

26. UPPER CRETACEOUS AND CENOZOIC CALCAREOUS NANNOFOSSILS OF THE KERGUELEN PLATEAU (SOUTHERN INDIAN OCEAN) AND PRYDZ BAY (EAST ANTARCTICA)¹

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ABSTRACT

ODP Leg 119 drilled 11 sites on the Kerguelen Plateau (southern Indian Ocean) and Prydz Bay (East Antarctica). Upper Pliocene through Quaternary sediments were recovered at Site 736 on the northern Kerguelen Plateau; calcareous nannofossils occurred in only a few samples. Over 700 m of middle Eocene through Quaternary sediments was cored at Site 737 on the northern Kerguelen Plateau, and calcareous nannofossils are abundant in the middle Eocene through the middle Miocene sediments. Nearly 500 m of sediments ranging from the lower Turonian to the Quaternary was recovered at Site 738 on the southern Kerguelen Plateau; calcareous nannofossils are abundant from the Miocene downward. Calcareous nannofossils are also abundant in the upper Eocene through Miocene section from Site 744 on the southern Kerguelen Plateau. Except for Core 119-746A-13H, the Neogene sequences drilled at deep-water Sites 745 and 746 off the southern Kerguelen Plateau are devoid of calcareous nannofossils. Occurrences of calcareous nannofossils were generally rare and sporadic at Sites 739 and 742 in Prydz Bay and suggest that the diamictite sequences recovered is as old as middle Eocene-early Oligocene age. Other sites drilled in Prydz Bay (Sites 740, 741, and 743) did not yield calcareous nannofossils.

Species diversity of calcareous nannofossils was low (about a dozen) in the southern Indian Ocean in the Late Cretaceous. High-latitude nannofloral characteristics are apparent after the Cretaceous/Tertiary boundary extinctions. Cold climatic conditions limited Oligocene calcareous nannofossil assemblages to fewer than a dozen species, and extinctions of species generally were not compensated by originations of new species. Only a few species of calcareous nannofossils were found in the Miocene sequences, in which *Coccolithus pelagicus* and one or two species of *Reticulofenestra* exhibit extreme (0%–100%) fluctuations in assemblage dominance, and these fluctuations may reflect rapid fluctuations in the surface-water temperatures. Further deterioration of climate in the late Neogene essentially excluded calcareous nannoplankton from the Southern Ocean. Significantly warmer water conditions during part of the early-middle Pleistocene were inferred by a few lower-middle Pleistocene calcareous nannofossil species found on the Kerguelen Plateau.

The calcareous nannofossil zonation of Roth (1978) can be applied to the Upper Cretaceous section recovered at Site 738, and the zonation of Okada and Bukry (1980) can be applied without much difficulty to the Paleocene to middle Eocene sequences from the Kerguelen Plateau. However, some conventional upper Paleogene markers are not useful for southern high latitudes, whereas a few nonconventional species events are useful for subdividing the upper Paleogene sequences. The latter species events include the first occurrence (FO) of *Reticulofenestra reticulata*, the FO and last occurrence (LO) of *Reticulofenestra oamaruensis*, the LO of *Isthmolithus recurvus*, and the LO of *Chiasmolithus altus*. As the Neogene sequences from the southern Indian Ocean contain only a few long-ranging, cold-water species, or are devoid of coccoliths, calcareous nannofossil zonations remain virtually unworkable for the Neogene in the high-latitude southern Indian Ocean as in other sectors of the Southern Ocean.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 119 was the first DSDP/ODP drilling on the world's largest submarine plateau, the Kerguelen Plateau in the southern Indian Ocean, as well as Prydz Bay on the shelf of East Antarctica (Fig. 1). The Kerguelen Plateau, located on the Antarctic plate, extends approximately 2500 km between 46°S and 64°S latitude in a northwest-southeast direction. The feature is between 200 and 600 km wide, and stands 2–4 km above the adjacent ocean basins. Surface currents over the plateau are dominated by the Antarctic Convergence, or Polar Front, which fluctuates over the plateau and separates subantarctic waters to the north from antarctic waters to the south. A principal objective of drilling in this region during Leg 119 was to provide evidence of the development of the Antarctic Convergence and the response of this oceanographic boundary to climatic change. A second major objective was to

investigate the origin and tectonic history of the Kerguelen Plateau and the breakup history of the Kerguelen Plateau from Broken Ridge. Prydz Bay is situated on the continental shelf of East Antarctica and drains over 20% of the East Antarctic ice sheet. Drilling in Prydz Bay was expected to have the best chance of recovering a relatively complete record of Antarctic glaciation and the preglacial continental climate.

A total of 11 sites were drilled during ODP Leg 119 (Table 1). Relatively few calcareous nannofossils were found at Site 736, which recovered only upper Neogene sediments. Significant numbers of calcareous nannofossils were recovered at ODP Sites 737 (middle Eocene to Quaternary), 738 (early Turonian to Quaternary), and 744 (late Eocene to Quaternary), which were continuously cored. Except for one core section from Site 746, Sites 745 and 746 off the Kerguelen Plateau are barren of nannofossils, because of their great water depths (4082 and 4059 m, respectively). Sites 739 and 742 in Prydz Bay yielded only rare and sporadic occurrences of calcareous nannofossils, whereas other sites in Prydz Bay were barren of nannofossils.

This paper documents the calcareous nannofossils recovered during Leg 119 and establishes nannofossil biostratigraphy for the core materials. The stratigraphic sequences of the calcareous nannofossils are important reference sections for the Southern Ocean and will serve as the southern anchor in the Indian

¹ Barron, J., Larsen, B., et al., 1991. *Proc. ODP, Sci. Results*, 119: College Station, TX (Ocean Drilling Program).

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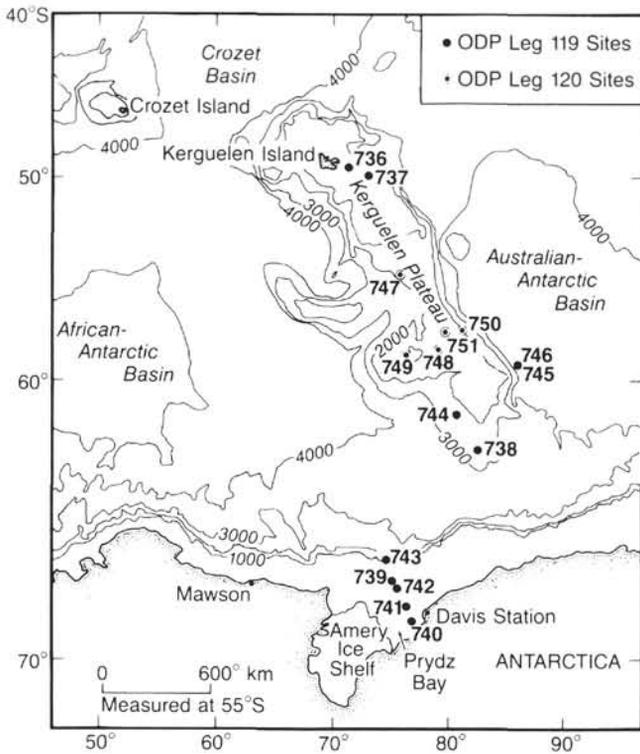


Figure 1. Locations of Ocean Drilling Program Leg 119 sites and subsequently drilled Leg 120 sites. Bathymetry in meters.

Ocean sector of the Southern Ocean for future paleobiogeographic and paleoecologic studies.

Previous biostratigraphic studies of calcareous nannofossils of the high southern latitudes have been published by Edwards (1971, 1973), Edwards and Perch-Nielsen (1975), Burns (1975), Haq (1976), Wind (1979a, b), Wise and Wind (1977), Wise (1983), Pospichal and Wise (1990a, b, c), and Wei and Wise (1990).

Calcareous nannofossil species considered in this paper are listed in the Appendix, where they are arranged alphabetically by generic and species epithets. Most of the species are illustrated in Plates 1 through 6, and the illustrations are cross referenced in the appendix. Most bibliographic references for these taxa can be found in Loeblich and Tappan (1966, 1968, 1969, 1970a, b, 1971, 1973), van Heck (1979a, b, 1980a, b, 1981a, b, 1982a, b, 1983), or Steinmetz (1985a, b, 1986, 1987a, b, 1988a, b, 1989), any not included therein are given in the references.

For Cenozoic biostratigraphy we use the zonation of Okada and Bukry (1980). For the Mesozoic section we apply the zonation of Roth (1978), because many of the biostratigraphic events used there have since been correlated directly to the magnetostratigraphy in various sections (e.g., Stradner and Steinmetz, 1984; Monechi and Thierstein, 1985). However, due to extreme high latitudes, calcareous nannofossils recovered by ODP Leg 119 are relatively low in diversity. The problem is most acute for the Neogene, where the calcareous nannofossil zonation is essentially unworkable. For the middle Eocene through Oligocene, latitudinal differentiation of the nannofossil assemblages are also quite apparent, and some marker species in the zonations of Martini (1971) or Okada and Bukry (1980) are absent or very rare, whereas some cool-water species markers are common and easily used. Therefore, in addition to making zonal assignments according to the zonation of Okada and Bukry (1980), we also adopt the zonation developed in the Weddell Sea by Wei and Wise (1990) for the middle Eocene through Oligocene to facilitate correlation with low-latitude sequences and to achieve a more refined biostratigraphy for Leg 119 cores. The zonation adopted for the middle Eocene through Oligocene interval is summarized in Figure 2, which is a slight modification of Wei and Wise's (1990) zonation with the erection of the last occurrence (LO) of *Discoaster saipanensis* as a subzonal marker and the use of LO of *Reticulofenestra bisecta* as a zonal marker.

METHODS AND PROCEDURES

Smear slides were made directly from unprocessed samples and examined using a light microscope to estimate the relative abundance of calcareous nannofossils in the fine fractions of the sediment and the relative abundance of each nannofossil species present. Usually several hundred fields of view were scanned at a magnification of about 1600x and the relative species abundances were estimated using the following scale:

- V = very abundant (>40%)
- A = abundant (10%–40%)
- C = common (1%–10%)
- F = few (0.1%–1%)
- R = rare (<0.1%)
- B = barren (no nannofossils seen in several hundred fields of view).

Selected samples were examined using a scanning electron microscope (SEM) to reveal ultrastructural details. A qualitative determination was made on the overall state of preservation of nannofossils in each sample. The following basic criteria were used to describe qualitatively the degree of dissolution and/or overgrowth of a nannofossil assemblage.

Table 1. Summary of sites drilled during Ocean Drilling Program Leg 119.

Site	Latitude	Longitude	Water depth (m)	Penetration (mbsf)	Percent recovery	Oldest sediment
736	49°24.121'S	71°39.611'E	629.0	371	51	late Pliocene
737	50°13.660'S	73°01.950'E	564.0	715.5	63	middle Eocene
738	62°42.543'S	82°47.245'E	2252.5	534	58	early Turonian
739	67°16.570'S	75°04.914'E	412.3	478	35	?Eocene
740	68°41.220'S	76°43.246'E	816.0	225.5	32	?Mesozoic or Permian
741	68°23.160'S	76°23.020'E	561.4	128.1	26	Early Cretaceous
742	67°32.982'S	75°24.270'E	410.0	316	53	?Eocene
743	66°54.994'S	74°41.423'E	987.0	98.1	22	Pliocene-Quaternary
744	61.34.656'S	80°35.463'E	2307.8	176.1	90	late Eocene
745	59°35.710'S	85°51.600'E	4082.0	215	103*	late Miocene
746	59°32.823'S	85°51.780'E	4059.0	281	75	late Miocene

*Core expansion gave more than 100% recovery.

Age	Zones of Okada and Bukry (1980)	Zones of this study	Datum	
late Oligocene	CP19	<i>Reticulofenestra bisecta</i>	┐ <i>Reticulofenestra bisecta</i>	
	CP18	<i>Chiasmolithus altus</i>	┐ <i>Chiasmolithus altus</i>	
early Oligocene	CP16	<i>Reticulofenestra daviesii</i>	┐ <i>Reticulofenestra umbilica</i>	
		<i>Blackites spinosus</i>	┐ <i>Isthmolithus recurvus</i>	
		<i>Reticulofenestra oamaruensis</i>	b	┐ <i>Reticulofenestra oamaruensis</i>
			a	┐ <i>Discoaster saipanensis</i>
late Eocene	CP15	b	┐ <i>Reticulofenestra oamaruensis</i>	
		a	<i>Isthmolithus recurvus</i>	┐ <i>Isthmolithus recurvus</i>
			<i>Chiasmolithus oamaruensis</i>	┐ <i>Chiasmolithus oamaruensis</i>
middle Eocene	CP14	b	┐ <i>Discoaster saipanensis</i>	
		a	<i>Reticulofenestra reticulata</i>	┐ <i>Chiasmolithus solitus</i>
			<i>Reticulofenestra umbilica</i>	┐ <i>Reticulofenestra reticulata</i>
			┐ <i>Reticulofenestra umbilica</i>	

Figure 2. Calcareous nannofossil zonation used in this study to achieve a finer biostratigraphy for the middle Eocene to Oligocene and its correlation with the zonation of Okada and Bukry (1980). Modified slightly from Wei and Wise (1990). "┐" indicates first occurrence and "┐" denotes last occurrence.

- G = Good: individual specimens exhibit little dissolution or recrystallization; delicate parts are preserved.
M = Moderate: dissolution (etching) and/or recrystallization (overgrowth) of individual specimens are apparent; identification of species are generally not impaired.
P = Poor: individual specimens exhibit considerable dissolution and/or recrystallization; identification of some species is not possible.

For Hole 738C, the degree of etching and overgrowth was recorded separately, using a scale of 0–3 as described by Roth and Thierstein (1972) and Roth (1973).

KERGUELEN PLATEAU SITES

Holes were drilled at two sites (Sites 736 and 737) on the northern Kerguelen Plateau, two sites (Sites 738 and 744) on the southern Kerguelen Plateau, and two sites (Sites 745 and 746) off the southern Kerguelen Plateau in deep waters (Fig. 1). These sites, along with those drilled by ODP Leg 120 in the central part of the Kerguelen Plateau, form excellent latitudinal and water depth transects for paleoceanographic studies. No calcareous nannofossils were recovered at Site 745, which will not be discussed further.

Site 736

Site 736, the northernmost site on the ODP Legs 119 and 120 north-south paleoceanographic transect, lies beneath the modern Antarctic Convergence. A major objective of paleoceanographic studies at Site 736 was to trace the movement of the Antarctic Convergence through time using both sediment types

and microfossil assemblages. The 371 m of Pliocene through Quaternary sediments cored at this site is poor in carbonate, mainly consisting of siliceous ooze with interspersed volcanic debris and glacial dropstones.

Calcareous nannofossil are either absent or rare in all core-catcher samples investigated at this site. Sample 119-736A-1H, 0–2 cm, from the mud line contains rare, well preserved *Gephyrocapsa oceanica*. For the next 250 m section, moderately to strongly etched specimens of *Coccolithus pelagicus* were encountered in the following core-catcher samples: 119-736A-9H (rare), -736A-25H (rare), -736A-27H (few), -736A-29H (common), -736A-30H (rare), -736C-4R (rare), -736C-5R (few), -736C-6R (rare), and -736C-7R (few). Sample 119-736C-7R-2, 66 cm, from a thin layer (about 5 cm) of calcareous nannofossil-diatom ooze at 257.2 meters below seafloor (mbsf) contained a well-preserved monospecific assemblage of *Reticulofenestra producta*. This species is rather small in size, commonly 3–4 μm (see discussion in the taxonomic note section), and is most abundant in high-latitude Pliocene sediments (Backman, 1980). Sample 119-736C-8R-CC contains strongly etched *C. pelagicus* (few) and *Gephyrocapsa* sp. (rare). A few moderately preserved *Reticulofenestra producta* were also found in Sample 119-736C-9R-CC.

These calcareous nannofossils are of limited biostratigraphic value. The upper 280-m sequence is assigned to the Pliocene or younger based on the presence of *Reticulofenestra producta* and the absence of *Reticulofenestra perplexa*. The absence or scarcity of calcareous nannofossils in the upper Neogene diatom ooze at such a shallow-water site (629 m) is due to unfavorable living conditions for the calcareous nannoplankton, rather than dissolution.

Site 737

Site 737 is situated on the northern Kerguelen Plateau about 100 km southeast of Site 736 (Fig. 1). Major drilling objectives of Site 737 were similar to those of Site 736, and included recovery of a high-resolution reference section from the northern end of the Kerguelen Plateau-Prydz Bay transect (ODP Legs 119 and 120) for both biostratigraphic and paleoceanographic analyses. The 715.5 m middle Eocene through lower Pliocene section cored in two holes at Site 737 begins stratigraphically almost exactly where coring was terminated at Site 736, so together, the two sites form a valuable reference section for the upper Paleogene through the Neogene at about 50°S in the Southern Ocean.

Hole 737A (Table 2)

The interval from the first core to Section 119-737A-2H-3 is barren of calcareous nannofossils. The rest of Core 119-737A-2H through Core 119-737A-5H yielded rare to common *Reticulofenestra producta*. *Coccolithus pelagicus* occurred only sporadically in this interval. Calcareous nannofossils occurred only sporadically farther downhole, until near the bottom of the hole (Cores 119-737A-26X through -28X), where abundant calcareous nannofossils of three to four species were found. The highest stratigraphic occurrence of *Reticulofenestra perplexa* (= *Dictyococcites antarcticus* Haq, see taxonomic note) was recognized in Sample 119-737A-19X-1, 45–47 cm. Because this species has been found only in middle to upper Miocene sediments in other areas of the Southern Ocean (Haq, 1976; Haq et al., 1977; Wise, 1983; Wei and Wise, 1990), the Miocene/Pliocene boundary is believed to lie above this sample, consistent with the diatom data (Baldauf and Barron, this volume).

Because the preservation of the calcareous nannofossil assemblages, where present, is generally good at this shallow-water site, the low species diversity and low abundance of the nannofloras are probably due to lack of supply, rather than dissolution. The intervals where calcareous nannofossils occur may indicate periods of weaker upwelling and warmer surface water at Site 737.

Hole 737B (Table 3, back pocket)

The first and fourth cores from Hole 737B are wash cores and no samples were available for this study. Calcareous nannofossils are abundant from Core 119-737B-5R downhole. Cores 119-737B-5R to -7R yielded abundant *Reticulofenestra perplexa*, and are of middle-late Miocene age.

The ranges of several species, namely, *Calcidiscus macintyreii*, *Chiasmolithus altus*, *Reticulofenestra bisecta*, and *Reticulofenestra daviesii*, are truncated between Samples 119-737B-11R-1, 50–51 cm, and -11R-2, 80–81 cm, indicating the presence of a disconformity between these two samples. This disconformity coincides with the lithologic change (313.4 mbsf) from diatom nannofossil ooze above to calcareous claystone below.

The upper Oligocene can usually be subdivided by sphenolith datums in tropical or temperate regions. However, only one specimen of *Sphenolithus ciperoensis* was observed in Hole 737B, Sample 119-737B-15R-CC. The only other *Sphenolithus* species found in this hole is *Sphenolithus moriformis*, a ubiquitous species that has little biostratigraphic utility. No other datums are available to make a finer nannofossil biostratigraphy possible for the upper Oligocene in this hole.

