25. THE NEOGENE AND QUATERNARY DIATOM BIOSTRATIGRAPHY OF SUBANTARCTIC SEDIMENTS, DEEP SEA DRILLING PROJECT LEG 71¹

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ABSTRACT

Subantarctic sediments recovered in the Southwest Atlantic during Leg 71 provide well-preserved and often diverse assemblages of diatoms representing much of the upper middle Miocene to Holocene. The magnetostratigraphic record of two hydraulic piston core (HPC) sites with high sediment accumulation rates, Sites 512 and 514, is used to establish precise absolute ages for the boundaries of all but three of 15 biostratigraphic zones used to define the upper middle Miocene to Holocene; ages of the remaining three zones are defined by means of piston cores. Of the fifteen zones identified, two are upper middle Miocene to upper Miocene, one brackets the Miocene/Pliocene boundary, and thirteen are Pliocene to Holocene. The existing antarctic-subantarctic Pliocene to Holocene diatom zonation of Weaver and Gombos is revised and further subdivided: five existing zones are revised, and five new zones described. Taxonomic notes on all species studied are presented and several new taxa are proposed.

INTRODUCTION

Leg 71 of the Deep Sea Drilling Project rotary drilled or hydraulic piston cored four sites in subantarctic areas of the Southwest Atlantic Ocean (Fig. 1). Two sites are located on the Falkland Plateau, Site 511 in the basin province of the Plateau and Site 512 on the northeastern part of the Maurice Ewing Bank. Sites 513 and 514 are located on the lower west flank of the Mid-Atlantic Ridge, east of the Argentine Basin. Sites 511 and 512 lie within the present-day Antarctic Convergence Zone (Gordon et al., 1977); whereas Sites 513 and 514 are positioned approximately 240 and 400 km, respectively, north of the Antarctic Convergence.

Deep Sea Drilling Project Leg 71 was the fifth cruise of the *Glomar Challenger* to the southern high latitudes. Three of the previous cruises were to the Pacific sector of the Southern Ocean: Legs 28 and 29 went to the Southwest Pacific and Leg 35 to the Southeast Pacific. The fourth high-latitude cruise, Leg 36, drilled in the Southwest Atlantic Ocean, on or near the Falkland Plateau.

Biostratigraphic studies of diatoms recovered by these previous DSDP cruises have resulted in the establishment of zonal schemes for most of the Tertiary; these studies were by McCollum (1975, Leg 28), Hajós (1976, Leg 29), Schrader (1976, Legs 35 and 29, Site 278), and Gombos (1977, Leg 36).

McCollum (1975) established the first detailed diatom zonation of the Neogene and Quaternary, based on his analysis of Leg 28 drill cores and selected *Eltanin* piston cores. Weaver and Gombos (1981) made a thorough comparison and summary of existing Neogene and Quaternary biostratigraphic data from the Southern Ocean and proposed a regional Neogene diatom zonation based on easily recognizable species with broad geographic distribution. The zonation of Weaver and Gombos (1981) contains 16 biostratigraphic zones, 5 as originally defined by McCollum (1975), 6 modified zones of McCollum (1975) and Schrader (1976), and 5 new zones.

In the present study, the upper middle Miocene-Holocene portion of the diatom zonation of Weaver and Gombos (1981) is revised and new zones added to increase biostratigraphic resolution. Particular emphasis is placed on determining the absolute age of all zonal boundaries. Absolute age determinations are based largely on the paleomagnetic record of HPC Sites 512 and 514.

PREPARATION OF SAMPLES AND METHOD OF STUDY

All samples used in this study were collected by the author during Leg 71. A total of 172 samples were processed for shore-based investigations using the following technique. Raw samples were placed in 200 ml beakers and heated with diluted hydrogen peroxide to disassociate the sediment and remove the organic carbon. Hydrochloric acid was then added to dissolve any carbonate present in the samples. The undissolved residues were diluted with distilled water, centrifuged, and decanted to remove the acid. This procedure was repeated three times. Next, the samples were washed with sodium pyrophosphate, centrifuged, and decanted to remove a significant proportion of the clay present in the samples. This final processing step was repeated until the sediment suspension obtained a neutral pH. Processed residues were diluted with distilled water and stored in 50-ml plastic bottles.

Strewn slides were prepared of all samples in the following manner. Bottles containing the sediment and water were shaken until all sediment was in solution and a small amount of the suspension was pipetted from the middle of the bottle. A few drops of the pipetted solution were placed on a slide and dispersed uniformly. After drying, cover slips were mounted using Hyrax (n.d. = 1.71) as the mounting medium.

Selected samples were sieved after preparation of the whole fraction slides in order to concentrate diatoms and eliminate the clay fraction of the sediment. The sieve size used varied with sediment type and was either 38 μ m, 45 μ m, or 63 μ m, or a combination of the three sizes. Slides were prepared of all sieved fractions; those intervals where sieved fractions were examined are indicated in the species occurrence tables by an asterisk beside the interval designations. Sieved fractions were examined to delineate species ranges more accurately. For a more detailed discussion of the advantage of this technique the reader is referred to Gombos and Ciesielski (this volume).

¹ Ludwig, W. J., Krasheninnikov, V. A., et al., *Init. Repts. DSDP*, 71: Washington (U.S. Govt. Printing Office).



Figure 1. Location of DSDP Sites 511, 512, 513, and 514.

ZONATION

The Neogene and Quaternary diatom zonation presented here represents the upper middle Miocene to Holocene; older Miocene sediments were missing from Leg 71 sites (Fig. 2). Defined are 15 diatom zones (Figs. 3 and 4): 5 zones are unchanged from McCollum (1975) and Weaver and Gombos (1981), 5 zones of these authors are revised, and 5 new zones are described. The Pliocene-Holocene zonation described herein is compared with the previous zonations of McCollum (1975) and Weaver and Gombos (1981) in Figure 5. Upper middle Miocene to upper Miocene diatom, radiolarian, and silicoflagellate zonations are correlated to magnetostratigraphy in Figure 6.

The Pliocene-Holocene zonal scheme presented here includes thirteen zones and the upper portion of a fourteenth, the Denticulopsis hustedtii Zone. The absolute ages of the boundaries of these zones, except the bases of the Coscinodiscus lentiginosus, Nitzschia angulata, and N. reinholdii zones, are based on the magnetostratigraphic record of Hole 514. To estimate the ages of the zonal boundaries, the sub-bottom depths were first determined for all paleomagnetic polarity boundaries and zonal boundaries. Most paleomagnetic polarity boundaries were determined to within a 2-20 cm interval by Salloway and Bloemendal (both this volume). The subbottom depths of diatom zonal boundaries were calculated as the midpoint between studied samples bracketing the zonal boundaries. Zonal boundary ages were then calculated by assuming constant sediment accumulation rates between adjacent chronozone or subchronozone boundaries and the sub-bottom depth estimated for the zonal boundaries.

The absolute age estimates of the diatom zones based on Hole 514 are more accurate than previous estimates based on studies of piston cores because of high sediment accumulation rates (up to 145 m/m.y.). I am now studying additional samples from the vicinity of zonal boundaries in order to define them more accurately by more precisely determining the sub-bottom depths of zonal boundaries. As presently defined, Pliocene-Holocene diatom zones have a duration ranging from a maximum of 980,000 yr. to a minimum of 140,000 yr., with an average of 373,000 yr.

No attempt is made here to establish a more detailed zonation of the upper Miocene to lower Pliocene (Chronozone 10 to lower Gilbert Chronozone). Several additional biostratigraphic datums were identified in this interval but were not used for further subdivision because there is no information on their regional significance. The following description of the diatom zonation does not discuss intrazonal biostratigraphic datums or assemblage characteristics. These data may be obtained by reference to McCollum (1975), Gombos (1977), Weaver and Gombos (1981), and the appropriate tables and figures in this chapter.

Coscinodiscus lentiginosus Partial Range Zone

Author. McCollum, 1975.

Top. Holocene.

Bottom. Last occurrence of *Actinocyclus ingens*. Age. Pleistocene.

Paleomagnetic correlation. McCollum (1975) placed the base of this zone coincident with the Brunhes/Matuyama Chronozone boundary. Weaver and Gombos (1981) place the same boundary in the lower Brunhes Chronozone (~0.6 to 0.5 Ma) but cite no reason for doing so. In all cores that I have examined from antarctic and subantarctic areas of the Southeast Indian and Atlantic sectors of the Southern Ocean, the base of the zone consistently occurs in the lower Brunhes Chronozone (Ciesielski et al., 1982; Ledbetter and Ciesielski, 1982; Osborn et al., in press). My best estimate for the age of the zone base comes from Islas Orcadas (IO) piston core 11-70 from the Southeast Atlantic (55°09.0'S, 09°58.9'E, 4521 m). Assuming a constant sediment accumulation rate for the Brunhes section of this core, the base of the zone between 1048 and 1068 cm is ~ 620,000 y.B.P.

Absolute age. 620,000 y.B.P.-Present.

Coscinodiscus elliptopora/Actinocyclus ingens Partial Range Zone

Authors. Bottom, Ciesielski, this chapter; top, Mc-Collum, 1975.

Top. Last occurrence of Actinocyclus ingens.

Bottom. Last occurrence of Rhizosolenia barboi.

Remarks. McCollum (1975) defined the base of the zone as the first occurrence of Coscinodiscus elliptopora. This boundary is emended here for two major reasons. First, McCollum's definition of the base of this zone differs from his definition of the top of the underlying Rhizosolenia barboi/Nitzschia kerguelensis Zone, which he defined by the last occurrence of R. barboi. Thus the boundary between the C. lentiginosus and R. barboi/N. kerguelensis zones may vary, because the first occurrence of C. elliptopora occurs prior to the last occurrence of R. barboi (Ciesielski, 1978; Ciesielski et al., 1982, fig. 10; Ciesielski, this chapter, Table 3). Second, the first occurrence of C. elliptopora has been observed to occur over a wide range of stratigraphic levels within the Matuyama Chronozone (Ciesielski, 1978; unpublished data from Ledbetter and Ciesielski, 1982; Osborn et al., in press). Diachrony in the first occurrence of C. elliptopora is caused by its sometimes sporadic occurrence, even in well-preserved sediments, and its scarcity or absence in poorly preserved sediments.

The base of the C. elliptopora/Actinocyclus ingens Zone is changed, therefore, to the last occurrence of R. barboi; thus it is now defined as being the same as the top of the underlying R. barboi/N. kerguelensis Zone.



Figure 2. Lithologic columnar sections of DSDP Sites 511, 512, 513, and 514.

Age. Pleistocene.

Paleomagnetic correlation. In Hole 514 the last occurrence of Rhizosolenia barboi occurs between Samples 514-5-4, 56-58 cm and 514-6-1, 77-79 cm at, an estimated sub-bottom depth of 18.91 meters and age of 1.58 Ma. A similar age, 1.53 Ma, is estimated for the boundary in piston core IO 16-107. In these and other sections the last R. barboi occurs above the top of the Olduvai Subchronozone of the Matuyama Chronozone.

Absolute age. 1.58-0.62 Ma.



Figure 3. Pliocene to Quaternary diatom and silicoflagellate zonation correlated to paleomagnetic stratigraphy.

Rhizosolenia barboi/Nitzschia kerguelensis Partial Range Zone

Authors. Bottom, McCollum, 1975, emended here; top, McCollum, 1975.

Top. Last occurrence of Rhizosolenia barboi.

Bottom. Last occurrence of Coscinodiscus kolbei.

Distinguishing characteristic. Joint occurrence of *Rhi*zosolenia barboi and *Nitzschia kerguelensis*, following the latest occurrence of *Coscinodiscus kolbei*.

Remarks. McCollum (1975) defined the base of the zone by the joint occurrence of *Rhizosolenia barboi* and



Figure 4. Names and definitions of the new Pliocene-Quaternary zonation presented here. (PRZ, Partial Range Zone; CRZ, Concurrent Range Zone; IZ, Interval Zone.)

Nitzschia kerguelensis following the latest occurrence of *Coscinodiscus kolbei*. This definition is unsatisfactory because it defines the zone itself, not the base. For the purpose of clarity the base is redefined here as solely the last occurrence of *C. kolbei*.

Age. earliest Pleistocene.

Paleomagnetic correlation. In Hole 514 the base of the zone (last *Coscinodiscus kolbei*) occurs between Samples 514-6-3, 77-79 cm and 514-6-2, 80-82 cm at an estimated sub-bottom depth of 21.85 meters and age of 1.89 Ma. The base of the Olduvai Subchronozone (1.88 Ma) occurs between 118 and 136 cm of Section 514-6-2, which places the paleomagnetic boundary within the samples bracketing the last occurrence of *C. kolbei*. Elsewhere in the Southern Ocean, the base of the Olduvai Subchronozone (Ciesielski, 1978; unpublished data from Ledbetter and Ciesielski, 1982; Osborn et al., in press). On the basis of fewer piston cores, McCollum (1975) placed the base of the zone within the Olduvai Subchronozone (1.80–1.85 Ma).

Absolute age. 1.89-1.58 Ma.

