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2. UPPER MIOCENE–PLEISTOCENE DIATOM BIOSTRATIGRAPHY IN THE NORTHWEST PACIFIC, ODP LEG 191[1]

Diane Winter,[2] James Arney,[3] and Sherwood W. Wise Jr.[3]

ABSTRACT

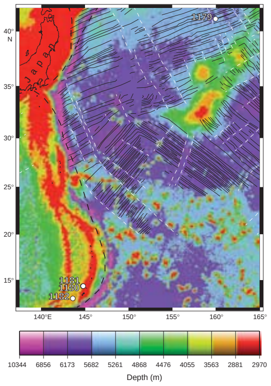
Although the objective of Ocean Drilling Program Leg 191 was to install a seismic monitoring station and to test a hard rock reentry drilling system, several good, near-continuous sedimentary core sequences were recovered during the cruise. Two holes, 1179B and 1179C, yielded an upper Miocene to Pleistocene diatom record through an expanded section with excellent recovery.

Because diatom species included in both low-latitude and high-latitude biostratigraphies are present, zonations for the equatorial Pacific and northwest Pacific are applied to the sediments. The oldest zones from each zonation that are represented in the cores are the *Nitzschia miocenica* Zone and the *Rouxia californica* Zone, respectively. Only one zonal boundary is not observed within the diatom assemblage, that being the top of the *Nitzschia jouseae* Zone and base of the *Rhizosolenia praebergonii* Subzone A (equatorial Pacific). Preservation is good overall, and sample abundances vary from rare to abundant. This would be an excellent section for further biostratigraphic, paleoclimatic, and paleoceanographic study.

INTRODUCTION

Site 1179 was drilled in the northwest Pacific during Ocean Drilling Program (ODP) Leg 191 (Fig. **F1**); it is located east of Japan between Japan and Shatsky Rise at 41°04.78′N and 159°57.78′E at a water depth of 5563.9 m (Kanazawa, Sager, Escutia, et al., 2001). The primary scientific

F1. Site 1179 location, p. 13.



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[2] Academy of Natural Sciences, Patrick Center for Environmental Research, Philadelphia PA 19003, USA.
winter@acnatsci.org
[3] Florida State University, Department of Geology, Tallahassee FL 32306-4100, USA.

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objective was to drill into the basaltic ocean crust to emplace a seismometer that would allow subsequent retrieval of data. During this process, advanced piston coring recovered 249.9 m of sediment in Holes 1179B and 1179C with 98.8% recovery.

The sediments consist of clayey siliceous ooze, clay, and chert. The two holes included in this study overlap slightly in depth and were divided aboard ship into four lithostratigraphic units. Samples reported here are from the uppermost unit, lithostratigraphic Unit 1, a 221.5-m-thick clay- and radiolarian-bearing diatom ooze. The sedimentation rate derived for Unit 1 from magnetic stratigraphy and the magnetic polarity reversal timescale is high (29.29 m/m.y.), which has been attributed to high productivity in divergent waters northeast of the western boundary current (Shipboard Scientific Party, 2001; see in particular fig. F37).

The upper Miocene to Pleistocene diatom biostratigraphy of the northwest Pacific Basin has been previously described in the *Initial Reports of the Deep Sea Drilling Project* (DSDP) for Legs 6, 20, 32, 86, and 87 and more recently in the *ODP Scientific Results* for Legs 185 and 186. During DSDP Leg 86, specifically, six holes were drilled in the same geographic area as the sites from Leg 191; Koizumi and Tanimura (1985) report the diatom biostratigraphic record of those holes. Maruyama (2000), Ikeda and Koizumi (2000), and Barron (2000) provide a recent documentation of the diatom record of the northeast Pacific from their work with material from ODP Leg 167. Yanagisawa and Akiba (1998) give an excellent summary of the northwest Pacific Neogene diatom biostratigraphy. Diatoms are present in all cores studied for this report (Cores 191-1179B-1H to 6H and 191-1179C-2H to 19H). Overall, diatom preservation is generally good and abundance is moderate. Silicoflagellates are also often quite abundant in the sediments, although they never dominate the microfossil assemblage.

METHODS

A total of 147 samples from Holes 1179B and 1179C were taken at ~150-cm intervals, one sample per core section (Tables T1, T2); samples were initially collected for both calcareous nannofossil and diatom analysis. The samples were then prepared for examination under the light microscope for diatom content and abundance. Samples were prepared by treating ~2 cm^3 of sediment with 20 mL of 30% H_2O_2 on a hot plate for 60 min to remove organic material. After cooling, 6 mL of 100% HCl was added to the solution and allowed to react until all carbonate dissolved. Samples were washed and centrifuged three times with distilled water to remove chemical residues from the solution. Samples were then centrifuged three times with a weak solution of Calgon (~5%) to suspend the clays. The diatom residue (0.5 mL) was diluted in 14 mL of distilled water, and 2 mL of the diluted solution was dried on a 22-mm × 40-mm coverslip. The diatoms were randomly dispersed over the entire coverslip as the solution dried. The coverslips were mounted onto glass slides using Norland optical adhesive-61 (refractive index = 1.56) mounting medium.

T1. Stratigraphic occurrence of diatoms, Hole 1179B, p. 15.

T2. Stratigraphic occurrence of diatoms, Hole 1179C, p. 18.

An Olympus BH compound microscope was used to examine the strewn slides at 1000×. Qualitative abundances of the present diatom species were estimated from 4 to 10 transects of the coverslip, depending on the abundance of diatoms in the sediment. Digital images were captured using either a Zeiss Axioscop with an Optronics camera or a Zeiss Axioscop II with a SPOT camera.

Relative abundance estimates of diatoms are based on the number of specimens observed per field of view at 1000×. These qualitative values presented in the distribution table are based on the following scale:

A = abundant (≥10 valves per field of view).
C = common (≥1 valve per field of view).
F = few (≥1 valve per 10 fields of view and <1 valve per field of view).
R = rare (≥3 valves per traverse of coverslip and <1 valve per 10 fields of view).
X = present (<3 valves per traverse of coverslip, including fragments).

Preservation of diatoms were determined qualitatively and recorded as follows:

G = good (slight to no fragmentation and dissolution).
M = moderate (moderate fragmentation and dissolution).
P = poor (severe effects of fragmentation and dissolution).

DIATOM BIOSTRATIGRAPHY

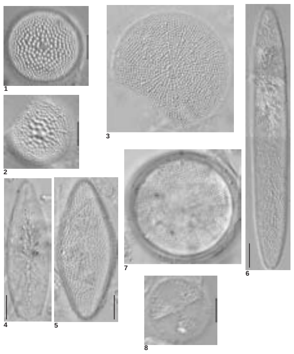
The samples included in this report are a subset of those examined by the second author for the presence of calcareous nannofossils. Diatoms are the main focus of this report, as they are the most abundant fossil group in these samples; the presence of silicoflagellate species is also recorded. Tables T1 and T2 provide abundance or presence/absence data of all species reported in this study, and Plates P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, and P11 illustrate selected diatoms and silicoflagellates.

The two zonations referred to and applied herein are those employed by Barron (1985a) and Yanagisawa and Akiba (1998) for the equatorial Pacific and northwest Pacific, respectively. Table T3 illustrates the zones and species that define the boundaries of each, along with the samples and depths at which these were observed in this study. Figure F2 illustrates the cores of the two holes with their approximate depths, the position of the zonal boundaries for both biostratigraphies, and some species that are present in higher abundances and/or are significant in the two zonations.

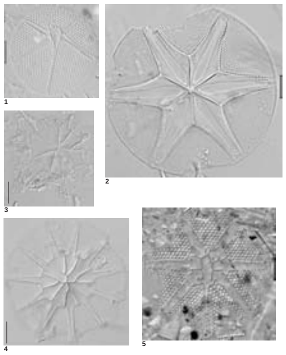
Hole 1179C

Overall, diatom abundance varies throughout the samples from Hole 1179C. In general, the Miocene portion of the section (Cores 191-1179C-19H to 13H) has a lower abundance, with more samples falling into the few and common categories than are observed in the overlying Pliocene and Pleistocene. Even so, there are two intervals of lower abundance in the younger sediments. These are from Sections 191-1179C-7H-7 to 7H-4 (105.83–101.55 meters below seafloor [mbsf]) and 191-1179B-4H-7 to 3H-7 (36.0–26.85 mbsf), from the middle and upper Pliocene, respectively. Samples from the second of these intervals fall into the rare and scarce categories, and the lowest abundances are reported in these two holes. Diatom preservation is most often moderate, with the lower-abundance samples often having poor preservation. Bro-

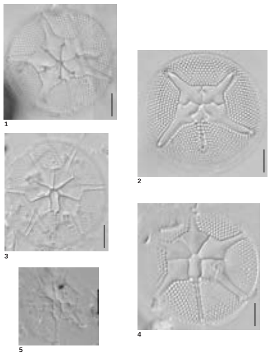
P1. *Actinocyclus* and *Actinoptychus*, p. 21.



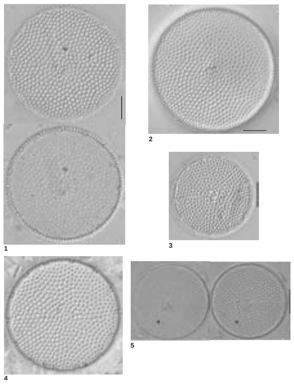
P2. *Asteromphalus* and *Asterolampra*, p. 22.



P3. Selected *Asteromphalus*, p. 23.



P4. Selected *Azpeitia*, p. 24.



ken and fragmented valves rather than dissolution distinguish poor preservation.

The diatom assemblage from the deepest core in this study, 191-1179C-19H, places the core in the *Rouxia californica* (Yanagisawa and Akiba, 1998) and *Nitzschia miocenica* (Barron, 1985a) Zones. This assemblage is characterized by a consistent presence of *Actinocyclus tenellus*, *Actinoptychus* spp., *Azpeitia nodulifer*, *Hemidiscus cuneiformis*, *Nitzschia fossilis*, *Nitzschia reinholdii*, *Nitzschia rolandii*, *Rhizosolenia* spp., *Thalassiosira leptopus*, and *Thalassionema*/*Thalassiothrix* spp. *Azpeitia tabularis* is present in moderate numbers in the middle of Core 191-1179C-19H and then is present only rarely in scarce abundance further uphole.

The transition from the *N. miocenica* Zone to the *Thalassiosira convexa* Zone (Barron, 1985a) is distinguished by the first occurrence (FO) of *T. convexa*, which is present in Sample 191-1179C-18H-2, 75–77 cm (203.05 mbsf). The last occurrence (LO) datum of *R. californica* marks the top of the *R. californica* Zone, between Samples 191-1179C-16H-7, 72–74 cm, and 16H-6, 75–77 cm (191.52–190.05 mbsf). Concurrent with this LO is the FO of *Thalassiosira oestrupii*. *N. miocenica* was observed only within the *R. californica* Zone. The base of the range of this species was not observed, but the LO is between Samples 191-1179C-11H-5, 75–77 cm, and 11H-4, 75–77 cm (141.05–139.55 mbsf). This quite distinctive species establishes a good temporal reference for the lower part of the *R. californica* Zone.

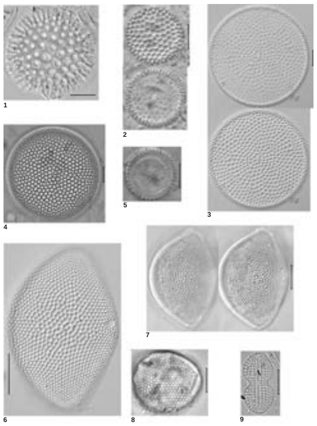
Within the *Neodenticula kamtschatica* (Yanagisawa and Akiba, 1998) and *T. convexa* (Barron, 1985a) Zones there are two LOs of Asteromphalaceae. *Asterolampra acutiloba* is absent from the assemblage after Sample 191-1179C-16H-4, 75–77 cm (187.05 mbsf), and the relatively consistent presence of *Asteromphalus symmetricus* ceases at Sample 14H-4, 73–75 cm (168.03 mbsf). The stratigraphic top of *A. acutiloba* is not well confined, however, as there is a 14.48-m gap between its LO and the next available adjacent sample. The FO of *N. kamtschatica* is present at 153.55 mbsf (Sample 191-1179C-12H-7, 75–77 cm), well within the *N. kamtschatica* Zone and very near the top of the *T. convexa* Zone. This species has a later appearance at this Leg 191 site relative to those from Legs 86 and 87 (Koizumi and Tanimura, 1985; Akiba, 1986). Yanagisawa and Akiba (1998) report observing the FO of this species in the *R. californica* Zone of Holes 438A and 584; they also comment on the difficulties in discerning the differences between *N. rolandii* and *N. kamtschatica* as the first gradually evolves into the second.

The top of the *T. convexa* Zone and bottom of the *Nitzschia jouseae* Zone (Barron, 1985a) are delineated by the FO of *N. jouseae*, which is observed in Sample 191-1179C-12H-5, 75–77 cm (150.55 mbsf). The consistent presence of *N. rolandii* ends upsection within the lower part of the *N. jouseae* Zone. This species is randomly present above Sample 191-1179C-11H-7, 35–37 cm (143.65 mbsf), and is absent above 116.05 mbsf.

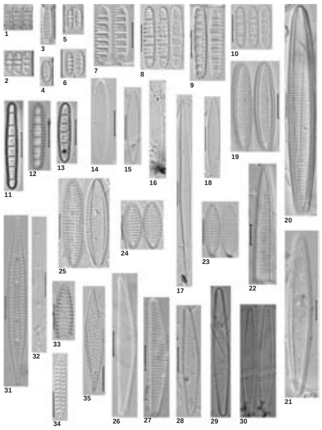
The dominant members of the diatom assemblage in the lower part of the Pliocene in Hole 1179C are *Actinocyclus curvatulus*, *A. nodulifer*, *Coscinodiscus marginatus*, *H. cuneiformis*, *N. kamtschatica*, *N. reinholdii*, *N. fossilis*, *Thalassiosira eccentrica*, *T. oestrupii*, *T. leptopus*, and *Thalassionema*/*Thalassiothrix* spp. *T. leptopus* is only frequent in the lower Pliocene, and *Stephanopyxis* spp. conversely becomes a more frequent member of the assemblage in the middle and upper Pliocene.

The FO of *Rhizosolenia praebergonii* at the top of the *N. jouseae* Zone and base of the *R. praebergonii* Subzone A (Barron, 1985a) is not observed in Hole 1179C. Another datum reported to have a similar age

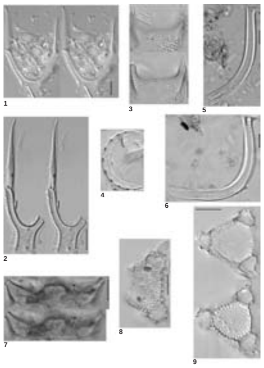
P5. *Coscinodiscus*, *Paralia, Hemidiscus, Roperia,* and *Diploneis*, p. 25.



P6. Selected diatoms, p. 27.



P7. *Hemiaulus, Dactyliosolen, Proboscia, Odontella,* and *Lithodesmium*, p. 29.