The rare occurrence of *Reticulofenestra umbilica* in Sample 119-737B-34R-6, 73–75 cm, is considered reworked. The LO of *Reticulofenestra umbilica* is placed between Samples 119-737B-34R-CC, and -35R-CC. Another species event worth noting is

the LO of *Clausicoccus fenestratus* (= *Clausicoccus subdistichus*, see taxonomic note) in Sample 119-737B-37R-1, 45–46 cm, where the species is abundant. This datum level is located between the LO of *Reticulofenestra umbilica* and that of *Isthmolithus recurvus*. A similar succession was observed at Sites 511 and 513 (Leg 71) at about the same latitude in the South Atlantic Ocean, where Wise (1983) used the LO of *Clausicoccus fenestratus* as a zonal marker in the lower Oligocene. This datum seems to be useful for biostratigraphic correlation at latitudes near 50°S. However, the biostratigraphic range of *C. fenestratus* has been shown to become shorter at higher latitudes and longer at lower latitudes (Wei and Wise, 1990). The LO of *Isthmolithus recurvus* is located at Sample 119-737B-37R-5, 45–46 cm. This species event has a relatively consistent age around 34.9 Ma from middle to high latitudes (Wei and Wise, 1989a, 1990) and is therefore useful for subdivision of the lower Oligocene sediments recovered by Leg 119.

The LO of *Coccolithus formosus* was observed in Sample 119-737B-38R-4, 126–127 cm. This datum was used to define the bottom of Subzone CP16c by Okada and Bukry (1980), but is not useful for Site 737, because the datum is below the end of *C. fenestratus* acme in Hole 737B, the reverse of the sequence observed at lower latitudes.

The LO of *Discoaster saipanensis* is placed above Sample 119-737B-41R-2, 102–103 cm, and defines the Eocene/Oligocene boundary in terms of calcareous nannofossil biostratigraphy. *Reticulofenestra oamaruensis*, the range of which straddles the Eocene/Oligocene boundary, was found only in Sample 119-737B-41R-3, 132–133 cm. This may be due to very low abundance of the species, a hiatus at this site, and/or poor preservation of the species, which becomes indistinct when the central area is dissolved.

The ranges of *Isthmolithus recurvus* and *Reticulofenestra reticulata* overlap in one sample only (Sample 119-737B-46R-1, 1–2 cm). This overlap is considerably shorter than at the lower latitudes, and is due to progressively earlier disappearance of *Reticulofenestra reticulata* toward the higher latitudes, rather than to a condensed section or hiatus (see further discussion in the following text). Similar to the observation of Wei and Wise (1989a, 1990) at Sites 516 (Leg 72) and 689 (Leg 113) in the South Atlantic, larger specimens (8–11 μm) of *R. reticulata* were found in the upper range of the species in Hole 737B, and smaller (generally less than 8 μm) specimens were observed in its lower range.

Samples 119-737B-46R-1, 90–91 cm, and -46R-2, 21–22 cm, are assigned to the *Chiasmolithus oamaruensis* Zone (Subzone CP15a) based on the first occurrence of *Isthmolithus recurvus* above the former sample and the first occurrence of *Chiasmolithus oamaruensis* in the latter sample. *Chiasmolithus altus* occurs farther downhole than *C. oamaruensis*, a situation similar to that at two higher latitude sites (689 and 690 on Leg 113) in the Weddell Sea (Wei and Wise, 1990). This sequence of events is opposite to that normally found at lower latitudes (Perch-Nielsen, 1985a).

Two specimens of *Chiasmolithus solitus* were seen in Sample 119-737B-47R-1, 44–45 cm, and they are probably reworked. The generally poor preservation of the nannoflora in Cores 119-737B-47R and -48R hinders the precise location of the LO of *C. solitus*, which is tentatively placed between Samples 119-737B-48R-3, 46–47 cm, and -48R-CC.

Reticulofenestra umbilica was found down to the bottom of the hole. In addition, a few specimens of *Discoaster bifax* were also observed at the bottom of the hole and in Sample 119-737B-52R-3, 121–122 cm. The presence of these two species constrains the oldest sediment in Hole 737B to be Subzone CP14a (middle Eocene).

Table 2. Distribution of calcareous nannofossils, Hole 737A.

Age	Sample (core, section, interval in cm)	Abundance	Preservation	<i>Calcidiscus leptoporus</i>	<i>Coccolithus pelagicus</i>	<i>Reticulofenestra galida</i>	<i>Reticulofenestra perplexa</i>	<i>Reticulofenestra producta</i>
?	1H-2, 45-47	B	.	.	.	.	.	.
	1H-3, 45-47	B	.	.	.	.	.	.
	1H-CC	B	.	.	.	.	.	.
	2H-1, 45-47	B	.	.	.	.	.	.
	2H-2, 45-47	B	.	.	.	.	.	.
	2H-3, 45-47	B	.	.	.	.	.	.
Pliocene	2H-4, 45-47	R	M	.	.	.	.	R
	2H-5, 45-47	R	G	.	.	.	.	F
	2H-6, 45-47	R	G	.	.	.	.	F
	2H-7, 45-47	R	G	.	.	.	.	F
	2H-CC	R	G	.	.	.	.	F
	3H-1, 45-47	R	G	.	R	.	.	F
	3H-2, 45-47	B	.	.	.	.	.	.
	3H-3, 45-47	R	G	.	.	.	.	R
	3H-4, 45-47	R	G	.	.	.	.	F
	3H-5, 45-47	B	.	.	.	.	.	.
	3H-6, 45-47	R	G	.	.	.	.	F
	3H-7, 45-47	R	G	.	.	.	.	R
	3H-CC	R	G	.	.	.	.	R
	4H-1, 45-47	R	G	.	.	.	.	F
	4H-2, 45-47	R	G	.	.	.	.	F
	4H-3, 45-47	R	G	.	.	.	.	F
	4H-4, 45-47	F	G	.	.	.	.	C
	4H-5, 45-47	F	G	.	.	.	.	C
	4H-6, 45-47	R	G	.	.	.	.	R
	4H-7, 45-47	R	G	.	.	.	.	R
	4H-CC	R	G	.	.	.	.	F
	5H-1, 45-47	R	G	.	.	.	.	R
	5H-2, 45-47	R	G	.	R	.	.	R
	5H-3, 45-47	R	G	.	.	.	.	R
5H-4, 45-47	R	G	.	F	.	.	F	
5H-5, 40-42	R	G	.	.	.	.	R	
5H-6, 45-47	R	G	.	.	.	.	R	
5H-CC	R	G	.	F	.	.	F	
6H-1, 45-47	B	.	.	.	.	.	.
6H-2, 45-47	R	G	.	.	.	.	R	
late Miocene	6H-3, 45-47	B	.	.	.	.	.	.
	6H-4, 45-47	B	.	.	.	.	.	.
	6H-5, 45-47	B	.	.	.	.	.	.
	6H-6, 45-47	B	.	.	.	.	.	.
	6H-CC	B	.	.	.	.	.	.
	7H-1, 45-47	B	.	.	.	.	.	.
	7H-2, 45-47	B	.	.	.	.	.	.
	7H-3, 45-47	B	.	.	.	.	.	.
	7H-4, 45-47	B	.	.	.	.	.	.
	7H-5, 45-47	B	.	.	.	.	.	.
	7H-6, 45-47	R	M	.	R	.	.	.
	7H-7, 45-47	B	.	.	.	.	.	.
	7H-CC	B	.	.	.	.	.	.
	8H-1, 45-47	B	.	.	.	.	.	.
	8H-2, 45-47	B	.	.	.	.	.	.
	8H-3, 45-47	B	.	.	.	.	.	.
	8H-4, 45-47	B	.	.	.	.	.	.
	8H-5, 45-47	B	.	.	.	.	.	.
	8H-6, 45-47	B	.	.	.	.	.	.
	8H-7, 45-47	B	.	.	.	.	.	.
	8H-CC	B	.	.	.	.	.	.
	9H-1, 45-47	B	.	.	.	.	.	.
	9H-2, 45-47	B	.	.	.	.	.	.
	9H-3, 45-47	R	M	.	F	.	.	.
	9H-4, 45-47	B	.	.	.	.	.	.
	9H-5, 45-47	B	.	.	.	.	.	.
	9H-6, 45-47	B	.	.	.	.	.	.
	9H-7, 45-47	C	G	.	F	R	C	.
	9H-CC	C	G	.	F	F	C	.
	10H-4, 45-47	B	.	.	.	.	.	.
	10H-5, 45-47	B	.	.	.	.	.	.
	10H-6, 45-47	B	.	.	.	.	.	.
	10H-CC	F	M	.	F	F	C	.
11H-1, 45-47	B	.	.	.	.	.	.
11H-2, 45-47	B	.	.	.	.	.	.
11H-3, 45-47	B	.	.	.	.	.	.
11H-4, 45-47	B	.	.	.	.	.	.
11H-5, 45-47	B	.	.	.	.	.	.

Table 2 (continued).

Age	Sample (core, section, interval in cm)	Abundance	Preservation	<i>Calcidiscus leptoporus</i>	<i>Coccolithus pelagicus</i>	<i>Reticulofenestra galida</i>	<i>Reticulofenestra perplexa</i>	<i>Reticulofenestra producta</i>
late Miocene	11H-6, 45-47	B	.	.	.	.	.	.
	11H-7, 45-47	B	.	.	.	.	.	.
	11H-CC	B	.	.	.	.	.	.
	12H-1, 45-47	B	.	.	.	.	.	.
	12H-2, 45-47	B	.	.	.	.	.	.
	12H-3, 45-47	B	.	.	.	.	.	.
	12H-4, 45-47	B	.	.	.	.	.	.
	12H-5, 45-47	B	.	.	.	.	.	.
	12H-6, 45-47	B	.	.	.	.	.	.
	12H-7, 45-47	B	.	.	.	.	.	.
	12H-CC	B	.	.	.	.	.	.
	13H-1, 45-47	B	.	.	.	.	.	.
	13H-2, 45-47	B	.	.	.	.	.	.
	13H-3, 45-47	B	.	.	.	.	.	.
	13H-4, 45-47	B	.	.	.	.	.	.
	13H-5, 45-47	B	.	.	.	.	.	.
	13H-6, 45-47	B	.	.	.	.	.	.
	13H-7, 45-47	B	.	.	.	.	.	.
	13H-CC	B	.	.	.	.	.	.
	15H-5, 45-47	B	.	.	.	.	.	.
	15H-6, 45-47	B	.	.	.	.	.	.
	15H-7, 45-47	B	.	.	.	.	.	.
	15H-CC	B	.	.	.	.	.	.
	16H-1, 45-47	B	.	.	.	.	.	.
	16H-2, 45-47	B	.	.	.	.	.	.
	16H-3, 45-47	B	.	.	.	.	.	.
	16H-4, 45-47	B	.	.	.	.	.	.
	16H-5, 45-47	B	.	.	.	.	.	.
	16H-6, 45-47	B	.	.	.	.	.	.
	16H-7, 45-47	B	.	.	.	.	.	.
	16H-CC	B	.	.	.	.	.	.
	17H-1, 46-48	B	.	.	.	.	.	.
	17H-2, 46-48	B	.	.	.	.	.	.
17H-3, 46-48	B	.	.	.	.	.	.
17H-4, 46-48	B	.	.	.	.	.	.
17H-5, 46-48	B	.	.	.	.	.	.
17H-6, 47-49	B	.	.	.	.	.	.
17H-7, 46-47	B	.	.	.	.	.	.
17H-CC	B	.	.	.	.	.	.
18H-1, 45-47	B	.	.	.	.	.	.
18H-2, 45-47	B	.	.	.	.	.	.
18H-3, 45-47	B	.	.	.	.	.	.
18H-4, 45-47	B	.	.	.	.	.	.
18H-5, 45-47	B	.	.	.	.	.	.
18H-6, 45-47	B	.	.	.	.	.	.
18H-7, 45-47	B	.	.	.	.	.	.
18H-CC	B	.	.	.	.	.	.
late Miocene / middle Miocene	19X-1, 45-47	R	M	.	R	.	F	F
	19X-CC	B	.	.	.	.	.	.
	20X-CC	B	.	.	.	.	.	.
	21X-1, 45-47	B	.	.	.	.	.	.
	21X-CC	B	.	.	.	.	.	.
	23X-1, 45-47	B	.	.	.	.	.	.
	23X-2, 45-47	B	.	.	.	.	.	.
	23X-CC	B	.	.	.	.	.	.
	25X-1, 45-47	B	.	.	.	.	.	.
	25X-2, 45-47	B	.	.	.	.	.	.
	25X-3, 45-47	R	P	.	.	.	F	.
	25X-CC	R	P	.	.	.	F	.
middle Miocene	26X-1, 45-47	B	.	.	.	.	.	.
	26X-2, 15-16	B	.	.	.	.	.	.
	26X-CC	A	G	.	R	V	.	.
	27X-1, 45-47	A	G	.	V	V	.	.
	27X-2, 45-47	B	.	.	.	.	.	.
	27X-3-CC	A	G	.	F	V	C	A
	27X-4, 45-47	A	G	.	F	V	.	A
	27X-CC	A	G	.	F	C	A	A
28X-1, 49-50	A	G	.	R	F	A	.	
28X-CC	A	G	.	.	C	A	A	

Note: Abundance is characterized by V, very abundant; A, abundant; C, common; F, few; R, rare; B, barren. For preservation, G, good; M, moderate; P, poor.

Site 738

Site 738 is located on the southern tip of the Kerguelen Plateau (Fig. 1). This site lies north of the modern Antarctic Divergence and near the southern limit of influence of the Antarctic Circumpolar Current. Drilling at Site 738 was to provide the southernmost pelagic record for documentation of changes in Late Cretaceous and Cenozoic climate of the southern Indian Ocean and to recover basement samples to investigate the origin and history of the Kerguelen Plateau.

Three holes were drilled at this site and a 490-m-thick lower Turonian through Quaternary pelagic sediment sequence plus 43 m of basaltic breccia and altered basalt in the basement were cored. Calcareous nannofossils are rare to common but occur sporadically in the condensed Neogene section. They are abundant and moderately preserved in the expanded (360 m thick) Paleogene section. Reworking of calcareous nannofossils is minimal. A relatively complete Danian section was recovered. A quantitative nannofossil study of this high-latitude Danian section is presented by Wei and Pospichal (this volume). In addition, an apparently complete Cretaceous/Tertiary boundary was recovered at this site. Detailed discussion of this boundary is provided by Thierstein et al. (this volume). The relatively continuous Upper Cretaceous sequence recovered at Site 738 is the first from the Indian Ocean sector of the Southern Ocean to extend the stratigraphic record as far back as early Turonian.

Hole 738A

Hole 738A only penetrated 2.80 m and recovered 2.76 m sediment, when technical problems prompted the drilling of a new hole (Hole 738B). One sample examined from this hole, Sample 119-738A-1H-CC, contains rare *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Gephyrocapsa caribbeanica*, *Helicosphaera kamptneri*, and *Pseudoemiliania lacunosa*, an assemblage of early-middle Pleistocene age. As no calcareous nannoplankton have been found in the modern ocean at this latitude, the presence of the lower Pleistocene calcareous nannofossils at Site 738 may indicate that surface waters during part of the early Pleistocene were significantly warmer than today.

Hole 738B (Table 4, back pocket)

The first two cores from Hole 738B yielded few *Coccolithus pelagicus* and rare *Gephyrocapsa oceanica*. Beginning from the middle of Core 119-738B-3H, calcareous nannofossils are abundant or very abundant throughout the rest of the hole. Samples 119-738B-3H-3, 43–44 cm, and -3H-3, 66–68 cm, contain *Reticulofenestra gelida* and *Reticulofenestra perplexa* and are of Miocene age.

Sample 119-738B-3H-4, 66–68 cm, contains *Chiasmolithus altus*, *Isthmolithus recurvus*, *Reticulofenestra daviesii*, *Reticulofenestra umbilica*, and a few other species. This is an early Oligocene assemblage of the *Blackites spinosus* Zone (about 35–36 Ma). A major disconformity thus exists between this sample and the overlying Miocene sample (Sample 119-738B-3H-3, 66–68 cm). This disconformity is similar to the one found at Site 737 on the northern Kerguelen Plateau associated with the Paleogene/Neogene boundary.

Reticulofenestra oamaruensis, a useful marker in the Southern Ocean (Edwards, 1971; Wise, 1983; Wei and Wise, 1990), was found in Samples 119-738B-4H-2, 66–68 cm, through -5H-2, 66–68 cm. Therefore, this interval can be placed into the *Reticulofenestra oamaruensis* Zone. The Eocene/Oligocene boundary should lie within this zone, but the paucity of *Discoaster saipanensis* and *Discoaster barbadiensis* in this hole prevented the use of their last occurrences for delineating the Eocene/Oligocene boundary at this site.

The lower boundary of the *Isthmolithus recurvus* Zone was drawn between Samples 119-738B-5H-5, 110–111 cm, and -5H-6,

66–68 cm, based on the first occurrence (FO) of *Isthmolithus recurvus* in the former sample. The latter sample contains *Reticulofenestra reticulata*. This lack of range overlap of the two species has previously been found at other high-latitude sites (Wei and Wise, 1990) and is due to time transgression of the LO of *R. reticulata* with latitude rather than a hiatus.

The FO of *Reticulofenestra bisecta* was found within the *Chiasmolithus oamaruensis* Zone (Subzone CP15a), slightly younger (about 1 m.y.) than at Site 737 to the north, but significantly younger than at middle or low latitudes. A time transgression of the FO of *R. bisecta* across latitudes is, therefore, apparent.

Reticulofenestra daviesii, a cold-water species, is generally abundant in this hole, but is rare or absent within some intervals in Core 119-738B-6H, as well as in several cores downhole (see Table 4). These intervals may represent relatively warm events.

The FO of *Chiasmolithus oamaruensis* and the LO of *Chiasmolithus solitus* are truncated between Samples 119-738B-8H-CC, and -9H-1, 66–68 cm. Thus the *Discoaster saipanensis* Zone (or Subzone CP14b) is missing due to a disconformity. A similar disconformity was also found at Site 690 in the Weddell Sea but not at Site 689 (slightly north of Site 690) (Wei and Wise, 1990).

The highest stratigraphic occurrence of *Coccolithus formosus* was found in Sample 119-738B-10H-3, 66–68 cm, within Subzone CP14a, considerably lower than at Site 737, where it can still be used to mark the top of Subzone CP16b as at lower latitudes. The decrease in abundance of *C. formosus* is drastic south of 50°S latitude, and this conventional marker species is not useful in the higher latitudes.

