

9. NEOGENE DIATOM BIOSTRATIGRAPHY OF THE MIDDLE LATITUDE WESTERN NORTH PACIFIC, DEEP SEA DRILLING PROJECT LEG 86¹

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ABSTRACT

The Pliocene and Pleistocene sections recovered in a south-north transect (38–42°N, 155°E) in the northwestern Pacific during Leg 86 are largely undeformed, owing to use of the hydraulic piston corer. Twenty-two diatom datum levels are ranked and tied directly to the paleomagnetic reversal record. The following datum levels are biostratigraphically useful: (1) first appearance datum (FAD) *Thalassiosira oestrupii*, 5.10–5.35 m.y. ago, (2) FAD *Nitzschia jouseae*, 4.50 m.y. ago, (3) FAD *Denticulopsis seminae* var. *fossilis*, 3.36–3.70 m.y. ago, (4) last appearance datum (LAD) *Denticulopsis kamtschatica*, 2.50–2.58 m.y. ago, (5) LAD *Thalassiosira convexa*, 2.30 m.y. ago, (6) FAD *Pseudoenotia doilolus*, 1.89–2.00 m.y. ago, (7) LAD *Actinocyclus oculatus*, 0.93–1.33 m.y. ago, (8) LAD *Nitzschia reinholdii*, 0.47–0.52 m.y. ago, (9) LAD *Rhizosolenia curvirostris*, 0.30–0.35 m.y. ago. A new diatom zonation, based on these first-order datum levels, is proposed for the middle latitude Pliocene and Pleistocene.

The middle to upper Miocene section recovered at Site 581 (44°N, 160°E) provides a new diatom zonation, based on second-order datum levels, for the high latitude Miocene. A late Miocene hiatus spanning the interval from 8.2 to 10.1 m.y. ago is identified at Site 581. The hiatus corresponds to Hiatus NH 5 of Keller and Barron (1983).

INTRODUCTION

A series of excellent biosiliceous sequences from Sites 578, 579, and 580 were recovered on a south-north transect between 34 and 42°N in the western North Pacific (Fig. 1). The Pliocene and Pleistocene sequences were largely undeformed, owing to use of the hydraulic piston corer (HPC). The middle to late Miocene section, recovered at Site 581, contains abundant and well-preserved diatoms.

Through detailed investigations of piston cores, Deep Sea Drilling Project (DSDP) drill cores, and land-exposed marine sections during the past 10 yr., two main problems have appeared: provincialism and accurate age assignment (Koizumi and Burckle, 1984).

Because of provincialism (i.e., the latitudinal dependence of diatom distribution after the Miocene) it is necessary to make up at least two kinds of zonal schemes or datum levels: one for low latitudes and another for high latitudes (Burckle and Opdyke, 1977). The correlation between low and high latitudes was provided by diatom zones (Koizumi, 1975a) and by paleomagnetic reversal records tied to micropaleontological studies (Burckle, 1971; Burckle and Opdyke, 1977). Meanwhile, the sites in middle latitudes allowed a comparison within the same material of zonal boundaries and datum levels in low- and high-latitude diatom zonation (Koizumi, 1975b). The spatial and temporal distribution of zonal boundaries and datum levels have not been discussed in detail be-

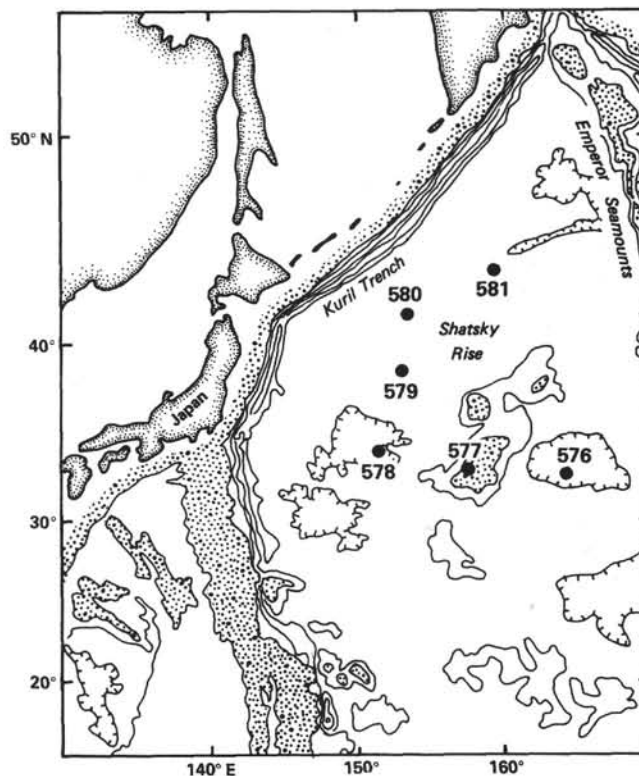


Figure 1. Location of sites occupied on Leg 86 in the western North Pacific Ocean. Areas shallower than 4 km stippled, 5-km contour plain, 6-km contour hachured.

cause of the lack of suitable and complete sections in middle latitudes.

As concerns age assignment, more than 40 diatom datum levels have been directly tied to the paleomagnet-

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ic reversal stratigraphy in low latitudes (Burckle, 1972, 1977, 1978; Burckle and Trainer, 1979). In low to middle latitudes, on the other hand, datum levels are tied to the paleomagnetism by such second-order methods as extrapolation from sediment accumulation rate curves based on these paleomagnetic ties in low latitudes (Barron, 1980, 1981; Keller and Barron, 1981; Keller et al., 1982; Barron and Keller, 1983). Datum levels for the Pliocene and Pleistocene in middle to high latitudes are chronologically calibrated against the paleomagnetic stratigraphy in several areas (Donahue, 1970; Koizumi and Kanaya, 1976; Burckle and Opdyke, 1977; Burckle et al., 1978, 1980; Ujiie et al., 1977). Miocene datum levels in Japan are chronologically tied to K-Ar and fission track dates (Koizumi, 1977).

The purpose of this chapter is (1) to present the distribution of selected diatom datum levels in a south-north transect from 34 to 42°N, (2) to propose a middle latitude diatom zonation for the Pliocene and Pleistocene, (3) to propose a high latitude diatom zonation for the middle to upper Miocene, and (4) to present accurate age assignment for the selected datum levels directly tied to the paleomagnetic stratigraphy (Bleil, this volume) in the same samples.

METHOD OF STUDY

In processing the materials before microscopic examination, Schrader (1974a) and Koizumi's (1980) procedures were modified on two points: (1) wet original material was dried in order to do quantitative analysis of diatoms, and (2) boiling and centrifuging were omitted so as not to destroy the more delicate diatoms. The procedure was as follows: About 1 ml of original wet material was placed in an oven at 60°C for 24 hr., 0.2 g of the dried-up material were placed in a 200-ml beaker of hydrogen peroxide solution (15%) and left to stand for 24 hr. After pouring off the suspension, the residue was diluted with 200 ml of distilled water and homogenized for about 3 s in an ultrasonic washer (Clean Matic; 20 W, 40 kHz). Using a micropipette with disposable plastic tip (Justor-Jv 500 μ l), 0.25 ml of this solution was placed on a grease-free cover glass (18 \times 18 mm in size), dried on a hot plate at 50°C, and then mounted on a glass slide using Pleurax (refractive index = min. 1.50, alcohol solvent).

All diatoms were identified and counted until the number of individual specimens reached 200 (Sites 577, 578, and 581) or 300 (Sites 579 and 580) total, excluding *Bacteriastrium* spp. and *Chaetoceros* spp. The frequencies of *Coscinodiscus wailiesii* and *Ethmodiscus rex*, which were found only as fragments, were excluded from the regular counting although they were larger in number. For the samples from Sites 577 and 578, 400 additional specimens were counted in order to decide the occurrence of stratigraphically important diatoms (a plus sign in Tables 1 and 2). The strewn slides that recorded poor preservation were examined entirely at $\times 700$ (a black dot in Tables 1 and 2).

Abundances for Sites 577 and 578 are graded as follows: B = barren, VR = very rare (<100 individuals on one slide), R = rare (101–1000 individuals), F = few (1001–2000 individuals), C = common (2001–4000 individuals), and A = abundant (>4001 individuals). Quantitative abundance of diatoms was defined for each sample and related to 1 g of dried material for Sites 579 through 581. Estimates of preservation were based on the number of broken and dissolved diatom valves and expressed as follows: p = poor, m = moderate, and g = good.

Diatoms at Sites 577 and 578 were researched by Y. Tanimura and the residues were examined by I. Koizumi.

DIATOMS AT EACH SITE

Site 577

Site 577 is located on the western flank of the Shatsky Rise. Hole 577 (32°26.5'N, 157°43.40'E, depth

2678 m) penetrated to a maximum depth of 118.8 m sub-bottom and terminated in a hard layer. The sediments recovered are nannofossil oozes.

Diatoms are few to very rare and their preservation is poor to moderate from 0.57 through 54.11 m (Samples 577-1-1, 56–57 cm to 577-6-7, 30–31 cm). Diatoms are absent below the core catcher of Core 6.

Diatom assemblages in the interval from Samples 577-1-1, 56–57 cm through 577-3-5, 74–75 cm (0.57–23.05 m below the seafloor) belong to the *Pseudoennotia doliolus* Zone of Burckle (1972). The *Rhizosolenia praebergonii* Zone in Samples 577-3-6, 74–75 cm to 577-4-2, 61–62 cm (24.14–27.92 m) is followed by the *Nitzschia jouseae* Zone in Samples 577-4-3, 61–62 cm to 577-5, CC (29.42–44.80 m), although it is difficult to examine zonal boundaries because of dissolution of such key species as *Rhizosolenia praebergonii* and *Nitzschia jouseae*. In samples from Core 6 (45.11–54.11 m), because zonal guide species such as *Nitzschia jouseae* and *Thalassiosira convexa* are absent, the corresponding zones can not be assigned (Table 1).

Site 578

Site 578 lies west of the Shatsky Rise in a large area of gently rolling seafloor. A thick section of late Neogene siliceous clay was recovered from Hole 578 (33°55.56'N, 151°37.74'E; depth 6010 m). The upper 76.8 m of siliceous clay is anoxic, gray and olive gray in color, with many pyrite-cemented layers. On the other hand, siliceous clay and clay from 76.8 to 124.5 m are oxidized, yellow brown and brown in color with rare ferromanganese nodules. From 124.5 to 176 m, the pelagic clay is "slick," predominantly dark to very dark brown, and very homogeneous. Drilling was stopped by chert at 176.8 m below the seafloor.

Diatoms are common to few and preservation is moderate. Sometimes they are very rare and poorly preserved in the upper 52.3 m (down to Sample 578-6, CC). From 53.5 to 116.7 m (between Samples 578-7-1, 121–122 cm and 578-13-5, 135–136 cm), diatoms are abundant to common and moderate to well preserved. They are absent below Core 13 (Table 2, back pocket).

The stratigraphic occurrence of selected diatoms at this site is shown in Figure 2.

The ten diatom zones defined in this chapter were recognized without zonal breaks.

Site 579

Site 579 lies near the southern margin of the transitional zone between the subtropical and subarctic gyres. A total of 149.5 m of siliceous clay was recovered from two holes at Site 579 (Hole 579, 38°37.68'N, 153°50.17'E, depth 5737 m and Hole 579A, 38°37.61'N, 153°50.28'E, depth 5737 m). Coring was terminated at 149.5 m because of increasingly poor recovery in well-indurated clayey diatom ooze.

Diatoms are generally abundant and well preserved throughout the entire section, except for two samples (579-2-4, 13–14 cm and 579-3-6, 115–116 cm), where they are few and moderately well preserved.

The eight diatom zones ranging from late Pleistocene through early Pliocene were recognized without breaks

in Holes 579 and 579A (Table 3, back pocket). Diatom assemblages in both the lower part of Hole 579 (from Sample 579-2-4, 123–124 cm through Sample 579-2-5, 123–124 cm) and the top of Hole 579A (from Sample 579A-1-1, 14–15 cm through Sample 579A-2-2, 13–14 cm) belong to the *Rhizosolenia curvirostris* Zone.

The stratigraphic ranges of diagnostic diatoms at this site are shown in Figure 3.

Site 580

Site 580 lies at the northern margin of the transitional zone between the subarctic and subtropical gyres. A total of 155.3 m of Pleistocene and late Pliocene siliceous gray to dark gray and olive gray clay was recovered from Hole 580 (41°37.47'N, 153°58.58'E, depth 5375 m).

Diatoms are abundant and well preserved throughout the section. Seven diatom zones were recognized without zonal breaks in Hole 580 (Table 4, back pocket).

The stratigraphic ranges of selected diatoms in this hole are shown in Figure 4.

Site 581

Site 581 lies in the modern subarctic gyre, the location proposed for the Leg 88 downhole seismometer experiment. Because of the limited time available and the need to drill to basement to allow Leg 88 to plan their casing program, HPC sampling of the upper part of the sediment section at Site 581 was deferred until Leg 88. Hole 581 (43°55.62'N, 159°47.76'E, depth 5476 m) terminated in basalt recovered from 343 to 352.5 m sub-bottom depth. After Core 1 was recovered at the mud line (0–1.0 m), an interval of 180.5 m of sediment was washed away. The section from 181.5 to 223.6 m is anoxic, gray and green in color, biosiliceous clay to ooze. On the other hand, the sediments from 223.6 to 244.8 m consist of oxidized, yellow brown, biosiliceous clay. From 244.8 to 276.6 m, the sediment is "slick," fine-grained pelagic clay. From 276.6 to 343.0 m, nothing but chert fragments were recovered.

Diatoms are abundant and well preserved in Cores 1 through 8 (above 248 m), except for one sample (581-8-5, 110–111 cm) where they are very rare. In Core 9 (248.0–257.5 m), diatoms are very rare and only solution-resistant valves were recovered in the shipboard analysis. Diatoms are absent below Core 10.

A hiatus separates the *Denticulopsis katayamae* Zone and the *Thalassionema schraderi* Zone between Section 6 and the core catcher of Core 6 (Fig. 8). The time gap over the zonal boundary is about 1.9 m.y. from 8.2 to 10.1 m.y. ago. This hiatus corresponds with Hiatus NH5 of Keller and Barron (1983).

An early Pliocene to middle Miocene diatom biostratigraphy, typical of the subarctic region, was recovered (Table 5). The stratigraphic ranges of selected species at this site are shown in Figure 5.

DISTRIBUTION OF LATEST MIOCENE TO PLIOCENE AND PLEISTOCENE DATUM LEVELS IN MIDDLE LATITUDES

Twenty-two important middle latitude diatom datum levels based on the data provided from Leg 86 are dis-

cussed. Figure 6 gives the temporal and areal distribution of these datum levels, which are defined by first and last occurrence of key species. As was done by Burckle (1977, 1978) and Keller et al. (1982), each datum level is ranked by order of reliability (Table 6), using the criteria of Hornibrook and Edwards (1970), as follows:

First order: "Easily identifiable, common and persistent, either first rapid evolutionary appearance or highly consistent range." Second order: "Easily identifiable, fairly consistently present but not necessarily common, or first gradual evolutionary appearance is fairly consistent range." Third order: "Consistency of identification difficult or rare, or well defined ecologically or local geographic restrictions, or known in very few sections, or limits of range uncertain due to sampling gaps or discordances."

The datum levels from youngest to oldest are as follows:

1. The last occurrence of *Thalassiosira nidulus* is slightly earlier in low-middle latitudes (0.39 m.y. ago) than in middle-high latitudes (0.28 m.y. ago). This datum level was first used to define the top of the *Rhizosolenia curvirostris* Zone (Koizumi, 1973). Because of the possible diachrony of this datum level in the middle-high latitude eastern North Pacific (Schrader, 1973) it is assigned to a second-order category.

2. The last occurrence of *Rhizosolenia curvirostris* is almost synchronous at 0.30–0.35 m.y. ago in middle-high latitudes. This datum level defines the top of the *Rhizosolenia curvirostris* Zone. This species is also distributed in the middle latitude eastern North Pacific (Barron, 1981). It is classified as a first-order datum level.

3. The last occurrence of *Nitzschia reinholdii* is almost synchronous at 0.47–0.52 m.y. ago in middle-high latitudes. Koizumi (1975a; Koizumi and Kanaya, 1976) indicated this datum level in the lower part of the Brunhes Epoch in the North Pacific. Burckle (1977) also reported this datum level as a first-order category with an age of approximately 0.63 m.y. in the equatorial regions. It is assigned to a first-order category.

4. The last occurrence of *Nitzschia fossilis* is remarkably synchronous at 0.55 m.y. ago in middle-high latitudes. Koizumi and Kanaya (1976) first reported this datum level in the lowest part of the Brunhes Epoch on the Choshi Peninsula, Central Japan. This species also disappears in the lowest part of the Brunhes Epoch in the equatorial regions (Burckle and Trainer, 1979) and is classified as a first-order datum level.

5. The last occurrence of *Rhizosolenia matuyamai* is slightly later in middle latitudes (0.85 m.y. ago) than in lower and higher latitudes (0.89–0.97 m.y. ago). Burckle et al. (1978) described this species as ranging consistently from just below the Jaramillo Event to the lower part of the Jaramillo Event over the middle latitude North Pacific. Because of rare and sporadic occurrences it is classified as a second-order datum level.

6. The first occurrence of *Rhizosolenia matuyamai* is slightly earlier in middle latitudes (1.05 m.y. ago) than in lower and higher latitudes (0.91–1.00 m.y. ago). This datum level is put in a second-order category.

7. The last occurrence of *Actinocyclus oculatus* is earlier in lower latitudes (1.33 m.y. ago) than in higher lati-

Table 1. Stratigraphic occurrences of Neogene diatoms in Hole 577.

Core-Section (interval in cm)	Depth below seafloor (m)	Abundance	Preservation	<i>Bacteriastrum</i> spp.	<i>Actinocyclus curvatus</i>	<i>A. ehrenbergii</i>	<i>A. ellipticus</i>	<i>A. ellipticus</i> f. <i>lancoolata</i>	<i>A. elongatus</i>	<i>A. moronensis</i>	<i>A. oculatus</i>	<i>Actinocyclus</i> sp.	<i>Actinocyclus senarius</i>	<i>Actinocyclus</i> sp.	<i>Asterolampra marylandica</i>	<i>Asterolampra</i> sp.	<i>Asteromphalus flabellatus</i>	<i>A. heptactis</i>	<i>A. imbricatus</i>	<i>A. peterssonii</i>	<i>A. robustus</i>	<i>Asteromphalus</i> sp.	<i>Cocconeis costata</i>	<i>Cocconeidiscus africanus</i>	<i>C. nodulifer</i>	<i>C. oculus-iridis</i>	<i>C. radiatus</i>	<i>C. stellaris</i>	<i>C. tabularis</i> v. <i>egregius</i>	<i>C. verusissimus</i>	<i>C. yabei</i>	
1-1, 56-57	0.57	R	p																													
1-2, 56-57	2.07	VR	p																													
1-3, 56-57	3.57	VR	p																													
1-4, 56-57	5.07	R	p																													
1-5, 56-57	6.57	R	p		•															•												
1, CC	6.80	F	m	1	4	1							8	1			1					1		1	10					7		
2-1, 47-48	7.28	VR	p																						•							
2-2, 47-48	8.78	VR	p										•											•								
2-3, 47-48	10.28	R	p																					•								
2-4, 47-48	11.78	F	m		2																			4	19	1					4	
2-5, 47-48	13.28	R	p																												•	
2, CC	16.30	VR	p																													
3-1, 74-75	17.05	F	m		2								2					1							2		1				9	
3-2, 74-75	18.55	VR	p																						•						•	
3-3, 74-75	20.05	C	m								1	1	3		1									1				1			7	
3-4, 74-75	21.55	F	m		3																			2	8						8	
3-5, 74-75	23.05	C	m		1											1								3							1	6
3-6, 74-75	24.14	R	p																						•							
3, CC	25.80	R	m		4	1																		4			1				3	
4-1, 61-62	26.42	VR	p																													
4-2, 61-62	27.92	R	m																													
4-3, 61-62	29.42	R	p																						•							•
4-4, 61-62	30.92	R	m																						•							r
4-5, 61-62	32.42	VR	p	1	5			1	1									1						1	18		1	3	1			
4-6, 61-62	33.92	R	p							•															•							
4, CC	35.30	F	g																					1	6						2	
5-1, 56-57	35.81	VR	p																						•							
5-2, 56-57	37.31	VR	p																													
5-3, 56-57	38.81	VR	p																													
5-4, 56-57	40.31	VR	p	•	•			•																								
5-5, 56-57	41.81	VR	p																													
5-6, 56-57	42.86	R	p																													
5, CC	44.80	R	p																													
6-1, 30-31	45.11	VR	p																													
6-2, 30-31	46.61	VR	p																													
6-3, 30-31	48.11	VR	p																													
6-4, 30-31	49.61	VR	p																													
6-5, 30-31	51.11	VR	p																													
6-6, 30-31	52.61	B																														
6-7, 30-31	54.11	VR	p																													
6, CC	54.30	B																														

Note: A = abundant, C = common, F = few, R = rare, VR = very rare, B = barren, r = reworked, + = found in 600 specimens counted, • = present in a strewn slide. Preservation: g = good, m = moderate, p = poor. See text for further explanation.

tudes (0.93–1.00 m.y. ago). Donahue (1970) showed that the extinction level of this species in the high latitude North Pacific is near the top of the Jaramillo Event. Because of the diachrony of this datum level, it is assigned to a second-order category.