(Yanagisawa and Akiba, 1998) is the FO of *Neodenticula koizumii*, which was placed at Sample 191-1179C-8H-3, 75–77 cm (109.55 mbsf). This datum is the lower boundary for the *N. kamtschatica–N. koizumii* Zone (Yanagisawa and Akiba, 1998). This zone is relatively short in Hole 1179C, as the upper boundary was placed 8 m upcore based on the LO of *N. kamtschatica* (Sample 191-1179C-7H-4, 75–77 cm); it is succeeded upsection by the *N. koizumii* Zone (Yanagisawa and Akiba, 1998). Another datum observed within the same part of the hole is the LO of *N. jouseae* at 112.55 mbsf (Sample 191-1179C-8H-5, 75–77 cm). This datum is the boundary for Subzone B of the *R. praebergonii* Zone (Barron, 1985a).

The FO of *Azpeitia neocrenulata* is observed in Sample 191-1179C-6H-7, 60–62 cm (96.4 mbsf). This species became a rare yet consistent part of the assemblage in the upper Pliocene and Pleistocene. The assemblage as a whole is very similar to that of the lower Pliocene with a few exceptions. *N. kamtschatica* is no longer present in the upper Pliocene, with *N. koizumii* and *Neodenticula seminae* replacing it in the assemblage. *Proboscia barboi* and *Stephanopyxis turris* have higher abundances and are more frequently present in the upper Pliocene.

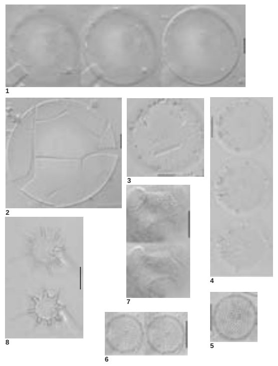
The upper part of Hole 1179C is Pleistocene in age and contains several important datums. The LO of *N. koizumii* in Sample 191-1179C-2H-4, 75–77 cm (54.05 mbsf), marks the top of the *N. koizumii* Zone and the base of the *Actinocyclus oculatus* Zone (Yanagisawa and Akiba, 1998). In Sample 191-1179C-2H-7, 71–73 cm (58.51 mbsf), the FO of *Pseudoeunotia doliolus* denotes the boundary between the *R. praebergonii* Subzone C and the *N. reinholdii* Zone (Barron, 1985a). Slightly upcore from both of these datums, at 52.55 mbsf, is the FO of *Proboscia curvirostris* (Sample 191-1179C-2H-3, 75–77 cm).

Hole 1179B

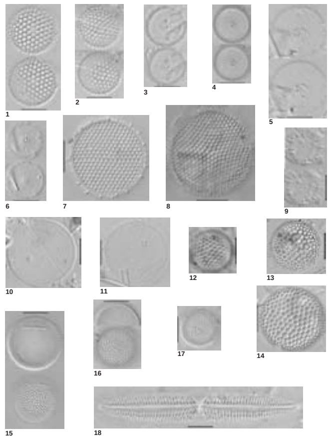
Hole 1179B is latest Pliocene and Pleistocene in age. Diatom abundance and preservation are good, with the exception of the previously mentioned interval from 36.0 to 26.85 mbsf that has low abundance. Four northwest Pacific and two equatorial zones are represented in sediments from Hole 1179B. There is a 5.61-m overlap between the two holes, which reveals no noticeable change in the diatom assemblage. In fact, the top of the *N. koizumii* Zone (Yanagisawa and Akiba, 1998) is present within this overlap, occurring between 52.35 and 49.35 mbsf (Samples 191-1179B-6H-5, 75–77 cm, and 6H-3, 75–77 cm) in Hole 1179B and 54.05 and 52.55 mbsf (Samples 191-1179C-2H-4, 75–77 cm, and 2H-3, 75–77 cm) in Hole 1179C. The upper boundary for this zone is based on the LO datum of *N. koizumii*. This datum point is defined in Leg 191 sediments as the consistent decrease in abundance (from few to rare) of *N. koizumii*, as it does not disappear entirely from the assemblage. Several authors have noted the difficulties in separating *N. koizumii* and *N. seminae* (Maruyama, 2000; Yanagisawa and Akiba, 1998), so this change in abundance was chosen as the best basis for this datum.

The top of the *A. oculatus* Zone and base of the *P. curvirostris* Zone (Yanagisawa and Akiba, 1998) is defined by the LO of *A. oculatus*, which is present in Sample 191-1179B-5H-7, 70–72 cm (45.8 mbsf). Curiously, the age at which this datum occurs in these sediments (1.21 Ma) is closer to the age presented by Maruyama (2000) from the northeastern Pacific (1.01–1.46 Ma) than the 1 Ma age for this datum presented by Yanagisawa and Akiba (1988). The upper boundary of the *N. reinholdii*

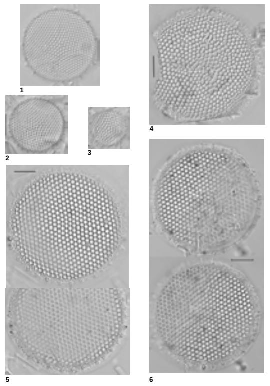
P8. *Thalassiosira, Triceratium,* and *Bacteriastrum*, p. 30.



P9. *Thalassiosira* and *Trachyneis*, p. 31.



P10. Selected *Thalassiosira*, p. 33.



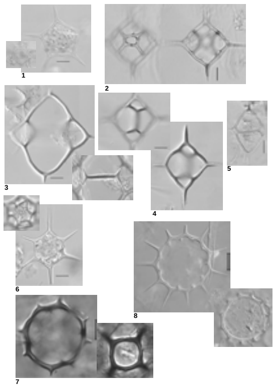
Zone (Barron, 1985a) is defined by the LO of *N. reinholdii* (Sample 191-1179B-3H-6, 75–77 cm). The diatom assemblage from this depth upward in Hole 1179B belongs to the youngest equatorial Pacific zone, *P. doliolus* (Barron, 1985a).

The last and highest significant datum in this hole is the LO of *P. curvirostris*, which is present in Sample 191-1179B-2H-5, 75–77 cm (14.35 mbsf). This marks the change from the *P. curvirostris* Zone to the *N. seminae* Zone of the northwest Pacific biostratigraphy (Yanagisawa and Akiba, 1998). Throughout the Pleistocene, the diatom assemblage experiences little change; the most marked distinction is the loss of *N. koizumii*, *N. fossilis*, and *N. reinholdii* as constant members of the assemblage. Dominant taxa are *A. curvatulus*, *Alveus marina*, *Coccolithus radiatus*, *N. seminae*, *T. eccentrica*, *T. oestrupii*, and *Thalassionema*/*Thalassiothrix* spp. Several species have periods of higher abundance (*A. neocrenulata*, *C. marginatus*, *Fragilariopsis doliolus*, and *S. turris*) but are not present continuously throughout the interval.

Because the diatom biostratigraphic record documented by Koizumi and Tanimura (1985) from DSDP Leg 86 was compiled from cores collected in a geographic area slightly southeast of the Leg 191 drill sites, it is of interest for comparison to this study. As would be expected, there are many datums in common between the two studies, some ages are comparable and some are not. Table T4 lists these datums. The ages for the Leg 191 diatom datums are estimated by the depths at which they occur in the cores and the ages assigned to these depths by the magnetostratigraphic sedimentation rate curve (Shipboard Scientific Party, 2001); the ages given for the Leg 86 datums are age ranges assigned to each datum from the four holes of this leg (Koizumi and Tanimura, 1985). Most datums are present in sediments of similar ages from the cores of the two cruises; they tend to be older in the Leg 191 cores with a few exceptions. The youngest datum listed is the LO of *P. curvirostris*, which is very close in age in both data sets. The LO of *N. reinholdii* is older than that observed in Leg 86, as is the following LO of *N. fossilis*. The second of these is downhole from an interval with low abundances of diatoms, making this LO datum rather tenuous. The next three datums (LO of *A. oculatus*, FO of *P. doliolus*, and LO of *Thalassiosira antiqua*) occur within the range of ages presented for them from Leg 86 sediments. From this point downhole, only the FO of *N. jouseae* and the FO of *T. convexa* are present in sediments younger than their equivalent observances in Leg 86. The rest of the Pliocene/Miocene datums in the table have ages older than those in Leg 86.

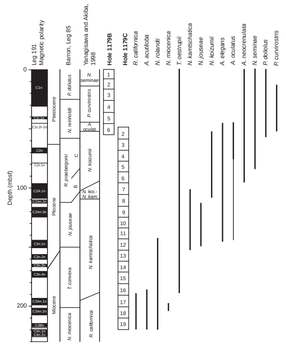
The silicoflagellate data presented in this report are meant only to record the taxa observed, without creating an accompanying zonation based on this fossil group. Tables T1 and T2 present the distribution of silicoflagellate species observed in each sample. A plus sign indicates the presence of a particular species in that sample. Age constraints provided by these taxa agree with those of the diatoms, but there is also obvious reworking of older species. One example is *Distephanus crux* ssp. *loeblichii* in Sample 191-1179B-2H-4, 74–77 cm (12.85 mbsf), to which Perch-Nielson (1985) assigned a confined age of upper Oligocene. The overall abundance of silicoflagellates in the samples was generally rare, with some reaching the few category of abundance. Preservation in general is moderate, as it also is for the diatoms, although some breakage did inevitably occur. Time constraints prevented a more detailed identification of species in the middle Pliocene, which are mostly grouped by genus in the upper part of the time column. It is hoped that

P11. Selected silicoflagellates, p. 34.



T3. Neogene diatom zonations, p. 19.

F2. Stratigraphic ranges of select diatom species, Holes 1179B and 1179C, p. 14.



T4. Ages of selected diatom datums, Legs 191 and 86, p. 20.

the inclusion of these data will provide some assistance to others who work with this group.

SUMMARY AND CONCLUSIONS

Overlapping ODP Holes 1179B and 1179C in the northwest Pacific Ocean between Japan and Shatsky Rise yielded a near-continuous, 221.5-m-thick upper Miocene to Pleistocene diatom record in an expanded section (sedimentation rate = 29.29 m/m.y.) with 98.8% recovery. Due to the presence of diatom species included in both low-latitude and high-latitude biostratigraphies, zonations for the equatorial Pacific and northwest Pacific were applied to these sediments. The oldest zones from each zonation are the *N. miocenica* Zone and the *R. californica* Zone, respectively. Only one zonal boundary is not present, that being the top of the *N. jouseae* Zone and base of the *R. praebergonii* Subzone A (equatorial Pacific). Overall preservation is good, and sample abundances vary from rare to abundant. No samples were barren of diatoms.

The entire section was apparently deposited below the calcite compensation depth; thus, little useful planktonic calcareous biostratigraphic information was obtained. However, the combined section did yield an excellent paleomagnetic record along with palynomorph, agglutinated foraminiferal, and radiolarian biostratigraphies. The palynomorph record extends down to Sample 191-1179C-11H-CC (143.84 mbsf), which is of late early Pliocene age, whereas the radiolarian record parallels the diatom record (Shipboard Scientific Party, 2001).

Therefore, when the diatom data presented here are combined with the other microfossil and paleomagnetic records, this section at Site 1179 should be a valuable addition to the drill core archives used to study the late Neogene paleoclimatic and paleoceanographic history of the northwest Pacific Ocean.

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REFERENCES

Akiba, F., 1986. Middle Miocene to Quaternary diatom biostratigraphy in the Nankai Trough and Japan Trench, and modified lower Miocene through Quaternary diatom zones for middle-to-high latitudes of the North Pacific. *In* Kagami, H., Karig, D.E., Coulbourn, W.T., et al., *Init. Repts. DSDP,* 87: Washington (U.S. Govt. Printing Office), 393–481.

Barron, J.A., 1985a. Late Eocene to Holocene diatom biostratigraphy of the equatorial Pacific Ocean, Deep Sea Drilling Project Leg 85. *In* Mayer, L, Theyer, F., Thomas, E., et al., *Init. Repts. DSDP,* 85: Washington (U.S. Govt. Printing Office), 413–456.

Barron, J.A., 1985b. Miocene to Holocene planktic diatoms. *In* Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy:* Cambridge (Cambridge Univ. Press), 763–809.

Barron, J.A., 2000. *Data report:* Mid-Pliocene diatom assemblages at sites 1016, 1021, and 1022. *In* Lyle, M., Koizumi, I., Richter, C., and Moore, T.C., Jr. (Eds.). *Proc. ODP, Sci. Results,* 167: College Station, TX (Ocean Drilling Program), 111–113.

Burckle, L.H., 1972. Late Cenozoic planktonic diatom zones from the eastern equatorial Pacific. *In* Simonsen, R. (Ed.), *First Symposium on Recent and Fossil Marine Diatoms*. Nova Hedwigia Beih., 39:217–246.

Burkle, L. H., 1977. Pliocene and Pleistocene diatom datum levels from the equatorial Pacific. *Quat. Res.*, 7:330–340.

Donahue, J.G., 1970. Pleistocene diatoms as climatic indicators in North Pacific sediments. *In* Hays, J.D. (Ed.), *Geological Investigations of the North Pacific.* Mem.— Geol. Soc. Am., 126:121–138.

Gladenkov, A.Y., and Barron, J.A., 1995. Early Miocene to Pleistocene diatom stratigraphy of Leg 145. *In* Rea, D.K., Basov, I.A., Scholl, D.W., and Allan, J.F. (Eds.), *Proc. ODP, Sci. Results,* 145: College Station, TX (Ocean Drilling Program), 3–19.

Harwood, D.M., and Maruyama, T., 1992. Middle Eocene to Pleistocene diatom biostratigraphy of Southern Ocean sediments from the Kerguelen Plateau, Leg 120. *In* Wise, S.W., Jr., Schlich, R., et al., *Proc. ODP, Sci. Results,* 120: College Station, TX (Ocean Drilling Program), 683–733.

Ikeda, A. and Koizumi, I., 2000. *Data report:* Diatom Flora of the Northern California margin since 3MA. *In* Lyle, M., Koizumi, I., Richter, C., and Moore, T.C., Jr. (Eds.), *Proc. ODP, Sci. Results,* 167: College Station, TX (Ocean Drilling Program), 119–125.

Kanazawa, T., Sager, W.W., Escutia, C., et al., 2001. *Proc. ODP, Init. Repts.,* 191 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station TX 77845-9547, USA.

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

Koizumi, I., and Tanimura, Y., 1985. Neogene diatom biostratigraphy of the middle latitude western North Pacific, Deep Sea Drilling Project Leg 86. *In* Heath, G.R., Burckle, L.H., et al., *Init. Repts. DSDP,* 86: Washington (U.S. Govt. Printing Office), 269–300.

Maruyama, T., 2000. Middle Miocene to Pleistocene diatom stratigraphy of Leg 167. *In* Lyle, M., Koizumi, I., Richter, C., and Moore, T.C., Jr. (Eds.), *Proc. ODP, Sci. Results,* 167: College Station, TX (Ocean Drilling Program), 63–110.

Olschesky, K.S., and Laws, R.A., 2002. Data report: Pliocene–late Pleistocene diatom biostratigraphic data from ODP Leg 185, Hole 1149A. *In* Ludden, J.N., Plank, T., and Escutia, C. (Eds.), *Proc. ODP, Sci. Results,* 185, 1–31 [Online]. Available from World Wide Web: <http://www-odp.tamu.edu/publications/185_SR/VOLUME/CHAPTERS/007.PDF>. [Cited 2003-11-25]

Perch-Nielsen, K., 1985. Silicoflagellates. *In* Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy:* Cambridge (Cambridge Univ. Press), 811–846.

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

Shipboard Scientific Party, 2001. Site 1179. *In* Kanazawa, T., Sager, W.W., Escutia, C., et al., *Proc. ODP, Init. Repts.,* 191, 1–159 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station TX 77845-9547, USA.