Coscinodiscus kolbei/Rhizosolenia barboi Partial Range Zone

Authors. Bottom; Ciesielski, this paper; top, McCollum, 1975, emended here.



Figure 5. Comparison of the Pliocene-Quaternary diatom zonation Presented here with the previous zonations of McCollum (1975) and Weaver and Gombos (1981).

Top. Last occurrence of Coscinodiscus kolbei.

Bottom. Last occurrence of Coscinodiscus vulnificus.

Distinguishing characteristic. Joint occurrence of *Coscinodiscus kolbei* and *Rhizosolenia barboi* in the absence of *C. vulnificus*.

Remarks. McCollum (1975) defined the base of the zone by the latest occurrence of *Cosmiodiscus insignis*. Weaver and Gombos (1981) were the first to note the last occurrence of *Coscinodiscus vulnificus* as an important datum within the zone but elected to use it as an intrazonal datum rather as a zonal indicator. During the course of recent studies of over 400 piston cores from the Atlantic and Southeast Indian sectors of the Southern Ocean, I have consistently noted the last occurrence of *C. vulnificus* in the lower Matuyama Chronozone of antarctic and subantarctic piston cores (Ledbetter and Ciesielski, 1982; Osborn, et al., in press; Ciesielski and



Figure 6. Upper middle Miocene to upper Miocene diatom, radiolarian, and silicoflagellate zones correlated to paleomagnetic stratigraphy.

Ledbetter, unpublished data). It therefore seems appropriate to use the last occurrence of *C. vulnificus* further to subdivide the lower Matuyama Chronozone.

Age. late Pliocene.

Paleomagnetic correlation. As defined by McCollum (1975), this zone included the entire Matuyama Chronozone below the Olduvai Subchronozone. The redefinition of the base of the zone here divides the portion of the Matuyama Chronozone below the Olduvai into two zones, the *Coscinodiscus kolbei/Rhizosolenia barboi* Zone and the *C. vulnificus* Zone.

In Hole 514, the base of the zone occurs between Samples 514-9-3, 63-65 cm and 514-9-2, 70-72 cm at an estimated sub-bottom depth of 34.95 meters and age of 2.22 Ma. Although the Réunion subchronozones were not recognized in Hole 514, the calculated age of 2.22 Ma for the base of the zone would fall below these subchronozones. In piston core IO 16-107 from the nearby Islas Orcadas Rise, the last *C. vulnificus* falls between the two Réunion subchronozones (2.04-2.12 Ma). There thus appears to be a 100,000-yr. difference in the age of the base of the zone as estimated from Hole 514 and from IO 16-107. A more definitive placement of the boundary with respect to the Réunion subchronozones awaits more detailed study of these and other sections.

Absolute age. 2.22-1.89 Ma.

Coscinodiscus vulnificus Partial Range Zone

Author. Ciesielski, this chapter.

Top. Last occurrence of *Coscinodiscus vulnificus*. **Bottom.** Last occurrence of *Cosmiodiscus insignis*. **Age.** late Pliocene.

Paleomagnetic correlation. The base of the zone in Hole 514 occurs between Samples 514-12-2, 26-28 cm and 514-12-1, 50-52 cm at an estimated sub-bottom depth of 46.29 meters, 1.58 meters below the Gauss/Matuyama Chronozone boundary. The estimated age of the basal boundary is 2.49 Ma, only 20,000 yr. older than the 2.47 Ma Gauss/Matuyama boundary. In piston cores examined, all with a sediment accumulation rate an order of magnitude less than the 98 m/m.y. rate for the age-equivalent section of Hole 514, the basal boundary of the zone also falls in the uppermost Gauss near the Gauss/Matuyama boundary. This age for the last occurrence of *Cosmiodiscus insignis* is in excellent agreement with the 2.5 Ma age assigned by McCollum from his studies of only a few piston cores.

Reference section. Sample 514-12-1, 50–52 cm through 514-9-3, 63–65 cm.

Absolute age. 2.49-2.22 Ma.

Cosmiodiscus insignis Partial Range Zone

Authors. Bottom, Ciesielski, this chapter; top, Mc-Collum, 1975.

Top. Last occurrence of *Cosmiodiscus insignis*. Bottom. Last occurrence of *Nitzschia weaveri*.

Remarks. McCollum defined the base of the zone by the last occurrence of *Nitzschia interfrigidaria*. The last occurrence of the new species *N. weaveri* is used here to redefine the base of the zone, thus increasing biostratigraphic resolution of the upper Gauss Chronozone.

Age. late Pliocene.

Paleomagnetic correlation. As defined by McCollum (1975) this zone encompassed most of the upper normalpolarity interval of the Gauss Chronozone, extending from just below the Gauss/Matuyama boundary (~ 2.5 Ma) to the Kaena Subchronozone (2.92 Ma). In Hole 514 the base of the zone occurs between Samples 514-15-3, 70-72 cm and 514-15-2, 70-72 cm at an estimated sub-bottom depth of 61.35 meters and age of 2.64 Ma. The *Cosmiodiscus insignis* Zone thus represents the upper portion of the upper normal-polarity portion of the Gauss Chronozone.

Absolute age. 2.64-2.49 Ma.

Nitzschia weaveri Partial Range Zone

Author. Ciesielski, this chapter.

Top. Last occurrence of Nitzschia weaveri.

Bottom. Last occurrence of Nitzschia interfrigidaria. Remarks. This zone and the newly defined Cosmiodiscus insignis Zone are correlative to the C. insignis Zone of McCollum (1975). The last occurrence of N. weaveri is used here to subdivide McCollum's (1975) C. insignis Zone into the N. weaveri Zone and newly defined C. insignis Zone.

Age. late Pliocene.

Paleomagnetic correlation. This zone represents the basal portion of the upper normal-polarity interval of the Gauss Chronozone. In Hole 514 the base of the zone occurs between Samples 514-19-2, 72-74 cm and 514-19-1, 72-74 cm at an estimated depth of 77.48 meters and age of 2.81 Ma.

Reference section. Samples 514-15-3, 70-72 cm through 514-19-1, 72-74 cm.

Absolute age. 2.81-2.64 Ma.

Nitzschia interfrigidaria/Coscinodiscus vulnificus Concurrent Range Zone

Author. Ciesielski, this chapter.

Top. Last occurrence of Nitzschia interfrigidaria.

Bottom. First concurrent occurrence of *Cosmiodis*cus insignis and *Coscinodiscus vulnificus*.

Remarks. One of the shortcomings of the diatom zonations of McCollum (1975) and Weaver and Gombos (1981) is that the upper Gilbert to lower Gauss Chronozones are embraced by a single diatom zone, the *Nitzschia interfrigidaria* Zone. This interval records major changes in Southern Ocean paleoceanography (Ciesielski et al., 1982; Ciesielski and Weaver, this volume) and needs further subdivision. Here the *N. interfrigidaria* Zone are closely representative of the *N. interfrigidaria* Zone as previously defined.

Age. late Pliocene.

Paleomagnetic correlation. In Hole 514 the base of the zone occurs between Samples 514-26-1, 98-100 cm and 514-25-1, 95-97 cm at an estimated sub-bottom depth of 105.58 meters and age of 3.1 Ma. The zone includes the lower portion of the upper normal-polarity portion of the Gauss Chronozone, the Kaena Sub-chronozone, and middle normal-polarity interval of the Gauss, and has its lower boundary within the mid-Mammoth Subchronozone.

Reference section. Samples 514-19-2, 72-74 cm through 514-25-1, 95-97 cm.

Absolute age. 3.10-2.81 Ma.

Nitzschia interfrigidaria Partial Range Zone

Author. Ciesielski, this chapter.

Top. First concurrent occurrence of *Cosmiodiscus insignis* and *Coscinodiscus vulnificus*.

Bottom. First occurrence of Nitzschia weaveri.

Remarks. The Nitzschia interfrigidaria Zone as defined here is partially equivalent to the N. interfrigidaria Zone of McCollum (1975) and Weaver and Gombos (1981). The complete zone is not present in any of the Leg 71 sites, and in Hole 514 only the upper and lower-most portions of the zone are present. Disconformities are present in most Southern Ocean piston cores containing the N. interfrigidaria Zone (Ciesielski, 1978; Ciesielski et al., 1982; Ledbetter and Ciesielski, 1982; and others). Further subdivision of this interval is needed but awaits examination of more complete sections.

Age. early-late Pliocene.

Paleomagnetic correlation. In Hole 514 the base of the zone occurs between Samples 514-28-1, 90-92 cm and 514-27-2, 84-86 cm at an estimated sub-bottom depth of 115.03 meters and age of 3.88 Ma. The *Nitzschia interfrigidaria* Zone extends from within the Mammoth Subchronozone to the uppermost Cochiti Subchronozone of the Gilbert Chronozone.

Reference section. None designated. Absolute age. 3.88–3.1 Ma.

Nitzschia praeinterfrigidaria Partial Range Zone

Author. Ciesielski, this chapter.

Top. First occurrence of Nitzschia weaveri.

Bottom. First occurrence of Nitzschia interfrigidaria. Remarks. McCollum (1975) established the Nitzschia praeinterfrigidaria Zone to include the interval from the last Denticulopsis hustedtii to the last N. interfrigidaria. As he defined the zone it includes the Gilbert Chronozone from the Cochiti to Sidufjall-Thvera subchronozones. Weaver and Gombos (1981) substituted the N. reinholdii and N. angulata zones for McCollum's (1975) N. praeinterfrigidaria Zone and suggested their use in regions north of 62°S latitude; south of this latitude they suggested use of McCollum's N. praeinterfrigidaria Zone. The N. angulata and N. reinholdii zones are utilized here, but the N. angulata Zone of Weaver and Gombos (1981) is emended and a third zone created to subdivide McCollum's (1975) N. praeinterfrigidaria Zone further. I here conserve the name N. praeinterfrigidaria Zone to refer to that portion of McCollum's original N. praeinterfrigidaria Zone between the first occurrence of N. interfrigidaria and first occurrence of N. weaveri.

Age. early Pliocene.

Paleomagnetic correlation. In Hole 514 the base of the zone occurs between Samples 514-33-1, 75-77 cm and 514-32-1, 77-79 cm at an estimated depth of 136.17 meters and age of 4.02 Ma. The zonal base occurs below the base of the Cochiti Subchronozone and above the Nunivak Subchronozone.

The base of the newly defined Nitzschia praeinterfrigidaria Zone, the first occurrence of N. interfrigidaria, is $\sim 120,000$ yr. older than the base of the N. interfrigidaria Zone of Weaver and Gombos (1981), as recognized by the change in dominance from N. praeinterfrigidaria to N. interfrigidaria. This change now occurs within the newly defined N. praeinterfrigidaria Zone, thus eliminating the necessity of making quantitative or qualitative estimates of changes from the dominance of N. praeinterfrigidaria to that of N. interfrigidaria.

Reference section. None designated at this time.

Occurrence. The zone appears to be applicable in all antarctic and subantarctic latitudes.

Absolute age. 4.02-3.88 Ma. The zone represents only $\sim 140,000$ yr. but is easily recognized in piston cores because of high sediment accumulation rates at this time throughout the Southern Ocean.

Nitzschia angulata Partial Range Zone

Authors. Bottom, Weaver and Gombos, 1981; top, Ciesielski, this chapter.

Top. First occurrence of Nitzschia interfrigidaria.

Bottom. First occurrence of Nitzschia angulata.

Remarks. Weaver and Gombos (1981) defined the top of the zone by the evolutionary transition from *Nitzschia praeinterfrigidaria* to *N. interfrigidaria*, which they recognize by the change in dominance from *N. praeinterfrigidaria* to *N. interfrigidaria*. This definition was utilized because McCollum's (1975) incomplete diagnosis of *N. praeinterfrigidaria* and *N. interfrigidaria* prevented recognition of the first occurrence of *N. interfrigidaria* (Weaver and Gombos, 1981; pers. comm. from F. M. Weaver, 1981). A full diagnosis of these species is given here (see taxonomy). Thus recognition of the first *N. interfrigidaria* is straightforward and is used to define the top of the zone.

Paleomagnetic correlation. Hole 514 was terminated before the base of the Nitzschia angulata Zone was encountered. Weaver and Gombos (1981) correlate the base of the zone with the top of the Nunivak Subchronozone of the Gilbert Chronozone. During the course of my examination of numerous Southern Ocean piston cores, I have noted that the basal boundary of the zone is diachronous. In some cores this boundary occurs in the upper portion of the Nunivak Subchronozone; however, in most cores the basal boundary occurs near the base of this Subchronozone. Until a more thorough study can be made of piston cores containing this zone, the basal boundary is placed in the lower Nunivak Subchronozone. The Nitzschia angulata Zone thus represents a portion of the reversed-polarity interval between the Cochiti and Nunivak/Subchronozones and most or all of the Nunivak Subchronozone.

Absolute age. 4.20–4.02 Ma. Even though this zone represents only \sim 180,000 yr. It is readily recognized where present, because this interval is characterized by very high sedimentation rates throughout the Southern Ocean (e.g., Hole 514, \sim 180 m/m.y.).

Nizschia reinholdii Interval Zone

Authors. Weaver and Gombos, 1981.

Top. First occurrence of Nitzschia angulata.

