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6. Lower Oligocene to Middle Miocene Diatom Biostratigraphy of ODP Site 1140, Kerguelen Plateau[1]

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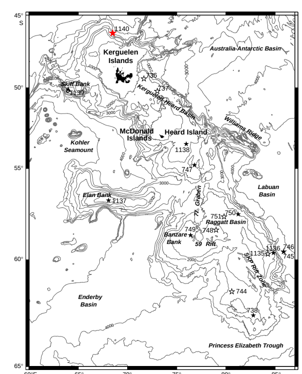
ABSTRACT

Ocean Drilling Program (ODP) Leg 183 Site 1140 provided a lower Oligocene to middle Miocene record of diatom assemblages from the northern Kerguelen Plateau. Samples were examined to improve the resolution of shipboard diatom biostratigraphy. The material is complementary to that recovered during ODP Legs 119 and 120, and the diatom zonation of Harwood and Maruyama could be readily applied. A standard succession of biostratigraphic zones from the middle Miocene and lower Oligocene was delineated, although some zones were unrecognizable because of poor core recovery. The detailed diatom biostratigraphy presented here agrees well with shipboard calcareous nannofossil biostratigraphy. Sediment accumulation rates based on diatom bioevents average 1.26 cm/k.y.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 183 Hole 1140A was rotary cored on the northernmost Kerguelen Plateau (KP), ~270 km north of the Kerguelen Islands (Fig. F1) in a water depth of 2406 m. The KP is a large igneous province (LIP) in the southern Indian Ocean and is believed to have formed via magmatism of the Kerguelen hotspot over the last 120 m.y. (Shipboard Scientific Party, 2000a). This feature is ~2500 km long, between 200 and 600 km wide, and rises ~2–4 km above the surrounding abyssal plain. The present location of Hole 1140A is 46°15.6′S,

F1. Bathymetry of the Kerguelen Plateau, p. 12.



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68°29.5′E (Fig. F1). The main science objective of drilling Hole 1140A was to core igneous basement, to characterize the petrography of the igneous rock, to provide minimum age constraints on the emplacement of igneous basement, and to test the hypothesis that the northern Kerguelen Plateau (NKP) formed at ~40 Ma. Hole 1140A reached a total depth of 321.9 meters below seafloor (mbsf), and 234.52 m of sediment was recovered that ranged in age from late Eocene to middle Miocene based on shipboard paleontological data (Shipboard Scientific Party, 2000b). Previous Eocene to Miocene diatom sections were recovered on the NKP during ODP Legs 119 and 120 (Baldauf and Barron, 1991; Harwood and Maruyama, 1992).

The main purpose of this study is to describe the abundance, preservation, and biostratigraphic distribution of Oligocene to Miocene diatoms in Hole 1140A. This site has been above the calcite compensation depth (CCD) since the late Eocene, allowing nannofossils and foraminifers to be preserved along with diatoms. Thus, there is the potential for an improved multi-microfossil biostratigraphic scheme for the Kerguelen Plateau region. This study will provide a lower Oligocene–middle Miocene diatom biostratigraphy for the NKP and will contribute to the overall diatom biostratigraphic scheme being developed for the Southern Ocean (Fenner, 1984, 1991a, 1991b; Gersonde and Burkle, 1990; Baldauf and Barron, 1991; Harwood, 1991; Harwood and Maryuma, 1992; Harwood et al., 1998; Scherer et al., 2000; Harwood and Bohaty, 2001).

METHODS

The diatom biostratigraphy presented here was constructed based on the examination of strewn slides, viewed using plane and differential interference contrast light microscopy at a magnification of 625× (Zeiss Apo 40×, NA = 0.65). Sediments recovered at Site 1140 were diatom nannofossil ooze, silty diatom ooze, foraminifer-bearing nannofossil ooze, and nannofossil chalk. To select samples for further diatom analysis in this study, shipboard reports of moderately abundant diatoms in core catcher smear slides (prepared for nannofossil analysis) were used to bracket intervals with abundant diatoms.

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 had been 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.

Individual diatom species relative abundances were recorded as follows:

A = abundant; 11–100 specimens per 10 fields of view (FOV).
C = common; 6–10 specimens per 10 FOV.
F = few; 1–5 specimens per 10 FOV.
R = rare; 1 specimen per longitudinal (40 mm) traverse.

The same definitions were used for estimations of total diatom abundance of each sample. Preservation of the diatom assemblage was determined as follows:

G = good: individual specimens exhibit little or no dissolution or fragmentation; diagnostic characteristics are preserved and nearly all specimens can be identified to the species level.
M = moderate: individual specimens show evidence of dissolution or fragmentation; some specimens cannot be identified to the species level.
P = poor: individual specimens exhibit considerable dissolution or fragmentation; many specimens cannot be identified to the species level.

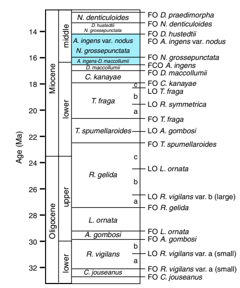
Each author prepared and examined every third slide in this sequence with the results tabulated in a composite range chart (Table T1). Estimated abundances presented in the distribution table should be considered qualitative abundances, reflecting that three separate people carried out preparation and examination. Before examination began, the authors agreed on key diatom characteristics used to define species concepts.

The biostratigraphy employed in this paper is that of Harwood and Maruyama (1992) and is presented in Figure F2. The ages of diatom datums (Table T2) are from ODP Leg 177 Shipboard Scientific Party (1999).

Diatom species considered in this paper are listed in the "Appendix," p. 8, where they are arranged alphabetically by generic epithet. Bibliographic references can be found in Harwood and Bohaty (2001), Scherer et al. (2000), Harwood et al. (1998), Harwood and Maruyama (1992), Harwood and Bohaty (1991), or Schrader and Fenner (1976).

T1. Distribution of diatom taxa, Hole 1140A, p. 15.

F2. Miocene and Oligocene zonation, p. 13.



T2. Biostratigraphic zones and LSRs, p. 16.

HOLE 1140A BIOSTRATIGRAPHY

Results

Coring in Hole 1140A recovered 234.52 m of sediment overlying submarine pillow basalts with minor dolomitized nannofossil chalk beds. The lower Oligocene to middle Miocene sediment consists of diatom nannofossil ooze, silty diatom ooze, foraminifer-bearing nannofossil ooze, and nannofossil chalk. The uppermost sample (183-1140A-1R-1, 25 cm) contains a mixed assemblage of middle Miocene and Pleistocene diatoms. All samples reported here fall below that interval. Several samples within Section 183-1140A-1R-1 contain well-preserved Pliocene–Pleistocene diatoms that were reworked as a result of severe drilling disturbance (Shipboard Scientific Party, 2000b). Stratigraphic distribution of diatoms is listed in Table T1. Key biohorizons are tabulated in Table T2 along with their average depth of occurrence. Diatoms are abundant in Cores 183-1140A-1R through 9R and 20R through 22R, based on shipboard examination of core catcher smear slides. These intervals were selected for more detailed analysis.