Yanagisawa, Y., and Akiba, F., 1990. Taxonomy and phylogeny of the three marine diatom genera, *Crucidenticula, Denticulopsis* and *Neodenticula. Bull. Geol. Surv. Jpn.,* 41:197–301.

Yanagisawa, Y., and Akiba, F., 1998. Refined Neogene diatom biostratigraphy for the northwest Pacific around Japan, with an introduction of code numbers for selected diatom biohorizons. *J. Geol. Soc. Jpn.,* 104:395–414.

APPENDIX

Floral references utilized for diatoms in this study are Akiba (1986), Barron (1985a, 1985b), Gladenkov and Barron (1995), Harwood and Maruyama (1992), Koizumi and Tanimura (1985), Olschesky and Laws (2002), Schrader (1973), Yanagisawa and Akiba (1990); silicoflagellate reference is Perch-Nielsen (1985).

Diatom Taxa Observed

Achnanthes spp.
Actinocyclus curvatulus Janisch in A. Schmidt
Actinocyclus ehrenbergii Ralfs in Pritchard (Pl. **P1,** fig. 3)
Actinocyclus ellipticus Grunow in Van Heurck (Pl. **P1,** figs. 4, 5)
Actinocyclus ellipticus var. *elongatus* (Grunow) Kolbe (Pl. **P1,** fig. 6)
Actinocyclus octonarius Ehrenberg
Actinocyclus oculatus Jousé (Pl. **P1,** figs. 1, 2)
Actinocyclus tenellus (Brébisson) Andrews (Pl. **P1,** fig. 7)
Actinoptychus spp. (Pl. **P1,** fig. 8)
Alveus marina (Grunow) Kaczmarska and Fryxell (Pl. **P6,** fig. 22)
Asterolampra acutiloba Forti in Tempère and Peragallo (Pl. **P2,** fig. 2)
Asterolampra grevillei (Wallich) Greville (Pl. **P2,** fig. 1)
Asteromphalus arachne (Brébisson) Ralfs (Pl. **P2,** fig. 3)
Asteromphalus elegans Greville
Asteromphalus heptactis (Brébisson) Ralfs (Pl. **P2,** fig. 5)
Asteromphalus hookeri Ehrenberg (Pl. **P3,** fig. 3)
Asteromphalus oligocenicus Schrader and Fenner (Pl. **P2,** fig. 4)
Asteromphalus parvulus Karsten (Pl. **P3,** fig. 4)
Asteromphalus symmetricus Schrader and Fenner (Pl. **P3,** figs. 1, 2)
Aulacoseira granulata (Ehrenberg) Simonsen
Azpeitia neocrenulata (Van Landingham) Fryxell and Watkins (Pl. **P4,** figs. 4, 5)
Azpeitia nodulifer (Schmidt) Fryxell and Sims (Pl. **P4,** figs. 1, 2)
Azpeitia tabularis (Grunow) Fryxell and Sims in Fryxell et al. (Pl. **P4,** fig. 3)
Bacteriastrum hyalinum Lauder (Pl. **P8,** fig. 8)
Bogorovia lancettula (Schrader) Yanagisawa (Pl. **P6,** fig. 33)
Cocconeis pinnata Gregory ex Greville
Coscinodiscus asteromphalus Ehrenberg
Coscinodiscus lewisianus Greville
Coscinodiscus marginatus Ehrenberg (Pl. **P5,** figs. 1, 2)
Coscinodiscus oculus-iridus Ehrenberg
Coscinodiscus radiatus Ehrenberg (Pl. **P5,** figs. 4, 5)
Cyclostephanos spp.
Dactyliosolen spp. (Pl. **P7,** fig. 4)
Delphineis surirella (Ehrenberg) Andrews
Denticulopsis lauta (Bailey) Simonsen (Pl. **P6,** figs. 1, 2)
Diploneis cf. *bombus* (Ehrenberg) Cleve (Pl. **P5,** fig. 9)
Eunotia spp.
Pseudoeunotia doliolus (Wallich) Medlin and Sims (Pl. **P6,** figs. 26–28)
Hemiaulus sp. 1 (Pl. **P7,** figs. 1, 2)
Hemiaulus sp. 2 (Pl. **P7,** fig. 3)
Hemidiscus cuneiformis Wallich (Pl. **P5,** figs. 6, 7)
Koizumia tatsunokuchiensis (Koizumi) Yanagisawa (Pl. **P6,** fig. 34)
Lithodesmium reynoldsii Barron (Pl. **P7,** figs. 8, 9?)
Neodenticula kamtschatica (Zabelina) Akiba and Yanigasawa (Pl. **P6,** figs. 5, 6)
Neodenticula koizumii Akiba and Yanagisawa (Pl. **P6,** figs. 7–10)
Neodenticula seminae (Simonsen and Kanaya) Akiba and Yanagisawa (Pl. **P6,** figs. 11–13)
Nitzschia cf. *cylindrica* Burckle

Nitzschia cf. *extincta* Kozurenko and Sheshukova-Poretzkaya sensu Kozumi (Pl. **P6,** figs. 14, 15)
Nitzschia cf. *grunowii* Hasle
Nitzschia cf. *interruptestriata* Simonsen (Pl. **P6,** figs. 16, 17)
Nitzschia fossilis (Frenguelli) Kanaya (Pl. **P6,** figs. 29, 30)
Nitzschia jouseae Burckle (Pl. **P6,** figs. 24, 25)
Nitzschia miocenica Burckle (Pl. **P6,** fig. 23)
Nitzschia praereinholdii Schrader
Nitzschia reinholdii Kanaya and Koizumi (Pl. **P6,** figs. 19–21)
Nitzschia rolandii Schrader emend. Koizumi (Pl. **P6,** figs. 3, 4)
Nitzschia sicula var. (Castracane) Hustedt (Pl. **P6,** fig. 18)
Odontella aurita (Lyngbye) C.A. Agardh (Pl. **P7,** fig. 7)
Paralia sulcata (Ehrenberg) Cleve (Pl. **P5,** fig. 5)
Planktoniella sol (Wallich) Schutt
Pleurosigma spp.
Proboscia barboi (Brun) Jorden and Priddle
Proboscia curvirostris (Jousé) Jorden and Priddle (Pl. **P7,** figs. 5, 6)
Rhizosolenia spp.
Roperia tesselata (Roper) Grunow
Rossiella elongata (Barron) Desikachary in Desikachary et al. (Pl. **P6,** fig. 35)
Rouxia californica Peragallo in Tempère and Peragallo (Pl. **P6,** fig. 32)
Rouxia spp. (Pl. **P6,** fig. 31)
Stellarima spp.
Stephanopyxis turris (Arnott in Greville) Ralfs in Pritchard
Thalassiosira antiqua (Grunow) Cleve-Euler (Pl. **P9,** figs. 1, 2)
Thalassiosira cf. *complicata* Gersonde (Pl. **P9,** fig. 6)
Thalassiosira cf. *T. decipiens* (Grunow) Jorgensen
Thalassiosira cf. *inura* Gersonde (Pl. **P9**, figs. 3–5)
Thalassiosira cf. *kolbei* (Jousé) Gersonde (Pl. **P10,** figs. 1–3)
Thalassiosira convexa Muchina
Thalassiosira eccentrica (Ehrenberg) Cleve (Pl. **P9,** figs. 7, 8)
Thalassiosira leptopus (Grunow) Hasle and Fryxell (Pl. **P10,** figs. 4–6)
Thalassiosira lineata Jousé (Pl. **P9,** figs. 10, 11)
Thalassiosira miocenica Schrader (Pl. **P9,** figs. 15–17)
Thalassiosira nativa Sheshukova-Poretzkaya sensu Schrader
Thalassiosira nordenskioeldii Cleve (Pl. **P9,** fig. 9)
Thalassiosira oestrupii (Ostenfeld) Proshkina-Lavrenko (Pl. **P9,** figs. 12–14)
Thalassiosira plicata Schrader
Thalassiosira poroseriata (Ramsfjell) Hasle ex Hasle and Heimdal
Thalassiosira sp. 10 (Pl. **P8,** figs. 5, 6)
Thalassiosira sp. C Akiba, 1986 (Pl. **P8,** figs. 3, 4)
Thalassiosira sp. D Akiba, 1986 (Pl. **P8,** figs. 1, 2)
Thalassiosira symmetrica Fryxell and Hasle
Thalassiothrix/*Thalassionema* spp.
Trachyneis aspera (Ehrenberg) Cleve (Pl. **P9,** fig. 18)
Triceratium sp. 1 (Pl. **P8,** fig. 7)

Silicoflagellate Taxa Observed

Corbisema spp. Hanna
Dictyocha cf. *aspera* (Lemmermann) Bukry and Foster (Pl. **P11,** fig. 3)
Dictyocha brevispina var.
Dictyocha brevispina brevispina (Lemmermann) Bukry
Dictyocha spp. Ehrenberg
Dictyocha fibula Ehrenberg (Pl. **P11,** fig. 4)
Dictyocha cf. *neonautica* Bukry
Dictyocha ornata (Bukry) Bukry
Dictyocha pulchella Bukry
Dictyocha rhombica (Schultz) Deflandre (Pl. **P11,** fig. 5)
Distephanus boliviensis binoculus Ciesielski (Pl. **P11,** fig. 6)
Distephanus crux crux (Ehrenberg) Haeckel (Pl. **P11,** fig. 2)

Distephanus crux ssp. *loeblichii* Bukry (Pl. **P11,** fig. 7)
Distephanus polyactis (Ehrenberg) Deflandre (Pl. **P11,** fig. 8)
Distephanus pseudofibula (Schulz) Bukry
Distephanus speculum pentagonus Lemmermann (Pl. **P11,** fig. 1)
Distephanus speculum f. *pentagonus geminum* Ciesielski
Distephanus speculum spp.
Mesocena circulus (Ehrenberg) Bukry
Mesocena diodon ssp. *nodosa* Bukry
Mesocena sp. 1

Figure F1. Location of Site 1179.

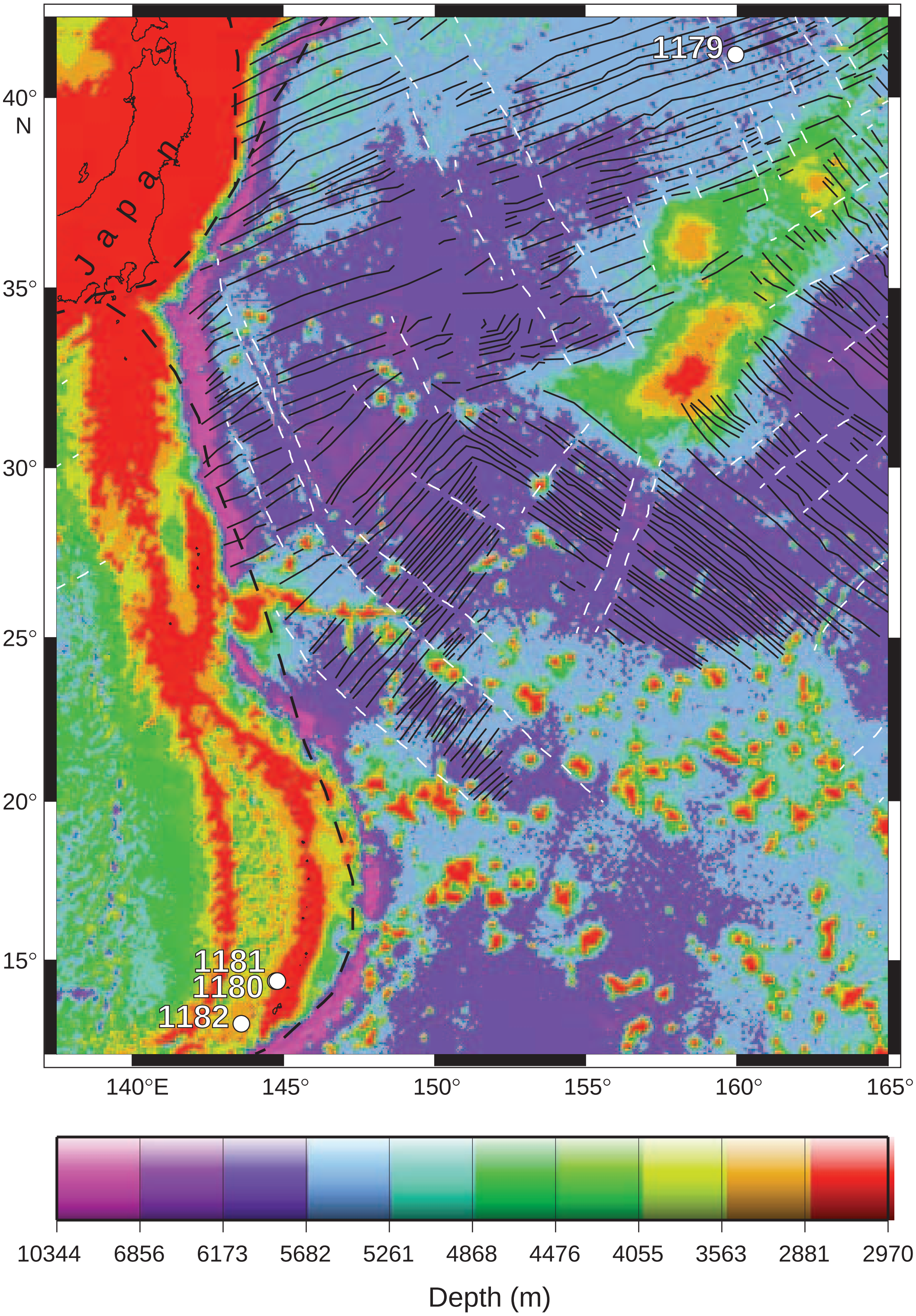


Figure F2. Stratigraphic ranges of select diatom species in Holes 1179B and 1179C. Position of zones in both zonal schemes illustrated along with depths of cores for each hole.

