17. LOWER MIOCENE TO QUATERNARY DIATOM BIOSTRATIGRAPHY OF LEG 57, OFF NORTHEASTERN JAPAN, DEEP SEA DRILLING PROJECT

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ABSTRACT

Sediments recovered during Leg 57 provide a nearly complete lower Miocene to Holocene composite reference section for diatoms in the northwestern Pacific. High- and middle-latitude diatoms dominate the assemblages; however, because of the influence of the warm-water Kuroshio Current, low-latitude diatoms are consistently present in low abundance. Low-latitude diatom datums tied to paleomagnetic stratigraphy in the equatorial Pacific show little or no displacement in time at the 40°N latitude of the Leg 57 sites. Both high- and low-latitude diatom zones are recognizable in the upper Miocene to Quaternary of Sites 438 and 440 and thus allow the first direct detailed correlation of these zonations for the upper Miocene. Eleven new subzones, which offer refinement of the existing high-latitude diatom zonation of the North Pacific, are proposed. In addition, the base of the *Denticula lauta* Zone is defined, and a new zone, the *Actinocyclus ingens* Zone, is proposed for the upper lower Miocene.

A late Miocene hiatus spanning the interval from about 5.6 to 6.7 m.y.B.P. is identified at Sites 438 and 440. Correlative hiatuses occur throughout the middle- and high-latitude North Pacific both on the continental slopes and in the ocean basins. Onshore in California, this interval corresponds with an increase in the rate of sediment accumulation associated with the transition from laminated diatomites to overlying, more massive diatomaceous mudstones. These latest Miocene sedimentologic events apparently are related to a global cooling event.

INTRODUCTION

Neogene diatom biostratigraphy in the North Pacific has progressed rapidly in recent years (Burckle and Opdyke, 1977; Koizumi, 1977). In low latitudes the diatom zonation of Burckle (1972, 1977) has found wide acceptance, whereas Koizumi's (1973, 1975b) zonation can readily be applied in high latitudes and in Japan. Several diatom datum levels (first and last occurrences) have been correlated directly with paleomagnetic stratigraphy both in low latitudes (Burckle, 1972; 1978) and in high latitudes (Donahue, 1970; Koizumi, 1975d). Burckle and Opdyke (1977) and Koizumi (1977) have provided cross-correlations of the high- and low-latitude diatom zonations for the Pliocene and Quaternary; however, the lack of suitable and complete stratigraphic sections has prevented detailed correlations of the zonations for the Miocene.

During the Japan Trench Transect of the Deep Sea Drilling Project (Legs 56 and 57, September to December, 1977), a series of excellent Miocene to Quaternary siliceous reference sections were cored along an east to west transect at about 40°N latitude across the Japan Trench (Figure 1). Leg 57 recovered a nearly complete Neogene siliceous record as a composite at two sites (Sites 438 and 440) which contains fairly common, moderately well-preserved to well-preserved diatoms throughout the section.

The Leg 57 sites lie near the present-day confluence of the cool-water Oyashio Current and the warm-water Kuroshio Current, and the mixture of tropical and high-latitude diatom assemblages that results allows detailed correlation of low- and high-latitude zonations for the middle Miocene through the Holocene. In addition, the Leg 57 sites are near enough to shore (about 130 to 200 km) that nearshore planktonic diatoms, which are useful in correlations in Japan and in California, are consistently present.

ZONATION

The diatom zonation of this chapter is modified slightly from the high-latitude North Pacific diatom zonation of Koizumi (1973, 1975b) (Figure 2). Eleven new subzones and one additional zone, the *Actinocyclus ingens* Zone, are proposed, and the base of the *Denticula lauta* Zone is defined. This zonation is summarized below, and additional comments appear in the biostratigraphy section.

***Denticula seminae* Zone (Koizumi, 1973)**

Definition: The interval from the last occurrence of *Rhizosolenia curvirostris* to the present.

Subzones: None.

Remarks: The last occurrence of *Thalassiosira nidulus* var. *nidulus* coincides with the base of the zone (Koizumi, 1977).

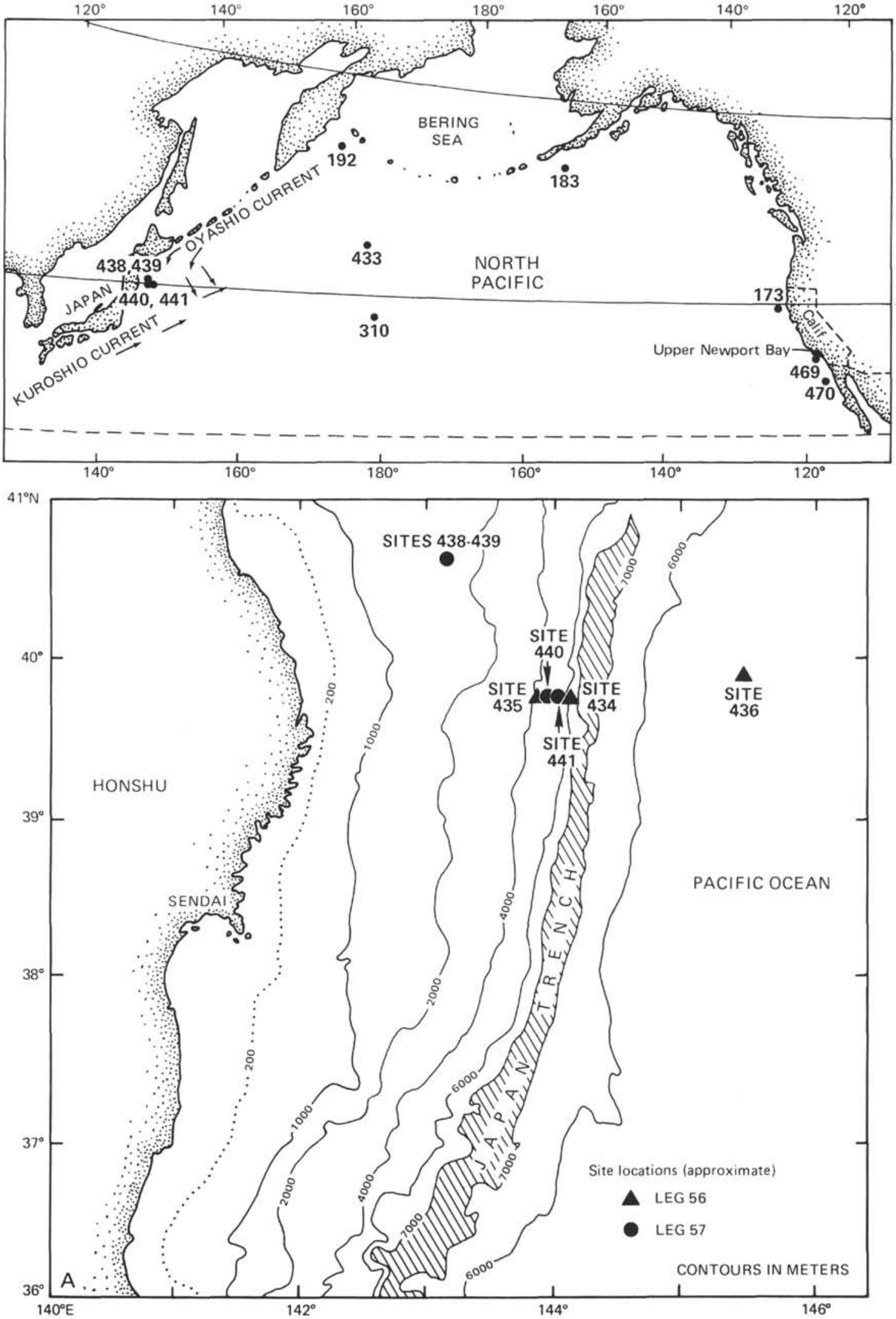

Figure 1. *Location of Leg 57 Sites 438 through 441 off northeast Japan and location of other sections in the North Pacific discussed in text. (Numbers refer to DSDP sites.)*

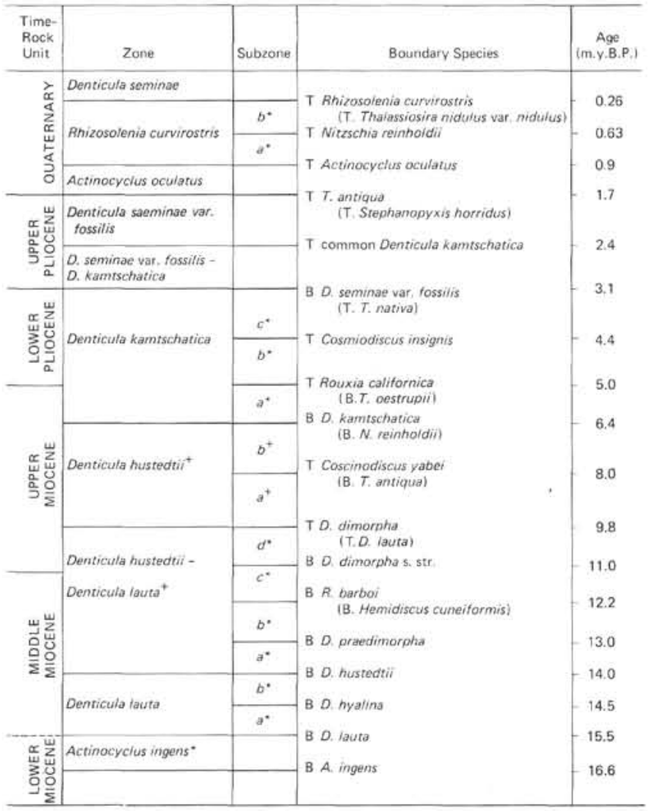

Figure 2. *Modification of the diatom zonation of Koizumi (1973, 1975b) used for Leg 57 material. (*B = *first occurrence,* T = *last occurrence. Boundary species that are secondary approximations of the zonal and subzonal boundaries appear in parentheses. Asterisk indicates new zones and subzones. Cross indicates modified zones and subzones.)*

Geographic Distribution: Recognizable in the middle- and high-latitude North Pacific.

Paleomagnetic Stratigraphy: The base of the *Denticula seminae* Zone is in the middle of the Brunhes Epoch (Donahue, 1970; Koizumi, 1975d; Burckle and Opdyke, 1977).

Absolute Age: 0 to 0.26 m.y.B.P. (Donahue, 1970).

Rhizosolenia curvirostris Zone (Koizumi, 1973)

Definition: The interval from the last occurrence of *Actinocyclus oculatus* to the last occurrence of *Rhizosolenia curvirostris.*

Subzones: Two new subzones are proposed. The last occurrence of *Nitzschia reinholdii* defines the top of Subzone *a* and the base of Subzone *b*.

Remarks: The last occurrence of *Thalassiosira nidulus* var. *nidulus* coincides with the base of the zone.

Discussion: Schrader (1973) and Burckle and Opdyke (1977) point out the value of the last occurrence datum of *Nitzschia reinholdii* for correlations in the middle-latitude North Pacific.

Geographic Distribution: The zone is recognizable in the middle- and high-latitude North Pacific. Use of the subzones is confined to the middle latitudes.

Paleomagnetic stratigraphy: The top of the *Rhizosolenia curvirostris* Zone correlates with the middle of the Brunhes Epoch (Donahue, 1970; Koizumi, 1975d; Burckle and Opdyke, 1977). The base of the zone is in the Jaramillo Event of the Matuyama Epoch (Donahue, 1970; Burckle and Opdyke, 1977).

The Subzone *a*/Subzone *b* boundary correlates with the lowermost Brunhes in the northwestern Pacific (Koizumi, 1975d; Burckle and Opdyke, 1977).

Absolute Age: Zone—0.26 to 0.9 m.y.B.P. (Donahue, 1970).
Subzone *b*—0.26 to 0.63 m.y.B.P.
Subzone *a*—0.63 to 0.9 m.y.B.P. (from Burckle, 1977).

Actinocyclus oculatus Zone (Koizumi, 1973)

Definition: The interval from the last occurrence of *Thalassiosira antiqua* to the last occurrence of *Actinocyclus oculatus.*

Subzones: None.

Remarks: The last occurrences of *Coscinodiscus pustulatus* and *Stephanopyxis horridus* coincide with the base of the zone (Koizumi, 1973).

Geographic Distribution: Recognizable in the middle- and high-latitude North Pacific.

Paleomagnetic stratigraphy: The top of the *Actinocyclus oculatus* Zone correlates with the Jaramillo Event (Donahue, 1970; Burckle and Opdyke, 1977). The base of the zone is in the Olduvai Event, above the first occurrence of *Pseudoeunotia doliolus* (Burckle and Opdyke, 1977).

Absolute Age: 0.9 to 1.7 m.y.B.P. (estimate, this chapter).

***Denticula seminae* var. *fossilis* Zone (Koizumi, 1975a)**

Definition: The interval from the last occurrence of *Denticula kamtschatica* to the last occurrence of *Thalassiosira antiqua.*

Subzones: None.

Remarks: The last occurrences of *Coscinodiscus pustulatus* and *Stephanopyxis horridus* coincide with the top of the zone. The base of the zone is recognized by the last common occurrence of *Denticula kamtschatica* in this chapter.

Geographic Distribution: Recognizable in the middle- and high-latitude North Pacific.

Paleomagnetic Stratigraphy: The top of the *Denticula seminae* var. *fossilis* Zone is in the Olduvai Event above the first occurrence of *Pseudoeunotia doliolus* (Burckle and Opdyke, 1977). The base of the zone correlates with the top of the Gauss Epoch (Koizumi, 1975d; Burckle and Opdyke, 1977).

Absolute Age: 1.7 to 2.4 m.y.B.P. (estimate, this chapter).

***Denticula seminae* var. *fossilis–Denticula kamtschatica* Zone (Koizumi, 1973)**

Definition: The interval from the first occurrence of *Denticula seminae* var. *fossilis* to the last occurrence of *Denticula kamtschatica.*

Subzones: None.

Remarks: In this chapter the top of the zone is recognized by the last common occurrence of *D. kamt-*

schatica. The last occurrence of *Thalassiosira nativa* sensu Koizumi (1975b) approximates the base of the zone in Leg 57 sediments.

Geographic Distribution: Recognizable in the middle- and high-latitude North Pacific.

Paleomagnetic Stratigraphy: The top of the *D. seminae* var. *fossilis–D. kamtschatica* Zone correlates with the top of the Gauss Epoch (Koizumi, 1975d; Burckle and Opdyke, 1977). The base of the zone is tentatively placed in the Gilbert Epoch between the "b" and "c" events by Burckle and Opdyke (1977). In Leg 57 sediments off northeastern Japan, however, the base of the zone appears to be somewhat younger — perhaps correlative with the middle part of the Gauss.

Absolute Age: 2.4 to 4.2 m.y.B.P. (Burckle and Opdyke, 1977).
2.4 to about 3.1 m.y.B.P. (estimate, this chapter).

***Denticula kamtschatica* Zone (Koizumi, 1973)**

Definition: The interval from the first occurrence of *Denticula kamtschatica* to the first occurrence of *Denticula seminae* var. *fossilis*.

Subzones: Three new subzones are proposed. The last occurrence of *Cosmiodiscus insignis* defines the base of Subzone *c* and the top of Subzone *b*. The base of Subzone *b* and the top of Subzone *a* are defined by the last occurrence of *Rouxia californica*.

Remarks: The last occurrence of *Thalassiosira nativa* sensu Koizumi (1975b) approximates the top of the zone in Leg 57 sediments. The first occurrences of *Thalassiosira oestrupii* and *Cussia tatsunokuchiensis* and the last occurrence of *Goniothecium tenue* coincide closely with the Subzone *a*/Subzone *b* boundary.

In the middle latitudes of the North Pacific, the first occurrences of *Denticula kamtschatica* and *Nitzschia reinholdii* appear to be correlative (Koizumi, 1977; Burckle, 1978; Burckle, written communication, 1978).

Discussion: It is important to distinguish *Denticula kamtschatica* s. str. from specimens that resemble it but are finer in structure. These finer specimens are referred to *Nitzschia rolandii* by Harper (1977a) and by Koizumi (in press) (= *Denticula* sp. cf. *D. kamtschatica* of this chapter), and they range below the *Denticula kamtschatica* Zone.

Geographic Distribution: The *D. kamtschatica* Zone is recognizable in the middle- and high-latitude North Pacific. The first occurrence of *Denticula kamtschatica* is later in southern California than in the western North Pacific (Harper, 1977a). The first occurrence of *N. reinholdii* in southern California approximates the base of the *D. kamtschatica* Zone in the western North Pacific.

All three subzones are recognizable in the western North Pacific. The Subzone *c*/Subzone *b* boundary can be determined in the Bering Sea but not in the California area. In California the first occurrence of *Thalassiosira oestrupii* correlates with the Subzone *b*/Subzone *a* boundary (this chapter), but the last occurrence of *Rouxia californica* is older than it is in the western North Pacific (Harper, 1977a).

Paleomagnetic Stratigraphy: Burckle and Opdyke (1977) tentatively place the top of the *D. kamtschatica* Zone between the "b" and "c" events of the Gilbert Epoch, but this boundary appears to be somewhat younger in the Leg 57 area off northeastern Japan. The base of the zone correlates with the lower part of Epoch 6 (Burckle, written communication, 1978).

Absolute Age: Zone—4.2 to 6.4 m.y.B.P. (Burckle and Opdyke, 1977; Burckle, written communication, 1978).
3.1 to 6.4 (estimate, this chapter).
Subzone *c*—3.1 to 4.4 m.y.B.P.
Subzone *b*—4.4 to 5.0 m.y.B.P.
Subzone *a*—5.0 to 6.4 m.y.B.P. (estimate, this chapter).

***Denticula hustedtii* Zone (Koizumi, 1973) (modified, this chapter)**

Definition: The interval from the last occurrence of *Denticula dimorpha* to the first occurrence of *Denticula kamtschatica*.

Subzones: Labeling of the two subzones of Koizumi (1977) is reversed in this chapter to conform with the convention of numbering zones from oldest to youngest, utilized by Cenozoic calcareous nannofossil and planktonic foraminifer workers.

The last occurrence of *Coscinodiscus yabei* defines the top of Subzone *a* and the base of Subzone *b*.

Remarks: The first occurrence of *Nitzschia reinholdii* approximates the top of the zone in the middle-latitude North Pacific. The Subzone *b*/Subzone *a* boundary coincides closely with the first occurrence of *Thalassiosira antiqua*. The last occurrence of *Denticula lauta* is near the base of the zone.

Discussion: The last occurrence of *Denticula lauta*, the traditional base of the *Denticula hustedtii* Zone, may be difficult to determine because of reworking upsection and because of confusion with *D. hyalina* in poorly preserved sediments. Schrader (1973), Barron (1976), and Koizumi (1977) indicate a close stratigraphic correspondence between the last occurrences of *Denticula lauta* and *D. dimorpha* in the North Pacific. *Denticula dimorpha* is a distinctive species with a robust morphology that has been shown to be resistant to dissolution. Consequently I propose to utilize the last occurrence of *Denticula dimorpha* to define the base of the *D. hustedtii* Zone.

Geographic Distribution: The *D. hustedtii* Zone and its subzones can be recognized throughout the middle- and high-latitude North Pacific. The first occurrence of *Thalassiosira antiqua* is useful for distinguishing the Subzone *b*/Subzone *a* boundary in California and in the Bering Sea (Barron, unpublished data).

Paleomagnetic Stratigraphy: The top of the *D. hustedtii* Zone is in the lower part of Epoch 6 (Burckle, written communication, 1978). The last occurrence of *Coscinodiscus yabei*, the Subzone *b*/Subzone *a* boundary, correlates with the middle of Epoch 8 in the equatorial Pacific (Burckle, 1972). This datum does not appear to be displaced in time in the area off northeastern Japan. The base of the *D. hustedtii* Zone is not tied to paleomagnetic stratigraphy, but Koizumi (1977) estimates the absolute age of the base at about 9.5 m.y.B.P. on the basis of radiometric dates in Japan.

Absolute Age: Zone—6.4 to 9.8 m.y.B.P.
Subzone *b*—6.4 to 8.0 m.y.B.P.
Subzone *a*—8.0 to 9.8 m.y.B.P. (estimate, this chapter).

***Denticula hustedtii-Denticula lauta* Zone (Koizumi, 1975b) (modified, this chapter)**

Definition: The interval from the first occurrence of *Denticula hustedtii* to the last occurrence of *Denticula dimorpha*.

Subzones: Four new subzones are proposed. The first occurrence of *Denticula dimorpha* s. str. defines the base of Subzone *d* and the top of Subzone *c*. The Subzone *c*/Subzone *b* boundary is defined by the first occurrence of *Rhizosolenia barboi*. The base of Subzone *b* and the top of Subzone *a* is defined by the first occurrence of *Denticula praedimorpha*.

Remarks: The last occurrence of *Denticula lauta* approximates the top of the zone. The first occurrence of *Hemidiscus cuneiformis* is stratigraphically very near the Subzone *c*/Subzone *b* boundary in the middle-latitude North Pacific.

Discussion: Akiba (1979) separates *Denticula praedimorpha* from *D. dimorpha* and includes specimens in which cross bars are not united to the septum.

The first common occurrence of *Denticula hustedtii*, near the base of the *D. hustedtii-D. lauta* Zone, probably correlates with the first occurrence of *D. hustedtii* in low latitudes.

Geographic Distribution: The zone and its subzones are recognizable throughout the middle- and high-latitude North Pacific, including the Bering Sea and off southern California and Baja California (Barron, unpublished data).

Paleomagnetic Stratigraphy: The top and the base of the *D. hustedtii-D. lauta* Zone are not tied to paleomagnetic stratigraphy. Koizumi (1977) estimates the absolute ages of the top of the zone at about 9.5 m.y.B.P. and the base at about 14 m.y.B.P. on the basis of radiometric dates in Japan.

Absolute Age: Zone—9.8 to 14.0 m.y.B.P.
Subzone *d*—9.8 to 11.0 m.y.B.P.
Subzone *c*—11.0 to 12.2 m.y.B.P.
Subzone *b*—12.2 to 13.0 m.y.B.P.
Subzone *a*—13.0 to 14.0 m.y.B.P. (estimate, this chapter).

***Denticula lauta* Zone (top—Koizumi, 1973) (base—this chapter)**

Definition: The interval from the first occurrence of *Denticula lauta* s. str. to the first occurrence of *Denticula hustedtii*.

Subzones: Two new subzones are proposed. The first occurrence of *Denticula hyalina* defines the base of Subzone *b* and the top of Subzone *a*.

Remarks: In southern California, the last occurrence of *Annellus californicus* approximates the first occurrence of *Denticula hyalina*, the Subzone *b*/Subzone *a* boundary.

Geographic Distribution: The *D. lauta* Zone and its subzones are recognizable throughout the middle- and high-latitude North Pacific, including the Bering Sea and off southern California (Barron, unpublished data).

Paleomagnetic Stratigraphy: Neither the top nor the base of the *D. lauta* Zone are tied to paleomagnetic stratigraphy. Koizumi (1977) estimates the absolute age of the top of the zone at 14 m.y.B.P. on the basis of radiometric dates in Japan. Burckle (1978) places the last occurrence of *Annellus californicus* in the lower part of Epoch 15 in the equatorial Pacific. If this datum is synchronous in southern California, the Subzone *b*/Subzone *a* boundary should also be in the lower part of Epoch 15.

Absolute Age: Zone—14.0 to about 15.5 m.y.B.P.
Subzone *b*—14.0 to about 14.5 m.y.B.P.
Subzone *a*—about 14.5 to about 15.5 m.y.B.P. (estimate, this chapter).

***Actinocyclus ingens* Zone (new zone, this chapter)**

Definition: The interval from the first occurrence of *Actinocyclus ingens* to the first occurrence of *Denticula lauta* s. str.

Subzones: None.

Geographic Distribution: Recognizable in the middle- and high-latitude North Pacific, including the Bering Sea and off southern California (Barron, unpublished data).

Paleomagnetic Stratigraphy: None.

Absolute Age: About 15.5 to about 16.6 m.y.B.P. (estimate, this chapter).

EPOCH BOUNDARIES

Ryan and others (1974) correlate the lower Miocene/middle Miocene boundary with the upper part of the calcareous nannofossil NN 4 (*Helicosphaera ampliaperta*) Zone of Martini (1971) and with the middle of the upper reversed event of Paleomagnetic Epoch 16. In the southern California Continental Borderland the first occurrence of *Denticula lauta* s. str. is high in the *H. ampliaperta* Zone of Bukry (1973a; Barron, unpublished data) and near the first occurrence of the diatom *Annellus californicus*. Burckle (1978) correlates the first *A. californicus* with the upper part of Paleomagnetic Epoch 16. These criteria both suggest that the first occurrence of *D. lauta* s. str. and, hence, the base of the *Denticula lauta* Zone lie near the lower Miocene/middle Miocene boundary of Ryan and others (1974).

Ryan and others (1974) place the middle Miocene/upper Miocene boundary within the calcareous nannofossil NN 9 (*Discoaster hamatus*) Zone of Martini (1971) and correlate it with the lower normal event of Paleomagnetic Epoch 11. The middle Miocene/upper Miocene boundary appears to be within Subzone *c* of the *Denticula hustedtii-Denticula lauta* Zone of this chapter.

The Miocene/Pliocene boundary is placed in the lowermost reversed event of the Gilbert Paleomagnetic Epoch by Cita (1975) and Van Couvering and others (1976). Correlations of this report suggest that the Miocene/ Pliocene boundary thus lies just below the Subzone *a*/Subzone *b* boundary within the *Denticula kamtschatica* Zone.

Haq and others (1977) correlate the Pliocene/Quaternary boundary with about the top of the Olduvai

Paleomagnetic Event and assign it an absolute age of about 1.6 m.y.B.P. This assignment places the Pliocene/ Quaternary boundary slightly above the base of the *Actinocyclus oculatus* Zone.

The paleomagnetic time scale of LaBrecque and others (1977) is followed except for the Gilbert Paleomagnetic Epoch and Epochs 5 and 6, where the scale of MacDougall and others (1977) offers more precision. Consequently the lower Miocene/middle Miocene boundary is about 15.5 m.y.B.P., the middle Miocene/ upper Miocene boundary is about 11.3 m.y.B.P., and the Miocene/Pliocene boundary is between 5.1 and 5.2 m.y.B.P. It should be remembered that use of these updated paleomagnetic time scales may result in absolute ages for the epoch boundaries different from those of Ryan and others (1974).

METHODS

Strewn slides of unprocessed sediment were prepared onboard the D/V *Glomar Challenger*. These were reexamined together with strewn slides of sediment treated with hydrogen peroxide and hydrochloric acid, using the procedures outlined by Barron (1976). One coverslip (22 × 40 mm) was traversed in entirety at 500× by light microscope. Identifications were checked at 1250×. Taxa were recorded as abundant if two or more specimens were present within one field of view at 500× (446-μm diameter); common, if one specimen occurred in two fields of view; few, if one specimen was encountered during one vertical traverse (22 mm long); and rare, if specimens were sparser.

In general, only stratigraphically diagnostic diatoms were tabulated. Schrader (1973), Koizumi (1973, 1975b, 1977), Burckle (1972, 1977, 1978), Burckle and Opdyke (1977), and Barron (1976) served as the more important references used to select stratigraphic taxa. In addition, a selected number of silicoflagellate taxa found by Barron (1976) and Burckle (1977) to provide useful checks of the diatom biostratigraphy were also tabulated. Brief notes and taxonomic references for these stratigraphically useful diatoms and silicoflagellates appear in the Appendix.

BIOSTRATIGRAPHY

Site 438

Site 438 (40°37.75′ N, 143°19.90′ E; water depth 1552 m) was drilled shoreward of the Japan Trench to test the seaward extent of continental crust and to provide a Miocene to Quaternary reference section for the upper continental slope.

Diatoms are present throughout the 1040.7-meter-thick lower Miocene to Holocene section (Holes 438, 438A, and 438B) cored at Site 438. Preservation is generally good to moderate in the upper Miocene to Holocene, mostly moderate in the middle Miocene, and moderate to poor in the lowermost middle Miocene and lower Miocene. Figure 3 gives the zonal assignments of the sediment cored at Site 438 and other Leg 57 sites.

Hole 438

The occurrence of selected stratigraphically important diatoms in the 106.9-meter section cored in Hole 438 is shown in Table 1. Diatom assemblages of the *Denticula seminae* var. *fossilis* Zone (upper Pliocene) through the *D. seminae* Zone (upper Quaternary) are present. Reworked middle and upper Miocene diatoms such as *D. hustedtii, D. lauta*, and *Actinocyclus ingens* occur sparsely throughout the hole.

The last occurrence of *Rhizosolenia curvirostris* in Sample 438-2-4, 79–81 cm (10.3 m), marks the top of the *Rhizosolenia curvirostris* Zone. The last occurrences of *Thalassiosira nidulus* var. *nidulus* and *R. barboi* also are at this zonal boundary at Sites 438 and 440. Koizumi (1977) reports the last occurrence of *R. barboi* within the lower Quaternary *Actinocyclus oculatus* Zone; but Donahue (1970) notes that the last occurrence of *R. curvirostris* var. *inermis*, a synonym of *R. barboi*, coincides with the last occurrence of *R. curvirostris*. Within the *R. curvirostris* Zone, *R. hebetata* f. *hiemalis* has its first occurrence in Sample 438-3-2, 34–36 cm (16.3 m), and corresponds with the last occurrence of the flat form of *Thalassiosira gravida. Rhizosolenia hebetata* f. *hiemalis* first occurs in the upper Pliocene in the high-latitude North Pacific (Koizumi, 1973). The later appearance of this cold-water form off northeastern Japan probably reflects warmer late Pliocene and early Quaternary paleotemperatures. The lower Quaternary *Actinocyclus oculatus* Zone is present only in Sample 438-3-6, 141–143 cm (20.4 m).

The last occurrence of *Thalassiosira antiqua* in Sample 438-5-1, 140–142 cm (35 m), marks the top of the upper Pliocene *Denticula seminae* var. *fossilis* Zone. The last occurrences of *T. zabelinae, Coscinodiscus pustulatus*, and *Stephanopyxis horridus* all coincide with the top of this zone as reported by Koizumi (1973).