Miocene

Samples 183-1140A-1R-1, 25–26 cm, through 9R-CC are early Miocene in age. Samples 183-1140A-1R-1, 25–26 cm, through 2R-CC, 17–22 cm, are included in the *Nitzschia denticuloides* Zone. Core recovery for Cores 183-1140A-1R through 2R was 68%. The first occurrence (FO) of *N. denticuloides* defines the base of the zone, and the top of the zone is placed at the FO of *Denticulopsis praedimorpha*. *D. praedimorpha* was not present in any of the examined samples, indicating that the top of the section is within the *N. denticuloides* Zone. The FO of *N. denticuloides* is assigned an age of 13.51 Ma (Shipboard Scientific Party, 1999). The diatom assemblage consists mainly of *Actinocyclus ingens, Actinoptychus senarius, Coscinodiscus marginatus, Denticulopsis hustedtii,* few *Nitzschia* species, *Triceratium macroporum,* and *Thalassiothrix longissima*.

Samples 183-1140A-3R-1, 100–101 cm, through 4R-2, 25–27 cm, are placed in the *D. hustedtii–Nitzschia grossepunctata* Partial Range Zone. Core recovery over this interval was low, at 23%. The bottom of the *D. hustedtii–N. grossepunctata* Zone is defined by the FO of *D. hustedtii,* with an age of 14.17 Ma (Shipboard Scientific Party, 1999). The diatom assemblage does not contain *T. macroporum* or any *Nitzschia* species but contains *Actinocyclus curvatulus, Coscinodiscus monicae, Crucidenticula ikebei,* and *Denticulopsis lauta,* which were not present in the overlying zone.

A. ingens var. *nodus* was not recognized in this sequence and *N. grossepunctata* was sporadically present, preventing the recognition of the *A. ingens* var. *nodus* Zone or the *N. grossepunctata* Zone. Samples 183-1140A-4R-CC through 6R-2, 100–102 cm, are therefore placed into an undefined zone that spans the *A. ingens* var. *nodus* Zone, *N. grossepunctata* Zone, and the *A. ingens–Denticulopsis maccollumii* Zone. It is possible that the *A. ingens* var. *nodus, N. grossepunctata,* and *A. ingens–D. maccollumii* zones were not recognized because of a disconformity, but it is more likely that they were not recognized because of the extremely poor core recovery (5%) throughout this interval. The bottom of this section is marked by the first common occurrence (FCO) of *A. ingens*. The diatom assemblage consists of *A. ingens, A. senarius, C. marginatus, D. hustedtii, D. maccollumii,* and *T. longissima*.

Samples 183-1140A-6R-CC through 7R-2, 26–26 cm, were placed in the *D. maccollumii* Zone. The bottom of this zone is marked by FCO of *D. maccollumii*. Through this interval there are occurrences of *A. senarius, C. marginatus, Hemiaulus* spp., *Rocella praenitida, Cavitatus jouseanus,* and *T. longissima*.

Samples 183-1140A-7R-CC through 8R-CC were placed in the *Crucidenticula kanayae* Zone. The base of this zone is marked by the FO of *C. kanayae*. The *C. kanayae* Zone spans ~1 m.y. but is limited to only two samples, as the core catcher sample was the only sample recovered from Core 183-1140A-8R. Sample 183-1140A-7R-CC also marks the lowest observed occurrence of *A. curvatulus*. *A. senarius, C. marginatus,* and *T. longissima* are common throughout this interval.

Samples 183-1140A-9R-1, 25–27 cm, through 9R-CC were placed in the *Thalassiosira fraga* "c" Subzone. The base of this gap zone (a negatively defined zone, based on the absence of key species, after Edwards, 1971) is indicated by the last occurrence (LO) of *T. fraga,* and the top of the zone is indicated by the FO of *C. kanayae*. These samples were placed into the subzone based on the absence of *T. fraga*. Samples below this interval through Sample 183-1140A-20R-1, 25–26 cm, were not examined because shipboard analysis of core catchers through this interval yielded scarce diatoms.

Lower Oligocene

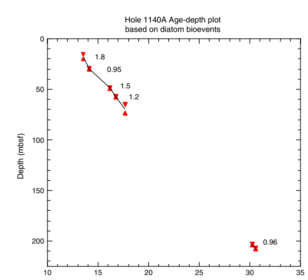
Samples 183-1140A-20R-1, 25–26 cm, through 22R-CC are early Oligocene in age and represent the *C. jouseanus* Zone and *Rocella vigilans* “a” Zone. Core recovery averaged 80% through this three-core interval. Samples 183-1140A-20R-1, 25–26 cm, through 22R-4, 25–26 cm, represent the lower Oligocene *R. vigilans* “a” Zone based on the presence of *R. vigilans* variety “a” (<40-µm form), whose FO and LO demarcate the nominate zone. The top of this zone is unclear, as samples between Cores 183-1140A-20R and 9R were not examined in this study. Other representative diatoms through this zone are *A. senarius, Asteromphalus oligocenicus, Coscinodiscus asteromphalus, C. marginatus, Ethmodiscus rex, Hemiaulus pungens, Pseudorocella barbadensis, Pseudotriceratium chenevieri, Sceptroneis propinqua, Stephanopyxis turris* group, *T. longissima,* and *Xanthyopyxis oblonga*.

The lower Oligocene *C. jouseanus* Zone ranges from Sample 183-1140A-22R-4, 100–101 cm, through 22R-CC, the lowermost sample analyzed for this study. The diatom assemblage differs from the *R. vigilans* “a” Zone in the absence of *R. vigilans* variety “a” and *Cestodiscus pulchellus*. Preservation declines rapidly from Sample 183-1140A-22R-6, 24–25 cm, to 22R-CC (Table T1). *C. jouseanus* is absent from the lowermost sample and rare in the two overlying samples, yet the base of the *C. jouseanus* Zone is not placed within the study set because of the paucity and highly dissolved state of the diatoms in the lowermost samples. Analysis of core catcher samples from 183-1140A-23R-CC through 25R-CC revealed few non-age-diagnostic diatoms; therefore, samples below 183-1140A-22R-CC were not analyzed for this study.

Linear Sedimentation Rates

Linear sedimentation rates (LSRs) were calculated based on seven diatom bioevents spanning the studied interval (Table T2). LSRs vary from 0.95 to 1.8 cm/k.y. with an average of 1.26 cm/k.y. (Fig. F3; Table T3). The sediment accumulation rate is poorly constrained by diatom datums from ~30 to 45 mbsf. This is the interval of our combined *A. ingens* var. *nodus, N. grossepunctata,* and *A. ingens–D. maccollumii* zones, where core recovery was only 5%. With such limited core recovery of rotary cored sediments, it is difficult to determine whether there is a disconformity present or whether the ambiguity is a result of the poor core recovery. Assuming a constant linear sedimentation rate throughout the studied interval, the bottommost sediments recovered (Section 183-1140A-25R-6) would be ~32.8 Ma, representing the lower Oligocene *Rhizosolenia oligocaenica* “c” Zone. This agrees with the shipboard assignment of an earliest Oligocene age to these sediments based on calcareous nannofossil data (Shipboard Scientific Party, 2000b).