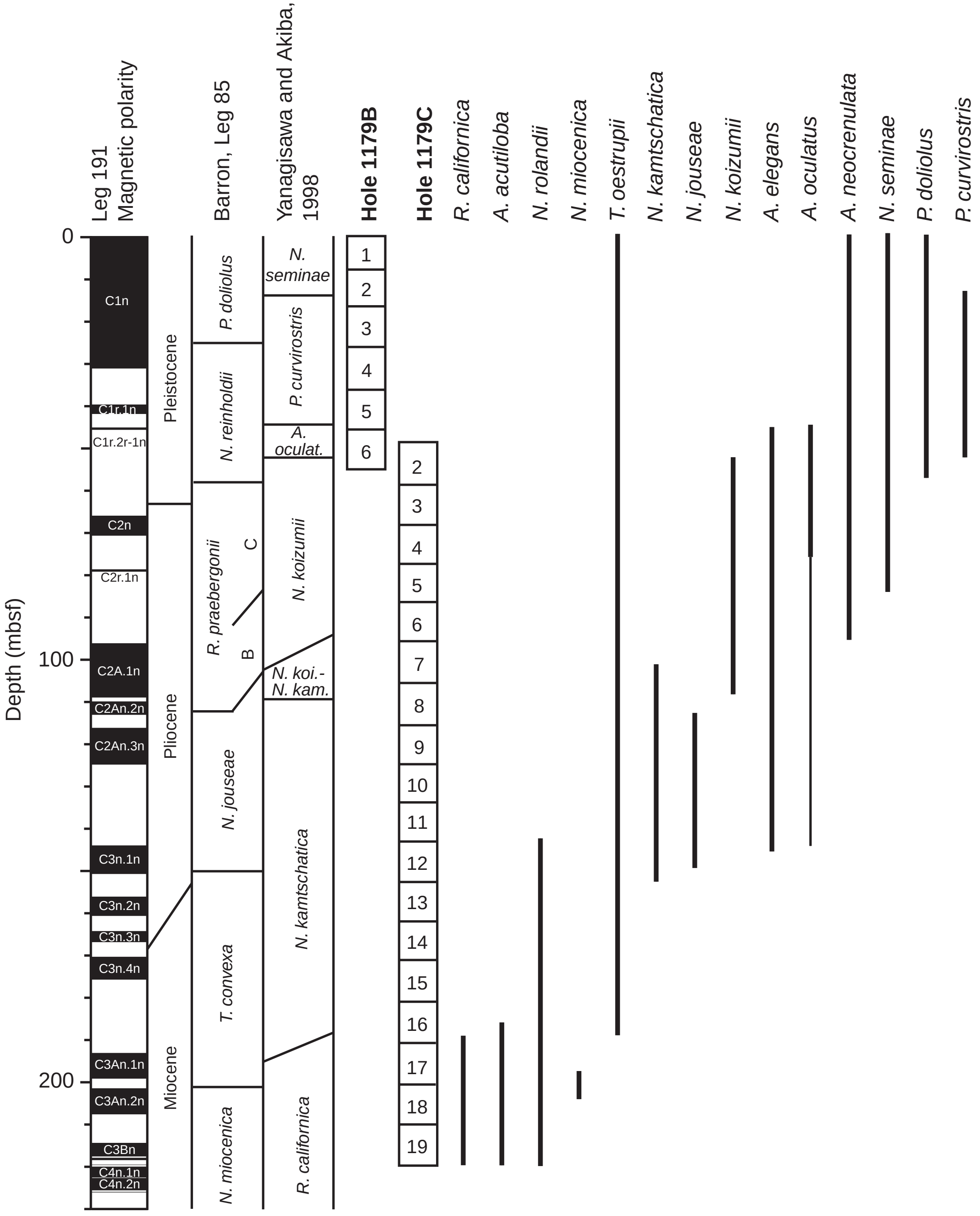


Table T1. Stratigraphic occurrence of diatoms, Hole 1179B. (Continued on next two pages.)

	Yanagisawa and Akiba, 1998	Barron, 1985a	Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Actinocyclus curvatulus*	*Actinocyclus ehrenbergii*	*Actinocyclus octonarius*	*Actinocyclus oculatus* Jousé	*Actinocyclus tenellus* ?(Akiba 1985)	*Actinoptychus* spp.	*Alveus marina*	*Asterolampra acutiloba*	*Asteromphalus arachne* (Brébisson) Ralfs	*Asteromphalus elegans*	*Asteromphalus parvulus*	*Aulacoseira granulata*	*Azpeitia neocrenulata*	*Azpeitia nodulifer*	*Bacteriastrum hyalinum* Lander	*Cocconeis pinnata*	*Coscinodiscus asteromphalus*	*Coscinodiscus marginatus*	*Coscinodiscus oculus-iridus*	*Coscinodiscus radiatus*	*Cyclostephanos* spp.	*Delphineis surella* (Akiba 1985)	*Diploneis* cf. *bombus*	*Eunotia* spp.	*Hemidiscus cuneiformis*
Pleistocene	*Neodenticula seminae* Zone	*Pseudoeunotia doliolus* Zone	191-1179B-																												
			1H-1, 66–68	0.66	A	M	F	X				X	R						R					R	R	R					
			1H-2, 75–77	2.25	C	P	R												R					R		R					
			1H-3, 75–77	3.75	A	M	F					X	R						F						X	R					
			1H-4, 75–77	5.25	A	M	R	X				X	R						F	X					R	R					
			1H-5, 75–77	6.75	C	P	R						R											R	R	R					
			2H-1, 75–77	8.35	A	P	F	R				X							X					X		R					
			2H-2, 75–77	9.85	A	P	R					R	R						R	X				R	X	F					X
			2H-3, 75–77	11.35	C	P	R	X				X	X						X	X					X	X				X	
			2H-4, 75–77	12.85	A	M	F	R			X		R		X								X	R	R	F	X				X
	Proboscia curvirostris Zone		2H-5, 75–77	14.35	A	M	F	R					R						X			X		R	R	R	X	X			
			2H-6, 75–77	15.85	C	M	F						R						X					X	R	R					
			3H-1, 75–77	17.85	C	M	F					X	R						R					R							
			3H-2, 75–77	19.35	A	M				X			R						R		X			R	X	F					
			3H-3, 75–77	20.85	A	M	F	X		X	R	R	R				X				X				R	R			X		
			3H-4, 75–77	22.35	A	M	X			X										X				R	R	R					X
			3H-5, 75–77	23.85	A	M	F	X		R	X		R						X	X	X			R	X	R					R
		Nitzschia reinholdii Zone	3H-6, 75–77	25.35	A	M	R	X		X		R	R				X		X	R	X				R	F			X		R
			3H-7, 75–77	26.85	R	P	R	X				X																			
			4H-1, 75–77	27.35	F	P	X													X					X						
			4H-2, 75–77	28.85	X	P																									
			4H-3, 75–77	30.35	F	P				X																					
			4H-4, 75–77	31.85	F	P	R			X		X														X					
			4H-5, 75–77	33.35	F	P	X					R	X	X											X						
			4H-6, 75–77	34.85	F	P	R					R	R					X								R			X		
			4H-7, 40–42	36	R	P	X					X													X						
			5H-1, 75–77	36.85	A	M	R					R	R				X		X	X				R		R					X
			5H-2, 75–77	38.35	F	P	R						R				X				X				R	X					
			5H-3, 75–77	39.85	A	M	R	X	X			X	R						X		X			R	X	X					X
			5H-4, 75–77	41.35	F	P	X				X	X	R						X		X			X							
			5H-5, 75–77	42.85	C	P	R				X	X	R					X	X	X					X	R					
			5H-6, 75–77	44.35	A	M	R			X		X					X					X		R	R						
	A. oculatus Zone		5H-7, 70–72	45.8	F	P	R			R		R	R			X	R			X			X		X						
			6H-1, 75–77	46.35	A	P	F			R		X	X				X		X		X			R	X	R					
			6H-3, 75–77	49.35	C	P	F					X	X											R	X	X					
	N. koizumii Zone		6H-5, 75–77	52.35	C	P	R			X			X						R				X								
			6H-7, 56–58	55.16	A	M	F			R			R				R								X	R					X

Notes: Abundance: A = abundant, C = common, F = few, R = rare, X = present. Preservation: M = moderate, P = poor. + = presence of silicoflagellate species.

Table T1 (continued).

	Yanagisawa and Akiba, 1998	Barron, 1985a	Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Neodenticula koizumii* Akiba and Yanagisawa	*Neodenticula seminae* (Simonsen and Kanaya) Akiba and Yanagisawa	*Nitzschia* cf. *grunowii*	*Nitzschia* cf. *interruptestriata* Simonsen	*Nitzschia fossilis*	*Nitzschia reinholdii*	*Nitzschia sicula* var.	*Odontella aurita*	*Paralia sulcata*	*Planktoniella sol*	*Proboscia barboi*	*Proboscia curvirostris*	*Pseudoeunotia doliolus*	*Rhizosolenia* spp.	*Roperia tesselata*	*Stellarima* spp.	*Stephanopyxis turris*	*Thalassiosira* cf. *T. decipiens*	*Thalassiosira convexa*	*Thalassiosira eccentrica*	*Thalassiosira lineata*	*Thalassiosira nordenskioeldii*	*Thalassiosira oestrupii*	*Thalassiosira plicata*	*Thalassiosira* sp. C Akiba 1985
Pleistocene	*Neodenticula seminae* Zone	*Pseudoeunotia doliolus* Zone	191-1179B-																												
			1H-1, 66–68	0.66	A	M		R		X									R	X		X				R			R		
			1H-2, 75–77	2.25	C	P		R		X			X						X	X		X	X			R			R		
			1H-3, 75–77	3.75	A	M		F									X		X	R	X	R				F			R		
			1H-4, 75–77	5.25	A	M		F		X			R	X						R		X	R			R	X		F		
			1H-5, 75–77	6.75	C	P		R							X					X		X	R		X	R			R		
			2H-1, 75–77	8.35	A	P		R											X	R			R			R	X		R		
			2H-2, 75–77	9.85	A	P	X	F					X						X	X	X	X	X			R	R		R		
			2H-3, 75–77	11.35	C	P		R											X	R		X	X			R			R		
			2H-4, 75–77	12.85	A	M	X	F		X			R		R					R		X	X	R		F			F		
	Proboscia curvirostris Zone		2H-5, 75–77	14.35	A	M	X	F		R			X					R	R	R			R			F			R		
			2H-6, 75–77	15.85	C	M	X	F		X			R		X			R		R						R	X		R		
			3H-1, 75–77	17.85	C	M				X	X								F	X						R	X		R		
			3H-2, 75–77	19.35	A	M		F		X								R	R		X		R			R			R		
			3H-3, 75–77	20.85	A	M		F		X			R	X	R			R	R	X			F			R		X	R		
			3H-4, 75–77	22.35	A	M	X	R		X								R	F	R			R			F	R		C	X	
			3H-5, 75–77	23.85	A	M	X	F		R				X				R	F	R			R	X	X	R	R		F		
		Nitzschia reinholdii Zone	3H-6, 75–77	25.35	A	M	X	F		X		R				R	X	R	F	X			R	R		F	R		F		
			3H-7, 75–77	26.85	R	P	X	R									X					X	X			X			X		
			4H-1, 75–77	27.35	F	P	R	R				R	X				X									X	X		R		
			4H-2, 75–77	28.85	X	P						X														X					
			4H-3, 75–77	30.35	F	P	R	R											R	X		X	R			R			X		
			4H-4, 75–77	31.85	F	P	X	X		X		X	X										X			X			R	X	
			4H-5, 75–77	33.35	F	P	R	R				R						X	X	X			X			R			R	R	
			4H-6, 75–77	34.85	F	P	R	R			R	R	R		X	X	X	X	R	R		X	X			R	R		R	X	
			4H-7, 40–42	36	R	P	X			X																X					
			5H-1, 75–77	36.85	A	M	R	R			R	R	X					R	R			X	R			F			R		
			5H-2, 75–77	38.35	F	P	X	R			X	R	X										R			R	X		X		
			5H-3, 75–77	39.85	A	M	R	R		X	R	R	X		R		X		X	X			R			R			R		
			5H-4, 75–77	41.35	F	P		R			R	X			X		X	X		R		X	R			R	X		R		
			5H-5, 75–77	42.85	C	P	R	R	X		X	R	X					X		R		R	R			F	X	X	R		
			5H-6, 75–77	44.35	A	M	R	F			R	R	X		X	X		R								R			F		
	A. oculatus Zone		5H-7, 70–72	45.8	F	P	R	R			X	R								R						R	X		X		
			6H-1, 75–77	46.35	A	P	R	R		X		R	X				X			R			R			F	X		F		
			6H-3, 75–77	49.35	C	P	R	R		X	X	R	X			X		R		X		X				F			F		
	N. koizumii Zone		6H-5, 75–77	52.35	C	P	F	R			R	R					X					X	R			R	X		F		X
			6H-7, 56–58	55.16	A	M	F	F			X	R					R			R						R			F		

Table T1 (continued).

	Yanagisawa and Akiba, 1998	Barron, 1985a	Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Thalassiosira* sp. D Akiba 1985	*Thalassiosira symmetrica*	*Thalassiothrix*/*Thalassionema* fragments		*Dictyocha* spp.	*Distephanus crux crux*	*Distephanus crux* ssp. *loeblichii*	*Distephanus speculum pentagonus*	*Distephanus pseudofibula*	*Distephanus speculum* spp.	*Mesocena* sp. 1
Pleistocene	*Neodenticula seminae* Zone	*Pseudoeunotia doliolus* Zone	191-1179B-														
			1H-1, 66–68	0.66	A	M			C		+						
			1H-2, 75–77	2.25	C	P			C								
			1H-3, 75–77	3.75	A	M			A		+					+	
			1H-4, 75–77	5.25	A	M			A		+					+	
			1H-5, 75–77	6.75	C	P			F								
			2H-1, 75–77	8.35	A	P		X	A								
			2H-2, 75–77	9.85	A	P			A								
			2H-3, 75–77	11.35	C	P		X	C								
			2H-4, 75–77	12.85	A	M	X	R	A		+		+	+		+	
	Proboscia curvirostris Zone		2H-5, 75–77	14.35	A	M		X	A		+					+	
			2H-6, 75–77	15.85	C	M		X	C		+						
			3H-1, 75–77	17.85	C	M			F		+						
			3H-2, 75–77	19.35	A	M			C		+						
			3H-3, 75–77	20.85	A	M		X	A							+	
			3H-4, 75–77	22.35	A	M			A								
			3H-5, 75–77	23.85	A	M		X	A		+					+	
		Nitzschia reinholdii Zone	3H-6, 75–77	25.35	A	M			A		+						
			3H-7, 75–77	26.85	R	P			R								
			4H-1, 75–77	27.35	F	P	X		F								
			4H-2, 75–77	28.85	X	P											
			4H-3, 75–77	30.35	F	P			F								
			4H-4, 75–77	31.85	F	P			R		+					+	
			4H-5, 75–77	33.35	F	P		X	F		+				+		
			4H-6, 75–77	34.85	F	P		X	F		+						
			4H-7, 40–42	36	R	P			R								
			5H-1, 75–77	36.85	A	M			A		+					+	+
			5H-2, 75–77	38.35	F	P			F		+						
			5H-3, 75–77	39.85	A	M	R		A		+					+	
			5H-4, 75–77	41.35	F	P			F			+		+			+
			5H-5, 75–77	42.85	C	P			F		+					+	
			5H-6, 75–77	44.35	A	M			A		+					+	
	A. oculatus Zone		5H-7, 70–72	45.8	F	P			F		+						
			6H-1, 75–77	46.35	A	P			A		+					+	
			6H-3, 75–77	49.35	C	P			C		+						
	N. koizumii Zone		6H-5, 75–77	52.35	C	P			C		+					+	
			6H-7, 56–58	55.16	A	M			A		+					+	

Table T2. Stratigraphic occurrence of diatoms, Hole 1179C. (This table is available in an **oversized format.**)

Table T3. Applied Neogene diatom zonations.