The FO of *Reticulofenestra umbilica* was placed between Samples 119-738B-15X-1, 66–68 cm, and -15X-2, 66–68 cm. The smaller forms (<14 μm) of *R. umbilica*, namely, *Reticulofenestra samodurovii*, are still common below this level. Interestingly, a few specimens of *R. umbilica* (14–15 μm) were observed farther downhole in Samples 119-738B-18X-1, 66–67 cm, -18X-3, 66–67 cm, and -18X-4, 66–67 cm. This phenomenon of sporadic, rare occurrences of *R. umbilica* at unusually low levels was also observed in the North Atlantic Ocean (Firth, 1989). It is clear that the FO of this species should not be taken at its “absolute” first occurrence, but as the level of sudden increase in abundance. Above this level specimens 16 μm or larger are generally common.

Only sporadic *Nannotetrina cristata* and *Nannotetrina fulgens* were observed in Hole 738B. The FO of *N. cristata* is used instead of *N. fulgens* for defining the base of the *Nannotetrina fulgens* Zone (CP13) in this study, as suggested by Perch-Nielsen (1985) for less than ideally preserved material. Because of the scarcity of *N. cristata* in Hole 738B, the lower boundary of the *N. fulgens* Zone (lower middle Eocene) in Table 4 should be considered tentative and may be stratigraphically lower.

Few *Discoaster sublodoensis* and rare *Discoaster lodoensis* were seen in the lowest sample from this hole (Sample 119-738B-24X-CC). The bottom of the hole, therefore, should be placed in the *Discoaster sublodoensis* Zone (CP12).

Hole 738C (Table 5, back pocket)

The first core in this hole is a wash core and no sample was available. Core 119-738C-2R was taken at about the same depth as the last core in Hole 738B (Core 119-738B-24X). It also contains rare *Nannotetrina cristata* and can be placed in Zone CP13. *Discoaster sublodoensis* was found down to Sample 119-738C-5R-1, 69–70 cm, which is taken as the base of Zone CP12. *Discoaster praebifax* occurs in Cores 119-738C-3R to -5R, further supporting the age assignment of CP12–13 for this interval (Wei and Wise, 1989b).

Rare occurrences of *Tribrachiatulus orthostylus* in Sample 119-738C-5R-2, 69–70 cm, are probably due to reworking, and the LO of *T. orthostylus* should probably be placed just above Sam-

ple 119-738C-8R-1, 66–68 cm. However, there are still some uncertainties concerning the use of the LO of *T. orthostylus* as a marker for the base of Zone CP10 (Bukry, 1973; Perch-Nielsen, 1985a; Wei and Wise, 1989a). We therefore do not rely on the LO of *T. orthostylus*, and combine Zones CP10 and CP11 in Hole 738C. The base of Zone CP11 is defined by the FO of *Discoaster lodoensis*, which was determined in Sample 119-738C-8R-CC. The FO of *Discoaster diastypus* was found in Sample 119-738C-10R-CC, which is taken as the base of Zone CP9.

Discoaster multiradiatus was found down to Sample 119-738C-11R-CC, and the bottom of Zone CP8 can be placed below this sample. Core 119-738C-12R did not recover any sediments, and Cores 119-738C-13R, -14R, and -15R have less than 2% core recovery. This has limited the biostratigraphic resolution for this stratigraphic interval. Samples 119-738C-13R-CC, and -14R-CC, contain *Discoaster mohleri* but no *Discoaster multiradiatus* or *Discoaster nobilis*. The two samples are thus assigned to the combined Zones CP6-7. Sample 119-738C-15R-CC has no *D. mohleri*, but contains *Heliolithus kleinpellii*, and should be placed in Zone CP5. *Fasciculithus tympaniformis* and *Chiasmolithus bidens* were found down to Sample 119-738C-17R-CC, which should be the base of Zone CP4. *Sphenolithus primus* was observed only down to Sample 119-738C-16R-CC. This species apparently occurs later than *F. tympaniformis* at this high latitude, a reversed succession of that at middle or low latitudes (see Perch-Nielsen, 1985a, p. 436).

Sample 119-738C-18R-CC contains *Chiasmolithus danicus*, *Prinsius martinii*, and several other species but no fasciculiths, and thus belongs to Zones CP2-3. The lowest occurrence of *Cruciplacolithus tenuis* was found in Sample 119-738C-20R-5, 70.5 cm, which is taken as the base of Subzone CP1b. *Cruciplacolithus primus* were found only sporadically in this hole. Detailed discussion of calcareous nannofossil assemblages and nannofossil biostratigraphy of Cores 119-738C-17R through -20R is provided by Wei and Pospichal (this volume).

A detailed stratigraphical study was performed in Section 119-738C-20R-5, which contains the Cretaceous/Tertiary boundary (see also Thierstein et al., this volume). The observable lithologic succession is a dark chert layer (103–118 cm) overlain by lithified, bioturbated, white chalk (103–96.2 cm) which contains green laminae in the uppermost 2 cm. These chalks are composed dominantly of micrite particles and contain an upper Maastrichtian nannofossil assemblage. Overlying this is a distinct, thin, gray clay layer (96.2–96.0 cm) (Fig. 3), which contains an iridium concentration peak (see Schmitz and Asario, this volume) and is, therefore, considered an equivalent of similar K/T boundary clays reported from other areas. Immediately above the K/T boundary clay is a 14-cm-thick interval of finely laminated white to green soft chalk (96–82 cm). Within this laminated interval the lowermost consistent occurrences of *Markalius inversus* (both oval and circular morphotypes), *Hornibrookina teuriensis*, *Prinsius dimorphosus*, *Zygodiscus sigmoides*, and *Thoracosphaera* spp. (including other calcified dinoflagellate cysts, such as *Orthopithonella congrua* and *Centrosphaera barbata*) were observed. The interval also contains the lowermost occurrences of sporadic *Biantholithus sparsus* and *Cruciplacolithus primus*. The first occurrences of these taxa are known from lowermost Danian sediments of other Cretaceous/Tertiary boundary sections, such as in Denmark (Perch-Nielsen, 1979), Gubbio (Monechi and Thierstein, 1985), Caravaca (Romein, 1979), and El Kef (Perch-Nielsen et al., 1982). Rare *Markalius inversus* (oval) and *Thoracosphaera* spp. (including fragments of other calcareous dinoflagellate cysts) have been found in uppermost Cretaceous assemblages of other geographic areas (Thierstein, 1981) and the presence of *Cruciplacolithus tenuis* and *Toweius* sp. below Sample 119-738C-20R-5, 80 cm, i.e., at a level considerably below their known and continuously recorded presence, must be downhole contaminants, as confirmed by

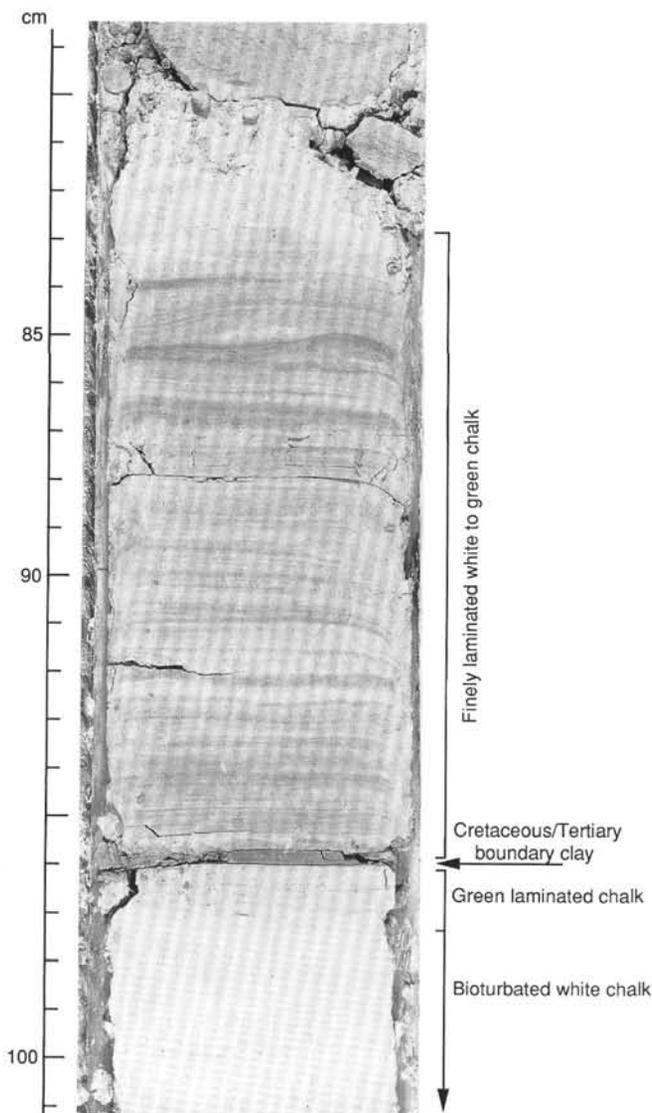


Figure 3. Lithology across the Cretaceous/Tertiary boundary in Section 119-738C-20R-5, 79–101 cm.

their abundance in light colored oozes smeared between core liner and sediment in the same level (see also discussion in Thierstein et al., this volume). Upward from Sample 119-738C-25R-5, 80 cm, are layers of semilithified, bioturbated chalks, which are interrupted by seams of crushed drilling breccia and soft white ooze. In the lowermost sample of the semilithified chalk at 80.2 cm the proportion of the newly evolving Tertiary nannofossil taxa attain 85% of the total (see Thierstein et al., this volume). The well-known replacement of the uppermost Cretaceous nannofossil assemblage by the early Tertiary nannofossil assemblage, thus, is gradual over a few centimeters within the laminated interval between the clay layer at 96 cm and the base of the semilithified chalk at 80 cm.

The Upper Cretaceous lithified chalk and limestone sequence yielded a seemingly continuous lower Turonian to upper Maastrichtian succession of poorly to moderately preserved nannofossil assemblages. Within the middle part of the Maastrichtian a possibly short break in sedimentation was identified.

The taxonomic composition of the mostly poorly preserved upper Maastrichtian assemblages in samples from Sections 119-738C-20R-5 to -24R-1 (377.16–409.1 mbsf) is comparable to

that of other high-latitude areas (Thierstein, 1976, 1981). The assemblages are dominated by relatively resistant high-latitude taxa, such as *Nephrolithus frequens*, *Arkhangelskiella cymbiformis*, *Kamptnerius magnificus*, and *Lucianorhabdus cayeuxii*, together with cosmopolitan *Prediscosphaera cretacea*, *Micula staurophora*, and *Biscutum constans*. Low-latitude taxa, such as *Watznaueria barnesae*, *Micula murus*, and *Cylindralithus* sp. are rare or absent. The first occurrence of *Nephrolithus frequens* has been shown to be just below that of *Micula murus* in magnetic Subchron 30N (Thierstein, 1976, 1981; Manivit, 1984; Chave, 1984) and is thus considered correlative to NC23 (Roth, 1978).

A late Campanian to early Maastrichtian age for the interval 119-738C-26R-2 to -26R-CC (430.7–438 mbsf) is documented by the presence of rare to few *Broinsonia parca*, whose stratigraphic range is known to extend from magnetic Subchron 33R to Subchron 32N, i.e., NC18–20 (Stradner and Steinmetz, 1984; Monnechi and Thierstein, 1985). The overlying interval (409.1–430.7 mbsf) represents the early to middle Maastrichtian (NC19–20), because it includes the highest occurrences of rare *Eiffellithus eximus*, rare to few *Reinhardtites levis* (up to Sample 119-738C-24R-CC), and rare to common *Biscutum coronum*. The latter species was considered to be latest Campanian to earliest Maastrichtian age by Wise (1983) and thus the middle part of the Maastrichtian may be missing. Surprisingly, *Monomarginatus* sp. or *Miseomarginatus pleniporus*, commonly found in Upper Cretaceous assemblages from the Falkland Plateau, were not found at Site 738; this may point to the bioprovincial peculiarity of the Falkland Plateau.

A Santonian age (NC16–17) is inferred for the interval 119-738C-27R-2 to -29R-CC (439.6–466.6 mbsf), which includes the last occurrence of *Lithastrinus floralis*, a middle Santonian event (Thierstein, 1976; Wise, 1983; Perch-Nielsen, 1985b) and the first occurrence of *Reinhardtites anthoporus*, an early Santonian event (Wise, 1983; Perch-Nielsen, 1985b). Other marker species of previously proposed high-latitude zonations, such as *Marthasterites furcatus* or *Thiersteinia eccleslastica* were not found at Site 738. Core 119-738C-31R (467.6–476.3 mbsf) is assigned lower Turonian to Coniacian age (NC13–15) because it includes the first occurrence of *Micula staurophora* (Thierstein, 1976; equivalent to *Quadrum gartneri* of Manivit et al., 1977). The assemblages in Core 119-738C-31R lack that species, but document the first occurrence of *Kamptnerius magnificus* and the last occurrence of *Gartnerago nanum* which can be correlated to earliest Turonian assemblages elsewhere (Bralower, 1988). The lowermost chalk recovered in Core 119-738C-31R is in depositional contact with volcanic basement and is considered to be of early Turonian age.

Site 744

Site 744 was cored on the southern Kerguelen Plateau in order to recover a more complete Neogene and Oligocene section than at Site 738. Three holes were drilled at Site 744 and sediments recovered range from upper Eocene to Holocene. Calcareous nannofossils are sporadic in the Pliocene-Holocene interval and are abundant throughout the lower sequence.

Hole 744A (Table 6, back pocket)

Rare specimens of *Pseudoemiliania lacunosa* are present in the first core-catcher sample, and indicate an age of late Pliocene-middle Pleistocene. *Reticulofenestra gelida* is common in Cores 119-744A-4H and -5H, whereas *Reticulofenestra pseudoumbilica* is absent in this hole. This contradicts the hypothesis of Backman (1980) that *R. gelida* is a winter morphotype of *R. pseudoumbilica* (see further discussion of *R. gelida* in the following taxonomic note).

The LO of *Reticulofenestra bisecta* is placed between Samples 119-744A-11H-CC, and -12H-1, 92–93 cm. This datum de-

fines the Oligocene/Miocene boundary in terms of calcareous nannofossil biostratigraphy. Rare *R. bisecta* and chiasmoliths above this level are considered reworked. The LO of *Chiasmolithus altus* was determined in Sample 119-744A-12-6, 92–93 cm, where it is abundant. Correlation with magnetostratigraphy at middle-latitude Site 516 (Leg 72) suggests an age of 27.0 Ma for this datum (Wei and Wise, 1989a). Since *C. altus* is more abundant in high latitudes than in temperate regions, some diachroneity of its extinction across latitudes is expected, and its LO at Site 744 may be slightly younger than 27.0 Ma.

Consistent occurrences of *Reticulofenestra samodurovii* and *Reticulofenestra umbilica* were found from Sample 119-744A-14H-CC, and downhole. The top of Zone CP16 is, therefore, drawn between Sample 119-744A-14H-6, 75–76 cm, and -14H-CC. Rare and sporadic occurrences of *R. samodurovii* and *R. umbilica* above this level are considered reworked. Rare, reworked specimens of *Isthmolithus recurvus* were also found in the upper Oligocene and Miocene sediments. This is the only Leg 119 site on the Kerguelen Plateau that shows extensive reworking of the calcareous nannofossils in the upper Oligocene and Miocene.

The range of *Reticulofenestra oamaruensis* is useful for biostratigraphic subdivision of the upper Eocene-lower Oligocene at Site 744, as at other sites in the Southern Ocean (Stradner and Edwards, 1968; Wise, 1983; Wei and Wise, 1990). *Discoaster saipanensis* is rare and sporadic; its last occurrence is placed in Sample 119-744A-19H-4, 75–76 cm. The Eocene/Oligocene boundary in terms of calcareous nannofossil biostratigraphy is traditionally defined by the LO of *D. saipanensis*. However, the species, as other species of *Discoaster*, disappeared earlier at higher latitudes where temperatures are less favorable for *Discoaster*. Therefore, the Eocene/Oligocene boundary placed between Samples 119-744A-19H-3, 75–76 cm, and -19H-4, 75–76 cm, is tentative. Similar to the situation at Site 738, the range of *Reticulofenestra reticulata* does not overlap with that of *Isthmolithus recurvus*. This differs from middle- or low-latitude successions and is due to the earlier extinction of *R. reticulata* at higher latitudes (Wei and Wise, 1990).

Paleomagnetic polarity data (Barron, Larsen, et al., 1989) and strontium isotopic data (Barrera et al., this volume; Wei and Wise, unpubl. data) are available for Hole 744A. Based on biostratigraphic and strontium isotopic data and comparison of the paleomagnetic polarity patterns with those in the reference polarity time scale of Berggren et al. (1985), magnetostratigraphy has been established for Hole 744A (see Barron et al., this volume for details). Correlation of Paleogene nannofossil datums with magnetostratigraphy in Hole 744A is presented in Figure 4.

Hole 744B (Table 7)

Hole 744B was cored to 78.5 mbsf using the advanced piston corer, and achieved a core recovery rate of 101.6% (core expansion gave more than 100% recovery). This relatively complete diatom nannofossil ooze section offers an excellent opportunity for biomagnetostratigraphic correlation and will be very useful for paleoceanographic studies of the Neogene.

Abundant *Reticulofenestra perplexa* were first encountered in Sample 119-744B-3H-CC, and is assigned to the middle-late Miocene. Downhole, *Coccolithus pelagicus* and one or two species of *Reticulofenestra* exhibit extreme fluctuations in assemblage dominance. This phenomenon has been seen in many Miocene sections from the Southern Ocean, such as at Site 737 on the northern Kerguelen Plateau, Site 329 (Leg 36) on the Falkland Plateau (Haq, 1980), and Sites 689 and 690 (Leg 113) in the Weddell Sea (Wei and Wise, 1990). Haq (1980) attributed these sharp fluctuations to climatically induced latitudinal migrations of Antarctic water assemblages during the Miocene.