F3. Age-depth plot, Hole 1140A, p. 14.



T3. Datums used for age-depth plot, p. 17.

SUMMARY

Site 1140 provided a lower Oligocene to middle Miocene record of diatoms from the northernmost Kerguelen Plateau. Samples were prepared and analyzed to provide a more detailed analysis of diatom distributions than that carried out by shipboard scientists (Shipboard Scientific Party, 2000b). The material is complementary to that recovered during ODP Legs 119 and 120, and the biostratigraphic zonation of Harwood and Maruyama (1992) was readily applied to the material analyzed. Low core recovery (5%) or a possible disconformity prevented the recognition of the *A. ingens* var. *nodus, N. grossepunctata,* and *A. ingens–D. maccollumii* zones and limited the *C. kanayae* Zone (spanning ~1 m.y.) to only two samples. Linear sedimentation rates average 1.26 cm/k.y. through the studied interval, indicating low oceanic sedimentation rates.

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APPENDIX

Plates **P1**, **P2**, **P3**, and **P4** figure some key diatom marker species as well as other typical diatoms found in Hole 1140A.

Actinocyclus curvatulus Janisch in Schmidt

Actinocyclus ingens Rattray (Pl. **P1**, fig. 6)

Actinocyclus karstenii Van Heurck

Actinocyclus ochotensis Jousé

Actinocyclus octonarius Ehrenberg (Pl. **P3**, fig. 2)

Actinocyclus oculatus Jousé

Actinocyclus thumii Hanna

Actinoptychus bipunctatus Lohman (Pl. **P1**, fig. 4)

Actinoptychus senarius (Ehrenberg) Ehrenberg; Hendey

Araniscus lewisianus (Greville) Komura (Pl. **P1**, fig. 15)

Asterolampra insignis Schmidt

Asterolampra marylandica Ehrenberg

Asteromphalus concavus Harwood and Maruyama

Asteromphalus inaequabilis Gersonde

Asteromphalus oligocenicus Schrader and Fenner (Pl. **P4**, fig. 1)

Asteromphalus symmetricus Schrader and Fenner

Azpeitia endoi Kanaya (Pl. **P3**, fig. 5)

Azpeitia tabularis (Grunow) Fryxell and Sims

Biddulphia deodora Hanna and Grant

Cavitatus jouseanus (Sheshukova-Poretzkaya) Williams (Pl. **P2**, fig.1)

Cestodiscus pulchellus Greville

Corethron criophilum Castracane

Coscinodiscus asteromphalus Ehrenberg (Pl. **P3**, fig. 3)

Coscinodiscus decrescens Grunow (Pl. **P3**, fig. 1)

Coscinodiscus marginatus Ehrenberg (Pl. **P1**, fig. 1)

Coscinodiscus monicae Grunow

Coscinodiscus rhombicus Castracane (Pl. **P2**, fig. 11)

Craspedodiscus coscinodiscus Ehrenberg

Crucidenticula ikebei Akiba and Yanagisawa

Crucidenticula kanayae Akiba and Yanagisawa

Crucidenticula nicobarica (Grunow) Akiba and Yanagisawa (Pl. **P1**, fig. 13)

Crucidenticula punctata (Schrader) Akiba and Yanagisawa

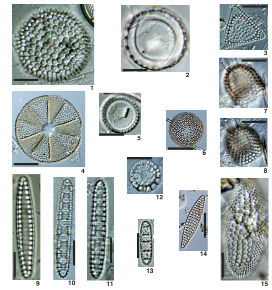
Dactyliozolen antarcticus Castracane (Pl. **P1**, fig. 2)

Denticulopsis hustedtii Simonsen and Kanaya (Pl. **P1**, figs. 10, 11)

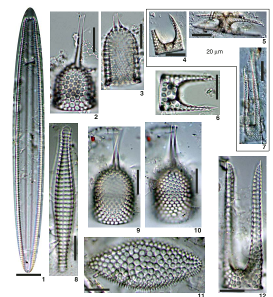
Denticulopsis lauta (Bailey) Simonsen

Denticulopsis maccollumii Simonsen (Pl. **P1**, fig. 9)

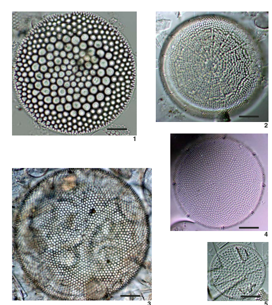
P1. Key diatom marker species in DIC illumination, p. 18.



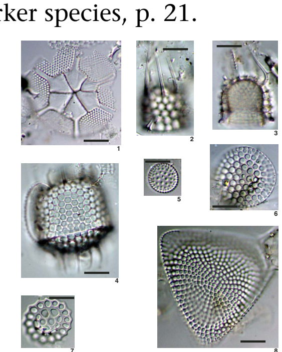
P2. Key diatom marker species, p. 19.



P3. Key diatom marker species and typical diatoms, p. 20.



P4. Typical diatoms and key marker species, p. 21.



Denticulopsis punctata Schrader

Dimerogramma fossile (Grunow) Cleve and Moller

Ethmodiscus rex Wallich

Eucampia antarctica (Castracane) Mangin

Goniothecium decoratum Brun

Hemiaulus sp. aff. *H. giganteus* Ehrenberg (Pl. **P2,** fig. 12)

Hemiaulus altus Hajós

Hemiaulus danicus Grunow

Hemiaulus inaequilaterus Gombos (Pl. **P2,** fig. 7)

Hemiaulus incisus Hajós

Hemiaulus polycystinorum Ehrenberg (Pl. **P2,** fig. 4)

Hemiaulus polymorphus Grunow

Hemiaulus pungens Grunow (Pl. **P2,** figs. 5, 6)

Hemiaulus spp.
Remarks: Original description of genus is from Ehrenberg, 1884. Valves are elliptical with long thin processes, linking by apical spines. Valve face is curved, merging with the deep mantles. Simple round pores or large elliptical to rectangular holes are closed by complex cribra. One rimoportula is usually present in a central of offset position, but is sometimes absent. Copulae are more finely areolate than the valves, split with pointed ends. Specimens identifiable to this genus but not to the species level were all indentified as *Hemiaulus* sp. in this paper.