Yanagisawa and Akiba, 1998 (Northwest Pacific)								
Diatom zone	Author	Subzone	Leg 191 boundary age (Ma)	Yanagisawa and Akiba (1998) boundary age (Ma)*	Datum boundary	Depth (mbsf)	Core, section, interval (cm)	
							191-1179B-	191-1179C-
Neodenticula seminae	Donahue (1970)		0.32	0.3	LO *Proboscia curvirostris*[†]	14.35	2H-4, 75–77; 2H-5, 75–77	
Proboscia curvirostris	Donahue (1970)		1.21	1	LO *Actinocyclus oculatus*	45.8	5H-6, 75–77; 5H-7, 70–72	
Actinocyclus oculatus	Donahue (1970)		1.45	2.0	LO *Neodenticula koizumii*	52.35 (1179B); 54.05 (1179C)	6H-3, 75–77; 6H-5, 75–77	2H-3, 75–77; 2H-4, 75–77
Neodenticula koizumii	Koizumi (1973)		2.8	2.6–2.7	LO *Neodenticula kamtschatica*	101.55		6H-7, 60–62; 7H-4, 75–77
N. koizumii–N. kamtschatica	Koizumi (1973)		3.1	3.5–3.9	FO *Neodenticula koizumii*	109.55		8H-3, 75–77; 8H-4, 75–77
Neodenticula kamtschatica	Koizumi (1973)		6.1	6.4	LCO *Rouxia californica*	195.05		16H-6, 75–77; 17H-3, 75–77
Rouxia californica	Akiba (1986)							

Barron, Leg 85 (Equatorial Pacific)								
Diatom zone	Author	Subzone	Leg 191 boundary age (Ma)	Barron (1985a) boundary age (Ma)*	Datum boundary	Depth (mbsf)	Core, section, interval (cm)	
							191-1179B-	191-1179C-
Pseudoeunotia doliolus	Burckle (1972, 1977)		0.63	0.65	LO *Nitzschia reinholdii*	25.35	3H-5, 75–77; 3H-6, 75–77	
Nitzschia reinholdii	Burckle (1977)		1.59	1.8	FO *Pseudoeunotia doliolus*	58.51		2H-7, 71–73; 3H-1, 75–77
Rhizosolenia praebergonii	Burckle (1972)	C	2.5	2.1	LO *Thalassiosira convexa*	92.05		5H-6, 75–77; 6H-4, 75–77
		B	3.21	2.6	LO *Nitzschia jouseae*	112.55		7H-4, 75–77; 8H-5, 75–77
		A		3	FO *Rhizosolenia praebergonii*[‡]	150.55		
Nitzschia jouseae	Burckle (1972)		4.3	4.5	FO *Nitzschia jouseae*			12H-5, 75–77; 12H-6, 75–77
Thalassiosira convexa	Burckle (1972)	C		5.1	LO *Thalassiosira miocenica*	203.05		
		B		5.8	LO *Thalassiosira praeconvexa*[‡]			
		A	6.4	6.1	FO *Thalassiosira convexa*[‡]			18H-2, 75–77; 18H-3, 75–77
Nitzschia miocenica	Burckle (1972)							

Notes: LO = last occurrence, FO = first occurrence. LCO = last common occurrence. * = as reported in reference cited. † = the Neodenticula seminae Zone is defined as the interval in which *N. seminae* is present above the LO of *R. curvirostris*. ‡ = marker species were not observed.

Table T4. Selected diatom datum ages, Legs 191 and 86.

Diatom datum	Age (Ma)	
	Leg 191	Leg 86*
LO *Proboscia curvirostris*	0.32	0.3–0.35
LO *Nitzschia reinholdii*	0.63	0.47–0.52
LO *Nitzschia fossilis*	0.89	0.55–0.57
LO *Actinocyclus oculatus*	1.21	0.93–1.33
FO *Pseudoeunotia doliolus*	1.59	1.89–2.0
LO *Thalassiosira antiqua*	1.7	1.43–3.14
LO *Thalassiosira convexa*	2.5	2.29–2.3
LO *Neodenticula kamtschatica*	2.8	2.5–2.58
LO *Nitzschia jouseae*	3.21	2.48–2.58
FO *Nitzschia jouseae*	4.3	4.45–4.5
LO *Thalassiosira miocenica*	5.94	5.1–5.35
LCO *Rouxia californica*	6.1	4.4–5.1
FO *Thalassiosira convexa*	6.4	6.6
FO *Thalassiosira oestrupii*	7.75	5.0–5.35

Notes: * = Holes 578–581. LO = last occurrence, FO = first occurrence. LCO = last common occurrence.

Plate P1. **1**, **2.** *Actinocyclus oculatus* Jousé (Samples 191-1179B-3H-6, 75–77 cm [1], and 191-1179C-2H-2, 75–77 cm [2]). **3.** *Actinocyclus ehrenbergii* Ralfs in Pritchard (Sample 191-1179-18H-4, 75–77 cm). **4, 5.** *Actinocyclus ellipticus* Grunow in Van Heurck (Sample 191-1179C-19H-1, 72–74 cm). **6.** *Actinocyclus ellipticus* var. *elongatus* (Grunow) Kolbe (Sample 191-1179C-17H-6, 75–77 cm). **7.** *Actinocyclus tenellus* (Brébisson) Andrews (Sample 191-1179C-19H-1, 72–74 cm). **8.** *Actinoptychus* spp. (Sample 191-1179B-3H-6, 75–77 cm). Scale bars = 10 µm.

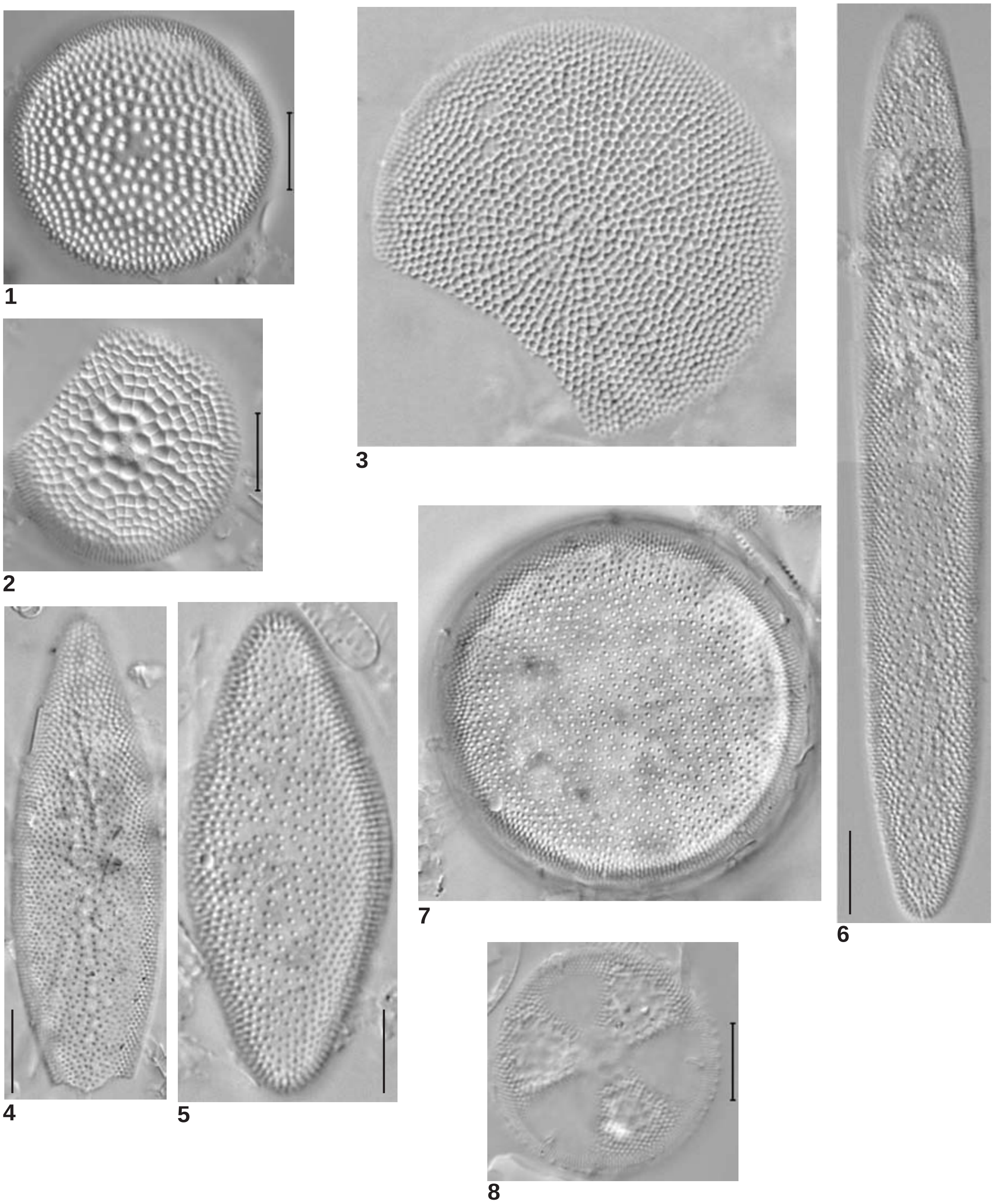
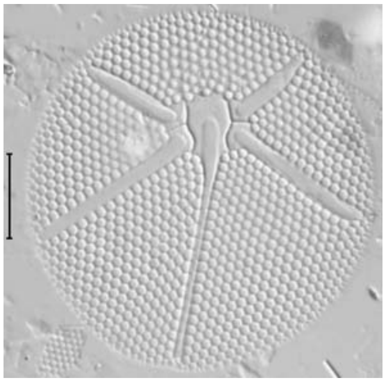


Plate P2. **1.** *Asteromphalus arachne* (Brébisson) Ralfs (Sample 191-1179C-2H-2, 75–77 cm). **2.** *Asterolampra acutiloba* Forti in Tempère and Peragallo (Sample 191-1179C-19H-3, 75–77 cm). **3.** *Asteromphalus oligocenicus* Schrader and Fenner (Sample 191-1179C-19H-5, 75–77 cm). **4.** *Asterolampra grevillei* (Wallich) Greville (Sample 191-1179C-16H-6, 75–77 cm). **5.** *Asteromphalus heptactis* (Brébisson) Ralfs (Sample 191-1179B-2H-4, 75–77 cm). Scale bars = 10 µm.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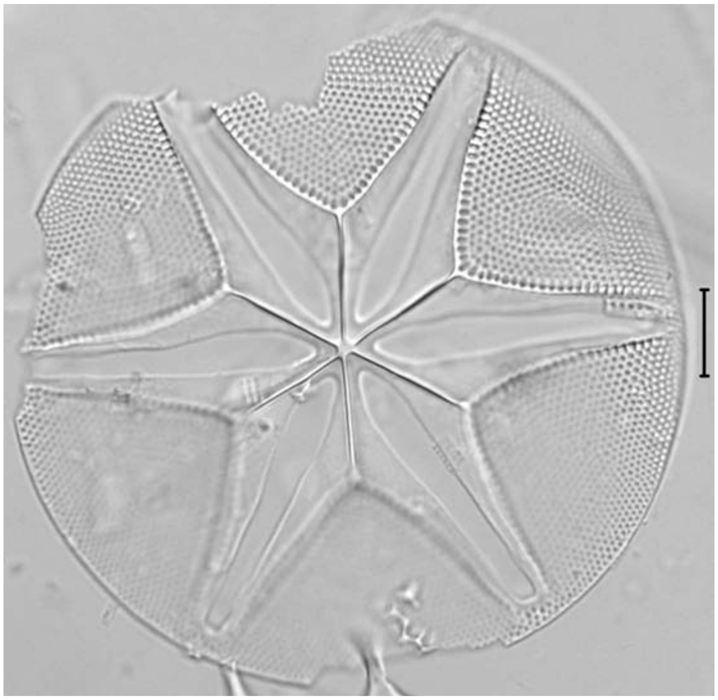
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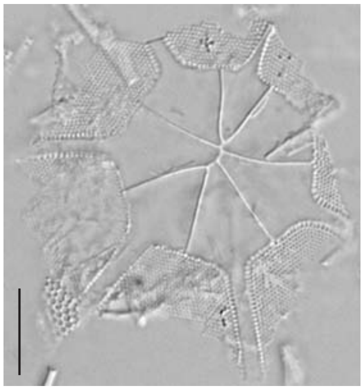
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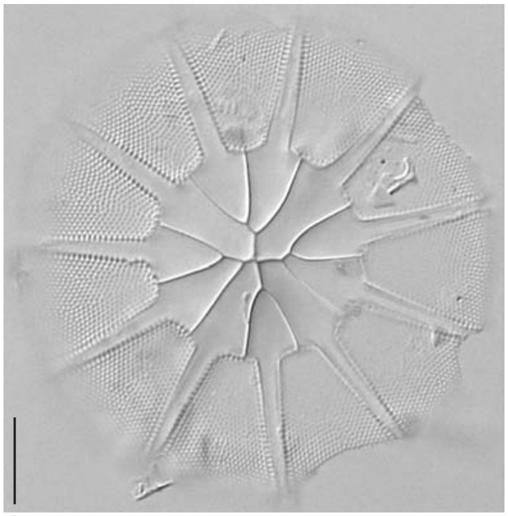
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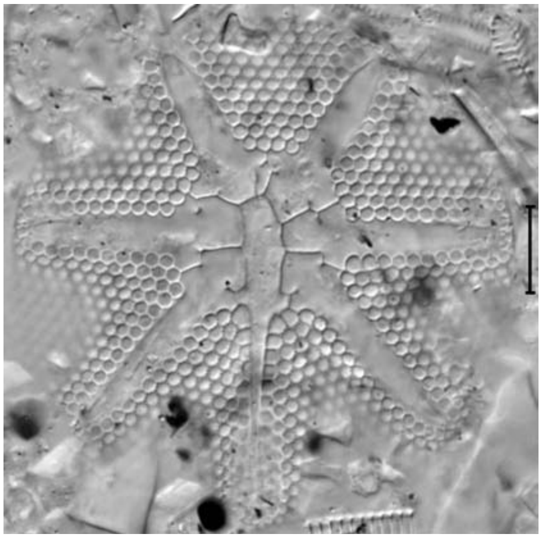
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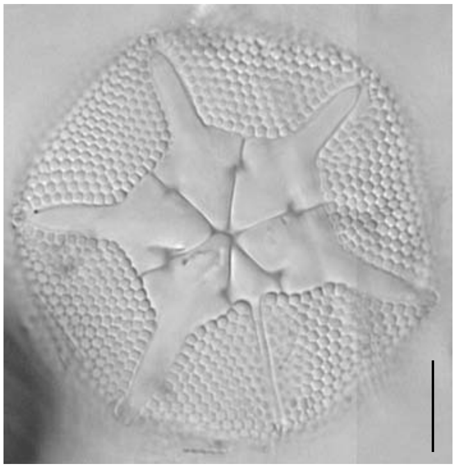
Plate P3. **1, 2.** *Asteromphalus symmetricus* Schrader and Fenner (Samples 191-1179C-18H-3, 75–77 cm [1], and 191-1179C-9H-5, 75–77 cm [2]). **3.** *Asteromphalus hookeri* Ehrenberg (Sample 191-1179C-12H-4, 75–77 cm). **4, 5.** *Asteromphalus parvulus* Karsten (Samples 191-1179C-12H-5, 75–77 cm [4], and 191-1179B-3H-6, 75–77 cm [5]). Scale bars = 10 µm.



