

## 5. LATE PALEOGENE DIATOM BIOSTRATIGRAPHY AND PALEOENVIRONMENTS OF THE NORTHERN NORWEGIAN-GREENLAND SEA<sup>1</sup>

Reed P. Scherer<sup>2</sup> and Nalân Koç<sup>3</sup>

### ABSTRACT

Diatom occurrence, abundance, and biostratigraphic position are documented from Paleogene sediments of Ocean Drilling Program (ODP) Leg 151 in the high-latitude Norwegian-Greenland Sea. Previous ocean drilling in the Norwegian-Greenland Sea (ODP Leg 104, Deep Sea Drilling Project [DSDP] Leg 38) provided incomplete Paleogene sections. Paleogene sediments recovered as part of ODP Leg 151 contribute toward a regional composite stratigraphic section, although significant gaps remain. The Paleogene diatom assemblages of Leg 151 differ from those previously recovered, thereby contributing to the development of a regional diatom biostratigraphic zonal scheme. Biosiliceous upper Paleogene sediments were recovered from Hole 908A in the Fram Strait and Hole 913B along the northeast Greenland Margin. Hole 908A contains an upper lower to lower upper Oligocene diatom assemblage dominated by resting spores and other diatoms that suggest high productivity in a neritic setting. The youngest diatom assemblage present in the sequence approximates the oldest Oligocene diatom assemblage of DSDP Leg 38, Site 338, of the *Sceptroneis pupa* Zone. Conformably beneath the *S. pupa* Zone in Hole 908A is the upper lower Oligocene *Sceptroneis fennerae* Zone, which is defined in this study. The *Cymatosira praecompacta* Zone, defined here, conformably underlies the *S. fennerae* Zone. Hole 913B contains biosiliceous successions containing a diatom assemblage with an upper upper Eocene character but also including lower lower Oligocene elements. This assemblage defines the *Actinopterychus irregularis* Zone, established here, which resembles biosiliceous sediments recovered at Site 339 of DSDP Leg 38. The lowermost in situ diatoms recovered include an assemblage of middle Eocene pyritized forms in Hole 913B. Reworked lower Paleogene diatoms occur in upper Paleogene sediments of Sites 908 and 913 and in Pliocene and Quaternary glacially influenced sediments, particularly those of the Yermak Plateau (Sites 910, 911, and 912). Two new species are described, *Sceptroneis fennerae* n. sp. and *Thalassiosira nansenii* n. sp. *T. nansenii* formally names the widely distributed high-latitude diatom previously known as *Thalassiosira* affn. *irregularata*. *Rhizosolenia oligocaenica* var. *styliforma* n. var. and *Sceptroneis humuncia* var. *rondipoda* n. var. are also defined.

### INTRODUCTION

#### Leg 151 Biosiliceous Paleogene

This paper reports on the occurrence, abundance, and biostratigraphic position of diatoms in Paleogene sediments recovered during Ocean Drilling Program (ODP) Leg 151 in the northern Norwegian-Greenland Sea (Fig. 1). These assemblages are used to interpret depositional environments, with regard to paleoproductivity and proximity to a paleoshoreline, and syndepositional and postdepositional bottom-water conditions. Upper Paleogene biosiliceous sediments were recovered from two sites in the northern Norwegian-Greenland Sea during ODP Leg 151 (Fig. 1). Site 908 was drilled on the Hovgaard Ridge in the Fram Strait at 78°23.1'N, 1°21.6'E, in 1273 m of water. Lower upper to upper lower Oligocene biosiliceous sediments were recovered. Site 913 was drilled along the East Greenland Margin at 75°29.4'N, 6°56.8'E, in 3318 m of water. Biosiliceous sediments were recovered that represent sedimentation very close to the Eocene/Oligocene boundary. Unfortunately, biostratigraphy in this interval is equivocal, and, thus far, independent dating of the recovered sections by magnetostratigraphy and radiometric methods has also proven problematic. The best estimate available suggests that the Eocene/Oligocene boundary was recovered in the biosiliceous interval of Hole 913B, between Sections 151-913B-24R-2 and 27R-5. The boundary is recognized by different microfossil groups at differ-

ent places within this interval, but the boundaries, as recognized by siliceous, calcareous, and organic-walled microfossils, are not confi-

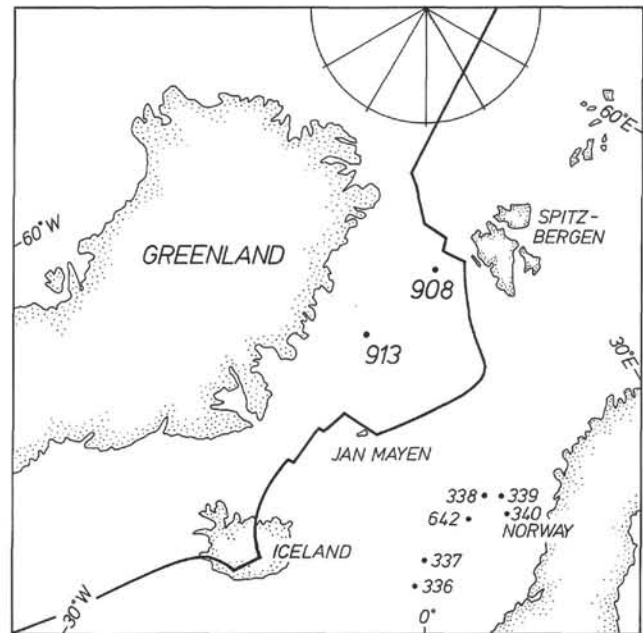


Figure 1. Location of Leg 151 Sites 908 and 913 in the Norwegian-Greenland Sea. Also shown are drill sites in the Norwegian-Greenland Sea from DSDP Leg 38 and ODP Leg 104 that contained biosiliceous Paleogene sediments.

<sup>1</sup>Thiede, J., Myhre, A.M., Firth, J.V., Johnson, G.L., and Ruddiman, W.F. (Eds.), 1996. *Proc. ODP. Sci. Results*, 151: College Station, TX (Ocean Drilling Program).

<sup>2</sup>Institute of Earth Sciences, Uppsala University, Norbyvägen 18B, S-752 36 Uppsala, Sweden. Reed.Scherer@natgeog.uu.se

<sup>3</sup>Department of Geology, University of Bergen, Allégaten 41, N-5007 Bergen, Norway.

dently drawn. This is due, in part, to biostratigraphic uncertainties in the high latitudes, but also because the "boundaries" tend to fall at some kind of lithologic transition. Consequently, the biosiliceous interval 151-913B-24R-2 through 27R-5 may be all or in part within either epoch. For further discussion, see the chronostratigraphic summary chapter (Hull et al., this volume) for ODP Leg 151. Biostratigraphic and paleoceanographic analyses of diatoms in Neogene sediments of Leg 151 can be found in Koç and Scherer (this volume).

### Late Eocene–Early Oligocene Paleoceanography

The late Paleogene was an interval of major climatic and oceanographic reorganization, characterized by the transition from warm Eocene to cold Oligocene conditions. Oxygen and carbon isotopic records across the Eocene–Oligocene transition suggest major changes in bottom-water exchange. Eocene bottom-water conditions are generally believed to have been warm, oxygenated, and relatively sluggish (Miller, 1994; Miller and Tucholke, 1983; Moore et al., 1978). Major changes in bottom-water production occurred in the earliest Oligocene, leading to the formation of widespread deep-sea hiatuses (Moore et al., 1978). Oxygen isotopes across this transition show significant cooling of bottom waters, and carbon isotopes suggest changing bottom-water sources (Miller, 1994). Bottom waters were being produced at both poles during a brief period in the early early Oligocene and exchanged throughout the global ocean (Miller, 1994).

The late Eocene and early Oligocene are notoriously difficult intervals to study because the invigoration of bottom waters led to the development of widespread deep-sea hiatuses (Moore et al., 1978). The Norwegian-Greenland Sea was the conduit for Arctic-produced bottom waters during the "pulse" of Northern Component Water documented by Miller (1994). Consequently, the Norwegian-Greenland Sea should be one of the key basins for study of Paleogene oceanic paleocirculation. Although Eocene and Oligocene sediments have been recovered during previous drilling in the Norwegian-Greenland Sea, an Eocene/Oligocene boundary section was not recovered.

These bottom-water events marked the beginnings of modern oceanic circulation. The most significant climatic event that followed was the establishment of extensive continental glaciation in East Antarctica (Barron et al., 1989). Accumulation of diatomaceous sediments, and the diatom assemblages contained therein, was also directly affected by changes in ocean circulation. Siliceous productivity surged in the Southern Ocean in the early Oligocene following this event (Baldauf, 1994; Baldauf and Barron, 1991; Harwood and Maruyama, 1992). There was a similar, though less dramatic, response in the early early Oligocene in the North Atlantic/Labrador Sea region (Baldauf, 1994; Baldauf and Monjanel, 1989).

Global diatom taxonomic overturn (first and last occurrences) across the Eocene/Oligocene boundary has been estimated to be as high as 45% (Fenner, 1985; 1986; Baldauf, 1994), indicating that there was not only an increase in productivity, but also a rapid speciation and extinction rate at this time. However, biosiliceous reference sections that include an Eocene/Oligocene boundary are scarce, particularly in the high latitudes. Previous drilling in the Norwegian-Greenland Sea has recovered considerable middle Eocene sediments (Sites 338 and 340) and a rather good upper Oligocene section (Site 338). Only rare and poorly dated upper Eocene? (Site 339) and lower Oligocene? sections (Site 336, Site 337, and Site 642) were recovered (Fenner, 1985; Dzinoridze et al., 1978; Schrader and Fenner, 1976; Eldholm, Thiede, Taylor, et al. 1987; Myhre, Thiede, Firth, et al., 1995). None of these sections has been reliably tied to magnetostratigraphy, and few have good cross-correlation with calcareous nannofossil stratigraphy; thus, their exact chronostratigraphic positions remain uncertain. ODP Leg 151 sediments include a biosiliceous interval that approximates the Eocene/Oligocene boundary

(Hole 913B), but this interval also lacks good independent chronostratigraphic control.

## METHODS

In order to gauge diatom abundance and preservation as accurately as possible, as well as to target the best samples for detailed biostratigraphic analysis, smear slides for diatom analysis were prepared from more than 200 stratigraphic positions within the diatom-bearing Paleogene sediments. Material was mechanically disaggregated in deionized water, spread across a 22-x-40-mm cover glass, and mounted in Norland optical adhesive. Smear slides provide an unaltered and unbiased representation of the original assemblage, provided that diatoms are not diluted with significant abundance of fine-grained carbonate.

Selected samples were prepared using the method described by Baldauf and Monjanel (1989), when possible. However, the nature of these sediments made standard diatom preparation procedures difficult or impossible. Furthermore, attempts at preparation of slides for quantitative analysis of the diatom assemblage, using the method of Scherer (1994), proved unsatisfactory. The difficulties came about because the sediments are partially cemented with an altered organic matrix, which makes disaggregation of the particles by chemical means very difficult without damaging fine siliceous structures. Most samples are devoid of carbonate and contain a high enough abundance of diatoms to make smear slide analysis sufficient for biostratigraphic purposes. Certain samples contain rare diatoms replaced by pyrite, in an unconsolidated and very clay-rich matrix. Oxidizers such as hydrogen peroxide destroy such fossil remains, but surfactants, such as sodium hexametaphosphate cause no damage. Pyritized diatoms, silicoflagellates, and ebridians were concentrated using a 20- $\mu$ m mesh sieve. This biases the assemblage against the smallest diatoms, but the high abundance of clay made concentration of diatom debris by other methods impracticable.

Diatom total and relative abundance was estimated from smear slides observed at 600 $\times$  magnification (60 $\times$  oil objective) on an Olympus BX50 interference contrast microscope. Diatom abundance was initially estimated by percentage, based on standard ODP smear slide guidelines, and recorded on a 10-step scale. These numerical estimates were then reduced to qualitative abundance categories following an approximate logarithmic scale. The abundance categories are defined in Table 1A. The relative abundance of each diatom taxon, as reported in the range charts, is estimated based on the qualitative scale described in Table 1B. Diatom preservation categories reported in the range charts are described in Table 1C.

Diatom identification was performed utilizing original references and figures whenever possible, in addition to modern references. Several genera and morphologic groups are tabulated as groups, at the generic level, despite apparent species-level diversity. This approach applies most often to resting spores. Generic identifications generally follow Round et al. (1990). Certain described species or species complexes do not fit the generic descriptions for their assigned genera. If an appropriate alternative genus is not known or has not been described, the original genus is retained but the genus name is placed in quotes to indicate that a taxonomic problem exists at the generic level (e.g., "*Rhizosolenia pokrovskayae*").

## NORWEGIAN-GREENLAND SEA DIATOM ZONATION

Biostratigraphic interpretation of the Paleogene diatom assemblages from Leg 151 comes largely by comparison with diatom assemblages of the Norwegian-Greenland Sea (Schrader and Fenner,

**Table 1. Diatom abundance and preservation categories.**

1A. Definition of categories for total diatom abundance (Tables 2-5)		
Abundance category	Descriptor	Definition
1	B (barren)	No diatom debris evident
2-3	R (rare)	Trace quantities to ~ 2% diatoms
4-5	F (few)	~2% to ~5% diatoms
6-7	C (common)	~5% to ~20% diatoms
8-9	A (abundant)	~20% to ~60% diatoms
10	M (mass)	> 60% diatoms

1B. Categories for relative abundance of individual taxa (Tables 3, 5)		
Descriptor	Definition	
M	Nearly monospecific diatom assemblage of mass abundance	
A	2 or more specimens per field of view	
C	1-5 specimens per 5 fields of view	
F	1-5 specimens per horizontal transect (40 mm)	
R	Fewer than 1 specimen per transect	
r	Rare, reworked	

1C. Diatom preservation categories (Tables 3, 5)		
Category	Definition	
G (good)	Finely silicified and robust forms present, no significant alteration of the frustules, other than moderate fragmentation	
M (moderate)	Concentration of more heavily silicified forms and/or a high degree of fragmentation of finely silicified forms	
P (poor)	Finely silicified forms virtually absent, heavily silicified forms fragmented and/or corroded	

1976; Dzinoridze et al., 1978; Fenner, 1985), the North Atlantic and Labrador Sea (Baldauf and Monjanel, 1989), the northwest Pacific region (Baldauf and Barron, 1987; Yanagisawa and Suzuki, 1987), and the antarctic offshore (including Harwood and Maruyama, 1992; Baldauf and Barron, 1991; Fenner, 1978, 1984; Gombos, 1983; Gombos and Ciesielski, 1983; Schrader, 1976; Hajós, 1976) and nearshore zones (Barron and Mahood, 1993; Harwood, 1989; Harwood et al., 1989). Many of the low-latitude biostratigraphic markers are very rare or are absent from the high latitudes; nevertheless, published studies of lower latitude Paleogene diatom assemblages, including those described by Palmer (1984), provide worthwhile comparison, particularly for the oldest diatom assemblages of Leg 151.

The Norwegian-Greenland Sea diatom zonation of Fenner (1985) builds on the best elements of previous zonations of Schrader and Fenner (1976) and Dzinoridze et al. (1978), which developed from studies of Deep Sea Drilling Project (DSDP) Leg 38 sites in the eastern Norwegian-Greenland Sea. The composite zonation of Fenner (1985) is shown in Figure 2, along with the two new zones proposed in this study. As can be noted from Figure 2, available upper Paleogene biosiliceous sediments of the Norwegian-Greenland Sea provide only a fragmentary record, with poor chronostratigraphic control. Leg 151 contributed significantly to this record, but a complete composite section is still not available.

Lower latitude zonations, including those used by Baldauf and Monjanel (1989) from the Labrador Sea, proved of rather limited value, due to the fact that few of the low-latitude biostratigraphic markers used in that study are present in sufficient abundance in Leg 151 material for reliable application. Many Oligocene taxa present in the Norwegian-Greenland Sea also occur in the southern high latitudes, where chronostratigraphic control is, on the whole, rather good. This allows a bipolar comparison of taxonomic distributions, but the poor chronostratigraphic control presently available in the Norwegian-Greenland Sea prevents reliable evaluation of bipolar diachrony or isochrony of diatom events.

