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11. CALCAREOUS NANNOFOSSILS FROM THE SOUTHEAST GREENLAND MARGIN: BIOSTRATIGRAPHY AND PALEOCEANOGRAPHY[1]

Wuchang Wei[2]

ABSTRACT

The distribution of calcareous nannofossils in Leg 152 sites on the southeast Greenland Margin is documented. The nannofossil biostratigraphy established here provides valuable age information for the recovered sediments and a number of important events, including the initiation of marine sedimentation in the Irminger Basin in the early Eocene (52−53 Ma), the onset of North Atlantic Deep Water around 11.5 Ma, and the earliest occurrence of dropstones in the Irminger Basin at about 7 Ma or older. Nannofossil assemblages indicate significant warmth in the high latitudes during the Eocene and progressive deterioration of the climate since the late Eocene. The last consistent occurrence of warm-water taxa at about 12 Ma in the Irminger Basin may suggest the onset of the cold East Greenland Current at this time. Reworked Cretaceous nannofossils in Pleistocene sediments may be the result of extensive discharge of icebergs from the North Sea-Denmark area beginning in the middle Pleistocene.

INTRODUCTION

Ocean Drilling Program Leg 152 drilled six sites on the southeast Greenland Margin, along a transect from the shelf to Irminger Basin (Fig. 1). The abundance of calcareous nannofossils in the recovered sediments varies considerably, but it generally decreases shoreward and uphole. Species diversity is lower than those at lower latitudes, and nannofossil biostratigraphic resolution is lower due to the scarcity or absence of many standard zonal markers. Nevertheless, calcareous nannofossils still provide the primary means of dating the recovered sediments. This chapter provides a detailed documentation of the stratigraphic distribution of the nannofossils and discusses their biostratigraphy. In addition, some brief remarks on paleoclimate and paleoceanography are made based on the semiquantitative nannofossil data.

METHODS

Samples for this study were taken aboard ship at a frequency of one sample per core section. Smear slides were made directly from unprocessed samples and examined with a light microscope at a magnification of 1000×. The abundance of calcareous nannofossils on each slide was estimated and recorded in the following semi-quantitative categories (each successive category is about 5 times the preceding category):

R (rare) = 1 specimen in 31−150 fields of view
F (few) = 1 specimen in 6−30 fields of view
C (common) = 1 specimen in 1−5 fields of view
A (abundant) = 2−10 specimens per field of view
V (very abundant) = >10 specimens per field of view

The abundance of reworked specimens was recorded in lowercase letter. For the preservation of nannofossil assemblages: 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.

Previous studies of nannofossils from drill sites in the northern high latitudes include Müller (1976), Steinmetz (1978), Donnally (1989), Firth (1989), and Knüttel et al. (1989). However, no Cenozoic calcareous nannofossil zonation for the northern high latitudes has yet been established. Nannofossil zones recognized in this study are given in the widely used zonation of Okada and Bukry (1980). The emphasis, however, has been on individual datums, including a number of datums that were not used in the original zonation but have since been documented in recent studies (Gartner, 1992; Wei and Wise, 1992; Young et al., 1994) and are useful for Leg 152 sediments. For convenience, the numerical ages of the datums used in this chapter are still in reference to the geomagnetic polarity time scale of Cande and Kent (1992), as presented graphically in Larsen, Saunders, Clift, et al. (1994). Some revisions of this geomagnetic polarity time scale have recently been made (Cande and Kent, 1995; Wei, 1995), but they do not significantly affect the ages discussed in this chapter.

Bibliographic references for the calcareous nannofossil species used in this study can be found in Perch-Nielsen (1985). Most species encountered and some critical occurrences of marker species are documented in Plates 1–3. A summary of nannofossil biostratigraphy of Leg 152 sites is presented in Table 1.

NANNOFOSSIL BIOSTRATIGRAPHY

Site 914

Core recovery for the glaciomarine sediments at this site was generally very poor, and no suitable sediments were available for nannofossil analysis for much of Hole 914B (see Table 2). Calcareous nannofossils are generally rare or absent in the Pleistocene sediments and common in the lower Oligocene sediments.

