Zone of Koizumi (1979b, 1980b) (see Fig. 28).

Remarks: The first appearance of *Actinocyclus ingens* var. *nodus* is noted in the middle of this zone in Northeast Honshu, Japan.

3. *Denticulopsis hyalina* Interval-zone

Definition: The interval from the FAD of *D. hyalina* to the FAD of *D. hustedtii*.

Age: Middle Miocene.

Important characteristics: This zone is characterized by common to abundant occurrences of *D. lauta* and *D. hyalina* and by common *Actinocyclus ingens* var. *nodus*.

Geographic distribution: This zone is recognized in the following sections: DSDP Hole 438A, core 73-5 (9-11) through core 68-4 (68-72) (see Fig. 4); the middle part of the Jumonji Sandstone Member of the Tomesaki Formation, sample SAW-7A to SAW-7B, Sawadasawa section, Sannohe area (see Fig. 8); the lower part of the Shimotezuna Formation, sample TAH-8 to TAH-9, Takahagi section, Takahagi area (see Fig. 18); the lower part of the Katsuta Formation, sample KT-1 to KT-3, Nakaminato section, Nakaminato area (see Fig. 24).

Correlation: This zone is correlated with the Subzone *b* of the *D. lauta* Zone of Barron (1980) and the Subzone A of the *D. lauta* Zone of Akiba *et al.* (1982a, b), and approximately corresponds to the upper part of the *D. lauta* Zone of Koizumi (1979b, 1980b) (see Fig. 28).

Remarks: In the region of Northeast Japan, the last occurrence of *Coscinodiscus lewsianus* and the last occurrence of *Kisseleviella carina* are discerned within this zone.

4. *Denticulopsis hustedtii* Interval-zone

Definition: The interval from the FAD of *D. hustedtii* to the RDD of *D. hyalina*.

Age: Middle Miocene.

Important characteristics: This zone is characterized by the occurrence of abundant *D. hyalina* and rare *D. hustedtii*.

Geographic distribution: This zone is recognized in the following sections: DSDP Hole 438A, core 68-1 (30-34) through core 67-1 (27-32) (see Fig. 4); the middle to upper part of the Katsuta Formation, sample KT-4 to KT-8, Nakaminato section, Nakaminato area (see Fig. 24).

Correlation: This zone probably corresponds to the lower part of the Subzone *a* of the *D. hustedtii-D. lauta* Zone of Barron (1980), the lower part of the *D. nicobarica* Zone of Akiba (1979; Akiba *et al.*, 1982a, b) and the lower part of the Subzone *a* of the *D. hustedtii-D. lauta* Zone of Koizumi (1980b) (see Fig. 28).

Remarks: A rapid decrease in abundance of *D. lauta* is recognized in the middle part of this zone in the Nakaminato area. On the other hand, in DSDP Hole 438A, the abundance of *D. lauta* rapidly declines near the top of the *D. hyalina* Interval-zone. If the FAD of *D. hustedtii* is isochronous in Northeast Honshu, regional differences exist in the timing of the rapid decrease of *D. lauta*.

5. *Denticulopsis nicobarica* Interval-zone

Definition: The interval from the RDD of *D. hyalina* to the FAD of *D. praedimorpha*.

Age: Middle Miocene.

Important characteristics: This zone

is characterized by the presence of common *D. nicobarica* and abundant *D. hustedtii*.

Geographic distribution: This zone is recognized in the following sections: The lower part of the Shimokurosawa Formation, sample IWS-1 to SHA-5, Iwaigawa section, Ichinoseki area (see Fig. 14); the middle part of the Shimotezuna Formation, sample TAH-10 to TAH-13, Takahagi section, Takahagi area (see Fig. 18); the upper part of the Katsuta Formation, sample KT-10, Nakaminato section, Nakaminato area (see Fig. 24).

Correlation: This zone corresponds to the upper part of the Subzone *a* of the *D. hustedtii-D. lauta* Zone of Barron (1980), the upper part of the *D. nicobarica* Zone of Akiba (1979; Akiba *et al.*, 1982a, b) and the middle part of the Subzone *a* of the *D. hustedtii-D. lauta* Zone of Koizumi (1975d, 1980b) (see Fig. 28).

Remarks: This zone, which is characterized by the occurrence of *D. nicobarica*, is confirmed in a wide geographic region of Northeast Honshu. It should be emphasized, however, that *D. nicobarica* has never been encountered in the diatom assemblages from strata equivalent to the *D. nicobarica* Interval-zone in the Ishiizawa section of eastern Hokkaido (Akiba *et al.*, 1982a; Takayanagi *et al.*, 1982). From the data accumulated it is inferred that *D. nicobarica*, possibly a warm-water species (Koizumi, 1981a), did not extend its distribution northward beyond Honshu during Middle Miocene time.

6. *Denticulopsis praedimorpha* Range-zone

Definition: The interval from the FAD of *D. praedimorpha* to the LAD of *D. praedimorpha*, namely, the total range of *D. praedimorpha*.

Age: Middle Miocene.

Important characteristics: This zone is characterized by the occurrence of common to abundant *D. praedimorpha* and common *D. hustedtii*.

Geographic distribution: This zone is recognized in the following sections: DSDP Hole 438A, core 66-1 (118-122) through core 64-3 (10-14) (see Fig. 4); the upper part of the Jumonji Sandstone Member of the Tomesaki Formation, sample SAW-11 to SAW-12 in the Sawadasawa section, sample KWG-3 to KWG-12 in the Kawaguchi section, Sannohe area (see Figs. 8, 10); the upper part of the Shimokurosawa Formation, sample SHA-4 to IWN-24, Iwaigawa section, Ichinoseki area (see Fig. 14); the middle part of the Hatatate Formation, sample HTT-3 to HTT-21, Taihakusan section, Sendai area (see Fig. 16); the upper part of the Shimotezuna Formation, sample TAH-14 to TAH-16, Takahagi section, Takahagi area (see Fig. 18); the middle part of the Kokubu Formation, sample AY-1 to AY-17, Ayukawa section, Hitachi area (see Fig. 20); the main part of the Isozaki Formation, sample IZ-1 to IZ-3, Nakaminato section, Nakaminato area (see Fig. 24).

Correlation: This zone is correlated with the *D. praedimorpha* Zone of Akiba (1979; Akiba *et al.*, 1982a, b) and approximately equatable with the Subzone *b* to the lower part of Subzone *c* of the *D. hustedtii-D. lauta* Zone of Barron (1980). This zone probably corresponds to the upper part of the Subzone *b* of the *D. hustedtii-D. lauta* Zone of Koizumi (1980b) (see Fig. 28).

7. *Coscinodiscus yabei* Interval-zone

Definition: The interval from the LAD of *D. praedimorpha* to the FAD of *D. dimorpha*.

Age: Late Miocene.

Important characteristics: This zone is characterized by the presence of abundant *D. hustedtii*, abundant to common *A. ingens*, few to rare *Goniothecium tenue* and *Rouxia californica*. *Coscinodiscus*

yabei occurs in few to rare abundances throughout this zone.

Geographic distribution: This zone is recognized in the following sections: DSDP Hole 438A, core 64-1 (10–14) through core 60–1 (34–38) (see Fig. 4); the main part of the Numanokubo Diatomaceous Mudstone Member of the Tomesaki Formation through the lower part of the Kamimetoki Sandstone Member of the Shitazaki Formation, sample SAW-13 to SAW-15 in the Sawadasawa section, sample KWG-13 to KWG-20 in the Kawaguchi section, sample YAC-16 to YAC-15 in the Yachizawa section, Sannohe area (see Figs. 8, 10, 11); the upper part of the Kokubu Formation, sample AY-19 to AY-38, Ayukawa section, Hitachi area (see Fig. 20).

Correlation: This zone is correlated with the *C. yabei* Subzone of the *D. hustedtii* Zone of Akiba (1979; Akiba *et al.*, 1982a, b). It also corresponds to the upper part of the Subzone *c* of the *D. hustedtii-D. lauta* Zone of Barron (1980). In the diatom zonation of Koizumi (1980b), a biostratigraphic interval corresponding to this zone was not recognized because he interpreted the LAD of *D. praedimorpha* to be coincidental with the FAD of *D. dimorpha* (see Fig. 28).

8. *Denticulopsis dimorpha* Range-zone

Definition: The interval from the FAD of *D. dimorpha* to the LAD of *D. dimorpha*, namely, the total range of *D. dimorpha*.

Age: Late Miocene.

Important characteristics: Abundant *D. dimorpha* and abundant to common *D. hustedtii* characterize this zone.

Geographic distribution: This zone is recognized in the following sections: DSDP Hole 438A, core 59–5 (17–21) through core 56–1 (20–24) (see Fig. 4); the upper part of the Kamimetoki Sandstone Member through the lower part of the Shitazaki Siltstone Member, both of the Shitazaki Formation, sample STZ-17 to STZ-27 in the Shitazaki section, sample YAC-14 to YAC-2 in the Yachizawa section, Sannohe area (see Figs. 9, 11).

Correlation: This zone is correlated with the *D. dimorpha* Subzone of the *D. hustedtii* Zone of Akiba (1979; Akiba *et al.*, 1982a, b), Subzone *d* of the *D. hustedtii-D. lauta* Zone of Barron (1980) and Subzone *c* of the *D. hustedtii-D. lauta* Zone of Koizumi (1980b) (see Fig. 28).

Remarks: The first appearance of *D. katayamae* is recognized in the middle part of this zone. *Thalassionema schraderi* first occurs in the middle part of this zone in DSDP Hole 438A and the Sannohe area, whereas in the Hitachi area, it is observed in the *Coscinodiscus yabei* Interval-zone.

9. *Denticulopsis katayamae* Interval-zone

Definition: The interval from the LAD of *D. dimorpha* to the LAD of *D. katayamae*.

Age: Late Miocene.

Important characteristics: This zone is characterized by the occurrence of abundant *D. katayamae* and abundant to common *D. hustedtii*.

Geographic distribution: This zone is recognized in the following sections: DSDP Hole 438A, core 55–3 (70–74) through core 49–6 (10–14) (see Fig. 4); the middle part of the Shitazaki Siltstone Member of the Shitazaki Formation, sample STZ-28 to STZ-34 in the Shitazaki section, sample YAC-1 to YAC-0 in the Yachizawa section, sample KOS-1 to KOS-4 in the Kosakazawa section, Sannohe area (see Figs. 9, 11, 12).

Correlation: This zone probably corresponds to the Subzone A of the *D. hustedtii* Zone and the basal part of the *Thalassionema schraderi* Zone of Akiba (1979, 1982c; Akiba *et al.*, 1982a, b). It is tentatively correlated with the lower part of the Subzone *a* of the *D. hustedtii* Zone of both Barron (1980) and

Koizumi (1980b) (see Fig. 28).

10. *Thalassionema schraderi* Interval-zone

Definition: The interval from the LAD of *D. katayamae* to the FAD of *D. kamtschatica*.

Age: Late Miocene.

Important characteristics: Abundant *Thalassionema schraderi*, abundant to common *Coscinodiscus marginatus*, and rare *D. hustedtii* characterize this zone.

Geographic distribution: This zone is recognized in the following sections: DSDP Hole 438A, core 49-3 (10-14) through core 42-6 (16-20) (see Fig. 4); the upper part of the Shitazaki Siltstone Member of the Shitazaki Formation through the lower part of the Kamasawa Tuff Member of the Kubo Formation, sample STA-35 to STZ-44 in the Shitazaki section, sample KOS-5 to KOS-15 in the Kosakazawa section, Sannohe area (see Figs. 9, 12).

Correlation: This zone is correlated with the main part of the *T. schraderi* Zone of Akiba (1982c). It also corresponds to the upper part of the Subzone *a* through Subzone *b* of the *D. hustedtii* Zone of both Barron (1980) and Koizumi (1980b) (see Fig. 28).

Remarks: It is difficult to distinguish this zone in onshore sequences, because abundance of coastal water species tends to increase in Northeast Japan in Late Miocene sediments.

11. *Denticulopsis kamtschatica* Zone

Definition: The base of this zone is defined by the FAD of *D. kamtschatica*. The top is not defined.

Age: Latest Miocene through Pliocene.

Important characteristics: Rare to abundant *D. kamtschatica* characterizes this zone. *D. hustedtii* occurs rarely throughout this zone in DSDP Hole 438A.

Geographic distribution: This zone is recognized in DSDP Hole 438A, core 42-4 (50-54) through core 41-1 (45-49) which is the uppermost sample examined in this hole (see Fig. 4).

Correlation: This zone is coeval with the *D. kamtschatica* Zone of Akiba (1982a, c; Akiba *et al.*, 1982a, b), Barron (1980) and Koizumi (1973a, 1980b) (see Fig. 28).

BIOSTRATIGRAPHY

Offshore sequence—DSDP Hole 438A

DSDP Hole 438A was drilled on the upper continental slope about 130 km off the coast of Northeast Honshu. An 878 m sequence of Lower Miocene to Pleistocene sediments was penetrated in Hole 438A and the sequence consists of a relatively uniform diatomaceous ooze, diatomaceous clay and diatomaceous claystone with volcanic detritus. These sediments provide an excellent reference section for the Miocene diatom biostratigraphy of the Northwest Pacific where diatoms provide the best biostratigraphic control (Barron *et al.*, 1980).

Hole 438A is selected as the subject of the present study from several holes cored during DSDP Legs 56 and 57, because the sedimentary sequence there was not only the best recovered but also reached the oldest horizon. Furthermore, the sedimentary sequence from this hole is regarded to provide an excellent basis for correlation with various land sections as described below, because diatom biostratigraphy of this hole has been closely investigated by Barron (1980) and Akiba *et al.* (1982b).

Sediments from Hole 438A yield abundant and diversified diatom assemblages.

The state of diatom preservation is mostly good or moderate throughout the Miocene sequence. The documentation of diatom biostratigraphy is given in Appendixes 1a and 1b. The stratigraphic distribution of diagnostic taxa is shown in Figs. 3 and 4.

The lower Middle Miocene *Denticulopsis lauta* Interval-zone, 79-1 (51-54) and 78-1 (54-56), is stratigraphically the lowest rock unit examined in this study. The *D. lauta* Interval-zone is characterized by abundant *D. lauta* and *Actinocyclus ingens* which display a wide morphologic variation. *Kisseleviella carina*, *Denticulopsis kanayae*, *D. nicobarica*, *Nitzschia challengeri*, and *A. ingens* var. *nodus* are rare to common in the *D. lauta* Interval-zone.

The first occurrence of *Denticulopsis hyalina* in sample 73-5 (9-11) marks the base of the *D. hyalina* Interval-zone. The top of the *D. hyalina* Interval-zone is drawn between samples 68-4 (68-72) and 68-1 (30-34) on the basis of the first appearance of *Denticulopsis hustedtii*. The *D. hyalina* Interval-zone is characterized by rare to common occurrences of *D. hyalina* in the lower part and abundant *D. hyalina* in the upper part of the zone. *D. lauta* is abundant throughout the *D. hyalina* Interval-zone and rapidly decreases its abundance immediately below the first appearance of *D. hustedtii*.

The *Denticulopsis hustedtii* Interval-zone is recognized in samples 68-1 (30-34) and 67-1 (27-32) and is characterized by dominant *D. hyalina*, rare *D. hustedtii*, and rare *D. lauta* occurrences. Barron (1980) reported the first dominant occurrence of *D. hustedtii* over *D. hyalina* in sample 66-CC, and suggested a hiatus separating the Subzones *a* and *b* of the *D. hustedtii-D. lauta* Zone between samples 66-2 (25-27) and 65-CC. However, the present author was unable to re-examine these stratigraphic events, nor able to recognize the *Denticulopsis nicobarica* Interval-zone, because samples within a wide stratigraphic interval between samples 67-1 (27-32) and 66-1 (118-122) were not available for the present study.

The first dominant appearance of *D. hustedtii* has been emphasized as a significant diatom event recognizable throughout the North Pacific (Koizumi, 1973a, 1977a; Schrader, 1973a; Barron, 1976) and probably corresponds to the level of the first occurrence of *D. hustedtii* in the tropical Pacific (Barron, 1980). In addition to these views, the present author emphasizes that the first dominant appearance of *D. hustedtii* is utterly coincidental with the rapid decrease of *D. hyalina* and that *D. hustedtii* first appears in the middle part of the Thriving Interval of *D. hyalina* in Northeast Honshu. From these observations, it is inferred that *D. hyalina*, in contrast to *D. hustedtii*, was unable to extend its geographical distribution into the tropical Pacific, although both species were originated in the North Pacific.

The *Denticulopsis praedimorpha* Range-zone covers sample 66-1 (118-122) through sample 64-3 (10-14). Within this interval, the last appearance of *D. nicobarica* in sample 66-1 (118-122), the first occurrence of *Rhizosolenia barboi* in sample 65-3 (100-103), and the last occurrence of *Mediaria splendida* in sample 64-3 (10-14) have been recognized. Also, the first occurrence of *Coscinodiscus yabei* in sample 65-5 (18-21) and the first probable occurrence of *Coscinodiscus temperei* in sample 64-5 (30-32) are noted. Barron (1980) and Schrader (1973a) regarded these paleontological events as useful datums for establishing a correlation in the North Pacific. However, the order of occurrences of these paleontological events are different from that given by Barron (1980). Such a discrepancy may have resulted from the paucity of these

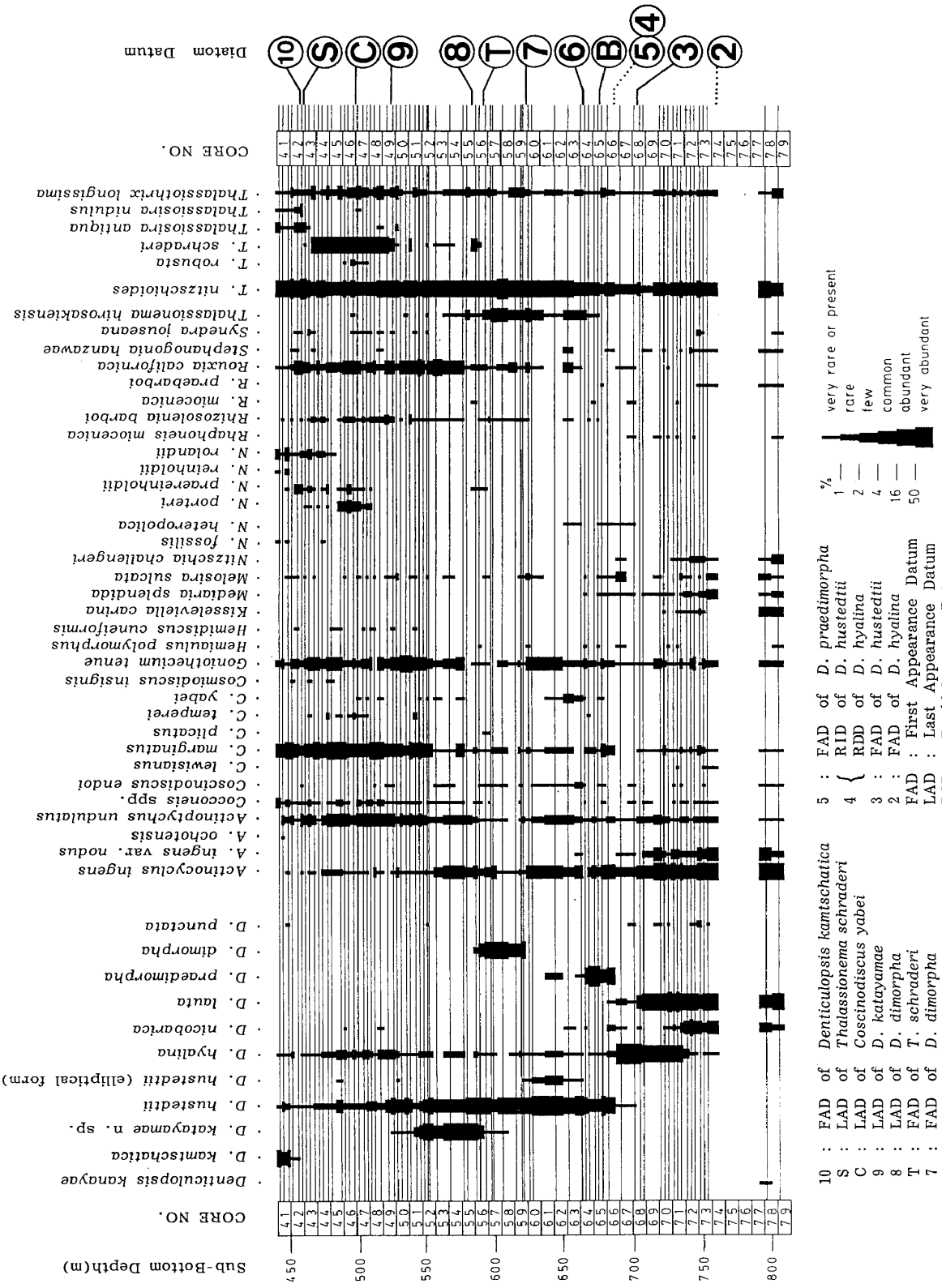


Fig. 3. Biostratigraphic distribution of selected diatoms in DSDP Hole 438A, core 41 through core 79.

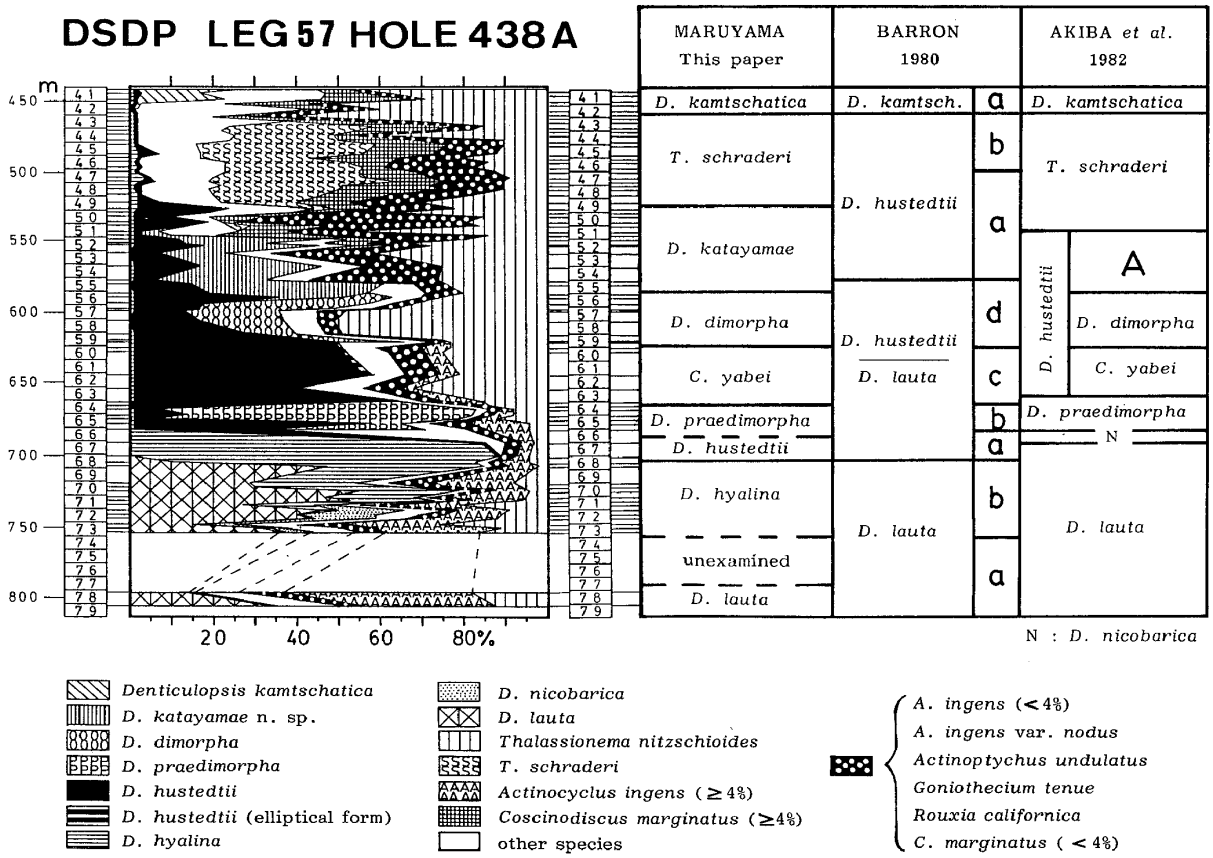


Fig. 4. Biostratigraphic distribution of selected diatom species and correlations of the proposed zones with zones of Barron (1980) and Akiba *et al.* (1982b).

species in Hole 438A.

The interval between samples 60-1 (34-38) and 59-5 (17-21) is assigned to the *Coscinodiscus yabei* Interval-zone which is characterized by the occurrence of abundant *D. hustedtii*, rare *D. hustedtii* (elliptical form), and rare *C. yabei*.

The stratigraphic interval from sample 59-5 (17-21) through sample 56-1 (20-24) is referable to the *Denticulopsis dimorpha* Range-zone based on the total range of *D. dimorpha*. Notable datum levels occurring within this zone are the first appearance of *Denticulopsis katayamae* between samples 59-1 (17-21) and 58-1 (16-20), and the first appearance of *Thalassionema schraderi* between samples 56-6 (20-24) and 56-3 (20-24). This zone is characterized by abundant occurrences of both *D. dimorpha* and *D. hustedtii* in its lower part, in addition to these forms, rare to abundant *D. katayamae* in its upper part.

The *Denticulopsis katayamae* Interval-zone ranges from sample 55-3 (70-74) through sample 49-6 (10-14). Occurrences of dominant *D. katayamae* and abundant *D. hustedtii* characterize the lower to middle part of *D. katayamae* Interval-zone and rare *D. katayamae* and common *D. hustedtii* the upper part. A rapid upward decrease in abundance of *D. katayamae* occurs between samples 52-1 (36-38) and 51-6 (16-20). A combined abundance of *D. hustedtii* and *D. katayamae* also rapidly decreases at the same level. Such phenomena in Hole 438A have been assumed to be the last common occurrence of *D. hustedtii* by Barron (1980) and the last appearance of *D. hustedtii* by Akiba (1982a). Another rapid decrease of *D. hustedtii* s.s. is recognizable at the top of the *D. katayamae* Interval-zone between samples 49-6 (10

-14) and 49-3 (10-14). These features should be considered in relation to the climatic warming reported in a middle Upper Miocene interval in California (Barron, 1973).

An interval above the last occurrence of *D. katayamae* in sample 49-6 (10-14) is assigned to the *Thalassionema schraderi* Interval-zone. Occurrences of dominant *T. schraderi*, abundant *Coscinodiscus marginatus* and rare to common *Rouxia californica* characterize the main part of this zone.

Some significant events within the *T. schraderi* Interval-zone include the last occurrence of *C. yabei* in sample 47-1 (10 -14), and the first occurrences of *Cosmiodiscus insignis* and *Nitzschia rolandii* in sample 45-1 (54-58). Also, a notable event is the rapid decrease in abundance of *T. schraderi* between samples 43-6 (82 -86) and 43-3 (30-34). Barron (1980) described this rapid decrease in abundance of *T. schraderi* as the last occurrence of *Thalassionema hirosakiensis*. He also considered this species to be useful for correlating the West Pacific deep sea sequence with those of California and the Bering Sea. Akiba (1982c) transferred *T. hirosakiensis* s.l. observed in a Upper Miocene interval to his new species *T. schraderi* and emphasized its biostratigraphic significance in the North Pacific.

The first appearance of *Denticulopsis kamtschatica* s.s. between samples 42-6 (16-20) and 42-4 (50-54) marks the base of the *D. kamtschatica* Zone. The presence of rare to abundant *D. kamtschatica*, abundant *Coscinodiscus marginatus*, and rare to few *N. rolandii* characterizes the *D. kamtschatica* Zone. On the basis of the occurrence of some species belonging to the genera *Nitzschia* and *Thalassiosira*, Barron (1980) argued that a hiatus spanning from about 5.6 to about 6.7 Ma is present in the upper part of section 4 of core 42. However, the present author was unable to re-examine the presence of this hiatus because samples of close stratigraphic intervals were not available.

Onshore sequences

1. Sannohe area

The Sannohe area, which has also been referred to as the Kadonosawa area (Chinzei, 1981) or the Mabechi River region (Koizumi *et al.*, 1980), is situated in a lowland between the Kitakami Massif and the Ou Range, and at nearly the same latitude as DSDP Hole 438A. This area represents one of the best-studied Neogene sequences in Japan, and has been subjected to intensive studies including molluscs (e.g., Otuka, 1934; Chinzei, 1958, 1966) and various microfossils (Samata, 1976; Akiba, 1977a, b; Koizumi, 1979a; Katayama, 1980MS).

According to Katayama (1980MS), Neogene deposits are divided into the Shiratorigawa and Sannohe Groups in upward sequence. The Shiratorigawa Group consists of the Yotsuyaku, Kadonosawa and Suenomatsuyama Formations, and the Sannohe Group comprises the Tomesaki, Shitazaki, Kubo and Utouzaka Formations in upward sequence. Each formation, except for the Utouzaka Formation, is subdivided into a few members. The lithostratigraphic classification of Neogene deposits in the Sannohe area is summarized in Fig. 5.

Diatom assemblages are systematically examined along six selected sections, namely, the Kadonosawa, Sawadasawa, Shitazaki, Kawaguchi, Yachizawa, and Kosakazawa sections. Locations of these sections and locations of samples are shown in Fig. 6.

a. Kadonosawa section

The Kadonosawa section covers a sequence from the Kadonosawa Formation to the lower part of the Suenomatsuyama Formation. Fifteen samples

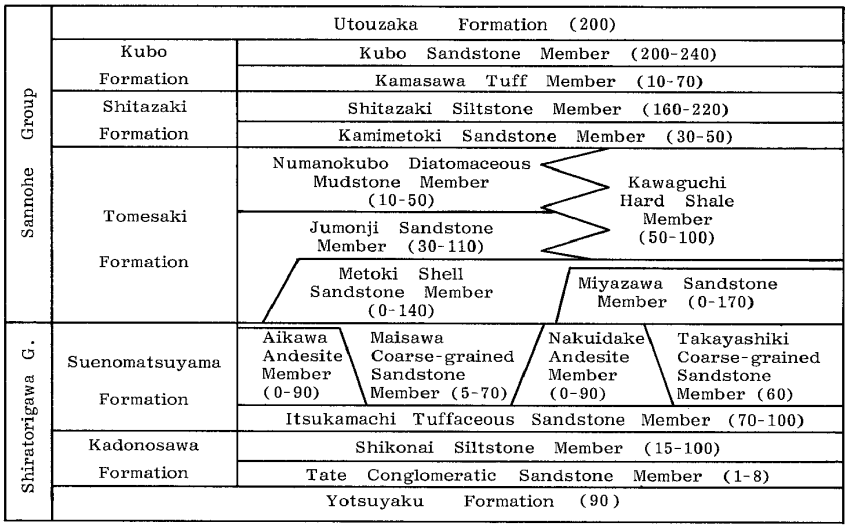


Fig. 5. Stratigraphic succession in Sannohe area (bracketed numbers represent thickness in meter, redrawn from Katayama, 1980MS).

studied (KDN-1～15) were originally collected by an investigation group led by Dr. Chinzei of the University of Tokyo along the Shiratori River (Fig. 6).

The Kadonosawa Formation consists mainly of a gray siltstone with some intercalations of pumice tuff. The basal part of the Suenomatsuyama Formation in the Kadonosawa section is largely composed of a tuffaceous sandstone which is assigned to the Itsukamachi Tuffaceous Sandstone Member. The lower part of the Kadonosawa Formation is barren of diatom fossils. The middle to upper part of the Kadonosawa Formation and the basal portion of the Suenomatsuyama Formation in the Kadonosawa section yield slightly dissolved to poorly preserved, rare diatoms. The documentation of diatom stratigraphy is given in Appendix 2. Distributions of diagnostic taxa in the Kadonosawa section are shown in Fig. 7.

Diatom assemblages in the Kadonosawa section are assignable to the *Actinocyclus ingens* Zone and the *Denticulopsis lauta* Interval-zone. The first appearance of *D. lauta* between samples KDN-5 and KDN-6 marks the zonal boundary between these zones. Abundant to dominant occurrences of *Thalassionema nitzschioides* and *Kisseleviella carina*, common to abundant *A. ingens*, and rare to abundant *Goniothecium tenue* characterize diatom floras of the Kadonosawa section.

Few to common *Aulacosira granulata* and rare to few *Melosira sulcata* occur throughout the Kadonosawa section. Their occurrence suggests that the middle to upper part of the Kadonosawa Formation and the basal part of the Suenomatsuyama Formation were deposited in a shallow marine environment influenced in a considerable degree by fresh waters.

Coscinodiscus lewisianus, *Denticulopsis nicobarica*, *D. norwegica*, *Rhizosolenia miocenica*, and *Synedra jouseana* occur rarely and sporadically in the Kadonosawa section.

b. Sawadasawa section

The Sawadasawa section exposes the Metoki Shell Sandstone, Jumonji Sandstone and Numanokubo Diatomaceous Mudstone Members of the Tomesaki Formation. Also, the base of the Sawadasawa section (sample SAW-0) covers the Maisawa Coarse-grained Sandstone Member of the Suenomatsuyama Formation.

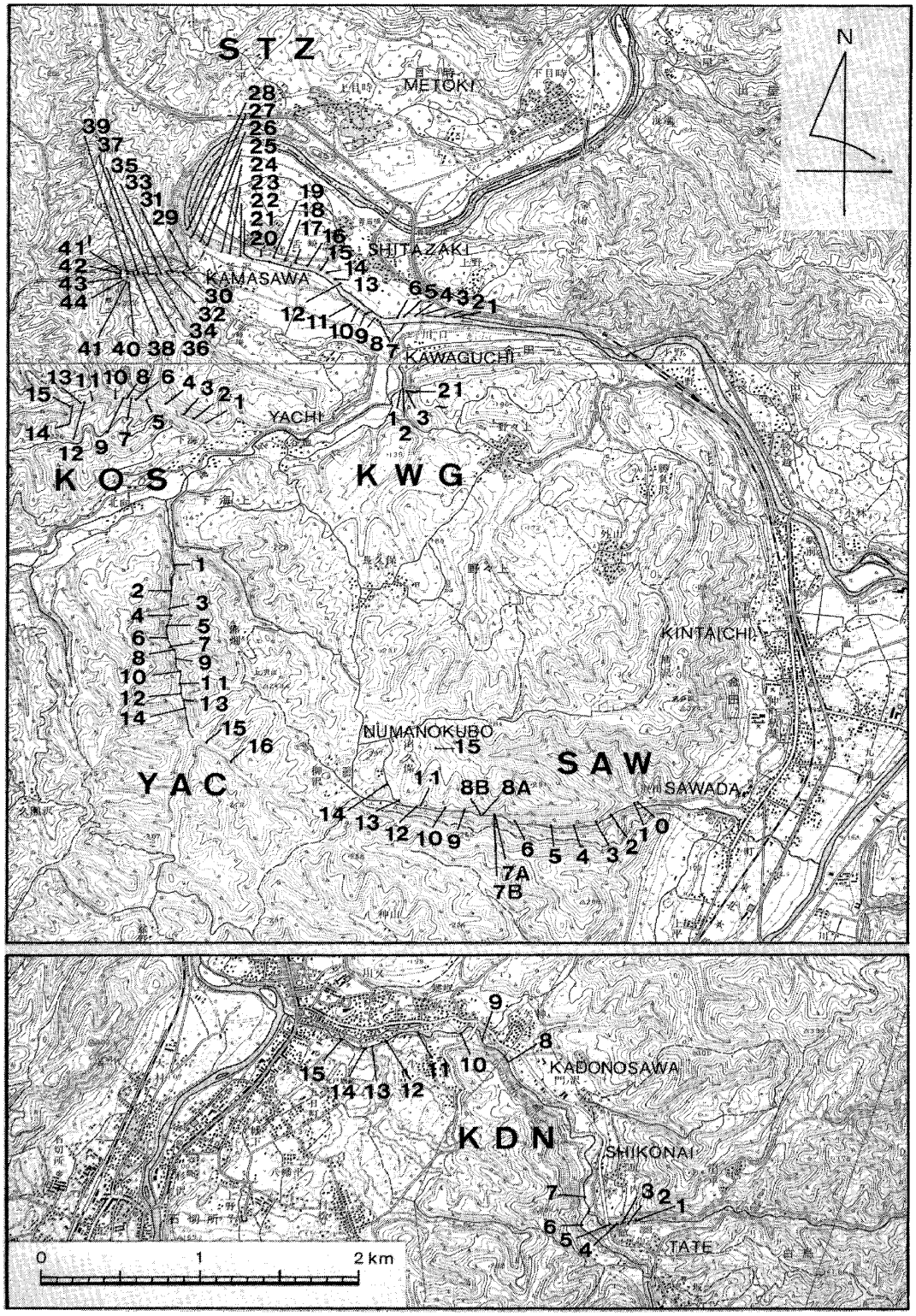


Fig. 6. Map showing the location of sections and sample localities in Sannohe area (Topographic maps "Sannohe" and "Mutsufukuoka", 1 : 25,000 in scale, Geographical Survey Institute).