Bottom. Last abundance appearance datum of *Denticulopsis hustedtii*.

Age. early Pliocene.

Paleomagnetic correlation. Weaver and Gombos (1981) were unable accurately to determine the base of the zone relative to paleomagnetic chronostratigraphy because their reference sections did not contain both the Sidufjall and Thvera subchronozones (informally known as the "c" subchronozones). The authors, therefore, extended the zone to these subchronozones, undifferentiated.

Final clarification of the position of the zonal base must await further study of a significant number of cores with both "c" subchronozones. At this time I tentatively place the base of the *Nitzschia reinholdii* Zone between the Sidufjall and Thvera subchronozones, based on preliminary studies of piston cores IO 11-66 and IO 7-5.

Piston cores containing the lower Gilbert Chronozones and Chronozone 5 are rare. Further studies of existing cores containing this interval are under way and should clarify the position of the base of the Nitzschia reinholdii Zone.

Absolute age. ~4.48-4.20 Ma.

Denticulopsis hustedtii Partial Range Zone

Authors. Bottom, McCollum, 1975; top, Weaver and Gombos, 1981.

Top. Last abundance appearance datum of *Denticulopsis hustedtii*.

Bottom. Last occurrence of *Denticulopsis lauta*. Age. late Miocene-early Pliocene.

Paleomagnetic correlation. Extrapolating from average sedimentation rates at DSDP Site 278, Weaver (1976) estimated the base of the zone at 6.8–7.0 Ma or within Chron 7. Ciesielski (1978) has shown the base of the zone to be at least as old as Chron 6. Ciesielski (1980) believed the basal boundary possibly fell in mid-Chron 7 (\sim 7.1 Ma) based on piston core IO 7–48.

During the course of Leg 71 micropaleontologic investigations, Ciesielski and Weaver re-examined piston cores IO 7-48 and IO 7-54 in an attempt to correlate the base of this and other upper Miocene diatom and radiolarian zones to magnetostratigraphy. Both piston cores have long normal-polarity sequences at their base (Ciesielski et al., 1982), which we correlate to upper Chronozone 9. Both *Denticulopsis hustedtii* and *D. lauta* are present throughout the interval we identify as Chronozone 9.

A portion of core IO 7-48 disconformably above Chronozone 9 was identified as mid-Chronozone 7 by Ciesielski (1980) and was thought to contain the lower boundary of the *D. hustedtii* Zone. Our subsequent reexamination of this core shows this boundary to be unreliable because of considerable reworking and a possible disconformity. Thus, based on piston core studies, the base of the *Denticulopsis hustedtii* Zone can be no more definitively placed than between upper Chronozone 9 and lower Chronozone 6.

A volcanic ash in Hole 513A radiometrically dated by R. D. Dallmeyer (University of Georgia; pers. comm., 1981) provides additional insight into the age of the last occurrence datum of Denticulopsis lauta. The 40Ar/36Ar versus ³⁹Ar/³⁶Ar isochron age for the incremental gas analysis of the ash from Sample 513A-10-1, 13-15 cm was 8.7 m.y. ± 0.2 m.y. Rare to sparse D. lauta occur above this ash up to the disconformity between Core 10 and Core 9; therefore, the last occurrence of the species is younger than 8.7 ± 0.2 Ma. Specimens above the ash layer are small and poorly silicified. These characteristics and the low abundance of D. lauta are usually indicative of the uppermost portion of its range. It seems likely, therefore, that the last occurrence of D. lauta is in lower Chronozone 8. The last abundance appearance datum of D. lauta is probably only slightly older than the volcanic ash, because the species is common in the sample immediately below the ash. Until a more complete section can be studied, the date of the ash layer will be used to approximate the last abundance appearance datum of D. lauta. The base of the D. hustedtii Zone, the last occurrence of D. lauta, is tentatively placed at approximately the Chronozone 9-Chronozone 8 boundary (~8.7-8.5 Ma).

The presence of *D. lauta* above the volcanic ash clearly indicates that the last occurrence of this species is younger in the subantarctic than in Japan, where Koizumi (1977) placed the datum at 9.5 Ma on the basis of a K-Ar date. A later disappearance of *D. lauta* in the subantarctic does not seem surprising given the cool-water affinity of the genus *Denticulopsis*.

Absolute age. Uncertain, 8.7 to 8.5-4.48 Ma.

Denticulopsis hustedtii/Denticulopsis lauta Concurrent Range Zone

Authors. Bottom, Weaver and Gombos, 1981; top, McCollum, 1975.

Top. Last occurrence of Denticulopsis lauta.

Bottom. Last abundant appearance datum of Nitzschia denticuloides.

Age. middle Miocene to early late Miocene. The last abundant appearance datum of *Nitzschia denticuloides* occurs abruptly in Hole 512, Core 2. This datum, the base of the zone, occurs just below the first *Neogloboquadrina acostaensis* and above the last *Globorotalia siakensis*; thus it is within the upper N15 planktonic foraminiferal zone and correlative to the basal Tortonian of the upper Miocene (Fig. 7).

Paleomagnetic correlation. The brevity of the Hole 512 upper middle to lower upper Miocene section prevents definitive correlation of the base of the zone to paleomagnetic stratigraphy. Interpretation of the paleomagnetic record is made more difficult by uncertain identification of the paleomagnetic polarity record of the type Tortonian section.

Two interpretations are presented here for the Miocene paleomagnetic polarity record of Hole 512 (Fig. 7). This section most likely represents either upper Chronozone 11 and lower through middle Chronozone 10 or most of Chronozone 11 and lower Chronozone 10. The Neogloboquadrina acostaensis datum first appears to be the key to interpreting the Hole 512 magnetostratigraphy. Opdyke et al. (1974) indirectly correlated this datum to upper Chronozone 11, whereas Ryan et al. (1974) placed the datum in the Tortonian stratotype within middle Chronozone 10 by correlating the stratotype magnetostratigraphy to a composite equatorial Pacific magnetostratigraphy. In both interpretations of the Hole 512 magnetostratigraphy presented here, the N. acostaensis datum occurs within Chronozone 10, thus appearing to favor Ryan et al.'s (1974) placement and suggesting a similar occurrence in Hole 512. The base of the Denticulopsis hustedtii/D. lauta Zone would thus be mid-Chronozone 10 in age.

Unfortunately, neither interpretation of the Hole 512 magnetostratigraphy fits with the upper Chronozone 12 age for the N14/N15 planktonic foraminiferal boundary, which in Hole 512 occurs either in lower Chronozone 10 or mid Chronozone 11. Diachrony of this or other foraminiferal boundaries here may be the result of water mass migrations at this high-latitude site. Therefore, neither interpretation of the Hole 512 magneto-



Figure 7. Ranges of selected diatoms, radiolarians, and silicoflagellates in the upper middle Miocene to upper Miocene of HPC Site 512. Magnetic polarity record by Ledbetter (this volume).

stratigraphy is followed at this time. A more definitive placement of the base of the *Denticulopsis hustedtii/D*. *lauta* Zone requires a more complete biostratigraphic record. For the present the base of the zone is designated as lower to middle Chronozone 10.

Absolute age. ~ 11.2-10.5 to 8.7-8.5 Ma.

Nitzschia denticuloides Partial Range Zone

Authors. Weaver and Gombos, 1981.

Top. Last abundance appearance datum of *Nitzschia* denticuloides.

Bottom. Last occurrence of Nitzschia grossepunctata.

Age. middle Miocene-earliest late Miocene. Weaver and Gombos (1981) estimate a 14.0 to 14.5 Ma age for the base of the zone, based on extrapolation of sedimentation rates in DSDP Site 278. This estimate is consistent with the occurrence of the base of the zone in Site 278 5 meters below the last occurrence of the nannofossil *Cyclicargolithus floridanus*, a datum which occurs within NN6 and is older than the 13.8 Ma age of the top of NN6 (Weaver and Gombos, 1981).

Absolute age. ~ 14.0-14.5 Ma to 11.2-10.5 Ma.

SITE SUMMARIES

Site 511 (Table 1)

Site 511 (51°00.28'S, 46°58.30'W; 2589 meters) is located in the basin province of the Falkland Plateau, about 10 km south of DSDP Site 330 on the Maurice Ewing Bank. The 70 cores drilled continuously at Site 511 range from Holocene to Neocomian age. This report examines only the diatoms of the Pliocene to Holocene sediments of Core 1. Diatoms from the upper Eocene-lower Oligocene sediments disconformably underlie Pliocene sediments of Core 1 and are described by Gombos and Ciesielski (this volume).

Diatoms are well preserved and abundant in Core 1. A detailed examination of this core revealed the presence of three disconformities. The siliceous gravelly sand and foraminiferal ooze from 0 to 37 cm of Section 1 is assigned to the *Coscinodiscus lentiginosus* Zone of the Brunhes Magnetic Chronozone.

The lithology change at 37 cm marks a disconformable boundary separating the upper *C. lentiginosus* Zone from the *C. elliptopora/Actinocyclus ingens* Zone encountered at 511-1-1, 52-53 cm. Sample 511-1-1, 91-92 cm is assigned to the *C. kolbei/Rhizosolenia barboi* Zone of the uppermost Pliocene.

No zonal designation is given to Sample 511-1-1, 120-121 cm because of considerable downhole slumping of younger microfossils and reworking of lower Pliocene and upper Miocene microfossils. This sample probably is close to an apparent disconformity separating lower Matuyama Chronozone sediments (511-1-1, 91-92 cm) from upper Gauss Chronozone sediments (511-1-1, 142-143 cm) and may represent the *Cosmiodiscus insignis* Zone. Sample 511-1-1, 142-143 cm contains a flora characteristic of the *Nitzschia weaveri* Zone. Three samples from Core 1, Section 2 (at 31-31, 65-66, and 89-90 cm) are assigned to the *N. interfrigidaria/Coscinodiscus vulnificus* Zone of the mid-Gauss and are ap-

Table 1. Relative abundances of selected diatoms from the Pliocene to Quaternary of Hole 511, Core 1.

Core/ Section (interval in cm)	Actinocyclus ingens	Asteromphalus parvulus	Coscinodiscus elliptopora	C. kolbei	C. lentiginosus	C. lentiginosus var. obovatus	C. marginatus	C. vulnificus	Cosmiodiscus insignis	Denticulopsis hustedtii	Ethmodiscus rex	Eucampia antarctica	Hemidiscus karstenii	Nitzschia angulata	N. clementia	N. interfrigidaria	N. kerguelensis	N. miocenica	N. praeinterfrigidaria	N. reinholdii	N. weaveri	Rhizosolenia barbol	Rouxia californica	R. naviculoides	Stephanopyxis turris	Thalassiosira torokina	Diatom Zone
1-1, 31-32					С							C		R	- 2-7		A				Γ						Coscinodiscus lentiginosu
1-1, 52-53 1-1, 91-92	s s	R	S	F	s s	F	S				s s	S F		s s			cc										C. elliptopora/ Actinocyclus ingens/
1-1, 120-121	s				F		C	S	S	ŕ	s	F	F	F	S	S	S	5	R	S		S	F	F	F	r	C. kolbei/
1-1, 142-143	s		r	С	S	S	F	С	C			F		С		1	с				R	s			s		Rhizosolenia barboi
1-2, 31-32	s				S	S	F	F	S	r	s	F	s	с		s	s		R		F		s	S	s		Cosmiodiscus insignis?
1-2, 65-66 1-2, 89-90	s s			FS	F F	F	F	F F	F C			F S	s	F		FS	F F			S	C C	F	s s	s s	FS		Nitzschia weaveri
																											N. interfrigidaria/ Coscinodiscus vulnificus

Note: A, abundant, at least 1 specimen/field of view; C, common, at least 1 specimen/2-5 fields of view; F, frequent, at least 1 specimer./6-10 fields of view; S, sparse, several specimens on entire slide; R, rare only 1-2 specimens on entire slide. Lower case letters are used for occurrences that are believed to represent reworked specimens.

parently conformable to the N. weaveri Zone of basal Section 1.

The third disconformity in Core 1 probably is coincident with the sharp lithology change at 144 cm of Section 2. This sharp boundary between the siliceous gravelly sand above and the diatom ooze below separates the middle Pliocene of Sample 511-1-2, 89-90 cm from the lower Oligocene of Sample 511-3-1, 4-5 cm.

Site 512 (Table 2, Fig. 7)

Site 512 (49°52.19'S, 40°50.71'W; 1846 m) lies on the northeastern part of the Maurice Ewing Bank at a location chosen to investigate further the depositional and erosional history of the Falkland Plateau. Hole 512 was continuously hydraulic piston cored to a sub-bottom depth of 77.9 meters where coring was suspended because sediments became too indurated to penetrate. A second hole, 512A, was rotary drilled after the hole was washed to the level where coring stopped in Hole 512. Only one core was recovered from Hole 512A, to a subbottom depth of 89.3 meters, before bad weather and sea conditions forced abandonment of the site.