Samples 152-914A-1H-1, 66 cm, and 1H-2, 66 cm, contain both *Emiliania huxleyi* and *Coccolithus pelagicus* and are most likely Holocene in age based on the Pleistocene nannofossil biochronology established for the subarctic North Atlantic by Gard and Backman (1990). The interval from Sample 152-914A-1H-CC through Sample 152-914A-2H-4, 66 cm, is barren of calcareous nannofossils, and probably represents the last glacial interval (oxygen isotope Stages 2–4) when the cold climate excluded the calcareous nannoplankton from the area. Samples 152-914A-2H-5, 66 cm, through 3H-CC contain rare specimens of *E. huxley*, and may be correlated with oxygen isotope stage 5 or, at the earliest, oxygen isotope stage 8 according to

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[2] Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093-0215, U.S.A. wwei@ucsd.edu

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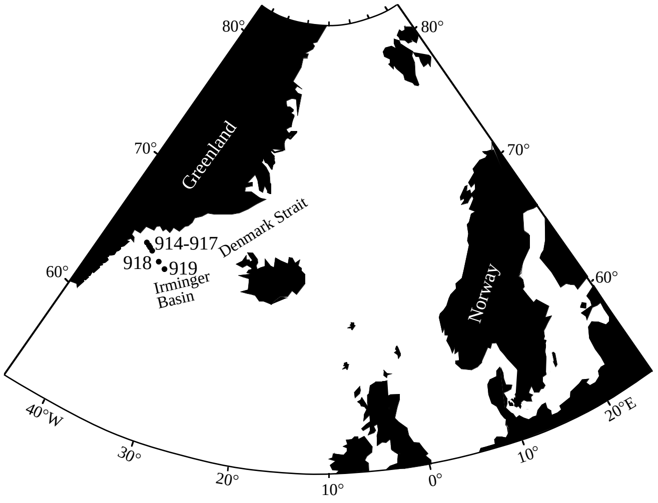

Figure 1. Location map of Leg 152 drill sites.

the chronology of Gard and Backman (1990). Sample 152-914B-8R-CC contains a mixture of nannofossils of different ages, including Cretaceous, Paleogene, and Pleistocene species (Table 2). Apparently, these have been reworked in this glaciomarine sediment. The youngest species found in this sample is *Gephyrocapsa* sp. (>4.0 µm), which indicates that the sediment is still Pleistocene in age.

Common and relatively diverse Paleogene nannofossil assemblages were found in Samples 152-914B-15R-CC through 17R-CC. Based on the presence of *Chiasmolithus altus, Reticulofenestra daviesii* and *R. umbilicus* in the absence of *Isthmolithus recurvus,* Samples 152-914B-15R-CC and 16R-2, 31 cm, can be placed near the top of CP16, close to 32 Ma. Samples 152-914B-16R-CC and 17R-CC contain all the above species in addition to *Isthmolithus recurvus,* whereas *R. reticulata* is absent. These assemblages suggest an early Oligocene age.

Site 915

One hole was drilled at this site and core recovery was very poor or zero for the upper 17 cores. Sample 152-915A-1R-CC is barren of calcareous nannofossils (Table 3). The next sedimentary sample suitable for nannofossil analysis is Sample 152-915A-11R-CC. The in-

Table 1. Summary of nannofossil biostratigraphy of Leg 152 sites.

