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28. OLIGOCENE-PLEISTOCENE CALCAREOUS NANNOFOSSILS FROM SOUTHERN OCEAN SITES 747, 748, AND 751[1]

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ABSTRACT

Detailed calcareous nannofossil range charts for the Oligocene-Pleistocene sections from high-latitude Ocean Drilling Program Sites 747, 748, and 751 in the southern Indian Ocean are presented in this report. Calcareous nannofossils are generally low in abundance in Pliocene-Pleistocene sediments, whereas they are very abundant throughout the Miocene and Oligocene. Species diversity, however, is low compared with assemblages in the lower latitudes. Nannofossil reworking is extensive in the middle Miocene at Site 751, less extensive in the lower Miocene at Site 748, and negligible for the entire Neogene at Site 747. Six nannofossil datums, which have previously been correlated with magnetostratigraphy in the Southern Ocean, were recognized in the upper Oligocene-Pleistocene sequence at Site 747. Three such nannofossil datums are available for the Neogene at Sites 748 and 751. A new subspecies, *Coccolithus pelagicus floralis*, is described.

INTRODUCTION

Neogene calcareous nannofossils were recovered only at three sites (747, 748, and 751) from Ocean Drilling Program (ODP) Leg 120 (Fig. 1). However, these assemblages provide an important bridge between those sampled between 50° and 52°S during ODP Legs 114 and 119, and those from 63° and 65°S recovered during Legs 113 and 119 (Ciesielski, Kristoffersen, et al., 1988; Barron, Larsen, et al., 1989; Barker, Kennett, et al., 1988). As such, the Leg 120 sites provide a unique sequence of transitional sites across which changes in the diversity and composition of nannofossil assemblages can be traced in reference to latitude.

Located well south of the present-day Polar Front, the Leg 120 sites studied lie at fairly shallow depths (water depths range from 1298 to 1634 m), and primarily for this reason Leg 120 succesfully recovered for the first time long sequences of Pliocene-Pleistocene carbonate sediments at these high latitudes (Schlich, Wise, et al., 1989). Among the 11 sites drilled on the Kerguelen Plateau during Legs 119 and 120, Hole 751A was a dedicated Neogene site chosen specifically to yield an expanded carbonate-rich section, at least for the Miocene. The expected high sedimentation rates would provide the basis for a high-resolution biostratigraphy, magnetostratigraphy, and chemostratigraphy of these high-latitude sites.

This report provides a description of the distribution of the Neogene nannofossil assemblages recovered at Sites 747, 748, and 751. Extensive Neogene sediments were recovered in only one hole at each site. The range chart for Hole 747A was extended down into the upper Oligocene to link up with the distribution chart for Paleogene assemblages (Aubry, this volume) for that site. Additional discussion and interpretation of the Neogene nannofossil assemblages, key datums, and their correlations with magnetostratigraphy at theses sites as well as at other Southern Ocean sites are given in Wei and Wise (this volume) and in Harwood et al. (this volume). Leg 120 Paleogene nannofossil assemblages are discussed by Aubry (this volume) and Wei et al. (this volume).

MATERIALS AND METHODS

Smear slides were made directly from unprocessed samples and were routinely examined using a light microscope at magnifications of either ×650 or ×1330 (for the identification of small coccoliths such as *Emiliania huxleyi* in the latter case). At the lower magnification, the abundance of calcareous nannofossils in each slide was estimated using the following criteria: V = very abundant (more than 10 specimens per field of view); A = abundant (1–10 specimens per field of view; C = common (1 specimen per 2–10 fields of view); F = few (1 specimen per 11–50 fields of view); R = rare (1 specimen per 51–200 fields of view); and B = barren (no specimen was found in 200 fields of view). Preservation of the calcareous nannofossil assemblage is recorded as G = good (little evidence of etching or overgrowth); M = moderate (etching or overgrowth is apparent); and P = poor (there is significant etching or overgrowth and identification of some species is impaired).

Calcareous nannofossil species considered in this paper are listed in the Appendix and are arranged alphabetically by generic epithets. Bibliographic references for these taxa can be found in Loeblich and Tappan (1966, 1968, 1969, 1970a, 1970b, 1971, 1973), Heck (1979a, 1979b, 1980a, 1980b, 1981a, 1981b, 1982a, 1982b, 1983), or Steinmetz (1985a, 1985b, 1986, 1987a, 1987b, 1988a, 1988b, 1989). Stratigraphically important occurrences and selected species are illustrated in Plates 1 and 2.

The upper Oligocene is zoned using the high-latitude nannofossil zonation of Wei and Thierstein (1991). The last occurrences (LOs) of *Reticulofenestra bisecta* and *Chiasmolithus altus* used for subdivision of the upper Oligocene have previously been correlated with magnetostratigraphy (Wei and Wise, 1989, 1990) and Wei and Thierstein (1991). For reference to lower latitude stratigraphies, combined Neogene zones are tentatively indicated according to the zonation of Okada and Bukry (1980). Most of the index taxa of Okada and Bukry (1980) are absent at these high latitudes, but a few nontraditional datums are useful for stratigraphic subdivision at these sites. These nontraditional datums include the LO of

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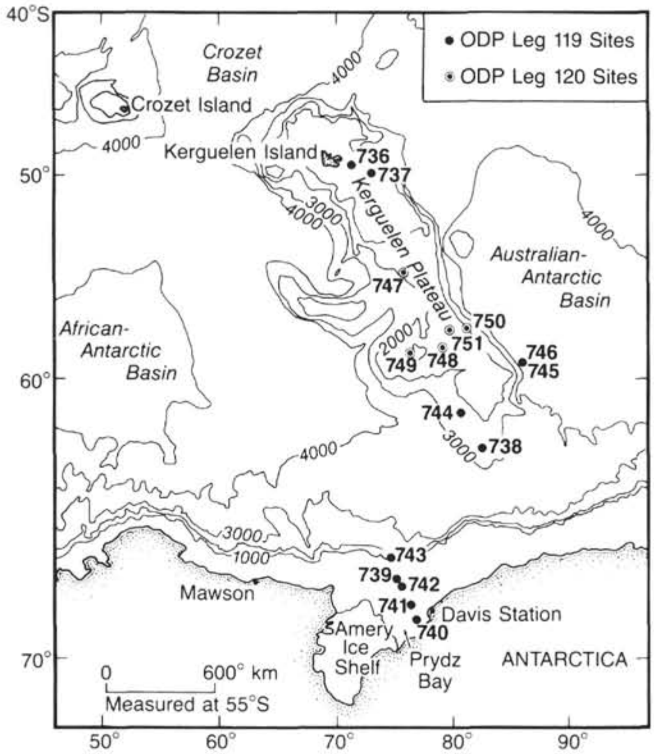


Figure 1. Location map of Leg 120 sites.

Reticulofenestra gelida, the LO of *Reticulofenestra hesslandii,* and the FO of *Calcidiscus leptoporus/C. macintyrei.*

HOLE DESCRIPTIONS

Hole 747A

Site 747 is located in the transition zone between the northern and southern parts of the Kerguelen Plateau, approximately 500 km south of the Polar Front, at 54°48.68′S, 76°47.64′E (Fig. 1) in a water depth of 1697 m. The Pliocene-Pleistocene sequence recovered consists of foraminifer diatom oozes with minor ice-rafted debris (IRD) and dropstones and sporadic vitric ash layers throughout. The Miocene to upper Oligocene section is a nannofossil ooze with some vitric ash layers.

The Oligocene-Pleistocene calcareous nannofossil distribution in Hole 747A is presented in Table 1. The abundance of calcareous nannofossils is generally low in the Pliocene-Pleistocene section, but consistently high throughout the Miocene-Oligocene section. Preservation of the nannofossils is generally moderate, with apparent overgrowth on most of the specimens. Nannofossil diversity in the sequence studied is low compared with lower latitudes. None of the *Discoaster* marker species used in the low latitudes for the subdivision of the Pliocene was found. Almost none of the traditional nannofossil datums for the Neogene are applicable because of their absence or scarcity. The biostratigraphic resolution is, therefore, quite low for the Neogene section. Nevertheless, several nannofossil datums have been identified in the Oligocene-Pleistocene sequence that provide useful data for constructing age-depth curves.

Common to abundant *Emiliania huxleyi* were found in Samples 120-747A-1H-1, 58–62 cm (Plate 1, Figs. 1 and 2) and -1H-2, 10–11 cm, but not in Sample 120-747A-1H-3, 59–62 cm, in which nannofossils are common. The first occurrence (FO) of *E. huxleyi* is, therefore, placed between Samples 120-747A-1H-2, 10–11 cm, and -1H-3, 58–62 cm. This datum defines the CN14/CN15 zonal boundary (Okada and Bukry, 1980) and has an age of 0.275 Ma (Berggren et al., 1985).