8. The last occurrence of *Thalassiosira antiqua* is remarkably diachronous from 3.14 m.y. ago in lower latitudes to 1.43 m.y. ago in higher latitudes. This datum level has been used to define the top of the *Thalassiosira zabelinae* Zone (Koizumi, 1973) and the *Denticulopsis seminae* var. *fossilis* Zone (Koizumi, 1975a) in middle-high latitudes. It is a good marker species for high latitudes, but it is assigned to the third-order datum level due to the diachrony.

9. The first occurrence of *Pseudoeunotia doliolus* is slightly earlier in lower latitudes (2.00 m.y. ago) than in higher latitudes (1.89 m.y. ago). Burckle (1972) reported this datum level in the lower part of the Olduvai Event in the equatorial Pacific. This species is broadly distributed over the tropical and middle-high latitudes. It is assigned to a first-order category with an approximate age of 1.90 m.y. in middle latitudes.

10. The last occurrence of *Rhizosolenia praebergonii* is earlier (2.14 m.y. ago) in higher latitudes than in lower latitudes (1.66 m.y. ago). Burckle (1972) reported

the extinction level of this species just after the Olduvai Event in the equatorial Pacific. It is a good marker species for low–middle latitudes, but it is classified as a second-order datum level because of the sporadic occurrence and the diachrony between low and high latitudes.

11. The last occurrence of *Thalassiosira convexa* is remarkably synchronous at 2.30 m.y. ago in middle-high latitudes. Burckle (1972) used this datum level to define the top of “B” Subzone of the *Rhizosolenia praebergonii* Zone in the equatorial Pacific. This species is a cosmopolitan species and is assigned to a first-order category.

12. The first occurrence of *Rhizosolenia praebergonii* is slightly earlier in lower latitudes (2.58 m.y. ago) than in higher latitudes (2.40 m.y. ago). It is about 3.0 m.y. old in the equatorial Pacific, according to Burckle (1978). Because of the diachrony between low and high latitudes, it is assigned to a second-order datum level.

13. The last occurrence of *Bogorovia tatsunokuchiensis* is almost synchronous at 2.50–2.55 m.y. ago in middle–high latitudes. This species, described by Koizumi (1972), was the first to be related to the paleomagnetic reversal record. Because this species has only been reported from middle–high latitudes of the western North Pacific, it is assigned to a second-order datum level.

Table 1. (Continued).

Coccolithus spp.	<i>Cyclotella striata</i>	<i>C. stylorum</i>	<i>Denticulopsis kamtschatica</i>	<i>D. seminae</i>	<i>D. seminae</i> v. <i>fossilis</i>	<i>Diploneis bomboides</i>	<i>D. bombus</i>	<i>Diploneis</i> sp.	<i>Endiccia</i> sp.	<i>Hemidiscus cuneiformis</i>	<i>H. simplicissimus</i>	<i>Hemidiscus</i> sp.	<i>Nitzschia bicapitata</i>	<i>N. dietrichii</i>	<i>N. fossilis</i>	<i>N. inflatula</i>	<i>N. interruptistriata</i>	<i>N. jouseae</i>	<i>N. kolaczekii</i>	<i>N. marina</i>	<i>N. reinholdii</i>	<i>N. seriata</i>	<i>N. sicula</i>	<i>Nitzschia</i> spp.	<i>Paralia sulcata</i>	<i>Planktoniella sol</i>	<i>Pseudoecionia dololus</i>	<i>Rhizosolenia barboi</i>	<i>R. bergonii</i>	<i>R. curvirostris</i>	<i>R. hebetata</i>	<i>R. praebergonii</i>	<i>R. styliformis</i>	<i>Rhizosolenia</i> spp.	<i>Roperia tessellata</i>				
•		r																																					
2	•		r																																				
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14. The last occurrence of *Nitzschia jouseae* is slightly later in middle latitudes (2.58 m.y. ago) than in lower and higher latitudes (2.48–2.50 m.y. ago). Burckle (1972) gave an approximate age of 2.55 m.y. for this datum level. Burckle and Trainer (1979) stated that the last true appearance of this species is older (2.7 m.y. ago) in a higher sedimentation rate core from the equatorial Pacific, and this datum occurs during the onset of a “glacial” event based on the isotopic data. The low Td (diatom temperature) values are observed for this stratigraphic datum at both Sites 579 and 580 (Koizumi, this volume). Because of the wide application of this datum level it is ranked as a first-order category.

15. The last occurrence of *Denticulopsis kamtschatica* is synchronous at 2.50–2.58 m.y. ago in middle-high latitudes. This well-known datum was first used by Koizumi (1973). Burckle and Opdyke (1977) were the first to relate it to the paleomagnetic reversal record. This species is broadly distributed over the middle-high latitude North Pacific. It is assigned to a first-order datum level.

16. The first occurrence of *Denticulopsis seminae* var. *fossilis* is earlier in middle latitudes (3.70 m.y. ago) than in lower latitudes (3.36 m.y. ago). Barron (1980, 1981) reported that this datum level has an absolute age estimated at about 3.1 m.y. by the sediment accumulation rate curves in the middle latitudes of both the western

and the eastern North Pacific. Burckle and Opdyke (1977) suggested, however, that this species occurred first at approximately 4.3 m.y. ago in two Lamont–Doherty Geological Observatory piston cores from the middle-high latitude western North Pacific, but they did not indicate the stratigraphic occurrence of this species. This species was not observed in Core 2 of Site 581, which is estimated by the sediment accumulation curve (Fig. 8) to be 3.4–4.4 m.y. old. Because of the diachrony of this datum level, it is classified as a second-order category.

17. The first occurrence of *Nitzschia jouseae* is at 4.50 m.y. ago at Site 578 (34°N). This age also agrees with an age estimated by the sediment accumulation rate curve for Site 581 (44°N). Burckle (1978) indicated that this species appeared in the upper “c” event of the Gilbert Epoch (~4.45 m.y. ago) in the equatorial Pacific. Because of the isochrony and the wide application of this datum level, it is ranked as a first-order category.

18. The first occurrence of *Bogorovia tatsunokuchiensis* is at 5.26 m.y. ago at Site 578, while the first occurrence of the datum is more recent (4.9–5.1 m.y. ago) at Site 581. Because it has only been reported from the middle latitude western North Pacific and is diachronous, it is assigned to the third-order datum.

19. The first occurrence of *Thalassiosira oestrupii* is at 5.35 m.y. ago at Site 578. Barron (1981) used this datum to define the base of his *Thalassiosira oestrupii*

Table 1. (Continued).

Core-Section (interval in cm)	Depth below seafloor (m)	Abundance	Preservation	Synedra sp.	<i>Thalassiosira bacillaris</i>	<i>T. nitzschoides</i>	<i>T. nitzschoides</i> v. <i>parva</i>	<i>Thalassiosira</i> spp.	<i>Thalassiosira convexa</i>	<i>T. decipiens</i>	<i>T. eccentrica</i>	<i>T. kryophila</i>	<i>T. leptopus</i>	<i>T. lineata</i>	<i>T. oestrupii</i>	<i>T. pacifica</i>	<i>T. plicata</i>	<i>T. symbolophora</i>	<i>T. symmetrica</i>	<i>Thalassiosira</i> spp.	<i>Thalassiothrix frauenfeldii</i>	<i>T. longissima</i>	<i>Thalassiothrix</i> spp.	<i>Triceratium cinnamomeum</i>	Diatom zones	Series
1-1, 56-57	0.57	R	p		•																					
1-2, 56-57	2.07	VR	p		•																					
1-3, 56-57	3.57	VR	p		•																					
1-4, 56-57	5.07	R	p		•	•																				
1-5, 56-57	6.57	R	p		•																					
1,CC	6.80	F	m		4	51	5							4	17	1			1	4	1	13			<i>P. doliolus</i>	
2-1, 47-48	7.28	VR	p		•																					
2-2, 47-48	8.78	VR	p		•																					
2-3, 47-48	10.28	R	p		•																					
2-4, 47-48	11.78	F	m		46	1	1			2				2	35				1	4	24		1			
2-5, 47-48	13.28	R	p		•																					
2,CC	16.30	VR	p																							
3-1, 74-75	17.05	F	m		2	47	1			2	2			2	29				1	7	2	11	1			<i>N. reinholdii</i>
3-2, 74-75	18.55	VR	p		•																					
3-3, 74-75	20.05	C	m		2	51					1			1	26				1	1	5	6				
3-4, 74-75	21.55	F	m		1	66	1	1						1	23					1	5	15				
3-5, 74-75	23.05	C	m		2	47				1	1			6	26				1	2	4	13				
3-6, 74-75	24.14	R	p		•																					
3,CC	25.80	R	m		2	77					3			2	31					3	1	24				
4-1, 61-62	26.42	VR	p		•																					
4-2, 61-62	27.92	R	m	•	•																					
4-3, 61-62	29.42	R	p		•																					
4-4, 61-62	30.92	R	m		2	58		+					1	1	3				1	4	3	13	1			
4-5, 61-62	32.42	VR	p		•																					
4-6, 61-62	33.92	R	p		•																					
4,CC	35.30	F	g		4	118		2											1	1	4	10				<i>N. jouseae- R. praebergonii</i>
5-1, 56-57	35.81	VR	p		•					2	1			1	2				1							
5-2, 56-57	37.31	VR	p		•																					
5-3, 56-57	38.81	VR	p		•																					
5-4, 56-57	40.31	VR	p		•																					
5-5, 56-57	41.81	VR	p		•																					
5-6, 56-57	42.86	R	p		•																					
5,CC	44.80	R	p		•																					
6-1, 30-31	45.11	VR	p		•																					
6-2, 30-31	46.61	VR	p		•																					
6-3, 30-31	48.11	VR	p		•																					
6-4, 30-31	49.61	VR	p		•																					
6-5, 30-31	51.11	VR	p		•																					
6-6, 30-31	52.61	B			•																					
6-7, 30-31	54.11	VR	p		•																					
6,CC	54.30	B			•																					

Zone in the middle latitude eastern North Pacific and estimated an age of about 5.0–5.1 m.y. for this datum (Barron, 1980; Keller and Barron, 1981; Keller et al., 1982). Because of the possible diachrony of this datum level, it is assigned to a second-order category.

20. The last occurrence of *Rouxia californica* is at 4.40 m.y. ago at Site 578. Harper (1977) pointed out that this datum marks the Miocene/Pliocene boundary. It has since proven to be a useful datum in the middle-high latitude North Pacific (Barron, 1980; Keller and Barron, 1981; Koizumi, 1981, 1983). In this restricted area it is placed in a second-order category and has an age of approximately 5.1 m.y.

21. The last occurrence of *Thalassiosira miocenica* is at 5.35 m.y. ago at Site 578, while an age of 5.25–5.35 m.y. is estimated for this datum by the sediment accumulation rate curve for Site 581 (Fig. 8). It indicates that the last appearance at middle latitudes is isochronous. Burckle (1978) reported that this species disappeared on the Miocene/Pliocene boundary in the equatorial Pacific. It is assigned to a second-order datum level with an approximate age of 5.35 m.y. in middle-high latitudes.

22. The last occurrence of *Asterolampra acutiloba* is at 5.35 m.y. ago at Site 578. The last *Asterolampra acutiloba* has an absolute age estimated at about 5.1–5.2

m.y. by the sediment accumulation rate curve for Site 581. Burckle (1978) indicated that this species disappears at the Gilbert/Epoch 5 boundary (~5.35 m.y. ago) in the equatorial Pacific. Because of the possible diachrony of this datum level, it is assigned to a second-order category.

Figure 6 gives the occurrence of these 22 important datum levels in a south–north transect from 34 to 44°N, centered about 155°E, and Table 6 indicates the stratigraphic occurrence and chronology of these datum levels defined by the first or last occurrence of these diatoms at each site.

PLIOCENE AND PLEISTOCENE DIATOM ZONATION IN MIDDLE LATITUDES

The Pliocene and Pleistocene sections recovered in a south–north transect from Sites 577 to 581 in the middle latitude of the western North Pacific contain a mixture of both subtropical and subarctic diatoms. This fact allows us to propose a new diatom zonation for the Pliocene and Pleistocene (Fig. 7). The zonal boundaries are judged to be first order because the datum levels that define them are tied directly to the paleomagnetic reversal record (Koizumi and Burckle, 1984).

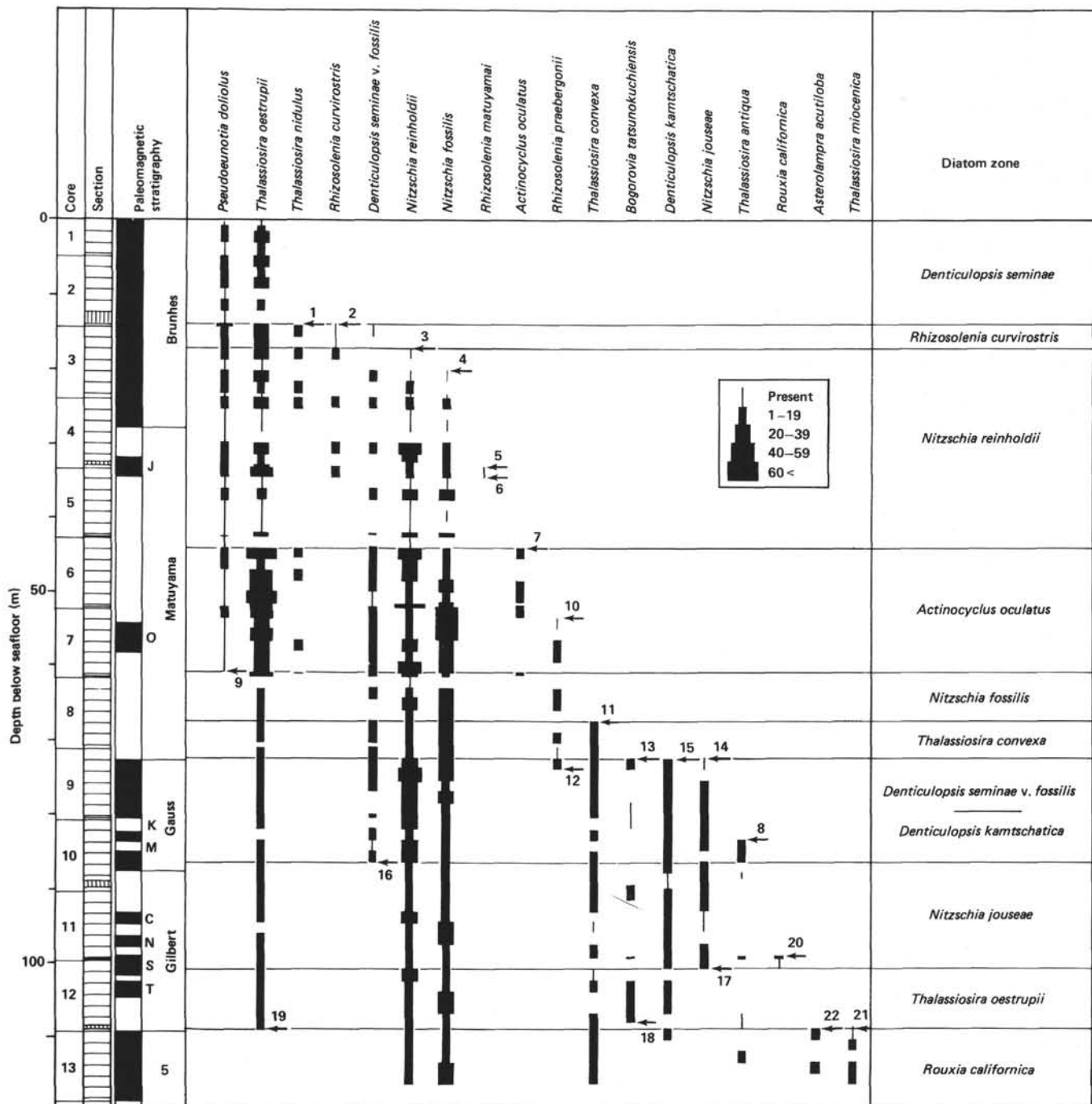


Figure 2. Ranges and abundances of stratigraphically important diatom species at Site 578. Numbers next to ranges indicate selected datum levels as specified in Table 6.

Zonal Definition³

Thalassiosira oestrupii Partial Range Zone

Top. First occurrence of *Nitzschia jouseae*.

Base. First occurrence of *Thalassiosira oestrupii*.

Age. Early Pliocene.

Paleomagnetic correlation. The top of the *Thalassiosira oestrupii* Zone is 4.50 m.y. ago and the base is

5.35 m.y. ago (between the base of the Sidufjall Event and the boundary of the Gilbert and Epoch 5 paleomagnetic polarity zone) at Site 578. The base of the *Thalassiosira oestrupii* Zone may be correlated with the lowest reversed event of the Gilbert Epoch (~5.1 m.y. ago) in the higher latitudes (Burckle and Opdyke, 1977).

Correlation with other zones. This *Thalassiosira oestrupii* Zone correlates with the lower one-third of the *Thalassiosira oestrupii* Zone of Barron (1981) for the middle latitude eastern North Pacific and with Subzone b of the *Denticulopsis kamtschatica* Zone of Barron

³ Prepared by I. Koizumi.

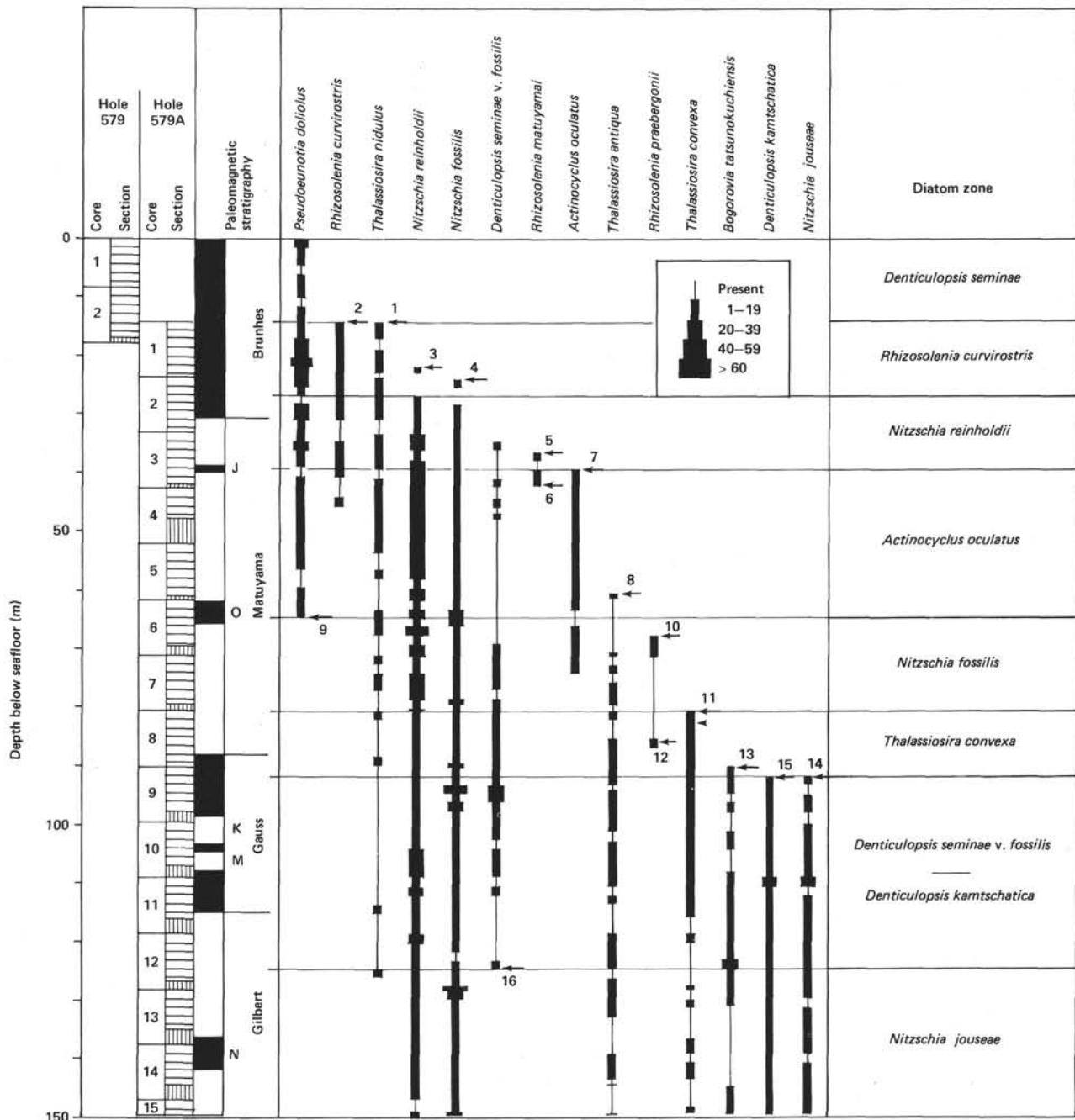


Figure 3. Ranges and abundances of stratigraphically important diatom species at Site 579. Numbers next to ranges indicate selected datum levels, as specified in Table 6.

(1980) for Leg 57, off northeastern Japan. In low-mid-
 middle latitudes, it correlates to the upper part of the *Thalassiosira convexa* Zone of Burckle (1972).

Important datums. The first occurrence of *Bogorovia tatsunokuchiensis* and the last occurrence of *Asterolampra acutiloba* and *Thalassiosira miocenica* coincides with the base of the *Thalassiosira oestrupii* Zone in middle-high latitudes. In the middle-high latitude western North Pacific, the first occurrence of *Rouxia californica* is used to approximate the base of this zone.

Remarks. The occurrence of *Cosmiodiscus insignis* has not been recognized in the materials from Leg 86.
Original definition. Barron (1980).

***Nitzschia jouseae* Partial Range Zone**

Top. First occurrence of *Denticulopsis seminae* var. *fossilis*.