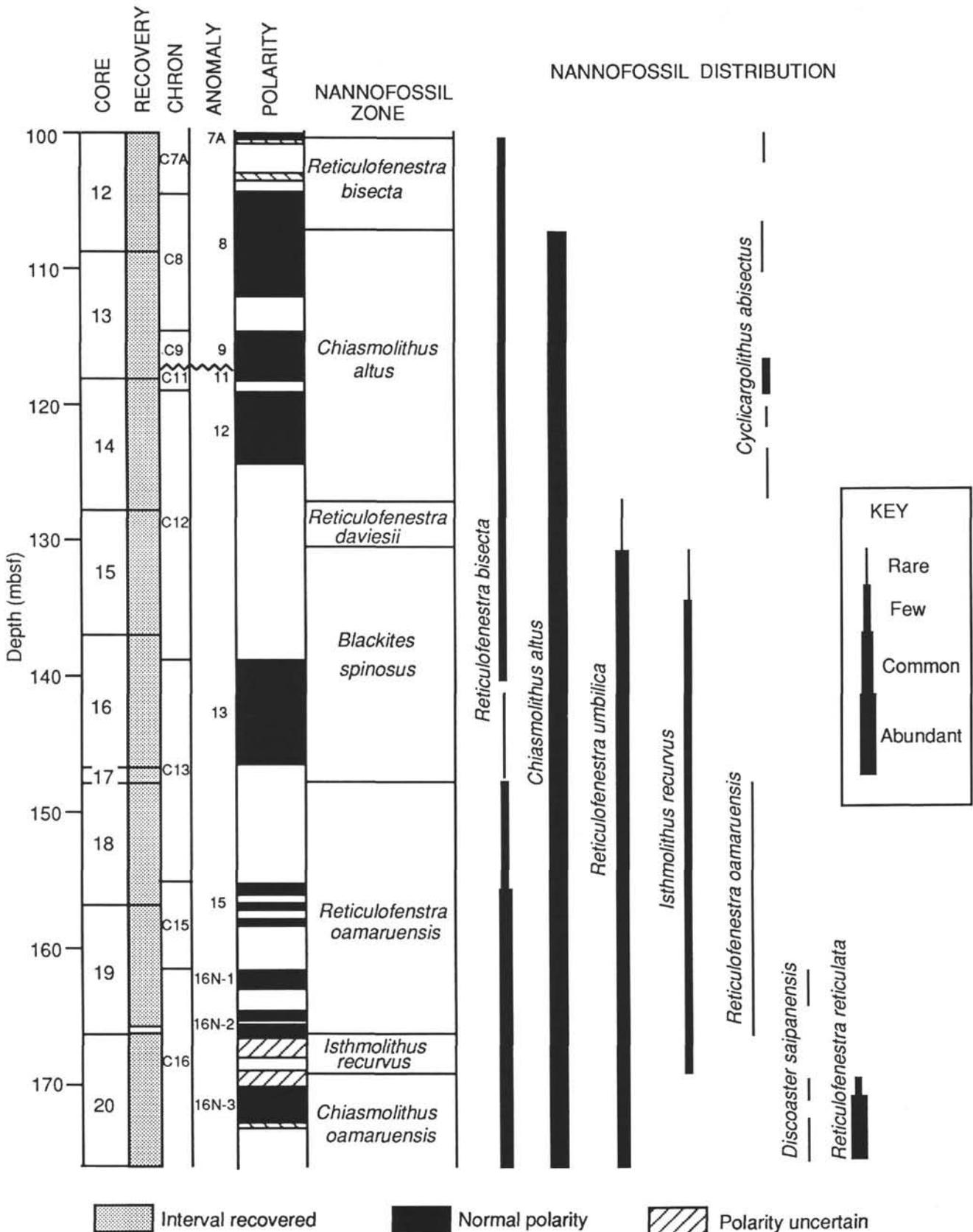


Figure 4. Correlation of simplified distribution patterns of calcareous nannofossil markers with magnetostratigraphy in Hole 744A, upper Eocene through Oligocene interval. Geomagnetic polarity data from Keating (this volume). Geomagnetic chron assignment is based on biostratigraphic and strontium isotopic data (see Barron et al., this volume, for details).

Table 7. Distribution of calcareous nannofossils, Hole 744B.

Age	Zone	Sample (core, section, interval in cm)	Abundance	Preservation	<i>Calcidiscus leptoporus</i>	<i>Calcidiscus macintyrei</i>	<i>Chiasmolithus altus</i>	<i>Coccolithus pelagicus</i>	<i>Cyclicargolithus abisectus</i>	<i>Cyclicargolithus floridanus</i>	Discoaster spp.	<i>Ishmolithus recurvus</i>	<i>Reticulofenestra getida</i>	<i>Reticulofenestra hesslandii</i>	<i>Reticulofenestra perplexa</i>	<i>Reticulofenestra producta</i>	<i>Reticulofenestra pseudoumbilica</i>	<i>Reticulofenestra umbilica</i>		
Pleistocene Pliocene		1H-CC	C	M	.	.	.	C	.	.	.	.	.	.	.	.	.	.
		2H-CC	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
late Miocene	CN10 CN5b	3H-CC	A	M	R	.	.	A	.	.	.	.	C	.	A	A	.	.	
		4H-1, 110-111	R	P	.	.	.	.	.	.	.	.	.	.	.	R	R	.	.
		4H-2, 110-111	A	M	.	.	.	.	C	.	.	.	.	C	.	A	A	.	.
		4H-3, 110-111	A	G	.	.	.	.	A	.	.	.	.	C	.	A	A	.	.
		4H-4, 110-111	A	G	.	.	.	.	A	.	.	.	.	C	.	A	A	.	.
		4H-5, 110-111	A	G	.	.	.	.	V	.	.	.	.	F	.	A	A	.	.
		4H-6, 110-111	A	G	.	.	r	.	C	.	.	.	r	C	.	F	V	.	r	
		4H-CC	A	G	.	.	.	.	R	.	.	.	.	.	.	V	V	.	.
		5H-1, 110-111	A	G	R	.	.	.	F	.	.	.	.	.	.	A	A	.	.
		5H-2, 110-111	A	G	R	.	.	.	A	A	.	.	C	C	F	.
		5H-3, 110-111	A	G	F	R	.	.	A	.	.	.	.	C	.	F	C	.	.
		5H-4, 110-111	A	G	.	.	.	.	A	.	.	.	.	C	.	R	A	.	.
		5H-5, 110-111	A	G	R	R	.	.	C	.	.	.	.	A	.	C	A	.	.
		5H-6, 110-111	A	G	A	A	r	.	F	.	.	.	.	F	.	A	C	.	.
		5H-CC	A	G	R	R	.	.	R	.	.	.	.	F	.	V	A	.	.
		6H-1, 110-111	A	G	R	R	.	.	F	.	.	.	.	R	.	V	A	.	.
		6H-2, 110-111	A	G	.	R	.	.	F	.	.	.	.	.	.	V	A	.	.
		6H-3, 110-111	A	G	.	R	.	.	R	.	.	.	.	.	.	V	A	.	.
		6H-4, 110-111	A	G	.	.	.	.	F	.	.	.	.	.	.	V	A	.	.
		6H-5, 110-111	A	G	.	R	.	.	R	.	.	.	.	.	.	V	A	.	.
		6H-6, 110-111	A	G	.	R	.	.	R	.	.	.	.	.	.	V	A	.	.
		6H-CC	A	G	R	.	.	.	F	.	.	.	.	R	.	V	A	.	.
		7H-1, 110-111	A	G	R	R	.	.	F	.	.	.	.	F	.	A	A	.	r
		7H-2, 110-111	A	G	.	F	.	.	R	.	.	.	.	.	F	A	A	.	.
		early-middle Miocene	CN5a CN1	7H-3, 110-111	A	G	R	R	r	C	.	F	.	.	.	F	C	C	R	.
				7H-4, 110-111	A	G	C	F	r	V	R	F	F
				7H-5, 110-111	A	G	C	.	r	V	F	F	A	.	.	.	F	.	.	r
				7H-6, 110-111	A	G	F	F	r	A	F	C	R	.	.	.	C	.	.	.
7H-CC	A			G	R	.	r	A	.	F	.	.	.	.	V	.	.	.	
8H-1, 110-111	A			M	.	R	r	A	R	R	R	.	.	.	A	.	.	.		
8H-2, 110-111	A			M	R	R	r	V	F	C	R	.	.	R	R	.	R	.		
8H-4, 110-111	A			G	R	R	r	A	.	C	R	.	.	C	.	.	F	.		
8H-5, 110-111	A			G	F	F	r	A	.	C	.	.	.	F	.	.	.	.
8H-6, 110-111	A			G	C	C	r	A	F	A	F	.	.	C	.	.	.	.
8H-CC	A			G	R	R	r	V	F	F	C	.	.	C	C	.	.	.		
9H-1, 118-119	A			G	R	R	r	C	R	R	.	.	.	V	.	.	.	.
9H-2, 118-119	A			G	F	.	r	A	.	.	.	.	.	A	.	.	.	.
9H-3, 118-119	A			G	F	.	r	A	.	.	.	.	.	F	A	.	.	.	
9H-4, 118-119	A			M	F	.	r	A	.	.	R	.	.	F	A	.	.	.		
9H-5, 118-119	A			G	R	R	r	A	.	.	.	.	.	.	V	.	.	.	
9H-6, 118-119	A			G	F	F	r	A	.	.	R	.	.	.	V	.	.	.		
9H-CC	A	G	.	.	r	A	.	.	.	.	.	.	A	.	.	.			

Note: Abundance is characterized by V, very abundant; A, abundant; C, common; F, few; R, Rare; B, barren. For preservation, G, good; M, moderate; P, poor. Lower case letters indicate material considered to be reworked.

Floras dominated by *Reticulofenestra perplexa* and/or other *Reticulofenestra* species constitute the southernmost assemblages and represent colder waters, whereas assemblages dominated by *C. pelagicus* represent somewhat warmer waters. Quantitative study of *S. perplexa/R. producta* vs. *C. pelagicus* and biometric study of *S. perplexa/R. producta* are presented in Wei and Wise (in press).

The highest level of *Cyclicargolithus floridanus* was found in Sample 119-744B-7H-3, 110-111 cm. This sample through Sample 119-744B-9H-CC, is assigned to Zones CN1-5a based on the presence of *C. floridanus* and the absence of *Reticulofenestra bisecta*.

Site 746

All 16 core-catcher samples from the recovered siliceous ooze sequence at Site 746 are barren of calcareous nannofossils. The only nannofossiliferous sample from this site is Sample 119-746A-13X-4, 36 cm. It contains abundant, strongly etched *Reticulofenestra perplexa* and common *Coccolithus pelagicus*, which are indicative of middle-late Miocene age.

PRYDZ BAY SITES

Prydz Bay was chosen for drilling by Leg 119 because it is a major drainage system outlet on the Antarctic continent, and

therefore should provide the best chance of recording all stages of Antarctic glaciation and a record of the preglacial continental climate. Holes were drilled along a profile between 66°55'S and 68°41'S, at four sites (739, 740, 741, and 742) on the shelf and one (743) on the continental slope (Fig. 1).

Site 739

Nearly 500 m of sediment were drilled at this site, but the core-recovery rate is low (34.6%). The sequence recovered is mostly diamictite. Calcareous nannofossils are rare and sporadic but generally well preserved in the sediments. Because the sequence is dominated by diamictite, the calcareous nannofossils present may have undergone redeposition to various extent. Consequently, the reliability of the biostratigraphy for these sediments should be considered low.

Sample 119-739C-2X-CC contains about a dozen calcareous nannofossil species (Table 8), mostly of Eocene age, but diatoms present suggest a Quaternary age for this level (Baldauf and Barron, this volume); therefore, the calcareous nannofossil species are reworked. The relatively diverse Eocene species may indicate relatively rich carbonate deposition in or near Prydz Bay sometime during the Eocene, and suggest significantly warmer temperatures than at present.

Sample 119-739C-8R-CC yielded 14 calcareous nannofossil species, including two Cretaceous species (*Arkhangelskiella cymbiformis* and *Cribrosphaerella ehrenbergii*). This sample and Sample 119-739C-13R-CC contain *Reticulofenestra producta*, a middle Miocene-Pliocene species and the youngest nannofossil ever found on the Antarctic continental margin. Two specimens of *Reticulofenestra reticulata* were found in Sample 119-739C-22R-2, 12–14 cm. All these nannofossils, except for *Coccolithus pelagicus*, *Reticulofenestra perplexa*, and *R. producta*, must be reworked.

Isthmolithus recurvus was found in Samples 119-739C-28R-1, 30–32 cm, and -30R-1, 108–110 cm, along with one or several Eocene-Oligocene nannofossil species. *Isthmolithus recurvus* is known to range from 35 to 39 Ma in middle and high latitudes (Wei and Wise, 1989a, 1990). Other species present in these two samples are consistent with this age range. The nannofossil assemblages are also comparable to those of late Eocene–early Oligocene intervals from the Kerguelen Plateau, Maud Rise in the Weddell Sea (Wei and Wise, 1990), and the CIROS-1 drill core in the Ross Sea (Edwards and Waghorn, 1989). Similarly, Baldauf and Barron (this volume) found that diatom assemblages present in this interval are comparable to those from the Kerguelen Plateau and the CIROS-1 drill core, and they argue for *in situ* early Oligocene diatoms in this interval. However, strontium isotope analyses of bivalve and scaphopod fragments from Core 119-739C-25R, -29R, -31R, -33R, -34R, and -36R suggest that Cores 119-739C-31R through -36R represent a near-continuous sediment deposition from 23.4 to 29.25 Ma and that the fossil fragments from Cores 119-739C-25R through -29R are reworked (MacDougall et al., this volume). A comparison of the results of calcareous nannofossils, diatoms, and strontium isotopic stratigraphy are summarized in Figure 5. If the strontium isotopic ages are correct, both the calcareous nannofossils and the diatoms would be considered reworked.

A few specimens of *Reticulofenestra umbilica* were found in Samples 119-739C-36R-2, 142–143 cm, and -38R-1, 35–37 cm. *Reticulofenestra umbilica* ranges from middle Eocene to early Oligocene age. *Reticulofenestra daviesii* is the most abundant and consistently present taxon in Hole 739C and occurs down to Sample 119-739C-46R-1, 123–125 cm, at 376.5 mbsf. This species prefers cool/cold waters and ranges from middle Eocene to latest Oligocene age at high latitudes. It is not certain whether or not all these nannofossils are reworked, but they restrict the age to middle Eocene or younger for samples down to 377 mbsf.

In addition, *Reticulofenestra reticulata*, which is abundant in the upper Eocene sediments on Kerguelen Plateau and at other high-latitude sites, was not found in Sample 119-739C-38R-1, 35–37 cm, which contains a relatively diverse assemblage. This negative evidence may suggest that the sample is late Eocene or younger.

Information from Site 739 has extended the known biogeographic ranges of the following species to the Antarctic margin: *Arkhangelskiella cymbiformis*, *Chiasmolithus altus*, *Chiasmolithus oamaruensis*, *Coccolithus formosus*, *Coccolithus pelagicus*, *Cribrosphaerella ehrenbergii*, *Cyclicargolithus floridanus*, *Isthmolithus recurvus*, *Neococcolithes dubius*, *Reticulofenestra bisecta*, *Reticulofenestra daviesii*, *Reticulofenestra hesslandii*, *Reticulofenestra hillae*, *Reticulofenestra perplexa*, *Reticulofenestra producta*, *Reticulofenestra reticulata*, *Reticulofenestra samodurovii*, *Reticulofenestra umbilica*, and *Zygrhablithus bijugatus*.

Sites 740–743

All the core-catcher samples from Sites 740, -741, and -743 are barren of calcareous nannofossils. Only three of the core-catcher samples from Site 742 contained calcareous nannofossils. Sample 119-742A-10R-CC yielded *Chiasmolithus altus*, *Coccolithus formosus*, and *Reticulofenestra daviesii*. Sample 119-742A-11R-CC contained rare *Chiasmolithus altus*, *Chiasmolithus repansus*, *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Reticulofenestra reticulata*, *Reticulofenestra samodurovii*, *Reticulofenestra umbilica*, and *Sphenolithus moriformis*. Rare specimens of *Reticulofenestra reticulata* were found in Sample 119-742A-13R-CC. The assemblages in these samples may indicate a middle to upper Eocene age, but are most likely reworked, because diatom data suggest a Pliocene age for this interval (Barron et al., 1989). Sample 119-742A-27R-5, 13 cm (246 mbsf), taken next to a pelecypod shell yielded rare but well preserved *Reticulofenestra daviesii*, a species of middle Eocene to late Oligocene age. Seismic stratigraphic data (Barron, Larsen, et al., 1989) suggest that this is the oldest glacial marine sequence drilled in Prydz Bay.

SUMMARY AND CONCLUSIONS

Recovery of relatively continuous calcareous sequences of lower Turonian through Miocene by Leg 119 makes it possible to extend the study of calcareous nannofossil biostratigraphy, biogeography, and paleoecology to the Indian Ocean sector of the Southern Ocean. The present study has established nannofossil biostratigraphy for these materials; nannofossil datums useful for constructing age-depth curves (see synthesis paper by Barron et al., this volume) are summarized in Table 9. This study has also provided semiquantitative data on the distribution of calcareous nannofossil assemblages.

Upper Cretaceous nannofossil assemblages from the Kerguelen Plateau have relatively low species diversity, partly due to poor preservation. The compositions of the assemblages, however, are comparable to those at other high-latitude sites. The assemblages are dominated by high-latitude taxa, such as *Nephrolithus frequens*, *Arkhangelskiella cymbiformis*, *Kamptnerius magnificus*, and *Lucianorhabdus cayeuxii*. Low-latitude taxa, such as *Watznaueria barnesae* and *Micula murus* are rare or absent.

After the Cretaceous/Tertiary boundary extinction event, only a few species occurred during the first million years. Some taxa reported common or abundant in low or middle latitudes (e.g., *Braarudosphaera*, *Biscutum parvulum*, *Biscutum romeinii*, and *Toweius petalosus*) are very rare or absent at Site 738 on the southern Kerguelen Plateau. *Thoracosphaera* are less abundant than at lower latitudes and no acme of this taxon was found at Site 738. On the other hand, abundant *Hornibrookina teurienensis* are present in Subzone CP1b at Site 738. Previously, *Horni-*

Table 8. Distribution of calcareous nannofossils, Site 739.

Age	Zones of Okada and Bukry (1980)	Zones of this study	Sample (core, section, interval in cm)	Depth (mbsf)	Abundance	Preservation	<i>Arkhangelskiella cymbiformis</i>	<i>Chiasmolithus altus</i>	<i>Chiasmolithus oamaruensis</i>	<i>Chiasmolithus solitus</i>	<i>Chiasmolithus</i> sp.	<i>Coccolithus formosus</i>	<i>Coccolithus pelagicus</i>	<i>Cribrospira ehrenbergii</i>	<i>Cyclocarolithus floridanus</i>	<i>Isthmolithus recurvus</i>	<i>Neococcolithes dubius</i>	<i>Pontospira</i> sp.	<i>Reticulofenestra bisecta</i>	<i>Reticulofenestra daviesii</i>	<i>Reticulofenestra hesslandii</i>	<i>Reticulofenestra hillae</i>	<i>Reticulofenestra perplexa</i>	<i>Reticulofenestra producta</i>	<i>Reticulofenestra reticulata</i>	<i>Reticulofenestra samodurovii</i>	<i>Reticulofenestra umbilica</i>	<i>Zygrhabdithus bijugatus</i>	
			Hole 739B																										
			2X-CC	3.1	R	G	.	X	.	X	.	X	X	.	X	.	X	X	X	X	.	.	.	.	.	X	.	X
			Hole 739C																										
			2R-CC	19.0	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			3R-CC	24.1	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			4R-CC	28.8	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			5R-CC	38.3	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pliocene			8R-CC	67.3	R	M	X	X	.	X	X	X	R	X	.	X	.	.	X	X	X	.	.	R	.	X	X	.	
			9R-CC	76.9	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			10R-CC	86.8	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
m. Miocene			12R-CC	105.9	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			13R-CC	115.5	R	M	.	.	.	X	.	.	R	.	X	.	.	.	X	X	X	.	R	R	.	X	.	.	
			14R-1, 40-42	116.8	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			14R-1, 131-133	117.6	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			14R-2, 56-58	119.1	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			14R-3, 56-58	125.5	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			15R-1, 28-30	125.7	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			15R-CC	130.3	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			16R-1, 126-128	126.5	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			16R-2, 109-111	132.9	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			16R-3, 124-126	134.5	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			16R-CC	135.0	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			17R-1, 117-119	136.1	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			17R-2, 117-119	137.7	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			17R-4, 51-53	140.0	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			17R-CC	140.1	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			18R-2, 19-21	141.7	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			18R-3, 44-45	143.4	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			18R-CC	144.7	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			19R-1, 80-82	145.5	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			19R-3, 62-64	148.3	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			19R-CC	149.7	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			20R-CC	154.0	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			21R-1, 142-144	155.6	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			21R-3, 72-74	158.0	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			22R-1, 34-36	159.6	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			22R-2, 12-14	160.9	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			22R-3, 123-125	163.5	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	X	.	.	.
			23R-1, 18-20	164.2	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			23R-2, 130-132	166.8	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			23R-CC	169.0	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.
			24R-CC	173.6	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.
			25R-1, 48-50	174.1	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.
			25R-CC	183.2	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.
			26R-1, 68-70	183.9	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.
			26R-2, 2-4	184.8	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	R	.	.
			26R-2, 45-47	185.2	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			26R-3, 132-134	187.5	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.