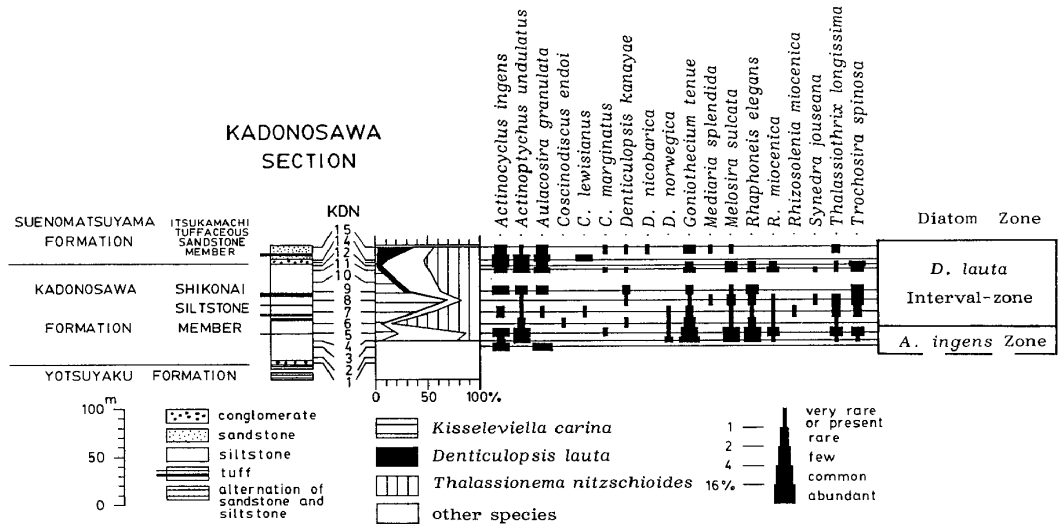


Fig. 7. Biostratigraphic distribution of selected diatom species in Kadonosawa section, Sannohe area.

Diatom fossils are present in the middle and uppermost parts of the Jumonji Sandstone Member, and the Numanokubo Diatomaceous Mudstone Member. The remainder of the Tomesaki Formation is barren of diatoms in the Sawadasawa section. Sample SAW-0 of the Suenomatsuyama Formation yields a trace of dissolved diatoms which include no age-diagnostic species.

Stratigraphic occurrences of diatoms are given in Appendix 3. The distribution of selected diatoms in the Sawadasawa section is shown in Fig. 8.

A diatom assemblage in sample SAW -6 includes *Denticulopsis lauta*, *D. nicobarica*, *Actinocyclus ingens* var. *nodus* and *Nitzschia challengeri* and is referable to the *D. lauta* Interval-zone. The lowest stratigraphic occurrence of *Denticulopsis hyalina* in sample SAW -7A marks the base of the *D. hyalina* Interval-zone. Diatom assemblages in samples SAW-11 and SAW-12 comprise *Denticulopsis praedimorpha* and *D. hustedtii* and are characteristic of the *D. praedimorpha* Range-zone.

A diatom association in the Numanokubo Diatomaceous Mudstone Member is assignable to the *Coscinodiscus yabei* Interval-zone.

c. Shitazaki section

The Shitazaki section covers the Tomesaki, Shitazaki and Kubo Formations. Forty-five samples examined were originally collected by an investigation group led by Dr. Chinzei of the University of Tokyo along the Mabechi River (Fig. 6).

The Tomesaki Formation in the Shitazaki section is subdivided into the Metoki Shell Sandstone, Jumonji Sandstone and Kawaguchi Hard Shale Members in upward sequence. The Shitazaki Formation in this section is lithologically divided into the Kamimetoki Sandstone and Shitazaki Siltstone Members in upward sequence. The Kamasawa Tuff Member occupies the basal part of the Kubo Formation.

The lower portion of the Tomesaki Formation in the Shitazaki section yields slightly dissolved to poorly preserved, rare diatoms, and the main part of the Kawaguchi Hard Shale Member is devoid of diatoms. Diverse but poorly to moderately preserved assemblages of diatoms occur in the Shitazaki and Kubo Formations occupying the middle to upper part of the Shitazaki section. The documentation of diatom stratigraphy is given in Appendix 4. Stratigra-

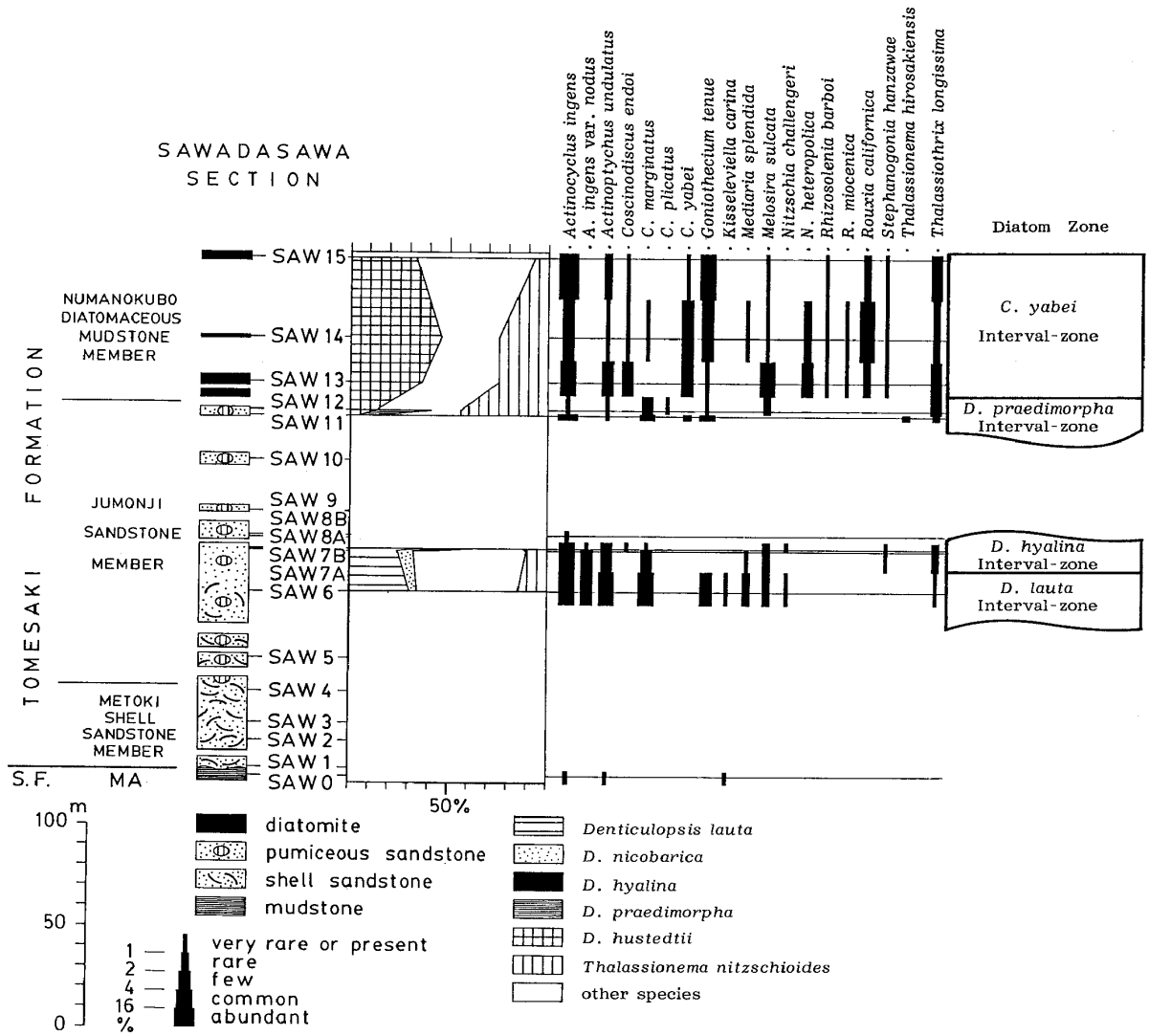


Fig. 8. Biostratigraphic distribution of selected diatom species in Sawadasawa section, Sannohe area (S.F.: Suenomatsuyama Formation, MA: Maisawa Coarse-grained Sandstone Member).

phic distributions of the selected taxa in the Shitazaki section are shown in Fig. 9.

Diatom assemblages from sample STZ-2 to STZ-16 include *Denticulopsis hustedtii* and *Actinocyclus ingens* and are assignable to a sequence from the *Denticulopsis nicobarica* Interval-zone to the *Coscinodiscus yabei* Interval-zone. However, the presence of the *Denticulopsis praedimorpha* Range-zone in between is not evident. The lowest stratigraphic occurrence of *Denticulopsis dimorpha* in sample STZ-17 marks the base of the *D. dimorpha* Range-zone. The top of the *D. dimorpha* Range-zone is indicated by the last occurrence of *D. dimorpha* in sample STZ-27. The last occurrence of *Denticulopsis katayamae* in sample STZ-34 marks the top of the *D. katayamae* Interval-zone. Assemblages from sample STZ-35 to STZ-44 contain rare to common *D. hustedtii* and sparse *Thalassionema schraderi* and are assignable to the *T. schraderi* Interval-zone.

Rare *D. hustedtii*, abundant *Melosira sulcata*, common to abundant *Actinoptychus undulatus* and *Cocconeis* spp. characterize the upper part of the Shitazaki Siltstone Member, which is assignable to the *D. katayamae* Interval-zone

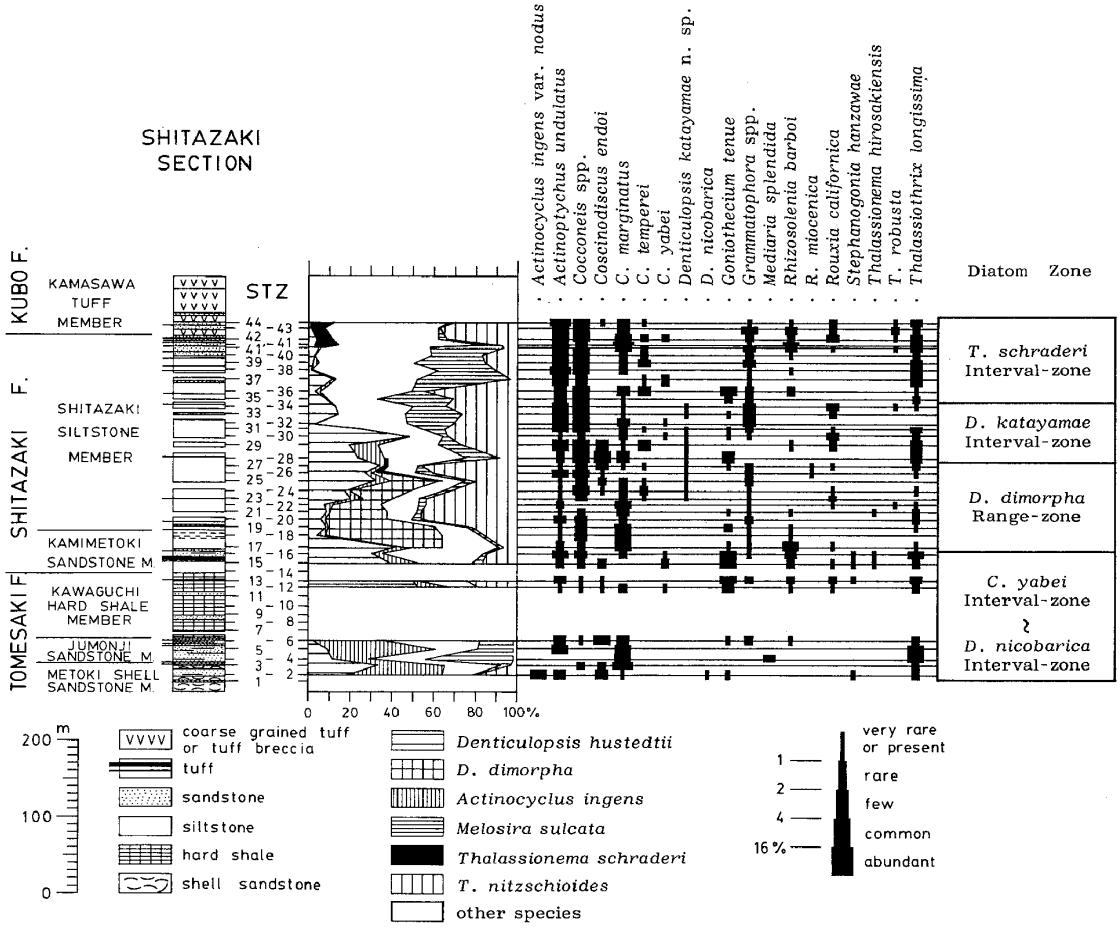


Fig. 9. Biostratigraphic distribution of selected diatom species in Shitazaki section, Sannohe area.

and the *T. schraderi* Interval-zone. These floral characteristics indicate that the upper part of the Shitazaki Formation was deposited under shallower marine conditions compared with the remainder of the Shitazaki section. The Kosakazawa section in the Sannohe area also shows a tendency similar to that of the Shitazaki section.

d. Kawaguchi section

The Tomesaki Formation was investigated in the Kawaguchi section which crops out in a steep cliff south of Kawaguchi, Ninohe City (Fig. 6). The Tomesaki Formation in this section is divided into the Jumonji Sandstone, Numanokubo Diatomaceous Mudstone and Kawaguchi Hard Shale Members in upward sequence. The Tomesaki Formation contains, slightly dissolved to moderately well-preserved, diverse diatom floras except for a barren sample KWG-21 near the top of the Kawaguchi section. Stratigraphic occurrences of diatoms in the Kawaguchi section are given in Appendix 5. The distribution of stratigraphically important diatoms is shown in Fig. 10.

Based upon diatom biostratigraphy, the Kawaguchi section is divided into the *Denticulopsis nicobarica* Interval-zone, *D. praedimorpha* Range-zone, and *Coscinodiscus yabei* Interval-zone. *D. praedimorpha* occurs from sample KWG-3 to KWG-12 and defines the *D. praedimorpha* Range-zone. The last appearance of *D. praedimorpha* between samples KWG-12 and KWG-13 roughly corresponds to the lithostratigraphic

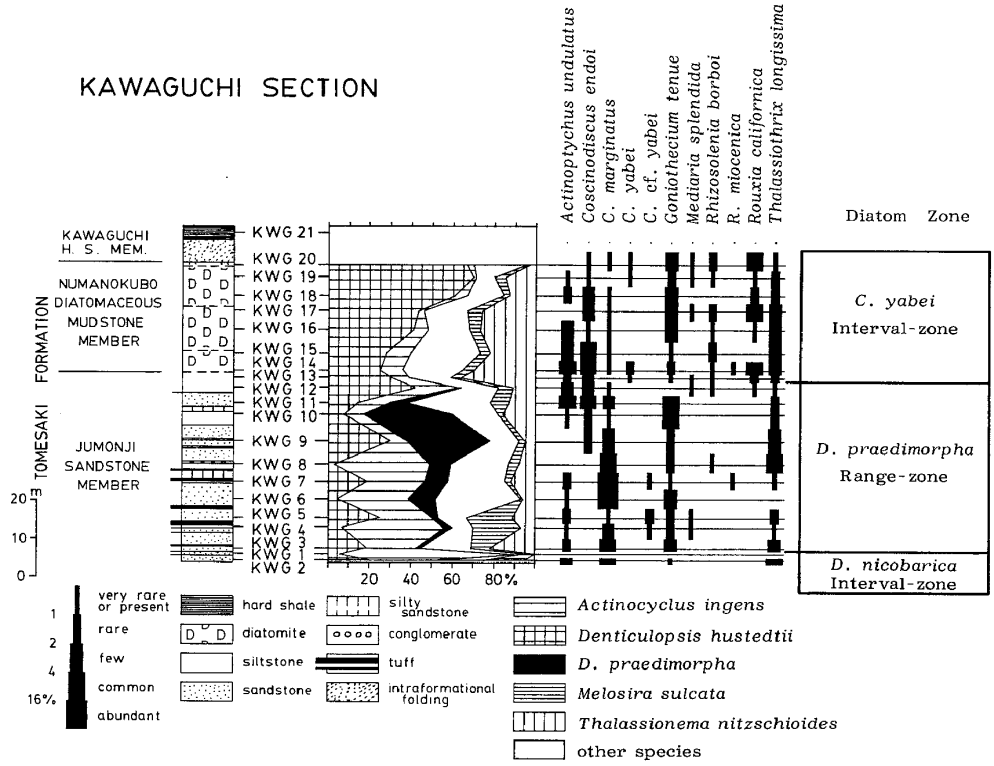


Fig. 10. Biostratigraphic distribution of selected diatom species in Kawaguchi section, Sannohe area.

boundary between the Jumonji Sandstone and Numanokubo Diatomaceous Mudstone Members both in the Kawaguchi and Sawadasawa sections.

e. Yachizawa section

The Yachizawa section encompasses the Kamimetoki Sandstone and Shitazaki Siltstone Members of the Shitazaki Formation, and the top portion of the Numanokubo Diatomaceous Mudstone Member of the Tomesaki Formation.

Poorly to moderately well-preserved but diverse assemblages of diatoms occur in the Yachizawa section. These assemblages are documented in detail in Appendix 6. Stratigraphic distributions of diagnostic taxa are shown in Fig. 11.

Diatom assemblages in the Yachizawa section are assignable to the *Coscinodiscus yabei* Interval-zone, *Denticulopsis dimorpha* Range-zone, and *D. katayamae* Interval-zone in upward sequence. The lowest stratigraphic occurrence of *D. dimorpha* in sample YAC-14 marks the base of the *D. dimorpha* Range-zone. The top of the *D. dimorpha* Range-zone is indicated by the last occurrence of *D. dimorpha* in sample YAC-2.

Abundant *Denticulopsis hustedtii* and *Thalassionema nitzschioides*, common *Actinocyclus ingens* are present throughout the Yachizawa section. *D. dimorpha* characterizes the *D. dimorpha* Range-zone, and common *Goniothecium tenue* and common *Rhizosolenia barboi* do the *C. yabei* Interval-zone in the Yachizawa section.

The first appearance of *Denticulopsis katayamae* between samples YAC-15 and YAC-14 coincides with the first appearance of *D. dimorpha* in the Yachizawa section, though *D. katayamae* first appears higher in stratigraphic horizon than *D. dimorpha* in both the Shitazaki section and DSDP Hole 438A. This is attributed to a wide interval between

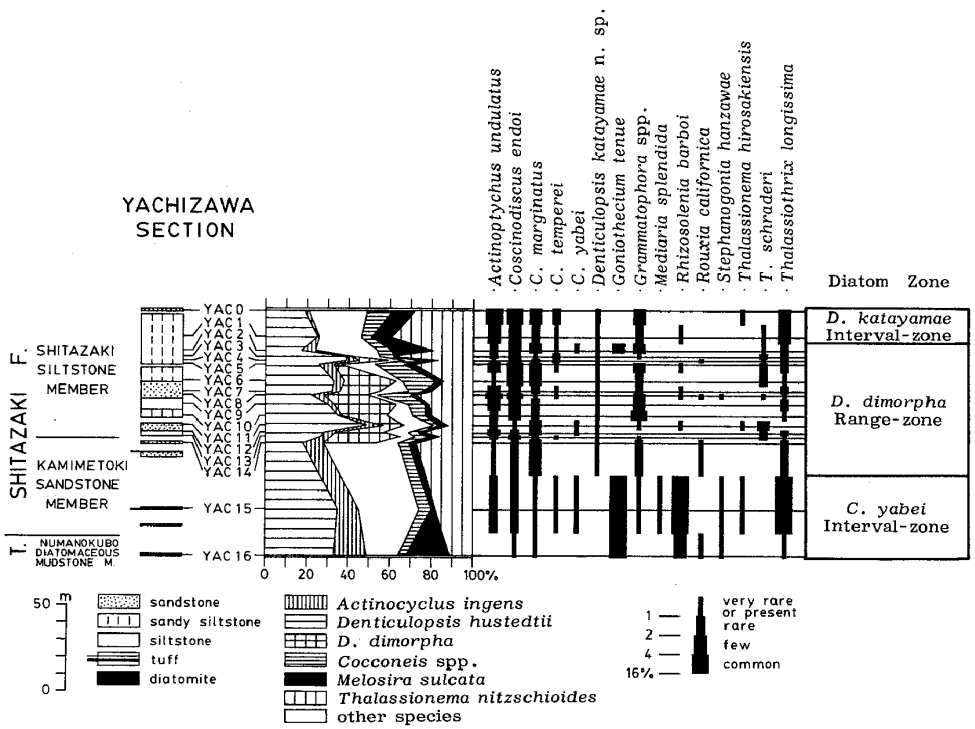


Fig. 11. Biostratigraphic distribution of selected diatom species in Yachizawa section, Sannohe area (T.: Tomesaki Formation).

samples YAC-15 and YAC-14, whereas both the Shitazaki section and DSDP Hole 438A revealed a more discriminating order of the first appearances of these species.

f. Kosakazawa section

In the Kosakazawa section, the Shitazaki Siltstone Member of the Shitazaki Formation which consists mostly of silty sandstone interbedded with pyroclastics was subjected to the present study. The Kosakazawa section yields rare, poorly preserved assemblages of diatoms. Stratigraphic occurrences of diatoms are summarized in Appendix 7, and stratigraphic distribution of selected diatoms are shown in Fig. 12.

The Kosakazawa section is divided biostratigraphically into the *Denticulopsis katayamae* and *Thalassionema schraderi* Interval-zones in upward sequence. The boundary between these two zones is marked by the last appearance of *D. katayamae* between samples KOS-4 and KOS-5. *Denticulopsis hustedtii* and *Thalassionema nitzschioides* abound in the lower part of the Kosakazawa section, but they are rare in the upper.

The Kosakazawa section is characterized by abundant *Cocconeis* spp., rare to common *Actinoptychus undulatus*, common to abundant *Melosira sulcata*, and rare to common *Grammatophora* spp. Such floral compositions are indicative of coastal waters, and suggest that the Shitazaki Siltstone Member in the Kosakazawa section was deposited under such an environment where oceanic influences were much stronger in the early period of sedimentation. In the Shitazaki section, a similar transition of diatom floras is also observed in the upper part of the Shitazaki Siltstone Member, with the increasing occurrence of coastal water species in the *D. katayamae* and *T. schraderi* Interval-zones.

2. Ichinoseki area

The Ichinoseki area lies in the southern part of the Kitakami Valley between

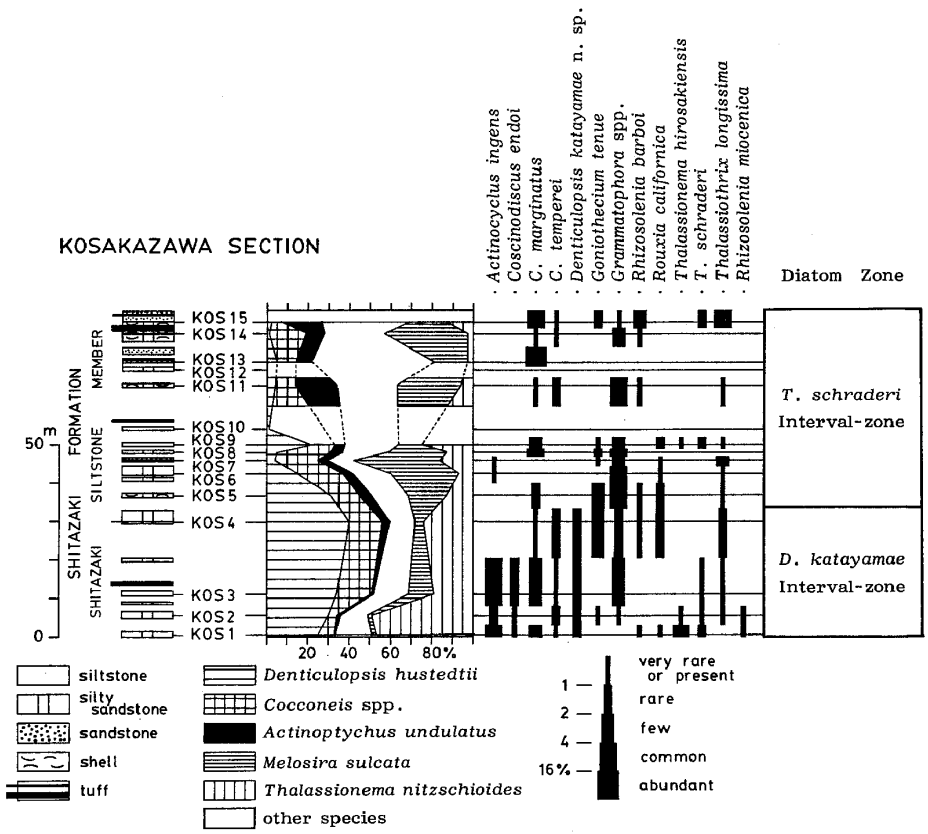


Fig. 12. Biostratigraphic distribution of selected diatom species in Kosakazawa section, Sannohe area.

the Kitakami Massif to the east and the Ou Range to the west. Neogene formations rest unconformably upon the basement rocks composed mainly of Paleozoic deposits. On the western hilly side of Ichinoseki City, Neogene deposits are well distributed in a simple geologic structure. Many published as well as unpublished works have dealt with the stratigraphy of the Ichinoseki area (Yamamoto, 1941MS ; Kinoshita, 1948MS ; Matsuno, 1948MS, 1967 ; Hayakawa *et al.*, 1954 ; Sasaki, 1955MS ; Onodera, 1956, 1957 ; Tsumaki, 1970MS ; Ueda, 1978MS ; Umeda, 1979MS ; Maruyama, 1980MS). Kitamura (1981) summarized the stratigraphy of this area and divided Neogene deposits into seven formations as follows :

Mataki Formation (50 m)
..... unconformity .....
Kazawa Formation (80 m)

Pliocene ..... unconformity .....
Yushima Formation (50 m)
..... interfinger .....
Ariga Formation (40 m)
..... unconformity .....
Genbi Formation (150 m)
..... unconformity .....
Miocene Shimokurosawa Formation (380 m)
..... interfinger .....
Jikyozan Andesite (300 m)

The Shimokurosawa Formation studied in this paper is lithologically subdivided into three units, the lower Junijin Sandstone Member, the middle "main part" and the upper Tsukumo Sandstone Member. The Junijin Sandstone Member is 80 m thick, and consists of alternating beds of conglomerate and coarse-grained sandstone containing rare molluscan fossils. The Tsukumo Sandstone Member is 100 m thick, and is composed of cross-bedded coarse-grained sandstone bearing no fossils. The "main part" is estimated to be more than 200 m thick,

and consists of massive, greenish sandy siltstone and silty sandstone with frequent intercalations of pumiceous tuff, tuff breccia and calcareous concretions. The "main part" contains abundant microfossils and rare molluscan fossils.

The type section of the "main part" of the Shimokurosawa Formation is exposed along the Iwai River between Shimokurosawa and Shizu, Ichinoseki City (Maruyama, 1980MS) and is called the Iwaigawa section herein (Fig. 13). A biostratigraphic examination of planktonic foraminifera, radiolarians and calcareous nannofossils was made along the Iwaigawa section by Takayanagi *et al.* (1976). They established the Ichinoseki I, II Zones, whose boundary is defined by a rapid decrease in abundance of the radiolarian *Cyrtocapsella tetrapera*. Maruyama (1980MS, 1981b) also examined fossil diatoms from the same section and recognized the first appearance of *Denticulopsis praedimorpha* immediately below the rapid decrease level of *C. tetrapera*.

Diatoms are moderately to well-preserved and abundant to common throughout the section, which represents one of the most complete reference sections of the Middle Miocene in Japan. Stratigraphic occurrences of diatoms in the Iwaigawa section are given in Appendix 9. The distribution of selected stratigraphically important diatoms is shown in Fig. 14.

The Shimokurosawa Formation in the Iwaigawa section comprises two diatom zones, namely, the *Denticulopsis nicobarica* Interval-zone in the lower and the *Denticulopsis praedimorpha* Range-zone in the upper. The zonal boundary

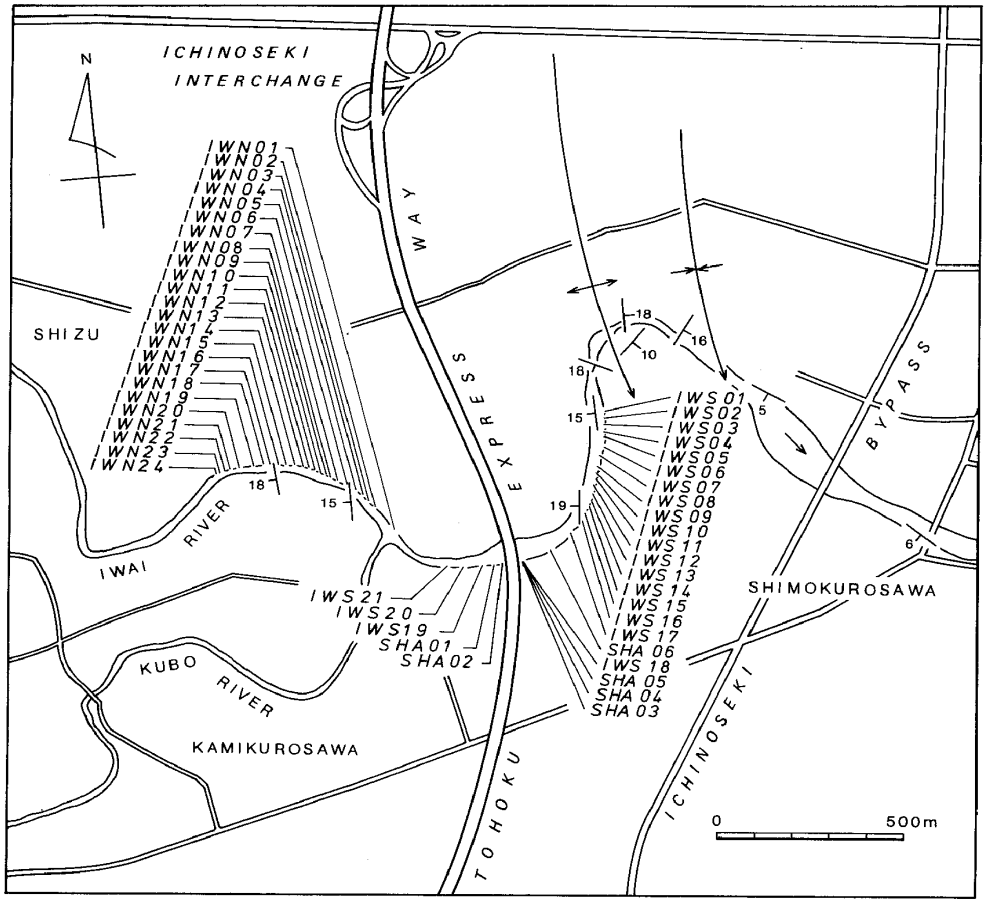


Fig. 13. Map showing sample localities in Iwaigawa section, Ichinoseki area.

between the two is indicated by the first appearance of *D. praedimorpha* between samples SHA-5 and SHA-4.

The diatom assemblage assigned to the *D. nicobarica* Interval-zone is characterized by abundant *Denticulopsis hustedtii* and common *D. nicobarica*. Common to abundant *D. hustedtii* and *D. praedimorpha* characterize the diatom assemblage assigned to the *D. praedimorpha* Range-zone. Abundant *Thalassionema nitzschioides*, few *Goniothecium tenue*, rare *Coscinodiscus plicatus*, rare *C. yabei*, rare *Hemiaulus polymorphus*, rare *Mediaria splendida*, rare *Nitzschia heteropolica*, rare *Rhizosolenia miocenica*, rare *Rouxia californica*, and rare *Stephanogonia hanzawae* are found throughout the Iwaigawa section. The first occurrence of *Coscinodiscus temperei* in sample IWN-7 and the first occurrence of *Thalassionema hirosakiensis* in sample IWN-17 are recognized in the upper part of this section.

Melosira sulcata, though generally rare in this section, tends to increase its abundance to more than 10% within an interval between samples IWS-15 and SHA -4. This increase of *M. sulcata* occurs just below the first appearance datum level of *D. praedimorpha* and the rapid decrease datum level of *C. tetrapera*. *Actinocyclus ingens* and *Coscinodiscus marginatus* show a similar tendency. Since *M. sulcata* can be taken as an indicator of coastal waters, this interval of the Shimokurosawa Formation was deposited under shallower marine conditions as compared with the rest of the formation.