Base. First occurrence of *Nitzschia jouseae*.

Age. Early Pliocene.

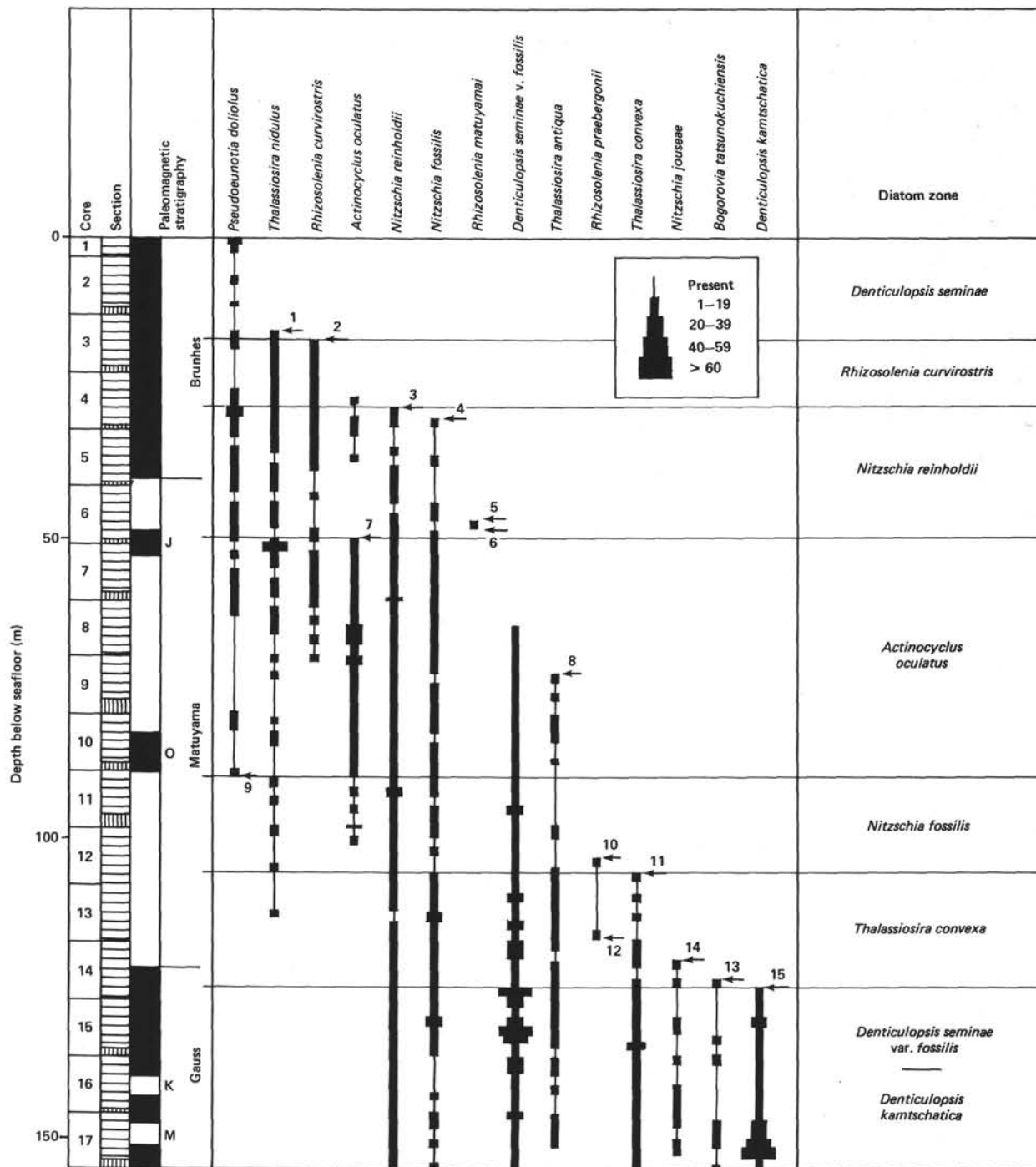


Figure 4. Ranges and abundances of stratigraphically important diatom species at Site 580. Numbers next to ranges indicate selected datum levels, as specified in Table 6.

Paleomagnetic correlation. The top of the *Nitzschia jouseae* Zone is approximately 3.70 m.y. ago and the base 4.50 m.y. ago (between the uppermost reversed event of the Gilbert Epoch and the base of the Sidufjall Event, Gilbert Epoch). The top of the *Nitzschia jouseae* Zone correlates with the base of the Gauss Epoch at Site 578 (Fig. 2) and the upper half of the reversed event of the Gilbert Epoch at Site 579 (Fig. 3), respectively.

Correlation with other zones. The *Nitzschia jouseae* Zone defined herein correlates with the lower half of the *Nitzschia jouseae* Zone of Burckle (1972). This zone al-

so correlates with Subzone c of the *Denticulopsis kamtschatica* Zone of Barron (1980) and the upper part of the *Thalassiosira oestrupii* Zone of Barron (1981).

Original definition. Burckle (1972).

Denticulopsis seminae var. *fossilis*-*Denticulopsis kamtschatica* Concurrent Range Zone

Top. Last occurrence of *Denticulopsis kamtschatica*.

Base. First occurrence of *Denticulopsis seminae* var. *fossilis*.

Age. Late Pliocene.

Table 5. Stratigraphic occurrences of Neogene diatoms in Hole 581.

Core-Section (interval in cm)	Depth below seafloor (m)	Abundance (10 ⁷ per g)	Preservation	<i>Actinocyclus curvatulus</i>	<i>A. ehrenbergii</i>	<i>A. ellipticus</i>	<i>A. ingens</i>	<i>A. ochotensis</i>	<i>Actinopychus senarius</i>	<i>Asterolampra actiloba</i>	<i>A. grevillei</i>	<i>A. marylandica</i>	<i>Asteromphalus brookei</i>	<i>A. darwinii</i>	<i>A. robustus</i>	<i>Bacterosira fragilis</i>	<i>Bogorovia praealpina</i>	<i>B. tatsunokuchiensis</i>	<i>Chaetoceros furcellatus</i>	<i>Cocconeis costata</i>	<i>Coccinodiscus elegans</i>	<i>C. endoi</i>	<i>C. marginatus</i>	<i>C. nodulifer</i>	<i>C. obscurus</i>	<i>C. oculus-iridis</i>	<i>C. plicatus</i>
1-1, 55-56	0.56	17.7	g	5				1	1						1				2				4				1
1,CC	1.00	4.7	g	5	1			1							2				1				7				
2-1, 134-135	182.85	12.0	g	2					1								1						9				
2-2, 54-55	183.55	12.0	g	1										1			1						2		3		
2-3, 134-135	185.85	8.0	g	1	2	1			1					1									6		5		
2-4, 134-135	187.35	4.8	g	4	5	2			2								2						12		26		
2-5, 134-135	188.85	8.0	g		3				1														11		2		
2-6, 134-135	190.35	3.4	g	1																			42		15		1
2-7, 25-26	190.76	2.0	g	13	1				3								3						48		2		
3-1, 90-91	191.91	3.2	g	2		1			2						1								40		2		1
3-2, 90-91	193.41	1.8	g						1									1					32		17		
3-3, 90-91	194.91	2.4	g	3					1		1							1					43		48		
3-4, 90-91	196.41	1.8	g	2	1	1			1														53		13		
3-5, 90-91	197.91	2.2	g	1					1	1													45		32		
3-6, 75-76	199.26	3.4	g	2	2	1			5	5									1				17		7		
3,CC	200.50	5.3	g	1	2				4	2													12		5		1
4-1, 98-99	201.49	2.7	g	2	1	9			2	2													20		4		7
4-2, 98-99	202.99	3.4	g						2	2		1											18		1		2
4-3, 98-99	204.49	10.7	g	1		5			2	2													5		7		
4-4, 98-99	205.99	3.2	g	1		5			3														26		41		
4-5, 98-99	207.49	6.0	g		5	1			11														20		29		1
4-6, 98-99	208.99	12.0	g						13					1									7		2		
4,CC	210.00	5.3	g		7	1			31	2													10		19		
5-1, 100-101	211.01	6.0	g		2				2	1													2		61		
5-2, 100-101	212.51	16.0	g		3				2														3		10		
5-3, 100-101	214.01	8.0	g	1					4														10		1		
5-4, 64-65	215.14	16.0	g		1				3														4		1		1
5,CC	219.50	8.0	g						5	1													10				
6-1, 100-101	220.51	3.2	g			1			5	2													34		2		
6-2, 100-101	222.01	3.4	g			1			4		1	2			2								33		1		
6-3, 100-101	223.51	2.2	g			1			1		2												53		4		
6-4, 100-101	225.01	3.2	g			1			6		1												36		2		
6-5, 100-101	226.51	2.3	g				6		16		2				1								61		3		
6-6, 100-101	228.01	5.3	g		2				11		3												27		6		2
6-7, 10-11	229.21	16.0	g				8		8		1												3		3		1
7-1, 100-101	230.01	4.0	g	1	1	32			9		2												5		9		1
7-2, 100-101	231.51	8.0	g		2	3																	7		11		
7-3, 100-101	233.01	8.0	g		1	5			3														8		7		3
7-4, 100-101	234.51	8.0	g		3	1																	6		5		2
7-5, 100-101	236.01	8.0	g		1	1			1					1									11		12		4
7-6, 100-101	237.51	5.3	g		1	12			1														8		4		7
7,CC	238.50	4.0	g		7	14			2														14		10		3
8-1, 110-111	239.61	5.3	g	1	3	9				1							4						13		6		3
8-2, 110-111	241.11	3.4	g			30			3		4						7						36		3		1
8-3, 110-111	242.61	5.3	g		1	12			1		2		1				4						16		1		13
8-4, 110-111	244.11	2.0	g		3	13			1														2		14		24
8-5, 110-111	245.61	0.2	m			2											1						4		2		
8,CC	248.00	5.3	g		1	13			1			1					2						19		11		3

Note: See Table 1 for explanation of symbols.

^a *D.s.* = *D. seminae*, *T.o.* = *Thalassiosira oestrupii*, *T.s.* = *T. schraderi*, *D.k.* = *D. katayamae*, *D.d.* = *D. dimorpha*, *D.p.* = *D. praedimorpha*.

Paleomagnetic correlation. The top of the *Denticulopsis seminae* var. *fossilis*-*Denticulopsis kamtschatica* Zone is 2.58 m.y. ago and the base is 3.70 m.y. ago (between the uppermost reversed event of the Gilbert Epoch and the uppermost part of the normal event of the Gauss Epoch).

Correlation with other zones. The *Denticulopsis seminae* var. *fossilis*-*Denticulopsis kamtschatica* Zone defined herein is the same zonal definition as Koizumi (1973) and Barron (1980). It correlates to the upper half of the *Nitzschia jouseae* Zone of Burckle (1972).

Important datums. The last occurrence of *Bogorovia tatsunokuchiensis* and *Nitzschia jouseae* coincides with

near the top of the *Denticulopsis seminae* var. *fossilis*-*Denticulopsis kamtschatica* Zone. The first occurrence of *Rhizosolenia praebergonii* is within this zone at Site 578.

Original definition. Koizumi (1973).

Other discussion. Barron (1980, 1981), Burckle and Opdyke (1977), Koizumi (1975a).

Thalassiosira convexa Partial Range Zone

Top. Last occurrence of *Thalassiosira convexa*.

Base. Last occurrence of *Denticulopsis kamtschatica*.

Age. Late Pliocene.

Table 5. (Continued).

<i>C. radianus</i>																				
<i>C. stellaris</i>	1																			
<i>C. symbolophorus</i>	1	6																		
<i>C. tabularis</i>		8																		
<i>C. tempere v. delicata</i>																				
<i>C. vetustissimus</i>			1	1																
<i>C. yabei</i>																				
<i>Cosmidiscus intersectus</i>																				
<i>Cymatosira lorenziana</i>																				
<i>Cymbella sinuata</i>			1	1																
<i>Delphineis surirelloides</i>																				
<i>Denticulopsis dimorpha</i>																				
<i>D. hustedtii</i>																				
<i>D. hyalina</i>																				
<i>D. kamtschatica</i>																				
<i>D. katayamae</i>																				
<i>D. lauta</i>																				
<i>D. praedimorpha</i>																				
<i>D. punctata</i>																				
<i>D. punctata v. hustedtii</i>																				
<i>D. seminae</i>																				
<i>Hemiaulus polymorphus</i>																				
<i>Hemidiscus cuneiformis</i>																				
<i>Mediaria splendida</i>																				
<i>Nitzschia braarudii</i>																				
<i>N. cylindrus</i>																				
<i>N. fossilis</i>																				
<i>N. grunowii</i>																				
<i>N. heteropolica</i>																				
<i>N. jouseae</i>																				
<i>N. marina</i>																				

Paleomagnetic correlation. The top of the *Thalassiosira convexa* Zone is 2.30 m.y. ago and the base is 2.58 m.y. ago (between the uppermost part of the normal event of the Gauss Epoch and one third of the lower normal event of the Matuyama Epoch).

Correlation with other zones. The *Thalassiosira convexa* Zone correlates to the lower two-thirds of the *Rhizosolenia praebergonii* Zone of Burckle (1972) and the lower half of the *Denticulopsis seminae* var. *fossilis* Zone of Barron (1980).

Important datums. The first occurrence of *Rhizosolenia praebergonii* occurs within the *Thalassiosira con-*

vexa Zone in middle-high latitudes (e.g., Sites 579 and 580).

Original definition. Burckle (1972).

Other discussion. Koizumi (1975a), Barron (1980, 1981).

***Nitzschia fossilis* Partial Range Zone**

Top. First occurrence of *Pseudoeunotia doliolus*.

Base. Last occurrence of *Thalassiosira convexa*.

Age. Late Pliocene.

Paleomagnetic correlation. The top of the *Nitzschia fossilis* Zone is 1.90 m.y. ago and the base is 2.30 m.y.

Table 5. (Continued).

Core-Section (interval in cm)	Depth below seafloor (m)	Abundance (10^7 per g)	Preservation	<i>N. miocenica</i>	<i>N. porteri</i>	<i>N. praerainholdii</i>	<i>N. rainholdii</i>	<i>N. rolandii</i>	<i>N. suikucensis</i>	<i>Parata sulcata</i>	<i>Pseudoeunotia doliolus</i>	<i>Rhabdonema japonicum</i>	<i>Rhizosolenia barboi</i>	<i>R. hebetata</i>	<i>R. styliformis</i>	<i>Rhizosolenia</i> spp.	<i>Rouxia californica</i>	<i>R. naviculoides</i>	<i>R. yabei</i>	<i>Stephanopyxis turris</i>	<i>Stephanopyxis</i> spp.	<i>Synedra jouseana</i>	<i>Thalassionema hiroakienis</i>	<i>T. nitzschoides</i>	<i>T. nitzschoides v. parva</i>	<i>T. nitzschoides</i> vars.	<i>T. schraderi</i>	
1-1, 55-56	0.56	17.7	g																									
1, CC	1.00	4.7	g							1	1			6	2					2				3				
2-1, 134-135	182.85	12.0	g				1								1					1				10	4			
2-2, 54-55	183.55	12.0	g										1		1					1				66	4			
2-3, 134-135	185.85	8.0	g										2		2					5				67	2			
2-4, 134-135	187.35	4.8	g										1							1				46	7			
2-5, 134-135	188.85	8.0	g				15																	35	3			
2-6, 134-135	190.35	3.4	g				9													1	2			29	2			
2-7, 25-26	190.76	2.0	g				2						3		3					2	2			26	4			
3-1, 90-91	191.91	3.2	g				4				4	1		6	2					5				50	6			
3-2, 90-91	193.41	1.8	g				14							8	2					2				10				
3-3, 90-91	194.91	2.4	g				25						1	5										7				
3-4, 90-91	196.41	1.8	g				6	5							1	11	1			3				22	3			
3-5, 90-91	197.91	2.2	g				6	7						3		11				1				46	1			
3-6, 75-76	199.26	3.4	g				36		4					1	3	23	1		1	3				33	3			
3, CC	200.50	5.3	g				21	5	5					4	1	6			7	1				52	14			
4-1, 98-99	201.49	2.7	g				6	2	2				1	3		20			2	1				38	12			
4-2, 98-99	202.99	3.4	g				8	5	5				3	2	3	12			2	8				59	3			
4-3, 98-99	204.49	10.7	g	8			7	5	23				5	3	1	4			1	2				43	16			
4-4, 98-99	205.99	3.2	g				2	2						3	1	8			3	4				47	3			
4-5, 98-99	207.49	6.0	g	6			3	1	3					3		3			1	2				39				
4-6, 98-99	208.99	12.0	g				2		1					1		1								146	2			
4, CC	210.00	5.3	g				4	1	1					1	1	9			4	5				32	2			
5-1, 100-101	211.01	6.0	g			2	6	3						1		1			1	2		1		45	2			
5-2, 100-101	212.51	16.0	g				1		2										2					149				
5-3, 100-101	214.01	8.0	g			2	10	16					1	1	6	2								75	4			
5-4, 64-65	215.14	16.0	g			2	7	12	1					3		1			3	1				128				
5, CC	219.50	8.0	g				22	11						2	1	1	1		2					93				
6-1, 100-101	220.51	3.2	g				1	6	10					5	1	7			2			2		70	1			
6-2, 100-101	222.01	3.4	g		21	3	8	7	1				1	3	1	1					1	2		71				
6-3, 100-101	223.51	2.2	g		18		1						1			3							12	32	7	47		
6-4, 100-101	225.01	3.2	g		10	1	1						6		4	4			1			1	10	41	2	53		
6-5, 100-101	226.51	2.3	g		8		3						4			1			1				8	28	6	7	15	
6-6, 100-101	228.01	5.3	g		17	3							6	2	1	2			2				1	25				
6-7, 10-11	229.21	16.0	g		3	1								2					2	1			2	84				
7-1, 100-101	230.01	4.0	g		1	1							4						1				3	49			15	
7-2, 100-101	231.51	8.0	g			3							1										27	29	31			
7-3, 100-101	233.01	8.0	g										4		2				1				4	93	13	6		
7-4, 100-101	234.51	8.0	g										3			3	6		9				14	56	9	24		
7-5, 100-101	236.01	8.0	g										6			6							3	44	5	16		
7-6, 100-101	237.51	5.3	g										5			4	4		3				19	65	8	12		
7, CC	238.50	4.0	g							4			3		1				2				11	53	7	11		
8-1, 110-111	239.61	5.3	g										5		4		1	1		1			21	77	14	4		
8-2, 110-111	241.11	3.4	g										3			1			2				6	38		7		
8-3, 110-111	242.61	5.3	g							1			2			2	1						1	70	3	8		
8-4, 110-111	244.11	2.0	g										4										1	17		8		
8-5, 110-111	245.61	0.2	m																				1	6		3		
8, CC	248.00	5.3	g							1					1								12	49	6	1		

ago (between one-third of the lower normal event and the bottom of the Olduvai Event of the Matuyama Epoch).

Correlation with other zones. The *Nitzschia fossilis* Zone correlates with the upper part of the *Rhizosolenia praebergonii* Zone of Burckle (1972) and the *Denticulopsis seminae* var. *fossilis* Zone of Barron (1980).

Important datums. The last occurrence of *Rhizosolenia praebergonii* is below the top of the *Nitzschia fossilis* Zone in middle-high latitudes although it is above the first occurrence of *Pseudoeunotia doliolus* in low latitudes (Burckle, 1977; Burckle and Trainer, 1979; Fig. 6).

Original definition. Koizumi, this chapter.

***Actinocyclus oculatus* Concurrent Range Zone**

Top. Last occurrence of *Actinocyclus oculatus*.

Base. First occurrence of *Pseudoeunotia doliolus*.

Age. Early Pleistocene.