The top of the *D. seminae* var. *fossilis–D. kamtschatica* Zone is placed at the last common occurrence of *D. kamtschatica* in Sample 438-8-1, 120–122 cm (63.2 m). *Denticula kamtschatica* occurs as rare, presumably reworked specimens throughout the upper Pliocene in Hole 438, but correlations with Hole 440B suggest that the last common *D. kamtschatica* closely approximates 2.4 m.y.B.P., or the top of the Gauss Paleomagnetic Epoch where Burckle and Opdyke (1977) and Koizumi (1975d) place the top of the *D. seminae* var. *fossilis–D. kamtschatica* Zone. The first common occurrence of *D. seminae* var. *fossilis* in Sample 438-9-4, 100–102 cm (77 m), is near the top of the zone, and the last occurrence of *Nitzschia jouseae* lies somewhat lower in Sample 438-12-1, 80–83 cm (100.8 m). Burckle and Opdyke (1977) correlate the last *N. jouseae* with the upper part of the Gauss, and Shackleton and Opdyke (1977) note an increase in the scale of glaciations near the top of the Gauss in the oxygen isotope record in the equatorial Pacific. The first common occurrence of *D. seminae* var. *fossilis* above the last occurrence of *Nitzschia jouseae* and immediately below the last common occurrence of *D. kamtschatica* in Hole 438 may represent this apparent early late Pliocene cooling. The last occur-

Zone	Subzone	438	438A	438B	439	440, 440A, 440B	441, 441A, 441B
Denticula seminae	–	1-4/2-3	1-1/1,CC			1-2/5,CC	1-2/1,CC
Rhizosolenia curvirostris	*b*	2-4/3-4	2-1			6,CC/B1,CC	
	a		2-4			B2,CC/B6,CC	
Actinocyclus oculatus	–	3-6/3,CC	2,CC/3,CC			B7,CC/B17,CC	
D. seminae var. *fossilis*	–	5-1/7,CC	4-2/5,CC			B18,CC/B25,CC	2-1/A2,CC
D. seminae var. *fossilis* - *D. kamtschatica*	–	8-1/12,CC	6-1/12-1			B26,CC/B33,CC	7-1/9,CC
D. kamtschatica	*c*		12,CC/28-1			B34,CC/B45,CC	B1-2/A8,CC
	b		28-4/35-5			B46,CC/B55,CC	A9,CC/A10,CC?
	a		35,CC/42-3			B56,CC/B60,CC	A11-1/B2-2
D. hustedtii	*b*		42-5/46-5		1,CC/2,CC	B61,CC/B71,CC	
	a		46,CC/54,CC	1,CC			
D. hustedtii - *D. lauta*	*d*		55-1/59,CC				
	c		60-1/64-1	2,CC	3,CC		
	b		64-3/65,CC				
	a		66-2/68-1				
D. lauta	*b*		68-5/73-5				
	a		73,CC/83,CC	3-3/4-1	4,CC/5,CC		
Actinocyclus ingens	–		84,CC/86,CC	6-1/23,CC	7,CC/11,CC		
lower Miocene (unzoned)	–				12,CC/20-1		

Figure 3. *Diatom zonation of selected samples from DSDP Leg 57. (Numbers assigned to zonal intervals are core and section numbers. Where several samples are assigned to a zone, the highest and lowest stratigraphic determinations are listed with a slash between.)*

TABLE 1
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellate *Distephanus boliviensis jimlingii* in Hole 438

Time-Rock Unit	Zone	Sample (Interval in cm)	Abundance	Preservation	*Actinocyclus ingens*	*A. ochotensis*	*A. oculatus*	*Bacteriastrum fragilis*	*Cosmiodiscus insignis*	*Coscinodiscus pustulatus*	*Cussia tatsunokuchiensis*	*Denticula hustedtii*	*D. kamtschatica*	*D. lauta* s. ampl.	*D. seminae*	*D. seminae* var. *fossilis*	*Hemidiscus cuneiformis*	*Nitzschia fossilis*	*N. jouseae*	*N. marina*	*N. reinholdii*	*Porosira glacialis*	*Pseudoeunotia doliolus*	*Rhizosolenia barboi*	*R. curvirostris*	*R. hebetata hiemalis*	*R. praebergonii*	*Stephanopyxis horridus*	*Thalassiosira antiqua*	*T. convexa* var. *aspinosa*	*T. gravida*	*T. gravida* (flat form)	*T. hyalina*	*T. nativa*	*T. nidulus* var. *nidulus*	*T. oestrupii*	*T. pacifica*	*T. zabelinae*	*T. convexa* var. 1	***Distephanus boliviensis jimlingii***
QUATERNARY UPPER	*D. seminae*	1-4 (13–15)	A	G	Ⓡ	R		R							R	F				R		R				F					F		R			R	R			
		2-1 (80–82)	C	G				R				Ⓡ			R	R				R						R					C		R			R	R			
		2-3 (24–26)	C	G		R		R							R	C				R		R				R					F		R			R	R			
	R. curvirostris	2-4 (79–81)	C	G		F		R				Ⓡ			R	R				R		R	R	R	F						C		R		F	R	F			
		2,CC	C	G	Ⓡ	R	Ⓡ	R				Ⓡ			R	F				R			R	R	R						F				R	R				
		3-2 (34–36)	C	G		R		R							R	R				R		R	R		R	R					C	R			F	R				
		3-4 (140–142)	C	M		R									R	R				R			R		R						C				R	R				
L.	*A. oculatus*	3-6 (141–143)	A	G	Ⓡ	F	R	R					Ⓡ		R	F				R			R	R	R						C	R			F	R				
UPPER PLIOCENE	*D. seminae fossilis*	5-1 (140–142)	C	M		R	F					Ⓡ	Ⓡ	Ⓡ		F				R		R		R				R	R		R	R		Ⓡ	R	R				
		5-4 (90–92)	A	G	Ⓡ	R	F			F			Ⓡ			C				R	R	R		R						R		R			R	R				
		5,CC	C	M	Ⓡ		F			R		Ⓡ	Ⓡ	Ⓡ		F				R				R			R	R			R	R		Ⓡ	F	R		R		
		7-1 (125–127)	A	G		F	F			R						C		R		R				F				R	R		R	F			F	F				
		7-6 (20–24)	A	G		F	R									A				R	R			F				R	F		R	F			R	R		R		
		7,CC	C	G		F	R						R			C		R		R				F					F		R	F			F	F				
	D. seminae fossilis– *D. kamtschatica*	8-1 (120–122)	A	G		R		R					C			A	R	R		R				R					R		R	R			R	F				
		8-4 (110–112)	A	G	Ⓡ		R	R	Ⓡ	R		Ⓡ	R			C	R							F					R	R	R	F			F	R		R		
		8,CC	A	G	Ⓡ	R						Ⓡ	A	Ⓡ		A	R	R		R	R	R		R				R	R		F	F			R	F				
		9-1 (100–102)	A	G		F							A			F	R			F				F				F	R		R	F			F	F		R		
		9-4 (50–52)	A	G		R	R	R					A			C	R							R				R	F	R	R	F			F	F		F		
		10-1 (51–53)	C	M		R	R						C			F				R		R								R	R	R			F	F		R		
		10-3 (118–120)	A	M	Ⓡ		R					Ⓡ	A	Ⓡ		R	F											R	R		R			Ⓡ	R	F		F		R
		10,CC	A	G		R	R	R	Ⓡ				A	Ⓡ		R	F			R				R					R	R		R			R	F		F		
		11-1 (20–22)	A	G		R							A				R			R									F		F	R			R	F		R		R
		11-6 (120–124)	A	G		R	R						A								R								R		R	R			R	F		F		
		11,CC	A	G		R	R		Ⓡ			Ⓡ	A				R											R	R	R	R	R			F	F		F	R	
		12-1 (80–83)	A	G		R	R						A				R		R	R	R			R				R	R		R	R			R	F		F		
		12-4 (22–24)	A	G	Ⓡ	R					R		A			R	R		R	R	R			R				R	R	R		R			R	R		F		R
		12,CC	A	G		R	R				R		A					R	R		R			R				R	R	R	R	R			F	F		F		R

Note: A = abundant, C = common, F = few, R = rare, Ⓡ = reworked. Preservation: G = good, M = moderate, P = poor.

rence of *Cussia tatsunokuchiensis* in Sample 438-12-4, 22–24 cm (104.7 m), is near the last occurrence of *N. jouseae*, but Koizumi (1977) reports that *C. tatsunokuchiensis* ranges into the overlying *Denticula seminae* var. *fossilis* Zone. The occurrence of *C. tatsunokuchiensis* at Site 440 is supportive of its extinction in the upper part of the *D. seminae* var. *fossilis–D. kamtschatica* Zone.

Hole 438A

Hole 438 was abandoned because of a medical emergency. Drilling was resumed nearby (40°37.79′ N, 143°14.15′ E; 1558 m water depth) a few days later in Hole 438A, from which 868.5 meters of lower Miocene through Quaternary sediment was recovered. Diatoms are present throughout Hole 438A, which represents one of the most complete siliceous microfossil reference sections in the North Pacific. Hole 438A was not cored between 4.0 and 23.0 meters (Cores 1 to 2) or between 59.0 and 106.5 meters (Cores 5 to 6); otherwise, coring was continuous.

The occurrences of selected stratigraphically important diatoms and silicoflagellates in Hole 438A are given in Tables 2 through 8. The tables divide Hole 438A into seven parts from top to bottom, and the occurrences of diatoms and silicoflagellates that are stratigraphically diagnostic within the given intervals are recorded. The stratigraphic ranges of selected diatoms and silicoflagellates in Hole 438A are shown in Figure 4.

The upper Pliocene to upper Quaternary (Cores 1 through 6) duplicates the section cored in nearby Hole 438. Assemblages in Cores 6 and 7 of Hole 438A correlate with the lower parts of Hole 438, as evidenced by the last occurrence of *Nitzschia jouseae* in Sample 438A-6,CC (113 m) and the last occurrence of *Cussia tatsunokuchiensis* in Sample 438A-7,CC (123 m). The common *Denticula kamtschatica* reported in Sample 438A-5,CC (57.5 m) comes from a limestone nodule within otherwise soft sediment and probably represents reworking.

The greater part of the *D. seminae* var. *fossilis–D. kamtschatica* Zone at Sites 438 and 440 is characterized by very rare or absent *D. seminae* var. *fossilis*. Studies at Site 440 suggest that *D. seminae* var. *fossilis* ranges at least as low as the last occurrence of *Thalassiosira nativa*. Correlations between Sites 440 and 438 indicate that the last occurrence of *T. nativa* is nearly synchronous in the immediate area, so that the base of the *D. seminae* var. *fossilis* Zone may be approximated by the last occurrence of *T. nativa* in Sample 438A-12,CC in Hole 438A.

Thalassiosira nidulus var. *delicata*, n. var., last occurs in Sample 438A-14,CC (190.3 m), and *Actinocyclus oculatus* first occurs in Sample 438A-17,CC (215.3 m) within the upper part of Subzone *c* of the *Denticula kamtschatica* Zone. Assemblages of Subzone *c* are characterized by abundant *D. kamtschatica*, common to few *Thalassiosira nativa*, and intervals of common *T. zabelinae* (Tables 2 and 3).

Koizumi (1977) reports the last occurrence of *Thalassiosira nativa* slightly above the first occurrence of *Actinocyclus oculatus* within the middle part of the *Denticula seminae* var. *fossilis–D. kamtschatica* Zone in middle latitudes of the North Pacific. Occurrences at Sites 438 and 440 suggest a younger first occurrence of *Denticula seminae* var. *fossilis* in the area off northeastern Japan.

The last occurrence of *Cosmiodiscus insignis* in Sample 438A-28-1, 140–142 cm (316.9 m), marks the top of Subzone *b* of the *D. kamtschatica* Zone. *Nitzschia jouseae* first occurs in Sample 438A-29-5, 10–12 cm (331 m), just below the last occurrence of *C. insignis*. The sediment accumulation rate curve (Figure 5) for Hole 438A suggests that this first occurrence of *N. jouseae* approximates the reported first occurrence of *N. jouseae* (about 4.5 m.y.B.P.) (Burckle, verbal communication, 1978) in the tropical Pacific between the "c" Events of the Gilbert Paleomagnetic Epoch. Burckle and Opdyke (1977) report the first occurrence of *Denticula seminae* var. *fossilis* slightly above the first occurrence of *N. jouseae* in the North Pacific and correlate it with the interval between the "b" and "c" Events of the Gilbert. It appears that *D. seminae* var. *fossilis* has a restricted range in the area of the Leg 57 sites and that the last occurrence of *C. insignis* in Sample 438A-28-1, 140–142 cm, approximates the first occurrence of *D. seminae* var. *fossilis* elsewhere in the North Pacific. At Site 192, to the north of the Leg 57 sites, Koizumi (1973) records the first occurrence of *D. seminae* var. *fossilis* slightly above the last occurrence of *C. insignis*.

Coscinodiscus temperei last occurs in Sample 438A-34-1, 85–87 cm (373.3 m), near the base of Subzone *b* of the *Denticula kamtschatica* Zone. Other than the presence of rare *Cosmiodiscus insignis*, the assemblages of Subzone *b* are very similar to those of Subzone *c* (Tables 3 and 4).

The last occurrence of *Rouxia californica* in Sample 438A-35,CC (391.5 mm) marks the top of Subzone *a* of the *D. kamtschatica* Zone and approximates the Miocene/Pliocene boundary (Harper, 1977a). The first occurrence of *Thalassiosira oestrupii* s. str. in Sample 438A-35-5, 135–137 cm (389.4 m), is coincident with this subzonal boundary. Burckle and Opdyke (1977) correlate the first *T. oestrupii* with the lowermost Gilbert Paleomagnetic Epoch, and it is likely that this datum level lies close to the Miocene/Pliocene boundary of Cita (1975) and Van Couvering and others (1976) in the lowermost reversed event of the Gilbert.

Cussia tatsunokuchiensis also has its first occurrence at the top of Subzone *a* of the *D. kamtschatica* Zone in Hole 438A, and the last occurrence of *Goniothecium tenue* is just below in Sample 438A-36-3, 80–82 cm (395.3 m). Koizumi (1977) also reports a coincidence of the last occurrences of *R. californica* and *G. tenue* with the first occurrence of *C. tatsunokuchiensis* in the middle-latitude northwestern Pacific. The silicoflagellate *Distephanus boliviensis jimlingii* first occurs in Sample 438A-37,CC (405 m) within Subzone *a*. *Thalassiosira miocenica* (*T. usatchevi* of Burckle, 1972) last occurs in Sample 438A-38-5, 110–112 cm (417.6 m), where it corresponds with an isolated occurrence of *Asterolampra acutiloba*. Burckle (1978) correlates the last *T. mio-*

TABLE 2
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellate *Distephanus boliviensis jimlingii*, Core 438A-1 through Section 438A-15-1, 44-46 cm

Time-Rock Unit		Zone		Sample (Interval in cm)	Abundance	Preservation	*Actinocyclus ingens*	*A. ochotensis*	*A. oculatus*	*Bacteriosira fragilis*	*Coscinodiscus pustulatus*	*Cussia tatsunokuchiensis*	*Denticula hustedtii*	*D. kamtschatica*	*D. seminae*	*D. seminae* var. *fossilis*	*Hemidiscus cuneiformis*	*Nitzschia fossilis*	*N. jouseae*	*N. marina*	*N. reinholdii*	*Porosira glacialis*	*Pseudoeunotia doliolus*	*Rhizosolenia barboi*	*R. curvirostris*	*R. hebetata hiemalis*	*Stephanopyxis horridus*	*Thalassiosira antiqua*	*T. convexa* var. *aspinosa*	*T. gravida*	*T. gravida* (flat form)	*T. hyalina*	*T. nativa*	*T. nidulus* var. *nidulus*	*T. nidulus* var. *delicata*	*T. oestrupii*	*T. pacifica*	*T. zabelinae*	*T. jacksonii*	*T. convexa* var. 1	*Distephanus boliviensis jimlingii*
QUATERNARY	UPPER	*D. seminae*		1-2 (80–82)	C	M									R	F										R				C		R				F	R				
				1,CC	C	G		F		R					R	F				R			R			R				C		R				F	F				
		R. curvirostris	*b*	2-1 (96–98)	A	G		R		R					R	C				R		R	R	R	R	R				C	R	R		R		R					
			a	2-4 (140–142)	C	G		R		R			(R)	(R)	R	F	R			R	R	R	R		R					C	R			R		R					
	LOWER	*A. oculatus*		2,CC	F	M	(R)		R					(R)	R	F				R	R		R		R					R	R			R							
				3-3 (140–142)	C	M		R	R						R	C				R	R	R		R	F					F	R			R		R					
				3,CC	F	M		R	F	R						C					R			R	R					F				R							
PLIOCENE	UPPER	*D. seminae fossilis*		4-2 (140–142)	A	G	(R)	R	F						R	A	F	R			R	R		R				R		R	R			F		R					
				4,CC	C	M		F	R					(R)		C		R			R			F			F	R		R	F			R		R					
				5-1 (100–102)	C	G		F	R	R	R					A				R	R			F			F		R	R	F			F		R		R			
				5-4 (115–117)	A	G		R	R	R				(R)		C				R	R			R				R		F	R			R		R					
				5,CC	A	G		F	R					(C)		A		R						R			R	F		R	F					R		R			
		D. seminae var. *fossilis*–*D. kamtschatica*		6-1 (122–124)	A	G			R					A			R				R							R			R			F		R		R		R	
				6-3 (110–112)	A	G		R	R					A						R	R							F		R				C		F		R		R	
				6,CC	A	G			R					A					R	R				R				R			F			R		F		F		R	R
				7-4 (111–113)	A	G		R						A			R			R	R							R		R	F			R		F		R			
				7,CC	A	G	(R)	R	R			R		A			F	R	R		R			R						F	F			R		R		F		R	R
				8-6 (130–132)	A	G		R	R			R		A					R	R								F		F	F			F		F		R		R	R
				8,CC	A	G			R					A						R		R						C			F	R		R		F		F			R
				9-1 (51–53)	A	G								A		R	R		R									F		R	R			F		R		F			R
				9,CC	A	M		R	R					A			R			R		R						F		R		R		R		F		R		R	R
				10-3 (100–102)	A	G						R		A			R		R	R				F				F		R	R			R		R		F		R	R
				10,CC	A	M		R	R			R		A				R	R	R				F				F		R	F	R		R		F		F		R	
				11-5 (130–132)	C	M						R		C			R	R	R	R								R		R				R				R			
				11,CC	A	M		R						A				R		R				R				C	R	R	R			R		F		R	R		R
				12-1 (138–140)	C	M			R					C				R										R			R					R		R			
	LOWER	*D. kamtschatica*	*c*	12,CC	A	M		R	R			R	(R)	A				R	R		R							C		R	R		R	R		R		F			
				13-2 (130–132)	A	G						R		A			R			R	R							C					R			R		R			
				13,CC	A	M			R			R		A			R	R		R	R			R				F		R			R	R		R		R	R	R	
				14-2 (130–132)	C	G						R		C			R	R	R	R	R							F		R						R					
				14,CC	A	G		R	R			R	(R)	A				R	R		R			R				C		R	R		R	R	R	R		R		R	R
				15-1 (44–46)	C	G		R	R					C			R				F							C			R		R	R	R	R		F	R	R	

Note: There is a coring gap of 4 to 23 meters between Cores 1 and 2 and 59 to 106.5 meters between Cores 5 and 6.

cenica with the lower Gilbert Epoch, midway between the lower "c" Event and the top of Epoch 5 and the last *A. acutiloba* with the top of Epoch 5. It is possible that *T. miocenica* ranges only as high as the top of Epoch 5 in Hole 438A because of a climatic cooling reported above this level for planktonic foraminifers by Keller (this volume).

The last occurrence of *N. miocenica* in Sample 438A-39,CC (429.5 m) correlates with the top of the reversed event of Paleomagnetic Epoch 5 (Burckle, 1972, 1978).

The base of the *Denticula kamtschatica* Zone is marked by the first occurrence of *D. kamtschatica* s. str. in Sample 438A-42-3, 110–112 cm (452.6 m). Specimens resembling *D. kamtschatica* but possessing greater than 6 pseudoseptae in 10 μm occur below that level and are referred to as *D.* sp. cf. *D. kamtschatica* in Tables 4 and 12. Such specimens include *N. rolandii* of Harper (1977b) and of Koizumi (in press).

The first occurrences of *N. reinholdii, T. convexa* var. *aspinosa, T. gravida, T. gravida* (flat form), *T. jacksonii,* and *T. nidulus* var. *delicata* all coincide closely with the base of the *D. kamtschatica* Zone in Hole 438A. The last occurrences of *N. pliocena* and *Synedra jouseana* lie immediately below in Sample 438A-42-5, 83–85 cm (455.3 m). These occurrences and the last occurrence of *N. porteri* in Sample 438A-43-3, 123–125 cm (462.2 m), argue that a hiatus spanning the interval from about 5.6 to about 6.7 m.y.B.P. is present in the lower part of Core 42 (Figure 5). A thin (0.5 m) siltstone layer containing pumice pebbles and overlain by glauconitic sediment in the upper part of Section 4 of Core 42 is a likely position for this hiatus.

The upper part of the *D. hustedtii* Zone above the last occurrence of *Coscinodiscus yabei* in Sample 438A-46,CC (497.7 m) is assigned to Subzone *b* of the *D. hustedtii* Zone. Subzone *b* is characterized by rare *D.*

TABLE 3
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellate *Distephanus boliviensis jimlingii*, Cores 438A-15, CC-438A-29

Time-Rock Unit	Zone		Sample (Interval in cm)	Abundance	Preservation	*Actinocyclus ingens*	*A. ochotensis*	*A. oculatus*	*Cosmiodiscus insignis*	*Coscinodiscus pustulatus*	*Cussia tatsunokuchiensis*	*Denticula hustedtii*	*D. kamtschatica*	*D. seminae* var. *fossilis*	*Hemidiscus cuneiformis*	*Nitzschia fossilis*	*N. jouseae*	*N. marina*	*N. reinholdii*	*Rhizosolenia barboi*	*Thalassiosira antiqua*	*T. convexa* var. *aspinosa*	*T. gravida*	*T. gravida* (flat form)	*T. nativa*	*T. nidulus* var. *nidulus*	*T. nidulus* var. *delicata*	*T. oestrupii*	*T. punctata*	*T. zabelinae*	*T. jacksonii*	*T. convexa* var. 1	*Distephanus boliviensis jimlingii*
LOWER PLIOCENE	*Denticula kamtschatica*	*c*	15,CC	A	G	R	F	R			R		A			R			R		C		R	R	R		R	R		R		R	R
			16-2 (110–112)	C	G		R		R			R	C					R	R		F		R	R	R		R	R		R	R	R	
			16,CC	A	G		R			R			A					R	R		F			R	R		R	F		R			
			17-3 (60–62)	A	G		R	R					A			R					F		R	R	R	R	R	F		R			R
			17,CC	A	G		F	R			R		A							R	F			R	R		R	F		R	R	R	R
			18-4 (70–72)	A	G								A					R							C			R					
			18,CC	A	G	R	F				R		A							R	F			R	R		R	F		R	R	R	R
			19-5 (125–127)	A	G		R						A			R					R			R	C			R					
			19,CC	A	G		R					R	A							R	R				C		R	R		R			
			20-4 (135–137)	A	G						R		A		R	R			R	R	R				C	R	R	F		R	R	R	R
			20,CC	A	G	R	R				R		A			R				R	R				C		R	F		R	R	R	
			21-1 (116–118)	A	G						R	R	A			F		R		R					C		R	F		R			
			21,CC	A	M	R	R					R	A			R		R	R	R	R		R		C		R	R		C	R	R	R
			22-1 (130–132)	A	G		F			R			A		R		R	R	R	F	F	R	R	R	C			F		F	R	R	
			22,CC	A	G		R			R			A			R		R	R		F	R	R	R	C	R	R	F	R	F	R	R	
			23-1 (120–122)	A	M								A			R					C			R	F		R	F	R	R			R
			23,CC	A	M		R						A					R		R	C		R	R	R		R	F	R	F	R	R	R
			24-3 (108–110)	A	G		R						A		R					R	R		R	F			R	F	R	F	R	R	
			24,CC	A	G		R		R		R		A			R		R	R		F		R	F	R		R	F	R	C	R	R	R
			25-3 (9–11)	A	G		R						A						R		R			R	F	R	R	F	R	F			R
			25,CC	A	G						R		A			R				R	R		R	R	F			F		C	R	R	R
			26-7 (8–10)	C	G						R	R	C		F					R	R			R	F		R	F	R				R
			26,CC	A	M		R			R	R	R	C							R	R			R	R		R	F		R	R	R	R
			27-4 (140–142)	A	G	R	R			R	F		A		R	R				R	R			R	R	R	F	F	R	R	R	R	R
			27,CC	A	M	R	R				F		A					R		R			R	R	F		R	F	R	C	R	R	R
		b	28-1 (140–142)	A	G	R			R	R	R	R	A		R	R		R	R	F	R				R		R	F	R	R			R
			28-4 (118–120)	A	G		R		R		R	R	A					R	F	F	R		R	R	R	R	R	R	R	F	R	R	R
			28,CC	A	G	R	R		R	R	R		A		R		R	R	F	F	R	R	R	R	F		R	F	R	F	R	R	R
			29-3 (10–12)	A	G		R				R		A			R	R	R	R		R	R	R	R	F	R	R	F	R	F			R
			29-5 (10–12)	A	G	R					R		A			R	R		C	R	F		R	R	F		R	F	R	C	R	R	R
			29,CC	A	G		R		R		R	R	A					R	F	R	F		R	R	F		R	R	R	F			R

hustedtii without *D. kamtschatica* s. str. but containing *D.* sp. cf. *D. kamtschatica*, which appears in Sample 438A-45,CC (487.5 m). *Denticula* sp. cf. *D. kamtschatica* also ranges into Subzone *b* in the Bering Sea (Barron, unpublished data).

Other significant events within Subzone *b* of the *D. hustedtii* Zone include the first occurrences of *N. miocenica* and *N. marina* in Sample 438A-43-3, 123–125 cm (462.2 m); the last occurrence of *Thalassionema hirosakiensis* in Sample 438A-43-5, 135–137 cm (465.4 m); the last occurrence of *Thalassiosira burckliana* in Sample 438A-44-3, 120–122 cm (473.7 m); the first occurrence of *Cosmiodiscus insignis* and the last occurrence of the silicoflagellate *Distephanus pseudofibula* in Sample 438A-44-5, 71–73 cm (476.2 m); the first occurrence of *T. zabelinae* s. ampl. in Sample 438A-45,CC (487.4 m); and the first occurrence of *N. pliocena* in Sample 438A-46-3, 91–93 cm (492.4 m). According to Burckle (1972, 1978), the last occurrence of *N. porteri* and the first occurrence of *N. miocenica* correlate with the middle part of Paleomagnetic Epoch 7; the last occurrence of *T. burckliana* correlates with the lower part of Epoch 7; and the last occurrence of *Coscinodiscus yabei* corrrelates with the middle part of Epoch 8. Burckle (written communication, 1979), however, suggests that the last occurrence of *C. yabei* may be younger in higher latitudes. The sediment accumulation rate curve for Hole 438A (Figure 5) shows that when referenced against other datum levels these tropical datum levels occur at the expected levels in Hole 438A.