The last appearance of *D. nicobarica* (between samples SHA-6 and IWS-18) is also noted in the interval showing the

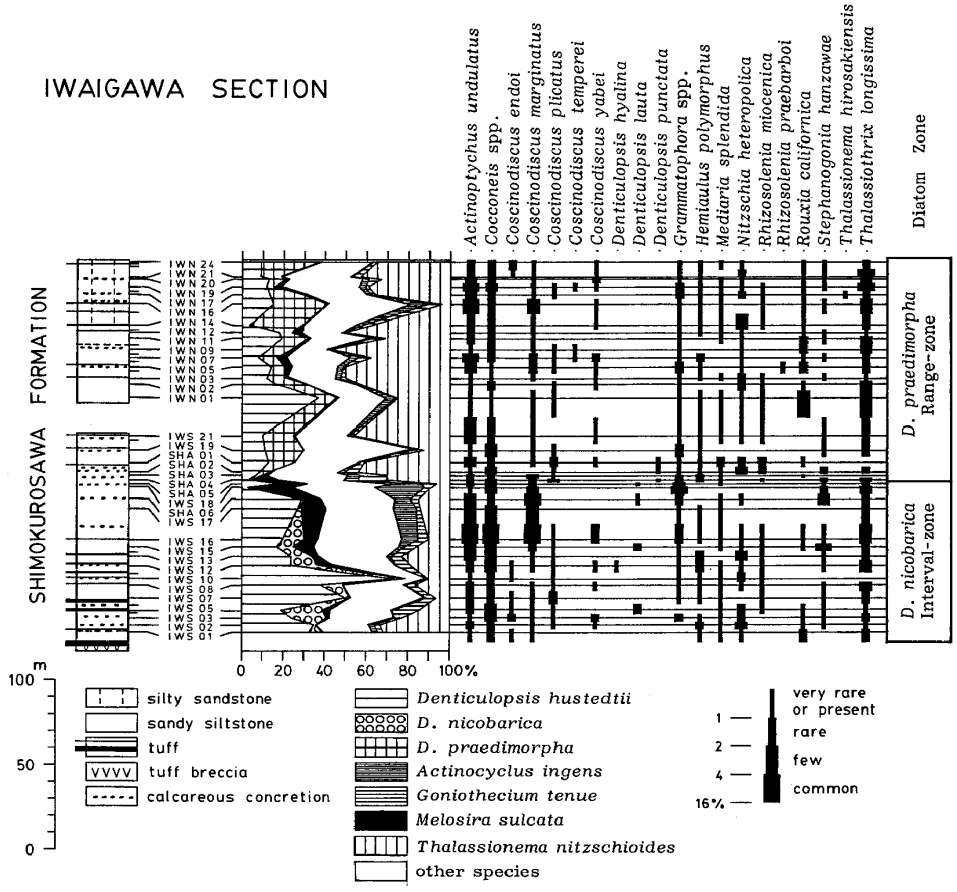


Fig. 14. Biostratigraphic distribution of selected diatom species in Iwaigawa section, Ichinoseki area.

increase of *M. sulcata*. In such a wide geographic area encompassing Sendai, Takahagi, Hitachi, Nakaminato and DSDP Hole 438A, however, the last occurrence of *D. nicobarica* is recognized above the first appearance of *D. praedimorpha*.

Two paleontological events defined by the increase in abundance of *M. sulcata* and the extinction of *D. nicobarica*, which took place near the zonal boundary between the Ichinoseki I/II Zones, should be examined further from a viewpoint of paleoceanography and paleoclimatology.

3. Sendai area

The Sendai area is located in the southern part of the Sendai Plain, one of the widest plains facing the Pacific, in Northeast Honshu. Neogene deposits are developed on low-lying hills around Sendai City.

According to Hanzawa *et al.* (1953), Neogene deposits are divided into three groups, the lower Natori, the middle Akyu and the upper Sendai Groups. Each group comprises several formations in downward sequence as follows:

	Dainenji Formation (30 m)
Pliocene	Mukaiyama Formation (30–40 m)
Sendai	..... unconformity .....
Group	Tatsunokuchi Formation (50–60 m)
	Kameoka Formation (10–20 m)
	..... local unconformity .....
Miocene	Shirasawa Formation (330 m)
Akyu	..... local unconformity .....
Group	Yumoto Formation (200 m)
	..... unconformity .....
	Tsunaki Formation (400 m)
	Hatatate Formation (180 m)
Miocene	Moniwa Formation (20–60 m)
Natori	... interfinger, local unconformity ...
Group	Takadate Formation (60–250 m)
	..... interfinger .....
	Tsukinoki Formation (20–150 m)

The Hatatate Formation referred to in this study is distributed around Mt. Taihaku in the southwestern part of Sendai City. This formation represents the middle part of the Natori Group which apparently exhibits a depositional cyclothem and is considered to be the deepest marine sediments of the group. The Hatatate Formation consists mainly of sandy siltstone and silty sandstone frequently intercalated with layers of pumiceous tuff.

Biostratigraphic studies of planktonic foraminifers and radiolarians were made by Oda and Sakai (1977, 1979) who dealt with the lower and middle parts of the Hatatate Formation. A reconnaissance survey of fossil diatoms was also made by Maruyama (1981a) from the same sequence. Ishizaki and Takayanagi (1981) summarized the biostratigraphy of the Sendai area.

Samples examined were originally collected by Oda and Sakai (1977) from two sections, one is the Iwanosawa section representing the lower part of the Hatatate Formation, and another is the Taihakusan section representing the middle part (Fig. 15). The Iwanosawa section contains a few fragments of dissolved specimens, but the Taihakusan section yields abundant, diverse, and moderately well-preserved assemblages of fossil diatoms. A detailed documentation of these assemblages in the Taihakusan section is given in Appendix 10. The distribution of stratigraphically diagnostic taxa is shown in Fig. 16.

Diatom assemblages from the middle part of the Hatatate Formation include common *Denticulopsis hustedtii*, rare to abundant *D. praedimorpha* and few to common *Actinocyclus ingens*, and are assigned to the *D. praedimorpha* Rangezone. Dominant *Thalassionema nitzschioides*, rare *Coscinodiscus yabei*, *Mediaria splendida*, *Nitzschia heteropolica* and *Rhizosolenia miocenica* characterize diatom assemblages throughout the Taihakusan section. The last occurrence of *Denticulopsis nicobarica* in sample HTT-8 and the first occurrence of *Rhizosolenia barboi* in sample HTT-19

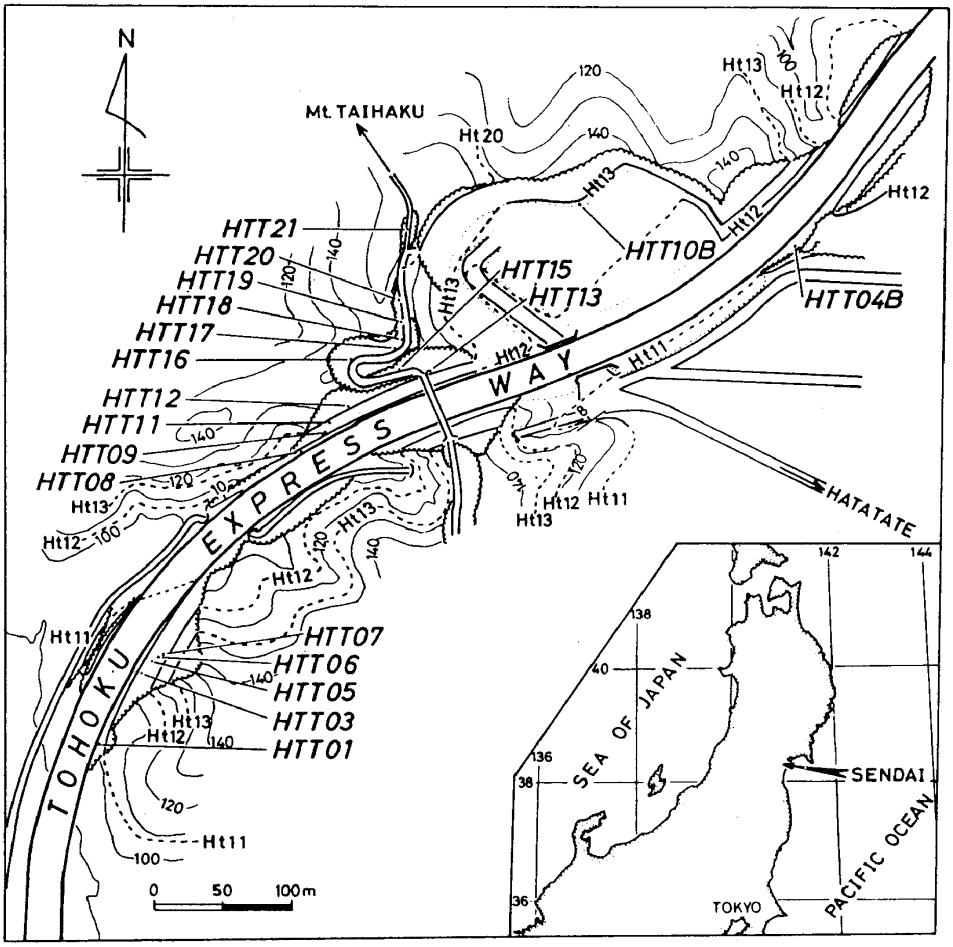


Fig. 15. Map showing sample localities in Taihakusan section, Sendai area (after Oda and Sakai, 1977).

are recognized.

Two levels of a rapid decrease in abundance of the radiolarian *Cyrtocapsella tetrapera* are recognized in the Taihakusan section; one is between samples HTT-3 and HTT-4B, and another between samples HTT-16 and HTT-17. Oda and Sakai (1977) pointed out that the lower level is correlated with the zonal boundary between the Ichinoseki I/II Zones of Takayanagi *et al.* (1976). In the Ichinoseki area, Maruyama (1980MS, 1981b) examined fossil diatoms and drew an interesting conclusion that the first appearance datum level of *Denticulopsis praedimorpha* was recognized directly below the rapid decrease datum level of *C. tetrapera*, and *D. praedimorpha* was found throughout the Ichinoseki II Zone. On the basis of the above result, the present author correlates the lower level of a rapid decrease of *C. tetrapera* in the Hatatate Formation with the zonal boundary of Ichinoseki I/II Zones. This agrees well with the result of Oda and Sakai (1977).

4. Takahagi area

Takahagi area facing the Pacific Ocean is situated 150 km NE of Tokyo, bordered on the west by the southeastern margin of the Abukuma Massif. This area occupies the southern part of the Joban Coal Field, which includes one of the best-studied Tertiary sequences in Japan.

New age interpretations for the Neogene sections in the Joban Coal Field

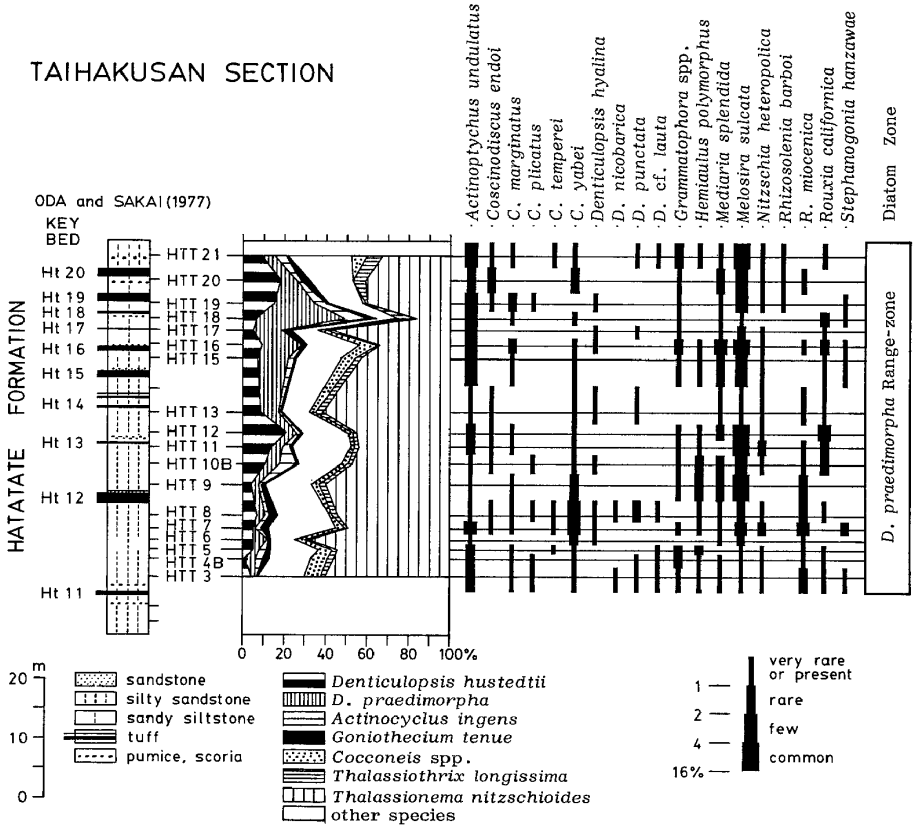


Fig. 16. Biostratigraphic distribution of selected diatom species in Taihakusan section, Sendai area.

have been published by recent studies of planktonic microfossils (Kato, 1980; Koizumi, 1981b; Koizumi *et al.*, 1980).

According to Mitsui *et al.* (1973), Neogene deposits in the Takahagi area are lithologically divided into the Shimotezuna and Kohama Formations in upward sequence. These formations are separated by a partial unconformity. The Shimotezuna Formation subjected to this study is 160 m thick, consists mostly of massive, olive-green sandy siltstone and siltstone, but intercalates some pumiceous tuff and tuffaceous sandstone.

The Takahagi section examined by this study exposes the Shimotezuna Formation in the southern cliff of a valley between Komakihara and Kohama, Takahagi City (Fig. 17). This section has been referred to as route 3 in the Takahagi area by Kato (1980, p. 56) and section A by Koizumi (1981b, p. 18).

The Shimotezuna Formation yields abundant and diverse diatom fossils which are moderately to poorly preserved. Detailed occurrences of diatom assemblages are given in Appendix 11. The stratigraphic distribution of selected diatom taxa in the Takahagi section is shown in Fig. 18.

The Shimotezuna Formation in the Takahagi section is subdivided into four diatom zones, namely, the *Denticulopsis lauta*, *D. hyalina* and *D. nicobarica* Interval-zones, and the *D. praedimorpha* Range-zone in upward sequence. The *D. hustedtii* Interval-zone has not been distinguished between the *D. hyalina* and *D. nicobarica* Interval-zones.

Diatom assemblages from samples TAH-4 to TAH-7 are assigned to the *D. lauta* Interval-zone and are characterized by dominant *D. lauta* and common *D. nicobarica*. The lowest stratigraphic occurrence of *D. hyalina* in sample TAH

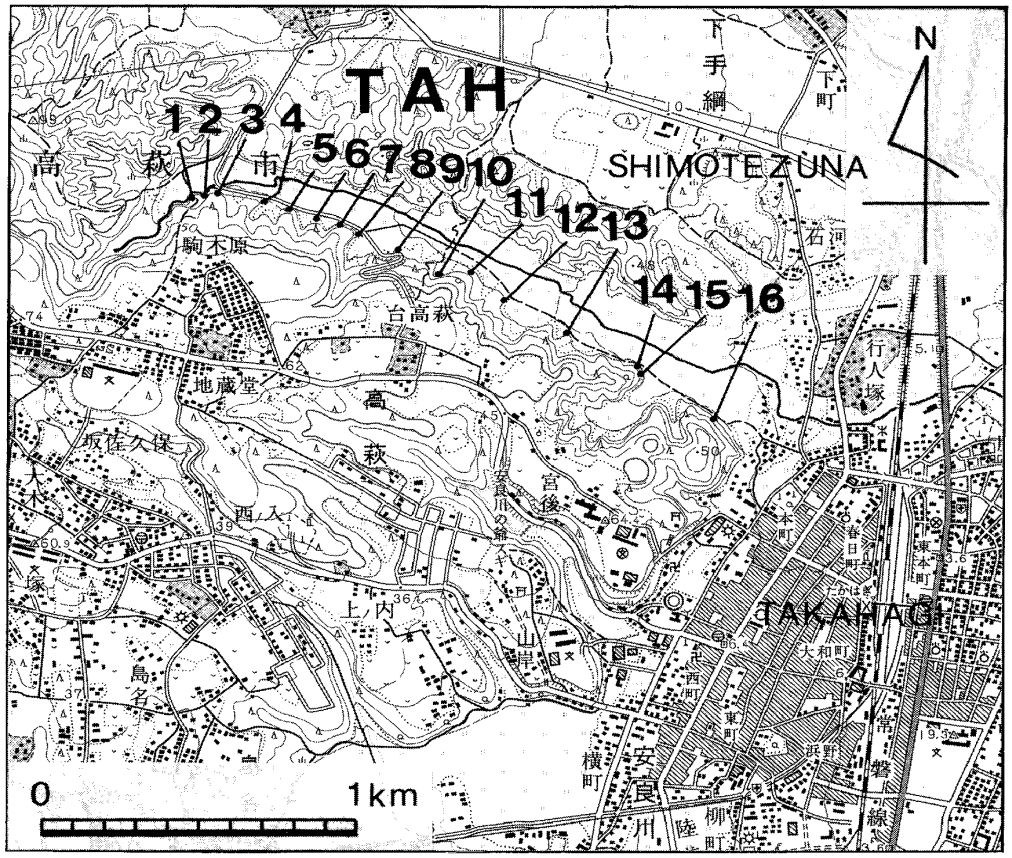


Fig. 17. Map showing sample localities in Takahagi section, Takahagi area (Topographic map "Takahagi", 1 : 25,000 in scale, Geographical Survey Institute).

-8 marks the base of the *D. hyalina* Interval-zone. Assemblages in samples TAH-10 to TAH-13 contain abundant *D. hustedtii*, common *D. nicobarica* and rare *D. lauta*, and are typical of the *D. nicobarica* Interval-zone. The base of the *D. praedimorpha* Range-zone is indicated by the first occurrence of *D. praedimorpha* in sample TAH-14. Dominant *Thalassionema nitzschioides* and common *Actinocyclus ingens* are found throughout the Shimotezuna Formation in the Takahagi section.

The rapid decrease datum level of *D. hyalina* is observed between samples TAH-9 and TAH-10, but the rapid increase datum level of *D. hustedtii* is not recognized between them. Namely, the stratigraphic interval characterized by abundant *D. hyalina* and rare *D. hustedtii* is not distinguished in the Shimotezuna Formation. There are two assumptions explaining the absence of the *D. hustedtii* Interval-zone. The first is that a hiatus occurs between these samples and the second is that the *D. hustedtii* Interval-zone exists in a 15 m stratigraphic interval between the two samples. Examination of samples collected at a much closer stratigraphic interval should set forth relative pertinence of these two assumptions.

5. Hitachi area

The Hitachi area facing the Pacific Ocean lies some 130 km NE of Tokyo, and is bordered on the west by the southeastern margin of the Abukuma Massif.

According to Fukudome (1974MS), Neogene deposits in the Hitachi area are lithologically divided into the following five formations in downward sequence.

Hatsuzaki Formation (30 m)

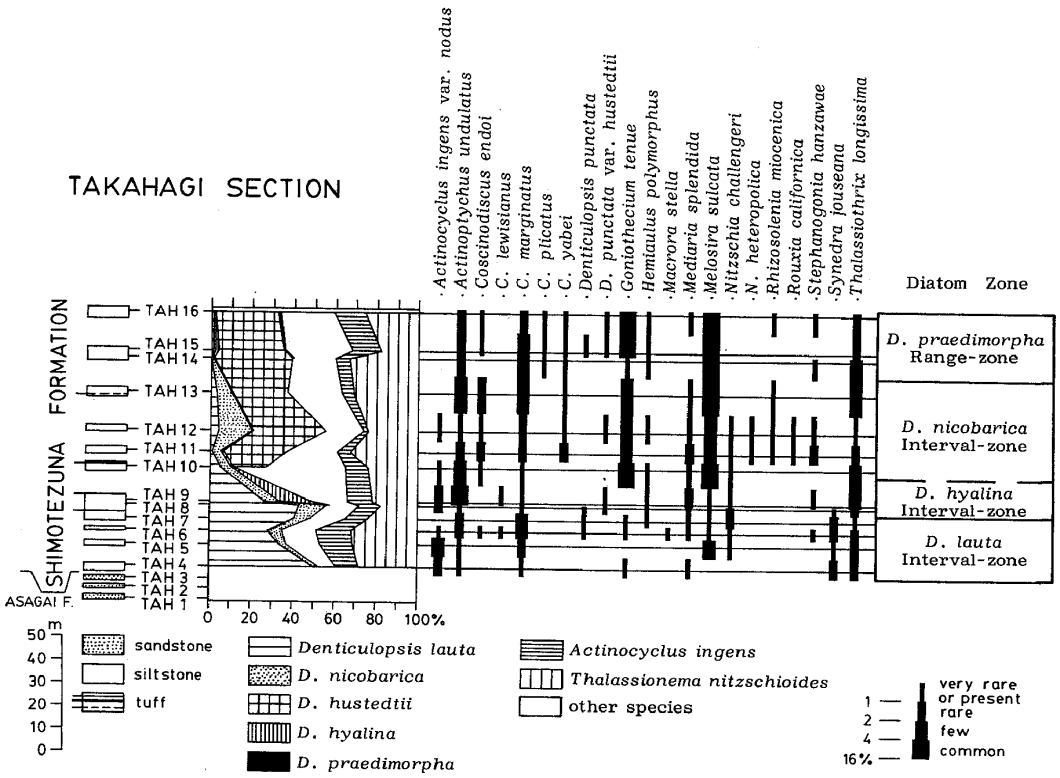


Fig. 18. Biostratigraphic distribution of selected diatom species in Takahagi section, Takahagi area.

	..... unconformity .....
Pliocene	Hanareyama Formation (20 m)
	Hitachi Formation (95 m)
	..... probable unconformity .....
	Mizuki Formation (110 m)
Miocene	..... probable unconformity .....
	Kokubu Formation (160 m)

Fukudome (1974MS) inferred that the Kokubu Formation, the lowest unit in this area, rests unconformably upon the pre-Tertiary basement with a 40 m thick basal conglomerate. This formation cosists mostly of a massive, bluish-green siltstone attaining to about 120 m in thickness in this area and including large amounts of intercalated tuff and numerous concretions. He reported that the Kokubu and Mizuki Formations yield diverse microfossil assemblages which appear to be of Middle or Late Miocene age.

The Measured section named "Ayukawa section" is located along the Ayu River emptying into the Pacific in the southern part of Hitachi City (Fig. 19). Samples examined from the Kokubu Formation were originally collected by Fukudome (1974MS).

Diverse but moderately to poorly preserved assemblages of diatoms occur in the Ayukawa section. A detailed documentation of these assemblages is given in Appendix 12. The distribution of stratigraphically diagnostic taxa is shown in Fig. 20.

The Kokubu Formation in the Ayukawa section is biostratigraphically subdivided into two diatom zones, the *Denticulopsis praedimorpha* Range-zone and the *Coscinodiscus yabei* Interval-zone in upward sequence. The boundary between these zones is marked by the last appearance of *D. praedimorpha* between samples AY-9 and AY-11 (sample AY-10 is not examined).

Diatom assemblages assigned to the *D. praedimorpha* Range-zone are characterized by dominant *Thalassionema nitzs-*

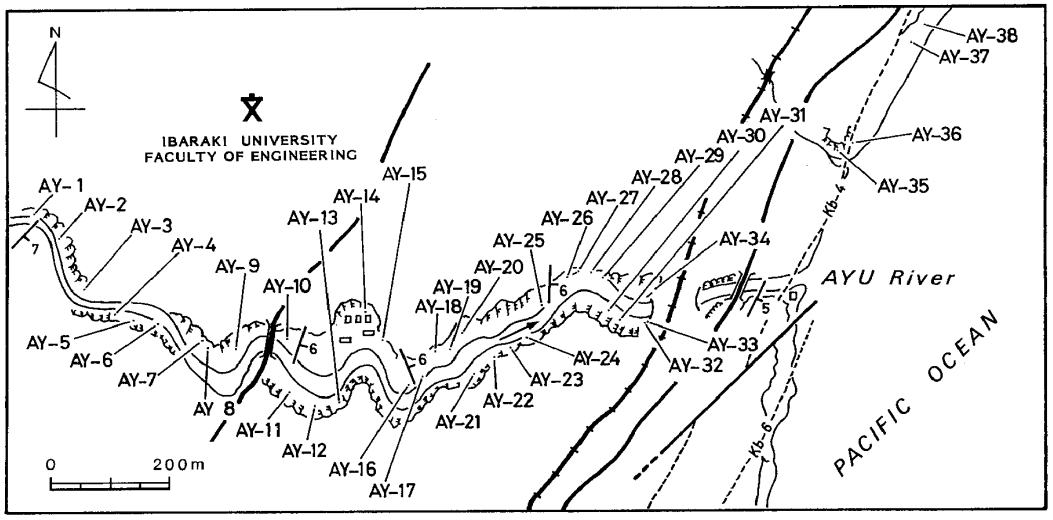


Fig. 19. Map showing sample localities in Ayukawa section, Hitachi area (modified from Fukudome, 1974MS).

chioides and common occurrences of such species as *D. praedimorpha*, *D. hustedtii*, *Actinocyclus ingens* and *Goniothecium tenue*. Diatom assemblages referred to the *C. yabei* Interval-zone are characterized by dominant *T. nitzschioides*, dominant *D. hustedtii* and rare *D. hustedtii* (elliptical form).

Coscinodiscus plicatus, *C. temperei*, *C. yabei*, *Nitzschia heteropolica* and *Thalassionema hirosakiensis* occur rarely throughout the section. It is not certain as to whether the rare occurrence of *D. lauta* s.s. throughout the section is represented by reworked specimens. The first occurrence of *Thalassionema schraderi* is recognized in sample AY-37 near the top of this section.

The following events of rare species are recognized in upward sequence; the first occurrence of *Rhizosolenia barboi* in sample AY-7, the last occurrence of *Denticulopsis nicobarica* in sample AY-9, the first occurrence of *Hemidiscus cuneiformis* in sample AY-23, the last occurrence of *Mediaria splendida* in sample AY-25, and the last occurrence of *Stephanogonia hanzawae* in sample AY -27. Barron (1980, 1981) and Konizumi (1980b) attached much importance to these events near the last appearance of *D. praedimorpha*.

6. Hitachiota area

The Hitachiota area lies some 120 km NE of Tokyo, bordered on the northeast by the southern margin of the Abukuma Massif, where granodiorite and metamorphic rocks form the basement for Neogene deposits. Fukudome (1974MS) classified Neogene deposits in this area into six formations in downward sequence as follows:

Pliocene	Kume Formation (150 m)
	..... unconformity .....
	Hase Formation (300 m)
	..... probable unconformity .....
	Genjigawa Formation (550 m)
Miocene	Zuiryu Formation (450 m)
	Okado Formation (300 m)
	..... interfinger .....
	Somewada Formation (1,000 m)

The Zuiryu and Genjigawa Formations examined in this study are distributed on the hilly side of the northwestern part of Hitachiota City. The Zuiryu Formation consists mostly of a siliceous hard siltstone and non-siliceous soft siltstone and contains numerous thin layers of intercalated sandstone. The Genjigawa Formation is composed of a

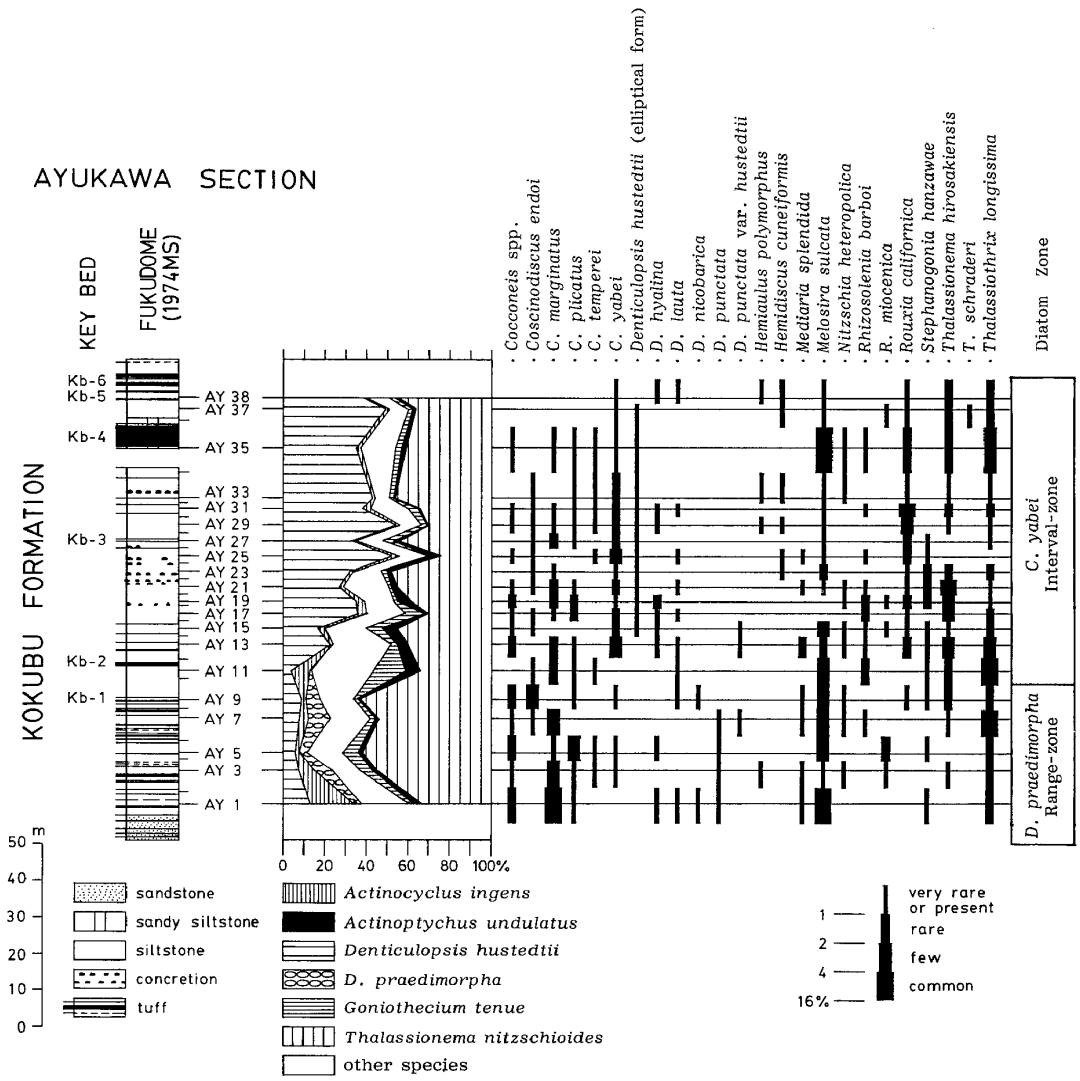


Fig. 20. Biostratigraphic distribution of selected diatom species in Ayukawa section, Hitachi area.

massive, diatomaceous greenish-gray siltstone and sandy siltstone, with some intercalations of sandstone, conglomerate and tuff. Both formations are generally very rich in microfossils, though the Zuiryu Formation is not diatomaceous.

The "Zuiryuzawa section" which encompasses stratotype sections of both the Zuiryu and Genjigawa Formations is located in the Zuiryu Valley near Matsuzaki, Hitachiota City. Biostratigraphic studies of planktonic foraminifera, calcareous nannofossils, radiolarians and diatoms were made in the Zuiryuzawa section by Fukudome (1974MS), who considered that the Zuiryu and Genjigawa Formations are of Middle Miocene age.

The stratigraphic columnar section along the Zuiryu Valley is shown in Appendix 14. A location map of sample localities along the section is Fig. 21. The stratigraphic occurrence of diatoms is tabled in Appendix 13. The stratigraphic distribution of selected diatom taxa is shown in Fig. 22.

The Zuiryu Formation yields no diatoms (sample ZIR-1 to ZIR-17b), but the Genjigawa Formation contains abundant diatoms (sample ZIR-18 to ZIR -39). The state of preservation is generally moderate to poor. Diatom assem-

blages of the *Denticulopsis lauta* Interval-zone are present.

This section is characterized by dominant *D. lauta* which occupies 40–70% of the diatom assemblages. *Thalassionema nitzschioides*, *Actinocyclus ingens* and *Actinoptychus undulatus* are abundant to common throughout the section. *Coscinodiscus lewisianus*, *C. symbolophorus*, *Mediaria splendida* and *Raphidodiscus marylandicus* occur rarely to commonly throughout the section. *A. ingens* var. *nodus* first occurs in sample ZIR-38 near the top of the Zuiryuzawa section.

Denticulopsis nicobarica do not occur in this section, although this species is present in the *D. lauta* Interval-zone in DSDP Hole 438A, the Kadonosawa section and the Usuitoge section. In DSDP Hole 438A and the Usuitoge section, *D. nicobarica* occurs together with *A. ingens* var. *nodus*, but it is absent in the Kadonosawa section. If the *D. lauta* Interval-zone be divided into two units on the basis of the first appearance of *D. nicobarica* or *A. ingens* var. *nodus*, the Genjigawa Formation in the Zuiryuzawa section can be assigned to the lower part

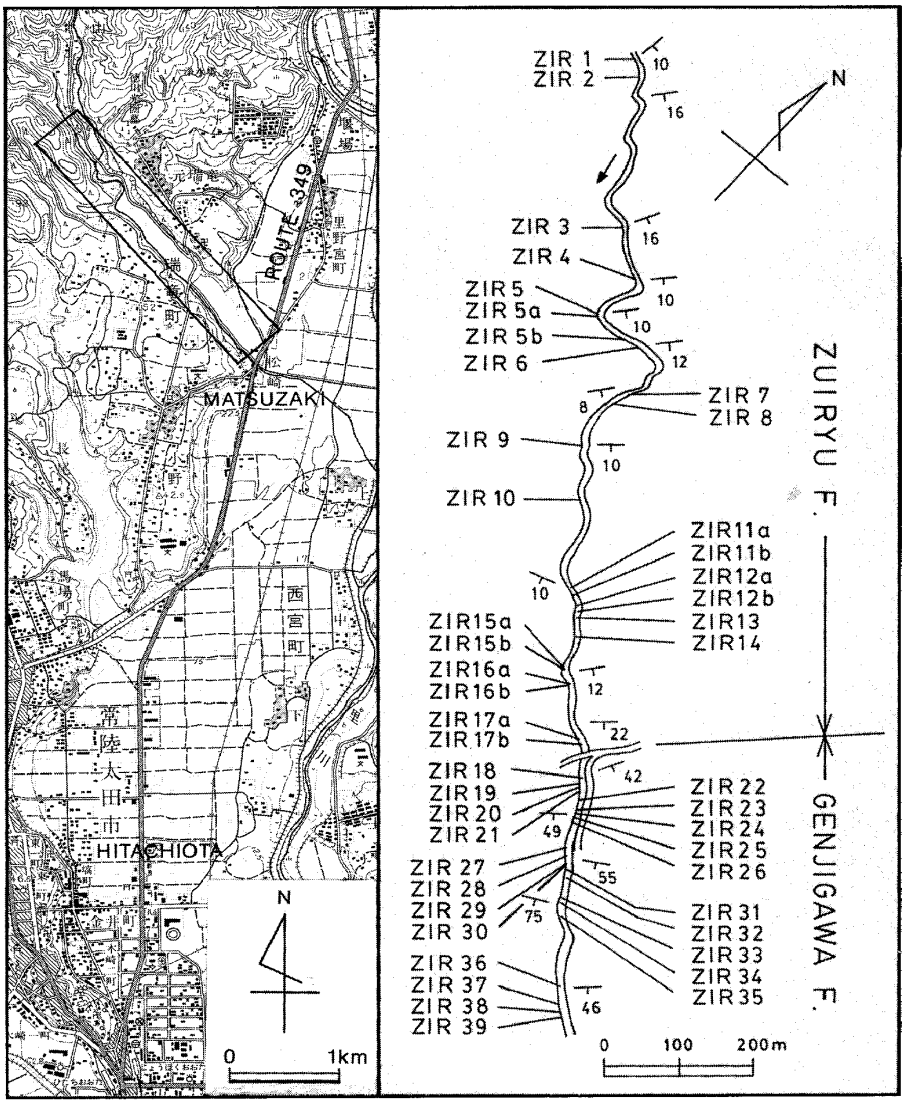


Fig. 21. Map showing sample localities in Zuiryuzawa section, Hitachiota area (Topographic map "Hitachiota", 1 : 25,000 in scale, Geographical Survey Institute).