Paleomagnetic correlation. The top of the *Actinocyclus oculatus* Zone is 0.95 m.y. ago and the base is 1.90 m.y. ago (between the bottom of the Olduvai Event and the bottom of the Jaramillo Event of the Matuyama Epoch). The top of this zone is 1.33 m.y. ago at the middle part between the Olduvai and Jaramillo Event owing

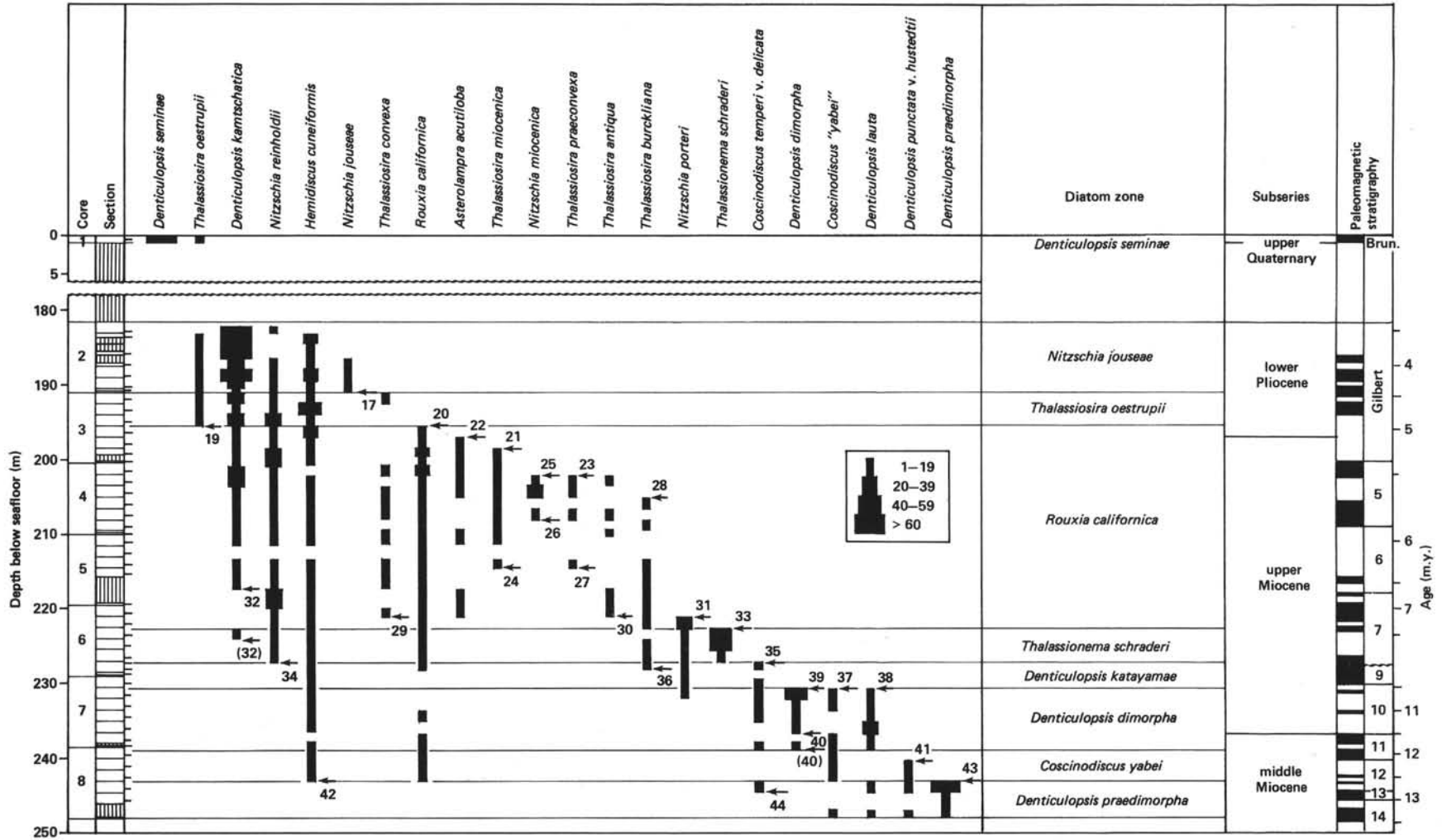


Figure 5. Ranges and abundances of stratigraphically important diatom species at Site 581. Numbers next to ranges indicate selected datum levels, as specified in Table 8.

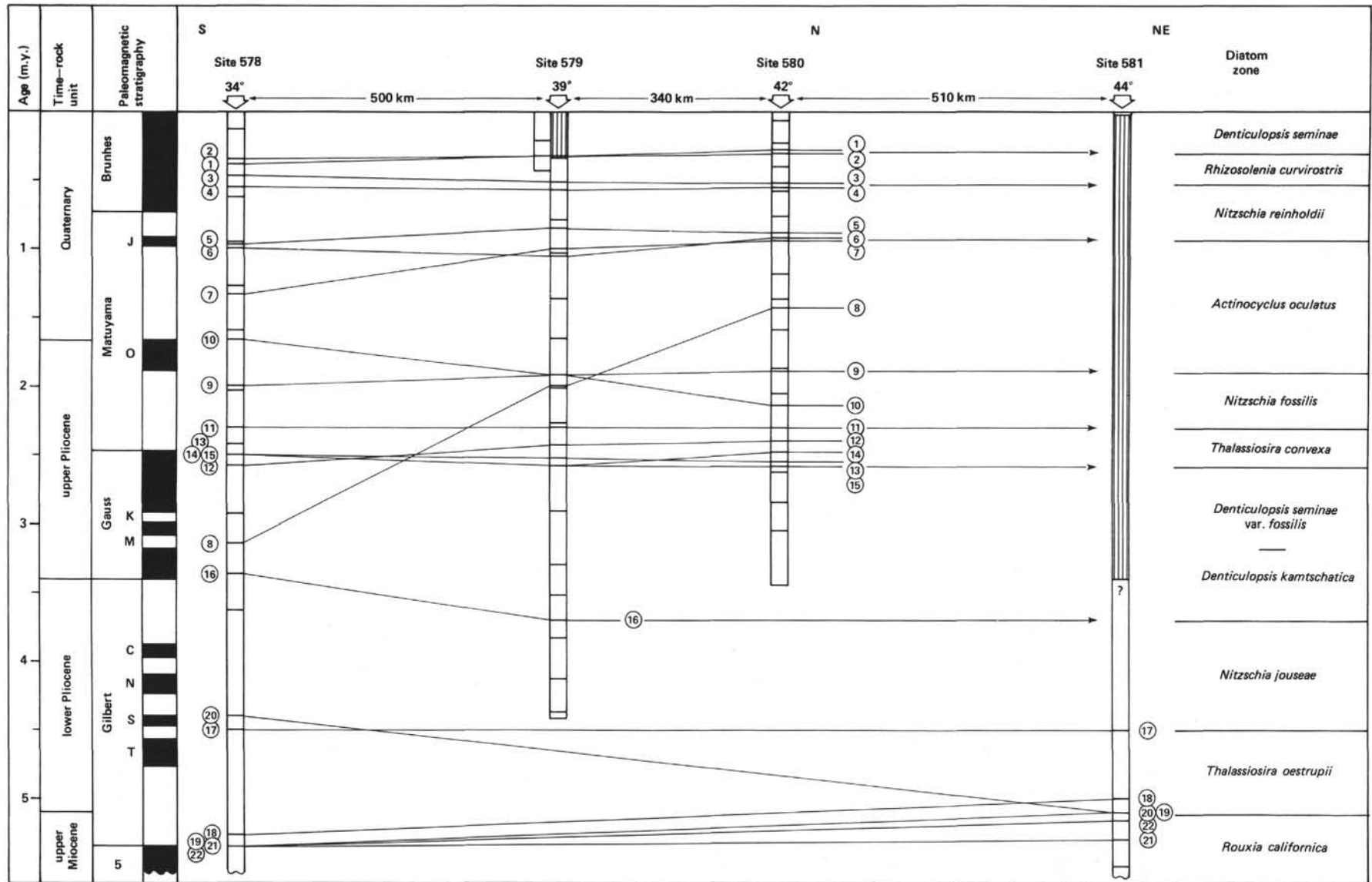


Figure 6. Occurrence of selected datum levels in a south-north transect from 34 to 44°N latitude, centered about 155°E longitude, and proposed middle latitude Neogene diatom zonation. (1 = last *Thalassiosira nidulus*, 2 = last *Rhizosolenia curvirostris*, 3 = last *Nitzschia reinholdii*, 4 = last *Nitzschia fossilis*, 5 = last *Rhizosolenia matuyamai*, 6 = first *Rhizosolenia matuyamai*, 7 = last *Actinocyclus oculatus*, 8 = last *Thalassiosira antiqua*, 9 = first *Pseudoeunotia doliolus*, 10 = last *Rhizosolenia praebergonii*, 11 = last *Thalassiosira convexa*, 12 = first *Rhizosolenia praebergonii*, 13 = last *Bogorovia tatsunokuchiensis*, 14 = last *Nitzschia jouseae*, 15 = last *Denticulopsis kamtschatica*, 16 = first *Denticulopsis seminae* var. *fossilis*, 17 = first *Nitzschia jouseae*, 18 = first *Bogorovia tatsunokuchiensis*, 19 = first *Thalassiosira oestrupii*, 20 = last *Rouxia californica*, 21 = last *Thalassiosira miocenica*, 22 = last *Asterolampra acutiloba*)

Table 6. Stratigraphic occurrences and chronology of datum levels in Holes 578, 579, and 580.

Datum level ^a	Reliability ^b	Hole 578		Hole 579		Hole 580	
		Stratigraphic level ^c	Age ^d (m.y.)	Stratigraphic level ^c	Age ^d (m.y.)	Stratigraphic level ^c	Age ^d (m.y.)
1. T <i>Thalassiosira nidulus</i>	2	2,CC/3-1,97	0.39	2-3,124/2-4,123	0.33	3-2,26/3-3,25	0.28
2. T <i>Rhizosolenia curvirostris</i>	1	2-5,115/2,CC	0.35	2-3,124/2-4,123	0.33	3-3,26/3-4,25	0.30
3. T <i>Nitzschia reinholdii</i>	1	3-2,96/3-3,97	0.47	1-5,15/1-6,14	0.51	4-4,122/4-5,121	0.52
4. T <i>Nitzschia fossilis</i>	1	3-4,96/3-5,97	0.55	1-7,15/2-1,33	0.57	4-5,122/4-6,121	0.55
5. T <i>Rhizosolenia matuyamai</i>	2	4,CC/5-1,117	0.97	3-2,116/3-3,115	0.85	6-4,26/6-5,25	0.89
6. B <i>Rhizosolenia matuyamai</i>	2	5-1,118/5-2,117	1.00	3-6,116/4-1,12	1.05	6-5,26/6-6,17	0.91
7. T <i>Actinocyclus oculatus</i>	2	6-1,110/6-2,109	1.33	3-5,116/3-6,115	1.00	6-6,18/6,CC	0.93
8. T <i>Thalassiosira antiqua</i>	3	10-2,119/10-3,118	3.14	6-6,11/6-6,115	2.00	9-2,24/9-3,23	1.43
9. B <i>Pseudoenotia doliolus</i>	1	7-6,122/7-7,47	2.00	6-4,26/6-5,25	1.92	11-1,23/11-2,22	1.89
10. T <i>Rhizosolenia praebergonii</i>	2	7-1,122/7-2,121	1.66	6-4,26/6-5,25	1.92	12-3,104/12-4,103	2.14
11. T <i>Thalassiosira convexa</i>	1	8-4,119/8-5,118	2.30	7,CC/8-1,132	2.29	11-5,106/11,CC	2.30
12. B <i>Rhizosolenia praebergonii</i>	2	9-2,119/9-3,118	2.58	8-4,133/8-5,132	2.43	13-6,16/13,CC	2.40
13. T <i>Bogorovia tatsunokuchiensis</i>	2	9-1,119/9-2,118	2.50	8-6,133/9-1,30	2.52	14-4,131/14-5,130	2.55
14. T <i>Nitzschia jouseae</i>	1	9-1,119/9-2,118	2.50	9-1,31/9-2,30	2.58	14-2,131/14-3,130	2.48
15. T <i>Denticulopsis kamtschatica</i>	1	9-1,119/9-2,118	2.50	9-1,31/9-2,30	2.58	14-5,131/14-6,130	2.58
16. B <i>Denticulopsis seminae</i> v. <i>fossilis</i>	2	10-4,119/10-5,118	3.36	12-4,17/12-5,16	3.70		
17. B <i>Nitzschia jouseae</i>	1	12-1,101/12-2,100	4.50				
18. B <i>Bogorovia tatsunokuchiensis</i>	3	12-6,111/12,CC	5.26				
19. B <i>Thalassiosira oestrupii</i>	2	12,CC/13-1,135	5.35				
20. T <i>Rouxia californica</i>	2	11-6,131/11-7,20	4.40				
21. T <i>Thalassiosira miocenica</i>	2	12,CC/13-1,135	5.35				
22. T <i>Asterolampra acutiloba</i>	2	12,CC/13-1,135	5.35				

^a B = first occurrence, T = last occurrence.

^b 1 = most reliable, 2 = reliable, 3 = least reliable.

^c The highest and lowest stratigraphic levels at each site for each datum level are presented (Core-Section, level in cm) with a slash between them.

^d Tied to the paleomagnetic time scale of Berggren et al. (in press).

Paleomagnetic correlation. The top of the *Nitzschia reinholdii* Zone is approximately 0.50 m.y. ago and the base is 0.95 m.y. ago (between the bottom of the Olduvai Event of the Matuyama Epoch and the lowest part of the Brunhes Epoch).

Correlation with other zones. The *Nitzschia reinholdii* Zone correlates to Subzone a of the *Rhizosolenia curvirostris* Zone of Barron (1980) and within the *Pseudoenotia doliolus* Zone of Burckle (1972).

Important datums. The last occurrence of *Nitzschia fossilis* is nearly coincident with the top of the *Nitzschia reinholdii* Zone. The last occurrence of *Rhizosolenia matuyamai* occurs in the bottom of the *Nitzschia reinholdii* Zone.

Original definition. Burckle and Opdyke (1977) described without definition.

Other discussion. Barron (1980, 1981).

Rhizosolenia curvirostris Partial Range Zone

Top. Last occurrence of *Rhizosolenia curvirostris*.

Base. Last occurrence of *Nitzschia reinholdii*.

Age. Late Pleistocene.

Paleomagnetic correlation. The top of the *Rhizosolenia curvirostris* Zone is 0.33 m.y. ago and the base is 0.50 m.y. ago (between the middle part and the lowest part of the Brunhes Epoch).

Correlation with other zones. The *Rhizosolenia curvirostris* Zone defined herein correlates with Subzone b of the *Rhizosolenia curvirostris* Zone of Barron (1980).

Important datums. The last occurrence of *Thalassiosira nidulus* coincides with the top of this zone.

Original definition. Donahue (1970).

Other discussion. Koizumi (1973, 1975a), Burckle and Opdyke (1977), Barron (1980, 1981).

Denticulopsis seminae Partial Range Zone

Top. Present.

Base. Last occurrence of *Rhizosolenia curvirostris*.

Age. Late Quaternary.

Paleomagnetic correlation. The base of the *Denticulopsis seminae* Zone is 0.33 m.y. ago (the base is in the middle part of the Brunhes Epoch).

Correlation with other zones. The *Denticulopsis seminae* Zone defined herein is the same zonal definition as Koizumi (1973) and Barron (1980).

Original definition. Donahue (1970).

Other discussion. Koizumi (1973, 1975a), Barron (1980).

Figure 7 shows the diatom zonation for Leg 86 in middle-high latitudes with primary and secondary datum levels plotted against a paleomagnetic time scale from Berggren and others (1984). Table 7 indicates the diatom zonation of samples from Leg 86, except Sites 576 and 577.

MIocene DIATOM ZONATION IN HIGH LATITUDE⁴

The Neogene diatom zonation of Koizumi (1973, 1975a) has been recognized in middle-high latitudes of the North Pacific (Burckle and Opdyke, 1977; Barron, 1980, 1981; Harper, 1980). New subzones and zones were proposed in order to make a critical resolution of stratigraphic problems (Barron, 1980; Koizumi, 1983). The subdivision, recently proposed in Japan (Akiba, 1982, 1983; Maruyama, 1982), was also recognized at

⁴ Prepared by I. Koizumi.

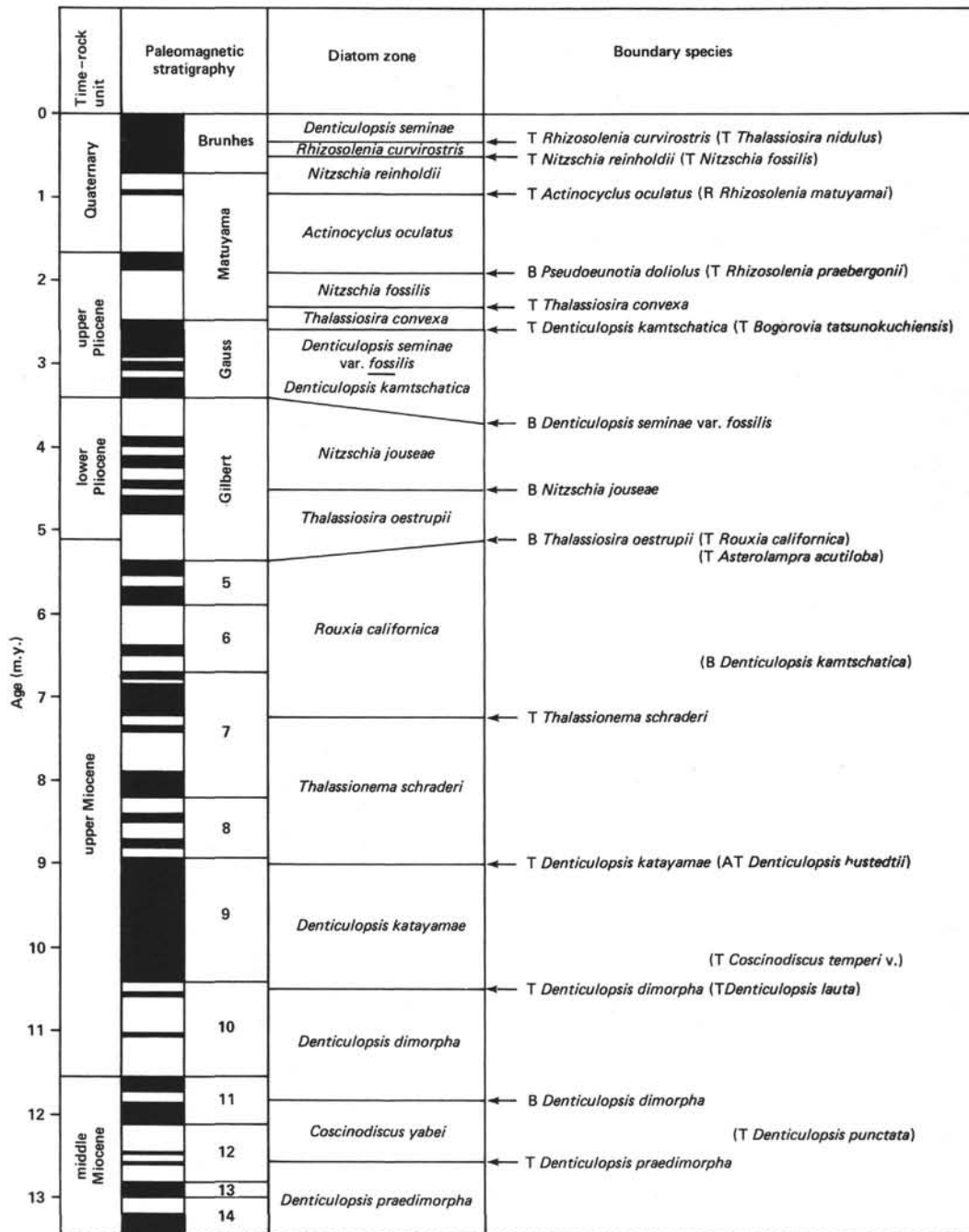


Figure 7. Estimated absolute ages for the Pliocene to Quaternary diatom zones in middle latitudes and the middle to late Miocene in middle-high latitudes. The paleomagnetic time scale is that of Berggren et al. (in press). The Pliocene and Quaternary datum levels are tied directly to the paleomagnetic time scale (Berggren et al., in press). Other datum levels are extrapolated from the sediment accumulation rate curve. (B = first occurrence, T = last occurrence.)

Site 581 in the high latitude North Pacific. These zones, instead of the Miocene zonation of Koizumi (1973, 1975a, 1983) and Barron (1980), are defined by the taxonomic subdivision of "*Denticulopsis lauta*" and "*Denticulopsis hustedtii*."

Sediment accumulation rate curves for many sites show that most of the upper and middle Miocene datum levels (Table 8), which were directly tied to the paleomagnetic stratigraphy of the equatorial Pacific by Bur-

ckle (1978), are almost synchronous in the lower-middle latitude regions. The sediment accumulation rate curve based on these secondary datum levels plotted against a paleomagnetic time scale of Berggren et al. (in press) (Fig. 8) and the occurrence chart (Fig. 5) for Site 581 provide the means of estimating the absolute ages of diatom zonal boundaries. In the 202.99 to 228.01 m sub-bottom interval (between Samples 581-4-2, 98-99 cm and 581-6-6, 100-101 cm), the large amount of reworking of

Table 7. Diatom zonation of samples from Leg 86, except Sites 576 and 577.

Age	Diatom zone	Core-Section (interval in cm)				
		Hole 578	Hole 579	Hole 579A	Hole 580	Hole 581
Quaternary	<i>Denticulopsis seminae</i>	1-1, 108-109 2-5, 115-116	1-1, 16-17 2-3, 123-124		1-1, 25-26 3-3, 25-26	1-1, 55-56 1,CC
	<i>Rhizosolenia curvirostris</i>	2,CC 3-2, 96-97	2-4, 123-124 2-5, 123-124	1-1, 14-15 1-5, 14-15	3-4, 25-26 4-4, 121-122	
	<i>Nitzschia reinholdii</i>	3-3, 96-97 6-1, 109-110		1-6, 14-15 3-5, 115-116	4-5, 121-122 6-6, 17-18	
	<i>Actinocyclus oculatus</i>	6-2, 109-110 7-6, 121-122		3-6, 115-116 6-4, 25-26	6,CC 11-1, 22-23	
upper Pliocene	<i>Nitzschia fossilis</i>	7-7, 47-48 8-4, 118-119		6-5, 25-26 7,CC	11-2, 22-23 11-5, 105-106	
	<i>Thalassiosira convexa</i>	8-5, 118-119 9-1, 118-119		8-1, 132-133 9-1, 30-31	11,CC 14-5, 130-131	
	<i>Denticulopsis seminae</i> v. <i>fossilis</i> <i>Denticulopsis kamtschatica</i>	9-2, 118-119 10-4, 118-119		9-2, 30-31 12-4, 16-17	14-6, 130-131 17,CC	
lower Pliocene	<i>Nitzschia jouseae</i>	10-5, 118-119 12-1, 100-101		12-5, 16-17 15,CC		2-1, 134-135 2-7, 25-26
	<i>Thalassiosira oestrupii</i>	12-2, 100-101 12,CC				3-1, 90-91 3-3, 90-91
upper Miocene	<i>Rouxia californica</i>	13-1, 135-136 13,CC				3-4, 90-91 6-2, 100-101
	<i>Thalassionema schraderi</i>					6-3, 100-101 6-5, 100-101
	<i>Denticulopsis katayamae</i>					6-6, 100-101 7-1, 100-101
	<i>Denticulopsis dimorpha</i>					7-2, 100-101 7,CC
middle Miocene	<i>Coscinodiscus yabei</i>					8-1, 110-111 8-3, 110-111
	<i>Denticulopsis praedimorpha</i>					8-4, 110-111 8,CC

upper Miocene marker taxa is recognized. This reworking is probably due to a hiatus, as reflected in the sediment accumulation rate curve (Fig. 8) and in the change in lithology from gray to green reduced (pyritic) biosiliceous clay to ooze downhole to yellow brown oxidized biosiliceous clay and a downhole contamination by breccia deformed by drilling.