TABLE 4
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellate *Distephanus boliviensis jimlingii*, Cores 438A-30–438A-40

Time-Rock Unit	Zone		Sample (Interval in cm)	Abundance	Preservation	*Actinocyclus ochotensis*	*Asterolampra acutiloba*	*Cosmiodiscus insignis*	*Coscinodiscus pustulatus*	*C. temperei*	*Cussia tatsunokuchiensis*	*Denticula hustedtii*	*D. hyalina*	*D. kamtschatica*	*Goniothecium tenue*	*Hemidiscus cuneiformis*	*Lithodesmium cornigerum*	*N. fossilis*	*N. marina*	*N. miocenica*	*N. praereinholdii*	*N. reinholdii*	*Rhizosolenia barboi*	*Rouxia californica*	*Synedra jouseana*	*Thalassiosira antiqua*	*T. convexa* var. *aspinosa*	*T. gravida*	*T. gravida* (flat form)	*T. miocenica*	*T. nativa*	*T. nidulus* s. ampl.	*T. nidulus* var. *delicata*	*T. oestrupii*	*T. punctata*	*T. zabelinae*	*T. jacksonii*	*T. convexa* var. 1	*Distephanus boliviensis jimlingii*
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	30-3 (129–131)	A	G	R					R			C		R		R	R			F	R			R	R	R	R		F		R	F	R	R	F	R	F
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	30-5 (129–131)	A	G	R		R	R		F	R		C			R	R	R			R	R			F		R	R		F	R	R	F	R	F	F		R
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	30,CC	A	G	R		R			R	R		C		R		R	R			R	R			R		R	R		F		R	F		F	R	R	
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	31,CC	A	M	R					R			C					R			R	R			R		R	R		F	R	R	F	R	F	F		R
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	32-1 (124–126)	A	G	R		R			R	R	R	C				R	R			F	R			R			R		F	R	R	F	R	R	F		
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	32-3 (124–126)	A	G	R		R	R	R	R			C		R			R			R	R			R		R	R		F		R	F	R	C	F	R	R
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	32,CC	A	G	R		R			R	R		C		R		R	R			R	F			R		R	F		R	R	R	F	R	F	F		R
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	33-1 (132–134)	A	G	R		R	R		R			C		F		R	R			F	R			F		R	R		R	R	R	R	R	F	F	R	R
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	33-5 (132–134)	A	G			R			R	R		C	R	R		R	R			F	F	R		R		R			R	R	R	R		R	R		R
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	33,CC	A	G	R		R			R	R		A		R		R	R			F	R	R		R		R	R		F		R	R	R	R	F	R	R
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	34-1 (85–87)	A	G					R	R	R		C		R	R	R				R	R			R			R		R	R		R	R	R	R		
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	34-5 (85–87)	A	G	R		R		R	R			A					R			R	F			F	R	R	R		R	R	F	R	R	R	R		
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	34,CC	C	G	R				R	R			C		R			R			R	R			F		R			R	R	F				R		
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	35-1 (135–137)	A	G	R		R	R	R	R			C		R		R	R		R					R	R	F	R		R		R	R		R	F	R	
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	35-5 (135–137)	C	G	R				R	R	R		C		R		R	R			R	R		R	R	R	R			R	R	R	R	R		R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	35,CC	C	M	R		R		R		R	R	C		R		R	F		R	R		R		R	R	R			F	R	R		R		R		R
UPPER MIOCENE	*Denticula kamtschatica*	*a*	36-3 (80–82)	A	M			R		R		R		C		F						R		R		R	R	R	R		F				R		R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	36-5 (80–82)	A	G			R		R		R		A	R	F						R		R		R	R		R		C		R			R	R		R
UPPER MIOCENE	*Denticula kamtschatica*	*a*	36,CC	C	G	R		R				R		C	R	F			R			R		R		F	R	R	R		C	R	R		R	F	R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	37-1 (145–147)	C	G	R		R				R		C	R	R		R	R			R		R		R		R			C		R				R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	37-3 (130–132)	C	G							R	R	F	R			R				R									F						R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	37,CC	C	M	R						R		C	R			R	R			R		F	R	F			R		C	R	R				R		R
UPPER MIOCENE	*Denticula kamtschatica*	*a*	38-3 (130–132)	C	G			R				R		F		R		R	R		R	R		F			R		R		F	R	R			R	R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	38-5 (110–112)	A	G	R	R	R	R	R		R		C	R	R		R	R		R	F		R		R	R	R	R	R	F	R	R			R	R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	38,CC	A	M	R		R	R	R		R		C	R	R		R	R			R		R		R		R		R	R	R	R			R	R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	39-1 (135–137)	C	G	R			R					C	R	R		R	R			R		R		R	R	R	R	R	R	R	F			R	R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	39-4 (130–132)	C	G	R								C	R	R			R			R		R	R	R	R	R		R	F	R	R				R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	39,CC	A	G	R		R		R		R		C	R	R		R	R	R		R		F	R	F	R	R	R	R	C	R	R			R	F		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	40-1 (110–112)	A	G	R		R	R			R		C	R		R	R	R	R		R		R	R	R	R	R	F	R	F		R		R	F	R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	40-4 (130–132)	C	G			R		R				C	R			R				R	R	F		F	R		R		R	R	R			R	R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	40-5 (150–152	C	M			R				R		C	R			R	R	R		R	R	R		F	R	R		R	R	R	R		R	R	R		
UPPER MIOCENE	*Denticula kamtschatica*	*a*	40,CC	A	M			R				R		C	R	R		R	R	R	F	R	R	R		F	R	R	F	R	F		R			R	R		

The last occurrences of *Thalassionema hirosakiensis* and *D. pseudofibula* are useful for correlations with California and the Bering Sea (Barron, 1976; unpublished data). *Cosmiodiscus insignis* also ranges into Subzone *b* of the *Denticula hustedtii* Zone in the Bering Sea (Barron, unpublished data), well below the range reported by Koizumi (1977).

Subzone *a* of the *D. hustedtii* Zone is characterized by common *D. hustedtii* in its lower part and few to rare *D. hustedtii* in its upper part. The first occurrence of *Thalassiosira antiqua* in Sample 438A-47-1, 70–72 cm (498.7 m), lies immediately below the top of this subzone and may be used in California to approximate the boundary. Other significant events within Subzone *a* of the *D. hustedtii* Zone include the first occurrence of *N. fossilis* in Sample 438A-48,CC (516.6 m); the first consistent occurrence of *T. burckliana* in Sample 438A-49,CC (525.9 m); the first occurrence of *T. nidulus* s. ampl. in Sample 438A-49-3, 140–142 cm (521.4 m); and the first occurrence of *N. porteri* in Sample 438A-51-1, 105–107 cm (537 m). All of these first occurrences fall above the last common occurrence of *D. hustedtii* (in Sample 438A-51,CC [544.8 m]) and may be related to a period of climatic warming reported in the middle part of the upper Miocene in California by Barron (1973). The last occurrences of *Coscinodiscus endoi* in Sample 438A-52-5, 128–130 cm (552.8 m), and *Rhizosolenia miocenica* in Sample 438A-53-1, 128–130 cm (556.3 m), lie near the base of the *D. hustedtii* Zone. These diatom events occur in the same sequence at Site 173 (Schrader, 1973) and in the Upper Newport Bay section of southern California (Barron, 1976).

The top of the *D. hustedtii–D. lauta* Zone is marked by the last occurrence of *D. dimorpha* in Sample 438A-55-1, 30–32 cm (574.3 m). *D. lauta* apparently has its last occurrence slightly higher in Sample 438A-54-3, 65–67 cm (578.2 m); however, *D. lauta* is commonly reworked into younger sediment in all of the Leg 57

TABLE 5
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellate *Distephanus pseudofibula*, Cores 438A-41-438A-50

Time-Rock Unit	Zone		Sample (Interval in cm)	Abundance	Preservation	*Cosmiodiscus insignis*	*Coscinodiscus plicatus*	*C. temperei*	*C. yabei*	*Cussia paleacea*	*Denticula hustedtii*	*D. hyalina*	*D. kamtschatica*	*D.* cf. *kamtschatica*	*Hemidiscus cuneiformis*	*Nitzschia fossilis*	*N. marina*	*N. miocenica*	*N. pliocena*	*N. porteri*	*N. praereinholdii*	*N. reinholdii*	*Rhizosolenia barboi*	*Rouxia californica*	*Thalassionema hirosakiensis*	*Thalassiosira antiqua*	*T. burckliana*	*T. convexa* var. *aspinosa*	*T. gravida*	*T. gravida* (flat form)	*T. miocenica*	*T. nativa*	*T. nidulus* var. *delicata*	*T. punctata*	*T. zabelinae* s. ampl.	*T. jacksonii*	*T.* sp. 1	*Synedra jouseana*	*Distephanus pseudofibula*	*T. nidulus* s. ampl.
UPPER MIOCENE	*D. kamtschatica*	*a*	41-1 (140-144)	A	G	R		R			R		A	C		R	R	R			R	R	R			F		R	R	R	R	F	R		R	R				R
			41-5 (90-92)	A	G	R							C	F	R	R		R			R	R		R		F		R	R	R	R	R	R	R	F	R		R		R
			41,CC	A	G	R		R			R		C	C	R	R	R	R			R	R		R		R		R	R	R	R	F	R		F	R				R
			42-1 (80-82)	A	M	R		R			R		R	F	R	R	R	R			R	R	R	F		R			R	R		C	R	R	R	R				R
			42-3 (110-112)	A	G	R		R			R		R	F	R	R	R				F	R	R	F		F		R	R	R		C			R	R		R		R
	Denticula hustedtii	*b*	42-5 (83-85)	A	G			R			R			F	R	R	R		F		F	R		F		C			R	R		C	R	R	F			F		R
			42,CC	A	M			R			R	R		F	R	R	R		R		F			C		R						F			R			F		R
			43-3 (123-125)	A	M			R			R			F	R	R	R	R	R	R	R		R	F		R	R					F			R			F		R
			43-5 (135-137)	C	G	R		R			R			R		R			R	F	F		R	F	F	R						F			R		R	F		R
			43,CC	A	G	R					R	R		R	F	R			R	R	R		R	F	F							F			R			F		R
			44-3 (120-122)	C	M			R			R	R		R		R				R			R	C	C	R	R					R		R				R		R
			44-5 (71-73)	C	G	R		R			R			F		R			R	R			R	C	C							F		R	R			R	R	R
			44,CC	C	M			R			R	R		R	R	R			R	R	R		R	A	C	R	R					F		R	R			R		R
			45-1 (126-128)	C	M			R			R	R		F	R	R				R			R	R	F		R					R		R	R		R	R	R	R
			45-5 (126-128)	C	G						F										F			C			R					R		R			R	R	R	
			45,CC	C	G			R			R			R	R	R			R	F			R	C	C	R	R					R		R	R		R	R	C	R
			46-3 (91-93)	C	M						R				R	R			R	R			R	F	F	R	R					R					R	R	F	
			46-5 (130-132)	C	M			R			R	R			R	R				R			F	F	C		R					R		R			R		F	R
		a	46,CC	C	M		R	R	R		R	R			R	R				R	R		F	C	C	R	R					R		R			R	R	C	R
			47-1 (70-72)	A	M			R	R		R				R	R				F	R		R	C	C	R	R					R		R				R	C	
			47-3 (70-72)	A	M			R	R		R	R				R				F			R	C	C		R					F						R	F	R
			47,CC	C	G			R	R		R	R			R	R				R			R	F	C		R					R		R				R	C	R
			48-3 (135-137)	C	M										R	R				R			R	F	C		R					F					R	R	R	
			48-7 (33-35)	C	G						R	R				R				R	R		R	C	C		R					C		R				R	C	R
			48,CC	C	G						R	R				R				R	R		R	F	F		R					F		R			R	R	F	R
			49-3 (140-142)	C	M						R	R			R						R		R	C	R		R					F		R				R	F	R
			49-5 (120-122)	C	G			R	R	R	F	R			R						R		R	F	R		R					R						R	R	
			49,CC	C	M						F	R			R					R	R		R	F			R					R					R			
			50-1 (100-102)	F	P			R			F										R		R	C								R		F			R	R		
			50-3 (100-102)	C	M					R	R	R			R						F		R	C	R							R					R	R		
			50,CC	C	M				R		R									R	R		R	C	R		R					R					R	R	R	

holes and may be confused with *D. hyalina* in a poorly preserved assemblage. For these reasons and the close stratigraphic association of the extinctions of *D. lauta* and *D. dimorpha* noted by Schrader (1973) and Barron (1976), the last occurrence of *D. dimorpha* rather than the last *D. lauta* is used to mark the top of the *D. hustedtii-D. lauta* Zone.

Subzone *d* of the *D. hustedtii-D. lauta* Zone represents the stratigraphic range of *D. dimorpha* s. str. and occurs from Sample 438A-55-1, 30-32 cm (574.3 m), through Sample 438A-59,CC (618.4 m). The last occurrence of *D. punctata* (Sample 438A-56-5, 60-62 cm [590.1 m]), the first occurrence of *T. nativa* (Sample 438A-57-3, 115-117 cm [597.2 m]), and the first occurrence of *Lithodesmium reynoldsii* (Sample 438A-58,CC [604.5 m]) lie within Subzone *d* in Hole 438A. These taxa have similar ranges at Site 173 (Schrader, 1973; Barron, unpublished data), but only the first occurrence of *L. reynoldsii* is within Subzone *d* in the Upper Newport Bay section in southern California (Barron, 1976).

The interval below Subzone *d* down to the first occurrence of *R. barboi* in Sample 438A-64-1, 126-128 cm (660.8 m), is assigned to Subzone *c* of the *D. hustedtii-D. lauta* Zone. The sediment accumulation rate curve (Figure 5) for Hole 438A suggests that the middle Miocene/upper Miocene boundary of Ryan and others (1974) lies just below the top of Subzone *c*. Notable datum levels within Subzone *c* in Hole 438A include the last occurrence of *N. heteropolica* (Sample 438A-60-1, 134-136 cm [622.8 m]), the last occurrence of *R. praebarboi* (Sample 438A-60,CC [625.2 m]), the first occurrence of the silicoflagellate *Distephanus pseudofibula* (Sample 438A-61,CC [631.1 m]), and the restricted range of the silicoflagellate *Mesocena hexagona* (Sample 438A-60,CC [625.2 m]) through Sample 438A-63,CC [651.2 m]). All of these datums are useful within Subzone *c* in the Bering Sea (Barron, unpublished data); but the first occurrence of *D. pseudofibula* is within overlying Subzone *d* at Site 173 (Bukry, 1973b) and in southern California (Barron, 1976), and the last occurrence of *N. heteropolica* is within underlying Subzone *b*

TABLE 6
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellates *Distephanus pseudofibula* and *Mesocena hexagona*, Cores 438A-51–438A-62

Time-Rock Unit	Zone		Sample (Interval in cm)	Abundance	Preservation	*Coscinodiscus endoi*	*C. plicatus*	*C. temperei*	*C. yabei*	*Cussia paleacea*	*Denticula dimorpha*	*D. hustedtii*	*D. lauta*	*D. punctata*	*Hemidiscus cuneiformis*	*Kieselviella carina*	*Lithodesmium reynoldsii*	*Mediaria splendida*	*Nitzschia heteropolica*	*N. porteri*	*N. praereinholdii*	*Rhizosolenia barboi*	*R. miocenica*	*R. praebarboi*	*Rouxia californica*	*Synedra jouseana*	*Thalassionema hirosakiensis*	*Thalassiosira burckliana*	*T. nativa*	*T.* sp. 1	*D. praedimorpha*	*Distephanus pseudofibula*	*Mesocena hexagona*
UPPER MIOCENE	*Denticula hustedtii*	*a*	51-1 (105–107)	F	M			R	R			R								R					R	R	R		R	F		R	
			51-3 (105–107)	F	M				R			R										R			F	F				R			
			51,CC	C	M		R					C			R							R			F	R	R		R	R		R	
			52-3 (128–130)	C	M		R		R			C	(R)									R			F			R		R			
			52-5 (128–130)	C	M	R	R		R	R		C			R						R	R			F	R	R		R				
			52,CC	C	M	R		R				C			R						R	R			C	R	R		R	R		R	
			53-1 (110–112)	C	M	R	R					C			R						F	R	R		C	R	R		R	C		R	
			53-2 (52–53)	C	G	R		R	R	R		C	(R)		R						F	R	R		F	R	R		R	F			
			53,CC	C	M	R		R		R		C			R						R	R	R		A	R	R		R	R			
			54-1 (65–67)	C	M	R			R			C			R						R	F			F	R	R		R	F		R	
			54-3 (65–67)	C	M							C	R		R										F		R			R			
			54,CC	C	M			R				F	R								R				F	R	R		R	R			
	D. hustedtii–D. lauta	*d*	55-1 (30–32)	C	M	R		R		R	R	C	R				R				R	R			F	R	R		R	R			
			55-5 (30–32)	C	M	R	R	R			R	C	R		R								R		F		F		R	F			
			55,CC	C	M						R	C	R		R						R	R			F	R	F		R	R			
			56-3 (60–62)	A	G	R	R	R			F	C	F								R	R			F	R	F		R	R		R	
			56-5 (60–62)	A	G	R		R			C	C	F	R	F		R				R	R	R		F	R	F			R		R	
			56,CC	A	M	R	R				C	C	C	R	R		R					R	R		F		F		R	F		R	
			57-1 (115–117)	A	G	R	R	R	R		C	C	C	R	R	R					F	R			F		F			F			
			57-3 (115–117)	C	M	R	R				C	C	F	R	R						R	F	R		R		C		R	R			
			57,CC	C	M						C	C	F		R		R				R	R			F		F					R	
			58-1 (101–103)	C	G	R					F	C	F		R						R	R			C	R	F						
			58,CC	C	M						F	F	F		R		R				R	R			R	R	F						
			59-1 (135–137)	C	M	R	R				F	F	F		R										R		F						
			59-3 (135–139)	C	P						R	C	R		R			R				R			R		F						
			59,CC	C	M	R			R		F	C	F		R						R	R			R		F						
		c	60-1 (134–136)	C	M	R	R					C	R						R			R			F	R	R			R			
			60-3 (15–17)	A	M		R					C	R		R				R		F	R	R		F		R			R		R	R
MIDDLE MIOCENE			60,CC	A	G	R	R		R			A			R			R	R		R	R	R	R	R		R					R	F
			61,CC	A	M		R	R	R			C	R		R	R		R	F		R	R		R	F	R	R					R	R
			62-1 (110–112)	A	M	R	R	R	R			A	R		R				R			R		R	R	R					R		R
			62,CC	C	G							C							R		R				F						R		

at Site 173 (Schrader, 1973). *Hemidiscus cuneiformis* s. ampl. first occurs in Sample 438A-63,CC (651.2 m) slightly above the first occurrence of *R. barboi,* a relationship which occurs at Site 173 off northern California and in the Upper Newport Bay Section in southern California (Figure 1).

Cores 64 and 65 are assigned to Subzone *b* of the *D. hustedtii–D. lauta* Zone on the basis of the presence of *D. praedimorpha* without *R. barboi.* The last consistent occurrence of *Mediaria splendida* in Sample 438A-64-3, 36–38 cm (662.8 m), coincides closely with the top of this subzone here, at Site 173 (Schrader, 1973), and in southern California (Barron, 1976). Also notable are the first occurrences of *N. heteropolica* (Sample 438A-64,CC [668.4 m]), *Coscinodiscus temperei* (Sample 438A-65-1, 136–137 cm [670.4 m]), and *Coscinodiscus yabei* (Sample 438A-65,CC [676.1 m]). *Nitzschia heteropolica* is associated with Subzone *b* in the Bering Sea (Barron, unpublished data) and at Site 173 (Schrader, 1973), as is the first occurrence of *Coscinodiscus temperei.*

A hiatus separates Subzones *a* and *b* of the *D. hustedtii–D. lauta* Zone between the core catcher of Core 65 and the top of Core 66 (Figure 5). Akiba (written communication, 1977) recognizes a hiatus in the same stratigraphic position in the Ninohe area in nearby northeast Honshu. Elsewhere in the North Pacific, the first occurrence of *C. yabei* is below the first occurrence of *D. praedimorpha.*

Subzone *a* of the *D. hustedtii–D. lauta* Zones occurs down through Sample 438A-68-1, 101–103 cm (698.5 m), the first occurrence of *D. hustedtii.* The last consis-

TABLE 7
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellates *Mesocena apiculata curvata* and *M. hexagona*, Cores 438A-63–438A-76

Time-Rock Unit	Zone		Sample (Interval in cm)	Abundance	Preservation	*Actinocyclus ingens*	*A. ingens* var. 1	*A. ingens* var. 2	*Actinoptychus minutus*	*Annellus californicus*	*Coscinodiscus lewisianus*	*C. plicatus*	*C. plicatus* s. ampl.	*C. praeyabei*	*C. temperi*	*C. yabei*	*Delphineis penelliptica*	*Nitzschia challengeri*	*Denticula praedimorpha*	*D. hustedtii*	*D. hyalina*	*D. lauta*	*D. miocenica*	*D. nicobarica*	*D. punctata*	*D. kanayae*	*Hemidiscus cuneiformis*	*Kieselviella carina*	*Mediaria splendida*	*Nitzschia heteropolica*	*Rhaphoneis miocenica*	*Rhizosolenia barboi*	*R. praebarboi*	*Stephanopyxis* cf. *schenckii*	*Synedra jouseana*	*Mesocena apiculata curvata*	*M. hexagona*
MIDDLE MIOCENE	*D. hustedtii–D. lauta*	*c*	63-1 (110–112)	C	M	F						R			R	R				C									R	R		R	R		R		R
			63,CC	A	M	C			R			R				R				A							R			R		R	R				R
			64-1 (126–128)	A	M	C						F			R	R				A										R		R	F				
		b	64-3 (36–38)	A	M	F						R			R	R			R	F	R	C							R	F			R				
			64,CC	C	M	R						R							F	F		C							R	R			F				
			65-1 (136–137)	C	M	F						R			R	R			F	C		C							R				R				
			65-5 (77–79)	C	M	C						R							R	C		C	R	R	R				R				R		R		
			65,CC	C	P	F										R			R	C	R	C	R						R								
		a	66-2 (25–27)	C	M	F						R						F		C	R			R					R						R		
			66,CC	A	M	C						R						C		C	F			C	R				R				R				
			67-1 (102–104)	A	M	C	R		R			R	R					R		R	A		R	R					R								
			67,CC	A	M	C	R		R		R							R		R	A	R	R	R					R								
			68-1 (101–103)	A	M	C	R	R					R	R				R		R	A		R						R								
	Denticula lauta	*b*	68-5 (70–72)	A	M	F	R							R				R			C	C	R	R					R						R		
			68,CC	C	M	C	R											R			C	R	R	R					R								
			69,CC	C	M	C	R											F			C	F	R	R					R						R		
			70-1 (78–81)	C	M	C	F											R			R	C	R	R					R						R		
			70-5 (121–123)	C	M	C	F	R										R			F	C	R					R	R						R		
			70,CC	A	M	C	R	R										F			R	C	R	R					R						R		
			71-1 (114–115)	C	M	C	R	R			R							R			R	C	R	R					R						R		
			71-5 (130–132)	C	M	C	R	R													R	C		R				R	R								
			71,CC	C	M	A	R	R										R			R	C		R					F						R		
			72-3 (147–148)	F	M	F	R	R			R							R			R	F		R					R								
			72-5 (120–121)	C	M	C	R	R													R	F		R		R		R	R						R		
			73-1 (46–48)	C	M	C	R	R			R											R		R		R		R	F						F		
			73-5 (46–48)	C	M	C	R	R										R			R	C		R					R		R		R		C		
		a	73,CC	C	M	A	R	R		R							R	R				C		C					R				R		C	R	
			74-1 (124–126)	C	M	C																C		R		R		R	R						F		
			74,CC	C	M	A	R	R			R											C		R		R		R	R				R		R	R	
			75-1 (70–72)	F	M	C																F		R				R	R						R		
			75,CC	C	M	C	R															F		R		R		R	R				R	R	R	R	
			76,CC	F	P	A												R				R		R		R		R	R					R	R		

tent occurrences of *D. nicobarica* and *N. challengeri* in Sample 438A-66-2, 25–27 cm (680.3 m), coincide with the truncated top of Subzone *a* at the hiatus. Within subzone *a*, *D. hustedtii* becomes dominant uphole over *D. hyalina* in Sample 438A-66,CC (681 m). The first occurrence of *C. plicatus* and the last occurrence of *Actinocyclus ingens* var. 1 are immediately below in Sample 438A-67-1, 102–104 cm (689 m).

The first dominant appearance of *D. hustedtii* over *D. lauta* and *D. hyalina* is a recognizable diatom event throughout the North Pacific (Koizumi, 1973; Schrader, 1973; Barron, 1976; Koizumi, 1977) and probably corresponds with the first occurrence of *D. hustedtii* in the tropical Pacific. The last occurrence of *A. ingens* var. 1 is immediately below this diatom datum in the Upper Newport Bay section in southern California and in sediments off southern California (Barron, unpublished data).

The interval below the first occurrence of *D. hustedtii* in Sample 438A-68-1, 101–103 cm (698.5 m), down through the first occurrence of *D. lauta* s. str. in Sample 438A-83,CC (840.2 m) is assigned to the lower middle Miocene *D. lauta* Zone. Assemblages are characterized by common to abundant *A. ingens* displaying many different variations in morphology and by common to few *D. lauta*. The first occurrence of *D. hyalina* divides the *D. lauta* Zone into two subzones, Subzone *a* and Subzone *b*. Relationships in southern California suggest that the last occurrence of *Annellus californicus* and the last occurrence of the silicoflagellate *Mesocena apiculata curvata* approximate the first occurrence of *D. hyalina* (Barron, unpublished data). An isolated occurrence of *A. californicus* in Sample 438A-73,CC (754.5 m) coincides with the last *M. apiculata curvata* and is immediately below the first occurrence of *D. hyalina* in Sample 438A-73-5, 46–48 cm (751.5 m) (Table 7).

Delphineis penelliptica, Kieselviella carina, Rhaphoneis miocenica, Cymatogonia amblyoceras, and *Denticula norwegica* occur sporadically within Subzone *a* of

TABLE 8
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellate *Mesocena apiculata curvata*, Cores 438A-77-438A-86

Time-Rock Unit	Zone		Sample (Interval in cm)	Abundance	Preservation	*Actinocyclus ingens*	*A. ingens* var. 1	*A. ingens* var. 2	*Coscinodiscus lewisianus*	*C. symbolophorus* var. 1	*C. symbolophorus* var. 2	*Cymatogonia amblyoceras*	*Delphineis penelliptica*	*Nitzschia challengeri*	*Denticula lauta*	*D.* cf. *lauta*	*D. miocenica*	*D. nicobarica*	*D. norwegica*	*D. kanayae*	*Kieselviella carina*	*Mediaria splendida*	*Rhaphoneis miocenica*	*Rhizosolenia praebarboi*	*Stephanopyxis* cf. *schenckii*	*S. hyalomarginata*	*S.* spp.	*Synedra jouseana*	*S. jouseana* var. 1	*D. punctata* var. *hustedtii*	*Mesocena apiculata curvata*
MIDDLE MIOCENE	*Denticula lauta*	*a*	77-1 (81–83)	C	M	C	F	R				R		R	F			R	R		R	R		R	R		R	R			
			77,CC	C	M	C	R							R	C			R		R	R	R		R	R		R	R			R
			78-3 (92–94)	C	P	C		R				R		R	F			R				R		R	R	R		R			
			78,CC	C	M	C	R		R					R	C		R	R			R	R	R	R				R			R
			79-1 (55–57)	C	M	C	F	R	R				R	R	F			R			R	R		F	R			R		R	
			79-3 (55–57)	F	P	F	R							R	R						R	R	R	R	R	R	R	R			
			79-5 (56–57)	C	P	C			R			R		R	F			R			R	R		R	R	R		R			
			79,CC	C	P	C			F					R	R						R	R		R				R	R		
			80,CC	C	M	C	R		R	R				R	C						R	R		R	R		R	C			
			81,CC	C	M	C				R				R	F			R	R		R	R	R	R	R	R		F			
			82,CC	C	M	F			R	R			R	R	R	C					R	R	R	R	R	R		F			R
			83,CC	C	P	F			R						R	R						R	R					R			
LOWER MIOCENE	*Actinocyclus ingens*		84,CC	F	P	F			R		R	R				F				R	R	R	R		R	R	R	R			
			85,CC	C	M	F				R	R					C			R	R	R	R			R	R		R			
			86,CC	F	P	F				R						R				R	R	R	R	R	R	R		R	R		

the *D. lauta* Zone. With the exception of *K. carina*, all of these species are present in Subzone *a* in southern California (Barron, unpublished data). *D. kanayae* of Akiba (1977) has its last occurrence in Sample 438A-72-5, 120–121 cm (742.7 m), in the lowermost part of Subzone *b* and occurs rarely and sporadically down through Subzone *a*. The lower part of Subzone *a* contains the apparent first occurrence of *A. ingens* var. 1 in Sample 438A-80,CC (817.5 m) and is characterized by varied forms of *Coscinodiscus symbolophorus* and of the genus *Stephanopyxis* (*S.* sp. cf. *S. schenckii*, *S. hyalomarginata*, and *S.* spp.) (Table 8). *N. challengeri* first occurs in Sample 438A-84,CC (857.3 m) near the first occurrence of *D. lauta* s. str. (Sample 438A-83,CC).

The upper lower Miocene *A. ingens* Zone is present from Sample 438A-84,CC through Sample 438A-86,CC (868.6 m), the base of the hole. Diatom assemblages are similar to those of the lower part of Subzone *a* of the *D. lauta* Zone and are better characterized in Hole 438B, where more of the zone is represented.

Hole 438B

Hole 438B (40°37.80′ N, 143°14.80′ E; 1564.5 m water depth) extends the stratigraphic record at Site 438 to 1040.7 meters, where lower Miocene sediment of the *Actinocyclus ingens* Zone was recovered. Diatoms are generally common, and preservation is moderate to poor above Core 9 (900.3 m). Below that level, diatoms become few to rare and preservation is usually poor.

Spot coring above 853.3 meters (Cores 1 through 3) provides correlation with the section cored in Hole 438A. Sample 438B-1,CC (567.5 m) contains *Coscinodiscus endoi* without *Denticula lauta* and correlates with the lower part of Subzone *a* of the *D. hustedtii* Zone in Hole 438A in the interval from Sample 438A-52-5, 128–130 cm (552.7 m), through Sample 438A-54-1, 65–67 cm (565 m). The silicoflagellates *Distephanus pseudofibula* and *Mesocena hexagona* in Sample 438B-2,CC (667 m) occur together in the lower part of Subzone *c* of the *Denticula hustedtii–D. lauta* Zone within an interval from Sample 438A-60-3, 15–17 cm (626.1 m), through Sample 438A-61,CC (631 m). The presence of *D. lauta, D. kanayae,* and *Kieselviella carina* in Sample 438B-3-3, 28–30 cm (789.3 m), argues for correlation with Subzone *a* of the *D. lauta* Zone within the interval of Cores 73 through 79 of Hole 438A. These data suggest that stratigraphic levels within the Miocene of Hole 438B are about 25 to 30 meters lower than they are in Hole 438A.

The occurrences of stratigraphically diagnostic diatoms and the silicoflagellate *M. apiculata curvata* in the continuously cored interval (Cores 4 through 23) of Hole 438B are given in Table 9. Cores 17 through 21 and Core 24, at the base of the hole, are barren of diatoms.

Cores 4 and 5 of Hole 438B correlate with Subzone *a* of the *D. lauta* Zone in Hole 438A. As in Hole 438A, the first occurrence of *D. lauta* s. str. in Sample 438B-5, CC (864.2 m) corresponds closely with the first occurrence of *Nitzschia challengeri* in Sample 438B-6-1, 16–19 cm (872.3 m).