No *Gephyrocapsa* were noted within this zone, although this genus is represented in the subjacent samples. Assuming that the zonation of Gartner (1977) can be applied at this high latitude, these two samples with high abundances of *E. huxleyi* to the the virtual exclusion of other taxa would fall into Gartner's *Emiliania huxleyi* Acme Zone, which is dated roughly as 0–70,000 yr (Gartner, 1977; Thierstein et al., 1977). The true age of this zone at this high latitude, however, could be different from that at lower latutides because of the tolerance of *E. huxleyi* for lower temperatures relative to other taxa. Detailed studies are necessary to date this zone more precisely in this region, which lies at a considerably higher latitude than any of the Southern Hemisphere cores analyzed by Thierstein et al. (1977).

The last occurrence (LO) of *Reticulofenestra gelida* is between Sample 120-747A-3H-2, 58–62 cm, and -3H-3, 34–36 cm. This datum has been calibrated with magnetostratigraphy at ODP Site 744 on the Southern Kerguelen Plateau at about 3.8 Ma (Wei and Thierstein, 1991; Barron et al., 1991), very close to the age of the LO of *Reticulofenestra pseudoumbilica* (3.5 Ma; Berggren et al., 1985). This is not surprising because *R. gelida* differs from *R. pseudoumbilica* mainly in its smaller central opening, and many workers consider the former species to be a junior synonym of the latter (see detailed discussion by Backman, 1980; Wise, 1983; Perch-Nielsen, 1985). Specimens of typical *R. pseudoumbilica* were found only in the lower Miocene in this hole. The LO of *R. gelida* is used here to delimit the CN11/CN12 zonal boundary.

The LO of *Reticulofenestra hesslandii* was recognized between Samples 120-747A-7H-4, 10–11 cm, and -7H-5, 58–62 cm. This datum occurs at ~11.1 Ma, as calibrated with magnetostratigraphy at Site 744 (Wei and Thierstein, 1991; Barron et al., 1991), an age similar to that of the LO of *Cyclicargolithus floridanus* at lower latitudes (11.6 Ma; see further discussion by Wei and Wise, this volume).

The FO of *Calcidiscus leptoporus/C. macintyrei* was placed between Samples 120-747A-11H-1, 58–62 cm, and -11H-2, 10–11 cm. This datum has been correlated with magnetic Chron C5D (~18.2 Ma) at Site 744 (Wei and Thierstein, 1991; Barron et al., 1991), and is a useful datum in the southern Indian Ocean (Wei and Wise, this volume).

The LO of *Reticulofenestra bisecta* was located between Samples 120-747A-14H-4, 58–62 cm, and -14H-5, 10–12 cm. The rare higher occurrences of this species (Samples 120-747A-14H-2, 10–12 cm, and -14H-4, 10–12 cm) are considered reworked. Except in the extreme high latitudes, such as at Site 690 in the Weddell Sea, where the species is very rare or virtually absent in the upper Oligocene, the LO of *R. bisecta* can be used to mark the Oligocene/Miocene boundary in the mid to high latitudes, where it has a magnetostratigraphically calibrated age of about 24.0 Ma (Wei and Wise, 1989; Wei and Thierstein, 1991).

Very abundant *Chiasmolithus altus* were first encountered downhole in Sample 120-747A-16H-1, 10–12 cm. The overlying sample (120-747A-15H-7, 10–12 cm) contains only few specimens of *C. altus*. These and other rare occurrences in higher samples are considered reworked. The LO of *C. altus* has an estimated age of about 27.2 Ma, based on its biomagnetostratigraphic correlation at Site 744 (Wei and Thierstein, 1991; Barron et al., 1991).

No *in-situ Reticulofenestra umbilica* or *Isthmolithus recurvus* were found in the sequence examined. Core 120-747A-17H, therefore, is younger than 33.0 Ma, the age for the LO of *R. umbilica* as calibrated by magnetostratigraphy at a number of Southern Ocean sites (Wei and Wise, 1990, and unpubl. data).

The datum levels that are useful for constructing age-depth curves (Harwood et al., this volume) are summarized in Table 2. Although most of these datums are not zonal/subzonal markers in the zonations of Martini (1971) or Okada and Bukry (1980), they have proven to be useful for nannofossil biostratigraphy in the Southern Ocean. A formal zonation using these datums will be described elsewhere.

Holes 748A and 748B

Site 748 is located on the Southern Kerguelen Plateau in the western part of the Raggatt Basin, east of Banzare Bank at 58°26.45′S, 78°58.89′E (water depth = 1290 m). The site was intended to recover an expanded section of Paleogene and Cretaceous sediments; it also proved to be valuable in that it yielded a reasonably complete Pleistocene to upper Eocene section not interrupted by chert beds. Full core recovery in the upper 180 m of the section in Hole 748B provided an excellent Neogene calcareous-biosiliceous sequence with good paleomagnetic control (Inokuchi and Heider, this volume); thus, this site is especially valuable for high-latitude biostratigraphic and magnetostratigraphic correlation.

The Pliocene-Pleistocene sequence consists of diatom ooze with radiolarian and foraminifer-enriched intervals, dropstones, and IRD. The Miocene to upper Oligocene sediments are nannofossil ooze with biosiliceous enriched intervals.

Hole 748A recovered two cores before it was terminated. The first two sections are barren of calcareous nannofossils (Table 3); this indicates that the *Emiliania huxleyi* Zone (CN15) was not recovered. Rare *Reticulofenestra perplexa* were found in Sections 120-748A-1H-3 and -2H-2, along with *Coccolithus pelagicus* and rare specimens of apparently reworked Paleogene species. These occurrences of *R. perplexa* are probably reworked; otherwise, they would be the youngest (~3 Ma according to Harwood et al., this volume) ever reported in the Southern Ocean.

The LO of *Reticulofenestra gelida* was recorded in Sample 120-748A-2H-3, 90–94 cm. Very abundant *Coccolithus pelagicus* and *Reticulofenestra perplexa* were also first encountered in this sample, coincident with the lithologic boundary between siliceous and calcareous ooze.

Table 4 provides a detailed documentation of the Neogene calcareous nannofossil distribution in Hole 748B. *Reticulofenestra gelida* was first encountered in Sample 120-748B-2H-7, 58–62 cm. As the overlying samples are barren of calcareous nannnofossils, the uppermost portion of the range of *R. gelida* could have been truncated by this barren interval. The CN11/CN12 boundary is, therefore, tentatively placed between Samples 120-748B-2H-5, 58–62 cm, and -2H-7, 58–62 cm.

The highest occurrence of of *Reticulofenestra hesslandii* is between Samples 120-748B-5H-7, 10 cm, and -5H-7, 58–62 cm, and thus an age of 11.1–11.6 Ma can be assigned to Sample 120-748B-5H-7, 58–62 cm. The FO of *Reticulofenestra perplexa* is also located in this sample, where the species is abundant. Elsewhere, the ranges of *R. hesslandii* and *R. perplexa* overlap for about 2 m.y. It can be inferred that a disconformity exists in the vicinity of Sample 120-748B-5H-7, 58–62 cm. This is in agreement with the siliceous biostratigraphy and magnetostratigraphy interpretations of Harwood et al. (this volume), who placed a disconformity at the very top of Core 120-748B-6H.

The FO of *Calcidiscus leptoporus* was recognized between Samples 120-748B-6H-3, 58–62 cm, and -6H-4, 58–62 cm. This datum (as *C. macintyrei*) is used here to define the CN3/CN4 zonal boundary at about 18.2 Ma.

In-situ Paleogene calcareous nannofossils are not present until Core 120-748B-9H (Aubry, this volume). Rare specimens of reworked upper Paleogene nannofossils, such as *Chiasmolithus altus* and *Reticulofenestra umbilica,* however, occur in almost every sample from Cores 12-748B-6H through -8H. This indicates that active bottom currents persisted throughout the early Miocene at Site 748.

Table 5 summarizes the Neogene nannofossil datums recognized at Site 748. Estimated ages are also given based on their correlations with magnetostratigraphy at other Southern Ocean sites.

Hole 751A

Site 751 lies on the Southern Kerguelen Plateau at 57°43.56′S, 79°48.89′E (water depth = 1633.8 m) in the central part of the Raggatt Basin. The Pliocene-Pleistocene interval consists of diatom ooze with minor IRD, calcareous nannofossils, foraminifers, volcanic ash, and porcellanite. The Miocene sequence is diatom nannofossil ooze, but diatoms occur in equal or greater abundance than calcareous nannofossils in some stratigraphic intervals.

The calcareous nannofossil distribution in Hole 751A is presented in Table 6. Similar to Sites 747 and 748, calcareous nannofossils are generally rare or absent in the Pliocene-Pleistocene and are very abundant throughout the Miocene. Preservation of the nannofossil assemblages is moderate in this hole. Most traditional marker species are absent or too rare to be useful for biostratigraphy at this site.