Nitzschia barronii Gersonde

Nitzschia denticuloides Schrader

Nitzschia grossepunctata Schrader

Nitzschia kerguelensis (O'Meara) Hasle (Pl. **P1,** fig. 14)

Opephora gemmata (Grunow) Hustedt

Paralia sulcata (Ehrenberg) Kützing (Pl. **P1,** fig. 5)

Pseudorocella barbadensis Deflandre (Pl. **P4,** fig. 7)

Pseudotriceratium chenevieri (Meister) Gleser (Pl. **P4,** fig. 8)

Pyxilla johnsoniana (Grevelle) Hendey

Rhaphoneis cocconeides Schrader

Rhaphoneis elongata (Schrader) Andrews

Rhizosolenia spp.
Remarks: Original description of genus is from Ehrenberg, 1841. Valves are asymmetrical, conelike, drawn out into a "spine," often with shoulders at the base. Areolae are small, round to quadrate, and arranged in vertical rows, often indistinct when viewed from the outside because each areola is closed externally by a delicate plate penetrated by one to several slits or pores. Specimens identifiable to this genus but not to the species level were all identified as *Rhizosolenia* sp. in this paper.

Riedelia claviger (Schmidt) Schrader and Fenner

Rocella gelida (Mann) Bukry

Rocella praenitida Schrader and Fenner, in Kim et Barron (Pl. **P4,** fig. 5)

Rocella vigilans var. “a” (<40 µm) (Schmidt) Fenner see var. “a” of Harwood and Maryuma (Pl. **P4,** fig. 6)

Rouxia granda Schrader in Schrader and Fenner

Rouxia spp.
Remarks: Original description of genus is from Brun and Heribaud, 1893. Valves are kidney shaped with broadly rounded apices. Valve surface is slightly convex with a central depression. The raphe bars are well developed with a rectangular, narrow central area. Two rudimentary raphes are present. Transapical ribs are present. Specimens identifiable to this genus but not to the species level were all indentified as *Rouxia* sp. in this paper.

Sceptroneis aff. *mayenica* Ehrenberg

Sceptroneis mayenica Fenner in Schrader and Fenner (Pl. **P2,** fig. 8)

Sceptroneis praecaducea Hajós and Stradner

Sceptroneis propinqua Schrader and Fenner

Sceptroneis spp.
Remarks: Original description of genus is from Ehrenberg, 1844. Valves are elongate and slightly curved, with a broad, slightly capitate head-pole and a narrow base-pole; swollen in the central part. Valve mantle is sharply turned down, virtually at a right angle to the flat valve face. Striae are uniseriate, oriented at right angles to a rather indistinct central sternum. Areolae are large, round, or elliptical, containing perforate rotae across their external apertures. Specimens identifiable to this genus but not to the species level were all indentified as *Sceptroneis* sp. in this paper.

Stephanogonia hanzawae Kanaya (Pl. **P1,** fig. 12)

Stephanopyxis sp. (1-spire) (Greville and Arnott) Ralfs in Pritchard

Stephanopyxis barbadensis Greville (Pl. **P4,** fig. 4)

Stephanopyxis eoceanica Hajós

Stephanopyxis spinosissima Grunow

Stephanopyxis turris group (Greville and Arnott) Ralfs in Pritchard (Pl. **P1,** figs. 7, 8; Pl. **P2,** figs. 2, 3; Pl. **P4,** figs. 2, 3)

Stephanopyxis turris var. *trispinosus* (Greville and Arnott) Ralfs in Pritchard (Pl. **P2,** figs. 9, 10)

Stictodiscus sp. cf. S. *kittonianus* Greville

Thalassionema schraderi Akiba

Thalassiosira spp.
Remarks: Original description of genus is from Cleve, 1873. Valve are circular, with a flat valve face and short downturned mantles or sometimes almost watchglasslike. Areolae are usually loculate, arranged in radial rows, tangential rows, or arcs, varying in size and prominence. The areolae are open to the outside by circular foramina, sometimes with fingerlike projections; internally they are occluded by slightly raised cribra. Valve mantle is plain or with spines of varied form; mantle edge is often very prominently ribbed and rimmed. Fultoportulae are present in a ring around the valve mantle opening externally by short tubes. Specimens identifiable to this genus but not to the species level were all identified as *Thalassiosira* sp. in this paper. (Pl. **P3,** fig. 4)

Thalassiothrix longissima Cleve and Grunow

Triceratium cruciforme Schmidt

Triceratium inelegans Greville

Triceratium macroporum Hajós (Pl. **P1,** fig. 3)

Triceratium pileus Ehrenberg

Triceratium schulzii Jousé

Triceratium spp.
Remarks: Original description of genus is from Ehrenberg, 1841. Valves are triangular or sometimes square, shallow, and often ornamented with simple or branched spines. Valve face is flat or slightly convex; mantles are very shallow. Areolae are loculate, opening externally via large foramina, the bases of the locules are formed by a continuous sheet of silica with rows of pores radiating from a central annulus. Margin of valves face is raised, with a single row of stalked or spathulate collared tubes, which are the exits on rimoportulae. Specimens identifiable to this genus but not to the species level were all identified as *Triceratium* sp. in this paper.

Xanthiopyxis oblonga Ehrenberg

Figure F1. Bathymetry of the Kerguelen Plateau. Solid stars = ODP Legs 119, 120, and 183 drill sites that recovered igneous basement. Open stars = sites that bottomed in sediments. Contour interval is 500 m (from Shipboard Scientific Party, 2000a).