Three new Paleogene diatom biozones are defined, based on analysis of ODP Leg 151 sediments. An additional contribution to the diatom biostratigraphic zonation for the Norwegian-Greenland Sea is the recognition and definition of an older base for the *Sceptroneis*

Age		DSDP Leg 38 (Fenner, 1985)	ODP Leg 151 (This paper)
late	O L I G O C E N E	<i>Thalassiosira irregularata</i> Zone	
		<i>P. filiformis</i> Zone	
		<i>Sceptroneis pupa</i> Zone	<i>Sceptroneis pupa</i> Zone
early	O L I G O C E N E		<i>Sceptroneis fennerae</i> Zone
			<i>C. praecompecta</i> Zone
		<i>Pyxilla reticulata</i> Zone	
		<i>H. polycystinorum</i> Zone	
late	O L I G O C E N E	<i>Coscinodiscus</i> aff. <i>tenerrimus</i> Zone	<i>Actinoptychus irregularis</i> Zone
		<i>Praecymatosira monomembrancea</i> Zone	
		<i>Craspedodiscus oblongus</i> Zone	
		<i>Trinacria excavata</i> forma <i>tetragona</i> Zone	
middle	O L I G O C E N E		
		<i>Pyxilla oligocaenica</i> Zone	

Figure 2. Diatom biozones, and their approximate ages, for the Norwegian-Greenland Sea, based on analysis of DSDP Leg 38 (Fenner, 1985; Dzinoridze et al., 1978; Schrader and Fenner, 1976) and ODP Leg 151 (this study), including new biozones defined here. Shaded areas are unzoned due to a lack of recovery or a lack of diatom occurrences in recovered sediments.

*pupa* Zone than was originally defined by Schrader and Fenner (1976) and Fenner (1985).

#### Definition of Paleogene Diatom Biozones of Leg 151

**Total range zone:** *Sceptroneis pupa* Zone (Schrader and Fenner, 1976; Fenner, 1985; Scherer and Koç, this study)

**Age:** early late Oligocene.

**Definition:** The top of the upper Oligocene *S. pupa* Zone, as defined by Schrader and Fenner (1976) and Fenner (1985), is the last occurrence of *S. pupa*, coinciding with the first occurrence of *Lisitzinia ornata*. Other floral elements include *Cavitatus jouseanus* and *Sceptroneis pesplanus*. The base of this zone, as originally defined from DSDP Site 338, coincides with a hiatus. The base of the *S. pupa* Zone is now extended, based on materials recovered from Hole 908A. The base is now defined as the first occurrence of *S. pupa*, which coincides with the last occurrence of *Sceptroneis fennerae* n. sp. The first occurrence of *Rhizosolenia oligocaenica* var. *styliforma* n. var. and the last occurrences of *Melosira ignota* and "*Detonia?*" sp. A are also associated with this zonal boundary in Hole 908A. *Sceptroneis pesplanus* is not found in the lower part of the *S. pupa* Zone of Hole 908A.

**Total range zone:** *Sceptroneis fennerae* Zone (Scherer and Koç, this study)

**Age:** late early to early late Oligocene

**Definition:** The top of this zone is defined by the last occurrence of *Sceptroneis fennerae* and the first consistent occurrence of *S. pupa*. Also associated with this boundary are the last consistent occurrences of "*Detonia?*" sp. A and *Melosira ignota*, and the first occurrence of *Rhizosolenia oligocaenica* var. *styliforma*. Other distinctive floral elements of the *S. fennerae* Zone include *Goniothecium decoratum*, *Cavitatus jouseanus*, *Eurossia irregularis*, *Thalassiosira nansenii* n. sp., *Pseudotrickeratium radiosoreticulatum* and *Rhizosolenia oligocaenica*. *Goniothecium coronata* occurs only in the upper part of the *S. fennerae* Zone, and *Hemiaulus incisus* occurs in the lower part. The base of the zone is defined by the first occurrences of *Sceptroneis fennerae* and *Sceptroneis humuncia* var. *rondipoda* n. var.

**Assemblage zone:** *Cymatosira praecompacta* (Scherer and Koç, this study)

**Age:** early Oligocene

**Definition:** Characterized by common and morphologically diverse examples of *C. praecompacta*. The top of the zone is defined by the first occurrence of *Sceptroneis fennerae* and *S. humuncia* var. *rondipoda*. Other floral elements include *Macrora barbadensis*, *Hemiaulus hostilis*, *Melosira ignota*, "*Detonia?*" spp., and *Thalassiosira nansenii* with a raised center, which is interpreted as a transitional form between *Thalassiosira mediaconvexa* and *T. nansenii*. The assemblage also includes *Rhizosolenia oligocaenica*, *Pseudotrickeratium radiosoreticulatum*, *Trochosira spinosa*, and rare *Craspedodiscus* spp. and *Distephanosira architecturalis*. The bottom of the zone is not defined.

**Assemblage zone:** *Actinoptychus irregularis* Zone (Scherer and Koç, this study)

**Age:** late late Eocene/early early Oligocene

**Definition:** This is an assemblage zone for which the upper and lower boundaries cannot be formally defined based on available materials, because the upper and lower contacts coincide with lithologic changes. Distinctive floral elements of this assemblage include *Actinoptychus irregularis*, *Coscinodiscus* affn. *tenerrimus*, *Navicula udintsevii*, *Costopyxis trochlea*, *Thalassiosira mediaconvexa*, *Thalassiosira dubiosa*, and *Sceptroneis mayenica*. Floral elements resemble the *Coscinodiscus* affn. *tenerrimus* Zone of Dzinoridze et al. (1978) and Fenner (1985), but the stratigraphic sections are not long enough or complete enough to determine the relative chronostratigraphic positions of these assemblages with assurance.

## DIATOM ASSEMBLAGES BY SITE

### Site 908

Two holes were drilled at Site 908 on the Hovgaard Ridge in the Fram Strait. The Hovgaard Ridge is a displaced block that likely rifted from the Svalbard margin. This ridge has considerable oceanographic and paleoceanographic significance in that it comprises a sig-

nificant part of the complex sill separating the Arctic Ocean and the Norwegian-Greenland Sea. Only Hole 908A, which penetrated below the unconformity recognized by seismic stratigraphy, recovered Paleogene sediment. A total of 180 m of Paleogene diatomaceous sediments was recovered. These successions lie between lower Pliocene to recent largely unfossiliferous sediments above the unconformity, which is identified at 185 m below seafloor (mbsf), and 24 m of largely unfossiliferous Paleogene sediments below the biosiliceous unit. Diatom abundance and preservation throughout this 180-m unit fluctuates from abundant and well preserved to nearly barren and very poorly preserved. The low abundance zones may represent brief hiatuses, but the diatoms do not indicate any significant stratigraphic gaps within these intervals. Qualitative diatom abundance through the interval is shown in Table 2 and graphically in Figure 3, plotted by depth.

The Paleogene diatom assemblage of Hole 908A is characterized by abundant and diverse meroplanktonic (largely resting spore forming), epiphytic, and epibenthic diatoms, indicating a neritic and relatively low salinity setting. Holoplanktonic diatoms are present in Site 908 Paleogene sediments, but these are of lower abundance than neritic indicators. Resting spores of numerous genera, including *Chaetoceros* and other spore-forming "genera" (e.g., *Pseudopyxilla*, *Goniothecium*, *Stephanogonia*, *Xanthiopyxis*; see discussion on spore genera in Hargraves, 1986), dominate the assemblage. A near-shore setting is indicated by the occurrence of common epipsammic, epipelagic, and epibenthic diatom taxa, as interpreted based on modern analogs for the genera (generally following Round et al., 1990). Epilithic/epipelagic taxa include members of the genera *Paralia*, "*Detonia?*", *Diploneis*, *Cocconeis*, *Grammatophora*, *Rhaphoneis*, *Mastagloia*, *Eunotigramma*, *Aulacodiscus*, and others. Taxa considered to represent the coastal plankton include *Cymatosira*, *Odontella*, and *Neodelphineis* as well as meroplanktonic genera *Chaetoceros*, *Stephanopyxis*, etc. Marine epiphytic diatoms are also common in Hole 908A Oligocene sediments. These are best typified by the abundant and diverse *Sceptroneis* species. The abundance of diatoms whose modern analogs occupy a marine epiphytic habitat may suggest that planktonic marine macrophytes were abundant in the high-latitude Norwegian-Greenland Sea during time of deposition of these sediments.

The assemblage of Paleogene diatoms in Hole 908A is suggestive of rapid sediment accumulation in a continental shelf setting, though actual paleodepth cannot be determined accurately because shallow-water diatoms may be displaced down the slope. Benthic foraminiferal assemblages in these sediments suggest a deep shelf setting (Osterman, this volume). Nonmarine diatoms are consistently present, although generally in low abundance. The occurrence of these diatoms provides clear evidence of a continental sediment source. The freshwater diatoms present most often represent acid water habitats, such as coastal bogs and marshlands, as indicated the presence of acidophilic diatoms of the genera *Eunotia* and *Pinnularia*. *Alaucoseira* spp. are also present. *Melosira ignota* is a consistent contributor to the diatom assemblage, particularly in the *Sceptroneis fennerae* Zone and the upper part of the *Cymatosira praecompacta* Zone. *M. ignota* is an arctic species, having been described from Oligocene sediments from western Siberia (Rubina, 1962; Gleser et al., 1992). The type section for *M. ignota* is described as nonmarine (Rubina, 1962), but the common occurrences of this taxon in Site 908 sediments argue against a strictly nonmarine, habitat. "*Fragilaria*" *miocenica* co-occurs with *M. ignota* in western Siberian strata (Rubina, 1968) as well as in Hole 908A. The diatom assemblage of Hole 908A suggests low salinity, marginal marine conditions.

Abundant *Chaetoceros* and morphologically similar diatom resting spores is generally interpreted as indicating high productivity and high sediment accumulation rates, typically a coastal upwelling setting. Another common habitat for high *Chaetoceros* productivity is a strongly stratified, stable water column with low salinity surface wa-

Table 2. Paleogene diatom samples, depth, and abundance, Hole 908A.

Core, section, interval (cm)	Depth (mbsf)	Abundance code	Core, section, interval (cm)	Depth (mbsf)	Abundance code
151-908A-			30X-1, 90-91	274.8	9
20X-4, 101-102	183.0	1	30X-2, 6-7	275.5	9
20X-5, 14-15	183.6	1	30X-2, 96-97	276.4	9
20X-5, 48-49	183.9	5	30X-3, 3-4	276.9	1
20X-5, 80-82	184.2	3	30X-3, 105-106	277.0	1
20X-5, 146-148	184.9	1	30X-4, 3-4	278.4	9
20X-6, 48-49	185.4	1	30X-4, 92-93	279.3	9
20X-6, 114-116	186.0	1	30X-2, 6-7	275.5	9
20X-6, 144-145	186.3	1	30X-5, 90-91	280.8	5
20X-CC	187.1	6	30X-6, 68-69	282.1	5
21X-1, 77-78	187.9	7	30X-7, 4-5	282.9	3
21X-2, 146-147	190.1	9	30X-CC	283.5	1
21X-3, 30-31	191.2	9	31X-1, 8-9	283.6	9
21X-4, 15-16	192.6	7	31X-1, 78-79	284.3	1
21X-4, 144-145	193.0	7	31X-2, 5-6	285.1	4
21X-5, 75-76	193.9	9	31X-3, 4-5	286.5	3
21X-6, 40-41	195.0	9	31X-4, 3-4	288.0	1
21X-6, 144-145	196.0	7	31X-4, 71-73	288.7	1
21X-CC	196.7	7	31X-5, 2-3	289.5	1
22X-1, 68-69	197.4	5	31X-6, 4-5	291.0	4
22X-1, 129-131	198.0	5	31X-6, 25-27	291.2	5
22X-2, 129-131	199.5	4	31X-7, 3-4	292.5	8
22X-3, 72-73	200.4	5	31X-7, 26-29	292.8	8
22X-3, 130-132	201.0	5	31X-CC	293.2	9
22X-4, 129-131	202.5	6	32X-1, 9-10	294.1	8
22X-5, 139-140	204.1	5	32X-1, 97-98	295.0	9
22X-6, 6-8	204.3	3	32X-2, 3-4	294.7	9
22X-CC	206.3	5	32X-2, 96-97	295.7	9
23X-1, 3-4	206.4	5	32X-3, 4-5	296.2	9
23X-1, 81-82	207.1	6	32X-3, 88-89	297.1	9
23X-2, 3-4	207.8	5	32X-4, 5-6	297.8	9
23X-2, 81-82	208.6	9	32X-4, 88-89	298.6	9
23X-3, 4-5	209.3	9	32X-5, 4-5	299.2	8
23X-4, 3-3	210.6	9	32X-5, 94-95	300.1	9
23X-4, 81-82	211.4	9	32X-6, 4-5	300.7	8
23X-5, 2-3	212.3	9	32X-6, 90-91	301.6	5
23X-5, 81-82	213.1	7	32X-7, 2-3	302.2	8
23X-6, 4-5	213.8	7	32X-7, 46-47	302.7	9
23X-7, 3-4	215.3	9	32X-CC	302.8	9
23X-CC	216.0	9	33X-1, 17-18	303.0	8
24X-1, 83-84	216.8	5	33X-1, 101-103	303.8	8
24X-2, 95-96	218.4	5	33X-2, 3-4	304.3	8
24X-3, 131-132	220.3	9	33X-2, 95-97	305.3	9
24X-4, 47-48	221.0	9	33X-3, 4-5	305.8	8
24X-4, 90-91	221.4	9	33X-3, 91-93	306.7	9
24X-5, 77-79	222.8	9	33X-4, 3-4	307.3	8
24X-6, 86-87	224.4	9	33X-4, 93-95	308.2	9
24X-7, 34-35	225.3	9	33X-5, 15-16	309.7	8
24X-CC	225.6	9	33X-5, 88-90	309.7	8
25X-1, 86-87	226.5	9	33X-6, 5-6	310.4	8
25X-2, 108-109	228.2	7	33X-6, 90-92	311.2	9
25X-3, 90-91	229.5	7	33X-7, 4-5	311.8	8
25X-4, 90-91	231.0	8	33X-7, 46-48	312.3	9
25X-5, 90-91	232.5	9	33X-CC	312.5	9
25X-CC	232.5	9	34X-1, 30-31	312.8	3
26X-1, 80-81	236.0	5	34X-1, 86-87	313.4	3
26X-2, 73-74	237.4	8	34X-2, 8-9	314.1	7
26X-3, 90-91	239.1	9	34X-3, 5-6	315.6	8
26X-4, 74-75	240.4	4	34X-3, 85-86	316.4	9
26X-5, 57-59	241.8	3	34X-4, 5-6	317.1	7
26X-5, 70-71	241.9	3	34X-4, 85-86	317.9	9
26X-6, 93-94	243.5	3	34X-5, 5-6	318.6	4
26X-CC	244.9	4	34X-5, 92-93	319.4	3
27X-1, 76-78	245.7	5	34X-CC	320.2	3
27X-2, 79-81	247.2	5	35X-1, 21-22	320.4	2
27X-3, 119-121	249.1	6	35X-1, 85-86	321.1	3
27X-4, 81-83	250.2	7	35X-2, 8-9	321.8	4
27X-5, 44-46	251.3	8	35X-2, 131-132	323.0	3
27X-CC	254.6	3	35X-3, 5-6	323.3	3
28X-1, 77-79	255.4	4	35X-3, 115-117	324.4	4
28X-2, 3-4	256.1	3	35X-4, 7-8	324.8	4
28X-2, 105-108	257.2	3	35X-4, 84-85	325.5	3
28X-3, 77-79	258.4	3	35X-5, 9-10	326.3	2
28X-3, 139-140	259.0	4	35X-5, 105-106	327.3	1
28X-4, 68-70	259.8	3	35X-6, 22-23	328.0	2
28X-5, 87-89	261.5	7	35X-CC	330.1	2
28X-6, 70-72	262.8	7	36X-1, 91-92	331.0	1
28X-CC	264.2	6	36X-2, 63-64	332.3	1
29X-1, 114-115	265.3	4	36X-3, 105-106	334.2	1
29X-2, 114-115	266.8	3	36X-4, 83-86	335.4	1
29X-3, 114-115	268.3	2	36X-CC	340.0	1
29X-4, 5-6	268.8	3	37X-1, 66-67	340.7	1
29X-4, 114-115	269.8	5	37X-2, 50-51	342.7	1
29X-5, 122-123	271.4	8	37X-2, 80-81	343.1	1
29X-6, 122-123	272.9	8	37X-CC	344.6	1
29X-CC	273.9	9			
30X-1, 13-14	274.0	9			

Note: Abundance codes defined in Table 1.  
Not all barren samples tabulated.