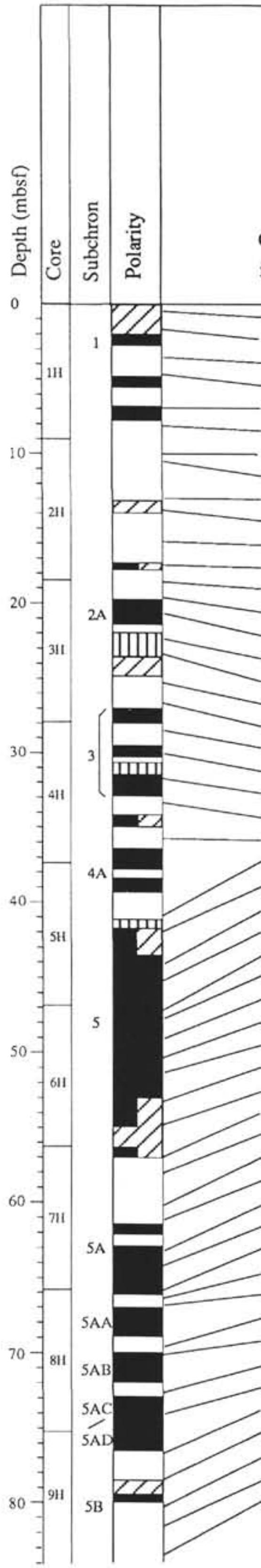
No *Emiliania huxleyi* was found in the first core. Sediments younger than Zone CN15 (0.275 Ma), therefore, were not recovered in this hole. Abundant nannofossils were first encountered in Sample 120-751A-5H-6, 5–7 cm. This sample contains *Reticulofenestra gelida* and is, therefore, older than 3.8 Ma. The LO of *Cyclicargolithus floridanus*/*Reticulofenestra hesslandii* is between Samples 120-751A-11H-6, 5–7 cm, and -11H-7, 5–7 cm. This datum is about 11.1–11.6 Ma as previously described above. The FO of *Calcidiscus leptoporus*/*C. macintyrei* was recognized between Samples 120-751A-16H-7, 2–4 cm, and -17H-1, 22–25 cm. This datum is about 18.2 Ma old and defines the CN3/CN4 zonal boundary.

In-situ Oligocene assemblages are absent in this hole, and the oldest sediment from the hole is, therefore, younger than 24.0 Ma (Oligocene/Miocene boundary). The nannofossil datums recognized in this hole that are useful for constructing age depth curves (Hardwood et al., this volume) are summarized in Table 7.

It is interesting to note that nannofossil reworking is significantly more extensive at this site than at Sites 747 and 748. Reworking is most severe in Cores 120-751A-12H to -16H, a middle Miocene interval (~11-17 Ma according to Harwood et al., this volume). This is in contrast to Site 748, where more reworking was found in the lower Miocene. All the reworked nannofossils recognized at Site 751 are Eocene-Oligocene taxa. This extensive reworking and different patterns from other Kerguelen Plateau sites have important implications for water circulation patterns and current activities, which will be discussed elsewhere.

Magnetostratigraphies have been established for all the holes examined in this study (Inokuchi and Heider, this volume; Heider et al., this volume), and are shown in Tables 1, 3, and 6 along with the distribution of calcareous nannofossils. Consequently, the nannofossil datums have been correlated with the magnetostratigraphies, and their estimated ages at Site 747, 748, and 751 are given in Table 8 using the Berggren et al. (1985) time scale. More detailed discussions and comparisons of these ages with those at other Southern Ocean sites are treated elsewhere (Wei and Wise, this volume; Harwood et al., this volume).

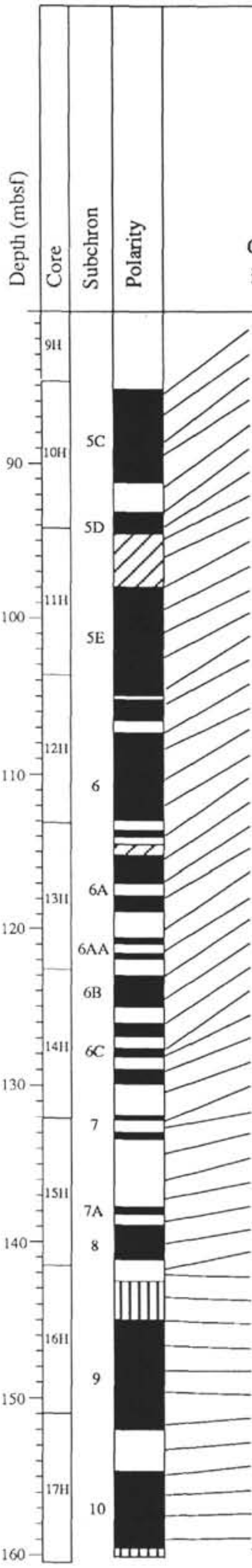
Table 1. Distribution of Oligocene-Pleistocene calcareous nannofossils in Hole 747A.



Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Bicolumnus ovatus*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Chiasmolithus altus*	*Coccolithus pelagicus*	*Coccolithus pelagicus floralis*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Discoaster* sp.	*Emiliania huxleyi*	*Gephyrocapsa oceanica*	*Gephyrocapsa* sp. (small)	*Helicosphaera carteri*	*Helicosphaera* sp.	*Pseudoemiliania lacunosa*	*Reticulofenestra bisecta*	*Reticulofenestra daviesii*	*Reticulofenestra gelida*	*Reticulofenestra hesslandii*	*Reticulofenestra perplexa*	*Reticulofenestra* cf. *producta*	*Reticulofenestra pseudoumbilica*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilica*	*Sphenolithus conicus*	*Sphenolithus moriformis*	*Triquetrorhabdulus carinatus*	*Zygrhablithus bijugatus*	Nannofossil zones of Okada and Bukry (1980)	Age
1H-1, 58-62	0.58	A	G		R								A			R																CN15	
1H-2, 10-11	1.60	C	G				r	R					C																				
1H-3, 58-62	3.58	C	G		R			R							C																		
1H-4, 10-11	4.60	V	G											A	A																		
1H-5, 84-88	6.84	F	G		R										F																	CN14	
1H-6, 56-62	8.08	R	M												R																		
2H-1, 115-119	10.15	R	M					R							R																		
2H-2, 10-14	10.60	B																															
2H-3, 67-71	12.67	C	M				r	C							R																		Pliocene - Pleistocene
2H-4, 10-11	13.60	R	G					R																									
2H-5, 58-62	15.58	A	M					A							R																	CN12	
2H-6, 58-62	17.08	R	G												R																		
2H-7, 58-62	18.58	A	G					A																									
3H-1, 111-114	19.61	V	M					V			r							R															
3H-2, 58-62	20.58	F	M					F			r				F																		
3H-3, 34-36	22.08	A	M		R			A			r										R		R	A									
3H-4, 10-11	23.10	V	M					A													R		R	V									
3H-5, 58-62	25.08	A	M					A									R				R		F										
3H-6, 50-54	26.50	V	M					A													R		F										
4H-1, 58-62	28.58	V	M					V													F		C										
4H-2, 58-62	30.08	V	M		R		r	A													V		R										
4H-3, 58-62	31.58	V	M					A													F		F										
4H-4, 58-62	33.08	V	M					V													A		R									CN11	
4H-5, 58-62	35.58	V	G					A													V		C										
5H-3, 58-62	41.08	V	M					A													F		V										
5H-4, 10-11	42.10	V	M					V													C		V										
5H-5, 58-62	44.08	V	M					V													A		V										
5H-6, 10-11	45.10	V	M					V													C		V										
5H-7, 58-62	47.08	V	M		R	R		F													C		V										
6H-1, 58-62	47.58	V	M					V													V		R										
6H-2, 58-62	49.08	V	M		C	C		V													V		C										
6H-3, 58-62	50.58	V	M			R		A													V		C										
6H-4, 10-11	51.60	V	M		F	F		A													V		A										
6H-5, 58-62	53.08	V	M		F	F		C													F		V										
6H-6, 58-62	54.58	V	M		R	R		C													F		V										
7H-1, 58-62	57.08	V	M		F	F		F													A		V										
7H-2, 15-16	58.15	V	M		F	F		F													A		V										Miocene
7H-3, 58-62	60.08	V	M		R	R		V															V										
7H-4, 10-11	61.15	V	M		R	R		A															V										
7H-5, 58-62	63.08	V	M		R	R		C													F	V	F										
7H-6, 58-62	64.15	V	M		C	R		C													V	A	F										
7H-7, 58-62	66.08	V	M					F													A	A	A										
8H-1, 58-62	66.58	V	M		R			V													A	V	A										
8H-2, 10-11	67.60	V	M		A	C	r	V													A	F											
8H-3, 58-67	69.58	V	M					V													A	R											
8H-4, 10-11	70.60	V	M		R			V																									
8H-5, 58-62	72.58	V	M		A			V		A	V	F																					
8H-6, 56-62	74.08	V	M		F	R		V		A	A	R					R					C											
9H-2, 58-62	77.56	V	M		F	R	r	V		A	A											V											
9H-3, 10-11	78.60	V	M			R		A		A												V										CN4	
9H-4, 58-62	80.56	V	M		R	R		A		C												V											
9H-5, 10-11	81.60	V	M		R			A		C												V											
9H-6, 58-62	83.56	V	M		R			V		A	A											C						R				

Notes: The high-latitude zonation of Wei and Thierstein (1991) is used for the upper Oligocene, and the zonation of Okada and Bukry (1980) is used for the Neogene. The abundance of calcareous nannofossils is characterized by V = very abundant, A = abundant, C = common, F = few, R = rare, r = rare reworked specimens, and f = few reworked specimens. For preservation, G = good, M = moderate, and P = poor. Paleomagnetic data are taken from Heider et al. (this volume). Normal paleomagnetic subchrons are shown in black and reversed ones in white (those less reliable ones are shown in half columns). Data gaps are indicated by vertical lines and uninterpretable data by diagonal lines.