Eleven samples examined from Hole 512, Core 1 are assigned to four diatom zones with a hiatus occurring between each zone. Samples 512-1-1, 13-14 cm, 512-1-1, 24-25 cm, and 512-1-1, 34-35 cm contain poorly to moderately preserved diatoms that are assigned to the Ouaternary Coscinodiscus lentiginosus Zone of McCollum (1975). This zonal assignment places a maximum age of 620,000 yr. on these samples. Abundant and moderately preserved diatoms observed in Sample 512-1-1, 64-65 cm include Rhizosolenia barboi, Cosmiodiscus insignis, Coscinodiscus vulnificus, Nitzschia weaveri and one specimen of N. interfrigidaria. This assemblage represents the N. interfrigidaria/C. vulnificus Zone and is correlative to the mid-Gauss Chronozone (~3.10-2.8 Ma). Sample 512-1-1, 80-81 cm contains a mixed assemblage of early Pliocene and late Miocene diatoms which appears to represent the N. angulata Zone (Weaver, 1976) with numerous reworked (by drilling) late Miocene diatoms. Another sample, taken slightly lower in

Section 1 (88–89 cm), contains abundant and moderately preserved N. angulata, N. praeinterfrigidaria, N. reinholdii, Stephanopyxis turris, and Coscinodiscus marginatus. This sample contains rare reworked microfossils and is confidently correlated to the N. angulata Zone. The limited lower Pliocene stratigraphic range of this zone restricts the age of this sample, and probably of 512-1-1, 80–81 cm, to approximately 4.3 to 4.0 Ma (Gilbert Magnetic Chron). Finally, Samples 512-1-1, 100– 102 cm through 512-1,CC contain a well-preserved assemblage of late Miocene diatoms, the most common of which include Denticulopsis lauta, D. hustedtii, D. dimorpha, and abundant Thalassiothrix spp. These latter samples are assigned to the upper Miocene D. hustedtii/D. lauta Zone of Weaver and Gombos (1981).

The diatom stratigraphy of Core 1 suggests the following sediment age, sedimentology, and hiatus relationships:

Depth	Age	Sediment Type
0–36 cm	<620,000 yr.	Diatomaceous to fora- miniferal quartz sand
Hiatus	<620,000 yr2.8 m.y.	
36-79 cm	~2.8-3.1 m.y.	Diatomaceous sandy gravel
Hiatus	~ 3.1-4.0 m.y.	
79-93 cm	~4.0-4.3 m.y.	Muddy sandy diato- maceous ooze
Hiatus	~4.3-10.3 m.y.	
93 cm-2.5 m	~10.3 m.y.	Diatomaceous ooze and diatomaceous, nan- nofossil ooze

Sample 512-2-1, 110-112 cm through Core 5, CC contain an assemblage indicative of the *N. denticuloides* Zone of Weaver and Gombos (1981). Among the common species present are *Thalassiothrix* spp., *Nitzschia denticuloides*, *Denticulopsis dimorpha*, *D. lauta*, *D. hustedii*, *Rhizosolenia styliformis*, *Coscinodiscus marginatus*, *C. endoi*, *Brunia mirabilis*, and *Actinocyclus ingens*. Table 2. Relative abundances of selected diatoms and silicoflagellates from the Middle Miocene to Quaternary of Hole 512.

																		Dia	tom	15																
Core/ Section (interval in cm)	Actinocyclus ingens	A. ingens (undulated)	Asteromphalus sp. 1	A. sp. 2	Brunia mirabilis	Chaetoceros spp.	Coscinodiscus deformans	C. elliptopora	C. endoi	C. kolbei	C. lentiginosus	C. lentiginosus var. obovatus	C. marginatus	C. ruboides	C. vulnificus	Cosmiodiscus insignis	Craspedodiscus coscinodiscus	Denticulopsis dimorpha	D. hustedtii	D. aff. kamtschatica	D. lauta	D. maccollumii	D. praedimorpha	Eucampia antarctica	Mediaria splendida frags.	Nitzschia angulata	N. claviceps	N. denticuloides	N. donahuensis	N. efferans	N. interfrigidaria	N. kerguelensis	N. praeinterfrigidaria	N. pseudokerguelensis	N. weaveri	N. sp. 14
1-1, 13-14 1-1, 24-25 1-1, 34-35 1-1, 64-65 1-1, 80-81								r s		r S	C C C S	r S	s r C S		r C	r C		s c	c		c			S C C S		S S S S S S					s	C A A			R	
1-1, 88-89 1-1, 100-102 1-1, 113-114 1-1, 140-142 1-2, 82-84	F	S F			s				S									CCCC	C F F		F F C					С							C			
*1,CC 2-1, 110–112 2-2, 96–98 2-3, 71–73 *2,CC	F C C C C	S F F F F	R		F C A C	C F			S S S				F	S S				C C C C C C C C	F F C C	s	CCCCCC			S S S			R R R	S F F C R	R S S R R	s				S		S
3-1, 70-72 3-2, 72-74 4-1, 55-57 4-2, 53-55 4-3, 03-05	C C C F F	F F R R		R	R		S		F S					S S F				C C C C C F	00000	R	F C F C F		F	S S S	R		s s	C C C C A C	S	s s						
*4,CC 5-1, 61–63 5-2, 70–72 *5,CC	F F C C	F R S F			R R				F								S S F	F F F	C C F F		F F F	S R R	S R R	F	R		R	C C C								

Note. * Indicates intervals where sieved fractions were examined. Other symbols are explained in Table 1.

The thinness of the upper Miocene Denticulopsis hustedtii/D. lauta Zone (between 512-1-1, 93 cm and 512-1,CC) suggests that another disconformity may exist between this zone and the underlying N. denticuloides Zone; however, diatom evidence suggests otherwise. First, the absence of Thalassiosira sp. 10 and the presence of D. dimorpha and sparse N. denticuloides indicate that only the lower portion of the D. hustedtii/D. lauta Zone is present in Cores 1 and 2. Secondly, the scarcity of D. maccollumii in Cores 2 through 5 limits this interval to the uppermost portion of the N. denticuloides Zone. Thus the section from 512-1-1, 93 cm through 512-5,CC contains the lower portion of the D. hustedtii/D. lauta Zone and the uppermost N. denticuloides Zone with a possible conformable boundary between 512-1,CC and 512-2-1, 110-112 cm. Correlation of the magnetic polarity sequence of this interval to the standard paleomagnetic time scale (Ledbetter, this volume) indicates that this interval represents most of paleomagnetic Chron 10 and upper Chron 11. The upper boundary of the N. denticuloides Zone approximates the first occurrence of Neogloboquadrina acostaensis in Sample 512-2-1, 106 cm (Thunell, pers. comm., 1982).

An unconformity between Cores 512-5 and 512-6 separates middle Miocene diatomaceous nannofossil ooze of the *Nitzschia denticuloides* Zone of Weaver and Gombos (1981) from middle Eocene siliceous nannofossil ooze. Gombos (this volume) describes the unique middle Eocene diatoms of this hole.

Site 513 (Table 3, Figs. 8-10)

Site 513 ($47^{\circ}34.99'$ S, $24^{\circ}38.40'$ W; 4373 m) is located on the lower western flank of the Mid-Atlantic Ridge, near the southeastern margin of the Argentine Basin. Two holes were rotary drilled and continuously cored to basement at a sub-bottom depth of 387 meters. The first hole at Site 513 was drilled to a depth of 104.0 meters sub-bottom; however, sediment recovery below 56.5 meters was limited to Core 9 (75.5–85.0 m). The second hole, 513A, filled in the drilling gap of the first hole (56.6 to 75.5 m) and then was continuously drilled to basement. This report describes only the Neogene diatoms of Hole 513 and Hole 513A, Cores 1–11. Early Miocene diatoms from Hole 513A, Cores 12–33, are described by Gombos and Ciesielski (this volume).

2											Sili	cof	age	llate	es		R	ewo	orke	d I	Diat	om	s ai	nd	Si	licc	fla	gell	ates		
N. sp. 17	Rhizosolenia barboi	R. hebetata f. hiemalis	R. praebarboi	R. styliformis	Rouxia antarctica	Stephanopyxis turris	Thalassiothrix miocenica	Trinacria excavata	Dictyocha aculeata	D. spp.	Distephanus boliviensis	D. crux crux	D. quinquangellus	D. speculum	Mesocena diodon	M. circulus	Rocella vigilans	Hemiaulus polycystinorum	H. polymorphus	H. sp.	Nitzschia maleinterpretaria	Pvxilla fragments	Rocella velida		Triceratium barbadense	Trinacria simulacrum	Corbisema triacantha	Mesocena apiculata	Naviculopsis constricta	Diatom Zone	Silico- flagellate Zone
	r S								R		R			RSSS																Coscinodiscus lentiginosus Nitzschia interfrigidaria/ C. vulnificus	None
	S	R		R									R	Ű																N. angulata?	
	17	S		S		C				R	S				r			6												N. angulata	~~~~
	F C F	5 F		F F F		r S S S				S						S R R		R	R			F								Denticulopsis hustedtii/ D. lauta	
	S	F		F	s	S	C	R				S	S			s						R	ŝ		R	R					
	S S S	•		C S F	R	0	F					S	S			SS	R					R	2					R			Meso-
	S S F			F F F S			s s c s			S S			F			R		R	R R	R	S	R	2						R	N. denticuloides	circulus
F	С		S	F			С			C		S				S						R	S.								
S	C C C		R S R	S F			C F C C			С		S				C F C						R R R	R				S				

Diatoms are well represented throughout the entire lower Oligocene to Quaternary sequence of Holes 513 and 513A. In Pliocene-Quaternary sediments diatoms are common to abundant, diverse, and moderately preserved. Diatoms are common to abundant, poorly to moderately well preserved, and of moderate to high diversity in Miocene sediments.

Age determinations of Miocene-Quaternary sediments were made using the zonal scheme of McCollum (1975), as modified by Weaver (1976), Weaver and Gombos (1981), and Ciesielski (this report). Major diatom datums found within the lower Miocene-Quaternary of Holes 513 and 513A are given in Figures 8 and 9. Figure 8 presents a correlation of the Pliocene-Quaternary of Site 513 to magnetostratigraphy; a similar correlation of the upper Miocene of Hole 513 (Cores 5-11) is given in Figure 10.

Cores 1-6 of Hole 513 contain an apparently continuous sequence of the upper Pliocene-Quaternary. Within this interval the youngest eight zones of Ciesielski's revised diatom zonation (this chapter) are present. The *Coscinodiscus lentiginosus* Zone of the Brunhes Chron is present from the surface through 513-1-6, 115-117 cm. The *C. elliptopora/Actinocyclus ingens* Zone of the lowermost Brunhes-upper Matuyama Chronozone occurs from 513-3-1, 45-47 cm through 513-4-2, 90-92 cm; thus the boundary between these two zones (~620,000 y.B.P.) and the Brunhes/Matuyama Chronozone boundary (720,000 y.B.P.) probably falls in the unrecovered interval of Core 2. The mid-Matuyama Chronozone is represented between 513-4-3, 90-92 cm and 513-5-4, 5-7 cm where the *Rhizosolenia barboi/Nitzschia kerguelensis* Zone is encountered. Lower Matuyama Chronozone sediments are represented by the *C. kolbei/R. barboi* Zone and *C. vulnificus* Zone, which are found from 513-5-5, 2-4 cm to 513-6-1, 2-4 cm and at 513-6-2, 2-4 cm respectively.

Gauss Chronozone sediments are first encountered in Sample 513-6-2, 73-75 cm, which has been assigned to the *Cosmiodiscus insignis* Zone. The Matuyama/Gauss boundary, which occurs in the lowermost *Coscinodiscus vulnificus* Zone, thus probably occurs between 4 and 73 cm of Section 513-6-2. Samples 513-6-2, 73-75 cm through 513-6-4, 2-4 cm contain the *Cosmiodiscus insignis* Zone and the underlying *N. weaveri* Zone occurs only in Sample 513-6-5, 2-4 cm; both zones represent the upper normal-polarity interval of the Gauss Chronozone. The *N. interfrigidaria/Coscinodiscus vulnificus*

Table 3. Relative abundances of select	ed diatoms from the late Mid	ocene to Quaternary of Hole 513 and 513A.