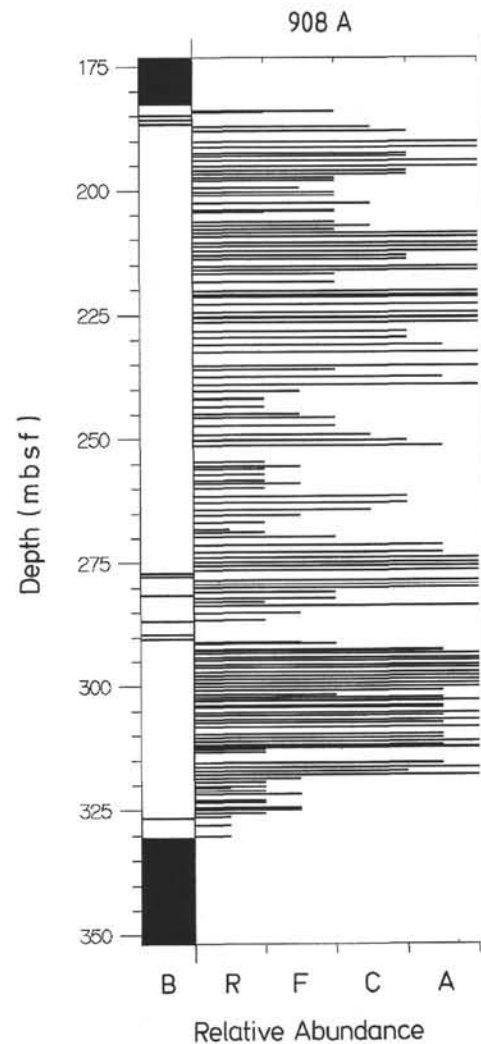


Figure 3. Diatom relative abundance in Paleogene sediments of Hole 908A, plotted on a linear depth scale. Abundance is based on smear-slide analysis. See Table 1 for definition of the abundance categories. Barren samples or intervals are indicated in black in the left column. Data are from Table 2.

ters (Leventer, 1991). Relatively low salinity conditions are also suggested by diatoms *Melosira ignota*, *Mastogloia* and others. It is interesting to note that the high surface-water productivity that characterized the early to middle Oligocene Fram Strait region, as evidenced by the abundant meroplanktonic diatoms of Hole 908A, apparently shut down before early Miocene time. This is suggested by sediments recovered from the nearby Site 909. Hole 909C recovered a thick Miocene section that lacks all evidence of biosiliceous productivity, despite high Miocene diatom productivity on the Vøring Plateau and the Iceland Plateau. Dissolved silica in the pore waters of the lower section of Hole 909C is so low that it seems unlikely that significant biosiliceous debris ever accumulated in this region at that time. Pore water silica concentrations in the lower part of Hole 909C are as low as  $\sim 100 \mu\text{mol/L}$ , compared with the Oligocene sequence of Hole 908A, which has pore water silica concentrations exceeding  $1000 \mu\text{mol/L}$  (Myhre, Thiede, Firth, et al., 1995). It is not yet clear how the relative paleogeographic positions of Site 908 and Site 909 influenced the dramatic differences in diatom paleoproductivity and accumulation, but the sediments do suggest significant ecological differences between Miocene Arctic and Norwegian-Greenland Sea waters.











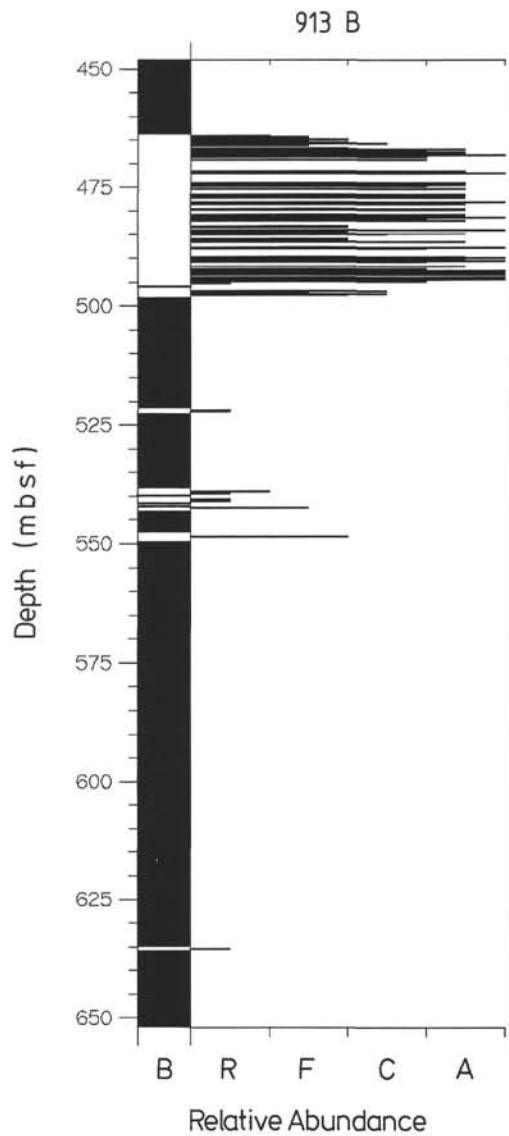


Figure 5. Diatom relative abundance in Paleogene sediments of Hole 913B, plotted on a linear depth scale. Abundance is based on smear-slide analysis. See Table 1 for definition of the abundance categories. Contourite deposit is recognized from 463.6 to 468.2 mbsf. Diatoms occurring below 539 mbsf are preserved as pyrite replacements. Barren samples or intervals are indicated in black in the left column. Data are from Table 4. The vertical scale in meters is the same as that of Figure 3.

### TAXONOMIC NOTES

*Actinocyclus ehrenbergii* group Ralfs in Prichard (1861); Schrader and Fenner (1976) pl. 14, fig. 17. (Pl. 5, Fig. 16)

*Actinoptocyclus hexagonis* var. *tenella* Schmidt in Schmidt et al. (1874) pl. 1, fig. 16

*Actinoptocyclus delicatissimus* Witt (1885) pl. 9, fig. 1. (Pl. 8, Fig. 12)

*Actinoptocyclus irregularis* Grunow in Van Heurck (1883) pl. 132, fig. 11. (Pl. 6, Figs. 10–13)

**Synonyms:** *Actinoptocyclus* sp. (triangular) Schrader and Fenner (1976) pl. 35 fig. 23 (late Eocene, Norwegian–Greenland Sea); *Actinoptocyclus* sp. (triangular) Yanagisawa and Suzuki (1987) pl. 1, figs. 3, 4 (early Oligocene, northern Japan).

Table 4. Paleogene diatom samples, depth, and abundance, Hole 913B.

Core, section, interval (cm)	Depth (mbsf)	Abundance code	Core, section, interval (cm)	Depth (mbsf)	Abundance code
151-913B-					
23R-1, 109–110	452.5	1	26R-5, 52–53	487.7	9
23R-1, 127–128	453.8	1	26R-5, 68–70	487.9	7
24R-1, 1–2	462.0	1	26R-6, 64–66	489.6	8
24R-1, 11–12	462.1	1	26R-6, 85–87	489.8	9
24R-1, 24–25	462.2	1	26R-6, 94–95	490.0	8
24R-1, 28–30	462.3	1	26R-7, 17–19	490.4	8
24R-1, 44–45	462.4	1	26R-7, 34–36	490.5	9
24R-1, 48–49	462.5	1	26R-CC	490.7	7
24R-2, 13–14	463.6	2	27R-1, 93–96	491.6	8
24R-2, 38–39	463.9	1	27R-1, 139–141	492.1	7
24R-2, 55–56	464.1	2	27R-2, 35–37	492.6	9
24R-2, 56–58	464.2	3	27R-2, 45–46	492.7	8
24R-2, 65–67	464.2	3	27R-2, 82–83	492.9	9
24R-2, 102–103	464.5	3	27R-2, 85–86	492.9	9
24R-2, 127–128	464.8	4	27R-2, 93–96	493.0	9
24R-2, 137–138	464.9	3	27R-2, 120–121	493.4	9
24R-2, 138–140	465.1	3	27R-3, 28–30	494.0	9
24R-3, 16–17	465.2	2	27R-3, 37–37	494.2	9
24R-3, 29–31	465.3	3	27R-3, 55–56	494.3	9
24R-3, 40–41	465.4	4	27R-3, 56–57	494.6	4
24R-3, 65–66	465.7	5	27R-3, 96–97	494.7	7
24R-3, 100–101	466.0	3	27R-3, 137–138	495.1	2
24R-3, 110–112	466.1	3	27R-4, 9–11	495.3	1
24R-4, 23–24	466.7	5	27R-4, 127–129	499.5	5
24R-4, 28–30	466.8	5	27R-5, 10–11	496.8	6
24R-4, 43–45	466.9	8	27R-5, 56–58	497.3	4
24R-4, 54–56	467.0	7	27R-5, 76–78	497.5	6
24R-4, 87–88	467.4	7	27R-5, 80–81	497.6	5
24R-4, 94–95	467.5	8	27R-5, 147–148	498.2	1
24R-4, 126–127	467.7	8	27R-6, 81–83	499.0	1
24R-4, 149–150	468.0	7	27R-6, 86–88	499.1	1
24R-5, 4–6	468.0	7	27R-CC	500.3	1
24R-5, 9–11	468.1	5	28R-1, 70–71	501.0	1
24R-5, 18–20	468.2	9	28R-1, 84–86	501.1	1
24R-5, 36–37	468.4	7	28R-1, 102–103	501.3	1
24R-5, 54–56	468.5	7	28R-2, 27–30	502.1	1
24R-5, 107–108	469.1	7	28R-2, 47–48	502.3	1
24R-CC	471.6	8	28R-2, 99–100	502.8	1
25R-1, 16–17	471.8	8	28R-2, 136–137	503.1	1
25R-1, 28–30	471.9	9	28R-3, 23–24	503.5	1
25R-1, 43–44	472.0	8	28R-3, 82–84	504.1	1
25R-1, 90–91	474.1	8	28R-4, 16–17	505.0	1
25R-2, 102–104	474.2	8	28R-4, 68–69	505.5	1
25R-2, 121–123	474.4	8	28R-4, 105–106	505.9	1
25R-2, 131–132	474.5	7	28R-6, 6–8	508.4	1
25R-3, 13–15	474.7	7	29R-1, 65–67	510.6	1
25R-3, 60–61	475.2	8	29R-2, 103–104	512.4	1
25R-3, 98–100	475.6	7	29R-3, 48–49	513.4	1
25R-4, 34–35	476.4	8	29R-3, 84–86	513.7	1
25R-4, 65–67	476.7	8	29R-4, 122–123	515.6	1
25R-4, 91–92	477.0	8	29R-4, 150–151	515.9	1
25R-5, 49–50	478.0	9	30R-1, 71–72	520.2	1
25R-5, 62–63	478.2	8	30R-2, 88–89	521.9	2
25R-5, 101–103	478.5	8	30R-2, 93–94	522.0	1
25R-6, 49–50	479.5	8	30R-5, 43–44	525.9	1
25R-6, 71–72	479.8	8	32R-1, 20–21	539.0	3
25R-7, 38–40	481.0	8	32R-1, 54–55	539.3	2
25R-7, 52–53	481.1	8	32R-1, 150–151	540.3	1
25R-7, 67–69	481.2	8	32R-2, 27–28	540.6	2
25R-CC	481.3	9	32R-2, 65–66	541.0	2
26R-1, 29–30	481.4	8	32R-2, 73–74	541.1	1
26R-1, 78–79	481.8	7	32R-2, 85–86	541.3	1
26R-1, 85–86	482.0	8	32R-3, 61–62	542.4	4
26R-2, 34–35	483.1	5	32R-4, 30–31	543.6	1
26R-2, 63–64	483.4	5	32R-CC	548.4	5
26R-2, 111–114	484.0	9	33R-1, 8–9	548.5	2
26R-2, 146–147	484.4	5	34R-CC	567.7	1
26R-3, 4–6	484.7	8	36R-CC	587.1	1
26R-3, 30–32	484.9	6	38R-CC	606.4	1
26R-3, 132–133	485.9	5	41R-CC	635.4	2
26R-4, 37–39	486.2	5	42R-CC	645.1	1
26R-4, 64–65	486.4	8	43R-CC	654.7	1
26R-4, 70–72	486.5	7	45R-CC	664.4	1

Note: Abundance codes defined in Table 1. Not all barren samples tabulated.

**Comments:** This taxon is closely akin to *A. undulatus* and may not justify independent species rank. Nevertheless, it is clearly identifiable and seems to have widespread distribution and stratigraphic utility, therefore the name is retained.

*Actinoptocyclus senarius* (Ehrenberg) Ehrenberg (1843) pl. 27, fig. 27

*Actinoptocyclus thumii* (Schmidt) Hanna (1932) pl. 4, figs 3, 4; Dzinoridze et al. (1978) pl. 12, figs. 1–3