Table 1 (continued).



Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Bicolumnus ovatus*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Chiasmolithus altus*	*Coccolithus pelagicus*	*Coccolithus pelagicus floralis*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Discoaster* sp.	*Emiliania huxleyi*	*Gephyrocapsa oceanica*	*Gephyrocapsa* sp. (small)	*Helicosphaera carteri*	*Helicosphaera* sp.	*Pseudoemiliania lacunosa*	*Reticulofenestra bisecta*	*Reticulofenestra daviesii*	*Reticulofenestra gelida*	*Reticulofenestra hesslandii*	*Reticulofenestra perplexa*	*Reticulofenestra* cf. *producta*	*Reticulofenestra pseudoumbilica*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilica*	*Sphenolithus conicus*	*Sphenolithus moriformis*	*Triquetrorhabdulus carinatus*	*Zygrhablithus bijugatus*	Nannofossil zones	Age
10H-1, 58-62	85.58	V	M		F	R		V		A	A	F										C											
10H-2, 58-62	87.08	V	M			R		V		A	A	F					R					A											
10H-3, 58-62	88.58	V	M		A	F		A		C												V											
10H-4, 10-11	89.60	V	M		C	R		A		C												V											
10H-5, 58-62	91.58	V	M		C			A														V			R								
10H-6, 58-62	93.08	V	M		R	R		A														V										CN4	
10H-7, 20-24	94.20	V	M		C			A														V			F								
11H-1, 58-62	95.08	V	M		R		r	A		A	C	R									F	V			F								
11H-2, 10-11	96.10	V	M					A		A	C	R									C	V			C								
11H-3, 62-64	98.12	V	M					V		C	A	F									F	V							R				
11H-4, 10-11	99.60	V	M					A		A	A										F	V							R				
11H-5, 63-67	101.13	V	M					A				R					R				F	V							R				
11H-6, 63-67	102.63	V	M					V													C	V							F				
12H-1, 60-64	104.60	V	M					V				C					R				C	C			A				F			CN3	
12H-2, 10-11	105.60	V	M					V				C									A	C			A				R				
12H-3, 62-66	107.62	V	M					A													A	V			R								Miocene
12H-4, 10-11	108.60	V	M					A				R									C	V			F								
12H-5, 58-62	110.58	V	M					C				R									C	V			C								
12H-6, 58-62	112.08	V	M					V			C	R										V					r						
13H-1, 58-62	114.08	V	M				r	V			C											V							R				
13H-2, 58-62	115.58	V	M					V														A											
13H-3, 58-62	117.08	V	M				r	V		R							R					V											
13H-4, 10-11	118.00	V	M					A		A																							
13H-5, 58-62	120.08	V	M				r	V		A	A																						
13H-6, 58-62	121.58	V	M					A		A	V																					CN1	
14H-1, 10-12	123.10	V	M				r	A		A	V																r						
14H-2, 10-12	124.60	V	M	F			r	V	V	A	V								r	F									R				
14H-3, 10-12	126.10	V	M				r	V			C									C							r		R				
14H-4, 10-12	127.60	V	M				r	V		F	F								r	A													
14H-4, 58-62	128.08	V	M					V		A	V									C													
14H-5, 10-12	129.10	V	M				r	A		A	V								C	F									F				
14H-6, 10-12	130.60	V	M					V		C	V	F							C	F									F				
14H-7, 10-12	132.10	V	M					V		C	V	R							C	R							r		F		R		
15H-1, 10-12	132.60	V	M				r	A		F	V								C	R													
15H-2, 10-12	134.10	V	M				r	A		R	V								F	R								R	R			*Reticulofenestra bisecta*	
15H-3, 10-12	135.60	V	M					A		F	V								F	R									R		R		
15H-4, 10-12	137.10	V	M					A		F	V								F										R	R	R		
15H-5, 10-12	138.60	V	M	R				V		F	V								C	F											F		
15H-6, 10-12	140.10	V	M				r	V			V								C	C							r		R				
15H-7, 10-12	141.60	V	M	R			f	A		R	A						R		A	A													
16H-1, 10-12	142.10	V	M				V	C		A	V								F	R													
16H-2, 10-12	143.60	V	M				V	C		F	V								F	R													
16H-3, 10-12	145.10	V	M				V	C		C	V								C	R													late Oligocene
16H-5, 10-12	146.60	V	M	R			V	A		C	V								C	C													
16H-6, 10-12	148.10	V	M				V	C		V	V								A	F											C		
16H-7, 10-12	149.60	V	M				V	C			V	F								R										R			
17H-1, 10-12	151.60	V	M				V	C		C	A								A	V									R				
17H-2, 10-12	153.10	V	M				V	A		R	C								R	V							r		R		R	*Chiasmolithus altus*	
17H-3, 10-12	154.60	V	M				V	A			C								C	V													
17H-4, 10-12	156.10	V	M				V	V		C	C								C	A						R			R		F		
17H-5, 10-12	157.60	V	M				V	V		F	F								A	V									R		F		
17H-6, 10-12	159.10	V	M				V	A		R	F								A	V													

Table 2. Calcareous nannofossil datum levels in Hole 747A and their estimated ages.

Species event	Core, section, interval (cm)	Depth (mbsf)	Age (Ma)	Source
FO *Emiliania huxleyi*	1H-2, 10/1H-3, 58	1.60–3.58	0.275	1
LO *Reticulofenestra gelida*	3H-2, 58/3H-3, 34	20.58–22.08	3.8	2
LO *Reticulofenestra hesslandii*	7H-4, 10/7H-5, 58	61.15–63.08	11.1	2
FO *Calcidiscus leptoporus*	11H-1, 58/11H-2, 58	95.08–96.10	18.2	2
LO *Reticulofenestra bisecta*	14H-4, 10/14H-5, 10	128.08–129.10	24.0	3
LO *Chiasmolithus altus*	15H-7, 10/16H-1, 10	141.60–142.10	27.2	2

Notes: 1 = Berggren et al. (1985); 2 = Wei and Thierstein (1991) and Barron et al. (1991); 3 = Wei and Wise (1989).

SUMMARY AND CONCLUSIONS

This report provides detailed calcareous nannofossil range charts for the Oligocene-Pleistocene sections from Sites 747, 748, and 751 on the Kerguelen Plateau in the southern Indian Ocean. Six nannofossil datums that have previously been correlated with magnetostratigraphy in the Southern Ocean are recognized in the upper Oligocene-Pleistocene sequence at Site 747. Three such nannofossil datums are available for the Neogene at Sites 748 and 751. These nannofossil datums provide useful age constraints for some stratigraphic intervals.

Calcareous nannofossils are generally low in abundance in the Pliocene-Pleistocene sediments, but very abundant throughout the Miocene and Oligocene. This indicates that surface-water temperatures during the Oligocene and Miocene were significantly higher than at present on the Kerguelen Plateau. Temperatures dropped below the tolerance levels of calcareous nannoplankton for much of Pliocene-Pleistocene time, when the Polar Front became established north of the study area. The presence of the uppermost Quaternary nannofossil marker species *Emiliania huxleyi* at Site 747 suggests that temperatures recovered sufficiently at some point during the last 70,000 yr to allow this coccolith to thrive in this portion of the Southern Ocean. This rather recently evolved taxon is thought to have the widest temperature tolerance of all extant forms. In the Pacific Ocean, its distribution is bounded poleward by the summer position of the 0°C surface-water isotherm (McIntyre et al., 1970).

Nannofossil reworking has been documented semiquantitatively. Reworking is quite extensive in the middle Miocene at Site 751, less extensive in the lower Miocene at Site 748, and negligible for the entire Neogene at Site 747. All reworked nannofossils recognized are of Eocene-Oligocene age. The different extent and patterns of reworking at different sites have important implications for water circulation patterns and current activities, a subject for future research.

Table 3. Distribution of Miocene-Pleistocene calcareous nannofossils in Hole 748A.