The upper lower Miocene *A. ingens* Zone is present from Sample 438B-6-1, 16–19 cm, through Sample 438B-23,CC (1,036.1 m). *C. lewisianus* and *C. endoi* first occur in Sample 438B-9-1, 85–87 cm (901.2 m). *D. kanayae* becomes a consistent member of the assemblage

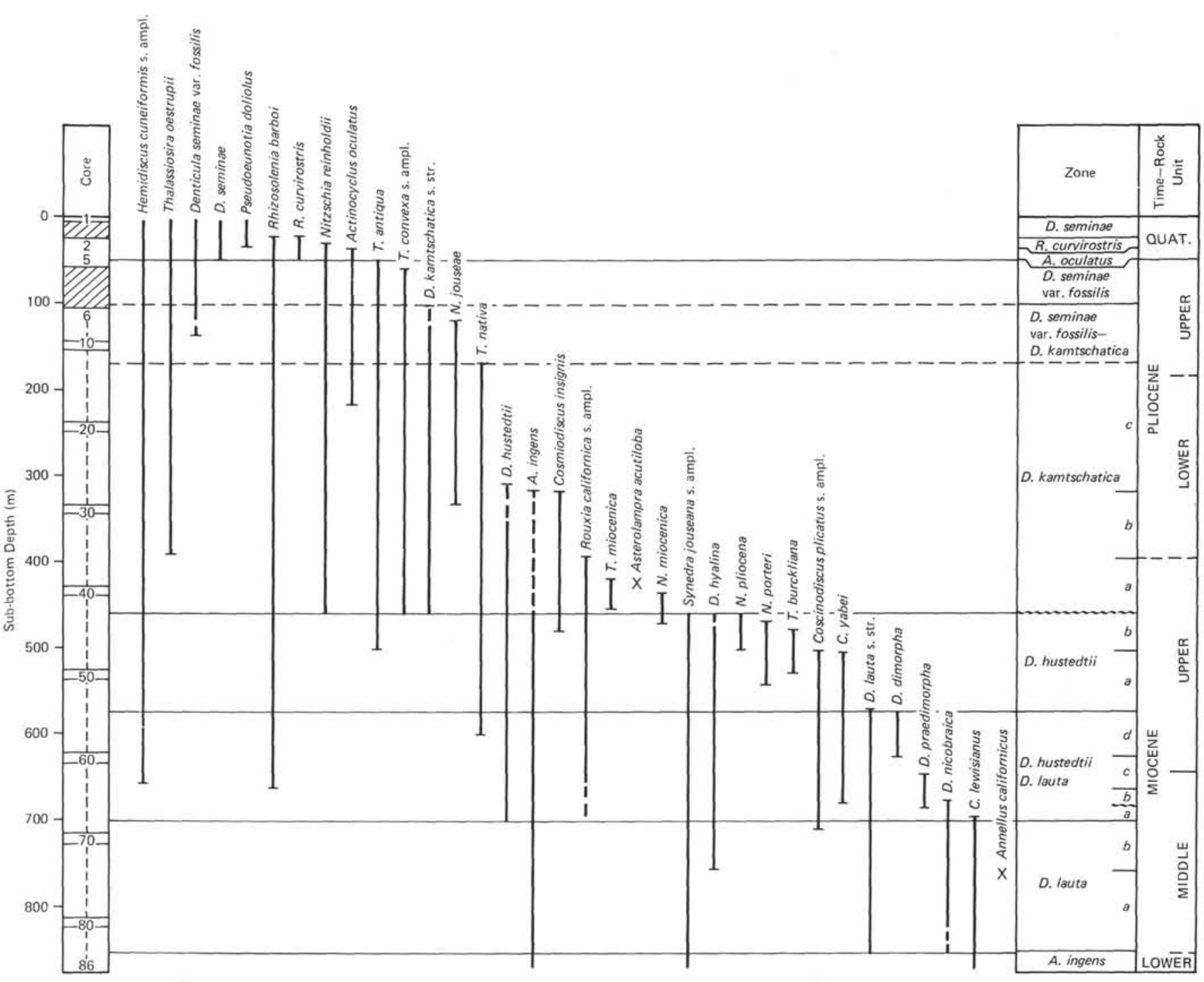

Figure 4. *Stratigraphic ranges of selected diatoms in Hole 438A. (Cross-hatched interval was not recovered.)*

immediately below in Sample 438B-9,CC (903.8 m). Specimens referred to as *D.* sp. cf. *D. lauta* in Tables 9 and 10 (Plate 1, Figures 13, 14) are present down through Core 10 but are more common in Core 5 near the first occurrence of *D. lauta* s. str. *D. ikebei* of Akiba (1977) last occurs in Sample 438B-11,CC (921.4 m), and *C.* sp. aff. *C. marginatus* of Schrader (1976) and *Thalassiosira* sp. 2 have last occurrences in Core 12. Other diatoms characteristic of the *A. ingens* Zone in Hole 438B include varieties of *C. symbolophorus, K. carina, Mediaria splendida, Rhaphoneis miocenica, Stephanopyxis* spp., and *Synedra jouseana* (Table 9). This upper lower Miocene interval is poorly known in the North Pacific, but sediments assignable to the *A. ingens* Zone have been dredged by the U.S. Geological Survey in the Bering Sea and off southern California (Barron, unpublished data). Hole 438B was abandoned owing to poor hole conditions.

Site 439

Site 439 (40°37.61′ N, 143°18.63′ E; 1656 m water depth) was drilled to complete the study objectives not met at Site 438. The probable acoustic basement, a well-indurated, silicified claystone of Late Cretaceous age, was reached in Core 37 (1145.5 m), and drilling was terminated soon thereafter in Core 39 (1157.5 m). This claystone unit is unconformably overlain by a lowermost Miocene dacite conglomerate (Core 32, Section 2, through Core 37, Section 1), and this in turn is overlain by lower Miocene sandstone and siltstone (Core 22, Section 2, through Core 32, Section 1). Diatoms are restricted to the overlying lower Miocene and younger section (Cores 1 through 20); however, they are rare and poorly preserved below Core 9 (897.0 m).

Spot coring (Cores 1 through 4) allows correlation with nearby Hole 438A. Sample 439-1,CC (499 m) con-

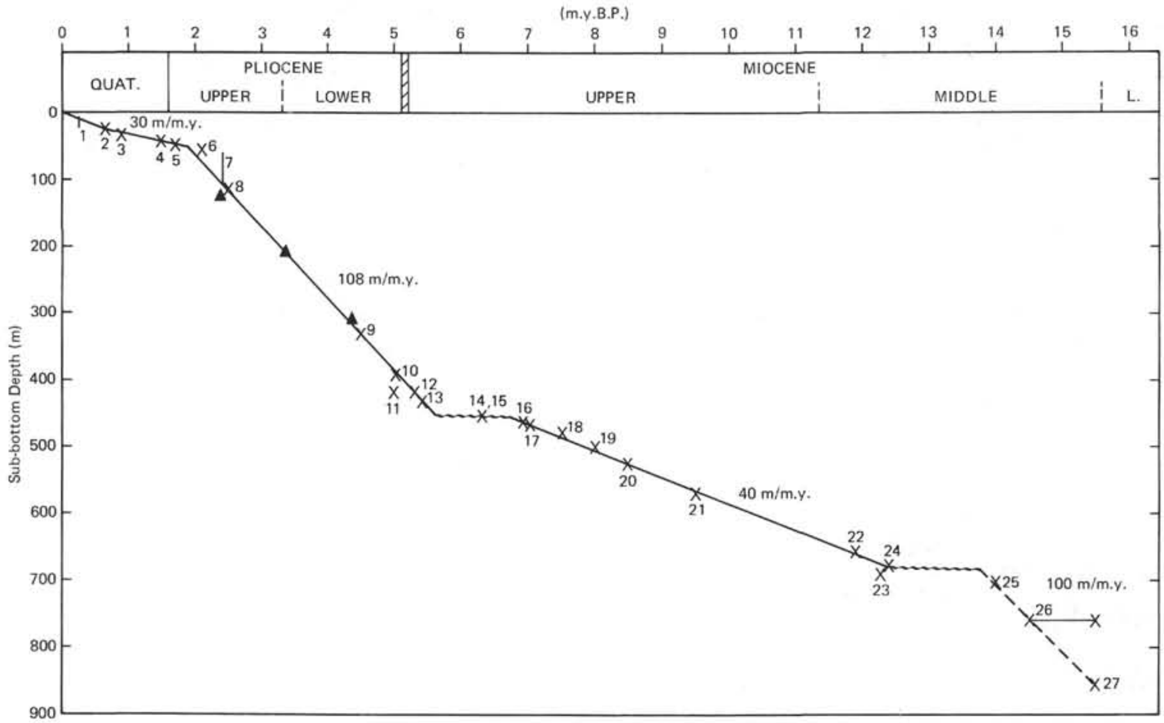

Figure 5. *Sediment accumulation rate curve calculated for Hole 438A using diatom datum levels listed below. (PM = Paleomagnetic boundaries in Hole 438A (Hall et al., this volume): Gauss/Matuyama = 120 m; Gauss/Gilbert = 210 m; top of upper "c" Event of Gilbert = 310 m. Diatom datums: 1 = last* Rhizosolenia curvirostris, *2 = last* Nitzschia reinholdii, *3 = last* Actinocyclus oculatus, *4 = first* R. curvirostris, *5 = last* Thalassiosira antiqua, *6 = last* T. convexa, *7 = last common* Denticula kamtschatica, *8 = last* N. jouseae, *9 = first* N. jouseae, *10 = first* T. oestrupii, *11 = last* T. miocenica, *12 = last* Asterolampra acutiloba, *13 = last* N. miocenica, *14 = first* N. reinholdii, *15 = first* D. kamtschatica, *16 = last* N. porteri, *17 = first* N. miocenica, *18 = last* T. burckliana, *19 = last* Coscinodiscus yabei, *20 = first* T. burckliana, *21 = last* D. lauta, *22 = first* Hemidiscus cuneiformis, *23 = last* C. lewisianus, *24 = last* D. nicobarica, *25 = first* D. hustedtii, *26 = range* Annellus californicus, *27 = first* D. lauta *s. str. See Table 14 for absolute ages of datum levels. Arrow indicates that the last* T. nativa, *at 166 meters in Hole 438A, has an estimated age of 2.95 m.y.B.P.)*

tains the diatom *Thalassiosira antiqua* and the silicoflagellate *Distephanus pseudofibula,* an overlap that is restricted to the interval from Sample 438A-44-5, 71–73 cm (476.2 m), through Sample 438A-47-1, 70–72 cm (498.7 m) (Subzone *b* of the *Denticula hustedtii* Zone). Sample 439-2,CC (556.6 m), which was cored over 50 meters below Core 1, contains the same diatom assemblage as Sample 439-1,CC, and downhole contamination is a possibility. The presence of *Rhizosolenia barboi, R. praebarboi,* and the silicoflagellate *Distephanus pseudofibula* in Sample 439-3,CC (649 m) argues for correlation with Cores 60 or 61 of Hole 438A (621.5–640.5 m) (Subzone *c* of the *Denticula hustedtii–D. lauta* Zone). *Denticula lauta, D. kanayae,* and *Delphineis penelliptica* in Sample 439-4,CC (749.3 m) occur within Subzone *a* of the *D. lauta* Zone within the interval from Cores 72 through 79 in Hole 438A. These data suggest that stratigraphic levels in the Miocene of Hole 439 are about 10 to 20 meters lower than they are in Hole 438A.

Continuous coring in Hole 439 began with Core 5 at 849.5 m. Diatoms were present, although they were generally rare and poorly preserved through Core 20. Below Core 20, no more than one or two specimens were observed on a microscope slide. These were usually specimens of the long-ranging, robust species, *Coscinodiscus marginatus,* and may represent contamination.

Sample 439-5,CC (852.1 m) is assigned to Subzone *a* of the *D. lauta* Zone; and although Sample 439-6,CC (859.1 m) is barren, Samples 439-7,CC (874.5 m) through 439-11,CC (910.8 m) correlate with the upper part of the *Actinocyclus ingens* Zone in Hole 438B. The presence of *C. endoi* and *C. lewisianus* in Sample 439-11,CC suggests correlation with the interval including Cores 6 through 8 and Sample 438B-9-1, 85–87 cm (872.1 to 901.2 m), in Hole 438B.

Below this interval in Hole 439, Cores 12 through 20 contain lower Miocene diatoms that are older than the *A. ingens* Zone. It is probable that a hiatus between Cores 11 and 12 of Hole 439 removes the lower part of the *A. ingens* Zone represented in Hole 438B.

The poorly preserved diatom assemblage of Cores 12 through 20 resembles the lower Miocene diatom assemblage reported at Site 348 in the Norwegian Sea by Schrader and Fenner (1976). Species observed include

TABLE 9
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellate *Mesocena apiculata curvata*, Cores 438B-4-438B-23

Time-Rock Unit	Zone		Sample (Interval in cm)	Abundance	Preservation	*Actinocyclus ingens*	*A. ingens* var. 1	*A. ingens* var. 2	*Coscinodiscus lewisianus*	*C. symbolophorus* var. 1	*C. symbolophorus* var. 2	*Nitzschia challengeri*	*Denticula ikebei*	*D. lauta*	*D.* cf. *lauta*	*D. nicobarica*	*D. norwegica*	*D. kanayae*	*Kieselviella carina*	*Mediaria splendida*	*Rhaphoneis miocenica*	*Rhizosolenia parebarboi*	*Stephanopyxis* cf. *schenckii*	*S. hyalomarginata*	*S.* spp.	*Synedra jouseana*	*S. jouseana* var. 1	*Thalassiosira* sp. 2	*Coscinodiscus endoi*	*C.* aff. *marginatus*	*Mesocena apiculata curvata*
MIDDLE MIOCENE	*D. lauta*	*a*	4-1 (92–94)	C	M	C	R	R	R			R		C		R			R	R		R	R		R	R			R		R
			4,CC	C	M	F						R		F	R	R		R	R	R		R	R			R			R		
			5-1 (87–89)	C	M	F				R		R		R	C			R	R	R		R	R	R	R	R			R		
			5,CC	C	M	C						R		R	C				R	R		R	R		R	R			R		
LOWER MIOCENE	*Actinocyclus ingens*		6-1 (16–19)	R	P	F			R	R		R			F				R	R	R		R	R							
			6,CC	C	P	F			R		R				R					R	R		R	R		R			R		R
			7-1 (128–130)	C	P	F				R					R		R		R		R		R			R			R		
			7,CC	C	M	F				F					R		R		R		R	R	R		R	R			R		
			8-1 (90–92)	C	M	F				R					R		R		F	R			R			R			R		R
			8,CC	F	P	F									R				R				R			R	R				
			9-1 (85–87)	F	P	F			R						R	R			R		R	R	R			F	R		R		
			9,CC	R	P	R				R	R				R			R			R		R			R					
			10-1 (9–10)	R	P	R				R					R			R					R	R		R					
			11-1 (60–61)	R	P	R				R	R							R					R			R					
			11,CC	F	M	R				R			R					R	R		R		R	R		R					
			12-1 (81–82)	F	P	R				R									R				R		R	R		R		R	
			12,CC	F	P	R				R			R					R	R				R			R				R	
			13-1 (68–70)	F	P	R				R			R					R	R				R							R	
			13,CC	F	P	R				R			R					F	R				F					R		R	
			14,CC	C	P	R				R			R					F	R	R			F			R		R		R	R
			15-2 (61–62)	R	P	R				R			R					R			R		R							R	
			15,CC	R	P	R					R							R			R		R			R				R	
			16-2 (82–84)	R	P	R				R	R		R					R					R					R		R	
			16,CC	F	P	R					R		R					R					F							R	
			barren																												
			22-1 (108–110)	R	P					R									R				R								
			22,CC	R	M													R								R					
			23,CC	R	P	R												R					R								

Note: Cores 17 through 21 are barren of diatoms.

C. symbolophorus varieties, *Synedra jouseana* var. 1 (large form), *Cestodiscus* spp., *T. fraga, T. spinosa, T. spinosa* var. *aspinosa,* and *T. spumellaroides.* These taxa and the lack of Oligocene diatoms argue strongly for an early Miocene age.

Site 440

Site 440 (39°44.13′ N, 143°55.74′ E; 4509 m water depth) was drilled on a midslope terrace of the Japan Trench landward wall to help determine the point of transition from continental to oceanic crust. A thick, nonfolded section of upper Miocene to Quaternary continental slope sediment showing no evidence of accretion was recovered from the composite of the three holes (Holes 440, 440A, and 440B) cored at this site.

Preservation of diatoms is good to moderate down through Core 38 (497.0 m) of Hole 440B, poor to moderate between Cores 39 (500.5 m) and 60 (705 m) of Hole 440B, and poor to the base of Hole 440B in Core 71 (814 m). Diatoms are common to abundant down to a depth of 497 meters, few to common between 500 and 733 meters, and generally rare below that level.

The occurrences of selected diatoms and silicoflagellates in the section cored at Site 440 are given in Tables 10 through 12. The stratigraphic ranges of diagnostic diatoms and silicoflagellates in this section are shown in Figure 6.

Cores 1 through 5 of Hole 440 are placed in the uppermost Quaternary *Denticula seminae* Zone. Reworked earlier Pleistocene diatoms such as *Nitzschia fossilis, N. reinholdii, Rhizosolenia barboi, R. curvirostris,* and *Thalassiosira nidulus* var. *nidulus* occur in Cores 1 and 2 of Hole 440 within a pebble-rich sediment. As at Site 438, the apparent last occurrences of *R. curvirostris, R. barboi,* and *Thalassiosira nidulus* var. *nidulus* in Sample 440-6,CC (52 m) mark the top of the *R. curvirostris*

TABLE 10
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellate *Mesocena quadrangula*, Holes 440, 440A, and Cores 440B-1–440B-18

Time-Rock Unit		Zone	Subzone	Sample (Interval in cm)	Abundance	Preservation	*Actinocyclus ingens*	*A. ochotensis*	*A. oculatus*	*Bacteriosira fragilis*	*Coscinodiscus pustulatus*	*Denticula kamtschatica*	*D. seminae*	*D. seminae* var. *fossilis*	*Nitzschia fossilis*	*N. marina*	*N. reinholdii*	*Porosira glacialis*	*Pseudoeunotia doliolus*	*Rhizosolenia barboi*	*R. curvirostris*	*R. hebetata hiemalis*	*Roperia tesselata*	*Stephanopyxis horridus*	*Thalassiosira antiqua*	*T. gravida*	*T. gravida* (flat form)	*T. hyalina*	*T. nidulus* var. *nidulus*	*T. oestrupii*	*T. pacifica*	*T. punctata*	*Mesocena quadrangula*
				Hole 440																													
QUATERNARY	UPPER	*D. seminae*		1,CC	C	G	Ⓡ	R					R	R	Ⓡ	R	Ⓡ		R	Ⓡ	Ⓡ	R				C			Ⓡ	R	R		
QUATERNARY	UPPER	*D. seminae*		2,CC	C	G		R		R			R	F		R		R	R	Ⓡ	Ⓡ	R				C			Ⓡ	R	R		
QUATERNARY	UPPER	*D. seminae*		3,CC	C	M		R		R			R	R		R		R				F				C				R	R		
QUATERNARY	UPPER	*D. seminae*		4,CC	A	G	Ⓡ	R		R			R	R		R				Ⓡ		F				F		R	Ⓡ	R	F		
QUATERNARY	UPPER	*D. seminae*		5,CC	C	M		R		R			R	R		R		R				R	R			C		R		F	R		
QUATERNARY	UPPER	*R. curvirostris*	*b*	6,CC	C	M		R						F		R		R		R	R	R				F		R	R	R	R		
QUATERNARY	UPPER	*R. curvirostris*	*b*	7,CC	C	M		R					R	F						R	F	R				F		R	R	R	R		
QUATERNARY	UPPER	*R. curvirostris*	*b*	8,CC	C	M		R		R			R	R		R		R		R	F	R				R		R	R	R	R		
				Hole 440A																													
QUATERNARY	UPPER	*R. curvirostris*	*b*	2,CC	A	M		F						R		R			R	R	R	R				F			R	F	R		
QUATERNARY	UPPER	*R. curvirostris*	*b*	3,CC	A	M		R		R				R		F			R	R	R	R				F		R	R	R	R		
QUATERNARY	UPPER	*R. curvirostris*	*b*	4,CC	C	M		R		R		Ⓡ		R		F					R	R			Ⓡ	F	R		R	R			
QUATERNARY	UPPER	*R. curvirostris*	*b*	5,CC	C	M	Ⓡ	R						R		F			R	R	R					F	F	R	R	R			
QUATERNARY	UPPER	*R. curvirostris*	*b*	6,CC	C	M		F					R	F		R			F	F	R	R				F	R		R	R			
QUATERNARY	UPPER	*R. curvirostris*	*b*	7,CC	A	M		R						R		R			R	R	R	R	R			R	R		R	F			
				Hole 440B																													
QUATERNARY	UPPER	*R. curvirostris*	*b*	1,CC	A	M	Ⓡ	F	Ⓡ	R			R	F		R			R	R	R	R				F	F		R	F			
QUATERNARY	UPPER	*R. curvirostris*	*a*	2,CC	C	M		R		R			R	F		F	R		R	F	F	R				F	F		F	F			
QUATERNARY	UPPER	*R. curvirostris*	*a*	3,CC	F	M		R		R				R	R	F	R		R	R	R					R	R	R		R			
QUATERNARY	UPPER	*R. curvirostris*	*a*	4,CC	F	M		R						R		R	R			R	R					R				R			
QUATERNARY	UPPER	*R. curvirostris*	*a*	5,CC	C	M		R		R			R	F	R	F	R		R	R	R					R	F			R			R
QUATERNARY	UPPER	*R. curvirostris*	*a*	6,CC	C	M		R					R	R		R	R	R	R	R	R					R	R			R			
QUATERNARY	LOWER	*A. oculatus*		7,CC	C	M			R				R	F	R	R	R		R	R	R					F	F			R			R
QUATERNARY	LOWER	*A. oculatus*		8,CC	F	M		R	F	R			R	R	R	R	R			R	R					R	R			R			
QUATERNARY	LOWER	*A. oculatus*		9,CC	F	M	Ⓡ	R	F				R			R	R		R		R					R	R			R			
QUATERNARY	LOWER	*A. oculatus*		10,CC	C	M		F	C				R	C		F	R		R	F	R					R	R			R			R
QUATERNARY	LOWER	*A. oculatus*		11,CC	C	M	Ⓡ	C	F					R		R	R		R	F	F					R	R			R			
QUATERNARY	LOWER	*A. oculatus*		12,CC	C	M	Ⓡ	F	C			Ⓡ	R	F		R	F		R	R	R					R	R			R			
QUATERNARY	LOWER	*A. oculatus*		13,CC	F	M	Ⓡ	R	F					R		R	R			R						R	R			R			
QUATERNARY	LOWER	*A. oculatus*		14,CC	F	M		R	R					F		R	R		R	R	R					R	R						
QUATERNARY	LOWER	*A. oculatus*		15,CC	F	M		F	R				R	F		R	R		R	F					R	R	R			R		R	
QUATERNARY	LOWER	*A. oculatus*		16,CC	C	M		F	R					F	R	R	F			F					R	R	R			R		R	
QUATERNARY	LOWER	*A. oculatus*		17,CC	F	M		C	R			Ⓡ		F	R	F	R		R	R					R	R				R		R	
UPPER PLIOCENE		*D. seminae fossilis*		18,CC	C	M		R	R		R	Ⓡ	R	R	R	F	F	R	R	R				R	R	R	R			R		R	

Note: Holes 440, 440A, and 440B comprise a composite section with no overlap.

Zone. The *R. curvirostris* Zone is divided into two subzones, Subzone *a* and Subzone *b*, by the last occurrence of *N. reinholdii* in Sample 440B-2,CC (149.3 m). The younger subzone, Subzone *b*, contains the first occurrence of *T. pacifica (Coscinodiscus excentricus* var. *leasareolatus* of Koizumi, 1973) in Sample 440A-3,CC (96 m), and the last occurrence of *T. gravida* (flat form) in Sample 440A-4,CC (104 m). The first occurrence of *R. hebetata* f. *hiemalis* in Sample 440B-2,CC (149.3 m) and the last occurrence of *N. fossilis* in Sample 440B-3,CC (168 m) lie near the top of Subzone *a*. Also notable is the probable last occurrence of the silicoflagellate *Mesocena quadrangula* in Sample 440B-5,CC (187 m).

The *T. pacifica, T. gravida* (flat form), and *R. hebetata* f. *hiemalis* datums occur in the same sequence within the *R. curvirostris* Zone at Site 438, a relationship that suggests their value for local correlation. The last occurrences of *N. fossilis* and *M. quadrangula* appear to approximate closely their last occurrences in the tropical Pacific (Burckle, 1977; Barron, in press).

The top of the lower Quaternary *Actinocyclus oculatus* Zone is placed in Core 7 (204 m) of Hole 440B at the last occurrence of the nominate species. *Rhizosolenia curvirostris* has its first occurrence near the base of the *A. oculatus* Zone in Sample 440B-14,CC (272.5 m). The base of the *A. oculatus* Zone apparently corresponds

TABLE 11
Stratigraphic Occurrence of Selected Diatoms, Cores 440B-18–440B-48

Time-Rock Unit	Zone	Sample (Interval in cm)	Abundance	Preservation	*Actinocyclus ochotensis*	*A. oculatus*	*Bacteriosira fragilis*	*Cosmiodiscus insignis*	*Coscinodiscus pustulatus*	*Cussia tatsunokuchiensis*	*Denticula hustedtii*	*D. kamtschatica*	*D. seminae*	*D. seminae* var. *fossilis*	*Hemidiscus cuneiformis*	*Nitzschia fossilis*	*N. jouseae*	*N. marina*	*N. reinholdii*	*Porosira glacialis*	*Rhizosolenia barboi*	*R. praebergonii* var. *robusta*	*Stephanopyxis horridus*	*Thalassiosira antiqua*	*T. convexa*	*T. convexa* var. *aspinosa*	*T. gravida*	*T. gravida* (flat form)	*T. hyalina*	*T. nativa*	*T. nidulus* var. *nidulus*	*T. nidulus* var. *delicata*	*T. oestrupii*	*T. punctata*	*T. zabelinae*	*T. jacksonii*	*T. convexa* var. 1
PLIOCENE, UPPER	*D. seminae* var. *fossilis*	19,CC	C	M	C	F			R			Ⓡ	R	R		R		R	R		R		R	R			R				R		R	R			
		20,CC	C	M	R	F	R		R			Ⓡ	R	F		R		R	R		R	R	R	R			R		R		R		R	R			
		21-3 (30–31)	A	M		R			R			Ⓡ	R	F	R	R		R	F		F	R		R			R				R		R				
		21,CC	F	M	R	R			R			Ⓡ	R	F	R	R		R	R		R		R				R	R			F		R	R			
		22-3 (123–124)	F	M	F	R			R					R		R		R	F		R			R			R				R		R		R		
		22,CC	C	M	C	R						Ⓡ		R		R		F	R		F		R	R			R	R			R		R		R		
		23,CC	C	M	R	R			R			Ⓡ		C	R	R		R			C		R	R				F			R		R		R		R
		24,CC	F	M	R	R			R			Ⓡ		F	R			R			F			R			R	R							R		
		25,CC	C	M	R	R						Ⓡ		C				R			R		R	R	R	R	R				R		R		R		R
	D. seminae var. *fossilis*–*D. kamtschatica*	26,CC	C	M		R						C		F	F			R			F		R	R		R		R			R		F		R		R
		27,CC	C	M	R	R						C		R	R	R		R	R		R			R			R	R		R	R		F		R	R	R
		28,CC	C	M		R						F		R	C	R		R	R		R			R		R					R		F		R	R	R
		29,CC	C	M								C		R	F	R	R	R			R			R		R	R				R		F		R		R
		30,CC	C	M	R	R					Ⓡ	C						R	R		R			R		R		R			R		R		F		R
		31,CC	C	M	R	R					Ⓡ	C		R	R			R	R		R			R		R	R	R			R		R		C		R
		32,CC	C	M	R	R				R	Ⓡ	C			R						R			R				F			R	R	R		C		R
		33,CC	C	M	R	R						C		R	R		R	R	R					R			R	F		R	R		F		F		R
PLIOCENE, LOWER	*Denticula kamtschatica*, c	34,CC	C	M	R	R						A			R		R	R	R		R					R		R		R	R		F		F		R
		35,CC	C	M	F							A						R			R			R				R		R	R		R		F		R
		36,CC	C	M	R					R		C				R		R			R							R		R			R		F		R
		37,CC	A	M	R							C			F	R		R			R									R			F		F		R
		38,CC	C	P	R					R		F			R	R		R	R					R						R			R		R	R	
		39,CC	F	P	R					R		F			R	R		R												R			R		R		
		40,CC	F	P	R							F				R					R			R							R		R		F		
		41,CC	F	P							R	F			R	R		R	R		R			R						R			R		R		
		42,CC	F	P	R							F				R		R						R						R			R		F		
		43,CC	F	P								F			R	R	R				R									R			R		F		R
		44,CC	F	M							R	C						R																	R		
		45,CC	C	M	R				R		R	C							R					F				R		R		R	R		F	R	
	Denticula kamtschatica, b	46,CC	C	M	R			R	R			C			R	R	R	R			R			F				R		R			R		F		R
		47,CC	C	M	F			R			R	C				R	R	R			F			R				R		R		R	R		F	R	R
		48,CC	C	M	R							F					R	R	R		F			F				R				R	R		F	R	R

with the last occurrences of *Stephanopyxis horridus* and *C. pustulatus* in Sample 440B-18,CC (307.6 m). Very rare *T. antiqua* and *T. punctata* in Cores 15 through 17 may represent reworking, because nannofossils (Shaffer, this volume) and radiolarians (Reynolds, this volume) assign these cores to the Quaternary.

Pseudoeunotia doliolus has its first occurrence in the uppermost part of the *Denticula seminae* var. *fossilis* Zone in Sample 440B-18,CC (307.6 m). The *D. seminae* var. *fossilis* Zone occurs downhole through Core 25 and contains the first occurrence of *D. seminae* in Sample 440B-21,CC (337 m) and the last occurrences of *T. zabelinae* (Sample 440B-22-3, 121–123 cm [341 m]) and *T. convexa* s. ampl. (Sample 440B-23,CC [355 m]), as reported by Koizumi (1977) for middle latitudes of the North Pacific.