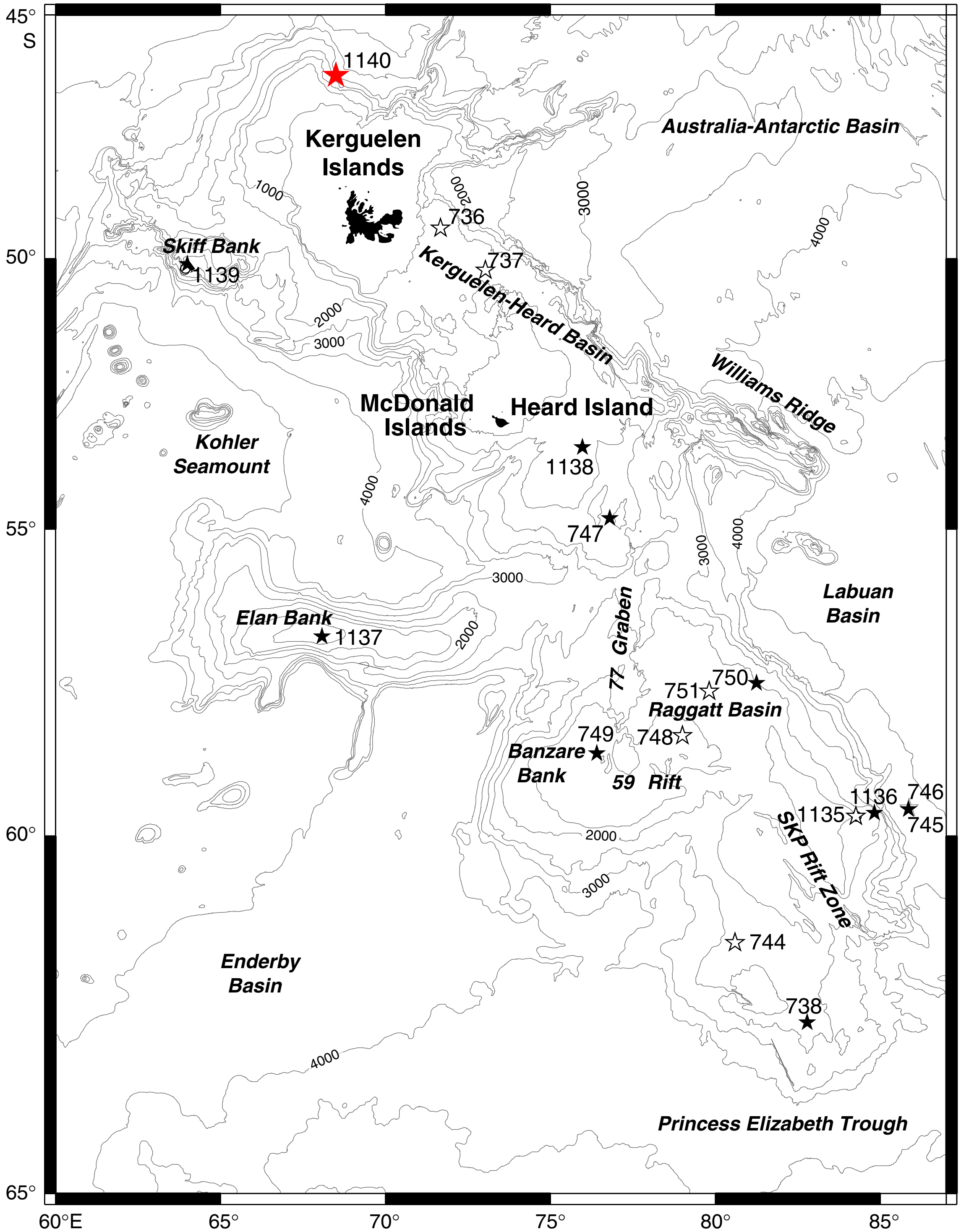


Figure F2. Miocene and Oligocene zonation (Harwood and Maruyama, 1992), adapted for this study. Blue shaded zone = zonal markers not recognized in sections of poor (~5%) core recovery. FO = first occurrence, FCO = first common occurrence, LO = last occurrence.

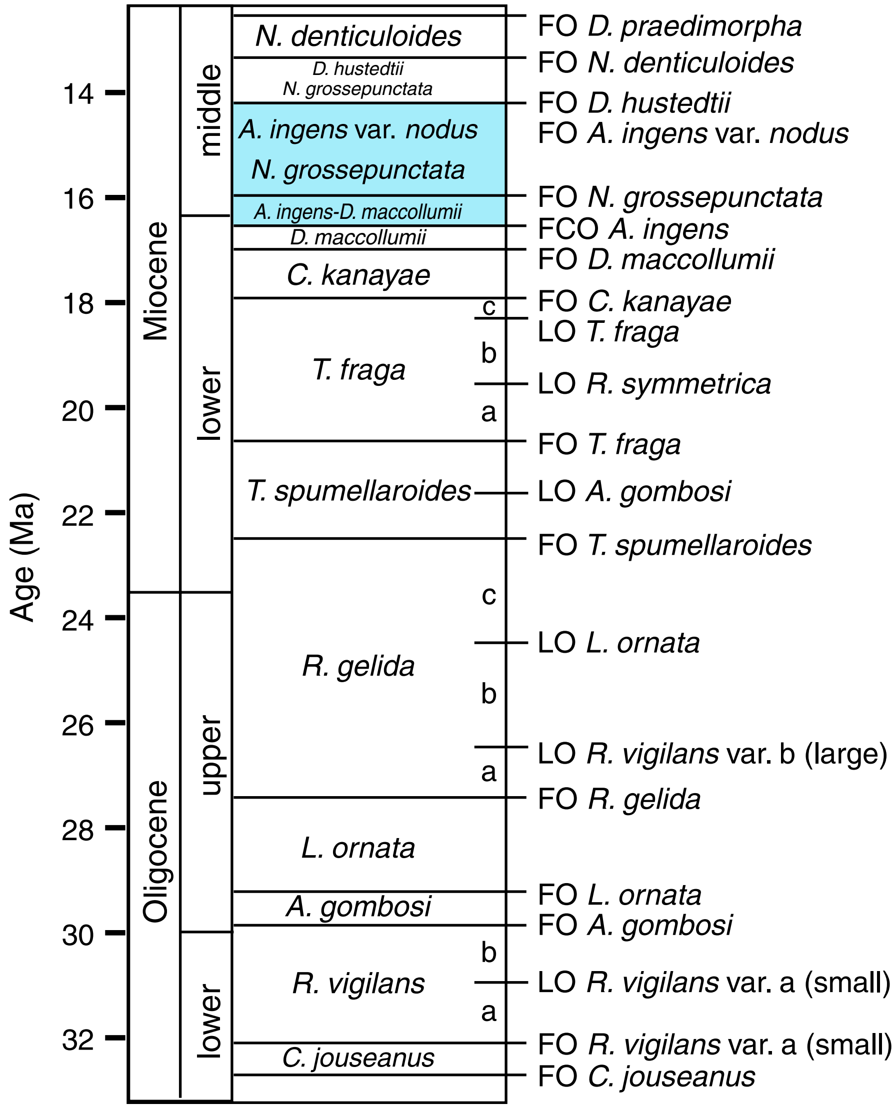


Figure F3. Age-depth plot, Hole 1140A. Pairs of opposed triangles = thickness range of each diatom datum. Linear sedimentation rates are given in centimeters per thousand years. See Table T2, p. 16, for definition of datums.