- Actinopychus undulatus* (Bailey) Ralfs in Prichard (1861) pl. 5, fig. 88; Dzinoridze et al. (1978) pl. 6, figs. 1–5, pl. 12, fig. 4. (Pl. 6, Fig. 16)
- Actinopychus* sp. A (Pl. 8, Fig. 1)
- Actinopychus* spp.
- Amphitetras* sp. (Pl. 8, Fig. 6)  
**Synonym:** *Biddulphia decepiens* sensu Gleser (1968) pl. 2, fig. 7.
- Anaulus* sp. (Pl. 8, Fig. 16)
- Anuloplicata ornata* (Grunow) Gleser in Gleser et al. (1992) pl. 49, figs. 1–6
- Arachnodiscus* spp.
- Asterolampra affinis* Greville (1862) pl. 7, figs. 7–9; Hendy and Sims (1990) pl. 3, figs. 13–15. (Pl. 6, Fig. 5)
- Asterolampra insignis* Schmidt (1874) pl. 137, figs. 1–3. (Pl. 6, Figs. 4, 20)
- Asterolampra punctifera* (Grove) Hanna (1927) pl. 17, fig. 3. (Pl. 6, Fig., 15; Pl. 8, Fig. 13)
- Asterolampra* spp. (fragments)
- Asteromphalus flabellatus* (Brébisson) Greville (1859) pl. 7, figs. 4, 5. (Pl. 6, Fig. 7)  
**Synonym:** *Asteromphalus robusta?* sensu Schrader and Fenner (1976) pl. 21, fig. 9.
- Asteromphalus oligocenicus* Schrader and Fenner (1976) pl. 21, figs. 8, 13, 14; pl. 28, fig. 1. (Pl. 6, Fig. 14)
- Asteromphalus?* affn. *symmetricus?* Schrader and Fenner (1976) pl. 21, figs. 7, 10–12. (Pl. 8, Fig. 13)  
**Comments:** Only two specimens were observed and identification is not certain. If the tentative identification is correct, then the stratigraphic range of *A. symmetricus* is extended downward into the lower Oligocene.
- Aulacodiscus* spp.
- Azpeitia oligocaenica* (Jousé) Sims in Fryxell et al. (1986) pl. 16, figs. 6–8. (Pl. 5, Fig. 6)
- Azpeitia tuberculata* var. *atlantica* (Gleser and Jousé) Sims in Fryxell et al. (1986) (Pl. 6, Fig. 1)  
**Basionym:** *Coscinodiscus tuberculatus* var. *atlantica* Jousé (1973) pl. 1, figs. 14–18; Schrader and Fenner (1976) pl. 14, fig. 4; pl. 29, figs. 3, 5, 6, 12, 13.
- Biddulphia* spp.
- Brightwellia* sp. (Pl. 8, Fig. 5)
- Cavitatus jouseanus* (Sheshukova) Williams (1989) p. 260; Akiba et al. (1993) fig. 6: 19, 20. (Pl. 2, Figs. 18–20)  
**Basionym:** *Synedra jouseana* Sheshukova-Poretzkaya (1962) fig. 4.
- Cestodiscus pulchellus* var. *novazealandica* Grove in Schmidt (1890) pl. 148, fig. 7; pl. 163, figs. 8, 10. (Pl. 5, Fig. 3)
- Cestodiscus* sp. A (Pl. 5, Figs. 2, 8, 12, 13)  
**Synonyms:** *Cestodiscus muhinae* (sic) Schrader and Fenner (1976) pl. 29, fig. 4 (not pl. 27, figs. 11, 12); *Cestodiscus* sp. 9 Baldauf and Monjanel (1989) pl. 1, figs. 2, 5; pl. 2, fig. 9  
**Comments:** Differs from *C. mukhinae* Jousé in pattern of areolae and marginal structure, but may be closely related.
- Cestodiscus* sp. B (Pl. 5, Figs. 4, 5)  
**Synonym:** *Cestodiscus muhinae* (sic) Schrader and Fenner (1976) pl. 27, figs. 11, 12 (not pl. 29 fig. 4). Cells small, finely areolate.
- Cestodiscus* sp. C (Pl. 5, Figs. 7, 11)  
**Comments:** Cells small, coarse, with slight central depression.
- Chaetoceros* spp.  
**Comments:** dominantly resting spores and or setae.
- Chasea* spp.
- Clavícula polymorpha* Grunow and Pantocsek in Pantocsek (1886) p. 37. (Pl. 2, Fig. 21)  
**Synonym:** *Synedra polymorpha* Schrader (1969).
- Cocconeis* spp.
- Coscinodiscus* aff. *tenerrimus* Dzinoridze et al. (1978) pl. 3, figs. 4a, b. (Pl. 7, Fig. 1)
- Coscinodiscus bulliens* Schmidt (1878) in Schmidt et al. (1878) pl. 61, fig. 11
- Coscinodiscus marginatus* Ehrenberg (1854) pl. 18, fig. 44
- Coscinodiscus oligocenicus* Jousé (1973) pl. 1, figs. 6–8, 16. (Pl. 8, Fig. 7)
- Coscinodiscus radiatus* Ehrenberg (1841) pl. 3, figs. 1a–c
- Coscinodiscus* spp.  
**Comments:** Includes several rare large, long-ranging (extant or non-age-diagnostic) taxa.
- Costopyxis trochlea* (Hanna) Strelnikova in Gleser et al. (1992) pl. 32, figs. 17, 18. (Pl. 8, Figs. 8–10)  
**Basionym:** *Trochosira trochlea* Hanna (1927) pl. 21, figs. 8, 9.  
**Synonym:** *Pterotheca* sp. 1 of Schrader and Fenner (1976) pl. 35, figs. 15–19.
- Craspedodiscus moelleri* Schmidt (1893) pl. 184, fig. 3 (only fragments encountered)
- Craspedodiscus?* sp. A (Pl. 5, Fig. 10)
- Cyclotella* sp. A (Pl. 8, Fig. 15)  
**Comments:** Compare with “Genus and Species unidentified 1” of Schrader and Fenner (1976) pl. 15, fig. 4., and *Cyclotella* affn. *ovata* Tynni (1982) pl. 17, fig. 4.
- Cymatosira compacta* Schrader and Fenner (1976) pl. 8, figs. 22, 25; pl. 25, figs. 30–32. (Pl. 3, Fig. 7)
- Cymatosira praecompecta* Schrader and Fenner (1976) pl. 8, figs. 19, 23, 24; pl. 25, figs. 14, 29. (Pl. 3, Figs. 2–6, 9–13)
- Cymatosira* sp. A  
**Synonyms:** “Genus and Species unidentified 10” of Schrader and Fenner (1976) pl. 22, fig. 8; *Cymatosira* sp. of Schrader and Fenner (1976) pl. 25, figs. 25, 26. (Pl. 3, Figs. 14–16).
- Delphineis* spp.
- “*Detonia?*” sp. A. This and the following species (“*Detonia?*” sp. B) belong to an undescribed genus in the family Rhaphoneidaceae. The genus is closely related to *Detonia*, *Diplomenora*, and *Rhaphoneis*. Further taxonomic investigation is in progress. (Pl. 2, Figs. 1–5).
- “*Detonia?*” sp. B. See above. (Pl. 2., Figs. 10, 11).
- Diploneis* spp.
- Distephanosira architecturalis* (Brun) Gleser et al. (1992) (Pl. 4, Figs. 14–17)  
**Basionym:** *Melosira architecturalis*.  
**Comments:** Has been referred to as *Paralia architecturalis* in the literature (e.g., Harwood and Maruyama, 1992), although there has never been a formal transfer to that genus. The genus *Distephanosira* was recently erected to include this taxon (Gleser et al., 1992).
- Drepanotheca bivittata* (Grunow and Pantocsek) Schrader (1969) (Pl. 2, Fig. 15)  
**Basionym:** *Eunotigramma bivittata* Grunow and Pantocsek in Pantocsek (1886) pl. 26, fig. 247.
- Endictya* spp.
- Eunotogramma* spp. (Pl. 2, Fig. 25)
- Eurossia irregularis* (Greville) Sims in Mahood et al. (1993) figs. 23, 24, 31–36, 65, 74, 75. (Pl. 6, Fig. 1)  
**Basionym:** *Triceratium irregulare* Greville (1864) pl. 12, fig. 5.  
**Synonyms:** *Triceratium polymorphus* Harwood and Maruyama (1992) pl. 1, figs. 1, 2; *Triceratium* sp. 2 Baldauf and Monjanel (1989) pl. 1, fig. 9; *Triceratium schultzi* Jousé sensu Schrader and Fenner (1976) pl. 27, figs. 14, 15.
- Eurossia irregularis* var. *incurvatus* Sims in Mahood et al. (1993) figs. 37–42, 66, 67. (Pl. 6, Fig. 2)  
**Synonyms:** *Triceratium macroporum* Hajós sensu Gombos and Ciesielski (1983) pl. 17, fig. 6; *Triceratium* cf. *megapora* Hajós sensu Baldauf and Monjanel (1989) pl. 1, fig. 10; *Triceratium latepes* Fenner in Schrader and Fenner (1976) pl. 26, fig. 12.
- “*Fragilaria*” spp., including “*Fragilaria*” sp. A

- Comments:** The following two taxa are assigned to the genus *Fragilaria* although it is recognized that their proper positions are likely elsewhere, requiring further investigation. (Pl. 2, Fig. 26).
- "*Fragilaria*" *miocenica* Jousé (after Gleser et al., 1974, pl. 64, figs. 11A, B). (Pl. 2, Fig. 27)
- Gephyria* sp.
- Glyphodiscus* sp.
- Goniothecium coronatum* Fenner in Schrader and Fenner (1976) pl. 44, fig. 7
- Goniothecium decoratum* Brun (1891) pl. 37, fig. 6; Schrader and Fenner (1976) pl. 6, figs. 3, 5, pl. 37, figs. 1–5, 11–14; Dzinoridze et al. (1978) pl. 15, figs. 1–5
- Goniothecium odontella* Ehrenberg (1854) pl. 18, fig. 94; pl. 33, fig. 15; Schrader and Fenner (1976) pl. 6, figs. 1, 2, 4
- Grammatophora* spp. (Pl. 2, Fig. 14)
- Grunoviella gemmata* (Grunow) Van Heurck (1896) (Pl. 1, Fig. 1)
- Comments:** Van Heurck (1896) described this genus to account for *Sceptroneis*? *gemmata* Grunow. Hustedt (1959) later transferred it to *Opephora*. According to the generic description in Round et al. (1990), *Opephora* lacks marginal spines, which would thus exclude *G. gemmata*. *G. gemmata* is often still assigned to *Sceptroneis* (e.g., Fenner, 1994), but structural differences in the areolae exclude it from this genus.
- Hemiaulus danicus* Grunow in Cleve and Möller (1878); Grunow (1884) pl. 2, fig. 40
- Hemiaulus dissimilis* Grove and Sturt (1887) pl. 13, fig. 43
- Hemiaulus elegans* (Heiberg) Grunow (1884) p. 14. (Pl. 7, Fig. 6)
- Hemiaulus horridus* group (Pl. 7, Figs. 4, 5)
- Hemiaulus hostilis* Heiberg (1863) pl. 1, fig. 11
- Hemiaulus incisus* Hajós (1976) pl. 23, figs. 4–9. (Pl. 7, Figs. 7, 12, 15, 16)
- Hemiaulus kittonii* Grunow in Van Heurck (1883) pl. 106, figs. 6–9; Schrader and Fenner (1976) pl. 10, fig. 19
- Hemiaulus polycistinatorum* Ehrenberg (1854) pl. 36, figs. 43a, b. (Pl. 7, Fig. 13)
- Hemiaulus* spp.
- Hyalodiscus subtilis* Bailey (1854) pl. 1, fig. 12
- Hyalodiscus* spp.
- Isthmia* sp.
- Kannoa* sp. (Pl. 2, Fig. 12)
- Licmophora*? sp. (Pl. 4, Fig. 21)
- Lithodesmium rotunda* Schrader in Schrader and Fenner (1976) pl. 11, fig. 5
- Mastagloia* spp.
- Melosira ignota* Rubina (after Gleser et al., 1992, pl. 66, figs. 6–12; Gleser and Posnova, 1974, pl. 61, figs. 4a–4c). (Pl. 4, Figs. 10–13)
- Comments:** Not often reported, this very distinctive diatom, known mostly from Siberian Arctic deposits, is occasionally common in lower Oligocene sediments of Site 908. Areolae on the valve face are fine, arranged in a distinctive "eccentric-concentric" pattern across the valve face. Areolae are densely packed and highly ordered across the deep mantle. *M. ignota* is similar to *Distephanosira architecturalis*, but it lacks the central hyaline area of *D. architecturalis*, and linking structures are reduced in *M. ignota*. *M. ignota* has a deeper mantle than *D. architecturalis* and finer areolation on the valve face and mantle. May be synonymous with *Melosira excentrica* Pantocsek (1892; pl. 6, fig. 90). This diatom may be restricted to circum-arctic sediments. Rubina (1962) described *Melosira ignota* as occurring in nonmarine deposits, although its common occurrence at Site 908 suggests a marginal marine affinity.
- Monobrachia unicornuta* Schrader and Fenner (1976) pl. 42, figs. 13, 14. (Pl. 3, Fig. 27)
- Monobrachia* spp. (Pl. 3, Fig. 23)
- Navicula udintsevii* Schrader and Fenner (1976) pl. 22, fig. 33; pl. 24, fig. 2. (Pl. 2, Figs. 23, 24)
- Comments:** Since its description, this taxon has been shown have a bipolar distribution (e. g., Harwood and Maruyama, 1992) in late Eocene to early Oligocene sediments.
- Neodelphineis pelagica* Takano (1982); Round et al. (1990) p. 412, figs. a–i. (Pl. 2, Fig. 17)
- Synonym:** *Fragilaria voeringia* Fenner in Schrader and Fenner (1976) pl. 25, figs. 22–24.
- Comments:** This diatom fits the generic description of the marine epiphytic genus *Neodelphineis*, according to Round et al. (1990), rather than the exclusively freshwater *Fragilaria*.
- Neosynedra* sp.
- Odontotropis carinata* Grunow (1884) p. 59. (Pl. 7, Figs. 8, 14)
- Comments:** This large, distinctive neritic diatom, probably a resting spore, is well known in Paleocene to lower Eocene deposits but occurs sporadically into lower Oligocene? strata. Occurrences in Sample 151-913B-25R-CC are high enough to rule out reworking, particularly because other reworked lower Paleogene taxa are quite rare.
- Paralia crenulata* (Grunow) Gleser in Gleser et al. (1992) pl. 41, figs. 1–8. (Pl. 4, Figs. 23, 24)
- Basionym:** *Paralia sulcata* var. *crenulata* Grunow (1884) pl. 5, fig. 34.
- Synonym:** *Melosira sulcata* var. *crenulata*.
- Paralia siberica* Schmidt (1892) pl. 177, figs. 12–22.
- Comments:** Rare in Hole 908A, tabulated with *Paralia crenulata*.
- Paralia sulcata* (Ehrenberg) Cleve (1873) p. 7
- Pleurosigma planktonica* Schrader in Schrader and Fenner (1976) pl. 5, fig. 25
- Porothea danica* (Grunow) Fenner (1994) pl. 4, figs. 16, 17; pl. 15, figs. 1–6
- Praecymatosira* sp. (Pl. 3, Fig. 8)
- Pseudopodosira bella* Gleser and Posnova (1964) fig. 1
- Pseudopodosira* spp.
- Pseudopyxilla* spp.
- Comments:** At least eight described *Pseudopyxilla* species are present, but many or most may be resting spores of other taxa (See Homann, 1991). *Pseudopyxilla* species are not differentiated in this study.
- Pseudostictodiscus picus* Hanna (1927) pl. 3, figs. 1–4; Schrader and Fenner (1976) pl. 35, figs. 25, 26. (Pl. 6, Fig. 8)
- Pseudotriceratium cheneveri* (Meister) Gleser et al. (1974); Strelnikova (1960) pl. 9, fig. 6
- Pseudotriceratium radiosoreticulatum* Grunow in Van Heurck et al. (1883) pl. 112, fig. 5. (Pl. 6, Fig. 3)
- Synonym:** *Pseudotriceratium* affn. *cheneveri* Schrader and Fenner (1976) pl. 26, figs. 6, 8, 9.
- Pteriptera* spp.
- Pterotheca aculeifera* Grunow in Van Heurck (1882), Van Heurck (1896) pl. 430, fig. 151. (Pl. 8, Fig. 11)
- Pterotheca* spp.
- Pyxilla oligocaenica* Jousé (1955) pl. 6, figs. 5, 6; pl. 7, figs. 3, 4. (Pl. 3, Fig. 17)
- Synonym:** *Pyrgopyxis oligocaenica* Schrader and Fenner (1976) pl. 43, figs. 20, 27 (see discussion in Gombos and Ciesielski, 1983).
- Pyxilla oligocaenica* var. *tenuis* Jousé (1955) pl. 6, figs. 4, 7; pl. 7, figs. 1–2. (Pl. 3, Fig. 18)
- Synonym:** *Pyrgopyxis oligocaenica* Schrader and Fenner (1976) pl. 43, fig. 18.
- Rhabdonema* sp.
- Rhaphoneis* affn. *amphiceros* (Pl. 2, Figs. 7, 8)
- Comments:** Strongly capitate. Structural features of areolae and labiate processes similar to *R. amphiceros* (Ehrenberg) Ehrenberg (1844).