The last common occurrence of *D. kamtschatica* in Sample 440B-26,CC (378.5 m) marks the top of the *D. seminae* var. *fossilis–D. kamtschatica* Zone. As in Hole 438, *D. seminae* var. *fossilis* is rare below the top of this zone, and the last occurrence of *N. jouseae* is in the upper part of the zone (Sample 440B-29,CC [410 m]).

The base of the *D. seminae* var. *fossilis–D. kamtschatica* Zone is placed at the first occurrence of *D. seminae* var. *fossilis* in Sample 440B-33,CC (450 m) and coincides with the last occurrence of *T. nativa*. The first occurrence of *A. oculatus* is immediately below in Sample 440B-34,CC (458.2 m).

Cores 34 through 45 of Hole 440B are assigned to Subzone *c* of the *D. kamtschatica* Zone, and the last occurrence of *Cosmiodiscus insignis* in Sample 440B-46,CC (572 m) marks the top of Subzone *b*. As at Site 438, the first occurrence of *N. jouseae* is immediately below the top of Subzone *b* in Sample 440B-48,CC (594 m).

The last occurrence of *Rouxia californica* and the first occurrence of *T. oestrupii* in Sample 440B-56,CC

TABLE 12
Stratigraphic Occurrence of Selected Diatoms and the Silicoflagellate *Distephanus pseudofibula*, Cores 440B-49–440B-71

Time-Rock Unit	Zone		Sample (Interval in cm)	Abundance	Preservation	*Actinocyclus ingens*	*A. ochotensis*	*Cosmiodiscus insignis*	*Coscinodiscus temperei*	*Cussia tatsunokuchiensis*	*D. hustedtii*	*D. kamtschatica*	*D. lauta*	*Goniothecium tenue*	*Nitzschia fossilis*	*N. marina*	*N. pliocena*	*N. praereinholdii*	*N. reinholdii*	*Rhizosolenia barboi*	*Rouxia californica*	*Synedra jouseana*	*Thalassionema hirosakiensis*	*Thalassiosira antiqua*	*T. convexa* var. *aspinosa*	*T. gravida*	*T. gravida* (flat form)	*T. nativa*	*T. nidulus* var. *nidulus*	*T. nidulus* var. *delicata*	*T. oestrupii*	*T. punctata*	*T. zabelinae* s. ampl.	*T. jacksonii*	*T. convexa* var. 1	*Distephanus pseudofibula*
LOWER PLIOCENE	*Denticula kamtschatica*	*b*	49,CC	C	P	R					R	C			R	R				R				R				R	R		R		F	R		
			50,CC	F	P	R	R					F				R				R				R				R			R	R	R	R		
			51,CC	C	M	R	R	R			R	C			R					R				R			R	R			R		C		R	
			52,CC	C	P						R	C								R				R				R			R	R	F			
			53,CC	C	M	R	R	R			R	C				R				R				R			R	R			R		C		R	
			54,CC	C	M		R					C			R	R			R	R					R					R	R		R			
			55,CC	F	M	R						C																R					F			
UPPER MIOCENE		*a*	56,CC	C	P		R			R	R	C				R				R	R							F			R		C			
			57,CC	F	P	R	R				R	F			R	R			R									R					F			
			58,CC	R	P	R					R	R				R					R												R			
			59,CC	R	P	R					R	R				R			R		R			R								R	R			
			60,CC	F	M	R	R				R	R			R	R			R		R			R				R				R	R			
	Denticula hustedtii	*b*	61,CC	F	P	R			R			cf.		R		R				R	R					R		F					R			
			62,CC	F	P	R					R	cf.		R							F	R						R								
			63,CC	F	P	R					R	cf.			R	R					F	R		R				F					R			
			64,CC	R	P							cf.		R		R					R	R		R				R					R			
			65,CC	R	P	R					R	cf.		R	R						R	R		R				R					R			
			66-3 (8–11)	R	P	R					R	cf.		R	R						R		R	R				R					R			
			66,CC	R	P						R										R		R													
			67,CC	R	P	R					R										R		R													
			68,CC	R	P	R									R						R		R										R			
			69,CC	R	P	R					R				R			R		R	R		R													
			70,CC	R	P	R							R				R			R	R		R													R
			71-2 (3–6)	F	P	R					R			R							R		F					R								
			71,CC	R	P	R					R			R	R						R		F													R

(667 m) define the base of Subzone *b* and the top of Subzone *a* of the *D. kamtschatica* Zone and approximate the Miocene/Pliocene boundary.

The base of the *D. kamtschatica* Zone is marked by the first occurrence of *D. kamtschatica* s. str. in Sample 440B-60,CC (705 m). The first occurrence of *N. reinholdii* is also at the base of the zone.

Assemblages in Cores 61 through 71 are correlated with Subzone *b* of the *D. hustedtii* Zone. The last occurrence of *Synedra jouseana* in Sample 440B-62,CC (721 m), the last occurrence of *Thalassionema hirosakiensis* in Sample 440B-66-3, 8–11 cm (761.5 m), the first occurrence of *Thalassiosira zabelinae* s. ampl. in Sample 440B-68,CC (780.6 m), and the last occurrence of the silicoflagellate *Distephanus pseudofibula* in Sample 440B-70,CC (795 m) suggest that this interval is correlative with Cores 43 through 45 of Hole 438A, so that the upper Miocene hiatus that was recognized in Core 42 of Hole 438A probably occurs between Cores 60 and 62 in Hole 440B (Figure 7).

Site 441

Site 441 (39°45.05′ N, 144°04.59′ E; 5655 m water depth) was drilled on the lower continental slope with the objective of penetrating the accretionary prism. Unfortunately the results were rather disappointing. Core recovery was small, and a third attempt at sampling at this site had to be terminated when the drill string became stuck.

Upper Miocene through Quaternary sediment was recovered from the three holes (441, 441A, and 441B) drilled at Site 441. The stratigraphic occurrences of selected diatoms in a composite of these three holes are shown in Table 13. At Site 441 a thin (about 3 m) cover of upper Quaternary (*Denticula seminae* Zone) unconformably overlies a thicker section of Pliocene and upper Miocene sediment. Although recovery was small and discontinuous, no repetition of section was observed; a normal sequence from the *D. seminae* var. *fossilis* through the *D. seminae* var. *fossilis*–*D. kamtschatica* Zone and into the *D. kamtschatica* Zone is present (Table 13). Cores 10 and 11 of Hole 441A (577–587 m), however, contain very poorly preserved middle Miocene diatoms such as *Coscinodiscus endoi, C. lewisianus, D. lauta,* and *Mediaria splendida* without younger diatoms. It is possible that the highly brecciated sediment of these cores represents a slump of material that is exposed upslope.

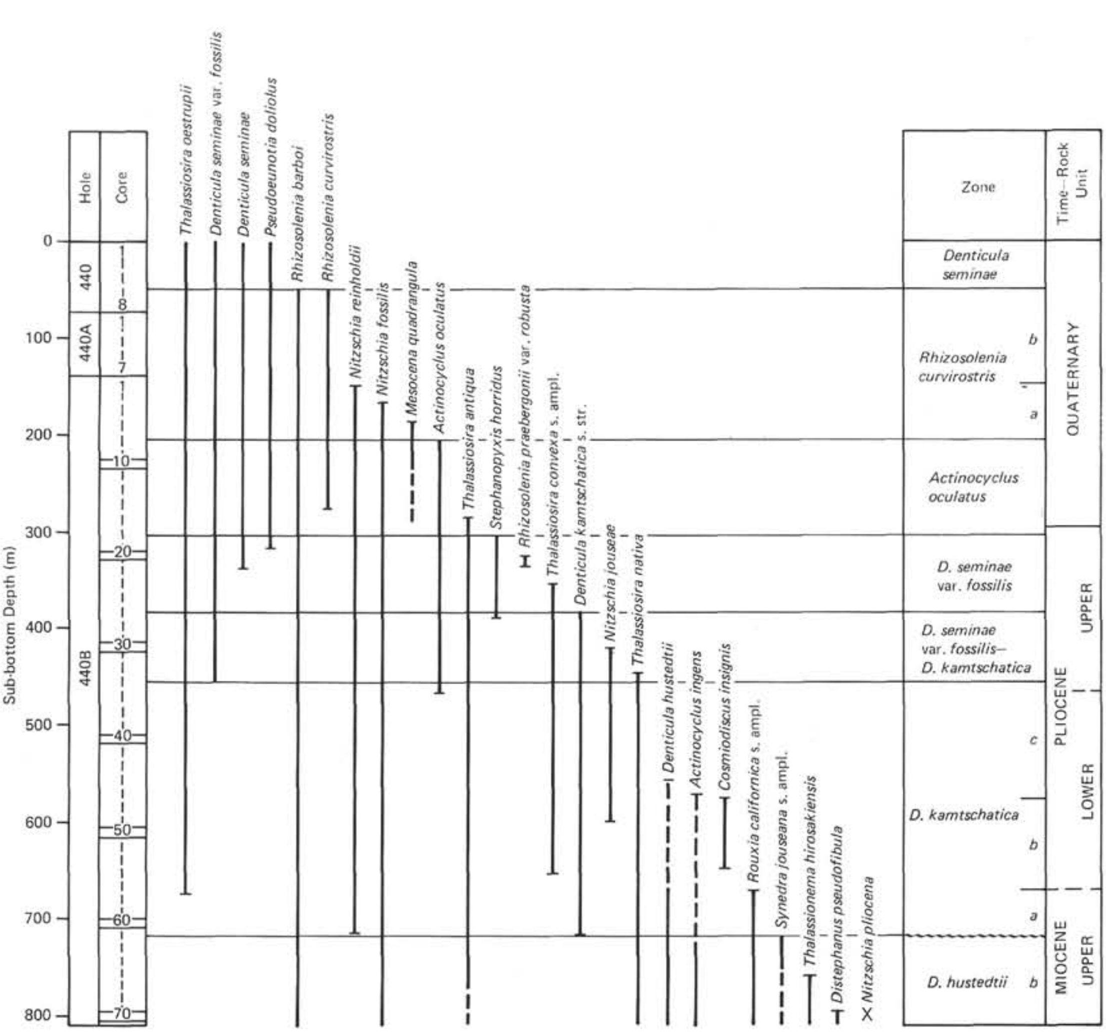

Figure 6. *Stratigraphic ranges of selected diatoms and the silicoflagellates* Mesocena quadrangula *and* Distephanus pseudofibula *in the section cored at Site 440. (Note the near correspondence between the first occurrence of* Denticula seminae *var.* fossilis *and the last occurrence of* Thalassiosira nativa.*)*

Preservation is good to moderate down to Sample 441-4,CC (26.0 m); generally moderate in the interval below through Sample 441-9,CC (267.2 m); moderate to poor from Sample 441B-1-2, 62–64 cm (337.6 m), through Sample 441A-8,CC (511.6 m); and poor below that level. Diatoms are common to abundant down to Core 9 of Hole 441 (264 m); few in the interval from Sample 441B-1-2, 62–64 cm (337.6 m), through Sample 441A-8,CC (511.6 m); and rare below that level.

Sample 441-2-1, 30–32 cm (7.3 m), lies just below the Pliocene–Quaternary boundary, as evidenced by the joint occurrences of *Rhizosolenia praebergonii* var. *robusta, Pseudoeunotia doliolus,* and *Thalassiosira antiqua.* The base of the *D. seminae* var. *fossilis* Zone is approximated by the last common occurrence of *D. kamtschatica* in Sample 441-7-1, 65–67 cm (150.1 m). *Nitzschia jouseae* has its last occurrence in the same sample. Important datum levels within the *D. seminae* var. *fossilis* Zone include the first occurrence of *P. doliolus* in Sample 441-2-3, 90–92 cm (10.9 cm), and the apparent last occurrence of *T. convexa* var. *aspinosa* in Sample 441-3,CC (16.7 m).

The *D. seminae* var. *fossilis–D. kamtschatica* Zone occurs from Sample 441-7-1, 65–67 cm (150.1 m), through approximately Sample 441-9,CC (267.2 m), where *Actinocyclus oculatus* has its first occurrence. *D. seminae* var. *fossilis* is rare or absent within this interval, as it was at Sites 438 and 440.

The interval from Sample 441B-1-2, 62–64 cm (337.6 m) through Sample 441A-8,CC (511.6 m) is assigned to Subzone *c* of the *D. kamtschatica* Zone. *Cosmiodiscus insignis* was not recorded in these fairly poorly preserved assemblages, and the base of the subzone is approximated by the first occurrence of *N. jouseae.*

The last occurrence of *Rouxia californica* in Sample 441A-11-1, 50–52 cm (568.5 m), marks the top of Subzone *a* of the *D. kamtschatica* Zone and the Miocene/Pliocene boundary. The poorly preserved assemblages down through Sample 441B-2-2, 78–80 cm (670.3 m), near the base of the section sampled at Site 441, are assigned to the upper Miocene Subzone *a* of the *D. kamtschatica* Zone, based on the co-occurrences of *D. kamtschatica* s. str., *N. reinholdii,* and *R. californica.* Wash core Sample 441B-H-2-4, 130–150 cm (402.0–668.0 m),

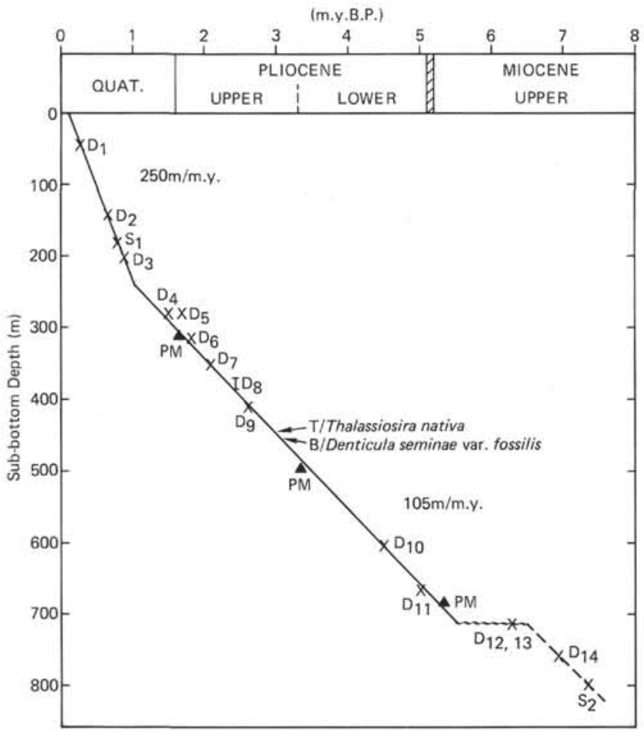

Figure 7. *Sediment accumulation rate curve for Site 440 plotted from diatom and silicoflagellate datum levels listed below. (PM = Paleomagnetic boundaries determined in Hole 440B [Hall et al., this volume]: top of Olduvai Event = 310 m; Gauss/Gilbert = 495 m; and Gilbert/Epoch 5 = 680 m. Datum levels:* D_1 = *last* Rhizosolenia curvirostris, D_2 = *last* Nitzschia reinholdii, S_1 = *last* Mesocena quadrangula *[silicoflagellate]*, D_3 = *last* Actinocyclus oculatus, D_4 = *first* R. curvirostris, D_5 = *last* Thalassiosira antiqua, D_6 = *first* Pseudoeunotia doliolus, D_7 = *last* T. convexa, D_8 = *last* Denticula kamtschatica, D_9 = *last* N. jouseae, D_{10} = *first* N. jouseae, D_{11} = *first* T. oestrupii, D_{12} = *first* D. kamtschatica, D_{13} = *first* N. reinholdii. *Other datum levels extrapolated from the sediment accumulation rate curve for Hole 438A:* D_{14} = *last* Thalassionema hirosakiensis, S_2 = *last* Distephanus pseudofibula *[silicoflagellate]. See Table 14 for absolute ages of datum levels. The last* Thalassiosira nativa, *at about 145 meters, has an absolute age estimated at 2.95 m.y.B.P. by the curve. The first* D. seminae *var.* fossilis, *at about 155 meters, has an absolute age estimated at about 3.1 m.y.B.P. by the curve.)*

contains *N. miocenica, T. miocenica,* and *D. kamtschatica* s. str. and is very similar to the uppermost Miocene assemblage recovered from Hole 438A.

DISCUSSION

In Figure 8 the holes drilled during Leg 57 are correlated by diatoms and silicoflagellates. Thin Quaternary sections in Holes 438 and 438A and at Site 441 are contrasted with a thick (about 300 m) Quaternary section at Site 440. The good biostratigraphic control suggests similar Pliocene and uppermost Miocene sections at Sites 438 and 440. Poor recovery at Site 441 results in relatively few correlations with the other sites, but an expanded Pliocene section at Site 441 is indicated. Whether this thickened section is due to imbrication or greater sediment accumulation rates at Site 441 cannot be determined from the available diatom data.

Figure 8 also shows that the uppermost Miocene hiatuses in Core 42 of Hole 438A and between Cores 60 and 62 of Hole 440B are correlative.

Miocene stratigraphic levels in Holes 438B and 439 appear to be about 10 to 30 meters lower than they are in Hole 438A. Figure 8 reveals that the composite section drilled at Sites 438, 439, and 440 represents a nearly complete upper lower Miocene through Quaternary reference section for diatoms.

A number of diatom and silicoflagellate datum levels in the equatorial and North Pacific have been correlated to paleomagnetic stratigraphy by Burckle (1972, 1977, 1978), Burckle and Opdyke (1977), Koizumi (1975d), and Donahue (1970) (Table 14). In addition, Koizumi (1977) provides estimates of the absolute age of the first occurrence of *Denticula hustedtii* and the last occurrence of *D. lauta* from potassium-argon dates in Japan.

In Figures 5 and 7 these datum levels and the results of paleomagnetic studies on Leg 57 sediments (Hall and others, this volume) are used to construct sediment accumulation rate curves for Hole 438A and Site 440. In both cases, all of the points corresponding to the datum levels lie on or very near the plotted curve and attest to the good biostratigraphic control available in both sections. Upper Miocene and middle Miocene datum levels, tied to paleomagnetic stratigraphy in the equatorial Pacific by Burckle (1978), appear to show little or no diachroneity at the 40° N latitude of Site 438.

Figure 5 suggests sediment accumulation rates at Site 438 of about 30 m/m.y. for the Quaternary and uppermost Pliocene, about 108 m/m.y. for the remainder of the Pliocene and the uppermost Miocene, about 40 m/m.y. for the bulk of the upper Miocene and upper middle Miocene, and about 100 m/m.y. for the lower middle Miocene and upper lower Miocene. The uppermost Miocene hiatus in Core 42 of Hole 438A and a middle Miocene hiatus between Cores 65 and 66 of Hole 438A are also revealed by the plot.

Control on the bottom portion of the curve in Figure 5 is poor. The single occurrence of *Annellus californicus* in Sample 438A-73,CC (754.5 m), however, appears to approximate its correlative last occurrence in the southern California Continental Borderland based on its position just below the first occurrence of *D. hyalina* in Sample 438A-73-5, 46–48 cm (751.5 m) (Barron, unpublished data). Studies in the southern California Continental Borderland also suggest that the first occurrence of *D. lauta* s. str. is close to the lower Miocene/middle Miocene boundary, or about 15.5 m.y.B.P.

At Site 440, Figure 7 predicts sediment accumulation rates of about 250 m/m.y. for the upper and middle parts of the Quaternary and about 105 m/m.y. for the lower Quaternary through upper Miocene. The lower rate is very similar to the rate plotted for the Pliocene of Hole

TABLE 13
Stratigraphic Occurrence of Selected Diatoms in Holes 441, 441A, and 441B

Time-Rock Unit	Zone	Subzone	Sample (Interval in cm)	Sub-bottom Depth (m)	Abundance	Preservation	*Actinocyclus ingens*	*A. oculatus*	*Coscinodiscus endoi*	*C. lewisianus*	*C. pustulatus*	*C. symbolophorus*	*Cussia tatsunokuchiensis*	*Denticula kamtschatica*	*D. hustedtii*	*D. lauta* s. ampl.	*D. seminae*	*D. seminae* var. *fossilis*	*Goniothecium tenue*	*Mediaria splendida?*	*Nitzschia fossilis*	*N. jouseae*	*N. marina*	*N. reinholdii*	*Pseudoeunotia doliolus*	*Rhizosolenia barboi*	*R. praebergonii*	*R. praebergonii* var. *robusta*	*Roperia tesselata*	*Synedra jouseana*	*Thalassiosira antiqua*	*T. convexa*	*T. convexa* var. *aspinosa*	*T. nativa*	*T. nidulus* var. *nidulus*	*T. oestrupii*	*T. zabelinae*	*T. jacksonii*	*Rouxia californica*	*Stephanopyxis horridus*
			Hole 441																																					
QUATERNARY	*Denticula seminae*		1-2 (31-33)	1.8	A	G		Ⓡ						Ⓡ			R						R													R				
			1,CC	3.0	A	G								Ⓡ			F	R					R		R											F				
UPPER PLIOCENE	*Denticula seminae* var. *fossilis*		2-1 (30-32)	7.3	A	G		F									F	A					R	R	R	F		R			R				R	R				
			2-2 (34-36)	8.8	C	G		F			R						F	C					R	R	R	R			R						R	R			Ⓡ	
			2-3 (90-92)	10.9	A	M		F			R			Ⓡ			R	A			R		R	R	R	F			R		R				R	F				
			2-4 (20-22)	11.7	A	G		F						Ⓡ			R	A			R		R	R		R		R	R		R				R	R	R			
			2-5 (50-51)	13.5	C	M	Ⓡ	R						Ⓡ			R	C			R		R	R		R									R	R				R
			2,CC	14.2	A	G		F			R			Ⓡ			R	C			R		R	R		F		R	R		R				R	R	R			F
			3,CC	16.7	C	G		F			R			Ⓡ			R	C			R		R	F		R			R				R		F	R				R
			4,CC	26.0	A	G		R										A			R		R	F		F		R			R		R		R	F	R			R
			6,CC	92.5	C	M		F			R			Ⓡ				C			R		R	R		F	R								R	F	R			R
			Hole 441A																																					
			2-1 (20-21)	130.2	F	M		F			R			Ⓡ				F			R		R	R		R									R	R				R
			2,CC	130.5	C	M		R			R			Ⓡ				C			R			R		F					R				R	R				
			Hole 441																																					
	Denticula seminae var. *fossilis*–*D. kamtschatica*		7-1 (65-67)	150.1	C	M	Ⓡ	R						F		Ⓡ		R			R	R	R			R					R		R		R	F	R			
			7,CC	151.5	A	M	Ⓡ	R					R	A		Ⓡ		R				R	R	R		R					R	R	R			F	R			
			8-1 (53-55)	207.0	C	M		R						C												R					R	R			R	R	F			
			8-2 (14-15)	208.1	C	M	Ⓡ	R			R			C										R		R							R			R	R			
			8,CC	208.4	C	M							R	A							R	R	F	R							R				R	F	R		Ⓡ	
			9-1 (51-52)	264	F	M		R						A								R		R							R					R	F			
			9,CC	267.2	A	M		R				R		A									R	R		R							R			F	R			
LOWER PLIOCENE	*Denticula kamtschatica*	c	Hole 441B																																					
			1-2 (62-64)	337.6	F	P								F							R		R	R		R					R					R	R			
			1,CC	339.1	F	M								A							R		R	R							R					R	R			
			Hole 441A																																					
			5-3 (71-73)	390.2	F	P						R		F	R								R											R			R			
			5,CC	391.2	F	P								F		Ⓡ					R			R							R					R	R			
			8-1 (116-118)	511.2	F	M								F	R						R	R		R		R					R		R			R	R	R		
			8,CC	511.6	F	P	R							C							R	R	R	R		R					R					R	R	R		
		b	9,CC	568	R	P	R							R												R								R				R		
			10-1 (89-91)	577.4	R	P										Ⓡ																								
			10-1 (130-131)	577.8	R	P	R			Ⓡ						Ⓡ																								
			10,CC	578.7	R	P																																		
UPPER MIOCENE		a	11-1 (50-52)	586.5	R	P	R		Ⓡ							Ⓡ				Ⓡ										R									R	
			11-1 (68-69)	586.7	R	P	R									Ⓡ				Ⓡ																				
			11,CC	587.5	R	P	R		Ⓡ	Ⓡ						Ⓡ																							R	
			12-1 (70-71)	605.7	R	P								R																									R	
			12,CC	607.2	R	P	R							R		Ⓡ					R																		R	
			13-1 (60-62)	624.6	R	P								R	R											R													R	
			13,CC	625.5	R	P								R																									R	
			14-1 (26-28)	643.3	R	P	R								R											R											R		R	
			14-1 (140-141)	644.4	R	P								R																									R	
			14,CC	644.7	R	P									R									R		R													R	
			15-1 (80-82)	653.3	R	P	R							R									R														R		R	
			15,CC	654.1	R	P								R							R																		F	
			Hole 441B																																					
			2-1 (149-150)	669.5	R	P	R							R	R	Ⓡ			R					R		R								R					R	
			2-2 (78-80)	670.3	R	P	R							R										R															F	
			2,CC	670.5	R	P																																	R	

438A (about 108 m/m.y.). An upper Miocene hiatus spanning the interval from about 6.5 to 5.5 m.y.B.P. is shown at about 710 meters, or between Cores 60 and 62 of Hole 440B. This hiatus corresponds closely in time and duration to an upper Miocene hiatus in Core 42 of Hole 438A (Figure 5).

The sediment accumulation rate curves (Figures 5 and 7) and the occurrence charts for Sites 438 and 440 provide the means of estimating the absolute ages of secondary diatom datum levels in the Leg 57 area. Figure 9 shows the diatom zonation for Leg 57, with primary and secondary datum levels plotted against a paleomagnetic time scale derived from LaBrecque and others (1977) and MacDougall and others (1977). Symbols indicate whether an individual datum level is correlated directly to the paleomagnetic scale or is extrapolated from the sediment accumulation rate curves. These secondary datum levels provide additional control and permit easy correlation with diatom zonations in use in other parts of the North Pacific.

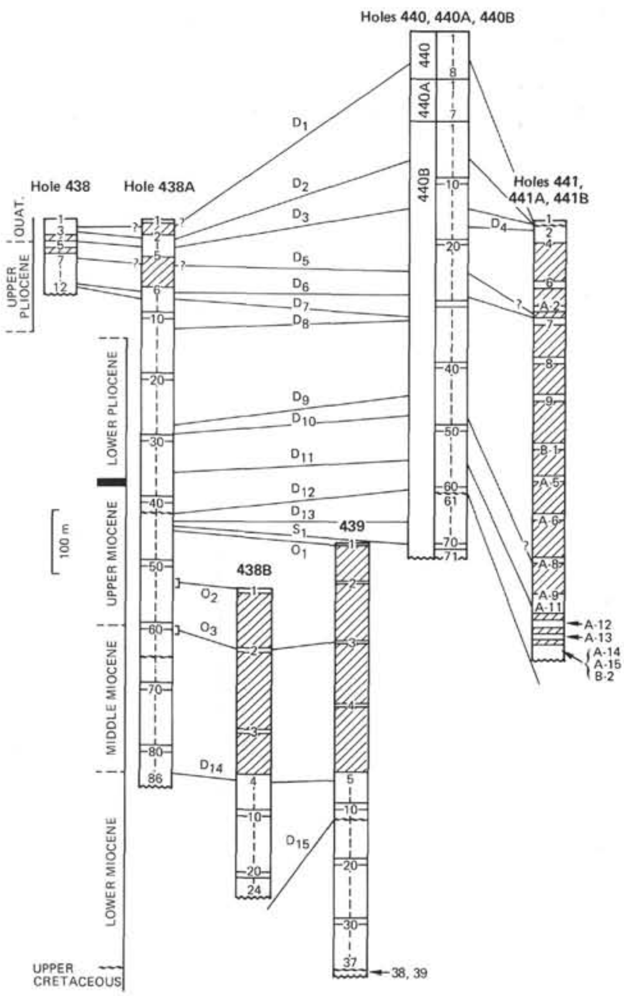

Figure 8. *Correlation of Leg 57 holes as determined by diatom and silicoflagellate datum levels. (*D_1 = *last* Rhizosolenia curvirostris, D_2 = *last* Actinocyclus oculatus, D_3 = *last* Thalassiosira antiqua, D_4 = *first* Pseudoeunotia doliolus, D_5 = *last* Denticula kamtschatica, D_6 = *last* Nitzschia jouseae, D_7 = *last* Cussia tatsunokuchiensis, D_8 = *last* Thalassiosira nativa, D_9 = *last* Cosmiodiscus insignis, D_{10} = *first* N. jouseae, D_{11} = *last* Rouxia californica, D_{12} = *first* D. kamtschatica *and first* N. reinholdii, D_{13} = *last* Thalassionema hirosakiensis, S_1 = *last* Distephanus pseudofibula *[silicoflagellate],* O_1 = *overlap of* D. pseudofibula *[silicoflagellate] and* Thalassiosira antiqua, O_2 = *occurrence of* Coscinodiscus endoi *above the last* Denticula lauta, O_3 = *overlap of* Distephanus pseudofibula *and* Mesocena hexagona *[silicoflagellates],* D_{14} = *first* Denticula lauta, D_5 = *first* Coscinodiscus endoi *and first* Coscinodiscus lewisianus. *Cross-hatched areas represent intervals not recovered.)*

In Figure 10 the middle Miocene and upper Miocene of Hole 438A are correlated by diatoms with the section cored at DSDP Site 173 (Figure 1) off northern California. Several datum levels result in a detailed correlation. The last occurrence of *Coscinodiscus yabei,* however, is diachronous; it occurs in the upper Miocene at Site 438

TABLE 14
Correlation of Diatom and Silicoflagellate Datum Levels to Paleomagnetic Stratigraphy and Estimate of Absolute Age

	Datum	Paleomagnetic Tie	Estimated Age (m.y.B.P.)
T	*Rhizosolenia curvirostris*	upper Brunhes (5, 6, 8)	0.26
T	*Nitzschia reinholdii*	lower Brunhes (5, 6, 7)	0.63
T	*Mesocena quadrangula* (silicoflagellate)	between Jaramillo and Brunhes (7)	0.79
T	*Actinocyclus oculatus*	in Jaramillo (5, 8)	0.9
B	*R. curvirostris*	between Olduvai and Jaramillo (3, 6)	1.5
T	*R. praebergonii* var. *robusta*	just above top of Olduvai (7)	1.55
B	*Thalassiosira antiqua*	middle Olduvai (5)	1.7
B	*Pseudoeunotia doliolus*	lower Olduvai (3, 5, 6, 7)	1.8
T	*T. convexa*	midway between Olduvai and top of Gauss (6, 7)	2.1
T	*Denticula kamtschatica*	top of Gauss (6)	2.4
T	*N. jouseae*	near top of Gauss (1, 5)	2.6
B	*D. seminae* var. *fossilis*	between "b" and "c" events of the Gilbert (5)	4.2
B	*N. jouseae*	between "c" events of Gilbert (4)	4.5
B	*T. oestrupii*	lowermost Gilbert (5)	5.0
T	*T. miocenica*	midway between "c" event of Gilbert and top of Epoch 5 (1)	5.0
T	*Asterolampra acutiloba*	top of Epoch 5 (1)	5.3
T	*N. miocenica*	top of "a" event, Epoch 5 (1, 3)	5.4
B	*T. convexa*	upper Epoch 6 (1, 3)	6.0
B	*T. miocenica*	upper Epoch 6 (1)	6.0
B	*D. kamtschatica*	lower Epoch 6 (4)	6.4
B	*N. reinholdii*	lower Epoch 6 (1)	6.4
T	*N. porteri*	middle Epoch 7 (1, 3)	6.9
B	*N. miocenica*	middle Epoch 7 (1, 3)	7.0
T	*T. burckliana*	lower Epoch 7 (1, 3)	7.5
T	*Coscinodiscus yabei*	middle Epoch 8 (1, 3)	8.0
B	*T. burckliana*	upper Epoch 9 (1)	8.5
T	*D. lauta*	K-Ar date (2)	9.5
B	*Hemidiscus cuneiformis*	middle Epoch 12 (1)	11.9
T	*C. lewisianus*	upper Epoch 13 (1)	12.3
T	*D. nicobarica*	upper Epoch 14 (1)	12.5
B	*D. hustedtii*	K-Ar date (2)	14.0
T	*Annellus californicus*	lower Epoch 15 (1)	14.5
B	*A. californicus*	upper Epoch 16 (1)	15.5

Note: I have used the paleomagnetic time scale of MacDougall and others (1977) for the Gilbert and Epochs 5 and 6 and of LaBrecque and others (1977) for the remainder of the upper Cenozoic. B = first occurrence, T = last occurrence. References: (1) Burckle, 1978; (2) Koizumi, 1977; (3) Burckle, 1972; (4) Burckle, personal communication, 1978; (5) Burckle and Opdyke, 1977; (6) Koizumi, 1975d; (7) Burckle, 1977; (8) Donahue, 1970.

and in the middle Miocene at Site 173. This relationship probably reflects warmer paleotemperatures at Site 438 than at Site 173 during the early late Miocene.