																								Dia	ton	15							_								_						_
Sample (interval in cm)	Actinocyclus ingens	A. ingens (undulated form) A steromologic hvolinus	A. parvulus	A. sp. 1	A. sp. 2	Brunia mirabilus	Cestodiscus sp. 2	Coscinodiscus deformans	C. elliptopora	C. endoi	C. intersectus	C. kolbei	C. lentiginosus	C. lentiginosus v. obovatus	C. lineatus	C. marginatus	C. aff. marginatus	C. vulnificus	Cosmiodiscus insignis	C. insignis f. triangula	Denticulopsis dimorpha	D. hustedtii	D. lauta	D. punctata v. hustedtii	Eucampia antarctica	Hemidiscus cuneiformis	H. karstenii	H. karstenü f. 1	Lithodesmium cf. minusculum	Nitzschia angulata	N. cylindrica	N. donahuensis	N. fossilis	N. heteropolica	N. interfrigidaria	N. januaria	N. jouseae	N. kerguelensis	N. miocenica	N. porteri	N. praeinterfrigidaria	N. praereinholdii	N. reinholdii	N. rolandii	N. sicula v. rostrata	N. weaveri	N. sp. 14
Hole 513																																															
$\begin{array}{c} 1\text{-}1,\ 123\text{-}125\\ 1\text{-}3,\ 55\text{-}57\\ 1\text{-}6,\ 45\text{-}47\\ 3\text{-}1,\ 45\text{-}47\\ 3\text{-}2,\ 57\text{-}59\\ 3\text{-}6,\ 05\text{-}07\\ 4\text{-}1,\ 90\text{-}92\\ 4\text{-}2,\ 90\text{-}92\\ 4\text{-}3,\ 90\text{-}92\\ 4\text{-}3,\ 90\text{-}92\\ 4\text{-}6,\ 90\text{-}92\\ \end{array}$	C C S S A R								F A S S R				CACCCSSSSS	FF		R									FFCCSSSSSSSS		R	2		SFFFFFFFFFF								D D A A A A A A A A									
5-1, 50-52 5-3, 05-07	R												S S												S C		R			F F								A A									
5-4, 05-07 5-5, 02-04 5-6, 02-04 6-1, 02-04 6-2, 02-04 6-2, 73-75 6-3, 02-04 6-4, 02-04		F	ł						r			SCCRRRC	SSCSSSSR	R R S		SCSCCCCS		CCCC	r S S C						S S S C C S C		R			FFFFFFFFF								CCCCCSR								r	
6-5, 02-04 6-6, 02-04										R		S R	R	S R		s s		C S	C C						S S		RS			S					s											RC	
6-7, 34-36 Hole 513A										R		R	R	R		R		S	С						C		R			S					C											S	
1-1, 40-42 1-2, 40-42 2-1, 05-07 2-2, 70-72 2-3, 70-72 2-6, 51-53										S S R R	R	R	S R			R S S F S S						S			C S R C R R C	R	C C S R			S F A C S	S				S r S S						C A S F S S		RFCSFCC				
Hole 513																																															
9-1, 07-09 9-2, 66-68 9-3, 66-68 9-4, 66-68 9-5, 66-68 9-6, 06-08 9-7, 63-65										R						R S R F S R S						R F R			S R R F F		S S C F R F			S	s						F				C R S		SFSCFCF				F F
Hole 513A					ŀ																																										
3-1, 38-40 3-2, 58-60 4-1, 04-06						R										FFC					r	S			FCR	c	FFR									s	r						S F C				F
4-5, 70-72 4-7, 25-27 5-1, 140-142 5-3, 140-142 5-5, 140-142	S F														s s	CCFCE				s	r r	S			RS	R	SESCO	000						R		S				s			CFFC		D		3
5-7, 33-35 6-1, 04-06 6-3, 70-72 6-5, 70-72	SSS					R F F	R R			s	RS					FFFC				S F F		SRFS			s	S R F	CFFF	S				F				s s			R R S F				FS		R		S
6-7, 30-32 7-2, 57-59 7-4, 70-72 7-6, 130-132	C S C F		R	s	C F	F F F	R	F F		S	RS				S	CFCE				S F R	r	RSC			s	RFSS	SSSC	C			F		SSS	s		s s			FR	c		S	s				
8-1, 140-142 8-3, 70-72 8-5, 140-142 9-1, 69-71 10-1, 13-15 10-3, 70-72	r S R			RRSFF	R	C C R R	R								F S F	FCCSCC	S F F				r r R	FFCCC	RS		R	SRFCSRF	CCCFS	F	S R S F		F		F	R		R				F				S S			
10-5, 70-72 10-7, 12-14 11-1, 34-36 11-1, 127-129 11-2, 53-55 11-2, 120-122 11-3, 140-142 11-7, 09-11 11-7, 46-48	F F S C I C I	14 14		F R	R	S F S	R	F R							s	C F C F S F	F				R R R S R	CCCCSCCC	S C F S S S	S R		F S F	S R									S						R					

Note: Symbols are explained in Table 1.

N sp. 17 N sp. 17 N sp. 18 N sp. 18 N sp. 18 N sp. 18 N sp. 18 N sp. 19 N sp. 10	0.0.0.4 Rhizosolenia barboi R. hebetata f. hiemalis R. styliformis	R. styllformis Rouxia antarctica R. conformica R. isopolica R. sp. 1 R. sp. 2	Stephanopyxis turris Thalassiosira convexa T. nativa T. praeconvexa T. torokina T. sp. 10 T. sp. 10 Trinatssiothrix miocenica	Mesocena diodon Silicoflage	Preservation Reworks Rocella vigilans	Coscinodiscus lewisianus C. rhombicus	C. superbus Denticulopsis maccollumii Hemiaulus incisus H. polymorphus H. polymorphus	H. sp. Lisitziana ornata Nitzschia denticuloides N. maleinterpretaria Pyxilla fragments	Raphiodiscus marylandicus Rocella gelida R. schraderi R. schraderi Synedra jouseana Synedra jouseana Synedra jouseana Synedra jouseana Corbisema archangelskiana Naviculopsis biapiculata	
SC CCCCSSSRRSR RRR RFSSSSRS RSCFSC FCFFF	s c c									Diatom Zone
SC CCCCSSSRRSR RRRR RFSSSSRS RSCFSSS FSC FCFFF	s c c c				G G G G G G G G G G M					Coscinodiscus lentiginosus C. elliptopora/ Actinocyclus ingens
SSSRRSR RRR RFSSSRS RSCFSCFFFF	C		R R R R		G G G G G G G G G G G G G G G G G G G					Rhizosolenia barboi/ Nitzschia kerguelensis
RRRSR RRRR RFSSSSRS RSCFSSSS FSC FCFFF	S S		R		GG					C. kolbei/ R. barboi
R RRRR RFSSSRS RSSCFSSSS FSC FCFFF	R R S		R R R		G G M					C. vulnificus Cosmiodiscus insignis
R R S S S S R S S S R S S S R S S S S S	R R R R		R C C		G G G					N. weaveri N. interfrigidaria/ Coscinodiscus vulnificu
R S S S S S S S S S S S S S S S F S S S F S S S F S S S F S S S F S S S S F S	R F S S S R S	S S S S R R	R S C A S A R A C C R		M G G G M G					N. praeinterfrigidaria
F S C F F F	R S C F S S S S	S R F C C F	C F C S C F C S S F C S F	R	M G M M M M					N. reinholdii
FFSSFSSFSSFSSFSSFSSFSSSFSSSFSSSFSSSSFSSSS	F F F S F F F S F S F S F S F S F S F S	F S F R S F S R F S S R F S S R F S S R F S S S S S S S S S S S F F F F S	C R F C F S S S R F S S S R F S S S R F F S S S R F S S S R S S S R F S S S R S S S R F S S S R S S S R F S S S R S S S R F S S S R S S S R S S S R F S S S R S S S R S S S R F S S S R S S S R S S S R F S S S R S S S R R R S S S R R R S S S R R R S S S R R R S S S R R R S S S R R R S S R R R S S S R R R S S S R R R S S S R S S S R S S S R S S S S R S S S S R S	R R R r r r S S C S F R S C R R S C	MGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG	R	R	R	R S R R R	Meso- cena diodon (S) hustedtii — ? – M. cir- culus/ M.

Table 3. (Continued).



Figure 8. Positions of significant diatom and silicoflagellate datums in the Pliocene to Quaternary of Holes 513 and 513A and their correlation to paleomagnetic stratigraphy.



Figure 9. Positions of significant diatom and radiolarian datums in the upper Miocene of Hole 513A. Radiolarian datums from Weaver (this volume).

Zone is present between 513-6-6, 2-4 cm and 513-6-7, 34-36 cm. This later zone is indicative of the mid-Gauss Chronozone, from the lower portion of the upper normal-polarity sequence to between the Kaena and Mammoth subchronozones.

No sediments were recovered from Cores 513-7 and 513-8; however, this interval (56.5-75.5 m) was partially

recovered in Cores 513A-1 and 513A-2. The youngest sediment examined from Hole 513A (Sample 513A-1-1, 40-42 cm) was assigned to the *N. praeinterfrigidaria* Zone of the Gilbert Chronozone. The *N. interfrigidaria* Zone is thus absent or restricted to the interval of less than one meter between samples examined from the base of Hole 513 and the top of Hole 513A. The pres-



Figure 10. Correlation of selected upper Miocene diatom and radiolarian datums of Hole 513A to paleomagnetic stratigraphy. For a thorough discussion of this portion of Hole 513A and its correlation to other southern high-latitude DSDP sites see Ciesielski and Weaver (this volume). Radiolarian datums from Weaver (this volume).

ence of a hiatus between 513-6-7, 34-36 cm and 513A-1-1, 40-42 cm is also supported by numerous first and last species occurrences at these levels, including the last occurrence of *N. praeinterfrigidaria*, *N. reinholdii*, *Rouxia naviculoides*, and *Thalassiosira nativa* in Sample 513A-1-1, 40-42 cm, as well as the first occurrence of *Cosmiodiscus insignis*, *N. weaveri*, *Coscinodiscus vulnificus*, and *C. lentiginosus* f. *obovatus* in Sample 513-6-7, 34-36 cm. This Pliocene hiatus represents the lower Gauss Chronozone below the normal-polarity interval between the Kaena and Mammoth subchronozones and the Gilbert Chronozone above the Cochiti Subchronozone. The age of the sediment bracketing the disconformity, when calculated by assuming constant sedimentation rates from known datums above and below the disconformity, is 3.05 and 3.85 Ma, respectively. This calculated age is in agreement with diatom and radiolarian assemblages above and below the disconformity.

An alternative explanation for the Pliocene hiatus between Hole 513, Core 6 and Hole 513A, Core 1 is that the missing *N. interfrigidaria* Zone may be accounted for by an inaccurate sub-bottom depth estimate for the base of Hole 513 and the top of Hole 513A. This explanation seems unlikely, however, because the missing interval should be 10-20 meters thick (if sedimentation rates were one-half to equal the prior 18.5 m/m.y. rate of sedimentation), and a depth error of more than a few meters seems unreasonable.

Sediments of the Gilbert Chronozone are present between 513A-1-1, 40-42 cm and 513A-4-7, 25-27 cm; the interval represents most of Gilbert from the base of the Cochiti Subchronozone to the lower Gilbert below the Thvera Subchronozone (Fig. 8). Diatom zones present within this interval include the *N. praeinterfrigidaria* Zone, 513A-1-1, 40-42 cm through 513A-2-1, 5-7 cm; the *N. angulata* Zone, 513A-2-2, 70-72 cm through 513-9-1, 7-9 cm; the *N. reinholdii* Zone, 513-9-2, 66-68 cm through 513-9-4, 66-68 cm; and the *Denticulopsis hustedtii* Zone, 513-9-5, 66-68 cm through 513A-4-7, 25-27 cm.

Diatom and radiolarian assemblages in Core 513A-5 indicate the presence of a hiatus between Cores 4 and 5 (Fig. 9). This hiatus spans an interval including the Miocene/Pliocene boundary (uppermost Chronozone 5 and lowermost Gilbert Chronozone) (Fig. 10). Samples 513A-5-1, 140-142 cm through 513A-9-1, 69-71 cm represent the late Miocene portion of the *D. hustedtii* Zone. Diatom and radiolarian datums within this interval (Fig. 9) allow it to be correlated to Chronozones 5 and 6 (Fig. 10).

A third disconformity occurs at Site 513, within a zone where no sediment was recovered between Sample 513A-9-1, 69-71 cm and 513A-10-1, 13-15 cm (Fig. 9). This disconformity separates the sediments of the *D. hustedtii* Zone above from the *D. hustedtii/D. lauta* Zone sediments found below. The missing interval includes lower Chronozone 6, Chronozone 7, and most or all of Chronozone 8.

The D. hustedtii/D. lauta Zone occurs between 513A-10-1, 13-15 cm and 513A-12-1, 9-11 cm. Age control for this interval was provided by a ${}^{40}\text{Ar}/{}^{39}\text{Ar}$ analysis of volcanic ash from Sample 513A-10-7, 10-13 cm (R. D. Dallmeyer, University of Georgia, pers. comm., 1981). The ${}^{40}\text{Ar}/{}^{36}\text{Ar}$ versus ${}^{39}\text{Ar}/{}^{36}\text{Ar}$ isochron age for the incremental gas analysis was 8.7 m.y. ± 0.2 m.y. (Fig. 10), thus the interval represented at this site by the D. hustedtii/D. lauta Zone can be correlated to upper Chronozone 9 or lower Chronozone 8.

A major change occurs in the late Miocene diatom assemblage between Samples 513A-11-2, 53-55 cm and 513A-11-2, 120-122 cm. Abundant middle Miocene and Oligocene diatoms are reworked in the upper Miocene sediments between 513A-11-2, 120-122 cm and 513A-12-1, 9-11 cm. These reworked diatoms were apparently transported to the site by bottom currents from the nearby exposures of older sediment that are seen on seismic reflection profile records (Ciesielski and Weaver, this volume). Reworked middle Miocene diatoms include representatives of the upper *N. maleinterpretaria* Zone, *Coscinodiscus lewisianus* Zone, and *N. denticuloides* Zone. Reworked Oligocene diatoms come primarily from the lower Oligocene *Pyxilla prolongata* Group Zone and all four upper Oligocene zones of Gombos and Ciesielski (this volume).