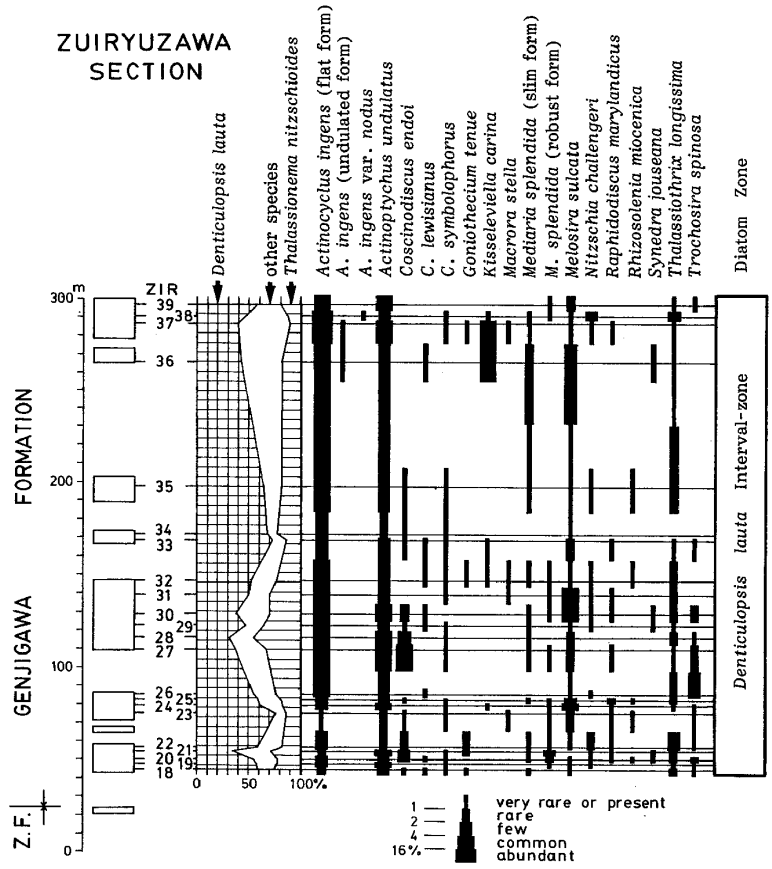


Fig. 22. Biostratigraphic distribution of selected diatom species in Zuiryu-zawa section, Hitachiota area (Z.F.: Zuiryu Formation).

of the *D. lauta* Interval-zone. A biostratigraphic significance of these two species is open to further investigation in the *D. lauta* Interval-zone as well as a reconstruction of their geographic distribution.

7. Nakaminato area

The Nakaminato area is situated on the Pacific coast about 100 km NE of Tokyo. The distribution of Tertiary sediments in this area are restricted along the seashore and the foot of hills. Tertiary deposits rest unconformably upon sedimentary rocks of a probable Cretaceous age and are subdivided into four stratigraphic units; the Tonoyama, Katsuta, Isozaki and Hetano Formations in upward sequence (Fukudome, 1974MS). These formations are separated from each other by unconformities. The Katsuta and Isozaki Formations are examined for diatom biostratigraphy.

The Katsuta Formation is composed of a massive, greenish-gray tuffaceous siltstone containing abundant siliceous microfossils, and is estimated to exceed 300 m in thickness. The Isozaki Formation consists mostly of a microfossiliferous greenish-gray sandy siltstone intercalated with numerous pumiceous tuff layers, and its total thickness exceeds 20 m. Both formations yield diverse radiolarian assemblages that appear to be of Middle Miocene age (Fukudome, 1974MS).

Rock samples were originally collected by Fukudome (1974MS) from two sections (Fig. 23), which constitute a composite section called the "Nakaminato section" in this study. Stratigraphic occurrences of diatoms in the Nakaminato section are given in Appendix 8. The distribution of selected strati-

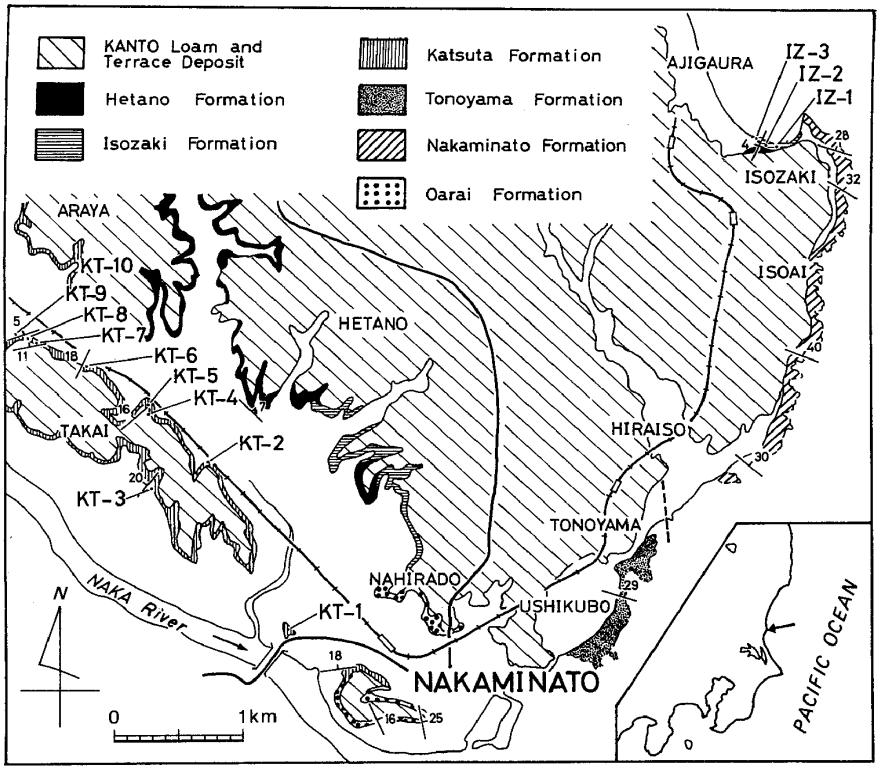


Fig. 23. Map sheowing sample localities in Nakaminato section, Nakaminato area (modified from Fukudome, 1974 MS).

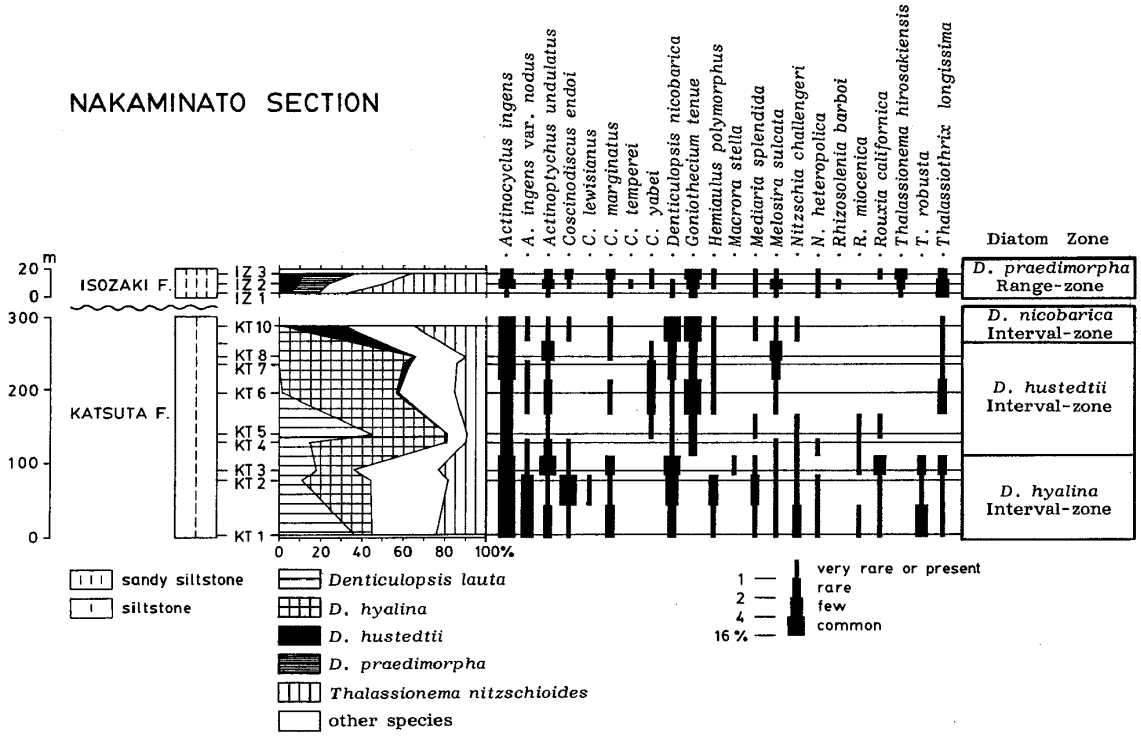


Fig. 24. Biostratigraphic distribution of selected diatom species in Nakaminato section, Nakaminato area.

graphically important diatoms is shown in Fig. 24.

The Katsuta and Isozaki Formations in the Nakaminato section yield abundant diatoms which are moderately well preserved. The Katsuta Formation is biostratigraphically subdivided into three diatom zones, namely, the *Denticulopsis hyalina*, *D. hustedtii* and *D. nicobarica* Interval-zones in upward sequence. Diatom assemblages in the Isozaki Formation are referable to the *Denticulopsis praedimorpha* Range-zone.

The lowest stratigraphic occurrence of *D. hustedtii* in sample KT-4 marks the base of the *D. hustedtii* Interval-zone. The base of the *D. nicobarica* Interval-zone is indicated by both the rapid decrease of *D. hyalina* and the rapid increase of *D. hustedtii* between samples KT-8 and KT-10 (sample KT-9 is not examined). The boundary between the *D. nicobarica* Interval-zone and the *D. praedimorpha* Range-zone, which is determined by the first appearance of *D. praedimorpha*, may coincide with the unconformity between the Katsuta and Isozaki Formations.

8. Usuitoge area

The Usuitoge area is located on the border between Gumma and Nagano Prefectures, 120 km NW of Tokyo. Neogene marine deposits in this area have actively been investigated by the Motojuku Collaborative Research Group (1968) and Akima Collaborative Research Group (1971, 1975, 1976).

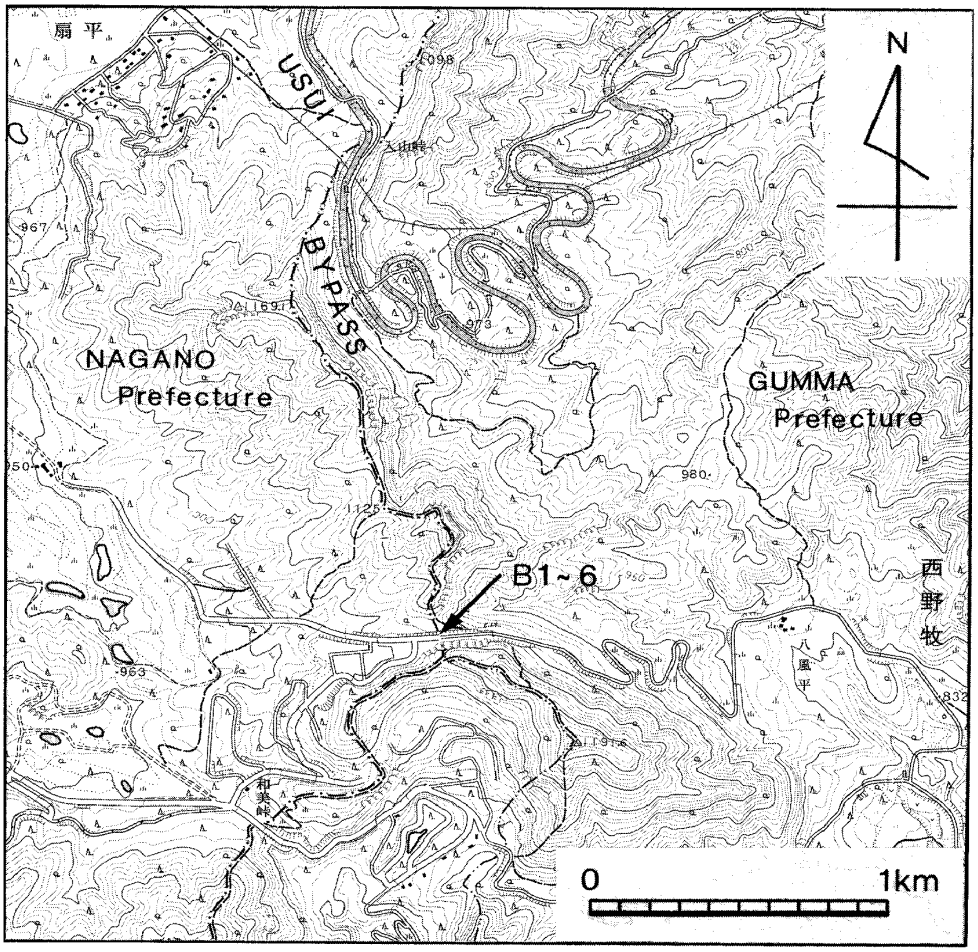


Fig. 25. Map showing sample locality in Usuitoge section, Usuitoge area (Topographic map "Minamikaruizawa", 1 : 25,000 in scale, Geographical Survey Institute).

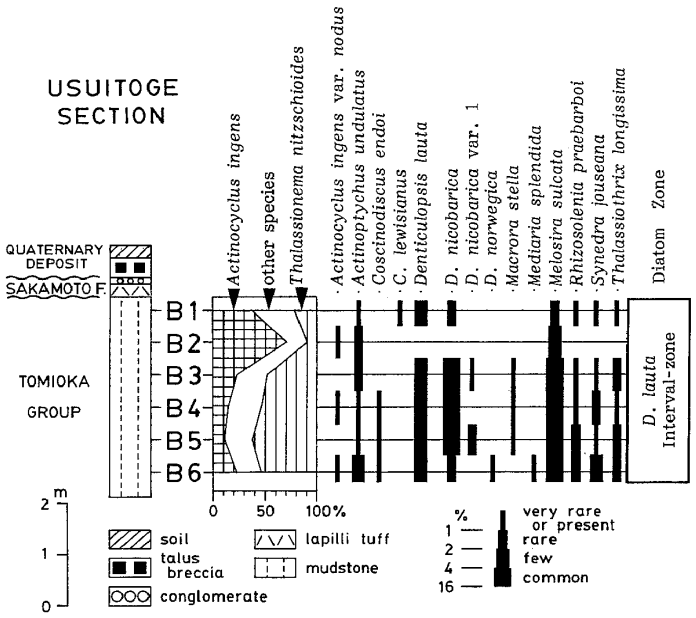


Fig. 26. Biostratigraphic distribution of selected diatom species in Usuitoge section, Usuitoge area.

Because these marine deposits are exposed in a few limited areas on the western side of Mt. Myogi, it is difficult to identify and correlate them with Neogene formations in the Tomioka area (Honma and Fujita, 1979; Nomura and Akima Collaborative Research Group, 1981). The Tomioka area exposes marine formations belonging to the Tomioka Group which has recently been subjected to intensive microbiostratigraphic studies by Matsumaru (1967, 1977), Takayanagi *et al.* (1976, 1978), Chiji and Konda (1978, 1981a, b) and Konda (1980).

Samples examined were originally collected from one outcrop by Tanaka *et al.* (1982MS, 1983) (Fig. 25). The stratigraphic occurrence of diatoms in the Usuitoge section is given in Appendix 15. The stratigraphic distribution of selected diatoms is shown in Fig. 26.

The Usuitoge section exposes about 4 m thick Middle Miocene sediments of the *Denticulopsis lauta* Interval-zone. Diatoms are generally common, and the state of preservation is moderate to poor throughout the section.

A dominant occurrence of *Thalassionema nitzschioides* characterizes the lower part of this section, and abundant *Actinocyclus ingens* the upper part. Throughout the section, few *D. lauta* occur in association with few to common *Denticulopsis nicobarica*. A common occurrence of *Melosira sulcata* throughout the section may suggest that the massive mudstone containing diatoms has accumulated in relatively shallow waters of an epicontinental sea.

Very rare *Denticulopsis norwegica* and *Mediaria splendida* are found in the lowermost sample B-6 only, and *Coscinodiscus lewisianus* is found in the uppermost sample B-1.

CORRELATION OF ONSHORE SEQUENCES WITH DSDP HOLE 438A

As in Fig. 27, Middle and Upper Miocene onshore sequences are correlated by diatoms with the section cored at DSDP Hole 438A off the coast of North-

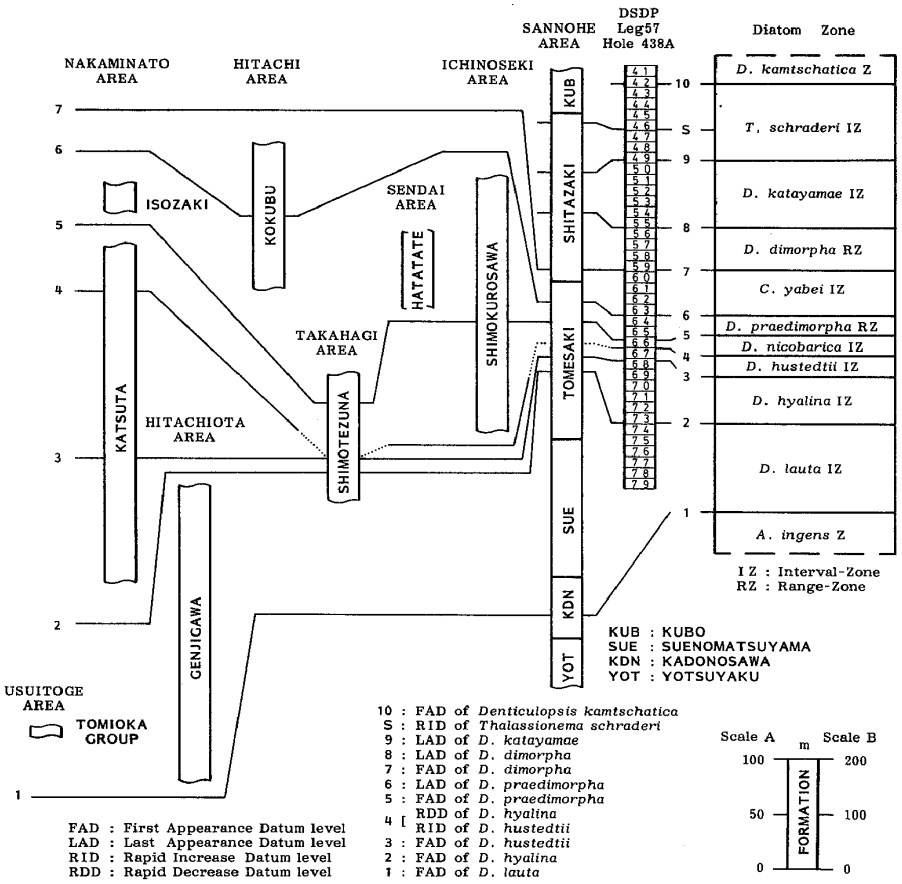


Fig. 27. Correlation of Miocene sequences based on the proposed diatom zones (scale B is applicable to Sannohe area, scale A the other areas).

east Japan. With the exception of the FAD of *D. kamtschatica* (datum level 10 in Fig. 27), all the other diatom datum levels are used to establish a correlation of all the examined sections.

The diatom zonation and datum levels recognized in the present work have refined considerably the previously proposed correlation of onshore sections in Northeast Japan.

The following additional remarks are given as the supplementary aspects of diatom biostratigraphy of each studied area which was not completely covered in the previous chapters:

1) In the Sannohe area, diatom assemblages of the *D. kamtschatica* Zone are reported from the Kubo Sandstone Member of the Kubo Formation and the lower part of the Utouzaka Formation by Akiba (1977b), Katayama (1980MS) and Maruyama (1982MS).

2) In the Ichinoseki area, the lower portion of the "main part" of the Shimokurosawa Formation yields sporadically diatom assemblages which are assignable to the *D. hyalina* Interval-zone and the *D. hustedtii* Interval-zone (Maruyama, 1980MS). Also, Maruyama (1980MS) recovered diatom assemblages bearing a close resemblance to those of *D. kamtschatica* Zone from the Yushima Formation.

3) Koizumi (1973b) described diatom assemblages including either *D. kamtschatica* or *D. seminae* from the Tatsunokuchi Formation in the Sendai area.

4) The Kohama Formation in the Takahagi area yields assemblages which are assigned to the Subzone *a* of the *D. hustedtii* Zone by Koizumi (1981b). These assemblages may be assignable to

the *C. yabei* Interval-zone of the present zonal scheme.

5) The diatom assemblages recovered from the Mizuki Formation were so poorly preserved that no datum levels were unequivocally drawn in the Hitachi area.

6) In the Hitachiota area, the Hase Formation evidently includes the last appearance datum level of *D. praedimorpha* and is therefore divided into the *D. praedimorpha* Range-zone and the *C. yabei* Interval-zone.

The problem of calibrating diatom biostratigraphy with magnetostratigraphy has been attacked by many workers especially on Pleistocene and Pliocene sequences. This promising type of research, however, has just begun with respect to the Miocene deposits in Japan.

ZONAL CORRELATION

As in Fig. 28, the diatom zones proposed in this study are correlated with the high-latitude North Pacific diatom zones of Koizumi (1973a, 1975d, 1979b, 1980b), DSDP Leg 57 diatom zones of Barron (1980, 1981; Keller and Barron, 1982), and diatom zones established for the Japanese onshore sections of Akiba (1982a; Akiba *et al.*, 1982a, b). In order to provide a sound basis for establishing correlation with these zonations by previous workers, comparisons are made by taking the results from DSDP Hole 438A by the present author, Barron (1980) and Akiba *et al.* (1982) (see Fig. 4).

Most of the zonal boundaries established by the present study correspond to zonal and/or subzonal boundaries of the zonations of other workers. Accordingly, many of these proposed zones are likely to have a broad application to stratigraphic work in the Northwest Pacific region including Japan.

For the interval from the base of the *D. lauta* Interval-zone to the top of the *D. dimorpha* Range-zone of the present author, the stratigraphic order of succession of primary datum levels adopted for the zonal and/or subzonal boundaries in various zonations are nearly identical with each other. However, the following discrepancies have emerged between the present work and the results of previous workers:

1. The FAD of *D. hustedtii*

The base of the *Denticulopsis hustedtii-D. lauta* Zone (namely, the top of the underlying *D. lauta* Zone) has been defined by the FAD of *D. hustedtii* (Koizumi, 1973a; Barron, 1980, 1981). Barron (Barron and Keller, 1983), however, questioned the isochroneity of the FAD of *D. hustedtii* in middle latitudes of the North Pacific, and redefined this zonal boundary. His new proposed datum level is the transition from *D. hyalina* to *D. hustedtii* (or the first abundance of *D. hustedtii* greater than that of *D. hyalina*), which appears to be isochronous in middle and high latitudes of the North Pacific (Barron, 1980, 1981; Keller and Barron, 1981). Barron and Keller (1983) has concluded that this new zonal boundary is estimated at 13.8 Ma and corresponds with the FAD of *D. hustedtii* in low latitudes.

The present author attaches biostratigraphic importance to both the FAD of *D. hustedtii* and the concurrence of the RDD of *D. hyalina* and the RID of *D. hustedtii*, and proposes the *D. hustedtii* Interval-zone. Figure 29 shows a zonal correlation of the proposed zones with zones of various authors on the basis of these datum levels.

The first abundant occurrence of *D. hustedtii* greater than that of *D. hyalina* is a very drastic event accompanied by a very drastic decline of *D. hyalina* (Fig 29). Barron and Keller (1983) described

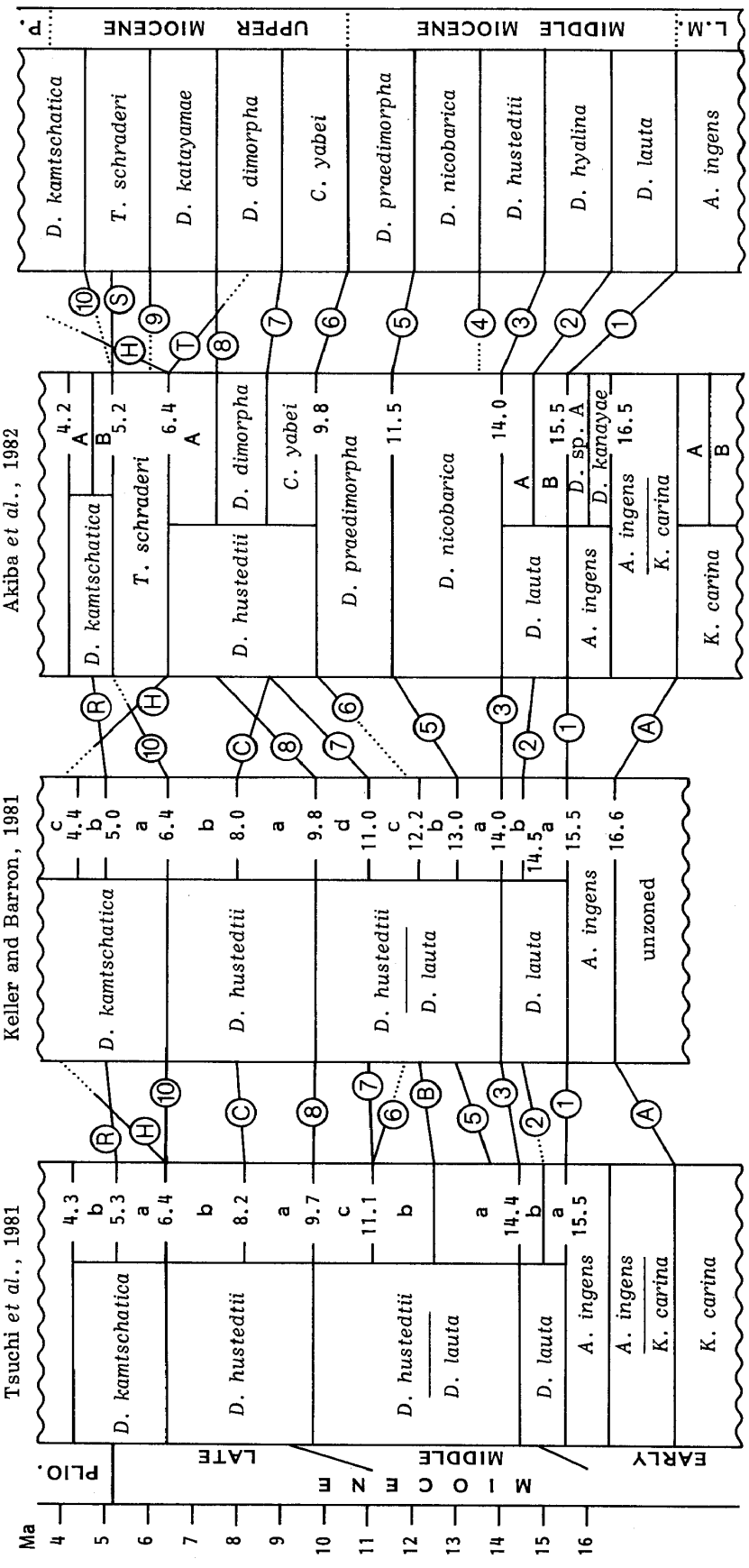


Fig. 28. Zonal correlation of the proposed zones with zones of various authors.

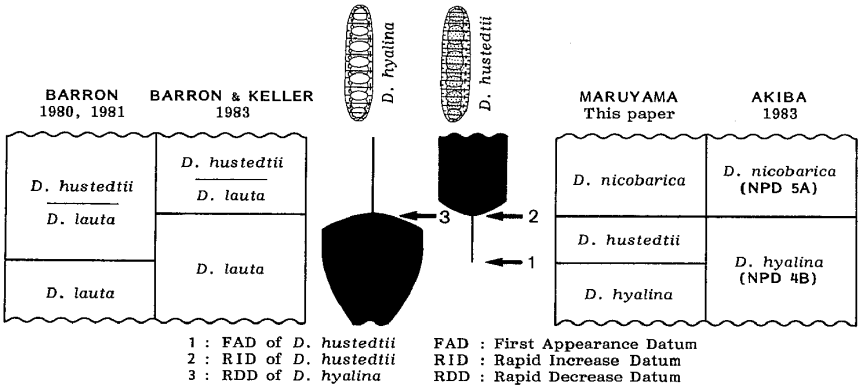


Fig. 29. Zonal correlation of the proposed zones with zones of various authors near the First Appearance Datum of *Denticulopsis hustedtii*.

this change in abundance of the two species as the transition from *D. hyalina* to *D. hustedtii*. The present author interprets, however, this "transition" not to be an evolutionary development in the genus *Denticulopsis* but an ecological event in response to a paleoenvironmental change in the North Pacific. Both *D. hyalina* and *D. hustedtii* evolved from an ancestor *D. lauta* following independent trends of evolutionary delelopment (see Part 1 of this study). Since a relatively warm condition is hypothesized for this time interval (13.8 Ma, Barron and Keller, 1983), it is likely that the introduction of middle to high-latitude species *D. hustedtii* into the tropics at this time was realized even in a small extent. On the other hand, *D. hyalina* was ruined by the onset of this climatic amelioration.

2. The LAD of *D. praedimorpha* and the FAD of *D. dimoprha*

With respect to the coincidence of the extinction of *D. praedimorpha* and the appearance of *D. dimorpha*, Koizumi (1980b, 1982) has not yet designated a reference section to verify this paleontologic event. On the other hand, Barron (1980), Akiba (e.g. 1982a; Akiba *et al.*, 1982a) and the present author have noticed an interval between the LAD of *D. praedimorpha* at the base and the FAD of *D. dimorpha* at the top, where *D. hustedtii* is abundant but *D. lauta* s.l. (*D. lauta* s.s., *D. praedimorpha* and *D. dimorpha*) is absent. This interval is represented by the upper part of the Subzone *c* of the *D. hustedtii-D. lauta* Zone of Barron (1980), the *C. yabei* Subzone of the *D. hustedtii* Partial Range-zone of Akiba (1982a), and the *C. yabei* Interval-zone of the present author, respectively.

Because *D. praedimorpha* and *D. dimorpha* appear to lie on a single evolutionary lineage (see Part 1 of this study), the presence of the stratigraphic interval corresponding to the *C. yabei* Interval-zone is very difficult to understand in the marginal northwestern Pacific. In DSDP Leg 63 off California, however, Barron (1981; Barron and Keller, 1983) reported a continuous occurrence of *D. praedimopha* from the Subzone *b* through the base of the Subzone *d* of the *D. hustedtii-D. lauta* Zone. He also recognized a rapid decline in abundance of *D. praedimorpha* in the Subzone *c* of this zone. The above data indicate that the LAD of *D. praedimorpha* in the northwestern Pacific region can be correlated with the rapid decline level of this species in the northeastern Pacific region. The present author suggests that a point of divergence from *D. praedimorpha* to *D. dimorpha* will be found precisely near the boundary of Middle/Upper Miocene deposits in the high-latitudes of the

North Pacific.

3. The LAD of *C. yabei*

Regarding the level of the last appearance of *C. yabei*, opinions diverse between Koizumi (1980b, 1982), Barron (1980) and Akiba (1982a). Koizumi and Barron assert that the last appearance datum of *C. yabei* lies between the last appearance datum of *D. dimorpha* and the first appearance datum of *D. kamtschatica*, and they divided the *D. hustedtii* Zone into two subzones by means of this datum. On the other hand, Akiba insists that the last appearance of *C. yabei* is approximately coincidental with the first appearance datum of *D. dimorpha*. Because of the rare and sporadic occurrence of *C. yabei* in the Middle and Upper Miocene interval and the presence of other species providing an effective means of correlation, the present author feels that there is no need to use this species for establishing a primary datum level.

The present author recognized in DSDP Hole 438A the last occurrence of *C. yabei* in sample 47-1, 10-14 cm between levels of the last occurrence of *D. katayamae* (sample 49-6, 10-14 cm) and the first occurrence of *D. kamtschatica* (sample 42-4, 50-54 cm). In the Shitazaki section of the Sannohe area, *C. yabei* is found above the last appearance datum of *D. katayamae*. These data appear to indicate that the interpretation of Koizumi and Barron is to be correct.

Akiba (1983) recently revised his view on the LAD of *C. yabei*. That is that the LAD of *C. yabei* in his earlier paper is really the RDD of this species and that the true LAD occurs above the LAD of *D. dimorpha*. His new interpretation agrees with views expressed by Koizumi, Barron and the present author. Furthermore, Akiba (1983) claimed that the plicated species belonging to the genus *Coscinodiscus* should be taxonomically transferred to the genus *Thalassiosira*, and noted that *Coscinodiscus yabei* should be referred to as *Thalassiosira yabei*.

4. The LAD of *D. hustedtii*

Koizumi, Barron and Akiba disagree with each other about the level of the last appearance of *D. hustedtii* near the Miocene/Pliocene boundary. Koizumi (e.g. 1975d, 1980b) asserts that its last appearance is coincident with the first appearance of *D. kamtschatica*. Barron (1980) did not specially discuss this last appearance level in DSDP Leg 57, but regarded it as a secondary datum level and placed it in the Early Pliocene near the base of the Subzone *c* of the *D. kamtschatica* Zone. On the other hand, Akiba (e.g. 1979, 1982a) argued that *D. hustedtii* becomes extinct below the first appearance of *D. kamtschatica* and assumed that the specimens of *D. hustedtii* encountered in and above his *T. schraderi* Interval-zone are all reworked.

These controversial problems as discussed above realistically show that it is very difficult to determine a true extinct horizon of a taxon. *D. hustedtii* occurs upward in sequence to the Thriving Interval of *D. kamtschatica*. Both Koizumi and Barron seem to have regarded the upper limit of the Declining Interval of *D. hustedtii* as the extinct horizon, although the stratigraphic ranges indicated by them are in fact different between the two authors. Akiba seems to have interpreted the rapid decrease level of *D. hustedtii* to be its extinction level. At present, the present author is inclined to follow the former view from a biostratigraphic viewpoint, though further study will be needed for precise solution of the problem.