Table 8 (continued).

Age	Zones of Okada and Bukry (1980)	Zones of this study	Sample (core, section, interval in cm)	Depth (mbsf)	Abundance	Preservation	<i>Arkhangelskiella cymbiformis</i>	<i>Chiasmolithus altus</i>	<i>Chiasmolithus oamaruensis</i>	<i>Chiasmolithus solitus</i>	<i>Chiasmolithus</i> sp.	<i>Coccolithus formosus</i>	<i>Coccolithus pelagicus</i>	<i>Cribrophaera ehrenbergii</i>	<i>Cyclicargolithus floridanus</i>	<i>Isthmolithus recurvus</i>	<i>Neococcolithes dubius</i>	<i>Pontosphaera</i> sp.	<i>Reticulofenestra bisecta</i>	<i>Reticulofenestra daviesii</i>	<i>Reticulofenestra hesslandii</i>	<i>Reticulofenestra hillae</i>	<i>Reticulofenestra perplexa</i>	<i>Reticulofenestra producta</i>	<i>Reticulofenestra reticulata</i>	<i>Reticulofenestra samodurovii</i>	<i>Reticulofenestra umbilica</i>	<i>Zygrhabdolithus bijugatus</i>			
middle Eocene-early Oligocene			Hole 739C (Cont.)																												
			41R-3, 4-6	330.8	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			42R-1, 50-52	338.0	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			42R-1, 122-124	338.7	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.
			42R-2, 35-37	339.4	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			42R-2, 105-107	340.1	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			43R-1, 34-36	347.4	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			43R-1, 139-141	348.5	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.
			44R-1, 33-35	357.1	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			44R-2, 33-35	357.9	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.
			44R-2, 122-124	358.6	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			46R-1, 31-33	359.5	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		46R-1, 123-125	376.5	R	G	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.
?			46R-2, 38-40	377.4	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			47R-1, 34-36	386.2	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			48R-1, 39-41	396.1	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			48R-1, 53-55	396.7	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			48R-1, 110-112	397.5	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			50R-1, 127-129	415.3	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			50R-2, 23-25	416.6	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			51R-1, 32-34	424.8	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			51R-1, 121-123	425.7	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			51R-2, 51-53	426.6	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			53R-1, 53-55	439.7	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			53R-1, 75-77	439.9	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			53R-CC	443.9	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			54R-1, 29-31	444.2	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			55R-2, 12-14	450.5	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			56R-1, 10-11	456.6	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			58R-1, 22-23	463.4	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			58R-2, 30-31	465.0	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			58R-2, 90-91	465.6	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			59R-CC	472.9	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Note: Abundance is characterized by C, common; F, few; R, rare; B, barren. For preservation, G, good; M, moderate. X indicates material reworked.

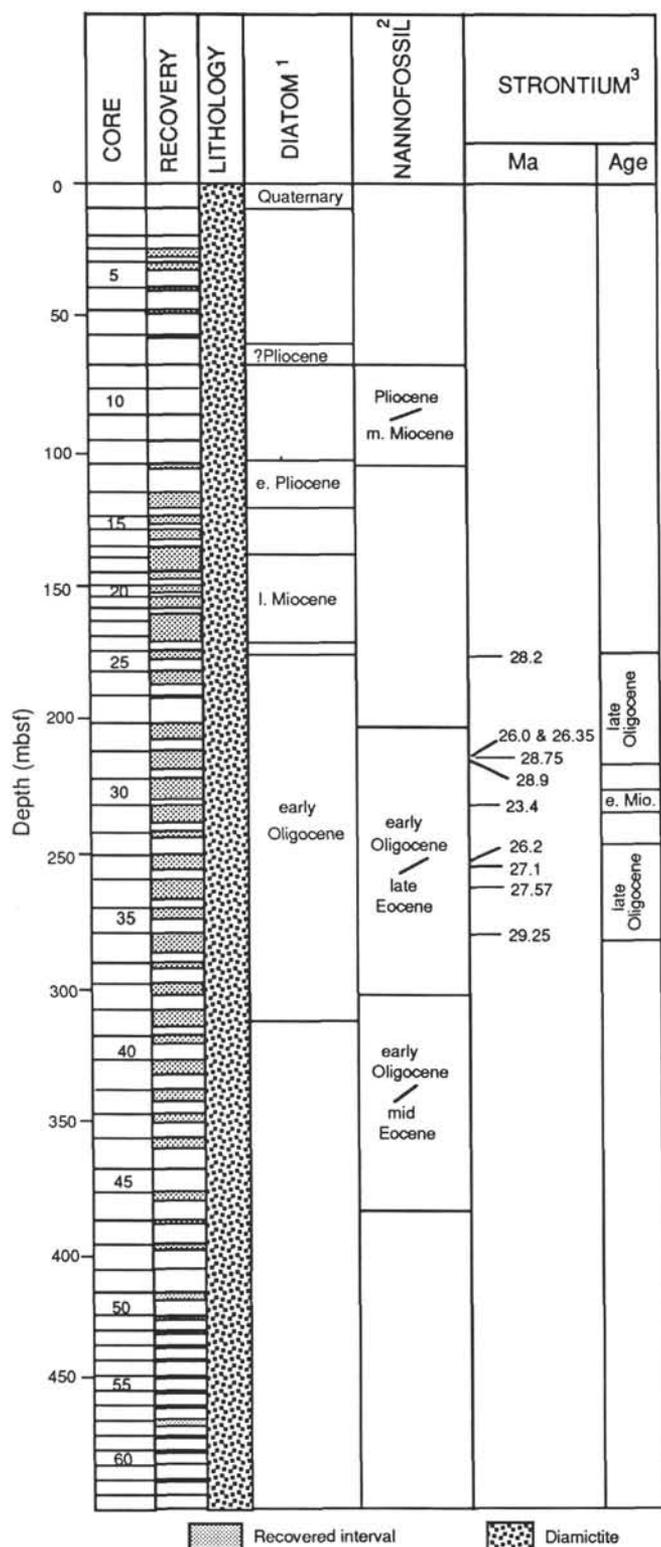


Figure 5. Summary of litho- and biostratigraphy of Site 739 and strontium isotopic dates of bivalves and scaphopod fragments from selected samples. Data are taken from Baldauf and Barron (this volume) for diatom biostratigraphy, this study for nannofossil biostratigraphy, and Macdougall et al. (this volume) for strontium isotopic dates.

brookina teuriensis and/or *Hornibrookina edwardsii* have been reported from the southwest Pacific (Edwards, 1973), the South Atlantic (Perch-Nielsen, 1977), Texas, U.S.A. (Jiang and Gartner, 1986), Argentina (Angelozzi, 1988), the North Sea (Varol, 1989), and the Weddell Sea (Pospichal and Wise, 1990b). These species are never abundant in any of these localities except in the Weddell Sea. The early Paleocene assemblages at Site 738 are distinctly different from those of the middle- and low-latitude sites but are quite similar to those found in the Weddell Sea. A latitudinal differentiation of calcareous nannofossils appears to exist between the southern high latitudes and the middle or low latitudes in the earliest Paleocene (see detailed discussion of the early Paleogene calcareous nannofossils by Wei and Pospichal, this volume).

In the upper Paleocene, *Chiasmolithus bidens*, *Prinsius martinii*, and *Toweius callosus* are abundant on the southern Kerguelen Plateau, whereas these species are few or rare in low-latitude areas. On the other hand, *Discoaster nobilis* is virtually absent, *Heliolithus* species are rare and sporadic, and *Sphenolithus primus* is less abundant and occurs later than *Fasciculithus tympaniformis* at Site 738. All these suggest significantly cooler water temperatures at Site 738 than at the middle- or low-latitude sites during the late Paleocene.

Large chiasmoliths (i.e., *Chiasmolithus expansus*, *Chiasmolithus grandis*, and *Chiasmolithus gigas*) are considerably fewer at this high-latitude site than in the temperate regions. It appears that cool or cold waters were not favorable for large chiasmoliths, whereas smaller chiasmoliths (e.g., *Chiasmolithus solutus* and *C. altus*) flourished in the relatively cold waters. This kind of size-temperature relationship has been noted previously for other genera of calcareous nannoplankton, such as *Discoaster* (Bukry, 1971). Though the abundance of *Discoaster* is generally low, most of the stratigraphically important *Discoaster* species are present in the Eocene sections from the Kerguelen Plateau. This may reflect warmer water temperatures for the Eocene than for other periods of the Cenozoic, as suggested by oxygen isotopic data (Shackleton and Kennett, 1975; Shackleton, 1986; Miller et al., 1987). By the end of the Eocene, virtually all discoasters disappeared from Kerguelen Plateau. *Chiasmolithus altus* and *Reticulofenestra daviesii* dominate the assemblages. These two species are known to prefer cool or cold waters.

Calcareous nannofossil species diversity is significantly lower in the Oligocene, during which time a few species disappeared, and virtually no new species appeared on Kerguelen Plateau. This is also reflected in the zonation scheme used where all the zones have to be defined by the last occurrences of calcareous nannofossil species.

Only a few calcareous nannofossil species were recorded in the Miocene sequences from the Kerguelen Plateau; the most important species include *Coccolithus pelagicus* and several species of *Reticulofenestra*. As in the Falkland Plateau region (Haq, 1980; Wise, 1983) and the Weddell Sea (Wei and Wise, 1990), *Coccolithus pelagicus* and one or two species of *Reticulofenestra* in the Miocene Kerguelen Plateau sequences exhibit extreme fluctuations in assemblage dominance. This may reflect sharp fluctuations of the surface-water temperatures in the Miocene, with intervals dominated by *C. pelagicus* representing warmer events and intervals dominated by *Reticulofenestra* species representing colder periods.

The upper Neogene sequences on Kerguelen Plateau are essentially devoid of calcareous nannofossils. When nannofloras were found, they usually consisted of monospecific assemblages of *Reticulofenestra producta*, a high-latitude species. Continuous deterioration of Neogene climate in the high latitudes and the expansion of the Antarctic surface water mass essentially drove out calcareous nannoplankton. However, a few early-middle Pleistocene species of calcareous nannofossils were found on

Table 9. Calcareous nannofossil datum levels and estimated ages.

Species events	Sample	Depth (m)	mid-point	Age* (Ma)
Hole 737B				
LO <i>Chiasmolithus altus</i>	11R-1, 50/11R-2, 80	312.0/313.80	312.90	^a 25.5
LO <i>Reticulofenestra umbilica</i>	34R-CC/35R-CC	543.30/552.90	548.10	^a 32.2
LO <i>Isthmolithus recurvus</i>	37R-4, 45/37R-5, 45	567.45/568.95	568.20	^a 34.8
LO <i>Discoaster saipanensis</i>	41R-1, 91/41R-2, 102	602.01/603.62	602.80	^a 36.4
FO <i>Reticulofenestra oamaruensis</i>	41R-3, 132/41R-4, 40	605.42/605.99	605.71	^a 38.0
FO <i>Isthmolithus recurvus</i>	46R-1, 1/46R-1, 90	649.30/650.20	649.75	^a 38.3
FO <i>Chiasmolithus oamaruensis</i>	46R-2, 21/46R-CC	651.01/658.60	654.81	^a 41.0
LO <i>Chiasmolithus solitus</i>	48R-3, 46/48R-CC	671.36/677.60	674.48	^a 41.4
FO <i>Reticulofenestra reticulata</i>	49R-CC/50R-1, 57	686.50/687.07	686.79	^a 42.1
Hole 738B				
LO <i>Reticulofenestra oamaruensis</i>	4H-1, 66/4H-2, 66	23.66/25.16	24.41	^a 36.0
FO <i>Reticulofenestra oamaruensis</i>	5H-2, 66/5H-3, 66	34.66/36.16	35.41	^a 38.0
FO <i>Isthmolithus recurvus</i>	5H-5, 110/5H-6, 66	39.16/40.66	39.91	^a 38.8
FO <i>Chiasmolithus oamaruensis</i>	8R-CC/9H-1, 66	70.50/71.16	70.83	^a 41.0
FO <i>Chiasmolithus solitus</i>	8R-CC/9H-1, 66	70.50/71.16	70.83	^a 41.4
FO <i>Reticulofenestra reticulata</i>	12H-2, 66/12H-3, 66	96.66/98.16	97.41	^a 42.1
FO <i>Reticulofenestra umbilica</i>	15X-1, 66/15X-2, 66	118.46/119.96	119.21	^a 44.6
FO <i>Nannotetrina fulgens</i>	23X-CC/24X-1, 66	204.60/205.26	204.93	^b 49.8
Hole 738C				
FO <i>Discoaster subloadoensis</i>	5R-1, 69/5R-2, 69	226.26/227.79	227.03	^c 52.6
FO <i>Discoaster lodoensis</i>	8R-CC/9R-1, 66	264.10/264.76	264.43	^c 55.4
FO <i>Discoaster diastypus</i>	10R-CC/11R-1, 90	283.40/284.30	283.85	^d 56.7
FO <i>Discoaster multiradiatus</i>	11R-CC/13R-CC	293.0/312.30	302.65	^b 59.2
FO <i>Discoaster mohleri</i>	14R-CC/15R-CC	321.90/331.60	326.75	^b 60.5
FO <i>Heliolithus kleinpellii</i>	15R-CC/16R-5, 97	331.60/338.30	334.95	^b 61.6
FO <i>Chiasmolithus bidens</i>	18R-1, 35/18R-1, 85	351.25/351.75	351.50	^b 63.2
FO <i>Prinsius martinii</i>	18R-CC/19R-1, 35	360.50/360.85	360.68	^b 65.5
FO <i>Chiasmolithus danicus</i>	19R-3, 85/19R-3, 135	364.35/364.85	364.60	^e 65.8
FO <i>Cruciplacolithus tenuis</i>	20R-5, 2/20R-5, 35	376.22/376.5 5	376.39	^b 65.9
FO <i>Biantholithus sparsus</i>	20R-5, 84/20R-5, 95	377.04/377.16	377.10	^c 66.4
FO <i>Nephrolithus frequens</i>	24R-1, 24/24R-2, 64	409.14/411.67	410.09	^f 68.0
FO <i>Broinsonia parca</i>	30R-CC/31R-1, 77	466.60/467.63	467.12	^f 81.9
Hole 744A				
LO <i>Reticulofenestra bisecta</i>	11H-CC/12H-1, 92	99.2/101.12	100.16	^a 24.0
LO <i>Chiasmolithus altus</i>	12H-5, 92/12H-6, 92	106.12/107.62	106.87	^a 25.5
LO <i>Reticulofenestra umbilica</i>	14H-6, 75/14H-CC	126.45/127.70	127.08	^a 32.2
LO <i>Isthmolithus recurvus</i>	15H-2, 75/15H-3, 75	129.95/131.45	130.70	^a 34.8
LO <i>Reticulofenestra oamaruensis</i>	17H-CC/18H-1, 75	147.60/148.35	147.98	^a 36.0
LO <i>Discoaster saipanensis</i>	19H-3, 75/19H-4, 7	160.86/162.35	161.61	^b 36.4
FO <i>Reticulofenestra oamaruensis</i>	19H-CC/20H-1, 75	166.60/167.35	166.97	^a 38.0
FO <i>Isthmolithus recurvus</i>	20H-2, 75/20H-3, 75	168.85/170.35	169.60	^a 38.8

*Age estimates are based on the following sources: ^a Wei and Wise (1990); ^b Wei and Wise (1989a); ^c Berggren et al. (1985); ^d Monechi et al. (1985); ^e Shackleton et al. (1984); ^f Monechi and Thierstein (1985).

the Kerguelen Plateau. This may suggest that during part of the early-middle Pleistocene surface waters on Kerguelen were significantly warmer than those of the present, because no calcareous nannoplankton have been reported from such a high latitude in the modern ocean.

Only rare and sporadic occurrences of calcareous nannofossils were found in the diamicite sequences recovered at Sites 739 and 742 in Prydz Bay. Cores 119-739C-28R and -30R yielded the most age-diagnostic calcareous nannofossil assemblages; the late Eocene-early Oligocene age (35-39 Ma) suggested by the nannofossil assemblages is consistent with the diatom age (Baldauf and Barron, this volume). *Reticulofenestra daviesii* is present down to Core 119-739C-46R (376 mbsf) and restricts the age to middle Eocene or younger for samples down to 376 mbsf.

TAXONOMIC NOTES OF SELECTED SPECIES

Clausicoccus fenestratus (Deflandre and Fert) Prins, 1979
(Pl. 4, Figs. 5, 6)

Discolithus fenestratus Deflandre and Fert, 1955, Ann. Paléont., vol. 40, p. 139, pl. 11, fig. 15.

Ellipsolithus subdistichus Roth and Hay, 1967, Trans. Gulf Coast. Ass. Geol. Soc., vol. 17, p. 446, pl. 6, fig. 7.

Ericsonia bireticulata Roth, 1970, Eclog. Geol. Helv. vol. 63, p. 840, pl. 1, figs. 4, 5.

Ericsonia pauciperforata Roth, 1970, Eclog. Geol. Helv. vol. 63, p. 842, pl. 2, fig. 1.

Ericsonia quadriperforata Roth, 1970, Eclog. Geol. Helv. vol. 63, p. 843, pl. 2, fig. 2.

Ericsonia subdisticha (Roth and Hay) Roth, Roth, 1970, Eclog. Geol. Helv. vol. 63, p. 843, pl. 2, figs. 3, 4.

Ericsonia obruta Perch-Nielsen, 1971, Kongl. Danske Vidensk. Selsk., Biol. Skr., vol. 18, p. 14, pl. 4, figs. 5, 6.

Ericsonia fenestrata (Deflandre and Fert) Stradner, Perch-Nielsen, 1971, p. 12, pl. 5, figs. 1-6; pl. 6, figs. 6-11.

Ericsonia? cf. *E. fenestrata*, Perch-Nielsen, 1971, p. 13, pl. 6, figs. 1-5.

Ericsonia? *singularis* Perch-Nielsen, 1971, p. 15, pl. 7, figs. 1-3, 5.