Age	Nannofossil zones of Okada and Bukry (1980)	Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Calcidiscus leptoporus*	*Coccolithus pelagicus*	*Reticulofenestra gelida*	*Reticulofenestra perplexa*	*Reticulofenestra producta*	*Chiasmolithus altus*	*Coccolithus formosus*	*Reticulofenestra umbilica*
Pliocene — Pleistocene	CN14	1H-1, 100-104	1.00	B									
		1H-1, 133-137	1.33	B									
		1H-2, 10-11	1.60	B									
		1H-2, 23-27	1.73	B									
		1H-2, 95-99	2.45	B									
		1H-3, 11-14	3.11	R	M		R						
		1H-3, 49-53	3.49	C	M		C		r				
		1H-3, 80-84	3.80	R	M		F		r		r	r	r
		1H-3, 95-99	3.95	R	M		R						
		1H-4, 10-11	4.60	B									
		1H-4, 29-33	4.79	B									
	CN12	1H-7, 80-84	9.50	B									
		2H-2, 10-11	11.80	R	M		R		r		r		r
		2H-2, 105-109	12.05	R	M		R		r		r		
		2H-3, 90-94	13.40	V	M	R	V	F	V	A	r		
	CN11	2H-3, 130-134	13.80	V	M		V	F	A	A	r		r
		2H-4, 10-11	14.10	V	M		V		A	C	r		

Notes: Nannofossil zones are given according to the zonation of Okada and Bukry (1980). The abundance of calcareous nannofossils is characterized by V = very abundant, A = abundant, C = common, F = few, R = rare, and r = rare reworked specimens. For preservation, M = moderate.

SYSTEMATIC PALEONTOLOGY

Genus COCCOLITHUS Schwarz, 1894

Coccolithus pelagicus (Wallich) Schiller, 1930

Coccolithus pelagicus floralis Wei and Wise, n. ssp.

Plate 2, Figures 5–8

Coccolithus pelagicus (Wallich) Schiller, Wei and Wise, 1990, p. 662, pl. 2, figs. 8 and 9.

Diagnosis. A subspecies of *Coccolithus pelagicus* with a calyx or crown or elements on the distal side that appears to project from the inner wall area. The calyx rises well above the distal shield to form what would otherwise be considered a third shield.

Description. This is an elliptical, medium-size coccolith in which the elements of the calyx number about 30 and correspond closely if not exactly to those of the proximal and distal shields. In the lateral view (Plate 2, Fig. 7), the height of the calyx may be equal to that of the proximal and distal shields combined. The width of the calyx is variable, but it may equal that of the proximal shield in some specimens (e.g., Plate 2, Fig. 7).

Under crossed nicols, the distal shield is at extinction in plan view, whereas the proximal shield is birefringent. Specimens show a high-order yellow interference color in lateral view.

Remarks. Morphologically, this taxon superficially resembles some Paleogene heliolithids; however, the extinction pattern is that of *Coccolithus*. The specimens illustrated show some overgrowth, as do most specimens in the samples studied. It is possible that the calyx is strictly the product of overgrowth of the inner wall elements. However, the calyx rises to a uniform height and at a different angle from that of the inner wall elements, which would be remarkable if these were simply overgrowths. We think that if these specimens have been diagenetically altered, then the overgrowths must be rooted in a distinctively genetic morphologic feature, however obscure it may be. *Coccolithus pelagicus* has a long stratigraphic range (Paleocene to Holocene according to Bukry, 1973). The fact that the subspecies has been observed only from the lower-middle Miocene of Holes 329, 690B, 747A, 748B, and 751A within otherwise uniform lithologies indicates that this morphology is not merely the result of random

Table 4. Distribution of Miocene-Pleistocene calcareous nannofossils in Hole 748B.

Core	Subchron	Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pelagicus*	*Coccolithus pelagicus floralis*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Discoaster* sp.	*Helicosphaera* sp.	*Reticulofenestra daviesii*	*Reticulofenestra gelida*	*Reticulofenestra hesslandii*	*Reticulofenestra perplexa*	*Reticulofenestra producta*	*Reticulofenestra pseudoumbilica*	*Sphenolithus moriformis*	*Chiasmolithus altus*	*Chiasmolithus oamaruensis*	*Isthmolithus recurvus*	*Reticulofenestra bisecta*	*Reticulofenestra reticulata*	*Reticulofenestra samodurovi*	*Reticulofenestra umbilica*	*Zygrhablithus bijugatus*	Nannofossil zones of Okada and Bukry (1980)	Age
	1	2H-1, 26-30	0.36	B																									CN14	Pliocene–Pleistocene
		2H-2, 10-11	1.70	B																										
		2H-3, 5-9	3.15	R	M			R													r									
2H	2A	2H-4, 10-11	4.70	B																										
		2H-5, 58-62	6.68	B																									CN12	
		2H-7, 58-62	9.50	C	M			C							F		F				r						r		CN11	
		3H-1, 129-131	10.89	V	M			V							F		V				r						r			
		3H-2, 10-11	11.20	V	M			V							R		A				r				r					
		3H-3, 58-62	13.18	V	M			V							F		A				r				r					
3H		3H-4, 10-11	14.20	V	M			F							A		V	V												
	3A	3H-5, 58-62	16.18	V	M			V							C		A	V												
		3H-6, 58-62	17.68	V	M			A							F		V	C												
		3H-7, 58-62	19.10	V	M			V							C		A	F												
	4	4H-1, 58-62	19.68	V	M			V							C		A	V			r						r			
		4H-2, 58-62	21.18	V	M			C							C		V	V			r						r			
		4H-3, 58-62	22.68	V	M	F	R	F									V	V												
4H	4A	4H-4, 58-62	24.18	V	M			F									V	V												
		4H-5, 58-62	25.68	V	M		R	R							R		V	V												
		4H-6, 58-62	27.18	V	M	R	R	R							R		V	V												
		5H-1, 58-62	29.18	V	M	R	F	F							R		V	V												
		5H-2, 58-62	30.68	V	M	F	F	F							R		V	V			r									
		5H-3, 58-62	32.18	V	M	R	F	R									V	A												
5H		5H-5, 58-62	35.18	V	M			C									V	V												Miocene
		5H-6, 58-62	36.68	V	M	R	R	F									V	V												
		5H-7, 10-11	37.62	V	M			F							C		V	V												
	5A	5H-7, 58-62	38.10	V	M			F							A	A	A	A												
		6H-1, 58-62	38.68	V	M	F		V							A	V					r									
	5D	6H-2, 58-62	40.18	V	M	F		V		F					C	V													CN4	
		6H-3, 58-62	41.68	V	M	R		V							V	F					f									
6H		6H-4, 58-62	43.18	V	M			V		V		R	R		F	A											r			
		6H-5, 58-62	44.68	V	M			V		C		R			A	A														
		6H-6, 58-62	46.18	V	M			V		F	F				A	A			R	R	r	r								
	5E	7H-1, 58-62	48.18	V	M			V		R	R	R			V	C					r						r		CN3	
		7H-2, 58-62	49.68	V	M			V				R			A	A					r			r						
		7H-3, 58-62	51.18	V	M			V	F			R			A	V				R	r						r			
7H	6	7H-4, 58-62	52.68	V	M			V				R			A	V			F		r						r			
		7H-5, 58-62	54.18	V	M			A							A	V														
		7H-6, 58-62	55.68	V	M			A							A	V					r				r		r			
	6A	8H-1, 58-62	57.68	V	M			V								F					r						r			
		8H-2, 58-62	59.18	V	M			V	R	R	C																			
		8H-3, 58-62	60.68	V	M			V						V							r		r							
8H	6AA	8H-4, 10-11	61.70	V	M			V			F			V							r								CN1	
		8H-5, 58-62	63.68	V	M			V			V			A							f	r		f		f				
	6B	8H-6, 58-62	65.18	V	M			A			V			C							r			r		f	f	r		
	6C	8H-7, 58-62	66.65	V	M			A			V			F						R	r			r		r	r			

Notes: Nannofossil zones are given according to the zonation of Okada and Bukry (1980). Dashed lines indicate tentative zonal boundaries. Wavy lines denote disconformity. The abundance of calcareous nannofossils is characterized by V = very abundant, A = abundant, C = common, F = few, R = rare, r = rare reworked specimens, and f = few reworked specimens. For preservation, M = moderate and P = poor. Paleomagnetic data are taken from Heider et al. (this volume). Normal paleomagnetic subchrons are shown in black, and reversed ones in white (those less reliable ones are shown in half columns). Data gaps are indicated by vertical lines and uninterpretable data by diagonal lines.

Table 5. Neogene calcareous nannofossil datum levels in Hole 748B and their estimated ages.

Species event	Core, section, interval (cm)	Depth (mbsf)	Age (Ma)	Source
LO *Reticulofenestra gelida*	2H-5, 58/2H-7, 58	6.08–9.50	3.8	1
LO *Reticulofenestra hesslandii*	5H-7, 10/5H-7, 58	37.62–38.10	11.1	1
FO *Calcidiscus leptoporus*	6H-3, 58/6H-4, 58	41.68–43.18	18.2	1

Notes: 1 = Wei and Thierstein (1991) and Barron et al. (1991).

overgrowth. It has only been observed in sediments from the Southern Ocean.