5. The FAD of *T. schraderi*

Akiba (1982a) pointed out that the first appearance of *T. schraderi* approximates his "last appearance of *D. hustedtii*", that is, the rapid decrease of *D.*

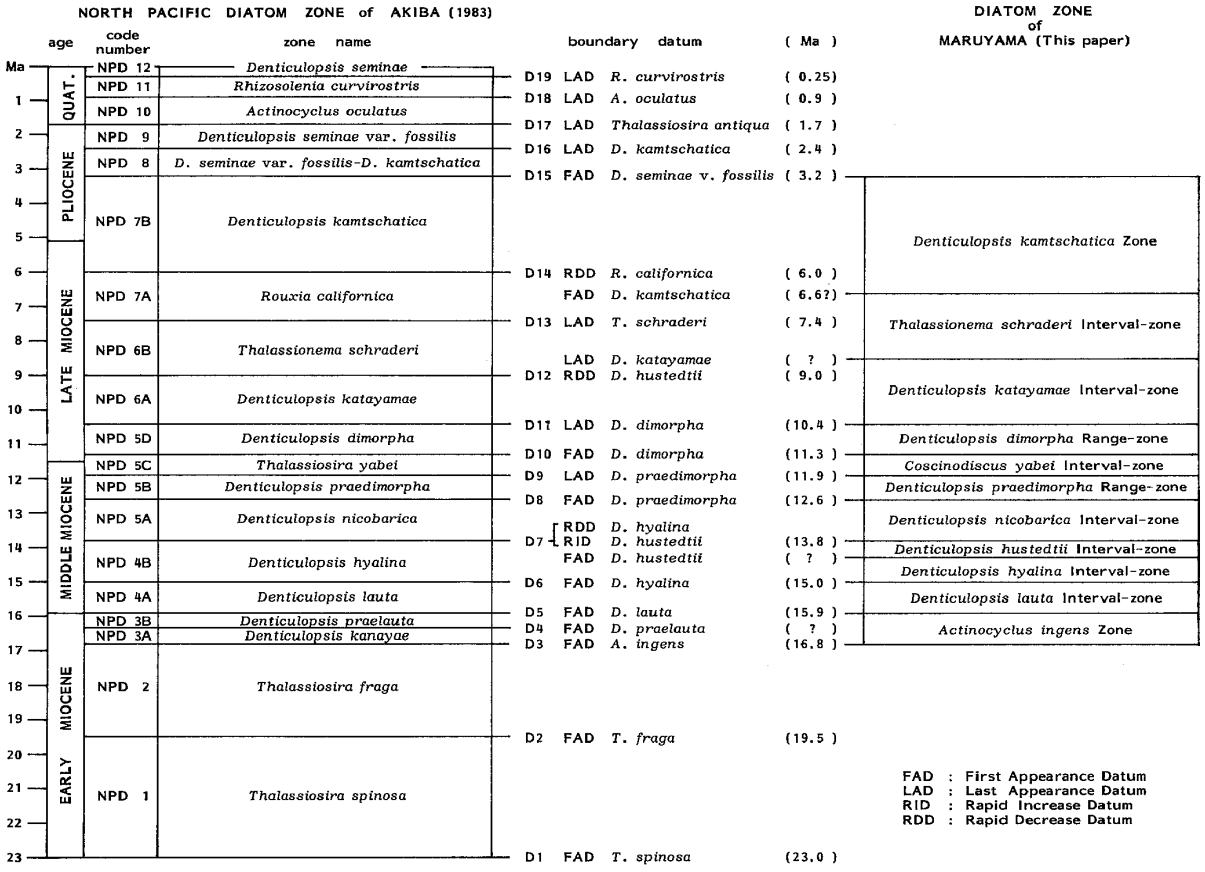


Fig. 30. Zonal correlation of the proposed zones with the North Pacific Diatom Zone of Akiba (1983).

hustedtii of the present author, in DSDP Hole 438A and DSDP Leg 63 off California. Data available from the Sannohe area and Hole 438A indicate that the first occurrence of *T. schraderi* is present in the middle part of the *D. dimorpha* Range-zone of the present author. On the other hand, this event is found in the *C. yabei* Interval-zone in the Hitachi area. Additional studies are needed to establish a precise range of *T. schraderi* as the stratigraphic value of this species has come to be realized only recently.

Late Cenozoic diatom zonation has been proposed by Koizumi, Barron, Akiba and the present author in the middle- to high-latitudes of the North Pacific. Many diatom zones and datum levels proposed thus far have shown a powerful ability to establish stratigraphic division and long-distance correlation. A large number of zones, however, would cause a wrong zonal-correlation among various authors and lose popularity among their users. Accordingly, Barron (in press) is preparing to propose a code number of NNPD (Neogene North Pacific Diatom zones) for the diatom zonation. Furthermore, Akiba (1983) already revised and simplified Barron's code number, and proposed a new code number of NPD 1-12 for the Late Cenozoic diatom zones. Figure 30 shows a zonal correlation of the zones of the present author with the North Pacific Diatom Zones of Akiba (1983). The present author agrees with a codification of diatom zones for common interests on the condition that an overissue of code number can be avoided.

CONCLUSIONS

The following summarizes the significant results of Parts 1 and 2 of the present study.

1) The present author placed a strong emphasis on the First and Last Appearance Datums (FAD, LAD), and the Rapid Increase and Rapid Decrease Datums (RID, RDD) in establishing the Miocene diatom biostratigraphy.

2) Eleven datums and eleven zones are established in Miocene sedimentary sequences on the Pacific side of Northeast Japan and from DSDP Hole 438A.

3) A detailed diatom correlation between onshore sections and sediments cored from DSDP Hole 438A proves that diatoms provide the best biostratigraphic control in the Northwestern Pacific.

4) Zonal correlations between the zones proposed herein and those of previous authors prove that diatom biostratigraphy has come to near completion throughout the North Pacific region.

5) Species belonging to the genus *Denticulopsis* are classified into six groups according to the structure of valve face and the presence or absence of secondary pseudosepta.

6) Morphologies of the representative species belonging to the genus *Denticulopsis* are expressed in terms of mathematical formulas.

7) *Denticulopsis praedimorpha* and *D. dimorpha* exhibit a very wide morphological variation.

8) Three evolutionary trends are discussed among the species of the genus *Denticulopsis*.

9) One new species, *Denticulopsis katayamae*, a very important species for the Upper Miocene diatom biostratigraphy, is described.

Appendix 1a. Table showing stratigraphic occurrence of

CORE	79	78	73	73	73	72	72	72	71	71	71	70	70	70
	1	1	5	3	1	5	3	1	5	3	1	5	3	1
INTERVAL	51	54	9	27	27	11	15	14	8	7	12	23	49	16
	54	56	11	31	31	13	17	18	12	11	16	27	53	20
ABUNDANCE	2	2	1	1	4	2	1	2	3	1	1	1	2	2
PRESERVATION	M	M	M	M	P	P	P	M	M	G	M	M	M	M
Actinocyclus ellipticus Grunow														
Actinocyclus ingens Rattray	175	250	117	122	99	101	49	75	70	89	100	49	75	115
Actinocyclus ingens var. *nodus* Baldauf	6	41	19	13	19	10	6	9	7	16	13	5	5	25
Actinoptychus undulatus (Bailey) Ralfs	4	2	6	5	6	8	3	8	5	5	5	9	5	15
Amphora costata Wm. Smith														1
Asteromphalus sp.														
Aulacosira granulata (Ehrenberg) Simonsen					2			1	1	2			2	4
Biddulphia aurita (Lyngbye) Brébisson and Godey														
Biddulphia spp.			2											
Cocconeis californica Grunow				1	2									
Cocconeis costata Gregory			1						1					
Cocconeis spp.						1		1	1		1			
Coscinodiscus endoi Kanaya	3	1		1					1		1			
Coscinodiscus lewisianus Greville			1	1						1				
Coscinodiscus marginatus Ehrenberg	4	1	5	5	11	4	5	6	7	6	3	2	10	6
Coscinodiscus plicatus Grunow														
Coscinodiscus symbolophorus Grunow	1		1	1	1	1	1							
Coscinodiscus temperei Brun														
Coscinodiscus vetustissimus Pantocsek					1	1	3	1	1			2	1	1
Coscinodiscus yabei Kanaya														
Denticulopsis kanayae Akiba		1												
Denticulopsis dimorpha (Schrader) Simonsen														
Connecting band														
Girdle view														
Valve view														
Denticulopsis katayamae Maruyama n. sp.														
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen														
Denticulopsis hustedtii (elliptical form)														
Denticulopsis hyalina (Schrader) Simonsen			+	+		+	+	22	70	139	113	150	135	154
Denticulopsis cf. *hyalina* (Schrader) Simonsen												1		1
Denticulopsis lauta (Bailey) Simonsen	188	80	179	132	61	302	149	279	108	386	248	360	118	174
Denticulopsis cf. *lauta* (Bailey) Simonsen	2													
Denticulopsis nicobarica (Grunow) Simonsen	6	12	36	16	41	106	68	95	9	3	6	2	1	
Denticulopsis cf. *nicobarica* (Grunow) Simonsen														
Denticulopsis praedimorpha Akiba														
Connecting band														
Girdle view														
Valve view														
Denticulopsis punctata (Schrader) Simonsen			1		5	1	1					1		6
Delphineis cf. *ovata* Andrews	1					2								
Goniothecium odontella Ehrenberg														
Goniothecium tenue Brun	6	11	7	14	2	28	13	6	11	6	5	3	4	22
Grammatophora angulosa Ehrenberg				1										
Hemiaulus polymorphus Grunow	3									1		1		
Hemidiscus cuneiformis Wallich														
Kisseleviella carina Sheshukova-Poretzkaya	14	17		2	6	2	3	4	2	2			1	
Mediaria splendida Sheshukova-Poretzkaya	6	2	11	8	7	5	7	9	2		1	5	2	2
Melosira sol (Ehrenberg) Kützing		1												
Melosira sulcata (Ehrenberg) Kützing	1	6	8		4		1	4	7					1
Navicula sp.			1											
Nitzschia challengeri Schrader	19	4	5	6	8	11	4	5	2	5	1			
Nitzschia heteropolica Schrader														
Nitzschia praereinholdii Schrader														
Nitzschia sp.A	2		3		2	1		2		1		1		1
Nitzschia spp.						9		10		2	1	15	4	
Rhaphoneis surirella (Ehrenberg) Grunow	8							1	1					
Rhaphoneis miocenica Schrader	1					3				1		1		1
Rhizosolenia barboi (Brun) Tempère and Peragallo														
Rhizosolenia hebetata Bailey									1			2	1	3
Rhizosolenia miocenica Schrader										1				
Rhizosolenia praebarboi Schrader	1	3	1	1	1									
Rhizosolenia sp.												1		
Rouxia californica Peragallo												4		
Rouxia naviculoides Schrader		2	2	1			3			1				2
Stephanogonia hanzawae Kanaya	3	2	1	2	2	1	4		1				2	
Stephanopyxis schenckii Kanaya		5		1	1		1		1	1			1	
Stephanopyxis turris (Greville and Arnott) Ralfs		1	1	1	1		1	3		1	1	1	1	6
Stephanopyxis spp.	3	3	1	3	1	1						1		1
Synedra jouseana Sheshukova-Poretzkaya	2			2	5									
Thalassionema hirosakiensis (Kanaya) Schrader								1						
Thalassionema nitzschioides Grunow	66	102	79	46	108	80	40	57	84	40	26	26	22	51
Thalassionema schraderi Akiba														
Thalassionema cf. *schraderi* Akiba														
Thalassiosira leptopus (Grunow) Hasle and Fryxell								2						
Thalassiosira manifesta Sheshukova-Poretzkaya														
Thalassiosira nordenskioeldii Cleve														
Thalassiothrix longissima Cleve and Grunow	14	5	9	8	8	5	6	5	7	7	6	2	6	7
Triceratium condecorum Ehrenberg														
MISCELLANEOUS	8	2	5	19	11	12	4	4	6	6	2	9	1	7
TOTAL VALVES	547	554	502	412	415	695	372	610	406	722	533	653	397	606

diatoms in DSDP Hole 438A, core 79 through core 56.

68	68	68	67	66	65	65	65	64	64	64	63	62	60	60	59	59	59	58	57	57	56	56	56
6	4	1	1	1	5	3	1	5	3	1	1	1	3	1	5	4	1	1	3	2	6	3	1
105	68	30	27	118	18	100	54	30	10	10	16	20	27	34	17	17	17	16	31	31	20	20	20
108	72	34	32	122	21	103	56	32	14	14	20	24	29	38	21	21	21	20	35	35	24	24	24
1	2	1	1	2	1	1	1	1	1	1	2	1	2	1	2	2	1	1	2	2	2	2	3
M	M	M	M	P	G	M	M	M	M	M	M	M	M	M	M	M	G	M	M	G	G	M	M
													6	2				1		5	1	1	
32	18	41	15	51	79	30	29	9		41	16	17	18	34	2	6	4	3	19	8	10	5	14
7		4	1							1													
5	3	7	2	6	5	5	7	3	5	4	13	9	5	4	5	3		1	2	2	3	4	3
																					1		
																						1	
																1							
				1																			
1																						1	1
					1				1							1				1			
		1																					1
		3			1	1			4	5	2	1	1			3		1	2	3	3	2	
1	1			13	33	6	11	4	9		7	6	1	5	3	5		5	6	1	2	3	3
																				1	1		
1				1					2	1			1	1		1		2				1	
								1															
	1										15	5	1	2		1		1	2				
					2	1			3	7	10	2											
															77	45	47	80	85	124	190	50	4
															42	22	25	47	53	85	120	36	1
															15	7	9	7	15	18	27	6	
															20	16	13	26	17	21	43	8	3
																		+	+	+	+	60	114
		8	3	165	313	51	76	24	176	241	185	193	210	230	226	136	122	74	46	64	84	143	53
										1	1	7	5	+	+								
185	198	1074	409	8	2	4	2	1		2	2	5	3	2	3	5	1		3	1	4	4	5
4	2	3	3																				
231	27	10	6	4																			
												1	3										
	2		1	10					1		1												
																					1	1	
				199	37	599	421	272	283	1		4											
				62	12	186	199	149	152			2											
				27	9	127	81	36	49														
				110	16	286	141	87	82	1		2											
		1																					
1																							
3	1	3	2	10	19	4	9	6	17	7	5	14	27	24	1	2							
												1			4	9	2	5		1	2	3	2
			1			3			2					1								1	
																2	1		1		1		
1		7	2	2	3	2			3														
						1																	
			16	4	5	2			1				1	5	1	1				3	1		
			2																				
		3	2	3	1	4				1	3										1	1	1
1				1				1		1	2			2						1			
4	2			2																			1
		1													1			1		2			
		1																					
						1		1			1			1	1	2	1	1	3	5	1	1	
	1	1	1						1														
		1					1																1
					1																		
		1	4							1	18		2	17	1	1	10	8	2	2	7	5	3
1				2							6												
		2																					
		6	1	1	1	2		2	2		5				1			1	2	1			
1				4				1	3		3			1		1							
						3	3	1	20	9	17	3	11	20	17	13	13	20	16	15	11	4	2
9	12	44	14	23	21	101	46	30	88	57	150	73	105	110	110	83	211	218	189	143	148	101	59
																						7	17
																					1	1	
						1																	
													1		1	1						1	
											1	1	2	3									
3	1	9	2	7	14	7	5	1	6	4	3	4	4	6	18	9	14	3	7	12	7	7	4
													1				2				1		
1	2	10	3	8	10	7	2	3	8	3	9	3	9	1	1	2	7	3	6	1	2	1	9
492	271	1241	490	525	548	835	612	360	635	387	475	349	417	471	473	333	435	428	391	396	483	409	297

Appendix 1b. Table showing stratigraphic occurrence of

CORE	55	55	54	53	52	52	52	51	51	51	50	50	50
	3	1	1	1	4	3	1	6	4	1	6	3	1
INTERVAL	70	70	110	77	36	36	36	16	16	16	20	20	20
	74	74	114	81	38	38	38	20	20	20	24	24	24
ABUNDANCE	1	2	1	1	2	2	2	3	3	2	2	2	4
PRESERVATION	M	M	G	M	M	M	M	M	P	M	M	M	P
Actinocyclus ehrenbergii Ralfs													
Actinocyclus ellipticus Grunow	1			2		1	1		4		2	1	
Actinocyclus ingens Rattray	8	16	19	15	2	9	2	2	3	3	2	2	4
Actinocyclus ochotensis Jousé													
Actinoptychus undulatus (Bailey) Ralfs	6	8	9	8	6	11	6	23	9	32	14	13	3
Amphora costata Wm. Smith													
Asteromphalus spp.				2									
Aulacosira granulata (Ehrenberg) Simonsen									3				
Biddulphia aurita (Lyngbye) Brébisson and Godey								7					
Bogorovia spp.					1	2	1						
Cocconeis californica Grunow				2	2	1							1
Cocconeis costata Gregory		1	2	2		2			1	2	1	1	
Cocconeis placentula Ehrenberg													
Cocconeis scutellum Ehrenberg		1						1			1		
Cocconeis vitrea Brun													
Cocconeis spp.					1								
Coscinodiscus asteromphalus Ehrenberg								1					
Coscinodiscus endoi Kanaya			1	4									
Coscinodiscus marginatus Ehrenberg	2	8	1	2	29	44	26	59	40	54	14	36	9
Coscinodiscus radiatus Ehrenberg												1	1
Coscinodiscus symbolophorus Grunow		1							1				1
Coscinodiscus temperei Brun									4				
Coscinodiscus vetustissimus Pantocsek			1			2	1						
Coscinodiscus yabei Kanaya		1		1		2		1					
Cosmiodiscus insignis Jousé													
Denticulopsis kamtschatica (Zabelina) Simonsen													
Denticulopsis katayamae Maruyama n. sp.	107	75	109	80	88	95	100	18	13	3	3	1	1
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen	35	15	59	34	57	55	31	6	5	36	80	22	27
Denticulopsis hustedtii (elliptical form)													1
Denticulopsis hyalina (Schrader) Simonsen		4	2		2	7	5	4	2	3	3	2	3
Denticulopsis nicobarica (Grunow) Simonsen													
Denticulopsis punctata (Schrader) Simonsen						1							
Denticulopsis praedimorpha Akiba													
Connecting band						2		1		1			
Girdle view					1					1			
Denticulopsis praedimorpha AND/OR *D. dimorpha*													
Valve view		2	1	1	1	3		5	2	1	3	2	4
Denticulopsis dimorpha (Schrader) Simonsen													
Connecting band					1								1
Girdle view		1	1				1			1		2	1
Diploneis sp.					1								
Goniothecium tenue Brun		11	12	8	9	25	33	38	22	49	213	87	26
Grammatophora angulosa Ehrenberg													
Grammatophora marina (Lyngbye) Kützing													
Hemidiscus cuneiformis Wallich									1				
Melosira sol (Ehrenberg) Kützing													
Melosira sulcata (Ehrenberg) Kützing			1			1			1	1			2
Nitzschia fossilis (Frenguelli) Kanaya													
Nitzschia porteri Frenguelli													
Nitzschia praereinholdii Schrader													
Nitzschia reinholdii Kanaya and Koizumi													
Nitzschia rolandii Schrader													
Nitzschia sp. A				3	3	5	1	1	18	1	2	7	4
Nitzschia spp.		1		1	2	5			1	1			
Plagiogramma staurophorum (Greville) Heiberg						1							
Pseudopodosira elegans (Sheshuk.) Sheshukova-Poretzkaya													1
Rhaphoneis surirella (Ehrenberg) Grunow				3				1				2	
Rhizosolenia barboi (Brun) Tempère and Peragallo		2	3	1	2	1	2	1	3	7		2	
Rouxia californica Peragallo	2	40	26	91	14	9	17	51	16	29	34	40	3
Rutilaria epsilon Greville													
Stephanogonia hanzawae Kanaya													
Stephanopyxis turris (Greville and Arnott) Ralfs			1	1	1							1	
Stephanopyxis spp.													
Synedra jouseana Sheshukova-Poretzkaya						2			2				
Thalassionema hirosakiensis (Kanaya) Schrader	7	2	3			1					1		
Thalassionema nitzschioides Grunow	56	72	94	204	93	155	55	37	153	50	90	40	62
Thalassionema robusta Schrader													
Thalassionema schraderi Akiba			3	3		1				16			1
Thalassiosira antiqua (Grunow) Cleve-Euler													2
Thalassiosira cf. *antiqua* (Grunow) Cleve-Euler													
Thalassiosira decipiens (Grunow) Jørgensen													
Thalassiosira excentrica Cleve													
Thalassiosira leptopus (Grunow) Hasle and Fryxell										1	2		
Thalassiosira manifesta Sheshukova-Poretzkaya						2		1					
Thalassiosira nativa Sheshukova-Poretzkaya													
Thalassiosira nidulus (Tempère and Brun) Jousé													
Thalassiosira nordenskioeldii Cleve				2					3			1	
Thalassiosira spp.			17	27	5	10							
Thalassiothrix longissima Cleve and Grunow	6	5	4	1	3	6	4	3	13	2	1	3	8
Triceratium condecorum Ehrenberg				1	1			2	1				
MISCELLANEOUS	1	9	8	3	7	13	4	6	10	11	9	2	6
TOTAL VALVES	231	275	377	502	332	474	290	269	331	305	475	268	172

diatoms in DSDP Hole 438A, core 55 through core 41.

49	49	48	48	48	47	47	47	46	46	46	45	45	45	44	44	44	43	43	43	42	42	42	41	41	41
6	3	6	3	1	6	4	1	6	3	1	6	6	1	6	3	1	6	3	1	6	4	1	6	3	1
10	10	26	46	14	4	110	10	14	18	18	30	5	54	10	10	60	82	30	59	16	50	14	10	30	45
14	14	30	50	18	8	114	14	18	22	22	34	9	58	14	14	64	86	34	63	20	54	18	14	34	49
4	3	3	3	2	2	2	2	2	1	2	2	1	1	2	1	1	2	2	1	1	1	2	2	1	1
M	G	G	M	M	M	M	M	M	M	M	M	G	M	M	M	M	G	M	G	G	M	G	G	M	M
							1																		
4																									
3		3	8		4	1	1	3	1	3	6	4	5	10	5		1	1		1			1		
																								1	
22	19	44	17	26	37	35	39	12	25	21	32	21	15	36	6	2	10	28	15	15	4	9	9	7	
										1	1	1													
1	1									1				1									1	2	
1					2												1				1	2			
														2				1	1	8	7	2			
1	1	1									2	1													1
2	1	2	2	2	6	2	4		2	1		4	2	4		1	1	6	1	1	2	2	6	2	8
										1															
					1									1									1		
																							1		
1				2	1		1					1												1	
																				1					
1	1		1																						
33	45	47	60	48	49	38	57	19	28	69	56	54	45	90	38	48	93	73	37	9	18	81	99	33	33
				1	2	1	1	1			1					1		2	1					1	
			1			1	1	1										3	1						
					2	2	2	4	1			1		7				1							
		1			1		2																		
													1	1				1				1			
																					2	2	102	45	95
1																						2			
76	17	3	6	4	14	5	6	5	3	5	15	3	5	7	4	4	8	1	3	2	2	3	5	7	2
											1														
9	8	6	2	4	12	9	5	8	4	7	7	2	4	6	3	2	4	1	1	1		6	3	1	4
		1								1															
																							1		
3	1	2		1	1						2		1	1				1	1			1			
1	1			2	1		1	1			1		1	1											
6	1		2		3	3	1	3	1		2	3	2		2		5	2	2	1		1			
1																									
																					1		1		
20	11	13		10	17	8	5	14	4	6	10	21	11	52	10	11	20	23	17	5	7	13	2	9	5
												1													
			1																						
1			2	1		1						2		2							1				
																	1								
1	1		1		2		2			1							2		1		3	1	1		
															1								4		1
				3	4	2	10	13	14	9	8	2		5		1		1	1						
				2		3	4	2	6	1	1	1		13	2		4	8	2	9	7		4		
																							7		3
													1	1	4	4	2	18	7	6	2	2	20	1	12
8	3	2				1	8	3	1	3	3	1	5	1	3	8	1	8	2	4	7	3	2	3	
5	3	2															4	1	6			1	10		
1	1								1				2			1	2	7		8	7				1
				1	1					1							1				1	1		3	
4	10	5	4	4	3	4	2	7	5	5	3	2		1	3	2	5	2		2		1		1	
31	31	3	16	6	11	5	32	57	32	26	4	11	8	18	4	12	9	14	18	22	25	8	3	2	4
														2											
		1															1				1	2			
2	1		1	2	1		5	3	1		1	2			1	6	9	17	5	3		1	6	1	1
2				1	1	1			1	1	1	1	2	1		1	3	6	2		1	10	2	2	2
1		1		1	1	1	1	1									1	8		2	1				
								1																	
81	107	50	26	23	44	22	49	67	38	68	37	36	27	53	120	50	71	151	275	196	123	205	136	124	191
					3	1	2	4		1															
17	63	75	80	66	204	93	133	132	78	86	115	126	117	133	71	91	164		3						
		1																1	13	9	7	2	4	1	9
										1															
					3	1	5	4			1	1	1	4		1	18	43	9	1		1	9	17	3
																		2							
1	2									1			1	2			1			1				3	
		1				1		1		5	2		1					3	3	1				1	1
																	2								
							1													15	5	1	2	1	1
2		1		1			1				1	1		2	1	6	2	7	1						
				1						1					1				19	31	63	25	23	54	24
8	7	22	9	3	10	9	24	9	9	6	5	20	4	23	5	1	20	7	6	7	5	13	4	2	3
16	17	5	16	13	9	2	12	21	10	3	3	1	11	29	9	19	14	23	5	9	6	2	7	7	17
367	353	292	255	228	450	252	418	396	265	335	321	324	272	509	293	272	480	471	458	370	309	404	476	332	421

Appendix 2. Table showing stratigraphic occurrence of diatoms in Kadonosawa section, Sannohe area.

FORMATION	KADONOSAWA FOR.									SUENO	
MEMBER	SHIKONAI SILTSTONE MEMBER									ITSUKA	
SAMPLE	KDN 3	KDN 4	KDN 5	KDN 6	KDN 7	KDN 8	KDN 9	KDN 11	KDN 12	KDN 14	KDN 15
ABUNDANCE PRESERVATION	DP	10 P	7 P	4 P	2 P	3 P	3 P	4 P	9 P	DP	6 P
Actinocyclus ehrenbergii var. *tenella* (Brébisson) Hustedt		1									
Actinocyclus ingens Rattray	2	3	32		3		10	9	27	1	6
Actinoptychus undulatus (Bailey) Ralfs		11	15	4	1	2	8	17	14	1	2
Aulacosira granulata (Ehrenberg) Simonsen	15				2		8	11	6	1	5
Aulacosira italica (Ehrenberg) Simonsen		2		1				1			
Biddulphia aurita (Lyngbye) Brébisson and Godey						1					
Biddulphia spp.		1									
Cocconeis californica Grunow									1		1
Cocconeis scutellum Ehrenberg		1	1								
Cocconeis spp.		1			1		2				
Coscinodiscus asteromphalus Ehrenberg			1								
Coscinodiscus endoi Kanaya				1							
Coscinodiscus lewisianus Greville					2					1	
Coscinodiscus marginatus Ehrenberg			2					2			1
Coscinodiscus symbolophorus Grunow		1									
Coscinodiscus spp.							1		1		
Denticulopsis kanayae Akiba				1		1	3	2			1
Denticulopsis lauta (Bailey) Simonsen				1	5	3	13	19	8	2	81
Denticulopsis nicobarica (Grunow) Simonsen											1
Denticulopsis norwegica (Schrader) Simonsen		3	1	1	1						
Denticulopsis punctata (Schrader) Simonsen								1			
Diploneis spp.		2			1						
Goniothecium tenue Brun		48	25	5	4	1	3	8	3		5
Grammatophora marina (Lyngbye) Kützing				1							
Grammatophora spp.								1			1
Hyalodiscus spp.		3	1					1			
Kisseleviella carina Sheshukova-Poretzkaya		8	51	11	106	181	61	6	3		8
Mediaria splendida Sheshukova-Poretzkaya						1					2
Melosira sulcata (Ehrenberg) Kützing		30	21	1	2	3	1	6	5		1
Navicula spp.								1			1
Nitzschia spp.							1				1
Plagiogramma staurophorum (Greville) Heiberg		3				1					
Rhaphoneis elegans (Pantocsek) Hanna		20	15	3	2	4	6	5	3		
Rhaphoneis miocenica Schrader		2	9	1	1	2		9	3		
Rhizosolenia miocenica Schrader					1						
Rhizosolenia styliformis Brightwell							1				
Rhizosolenia spp.							1				1
Stephanopyxis schenkii Kanaya				1	1		1	6			
Stephanopyxis turris (Greville and Arnott) Ralfs		3	1	3	2		4	2	5		
Stephanopyxis spp.		5	4		4	2	3			1	
Synedra jouseana Sheshukova-Poretzkaya						1		1			
Thalassionema nitzschioides Grunow		49	34	200	121	49	86	116	116	10	102
Thalassiothrix longissima Cleve and Grunow		2	6	1	3	3		1	1		3
Triceratium condecorum Ehrenberg						1	1	1			
Trochosira spinosa Kitton		2	8		3	7	6	7	27		
Rhaphoneis cf. *amphiceros* Ehrenberg					+						
Thalassionema robusta Schrader					+						
MISCELLANEOUS		17	15	2	3	3	8	6	2	2	9
TOTAL VALVES	17	218	242	238	269	266	228	239	225	19	232

SUENO: Suenomatsuyama Formation, ITSUKA: Itsukamachi Tuffaceous Sandstone Member.

Appendix 3. Table showing stratigraphic occurrence of diatoms in Sawadasawa section, Sannohe area.

FORMATION	SU	TOMESAKI FOR.								
MEMBER	MA	JUMONJI SANDSTONE						NUMANOKUBO		
SAMPLE		SAW 0	SAW 6	SAW 7A	SAW 7B	SAW 8B	SAW 11	SAW 12	SAW 13	SAW 14	SAW 15
ABUNDANCE		-	5	8	3	-	2	2.5	2	0.5	0.8
PRESERVATION		DP	P	P	P	DP	M	M	M	G	G
Actinocyclus ehrenbergii Ralfs							2				
Actinocyclus ingens Rattray		+	42	40	30	+	60	2	25	9	64
Actinocyclus ingens var. *nodus* Baldauf			16	21	1						
Actinoptychus splendens (Shadbolt) Ralfs					1						
Actinoptychus undulatus (Bailey) Ralfs		+	13	6	12		2	2	6	3	3
Biddulphia spp.			1	1							
Cocconeis californica Grunow			1					1	1		1
Cocconeis costata Gregory											1
Cocconeis placentula Ehrenberg			1	1							
Cocconeis scutellum Ehrenberg				1							2
Cocconeis vitrea Brun			1	1			1		1		2
Coscinodiscus asteromphalus Ehrenberg							1				
Coscinodiscus endoi Kanaya					1				7	1	2
Coscinodiscus marginatus Ehrenberg			14	8	2		13	6		3	
Coscinodiscus plicatus Grunow								1			
Coscinodiscus symbolophorus Grunow										1	
Coscinodiscus vetustissimus Pantocsek			3	5	2		16			1	
Coscinodiscus yabei Kanaya							4		7	11	1
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen							13	34	100	169	79
Denticulopsis hyalina (Schrader) Simonsen				32	57	+					
Denticulopsis lauta (Bailey) Simonsen			91	66	120						
Denticulopsis nicobarica (Grunow) Simonsen			13	21	29						
Denticulopsis praedimorpha Akiba							26	71			
Denticulopsis punctata (Schrader) Simonsen			1								
Diploneis spp.			1				1		1		
Goniothecium tenue Brun			7				14	1	1	10	30
Grammatophora angulosa Ehrenberg										1	1
Hemiaulus polymorphus Grunow					1						
Hyalodiscus spp.			4	1			1				
Kisseleviella carina Sheshukova-Poretzkaya		+	1								
Mediaria splendida Sheshukova-Poretzkaya			6	1						1	
Melosira sol (Ehrenberg) Kützing				1					2		
Melosira sulcata (Ehrenberg) Kützing			8	6	5			6	13	3	1
Nitzschia challengeri Schrader			1		1						
Nitzschia heteropolica Schrader									6	6	
Nitzschia spp.				1	1					+	
Plagiogramma staurophorum (Greville) Heiberg											1
Pseudopodosira elegans Sheshukova-Poretzkaya										1	
Rhaphoneis miocenica Schrader			1								
Rhizosolenia barboi (Brun) Tempère and Peragallo									1	+	2
Rhizosolenia hebetata Bailey									3	3	5
Rhizosolenia miocenica Schrader									1	1	
Rhizosolenia styliformis Brightwell							2	4	6	1	3
Rhizosolenia spp.			2		2				5		
Rouxia californica Peragallo									7	26	5
Stephanogonia hanzawae Kanaya				2	1				2	3	2
Stephanopyxis schenckii Kanaya			1	1							
Stephanopyxis turris (Greville and Arnott) Ralfs				6	3	+	1		1	8	3
Stephanopyxis spp.											2
Synedra spp.			16	4	4						
Thalassionema hirosakiensis (Kanaya) Schrader							4				
Thalassionema nitzschioides Grunow			44	31	38		134	113	71	90	16
Thalassiosira nordenskioeldii Cleve									1	1	
Thalassiothrix longissima Cleve and Grunow			2	4	7		6	6	8	5	8
Triceratium condecorum Ehrenberg				1			1				
MISCELLANEOUS			10	9	9		5	8	5	9	5
TOTAL VALVES			301	271	327		307	255	281	367	239

SU: Suenomatsuyama Formation, MA: Maisawa Coarse-grained Sandstone Member.

Appendix 4. Table showing stratigraphic occurrence

FORMATION	TOMESAKI F.											
MEMBER	METOKI		JUMONJI			KAWA-GUCHI		KAMIMETOKI				
SAMPLE	STZ 2	STZ 3	STZ 4	STZ 5	STZ 6	STZ 12	STZ 13	STZ 15	STZ 16	STZ 17	STZ 18	STZ 19
ABUNDANCE PRESERVATION	8 DP	10 DP	10 DP	10 DP	10 DP	2 P	1 DP	5 DP	10 DP	10 DP	4 DP	10 DP
Actinocyclus ellipticus Grunow												
Actinocyclus ingens Rattray	119	30	8	12	60	32	7	35	13	19	11	2
Actinocyclus ingens var. *nodus* Baldauf	11											
Actinocyclus spp.												
Actinoptychus splendens (Shadbolt) Ralfs												
Actinoptychus undulatus (Bailey) Ralfs	6			1	6	1	7	4	10	4	3	1
Actinoptychus vulgaris (Ehrenberg) Grunow												
Amphora spp.												
Arachnoidiscus ehrenbergii Bailey					1							1
Auliscus caelatus Bailey												
Biddulphia aurita (Lyngbye) Brébisson and Godey												
Bogorovia sp.												
Cocconeis californica Grunow					1			1	2		2	
Cocconeis costata Gregory							1		1			
Cocconeis decipiens Cleve												
Cocconeis grata A. Schmidt												
Cocconeis maxima (Grunow) Peragallo												
Cocconeis pellucida Grunow												
Cocconeis placentula Ehrenberg		1				1						
Cocconeis pseudomarginata Gregory												
Cocconeis scutellum Ehrenberg											2	1
Cocconeis vitrea Brun									2	1	1	2
Cocconeis spp.							1		3	2	7	2
Coscinodiscus asteromphalus Ehrenberg												
Coscinodiscus endoi Kanaya	6	1			13	1	1	5				
Coscinodiscus marginatus Ehrenberg	2	19	6	1	4	3			3	22	28	14
Coscinodiscus obscurus A. Schmidt												
Coscinodiscus radiatus Ehrenberg												
Coscinodiscus symbolophorus Grunow								1				
Coscinodiscus temperei Brun												
Coscinodiscus vetustissimus Pantocsek		1							15			
Coscinodiscus yabei Kanaya						1		5	1			
Cosmiodiscus insignis Jousé												
Cymbella spp.												
Denticulopsis dimorpha (Schrader) Simonsen										44	176	128
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen	47	31	5	2	3	113	143	101	74	109	13	21
Denticulopsis hyalina (Schrader) Simonsen												
Denticulopsis katayamae Maruyama n. sp.												
Denticulopsis nicobarica (Grunow) Simonsen	1											
Diploneis smithii (Brébisson) Cleve												
Diploneis spp.											1	2
Goniothecium tenue Brun	1				1	8	29	20	22	2		3
Grammatophora angulosa Ehrenberg											2	2
Grammatophora japonica Grunow												
Grammatophora marina (Lyngbye) Kützing							1					
Grammatophora spp.					2		2		2	2		
Hyalodiscus spp.					3							
Mastogloia splendida (Gregory) Cleve												
Mediaria splendida Sheshukova-Poretzkaya			1									
Melosira sol (Ehrenberg) Kützing	1				16		1	1	6		1	1
Melosira sulcata (Ehrenberg) Kützing	1	5	19	4	30		1	13	6	3	1	3
Navicula lyra Ehrenberg												
Navicula spp.											1	
Nitzschia spp.							1					
Opephora spp.					2					3		
Plagiogramma staurophorum (Greville) Heiberg								1	1	8	4	1
Pseudopodosira elegans (Shushuk.) Sheshukova-Poretzkaya								1				
Rhaphoneis amphiceros Ehrenberg												
Rhaphoneis surirella (Ehrenberg) Grunow										1	2	1
Rhizosolenia barboi (Brun) Tempère and Peragallo					1	2	5	5	5	12	1	1
Rhizosolenia hebetata Bailey					11	1	2		2			
Rhizosolenia miocenica Schrader												
Rhizosolenia spp.	1					1	1	1	4			
Rouxia californica Peragallo						2	3	1		1		
Rouxia naviculoides Schrader												
Rutilaria epsilon Greville					2							
Stauroneis sp.												
Stephanogonia hanzawae Kanaya	1						2	2	1			
Stephanopyxis schenkii Kanaya					12	1						
Stephanopyxis turris (Greville and Arnott) Ralfs		2			1		1		2			1
Stephanopyxis spp.					1			1	1	1		
Synedra jouseana Sheshukova-Poretzkaya												
Thalassionema hirosakiensis (Kanaya) Schrader								1	2			
Thalassionema nitzschioides Grunow	52	3	1		4	41	68	45	37	20	49	55
Thalassionema robusta Schrader												
Thalassionema schraderi Akiba												
Thalassionema cf. *schraderi* Akiba										1		
Thalassiosira antiqua (Grunow) Cleve												
Thalassiosira nidulus (Tempère and Brun) Jousé												
Thalassiosira spp.												
Thalassiothrix longissima Cleve and Grunow	3	1	2	2	2	4	6	4	13	2		1
Trachyneis aspera (Ehrenberg) Cleve											1	
MISCELLANEOUS	3	1	3	1	8	6	3	11	15	10	6	6
TOTAL VALVES	255	95	45	23	184	218	286	259	243	267	312	249

of diatoms in Shitazaki section, Sannohe area.