Clausicoccus fenestratus (Deflandre and Fert) Prins, 1979, p. N-4, fig. 3.

Clausicoccus fenestratus (Deflandre and Fert) Prins, Wise, 1983, p. 516, pl. 1, figs. 8, 9.

Remarks. Since the description of *Discolithus fenestratus* by Deflandre and Fert (1955), a number of species names have been intro-

duced for forms with a different numbers of perforations in the central area relative to the holotype of *D. fenestratus*, which has 20. According to Roth (1970), *Ericsonia bireticulata* has two superimposed grills, *Ericsonia pauciperforata* has an irregular arrangement of the perforations in the central area, *Ericsonia quadriperforata* has 4 pores, and *Ericsonia subdisticha* has 10 pores. *Ericsonia obruta* Perch-Nielsen also has 4 pores, and *Ericsonia? singularis* Perch-Nielsen shows various numbers of pores up to 24 (Perch-Nielsen, 1971, pl. 7). However, examination of the literature reveals that the number of pores in the *Clauisococcus fenestratus* group varies in a seemingly continuous spectrum. This can be seen in the three plates (pls. 5-7) illustrated by Perch-Nielsen (1971), where the *C. fenestratus* group shows the following pore numbers: 7, 7, 8, 9, 9, 11, 13, 13, 15, 15, 18, 18, 19, 19, 20, 20, 21, and 25. The superimposed grills in *E. bireticulata* as described by Roth (1970) are not useful for species diagnosis either, because only one layer of grill can usually be seen. Other species of *Clauisococcus* may also possess two grills but only one has been seen. All species previously mentioned seem to have similar stratigraphic ranges (Eocene-Oligocene). Furthermore, it is difficult or impossible to count the pore numbers in a light microscope, especially when the specimens are less than perfectly preserved. Therefore, the species listed can be considered as junior synonyms of *Clauisococcus fenestratus*.

Reticulofenestra gelida (Geitzenauer) Backman, 1979.
(Pl. 1, Figs. 1-4)

Remarks. Backman (1980) analyzed and discussed the relationship between *Reticulofenestra gelida* and *Reticulofenestra pseudoubilica* at length, concluding that the former is a winter morphovariant of the latter and that *R. gelida* is a junior synonym of *R. pseudoubilica*. *Reticulofenestra gelida* is usually found in the high latitudes whereas *R. pseudoubilica* is not, and the distribution patterns of these two species show no annual cycles. Thus, as has already been pointed out by Wise (1983), *R. gelida* should not be considered a winter morphotype of *R. pseudoubilica*.

Reticulofenestra perplexa (Burns) Wise, 1983.
(Pl. 1, Figs. 5-10)

Dictyococcites perplexa Burns, 1975, p. 594, figs. 13, 19-20.
Dictyococcites antarcticus Haq, 1976, p. 567, figs. 1-5, 7, 8.

Remarks. Backman (in Heck, 1981a, p. 40) was the first to point out that *Dictyococcites antarcticus* Haq (1976) is a junior synonym of *Dictyococcites perplexa* Burns (1975). Wise (1983, p. 505-506) remarks that "all of Burns's magnifications in his article are overstated by a factor of about 2.5. The dimensions he attributed the holotype of *D. perplexa* are also overstated by the same factor; thus the holotype measures about 5 to 6 μm along the length of the distal surface rather than 18-20 μm as originally stated. The revised measurement is similar to those given by Haq (1976) for *D. antarcticus* (4 to 7 μm , rarely 8 μm)." Wise (1983) transferred the species to *Reticulofenestra*. In spite of all this, there is still confusion in the literature. Recently, Driever (1988), based on a written communication with Burns in 1981, claimed that *D. perplexa* has a size of 18-20 μm , and thus *D. perplexa* is different from *D. antarcticus*. Careful reexamination of Burns (1975) reveals that the magnifications in his figure captions are understated by a factor of 2-4, whereas in the description of *D. perplexa*, the size of the species is overstated by a factor of about 3. The correct size of *D. perplexa* should be 5-7 μm , a similar size range as for *D. antarcticus*. Both *D. perplexa* and *D. antarcticus* have about 60 elements and a closed central area. The isotypes of Haq (1976) (his paratypes) are strongly etched specimens. By all recognized criteria, *D. antarcticus* is a junior synonym of *D. perplexa*.

Reticulofenestra perplexa has been found in high-latitude middle to upper Miocene sediments only. It is most abundant in high southern latitudes, where it constitutes nearly 100% of the nannofossil assemblage in many intervals (Wise, 1983; Wei and Wise, 1990; this study). Clearly, *Reticulofenestra perplexa* is a cold-water species that has special importance in paleoceanographic studies, as has been pointed out by Haq (1980, for his *D. antarcticus*).

Reticulofenestra producta (Kamptner) Wei and Thierstein, n. comb.
(Pl. 1, Figs. 11 and 12)

Basionym. *Ellipsoplacolithus productus* Kamptner, 1963.
Dictyococcites productus (Kamptner) Backman, 1980.

Remarks. As pointed out by Wise (1983, p. 505), *Dictyococcites* is an ill-defined genus, and it is very difficult and of little profit to separate *Dictyococcites* from *Reticulofenestra*. *Reticulofenestra producta* has essentially the same structure as *Reticulofenestra perplexa*. The only difference is that *R. producta* is consistently smaller (3-4 μm) than *R. perplexa* (5-7 μm). It seems that *R. producta* grades into *R. perplexa*. However, *R. perplexa* is limited to the Miocene, whereas *R. producta* is found in both the Miocene and Pliocene, and the latter is the dominant species in high-latitude Pliocene nannofossil assemblages.

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- Wise, S. W., Jr., and Wind, F. H., 1977. Mesozoic and Cenozoic calcareous nannofossils recovered by DSDP Leg 36 drilling on the Falkland Plateau, Southwest Atlantic sector of the Southern Ocean. In Barker, P., Dalziel, I.W.D., et al., *Init. Repts. DSDP*, 36: Washington (U.S. Govt. Printing Office), 269-492.
- Clausicoccus fenestratus* (Deflandre and Fert) Prins, 1979. Pl. 4, Figs. 5, 6
- Coccolithus formosus* (Kamptner) Wise, 1973. Pl. 4, Figs. 14, 15
- Coccolithus pelagicus* (Wallich) Schiller, 1930
- Cruciplacolithus edwardsii* Romein, 1979
- Cruciplacolithus primus* Perch-Nielsen, 1977
- Cruciplacolithus tenuis* (Stradner) Hay and Mohler in Hay et al., 1967
- Cyclicargolithus abisectus* (Müller) Wise, 1973. Pl. 2, Fig. 10
- Cyclicargolithus floridanus* (Roth and Hay in Hay et al.) Bukry, 1971. Pl. 2, Figs. 5-9
- Discoaster barbadiensis* Tan, 1927. Pl. 6, Figs. 2, 3
- Discoaster bifax* Bukry, 1971. Pl. 5, Fig. 6
- Discoaster deflandrei* Bramlette and Riedel, 1954
- Discoaster diastypus* Bramlette and Sullivan, 1961
- Discoaster kuepperi* Stradner, 1959. Pl. 5, Figs. 16, 17
- Discoaster lodoensis* Bramlette and Riedel, 1954. Pl. 6, Figs. 4, 5
- Discoaster mohleri* Bukry and Percival, 1971
- Discoaster multiradiatus* Bramlette and Riedel, 1954. Pl. 6, Fig. 13
- Discoaster praebifax* Wei and Wise, 1989b
- Discoaster saipanensis* Bramlette and Riedel, 1954. Pl. 5, Fig. 1
- Discoaster sublodoensis* Bramlette and Sullivan, 1961
- Discoaster tanii* Bramlette and Riedel, 1954
- Discoaster variabilis* Martini and Bramlette, 1963
- Ellipsolithus distichus* (Bramlette and Sullivan) Sullivan, 1964. Pl. 6, Fig. 16
- Ericsonia subpertusa* Hay and Mohler, 1967
- Fasciculithus pileatus* Bukry, 1973
- Fasciculithus tympaniformis* Hay and Mohler in Hay et al., 1967
- Fasciculithus ulii* Perch-Nielsen, 1971
- Gephyrocapsa oceanica* Kamptner, 1943
- Helicosphaera compacta* Bramlette and Wilcoxon, 1967
- Helicosphaera euphratis* Haq, 1966
- Helicosphaera recta* Haq, 1966
- Heliolithus kleinpellii* Sullivan, 1964. Pl. 6, Figs. 14, 15
- Hornibrookina teuriensis* Edwards, 1973
- Isthmolithus recurvus* Deflandre, 1954. Pl. 4, Figs. 9-11
- Laternithus minutus* Stradner, 1962
- Markalius apertus* Perch-Nielsen, 1979
- Markalius inversus* (Deflandre) Bramlette and Martini, 1964. Pl. 4, Fig. 16
- Nannotetrina cristata* (Martini) Perch-Nielsen, 1971
- Nannotetrina fulgens* (Stradner) Achuthan and Stradner, 1969
- Neochiastozygus concinnus* (Martini) Perch-Nielsen, 1971
- Neococcolithes dubius* (Deflandre) Black, 1967. Pl. 5, Fig. 15
- Pontosphaera multipora* (Kamptner) Roth, 1970. Pl. 2, Fig. 3
- Prinsius bisulcus* (Stradner) Hay and Mohler, 1967
- Prinsius dimorphosus* (Perch-Nielsen) Perch-Nielsen, 1977
- Prinsius martinii* (Perch-Nielsen) Haq, 1977
- Pseudoemiliania lacunosa* (Kamptner) Gartner, 1969
- Pyrocyclus orangensis* (Bukry) Perch-Nielsen, 1986
- Reticulofenestra bisecta* (Hay, Mohler, and Wade) Roth, 1970. Pl. 3, Fig. 5; Pl. 4, Fig. 1
- Reticulofenestra bisecta filewiczii* Wise and Wiegand in Wise, 1983. Pl. 3, Fig. 6; Pl. 4, Fig. 2
- Reticulofenestra daviesii* (Haq) Haq, 1971. Pl. 4, Fig. 4
- Reticulofenestra gelida* (Geitzenauer) Backman, 1978. Pl. 1, Figs. 1-4
- Reticulofenestra hesslandii* (Haq) Roth, 1970. Pl. 2, Figs. 1, 2; Pl. 2, Fig. 4
- Reticulofenestra oamaruensis* (Deflandre) Stradner and Edwards, 1968. Pl. 4, Fig. 12
- Reticulofenestra onusta* (Perch-Nielsen) Wise, 1983. Pl. 3, Fig. 7
- Reticulofenestra perplexa* (Burns) Wise, 1983. Pl. 1, Figs. 5-10
- Reticulofenestra producta* Wei and Thierstein, n. com. Pl. 1, Figs. 11, 12
- Reticulofenestra pseudoumbilica* (Gartner) Gartner, 1969
- Reticulofenestra reticulata* (Gartner and Smith) Roth and Thierstein, 1972. Pl. 3, Figs. 8, 9; Pl. 5, Figs. 2-4
- Reticulofenestra samodurovii* (Hay, Mohler, and Wade) Roth, 1970
- Reticulofenestra umbilica* (Levin) Martini and Ritzkowski, 1968. Pl. 5, Fig. 7
- Rhabdosphaera perlongus* Deflandre in Grasse, 1952. Pl. 5, Fig. 14
- Sphenolithus ciperoensis* Bramlette and Wilcoxon, 1967
- Sphenolithus moriformis* (Bronnimann and Stradner) Bramlette and Wilcoxon, 1967. Pl. 5, Figs. 12, 13

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APPENDIX

Calcareous Nannofossils Considered in This Paper

In alphabetical order of generic epithets (plate and figure numbers refer to illustrations in this paper).

Cenozoic Species

- Biantholithus sparsus* Bramlette and Martini, 1964
- Bicolumnus ovatus* Wei and Wise, 1990
- Blackites spinosus* (Deflandre and Fert) Hay and Towe, 1962
- Braarudosphaera bigelowii* (Gran and Braarud) Deflandre, 1974
- Calcidiscus leptoporus* (Murray and Blackman) Loeblich and Tappan, 1978. Pl. 3, Fig. 3
- Calcidiscus macintyreii* (Bukry and Bramlette) Loeblich and Tappan, 1978. Pl. 3, Figs. 1, 2
- Chiasmolithus altus* Bukry and Percival, 1971. Pl. 2, Fig. 11; Pl. 3, Fig. 4
- Chiasmolithus bidens* (Bramlette and Sullivan) Hay and Mohler, 1967
- Chiasmolithus danicus* (Brotzen) Hay and Mohler, 1967
- Chiasmolithus expansus* (Bramlette and Sullivan) Gartner, 1970. Pl. 5, Fig. 10
- Chiasmolithus gigas* (Bramlette and Sullivan) Radomski, 1968
- Chiasmolithus grandis* (Bramlette and Sullivan) Radomski, 1978. Pl. 5, Fig. 11
- Chiasmolithus oamaruensis* (Deflandre) Hay, Mohler and Wade, 1966. Pl. 5, Fig. 9
- Chiasmolithus solitus* (Bramlette and Sullivan) Locker, 1968

Sphenolithus radians Deflandre in Grasse, 1952
Toweius callosus Perch-Nielsen, 1971. Pl. 6, Figs. 9, 10
Toweius craticulus Hay and Mohler, 1967
Toweius magnicrassus (Bukry) Romein, 1979. Pl. 6, Figs. 11, 12
Tribrachiatius orthostylus Shamrai, 1963. Pl. 6, Fig. 6
Zygodiscus sigmoides Bramlette and Sullivan, 1961
Zygrhablithus bijugatus (Deflandre) Deflandre, 1959. Pl. 4, Fig. 8

Cretaceous Species

Ahmuellereella octoradiata (Gorka) Bukry, 1969
Arkhangelskiella cymbiformis Veskschina, 1959
Biscutum constans (Gorka) Black, 1967
Biscutum coronum Wind and Wise in Wise and Wind, 1977
Biscutum magnum Wind and Wise in Wise and Wind, 1977
Broinsonia enormis (Shumenko) Bukry, 1969
Broinsonia parca (Stradner) Bukry, 1969
Broinsonia signata (Noël) Noël, 1970
Chiastozygus litterarius (Gorka) Manivit, 1971
Crepidolithus conicus Bramlette and Martini, 1964
Cretarhabdus surirellus (Deflandre) Reinhardt, 1970
Cribrosphaerella daniae Perch-Nielsen, 1977
Cribrosphaerella ehrenbergii (Arkhangelsky) Deflandre, 1952
Cyclagelosphaera reinhardtii (Perch-Nielsen) Romein, 1977
Cyclageolsphaera margerelii Nol, 1965
Eiffellithus eximius (Stover) Perch-Nielsen, 1968
Eiffellithus trabeculatus (Gorka) Reinhardt and Gorka, 1967
Eiffellithus turriseiffeli (Deflandre) Reinhardt, 1965
Gartnerago nanum Thierstein, 1974
Gartnerago obliquium (Stradner) Nol, 1970
Kamptnerius magnificus Deflandre, 1959
Lithastrinus floralis Stradner, 1962
Lithraphidites carniolensis Deflandre, 1963
Lucianorhabdus cayeuxii Deflandre, 1959
Microrhabdulus decoratus Deflandre, 1959
Micula staurophora (Gardet) Stradner, 1963.
Nephrolithus corystus Wind, 1983
Nephrolithus frequens Gorka, 1957
Parhabdololithus angustus (Stradner) Strandner, Adamiker, and Maresch, 1968
Prediscosphaera cretacea (Arkhangelsky) Gartner, 1968
Prediscosphaera spinosa (Bramlette and Martini) Gartner, 1968
Prediscosphaera stoveri (Perch-Nielsen) Shafik and Stradner, 1971
Reinhardtites anthophorus (Deflandre) Perch-Nielsen, 1968
Reinhardtites levis Prins and Sissing, 1977
Seribiscutum primitivum (Thierstein) Filewicz et al. in Wise and Wind, 1977
Tranolithus orionatus (Reinhardt) Reinhardt, 1966
Watznaueria barnesae (Black) Perch-Nielsen, 1968
Zygodiscus diplogrammus (Deflandre) Gartner, 1968
Zygodiscus spiralis Bramlette and Martini, 1964

In alphabetical order of species epithets (plate and figure numbers refer to illustrations in this paper).