Zonal Definition

Denticulopsis praedimorpha Range Zone

Top. Last occurrence of *Denticulopsis praedimorpha*.

Base. Not defined herein, but Akiba (1983) proposed the first occurrence of *Denticulopsis praedimorpha* as the base of this zone.

Age. Middle Miocene (12.6-13.6 m.y. ago).

Paleomagnetic correlation. None available.

Correlation with other zones. The *Denticulopsis praedimorpha* Zone correlates to Subzone b of the *Denticulopsis hustedtii*-*Denticulopsis lauta* Zone of Barron (1980) and Koizumi (1983).

Important datums. The first occurrence of *Hemidiscus cuneiformis* occurs at the top of the *Denticulopsis praedimorpha* Zone.

Original definition. Akiba (1979).

Other discussion. Maruyama (1982), Akiba (1983).

Coscinodiscus yabei Partial Range Zone

Top. First occurrence of *Denticulopsis dimorpha*.

Base. Last occurrence of *Denticulopsis praedimorpha*.

Age. Late middle Miocene (11.9-12.6 m.y. ago).

Paleomagnetic correlation. None available.

Correlation with other zones. The *Coscinodiscus yabei* Zone correlates with Subzone c of the *Denticulopsis hustedtii*-*Denticulopsis lauta* Zone of Barron (1980).

Important datums. The last occurrence of *Denticulopsis punctata* var. *hustedtii* occurs within this zone. The first occurrence of *Thalassiosira* sp. 1 Barron (1980) occurs in the upper part of the *Coscinodiscus yabei* Zone.

Remarks. A biostratigraphic interval that is correlative with the *Coscinodiscus yabei* Zone defined herein has not been recognized in the zonal subdivisions by Koizumi (1983).

Original definition. Maruyama (1982).

Denticulopsis dimorpha Range Zone

Top. First occurrence of *Denticulopsis dimorpha*.

Base. Last occurrence of *Denticulopsis dimorpha*.

Age. Latest middle Miocene to early late Miocene (10.5-11.9 m.y. ago).

Paleomagnetic correlation. None available.

Correlation with other zones. The *Denticulopsis dimorpha* Zone correlates with Subzone d of the *Denticu-*

Table 8. Estimate of absolute ages of late middle to late Miocene diatom datum levels and stratigraphic occurrences in Hole 581.

	Datum level ^a	Age ^b (m.y.)	Reference ^c	Stratigraphic level ^d
17.	B <i>Nitzschia jouseae</i>	4.45	2	2-7,26/3-1,90
18.	B <i>Bogorovia tatsunokuchiensis</i>	4.9-5.1	3	3-3,91/3-4,90
19.	B <i>Thalassiosira oestrupii</i>	5.0-5.1	3-6	3-3,91/3-4,90
20.	T <i>Rouxia californica</i>	5.1	3,5	3-3,91/3-4,90
21.	T <i>Thalassiosira miocenica</i>	5.1	2,6	3-5,91/3-6,75
22.	T <i>Asterolampra acutiloba</i>	5.35	2,6	3-4,91/3-5,90
23.	T <i>Thalassiosira praeconvexa</i>	5.75	6	4-1,99/4-2,98
24.	B <i>Thalassiosira miocenica</i>	6.1	2,6	5-3,101/5-4,64
25.	T <i>Nitzschia miocenica</i>	5.5-5.75	1-3,6	4-1,99/4-2,98
26.	B <i>Nitzschia miocenica</i>	7.3	1-3,6	4-5,99/4-6,98
27.	B <i>Thalassiosira praeconvexa</i>	6.3	6	5-3,101/5-4,64
28.	T <i>Thalassiosira burckliana</i>	7.95	1,2,5,6	4-3,99/4-4,98
29.	B <i>Thalassiosira convexa</i>	6.6	1-3,6	6-1,101/6-2,100
30.	B <i>Thalassiosira antiqua</i>	8.55-8.75	3-7	6-1,101/6-2,100
31.	T <i>Nitzschia porteri</i>	7.2	1-3	6-1,101/6-2,100
32.	B <i>Denticulopsis kamtschatica</i>	6.5-6.7	3,6	6-3,101/6-4,100
33.	T <i>Thalassionema schraderi</i>	7.2-7.3	5	6-2,101/6-3,100
34.	B <i>Nitzschia reinholdii</i>	6.5-6.9,8.0 ^e	2-6	6-5,101/6-6,100
35.	T <i>Coscinodiscus temperi</i> v. <i>delicata</i>	10.1	5,6	6-5,101/6-6,100
36.	B <i>Thalassiosira burckliana</i>	9.0	2,5,6	6-6,101/6-7,10
37.	T <i>Coscinodiscus yabei</i>	8.6-8.9	1,3-6	7-1,101/7-2,100
38.	T <i>Denticulopsis lauta</i>	10.5-10.6	3,5	7-1,101/7-2,100
39.	T <i>Denticulopsis dimorpha</i>	10.5-10.6	3-6	7-1,101/7-2,100
40.	B <i>Denticulopsis dimorpha</i>	11.5-11.7	3-6	7,CC/8-1,110
41.	T <i>Denticulopsis punctata</i> v. <i>hustedtii</i>	12.3	5,6	8-1,111/8-2,110
42.	B <i>Hemidiscus cuneiformis</i>	12.5-12.7	2,3,6	8-3,111/8-4,110
43.	T (common) <i>Denticulopsis praedimorpha</i>	12.4	7	8-3,111/8-4,110
44.	B <i>Coscinodiscus temperi</i> v. <i>delicata</i>	12.85	5,6	8-4,111/8-5,110

^a B = first occurrence, T = last occurrence.

^b Tied to the paleomagnetic time scale of Berggren et al. (in press).

^c (1) Burckle, 1972; (2) Burckle, 1978; (3) Barron, 1980; (4) Barron, 1981; (5) Keller and Barron, 1981; (6) Keller et al., 1982; (7) Barron and Keller, 1983.

^d The highest and lowest stratigraphic levels of datum levels in Hole 581 are listed (Core-Section, level in cm) with a slash between them.

^e Barron, pers. comm., 1984.

lopsis hustedtii-*Denticulopsis lauta* Zone of Barron (1980) and Subzone c of the *Denticulopsis hustedtii*-*Denticulopsis lauta* Zone of Koizumi (1983).

Important datums. The last occurrence of *Coscinodiscus yabei* and *Denticulopsis lauta* is coincident with the top of this zone. The first occurrence of *Nitzschia porteri* is in the upper part of the *Denticulopsis dimorpha* Zone.

Original definition. Maruyama (1982).

Denticulopsis katayamae Partial Range Zone

Top. Last occurrence of *Denticulopsis katayamae*.

Base. Last occurrence of *Denticulopsis dimorpha*.

Age. Early late Miocene (8.6-10.5 m.y. ago).

Paleomagnetic correlation. None available.

Correlation with other zones. The *Denticulopsis katayamae* Zone correlates with the lower part of the *Denticulopsis hustedtii* Zone of Barron (1980) and Koizumi (1983).

Remarks. The Subzone a/Subzone b boundary of the *Denticulopsis hustedtii* Zone, which correlates with the top of the *Denticulopsis katayamae* Zone, is within the middle part of Epoch 8 (about 8.6 m.y. ago) in the equatorial Pacific (Burckle, 1972) and also in the middle latitude North Pacific (Barron, 1980; Keller et al., 1982) by the last occurrence of *Coscinodiscus yabei*.

Original definition. Maruyama (1982).

Thalassionema schraderi Range Zone

Top. Last occurrence of *Thalassionema schraderi*.

Base. Last occurrence of *Denticulopsis katayamae*.

Age. Middle late Miocene (7.3-8.6 m.y. ago).

Paleomagnetic correlation. None available.

Correlation with other zones. The *Thalassionema schraderi* Zone presumably correlates with the upper part of the *Denticulopsis hustedtii* Zone of Barron (1980) and Koizumi (1983) by the sporadic occurrence of *Denticulopsis kamtschatica* near the top of this zone.

Original definition. Akiba (1982).

Rouxia californica Partial Range Zone

Top. Last occurrence of *Rouxia californica*.

Base. Last occurrence of *Thalassionema schraderi*.

Age. Late Miocene (5.1-7.3 m.y. ago).

Paleomagnetic correlation. None available.

Correlation with other zones. The *Rouxia californica* Zone correlates with Subzone a of the *Denticulopsis kamtschatica* Zone of Barron (1980) and Koizumi (1983).

Important datums. The first occurrence of *Bogorovia tatsunokuchiensis* and *Thalassiosira oestrupii* is coincident with the top of the *Rouxia californica* Zone. Also, the last occurrence of *Asterolampra acutiloba* occurs near the top of this zone. The last occurrence of *Thalassiosira praeconvexa* and *Nitzschia miocenica* is

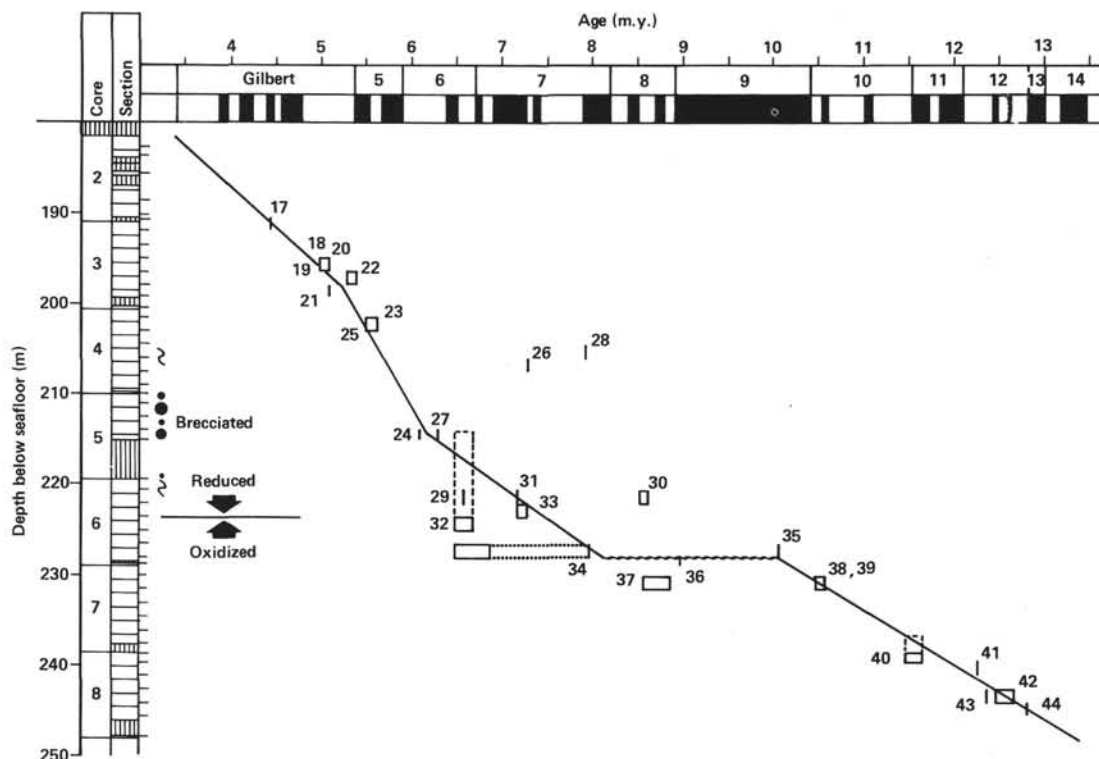


Figure 8. Sediment accumulation rate curve for Site 581 plotted from datum levels listed below. (17 = first *Nitzschia jouseae*, 18 = first *Bogorovia tatsunokuchiensis*, 19 = first *Thalassiosira oestrupii*, 20 = last *Rouxia californica*, 21 = last *Thalassiosira miocenica*, 22 = last *Asterolampra acutiloba*, 23 = last *Thalassiosira praeconvexa*, 24 = first *Thalassiosira miocenica*, 25 = last *Nitzschia miocenica*, 26 = first *Nitzschia miocenica*, 27 = first *Thalassiosira praeconvexa*, 28 = last *Thalassiosira burckliana*, 29 = first *Thalassiosira convexa*, 30 = first *Thalassiosira antiqua*, 31 = last *Nitzschia porteri*, 32 = first *Denticulopsis kamschatica*, 33 = last *Thalassionema schraderi*, 34 = first *Nitzschia reinholdii*, 35 = last *Coscinodiscus temperi* var. *delicata*, 36 = first *Thalassiosira burckliana*, 37 = last *Coscinodiscus yabei*, 38 = *Denticulopsis dimorpha*, 39 = last *Denticulopsis dimorpha*, 40 = first *Denticulopsis dimorpha*, 41 = last *Denticulopsis punctata* var. *hustedtii*, 42 = first *Hemidiscus cuneiformis*, 43 = last common *Denticulopsis praedimorpha*, 44 = first *Coscinodiscus temperi* var. *delicata*). Most of Core 5 is very deformed to brecciated and both Section 4 of Core 4 and Section 1 of Core 6 are very deformed by drilling. The lithologic change occurs from reduced biosiliceous clay to ooze downhole to oxidized biosiliceous clay at 223.6 m sub-bottom depth (Sample 581-6-3, 111 cm).

within the upper part of this zone. The first occurrence of *Nitzschia miocenica* occurs within the middle part of this zone.

Original definition. Akiba (1983).

In Figure 9, the proposed diatom zonation is correlated with the lower latitude diatom zonation of Burckle (1972), middle-high latitude diatom zonation of Koizumi (1973, 1975a, 1983), the diatom zonation off northeast Japan of Barron (1980) and Akiba (1983), and the low-middle eastern North Pacific and the California area of Barron (1981; Keller and Barron, 1981; Barron and Keller, 1983).

CONCLUSIONS

Twenty-two diatom datum levels for the latest Miocene to Quaternary, which were defined according to first or last occurrences of a species, are evaluated on the basis of their spatial and temporal distribution in middle latitudes.

Nine diatom zones, based on first-order datum levels, are proposed for the Pliocene and Quaternary in the middle latitudes.

Six diatom zones are proposed for the middle and upper Miocene in high latitudes.

ACKNOWLEDGMENTS

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FLORAL REFERENCES

- Achnanthes lanceolata* (Brébisson) Grunow: Hustedt, 1933, p. 408, fig. 863.
Actinocyclus curvatus Janisch: Hustedt, 1930b, p. 538, fig. 307; Koizumi, 1973, p. 831, pl. 1, figs. 1-6; Sancetta, 1982, p. 222, pl. 1, figs. 1-3. (Plate 3, Fig. 9)
Actinocyclus ellipticus Grunow: Hustedt, 1930b, p. 533, fig. 303; Koizumi, 1980, pl. 1, fig. 19.
Actinocyclus ellipticus forma *lanceolata* Kolbe, 1954, p. 20, pl. 3, fig. 27; Koizumi, 1980, pl. 1, fig. 20.
Actinocyclus elongatus Grunow: Kolbe, 1954, p. 20, pl. 3, figs. 28, 31; Simonsen, 1974, p. 21, pl. 20, fig. 1-3. (Plate 4, Fig. 16)
Actinocyclus ingens Rattray, 1890, p. 149, pl. 11, fig. 7; Koizumi, 1973, p. 831, pl. 1, figs. 13, 14, pl. 2, figs. 1, 2.
Actinocyclus moronensis Deby: Schrader, 1974b, p. 911, pl. 17, figs. 9-12; Kanaya, 1971, p. 554, pl. 40.2, fig. 7.
Actinocyclus ochotensis Jousé, 1968, p. 17, pl. 2, figs. 2-5; Koizumi, 1973, p. 831, pl. 2, figs. 8, 9.

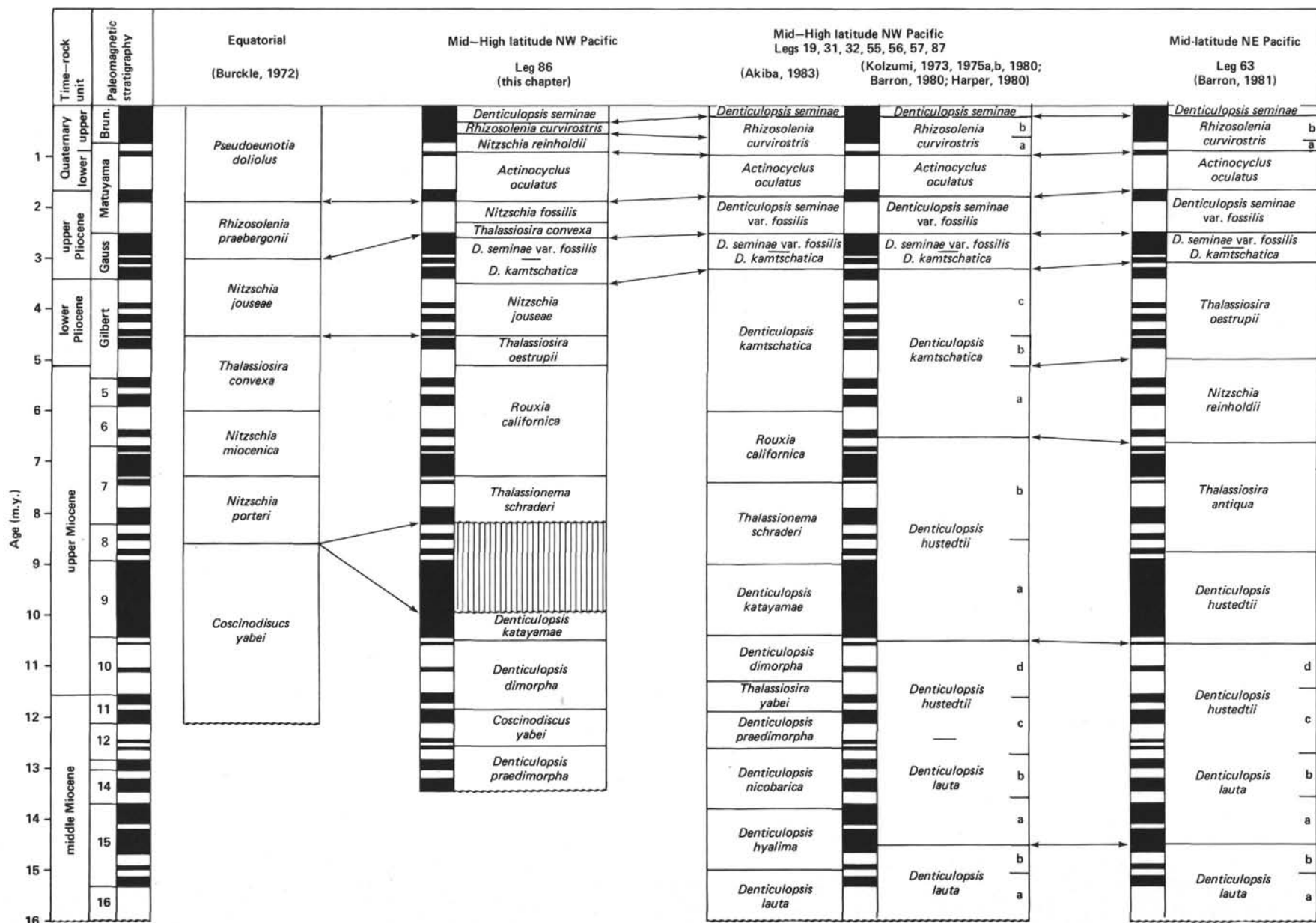


Figure 9. Correlation of the diatom zones in this chapter with the low latitude diatom zonation of Burckle (1972), the middle-high latitude western North Pacific zonation in DSDP Legs 19, 31, 32, and 55 by Koizumi (1973, 1975a, 1975b, 1980), Leg 56 by Harper (1980), Leg 57 by Barron (1980) and Leg 87 by Akiba (1983), and the low-middle eastern North Pacific zonation in Leg 63 by Barron (1981).