SHITAZAKI FORMATION																									KUBO F.
SHITAZAKI									SILTSTONE MEMBER																KAMASAWA
STZ 20	STZ 21	STZ 22	STZ 23	STZ 24	STZ 25	STZ 26	STZ 27	STZ 28	STZ 29	STZ 30	STZ 31	STZ 32	STZ 33	STZ 34	STZ 35	STZ 36	STZ 37	STZ 38	STZ 39	STZ 40	STZ 41'	STZ 41	STZ 42	STZ 43	STZ 44
10 DP	10 DP	2 P	2 M	2 M	7 M	5 M	8 P	10 P	10 P	2 M	12 P	10 P	4 P	3 P	6 DP	10 DP	15 DP	15 DP	11 DP	5 P	8 M	20 P	4 M	3 M	2 G
2	3	10	15	5	20	8	3	7	1 20		1				2	1	1 2	1	3		1				
						1							1												
2	2	4	1	1	2	11	1	1	7	2	10	21	20	19	8	1 5	8	29	6	1 16	10	13	25	11	70
			1		1									1		1				1	1	2	1 1	6 1 1	
									1				1												
						1					1		1	5	2	2 1				1		1			
			1 5	4		1 2	1 1	2		1	6	1	1 7	2						2 1 2	1 1		5	1 6	3 2 1
									1						1										
					1	1		1	2 1	1		1 1		3 2	2				1 1	2	1 1		1	2	1 1
	1			3	2 2	1 1		1	1	3	1 1	1	4 1	4	4 2	2	1	4	1	1 1	2 6	1	6 2	1 2	2 2
3	3		+ 1 1	5	4	5	2	1	2		4	2	5	3	7	4	2	1	4	16	9	3	7	14	3
				1	3	2	5	4	3																+
1	8	28	4	5	4		1	2	1	3	4	3	3	1	2	3		2	1	3	13	27	13	8	9
														1							1 2			1	1
			1	3	1		1		3		2					3	1		3	4 4	10 4	1	2 4	3		1
									2	1		1					2						4		
		1																	1			1			
28	68	64	37	92	68	1	2										1								
6	20	20	48	51	95	63	85	13	27	122	51	4	41	28	18	4	11	1	1	7	11	3	10 1	3	1
			+	+	+	+	+	+	+	+	+		+	+											
	2					2	1						1				3	5	2	9	4	5		4	4
	2						1	2		1	2		3		3	7					4		1	2	
	1		1			3	3			2	2	2	5	4	1	2	1	1	3	4	1 1		3	3	2
				2	4	1					1	1	1	1							2		2	9	1
1		2			1							1	1		2						1	1			
						1	2	3		1	5	6	4	5	1	1			1	6 1	5	2	3	2	
																		2							
		1							1	1	1					1	3								
5	4	8	7	3	14	18	4	9	15	5	22	31	83	35	88	8	44	31	31	55	83	11	10	2	10
	1	3	1		1	1	1			2	1		3		1		1	1	4	8	1			3	1
			1	1	1	1				1			3		1	1					1			9	7
	1									1	1	1													
	3	5		2	4	2	2		1		2	4	8	2		6	3	1	1	10	1		1	5	1
																									+
	2	1												2	1			1		1	1		1		1
	2								1							2		1		2	7	7	5	7	3
									1					1											
						1	2																		
		1	4	2			2		2	7	2		6	5							1		6	3	6
																						1	2		3
		1									1														
	2	1							1			1			1						2	5	6	3	6
							1																		1
	1											1											2		
44	115	123	108	98	59	94	115	5	38	87	72	44	83	75	74	61	4	13	15	40	16	9	92	96	95
		1												1							1		2	4	3
					6	3	1	1													3	10	20	17	36
														1											+
										1		1									2		4	6	4
1	4	1		2		2	4	2	3	4	6			1	3	1	3	3	3	4	5	4	9	4	7
																				1	3	1		1	+
3	6	6	6	14	7	3	4	2	6	9	9	16	16	14	15	19	10	19	9	27	20	12	17	19	26
96	251	281	243	294	300	230	248	56	141	255	208	143	303	216	239	136	101	116	91	230	239	120	268	259	314

Appendix 5. Table showing stratigraphic occurrence of diatoms in Kawaguchi section, Sannohe area.

FORMATION	TOMESAKI FORMATION																		
MEMBER	JUMONJI SANDSTONE MEMBER													NUMANOKUBO D. M. MEM.					
SAMPLE	KWG 2	KWG 1	KWG 3	KWG 4	KWG 5	KWG 6	KWG 7	KWG 8	KWG 9	KWG 10	KWG 11	KWG 12	KWG 13	KWG 14	KWG 15	KWG 16	KWG 17	KWG 18	KWG 19	KWG 20
ABUNDANCE PRESERVATION	10 DP	5 DP	10 DP	10 DP	2 M	10 DP	6 DP	11 DP	10 DP	10 DP	7 DP	2 DP	2 M	2 P	10 P	2 P	1 M	2 P	0.6 M	0.5 G
Actinocyclus ehrenbergii Ralfs						2														
Actinocyclus ingens Rattray	49	26	36	103	72	37	75	111	18	22	41	46	34	40	24	15	5	20	3	11
Actinocyclus spp.														3	2	3	1	2	2	
Actinoptychus undulatus (Bailey) Ralfs	3		2	1	5	1	4			2	17	9	6	17	5	6		4	1	
Arachnoidiscus ehrenbergii Bailey							1	1	1											
Asterolampra spp.											1									1
Aulacosira granulata (Ehrenberg) Simonsen										7										
Biddulphia aurita (Lyngbye) Brébisson and Godey																				1
Cocconeis costata Gregory														1				1		
Cocconeis placentula Ehrenberg															1					1
Cocconeis vitrea Brun											1				1					
Cocconeis spp.											1			1	1					
Coscinodiscus argus Ehrenberg											4		5	2						
Coscinodiscus curvatulus Grunow					1															
Coscinodiscus endoi Kanaya									3	3	11	6	15	22	16	2	5	13	3	3
Coscinodiscus marginatus Ehrenberg	10		8	5	1	32	54	34	7	2	5	2		2	1	2	1	2		1
Coscinodiscus symbolophorus Grunow						1	1					2			1			1		3
Coscinodiscus vetustissimus Pantocsek					4					1										1
Coscinodiscus yabei Kanaya													1	4					2	3
Coscinodiscus cf. *yabei* Kanaya				1	3		1													
Coscinodiscus spp.					1		3	3												
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen	12	2	29	14	74	5	52	8	72	21	36	99	120	96	54	102	97	217	210	233
Denticulopsis hyalina (Schrader) Simonsen				2		1														
Denticulopsis cf. *nicobarica* (Grunoe) Simonsen			1																	
Denticulopsis praedimorpha Akiba			3	8	9	14	29	24	97	110	22	3								
Diploneis sp.																		1		
Goniothecium odontella Ehrenberg	1																			
Goniothecium tenue Brun	1		6	3	5	3	1	3	4	12	14		2	5	1	6	5	10	4	10
Grammatophora angulosa Ehrenberg												1		1						
Grammatophora spp.			1	1		1		3	1		2		1		1			1	1	
Hyalodiscus spp.	1													1				1		
Mediaria splendida Sheshukova-Poretzkaya				2	1							1	1				2		1	2
Melosira sol (Ehrenberg) Kützing	2	1		1	1	1	1	1	1	3	3	1	1	1	1	1	1		1	
Melosira sulcata (Ehrenberg) Kützing	23	2	13	49	63	1	9	13	7	5	22	17	20	18	10	13	15	11	16	1
Navicula spp.					1										1					
Nitzschia spp.					1		1		1					3	1	1	3			8
Rhaphoneis surirella (Ehrenberg) Grunow															5					
Rhaphoneis spp.					1									1						
Rhizosolenia barboi (Brun) Tempère and Peragallo								1				1	3	1	2	1	3		3	5
Rhizosolenia hebetata Bailey					1					3	14	4	12	8	5	6	1	2		1
Rhizosolenia miocenica Schrader							1							2						
Rhizosolenia styliformis Brightwell			4		1		1	1	1			3	5	4	1	10	1	3		4
Rhizosolenia spp.											9	3	2							
Rouxia californica Peragallo												1	7	19		1	10	5	2	18
Stauroneis sp.			1																	
Stephanogonia hanzawae Kanaya											+		1					1		
Stephanopyxis schenckii Kanaya			1																	
Stephanopyxis turris (Greville and Arnott) Ralfs			1		1	1	1								1		1			5
Stephanopyxis spp.															2		1	6	1	5
Thalassionema nitzschioides Grunow	6		34	14	33	6	33	20	13	41	33	26	142	112	43	65	58	46	45	14
Thalassiosira leptopus (Grunow) Hasle and Fryxell											1									
Thalassiothrix longissima Cleve and Grunow	6		4	2	5		1	10	5	3	4	1	6	11	6	7	5	7	4	1
Trachyneis aspera (Ehrenberg) Cleve									1											
Triceratium sp.						1														
Trochosira spinosa Kitton										1										
MISCELLANEOUS	1		8	3	8	1	2	8	8	20	9	7	11	4	10	3	4	3	3	16
TOTAL VALVES	115	31	152	209	292	108	271	241	240	256	250	233	395	379	196	244	219	357	302	348

Appendix 6. Table showing stratigraphic occurrence of diatoms in Yachizawa section, Sannohe area.

FORMATION	TOME	SHITAZAKI FORMATION															
MEMBER	NUMA	KAMIMETOKI			SHITAZAKI					SILTSTONE			MEMBER				
SAMPLE		YAC 16	YAC 15	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	YAC 1	YAC 0
ABUNDANCE		2	2	4	1.5	3	5	5	2.7	2	8	2	4	2	3	7	2	8
PRESERVATION		M	M	P	P	P	P	P	P	P	P	P	P	P	P	P	M	P
Actinocyclus ellipticus Grunow																1	1	2
Actinocyclus ingens Rattray		68	33	26	13	16	23	4	8	20	11	16	19	19	6	17	2	5
Actinocyclus ingens var. *nodus* Baldauf														2				
Actinoptychus undulatus (Bailey) Ralfs			6	1	5	6	3	4	8	20	6	3	10	2	5	4	6	9
Amphora costata Wm. Smith			1			2	1						2			2	2	1
Arachnoidiscus ehrenbergii Bailey										1						1		1
Aulacosira granulata (Ehrenberg) Simonsen										1								
Cocconeis californica Grunow		2						1	1	2	1			2	1		1	1
Cocconeis costata Gregory				1				2	4	3	2	2	5	1	1	2		2
Cocconeis placentula Ehrenberg												1	2				1	
Cocconeis scutellum Ehrenberg		1	2	3	3	2		2	1	1	1	1	2	1	1	2		1
Cocconeis vitrea Brun						2	1			2	1	5	1			2	2	5
Cocconeis spp.			4	1	3	1	1	1	2	8	2	7	4	3	4	1	1	3
Coscinodiscus asteromphalus Ehrenberg		1																
Coscinodiscus curvatulus Grunow																1		
Coscinodiscus endoi Kanaya		4	6	1	1	2	1	1	2	1		2	1	1	1	4		2
Coscinodiscus marginatus Ehrenberg		2	2	9	4	7	9	4	5	2	3	12	10	5	2	9	4	5
Coscinodiscus radiatus Ehrenberg		2	1															
Coscinodiscus symbolophorus Grunow										1				1	1			1
Coscinodiscus temperei Brun			1		1					1	1		1	4	3	1	1	3
Coscinodiscus vetustissimus Pantocsek		1																
Coscinodiscus yabei Kanaya			2			1	1									1		
Coscinodiscus spp.		3									4	1	2	1				2
Denticulopsis dimorpha (Schrader) Simonsen				71	86	66	28	59	94	76	54	88	9	46	2	1		
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen		143	120	49	72	80	134	94	94	77	91	115	71	119	102	42	59	43
Denticulopsis hyalina (Shrader) Simonsen																1		
Denticulopsis katayamae Maruyama n. sp.				+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Diploneis spp.		1		2	2	3	1	3	1		3	2	1	2	1	2	3	1
Epithemia sp.									1									
Goniothecium tenue Brun		36	27													6		
Grammatophora angulosa Ehrenberg			2	2	1		1	4	2	6	1	3	1			1	1	
Grammatophora marina (Lyngbye) Kützing								10	7	4	3	3	4		1	1	2	3
Grammatophora spp.				2	1		1			3		1	3			6	1	2
Hyalodiscus spp.										1	1	3	5	1	3	5	3	1
Mediaria splendida Sheshukova-Poretzkaya			2															
Melosira sol (Ehrenberg) Kützing													2			2		1
Melosira sulcata (Ehrenberg) Kützing		89	8	10	15	10	13	8	5	11	10	13	13	27		48	24	25
Navicula lyra Ehrenberg																	1	
Navicula spp.							3						1	2	4	3	1	10
Nitzschia spp.		1	1						1				1			1	1	2
Plagiogramma staurophorum (Greville) Heiberg				2		1	2			3		2	1	2		2	1	6
Rhaphoneis surirella (Ehrenberg) Grunow		1			1		1		2	2	1	5	1		1			
Rhizosolenia barboi (Brun) Tempère and Peragallo		9	24				1			1	1		2				1	
Rhizosolenia hebetata Bailey		3	6															
Rhizosolenia styliformis Brightwell			2	2				1			3	1						
Rhizosolenia spp.			1			2		2				1				1		
Rouxia californica Peragallo		2		2						1				1				
Stauroneis sp.																	1	
Stephanogonia hanzawae Kanaya		3	1							1								
Stephanopyxis turris (Greville and Arnott) Ralfs		1						1	1		1			1				
Synedra spp.								1			1							
Thalassionema hirosakiensis (Kanaya) Schrader			1				1											1
Thalassionema nitzschioides Grunow		47	61	73	42	66	32	54	66	94	58	49	77	51	101	47	92	64
Thalassionema robusta Schrader						2												
Thalassionema schraderi Akiba					4	4	6			1		5	4	3	3	2	1	
Thalassiosira excentrica Cleve								1					1	3				
Thalassiosira manifesta Sheshukova-Poretzkaya								1				1						
Thalassiosira spp.							1			1					5		1	
Thalassiothrix longissima Cleve and Grunow		1	20	3	1	3		1	4	1	3	2	4	5	3	4	6	5
Trachyneis aspera (Ehrenberg) Cleve						1						1						
Triceratium condecorum Ehrenberg			1															
Mastogloia splendida (Gregory) Cleve						+												
MISCELLANEOUS		6	8	12	9	9	11	6	6	8	16	7	13	1	13	21	13	18
TOTAL VALVES		427	343	272	264	286	276	265	315	354	285	352	273	306	264	244	233	225

TOME: Tomesaki Formation, NUMA: Numanokubo Diatomaceous Mudstone Member, KAMIMETOKI: Kamimetoki Sandstone Member.

Appendix 7. Table showing stratigraphic occurrence of diatoms in Kosakazawa section, Sannohe area.

FORMATION	SHITAZAKI FORMATION														
MEMBER	SHITAZAKI SILTSTONE MEMBER														
SAMPLE	KOS 1	KOS 2	KOS 3	KOS 4	KOS 5	KOS 6	KOS 7	KOS 8	KOS 9	KOS 10	KOS 11	KOS 12	KOS 13	KOS 14	KOS 15
ABUNDANCE PRESERVATION	2.7 M	1.5 M	9 P	4 P	6 P	10 P	9.5 P	10.7 P	8.7 P	- DP	15.3 DP	- DP	17 P	2 P	4 P
Actinocyclus ehrenbergii Ralfs									2					1	
Actinocyclus ingens Rattray	27	3	13			1	1								
Actinoptychus undulatus (Bailey) Ralfs	2	3	1	9	15	12	11	16	11		29		8	24	48
Amphora costata Wm. Smith				1	2			1	1						
Amphora spp.														1	2
Arachnoidiscus ehrenbergii Bailey					1		1	1			2		1		
Aulacosira granulata (Ehrenberg) Simonsen														13	
Aulacosira italica (Ehrenberg) Simonsen														5	2
Biddulphia aurita (Lyngbye) Brébisson and Godey	1		1		2				1						1
Epithemia sp.														1	
Cocconeis californica Grunow	2				3		5	5							
Cocconeis costata Gregory	1		1	2	2	5	1	5	4					1	
Cocconeis placentula Ehrenberg	1					1								1	
Cocconeis scutellum Ehrenberg	4	1		3	3	1	4				2		1	4	1
Cocconeis vitrea Brun		3	2	5	2	9	2	8			5	+		5	3
Cocconeis spp.			4	6	3	6	9	8	7		3		8	7	1
Coscinodiscus asteromphalus Ehrenberg		1			1									2	5
Coscinodiscus endoi Kanaya	1	2	3												
Coscinodiscus marginatus Ehrenberg	9		7	1	5			18	5		1		22	2	10
Coscinodiscus symbolophorus Grunow	1		1				1	1	1						1
Coscinodiscus temperei Brun	2	4	1	4							2			1	2
Coscinodiscus spp.	1										3		1		
Denticulopsis dimorpha (Schrader) Simonsen							1								
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen	76	64	78	92	80	32	8	14	51	+	6		5	1	4
Denticulopsis hyalina (Schrader) Simonsen															1
Denticulopsis katayamae Maruyama n. sp.	R	R	R	R											
Diploneis smithii (Brébisson) Cleve	1					1									
Diploneis spp.	1	1		1	1	4	5	2	5		2		6	1	9
Goniothecium tenue Brun		2		5	7		1	3	1						4
Grammatophora angulosa Ehrenberg		1	5		8	4	1	10	2		3			5	1
Grammatophora marina (Lyngbye) Kützing			1	1	2	10	1	4	1		1				
Grammatophora spp.			4	3	2	1	3	1	4		5			1	
Hemiaulus polymorphus Grunow				1											
Hyalodiscus spp.				4	3	2	6	4	1		5		2	1	11
Melosira sol (Ehrenberg) Kützing						1	1	2						1	
Melosira sulcata (Ehrenberg) Kützing	7	5	28	10	46	72	92	73	25		44		16	106	43
Navicula lyra Ehrenberg							1		2				1		
Navicula spp.	2	1	4		4		2	6	4		1		6	6	6
Nitzschia spp.			3				1	2	1					1	
Plagiogramma staurophorum (Greville) Heiberg			3	1	1	7	4	4	7				9	6	3
Rhaphoneis surirella (Ehrenberg) Grunow					1		2		1		1			1	1
Rhizosolenia barboi (Brun) Tempère and Peragallo	1			2	1						1			1	5
Rhizosolenia miocenica Schrader	1	2													
Rhizosolenia styliformis Brightwell		1													
Rhizosolenia spp.														1	
Rouxia californica Peragallo	1			4	3	+	1		3						
Stephanopyxis turris (Greville and Arnott) Ralfs					1				1		1			5	13
Stephanopyxis spp.	1														+
Thalassionema hirosakiensis (Kanaya) Schrader	6	1							2						
Thalassionema nitzschioides Grunow	144	104	44	55	34	16	37	34	59		9		3	7	30
Thalassionema robusta Schrader		1				1									
Thalassionema schraderi Akiba	4	2	1						3						5
Thalassiosira decipiens (Grunow) Jørgensen								1							
Thalassiosira nidulus (Tempère and Brun) Jouse									1						
Thalassiosira punctata Jousé								1							
Thalassiosira spp.			3	2	6	2	1		3		1			1	1
Thalassiothrix longissima Cleve and Grunow		1	1	3	1	1	7		1		1				10
Trachyneis aspera var. *elliptica* Hendey						3	1	1			1		3		1
Triceratium spp.															1
MISCELLANEOUS	8	8	23	13	17	24	15	39	25		13		9	50	15
TOTAL VALVES	305	211	232	228	257	216	226	264	235		142		101	263	240

Appendix 8. Table showing stratigraphic occurrence of diatoms in Nakaminato section, Nakaminato area.

FORMATION	KATSUTA FORMATION									ISOZAKI F.		
SAMPLE	KT 1	KT 2	KT 3	KT 4	KT 5	KT 6	KT 7	KT 8	KT 10	IZ 1	IZ 2	IZ 3
ABUNDANCE	1	1	2	0.5	1	2	2	2	1.7	1	2	2
PRESERVATION	G	M	M	M	M	M	M	M	M	M	M	M
Actinocyclus ehrenbergii Ralfs		8									1	
Actinocyclus ellipticus Grunow							2				3	1
Actinocyclus ingens Rattray	47	24	27	10	8	14	56	17	30	1	12	11
Actinocyclus ingens var. *nodus* Baldauf	13	16	4	1		1	3		1			
Actinoptychus undulatus (Bailey) Ralfs	10	3	17	5	3	7	2	8	3	3	11	7
Amphora sp.					1							
Arachnoidiscus ehrenbergi Bailey											1	
Biddulphia aurita (Lyngbye) Brébisson and Godey			2						3	1		
Biddulphia sp.		1										
Cocconeis californica Grunow		3		1				1	1	2		
Cocconeis scutellum Ehrenberg						2		1			2	
Cocconeis vitrea Brun		1	+	1				1				1
Cocconeis spp.	1			1		1			1	2		1
Coscinodiscus argus Ehrenberg			3									1
Coscinodiscus asteromphalus Ehrenberg		1							2			
Coscinodiscus endoi Kanaya	2	12	3	1					2		1	5
Coscinodiscus lewisianus Greville		1										
Coscinodiscus marginatus Ehrenberg	8	2	5			1		1	2	3	2	5
Coscinodiscus oculus-iridis Ehrenberg			+							1	1	
Coscinodiscus symbolophorus Grunow	2	3	2		2				4	2	4	1
Coscinodiscus temperei Brun											1	
Coscinodiscus vetustissimus Pantocsek	2		4				8		1		1	
Coscinodiscus yabei Kanaya					1	5	7	3			3	1
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen				2		2	14	2	133	16	41	49
Denticulopsis hyalina (Schrader) Simonsen	49	139	71	265	139	236	294	198	1		1	
Denticulopsis cf. *hyalina* (Schrader) Simonsen						1		2				
Denticulopsis lauta (Bailey) Simonsen	186	48	71	60	174	10						1
Denticulopsis miocaenica (Schrader) Simonsen		1										
Denticulopsis nicobarica (Grunow) Simonsen	8	16	26	2	3	3	7	5	31	2	2	
Denticulopsis praedimorpha Akiba										44	63	91
Connecting band B1										3	16	29
B2											3	2
B3										10	11	15
B5										3	4	
B6											1	
B13											1	
B fragment										6	4	1
Girdle view G1											6	2
G3										4		1
G fragment										1		2
Valve view V3										3	1	1
V5										7	7	26
V7										4	3	7
V fragment										3	6	5
Denticulopsis punctata (Schrader) Simonsen			1									1
Denticulopsis punctata var. *hustedtii* (Schrader) Simonsen			1									
Diploneis spp.			1	2		1						
Goniothecium tenue Brun				8	7	22	4	7	22	4	15	19
Grammatophora angulosa Ehrenberg	1	1	3			1						
Grammatophora marina (Lyngbye) Kützing		2										
Grammatophora sp.					1							
Hemiaulus polymorphus Grunow	1	5				1	1	2	2		1	1
Kisseleviella carina Sheshukova-Poretzkaya									1			
Macrora stella (Azpeitia) Hanna			1									
Mediaria splendida Sheshukova-Poretzkaya	4	7	3		3				2	1	1	1
Melosira sol (Ehrenberg) Kützing												1
Melosira sulcata (Ehrenberg) Kützing	1	1	1	1		3	5	9	3	1	10	2
Nitzschia challengeri Schrader	6	3	3	1	1				1			
Nitzschia heteropolica Schrader	1	2		1						1	1	1
Nitzschia sp. A												1
Nitzschia spp.									4		1	4
Plagiogramma staurophorum (Gregory) Heiberg		1										1
Rhaphoneis cf. *biseriata* Grunow	1											
Rhaphoneis surirella (Ehrenberg) Grunow						6		2	10	1		
Rhaphoneis spp.	1	6	1			3	1					
Rhizosolenia barboi (Brun) Tempère and Peragallo											1	
Rhizosolenia hebetata Bailey	1	2	1									
Rhizosolenia miocenica Schrader	2		2	2	1							
Rhizosolenia styliformis Brightwell						2				2		
Rouxia californica Peragallo	3	1	9		1							1
Stephanogonia hanzawae Kanaya												5
Stephanopyxis schenckii Kanaya	4	3	7		1	2	2					
Stephanopyxis turris (Greville and Arnott) Ralfs	9	8	13	1	1	13	6	1	3	3	3	3
Stephanopyxis sp.			1									
Synedra jouseana Sheshukova-Poretzkaya												1
Thalassionema hirosakiensis (Kanaya) Schrader										2	6	8
Thalassionema nitzschioides Grunow	123	78	92	39	36	67	67	34	149	211	219	141
Thalassionema robusta Schrader	11	4	9									
Thalassiosira leptopus (Grunow) Hasle and Fryxell	3	2	2				1					
Thalassiosira nordenskioeldii Cleve										1		
Thalassiosira spp.	2	3										1
Thalassiothrix longissima Cleve and Grunow	5	1	5			8	1	2	3	7	11	6
Triceratium condecorum Ehrenberg	1	1	1			1						1
MISCELLANEOUS	8	12	11	6	2	20	12	9	12	6	28	21
TOTAL VALVES	516	422	403	410	385	433	493	305	426	317	447	396

Appendix 9. Table showing stratigraphic occurrence of diatoms in Iwaigawa section, Ichinoseki area.

FORMATION	SHIMOKUROSAWA FORMATION																																			
SAMPLE	IWS 1	IWS 2	IWS 3	IWS 5	IWS 7	IWS 8	IWS 10	IWS 12	IWS 13	IWS 15	IWS 16	IWS 17	SHA 6	IWS 18	SHA 5	SHA 4	SHA 3	SHA 2	SHA 1	IWS 19	IWS 21	IWN 1	IWN 2	IWN 3	IWN 5	IWN 7	IWN 9	IWN 11	IWN 12	IWN 14	IWN 16	IWN 17	IWN 19	IWN 20	IWN 21	IWN 24
ABUNDANCE	A	A	C	A	A	A	A	A	A	A	A	A	A	C	C	A	A	A	A	A	A	A	A	A	C	A	A	A	A	C	A	A	A	A	A	A
PRESERVATION	M	M	G	G	M	M	G	M	M	M	M	M	P	P	M	M	M	M	G	M	M	M	M	G	M	M	M	M	M	M	M	M	M	M	M	G
Actinocyclus ehrenbergii Ralfs		3	1			+		2			1	+					2	3	4	+	3	2	1	2	1	2			+		+	2	2	+		+
Actinocyclus ellipticus Grunow								+				1												+	+		+	1	+				+		1	+
Actinocyclus ingens Rattray	10	10	2	2	3	1	4	3	6	7	25	40	21	43	22	20	19	8	3	3	5	17	2	6	11	15	3	6	3	9	33	7	10	16	1	2
Actinoptychus splendens (Shadbolt) Ralfs														2		1	1					+														
Actinoptychus undulatus (Bailey) Ralfs	2	3	1	3	5	5	2	6	13	12	13	12	7	1	2	3	3	3	7	1	12	2	1	3	13	14	2	5	5	6	18	9	14	12	6	7
Amphora cf. *costata* Wm. Smith					1													1																		
Amphora spp.		2				1				1	+	2								3		1	1			1	2	1			1	1		1		+
Arachnoidiscus ehrenbergi Bailey		1												1														1	+	+	1				+	
Asteromphalus spp.	1	1	1		1					1		+						4										1								1
Biddulphia aurita (Lyngbye) Brébisson and Godey		5	1	3	1	5	1	4	1	1	1	2	1	1	2	+	2	3		3	+	1	4	2	2	2	3	4	2	1			3	12	13	1
Biddulphia spp.			2	2				3	1						1				1			2			+	+										
Bogorovia paleacea var. *paleacea* (Grunow) Jousé																					+															+
Cocconeis californica Grunow		1	1	2	1	1		3	4	3		5	2		1				3		2	1								1	2	1	3	1	1	3
Cocconeis californica var. *kerguelensis* Heiden and Kolbe	1		1	3			+	3	1	1		3	1				1	2		1	1	1		2	1		1	2		1			1		1	
Cocconeis costata Gregory	1	1	3	1	2	2	3	1	3	2	3	1				1	1	1	1	3	+		1			2		3		+	2			2	1	1
Cocconeis decipiens Cleve				1		2		1			1										+	+				1										
Cocconeis pellucida Grunow									1	1																			3			+	+			
Cocconeis placentula Ehrenberg																							2								1					
Cocconeis pseudomarginata Gregory							+					1									1															
Cocconeis scutellum Ehrenberg	1	1		1		1	+	2	+	1	5			1	1	3		2		3	1	1	1		+		2	+	+			1	1	2	1	
Cocconeis vitrea Brun		+	+	1				+		+	3	2	1	2	2	2	1	1					1	1	1	1		+	1	1			2	1		
Cocconeis spp.	1	1	4	1	3		+		2	2	1	3	2	1	1	2	1	4	1		1				1	1	1		1	2		2		1		1
Coscinodiscus apiculatus var. *ambigua* Grunow		1			3	1				1																		+								
Coscinodiscus asteromphalus Ehrenberg						1		+			1												1													
Coscinodiscus curvatulus Grunow	1	+				+		+												+	+	1		+	+		+	+	+	1		2	+	+		+
Coscinodiscus divisus Grunow												+													+											
Coscinodiscus endoi Kanaya	1		4	1	2		+	+																											2	5
Coscinodiscus excentricus Ehrenberg				+																										1						
Coscinodiscus marginatus Ehrenberg	1	1	1	1	3	+		2	2	5	17	9	26	7	2	3	7		1	3	+	1		1	4	4	1	2	2	3	7	1	2	+	2	+
Coscinodiscus nitidus Gregory													1												+				+							
Coscinodiscus oculus-iridis Ehrenberg																						+							+		2					+
Coscinodiscus plicatus Grunow		1	3	2	4	1	+	+	2	1	2					6	2	3	4	2		1	1		1	1	2					2	3			
Coscinodiscus radiatus Ehrenberg					1		+	+						1		1								+	+	2	1							+		
Coscinodiscus symbolophorus Grunow	2		3	+	1	2	+	+	1		1	2				1				3	2		1	3	+				+	+	2			+	1	+
Coscinodiscus tabularis Grunow		+	1			1	+	5		2	8							1			2	+			+				+				3	2		1
Coscinodiscus temperei Brun																										+	+						+			
Coscinodiscus vetustissimus Pantocsek				+			+									1							2	2	2	+			1	+	+			1		
Coscinodiscus yabei Kanaya		1	6			3		1			4								2		3		1	1	+	4				2	2		2	7	+	2
Coscinodiscus spp.	4				1				+				1					3			+		1	1		1	+	1	+		+		+			
Cymatosira debyi Tempère and Brun	1	1	1			2			1	1											+	1	1					+	1	1	3		1	3	1	1
Cymbella spp.									+		1						8																			
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen	122	100	80	54	160	131	212	82	87	53	63	102	87	5	27	12	21	27	39	39	36	130	43	40	51	25	40	59	53	14	54	49	39	48	31	39
Denticulopsis hyalina (Schrader) Simonsen								1																												
Denticulopsis lauta (Bailey) Simonsen				3						5			3		1																					
Denticulopsis nicobarica (Grunow) Simonsen	27	1	57	57	7	38	15	43	35	26	32	9	4																							
Denticulopsis praedimorpha Akiba																+	9	15	39	64	50	31	40	29	21	31	33	40	19	81	92	58	12	28	36	120
Denticulopsis punctata (Schrader) Simonsen																1		2	2																	
Denticulopsis? spp.				1	1			4	2		6	5		3	6	1	26			1				3		3										
Diploneis smithii (Brébisson) Cleve				2						2		1	1														+	+			+					1
Diploneis spp.						+	+	1	1		+	1				1		1						1	+			+			1	1				

Goniothecium odontella Ehrenberg										+						+																			
Goniothecium tenue Brun	9	9	9	33	12	15	2	23	20	19	15	7	13	5	11	38	37	23	7	10	6	3	4	9	1	16	3	16	2	15	22	6	6	22	16	6
Grammatophora angulosa Ehrenberb			2					1	2	1	2	1				2					3	2	1		1	2	+	+	1		1	2	2			
Grammatophora arcuata Ehrenberg							+		+		2													1							+	1		1		
Grammatophora hamulifera Kützing					2																				2										
Grammatophora marina (Lyngbye) Kützing						2		1		1	1		1						1					1	+			1		2			2	1		
Grammatophora spp.			2		1	1			1		1	2	5	8	3	1	4	1		5	+		1		2				1		1	1		1	2	4
Hemiaulus polymorphus Grunow	3	4	2		3	2	+	5	5		3	1				4	3	1	2	1	1	2		1	1	6			1	2	2	1	1	1	3	1
Hyalodiscus spp.	1		3	4		3		2		8	4		3	2				1	1		2			2	4	6		4	4		3		3			
Mediaria splendida Sheshukova-Poretzkaya	3	2	1	2	1	2	1	1		2	2	1	2		1	2	1	2	4		+	1		+				+	3	1	1	2	2	1		1
Melosira sol (Ehrenberg) Kützing									2	2	1	4		6	4	2			1				1		+	1		+	+	1	1		1	+	+
Melosira sulcata (Ehrenberg) Kützing	1		1		1	1	1	13	12	32	22	46	30	40	21	36	6	3			1	2		4	13	19		2	15	3	2	6	6	7	1	3
Melosira sulcata var. *radiolata* (Grunow) F. W. Mills				10				6			2	1	1		1	4	1	1								2									+
Melosira sulcata var. *coronata* (Ehrenberg) Grunow								4																								1			
Melosira spp.					1					1		2		2																					
Navicula lyra Ehrenberg							+	+		1																						+			
Navicula optima Hanna																1																			
Navicula spp.	2	1	1		1	1	+	2	1	3	3	1	1	12	1			1	3	4	+	1	1		1			3	+	2	1		2	1	1	+
Nitzschia heteropolica Schrader	3	9	5	4		3	3	1	13	3	1		2					9	3		3	1	3	4	+	2	1	3	2	8		5	1	3	4	1
Nitzschia sp. A	2	2	4	1		2	1	2	1	3	1	4	1				1	1	6	38	2	4	2	2	2		3	2	4	4		2	3	3	1	1
Nitzschia spp.	2	2	3	4	4	4	1	3	6	2	2	4	5	1			21	2	3	1					1						9	1				
Ophephora spp.																															2					
Plagiogramma staurophorum (Greville) Heiberg			+																												1	1		1		
Pseudopodosira elegans Sheshukova-Poretzkaya		1	2			2	1													36	5	1	2		1	1	1	3	1		3	7	2	3	3	5
Pterotheca subulata Grunow		+			1			+											1														+			
Rhabdonema japonicum Tempère and Brun				+					1	1	1	+		1	2							+		+	1			+	+		+		+			
Rhabdonema spp.					1																							+				1	+			
Rhaphoneis amphiceros Ehrenberg	1		2		1	1	+	1		2		4									1							1								+
Rhaphoneis surirella (Ehrenberg) Grunow	1			2	3			2			6		7					1										1	2	1			1			1
Rhaphoneis spp.		2		1	1	1	2			1	1	1									1			1											
Rhizosolenia cf. *hebetata* Bailey																																		1		
Rhizosolenia miocenica Schrader				1	1	1	+	1	1	1	+					1		4	5		1	+	1	2						1	1	2	2			
Rhizosolenia cf. *miocenica* Schrader																								1			+					2				
Rhizosolenia praebarboi Schrader																									+											
Rhizosolenia styliformis Brightwell	3	3	2	4	2	10	1	3	1	10	+		1				1	4	5	11	4	4	4	7	7	9	2	7	2	7	4	8	16	11	6	7
Rhizosolenia spp.	8	2	7	4	16	5		6	14	2	3	5	6		2	10	4	4	1	10	16	3	7	4	5	1	5	8	2	4	8	14	7	17	9	5
Rouxia californica Peragallo	5	2	1	1						1	+						1		1			9	+		4	3	4	4	+	1	+	1	1	+	2	2
Rouxia naviculoides Schrader																			1											1				+	1	
Rouxia spp.	1								2															2						1						
Ruttilaria epsilon Greville																														1						
Sawamuraia biseriata Komura				3						1		1														1					1		+		1	+
Sawamuraia spp.						1																										1				
Stauroneis spp.	1				1	1						1								1	+									1						
Stephanogonia hanzawae Kanaya		2	1	2	2	1		2	1	13	2		7	2	1	4		4		3	+			1		1		2	+		2		2	2	2	1
Stephanogonia spp.			1	1																															
Stephanopyxis schenckii Kanaya										2	2		2		4	3	9		4							1		+		1	1		+	+	1	
Stephanopyxis turris (Greville and Arnott) Ralfs		4	2	3	5	1	1	6	1	2	2	3	1	4	12	10	5	4	2		+	3	1	2	1	8	2	5	+	1	6	1	3	4	5	1
Stephanopyxis spp.					1					1				3			1			1	+				2	3	1							7		
Synedra spp.	6		5		3		+			+		7		1						2		2			2		1							5	7
Thalassionema hirosakiensis (Kanaya) Schrader																																+				
Thalassionema nitzschioides Grunow	124	95	76	41	24	57	29	59	83	50	33	54	46	16	9	83	88	140	120	40	157	86	117	161	180	125	178	96	150	120	14	133	129	124	153	144
Thalassiosira leptopus (Grunow) Hasle and Fryxell		1	1	1												1									2	1	+	+	1	2					+	
Thalassiosira manifesta Sheshukova-Poretzkaya				1			+	1	2	4	2		1			1			1	+	1						+	2		1		1	1		+
Thalassiosira nordenskioeldii Cleve		+	1																	12			2					1			1		1	2	2
Thalassiosira spp.	9	1				3	1	2		2	2	3			1		4	4	3	16	1	4	4	4	3	2	4	7	8	5	12	5	6	3	6	14
Thalassiothrix longissima Cleve and Grunow	4	2	4	2	5	7		9	4	6	7	6	6	4	2	6		6		4	6	8	8	3	6	5	7	9	3	6	7	5	24	9	17	8
Trachyneis aspera (Ehrenberg) Cleve						+																		+												
Trachyneis spp.								1																												
Triceratium condecorum Ehrenberg		1					+	1									1		2	2			1	+				1			1		1			
Triceratium spp.																1					1	3		6	2	3	+	1	1	1						
MISCELLANEOUS	18	7	18	13	29	19	9	12	28	10	12	17	4	6	5	11	4	16	6	14	12	15	4	8	9	4	7	8	8	10	22	23	11	16	12	16
TOTAL VALVES	383	287	329	279	322	343	290	337	364	315	323	377	303	181	148	280	296	316	290	340	343	347	269	323	362	332	310	313	302	326	350	369	332	371	360	414

Appendix 10. Table showing stratigraphic occurrence of diatoms in Taihakusan section, Sendai area.