Occurrence. Very abundant in Sample 120-747A-14H-2, 10–12 cm (lower Miocene). It has been figured by Wei and Wise (1990, plate 2, figs. 8 and 9) under *Coccolithus pelagicus* for sediments from the middle Miocene at Sites 329 (Falkland Plateau) and 690 (Maud Rise). It was also found in the lower Miocene at Site 748 and in the middle Miocene at Site 751.

Size. Holotype: 6 μm; isotypes: 6–8.5 μm.

Holotype. Plate 2, Figure 7.

Isotypes. Plate 2, Figures 5, 6, and 8.

Type locality. Sample 120-747A-14H-2, 10–12 cm.

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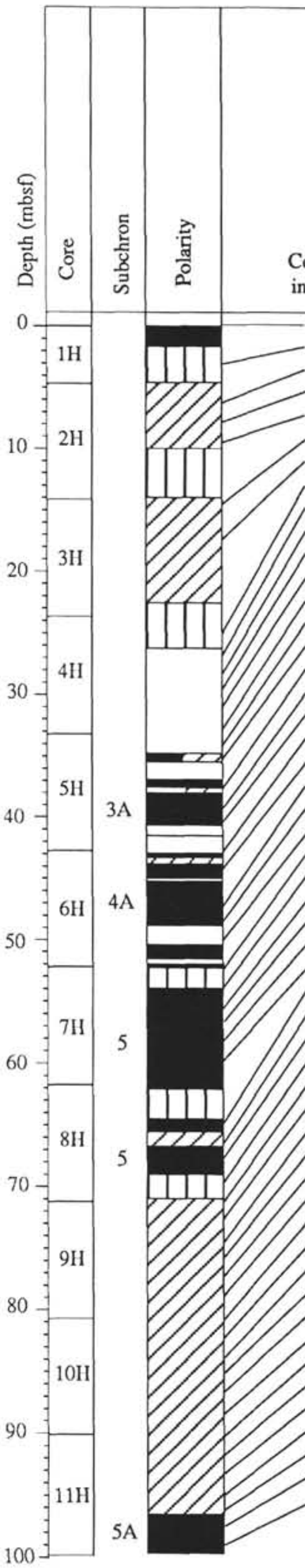
APPENDIX

Calcareous Nannofossils Considered in This Paper in Alphabetical Order of Generic Epithets. Plate and figure numbers refer to illustrations in this paper.

Bicolumnus ovatus Wei and Wise, 1990
Calcidiscus leptoporus (Murray and Blackman) Loeblich and Tappan, 1978
Calcidiscus macintyrei (Bukry and Bramlette) Loeblich and Tappan, 1978
Chiasmolithus altus Bukry and Percival, 1971.
Chiasmolithus oamaruensis (Deflandre) Hay, Mohler and Wade, 1966
Chiasmolithus solitus (Bramlette and Sullivan) Locker, 1968
Coccolithus formosus (Kamptner) Wise, 1973
Coccolithus pelagicus (Wallich) Schiller, 1930. Plate 1, Fig. 6.
Coccolithus pelagicus floralis Wei and Wise, n. ssp., this report. Plate 2, Figs. 5-8.
Cyclicargolithus abisectus (Müller) Wise, 1973.
Cyclicargolithus floridanus (Roth and Hay *in* Hay et al.) Bukry, 1971. Plate 2, Fig. 4.
Discoaster lodoensis Bramlette and Riedel, 1954
Emiliania huxleyi (Lohmann) Hay and Mohler *in* Hay et al., 1967. Plate 1, Figs. 1 and 2.
Gephyrocapsa oceanica Kamptner, 1943. Plate 1, Figs. 3 and 4.
Helicosphaera carteri (Wallich) Kamptner, 1954
Isthmolithus recurvus Deflandre, 1954.
Pseudoemiliania lacunosa (Kamptner) Gartner, 1969
Reticulofenestra bisecta (Hay, Mohler, and Wade) Roth, 1970.
Reticulofenestra daviesii (Haq) Haq, 1971. Plate 2. Fig. 9.
Reticulofenestra gelida (Geitzenauer) Backman, 1978. Plate 1, Figs. 7 and 8.
Reticulofenestra hesslandii (Haq) Roth, 1970. Plate 2, Fig. 3.
Reticulofenestra perplexa (Burns) Wise, 1983. Plate 2, Figs. 1 and 2.
Reticulofenestra producta (Kamptner) Wei and Thierstein, 1991.
Reticulofenestra pseudoumbilica (Gartner) Gartner, 1969
Reticulofenestra reticulata (Gartner and Smith) Roth and Thierstein, 1972
Reticulofenestra samodurovii (Hay, Mohler, and Wade) Roth, 1970
Reticulofenestra umbilica (Levin) Martini and Ritzkowski, 1968
Sphenolithus conicus Bukry, 1971
Sphenolithus moriformis (Br×nnimann and Stradner) Bramlette and Wilcoxon, 1967.
Triquetrorhabdulus carinatus Martini, 1965
Zygrhablithus bijugatus (Deflandre) Deflandre, 1959

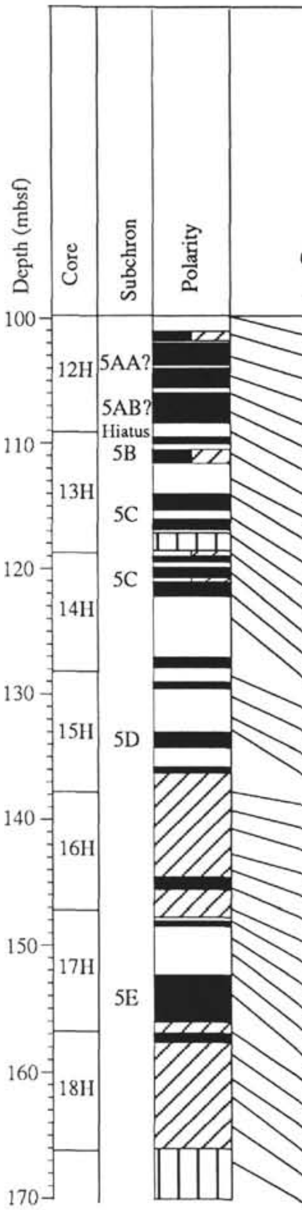
Table 6. Distribution of Miocene-Pleistocene calcareous nannofossils in Hole 751A.



Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pataecus*	*Coccolithus pelagicus*	*Coccolithus pelagicus floralis*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Discoaster* sp.	*Helicosphaera* sp.	*Pontosphaera* sp.	*Pseudoemiliania lacunosa*	*Reticulofenestra gelida*	*Reticulofenestra hesslandii*	*Reticulofenestra perplexa*	*Reticulofenestra producta*	*Reticulofenestra* cf. *producta*	*Reticulofenestra pseudoumbilica*	*Sphenolithus moriformis*	*Chiasmolithus altus*	*Chiasmolithus oamaruensis*	*Chiasmolithus solitus*	*Coccolithus formosus*	*Discoaster lodoensis*	*Isthmolithus recurvus*	*Reticulofenestra bisecta*	*Reticulofenestra daviesii*	*Reticulofenestra reticulata*	*Retitulofenestra samodurovii*	*Retitulofenestra umbilica*	*Zygrhablithus bijugatus*	Nannofossil zones	Age
1H-1, 5-7	0.05	R	M	R																		r													Pliocene – Pleistocene
1H-3, 5-7	3.05	R	M				R																									r		CN14	
2H-2, 5-7	6.25	F	M				F																												
2H-3, 5-7	7.75	C	M				F							R			r					r													
2H-4, 5-7	9.25	B																	C																
3H-1, 45-46	14.65	B																																	
3H-3, 47-48	17.65	B																																	
4H-2, 5-7	25.25	B																																	
4H-3, 5-7	26.75	B																																	
4H-4, 5-7	28.25	R	M				R						R									r						r	r						
4H-5, 5-7	29.75	R	M				R															r							r			r			
4H-6, 5-7	31.25	R	M				F																												
5H-1, 5-7	33.25	R	M				F										r															r			
5H-2, 5-7	34.75	B																																	
5H-3, 5-7	36.25	B																																CN12	
5H-4, 5-7	37.75	B																																	
5H-5, 5-7	39.25	B																																	
5H-6, 5-7	40.75	A	M				A								F		F					r										r			Miocene
6H-1, 5-7	42.75	V	M				A								A		A					r													
6H-2, 5-7	44.25	V	M				A								C		V	V				r						r							
6H-4, 5-7	47.25	V	M				V								F		V	V				r													
6H-5, 5-7	48.75	V	M				V								R		A	A																	
6H-6, 5-7	50.25	V	M				A								F		V	V				r										r		CN11	
7H-1, 5-7	52.73	V	M				A					R			A		A	V				r													
7H-2, 5-7	53.75	V	M				A								A		A	A																	
7H-3, 5-7	55.25	V	M	R			F								C		V	V				r													
7H-4, 5-7	56.75	V	M				F								R		V	V																	
7H-5, 5-7	58.25	V	M				A								C		A	V		R															
7H-6, 5-7	59.75	V	M				V								V		R	A		C															
8H-3, 5-7	64.75	V	P	R	R		V								V		C	A		F		r													
8H-4, 5-7	66.25	V	M				A								A		C	V				r													
8H-5, 5-7	67.75	V	M		R		C								V		C	V				f					r								
8H-6, 5-7	69.25	V	M				C								A		V	C				f										r			
9H-1, 5-7	71.25	V	M				R										V	V				r													
9H-2, 5-7	72.75	V	M	R			R								R		V	V				r						r				r			
9H-3, 5-7	74.25	V	M	R	R		F								F		V	A										r							
9H-4, 5-7	75.75	V	M		R		F								F		V	V																	
9H-5, 5-7	77.25	V	M		R		R								F		V	V																	
9H-6, 5-7	78.75	V	M	F	F		F								F		V	V																	
10H-1, 5-7	80.75	V	M		R		F								R		V	V																	
10H-2, 5-7	82.25	V	M	R			R										V	A																	
10H-3, 5-7	83.75	V	M				R										V	V																	
10H-4, 5-7	85.25	V	M				F										V	V																	
10H-5, 5-7	86.75	V	M		R		R										V	V																	
10H-6, 5-7	88.25	V	M				R										V	A																	
11H-1, 5-7	90.25	V	M		R		R										V	V																	
11H-2, 5-7	91.75	V	M				F										V	V																	
11H-3, 5-7	93.25	V	M	R			F										V	V				r													
11H-4, 5-7	94.75	V	M				F										V	V																	
11H-5, 5-7	96.25	V	M		R		A										V	V				r												CN4	
11H-6, 5-7	97.75	V	M				F										V	V														r			
11H-7, 5-7	99.25	V	M		R	V	C			F						F	C	V													r	r			