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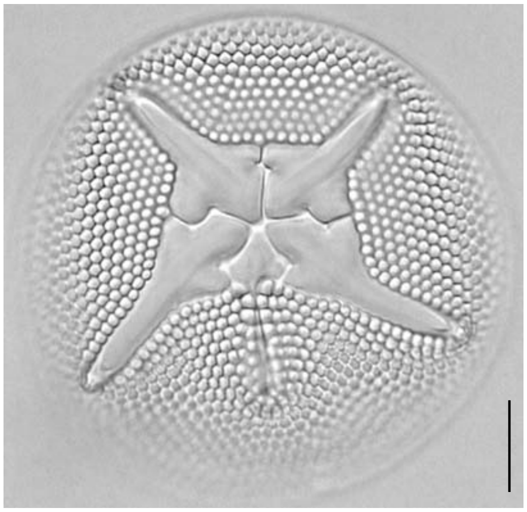

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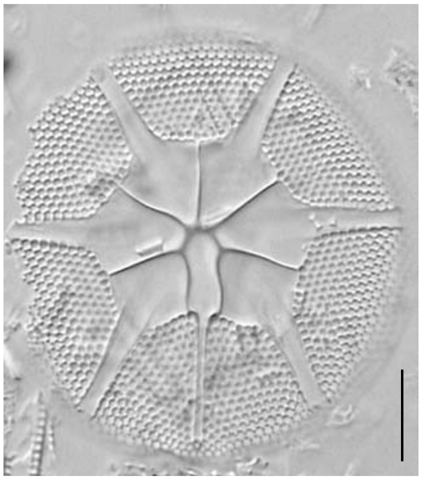

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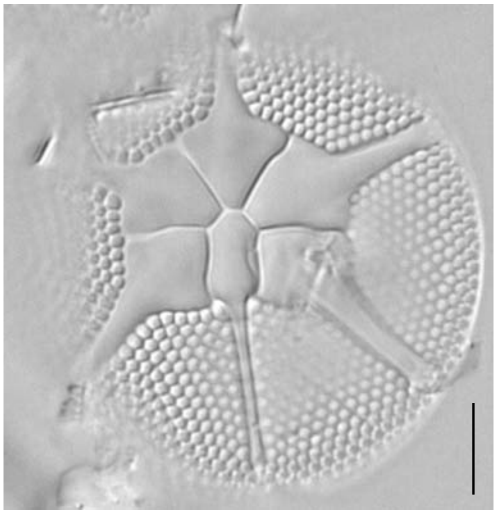

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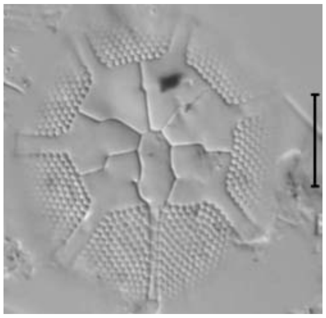

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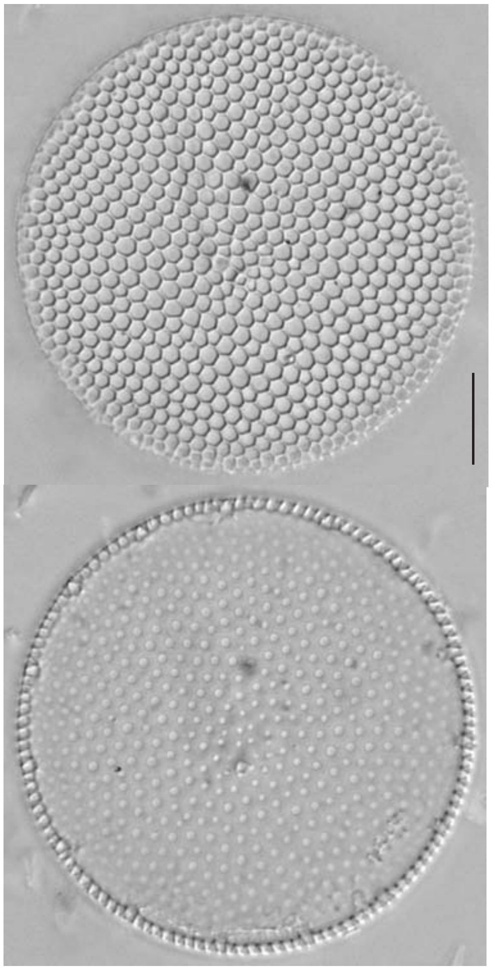
Plate P4. 1, 2. *Azpeitia nodulifer* (Schmidt) Fryxell and Sims (Samples 191-1179C-19H-4, 75–77 cm [1], and 191-1179C-18H-1, 75–77 cm [2]). **3.** *Azpeitia tabularis* (Grunow) Fryxell and Sims in Fryxell et al. (Sample 191-1179C-19H-3, 75–77 cm). **4, 5.** *Azpeitia neocrenulata* (Van Landingham) Fryxell and Watkins (Samples 191-1179C-2H-6, 75–77 cm [4], and 191-1179B-3H-5, 75–77 cm [5]). Scale bars = 10 µm.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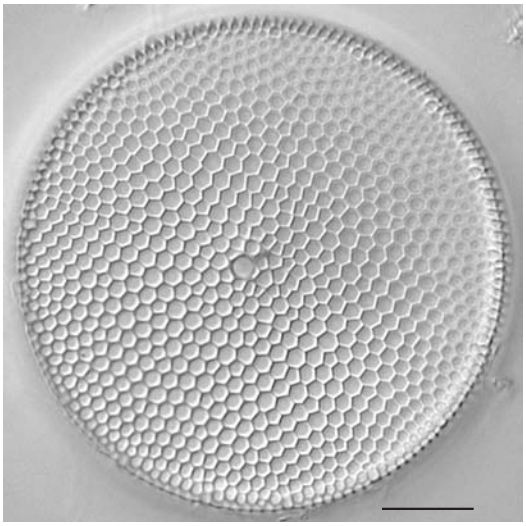
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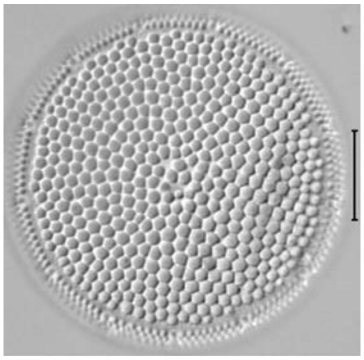
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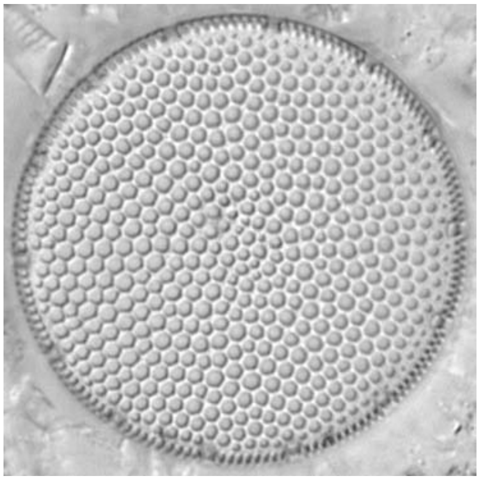
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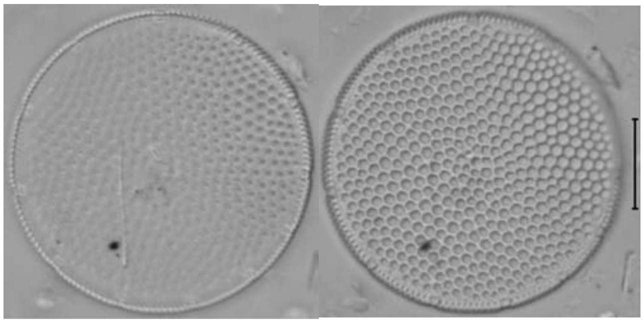
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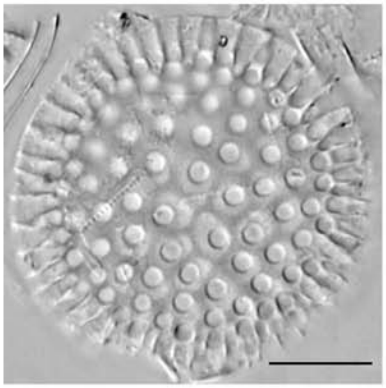
Plate P5. **1, 2.** *Coscinodiscus marginatus* Ehrenberg (Samples 191-1179C-19H-5, 75–77 cm [1], and 191-1179C-2H-4, 75–77 cm [2]). **3, 4.** *Coscinodiscus radiatus* Ehrenberg (Samples 191-1179B-4H-3, 75–77 cm [3], and 191-1179B-3H-5, 75–77 cm [4]). **5.** *Paralia sulcata* (Ehrenberg) Cleve (Sample 191-1179B-2H-4, 75–77 cm). **6, 7.** *Hemidiscus cuneiformis* Wallich (Samples 191-1179C-16H-5, 75–77 cm [6], and 191-1179C-19H-3, 75–77 cm [7]). **8.** *Roperia tesselata* (Roper) Grunow (Sample 191-1179B-3H-5, 75–77 cm). **9.** *Diploneis* cf. *bombus* (Ehrenberg) Cleve (Sample 191-1179B-3H-5, 75–77 cm). Scale bars = 10 µm. (**Plate shown on next page.**)

Plate P5 (continued). (Caption shown on previous page.)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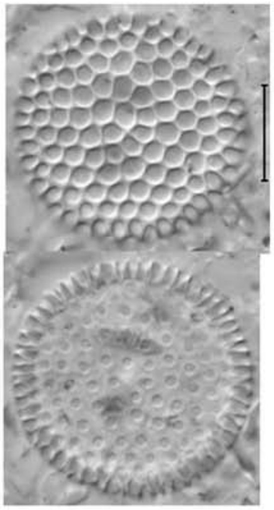
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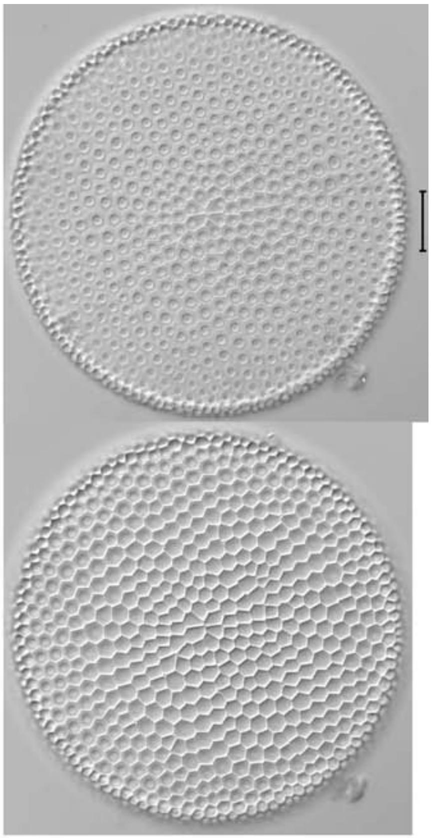
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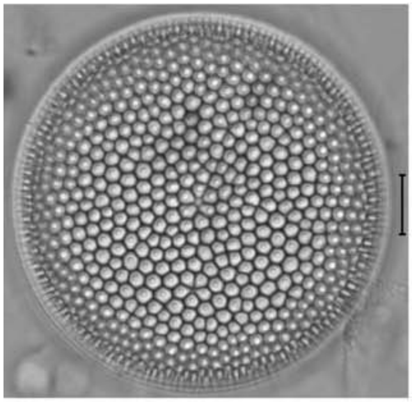
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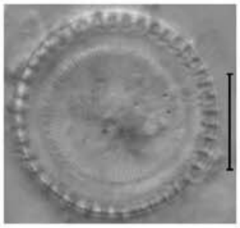
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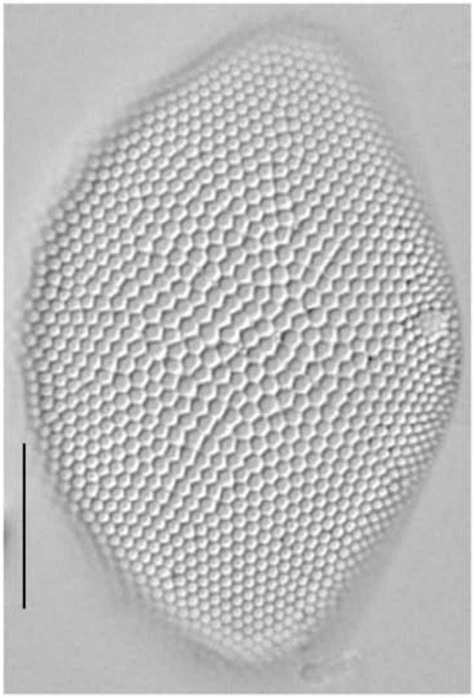
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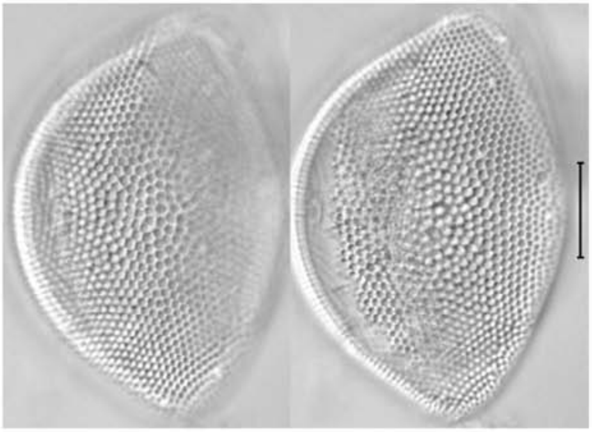
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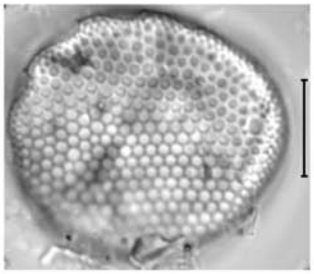
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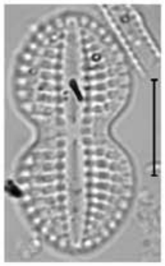
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Plate P6. **1, 2.** *Denticulopsis lauta* (Bailey) Simonsen (Sample 191-1179C-19H-6, 75–77 cm). **3, 4.** *Nitzschia rolandii* Schrader emend. Koizumi (Sample 191-1179C-19H-1, 72–74 cm). **5, 6.** *Neodenticula kamtschatica* (Zabelina) Akiba and Yanigasawa (Sample 191-1179C-12H-6, 75–77 cm). **7–10.** *Neodenticula koizumii* Akiba and Yanagisawa (Samples 191-1179C-2H-2, 75–77 cm [7], 191-1179C-7H-5, 75–77 cm [8], 191-1179C-6H-4, 75–77 cm [9], and 191-1179C-7H-6, 75–77 cm [10]). **11–13.** *Neodenticula seminae* (Simonsen and Kanaya) Akiba and Yanagisawa (Sample 191-1179B-3H-5, 75–77 cm). **14, 15.** *Nitzschia* cf. *extincta* Kozurenko and Sheshukova-Poretzkaya sensu Kozumi (Samples 191-1179C-2H-2, 75–77 cm [14], and 191-1179C-6H-7, 60–62 cm [15]). **16, 17.** *Nitzschia* cf. *interruptestriata* Simonsen (Samples 191-1179B-3H-5, 75–77 cm [16], and 191-1179C-5H-5, 75–77 cm [17]). **18.** *Nitzschia sicula* var. (Castracane) Hustedt (Sample 191-1179C-12H-6, 75–77 cm). **19–21.** *Nitzschia reinholdii* Kanaya and Koizumi (Samples 191-1179C-19H-3, 75–77 cm [19], 191-1179C-19H-1, 72–74 cm [20], and 191-1179B-5H-5, 75–77 cm [21]). **22.** *Nitzschia marina* Grunow in Cleve and Grunow (Sample 191-1179B-3H-6, 75–77 cm). **23.** *Nitzschia miocenica* Burckle (Sample 191-1179C-18H-3, 75–77 cm). **24, 25.** *Nitzschia jouseae* Burckle (Sample 191-1179C-12H-4, 75–77 cm). **26–28.** *Fragilariopsis doliolus* (Wallich) Medlin and Sims (Samples 191-1179B-5H-6, 75–77 cm [26], 191-1179B-3H-6, 75–77 cm [27], and 191-1179B-3H-5, 75–77 cm [28]). **29, 30.** *Nitzschia fossilis* (Frenguelli) Kanaya (Sample 191-1179C-7H-3, 75–77 cm). **31.** *Rouxia* spp. (Sample 191-1179C-17H-4, 75–77 cm). **32.** *Rouxia californica* Peragallo in Tempère and Peragallo (Sample 191-1179C-18H-1, 75–77 cm). **33.** *Bogorovia lancettula* (Schrader) Yanagisawa (Sample 191-1179C-18H-5, 75–77 cm). **34.** *Koizumia tatsunokuchiensis* (Koizumi) Yanagisawa (Sample 191-1179C-14H-4, 73–75 cm). **35.** *Rossiella elongata* (Barron) Desikachary in Desikachary et al. (Sample 191-1179C-18H-5, 75–77 cm). Scale bars = 10 µm. (**Plate shown on next page.**)