The uppermost Miocene hiatus in Core 42 of Hole 438A correlates with a hiatus of similar duration in Core 15 of Site 173. The middle Miocene hiatus between Cores 65 and 66 of Hole 438A apparently removes the interval equivalent to about Cores 23 through 25 of Site 173. Figure 10 also suggests that the single occurrence of *Annellus californicus* in Sample 438A-73,CC correlates with its last occurrence at Site 173.

Diatom Zonal Correlations

In Figure 11 the modified diatom zonation of Koizumi (1973, 1975b) that was used for Leg 57 is correlated with the low-latitude diatom zonation of Burckle (1972, 1977), the North Pacific diatom zonation of the California area of Schrader (1973) and Barron (1976), and the diatom zonation used onshore in Japan by Akiba (1979; written communication, 1977). The occurrence charts for Sites 438 and 440 and Figures 9 and 10 provide background for these correlations.

Most of the subzones proposed for Koizumi's (1973, 1975b) diatom zonation were chosen so that their boundaries correspond with zonal boundaries of the other zonations. It is suggested that many of these subzones will

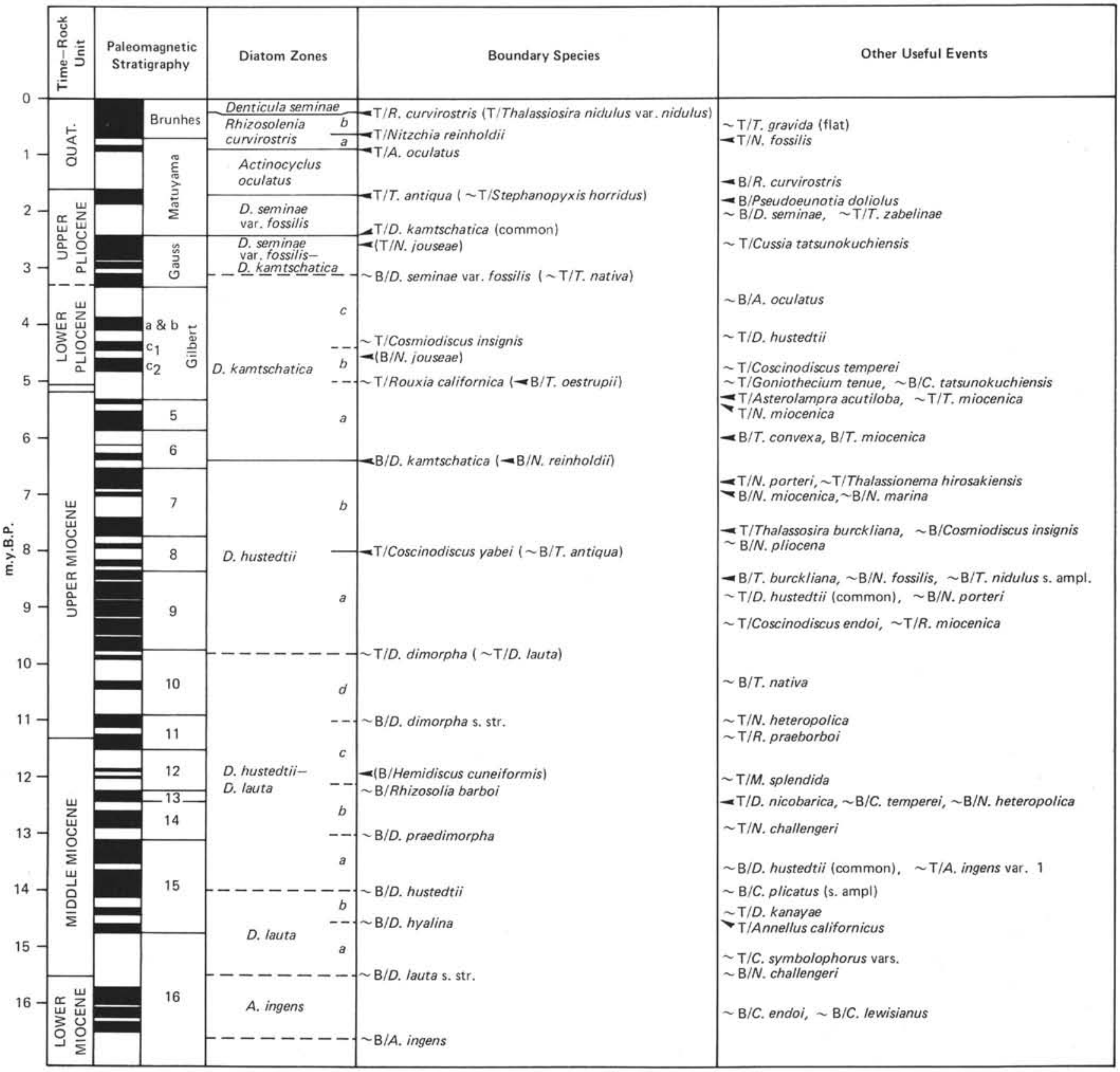

Figure 9. *Estimated absolute ages for the Leg 57 diatom zones and selected datum levels. (The paleomagnetic time scale is that of MacDougall and others [1977] for the Gilbert Paleomagnetic Epoch and Epochs 5 and 6 and LaBrecque and others [1977] for the remainder of the period covered. Datum levels established directly from paleomagnetically dated cores are indicated by arrows [←]. Other datum levels are extrapolated from sediment accumulation rate curves and are indicated by a wavy line.)*

have broad application throughout the North Pacific. On Leg 63, the subzones of the *Denticula hustedtii* Zone, the *D. hustedtii–D. lauta* Zone, and the *D. lauta* Zone were consistently recognized in sediments off southern California and Baja California, Mexico (Barron, unpublished data).

Uppermost Miocene Hiatus

The uppermost Miocene hiatus that was recognized in Core 42 of Hole 438A and between Cores 60 and 62 of Hole 440B appears to be widespread in the mid- to high-latitude North Pacific. It is present in the lower part of Core 15 (135 m) at DSDP Site 173 off northern California (Figure 1), where it is of approximately the same duration (about 1 m.y.) as it is at Site 438 (Figure 10). Onshore in California, it seems to correspond with the lithologic break between the laminated diatomaceous shales of the Monterey Formation and the overlying more terrigenous, massive diatomaceous mudstones represented by the Capistrano, the Sisquoc, the Pancho

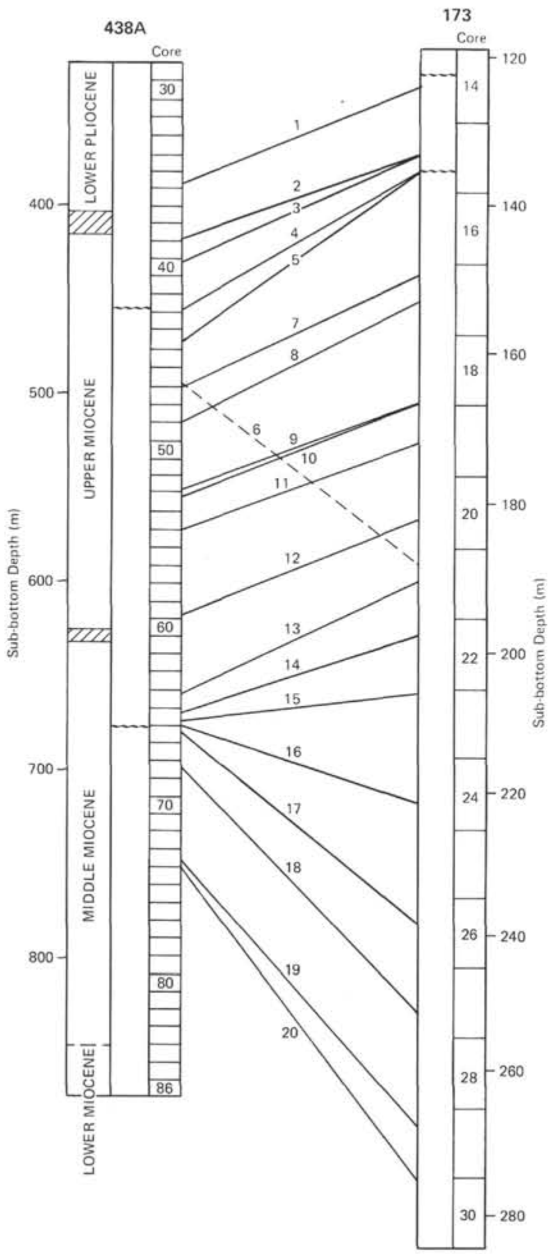

Figure 10. *Correlation of the upper and middle Miocene in Hole 438A with the upper and middle Miocene at Site 173 off northern California by diatom datums. (1 = first* Thalassiosira eostrupii, *2 = last* T. miocenica, *3 = last* Nitzschia miocenica, *4 = first* N. reinholdii, *5 = last* T. burckliana, *6 = last* Coscinodiscus yabei, *7 = first* T. antiqua, *8 = first* N. fossilis, *9 = last* C. endoi, *10 = last* Rhizosolenia miocenica, *11 = last* Denticula dimorpha, *12 = first* D. dimorpha, *13 = first* R. barboi, *14 = first* C. temperei, *15 = last* D. nicobarica, *16 = first* D. praedimorpha, *17 = first common* D. hustedtii, *18 = first* D. hustedtii, *19 = first* D. hyalina, *20 = last* Annellus californicus. *Note the correlation of the hiatus in Core 42 of Hole 438A with a hiatus in Core 15 of Site 173. Note also the time-transgressive nature of the last occurrence of* C. yabei *[6] between Japan and California.)*

Rico, and the Purisima formations. On Leg 63, uppermost Miocene hiatuses were identified at Site 469 off southern California and at Site 470, which was drilled near Guadalupe Island off northern Mexico, very near the site of the Experimental Mohole Drilling (Figure 1) (Barron, unpublished data).

In the western North Pacific, Koizumi (in press) reports a hiatus between uppermost Miocene and middle Miocene sediments in the lower part of Core 6 (52 m) of DSDP Site 433 in the Emperor Seamount Chain, and Harper (this volume) records a possible break between uppermost Miocene and lower upper Miocene sediments between Cores 29 and 30 (about 280 m) at Site 436, just east of the Japan Trench (Figure 1). These relations support the presence of a widespread sedimentologic event in the North Pacific which may be related to the Messinian Event of the Mediterranean Sea.

At Site 183 in the Gulf of Alaska, an assemblage including *Denticula kamtschatica* s. str., *Thalassiosira miocenica, T. convexa* var. *aspinosa,* and *T. jacksonii* is present in Sample 183-17-5, 100–101 cm (171 m). Immediately below in Sample 183-18-1, 130–131 cm (174.3 m), *T. hirosakiensis* occurs with *Nitzschia pliocena* and *Synedra jouseana* and without the younger diatoms present in Core 17. The younger assemblage is no older than 6 m.y.B.P. (Table 14), whereas occurrences in Hole 438A suggest that the older assemblage is not younger than 7 m.y.B.P. Gravel-sized pebbles in the upper 20 cm of Core 18 are further evidence of an uppermost Miocene hiatus at this horizon at Site 183.

Site 192 in the extreme northwest Pacific was discontinuously cored; however, Koizumi's (1973) and Harper's (1977a) data together suggest that the sediment accumulation rate increases significantly upsection between Core 23 (569–578 m) and Core 22 (522–531 m), corresponding with the first occurrence of *D. kamtschatica* s. str. in Core 22. Harper (1977a) records the last occurrence of *S. jouseana,* and Koizumi (1973) reports *N. pliocena* in Core 23 at Site 192, so it is possible that a hiatus is present between Cores 22 and 23 in the upper upper Miocene of Site 192.

These DSDP sites include three located on the continental slope (173, 438, and 440), two in the Emperor Seamount Chain (192 and 433), and four on the ocean floor (183, 436, 469, and 470). They range in depth from 1558 meters (Hole 438A) to 5240 meters (Site 436). During the latest Miocene, Sites 183 and 436 were located well away from land in the ocean basins. Subsequent movement of the Pacific Plate has brought them near the Aleutian and Japan Trenches, respectively. The widespread geographic distribution and varied tectonic settings of these sites argue against local tectonic events as the primary causes of these latest Miocene hiatuses.

Kennett (1977) presents evidence for global cooling in the latest Miocene, including a latest Miocene to earliest Pliocene development of the Antarctic ice sheet thicker than present; conspicuous global sea level regression, including isolation of the Mediterranean Basin ("the Messinian Event"); and increases in ice rafting and siliceous biogenic sedimentation rates in the Antarctic Southern Ocean. Planktonic foraminiferal faunas record a latest

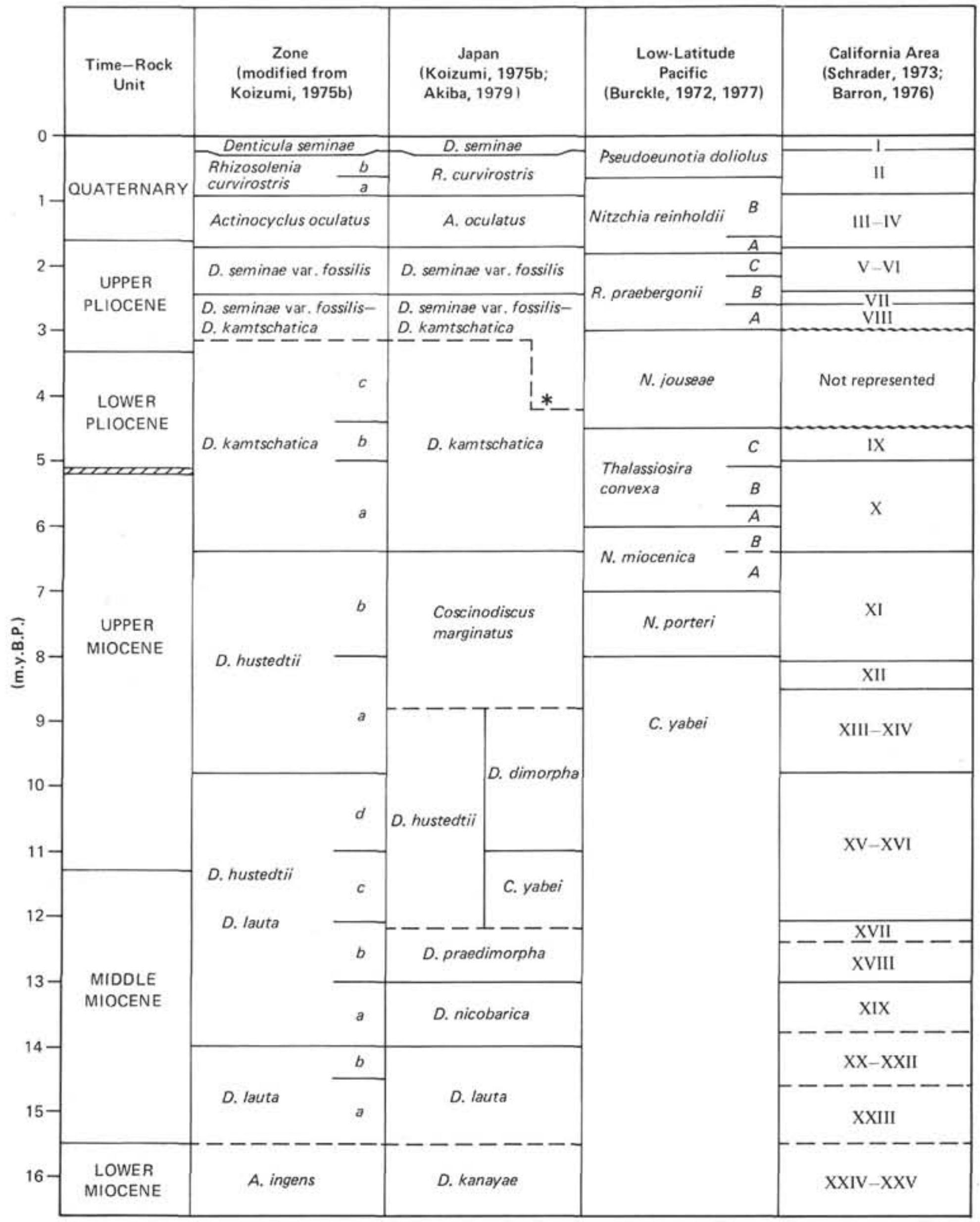

Figure 11. *Correlation of the Leg 57 diatom zones modified from Koizumi (1973, 1975b) with the low-latitude diatom zonation of Burckle (1972, 1977), the North Pacific Diatom Zonation of the California area of Schrader (1973, 1977), and with the diatom zonation used onshore in Japan by Akiba (in press, written communication, 1977). (*indicates that the base of the* Denticula seminae *var.* fossilis–D. kamtschatica *Zone appears to be somewhat older in more northern areas of the North Pacific [Burckle and Opdyke, 1977].)*

Miocene cooling in the South Pacific and in New Zealand (Kennett, 1978), in Morocco (Cita and Ryan, 1978), and in the North Pacific (Ingle, 1978). In the Gulf of Alaska area, Armentrout and others (1978) report uppermost Miocene glacial marine sediments in the Yakataga Formation. Increased production of Antarctic ice results in increased activity of Antarctic bottom water (Gordon, 1971); and Kennett (1977) relates increased Antarctic bottom water production, which is associated with climatic deterioration near the beginning of the Oligocene, with extensive deep sea erosion throughout the ocean basins. Ciesielski and others (1978) report major erosion during the late late Miocene (from about 7.4 to 6.2 m.y.B.P.) on the Maurice Ewing Bank in the southwest Atlantic and relate it to an increase in velocity of the Antarctic Circumpolar Current. It is possible that the widespread latest Miocene hiatuses in the North Pacific are the result of erosion owing to increased bottom water activity associated with a climatic cooling in the latest Miocene. The correspondence of the first occurrences of such high-latitude diatom species as *T. gravida* (two forms), *T. jacksonii, T. zabelinae* s. ampl., and *T.*

nidulus var. *delicata* with the hiatus in Core 42 of Hole 438A is support for this latest Miocene cooling at Site 438.

Observations on Paleoclimatology

Biostratigraphy is the primary aim of this study, and the assemblages are treated by qualitative rather than quantitative methods. Nevertheless, some observations on the response of the diatom assemblages to late Cenozoic climatic trends and events are offered.

Quaternary

In equatorial Pacific cores Burckle (1977) notes a shift in dominance from tropical diatoms to cosmopolitan forms at about 0.8 m.y.B.P., corresponding with the last occurrence of the silicoflagellate *Mesocena elliptica (M. quadrangula).* Burckle (1977) points out that this change is correlative with the onset of Isotopic Stage 22, which Shackleton and Opdyke (1976) call the first major Northern Hemisphere glaciation in the mid-Pleistocene. In the western North Pacific, Koizumi (1975d) also identifies a general decrease in diatom temperature values (Td) during the same interval of time.

At Site 440 certain cold-water diatoms, including *Bacteriosira fragilis, Porosira glacialis, Rhizosolenia hebetata* f. *hiemalis, Thalassiosira hyalina,* and *T. pacifica,* are restricted to or occur more consistently above the middle part of Subzone *a* of the *Rhizosolenia curvirostris* Zone (about 0.8 m.y.B.P.). In addition, the cold-water diatom *Thalassiosira gravida* increases in abundance upsection during this interval at Sites 438 and 440. These occurrences and trends suggest that the late Quaternary (younger than about 0.8 m.y.B.P.) off northwestern Japan was, in general, cooler than the early Quaternary.

Pliocene

Oxygen isotope and paleomagnetic analysis by Shackleton and Opdyke (1977) on a piston core in the equatorial Pacific shows that "glacial–interglacial fluctuations have characterized the Earth's climate for the last 3.2 m.y." and that the intensity of glaciation increased at about 2.5 m.y.B.P. In the middle latitudes of the North Pacific, planktonic foraminifers also record cold periods at about 3.2 m.y.B.P. and 2.4 m.y.B.P. (Keller, 1978).

At Sites 438 and 440, the first common occurrence of the cold-water diatom *Denticula seminae* var. *fossilis* is at about 2.5 m.y.B.P. and follows the last occurrence of the warm-water diatoms *Nitzschia jouseae* and *Cussia tatsunokuchiensis.* The last common occurrence of *D. kamtschatica* is also closely associated with the first common occurrence of *D. seminae* var. *fossilis* at Sites 438 and 440 and in many areas of the high-latitude North Pacific (Koizumi, 1973). These diatom events apparently are related to a widespread cooling at about 2.5 m.y.B.P.

The first occurrence of *D. seminae* var. *fossilis* in Leg 57 sediments off northeastern Japan is at about 3.1 m.y.B.P., much later than the datum reported by Burckle and Opdyke (1977) — about 4.2 m.y.B.P. — in a more central area of the North Pacific (42°05′N, 160° 36′E). Presumably, influence of the warm-water Kuroshio Current delayed the appearance of this cold-water diatom in Leg 57 sediments until after the initiation of global cooling at about 3.2 m.y.B.P.

Late Miocene

In the South Pacific, Kennett (1978) reports a severe cooling episode in the early late Miocene, followed by a middle late Miocene warming, and then a latest Miocene cooling. Ingle (1973) and Barron (1973) also give evidence of an early late Miocene cooling and a warming trend in the middle late Miocene in the eastern North Pacific. A latest Miocene to early Pliocene cooling is recorded by Keller (1978) in middle latitudes across the North Pacific.

At Site 438 lower upper Miocene diatom assemblages are dominated by species of the cold-water genus *Denticula (D. hustedtii, D. lauta,* and *D. dimorpha).* Specimens of *Denticula* are sparse in the middle upper Miocene (the upper part of the *D. hustedtii* Zone) but increase in numbers in the upper upper Miocene (lower part of the *D. kamtschatica* Zone). In the middle upper Miocene the first occurrences of such low-latitude diatoms as *Nitzschia porteri, N. fossilis,* and *Thalassiosira burckliana* are just above the last common occurrence of *D. hustedtii.* Consistent presence of key tropical diatoms in the middle upper Miocene of Site 438 allows recognition of all of the low-latitude diatom zones and subzones of Burckle (1972).

At Site 438 and 440 an uppermost Miocene hiatus corresponds with the base of the *D. kamtschatica* Zone. Correlative hiatuses throughout the middle- and high-latitude North Pacific suggest the possibility of widespread erosion during the late late Miocene owing to intensification of bottom water activity associated with climatic cooling. The first occurrences of such cold-water diatoms as *T. gravida* (two forms), *T. jacksonii, T. nidulus* var. *delicata,* and *T. zabelinae* s. str. coincide with the hiatus at Site 438 and Site 440 and support a cooling episode in the late late Miocene.

Future Studies

Studies of the middle Miocene to Quaternary paleoclimatology of the North Pacific will benefit from the refined interregional correlations that are now possible with diatoms. Quantitative comparisons of "time slices" should identify fossil diatom complexes that are associated with different paleoceanographic regions of the North Pacific. The Leg 57 sites, near the present-day confluence of the warm-water Kuroshio Current and cold-water Oyashio Current, offer a record that is characterized by fluctuations in abundance of numerous diatom taxa. These sites undoubtedly will be of great value in reconstructing the late Cenozoic climatic history of the entire North Pacific.

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REFERENCES

Abbot, W. H., 1978. Correlation and zonation of Miocene strata along the Atlantic margin of North America using diatoms and silicoflagellates. *Mar. Micropaleont.*, 3, 15–34.

Akiba, F., 1977. *Denticula kanayae* n. sp. in the *Denticula kanayae* Zone, a biostratigraphically significant diatom. *Japan Petroleum Exploration Company, Technical Research Institute Report*, 20 (Nos. 3–4), 126–146.

________, 1979. The morphologies of *Denticula dimorpha* and its allied species, and the Neogene diatom biostratigraphy of Japan. *Japan Petroleum Exploration Company, Technical Research Institute Report*, 22, 148–189.

Armentrout, J. M., Echols, R. J., and Nash, K. W., 1978. Late Miocene climatic cycles of the Yakataga Formation, Robinson Mountains, Gulf of Alaska area. *Correlation of Tropical through High Latitude Marine Neogene Deposits of the Pacific Basin* (Vol. XIV): Stanford (Stanford University Press), 3–4.

Barron, J. A., 1973. Late Miocene early Pliocene paleotemperatures for California from marine diatom evidence. *Palaeogeog., Palaeoclimatol., Palaeoecol.*, 14, 277–291.

________, 1976. Revised Miocene and Pliocene diatom biostratigraphy of Upper Newport Bay, Newport Beach, California. *Mar. Micropaleont.*, 1, 27–63.

________, in press. Upper Pliocene and Quaternary diatom biostratigraphy of DSDP Leg 54, eastern tropical Pacific. *In* Hekinian, R., Rosendahl, B. R., et al., *Init. Repts. DSDP*, 54: Washington (U.S. Govt. Printing Office).

Bukry, D., 1973a. Low-latitude coccolith biostratigraphic zonation. *In* Edgar, N. T., Saunders, J. B., et al., *Init. Repts. DSDP*, 15: Washington (U.S. Govt. Printing Office), 685–703.

________, 1973b. Coccolith and silicoflagellate stratigraphy, Deep Sea Drilling Project Leg 18, eastern North Pacific. *In* Kulm, L. D., von Huene, R., et al., *Init. Repts. DSDP*, 18: Washington (U.S. Govt. Printing Office), 817–831.

________, 1976. Silicoflagellate and coccolith stratigraphy of the Norwegian-Greenland Sea, Deep Sea Drilling Project Leg 38. *In* Talwani, M., Udintsev, G., et al.. *Init. Repts. DSDP*, 38: Washington (U.S. Govt. Printing Office), 843–855.

Burckle, L. H., 1972. Late Cenozoic planktonic diatom zones from the eastern equatorial Pacific. *Nova Hedwigia Beih*, 39, 217–246.

________, 1977. Pliocene and Pleistocene diatom datum levels from the equatorial Pacific. *Quat. Geol.*, 7, 330–340.

________, 1978. Early Miocene to Pliocene diatom datum levels for the equatorial Pacific. Geol. Soc. Indonesia Proc., IGCP Project 114 Meetings, Indonesia, 1977. *Geol. Res. Devel. Cent., Spec. Publ.*, 1, 25–44.

Burckle, L. H., and Opdyke, N., 1977. Late Neogene diatom correlations in the circum-Pacific. *Proceedings of the First International Congress on Pacific Neogene Stratigraphy:* Tokyo (Kaiyo Shuppan), 255–284.

Burckle, L. H., and Trainer, J., in press. Middle and late Pliocene diatom datum levels from the central Pacific. *Micropaleontology*.

Ciesielski, P. F., Dinkelman, M. G., Ledbetter, M. T., and Ellwood, B. B., 1978. New evidence on the timing of late Miocene–middle Pliocene glacial fluctuations from the southwest Atlantic sector of the Southern Ocean. *Geol. Soc. Am. Abstracts with Programs*, 10 (No. 7), 380. (Abstract)

Cita, M. B., 1975. The Miocene/Pliocene boundary: History and definition. *In* Saito, T., and Burckle, L. H. (Eds.), *Late Neogene Epoch Boundaries:* New York (Micropaleontology Press), pp. 1–30.