The fourth and lowermost detected disconformity occurs between Samples 513A-12-1, 9-11 cm and 513A-12-1, 123-125 cm; separating the upper Miocene above from a lengthy and apparently continuous lower Oligocene-lower Miocene section. Eight diatom zones occur in Hole 513A between Sample 12-1, 123-125 cm and the chert and basalt sill encountered in Cores 34-36. Seven of these zones are described for the first time by Gombos and Ciesielski (this volume).

Site 514 (Table 4)

Site 514 (46°02.77'S, 26°51.30'W; 4318 m) is east of the Argentine Basin on the lower west flank of the Mid-Atlantic Ridge. A continuous Pliocene through Quaternary sequence of diatomaceous clays and muddy diatomaceous oozes was hydraulic piston cored to a sub-bottom depth of 150.8 meters. Site 514 is about 400 km north of the present-day position of the Polar Front and about 300 km north of Site 513. A major objective at both sites was to determine the late Cenozoic history of the Polar Front.

Abundant and diverse diatom assemblages of early Pliocene to Quaternary age occur throughout all of Hole 514. This continuously cored HPC section is characterized by good preservation of siliceous microfossils, high sediment accumulation rates, nearly continuous deposition, and an excellent paleomagnetic record.

Site 514 and several piston cores were used to establish the revised diatom zonation of southern high-latitude sediments presented here. Eleven diatom zones are recognized in Hole 514. The stratigraphic occurrence of each zone is as follows: Samples 514-1-1, 47-49 cm through 514-3-1, 72-74 cm, Coscinodiscus lentiginosus Zone; 514-3-2, 70-72 cm through 514-5-4, 54-56 cm, C. elliptopora/Actinocyclus ingens Zone; 514-6-1, 77-79 cm through 514-6-2, 80-82 cm, Rhizosolenia barboi/ Nitzschia kerguelensis Zone; 514-6-3, 77-79 cm through 514-9-2, 70-72 cm, C. kolbei/R. barboi Zone; 514-9-3, 63-65 cm through 514-12-1, 50-52 cm, C. vulnificus Zone; 514-12-2, 26-28 cm through 514-15-2, 70-72 cm, Cosmiodiscus insignis Zone; 514-15-3, 70-72 cm through 514-19-1, 72-74 cm, N. weaveri Zone; 514-19-2, 72-74 cm through 514-25-1, 95-97 cm, N. interfrigidaria/Coscinodiscus vulnificus Zone; 514-26-1, 98-100 cm through 514-27-2, 84-86 cm, N. interfrigidaria Zone; 514-28-1, 90-92 cm through 514-32-1, 77-79 cm, N. praeinterfrig*idaria* Zone; and 514-33-1, 75-77 cm through 514-35-3, 73-75 cm, N. angulata Zone.

All index diatom species found in the subantarctic Hole 514 are also common to antarctic sediments of similar age (Ciesielski, 1978; Weaver and Gombos, 1981). The stratigraphic ranges of the zonal guide species of this site are also similar in the antarctic. Previous correlations of index diatom species to paleomagnetic stratigraphy elsewhere in the southern high latitudes (McCollum, 1975; Ciesielski, 1978; Weaver and Gombos, 1981; and Ciesielski, this chapter) are used to correlate the magnetic polarity sequence of Hole 514 to the standard paleomagnetic time scale (Table 4). A single hiatus is identified within the lower portion of the N. interfrigidaria Zone, between Samples 514-26-3, 54-56 cm and 514-27-1, 84-86 cm. The diatom assemblage and magnetic polarity record immediately above and below the disconformity indicate that the missing interval represents a portion of the Mammoth Subchronozone, the entire lower normal-polarity portion of the Gauss Chronozone, and most of the uppermost reversed-polarity portion of the Gilbert Chronozone ($\sim 3.86-3.16$ Ma).

Scattered occurrences of rare to few *Denticulopsis* hustedtii are reworked into Cores 25-30 and Core 34. Common to abundant reworked late Oligocene to earliest Miocene diatoms are found in upper Gauss Chronozone sediments of Core 19, Section 1 (20-22 cm and 72-74 cm). Common reworked diatoms in Core 19 include Synedra jouseana, Hemiaulus tauris, Rossiella sp. A, Rocella gelida, R. vigilans, and Asterolampra affinis. Several of these reworked species have stratigraphic ranges restricted to the latest Oligocene-early Miocene R. vigilans through R. gelida Zones of Gombos and Ciesielski (this volume).

TAXONOMIC REFERENCES

Taxonomic references for all taxa recorded during this study are listed here, with species authors, one or more readily accessible references with descriptions and illustrations, and a plate reference for those species illustrated here.

Descriptions of New Taxa and Taxonomic Revision

Genus COSCINODISCUS Ehrenberg (1838)

Coscinodiscus lentiginosus var. obovatus (Castracane) Ciesielski n. comb. (Plate 4, Figs. 6-8)

Coscinodiscus obovatus Castracane, 1886, p. 160, pl. 22, fig. 9.

Remarks. DeFelice (1979) discussed fully the morphology of *Coscinodiscus obovatus* and its similarity to *C. lentiginosus*. He suggested that the former species was an extinct Pliocene form of *C. lentiginosus* but did not formally establish it as such.

The range of *C. obovatus* in Leg 71 sediments adds to the evidence that this species is a variation of *C. lentiginosus. C. obovatus* is not extinct, as was previously thought, for it occurs sporadically in the Brunhes and Matuyama chronozones (Sites 511, 512, and 513). I have also noted the species in surface sediments of some Southern Ocean piston cores (unpublished data). The sporadic occurrences of *C. obovatus* within the Gauss, Matuyama, and Brunhes chronozones suggests that this species is an elliptical variation of *C. lentiginosus*; it is now formally named *C. lentiginosus* var. obovatus.

The earliest occurrence of the variety is within the Mammoth Subchronozone of the Gauss Chron. It occurs widely in mid-upper Gauss Chronozone sediments, whereas occurrences in younger sediments are sporadic and local in extent.

														Di	ator	ns									Sil	icol	lage	ellat	es		R	ewor	rkec	1		Τ	
Age (m.y.)	Age	Mag- netic Chron (normal polarity is ha- chured)	Core/ Section (interval in cm)	Actinocyclus ingens Asteromphalus hookerii	A. parvulus	Coscinodiscus elliptopora C. kolbei	C. lentiginosus	C. tentiginosus v. opovatus C. mareinatus	C. vulnificus	Cosmiodiscus insignis	Ethmodiscus rex	Eucampia antarctica	Hemidiscus cuneijormis	n. karsienu Nitzschia angulata	N. interfrigidaria	N. kerguelensis	N. praeinterfrigidaria	N. reinholdii	N. weaveri	Rhizosolenia barboi	Stephanopyxis turris	Powia odifornia	Kouxia canjornica D maniauloidae	Distenhanus holiviencis	D. holiviensis maior	D. crux	D. polyactis	D. auinquangellus	Dictyocha spp.	Denticulopsis hustedtii	Rocella gelida	Rossiella sp.	Synedra Jouseana	5. mtocentca Naviculonsis hianiculata	Preservation		Diatom Zone
		Brunhes	1-1, 47-49 1-1, 98-99 2-1, 77-79 2-2, 79-81 2-3, 90-92 3-1, 72-74		R S		C C C C C C F F					00000 0		R S F F R S R S		A A A A A A C											S		S						M G M G M M		Coscinodiscus lentiginosus
0.72 0.91 0.98	Quater-		3-2, 70-72 3-3, 49-51 4-1, 123-125 4-2, 120-122 4-3, 49-51	F F F F	R	C S	C F F F F				S S S	FFFS		C F F S S		D C C A F C						0 1011 111							s						G M M M		C. elliptopora/ Actinocyclus ingens
1.66 1.88	nary		5-3, 54-56 5-4, 54-56 6-1, 77-79 6-2, 80-82	C C C R C	S F	S	F F F				F F S	S F F	ļ	R A		C A A				F C							F		s						MGG		Rhizosolenia barboi/ Nitzschia kerguelensis
		Matu-	6-3, 77-79 8-1, 57-59 8-2, 57-59 8-3, 22-24 9-1, 86-88	C C S F S		S F F C F F F	FFFC	F C F F		r s	S F F F C F	FCFF		CCCCA		AACCS				CCCFC	04000						С								GGGGGG		C. kolbei/ R. barboi
		yama	9-2, 70-72 9-3, 63-65 10-1, 33-35 10-2, 77-79 10-3, 136-138	R R R R	P	5 F F F F F S	FFFFSF	FFCCCC	F F C C	R	r S S	F S S F		S A C A C C C		F				FFFS		F	F	5	s			F	s						G G G M G		C. vulnificus
2.47			12-1, 50-52 12-2, 26-28 12-3, 02-04 13-1, 60-62 13-2, 49-51 13-3, 130-132			F	FFSF FSC	F C A S R	CCCF CCC	S S F F F F	SFFFS	F (F) F) S) S)		SCCCC CF						S S R R			<	S F F F C S c	F S F S			c s	s s						GGGG GM		Cosmiodiscus insignis
	Plio- cene		15-1, 96-98 15-2, 70-72 15-3, 70-72 16-2, 100-102 17-1, 50-52 18-1, 51-53 19-1, 72-74			F F S S R	FFFSF	R	FFFFF	FC CFCC	SSSSFS	F S S R S		C C F S F F F F					cccc	R S R	F F F F F F F F F F F F F F F F F F F	F		S F S S F	s		S				D	E (M G M M G M B		N. weaveri
2.92 2.99		Gauss	19-2, 72-74 19-3, 72-74 20-1, 75-77 20-2, 68-70 20-3, 57-59 21-1, 83-85 22-1, 125-127 23-1, 88-90 23-3, 05-07	S S F F		5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	S S S S S S S S S	R	F FFF FFF C	CCCFC FFRS	SSFFF SFFS	C I S S S F F S C		S S F S S F S S S	RRRSS FSFF		s	SF	FCCCC CCF	SSS	F C F C F C F F F F F F F F F F F F F F	s	5	S S C F S C F S C	S			FS	S		K			5 5	MGGMG GMPM		N. interfrigidaria/ Coscinodiscus vulnificus
3.08			24-1, 90-92 24-2, 88-90 25-1, 95-97 26-1, 98-100 26-3, 54-56 27-1, 84-86	C F F S		F R	S I S I S I S I		F S R R R	S F R	F S F F F S	S F F F F F C S C C C		FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF	F F F F F C		F	F	C S S S S S S S S S S S S S S S S S S S	S S R	F D C A F A F A F A	S F S	S S F	C S S S S S S	S				C S	R R					G M M P M		N. interfrigidaria
3.95			27-2, 84-86 28-1, 90-92 28-2, 90-92 29-2, 72-74 30-2, 66-68 31-2, 56-58	S	с		s	R	t		S F F F F F F	F S S F F	F	FFCCCCF	CCCCC P		S I S C F I S I F	FOFFF F	FI	R		SR	S F F	S S S S S F				S	S F F	R R R					M G M M G P		V. praeinterfrigidaria
			32-1, 77-79 33-1, 75-77 33-3, 80-82 34-1, 74-76 34-2, 74-76				ſ	FF			FCFFF	F S S S	FCCFF	-0000 C	C e		FICCCC	n. h. n. 1 1 n	H H H	REE		S	F	F F F	S F S	S		SFFFC	SFFF	R					M G M G G		
		Gilbert	34-3, 74-76 35-1, 73-75 35-2, 73-75 35-3, 73-75				5	SSF			S F F	S S F F	FCSF	FCCC	e e		S I F I F I F I		S H H H	SEFE	CCCCA		S	FSSS	FRR	3		~	FFC						GGGGG		N, angulata

Table 4. Relative abundances of selected diatoms and silicoflagellates of Hole 514.

Note: "e" represents transitional form between N. praeinterfrigidaria and N. interfrigidaria. Other symbols are defined in Table 1. Magnetic polarity measurements by Salloway and Bloemendal (this volume). Ages of magnetic chrons and subchrons Dalrymple (1979)

Genus NITZSCHIA Hassal (1854)

Nitzschia interfrigidaria McCollum, 1975, emend. Ciesielski, this chapter (Plate 1, Figs. 11-18)

Nitzschia interfrigidaria McCollum, 1975, p. 535, pl. 9, figs. 7-9.

Discussion. McCollum's (1975) incomplete and partially inaccurate diagnosis of this species has resulted in some uncertainty over the concept of this species (Gombos, 1977; Schrader, 1976); therefore, *Nitzschia interfrigidaria* is emended here.

Description. Valves elliptical-linear, flat, broadly rounded apices; 28–75 μ m long, 7–9 μ m wide. Transapical ribs 9.5–12 in 10 μ m, nearly transapical parallel, straight or curved at the apices. In light microscope, transapical ribs are more strongly developed along the valve margin. In some specimens the transapical ribs are very indistinct toward the center of the valve, giving the valve surface a hyaline appearance. Intercostal membrane perforated by a single row of punctae which are unevenly spaced and variable in size, shape, and number. Wide spacing of punctae gives portions of the valve surface a hyaline appearance. Raphe marginal, keel distinct and punctate.