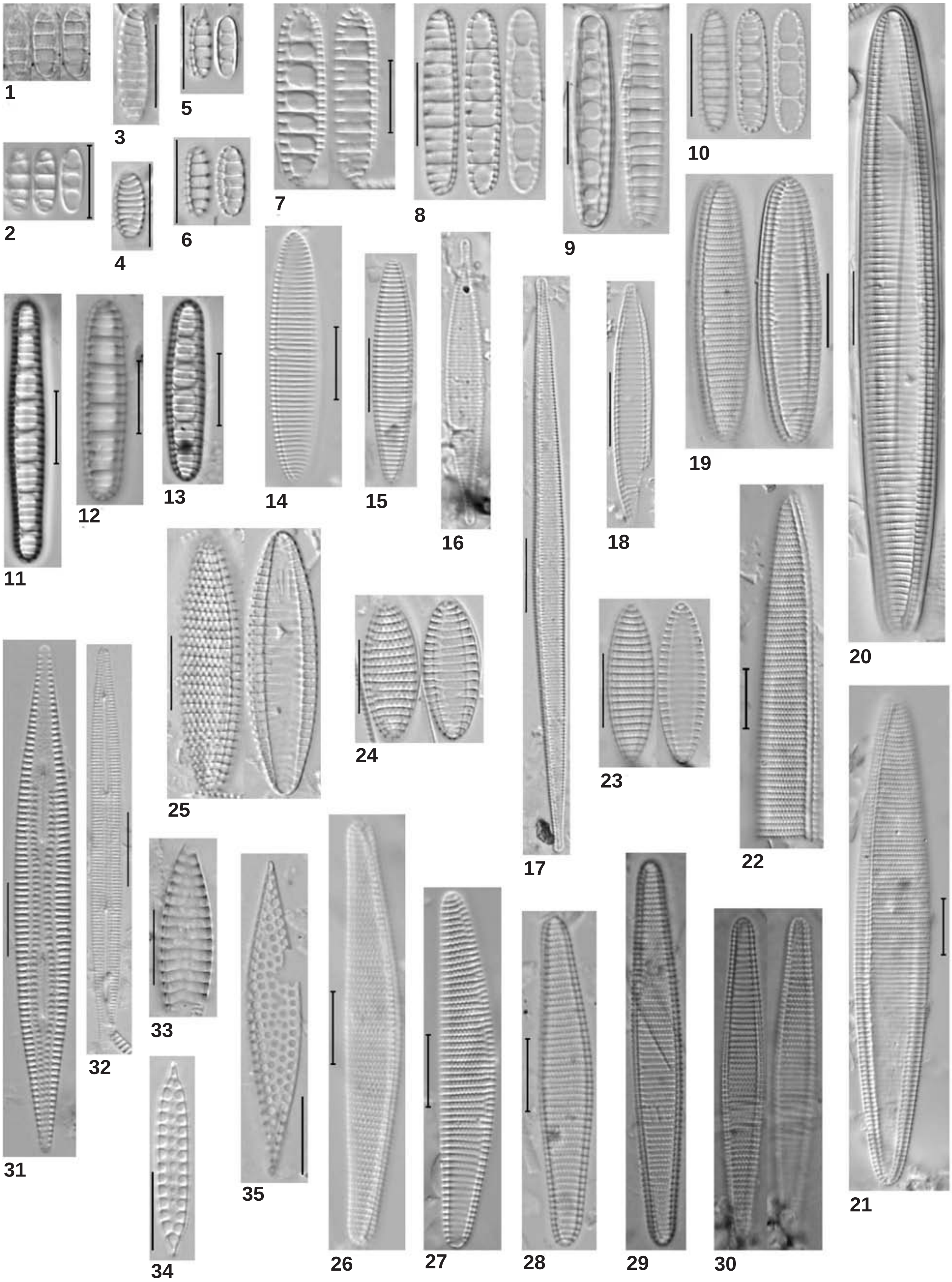
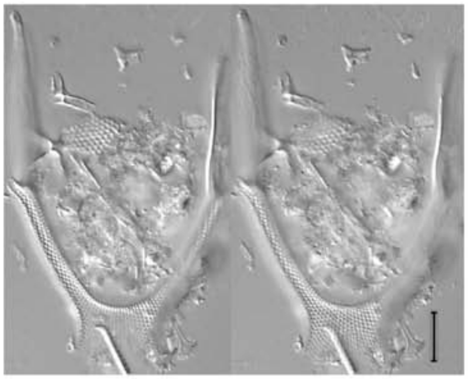


Plate P6 (continued). (Caption shown on previous page.)

Plate P7. **1, 2.** *Hemiaulus* sp. 1 (Samples 191-1179C-19H-6, 75–77 cm [1], and 191-1179C-19H-3, 75–77 cm [2]). **3.** *Hemiaulus* sp. 2 (Sample 191-1179C-2H-7, 71–73 cm). **4.** *Dactyliosolen* spp. (Sample 191-1179C-19H-1, 72–74 cm). **5, 6.** *Proboscia curvirostris* (Jousé) Jorden and Priddle (Sample 191-1179B-3H-5, 75–77 cm). **7.** *Odontella aurita* (Lyngbye) C.A. Agardh (Sample 191-1179B-3H-5, 75–77 cm). **8.** *Lithodesmium reynoldsii* Barron (Sample 191-1179C-19H-6, 75–77 cm). **9.** *Lithodesmium reynoldsii* Barron? (Sample 191-1179C-17H-3, 75–77 cm). Scale bars = 10 µm.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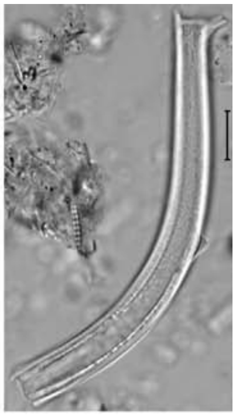
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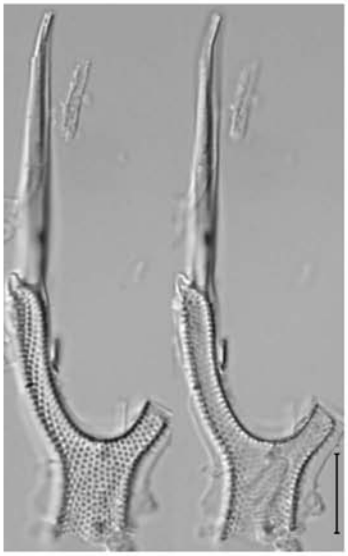
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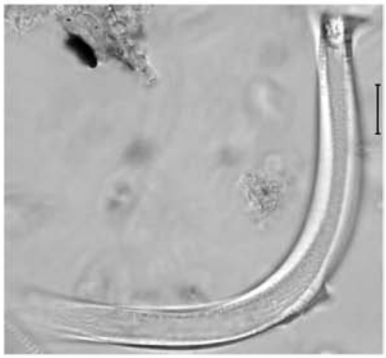
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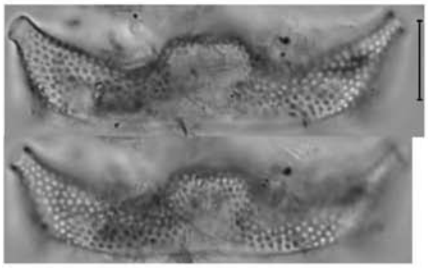
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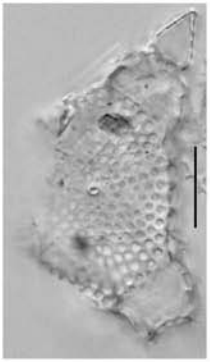
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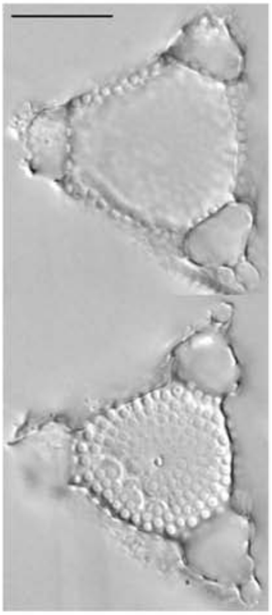
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Plate P8. **1, 2.** *Thalassiosira* sp. D Akiba, 1985 (Sample 191-1179B-5H-3, 75–77 cm). **3, 4.** *Thalassiosira* sp. C Akiba 1985 (Samples 191-1179C-5H-5, 75–77 cm [3], and 191-1179C-7H-2, 75–77 cm [4]). **5, 6.** *Thalassiosira* sp. 10 (Sample 191-1179C-18H-3, 75–77 cm). **7.** *Triceratium* sp. 1 (Sample 191-1179C-11H-6, 75–77 cm). **8.** *Bacteriastrum hyalinum* Lauder (Sample 191-1179C-6H-4, 75–77 cm). Scale bars = 10 µm.

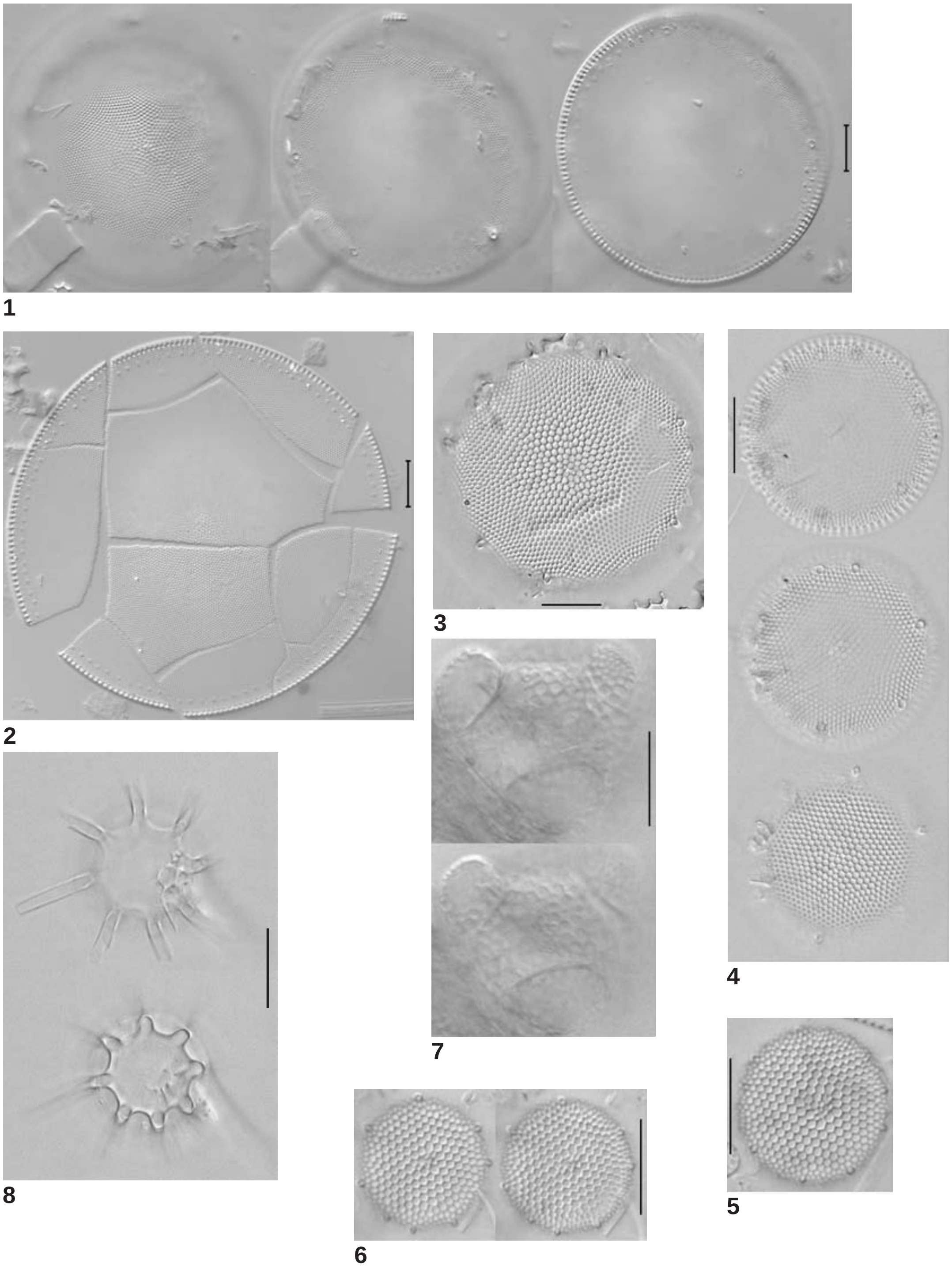
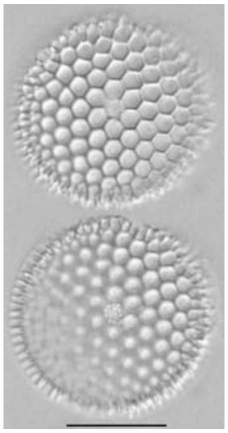


Plate P9. **1, 2.** *Thalassiosira antiqua* (Grunow) Cleve-Euler (Sample 191-1179C-9H-5, 75–77 cm). **3–5.** *Thalassiosira* cf. *inura* Gersonde (Samples 191-1179C-12H-5, 75–77 cm [3], and 191-1179C-17H-3, 75–77 cm [4, 5]). **6.** *Thalassiosira* cf. *complicata* Gersonde (Sample 191-1179C-14H-4, 73–75 cm). **7, 8.** *Thalassiosira eccentrica* (Ehrenberg) Cleve (Samples 191-1179C-19H-1, 72–74 cm [7], and 191-1179C-16H-5, 75–77 cm [8]). **9.** *Thalassiosira nordenskioeldii* Cleve (Sample 191-1179B-5H-5, 75–77 cm). **10, 11.** *Thalassiosira lineata* Jousé (Sample 191-1179B-3H-6, 75–77 cm). **12–14.** *Thalassiosira oestrupii* (Ostenfeld) Proshkina-Lavrenko (Samples 191-1179B-2H-4, 75–77 cm [12], 191-1179B-3H-5, 75–77 cm [13], and 191-1179C-11H-7, 35–37 cm [14]). **15–17.** *Thalassiosira miocenica* Schrader (Samples 191-1179C-17H-5, 75–77 cm [15], 191-1179C-18H-4, 75–77 cm [16], and 191-1179C-14H-4, 73–75 cm [17]). **18.** *Trachyneis aspera* (Ehrenberg) Cleve (Sample 191-1179C-2H-7, 71–73 cm). Scale bars = 10 µm. (**Plate shown on next page.**)