- Rhaphoneis angulata* Fenner in Schrader and Fenner (1976) pl. 7, fig. 18. (Pl. 2, Fig. 9)
- Rhaphoneis elongata* (Schrader) Andrews (1975) pl. 1, fig. 2
- Rhaphoneis* spp.
- Rhizosolenia oligocaenica* Schrader (1976) pl. 9, fig. 7. (Pl. 3, Figs. 28, 29)
- Synonym:** *Rhizosolenia gravida* Gombos and Ciesielski (1983), pl. 11, figs. 1–7; Fenner (1985) pl. 11, fig. 18.
- Rhizosolenia oligocaenica* var. *styliforma* n. var. (Pl. 3, Figs. 24–26)
- Description:** The apical spine of *Rhizosolenia oligocaenica* var. *styliforma* n. var. differs from that of *Rhizosolenia oligocaenica* Schrader by the presence of winglike siliceous projections that reach about two-thirds from the base of the spine to the tip. The wing is thicker and wider on one side of the spine than the other. Although no whole valves were observed, the size, shape, and areolar pattern of the deep *Rhizosolenia* mantle follow that of *R. oligocaenica* early in its range.
- Holotype:** (RPS95-151-V1), Sample 151-908A-21X-3, 30–31 cm, Pl. 3, Fig. 24.
- Rhizosolenia oligocaenica* var. A. (Pl. 3, Figs. 21, 22)
- Comments:** Similar to *Rhizosolenia oligocaenica* Schrader, except that the apical spine is large and strongly curved. Compare *Rhizosolenia* sp. 1 of Fenner (1977) pl. 20, fig. 9.
- Rhizosolenia palleola* Schrader and Fenner (1976) pl. 41, fig. 11
- “*Rhizosolenia?*” spp., including “*Rhizosolenia?*” sp. A (Pl. 3, Figs. 20, 30)
- Comments:** The taxa below referred to as “*Rhizosolenia?*” are in a problematic group, probably related to *Proboscia* Sündstrom, and certainly not related to the modern concept of *Rhizosolenia* Ehrenberg. This is a large group, with a long stratigraphic record and many formally or informally described fossil species. Taxonomic evaluation is further complicated by the fact that whole specimens are rarely preserved, which may lead to confusion with fragments of *Riedelia* or other genera. Detailed taxonomic evaluation of this genus and related or morphologically similar genera is badly needed. For the present report, in an effort to avoid further complications, *Rhizosolenia* is retained for identification purposes.
- “*Rhizosolenia?*” *pokrovskayae* (Jousé) Strelnikova (1964) pl. 28, figs. 1–9; Schrader and Fenner (1976) pl. 7, figs. 8, 9. (Pl. 3, Fig. 19)
- Riedelia claviger* (Schmidt) Schrader and Fenner (1976) pl. 41, figs. 6–8, 9; pl. 42, figs. 3, 4, 10, 11, 15. (Pl. 3, Fig. 31)
- Basionym:** *Hemiaulus claviger* Schmidt (1888) pl. 143, figs. 5, 6.
- Riedelia* spp.
- Rocella praenitida* (Fenner) Fenner in Kim and Barron (1986) pl. 4, fig. 3. (Pl. 7, Figs. 9–11)
- Basionym:** *Coscinodiscus praenitidus* Fenner in Schrader and Fenner (1976) pl. 14, figs. 7–9, 12; pl. 27, fig. 8; pl. 35, fig. 24; pl. 36, fig. 5.
- Rouxia* sp. A
- Comments:** Resembles *R. obesa*, a widespread lower Oligocene taxon described from DSDP Leg 38 material (Schrader and Fenner, 1976), but *Rouxia* sp. A has a more tapered outline. (Pl. 2, Fig. 22).
- Rutilaria areolata* Sheshukova in Gleser et al. (1974) pl. 33, fig. 3a, b; Schrader and Fenner (1976) pl. 8, figs. 11, 12; pl. 37, fig. 16. (Pl. 3, Fig. 1)
- Sceptroneis fennerae* n. sp. (Pl. 1, Figs. 3–6)
- Description:** Valve face slightly arched, apices capitate, center swollen. Small but prominent labiate process at center of head pole, beneath an apical pore field. Pore field is surrounded at the apex by a single row of punctae that are supported by thick siliceous struts. Foot pole rounded, headpole flattened to broadly rounded, particularly in smaller specimens. Length overall, 22–44  $\mu\text{m}$ , width in the center 9–11  $\mu\text{m}$ . Head pole 6–7  $\mu\text{m}$  wide, foot pole 5–6  $\mu\text{m}$  wide. Areolae punctate with complex rotae, 5 in 10  $\mu\text{m}$ ; striae, 4 in 10  $\mu\text{m}$ . Closely related to *S. humuncia* var. *rondipoda*. The *Sceptroneis* species complex includes many related other forms (e.g., Pl. 1, Figs. 2, 15), but the characteristics of *S. fennerae* sensu stricto are consistent within the population.
- Holotype:** (RPS95-151-S1), Sample 151-908A-25R-CC, Pl. 1, Fig. 4. Named in honor of Julianne Fenner.
- Sceptroneis grunowii* Anissimova in Proschkina-Lavrenko (1949) p. 217. (Pl. 1, Figs. 25, 26)
- Comments:** Slender outline in the Eocene, becoming progressively broader through the early Oligocene. *S. pupa* diverges from the *S. grunowii* lineage in the early late Oligocene.
- Sceptroneis humuncia* var. *rondipoda* n. var. (Pl. 1, Figs. 7–9, 14)
- Description:** The main morphologic difference between *S. humuncia* var. *rondipoda* and *S. humuncia* Schrader and Fenner (1976, pl. 2, figs. 5–7; pl. 24, figs. 17, 26) sensu stricto (s.s.), is that the foot pole tapers to a rounded apex, instead of the flattened to concave foot pole apex of *S. humuncia* s.s. The minimum and maximum length of *S. humuncia* var. *rondipoda* (75–135  $\mu\text{m}$ ) both exceed the published limits for *S. humuncia* (90–106  $\mu\text{m}$ ). The head pole of *S. humuncia* var. *rondipoda* is often less concave than that of the nominate variety. Specimens are slightly to moderately twisted. Micrographs of the nominate variety in Schrader and Fenner (1976) suggest that twisting occurs in some specimens of *S. humuncia* s.s. Striae, punctae, and general shape are consistent features in the lineage. *S. humuncia* var. *rondipoda* occurs further down in the stratigraphic column than *S. humuncia* s.s., implying that *S. humuncia* evolved from variety *rondipoda*. *S. humuncia* var. *rondipoda* is related to *Sceptroneis fennerae*, both morphologically and stratigraphically.
- Holotype:** (RPS95-151-V2), Sample 151-908A-25X-CC, Pl. 1, Fig. 7.
- Sceptroneis mayenica* Fenner in Schrader and Fenner (1976) pl. 22, figs. 22–25; pl. 23, figs. 1–4; pl. 25, figs. 6, 8. (Pl. 1, Fig. 27)
- Sceptroneis pesplanus* Schrader and Fenner (1976) pl. 22, figs. 30, 31; pl. 25, figs. 10, 11
- Sceptroneis praecaducea* Hajós and Stradner (1975) pl. 13, figs. 13, 14; pl. 14, figs. 1–4. (Pl. 1, Figs. 10, 11, 16)
- Comments:** All specimens observed have a strongly twisted valve. This is a consistent enough feature that varietal status may be warranted.
- Sceptroneis propinqua* Schrader and Fenner (1976) pl. 4, figs. 1–8. (Pl. 2, Fig. 6)
- Sceptroneis pupa* Schrader and Fenner (1976) pl. 22, figs. 17–21; pl. 24, figs. 11–13. (Pl. 1, Figs. 22, 23)
- Sceptroneis pupa/grunowii* transitional forms. (Pl. 1, Figs. 18–21)
- Sceptroneis talwanii* Schrader and Fenner (1976) pl. 24, figs. 28–30
- Sceptroneis tenue* Schrader and Fenner (1976) pl. 3, figs. 2–4; pl. 25, figs. 12, 22, 24. (Pl. 1, Fig. 13)
- Sceptroneis* affn. *tenue*
- Comments:** Found almost exclusively as fragments; thus, identification is often uncertain.
- Sceptroneis vermiformis* Schrader in Schrader and Fenner (1976) pl. 22, fig. 29; pl. 25, figs. 1–4
- Sceptroneis* spp. (Pl. 1, Figs. 12, 24; Pl. 2, Fig. 16)
- Sheshukovia* spp.
- “*Skeletonema*” *utriculosa* Brun (1891) pl. 11, figs. 1a, b; Sims (1994) figs. 33–36, 51. (Pl. 4, Fig. 26)
- Comments:** See Sims (1994) for a discussion of the taxonomic position of this diatom.
- Solium exculptum* Heiberg (1863) pl. 4, fig. 10
- Comments:** Documented as reworked specimens.
- Stellarima* spp.
- Stephanogonia polycantha* Forti (1913) pl. 12, fig. 11
- Stephanopyxis turris* group (Greville and Arnot) Ralfs in Pritchard (1861) pl. 5, fig. 74
- Stephanopyxis* spp.
- Comments:** Category includes *S. barbadensis*, *S. hyalomarginata*, *S. grossecellulata*, *S. grunowii*, *S. marginata*, *S. schenkii?*, *S. turris*, and possibly others.
- Stictodiscus kittonianus* Greville (1861) pl. 10, figs. 2, 3
- Stictodiscus nitidus* (Grove and Sturt) Schmidt (1888) pl. 131, figs. 7, 8. (Pl. 5, Fig. 14)
- “*Synedra?*” sp. 1 of Schrader and Fenner (1976) pl. 24, figs. 7, 8. (Pl. 2, Fig. 13)

*Tetracyclus* spp.

*Thalassiosira dubiosa* Schrader and Fenner (1976) (Pl. 4, Figs. 6, 7)

**Comments:** This taxon is closely related to *T. mediaconvexa*, though is much smaller. Perhaps seasonal dimorphism of the same species (see discussion of *T. nansenii*)?

*Thalassiosira mediaconvexa* Schrader and Fenner (1976) pl. 36, fig. 1. (Pl. 4, Figs. 8, 9)

*Thalassiosira nansenii* n. sp. (Pl. 4, Figs. 1–5)

**Description:** Originally described as *Thalassiosira* affn. *irregulata* by Schrader and Fenner (1976) pl. 20, fig. 13, from lower Miocene Norwegian-Greenland Sea strata, along with *T. irregulata* Schrader s.s. Subsequently *T. affn. irregulata* has been reported from high-latitude lower Oligocene to lower Miocene strata from the Norwegian-Greenland Sea (Schrader and Fenner, 1976; this study), the North Pacific (Barron, 1985) and Bering Sea (Barron, 1985; Baldauf and Barron, 1987, as *Thalassiosira* sp. aff. *T. mediaconvexa*), and the Antarctic (Harwood et al., 1989), and is sparse in low-latitude sediments (Kim and Barron, 1986), whereas *Thalassiosira irregulata* s.s. is more rare and of restricted distribution. The two taxa differ considerably in morphologic characteristics. The morphologic distinctiveness, bipolar distribution and stratigraphic utility of this taxon justifies the erection of a new species. *T. nansenii* is described based on taxonomic evaluation of specimens recovered from Site 908 upper lower Oligocene to lower upper Oligocene sediments and lower Miocene diatomite clasts recovered from beneath the Ross Ice Shelf, Antarctica (Harwood et al., 1989), with reference to figures published in the above references, representing many regions and ages. *T. nansenii* is characterized by a gently convex curvature of the valve (although Barron [1985] describes *T. affn. irregulata* as flat), with a ring of small, marginal spines (occluded processes?). Areolae are irregularly shaped and arranged radially, with distinctive bifurcation about half way across the valve. More coarsely areolate specimens show a rough fasciculation. Areolae are of similar size across most of the valve, with only slight reduction in size toward the margin. One marginal labiate process is often visible in the light microscope, especially in lightly silicified but well-preserved specimens. A few strutted processes are often visible in the central area, either as a small cluster or separately, between tightly spaced areolae. The overall cell size of *T. nansenii* ranges from 11  $\mu\text{m}$  to a maximum of about 45  $\mu\text{m}$ .

Two populations of *T. nansenii* co-occur in material studied by the first author (including Oligocene sediments of ODP Site 908 (this study) and lower Miocene sediments from Antarctica [Harwood et al., 1989]). The populations are distinguished by coarse areolation (12–14 areolae in 10  $\mu\text{m}$ ), and a more fine areolation (15–18 areolae in 10  $\mu\text{m}$ ). Most of the published illustrations of *T. affn. irregulata* are of the latter type. The coarsely areolate form is far more common in Site 908 sediments, but this could be a function of preferential preservation. We speculate that the two forms may represent seasonal dimorphism (summer and winter varieties). *T. nansenii* apparently evolved from *T. mediaconvexa* in the early Oligocene (see discussion below).

*T. nansenii*, a bipolar diatom, is named for the Norwegian “bipolar” explorer F. Nansen, in honor of the centenary of his historic voyage to the Arctic (1893–1896), via the Fram Strait, aboard the research ship *Fram*.

**Holotype:** (RPS95-151-S2), Sample 151-908A-26-3, 90–91 cm, Pl. 4, Fig. 2.

*Thalassiosira nansenii/mediaconvexa* transitional forms

**Synonyms:** *Thalassiosira mediaconvexa* sensu Yanagisawa and Suzuki (1987) pl. 1, fig. 10 (lower Oligocene of northern Japan); *Thalassiosira* aff. *irregulata* sensu Baldauf and Monjanel (1989) pl. 4, fig. 2 (lower Oligocene of Labrador Sea); *Thalassiosira* sp.? cf. *mediaconvexa* of Barron and Mahood (1993) pl. 4, figs. 9, 12 (lower Oligocene of Antarctic continental shelf); *Thalassiosira mediaconvexa* of Gladkov and Barron (1995) pl. 2, figs 8, 16 (lower Oligocene of north Pacific); *Thalassiosira*? sp. 1 of Fenner (1977) pl. 3, fig. 7 (lower Oligocene of tropical Atlantic).

**Comments:** Forms transitional between *T. mediaconvexa*, an Eocene form, and the Oligocene to lower Miocene *T. nansenii* occur in lower Oligocene strata, mostly in high, but rarely in low, latitudes. This diatom has been reported in the Antarctic (Barron and Mahood, 1993),

northern Japan (Yanagisawa and Suzuki, 1987), and in the Labrador Sea (Baldauf and Monjanel, 1989), with one report in the low-latitude Atlantic (Fenner, 1977). Hole 908A records the replacement of transitional forms with exclusively *T. nansenii* s.s. in Core 151-908A-32X. Transitional forms are distinguished from *T. nansenii* s.s. by the distinctly raised center and relatively small and rounded areolae, which are characteristics of *T. mediaconvexa*. The change in slope of the valve face is about one-fourth the diameter away from the margin and is generally smooth, unlike *T. mediaconvexa* s.s., which usually has a more abrupt change in slope. Transitional forms also differ from *T. mediaconvexa* s.s. in the reduction in size and prominence of the ring of occluded(?) marginal processes and the large marginal labiate process.

*Thalassiosira* sp. A (Pl. 5, Fig. 9)

**Comments:** Rare. Note strutted processes positioned between large areolae.

*Thalassiosira* sp. B (Pl. 5, Fig. 15)

**Comments:** Rare. Note large central labiate process.

*Triceratium favus* Ehrenberg (1841) pl. 4, fig. 10

*Triceratium inconspicuum* Greville (1861) pl. 8, fig. 10; Fenner (1978) pl. 30. (Pl. 8, Fig. 4)

*Triceratium inconspicuum* var. *trilobata* Fenner (1978) pl. 30, figs. 23–26

**Synonym:** *Triceratium barbadensis* Kanaya (1957) pl. 7, figs. 1–4.

*Triceratium* spp. (Pl. 8, Figs. 2, 3)

*Trinacria excavata* Heiberg (1863) pl. 4, fig. 9

*Trinacria cornuta* (Schmidt) Sims and Ross (1988) pl. 1, figs. 1–9; pl. 12, figs. 78, 79. (Pl. 8, Fig. 14)

**Synonym:** *Trinacria excavata* forma *tetragona* Schmidt (1890) in Schmidt et al. (1890) pl. 152, figs. 26–28; Dzinoridze et al. (1978) pl. 10, fig. 5.

*Trinacria* affn. *simulacrum* Grove and Sturt (1887) pl. 13, fig. 46

**Comments:** Reworked fragments and rare whole specimens occur.

*Trochosira coronata* Schrader and Fenner (1976) pl. 29, figs. 9–11; pl. 35, figs. 7–13, 20, 21. (Pl. 4, Figs. 22, 25)

*Trochosira spinosa* Kitton (1871) pl. 14, figs. 6, 7. (Pl. 4, Figs. 18–20)

*Tubaformis* cf. *unicornis* Gombos (1983) pl. 5, figs. 1–6, pl. 6, figs. 1, 2. (Pl. 7, Figs. 2, 3)

**Comments:** Whole specimens have never been reported. This diatom has never been reported from the high northern latitudes, and has never been reported from deposits younger than middle Eocene. The high abundance of *T. cf. unicornis* in Site 913 Paleogene sediments rules out reworking from older sediments. Site 913 specimens have a large labiate process near the terminus of the “horns” (Pl. 7, Fig. 2).

*Tumulopsis fagedi* Hendy (1982) pl. 1, figs. 1–3

**Synonym:** Genus and Species unidentified 5 of Schrader and Fenner (1976) pl. 13, fig. 12.

*Xanthiopyxis panduriformis* Pantocsek (1886) pl. 29, fig. 297

*Xanthiopyxis* spp.