Remarks. This species is a member of the Nitzschia praeinterfrigidaria-N. interfrigidaria-N. weaveri lineage. Specimens of N. praeinterfrigidaria transitional to, but not included in N. interfrigidaria, are shown in Plate 2, Figs. 13-16. Specimens of N. interfrigidaria transitional to but not included in N. weaveri are shown in Plate 1, Figs. 17-18.

Lectotype. Plate 9, figure 8 of McCollum (1975). McCollum did not designate a holotype; therefore, this lectotype is selected from his original material. McCollum apparently did not deposit his specimens in a permanent, responsible institution; thus a neotype may have to be selected in the future.

Occurrence. The earliest occurrence of *N. interfrigidaria* in Southern Ocean sediments occurs between the base of the Cochiti Subchronozone and the top of the Nunivak Subchronozone of the Gilbert Chronozone. The last occurrence of the species is in the upper normal-polarity interval of the Gauss Chronozone.

Nitzschia praeinterfrigidaria McCollum, 1975, emend. Ciesielski, this chapter (Plate 2, Figs. 1-8, 13-16; Plate 3, Fig. 5)

(1 late 2, 1 lgs. 1-0, 15-10, 1 late 5, 1 lg. 5)

Nitzschia praeinterfrigidaria McCollum, 1975, p. 535, pl. 10, fig. 1.

Discussion. McCollum's (1975) incomplete diagnosis of this species has resulted in some uncertainty over the concept of the species (Gombos, 1976; Schrader, 1976); therefore, *Nitzschia praeinterfrigidaria* is emended here.

Description. Valves elliptical-linear, flat, broadly rounded apices; $34-76 \ \mu m \ \log, 7-9 \ \mu m$ wide. Transapical ribs $9.5-10.5 \ in 10 \ \mu m$. One side of the valve nearly straight, the other more rounded. Transapical ribs distinct over the entire valve, may be transapical parallel but most commonly are inclined slightly over a portion of the valve surface and slightly curved at the poles. Intercostal membrane with a single row of punctae, unevenly spaced, with no large nonpunctate regions. Raphe marginal, canal raphe with distinct keel punctae.

Remarks. Nitzschia praeinterfrigidaria is the ancestor of N. interfrigidaria and N. weaveri. This species differs from N. interfrigidaria by its more completely punctate intercostal membrane and absence of hyaline areas on the valve surface. N. praeinterfrigidaria is also less symmetric: one side of the valve is generally more rounded than the other. McCollum's (1975) diagnosis of N. interfrigidaria states that "occasionally one side is slightly more curved than the other;" however, his figures do not verify this claim. None of McCollum's figures of N. interfrigidaria exhibits this characteristic, whereas, his sole figure of N. praeinterfrigidaria does. The results of the present study clearly reveal that N. praeinterfrigidaria, not N. interfrigidaria, is characterized by having one side of the valve more rounded than the other. McCollum must have meant to attribute this characteristic to N. praeinterfrigidaria, but mistakenly attributed it to N. interfrigidaria.

McCollum (1975) figured only one specimen of *N. praeinterfrigidaria*, which is the holotype of the species even though it was not so designated. McCollum apparently did not deposit his holotype in a permanent, responsible institution; I do not now know where it is, and unless it can be located, it will be necessary to designate a neotype. **Occurrence.** The first occurrence of *N*. *praeinterfrigidaria* is in the vicinity of the Sidufjall Subchronozone and its last occurrence is in the upper Gilbert Chronozone between the Cochiti Subchronozone and the Gilbert/Gauss boundary.

Nitzschia weaveri Ciesielski, n. sp. (Plate 1, Figs. 1-10)

Description. Valves elliptical-linear, strongly silicified, flat, with rounded apices; 27-80 μ m long, 6-9 μ m wide. Transapical ribs, 11-13.5 in 10 μ m, transapical parallel, strongly expressed on the valve margin, indistinct away from the margin. One large circular to elliptical pore on the valve margin between distinct transapical ribs. Prominent, lanceolate, hyaline, middle area. Intercostal membrane usually nonperforate; punctae, when present, small; no more than 2-3 per valve. Raphe marginal, canal raphe with distinct keel punctae. Raphe rises close to valve surface near the apices.

Discussion. This species is the younger end member of the *N. prae*interfrigidaria-N. interfrigidaria-N. weaveri evolutionary lineage. N. weaveri differs from its ancestor N. interfrigidaria by the total or near absence of punctae on the intercostal membrane. The gradual reduction in the abundance of punctae has been noticed in Pliocene sediments of Hole 514 and in numerous piston cores. Two specimens of N. interfrigidaria with reduced abundance of punctae are shown on Plate 1, Figs. 17-18.

Holotype. Plate 1, Figure 3, 33 μ m long, 6 μ m wide, Sample 513-6-6, 2-4 cm. USNM No. 353318.

Paratypes. Plate 1, Figures 1 and 2 (USNM No. 353319); Figures 4 and 5 (USNM No. 353320).

Occurrence. I have noted the species in sediments from all sectors of the Southern Ocean. Its latitudinal range extends from the subantarctic to the Ross Sea. *Nitzschia weaveri* has its lowest occurrence in the Cochiti Subchronozone of the Gilbert Chronozone and its highest occurrence is in the middle of the upper normal-polarity portion of the Gauss Chronozone.

Taxonomic Notes and Illustration References

The first citation is the original description of the species, the second is a more recent and accessible reference. Only the second citation is included in the reference list.

- Actinocyclus ingens Rattray. Flat form, Schrader, 1973, pl. 18, figs. 2-4, 7; undulated form, Baldant and Barron, 1980, pl. 1, figs. 1-2.
- Asteromphalus hookeri Ehrenberg, 1844. Fenner et al., 1976, pp. 768-769, pl. 4, fig. 24.
- Asteromphalus hyalinus Karsten, 1905. Fenner et al., 1976, pl 4, figs. 17-19.

Asteromphalus parvulus Karsten, 1905. Hustedt, 1958, pl. 8, fig. 91.

Asteromphalus sp. 1 (Plate 6, Figs. 1-2, 6, 9). Cells discord, valves slightly convex, generally 65-95 μ m in diameter. Valve surface with a central hyaline space occupying two-fifths of the diameter; 9-13 rays divide the valve into equal sectors. All rays not of equal length; shorter rays with junction points marginal to the center. Areolated segments between elevated rim and outer region of the ray central expansion zone. Areolae pentagonal-hexagonal, arranged in tangential rows.

Asteromphalus sp. 2 Schrader, 1976, pl. 8, fig. 1.

Asteromphalus sp. 3 (Plate 6, Fig. 5). Occurs rarely in the late Miocene of Hole 513A.

Brunia mirabilis (Brun in Brun and Tempère) Tempère, 1890 (Plate 7, Figs. 1-2). Barron, 1975, p. 127, pl. 4, fig. 16. Synonyms: As Bruniopsis mirabilis (Brun) Karsten, referenced in Schrader, 1973, p. 702, pl. 13, fig. 16, Gombos, 1977, p. 592, pl. 6, fig. 4.

Cestodiscus sp. 2 Schrader, 1976, p. 630, pl. 12, fig. 7.

- Coscinodiscus deformans Schrader, 1976, p. 630, pl. 11, figs. 1-2.
- Coscinodiscus elliptopora Donahue. Gombos, 1977, pl. 3, figs. 1-3, 6; pl. 9, fig. 3.

Coscinodiscus endoi Kanaya. Schrader, 1973, pl. 8, figs. 1-6, 10, 15.

Coscinodiscus kolbei Jousé. McCollum, 1975, pl. 4, figs. 7-9. Coscinodiscus lentiginosus Janish in Schmidt et al., 1878. Gombos,

1976, pl. 3, figs. 4–5.

- Coscinodiscus lewisianus Greville, 1866. McCollum, 1975, pl. 5, figs. 2-4. Reworked.
- Coscinodiscus lineatus Ehrenberg, 1838. Hustedt, 1930, pp. 392-393, fig. 204.

- Coscinodiscus marginatus Ehrenberg, 1841. Hustedt, 1930, pp. 416-418, fig. 223.
- Coscinodiscus sp. aff. C. marginatus Ehrenberg, of Schrader, 1976, pl. 10, fig. 3.
- Coscinodiscus rhombicus Castracane, 1886. Schrader, 1976, pl. 21, figs. 1-3, 5.
- Coscinodiscus ruboides Schrader, 1976, pl. 6, figs. 4, 8.
- Coscinodiscus superbus Hardman in Rattray, 1899. Gombos and Ciesielski, this volume, Pl. 4, Figs. 1-8. Synonyms: as Cestodiscus pulchellus, Greville, 1866, p. 123, pl. 11, fig. 5; Cestodiscus robustus, Jouse, 1974, p. 345, pl. 1, figs. 14-15. Reworked.
- Coscinodiscus vulnificus Gombos, 1977, pl. 4, Figs. 1-3, pl. 42, figs. 1-2 (Plate 6, Figs. 7-8).
- Cosmiodiscus insignis Jousé, 1961. McCollum, 1975, pl. 8, fig. 5; Gombos, 1977, pl. 4, figs. 4-5.
- Cosmiodiscus insignis f. triangula Jousé, 1977, pl. 79, fig. 2 (Plate 5, Figs. 1-10). This distinctive triangular form of Cosmiodiscus insignis is highly variable in size, ranging from $32 \ \mu m$ (Figs. 1-2) to $98 \ \mu m$ (Figs. 7-8). Its first occurrence is in the upper reversed portion of Chronozone 6 and its last occurrence is in the lowermost Gilbert Chronozone, below the Thvera Subchronozone.
- Cosmiodiscus intersectus (Brun) Jousé, 1961, p. 68, pl. 2, figs. 9-10; Koizumi, 1973, p. 832, pl. 4, figs. 12-13.
- Craspedodiscus coscinodiscus Ehrenberg, 1884. Kanaya, 1971, p. 555, pl. 40.4, figs. 1-3; Schrader, 1974, p. 541.
- Denticulopsis dimorpha (Schrader) Simonsen, 1979. Schrader, 1973, p. 704, pl. 1, figs. 28-34, 36-47; Barron, 1975, p. 138, pl. 8, fig. 7.
- Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen, 1979. Schrader, 1973, pl. 2, figs. 28-34, 36-47.
- Denticulopsis aff. kamtschatica (Zabelina) Simonsen, 1979, of Schrader, 1976, p. 632, pl. 4, fig. 18.
- Denticulopsis lauta (Bailey) Simonsen, 1979. Schrader, 1973, pl. 2, figs. 14-24.
- Denticulopsis maccollumii Simonsen, 1979. Schrader, 1976, pl. 4, figs. 3, 22-23, 25.
- Denticulopsis praedimorpha (Akiba) Simonsen, 1979. Barron, 1980, pl. 1, figs. 18-20.
- Denticulopsis punctata var. hustedtii (Schrader) Simonsen, 1979. Schrader, 1973, pl. 1, figs. 23-24.
- Ethmodiscus rex (Rattray) Hendey, 1953, pp. 51-57, pl. 1, figs. 1-6, pl. 2, figs. 1-3.
- *Eucampia antarctica* Castracane, 1886. Fenner et al., 1976, p. 774, pl. 5, figs. 7–9; DeFelice and Wise, 1981, p. 62, pl. 5, figs. 7–9.
- Hemiaulus incisus Hajós, 1976, p. 829, pl. 23, figs. 4-9; Gombos, 1976, p. 594, pl. 15, fig. 3. Synonyms: Hemiaulus kittonii Schmidt, 1888, pl. 142, fig. 11; Hemiaulus sp. 1 McCollum, 1975, p. 535, pl. 9, fig. 2. Reworked.
- Hemiaulus polycystinorum Ehrenberg, 1854. Fenner, 1979, p. 521, pl. 21, figs. 13-14; pl. 22, figs. 4-5, 7-10; pl. 23, figs. 1-4. Reworked.
- Hemiaulus polymorphus Grunow, 1884. Fenner, 1979, p. 522, pl. 21, fig. 11; pl. 23, figs. 10-11; pl. 22, fig. 13. Reworked.
- Hemidiscus cuneiformis Wallich, 1860. Schrader, 1973, pl. 24, fig. 14.
- Hemidiscus karstenii Jousé, 1962. Abbott, 1972, pp. 110-112, pl. 1, figs. D-F.
- Hemidiscus karstenii f. 1 (Plate 4, Figs. 2-5). This form of Hemidiscus karstenii is characterized by the presence of widely spaced areolae in the central portion of the valve. Maximum valve dimension is generally 65-75 μ m. This form is common only in sediments of Chronozone 5 and upper Chronozone 6. Pliocene-Pleistocene specimens are smaller, more elliptical, and more completely areolated in the valve center.
- Hemiaulus sp. Gombos and Ciesielski, this volume, Plate 20, Figures 7-9. Reworked.
- Lithodesmium cf. minusculum Grunow in Van Heurck, 1883. Schrader, 1973, p. 706, pl. 12, figs. 7 (?), 15, 17; Barron, 1975, p. 19, pl. 10, fig. 3. (Plate 6, Figs. 3-4). In the North Pacific, Schrader (1973) found this species in NPD Zones XI-XV, which he correlated indirectly to upper magnetic Chron 7 through the Thvera Subchron of the Gilbert Chron. In the present study the species was found only in Hole 513A, in Samples 513A-8-3, 70-72 cm through 513A-10-1, 13-15 cm, correlative to latest Chron 9 through mid-Chron 6.
- Lizitziana ornata Jousé, 1978, pp. 47-48, pl. 10, figs. 1-4; Gombos and Ciesielski, this volume, Plate 18, Figures 1-4. Synonym: Triceratium cruciforme Schmidt, 1887, pl. 77, fig. 41. Reworked.