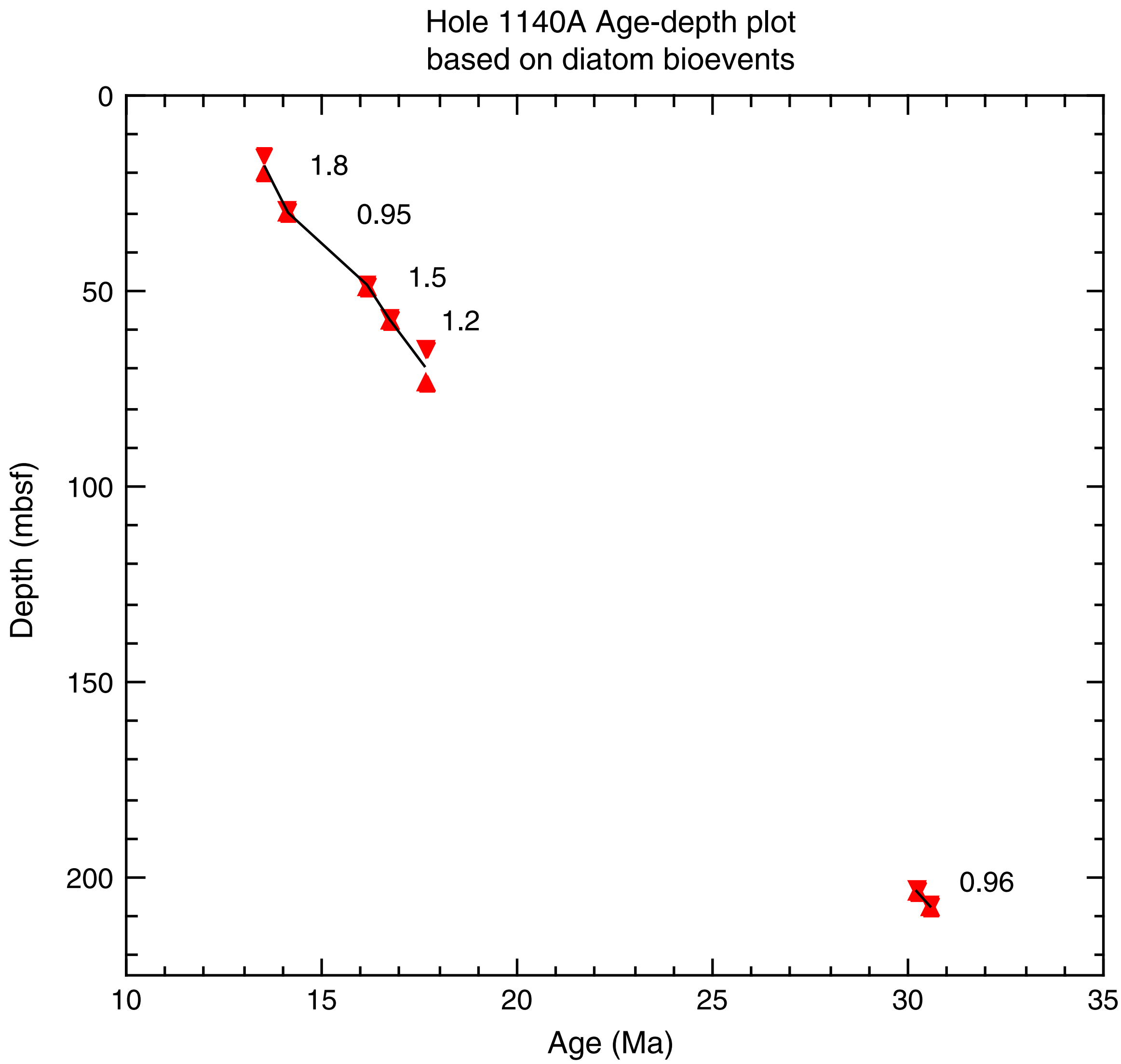


Table T1. Stratigraphic distribution of diatom taxa, Hole 1140A. (This table is available in an **oversized format.**)

Table T2. Age assignments of biostratigraphic zones and linear sedimentation rates.

Zone	Age (Ma)	Datum used to define base	Depth (mbsf)	Error ± (m)	LSR (cm/k.y.)
Miocene					
Nitzschia denticuloides	13.51	FO *N. denticuloides*	17.65	1.95	1.84
Denticulopsis hustedtii/Nitzschia grossepunctata	14.17	FO *D. hustedtii*	29.82	0.17	0.95
Actinocyclus ingens/Denticulopsis maccollumii	16.20	FCO *A. ingens*	49.17	0.16	1.53
Denticulopsis maccollumii	16.75	FO *D. maccollumii*	57.60	0.25	1.22
Crucidenticula kanayae	17.72	FO *C. kanayae*	69.41	4.54	1.07
Oligocene					
Rocella vigilans a	30.24	FO *R. vigilans* var. a (<40 µm)	203.83	0.38	0.97
Cavitatus jouseanus	30.62	FO *C. jouseanus*	207.50	0.30	

Notes: Age assignments of biostratigraphic zones are taken from Shipboard Scientific Party (1999). Depth indicated = the midpoint depth between two samples. Error = the distance from midpoint depth to the two samples that mark the top and bottom of that interval. LSR = linear sedimentation rate, FO = first occurrence, FCO = first common occurrence.

Table T3. Datums used for age-depth plot.

Age (Ma)	Datum used to define base	Depth (mbsf) Top	Bottom	Average	Sedimentation rate (cm/k.y.)
10.23	FO *T. kennettii*				
10.63	LO *D. dimorpha*				
11.67	LO *N. denticuloides*				
12.20	FO *D. dimorpha*				
12.84	FO *D. praedimorpha*				
13.51	LO *N. grossepunctata,* FO *N. denticuloides*	15.70	19.60	17.65	1.84
14.17	FO *D. hustedtii*	29.65	29.99	29.82	0.95
14.38	FO *A. ingens* var. *nodus*				
15.38	FO *N. grossepunctata*				
16.20	FO *A. ingens*	49.00	49.33	49.17	1.53
16.75	FO *D. maccollumii*	57.35	57.84	57.60	1.22
17.72	FO *C. kanayae*	64.87	73.95	69.41	1.07
20.79	FO *T. fraga*				
22.58	FO *T. spumellaroides*				
26.50	FO *R. gelida*				
27.95	FO *L. ornata*				
28.35	FO *A. gombosii*				
30.24	FO *R. vigilans* (<40 μm)	203.45	204.20	203.83	0.97
30.62	FO *C. jouseanus*	207.20	207.79	207.50	
33.22	FO *R. oligocaenica*				

Note: LO = last occurrence, FO = first occurrence.

Plate P1. All photographs were taken using differential interference contrast (DIC) illumination. Scale bars = 10 µm. **1.** Sample 183-1140A-2R-CC; *Coscinodiscus marginatus*. **2, 9, 12, 15.** Sample 183-1140A-6R-1, 100–102 cm; (2) *Dactyliozolen antarcticus,* (9) *Denticulopsis maccollumii,* (12) *Stephanogonia hanzawae,* (15) *Araniscus lewisianus*. **3, 5, 10, 11, 13.** Sample 183-1140A-2R-2, 100–102 cm; (3) *Triceratium macroporum,* (5) *Paralia sulcata,* (10, 11) *Denticulopsis hustedtii,* (13) C*rucidenticula nicobarica*. **4.** Sample 183-1140A-1R-CC; *Actinoptychus bipunctatus*. **6.** Sample 183-1140A-20R-1, 25–27 cm; *Actinocyclus ingens*. **7, 8.** Sample 183-1140A-4R-CC; *Stephanopyxis turris*. **14.** Sample 183-1140A-1R-3, 75–76 cm; *Nitzschia kerguelensis*.