Cenozoic Species

Cyclicargolithus abisectus (Müller) Wise, 1973. Pl. 2, Fig. 10
Chiasmolithus altus Bukry and Percival, 1971. Pl. 2, Fig. 11; Pl. 3, Fig. 4
Markalius apertus Perch-Nielsen, 1979
Discoaster barbadiensis Tan, 1927. Pl. 6, Figs. 2, 3
Chiasmolithus bidens (Bramlette and Sullivan) Hay and Mohler, 1967
Discoaster bifax Bukry, 1971. Pl. 5, Fig. 6
Braarudosphaera bigelowii (Gran and Braarud) Deflandre, 1974
Zygrhablithus bijugatus (Deflandre) Deflandre, 1959. Pl. 4, Fig. 8
Reticulofenestra bisecta filewiczii Wise and Wiegand in Wise, 1983. Pl. 3, Fig. 6; Pl. 4, Fig. 2
Reticulofenestra bisecta (Hay, Mohler and Wade) Roth, 1970. Pl. 3, Fig. 5; Pl. 4, Fig. 1
Prinsius bisulcus (Stradner) Hay and Mohler, 1967
Toweius callosus Perch-Nielsen, 1971. Pl. 6, Figs. 9, 10
Sphenolithus ciperoensis Bramlette and Wilcoxon, 1967
Helicosphaera compacta Bramlette and Wilcoxon, 1967
Neochiastozygus concinnus (Martini) Perch-Nielsen, 1971
Toweius craticulus Hay and Mohler, 1967
Nannotetrina cristata (Martini) Perch-Nielsen, 1971

Chiasmolithus danicus (Brotzen) Hay and Mohler, 1967
Reticulofenestra daviesii (Haq) Haq, 1971. Pl. 4, Fig. 4
Discoaster deflandrei Bramlette and Riedel, 1954
Discoaster diastypus Bramlette and Sullivan, 1961
Prinsius dimorphosus (Perch-Nielsen) Perch-Nielsen, 1977
Ellipsolithus distichus (Bramlette and Sullivan) Sullivan, 1964. Pl. 6, Fig. 16
Neococcolithes dubius (Deflandre) Black, 1967. Pl. 5, Fig. 15
Cruciplacolithus edwardsii Romein, 1979
Helicosphaera euphratis Haq, 1966
Chiasmolithus expansus (Bramlette and Sullivan) Gartner, 1970. Pl. 5, Fig. 10
Clausicoccus fenestratus (Deflandre and Fert) Prins, 1979. Pl. 4, Figs. 5, 6
Cyclicargolithus floridanus (Roth and Hay in Hay et al.) Bukry, 1971. Pl. 2, Figs. 5-9
Coccolithus formosus (Kamptner) Wise, 1973. Pl. 4, Figs. 14, 15
Nannotetrina fulgens (Stradner) Achuthan and Stradner, 1969
Reticulofenestra gelida (Geitzenauer) Backman, 1978. Pl. 1, Figs. 1-4
Chiasmolithus gigas (Bramlette and Sullivan) Radomski, 1968
Chiasmolithus grandis (Bramlette and Sullivan) Radomski, 1978. Pl. 5, Fig. 11
Reticulofenestra hesslandii (Haq) Roth, 1970. Pl. 2, Figs. 1, 2; Pl. 2, Fig. 4
Markalius inversus (Deflandre) Bramlette and Martini, 1964. Pl. 4, Fig. 16
Heliolithus kleinpellii Sullivan, 1964. Pl. 6, Figs. 14, 15
Discoaster kuepperi Stradner, 1959. Pl. 5, Figs. 16, 17
Pseudoemiliania lacunosa (Kamptner) Gartner, 1969
Calcidiscus leptoporus (Murray and Blackman) Loeblich and Tappan, 1978. Pl. 3, Fig. 3
Discoaster lodoensis Bramlette and Riedel, 1954. Pl. 6, Figs. 4, 5
Calcidiscus macintyreii (Bukry and Bramlette) Loeblich and Tappan, 1978. Pl. 3, Figs. 1, 2
Toweius magnicrassus (Bukry) Romein, 1979. Pl. 6, Figs. 11, 12
Prinsius martinii (Perch-Nielsen) Haq, 1977
Lanternithus minutus Stradner, 1962
Discoaster mohleri Bukry and Percival, 1971
Sphenolithus moriformis (Bronnimann and Stradner) Bramlette and Wilcoxon, 1967. Pl. 5, Figs. 12, 13
Pontosphaera multipora (Kamptner) Roth, 1970. Pl. 2, Fig. 3
Discoaster multiradiatus Bramlette and Riedel, 1954. Pl. 6, Fig. 13
Chiasmolithus oamaruensis (Deflandre) Hay, Mohler, and Wade, 1966. Pl. 5, Fig. 9
Reticulofenestra oamaruensis (Deflandre) Stradner and Edwards, 1968. Pl. 4, Fig. 12
Gephyrocapsa oceanica Kamptner, 1943
Reticulofenestra onusta (Perch-Nielsen) Wise, 1983. Pl. 3, Fig. 7
Pyrocyclus orangensis (Bukry) Perch-Nielsen, 1986
Tribrachiatius orthostylus Shamrai, 1963. Pl. 6, Fig. 6
Bicolumnus ovatus Wei and Wise, 1990
Coccolithus pelagicus (Wallich) Schiller, 1930
Rhabdosphaera perlongus Deflandre in Grasse, 1952. Pl. 5, Fig. 14
Reticulofenestra perplexa (Burns) Wise, 1983. Pl. 1, Figs. 5-10
Fasciculithus pileatus Bukry, 1973
Discoaster praebifax Wei and Wise, 1989b
Cruciplacolithus primus Perch-Nielsen, 1977
Reticulofenestra producta Wei and Thierstein, n. com. Pl. 1, Figs. 11, 12
Reticulofenestra pseudoumbilica (Gartner) Gartner, 1969
Sphenolithus radians Deflandre in Grasse, 1952
Helicosphaera recta Haq, 1966
Isthmolithus recurvus Deflandre, 1954. Pl. 4, Figs. 9-11
Reticulofenestra reticulata (Gartner and Smith) Roth and Thierstein, 1972. Pl. 3, Figs. 8, 9; Pl. 5, Figs. 2-4
Discoaster saipanensis Bramlette and Riedel, 1954. Pl. 5, Fig. 1
Reticulofenestra samodurovii (Hay, Mohler, and Wade) Roth, 1970
Zygodiscus sigmoides Bramlette and Sullivan, 1961
Chiasmolithus solitus (Bramlette and Sullivan) Locker, 1968
Biantholithus sparsus Bramlette and Martini, 1964
Blackites spinosus (Deflandre and Fert) Hay and Towe, 1962
Discoaster sublodoensis Bramlette and Sullivan, 1961
Ericsonia subpertusa Hay and Mohler, 1967
Discoaster tanii Bramlette and Riedel, 1954
Cruciplacolithus tenuis (Stradner) Hay and Mohler in Hay et al., 1967

Hornibrookina teuriensis Edwards, 1973
Fasciculithus ulii Perch-Nielsen, 1971
Reticulofenestra umbilica (Levin) Martini and Ritzkowski, 1968. Pl. 5,
 Fig. 7
Discoaster variabilis Martini and Bramlette, 1963
Fasciculithus tympaniformis Hay and Mohler in Hay et al., 1967

Cretaceous Species

Parhabdolithus angustus (Stradner) Strandner, Adamiker, and Maresch,
 1968
Reinhardtites anthophorus (Deflandre) Perch-Nielsen, 1968
Watznaueria barnesae (Black) Perch-Nielsen, 1968
Lithraphidites carniolensis Deflandre, 1963
Lucianorhabdus cayeuxii Deflandre, 1959
Crepidolithus conicus Bramlette and Martini, 1964
Biscutum constans (Gorka) Black, 1967
Biscutum coronum Wind and Wise in Wise and Wind, 1977
Nephrolithus corystus Wind, 1983
Prediscosphaera cretacea (Arkhangelsky) Gartner, 1968
Arkhangelskiella cymbiformis Vesekhina, 1959
Cribrosphaerella daniae Perch-Nielsen, 1977
Microrhabdulus decoratus Deflandre, 1959
Zygodiscus diplogrammus (Deflandre) Gartner, 1968
Cribrosphaerella ehrenbergii (Arkhangelsky) Deflandre, 1952

Broinsonia enormis (Shumenko) Bukry, 1969
Eiffellithus eximius (Stover) Perch-Nielsen, 1968
Lithastrinus floralis Stradner, 1962
Nephrolithus frequens Gorka, 1957
Reinhardtites levis Prins and Sissing, 1977
Chiaστοzygus litterarius (Gorka) Manivit, 1971
Kamptnerius magnificus Deflandre, 1959
Biscutum magnum Wind and Wise in Wise and Wind, 1977
Cyclagelosphaera margerelii Noël, 1965
Gartnerago nanum Thierstein, 1974
Gartnerago obliquium (Stradner) Noël, 1970
Seribiscutum primitivum (Thierstein) Filewicz et al. in Wise and Wind,
 1977
Ahmuellerella octoradiata (Gorka) Bukry, 1964
Tranolithus orionatus (Reinhardt) Reinhardt, 1966
Broinsonia parca (Stradner) Bukry, 1969
Cyclagelosphaera reinhardtii (Perch-Nielsen) Romein, 1977
Broinsonia signata (Noël) Noël, 1970
Prediscosphaera spinosa (Bramlette and Martini) Gartner, 1968
Zygodiscus spiralis Bramlette and Martini, 1964
Micula staurophora (Gardet) Stradner, 1963.
Prediscosphaera stoveri (Perch-Nielsen) Shafik and Stradner, 1971
Cretarhabdus surirellus (Deflandre) Reinhardt, 1970
Eiffellithus trabeculatus (Gorka) Reinhardt and Gorka, 1967
Eiffellithus turriseiffeli (Deflandre) Reinhardt, 1965

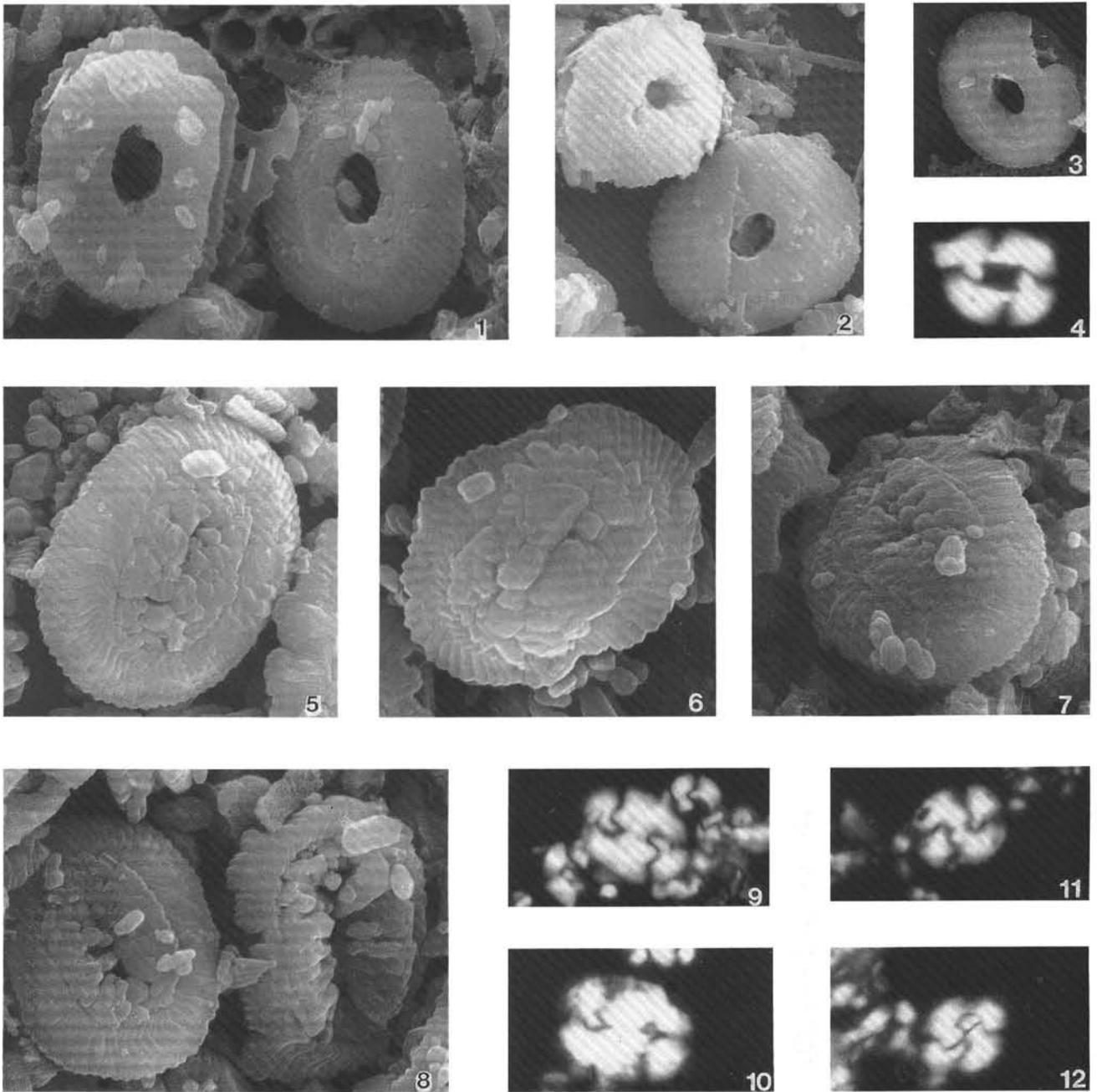


Plate 1. 1-4. *Reticulofenestra gelida* (Geitzenauer) Backman, Sample 119-737B-5R-3, 45-47 cm; (1) proximal view on left and distal view on right, 5,500 \times ; (2) distal view, 4,000 \times ; (3) distal view, 3,800 \times ; (4) 3,400 \times . 5-10. *Reticulofenestra perplexa* (Burns) Wise, Sample 119-738B-6R-CC; (5) distal view, 6,000 \times ; (6) distal view, 8,000 \times ; (7) distal view, 6,000 \times ; (8) both specimens are distal view, 6,500 \times , poorly preserved specimen on right; (9, 10) 3,200 \times . 11, 12. *Reticulofenestra producta* (Kamptner) Wei and Thierstein, 3,400 \times , Sample 119-737B-5R-3, 45-47 cm.

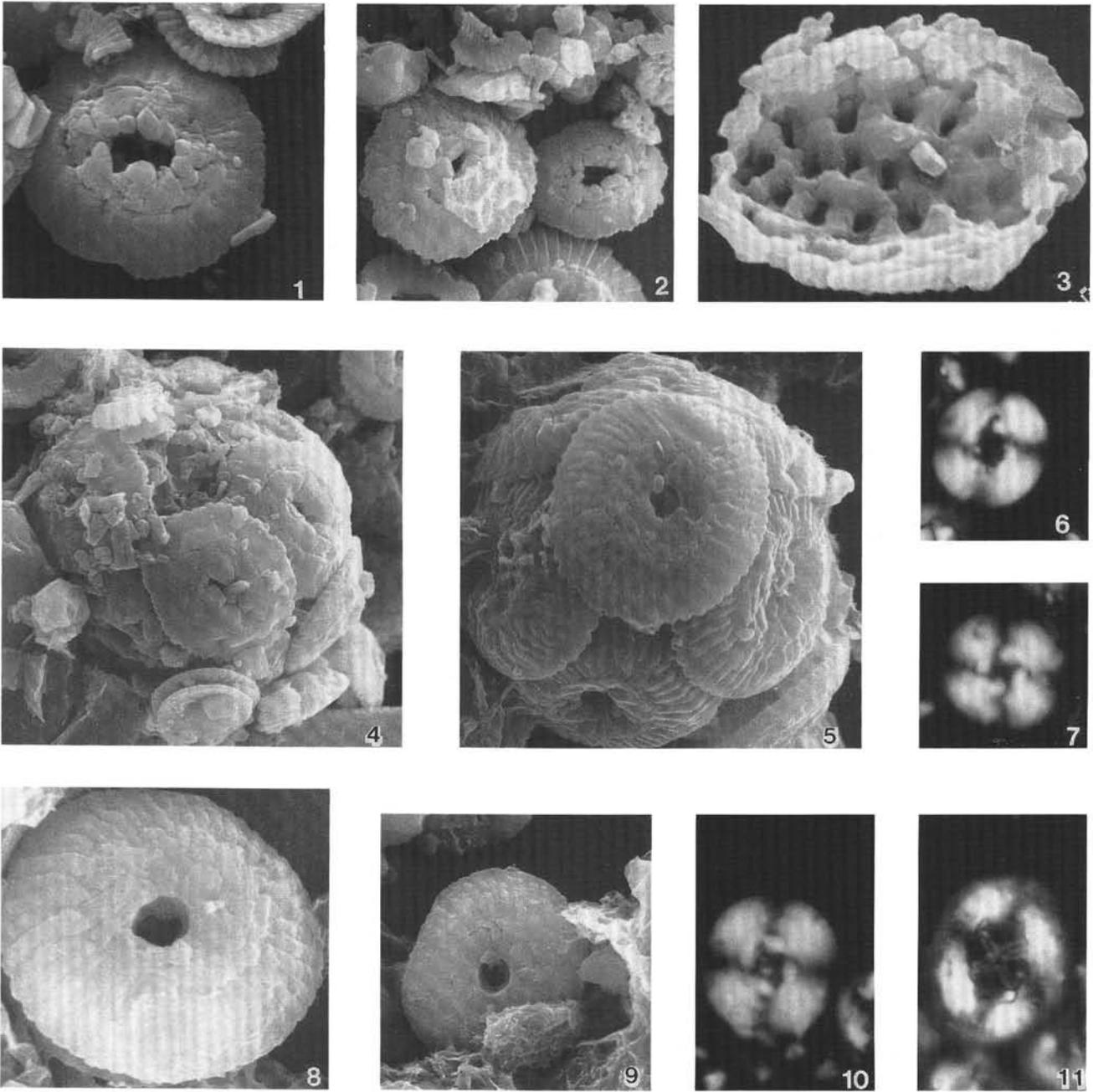


Plate 2. 1, 2. *Reticulofenestra hesslandii* (Haq) Roth, Sample 119-737B-10R-3, 45-47 cm; (1) distal view, 5,500 \times ; (2) both specimens are distal view, note variation in size, 4,000 \times . 3. *Pontosphaera multipora* (Kamptner) Roth, 9,000 \times , Sample 119-737B-17R-4, 36-38 cm. 4. Coccosphere of *Reticulofenestra hesslandii* (Haq) Roth, 3,500 \times , Sample 119-737B-10R-3, 45-47 cm. 5-9. *Cyclicargolithus floridanus* (Roth and Hay) Bukry; (5) coccosphere, 5,000 \times , Sample 119-737B-12R-5, 30-31 cm; (6, 7) 2,700 \times , Sample 119-744A-8H-1, 75-76 cm; (8) distal view, 7,000 \times , Sample 119-737B-13R-1, 43-44 cm; (9) distal view, 4,300 \times , Sample 119-737B-12R-5, 30-31 cm. 10. *Cyclicargolithus abisectus* (Müller) Wise, 2,700 \times , Sample 119-737B-15R-1, 45-47 cm. 11. *Chiasmolithus altus* Bukry and Percival, 2,700 \times , Sample 119-737B-15R-1, 45-46 cm.