Age	Zones	Site 914	Site 915	Site 917	Site 918	Site 919
Pleist.	CN15	A: 1R-1/3R-CC			A: 1H-1/4H-1	A: 1H-1/4H-5
	CN14	B: 8R-CC			A: 4H-3/24X-CC	A: 4H-CC/7H-3
	CN13					A: 7H-5/10H-CC B: 3H-1/8H-CC
Pliocene	CN12				A: 25X-CC/31X-CC	
	CN11				D: 14R-1/24R-2	
	CN10					
Miocene	CN9				D: 24R-3/37R-3	
	CN8					
	CN7					
	CN6				D: 37R-5/42R-6	
	CN5					
	CN4				D: 42R-CC/53R-3	
	CN3					
	CN2				D: 53R-4/57R-3	
	CN1					
Oligocene	CP19				D: 58R-CC/86R-2	
	CP18					
	CP17					
	CP16	B: 15R-CC/17R-CC				
Eocene	CP15		A: 11R-CC/17R-CC			
	CP14		A: 21R-1/22R-CC	A: 4R-CC	D: 88R-1, 2	
	CP13				D: 88R-1/91R-CC	
	CP12					
	CP11					
	CP10				D: 92R-1/93R-2	
	CP9				D: 93R-CC	

Notes: A, B, and D indicate Holes A, B, and D, respectively. Where more than one core section is assigned to a single zone, the highest and lowest sections are listed with a slash between them.

Table 2. Distribution of calcareous nannofossils, Site 914.

Age	Zone	Core, section interval (cm)	Abundance	Preservation	*Blakites spinosus*	*Braarudosphaera bigelowii*	*Calcidiscus leptoporus*	*Chiasmolithus altus*	*Clausicoccus fenestratus*	*Coccolithus pelagicus*	*Cyclicargolithus floridanus*	*Emiliania huxleyi*	*Gephyrocapsa* spp. >4 µm	*Isthmolithus recurvus*	*Pontosphaera multipora*	*Reticulofenestra bisecta*	*Reticulofenestra daviesii*	*Reticulofenestra hillae*	*Reticulofenestra reticulata*	*Reticulofenestra samodurovii*	*Reticuolfenestra umbilicus*	*Sphenolithus moriformis*	*Watznaueria barnesae*	*Zygrhablithus bijugatus*
Pleistocene	CN15	**152-914A**																						
		1H-1, 66	F	M	.	.	F	.	.	C	.	F	.	.	.	.	.	.	.	.	.	.	.	.
		1H-2, 66	R	M	.	.	R	.	.	F	.	R	.	.	.	.	.	.	.	.	.	.	.	.
		1H-3, 66	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		1H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		2H-2, 65	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		2H-3, 66	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		2H-4, 66	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		2H-5, 66	R	M	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.
		2H-CC	R	P	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.
		3H-CC	R	P	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.
	CN13/ CN14	**152-914B**																						
		8R-CC	R	P	.	.	.	r	.	R	r	.	R	.	.	r	r	r	r	.	r	.	r	.
?	?	13R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
early Olig.	CP16	15R-CC	C	M	.	.	.	R	R	C	R	.	.	.	R	C	C	R	.	R	R	R	.	.
		16R-2, 31	C	M	R	R	.	R	.	C	R	.	.	.	R	F	C	F	.	.	F	.	.	R
		16R-CC	C	M	.	.	.	R	.	.	.	.	.	R	.	F	C	R	.	.	R	.	.	.
		17R-CC	F	P	.	.	.	R	.	.	.	.	.	R	.	F	F	R	.	.	R	.	.	.

Note: C = common, F = few, R = rare, B = barren, M = moderate, and P = poor.

terval from this sample down to Sample 152-915A-17R-CC yielded relatively diverse nannofossil assemblages, including several age-diagnostic species, such as *Chiasmolithus oamaruensis, Isthmolithus recurvus, Reticulofenestra reticulata,* and *R. umbilicus.* These assemblages suggest an age of late Eocene (CP15). Samples 152-915A-18R-1, 70 cm, through 21R-1, 2 cm, are barren of calcareous nannofossils. Samples 152-915A-21R-1, 4 cm, through 22R-CC yielded generally rare and sporadic nannofossils. However, the presence of *C. solitus* and *R. umbilicus* in this interval suggests that Subzone CP14a is of middle Eocene age. Core 152-915A-23R, which overlies weathered basalt, is barren of nannofossils and probably represents an alluvial fan deposit (Larsen, Saunders, Clift, et al., 1994).