Notes: Nannofossil zones are given according to the zonation of Okada and Bukry (1980). Abundance of calcareous nannofossils is characterized by V = very abundant, A = abundant, C = common, F = few, R = rare, r = rare reworked specimens, and f = few reworked specimens. For preservation, G = good, M = moderate, and P = poor. Paleomagnetic data are taken from Heider et al. (this volume). Normal paleomagnetic subchrons are shown in black, and reversed ones in white (those less reliable ones are shown in half columns). Data gaps are indicated by vertical lines and uninterpretable data by diagonal lines.

Table 6 (continued).



Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pataecus*	*Coccolithus pelagicus*	*Coccolithus pelagicus floralis*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Discoaster* sp.	*Helicosphaera* sp.	*Pontosphaera* sp.	*Pseudoemiliania lacunosa*	*Reticulofenestra gelida*	*Reticulofenestra hesslandii*	*Reticulofenestra perplexa*	*Reticulofenestra producta*	*Reticulofenestra* cf. *producta*	*Reticulofenestra pseudoumbilica*	*Sphenolithus moriformis*	*Chiasmolithus altus*	*Chiasmolithus oamaruensis*	*Chiasmolithus solitus*	*Coccolithus formosus*	*Discoaster lodoensis*	*Isthmolithus recurvus*	*Reticulofenestra bisecta*	*Reticulofenestra daviesii*	*Reticulofenestra reticulata*	*Retitulofenestra samodurovii*	*Retitulofenestra umbilica*	*Zygrhablithus bijugatus*	Nannofossil zones	Age
12H-1, 5-7	99.75	V	M	R	F		R			F							A	V														r			
12H-2, 5-7	101.25	V	P				C			C						C						c										f		CN11	
12H-3, 5-7	102.75	V	P				F		R	C						R						f	r				r	r	r			f			
12H-4, 5-7	104.25	V	M	F	C		V		R	F							R					f							f			f			
12H-5, 5-7	105.75	V	M		R		A		R								A					f			r		r	f	c		c	c			
12H-6, 5-7	107.25	V	M	F	R		A		R								F					c						r	f	r		f			
12H-7, 5-7	108.75	V	M				F															c	f	r	r	r		r	f	f		c			
13H-2, 5-7	110.75	V	M	C			V		A	C												f						r	r			f			
13H-3, 5-7	112.25	V	M	F			V			R	R											f			r			r				r			
13H-4, 5-7	113.75	V	M	R			V			F	R											f					r		r	r	f	r	f		
13H-5, 5-7	115.25	V	M	F			V		F	A						V						c							r	r		r	r		
13H-6, 5-7	116.75	V	M		R		V	C	F	A						V						r						r							
13H-7, 5-7	118.25	V	M	F	R		A	F	C	A		R				A						r										r	r		
14H-2, 5-7	120.25	V	M	R	R		V		F	A	R					V						f									f	f	r		Miocene
14H-4, 5-7	121.75	V	M	R	R		V		F	F	R					A						f						r			r	f	r		
14H-5, 63-65	123.25	V	M	R	R		V		F	C												f						r	f	r	r	f	r		
15H-1, 63-65	128.83	V	M	F	R		V		F	F	R											f		r			r					r			
15H-2, 5-6	129.75	V	M	F	R		V		F	C												f						r	f			f			
15H-3, 63-65	131.83	V	M	R			V		F	C	R											f					r	r	f		f	f			
15H-4, 5-6	132.75	V	M	F	F		V		F	C	R											f										r	r		
16H-1, 2-4	137.72	V	M	R			C			V						A						f					r	r				r			
16H-2, 2-4	139.22	V	M				C			C						V						f										r			
16H-3, 2-4	140.72	V	M	R			C			C						V																			
16H-4, 2-4	142.22	V	M	F			V		R	F						V					R										r	r		CN4	
16H-5, 2-4	143.72	V	M	F			V									A																			
16H-6, 2-4	145.22	V	M				V									C						r									f	r			
16H-7, 2-4	146.72	V	M	F			A									A																			
17H-1, 22-25	147.42	V	M				A		C	F	R					V																r			
17H-2, 5-6	148.92	V	M				V		C	V	R					V						r												CN3	
17H-3, 63-65	150.42	V	M				A		C	A	R					A					R	r						r				r			
17H-4, 5-6	151.92	V	M				V		C	V						A						r									r	r			
17H-5, 5-6	153.42	V	M				V		F	V	R					A					R							r							
18H-1, 63-65	157.33	V	M				V			A	F										R	r						r		r	r	r	r		
18H-2, 5-6	158.25	V	M				V			A	R					A						r													
18H-3, 63-65	160.33	V	M				A		F	A						V																r			
18H-4, 5-6	161.25	V	M				V		F	A						V						r		r											
18H-5, 63-65	163.33	V	M				A		F	A	R					V					R											r		CN1	
18H-7, 63-65	166.83	V	M				A		F	C						A						r										r			

Table 7. Neogene calcareous nannofossil datum levels in Hole 751A and their estimated ages.

Species event	Core, section, interval (cm)	Depth (mbsf)	Age (Ma)	Source
LO *Reticulofenestra gelida*	5H-5, 5/5H-6, 5	39.25–40.75	3.8	1
LO *Reticulofenestra hesslandii*	11H-6, 5/11H-7, 5	97.75–99.25	11.1	1
FO *Calcidiscus leptoporus*	16H-7, 2/17H-1, 22	146.72–147.42	18.2	1

Notes: 1 = Wei and Thierstein (1991) and Barron et al. (1991).

Table 8. Magnetostratigraphically calibrated ages of calcareous nannofossil datums at Site 747, 748, and 751.

Species event	Site 747	Site 748	Site 751
LO *Reticulofenestra gelida*	3.3 Ma	3.4 Ma	<5.8 Ma
LO *Reticulofenestra hesslandii*	11.6 Ma	11.7 Ma	11.7 Ma
FO *Calcidiscus leptoporus*	18.0 Ma	18.1 Ma	18.1 Ma
LO *Reticulofenestra bisecta*	23.9 Ma		
LO *Chiasmolithus altus*	27.7 Ma		

Note: Magnetostratigraphic data are taken from Heider et al. (this volume) and Inokuchi and Heider (this volume).