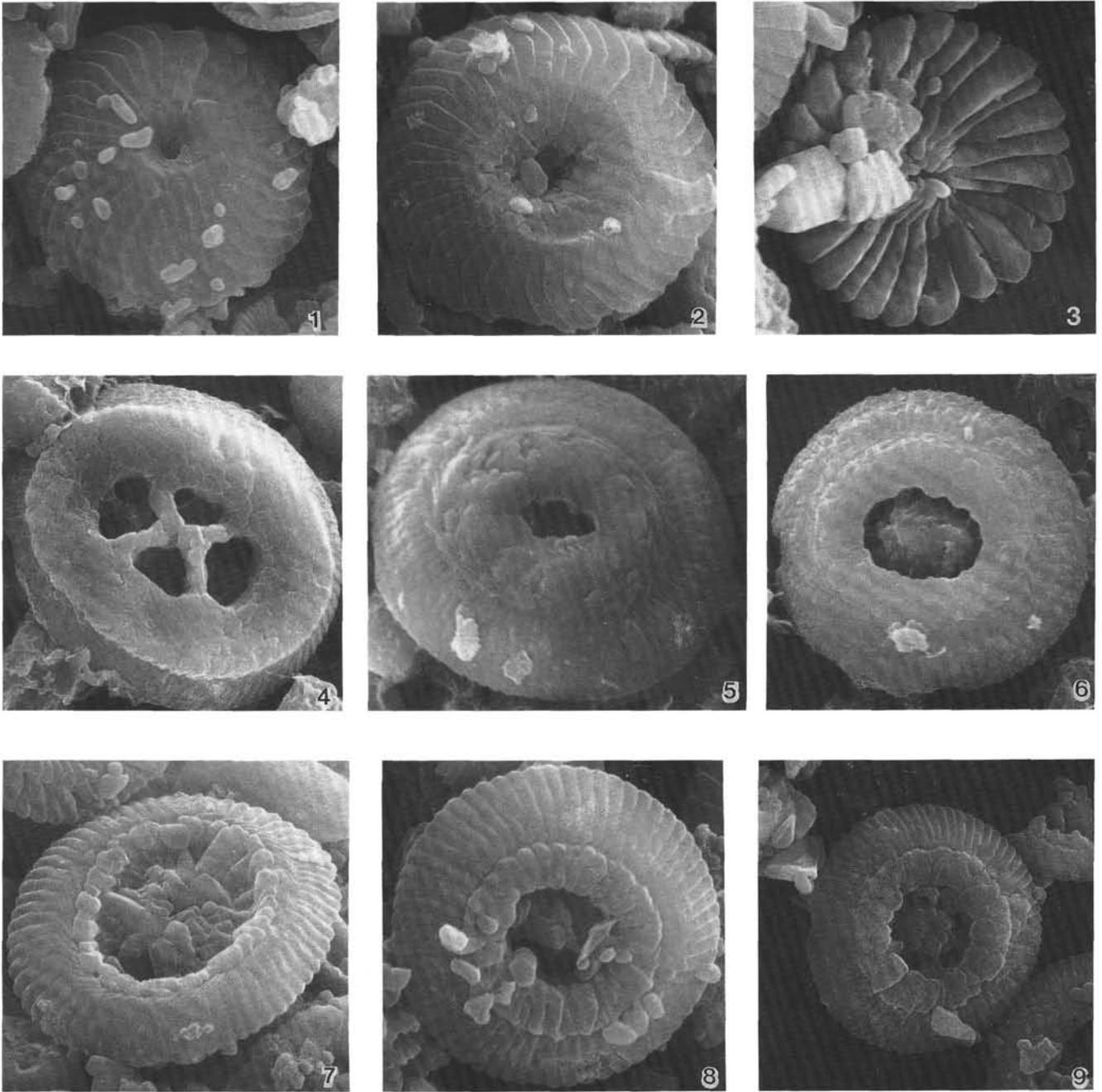


Plate 3. 1, 2. *Calcidiscus macintyreii* (Bukry and Bramlette) Loeblich and Tappan; (1) distal view, 5,500 \times , Sample 119-744B-7H-1, 110-111 cm; (2) distal view, 6,500 \times , Sample 119-744B-8H-6, 110-111 cm. 3. *Calcidiscus leptoporus* (Murray and Blackman) Loeblich and Tappan, proximal view, 7,500 \times , Sample 119-744B-8H-6, 110-111 cm. 4. *Chiasmolithus altus* Bukry and Percival, distal view, 4,300 \times , Sample 119-737B-12R-5, 30-31 cm. 5. *Reticulofenestra bisecta* (Hay, Mohler, and Wade) Roth, distal view, 4,300 \times , Sample 119-737B-12R-5, 30-31 cm. 6. *Reticulofenestra bisecta filewiczii* Wise and Wiegand, distal view, 5,500 \times , Sample 119-737B-12R-5, 30-31 cm. 7. *Reticulofenestra onusta* (Perch-Nielsen) Wise, distal view, note the wide and flat central area, 7,500 \times , Sample 119-738B-17X-1, 66-68 cm. 8, 9. *Reticulofenestra reticulata* (Gartner) Roth; (8) distal view, 6,500 \times , Sample 119-744A-20H-6, 75-76 cm; (9) distal view, 4,300 \times , Sample 119-738B-5H-7, 60-62 cm.

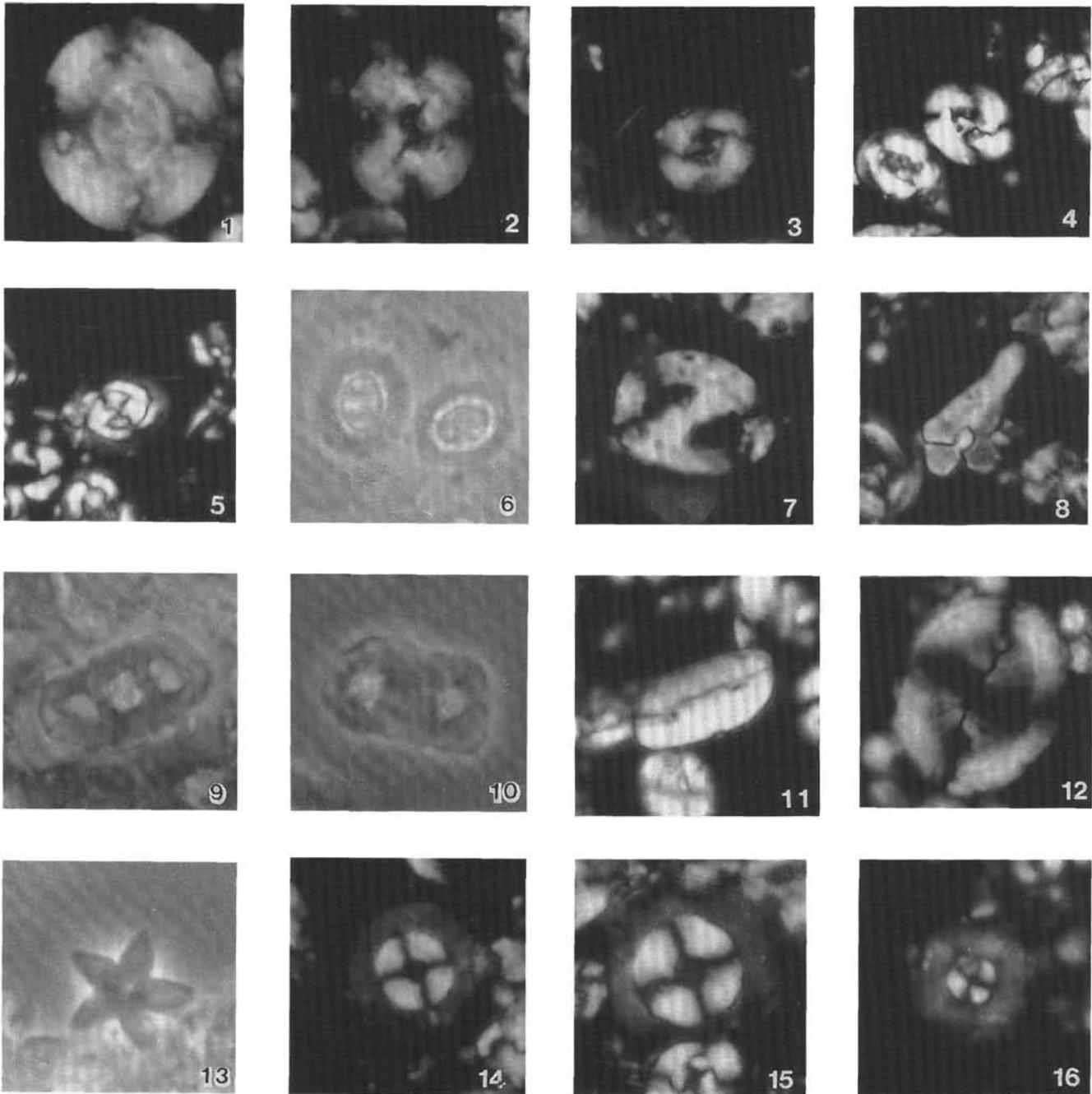


Plate 4. 1. *Reticulofenestra bisecta* (Hay, Mohler, and Wade) Roth, 2,700 \times , Sample 119-744A-13H-6, 25–26 cm. 2. *Reticulofenestra bisecta filewiczii* Wise and Wiegand, 2,700 \times , Sample 119-744A-13H-6, 25–26 cm. 3, 4. *Reticulofenestra daviesii* (Haq) Haq, 2,700 \times , Sample 119-737B-39R-5, 28–29 cm. 5, 6. *Clausicoccus fenestratus* (Deflandre and Fert) Prins, 2,700 \times , Sample 119-744A-15H-CC. 7. *Transversopontis* sp., 2,700 \times , Sample 119-737B-43R-1, 62–64 cm. 8. *Zygrhablithus bijugatus* (Deflandre) Deflandre, 2,700 \times , Sample 119-738C-24X-CC. 9–11. *Isthmolithus recurvus* Deflandre, 3,200 \times , note variation in overgrowth; (9, 10) Sample 119-737B-38R-3, 27–28 cm; (11) Sample 119-744A-16H-1, 75–76 cm. 12. *Reticulofenestra oamaruensis* (Deflandre) Stradner and Edwards, 2,300 \times , Sample 119-744A-18H-4, 75–76 cm. 13. *Discoaster* sp., 2,700 \times , Sample 119-738B-4H-5, 66–68 cm. 14, 15. *Coccolithus formosus* (Kamptner) Wise, 3,500 \times , Sample 119-737B-39R-3, 86–87 cm. 16. *Markalius inversus* (Deflandre) Bramlette and Martini, 2,700 \times , Sample 119-744A-20H-1, 75–76 cm.

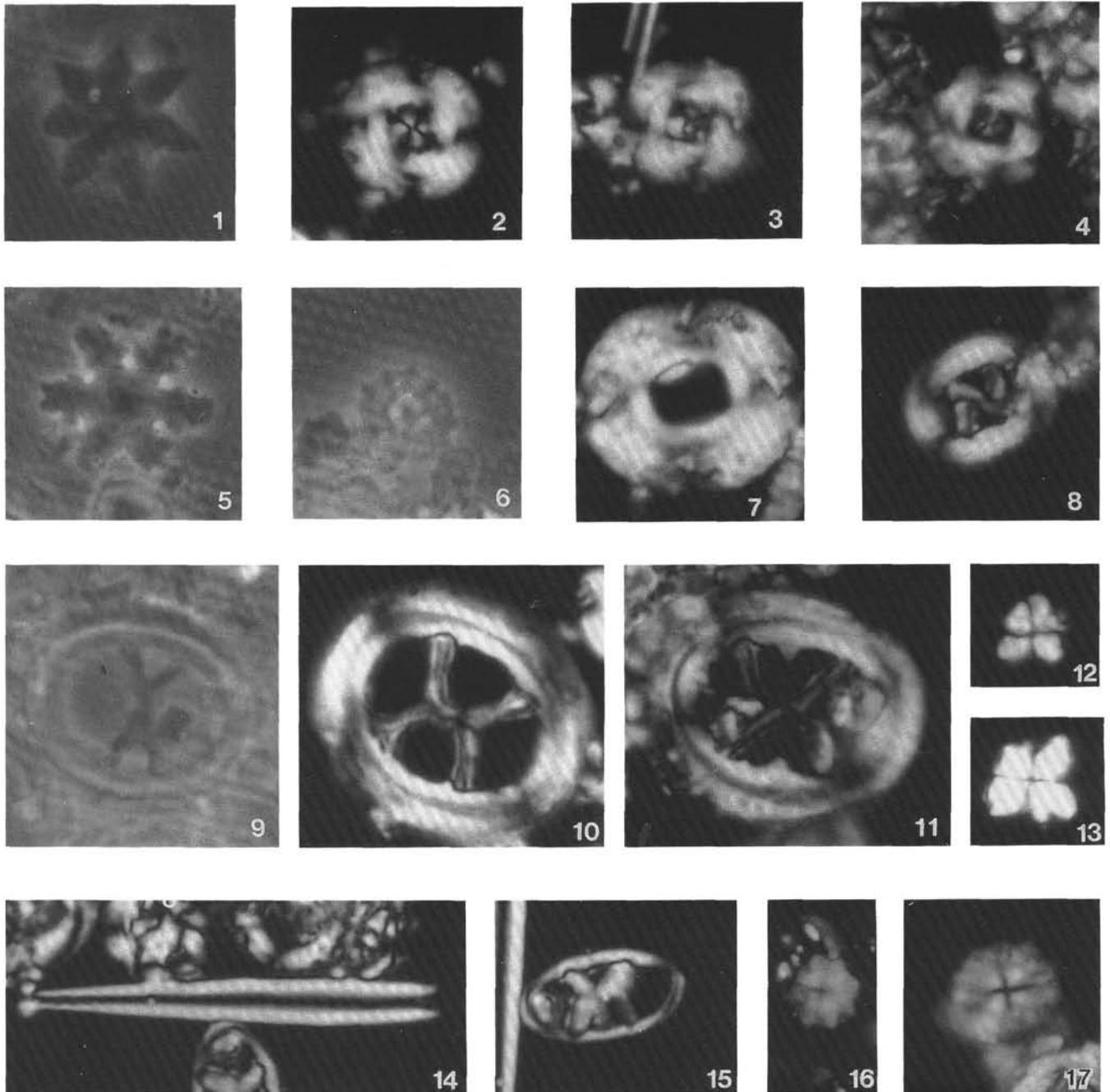


Plate 5. 1. *Discoaster saipanensis* Bramlette and Riedel, 2,300 \times , Sample 119-744A-19H-5, 75-76 cm. 2-4. *Reticulofenestra reticulata* (Gartner) Roth, 2,300 \times , Sample 119-744A-20H-4, 75-76 cm. 5. *Discoaster* sp., 2,300 \times , Sample 119-737B-48R-2, 22-23 cm. 6. *Discoaster bifax* Bukry, 2,100 \times , Sample 119-737B-52R-CC. 7. *Reticulofenestra umbilica* (Levin) Martini and Ritzkowski, 2,300 \times , Sample 119-738B-12H-3, 66-68 cm. 8. *Chiasmolithus solitus* (Bramlette and Sullivan) Locker, 2,700 \times . 9. *Chiasmolithus oamaruensis* (Deflandre) Hay, Mohler, and Wade, 2,700 \times , Sample 119-744A-16H-1, 75-76 cm. 10. *Chiasmolithus expansus* (Bramlette and Sullivan) Gartner, 2,100 \times , Sample 119-738B-15X-4, 66-68 cm. 11. *Chiasmolithus grandis* (Bramlette and Riedel) Gartner, 2,700 \times , Sample 119-738B-23X-CC. 12, 13. *Sphenolithus moriformis* (Brönnimann and Stradner) Bramlette and Wilcoxon, 2,300 \times , Sample 119-738B-5H-7, 60-62 cm. 14. *Rhabdosphaera perlongus* Deflandre, 2,700 \times , Sample 119-738B-21X-2, 66-68 cm. 15. *Neococcolithes dubius* (Deflandre) Black, 2,700 \times , Sample 119-738B-21X-2, 66-68 cm. 16, 17. *Discoaster kuepperi* Stradner, Sample 119-738C-6R-1, 66-67 cm. (16) 2,100 \times (17) 2,700 \times .

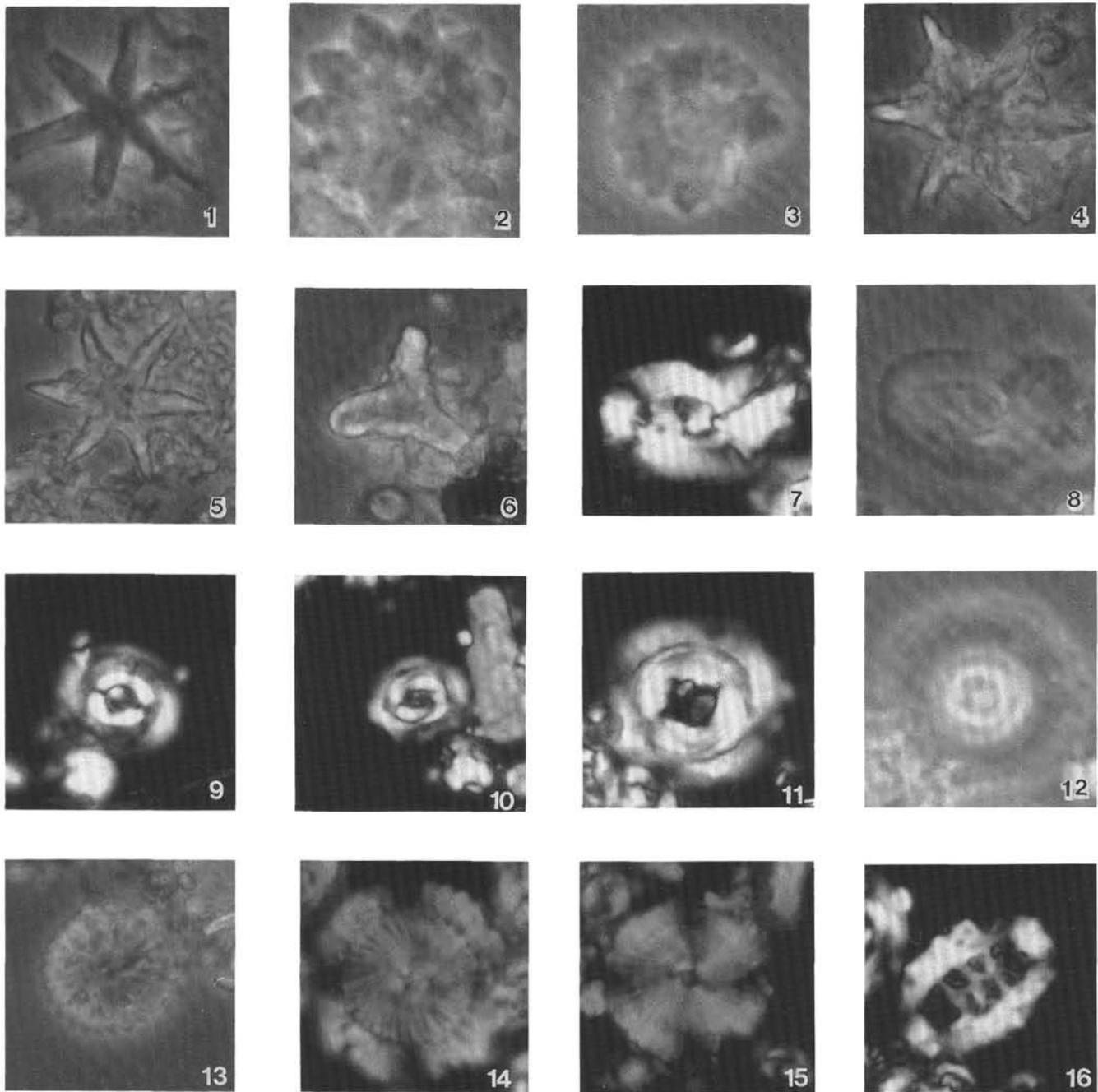


Plate 6. 1. *Discoaster* sp. 2,700 \times , Sample 119-737B-46R-1, 1-2 cm. 2, 3. *Discoaster barbadiensis* Tan, Sample 119-737B-52R-CC; (2) 2,700 \times ; (3) 2,500 \times . 4, 5. *Discoaster lodoensis* Bramlette and Riedel, 1,900 \times , Sample 119-738C-5R-1, 69-70 cm. 6. *Tibrachiatus orthostylus* Shamrai, 2,700 \times , Sample 119-738C-10R-1, 66-68 cm. 7, 8. *Helicosphaera* sp., 2,300 \times , Sample 119-738B-10H-2, 66-68 cm. 9, 10. *Toweius callosus* Perch-Nielsen, 2,300 \times ; (9) Sample 119-738C-5R-2, 69-70 cm; (10) Sample 119-738C-11R-1, 90-91 cm. 11, 12. *Toweius magnicrassus* (Bukry) Romein, 2,300 \times , Sample 119-738B-24X-3, 66-67 cm. 13. *Discoaster multiradiatus* Bramlette and Riedel, 1,400 \times , Sample 119-738C-11R-11, 90-91 cm. 14-15. *Heliolithus kleinpellii* Sullivan, 2,300 \times , Sample 119-738C-15R-CC. 16. *Ellipsolithus distichus* (Bramlette and Sullivan, 2,700 \times , Sample 119-738C-2R-2, 22-23 cm.