Assuming general carbonate saturation at this relatively shallow water site (present water depth = 533 m), the scarcity or absence of calcareous nannofossils in CP14a appears to indicate that the sediment was deposited in a relatively shallow water environment, probably no more than 100 m of water. The total absence of planktonic foraminifers in this subzone (Spezzaferri, this volume) is consistent with this interpretation. The absence of both calcareous nannofossils (Table 3) and planktonic foraminifers in the presence of rare benthic foraminifers in the interval between Samples 152-915A-18R-1, 70 cm, and 21R-1, 2 cm, may indicate that water depth was probably no more than a few tens of meters during that time. The common to abundant calcareous nannofossils in Zone CP15 (Table 3) suggest an increase in water depth, most likely over 100 m in this time. However, examination of the sea level curve of Haq et al. (1987) shows a large drop of sea level Zone CP15. Therefore, the increase in water depth at Site 915 in CP15 does not appear to be caused by global sea level rise but may be the result of rapid local subsidence.

Site 916

Mostly gravels were recovered for the sedimentary section at this site. The following samples were available for nannofossils analysis: 152-916A-5R-1, 60 cm; 9R-CC; 13R-1, 79 cm; 13R-2, 4 cm; 13R-2, 118 cm; 13R-2, 140 cm; 13R-3, 72 cm; 13R-CC; and 14R-CC. No in situ nannofossils are present in these samples.

Site 917

Sample 152-917A-1R-CC is barren of calcareous nannofossils. Core 152-917A-2R did not recover any sediment, whereas Core 152-917A-3R recovered only a piece of gravel. The core catcher from Core 152-917A-4R yielded rare specimens of calcareous nannofossils, including *Blackites spinosus, Chiasmolithus solitus, Cyclicargolithus floridanus, Reticulofenestra bisecta, R. daviesii, R. hillae,* and *R. umbilicus.* This sample can be assigned to Subzone CP14a (middle Eocene) based on the presence of *C. solitus* and *R. umbilicus.* Core 152-917A-5R did not recover any sediment. Core 152-917A-6R is barren of calcareous nannofossils. Cores 152-917A-7R through 101R are from a basalt sequence. The rest of the cores (152-917A-102R through 110R) are from a metamorphosed sediment sequence of unknown age. The following samples were analyzed for nannofossils: 152-917A-102R-3, 20 cm; 103R-1, 10 cm; 103R-4, 15 cm; 104R-1, 90 cm; 104R-4, 20 cm; 105R-1, 65 cm; and 110R-1, 31 cm. No nannofossils were found in these samples.

Site 918

Four holes were drilled at this site. Holes 918A and 918D yielded the longest and most important sedimentary sequence drilled by Leg 152. Core 152-918D-4R begins at the same stratigraphic level where Hole 918A terminated. Nannofossil range charts for the entire Hole 918A and Cores 152-918D-4R through 97R are constructed (Tables 4, 5).

Samples 152-918A-1H-1, 1 cm, and 1H-1, 30 cm, contain common to abundant *Emiliania huxleyi* and *Coccolithus pelagicus* (Table 4). These samples can be assigned to the Holocene based on the bio-

Table 3. Distribution of calcareous nannofossils, Hole 915A.