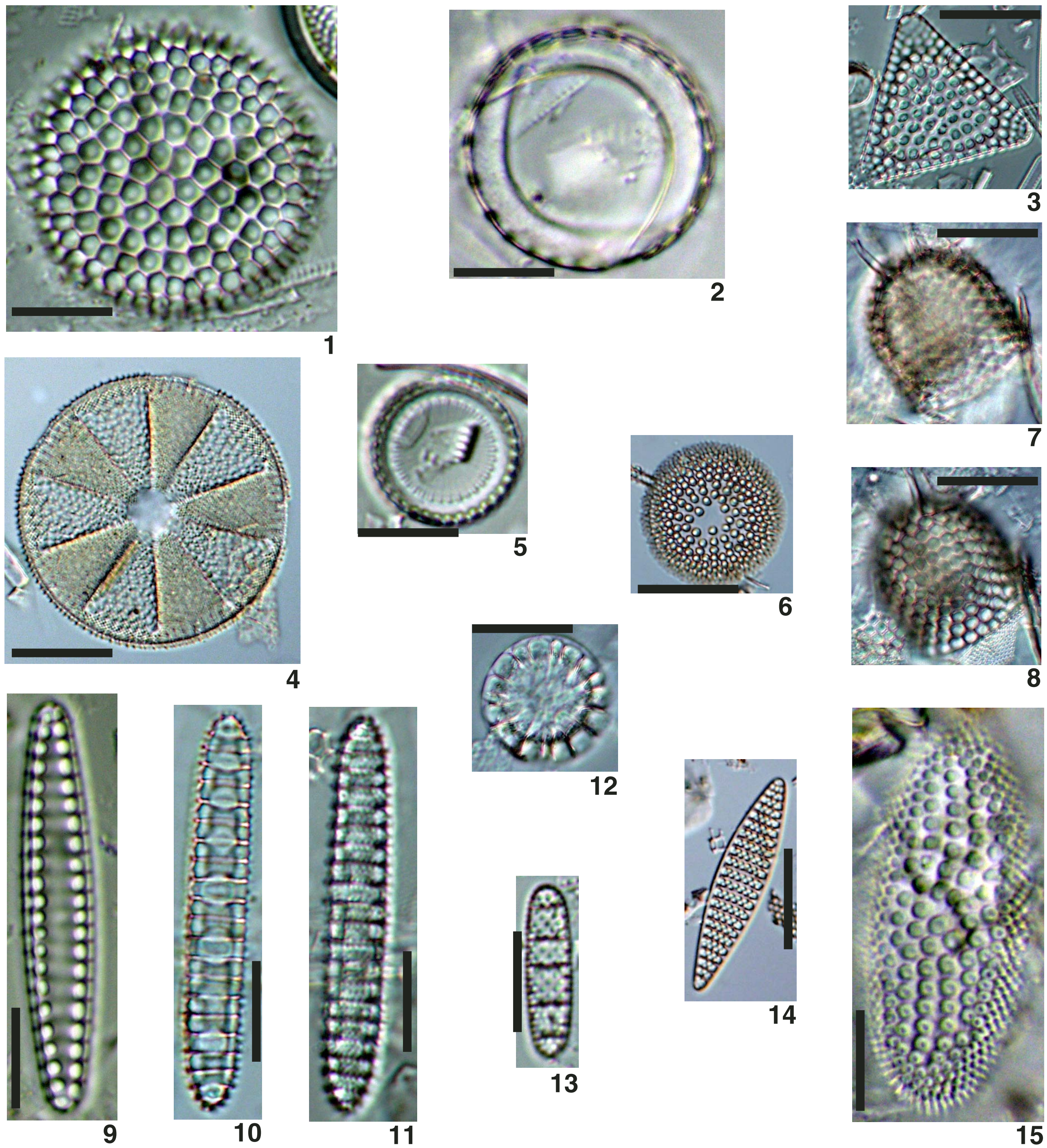


Plate P2. Scale bar = 10 µm, except upper right corner where scale bar = 20 µm. **1.** *Cavitatus jouseanus* (Sample 183-1140A-7R-2, 25–27 cm). **2, 3.** *Stephanopyxis turris* group (Sample 183-1140A-20R-4, 25–27 cm). **4.** *Hemiaulus polycystinorum* (Sample 183-1140A-22R-1, 100–102 cm). **5, 6.** *Hemiaulus pungens;* (5) Sample 183-1140A-22R-3, 25–27 cm; (6) Sample 183-1140A-20R-1, 25–27 cm. **7.** *Hemiaulus inaequilaterus* (Sample 183-1140A-21R-4, 100–102 cm). **8.** *Sceptroneis mayenica* (Sample 183-1140A-20R-1, 25–27 cm). **9, 10.** *Stephanopyxis turris* var. *trispinosus* (Sample 183-1140A-20R-2, 100–102 cm). **11.** *Coscinodiscus rhombicus* (Sample 183-1140A-9R-1, 25–27 cm). **12.** *Hemiaulus* sp. aff. *H. giganteus* (Sample 183-1140A-20R-2, 100–102 cm).