FORMATION	HATATATE FORMATION																			
SAMPLE	HTT 3	HTT 4B	HTT 5	HTT 6	HTT 7	HTT 8	HTT 9	HTT 10B	HTT 11	HTT 12	HTT 13	HTT 15	HTT 16	HTT 17	HTT 18	HTT 19	HTT 20	HTT 21a	HTT 21c
ABUNDANCE PRESERVATION	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M
Actinocyclus ehrenbergii Ralfs		3	4	3	6	2	5	2	1									1	
Actinocyclus ellipticus Grunow	3	1	1		1	1	1		2	1	1					1			
Actinocyclus ingens Rattray	5	12	13	2	10	7	3	23	11	6	2	9	4	3	30	18	7	24	14
Actinoptychus undulatus (Bailey) Ralfs	5	4	8	2	8	3	2	2	5	5	1	7	10	7	8	9	4	9	8
Amphora spp.			1							1						1			
Arachnoidiscus ehrenbergi Bailey	3	1																	
Asteromphalus spp.		1		1	1	1					1							2	
Biddulphia aurita (Lyngbye) Brébisson and Godey	2	2	3		2	4				4		1				1		2	
Cocconeis californica Grunow	2	4	2	2	1		1				2	4	3	1	2	1		4	3
Cocconeis costata Gregory	2	1			1			1	1	1	1	2	1	3	1			1	
Cocconeis placentula Ehrenberg					1	1	1			1									
Cocconeis scutellum Ehrenberg	2	1							1						1	1		1	
Cocconeis vitrea Brun	1	1	2	1	1	1		1			1	1	1		1				1
Cocconeis spp.	1	2	2	2			2	1	1				3		3			2	2
Coscinodiscus asteromphalus Ehrenberg					1														
Coscinodiscus curvatulus Grunow			1			1										1			
Coscinodiscus endoi Kanaya					1	1		1	1	1	1					1	3		3
Coscinodiscus marginatus Ehrenberg	1	1	2		2	1	1		1	2		2	4		1	4			1
Coscinodiscus oculus-iridis Ehrenberg			1																
Coscinodiscus plicatus Grunow	1	1				1		1								1			
Coscinodiscus symbolophorus Grunow	1				1			1	1										
Coscinodiscus tabularis Grunow					1	1	2	4											
Coscinodiscus temperei Brun			1		1	1													1
Coscinodiscus vetustissimus Pantocsek	3	3	2		1							1		1		5			
Coscinodiscus yabei Kanaya	3	1	2	5	11	9	4	1	1	1	1	1	1		2		4	2	2
Cymatosira debyi Tempère and Brun	1		1				2					1		1				1	3
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen	15	4	18	13	18	21	11	32	44	67	23	19	29	13	20	43	52	40	27
Denticulopsis hyalina (Schrader) Simonsen				1	2	1		1			1		1	2		1			
Denticulopsis nicobarica (Grunow) Simonsen	3					1													
Denticulopsis praedimorpha Akiba	8	15	9	17	4	12	11	19	21	17	22	39	62	38	111	53	24	27	23
Denticulopsis punctata (Schrader) Simonsen	2	1				5					1			1				1	
Denticulopsis cf. *lauta* (Bailey) Simonsen	3	2	3			1												3	1
Diploneis smithii (Brébisson) Cleve						1						1							
Diploneis spp.	1		1		1			2	1	1		1	1					1	2
Eunotia sp.	1																		
Goniothecium tenue Brun	3	8	6	2	14	13	7	3	3	2	3	2	6	7	11	4	12	5	7
Grammatophora angulosa Ehrenberg		1	1						1										
Grammatophora arcuata Ehrenberg		1															1		
Grammatophora spp.	1	3	6		1		2	2	1	3		1	4	1	1	2		8	3
Hemiaulus polymorphus Grunow	3	3	4		3	1	3	3	1	2		1	1					1	
Mediaria splendida Sheshukova-Poretzkaya	2	2		1	2	2	3	4		4	2	3	7	2	2	1	4		1
Melosira sol (Ehrenberg) Kützing	2		1			1			1							1		1	1
Melosira sulcata (Ehrenberg) Kützing	3	3	2	5	9	6	12	7	16	13	2	10	31	4	2	7	10	18	10
Navicula lyra Ehrenberg		1		1		1													
Navicula spp.	1	1	2																
Nitzschia heteropolica Schrader	1	1	1		6	3		2	5	2	1	1	2	1		1	1	2	2
Nitzschia spp.		1	1	1	1		2	2	2	3	1	1	3			2	2		
Pseudopodosira elegans (Sheshuk.) Sheshukova-Poretzkaya								1	4					2			3	1	
Rhaphoneis surirella (Ehrenberg) Grunow	1		1		1					1								1	1
Rhaphoneis spp.		1		1					1	1		1	2	1				1	
Rhizosolenia barboi (Brun) Tempère and Peragallo																1	1		2
Rhizosolenia miocenica Schrader	5	1	1	1	7	6	5	1	2		1		2				1		
Rhizosolenia styliformis Brightwell	7	3	9	2	4	1	1	1	10	2	7	6	6	3	3		2	3	
Rhizosolenia spp.	14	14	5	7	10	7	9	6	15	11	12	9	5	4	9	2	5	30	4
Rouxia californica Peragallo	1	1	1			1		5	5	7	2	2	5	2	4			1	
Rouxia naviculoides Schrader			1																
Rutilaria epsilon Greville																		1	1
Sawamuraia? spp.			1	1			1		1								2	1	
Stephanogonia hanzawae Kanaya	1				4							1	1		2	1			
Stephanopyxis turris (Greville and Arnott) Ralfs	2	2	1		4	2		3	1	1	1	5	3	1		1	1	1	1
Stephanopyxis spp.	3	3	5	1	3	1			1										2
Synedra spp.	1	2	4		2				2									7	
Thalassionema nitzschioides Grunow	207	171	193	178	163	165	173	134	142	142	160	115	112	149	43	115	117	140	124
Thalassiosira leptopus (Grunow) Hasle and Fryxell	1		1				1			1	1					1		1	1
Thalassiosira spp.			5		3	4	2	5	3	6	1	7	6	3			1	5	5
Thalassiothrix longissima Cleve and Grunow	8	9	9	5	7	9	10	7	7	7	8	7	6	7	4	4	16	32	33
Triceratium spp.	1	1																3	3
MISCELLANEOUS	17	18	25	6	15	15	12	8	13	5	6	6	6	6	6	3	14	44	14
TOTAL VALVES	354	312	363	261	335	315	289	286	329	321	266	267	328	263	267	287	287	428	306

Appendix 11. Table showing stratigraphic occurrence of diatoms in Takahagi section, Takahagi area.

FORMATION	SHIMOTEZUNA FORMATION												
SAMPLE	TAH 4	TAH 5	TAH 6	TAH 7	TAH 8	TAH 9	TAH 10	TAH 11	TAH 12	TAH 13	TAH 14	TAH 15	TAH 16
ABUNDANCE	1	2	2	1	1	1	3	1	1	2	1	2	2
PRESERVATION	M	P	P	P	P	P	P	M	M	P	M	P	P
Actinocyclus ehrenbergii Ralfs						1					1		
Actinocyclus ehrenbergii var. *tenella* (Brébisson) Hustedt									1				
Actinocyclus ellipticus Grunow												2	4
Actinocyclus ingens Rattray	38	67	92	45	37	42	37	28	10	19	33	47	90
Actinocyclus ingens var. *nodus* Baldauf	6	10	4		4	7	3		1				
Actinoptychus undulatus (Bailey) Ralfs	2	3	8	4	2	15	12	7	4	9	6	6	8
Amphora costata Wm. Smith												1	
Arachnoidiscus ehrenbergi Bailey												1	
Asteromphalus spp.								1			1		
Biddulphia aurita (Lyngbye) Brébisson and Godey			1	1			1			1	2		1
Bogorovia sp.												1	
Cocconeis californica Grunow					1	1				2	1	1	2
Cocconeis costata Gregory				1			1			1			1
Cocconeis pellucida Grunow						1							
Cocconeis pseudomarginata Gregory								1		1			
Cocconeis scutellum Ehrenberg										1			
Cocconeis vitrea Brun						1						1	
Cocconeis spp.					1		1	1				2	
Coscinodiscus asteromphalus Ehrenberg				1							1		
Coscinodiscus endoi Kanaya			1				3	5	4	4		1	1
Coscinodiscus lewisianus Greville			1			1							
Coscinodiscus marginatus Ehrenberg	3	8	11	8	4	3	2	8	7	9	14	12	10
Coscinodiscus nitidus Gregory			1										
Coscinodiscus obscurus A. Schmidt						1							
Coscinodiscus plicatus Grunow											1	1	1
Coscinodiscus symbolophorus Grunow		3	2	1		1	1	1					
Coscinodiscus vetustissimus Pantocsek					4	4					1	1	
Coscinodiscus yabei Kanaya								6	1	2	4	1	2
Coscinodiscus cf. *yabei* Kanaya							3	2	2				1
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen							54	126	139	79	164	104	174
Denticulopsis hyalina (Schrader) Simonsen					6	54	3	3	2	1	2	5	
Denticulopsis cf. *hyalina* (Schrader) Simonsen					1								
Denticulopsis lauta (Bailey) Simonsen	168	137	144	163	159	95	15	4	16	9		2	2
Denticulopsis nicobarica (Grunow) Simonsen	8	14	36	28	49	25	17	16	66	20	5	1	1
Denticulopsis praedimorpha Akiba Connecting band											1	2	2
Valve view												2	6
Girdle view													1
Denticulopsis punctata (Schrader) Simonsen			3	1	2							1	
Denticulopsis punctata var. *hustedtii* (Schrader) Simonsen					2	1			1			1	4
Diploneis spp.			2										
Goniothecium odontella Ehrenberg			1								1	1	
Goniothecium tenue Brun	2		3	1			20	12	12	11	2	16	38
Grammatophora angulosa Ehrenberg		1		1				1					
Hemiaulus polymorphus Grunow				1	1	2	1		2		1	1	5
Kisseleviella carina Sheshukova-Poretzkaya													1
Macrora stella (Azpeitia) Hanna			2										
Mediaria splendida Sheshukova-Poretzkaya (slim form)	2		5	2	1	3	3	9	4	1			1
Mediaria splendida Sheshukova-Poretzkaya (robust form)					1	1							
Melosira sol (Ehrenberg) Kützing									1		1		
Melosira sulcata (Ehrenberg) Kützing		12	2	3	1	1	35	9	9	17	27	40	29
Nitzschia challengeri Schrader		2	2	5	4	2	2	3	4				
Nitzschia heteropolica Schrader								3	3				
Nitzschia sp. A												1	
Nitzschia spp.				3			1						
Rhaphoneis surirella (Ehrenberg) Grunow			2	1			1	1		1	1		1
Rhaphoneis sp.								1					
Rhizosolenia hebetata Bailey				2									
Rhizosolenia miocenica Schrader								1	2	3			1
Rhizosolenia styliformis Brightwell					1								
Rouxia californica Peragallo								2	4				
Rouxia naviculoides Schrader			1	2									
Rutilaria epsilon Greville										1			
Stephanogonia hanzawae Kanaya			1			1		6	2		2		1
Stephanopyxis schenckii Kanaya					1								
Stephanopyxis turris (Greville and Arnott) Ralfs	1	3	3	7	6	2	18		2	1	2	1	7
Stephanopyxis spp.			3		2	2		1	2	2	3	3	4
Synedra jouseana Sheshukova-Poretzkaya	5	3	7	8	1								
Thalassionema hirosakiensis (Kanaya) Schrader													1
Thalassionema nitzschioides Grunow	93	127	164	97	69	81	79	127	97	95	144	59	149
Thalassiosira leptopus (Grunow) Hasle and Fryxell						1	2	1					
Thalassiothrix longissima Cleve and Grunow	6	8	9	1	5	9	9	8	3	9	10	5	7
Triceratium condecorum Ehrenberg						1							
MISCELLANEOUS	4	9	7	10	8	7	7	7	9	7	7	10	18
TOTAL VALVES	338	407	518	397	373	366	331	401	410	306	438	333	574

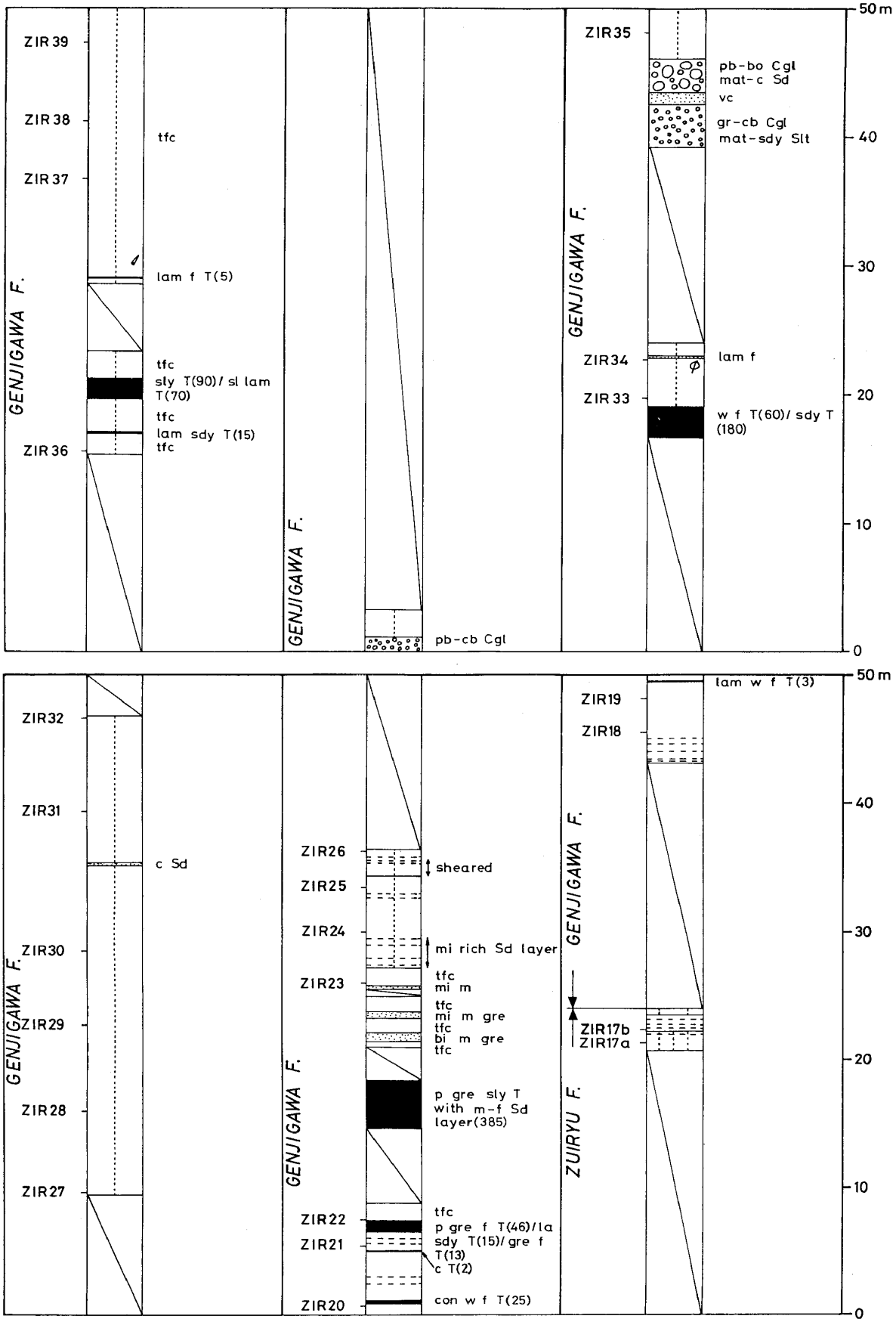
Appendix 12. Table showing stratigraphic occurrence of diatoms in Ayukawa section, Hitachi area.

FORMATION	KOKUBU FORMATION																			
SAMPLE	AY 1	AY 3	AY 5	AY 7	AY 9	AY 11	AY 13	AY 15	AY 17	AY 19	AY 21	AY 23	AY 25	AY 27	AY 29	AY 31	AY 33	AY 35	AY 37	AY 38
ABUNDANCE	2	2	2	2	1	3	1	2	1	1	1	1	1	1	1	2	1	1	1	1
PRESERVATION	P	P	P	P	P	DP	M	P	P	M	M	M	M	M	M	M	M	M	M	M
Actinocyclus ehrenbergii Ralfs					2															
Actinocyclus ehrenbergii var. *tenella* (Brébisson) Hustedt		1	1		1				1											
Actinocyclus ehrenbergii vars.	1									1			1							
Actinocyclus ellipticus Grunow		4				1					1	1				1			2	
Actinocyclus ingens Rattray	84	33	7	14	7	18	2	13	10	11	5	11	13	6	6	15	3	4	5	2
Actinocyclus ingens var. *nodus* Baldauf									1											
Actinoptychus undulatus (Bailey) Ralfs	15	11	11	1	3	14	18	30	4	19	12	8	16	9	3	3	3	4	6	6
Amphora costata Wm. Smith							1													
Aulacosira granulata (Ehrenberg) Simonsen							1													
Biddulphia aurita (Lyngbye) Brébisson and Godey			1					1						1						
Bogorovia spp.					1															
Cocconeis californica Grunow	1	1	3				1	2	2	1	1		1		1			1		
Cocconeis costata Gregory					1		1			1					1					
Cocconeis placentula Ehrenberg					1															
Cocconeis scutellum Ehrenberg	2		1																	
Cocconeis vitrea Brun				3			1	1												
Cocconeis spp.	3	2	1		3		1	1		1						1				
Coscinodiscus argus Ehrenberg										1						1				
Coscinodiscus asteromphalus Ehrenberg													1							
Coscinodiscus endoi Kanaya				2	8	1		1	2		2	1	1	2	1	1	1			
Coscinodiscus marginatus Ehrenberg	16	12	2	10		2	5		1	3	4	4		4	2	2		1		
Coscinodiscus plicatus Grunow	1	3	10		1	1	2		4	3	1			1	2	2	1	1		
Coscinodiscus radiatus Ehrenberg			1	1		1														
Coscinodiscus symbolophorus Grunow	1	2	1								1		2	2	1	1		1		
Coscinodiscus temperei Brun		1	3			1							1		2	2	1	1		
Coscinodiscus vetustissimus Pantocsek		3	1	2			2	4	3	2	7	2	7	5	2	5	2	4	2	1
Coscinodiscus yabei Kanaya		1	2		1		8	7	6	1	9	3	9	6	7	5	5	1	3	1
Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen	51	37	32	29	35	8	90	71	117	101	99	130	182	112	221	160	194	96	209	109
Denticulopsis hustedtii (elliptical form)								R	R	R	R	R	R	R	R	R	R	R	R	
Denticulopsis hyalina (Schrader) Simonsen	2		1				2	3	3	3					1	1				1
Denticulopsis lauta (Bailey) Simonsen	2				1	1	3		1		1		1			2				1
Denticulopsis cf. *lauta* (Bailey) Simonsen	1																			
Denticulopsis nicobarica (Grunow) Simonsen	1				1															
Denticulopsis praedimorpha Akiba Connecting band	1	14	13	23	14															
Girdle view	1	1	1		3															
Valve view	2	26	7	15	11	1		1	1											
Denticulopsis punctata (Schrader) Simonsen	1	2	2	3																
Denticulopsis punctata var. *hustedtii* (Schrader) Simonsen				3			2	1												
Diploneis spp.	1		1			2	1		1		2	1								
Goniothecium odontella Ehrenberg						2														
Goniothecium tenue Brun	6	28	36	9	6	29	12	32	30	5	2	13	8	17	8	19	6	7	6	7
Grammatophora angulosa Ehrenberg							1		1									1		
Grammatophora marina (Lyngbye) Kützing			1								1	1		3						
Grammatophora spp.																1				
Hemiaulus polymorphus Grunow		1													1		1			1
Hemidiscus cuneiformis Wallich												1	1		1		1		1	2
Hyalodiscus spp.	1					1														
Mediaria splendida Sheshukova-Poretzkaya	2	1		1	1		4				1		1							
Melosira sol (Ehrenberg) Kützing		1																		
Melosira sulcata (Ehrenberg) Kützing	38	1	17	11	8	6	6	10			3	6	2	1	2	4	4	11	4	2
Navicula spp.							1	1												
Nitzschia challengeri Schrader								1												
Nitzschia heteropolica Schrader		1		3	3		3	1		1	1						3	1		
Nitzschia miocenica Burckle															1	1				
Nitzschia sp. A	1	1									2									1
Nitzschia spp.							1	2			2	3	1	1						
Plagiogramma staurophoram (Greville) Heiberg	1				1			1					1							
Pseudopodosira elegans Sheshukova-Poretzkaya									2		3				1		1			
Rhaphoneis amphiceros Ehrenberg		1					1			1										
Rhaphoneis surirella (Ehrenberg) Grunow	2	1		3	2	2	4	1	1					1			2	3	1	
Rhaphoneis spp.			7																	
Rhizosolenia barboi (Brun) Tempère and Peragallo				1		2	1	2	6	5	2		1			1		1		
Rhizosolenia hebetata Bailey					2	4		2												
Rhizosolenia miocenica Schrader		2	5					2		1									1	
Rouxia californica Peragallo					1		6	3	2	3	3	3	7	6	10	19	3	4	3	2
Rouxia naviculoides Schrader								1									1	1	2	
Rutilaria epsilon Greville							1													
Stephanogonia hanzawae Kanaya	1		1		3	1	2	4		3	4	7	1	1						
Stephanopyxis schenckii Kanaya			2			2														
Stephanopyxis turris (Greville and Arnott) Ralfs	1	3	2	4		1			5		6	1	1							
Stephanopyxis spp.		1									1					1				
Thalassionema hirosakiensis (Kanaya) Schrader		1		1	5	3	13	4	8	6	17	6			1	5	1	4	8	3
Thalassionema nitzschioides Grunow	130	265	308	188	236	65	155	185	96	112	169	195	86	148	121	142	203	113	154	121
Thalassionema schraderi Akiba																			1	
Thalassiosira leptopus (Grunow) Hasle and Fryxell			1	2	3				1	1										1
Thalassiosira nordenskioeldii Cleve																1			2	
Thalassiosira spp.															4	3	3	2	3	2
Thalassiothrix longissima Cleve and Grunow	7	6	9	14	5	15	12	7	5	1	2	5		2	2	7	3	7	6	3
Triceratium condecorum Ehrenberg		1				1	4	1												1
Triceratium sp.									1											
MISCELLANEOUS	17	12	8	7	9	8	19	11	9	4	9	5	8	7	5	11	4	4	4	10
TOTAL VALVES	394	481	499	350	379	193	387	407	324	291	373	407	353	335	407	417	446	273	423	278

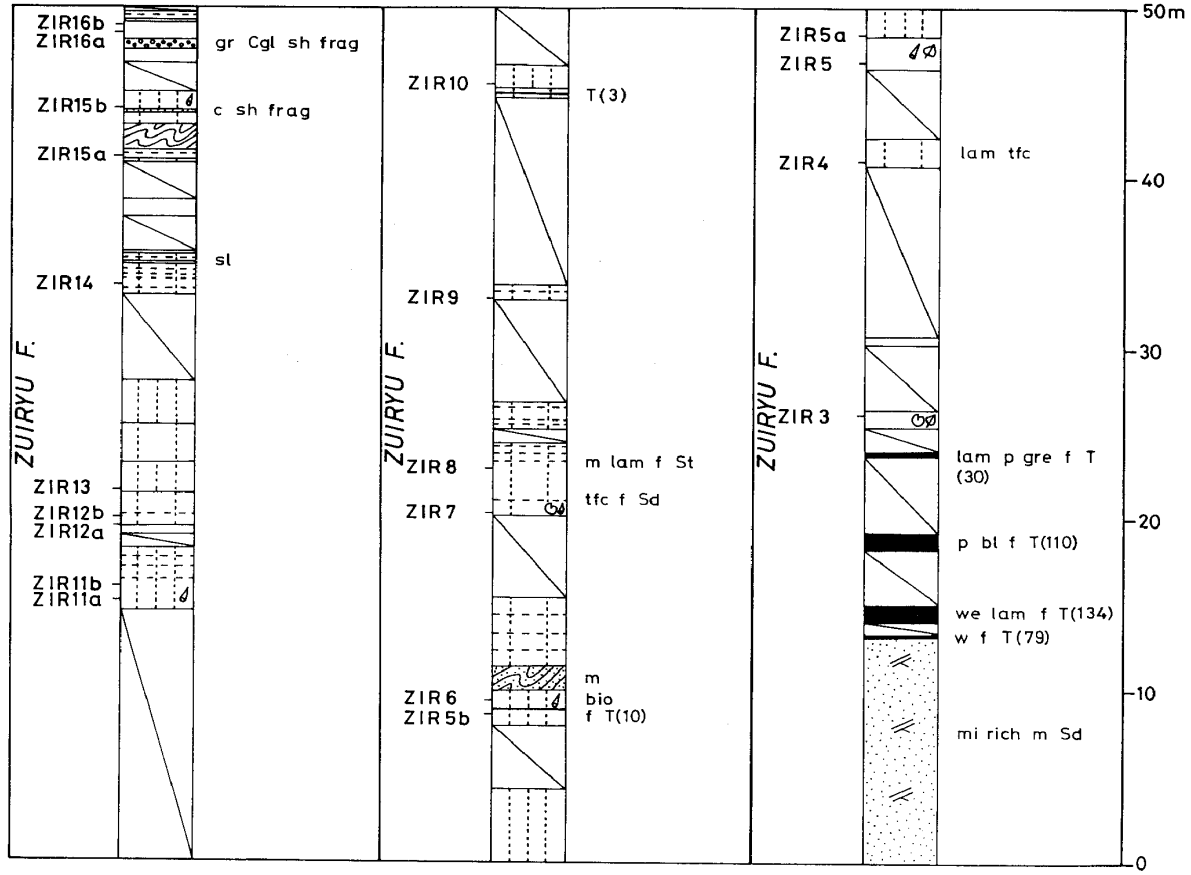
Appendix 13. Table showing stratigraphic occurrence of diatoms in Zuiryuzawa section, Hitachiota area.

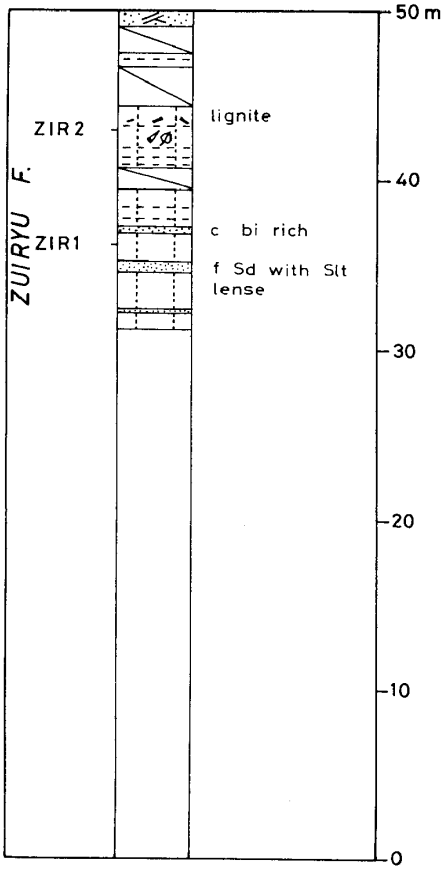
FORMATION	GENJIGAWA FORMATION																						
SAMPLE	ZIR 18	ZIR 19	ZIR 20	ZIR 21	ZIR 22	ZIR 23	ZIR 24	ZIR 25	ZIR 26	ZIR 27	ZIR 28	ZIR 29	ZIR 30	ZIR 31	ZIR 32	ZIR 33	ZIR 34	ZIR 35	ZIR 36	ZIR 37	ZIR 38	ZIR 39
ABUNDANCE PRESERVATION	2 P	1 M	1 M	1 P	1.3 P	1 M	1 P	1 M	1 M	1 P	2 P	1 M	1 M	1 M	1 M	1 M	1 M	1 M	2 P	1 P	1 P	2 P
Actinocyclus ehrenbergii var. *tenella* (Brébisson) Hustedt																1	1					
Actinocyclus ellipticus Grunow		1																				
Actinocyclus ingens Rattray (flat form)	5	7	18	4	9	2	8	7	12	19	12	21	21	14	23	11	6	18	38	91	63	16
Actinocyclus ingens Rattray (undulated form)																			1	2		
Actinocyclus ingens var. *nodus* Baldauf																					1	
Actinocyclus spp.								1			1	2										
Actinoptychus undulatus (Bailey) Ralfs	7	11	19	11	4	9	11	9	7	10	13	9	13	8	14	11	3	9	7	15	15	14
Aulacosira granulata (Ehrenberg) Simonsen					1											1				1		
Biddulphia aurita (Lyngbye) Brébisson and Godey																			1			1
Cocconeis californica Grunow									2								1			1		1
Cocconeis costata Gregory																						1
Cocconeis placentula Ehrenberg																						1
Cocconeis scutellum Ehrenberg							1															
Cocconeis vitrea Brun			1																			
Cocconeis spp.					1									1	1						1	
Coscinodiscus argus Ehrenberg										1		1	1	1								
Coscinodiscus asteromphalus Ehrenberg													1									
Coscinodiscus endoi Kanaya	2		14	6	5	1		2		10	7	2	5			2	1	2				
Coscinodiscus lewisianus Greville	1		3						+			1	1		1	2			+			
Coscinodiscus marginatus Ehrenberg				1			2	+		3				1	1		1		1	2	1	
Coscinodiscus cf. *nodulifer* A. Schmidt								2					1		1							
Coscinodiscus plicatus Grunow			1																1			
Coscinodiscus symbolophorus Grunow	2	1	2	1		1	2	2		1	1	1		1	5	2	2	1		2	1	
Coscinodiscus vetustissimus Pantocsek									1	1												
Coscinodiscus yabei Kanaya																						1
Denticulopsis kanayae Akiba			+																			
Denticulopsis lauta (Bailey) Simonsen	147	141	297	87	158	464	165	151	140	93	75	141	117	156	192	288	204	230	133	131	182	184
Denticulopsis norwegica (Schrader) Simonsen																			1			
Diploneis sp.					1																	
Goniothecium tenue Brun	2			4	4										2					2		
Grammatophora angulosa Ehrenberg			1		1														1			
Grammatophora spp.			1	1		1		2													1	
Hemiaulus polymorphus Grunow	1	2		2		1				1			1							1	3	1
Kisseleviella carina Sheshukova-Poretzkaya							1								3	2			15	24	1	
Macrora stella (Azpeitia) Hanna						1								1	1					1		
Mediaria splendida Sheshukova-Poretzkaya (slim form)	1		3	2	1			1		1	2	1	1		1			3	4	1	3	
Mediaria splendida Sheshukova-Poretzkaya (robust form)		1	8	6	1	1	3	2		1			1	1	3						1	1
Melosira sol (Ehrenberg) Kützing												1	5									
Melosira sulcata (Ehrenberg) Kützing	1	2	4		2	8	15	8	1	4	4	1	19	16	2	4	3	1	11	2	2	8
Navicula spp.			1										1		2							
Nitzschia challengeri Schrader		2	3	1	5				1			1	3	2	3			1		2	10	
Nitzschia heteropolica Schrader																					5	1
Plagiogramma staurophorum (Greville) Heiberg																					1	
Raphidodiscus marylandicus Christian			+	2	1	1	1	3		1			3	1		1				1		
Rhaphoneis surirella (Ehrenberg) Grunow																			1			
Rhaphoneis spp.			3	10	3	3	1	3	4	2		2	3	5	2	3	1	7	4	1	2	10
Rhizosolenia miocenica Schrader			1			1		2							+			1				
Rhizosolenia praebarboi Schrader															+				1	+		
Rouxia californica Peragallo													1									
Rouxia naviculoides Schrader				1	1	3						1								1	1	
Rouxia sp.			1																			
Stephanogonia hanzawae Kanaya															1							
Stephanopyxis schenckii Kanaya	1	2	1	5	1	3	1	2	2	1	1	1	1	2	4	2		1	4	3	4	2
Stephanopyxis turris (Greville and Arnott) Ralfs	5	6	7	5		3	1	3	3	1	6	1			8	1		3	3	2	11	3
Synedra jouseana Sheshukova-Poretzkaya			1	2								1	1						2			
Synedra spp.	2	3	8	6	3	3	2	1	3	2												
Thalassionema nitzschioides Grunow	63	59	124	74	48	85	48	49	61	80	112	97	92	93	90	54	70	68	58	37	48	66
Thalassiosira leptopus (Grunow) Hasle and Fryxell														1		1			1			2
Thalassiosira spp.	1	1	2	1		1	1	2	2	1		2			1	1	1		1	1	1	1
Thalassiothrix longissima Cleve and Grunow	3	2	6	3	6		1	3	3	2	3	1	3	3	5	2		4	2	2	11	3
Triceratium condecorum Ehrenberg	1		1			1				1		1	2			2						
Trochosira spinosa Kitton	2	1	10		1	4	1		10	4	2		5			2						1
MISCELLANEOUS	4	6	20	24	12	11	4	3	3	4	6	8	8	4	4	6	5	11	17	7	8	5
TOTAL VALVES	251	248	561	259	269	608	269	258	255	244	245	297	310	311	379	399	299	360	308	333	377	323

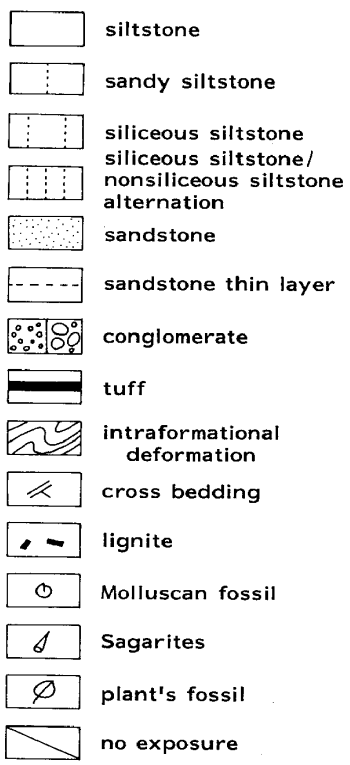
Appendix 14. Stratigraphic columnar section of the Zuiryu and Genjigawa Formations,



Hitachiota area (provided by Prof. Takahashi and Dr. Amano of Ibaraki University).