Age	Zone	Core, section interval (cm)	Abundance	Preservation	*Blakites spinosus*	*Braarudosphaera bigelowii*	*Chiasmolithus altus*	*Chiasmolithus oamaruensis*	*Chiasmolithus solitus*	*Clausicoccus fenestratus*	*Coccolithus formosus*	*Coccolithus pelagicus*	*Cyclicargolithus floridanus*	*Discoaster saipanensis*	*Discoaster tanii*	*Isthmolithus recurvus*	*Markalius inversus*	*Neococcolithes dubius*	*Pontosphaera multipora*	*Reticulofenestra bisecta*	*Reticulofenestra daviesii*	*Reticulofenestra hillae*	*Reticulofenestra reticulata*	*Reticulofenestra samodurovii*	*Reticuolfenestra umbilicus*	*Sphenolithus moriformis*	*Zygrhablithus bijugatus*
		152-915A																									
?	?	1R-CC	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
late Eocene	CP15	11R-CC	R	P	.	.	.	.	.	.	.	R	.	.	.	R	.	.	.	R	R	R	R	.	.	.	R
		14R-CC	A	M	.	.	R	.	.	.	.	F	.	.	.	R	.	.	R	R	C	R	R	.	R	.	.
		15R-CC	A	M	.	.	F	1	.	.	1	R	.	R	.	R	1	R	.	F	C	R	F	R	R	R	R
		16R-1, 58	A	M	.	R	R	R	.	.	.	C	R	.	.	R	.	R	R	F	C	R	C	R	R	R	R
		16R-CC	A	M	R	R	R	R	.	R	R	C	.	R	1	R	.	.	R	F	A	R	C	F	F	.	R
		17R-CC	C	G	.	R	F	.	.	.	.	F	.	.	.	.	1	.	R	.	C	.	F	F	F	.	R
?	?	18R-1, 70	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		18R-2, 63	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		18R-3, 79	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		18R-CC	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		19R-1, 74	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		19R-2, 65	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		19R-3, 58	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		19R-4, 65	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		19R-CC	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		20R-1, 73	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		20R-CC	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		21R-1, 2	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
middle Eocene	CP14a	21R-1, 4	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		21R-1, 58	B		.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		21R-2, 102	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	R	R	.	.
		21R-3, 64	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		21R-4, 60	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		21R-5, 25	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		21R-CC	F	M	.	.	.	.	R	.	.	R	R	.	.	.	.	.	.	.	.	.	.	F	R	.	.
		22R-1, 67	R	M	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	R	.	.
		22R-2, 65	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		22R-3, 10	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.
		22R-CC	R	P	R	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	R	.	.
?	?	23R-2, 6	B		.	.	.	.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Note: A = abundant, C = common, F = few, R = rare, B = barren, M = moderate, and P = poor.

chronology of Gard and Backman (1990). Application of this biochronology further downhole is difficult as the distribution of the assemblages appears to be significantly different from that described by Gard and Backman (1990) for the Arctic/Subarctic areas. This may be due to warmer water conditions at Site 918 than at the higher latitude sites Gard and Backman (1990) investigated. Nevertheless, the lowest occurrence of *E. huxleyi* in Sample 152-918A-4H-1, 65 cm, allows the recognition of the base of Zone CN15 below this sample, which is correlated with oxygen isotope Stage 8 (Thierstein et al., 1977).

The lowest occurrence of *Gephyrocapsa* spp. (>4 µm) generally approximates the Pliocene/Pleistocene boundary based on low- to middle-latitude data (Wei, 1993). If this datum is applied to Site 918, the Pliocene/Pleistocene boundary may be drawn below Sample 152-918A-24X-CC (Table 4). This boundary should be considered tentative because the reliability of the datum at this high latitude has not been tested. In addition, *Gephyrocapsa* spp. (>4 µm) are generally rare and sporadic and it is difficult to determine their true first occurrence. Furthermore, the use of this datum also disagrees with the magnetostratigraphic interpretation of Larsen, Saunders, Clift, et al. (1994). Other independent biostratigraphic or isotope stratigraphic data may help resolve the Pliocene/Pleistocene boundary problem at this site.

Pseudoemiliania lacunosa occurs in Sample 152-918A-31X-CC; this suggests that the sample is no older than late Pliocene. As the lowest five samples from Hole 918A are barren of calcareous nannofossils, the position of the lower Pliocene/upper Pliocene boundary cannot be precisely determined, but is tentatively drawn below Sample 152-918A-31X-CC (Table 4).