- Mediaria splendida Sheshukova-Poretzkaya, 1962. Schrader, 1973, pl. 3, figs. 14-15.
- Nitzschia angulata (O'Meara) Hasle, 1972. Hasle, 1965, pl. 1, fig. 6; pl. 4, fig. 19; pl. 6, fig. 5; pl. 8, fig. 11; pl. 9, figs. 1-6; pl. 10, figs. 2-6.
- Nitzschia claviceps Schrader, 1976, p. 633, pl. 2, figs. 2, 4.
- Nitzschia clementia Gombos, 1977, p. 595, pl. 8, figs. 18-19.
- Nitzschia cylindrica Burckle, 1972, pp. 239-240, pl. 2, figs. 1-6; Schrader, 1973, p. 707, pl. 5, figs. 27, 32-33.
- Nitzschia denticuloides Schrader, 1976, pl. 3, figs. 7-8, 10, 12, 18-24; pl. 15, fig. 22.
- Nitzschia donahuensis Schrader, 1976, p. 633, pl. 2, fig. 30.
- Nitzschia efferans Schrader, 1976, p. 633, pl. 2, figs. 1, 3, 5-7.
- Nitzschia fossilis (Frenguelli) Kanaya in Kanaya and Koizumi, 1970. Schrader, 1973, pl. 4, figs. 4, 5, 9-11, 24-25.
- Nitzschia heteropolica Schrader, 1973, pl. 26, figs. 1-2.
- Nitzschia januaria Schrader, 1976, p. 634, pl. 2, figs. 25-29.
- Nitzschia jouseae Burckle, 1972. Schrader, 1974, pl. 7, figs. 14-23.
- Nitzschia kerguelensis (O'Meara) Hasle, 1972. Hasle, 1968, figs. 1, 2, 7-9.
- Nitzschia maleinterpretaria Schrader, 1976, p. 634, pl. 2, figs. 9, 11-19, 21, 24. Reworked.
- Nitzschia miocenica Burckle, 1972, pp. 240-241, pl. 2, figs. 10-15 (Plate 2, Figs. 9-12).
- Nitzschia porteri Frenguelli sensu Burckle, 1972, pl. 2, fig. 16.
- Nitzschia praereinholdii Schrader, 1973, pl. 5, figs. 20, 23-26.
- Nitzschia pseudokerguelensis Schrader, 1976, p. 634, pl. 15, figs. 13-15.
- Nitzschia reinholdii Kanaya sensu Koizumi. Schrader, 1973, pl. 4, figs. 12-16; pl. 5, figs. 1-9.
- Nitzschia rolandii Schrader, 1973, p. 708, pl. 5, fig. 31; pl. 26, figs. 3-4.
- Nitzschia sicula v. rostrata Hustedt, 1958, p. 180, pl. 11, figs. 128-132; Schrader, 1976, p. 634, pl. 2, fig. 31.
- Nitzschia sp. 14 Schrader, 1976, p. 634, pl. 2, figs. 8, 36.
- Nitzschia sp. 16 Schrader, 1976, p. 634, pl. 2, fig. 37.
- Nitzschia sp. 17 Schrader, 1976, p. 634, pl. 3, figs. 13-15, 17; pl. 2, fig. 10.
- Nitzschia sp. 18 Schrader, 1976, p. 634, pl. 15, fig. 19.
- Pyxilla fragments. Only reworked fragments of this genus were found in Neogene sediments.
- Raphiodiscus marylandicus Christian, 1887. Schrader, 1973, p. 708, pl. 22, fig. 7; Andrews, 1974, p. 232, pls. 1-5, figs. 1-29. Rhizosolenia barboi Brun, 1894. Donahue, 1970, p. 136; Schrader,
- Rhizosolenia barboi Brun, 1894. Donahue, 1970, p. 136; Schrader, 1976, p. 635, pl. 9, figs. 11-13.
- Rhizosolenia hebetata f. hiemalis Grun, 1904. Hustedt, 1930, pp. 590– 592, fig. 337; Schrader, 1973, p. 709, pl. 9, figs. 11, 13–17, 19–21, 24, 25.
- Rhizosolenia praebarboi Schrader, 1973, pp. 709-710, pl. 24, figs. 1-3.
- Rhizosolenia styliformis Brightwell, 1858. Schrader, 1973, p. 710, pl. 10, figs. 1, 18–21.
- Rocella gelida (Mann) Bukry, 1978, p. 788, pl. 5, figs. 1-13. Reworked; this heavily silicified species is one of the most commonly reworked species in Southern Ocean sediments.
- Rocella schraderia Bukry, 1978, p. 788, pl. 6, figs. 1-10; pl. 7, fig. 1. Reworked.
- Rocella vigilans (Schmidt) Fenner, in press. Gombos and Ciesielski, this volume, Plate 6, Figures 7-10; pl. 26, fig. 2. Reworked.
- Rossiella sp. Gombos and Ciesielski, this volume, Plate 24, Figures 1-2. Synonym: Bogorovia veniamini Jousé in Gombos, 1977, p. 593, pl. 1, figs. 6-7; pl. 12, figs. 1-2, 4. Reworked.
- Rouxia antarctica Heiden and Kolbe, 1928. Gombos, 1977, p. 596, pl. 7, fig. 12; Schrader, 1976, p. 635, pl. 5, figs. 1-8.
- Rouxia californica M. Peragallo in Tempère and Peragallo, 1910. Schrader, 1976, p. 635, pl. 5, fig. 21; Gombos, 1977, p. 596, pl. 7, fig. 13.
- Rouxia isopolica Schrader, 1976, p. 635, pl. 5, figs. 9, 14-15, 20.
- Rouxia naviculoides Schrader, 1973, p. 710, pl. 3, figs. 27-32; Gombos, 1977, p. 597, pl. 7, figs. 10-11.
- *Rouxia* sp. 1 (Plate 2, Figs. 17–20). Valves heteropolar-elliptical, 45– 55 μ m long, 11.5 μ m maximum width. One apex rounded, the other cuneate; one apex 1 to 1.5 μ m closer to the raphe than the other. Raphe bars well developed with a subrectangular depressed central area, pole fields with a sharp triangular hyaline area. Valve

striate with 9 to 9.5 in 10 μ m, transapical over the middle part of the valve and bent slightly toward the apices. Transapical striae faintly punctuate, 4 to 5 within one striae. Striae crossed by two apical lines, one faint.

- Rouxia sp. 2 (Plate 2, Figs. 21–22). Valves linear with rounded apices, 60–70 μ m long, 9 μ m maximum width. Rudimentary raphe bars, widely separated, 16–18 μ m long. Transapical ribs 8 to 9 in 10 μ m, transapical parallel. Marginal apical ribs parallel to valve margin. Rectangular central area 3–4 μ m wide, narrow tapering apical areas. Inner pores interior to transapical ribs. Valve structure isopolar.
- Stephanopyxis "turris" (Greville and Arn.) Ralfs in Pritchard, 1861. Hustedt, 1930, pp. 304–305, fig. 140; Schrader, 1976, p. 636, pl. 13, fig. 7.
- Synedra jouseana Sheshukova-Poretzkaya. Schrader, 1973, pl. 23, figs. 21-23, 25, 38. Reworked.
- Synedra miocenica Schrader, 1976, p. 636, pl. 1, fig. 1. Reworked.
- Thalassiosira convexa Mikhina. Schrader, 1974, pl. 2, figs. 1-5, 10-13.
- Thalassiosira nativa Sheshukova-Poretzkaya, sensu Koizumi, 1975b, pl. 2, fig. 9; Koizumi, 1975a, pl. 4, figs. 21–22.
- Thalassiosira praeconvexa Burckle, 1972, p. 242, pl. 2, figs. 7-9; Schrader, 1973, p. 712, pl. 11, figs. 10-15.
- Thalassiosira torokina Brady, 1977, pp. 122-123, figs. 1-5 (Plate 7, Figs. 3-6).
- Thalassiosira sp. 10 Schrader, 1976, p. 637, pl. 15, figs. 6-8.
- Thalassiothrix miocenica Schrader, 1973, p. 713, pl. 23, figs. 2-5.
- Triceratium barbadense Greville, 1861. Kanaya, 1957, pp. 100-101, pl. 7, figs. 1-4. Reworked.
- Trinacria excavata Heiberg, 1863. McCollum, 1975, p. 536, pl. 15, figs. 1-2; Gombos, 1977, p. 599, pl. 37, fig. 6.
- Trinacria simulacrum Grove and Sturt, 1887. Gombos, 1977, p. 599, pl. 35, figs. 1-2, 4; pl. 36, figs. 1-4. Reworked.

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Plate 1. (All specimens magnified × 1500 unless otherwise indicated.) 1-10. *Nitzschia weaveri* n. sp., (1-2) paratype, Sample 514-24-2, 89-91 cm, (3) holotype, Sample 513-6-6, 2-4 cm, (4-5) paratype, ×1000, Sample 514-24-2, 89-91 cm, (6) ×1200, Sample 513-6-6, 2-4 cm, (7-8) Sample 514-16-2, 100-102 cm, (9) Sample 513-6-6, 2-4 cm, (10) Sample 514-16-2, 100-102 cm. 11-18. *Nitzschia interfrigidaria*, (11) Sample 514-28-1, 90-92 cm, (12) Sample 514-30-2, 66-68 cm, (13) Sample 514-29-1, 72-74 cm, (14) Sample 514-28-1, 90-92 cm, (15) Sample 514-28-1, 90-92 cm, (16) Sample 514-19-3, 72-74 cm, (17) ×1000, Sample 514-28-1, 90-92 cm, (18) Sample 514-16-2, 100-102 cm.



Plate 2. (All specimens magnified × 1500 unless otherwise indicated.) 1-8. *Nitzschia praeinterfrigidaria* (1) × 1000, Sample 514-28-1, 90-92 cm, (2-4) Sample 514-34-2, 74-76 cm, (2-3, × 1000), (5) Sample 514-30-2, 66-68 cm, (6-7) Sample 514-31-3, 56-58 cm, (8) Sample 514-34-2, 66-68 cm, 9-12. *Nitzschia miocenica*, Sample 513A-7-2, 57-59 cm. 13-16. *Nitzschia praeinterfrigidaria* (transitional to *N. interfrigidaria*), Sample 514-34-2, 74-76 cm. 17-20. *Rouxia* sp. 1, × 1000, Sample 513A-5-5, 140-142 cm. 21-22. *Rouxia* sp. 2, × 1000, Sample 513A-4-7, 25-27 cm.



Plate 3. 1-4. Nitzschia cf. praeinterfrigidaria, SEM micrographs, Sample Eltanin 38-8, 320-322 cm, (1) ×10,000, (2) ×2200, (3) ×2000, (4) ×5000. 5. Nitzschia praeinterfrigidaria, SEM micrograph, Sample Eltanin 38-8, 480-482 cm, ×6000. 6. Hemidiscus karstenii f. 1, ×800, Sample 513A-5-3, 140-142 cm.



Plate 4. 1-5. Hemidiscus karstenii f. 1, ×800. (1-2, 4-5). Sample 513A-5-3, 140-142 cm, (3) Sample 513A-5-5, 140-142 cm. 6-8. Coscinodiscus lentiginosus f. obovatus n. subsp., ×1000, Sample 514-20-3, 57-59 cm, (7) holotype, (6, 8) paratype.



Plate 5. 1-10. Cosmiodiscus insignis f. triangula, (1-2, 5-6) ×1200, Sample 513A-6-5, 140-142 cm, (3-4) ×600, Sample 513A-6-7, 30-32 cm, (7-10) ×1000, Sample 513A-6-5, 70-72 cm.



Plate 6. (All specimens magnified ×700 unless otherwise indicated.) 1-2, 6, 9. Asteromphalus sp. 1, (1-2) Sample 513A-10-7, 12-13 cm, (6, 9) Sample 513A-10-3, 70-72 cm. 5. Asteromphalus sp. 2, Sample 513A-6-7, 30-32 cm. 3-4. Lithodesmium cf. minusculum, Sample 513A-9-1, 69-71 cm. 7-8. Coscinodiscus vulnificus, ×1000, (7) Sample 514-13-2, 49-50 cm, (8) Sample 513-6-5, 2-4 cm.



Plate 7. 1-2. Brunia mirabilis, Sample 512-2-2, 96-98 cm. (1) Field of view with large and small fragments of Brunia mirabilis, ×240, (2) ×480. 3-6. Thalassiosira torokina, ×600, Sample 513A-8-1, 140-142 cm.