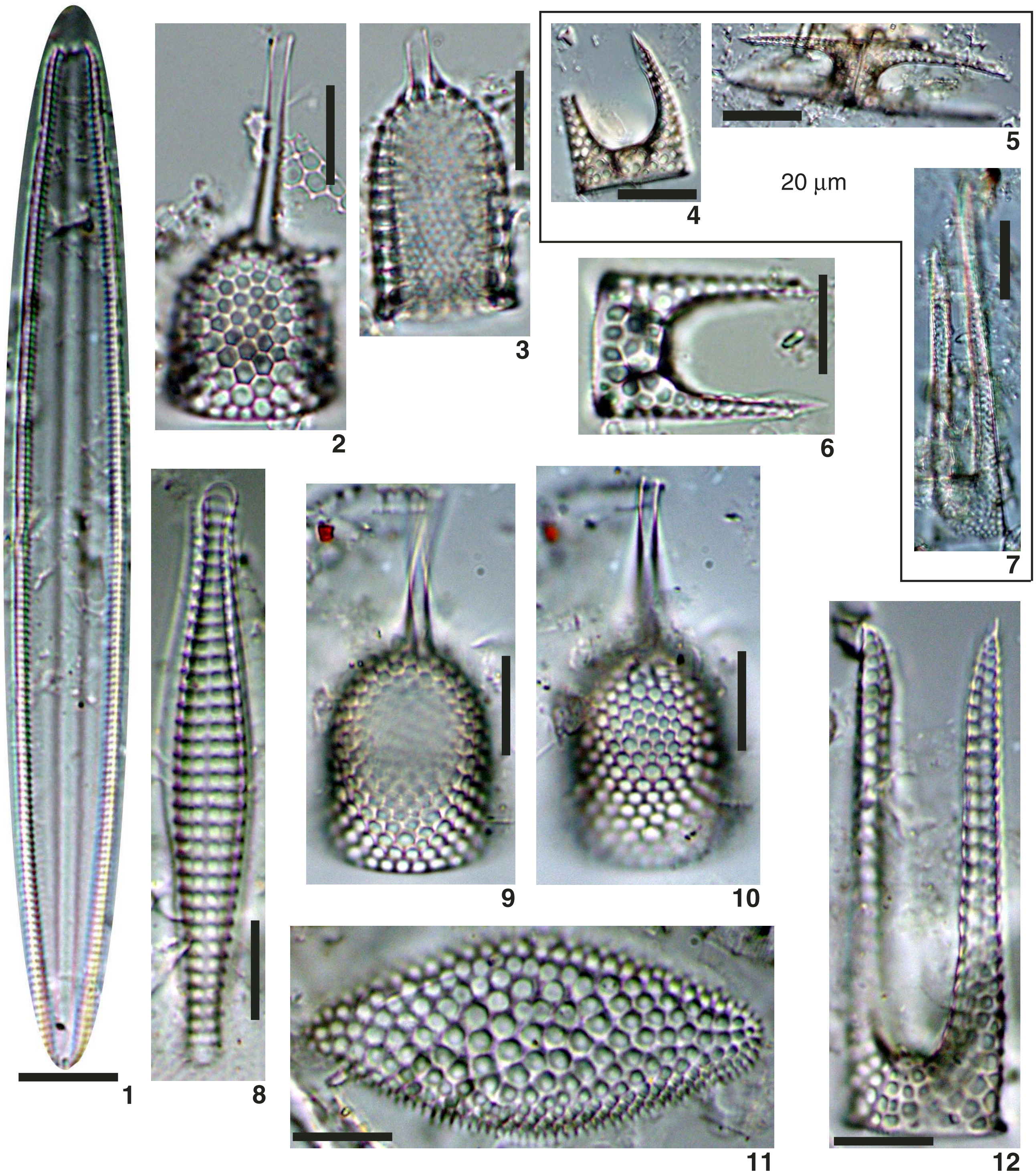


Plate P3. Scale bar = 10 µm. **1.** *Coscinodiscus decrescens* (Sample 183-1140A-20R-4, 25–27 cm). **2.** *Actinocyclus octonarius* (Sample 183-1140A-6R-1, 100–102 cm). **3.** *Coscinodiscus asteromphalus* (Sample 183-1140A-4R-CC). **4.** *Thalassiosira* sp. (Sample 183-1140A-20R-1, 25–27 cm). **5.** *Azpeitia endoi* (Sample 183-1140A-2R-2, 100–102 cm).

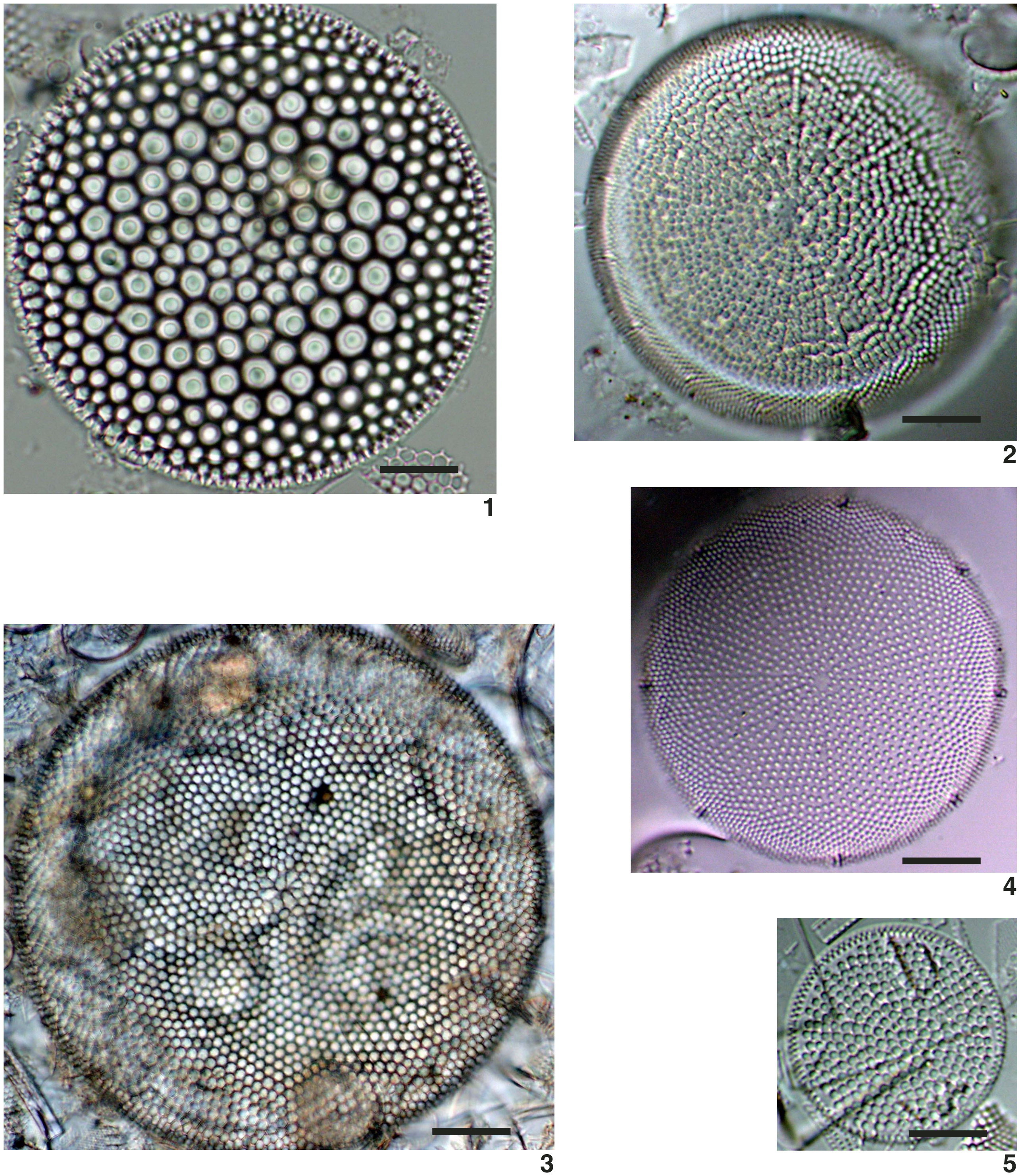


Plate P4. Scale bars = 10 µm. **1, 6.** Sample 183-1140A-20R-2, 100–102 cm; (1) *Asteromphalus oligocenicus,* (6) *Rocella vigilans* var. *a.* **2–5, 7, 8.** Sample 183-1140A-21R-3, 25–27 cm; (2, 3) *Stephanopyxis turris,* (4) *Stephanopyxis barbadensis,* (5) *Rocella praenitida,* (7) *Pseudorocella barbadensis,* (8) *Pseudotriceratium chenevieri.*