Plate P9 (continued). (Caption shown on previous page.)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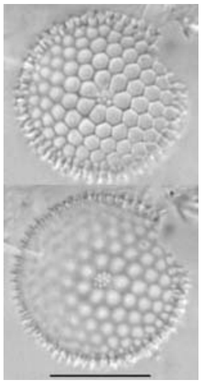
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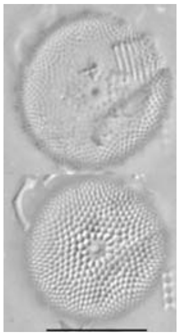
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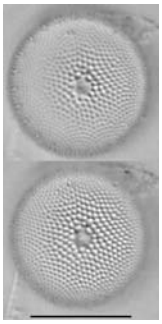
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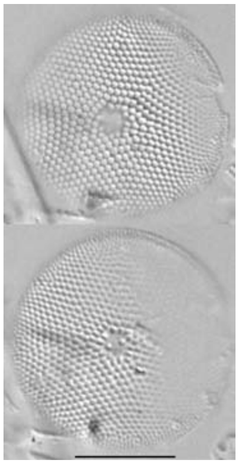
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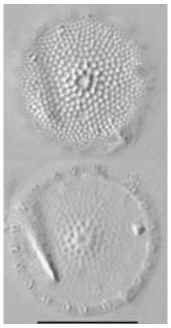
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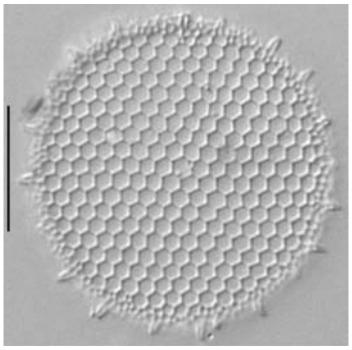
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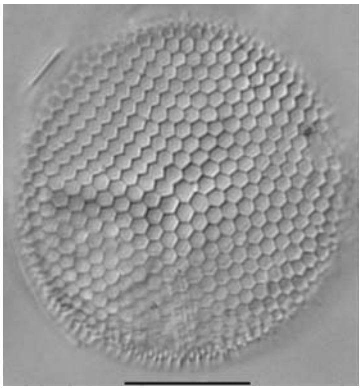
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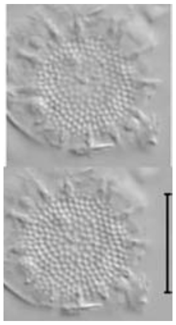
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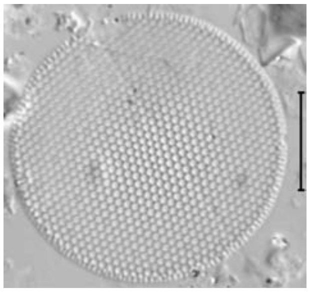
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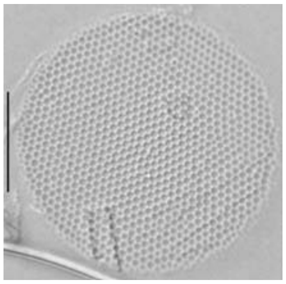
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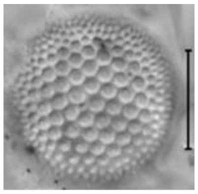
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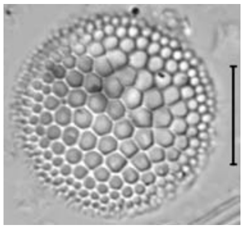
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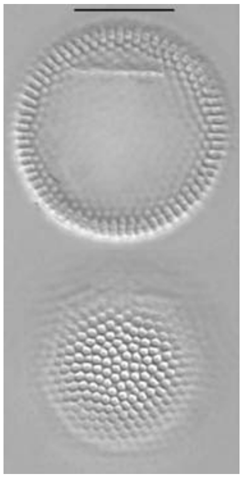
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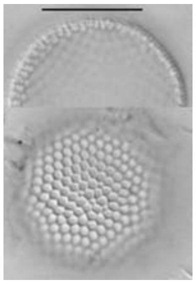
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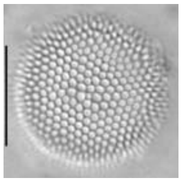
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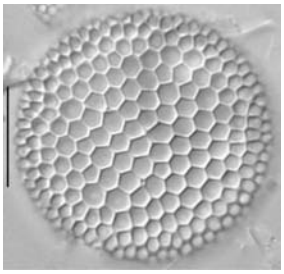
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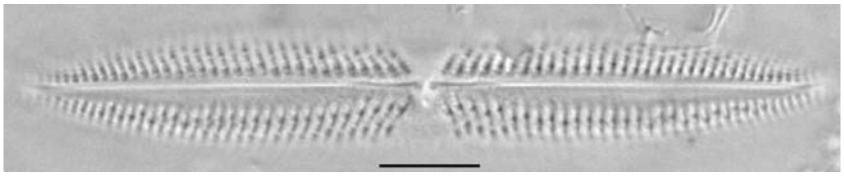
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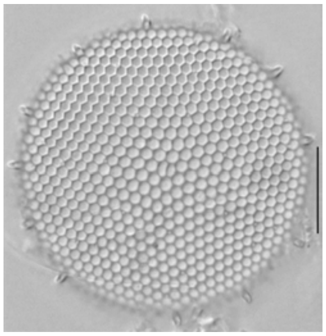
Plate P10. 1–3. *Thalassiosira* cf. *kolbei* (Jousé) Gersonde (Samples 191-1179C-18H-1, 75–77 cm [1], and 191-1179C-19H-1, 72–74 cm [2, 3]). **4.** *Thalassiosira leptopus* (Grunow) Hasle and Fryxell—aberrant specimen (Sample 191-1179C-19H-6, 75–77 cm). **5, 6.** *Thalassiosira leptopus* (Grunow) Hasle and Fryxell (Samples 191-1179C-19H-3, 75–77 cm [5], and 191-1179C-19H-5, 75–77 cm [6]). Scale bars = 10 µm.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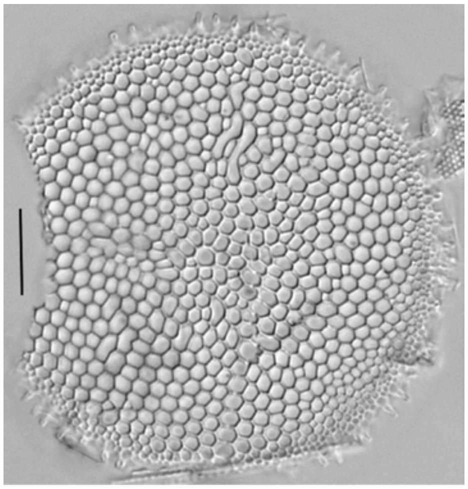
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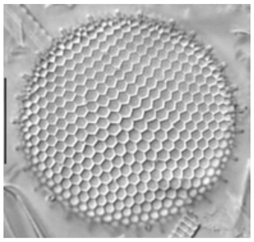
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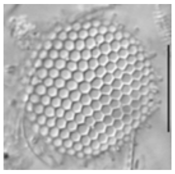
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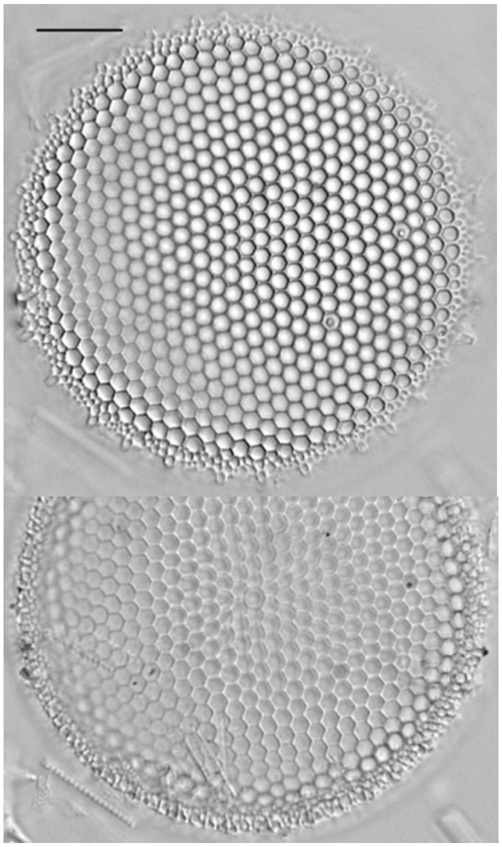
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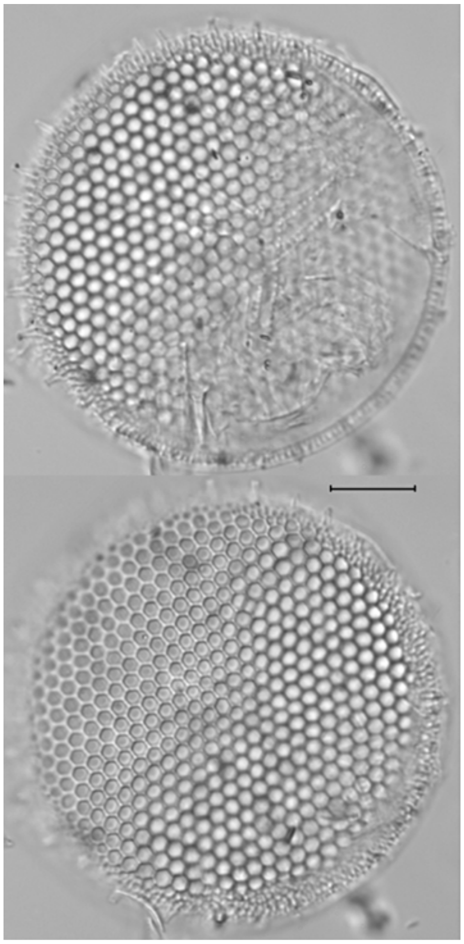
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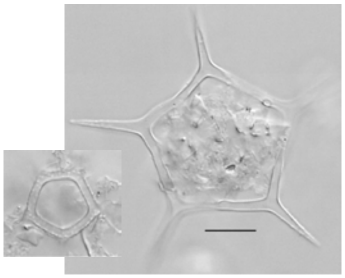
Plate P11. **1.** *Distephanus speculum pentagonus* Lemmermann (Sample 191-1179C-5H-5, 75–77 cm). **2.** *Distephanus crux crux* (Ehrenberg) Haeckel (Sample 191-1179C-11H-5, 75–77 cm). **3.** *Dictyocha* cf. *aspera* (Lemmermann) Bukry and Foster (Sample 191-1179C-14H-5, 73–75 cm). **4.** *Dictyocha fibula* Ehrenberg (Sample 191-1179C-18H-6, 75–77 cm). **5.** *Dictyocha rhombica* (Schultz) Deflandre (Sample 191-1179C-18H-5, 75–77 cm). **6.** *Distephanus boliviensis binoculus* Ciesielski (Sample 191-1179C-14H-5, 73–75 cm). **7.** *Distephanus crux* ssp. *loeblichii* Bukry (Sample 191-1179B-2H-4, 75–77 cm). **8.** *Distephanus polyactis* (Ehrenberg) Deflandre (Sample 191-1179C-2H-2, 75–77 cm). Scale bars = 10 µm. (**Plate shown on next page.**)

Plate P11 (continued). (Caption shown on previous page.)



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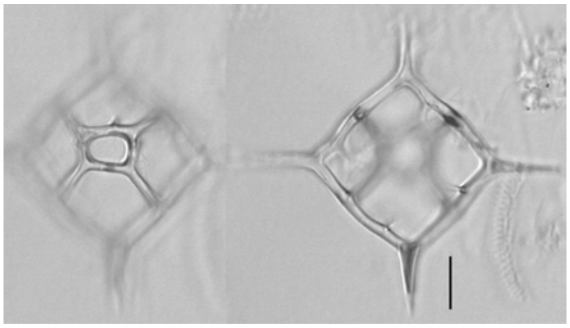

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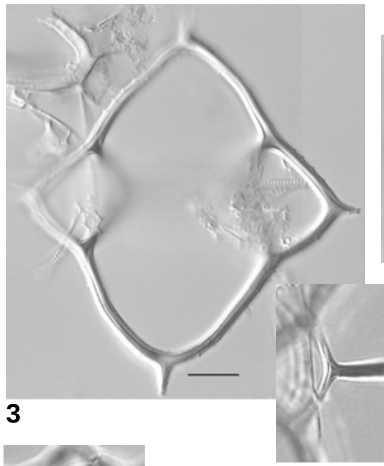

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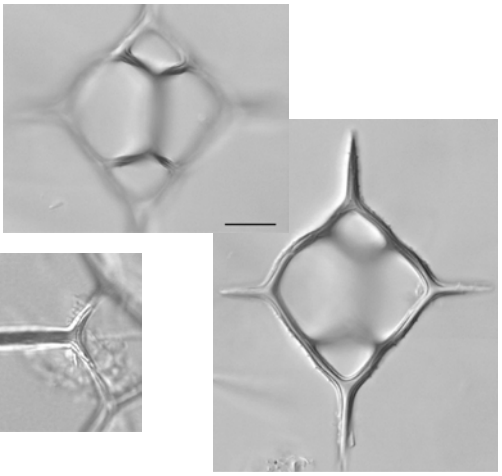

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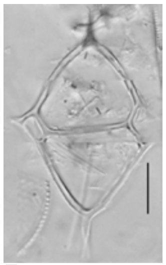

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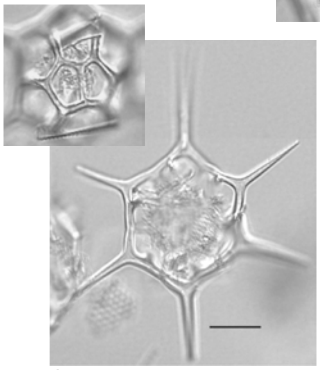

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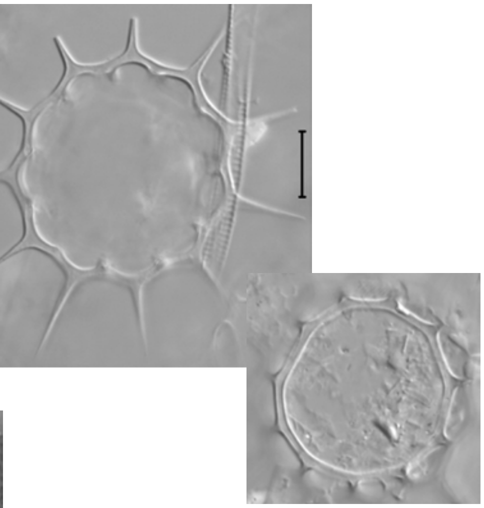

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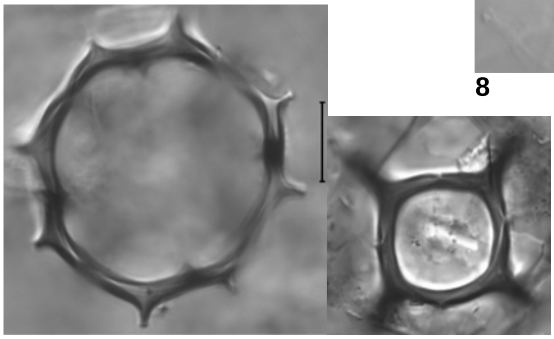

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