Incertae sedis

*Macrora stella* (Azpeitia) Hanna (1932) pl. 12, figs. 13, 14. (Pl. 6, Fig. 19)

*Macrora barbadensis* (Deflandre) Bukry (1977) pl. 2, figs. 3–8. (Pl. 6, Figs. 9, 17, 18)

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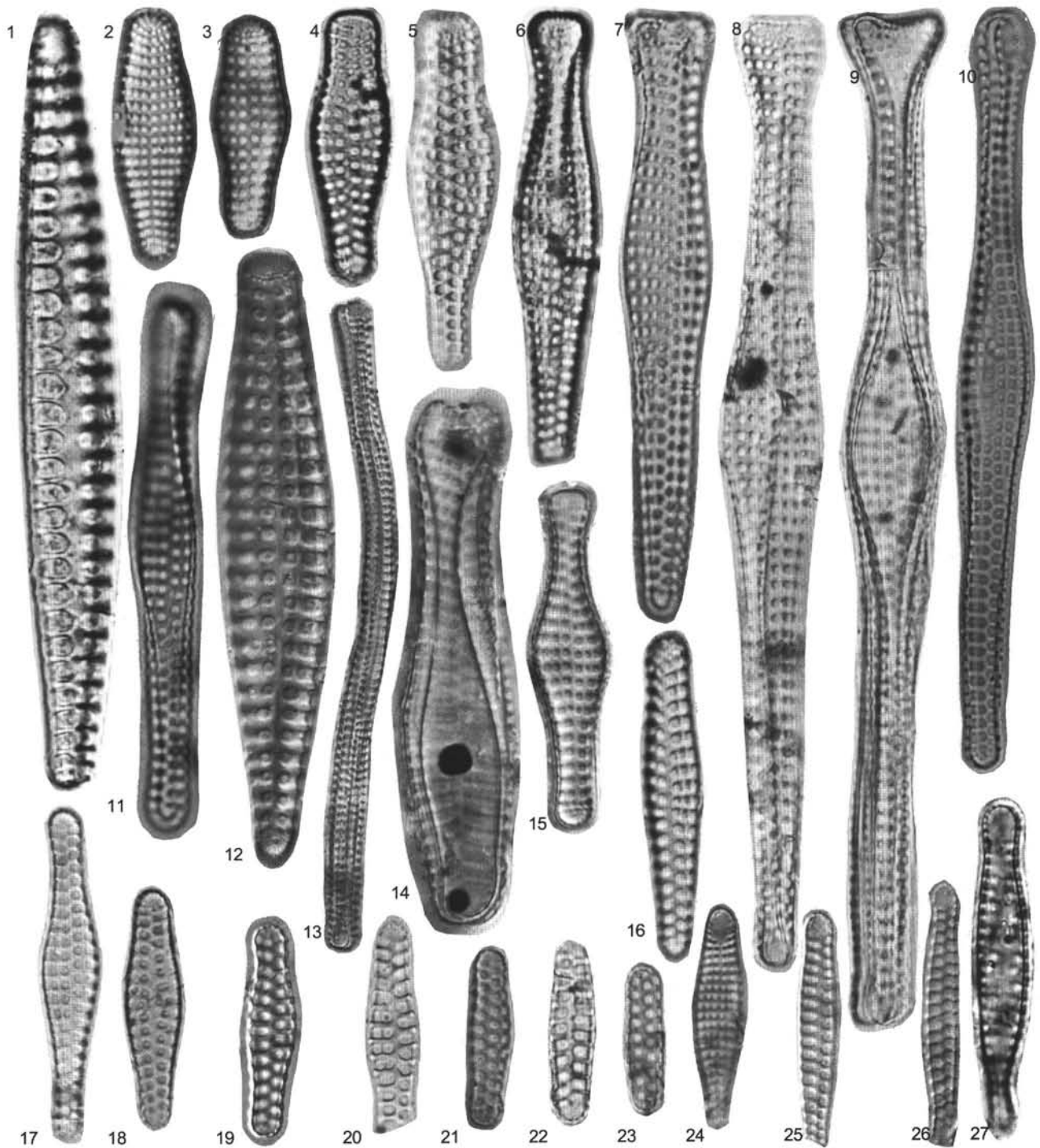


Plate 1. Paleogene diatoms, magnification 1425 $\times$  unless otherwise indicated. **1.** *Grunoviella gemmata*, Sample 151-908A-34X-2, 8–9 cm. **2.** *Sceptroneis fennerae?*, Sample 151-908A-32X-3, 88–89 cm. **3.** *Sceptroneis fennerae*, Sample 151-908A-30X-2, 6–7 cm. **4.** *Sceptroneis fennerae*, Sample 151-908A-25X-CC, holotype. **5.** *Sceptroneis fennerae*, Sample 151-908A-24X-CC. **6.** *Sceptroneis fennerae*, Sample 151-908A-26X-3, 90–91 cm. **7.** *Sceptroneis humuncia* var. *rondipoda*, holotype. Sample 151-908A-25X-CC. **8.** *Sceptroneis humuncia* var. *rondipoda*, Sample 151-908A-26X-3, 90–91 cm. **9.** *Sceptroneis humuncia* var. *rondipoda*, Sample 151-908A-21X-3, 3–4 cm. **10.** *Sceptroneis praecaducea*, note twist in the valve, Sample 151-908A-21X-5, 75–76 cm. **11.** *Sceptroneis praecaducea*, note twist, Sample 151-908A-21X-5, 75–76 cm. **12.** *Sceptroneis* sp., Sample 151-908A-32X-3, 88–89 cm. **13.** *Sceptroneis tenue*, Sample 151-908A-26X-3, 90–91 cm, 950 $\times$ . **14.** *Sceptroneis* affn. *humuncia* var. *rondipoda* (tetralogical form), Sample 151-908A-26X-3, 90–91 cm. **15.** *Sceptroneis fennerae*, Sample 151-908A-X-4, 3–4 cm. **16.** *Sceptroneis praecaducea*, Sample 151-908A-24X-CC. **17.** *Sceptroneis praecaducea*, Sample 151-908A-27X-5, 44–45 cm. **18.** *Sceptroneis pupa/grunowii* transitional form, Sample 151-908A-21X-3, 3–4 cm. **19.** *Sceptroneis pupa/grunowii* transitional form, Sample 151-908A-21X-3, 3–4 cm. **20.** *Sceptroneis pupa/grunowii* transitional form, Sample 151-908A-21X-3, 3–4 cm. **21.** *Sceptroneis pupa/grunowii* transitional form, Sample 151-908A-25X-CC. **22.** *Sceptroneis pupa*, Sample 151-908A-21X-3, 30–31 cm. **23.** *Sceptroneis pupa*, Sample 151-908A-21X-3, 30–31 cm. **24.** *Sceptroneis* sp., Sample 151-908A-25X-CC. **25.** *Sceptroneis grunowii*, Sample 151-913B-25X-CC. **26.** *Sceptroneis grunowii*, Sample 151-913B-26R-3, 4–5 cm. **27.** *Sceptroneis mayenica*, Sample 151-913B-26R-3, 4–5 cm.

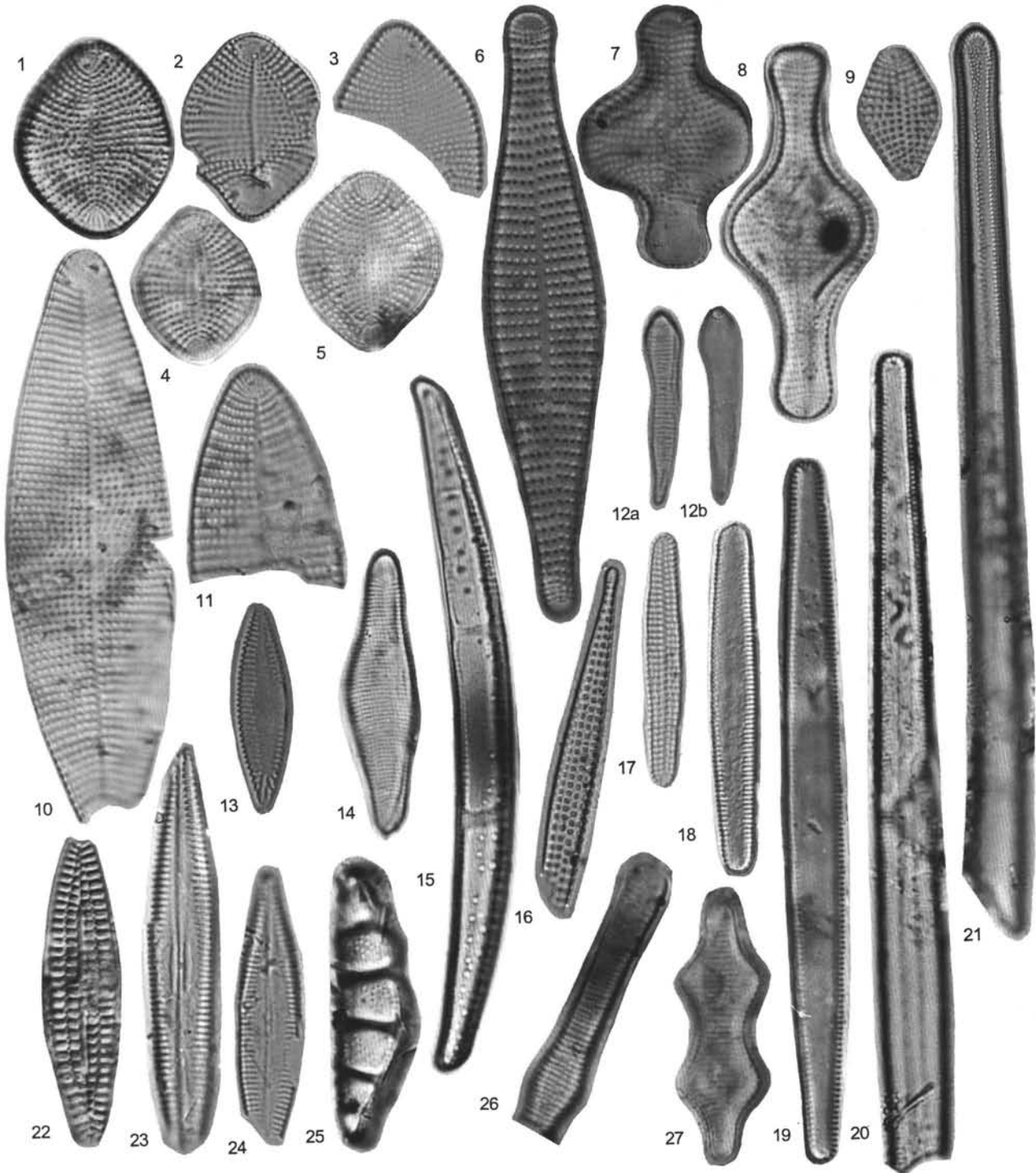


Plate 2. Paleogene diatoms, magnification 1425 $\times$  unless otherwise indicated. 1. "*Detonia?*" sp. A, Sample 151-908A-29X-5, 12–13 cm. 2. "*Detonia?*" sp. A, Sample 151-908A-29X-CC. 3. "*Detonia?*" sp. A, Sample 151-908A-29X-5, 122–123 cm. 4. "*Detonia?*" sp. A, Sample 151-908A-24X-CC. 5. "*Detonia?*" sp. A, Sample 151-908A-21X-3, 3–4 cm. 6. *Sceptroneis propinqua*, Sample 151-908A-31X-CC. 7. *Rhaphoneis* sp. A, Sample 151-908A-31X-1, 8–9 cm. 8. *Rhaphoneis* sp. A, Sample 151-908A-21X-3, 30–31 cm. 9. *Rhaphoneis angulata*, Sample 151-908A-31X-1, 8–9 cm. 10. "*Detonia?*" sp. B, Sample 151-908A-29X-CC. 11. "*Detonia?*" sp. B, Sample 151-913B-24R-CC. 12a, b. *Kannoa* sp., two levels of focus, Sample 151-908A-24X-CC. 13. "*Synedra?*" sp. 1, Sample 151-913B-24R-CC. 14. *Grammatophora* sp., Sample 151-908A-29X-CC. 15. *Drepanotheca bivittata*, Sample 151-908A-21X-5, 75–76 cm. 16. *Sceptroneis* sp., Sample 151-908A-23X-CC. 17. *Neodelphineis pelagica*, Sample 151-908A-24X-CC. 18. *Cavitatus jouseanus*, Sample 151-908A-23X-CC. 19. *Cavitatus jouseanus*, Sample 151-908A-32X-7, 46–47 cm. 20. *Cavitatus jouseanus*, Sample 151-908A-31X-1, 8–9 cm. 21. *Clavicula polymorpha*, Sample 151-913B-24R-CC, magnification 950 $\times$ . 22. *Rouxia* sp. A, Sample 151-908A-31X-CC. 23. *Navicula udintsevii*, Sample 151-913B-24R-CC. 24. *Navicula udintsevii*, Sample 151-913B-25R-CC. 25. *Eunotogramma* sp., Sample 151-908A-X-2, 6–7 cm. 26. "*Fragilaria?*" sp. A, Sample 151-908A-34X-3, 85–86 cm. 27. "*Fragilaria?*" *miocena*, Sample 151-908A-32X-7, 46–47 cm.