Cita, M. B., and Ryan, W. B. F., 1978. The Bou Regreg Section of Morocco: Evidence of a late-Miocene regression. *Geol. Soc. Am. Abstracts with Programs*, 10 (No. 7), 380. (Abstract)

Donahue, J. G., 1970. Pleistocene diatoms as climatic indicators in North Pacific sediments. *Geol. Soc. Am. Mem.*, 126, 121–138.

Gordon, A. L., 1971. Oceanography of Antarctic waters. *In* Reid, J. L. (Ed.), *Antarctic Oceanology I*, Vol. 15: Washington (American Geophysical Union, Antarctic Research Series), 169.

Hanna, G. D., 1932. The diatoms of Sharktooth Hill, Kern County, California. *Calif. Acad. Sci. Proc.*, 4th ser., 20 (No. 6), 161–263.

Haq, B. U., Berggren, W. A., and Van Couvering, J. A., 1977. Corrected age of the Pliocene-Pleistocene boundary. *Nature*, 269, 483–488.

Harper, H. E., Jr., 1977a. Diatom biostratigraphy of the Miocene-Pliocene boundary in marine strata of the Circum-North Pacific [Ph.D. dissert.]. Harvard University.

________, 1977b. Diatom biostratigraphy. *In* Ujiie, H., Saito, T., Kent, D. V., Thompson, P. R., Okada, H., Klein, G. deVries, Koizumi, I., Harper, H. E., Jr., and Sato, T., Biostratigraphy, paleomagnetism and sedimentology of late Cenozoic sediments in northwestern Hokkaido, Japan. *Natl. Sci. Mus. Bull. Ser. C Geol.*, 3 (No. 2), 49–102.

Ingle, J. C., Jr., 1973. Summary comments on Neogene biostratigraphy, physical stratigraphy and paleo-oceanography in the marginal northeastern Pacific Ocean. *In* Kulm, L. D., von Huene, R., et al., *Init. Repts. DSDP,* 18: Washington (U.S. Govt. Printing Office), 949–960.

________, 1978. Evidence of latest Miocene refrigeration and associated eustatic events in California and the North Pacific. *Geol. Soc. Am. Abstracts with Programs*, 10 (No. 7), 427. (Abstract)

Jousé, A. P. (Ed.), 1977. *Atlas of Microorganisms in Bottom Sediments of the Oceans:* Moscow (Nauka).

Keller, G., 1978. Late Neogene climatic oscillations across the mid latitudes of the North Pacific. *Geol. Soc. Am. Abstracts with Programs*, 10 (No. 7), 433. (Abstract)

Kennett, J. P., 1977. Cenozoic evolution of Antarctic glaciation, the circum-Antarctic Ocean, and their impact on global paleoceanography. *J. Geophys. Res.*, 82 (No. 27), 3843–3860.

________, 1978. The Kapitean (latest Miocene) paleoclimatic event in the South Pacific. *Geol. Soc. Am. Abstracts with Programs*, 10 (No. 7), 433–434. (Abstract)

Koizumi, I., 1973. The late Cenozoic diatoms of Sites 183–193, Leg 19, Deep Sea Drilling Project. *In* Creager, J. S., Scholl, D. W., et al., *Init. Repts. DSDP*, 19: Washington (U.S. Govt. Printing Office), 805–855.

________, 1975a. Neogene diatoms from the western margin of the Pacific Ocean, Leg 31, Deep Sea Drilling Project. *In* Karig, D. E., Ingle, J. C., Jr., et al., *Init. Repts. DSDP*, 31: Washington (U.S. Govt. Printing Office), 779–819.

________, 1975b. Late Cenozoic diatom biostratigraphy in the circum-North Pacific region. *Geol. Soc. Japan J.*, 81 (No. 10), 611–627.

———, 1975c. Neogene diatoms from the northwestern Pacific Ocean, Deep Sea Drilling Project. *In* Larson, R. L., Moberly, R., et al., *Init. Repts. DSDP*, 32: Washington (U.S. Govt. Printing Office), 865–889.

———, 1975d. Diatom events in late Cenozoic deep sea sequences in the North Pacific. *Geol. Soc. Japan J.*, 81 (No. 9), 567–578.

———, 1977. Diatom biostratigraphy in the North Pacific region. *Proceedings of the First International Congress on Pacific Neogene Stratigraphy:* Tokyo (Kaiyo Shuppan), pp. 235–253.

———, in press. Neogene diatoms from the Emperor Seamount Chain, Leg 55, Deep Sea Drilling Project. *In* Koizumi, I., Jackson, E. D., et al., *Init. Repts. DSDP*, 55: Washington (U.S. Govt. Printing Office).

LaBrecque, J. L., Kent, D. V., and Cande, S. C., 1977. Revised magnetic polarity time scale for Late Cretaceous and Cenozoic time. *Geology*, 5, 330–335.

Ling, H. Y., 1977. Late Cenozoic silicoflagellates and ebridians from the eastern North Pacific. *Proceedings of the First International Congress on Pacific Neogene Stratigraphy:* Tokyo (Kaiyo Shuppan), 205–233.

MacDougall, I., Saemundsson, K., Johannesson, H., Watkins, N. D., and Kristjansson, I., 1977. Extension of the geomagnetic polarity time scale to 6.5 m.y.: K-Ar dating, geological and paleomagnetic study of a 3,500-m lava succession in western Iceland. *Geol. Soc. Am. Bull.*, 88, 1–15.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. *In* Farinacci, A. (Ed.), *Proceedings of the Second Planktonic Conference, Roma, 1970 (Vol. 2)*: Rome (Ediziomi Tecnoscienza), 739–777.

Ryan, W. B. F., Cita, M. B., Rawson, M., Burckle, L. H., and Saito, T., 1974. A paleomagnetic assignment of Neogene stage boundaries and the development of isochronous datum planes between the Mediterranean, the Pacific and Indian Oceans in order to investigate the response of the world ocean to the Mediterranean "salinity crisis." *Riv. Ital. Paleontol.*, 80, 631–688.

Schrader, H.-J., 1973. Cenozoic diatoms from the northeast Pacific, Leg 18. *In* Kulm, L. D., von Huene, R., et al., *Init. Repts. DSDP*, 18: Washington (U.S. Govt. Printing Office), 673–797.

———, 1974. Cenozoic marine planktonic diatom stratigraphy of the tropical Indian Ocean. *In* Fisher, R. L., Bunce, E. T., et al., *Init. Repts. DSDP*, 24: Washington (U.S. Govt. Printing Office), 887–967.

Schrader, H.-J., 1976. Cenozoic planktonic diatom biostratigraphy of the southern Pacific Ocean. *In* Hollister, C. D., Craddock, C., et al., *Init. Repts. DSDP*, 35: Washington (U.S. Govt. Printing Office), 605–671.

Schrader, H.-J., and Fenner, J., 1976. Norwegian diatom biostratigraphy and taxonomy. *In* Talwani, M., Udintsev, G., et al., *Init. Repts. DSDP*, 38: Washington (U.S. Govt. Printing Office), 921–1098.

Shackleton, N. J., and Opdyke, N. D., 1976. Oxygen-isotope and paleomagnetic stratigraphy of Pacific core V28-239, late Pliocene to latest Pliocene. *Geol. Soc. Am. Mem.*, 145, 449–464.

———, 1977. Oxygen isotope and paleomagnetic evidence for early Northern Hemisphere glaciation. *Nature*, 20 (No. 5634), 216–219.

Sheshukova-Poretzkaya, V. S., 1967. *Neogene marine diatoms of Sakhalin and Kamtschatka:* Leningrad (University of Leningrad Press), pp. 1–327, pls. 1–50. (in Russian)

Van Couvering, J. A., Berggren, W. A., Drake, R. F., Aguirre, F., and Curtis, G. H., 1976. The terminal Miocene event. *Mar. Micropaleont.*, 1, 263–286.

Wornardt, W. W., Jr., 1967. Miocene and Pliocene marine diatoms from California. *Calif. Acad. Sci. Occas. Pap.*, 63, 1–108.

APPENDIX

Description of a New Diatom Taxon

Genus THALASSIOSIRA Cleve (1873) emend. Hasle (1973)

Thalassiosira nidulus var. *delicata* Barron, n. var.

Description: Valves circular, 14 to 40 μm in diameter, flat across the center with depressed margins. Margins distinctive (about 2 μm wide), with prominent marginal spines (about 1.5 μm long) which bifurcate at their end to a 1.5-μm width. Spines distributed about 3.5 in 10 μm. Subrounded areolae arranged in radial, linear rows which terminate toward the center of the valve with a small pore. Areolae increase in size toward the margin and range from about 9 to 13 in 10 μm.

Discussion: This variety is generally more delicate in appearance than *T. nidulus* var. *nidulus* (Tempère and Brun) Jousé. The margin is not as prominent, the areolae are smaller, and the radial, linear pattern of the areolae is better developed. Compare Figures 4 and 5 of Plate 6.

Holotype: Plate 6, Figure 1, 32-μm diameter, DSDP 438A-20-4, 135–137 cm (245.4 m), USNM 689960.

Isotope: Plate 6, Figure 4, 33-μm diameter, DSDP 438A-34-5, 85–87 cm (379.4 m), USNM 689961.

Occurrences: *Thalassiosira nidulus* var. *delicata* occurs in the lower Pliocene and upper Miocene *Denticula kamtschatica* Zone at DSDP Sites 438 and 440 off northeast Japan.

Taxonomic Notes and Illustration References

Actinocyclus ingens Rattray: Schrader, 1973, pl. 18, figs. 2–4, 7. (Plate 5, Figure 2)

Actinocyclus ingens var. 1: **Synonym:** *Actinocyclus ingens,* Jousé, 1977, pl. 53, fig. 1. **Remarks:** This variety is characterized by an undulating valve surface; the central area and a submarginal ring rise to an equal elevation. (Plate 5, Figures 8, 12)

Actinocyclus ingens var. 2: **Synonym:** *Actinocyclus ingens*, Sheshukova-Poretzkaya, 1967, pl. 30, fig. 1a. **Remarks:** This form is also characterized by an undulating valve surface, but the central area is depressed relative to the raised submarginal ring.

Actinocyclus ochotensis Jousé: Koizumi, 1973, pl. 2, figs. 3–7.

Actinocyclus oculatus Jousé: Koizumi, 1973, pl. 2, figs. 8, 9. **Remarks:** Small specimens with a large hyaline central area closely resemble *Cosmiodiscus insignis* Jousé. (Plate 5, Figures 1, 3)

Actinoptychus minutus Greville: Barron, 1976, pl. 1, fig. 2.

Annellus californicus Tempère *in* Tempère and Peragallo: Hanna, 1932, pl. 4, figs. 5–9.

Asterolampra acutiloba Forti *in* Tempère and Peragallo: Schrader, 1974, pl. 9, figs. 7, 8. (Plate 3, Figure 9).

Bacteriosira fragilis Gran: Schrader, 1973, pl. 16, fig. 7.

Coscinodiscus endoi Kanaya: Schrader, 1973, pl. 7, figs. 14, 21; pl. 20, figs. 1, 2. (Plate 4, Figure 6)

Coscinodiscus lewisianus Greville: Schrader, 1973, pl. 8, figs. 1–6, 10, 15. (Plate 3, Figure 10)

Coscinodiscus sp. aff. *C. marginatus* Ehrenberg, of Schrader, 1976, pl. 10, fig. 3.

Coscinodiscus plicatus Grunow s. ampl.: Schrader and Fenner, 1976, pl. 15, figs. 5, 8, 9, 11–13. **Remarks:** A broad concept of this species that includes several varieties of plicate *Coscinodiscus*, not otherwise separated, is used in this chapter. (Plate 3, Figure 12)

Coscinodiscus praeyabei Schrader, 1973, pl. 6, fig. 16; pl. 7, figs. 17–20, 22, 23

Coscinodiscus pustulatus Mann: Koizumi, 1973, pl. 4, figs. 1–4. (Plate 5, Figure 10)

Coscinodiscus ruboides Schrader, 1976, pl. 6, figs. 4, 8.

Coscinodiscus symbolophorus Grunow: **Remarks:** Only the distinctive varieties found in lower middle Miocene and lower Miocene sediments have been recorded.

C. symbolophorus var. 1. Synonym: *C. symbolophorus* group 5 of Schrader, 1976, pl. 4, fig. 4.

C. symbolophorus var. 2. Synonym:*C. symbolophorus* group 2 of Schrader, 1976, pl. 7, fig. 2.

Coscinodiscus temperei Brun *in* Brun and Tempère: Schrader, 1973, pl. 6, figs. 18, 19; pl. 7, figs. 1-5, 8, 9. **Remarks:** Larger specimens are more typical of the later forms of this species. (Plate 4, Figure 5)

Coscinodiscus yabei Kanaya: Schrader, 1973, pl. 6, figs. 1-6, 15. (Plate 3, Figure 11)

Cosmiodiscus insignis Jousé: Koizumi, 1973, pl. 4, figs 7-11. (Plate 4, Figure 1)

Cussia paleacea (Grunow) Schrader: **Synonym:** *Coscinodiscus paleaceus* Grunow: Burckle, 1972, pl. 1, figs. 7, 8.

Cussia tatsunokuchiensis (Koizumi) Schrader: Koizumi, 1975b, pl. 1, fig. 23; Koizumi, 1975c, pl. 4, figs. 33-35. **Remarks:** Earlier forms of this species tend to be longer and thinner (Plate 1, Figure 31) than later forms (Plate 1, Figure 31; Plate 4, Figure 3)

Cymatogonia amblyoceras Hanna: Schrader, 1973, pl. 26, fig. 8.

Delphineis penelliptica Andrews: Abbott, 1978, pl. 1, fig. 6. (Plate 1, Figure 25)

Denticula dimorpha Schrader, 1973, pl. 1, figs. 37-46. (Plate 1, Figure 21)

Denticula hustedtii Simonsen and Kanaya: Schrader, 1973, pl 2, figs. 28-34, 36-47. (Plate 1, Figures 9-11)

Denticula hyalina Schrader, 1973, pl. 1, figs. 12-22. (Plate 1, Figure 12)

Denticula ikebei Akiba, 1977, pl. 1, fig. 15, pl. 2, figs. 1-3. **Remarks:** Akiba (1977) notes a length of 41 to 63 μm and a width of 6.5 to 7 μm for this species. There are 3 pseudosepta in 10 μm and 10 to 12 puncta in 10 μm. The quincunx arrangement is not clear and the apices are rounded. (Plate 1, Figure 30)

Denticula kamtschatica Zabelina: Schrader, 1973, pl. 2, figs. 1-3, 6-13 (4, 5?); Harper, 1977b, pl. 3, figs. 1-4, pl. 5, figs. 1-4, 8. **Remarks:** According to the type description of Zabelina (1934), *D. kamtschatica* has 5 to 6 pseudosepta per 10 μm. Harper (1977b) refers specimens resembling *D. kamtschatica*, but having 7 to 11 transapical costae or pseudosepta, to *Nitzschia rolandii* Schrader emend. Harper (see Harper, 1977b, pl. 3, figs. 9-11; pl. 5, figs 5-7). For purposes of this report, these latter forms are referred to *D.* sp. cf. *D. kamtschatica* in the occurrence charts (Plate 1, Figures 15-17). Whether they should be referred to *Denticula* or *Nitzschia* is presently unclear. (Plate 1, Figures 5-8)

Denticula kanayae Akiba, 1977, pl. 1, figs. 1-10, pl. 2, fig. 13. **Remarks:** Akiba (1977) states this species is 14 to 43 μm in length and 4 to 8 μm in width. There are 2 pseudosepta in 10 μm and 6 puncta in 10 μm. The apex is rounded and the quincunx arrangement is unclear. (Plate 1, Figures 26-28)

Denticula lauta Bailey: Schrader, 1973, pl. 2, figs. 14-25, 35. **Remarks:** Specimens stratigraphically below *D. lauta* s. str. (Plate 1, Figures 13, 14) are listed as *D.* sp. cf. *D. lauta*. A synonym of this latter form is *D.* sp. aff. *D. kamtschatica*, Schrader, 1976, pl. 4, fig. 18. (Plate 1, Figure 24).

Denticula miocenica Schrader, 1973, pl. 2, figs. 26-28.

Denticula nicobarica Grunow: Schrader, 1976, pl. 4, figs. 19-21. **Remarks:** *Denticula paranicobarica* of Akiba, 1977, pl. 1, figs. 11-14, is included here for the purposes of this report. (Plate 1, Figures 22, 23)

Denticula norwegica Schrader: Schrader and Fenner, 1976, pl. 1, fig. 38.

Denticula praedimorpha Akiba, 1979. **Remarks:** Akiba (in press) separates this species from *D. dimorpha* Schrader (1973) on the basis of the presence of secondary pseudosepta near the apex and cross-bars that are not united to a septum. (Plate 1, Figures 18-20)

Denticula punctata Schrader, 1973, pl. 1, figs. 25-30.

Denticula punctata var. *hustedtii* Schrader, 1973, pl. 1, figs. 23, 24. (Plate 1, Figure 29)

Denticula seminae Simonsen and Kanaya: Koizumi, 1975b, pl. 1, figs. 1, 2. (Plate 1, Figure 1)

Denticula seminae var. *fossilis* Schrader: Koizumi, 1975b, pl. 1, figs. 3, 4. (Plate 1, Figures 2-4)

Goniothecium tenue Brun: Koizumi, 1973, pl. 7, figs. 7-9. (Plate 4, Figure 2)

Hemidiscus cuneiformis Wallich: Schrader, 1973, pl. 24, fig. 14. **Remarks:** Also included here is *H. simplicissimus* of Schrader, 1973, pl. 24, figs. 12, 13. (Plate 3, Figure 13)

Kisselviella carina Sheshukova-Poretzkaya: Koizumi, 1973, pl. 7, figs. 3, 4. **Remarks:** Compare *Cymatospira* spp. of Schrader and Fenner, 1976. (Plate 1, Figure 32).

Lithodesmium cornigerum Brun: Wornardt, 1967, fig. 131.

Lithodesmium reynoldsii Barron, 1976, pl. 1, figs. 17, 18. (Plate 4, Figure 10)

Mediaria splendida Sheshukova-Poretzkaya: Schrader, 1973, pl. 3, figs. 14, 15. **Remarks:** Generally observed as fragments.

Nitzschia challengeri Schrader, 1973, pl. 5, figs. 10-14, 34. (Plate 2, Figure 10)

Nitzschia fossilis (Frenguelli) Kanaya: Schrader, 1973, pl. 4, figs. 4, 5, 9-11, 24, 25. (Plate 2, Figures 3, 4)

Nitzschia heteropolica Schrader, 1973, pl. 26, figs. 1, 2. (Plate 2, Figure 7; Plate 4, Figure 9)

Nitzschia jouseae Burckle: Schrader, 1974, pl. 7, figs. 14-23. (Plate 3, Figure 2)

Nitzschia marina Grunow *in* Cleve and Grunow: Schrader, 1973, pl. 4, figs. 17-19.

Nitzschia miocenica Burckle: Schrader, 1974, pl. 5, figs. 10-11. **Remarks:** In his type description, Burckle (1972) states that the number of costae of *N. miocenica* is quite "regular, generally within the range of ten to eleven per ten microns." Younger forms of this taxon, however, seem to be somewhat finer in structure than older forms. (Plate 2, Figure 8; Plate 3, Figures 3, 4)

Nitzschia pliocena (Brun) Kanaya and Koizumi: Harper, 1977b, pl. 3, figs. 16, 17. **Synonym:** *Fragilariopsis pliocena*, Sheshukova-Poretzkaya, 1967, pl. 47, fig. 13. (Plate 2, Figures 1, 2)

Nitzschia porteri Frenguelli, sensu Burckle, 1972, pl. 2, fig. 16. (Plate 2, Figure 9; Plate 3, Figure 5)

Nitzschia praereinholdii Schrader, 1973, pl. 5, figs. 20, 23-26. **Remarks:** Younger forms of this taxon tend to be more finely silicified and finer in structure than earlier forms.

Nitzschia reinholdii Kanaya and Koizumi: Schrader, 1973, pl. 4, figs. 12-16, pl. 5, figs. 1-9. (Plate 2, Figure 11; Plate 3, Figure 1)

Porosira glacialis (Grunow) Joergensen: Koizumi, 1973, pl. 4, figs. 15-18. (Plate 6, Figure 13)

Pseudoeunotia doliolus (Wallich) Grunow *in* Van Heurck: Schrader, 1973, pl. 4, figs. 1, 3, 6-8. (Plate 2, Figure 5)

Rhaphoneis miocenica Schrader, 1973, pl. 25, figs. 1, 11.

Rhizosolenia barboi Brun: Schrader, 1973, pl. 24, figs. 4, 7. **Synonym:** *R. curvirostris* var. *inermis*, Koizumi, 1973, pl. 5, figs. 32, 33. (Plate 2, Figure 17)

Rhizosolenia curvirostris Jousé: Koizumi, 1973, pl. 5, figs. 29-31. (Plate 2, Figure 12)

Rhizosolenia hebeata f. *hiemalis* Gran: Koizumi, 1973, pl. 5, figs. 34, 35; Schrader, 1973, pl. 9, figs. 14-17. (Plate 2, Figure 15)

Rhizosolenia miocenica Schrader, 1973, pl. 10, figs. 2-6, 9-11. (Plate 4, Figure 8)

Rhizosolenia praebarboi Schrader, 1973, pl. 24, figs. 1-3. (Plate 2, Figure 18)

Rhizosolenia praebergonii Mukhina: Burckle, 1972, pl. 1, fig. 1. (Plate 2, Figure 16)

Rhizosolenia praebergonii var. *robusta* Burckle and Trainer, in press: **Synonym:** *R. praebergonii*, Schrader, 1974, pl. 9, figs. 1-3; Burckle, 1972, pl. 1, figs. 2, 3.

Roperia tesselata (Roper) Grunow *in* Van Heurck: Schrader, 1973, pl. 19, figs. 8, 9.

Rouxia californica Peragallo in Tempère and Peragallo: Schrader, 1973, pl. 3, figs. 18-20, 22, 26. **Remarks:** A broad concept of this species is followed here. (Plate 4, Figure 4)

Stephanopyxis horridus Koizumi: Koizumi, 1973, pl. 6, figs. 1-4. (Plate 5, Figure 13)

Stephanopyxis hyalomarginata Hajos: Schrader and Fenner, 1976, pl. 19, figs. 6, 9.

Stephanopyxis schenckii Kanaya: Schrader and Fenner, 1976, pl. 19, figs. 7, 8.

Synedra jouseana Sheshukova-Poretzkaya: Schrader, 1973, pl. 23, figs. 21-23, 25, 38. (Plate 2, Figures 13, 14)

Synedra jouseana var. 1: **Synonym:** *Thalassionema hirosakiensis*, Schrader and Fenner, 1976, pl. 5, figs. 3, 4, 6, 7; Schrader, 1976, pl. 1, figs. 14-16. **Remarks:** Generally more robust than other forms referred to the species in Leg 57 samples. (Plate 1, Figure 33)

Thalassionema hirosakiensis (Kanaya) Schrader, 1973, pl. 23, figs. 31-33. (Not *T. hirosakiensis*, Schrader, 1976, pl. 1, figs 15-16; Schrader and Fenner, 1976, pl. 5, figs. 3, 4, 6, 7. (Plate 2, Figure 6)

Thalassiosira antiqua (Grunow) Cleve-Euler: Schrader, 1973, pl. 11, fig. 25, pl. 25, fig. 19. (Plate 5, Figure 5)

Thalassiosira burckliana Schrader, 1974, pl. 1, figs. 21-26. **Synonym:** *T. nativa*, Schrader, 1973, pl. 11, figs. 24, 25. (Plate 3, Figure 7)

Thalassiosira convexa Mukhina: Schrader, 1974, pl. 2, figs. 1-5, 10-13.

Thalassiosira convexa var. *aspinosa* Schrader, 1974, pl. 2, figs. 8, 9, 13a-21. **Synonym:** *T. convexa*, Koizumi, 1975a, pl. 4, figs. 15-18. (Plate 3, Figure 8)

Thalassiosira convexa? var. 1. **Remarks:** This form has the size and general morphology of *T. zabelinae* Jousé but has a pattern of areolation that closely resembles *T. convexa*. This form probably should be placed under *T. zabelinae*; however, it is placed here because of its similarity to *T. convexa*. Koizumi (1975a) figures this form as *T. convexa* (pl. 4, figs. 19, 20). (Plate 5, Figure 14; Plate 6, Figure 16)

Thalassiosira fraga Schrader, *in* Schrader and Fenner, 1976, pl. 16, figs. 9-12.

Thalassiosira gravida Cleve: Koizumi, 1973, pl. 7, figs. 19-21. **Remarks:** Included for this chapter is *T. gravida* f. *fossilis* of Koizumi, 1973, pl. 7, figs. 22-24. (Plate 6, Figures 11, 14)

Thalassiosira gravida Cleve (flat form): **Synonyms:** *T. gravida*, Koizumi, 1972, pl. 43, fig. 11; *T.* aff. *margaritae*, Sheshukova-Poretzkaya, 1967, pl. 4, fig. 6, pl. 14, fig. 5. **Remarks:** Specimens of *T. gravida* with flattened valves are tabulated here. (Plate 5, Figure 11; Plate 6, Figure 15)

Thalassiosira hyalina (Grunow) Grunow: Koizumi, 1973, pl. 8, figs. 1, 2.

Thalassiosira jacksonii Koizumi and Barron, in Koizumi, in press, pl. 1, figs. 11-14. (Plate 6, Figures 2, 6, 10?)

Thalassiosira miocenica Schrader, 1974, pl. 22, figs. 1-5, 11-13. (Plate 3, Figure 6)

Thalassiosira nativa Sheshukova-Poretzkaya, sensu Koizumi, 1975b, pl. 2, fig. 9; Koizumi, 1975a, pl. 4, figs. 21, 22. **Synonym:** *T. decipiens* (?), Schrader, 1973, pl. 16, fig. 12. **Remarks:** Included here are specimens with marginal spines that have recently been separated into a new species, *T. borealis*, by Koizumi, in press. (Plate 6, Figures 8, 9, 12)

Thalassiosira nidulus (Tempère and Brun) Jousé, var. *nidulus:* Schrader, 1973, pl. 11, figs. 1-7. **Remarks:** Miocene specimens are more heavily silicified than younger specimens. (Plate 6, Figure 5)

Thalassiosira oestrupii (Ostenfeld) Proshkina-Lavrenko: Schrader, 1973, pl. 11, figs. 16-22, 26-33, 36, 39-45. (Plate 5, Figure 4)

Thalassiosira pacifica Gran and Angst: Schrader, 1973, pl. 25, figs. 18, 20, 21. **Synonym:** *Coscinodiscus excentricus* var. *leasareolatus* Koizumi, 1973, pl. 3, figs. 7-11.

Thalassiosira punctata Jousé: Koizumi, 1973, pl. 8, figs. 7-9. (Plate 6, Figure 3)

Thalassiosira spinosa Schrader, 1976, pl. 6, figs 5-7.

Thalassiosira spinosa var. *aspinosa* Schrader, 1976, pl. 6, fig. 3

Thalassiosira spumellaroides Schrader, 1976, pl. 6, figs. 1, 2.

Thalassiosira zabelinae Jousé: Koizumi, 1973, pl. 8, figs. 10-12. **Remarks:** Included here is *T. usatchevii* of Koizumi, 1973, pl. 8, figs. 13-15. (Plate 6, Figure 7)

Thalassiosira sp. 1. **Synonym:** *T. praeconvexa* of Schrader, 1973, pl. 11, figs. 10-15. (Plate 5, Figures 6, 7)

Thalassiosira sp. 2. (Plate 5, Figure 9)

Silicoflagellates

Distephanus boliviensis jimlingii Bukry: Barron, 1976, pl. 3, fig. 31.

Distephanus pseudofibula (Schulz) Bukry: Barron, 1976, pl. 3, fig. 29. **Synonym:** *Dictyocha pseudofibula*, Bukry, 1973b, pl. 1, figs. 7-9. (Plate 4, Figure 7)

Mesocena apiculata curvata Bukry, 1976, pl. 2, figs. 15, 16. (Plate 5, Figure 16)

Mesocena hexagona Haeckel: Barron, 1976, pl. 3, figs. 28, 33. (Plate 5, Figure 15)

Mesocena quadrangula Ehrenberg ex Haeckel: Bukry, 1973b, pl. 7, figs. 1-5; Ling, 1977, pl. 3, fig. 5.

PLATE 1
Diatoms from DSDP Leg 57 and Japan
(Scale bar represents 20 μm.)