Abbreviations

Cgl	:	conglomerate
Sd	:	sandstone
Slt	:	siltstone
T	:	tuff
sdy	:	sandy
sly	:	silty
tfc	:	tuffaceous
f	:	fine
m	:	medium
c	:	coarse
vc	:	very coarse
gr	:	granule
pb	:	pebble
cb	:	cobble
bo	:	boulder
mat	:	matrix
sh	:	shell
frag	:	fragment
lam	:	laminated
sl	:	slumping
con	:	convolute lamination
p	:	pale
we	:	weakly
bl	:	blue
gre	:	green
w	:	white
mi	:	mica
bi	:	biotite
bio	:	bioturbation
(18)	:	thickness (cm)

Appendix 15. Table showing stratigraphic occurrence of diatoms in Usuitoge section, Usuitoge area.

STRATIGRAPHIC UNIT	TOMIOKA GROUP					
SAMPLE	B6	B5	B4	B3	B2	B1
ABUNDANCE PRESERVATION	A M	C P	C M	C M	R P	C M
Actinocyclus curvatulus Janisch						1
Actinocyclus cf. *curvatulus* Janisch	2		2			
Actinocyclus ehrenbergii Ralfs				1		
Actinocyclus ehrenbergii var. *tenella* (Brébisson) Hustedt	1					
Actinocyclus ingens Rattray	103	29	41	75	119	107
Actinocyclus ingens var. *nodus* Baldauf	4		1		2	
Actinoptychus undulatus (Bailey) Ralfs	10	1	3	5	2	3
Aulacosira granulata (Ehrenberg) Simonsen						2
Cocconeis sp.					2	
Coscinodiscus asteromphalus Ehrenberg				1		
Coscinodiscus endoi Kanaya	2	1	2			
Coscinodiscus lewisianus Greville						1
Coscinodiscus marginatus Ehrenberg	3	1		1	13	3
Coscinodiscus radiatus Ehrenberg	2				1	1
Coscinodiscus symbolophorus Grunow	1					1
Denticulopsis lauta (Bailey) Simonsen	13	10	10	12		9
Denticulopsis cf. *lauta* (Bailey) Simonsen						1
Denticulopsis nicobarica (Grunow) Simonsen	6	16	16	20		5
Denticulopsis nicobarica var. 1		4		1		
Denticulopsis norwegica (Schrader) Simonsen	1					
Denticulopsis cf. *punctata* (Schrader) Simonsen						1
Eunotia sp.				1		
Grammatophora angulosa Ehrenberg			1			
Grammatophora cf. *marina* (Lyngbye) Kützing	1		1			
Macrora stella (Azpeitia) Hanna		1	1	2		
Mediaria splendida Sheshukova-Poretzkaya	1					
Melosira sol (Ehrenberg) Kützing	1	1				2
Melosira sulcata (Ehrenberg) Kützing	27	15	23	31	5	3
Melosira cf. *sulcata* (Ehrenberg) Kützing						69
Rhaphoneis cf. *biseriata* Grunow			1			
Rhaphoneis sp.	1			1		2
Rhizosolenia praebarboi Schrader	5	4	2	2		1
Stephanopyxis schenckii Kanaya					1	
Stephanopyxis turris (Greville and Arnott) Ralfs	3	1	1		1	
Stephanopyxis cf. *turris* (Greville and Arnott) Ralfs	1	1			1	
Synedra jouseana Sheshukova-Poretzkaya	11	1	3	2		3
Thalassionema nitzschioides Grunow	252	164	148	161	9	67
Thalassiosira leptopus (Grunow) Hasle and Fryxell	2			2	1	4
Thalassiothrix longissima Cleve and Grunow	7	4	2	4		2
Trachyneis aspera (Ehrenberg) Cleve		1				
Trochosira spinosa Kitton						1
MISCELLANEOUS	8	6	17	10	14	9
TOTAL VALVES	468	261	275	332	171	298

Plates 11–15

Plate 11

All figures transmitted photomicrographs
Scale bar represents 10 μm

Figs. 1, 2. *Thalassionema nitzschioides* Grunow
1. Sample IWS-13, Shimokurosawa Formation, Ichinoseki area.
2. Sample B-6, Tomioka Group, Usuitoge area.

Figs. 3, 4. *Thalassionema hirosakiensis* (Kanaya) Schrader
3. Sample DSDP Hole 438A 64-1 (10-14).
4. Sample B-6, Tomioka Group, Usuitoge area.

Figs. 5, 6. *Thalassionema schraderi* Akiba
Sample STZ-44, Kamasawa Tuff Member, Kubo Formation, Sannohe area.

Fig. 7. *Plagiogramma staurophorum* (Greville) Heiberg
Sample STZ-44, Kamasawa Tuff Member, Kubo Formation, Sannohe area.

Fig. 8. *Synedra jouseana* Sheshukova-Poretzkaya
Sample B-6, Tomioka Group, Usuitoge area.

Figs. 9-11. *Goniothecium tenue* Brun
9. Valve view, sample IWS-3, Shimokurosawa Formation, Ichinoseki area.
10. Girdle view, sample IWS-5, Shimokurosawa Formation, Ichinoseki area.
11. Girdle view, sample IWS-7, Shimokurosawa Formation, Ichinoseki area.

Figs. 12-14. *Melosira sulcata* (Ehrenberg) Kützing
12, 13. Valve view, sample B-6, Tomioka Group, Usuitoge area.
14. Girdle view, sample ZIR-37, Genjigawa Formation, Hitachiota area.

Fig. 15. *Nitzschia heteropolica* Schrader
Sample AY-21, Kokubu Formation, Hitachi area.

Fig. 16. *Rouxia californica* Peragallo
Sample STZ-44, Kamasawa Tuff Member, Kubo Formation, Sannohe area.

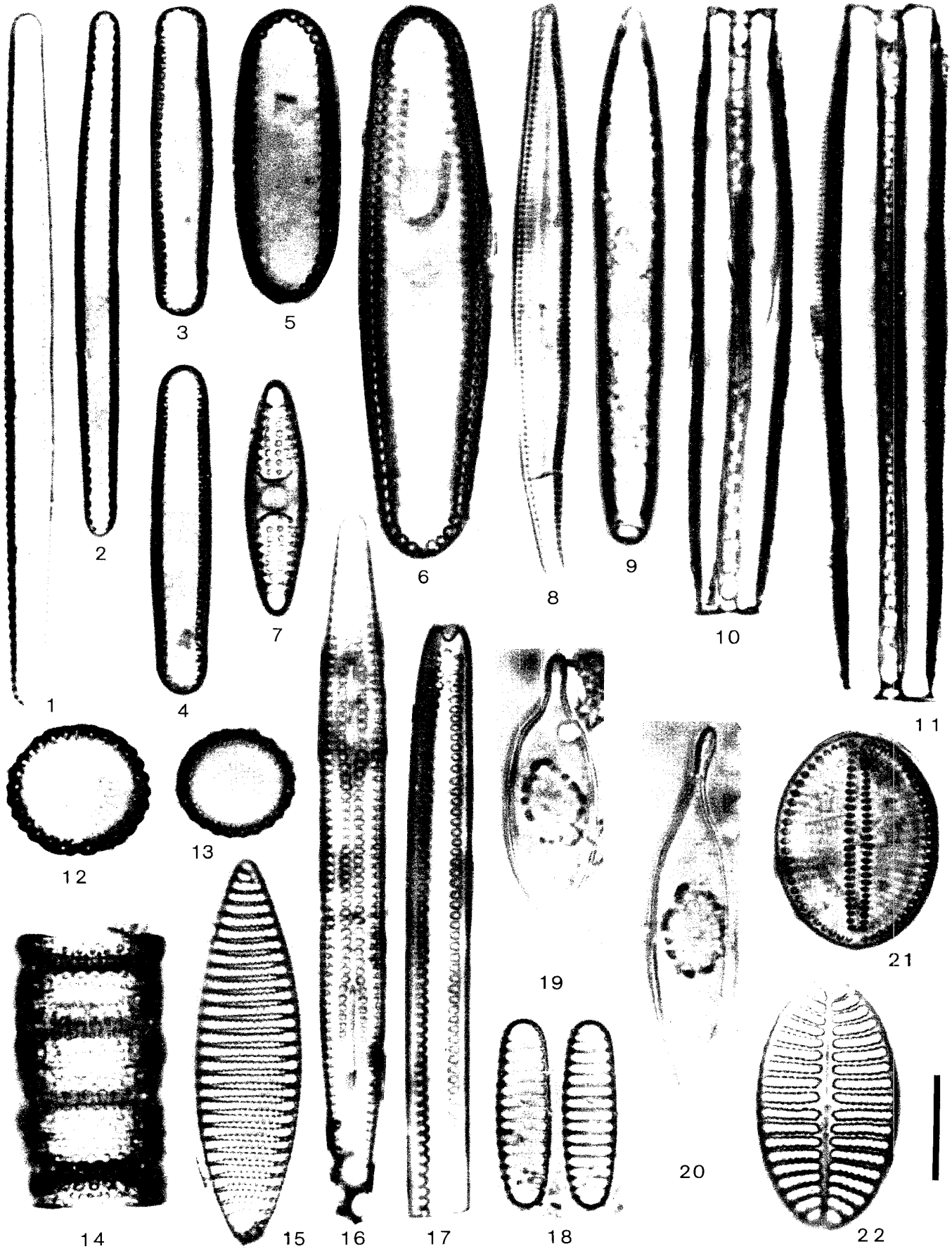
Fig. 17. *Thalassiothrix longissima* Cleve and Grunow
Sample TAH-9, Shimotezuna Formation, Takahagi area.

Fig. 18. *Nitzschia challengeri* Schrader
Sample DSDP Hole 438A 79-1 (51-54).

Figs. 19, 20. *Kisseleviella carina* Sheshukova-Poretzkaya
19. Sample KDN-8, Shikonai Siltstone Member, Kadonosawa Formation, Sannohe area.
20. Sample KDN-6, Shikonai Siltstone Member, Kadonosawa Formation, Sannohe area.

Fig. 21. *Cocconeis californica* Grunow
Sample AY-13, Kokubu Formation, Hitachi area.

Fig. 22. *Cocconeis costata* Gregory
Sample AY-9, Kokubu Formation, Hitachi area.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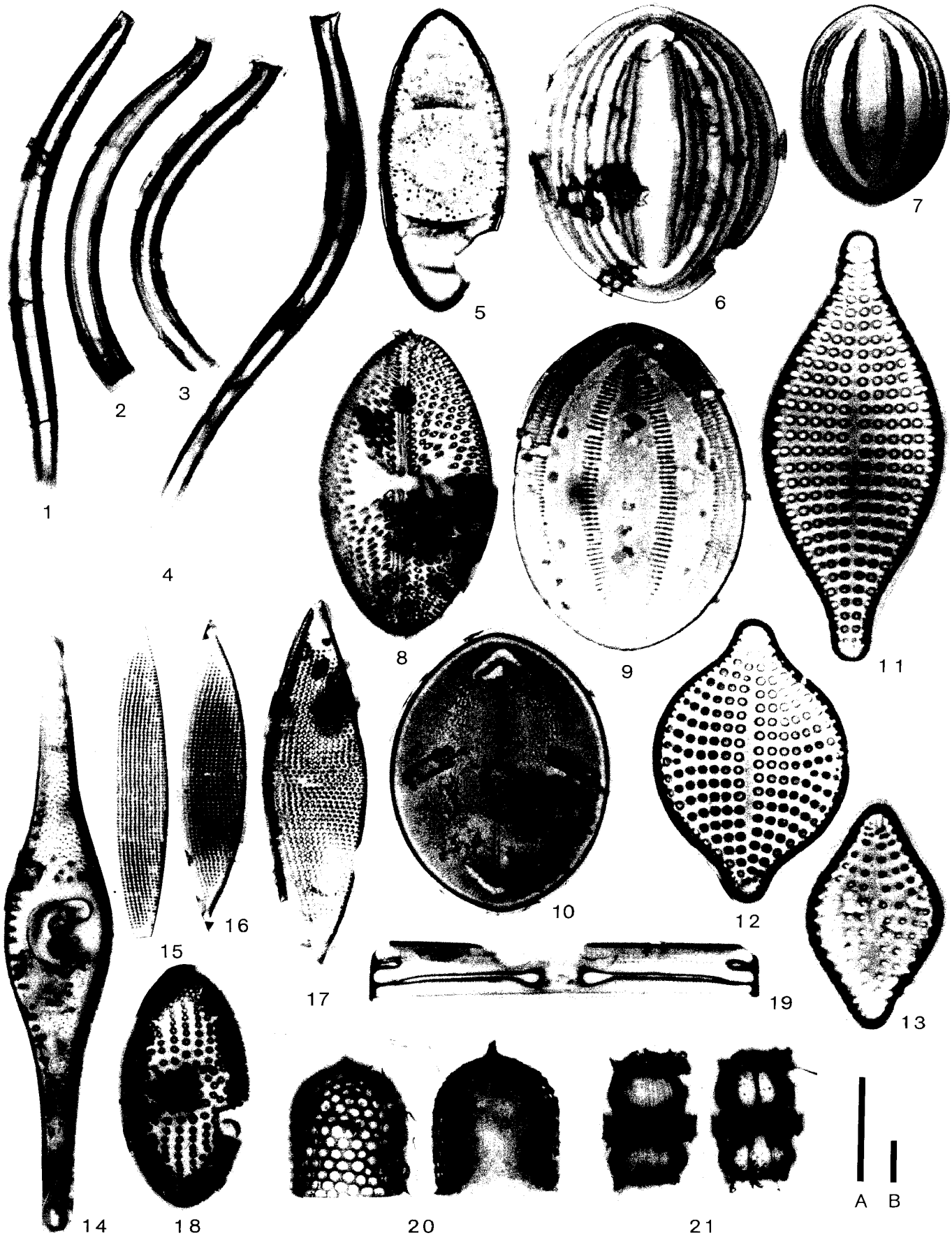
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Plate 12

All figures transmitted photomicrographs
Scale bars represent 10 μm
Scale A ; Figs. 9–13
Scale B ; Figs. 1–8, 14–21

Figs. 1, 2. *Rhizosolenia praebarboi* Schrader
1. Sample IWN-5, Shimokurosawa Formation, Ichinoseki area.
2. Sample ZIR-32, Genjigawa Formation, Hitachiota area.

Figs. 3, 4. *Rhizosolenia barboi* (Brun) Tempère and Peragallo
3. Sample YAC-15, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
4. Sample STZ-44, Kamasawa Tuff Member, Kubo Formation, Sannohe area.

Fig. 5. *Goniothecium odontella* Ehrenberg
Sample IWS-15, Shimokurosawa Formation, Ichinoseki area.

Figs. 6, 10. *Cocconeis pellucida* Grunow
6. Sample TAH-9, Shimotezuna Formation, Takahagi area.
10. Sample STZ-42, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.

Figs. 7, 9. *Cocconeis vitrea* Brun
7. Sample KT-3, Katsuta Formation, Nakaminato area.
9. Sample STZ-23, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.

Fig. 8. *Trachyneis aspera* (Ehrenberg) Cleve
Sample STZ-44, Kamasawa Tuff Member, Kubo Formation, Sannohe area.

Figs. 11, 12. *Rhaphoneis amphiceros* Ehrenberg
11. Sample STZ-44, Kamasawa Tuff Member, Kubo Formation, Sannohe area.
12. Sample AY-13, Kokubu Formation, Hitachi area.

Fig. 13. *Rhaphoneis miocenica* Schrader
Sample KDN-8, Shikonai Siltstone Member, Kadonosawa Formation, Sannohe area.

Fig. 14. *Rutiaria epsilon* Greville
Sample AY-13, Kokubu Formation, Hitachi area.

Figs. 15–17. *Mediaria splendida* Sheshukova-Poretzkaya
15. Slim form, sample IWS-3, Shimokurosawa Formation, Ichinoseki area.
16. Robust form, sample KT-1, Katsuta Formation, Nakaminato area.
17. Robust form, sample ZIR-32, Genjigawa Formation, Hitachiota area.

Fig. 18. *Coscinodiscus lewisianus* Greville
Sample TAH-9, Shimotezuna Formation, Takahagi area.

Fig. 19. *Grammatophora marina* (Lyngbye) Kützing
Sample IWN-5, Shimokurosawa Formation, Ichinoseki area.

Fig. 20. *Stephanopyxis turris* (Greville and Arnott) Ralfs
Sample IWS-18, Shimokurosawa Formation, Ichinoseki area.

Fig. 21. *Stephanogonia hanzawae* Kanaya
Sample IWN-7, Shimokurosawa Formation, Ichinoseki area.

Plate 13

All figures transmitted photomicrographs
Scale bars represent 10 μm
Scale A ; Figs. 2-3, 8, 10-11
Scale B ; Figs. 1, 4-7, 9

Figs. 1-3. *Actinocyclus ingens* Rattray (flat from)
1. Sample STZ-23, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.
2. Sample IWS-15, Shimokurosawa Formation, Ichinoseki area.
3. Sample B-6, Tomioka Group, Usuitoge area.

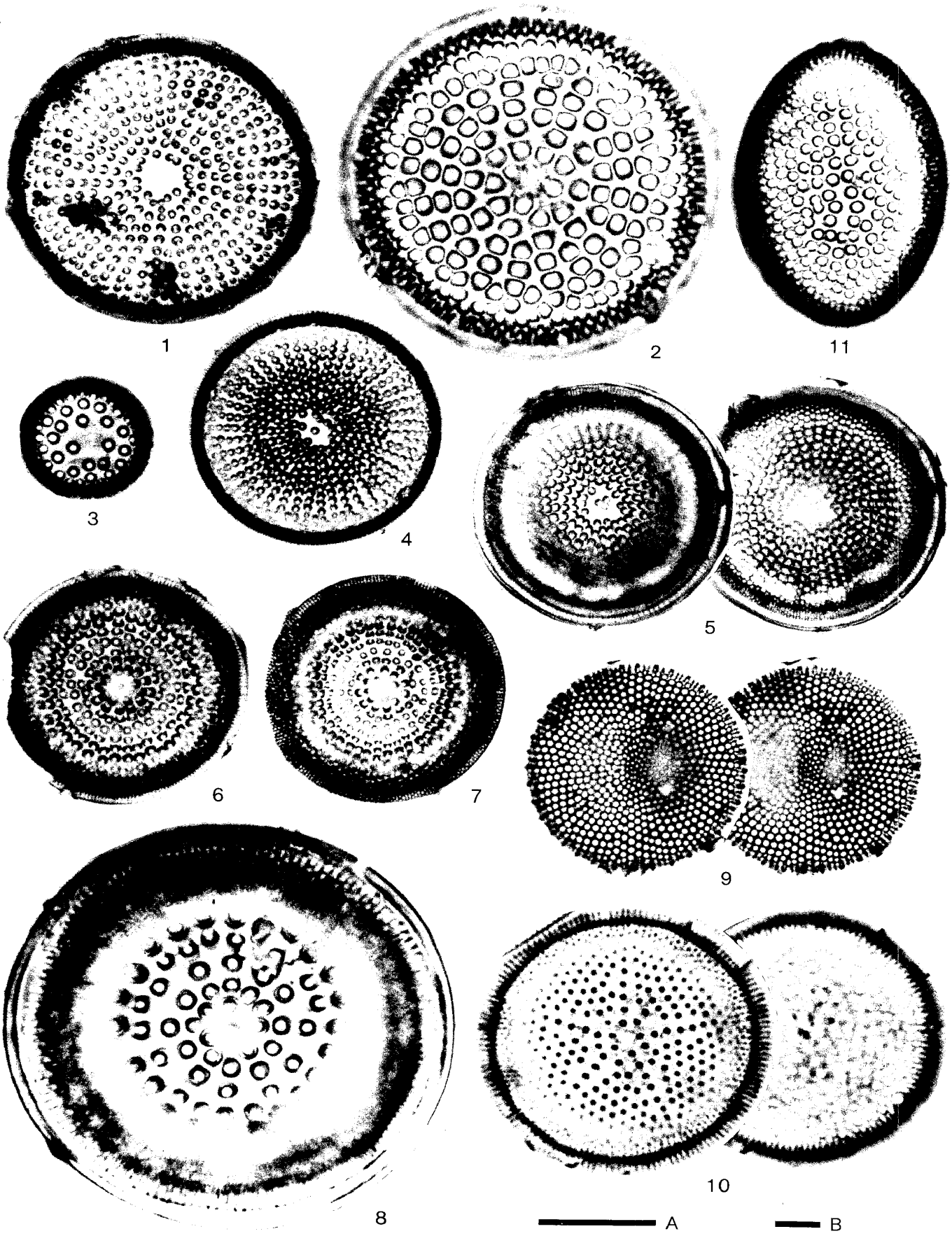
Figs. 4, 5.. *Actinocyclus ingens* Rattray (undulated form)
4. Sample IWN-5, Shimokurosawa Formation, Ichinoseki area.
5. Sample B-1, Tomioka Group, Usuitoge area.

Figs. 6-8. *Actinocyclus ingens* var. *nodus* Baldauf
6. Sample B-6, Tomioka Group, Usuitoge area.
7. Sample TAH-6, Shimotezuna Formation, Takahagi area.
8. Sample TAH-9, Shimotezuna Formation, Takahagi area.

Fig. 9. *Coscinodiscus plicatus* Grunow
Sample IWN-5, Shimokurosawa Formation, Ichinoseki area.

Fig. 10. *Actinocyclus ehrenbergii* var. *tenella* (Brébisson) Hustedt
Sample IWN-1, Shimokurosawa Formation, Ichinoseki area.

Fig. 11. *Actinocyclus ellipticus* Grunow
Sample IWN-3, Shimokurosawa Formation, Ichinoseki area.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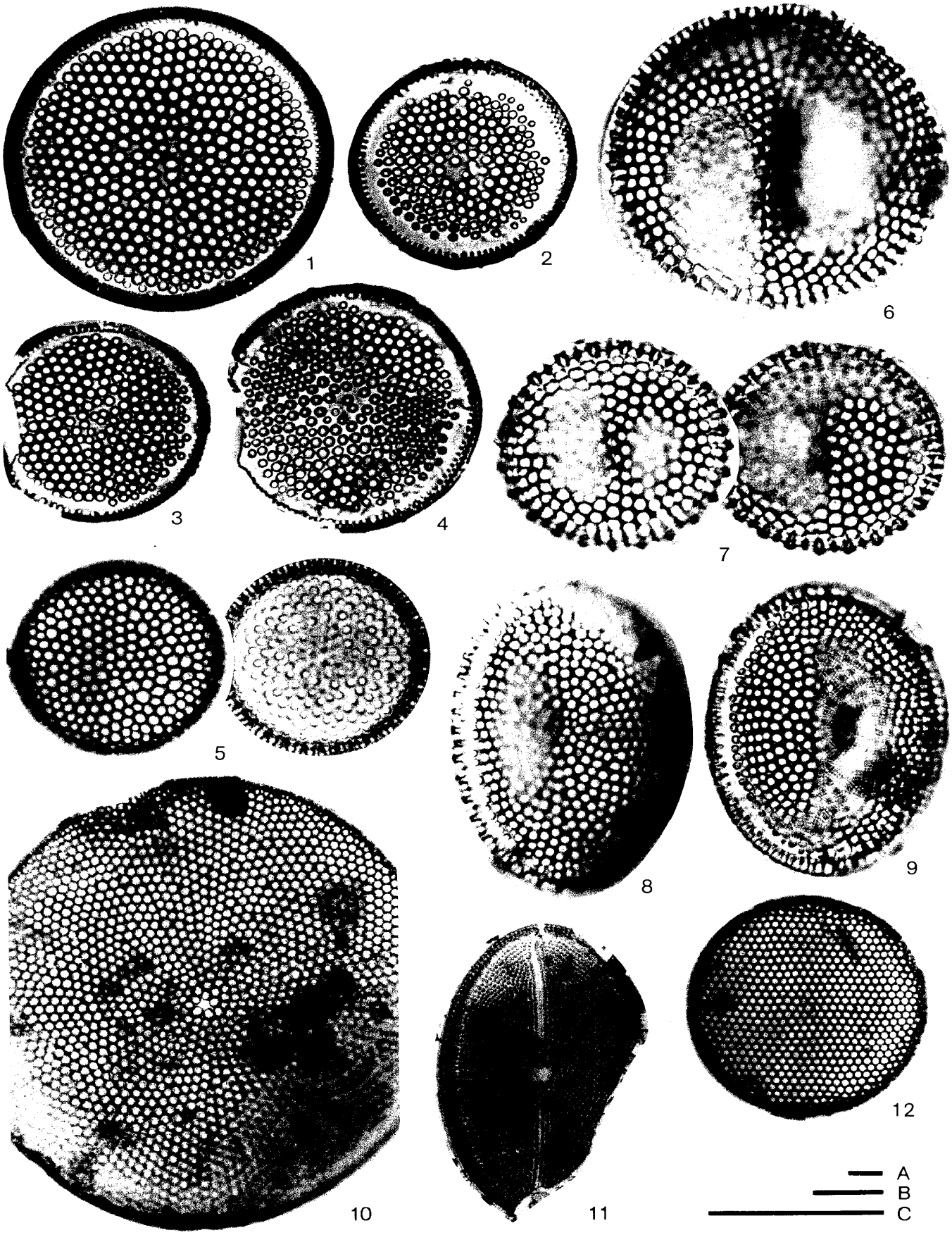
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Plate 14

All figures transmitted photomicrographs
Scale bars represent 20 μm
Scale A ; Figs. 10, 11
Scale B ; Figs. 5, 12
Scale C ; Figs. 1–4, 6–9

Figs. 1–4. *Coscinodiscus endoi* Kanaya
1. Sample AY-29, Kokubu Formation, Hitachi area.
2, 3. Sample SAW-14, Numanokubo Diatomaceous Mudstone Member, Tomesaki Formation, Sannohe area.
4. Sample STZ-44, Kamasawa Tuff Member, Kubo Formation, Sannohe area.

Fig. 5. *Coscinodiscus marginatus* Ehrenberg
Sample IWS-1, Shimokurosawa Formation, Ichinoseki area.

Figs. 6, 7. *Coscinodiscus yabei* Kanaya
6. Sample SAW-14, Numanokubo Diatomaceous Mudstone Member, Tomesaki Formation, Sannohe area.
7. Sample IWN-5, Shimokurosawa Formation, Ichinoseki area.

Figs. 8, 9. *Coscinodiscus temperei* Brun
8. Sample IWN-19, Shimokurosawa Formation, Ichinoseki area.
9. Sample IWN-9, Shimokurosawa Formation, Ichinoseki area.

Fig. 10. *Coscinodiscus oculus iridis* Ehrenberg
Sample KT-3, Katsuta Formation, Nakaminato area.

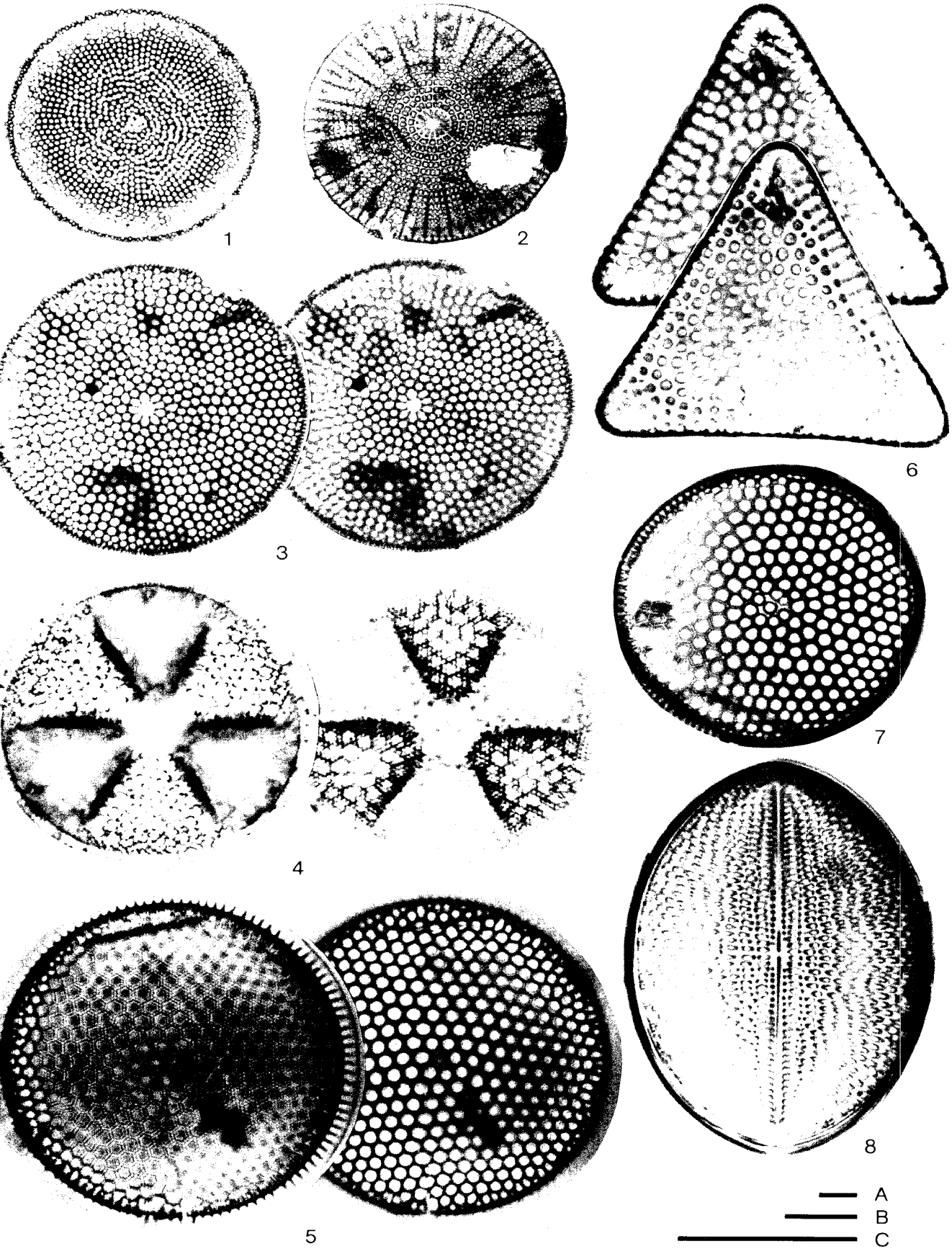
Fig. 11. *Mastogloia splendida* (Gregory) Cleve
Sample YAC-12, Shitazaki Siltstone Member, Shitazaki Formation, Sannohe area.

Fig. 12. *Thalassiosira leptopus* (Grunow) Hasle and Fryxell
Sample AY-9, Kokubu Formation, Hitachi area.

Plate 15

All figures transmitted photomicrographs
Scale bars represent 20 μm
Scale A ; Figs. 2, 3
Scale B ; Fig. 1
Scale C ; Figs. 4–8

Fig. 1. *Actinocyclus ehrenbergii* Ralfs
Sample IWN-5, Shimokurosawa Formation, Ichinoseki area.
Fig. 2. *Arachnoidiscus ehrenbergii* Bailey
Sample AY-9, Kokubu Formation, Hitachi area.
Fig. 3. *Coscinodiscus obscurus* A. Schmidt
Sample TAH-9, Shimotezuna Formation, Takahagi area.
Fig. 4. *Actinoptychus undulatus* (Bailey) Ralfs
Sample IWS-13, Shimokurosawa Formation, Ichinoseki area.
Fig. 5. *Thalassiosira antiqua* (Grunow) Cleve
Sample STZ-44, Kamasawa Tuff Member, Kubo Formation, Sannohe area.
Fig. 6. *Triceratium condecorum* Brightwell
Sample IWN-3, Shimokurosawa Formation, Ichinoseki area.
Fig. 7. *Coscinodiscus vetustissimus* Pantocsek
Sample KT-7, Katsuta Formation, Nakaminato area.
Fig. 8. *Navicula* sp.
Sample IWN-21, Shimokurosawa Formation, Ichinoseki area.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