- Actinocyclus octonarius* Ehrenberg: Andrews, 1980a, p. 23, pl. 1, fig. 1, pl. 4, fig. 1.
- Actinocyclus oculatus* Jousé, 1968, p. 18, pl. 2, figs. 6, 7; Koizumi, 1973, p. 831, pl. 2, figs. 8, 9. (Plate 3, Fig. 12)
- Actinoptychus senarius* (Ehrenberg) Ehrenberg: Kanaya, 1959, p. 89, pl. 6, figs. 4, 5; Sancetta, 1982, p. 225, pl. 1, fig. 7.
- Actinoptychus splendens* (Shadbolot) Ralfs: Hustedt, 1930b, p. 478, fig. 265.
- Actinoptychus vulgaris* Schumann: Sancetta, 1982, p. 223, pl. 1, fig. 8.
- Asterolampra acutiloba* Forti: Schrader, 1974b, pl. 9, fig. 7, 8; Koizumi, 1980, pl. 1, fig. 18. (Plate 2, Fig. 5)
- Asterolampra grevillei* (Wallich) Greville: Hustedt, 1930b, p. 489, fig. 274; Schrader, 1974b, pl. 8, fig. 5.
- Asterolampra marylandica* Ehrenberg: Hustedt, 1930b, p. 485, figs. 270, 271; Koizumi, 1980, pl. 2, fig. 24.
- Asteromphalus arachne* (Brébisson) Ralfs: Hustedt, 1930b, p. 493, fig. 276; Schrader, 1974b, pl. 9, fig. 11.
- Asteromphalus brookei* Bailey: Sancetta, 1982, p. 226, pl. 1, fig. 9. (Plate 2, Fig. 7)
- Asteromphalus darwinii* Ehrenberg: Greville, 1860, p. 116, pl. 4, figs. 12, 13; Koizumi, 1980, p. 397, pl. 2, fig. 26. (Plate 2, Fig. 2)
- Asteromphalus flabellatus* (Brébisson) Greville: Hustedt, 1930b, p. 498, fig. 279; Schrader, 1974b, p. 912, pl. 8, fig. 3.
- Asteromphalus heptactis* (Brébisson) Ralfs: Hustedt, 1930b, p. 494, fig. 277; Schrader, 1974b, pl. 8, fig. 1. (Plate 2, Fig. 1)
- Asteromphalus hookeri* Ehrenberg: Schrader, 1974b, pl. 8, fig. 7.
- Asteromphalus imbricatus* Wallich: Kolbe, 1957, p. 25, pl. 1, fig. 1; Simonsen, 1974, p. 25, pl. 22, fig. 1.
- Asteromphalus petterssonii* (Kolbe) Thornington-Smith, 1970, p. 822, pl. 1, fig. 5; Schrader, 1974b, p. 912, pl. 12, figs. 10–13. (Plate 2, Fig. 3)
- Asteromphalus robustus* Castracane: Hustedt, 1930b, p. 496, fig. 278; Koizumi, 1975b, pl. 3, fig. 5.
- Aulacosira granulata* (Ehrenberg) Simonsen, 1979, p. 58; as *Melosira granulata* (Ehrenberg) Ralfs, Hustedt, 1930b, p. 248, fig. 104.
- Bacteriosira fragilis* (Gran) Gran: Koizumi, 1975a, pl. 2, figs. 5, 6; Sancetta, 1982, p. 227, pl. 2, figs. 1–4.
- Biddulphia pulchella* Gray: Hustedt, 1930b, p. 832, fig. 490.
- Bogorovia praepaleacea* (Schrader) Jousé, 1976, p. 1233; Barron, 1981, p. 529, pl. 4, fig. 14.
- Bogorovia tatsunokuchiensis* (Koizumi) Jousé, 1976, p. 1233; Barron, 1981, p. 529, pl. 4, fig. 17. (Plate 1, Fig. 19)
- Chaetoceros furcellatus* Bailey: Hustedt, 1930b, p. 749, fig. 433.
- Cocconeis californica* Grunow: Hustedt, 1933, p. 343, fig. 796.
- Cocconeis costata* Gregory: Hustedt, 1933, p. 332, fig. 785.
- Cocconeis disculus* Schumann: Hustedt, 1933, p. 345, fig. 799.
- Cocconeis pellucida* Grunow: Hustedt, 1933, p. 357, fig. 812.
- Cocconeis placentula* var. *euglypta* (Ehrenberg) Cleve: Hustedt, 1933, p. 349, fig. 802c.
- Cocconeis scutellum* Ehrenberg: Hustedt, 1933, p. 337, fig. 790.
- Cocconeis scutellum* var. *stauroneiformis* Rabenhorst: Hustedt, 1933, p. 339, fig. 792.
- Coscinodiscus africanus* Janisch: Hustedt, 1930b, p. 428, fig. 231; Koizumi, 1975b, pl. 2, figs. 1, 2; Simonsen, 1974, p. 13, pl. 9, fig. 1.
- Coscinodiscus argus* Ehrenberg: Hustedt, 1930b, p. 422, fig. 226.
- Coscinodiscus asteromphalus* Ehrenberg: Hustedt, 1930b, p. 452, figs. 250, 251a.
- Coscinodiscus centralis* Ehrenberg: Hustedt, 1930b, p. 444, fig. 243.
- Coscinodiscus elegans* Greville, 1866, p. 3, pl. 1, fig. 6; Kanaya, 1959, p. 75, pl. 3, figs. 6, 7.
- Coscinodiscus endoi* Kanaya, 1959, p. 76, pl. 3, figs. 8–11; Schrader, 1973, p. 702, pl. 7, figs. 14, 21, pl. 20, figs. 1, 2. (Plate 4, Fig. 12)
- Coscinodiscus gigas* Ehrenberg: Hustedt, 1930b, p. 456, figs. 254, 256a.
- Coscinodiscus marginatus* Ehrenberg: Hustedt, 1930b, p. 416, fig. 223; Koizumi, 1975b, pl. 2, fig. 18.
- Coscinodiscus nitidus* Gregory: Hustedt, 1930b, p. 414, fig. 221.
- Coscinodiscus nodulifer* Schmidt: Hustedt, 1930b, p. 426, fig. 229; Koizumi, 1975b, p. 1, figs. 3–10. (Plate 3, Fig. 8)
- Coscinodiscus obscurus* Schmidt: Hustedt, 1930b, p. 418, fig. 224.
- Coscinodiscus oculus-iridis* Ehrenberg: Hustedt, 1930b, p. 454, fig. 252.
- Coscinodiscus perforatus* Ehrenberg: Hustedt, 1930b, p. 445, figs. 244, 245.
- Coscinodiscus plicatus* Grunow: Kanaya, 1971, p. 555, pl. 40.4, figs. 4–6. (Plate 3, Figs. 3, 4)
- Coscinodiscus radiatus* Ehrenberg: Hustedt, 1930b, p. 240, fig. 225.
- Coscinodiscus stellaris* Roper: Hustedt, 1930b, p. 395, fig. 207.
- Coscinodiscus symbolophorus* Grunow: Schrader, 1973, p. 703, pl. 22, figs. 8, 9; as *Coscinodiscus stellaris* Roper var. *symbolophorus* (Grunow) Jørgensen, Koizumi, 1973, p. 832, pl. 4, figs. 5, 6.
- Coscinodiscus tabularis* Grunow var. *egregius* (Rattray) Hustedt, 1930b, p. 427, fig. 230b; Koizumi, 1975b, pl. 2, figs. 14, 15. (Plate 5, Figs. 13, 14)
- Coscinodiscus temperei* Brun var. *delicata* Barron, 1981, p. 528, pl. 3, figs. 1, 3, 4.
- Coscinodiscus vetustissimus* Pantocsek: Hustedt, 1930b, p. 412, fig. 220; Kanaya, 1971, p. 555, pl. 40.2, figs. 1–5; Koizumi, 1975b, pl. 1, figs. 13, 14. (Plate 4, Fig. 11)
- Coscinodiscus yabei* Kanaya, 1959, p. 86, pl. 5, figs. 6–9. (Plate 3, Figs. 10, 11)
- Cosmidiscus intersectus* (Brun) Jousé, 1961, p. 68, pl. 2, figs. 9, 10; Koizumi, 1973, p. 832, pl. 4, figs. 12, 13.
- Cyclotella chaetoceras* Lemmermann: Hustedt, 1930b, p. 344, fig. 175.
- Cyclotella comta* (Ehrenberg) Kützing: Hustedt, 1930b, p. 103, fig. 69.
- Cyclotella kützingiana* Thwaites: Hustedt, 1930b, p. 338, fig. 171.
- Cyclotella meneghiniana* Kützing: Hustedt, 1930b, p. 341, fig. 174.
- Cyclotella striata* (Kützing) Grunow: Hustedt, 1930b, p. 344, fig. 176.
- Cyclotella stylorum* Brightwell: Hustedt, 1930b, p. 348, fig. 179.
- Cymatodiscus planetophorus* (Meister) Hendey, 1958, p. 42, pl. 5, fig. 8.
- Cymatosira lorenziana* Grunow: Hustedt, 1931, p. 127, fig. 648.
- Cymbella leptoceros* Kützing: Hustedt, 1930b, p. 353, fig. 645.
- Cymbella sinuata* Gregory: Hustedt, 1930b, p. 361, fig. 668.
- Delphineis surirella* (Ehrenberg) Andrews, 1980b, p. 83, pl. 1, 2, figs. 1–7.
- Delphineis surirelloides* (Simonsen) Andrews, 1980b, p. 86; as *Rhaphoneis surirelloides* Simonsen, 1974, p. 35, pl. 23, figs. 2–8.
- Denticulopsis dimorpha* (Schrader) Simonsen, 1979, p. 64; Barron, 1981, p. 529, pl. 4, fig. 7. (Plate 1, Fig. 1)
- Denticulopsis hustedtii* (Kanaya and Simonsen) Simonsen, 1979, p. 64; Barron, 1981, p. 529, pl. 4, fig. 21. (Plate 1, Figs. 7, 8)
- Denticulopsis hyalina* (Schrader) Simonsen, 1979, p. 64; Barron, 1981, p. 529, pl. 4, figs. 3, 4. (Plate 1, Fig. 3)
- Denticulopsis kamtschatica* (Zabelina) Simonsen, 1979, p. 64; emend: Koizumi, 1980, p. 396, pl. 2, figs. 1–10. (Plate 6, Fig. 7)
- Denticulopsis katayamae* Maruyama, 1982: Remarks: This species differs from *Denticulopsis hyalina* (Schrader) Simonsen in the presence of the secondary pseudosepta, and from *Denticulopsis hustedtii* (Kanaya and Simonsen) Simonsen in its heavily silicified and hyaline valve face. (Plate 1, Figs. 5, 6)
- Denticulopsis lauta* (Bailey) Simonsen, 1979, p. 64; Barron, 1981, p. 529, pl. 4, fig. 5. (Plate 1, Fig. 4)
- Denticulopsis praedimorpha* (Akiba) Barron, 1981, p. 529, pl. 4, figs. 8–10. (Plate 1, Fig. 2)
- Denticulopsis punctata* forma *hustedtii* (Schrader) Simonsen, 1979, p. 65; Barron, 1981, pl. 4, fig. 1. (Plate 1, Figs. 9, 10)
- Denticulopsis seminae* (Simonsen and Kanaya) Simonsen, 1979, p. 65; as *Denticula seminae* Simonsen and Kanaya, Koizumi, 1975a, pl. 1, figs. 1, 2.
- Diploneis bomboides* (Schmidt) Cleve: Hustedt, 1937, p. 695, fig. 1080.
- Diploneis bombus* Ehrenberg: Hustedt, 1937, p. 704, fig. 1086a–c, g, h.
- Diploneis coffeiformis* (Schmidt) Cleve: Hustedt, 1937, p. 611, fig. 1025.
- Diploneis interrupta* (Kützing) Cleve: Hustedt, 1930a, p. 252, fig. 400.
- Diploneis nitescens* (Gregory) Cleve: Hustedt, 1937, p. 640, fig. 1047.
- Diploneis oculata* (Brébisson) Cleve: Hustedt, 1930a, p. 250, fig. 392.
- Diploneis ovalis* (Hilse) Cleve: Hustedt, 1930a, p. 249, fig. 390.
- Diploneis parma* Cleve: Hustedt, 1937, p. 673, fig. 1066.
- Diploneis smithii* (Brébisson) Cleve: Hustedt, 1937, p. 647, fig. 1051.
- Diploneis weissflogi* (Schmidt) Cleve: Hustedt, 1937, p. 703, fig. 1085.
- Epithemia zebra* (Ehrenberg) Kützing: Hustedt, 1930a, p. 384, fig. 729.
- Eunotia praeurupta* Ehrenberg: Hustedt, 1932, p. 280, fig. 747a–e.
- Eunotia sibirica* Cleve: Hustedt, 1932, p. 310, fig. 776.
- Fragilaria construens* (Ehrenberg) Grunow: Hustedt, 1931, p. 156, fig. 670a–c.
- Fragilaria leptostauron* (Ehrenberg) Hustedt, 1931, p. 153, fig. 668a–f.
- Gomphonema augur* Ehrenberg: Hustedt, 1930a, p. 372, fig. 689.
- Gomphonema gracile* Ehrenberg: Hustedt, 1930a, p. 376, fig. 702.
- Grammatophora marina* (Lyngbye) Kützing: Hustedt, 1931, p. 43, fig. 569.
- Grammatophora oceanica* Ehrenberg: Hustedt, 1931, p. 45, fig. 573.

- Hemiaulus polymorphus* Grunow: Hustedt, 1930b, p. 880, fig. 525.
Hemiaulus sinensis Greville: Hustedt, 1930b, p. 875, fig. 519.
Hemidiscus cuneiformis Wallich: Hustedt, 1930b, p. 904, fig. 542; Koizumi, 1975a, pl. 4, fig. 2. (Plate 5, Fig. 12)
Hemidiscus simplicissimus Hanna and Grant, 1926, p. 147, pl. 16, fig. 13; Schrader, 1973, p. 706, pl. 24, figs. 12, 13.
Hyalodiscus scoticus (Kützing) Grunow: Hustedt, 1930b, p. 293, fig. 133.
Kisseleviella carina Sheshukova-Poretzkaya, 1962, p. 207, fig. 1a–b, 2; Koizumi, 1973, p. 833, pl. 7, figs. 3, 4.
Liriogramma hustedtii Kolbe, 1955, p. 173, pl. 2, fig. 21.
Lithodesmium undulatum Ehrenberg: Hustedt, 1930b, p. 789, fig. 461.
Mediaria splendida Sheshukova-Poretzkaya, 1962, p. 210, fig. 2, 5; Koizumi, 1973, p. 832, pl. 7, figs. 5, 6.
Melosira albicans Sheshukova-Poretzkaya, 1964, p. 69, fig. 1, 2, pl. 2, fig. 3; Koizumi, 1972, p. 351, pl. 43, figs. 1, 2.
Navicula lyra Ehrenberg: Hustedt, 1964, p. 500, figs. 1548–1555; Hendey, 1964, p. 209, pl. 33, fig. 2.
Navicula mutica Kützing: Hustedt, 1966, p. 583, fig. 1592a–f.
Nitzschia bicapitata Cleve: Hustedt, 1958, p. 169, figs. 176–190; Hasle, 1960, p. 21, pl. 6, figs. 53–57; Simonsen, 1974, p. 50, pl. 35, figs. 3–15.
Nitzschia braarudii Hasle, 1960, p. 22, fig. 11, pl. 7, figs. 58–63; Simonsen, 1974, p. 50, pl. 35, fig. 2.
Nitzschia constricta (Gregory) Grunow: Cleve-Euler, 1952, p. 55, pl. 7, fig. 8.
Nitzschia cylindrica Burckle, 1972, p. 239, pl. 2, figs. 1–6; Schrader, 1973, pl. 5, figs. 27, 32, 33.
Nitzschia cylindrus (Grunow) Hasle, 1972, p. 115; Koizumi, 1975a, p. 802, pl. 1, fig. 49; as *Nitzschia cylindra* (Grunow) Hasle, Sancetta, 1982, p. 232, pl. 3, figs. 6, 7.
Nitzschia dietrichii Simonsen, 1974, p. 51, pl. 36, figs. 1–3.
Nitzschia fossilis (Frenguelli) Kanaya: Koizumi and Kanaya, 1976, p. 155, pl. 1, figs. 11–14. (Plate 1, Fig. 18; Plate 6, Fig. 6)
Nitzschia grunowii Hasle, 1972, p. 115; Sancetta, 1982, p. 233, pl. 3, figs. 8–10. (Plate 3, Figs. 5, 6)
Nitzschia heteropolica Schrader, 1973, p. 707, pl. 26, figs. 1, 2. Remarks: Valves heteropolar, one apex broadly rounded, the other acutely rounded. Barron, 1980, pl. 2, fig. 7, pl. 4, fig. 9.
Nitzschia inflatula Hasle, 1965, p. 33, pl. 13, figs. 7–10, pl. 15, figs. 1–8; Simonsen, 1974, p. 52, pl. 36, figs. 7, 8.
Nitzschia interruptestriata Simonsen, 1974, p. 52, pl. 36, figs. 9–11, pl. 37, fig. 1a–7, pl. 38, figs. 1–7. (Plate 6, Fig. 8)
Nitzschia jouseae Burckle, 1972, p. 240, pl. 2, figs. 17–21; Koizumi, 1980, p. 397, pl. 3, figs. 9, 10. (Plate 1, Fig. 12; Plate 6, Fig. 12)
Nitzschia kolaczekii Grunow: Kolbe, 1955, p. 174, pl. 2, figs. 22, 23; Hasle, 1960, p. 24, pl. 5, fig. 50b, c.
Nitzschia marina Grunow: Kolbe, 1954, p. 40, pl. 3, figs. 38–40. (Plate 6, Figs. 1, 2)
Nitzschia miocenica Burckle, 1972, p. 240, pl. 2, figs. 10–15; Schrader, 1974b, p. 915, pl. 5, figs. 10, 11; Koizumi, 1980, p. 397, pl. 3, figs. 15–18. (Plate 1, Fig. 13; Plate 6, Fig. 9)
Nitzschia panduriformis Gregory: Hustedt, 1921, pl. 331, figs. 19, 21.
Nitzschia porteri Frenguelli sensu Burckle, 1972, pl. 2, fig. 16; Barron, 1981, pl. 4, fig. 20. (Plate 1, Fig. 11)
Nitzschia praefossilis Schrader, 1973, p. 708, pl. 5, figs. 19, 21, 22. (Plate 1, Fig. 15)
Nitzschia praereinholdii Schrader, 1973, p. 708, pl. 5, fig. 20, 23–26. (Plate 1, Fig. 16)
Nitzschia reinholdii Kanaya: Koizumi and Kanaya, 1976, p. 155, pl. 1, figs. 15–18. (Plate 6, Figs. 3, 4)
Nitzschia rolandii Schrader emend. Koizumi, 1980, p. 396, pl. 2, figs. 15–20.
Nitzschia seriata Cleve: Hendey, 1964, p. 284, pl. 21, fig. 6.
Nitzschia sicula (Castracane) Hustedt, 1958, p. 180, figs. 128–132; Hasle, 1960, p. 26, pl. 7, figs. 64, 65.
Nitzschia suikoensis Koizumi, 1980, p. 394, pl. 1, figs. 1–6.
Nitzschia trybionella Hantzsch: Hustedt, 1930a, p. 399, fig. 757.
Odontella aurita (Lyngbye) Agardh: Sancetta, 1982, p. 234, pl. 3, figs. 11, 12.
Paralia sulcata (Ehrenberg) Cleve: Andrews, 1976, p. 8, pl. 1, figs. 5, 6; Sancetta, 1982, p. 235, pl. 3, figs. 13–15.
Planktoniella sol (Wallich) Schütt: Hustedt, 1930b, p. 465, fig. 259; Fryxell and Hasle, 1972, figs. 34–36.
Porosira glacialis (Grunow) Jørgensen: Hustedt, 1930b, p. 315, fig. 153; Koizumi, 1973, p. 833, pl. 4, figs. 15–18; Sancetta, 1982, p. 235, pl. 3, figs. 16–18.
Pseudoeunotia doliolus (Wallich) Grunow: Hustedt, 1932, p. 259, fig. 737; Koizumi and Kanaya, 1976, p. 155, pl. 1, figs. 9, 10. (Plate 1, Fig. 17; Plate 6, Fig. 5)
Pseudopodosira elegans Sheshukova-Poretzkaya, 1964, p. 75, pl. 2, figs. 4, 5; Koizumi, 1972, p. 352, pl. 43, figs. 3, 4. (Plate 4, Fig. 10)
Rhabdonema arcuatum (Lyngbye? Agardh) Kützing: Hustedt, 1931, p. 20, fig. 549.
Rhabdonema japonicum Tempère and Brun: Hanna, 1970, p. 192, figs. 47, 92, 93, 95; Schrader, 1973, pl. 12, fig. 10.
Rhaphoneis amphiceros Ehrenberg: Hustedt, 1931, p. 174, fig. 680; Schrader, 1973, pl. 25, figs. 2, 3.
Rhizosolenia alata Brightwell: Hustedt, 1930b, p. 600, fig. 345; Koizumi, 1975a, pl. 1, fig. 38.
Rhizosolenia barboi Brun: Schrader, 1973, p. 709, pl. 24, figs. 4, 7; Koizumi, 1975b, pl. 4, figs. 52, 53. (Plate 6, Fig. 16)
Rhizosolenia bergonii Peragallo: Hustedt, 1930b, p. 575, fig. 327; Koizumi and Kanaya, 1976, p. 155, pl. 1, figs. 20, 21. (Plate 2, Fig. 4; Plate 6, Fig. 14)
Rhizosolenia curvirostris Jousé, 1968, p. 19, pl. 3, fig. 2; Donahue, 1970, p. 135, pl. 1, fig. a; Koizumi, 1973, pl. 5, figs. 29–31. (Plate 4, Fig. 15; Plate 6, Fig. 15)
Rhizosolenia hebetata forma *hiemalis* (Bailey) Gran: Hustedt, 1930b, p. 590, fig. 337; Koizumi, 1973, p. 833, pl. 5, figs. 34, 35; Sancetta, 1982, p. 237, pl. 4, figs. 5, 6.
Rhizosolenia matuyamai Burckle: Burckle et al., 1978, p. 213, figs. 3–6.
Rhizosolenia praebergonii Mukhina, 1965, p. 24, pl. 2, figs. 3, 4; Koizumi, 1968, p. 217, pl. 34, figs. 20a–21b; Burckle, 1972, pl. 3, figs. 1–3. (Plate 6, Fig. 13)
Rhizosolenia setigera Brightwell: Hustedt, 1930b, p. 588, fig. 336.
Rhizosolenia styliformis Brightwell: Hustedt, 1930b, p. 584, fig. 333; Koizumi, 1975a, pl. 1, fig. 33.
Rhoicosphenia curvata (Kützing) Grunow: Hustedt, 1933, p. 430, fig. 879.
Roperia praetesselata Schrader, 1974b, p. 915, pl. 21, figs. 13, 14, pl. 14, figs. 3, 4.
Roperia tessellata (Roper) Grunow: Hustedt, 1930b, p. 524, fig. 297; Koizumi, 1975b, pl. 2, figs. 3, 4. (Plate 5, Figs. 5, 6)
Rouxia californica Peragallo: Hanna, 1930, p. 186, pl. 14, figs. 6, 7; Koizumi, 1975a, p. 802, pl. 1, fig. 52. (Plate 1, Fig. 21)
Rouxia naviculoides Schrader, 1973, p. 710, pl. 3, figs. 27–32.
Rouxia yabei Hanna, 1930, p. 185, pl. 15, figs. 2–4; Schrader, 1973, p. 710, pl. 3, figs. 21, 23. (Plate 1, Fig. 20)
Stephanodiscus astraee (Ehrenberg) Grunow: Hustedt, 1930a, p. 110, fig. 85; Schrader, 1978, p. 863, pl. 2, figs. 7, 11, pl. 3, figs. 11, 12, pl. 4, figs. 15, 22, 23, pl. 8, fig. 13, pl. 12, fig. 15, pl. 13, figs. 2, 8, pl. 16, figs. 5, 6.
Stephanodiscus carconensis Grunow: Van Landingham, 1967, p. 17, pl. 21, fig. 18; Schrader, 1978, p. 863, pl. 4, fig. 24a, pl. 6, figs. 4, 8–10, pl. 7, figs. 6, 9, pl. 9, figs. 5, 8, 11–15, 18–23, 27, pl. 10, figs. 5–8, 10, pl. 11, figs. 9, 14, 15, 20, pl. 12, fig. 14, pl. 16, fig. 4.
Stephanopyxis dimorpha Schrader, 1973, p. 711, pl. 15, figs. 9–11, 19, 20, pl. 16, figs. 1–3, 8–11, pl. 24, fig. 10.
Stephanopyxis horridus Koizumi, 1972, p. 348, pl. 42, figs. 1a–2b; Koizumi, 1973, p. 833, pl. 6, figs. 1–4.
Stephanopyxis turris (Greville and Arnott) Ralfs: Hustedt, 1930b, p. 304, fig. 140; Koizumi, 1973, p. 833, pl. 6, figs. 13–16.
Surirella axmorica Peragallo: Hendey, 1964, p. 289, pl. 40, fig. 6.
Synedra jouseana Sheshukova-Poretzkaya, 1962, p. 208, fig. 4; Koizumi, 1973, p. 833, pl. 6, fig. 17.
Thalassionema bacillaris (Heiden) Kolbe: Hasle and Mendiola, 1967, p. 109, figs. 1–4, 19, 22–26; Simonsen, 1974, p. 37, pl. 24, fig. 1.
Thalassionema hirosakiensis (Kanaya) Schrader, 1973, p. 711, pl. 23, figs. 31–33; Akiba, 1982, p. 49, figs. 1–5.
Thalassionema schraderi Akiba, 1982, p. 50, figs. 6–11, 16–18. (Plate 1, Fig. 14)
Thalassionema nitzschoides Grunow: Hustedt, 1959, p. 244, fig. 725; Koizumi, 1975a, pl. 1, fig. 50, 51. (Plate 6, Fig. 10)
Thalassionema nitzschoides var. *parva* Heiden and Kolbe, 1928, p. 564, pl. 35, fig. 118; Hasle, 1960, p. 18, fig. 5a. (Plate 6, Fig. 11)
Thalassiosira antiqua (Grunow) Cleve-Euler, 1951, p. 72, fig. 119a; Koizumi, 1973, p. 834, pl. 7, fig. 12. (Plate 4, Fig. 14)