Figure 1	*Denticula seminae* Simonsen and Kanaya. Sample 438A-2-1, 96–98 cm.
Figures 2–4	*Denticula seminae* var. *fossilis* Schrader. 2. Sample 438A-2-1, 96–98 cm. 3, 4. Sample 438A-5,CC.
Figures 5–8	*Denticula kamtschatica* Zabelina. 5. Sample 438A-7,CC. 6. Sample 438A-41-5, 90–92 cm. 7. Sample 438A-6,CC. 8. Sample 438A-28-4, 118–120 cm.
Figures 9–11	*Denticula hustedtii* Simonsen and Kanaya. 9. Sample 438A-33-5, 132–134 cm. 10. Sample 438A-66-2, 25–27 cm. 11. Sample 438A-54-1, 65–67 cm.
Figure 12	*Denticula hyalina* Schrader. Sample 438A-68-1, 101–103 cm.
Figures 13, 14	*Denticula* sp. cf. *D. lauta* Bailey. Sample 438A-85,CC.
Figures 15–17	*Denticula* sp. cf. *D. kamtschatica* Zabelina (*Nitzschia rolandii* of Harper, 1977b). 15. Sample 438A-40,CC. 16. Sample 438A-41-5, 90–92 cm. 17. Sample 438A-43-3, 123–125 cm.
Figures 18–20	*Denticula praedimorpha* Akiba. 18, 20. Sample 438A-65-1, 136–137 cm. 19. Sample JDS-3663, Biratori Formation, Umaoi area, Hokkaido, Japan.
Figure 21	*Denticula dimorpha* Schrader. Sample 438A-57-1, 115–117 cm.
Figures 22, 23	*Denticula nicobarica* Grunow. Sample 438A-66,CC.
Figure 24	*Denticula lauta* Bailey. Sample 438A-56-5, 60–62 cm.
Figure 25	*Dephineis penelliptica* Andrews. Sample 438A-82,CC.
Figures 26–28	*Denticula kanayae* Akiba. 26, 27. Sample 438B-14,CC. 28. Sample JDS-5675, Tsurikake Formation, Okushiri Island, Hokkaido, Japan.
Figure 29	*Denticula punctata* var. *hustedtii* Schrader. Sample 438A-79-1, 55–57 cm.
Figure 30	*Denticula ikebei* Akiba. Sample 438B-14,CC.
Figure 31	*Cussia tatsunokuchiensis* (Koizumi) Schrader. Sample 438A-33-5, 132–135 cm.
Figure 32	*Kieselviella carina* Sheshukova-Poretzkaya. Sample 438A-77-1, 81–83 cm.
Figure 33	*Synedra jouseana* Sheshukova-Poretzkaya var. 1. Sample 438A-79,CC.

PLATE 1

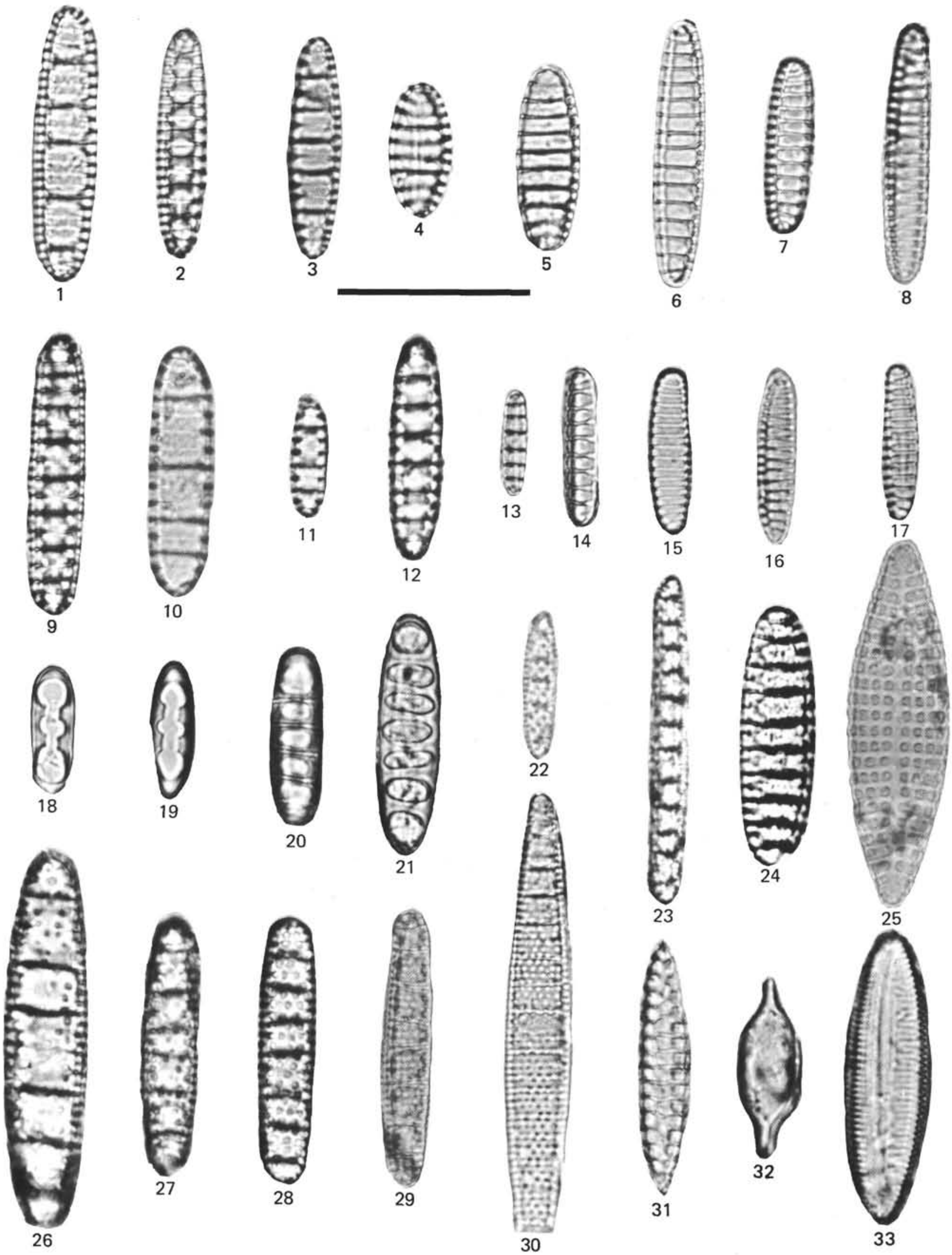
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PLATE 2
Diatoms from DSDP Leg 57

Figures 1, 2	*Nitzschia pliocena* (Brun) Kanaya and Koizumi. Sample 438A-42-5, 83–85 cm; scale bar represents 15 μm.
Figures 3, 4	*Nitzschia fossilis* (Frenguelli) Kanaya. 3. Sample 438A-38-5, 110–112 cm; scale bar represents 15 μm. 4. Sample 438A-43-3, 123–125 cm; scale bar represents 20 μm.
Figure 5	*Pseudoeunotia doliolus* (Wallach) Grunow. Sample 438A-2-1, 96–98 cm; scale bar represents 15 μm.
Figure 6	*Thalassionema hirosakiensis* (Kanaya) Schrader. Sample 438A-44-5, 71–73 cm; scale bar represents 15 μm.
Figure 7	*Nitzschia heteropolica* Schrader. Sample 438A-64-3, 36–38 cm; scale bar represents 15 μm.
Figure 8	*Nitzschia miocenica* Burckle. Sample 438A-41-5, 90–92 cm; scale bar represents 15 μm.
Figure 9	*Nitzschia porteri* Frenguelli, sensu Burckle, 1972. Sample 438A-44-5, 71–73 cm; scale bar represents 15 μm.
Figure 10	*Nitzschia challengeri* Schrader. Sample 438A-66-2, 25–27 cm; scale bar represents 15 μm.
Figure 11	*Nitzschia reinholdii* Kanaya and Koizumi. Sample 438A-28-4, 118–120 cm; scale bar represents 20 μm.
Figure 12	*Rhizosolenia curvirostris* Jousé. Sample 438A-3-3, 140–142 cm; scale bar represents 45 μm.
Figures 13, 14	*Synedra jouseana* Sheshukova-Poretzkaya. 13. Sample 438A-80,CC; scale bar represents 35 μm. 14. Sample 438A-43-5, 135–137 cm; scale bar represents 20 μm.
Figure 15	*Rhizosolenia hebetata* f. *hiemalis* Gran. Sample 438A-1,CC; scale bar represents 35 μm.
Figure 16	*Rhizosolenia praebergonii* Mukhina. Sample 438A-5,CC; scale bar represents 15 μm.
Figure 17	*Rhizosolenia barboi* Brun. Sample 438A-59,CC; scale bar represents 35 μm.
Figure 18	*Rhizosolenia praebarboi* Schrader. Sample 438A-61,CC; scale bar represents 35 μm.

PLATE 2

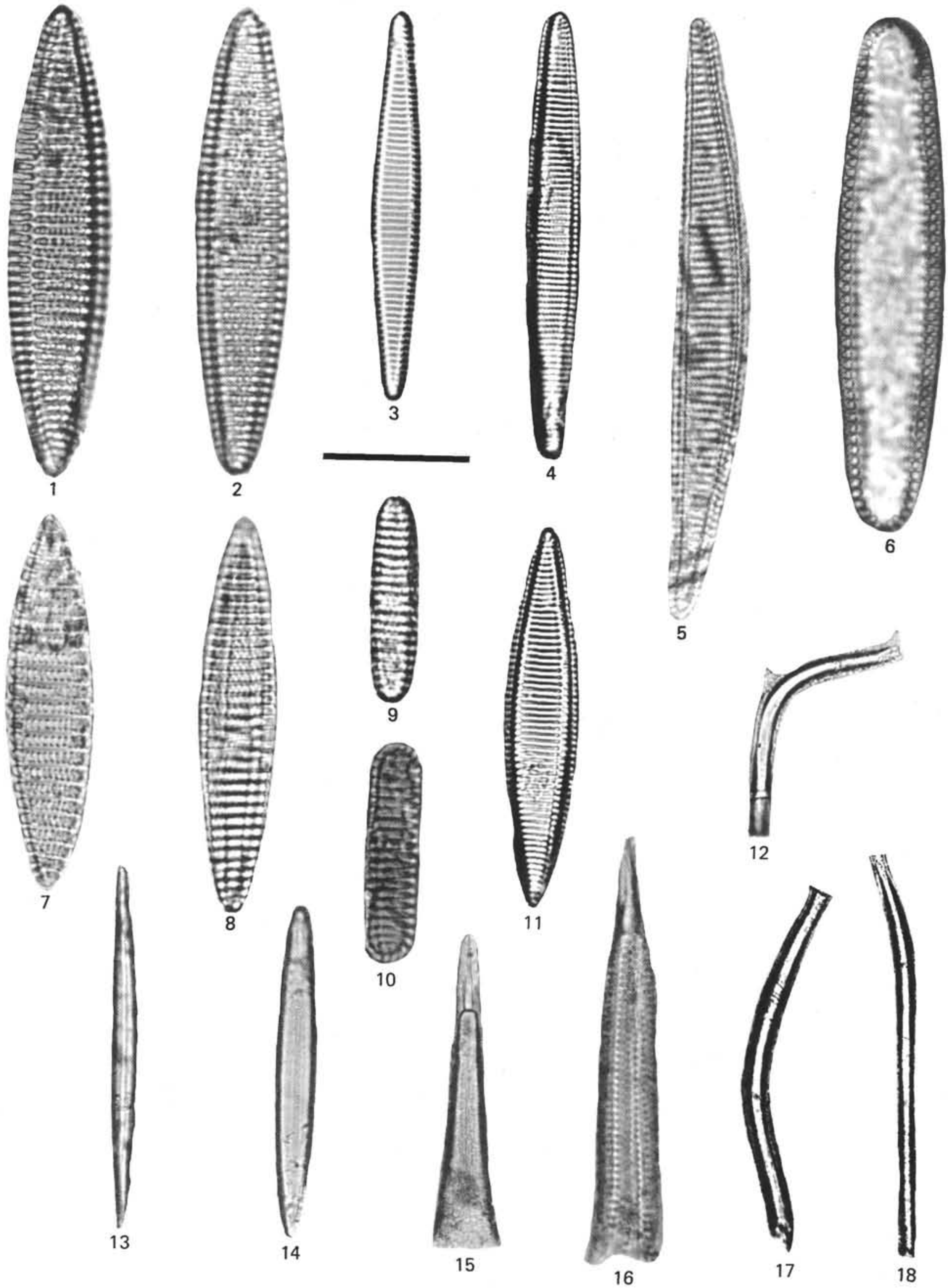

PLATE 3
Diatoms from DSDP Leg 57

Figure 1	*Nitzschia reinholdii* Kanaya and Koizumi. Sample 438-28-4, 118–20 cm; scale bar represents 20 μm.
Figure 2	*Nitzschia jouseae* Burckle. Sample 440B-47,CC: scale bar represents 20 μm.
Figure 3	*Nitzschia miocenica* Burckle. Sample 438A-41,CC: scale bar represents 12.5 μm.
Figure 4	*Nitzschia* sp. aff. *N. miocenica* Burckle. Sample 438A-39,CC; scale bar represents 12.5 μm.
Figure 5	*Nitzschia porteri* Frenguelli, sensu Burckle, 1972. Sample 438A-43-5, 135–137 cm; scale bar represents 12.5 μm.
Figure 6	*Thalassiosira miocenica* Schrader. Sample 438A-38-5, 110–112 cm; scale bar represents 20 μm.
Figure 7	*Thalassiosira burckliana* Schrader. Sample 438A-47-1, 70–72 cm; scale bar represents 12.5 μm.
Figure 8	*Thalassiosira convexa* var. *aspinosa* Schrader. Sample 438A-38-3, 130–132 cm; scale bar represents 20 μm.
Figure 9	*Asterolampra acutiloba* Forti. Sample 438A-38-5, 110–112 cm; scale bar represents 35 μm.
Figure 10	*Coscinodiscus lewisianus* Greville. Sample 438A-79,CC; scale bar represents 28 μm.
Figure 11	*Coscinodiscus yabei* Kanaya. Sample 438A-53-2, 52–53 cm; scale bar represents 20 μm.
Figure 12	*Coscinodiscus plicatus* Grunow s. ampl. Sample 438A-68-1, 101–103 cm; scale bar represents 20 μm.
Figure 13	*Hemidiscus cuneiformis* Wallich. Sample 438A-35-5, 135–137 cm; scale bar represents 20 μm.

PLATE 3

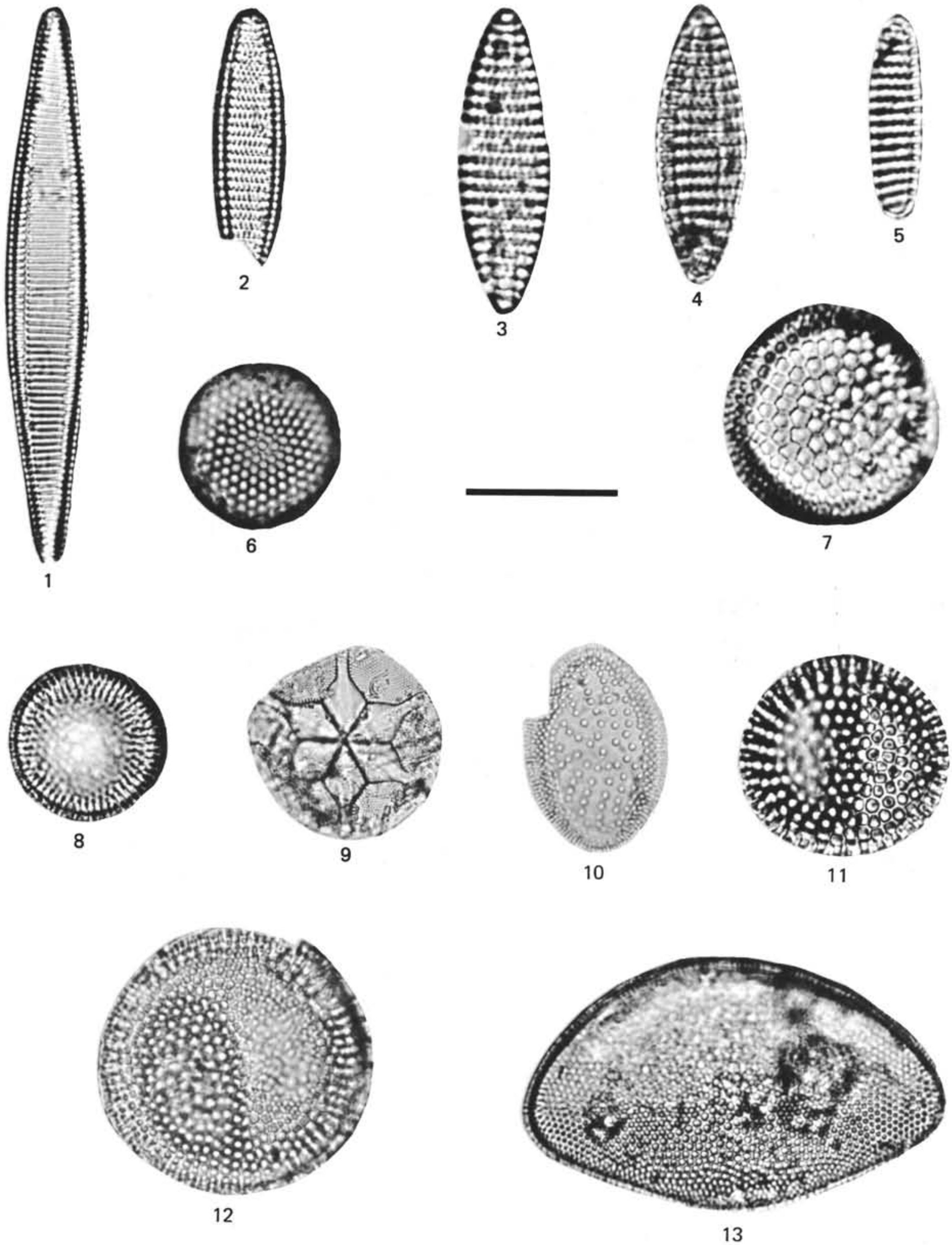

PLATE 4
Diatoms and Silicoflagellates from DSDP Leg 57

Figure 1	*Cosmiodiscus insignis* Jousé. Sample 438A-41-1, 140–144 cm; scale bar represents 20 μm.
Figure 2	*Goniothecium tenue* Brun. Sample 438A-36-5, 82–82 cm; scale bar represents 20 μm.
Figure 3	*Cussia tatsunokuchiensis* (Koizumi) Schrader. Sample 438A-28-4, 118–120 cm; scale bar represents 12.5 μm.
Figure 4	*Rouxia californica* Peragallo s. ampl. Sample 438A-42-1, 80–82 cm; scale bar represents 20 μm.
Figure 5	*Coscinodiscus temperei* Brun. Sample 438A-42-1, 80–82 cm; scale bar represents 20 μm.
Figure 6	*Coscinodiscus endoi* Kanaya. Sample 438A-53-2, 52–53 cm; scale bar represents 20 μm.
Figure 7	*Distephanus pseudofibula* (Schulz) Bukry. Sample 438A-47-1, 70–72 cm; scale bar represents 30 μm.
Figure 8	*Rhizosolenia miocenia* Schrader. Sample 438A-53-2, 52–53 cm; scale bar represents 20 *μm*.
Figure 9	*Nitzschia heteropolica* Schrader. Sample 438A-64-3, 36–38 cm; scale bar represents 20 μm.
Figure 10	*Lithodesmium reynoldsii* Barron. Sample 438A-55-1, 30–32 cm; scale bar represents 20μm.

PLATE 4

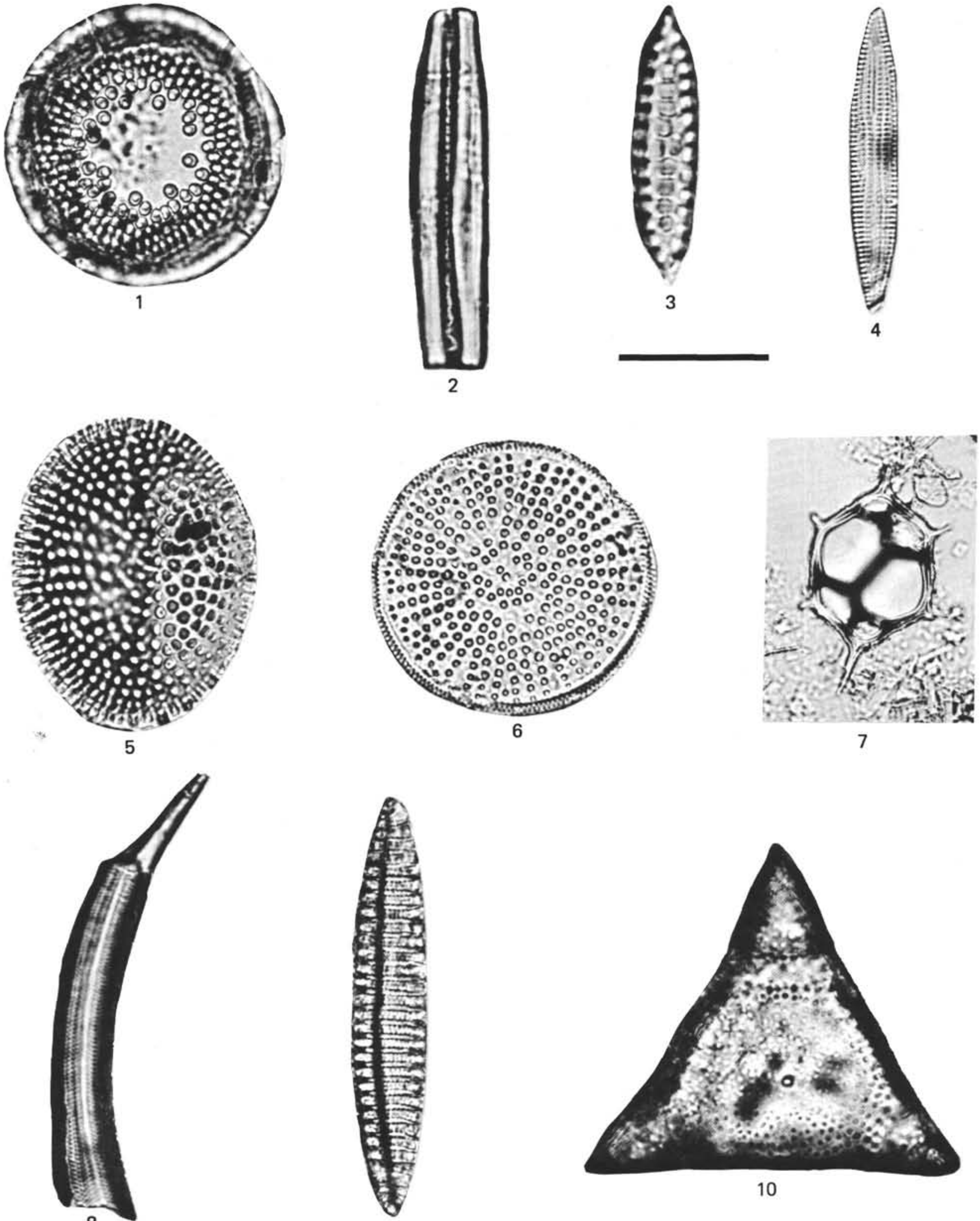

PLATE 5
Diatoms and Silicoflagellates from DSDP Leg 57

Figures 1, 3	*Actinocyclus oculatus* Jousé. Sample 438A-4-2, 140–142 cm; scale bar represents 20 μm.
Figure 2	*Actinocyclus ingens* Rattray. Sample 438A-79-1, 55–57 cm; scale bar represents 20 μm.
Figure 4	*Thalassiosira oestrupii* (Ostenfeld) Proshkina-Lavrenko. Sample 438A-32-1, 124–126 cm; scale bar represents 15 μm.
Figure 5	*Thalassiosira antiqua* (Grunow) Cleve-Euler. Sample 438A-42-5, 83–85 cm; scale bar represents 15 μm.
Figures 6, 7	*Thalassiosira* sp. 1 (*T. praeconvexa* of Schrader, 1973). 6. Sample 438A-56,CC; scale bar represents 20 μm. 7. Sample 438A-53-1, 110–112 cm; scale bar represents 20 μm.
Figures 8, 12	*Actinocyclus ingens* var. 1. Sample 438A-70-5, 121–123 cm; scale bar represents 35 μm.
Figure 9	*Thalassiosira* sp. 2. Sample 438B-14,CC: scale bar represents 15 μm.
Figure 10	*Coscinodiscus pustulatus* Mann. Sample 438A-5-4, 115–117 cm; scale bar represents 35 μm.
Figure 11	*Thalassiosira gravida* Cleve (flat form). Sample 438A-32-3, 124–126 cm; scale bar represents 35 μm.
Figure 13	*Stephanopyxis horridus* Koizumi. Sample 438-7-6, 20–24 cm; scale bar represents 35 μm.
Figure 14	*Thalassiosira convexa* Mukhina? var. 1. Sample 438A-15-1, 44–46 cm; scale bar represents 35 μm.
Figure 15	*Mesocena hexagona* Haeckel. Sample 438A-60,CC; scale bar represents 45 μm.
Figure 16	*Mesocena apiculata curvata* Bukry. Sample 438B-14,CC; scale bar represents 45 μm.

PLATE 5

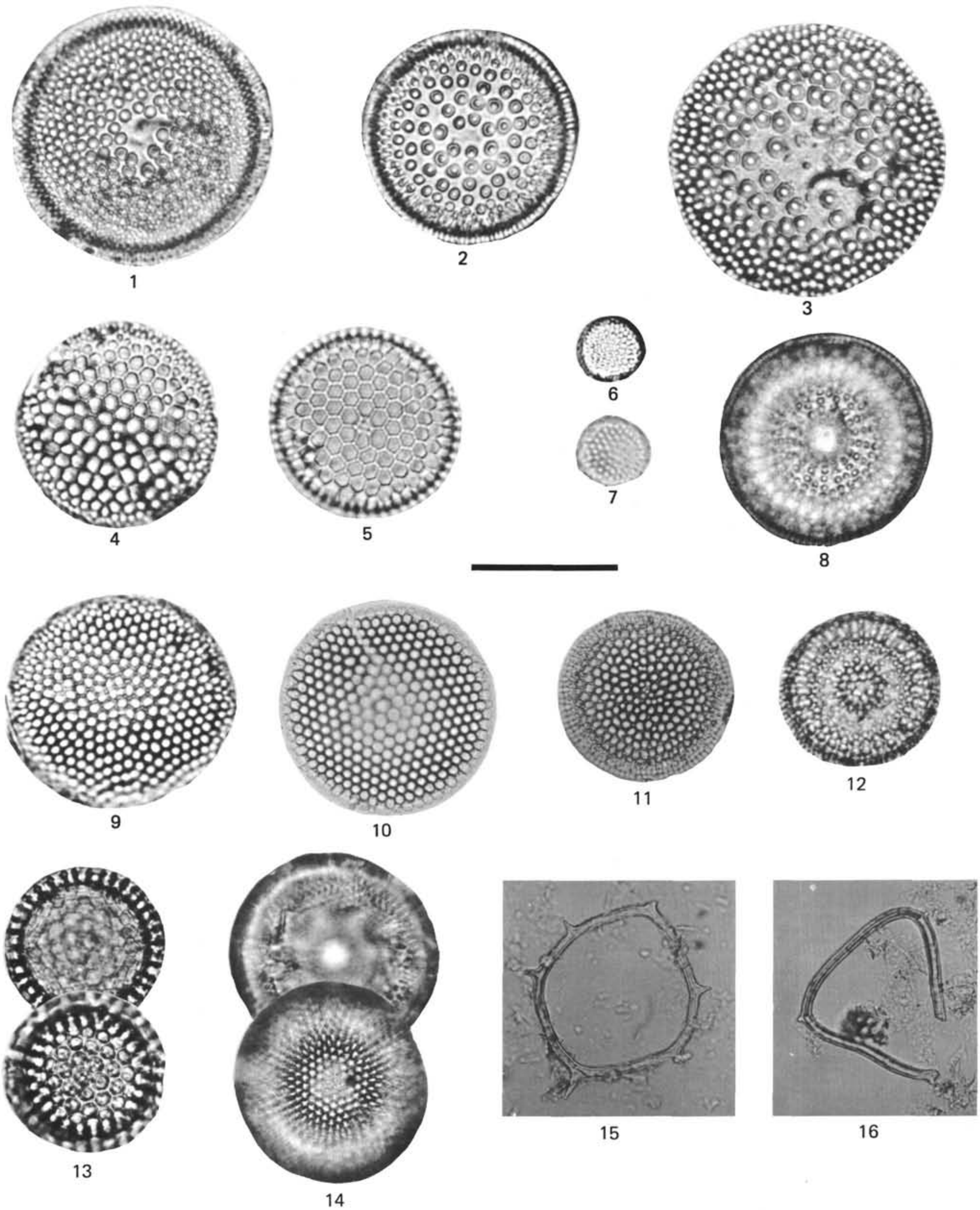

PLATE 6
Diatoms from DSDP Leg 57

Figures 1, 4	*Thalassiosira nidulus* var. *delicata* n. var. 1. Sample 438A-20-4, 135–137 cm (Holotype USNM 689960); scale bar represents 20 μm. 4. Sample 438A-34-5, 85–86 cm (Isotype USNM 689961); scale bar represents 35 μm.
Figures 2, 6	*Thalassiosira jacksonii* Koizumi and Barron. 2. Sample 438A-31,CC; scale bar represents 15 μm. 6. Sample 438A-34,CC; scale bar represents 20 μm.
Figure 3	*Thalassiosira punctata* Jousé. Sample 438A-32-1, 124–126 cm; scale bar represents 20 μm.
Figure 5	*Thalassiosira nidulus* (Tempère and Brun) Jousé var. *nidulus.* Sample 438-5-1, 140–142 cm; scale bar represents 20 μm.
Figure 7	*Thalassiosira zabelinae* Jousé. Sample 438A-28-4, 118–120 cm; scale bar represents 20 μm.
Figures 8, 9, 12	*Thalassiosira nativa* Sheshukova-Poretzkaya. Sample 438A-20-4, 135–137 cm; scale bar represents 20 μm.
Figure 10	*Thalassiosira* sp. aff. *T. jacksonii* Koizumi and Barron. Sample 438A-30-3, 129–131 cm; scale bar represents 45 μm.
Figures 11, 14	*Thalassiosira gravida* Cleve. 11. Sample 438A-2-1, 96–98 cm; scale bar represents 20 μm. 14. Sample 438A-30-3, 129–131 cm; scale bar represents 20 μm.
Figure 13	*Porosira glacialis* (Grunow) Joergensen. Sample 438A-2-1, 96–98 cm; scale bar represents 20 μm.
Figure 15	*Thalassiosira gravida* Cleve (flat form). Sample 438A-42-3, 110–112 cm; scale bar represents 20 μm.
Figure 16	*Thalassiosira convexa* Mukhina? var. 1. Sample 438A-14,CC; scale bar represents 45 μm.

PLATE 6