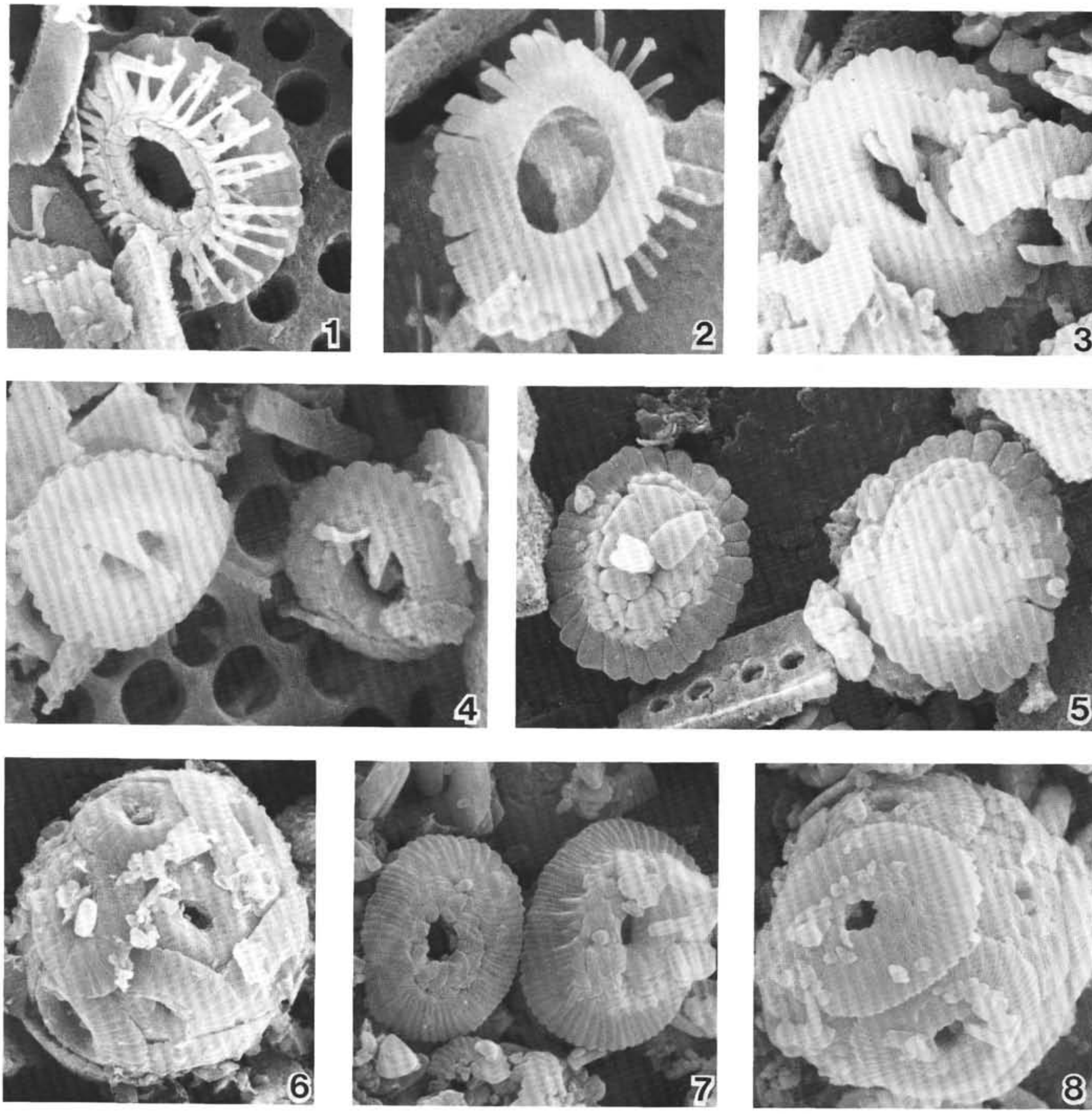


Plate 1. **1–2.** *Emiliania huxleyi* (Lohmann) Hay and Mohler, Sample 120-747A-1H-1, 58–62 cm. (1) ×11,000; (2) ×17,000. **3–4.** *Gephyrocapsa oceanica* Kamptner, Sample 120-747A-1H-4, 10–11 cm. (3) ×14,000; (4) ×12,000. **5.** *Reticulofenestra* sp. cf. *producta* (Kamptner) Wei and Thierstein, Sample 120-747A-3H-4, 10–11 cm. **6.** Coccosphere of *Coccolithus pelagicus,* Sample 120-747A-3H-4, 10–11 cm, ×2,700. **7–8.** *Reticulofenestra gelida* (Geitzenauer) Backman, Sample 120-747A-6H-4, 10–11 cm. (7) ×4500; (8) ×3300.

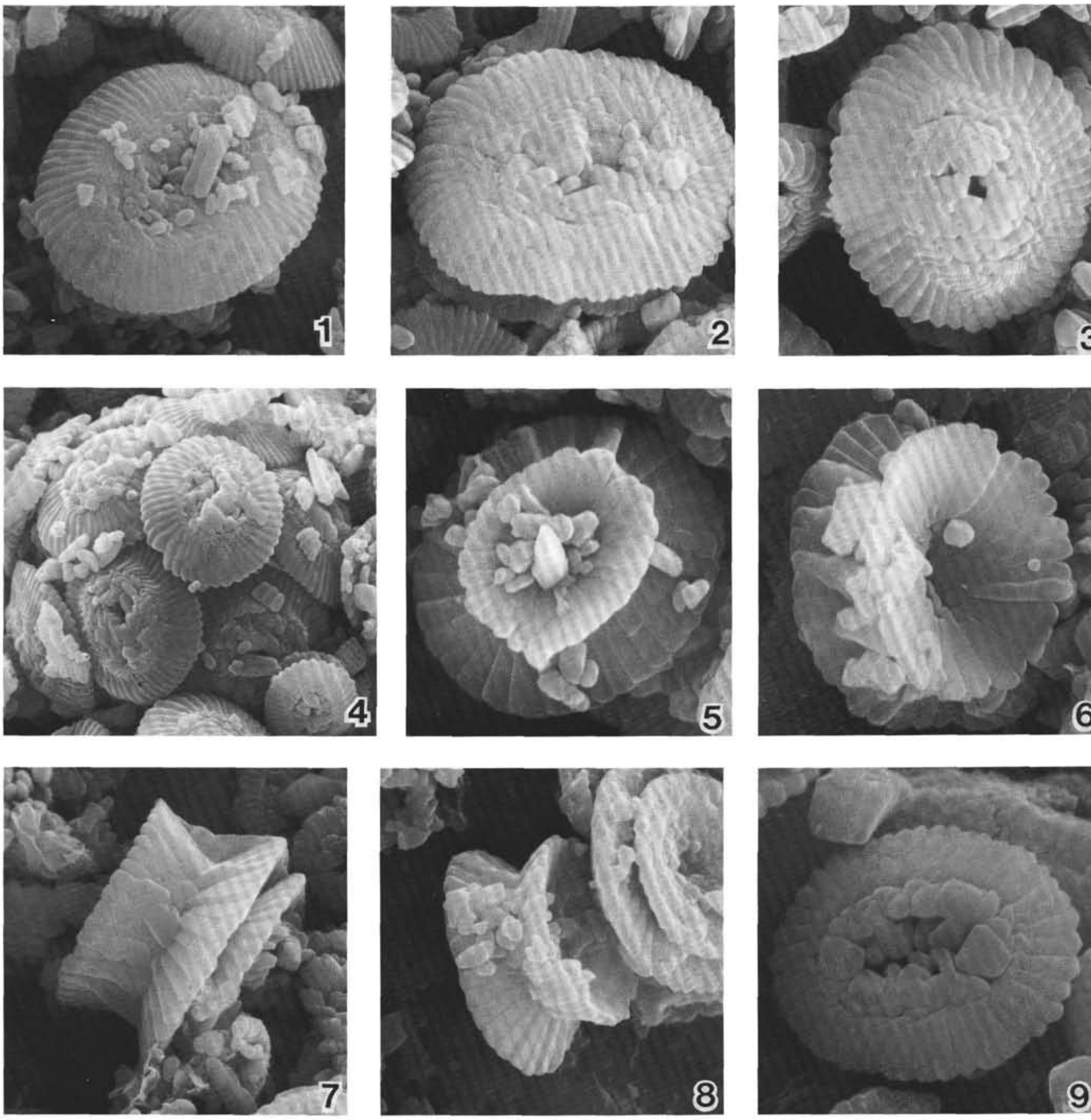


Plate 2. **1–2.** *Reticulofenestra perplexa* (Burns) Wise, Sample 120-747A-6H-4, 10–11 cm. (1) ×5000; (2) ×6500. **3.** *Reticulofenestra hesslandii* (Haq) Roth, Sample 120-747A-9H-2, 58–62 cm. **4.** Coccosphere of *Cyclicargolithus floridanus* (Roth and Hay) Bukry, Sample 120-747A-9H-2, 58–62 cm. **5–8.** *Coccolithus pelagicus floralis* Wei and Wise, n. ssp., Sample 120-747A-14H-2, 10–11 cm. (5) ×8000, isotype; (6) ×6500, isotype; (7) ×7000, holotype; (8) ×5000, isotype. **9.** Overgrown specimen of *Reticulofenestra daviesii* (Haq) Haq, Sample 120-747A-17H-1, 10–11 cm, ×9500.