- Thalassiosira borealis* Koizumi, 1980, p. 395, pl. 1, figs. 7–10 (Plate 4, Fig. 8)
- Thalassiosira burckliana* Schrader, 1974, p. 916, pl. 1, figs. 21–26; Barron, 1981, p. 530, pl. 5, fig. 2.
- Thalassiosira convexa* Mukhina, 1965, p. 22, pl. 11, fig. 1, 2; Koizumi, 1975a, pl. 4, figs. 15–20.
- Thalassiosira decipiens* (Grunow) Jørgensen: Hustedt, 1930b, p. 322, fig. 158; Koizumi, 1973, p. 834, pl. 7, figs. 16–18; Sancetta, 1982, p. 241, pl. 5, figs. 1–3. (Plate 4, Fig. 9)
- Thalassiosira eccentrica* (Ehrenberg) Cleve: Fryxell and Hasle, 1972, p. 297, pl. 1–4, figs. 1a–18; Simonsen, 1974, p. 9, pl. 2, figs. 1–3; as *Coscinodiscus excentricus* Ehrenberg, Koizumi, 1973, pl. 2, figs. 11, 12.
- Thalassiosira gravida* Cleve: Hustedt, 1930b, p. 325, fig. 161; Koizumi, 1973, p. 834, pl. 7, figs. 19–21.
- Thalassiosira hyalina* (Grunow) Gran: Hustedt, 1930b, p. 323, fig. 159; Koizumi, 1973, p. 834, pl. 8, figs. 1, 2; Sancetta, 1982, p. 242, pl. 5, figs. 4, 5.
- Thalassiosira jacksonii* Koizumi and Barron, 1980, p. 396, pl. 1, figs. 11–14. (Plate 4, Fig. 7)
- Thalassiosira kryophila* (Grunow) Goerg: Hustedt, 1930b, p. 324, fig. 160; Koizumi, 1973, p. 834, pl. 8, fig. 3.
- Thalassiosira lacustris* (Grunow) Hasle: Sancetta, 1982, p. 241, pl. 5, figs. 6, 7.
- Thalassiosira leptopus* (Grunow) Hasle and Fryxell, 1977, p. 20, figs. 1–14; as *Coscinodiscus lineatus* Ehrenberg, Koizumi, 1975b, pl. 2, figs. 5, 6.
- Thalassiosira lineata* Jousé, 1968, p. 13, pl. 1, figs. 1, 2; Hasle and Fryxell, 1977, p. 22, figs. 15–25; Simonsen, 1974, p. 9, pl. 1, figs. 4–7.
- Thalassiosira manifesta* Sheshukova-Poretzkaya, 1964, p. 72, pl. 1, figs. 6, 7; Koizumi, 1968, p. 218, pl. 35, figs. 16, 17.
- Thalassiosira miocenica* Schrader, 1974, p. 916, pl. 22, figs. 1–5, 11–13; Barron, 1981, pl. 5, fig. 3. (Plate 3, Fig. 1, 2)
- Thalassiosira nativa* Sheshukova-Poretzkaya, 1964, p. 75, pl. 1, figs. 4, 5; Koizumi, 1968, p. 219, pl. 35, figs. 19, 20.
- Thalassiosira nidulus* (Tempère and Brun) Jousé, 1961, p. 63, pl. 3, figs. 4, 5; Koizumi, 1973, pl. 7, figs. 25, 26. (Plate 2, Fig. 6)
- Thalassiosira nodulolineata* (Hendey) Hasle and Fryxell, 1977, p. 35, figs. 86–93.
- Thalassiosira nordenskiöldii* Cleve: Hustedt, 1930b, p. 321, fig. 157; Hasle, 1968, p. 196, figs. 2, 4, 8; Koizumi, 1973, p. 834, pl. 8, fig. 4; Sancetta, 1982, p. 243, pl. 5, figs. 8, 9.
- Thalassiosira oestrupii* (Osterfeld) Proshkina-Lavrenko: Hasle, 1960, p. 8, pl. 1, figs. 5–7; Koizumi, 1973, p. 834, pl. 7, fig. 27. (Plate 4, Figs. 4–6; Plate 5, Figs. 1–4, 11)
- Thalassiosira opposita* Koizumi, 1980, p. 396, pl. 1, figs. 15–17.
- Thalassiosira pacifica* Gran and Angst: Schrader, 1973, pl. 14, figs. 13, 14. (Plate 4, Fig. 13)
- Thalassiosira plicata* Schrader, 1974b, p. 917, pl. 3, figs. 1, 2, 4–9; Koizumi, 1980, p. 398, pl. 3, figs. 22–25. (Plate 3, Fig. 13; Plate 5, Figs. 7, 8)
- Thalassiosira praeconvexa* Burckle, 1972, p. 242, pl. 2, figs. 7–9; Koizumi, 1975b, p. 878, pl. 3, figs. 21–28.
- Thalassiosira symbolophora* Schrader, 1974b, p. 917, pl. 4, figs. 1, 2, 4–6, 7, 8. (Plate 5, Figs. 9, 10)
- Thalassiosira symmetrica* Fryxell and Hasle, 1972, p. 312, figs. 37–46; Simonsen, 1974, p. 11, pl. 6, figs. 1, 2.
- Thalassiosira trifulta* Fryxell, in Fryxell and Hasle, 1979, p. 16, figs. 1–24; Sancetta, 1982, p. 244, pl. 5, figs. 10–12, pl. 6, figs. 1, 2. (Plate 3, Fig. 7)
- Thalassiosira zabelinae* Jousé, 1961, p. 66, pl. 2, figs. 1–7; Koizumi, 1973, p. 834, pl. 8, figs. 10–12.
- Thalassiosira* sp. 1 Barron, 1980, p. 673, pl. 5, figs. 6, 7; Barron, 1981, p. 530, pl. 5, fig. 5. (Plate 4, Figs. 1–3)
- Thalassiothrix frauenfeldii* Grunow: Hustedt, 1932, p. 247, fig. 727; Hasle and Mendiola, 1967, p. 113, fig. 21a–c.
- Thalassiothrix longissima* (Cleve) Cleve and Grunow: Hustedt, 1932, p. 247, fig. 726; Hasle and Mendiola, 1967, p. 114, fig. 20; Sancetta, 1982, pl. 6, figs. 3, 4.
- Thalassiothrix vanhoeffenii* Heiden: Simonsen, 1974, p. 38, pl. 25, figs. 1–3.
- Trachyneis aspera* (Ehrenberg) Cleve: Hendey, 1964, p. 236, pl. 29, fig. 13.
- Triceratium alternans* Bailey: Hustedt, 1930b, p. 825, fig. 488.
- Triceratium cinnamomeum* Greville: Kolbe, 1954, p. 47, pl. 2, fig. 18; Schrader, 1974b, pl. 20, figs. 10, 11.
- Triceratium reticulum* Ehrenberg: Hustedt, 1930b, p. 823, figs. 485, 486.

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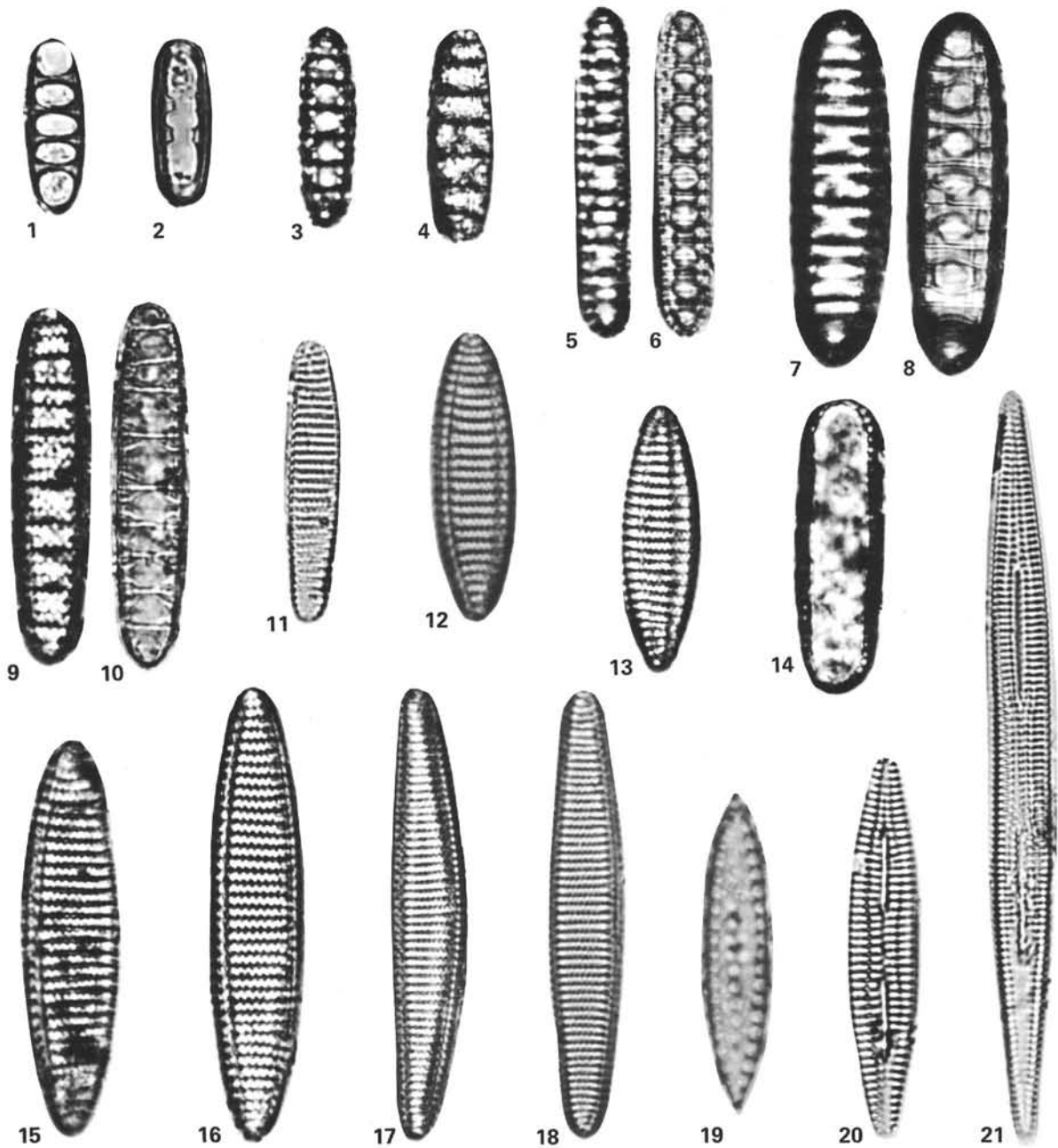


Plate 1. (Magnifications are $\times 1500$.) 1. *Denticulopsis dimorpha* (Schrader) Simonsen, Sample 581-7-2, 100–101 cm. Length 18 μm . 2. *Denticulopsis praedimorpha* (Akiba) Barron. Sample 581-8-4, 110–111 cm. Length 17 μm . 3. *Denticulopsis hyalina* (Schrader) Simonsen. Sample 581-8-4, 110–111 cm. Length 20 μm . 4. *Denticulopsis lauta* (Bailey) Simonsen. Sample 581-7-2, 100–101 cm. Length 22 μm . 5–6. *Denticulopsis katayamae* Maruyama. Sample 581-7-1, 100–101 cm. Length 32 μm . 7–8. *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen. Sample 581-6-6, 100–101 cm. Length 35 μm . 9–10. *Denticulopsis punctata* forma *hustedtii* (Schrader) Simonsen. Sample 581-8-3, 110–111 cm. Length 36 μm . 11. *Nitzschia porteri* Frenguelli sensu Burckle. Sample 581-6-2, 100–101 cm. Length 29 μm . 12. *Nitzschia jouseae* Burckle. Sample 579A-13-3, 16–17 cm. Length 15 μm . 13. *Nitzschia miocenica* Burckle. Sample 581-4-2, 98–99 cm. Length 26 μm . 14. *Thalassionema schraderi* Akiba. Sample 581-6-3, 100–101 cm. Length 29 μm . 15. *Nitzschia praefossilis* Schrader. Sample 581-7-6, 100–101 cm. Length 40 μm . 16. *Nitzschia praereinholdii* Schrader. Sample 579A-13-3, 91–92 cm. Length 46 μm . 17. *Pseudoenotia doliolus* (Wallich) Grunow. Sample 580-5-4, 40–41 cm. Length 45 μm . 18. *Nitzschia fossilis* (Frenguelli) Kanaya. Sample 580-10-5, 110–111 cm. Length 45 μm . 19. *Bogorovia tatsunokuchiensis* (Koizumi) Jousé. Sample 579A-12-4, 16–17 cm. Length 32 μm . 20. *Rouxia yabei* Hanna. Sample 581-6-6, 100–101 cm. Length 38 μm . 21. *Rouxia californica* Peragallo. Sample 581-4-4, 98–99 cm. Length 70 μm .

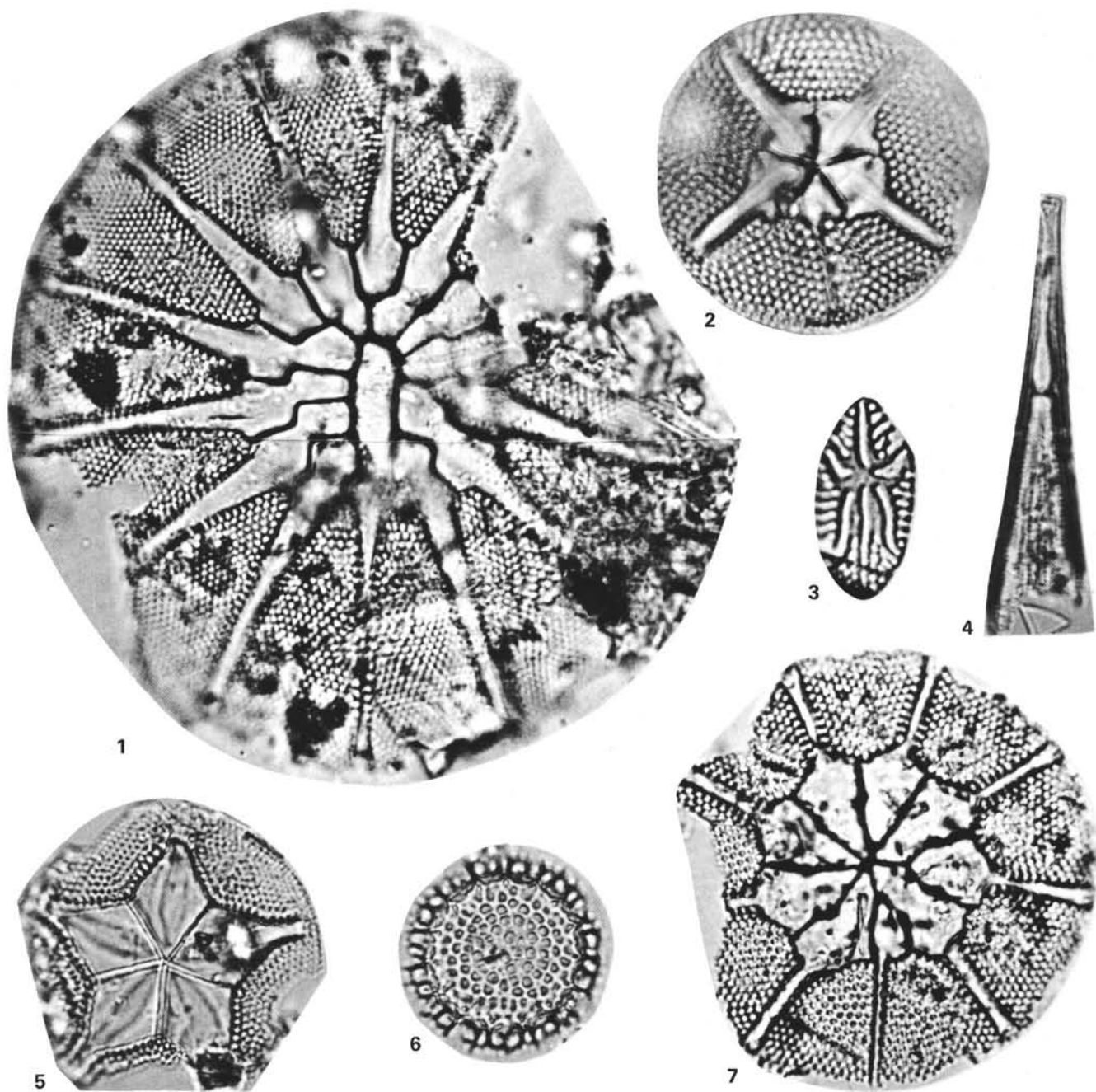


Plate 2. (Magnifications are $\times 1500$.) 1. *Asteromphalus heptactis* (Brebisson) Ralfs. Sample 579A-3-5, 116-117 cm. Diameter $82 \mu\text{m}$. 2. *Asteromphalus darwinii* Ehrenberg. Sample 581-4-6, 98-99 cm. Diameter $35 \mu\text{m}$. 3. *Asteromphalus petterssonii* (Kolbe) Thornington-Smith. Sample 579A-9-5, 13-131 cm. Length $22 \mu\text{m}$. 4. *Rhizosolenia bergonii* Peragallo. Sample 580-7-1, 8-9 cm. Broken specimen. 5. *Asterolampra acutiloba* Forti. Sample 581-3-6, 75-76 cm. Diameter $33 \mu\text{m}$. 6. *Thalassiosira nidulus* (Tempere and Brun) Jousé. Sample 580-5-5, 40-41 cm. Diameter $21 \mu\text{m}$. 7. *Asteromphalus brookei* Bailey. Sample 581-8-3, 110-111 cm. Diameter $47 \mu\text{m}$.