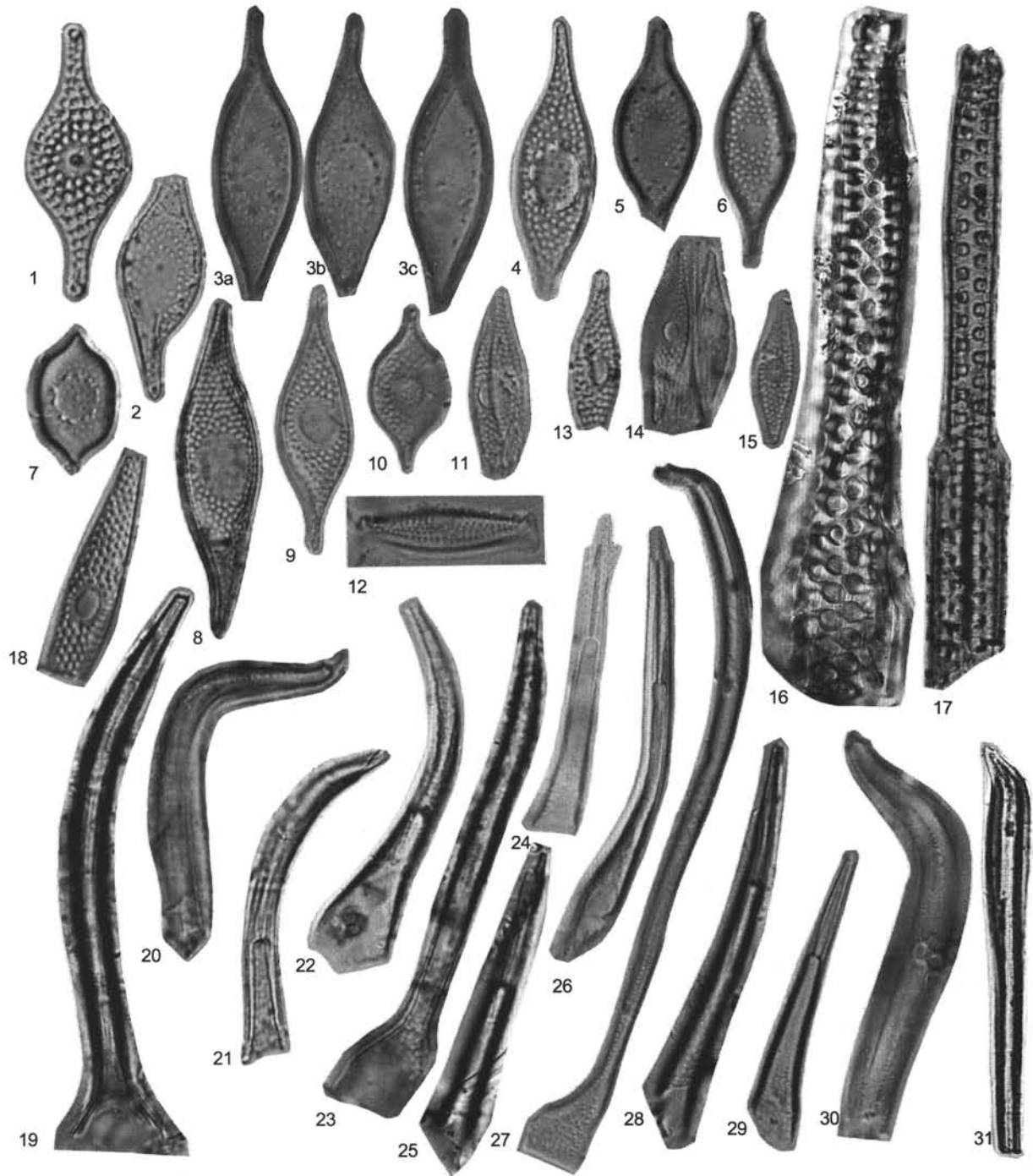


Plate 3. Paleogene diatoms, magnification 1350 $\times$  unless otherwise indicated. **1.** *Rutilaria areolata*, Sample 151-908A-25X-CC. **2.** *Cymatosira praecompacta*, Sample 151-908A-29X-CC. **3a, b, c.** *Cymatosira praecompacta*, vertical focus through three attached valves, demonstrating the considerable polymorphy in this genus, Sample 151-908A-31X-CC. **4.** *Cymatosira praecompacta*, Sample 151-908A-31X-1, 8–9 cm. **5.** *Cymatosira praecompacta*, Sample 151-908A-31X-CC. **6.** *Cymatosira praecompacta*, Sample 151-908A-31X-CC. **7.** *Cymatosira compacta*, Sample 151-908A-31X-1, 8–9 cm. **8.** *Praecymatosira* sp., Sample 151-913B-26R-7, 17–19 cm. **9.** *Cymatosira praecompacta*, Sample 151-908A-29X-CC. **10.** *Cymatosira praecompacta*, Sample 151-908A-31X-CC. **11.** *Cymatosira praecompacta*, Sample 151-908A-32X-5, 94–95 cm. **12.** *Cymatosira praecompacta*, Sample 151-908A-32X-5, 94–95 cm. **13.** *Cymatosira praecompacta*, Sample 151-908A-32X-5, 94–95 cm. **14.** *Cymatosira* sp. A, Sample 151-913B-24R-CC. **15.** *Cymatosira* sp. A, Sample 151-913B-24R-CC. **16.** *Cymatosira* sp. A, Sample 151-913B-24R-CC. **17.** *Pyxilla oligocaenica*, Sample 151-908A-27X-5, 44–45 cm, magnification 900 $\times$ . **18.** *Pyxilla oligocaenica* var. *tenuis*, Sample 151-908 21X-3, 30–31 cm, magnification 900 $\times$ . **19.** “*Rhizosolenia?*” *pokrovskayae*, Sample 151-908A-23X-5, 2–3 cm. **20.** “*Rhizosolenia?*” sp. A, Sample 151-908A-29X-5, 122–123 cm. **21.** *Rhizosolenia oligocaenica* var. A, Sample 151-908A-21X-3, 30–31 cm. **22.** *Rhizosolenia oligocaenica* var. A, Sample 151-908A-24X-4, 90–91 cm. **23.** *Monobrachia?* sp., Sample 151-913B-24R-CC. **24.** *Rhizosolenia oligocaenica* var. *styliforma*, Sample 151-908A-21X-3, 30–31 cm, holotype. **25.** *Rhizosolenia oligocaenica* var. *styliforma*, Sample 151-908A-21X-3, 30–31 cm. **26.** *Rhizosolenia oligocaenica* var. *styliforma*, Sample 151-908A-21X-3, 30–31 cm. **27.** *Monobrachia unicornuta*, Sample 151-913B-24R-CC. **28.** *Rhizosolenia oligocaenica*, Sample 151-908A-21X-5, 75–76 cm. **29.** *Rhizosolenia oligocaenica*, Sample 151-908A-21X-5, 75–76 cm. **30.** “*Rhizosolenia?*” sp. A, Sample 151-908A-30X-2, 6–7 cm. **31.** *Riedelia?* *claviger?*, Sample 151-908A-33X-CC, 900 $\times$  magnification.

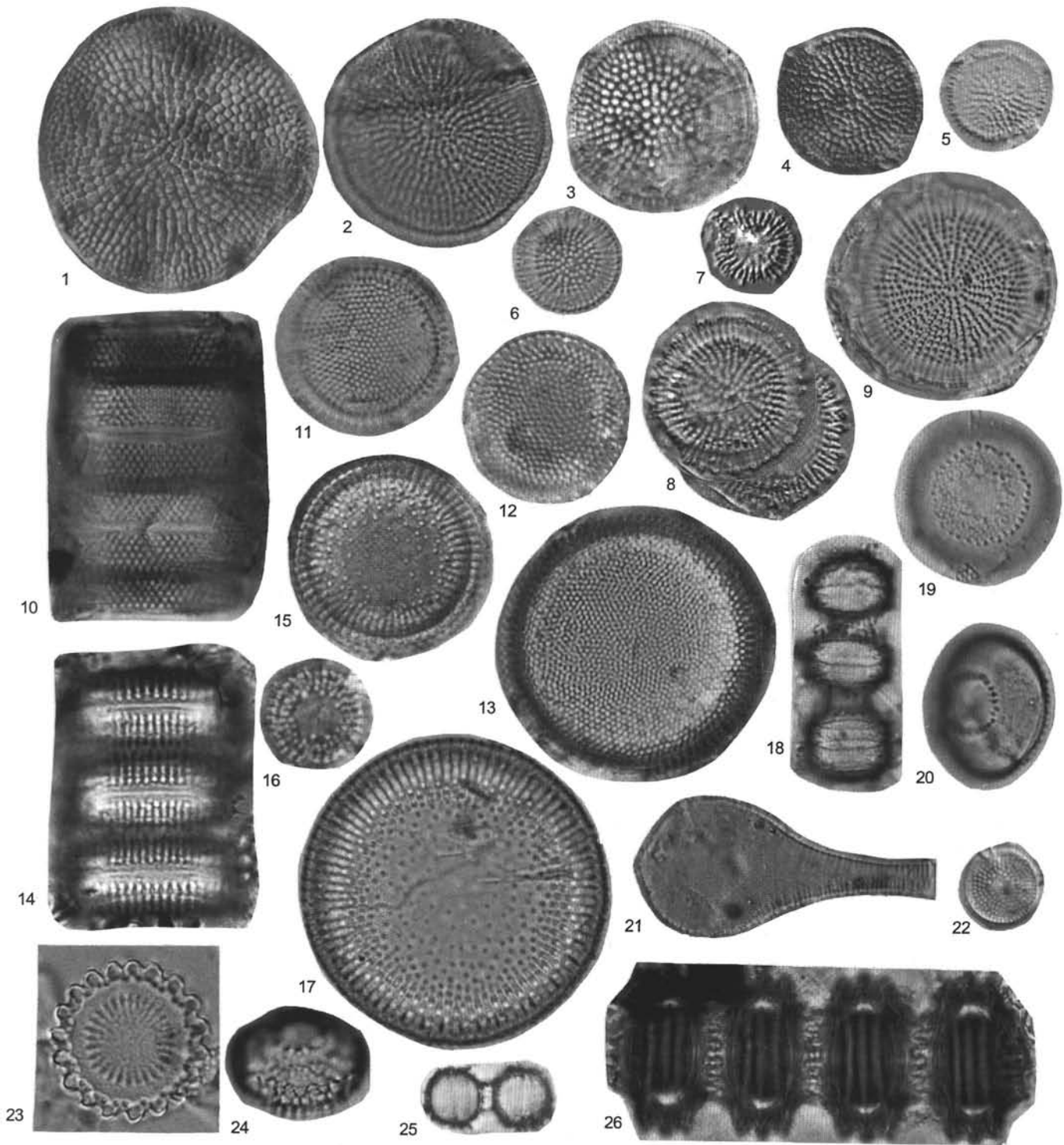


Plate 4. Paleogene diatoms, magnification 1500 $\times$  unless otherwise indicated. 1. *Thalassiosira nansenii* n. sp., Sample 151-908A-32X-3, 88–89 cm. 2. *Thalassiosira nansenii* n. sp., Sample 151-908A-21X-5, 75–76 cm. 3. *Thalassiosira nansenii* n. sp., Sample 151-908A-30X-4, 3–4 cm. 4. *Thalassiosira nansenii* n. sp., Sample 151-908A-29X-5, 122–123 cm. 5. *Thalassiosira dubiosa/mediacconvexa*, Sample 151-913B-26R-3, 4–5 cm. 6. *Thalassiosira dubiosa/mediacconvexa*, Sample 151-913B-26R-3, 4–5 cm. 7. *Thalassiosira dubiosa*, Sample 151-913B-25R-CC. 8. *Thalassiosira mediacconvexa*, Sample 151-913B-26R-3, 4–5 cm. 9. *Thalassiosira mediacconvexa*, Sample 151-913B-26R-3, 4–5 cm. 10. *Melosira ignota*, Sample 151-908A-31X-1, 8–9 cm. 11. *Melosira ignota*, Sample 151-908A-31X-1, 8–9 cm. 12. *Melosira ignota*, Sample 151-908A-32X-3, 88–89 cm. 13. *Melosira ignota*, Sample 151-908A-31X-CC. 14. *Distephanosira architecturalis*, Sample 151-913B-24R-CC. 15. *Distephanosira architecturalis*, Sample 151-908A-34X-3, 8–9 cm. 16. *Distephanosira architecturalis*, Sample 151-913B-24R-CC. 17. *Distephanosira architecturalis*, Sample 151-913B-25R-5, 49–50 cm. 18. *Trochosira spinosa*, Sample 151-908A-21X-3, 30–31 cm. 19. *Trochosira spinosa*, Sample 151-908A-24X-CC. 20. *Trochosira spinosa*, Sample 151-908A-21X-3, 30–31 cm. 21. *Licmophora?* sp., Sample 151-908A-26X-3, 90–91 cm. 22. *Trochosira coronata*, Sample 151-913B-25R-CC. 23. *Paralia crenulata*, Sample 151-908A-24X-CC. 24. *Paralia crenulata*, Sample 151-908A-21X-5, 75–76 cm. 25. *Trochosira coronata*, Sample 151-913B-25R-CC. 26. "*Skeletonema*" *utriculosa*, Sample 151-908A-31X-CC.

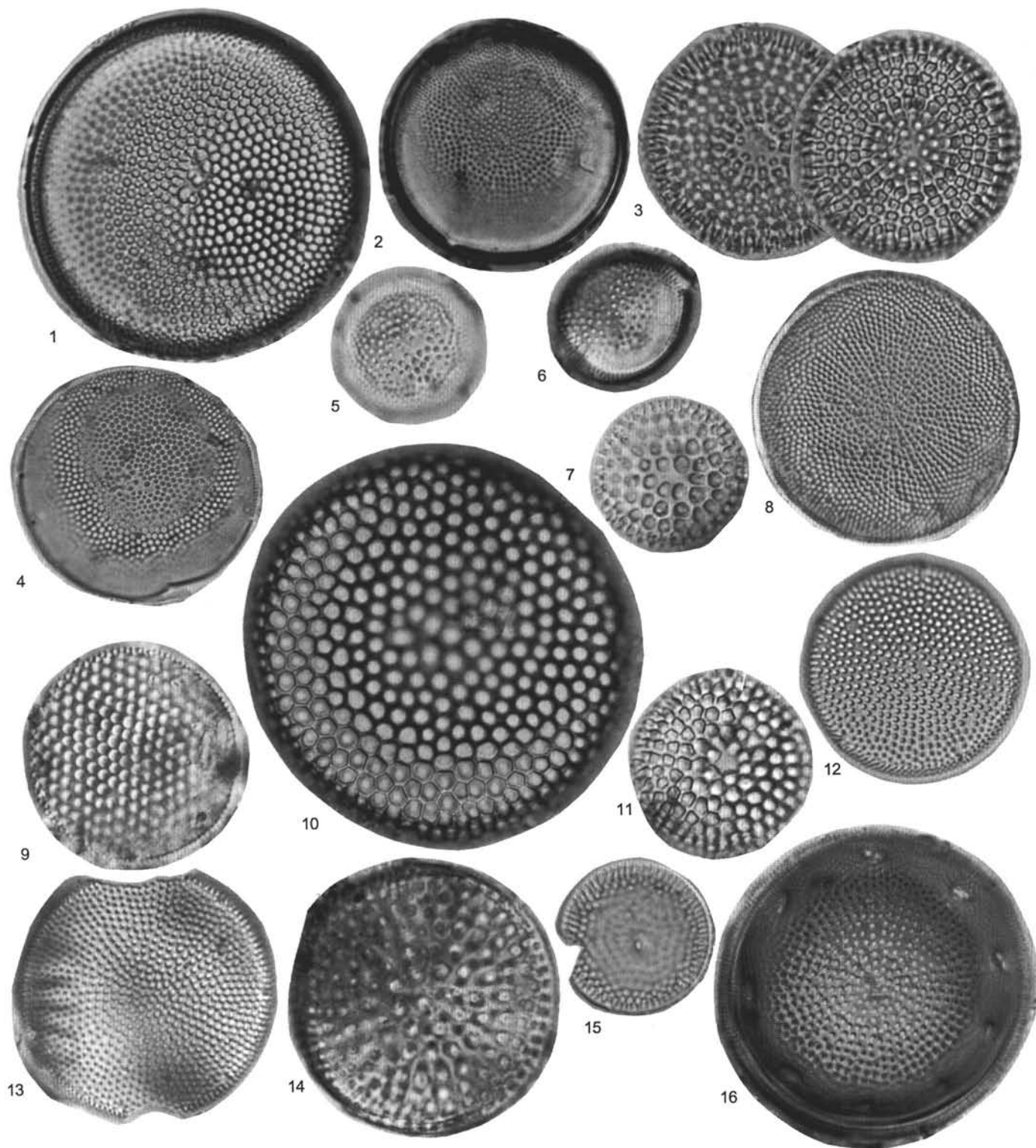


Plate 5. Paleogene diatoms, magnification 1500 $\times$  unless otherwise indicated. **1.** *Azpeitia tuberculata* var. *atlantica*, Sample 151-908A-26X-3, 90–91 cm. **2.** *Cestodiscus* sp. A, Sample 151-908A-33X-3, 4–5 cm. **3.** *Cestodiscus pulchellus* var. *novazealandica*, Sample 151-908A-26X-3, 90–91, cm, magnification, 1000 $\times$ . **4.** *Cestodiscus* sp. B, Sample 151-908A-34X-3, 85–86 cm. **5.** *Cestodiscus* sp. B, Sample 151-908A-29X-5, 122–123 cm. **6.** *Azpeitia oligocaenica*, Sample 151-908A-21X-CC, magnification 1000 $\times$ . **7.** *Cestodiscus* sp. C, Sample 151-908A-34X-3, 85–86 cm. **8.** *Cestodiscus* sp. A, Sample 151-913B-24R-CC. **9.** *Thalassiosira* sp. A (note focus on strutted processes), Sample 151-908A-27X-5, 44–45 cm. **10.** *Craspedodiscus?* sp., Sample 151-908A-31X-1, 8–9 cm, magnification 800 $\times$ . **11.** *Cestodiscus* sp. C, Sample 151-908A-29X-5, 122–123 cm. **12.** *Cestodiscus* sp. A?, Sample 151-913B-24R-CC. **13.** *Cestodiscus* sp. A, Sample 151-913B-24R-CC. **14.** *Stictodiscus nitidus*, Sample 151-908A-26X-3, 90–91 cm. **15.** *Thalassiosira* sp. B, Sample 151-913B-25R-CC. **16.** *Actinocyclus ehrenbergii* group (note pseudonodulus and labiate processes, accentuated by a trapped bubble), Sample 151-908A-32X-5, 94–95 cm.

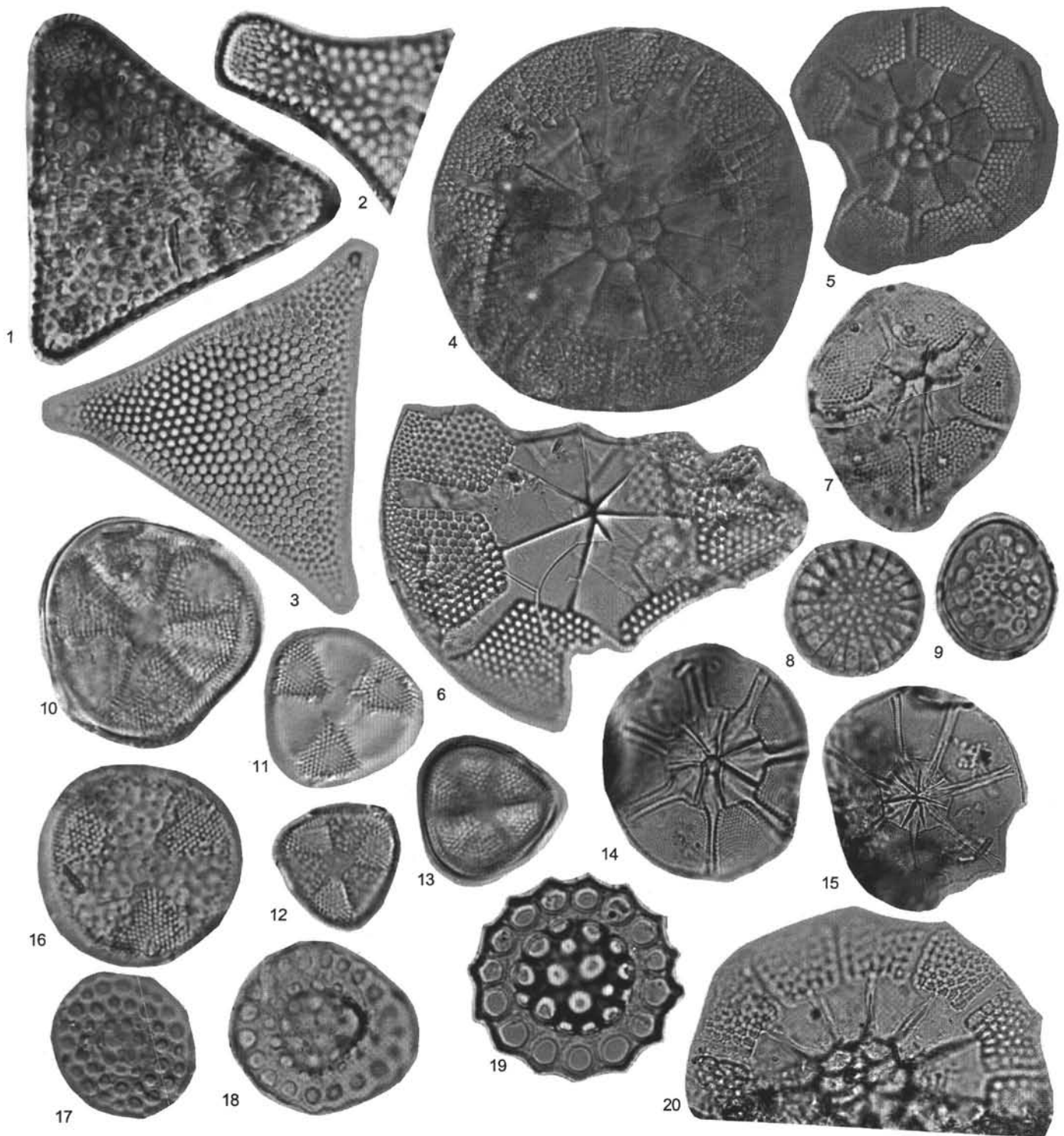


Plate 6. Paleogene diatoms, magnification 1500 $\times$  unless otherwise indicated. **1.** *Eurossia irregularis*, Sample 151-908A-32X-3, 88–89 cm. **2.** *Eurossia irregularis* var. *incurvatus*, (apex) Sample 151-908A-27X-5, 44–46 cm. **3.** *Pseudotriceratium radiosoreticulatum*, Sample 151-908A-21X-3, 30–31 cm. **4.** *Asterolampra insignis*, Sample 151-913B-24R-CC, magnification 750 $\times$ . **5.** *Asterolampra affinis*, Sample 151-913B-24R-CC, magnification 500 $\times$ . **6.** *Asteromphalus symmetricus?*, Sample 151-913B-24R-CC. **7.** *Asteromphalus flabellatus*, Sample 151-908A-27X-5, 44–45 cm. **8.** *Pseudostictodiscus picus*, Sample 151-913B-24R-CC. **9.** *Macrora barbadensis*, Sample 151-908A-25X-CC. **10.** *Actinoptychus irregularis*, Sample 151-913B-24R-CC. **11.** *Actinoptychus irregularis*, Sample 151-913B-24R-CC. **12.** *Actinoptychus irregularis*, Sample 151-913B-25R-CC. **13.** *Actinoptychus irregularis*, Sample 151-913B-24R-CC. **14.** *Asteromphalus oligocenicus*, Sample 151-908A-23X-CC, magnification 600 $\times$ . **15.** *Asterolampra punctifera*, Sample 151-913B-24R-CC, magnification 600 $\times$ . **16.** *Actinoptychus undulatus*, Sample 151-908A-25X-CC. **17.** *Macrora barbadensis*, Sample 151-908A-31X-1, 8–9 cm. **18.** *Macrora barbadensis*, Sample 151-908A-31X-CC. **19.** *Macrora stella*, Sample 151-908A-29X-CC. **20.** *Asterolampra insignis*, Sample 151-913B-25R-CC.

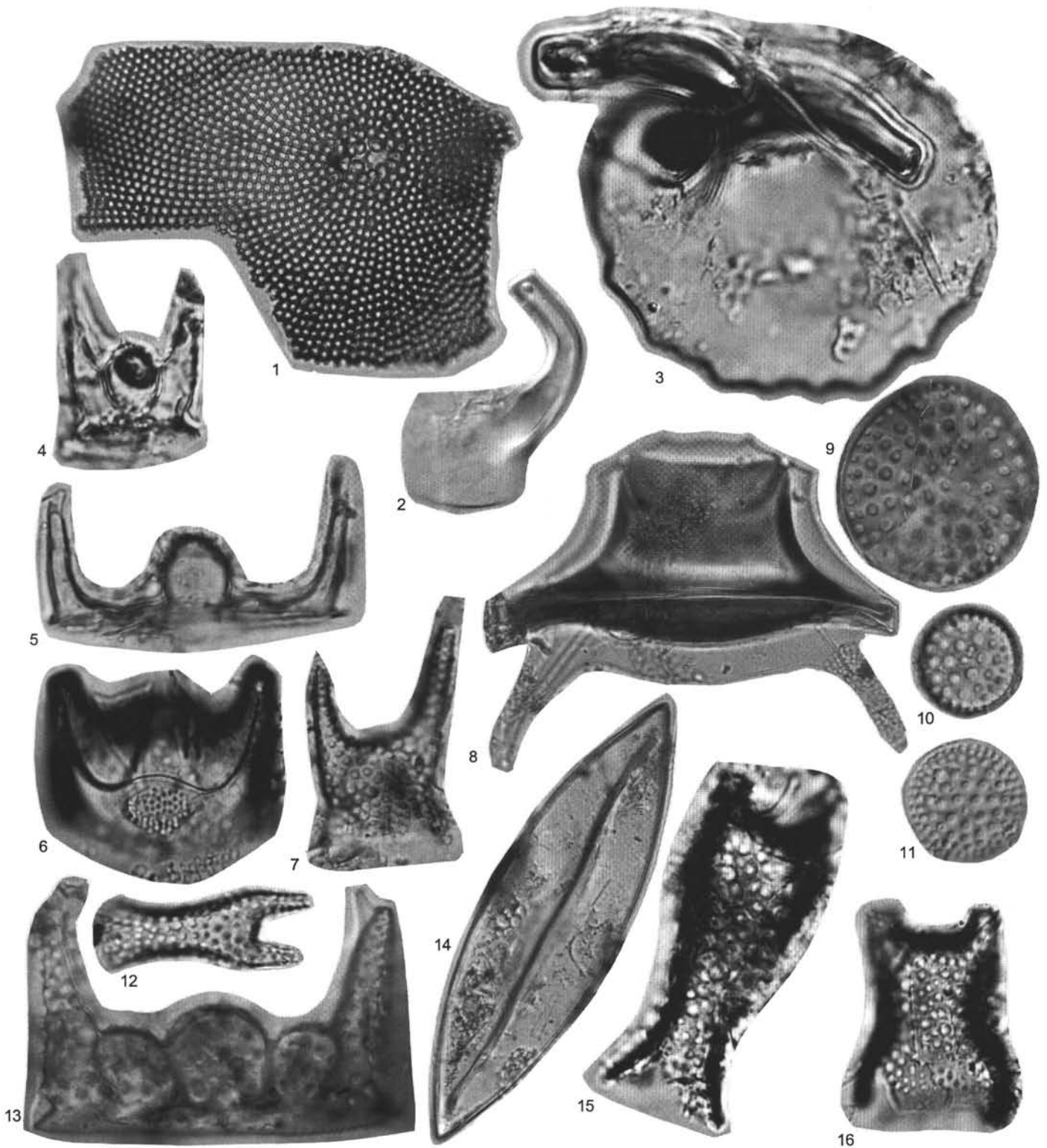


Plate 7. Paleogene diatoms, magnification 1500× unless otherwise indicated. **1.** *Coscinodiscus* affn. *tenerrimus*, Sample 151-913B-24R-CC, magnification 1000×. **2.** *Tubaformis* cf. *unicornis*, single tube (note large labiate process), Sample 151-913B-25R-CC, magnification 1000×. **3.** *Tubaformis* cf. *unicornis*, Sample 151-913B-25R-CC. **4.** *Hemiaulus horridus* group, Sample 151-908A-25R-CC. **5.** *Hemiaulus horridus* group, Sample 151-908A-X-2, 6–7 cm. **6.** *Hemiaulus elegans*, Sample 151-908A-25X-CC. **7.** *Hemiaulus incisus*, Sample 151-908A-32X-3, 88–89 cm. **8.** *Odontotropis carinifera*, Sample 151-913B-25R-CC, magnification 750×. **9.** *Rocella praenitida*, Sample 151-908A-X-2, 6–7 cm. **10.** *Rocella praenitida*, Sample 151-908A-21X-3, 30–31 cm. **11.** *Rocella praenitida*, Sample 151-908A-32X-3, 88–89 cm. **12.** *Hemiaulus incisus*, Sample 151-913B-26R-3, 4–5 cm. **13.** *Hemiaulus polycistinorum*, Sample 151-908A-24X-CC. **14.** *Odontotropis carinifera*, (epitheca), Sample 151-913B-25R-CC, magnification 1000×. **15.** *Hemiaulus* affn. *incisus*?, Sample 151-913B-26R-3, 4–5 cm. **16.** *Hemiaulus* affn. *incisus*?, Sample 151-913B-25R-CC.



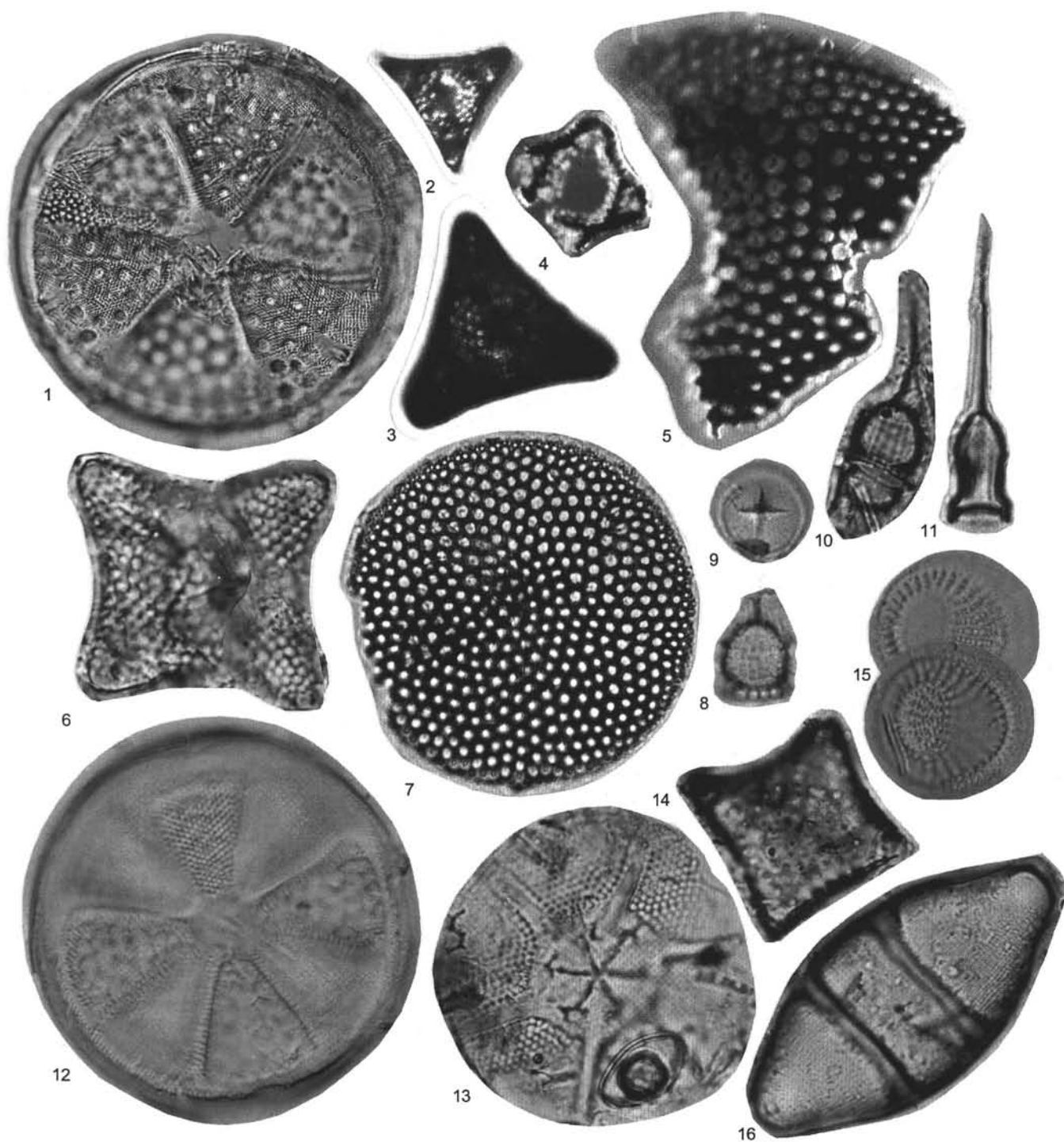


Plate 8. Paleogene diatoms, magnification 1500 $\times$  unless otherwise indicated. **1.** *Actinoptychus* sp. A, Sample 151-913B-24R-CC, magnification 750 $\times$ . **2.** *Triceratium* sp., (pyritized) Sample 151-913B-32R-CC. **3.** *Triceratium* sp., (pyritized) Sample 151-913B-32R-CC. **4.** *Triceratium inconspicuum*, (pyritized) Sample 151-913B-32R-CC. **5.** *Brightwellia* sp., (pyritized) Sample 151-913B-32R-CC, magnification 750 $\times$ . **6.** *Amphitetras* sp., Sample 151-913B-26R-7, 17–19 cm. **7.** *Coscinodiscus oligocenicus*, Sample 151-913B-25R-CC, magnification 750 $\times$ . **8.** *Costopyxis trochlea*, Sample 151-913B-24R-CC. **9.** *Costopyxis trochlea*, Sample 151-913B-25R-CC. **10.** *Costopyxis trochlea*, Sample 151-913B-25R-5, 49–50 cm. **11.** *Pterotheca aculeifera*, Sample 151-913B-26R-3, 4–5 cm. **12.** *Actinoptychus delicatissimus*, Sample 151-908A-31X-1, 8–9 cm, magnification 1000 $\times$ . **13.** *Asteromphalus?* affn. *symmetricus?*, Sample 151-908A-27X-5, 44–45 cm. **14.** *Trinacria cornuta*, Sample 151-908A-32X-5, 2–3 cm, small, reworked specimen. **15a, b.** *Cyclotella* sp. A, Sample 151-908A-31X-1, 8–9 cm. **16.** *Anaulus* sp., Sample 151-908A-32X-3, 88–89 cm.