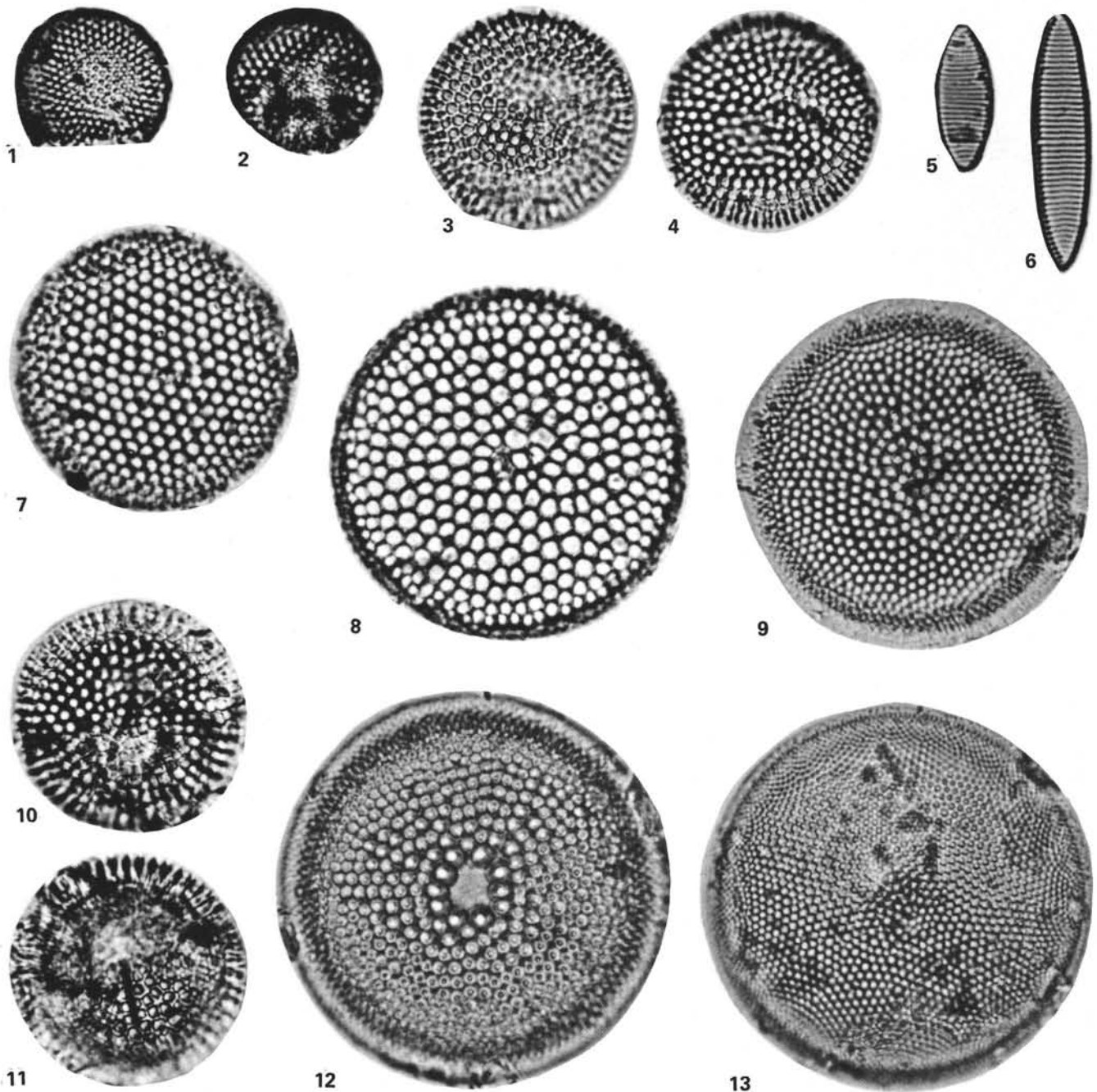


Plate 3. (Magnifications are $\times 1500$.) 1. *Thalassiosira miocenica* Schrader. Sample 581-4, CC. Diameter $16\ \mu\text{m}$. 2. *Thalassiosira miocenica* Schrader. Sample 581-3-6, 75-76 cm. Diameter $17\ \mu\text{m}$. 3-4. *Coscinodiscus plicatus* Grunow. Sample 581-7-3, 100-101 cm. Diameter $23\ \mu\text{m}$. 5-6. *Nitzschia grunowii* Hasle. (5) Sample 581-4, CC. Length $16\ \mu\text{m}$. (6) Sample 580-3, CC. Length $28\ \mu\text{m}$. 7. *Thalassiosira trifulta* Fryxell. Sample 580-5-1, 40-41 cm. Diameter $30\ \mu\text{m}$. 8. *Coscinodiscus nodulifer* Schmidt. Sample 580-5-4, 40-41 cm. Diameter $38\ \mu\text{m}$. 9. *Actinocyclus curvatulus* Janisch. Sample 580-9-2, 99-100 cm. Diameter $38\ \mu\text{m}$. 10-11. *Coscinodiscus yabei* Kanaya. Sample 581-8-1, 110-111 cm. Diameter $25\ \mu\text{m}$. 12. *Actinocyclus oculatus* Jousé. Sample 580-10-1, 25-26 cm. Diameter $42\ \mu\text{m}$. 13. *Thalassiosira plicata* Schrader. Sample 580-10-1, 25-26 cm. Diameter $40\ \mu\text{m}$.

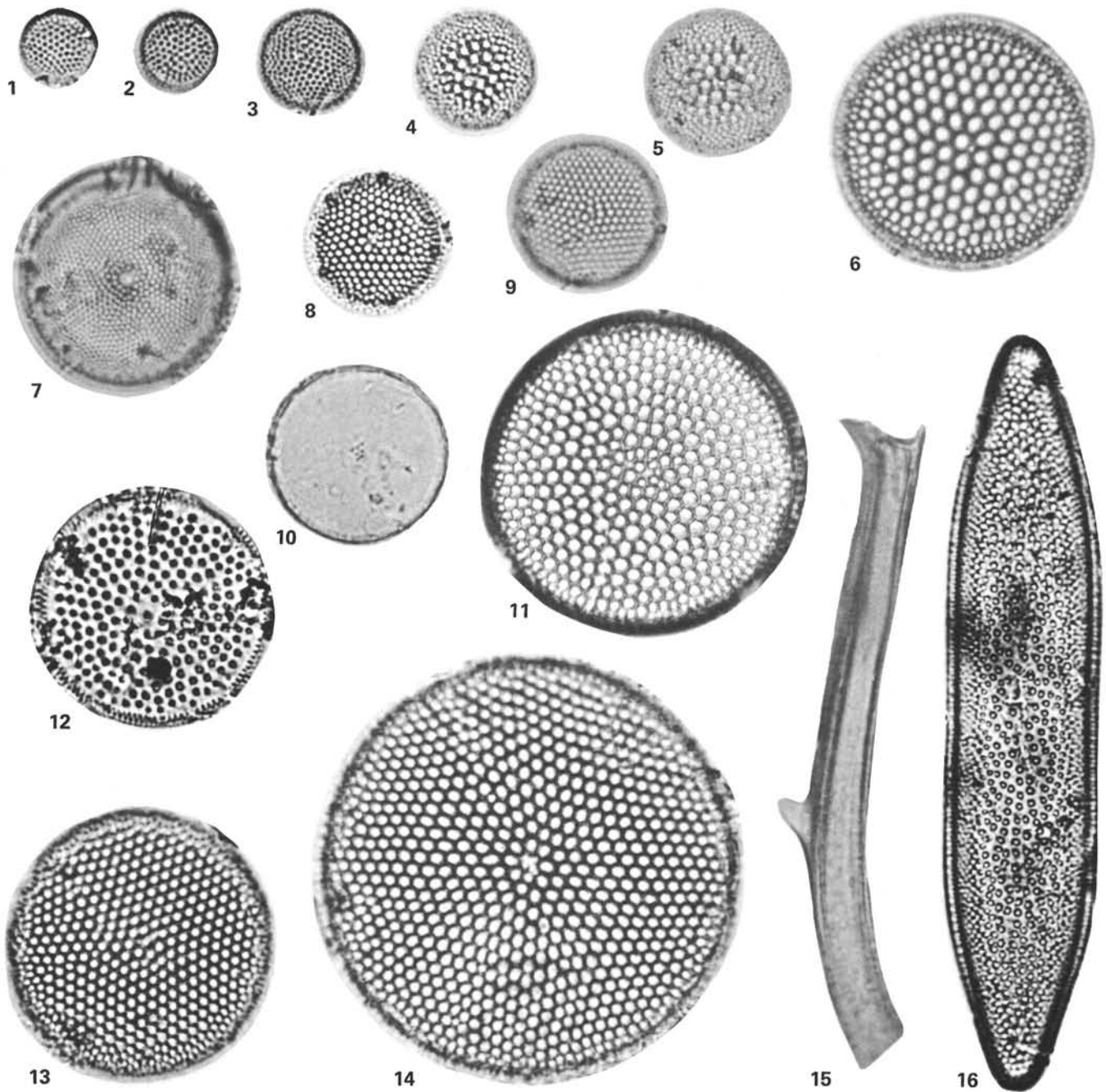


Plate 4. (Magnifications are $\times 1500$.) 1-3. *Thalassiosira* sp. 1 Barron. (1) Sample 581-6, CC. Diameter 9 μm . (2) Sample 581-6-6, 100-101 cm. Diameter 8 μm . (3) Sample 581-5-1, 100-101 cm. Diameter 11 μm . 4-6. *Thalassiosira oestrupii* (Ostenfeld) Proshkina-Lavrenko. (4) Sample 580-6-1, 112-113 cm. Diameter 13 μm . (5) Sample 580-3-5, 25-26 cm. Diameter 16 μm . (6) Sample 579A-5-3, 25-26 cm. Diameter 28 μm . 7. *Thalassiosira jacksonii* Koizumi and Barron. Sample 579A-14-3, 2-3 cm. Diameter 24 μm . 8. *Thalassiosira borealis* Koizumi. Sample 581-5-3, 100-101 cm. Diameter 17 μm . 9. *Thalassiosira decipiens* (Grunow) Jorgensen. Sample 579A-5-3, 100-101 cm. Diameter 17 μm . 10. *Pseudopodosira elegans* Sheshukova-Poretzkaya. Sample 580-2-4, 128-129 cm. Diameter 22 μm . 11. *Coscinodiscus vetustissimus* Pantocsek. Sample 580-10-1, 25-26 cm. Diameter 35 μm . 12. *Coscinodiscus endoi* Kanaya. Sample 581-7-1, 100-101 cm. Diameter 27 μm . 13. *Thalassiosira pacifica* Gran and Angst. Sample 580-6-6, 94-95 cm. Diameter 29 μm . 14. *Thalassiosira antiqua* (Grunow) Cleve-Euler. Sample 580-10-5, 25-26 cm. Diameter 46 μm . 15. *Rhizolenia curvirostris* Jousé. Sample 579A-1-6, 14-15 cm. Length 67 μm . 16. *Actinocyclus elongatus* Grunow. Sample 579A-12, CC. Length 82 μm .

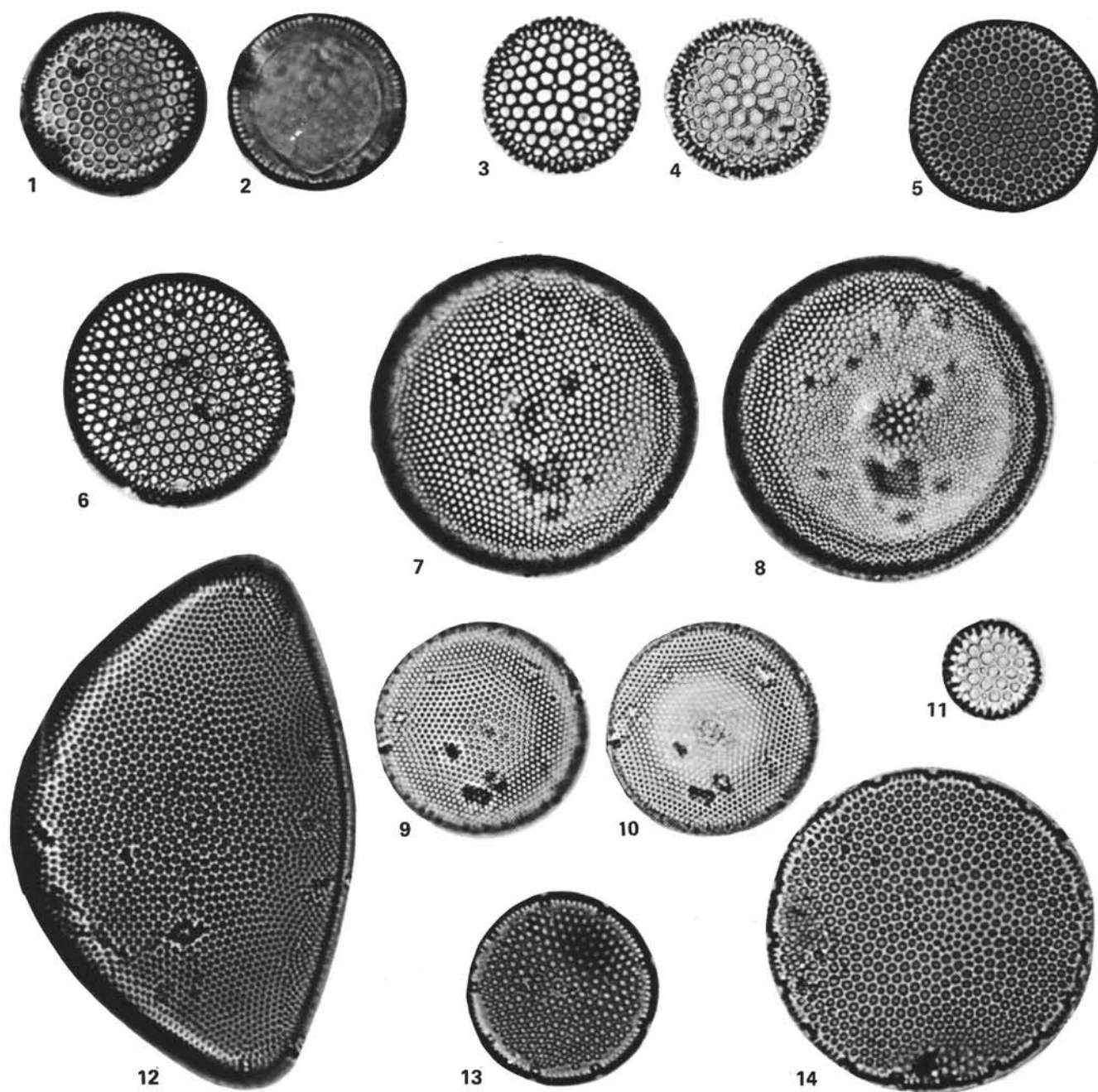


Plate 5. (Magnifications are $\times 1500$.) 1-4. *Thalassiosira oestrupii* (Ostenfeld) Proshkina-Lavrenko. (1-2) Sample 578-8-2, 118-119 cm. Diameter 20 μm . (3-4) Sample 578-7-1, 121-122 cm. Diameter 17 μm . 5-6. *Roperia tessellata* (Roper) Grunow. (5) Sample 578-8-2, 118-119 cm. Diameter 21 μm . (6) Sample 578-5-1, 117-118 cm. Diameter 26 μm . 7-8. *Thalassiosira plicata* Schrader. Sample 578-6-6, 121-122 cm. Diameter 34 μm . 9-10. *Thalassiosira symbolophora* Schrader. Sample 578-3-3, 96-97 cm. Diameter 24 μm . 11. *Thalassiosira oestrupii* (Ostenfeld) Proshkina-Lavrenko. Sample 578-3-3, 96-97 cm. Diameter 11 μm . 12. *Hemidiscus cuneiformis* Wallich. Sample 577-3, CC. Length 56 μm . 13-14. *Coscinodiscus tabularis* var. *egregius* (Rattray) Hustedt. (13) Sample 578-8-2, 118-119 cm. Diameter 21 μm . (14) Sample 577-1, CC. Diameter 35 μm .

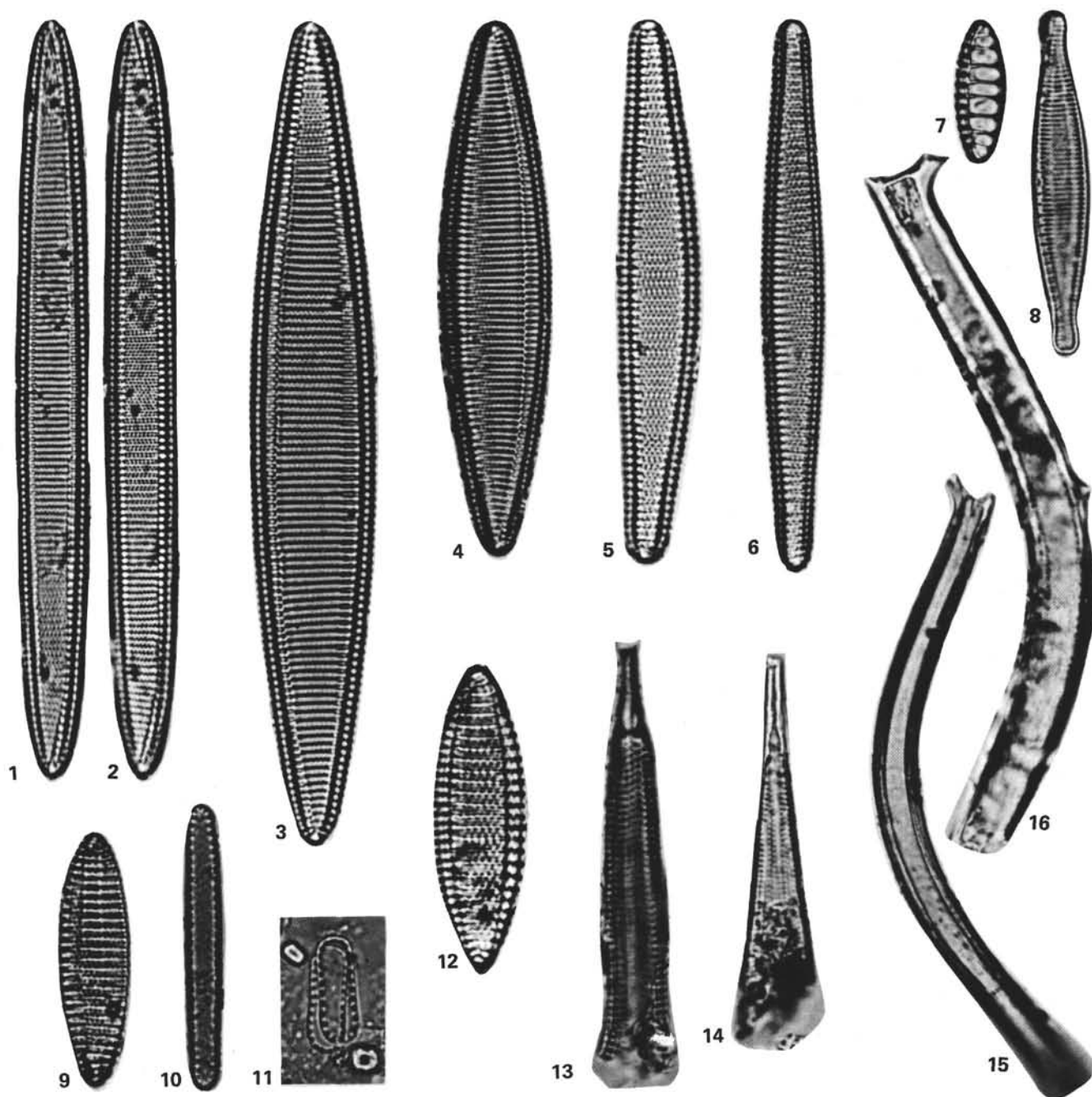


Plate 6. (Magnifications are $\times 1500$, except for Figs. 1, 2, and 15 which are $\times 1050$.) 1-2. *Nitzschia marina* Grunow. Sample 578-2-5, 115-116 cm. Length 116 μm . 3-4. *Nitzschia reinholdii* Kanaya and Koizumi. (3) Sample 578-4-5, 95-96 cm. Length 89 μm . (4) Sample 578-6-3, 109-110 cm. Length 58 μm . 5. *Pseudoeunotia doliolus* (Wallich) Grunow. Sample 578-2, CC. Length 58 μm . 6. *Nitzschia fossilis* (Frenguelli) Kanaya. Sample 578-6-7, 43-44 cm. Length 59 μm . 7. *Denticulopsis kamschatica* (Zabelina) Simonsen. Sample 578-8-1, 118-119 cm. Length 15 μm . 8. *Nitzschia interruptstriata* Simonsen. Sample 578-2-2, 115-116 cm. Length 37 μm . 9. *Nitzschia miocenica* Burckle. Sample 578-13-3, 135-136 cm. Length 27 μm . 10. *Thalassionema nitzschioides* Grunow. Sample 578-11, CC. Length 31 μm . 11. *Thalassionema nitzschioides* var. *parva* Heiden and Kolbe. Sample 578-1, CC. Length 12 μm . 12. *Nitzschia jouseae* Burckle. Sample 578-10, CC. Length 33 μm . 13. *Rhizosolenia praebergonii* Mukhina. Sample 578-9-2, 118-119 cm. Length 45 μm . 14. *Rhizosolenia bergonii* Peragallo. Sample 578-2, CC. Length 40 μm . 15. *Rhizosolenia curvirostris* Jousé. Sample 578-5-1, 117-118 cm. Length 75 μm . 16. *Rhizosolenia barboi* Brun. Sample 578-5-1, 117-118 cm. Length 91 μm .