Cores 152-918D-4R through 13R (Table 5) are either barren of nannofossils or contain rare specimens of *C. pelagicus* and *Reticulofenestra producta,* neither being age-diagnostic. As these cores are stratigraphically below the bottom of Hole 152-918A and overlie lower Pliocene sediments, they can be assigned a general Pliocene age. The highest occurrence of *Reticulofenestra gelida* (Pl. 1, Figs. 5, 6) is in Sample 152-918D-14R-1, 109 cm, and marks the top of Zone CN11.

The highest occurrence of *Discoaster quinqueramus* (Pl. 1, Figs. 7, 8) is in Sample 152-918D-24R-3, 49 cm. This datum is commonly used to approximate the Miocene/Pliocene boundary in low to middle latitudes. As discoasters generally disappeared from high latitudes earlier, the Miocene/Pliocene boundary is most likely to be higher

Table 4. Distribution of calcareous nannofossils, Hole 918A.

Age	Zone	Core, section interval (cm)	Abundance	Preservation	*Arkhangelskiella cymbiformis*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pelagicus*	*Cruciplacolithus tenuis*	*Emiliania huxleyi*	*Gephyrocapsa* spp. >4 µm	*Micula decussata*	*Prediscosphaera cretacea*	*Pontosphaera multipora*	*Pseudoemiliania lacunosa*	*Sphenolithus abies*	*Watznaueria barnesae*
Pleistocene	CN15	**152-918A**															
		1H-1, 1	A	M	.	R	.	A	.	A	.	.	.	.	.	.	.
		1H-1, 30	C	M	.	R	.	C	.	C	.	.	.	.	.	.	.
		1H-1, 60	R	M	.	R	.	.	.	R	R	.	.	.	.	.	.
		1H-1, 90	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		1H-2, 1	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		1H-2, 30	F	M	.	.	.	.	.	R	F	.	.	.	.	.	.
		1H-2, 60	R	M	.	.	.	.	.	R	R	.	.	.	.	.	.
		1H-3, 60	B	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		1H-CC	R	M	.	.	.	.	.	R	R	.	.	.	.	.	.
		2H-1, 30	R	M	.	.	.	R	.	R	R	.	.	.	.	.	.
		2H-1, 60	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.
		2H-1, 90	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.
		2H-1, 120	R	M	.	.	.	.	.	R	R	.	.	.	.	.	.
		2H-2, 30	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.
		2H-2, 60	R	M	.	.	.	.	.	R	R	.	.	.	.	.	r
		2H-2, 90	R	M	.	.	.	.	.	R	R	.	.	.	.	.	r
		2H-2, 120	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.
		2H-3, 30	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.
		2H-3, 60	F	M	.	.	.	.	.	F	R	.	.	.	.	.	.
		2H-3, 90	C	M	r	.	.	.	.	C	.	.	.	.	.	.	.
		2H-3, 120	C	M	.	.	.	.	.	C	.	.	.	.	.	.	.
		2H-4, 30	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.
		2H-4, 60	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.
		2H-4, 90	R	M	.	.	.	R	.	R	R	.	.	.	.	.	r
		2H-4, 120	R	M	.	.	.	.	.	R	.	.	.	.	.	.	r
		2H-5, 30	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.
		2H-5, 60	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		2H-5, 90	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		2H-5, 120	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.
		2H-6, 30	C	M	.	.	.	R	.	C	.	.	.	.	.	.	.
		2H-6, 60	R	M	.	.	.	.	.	R	.	.	.	.	.	.	.
		2H-6, 90	C	M	.	.	.	.	.	C	.	.	.	.	.	.	.
		2H-7, 30	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		2H-CC	F	M	.	.	.	.	.	F	.	.	.	.	.	.	.
		3H-CC	R	M	.	.	.	R	.	R	R	.	.	.	.	.	.
		4H-1, 65	F	M	.	.	.	R	.	R	F	.	.	.	.	.	.
	CN13-CN14	4H-3, 66	R	M	.	.	.	.	.	.	R	.	.	.	.	.	.
		4H-5, 67	F	M	.	.	.	R	.	.	R	.	.	.	.	.	r
		4H-CC	R	M	.	.	.	R	.	.	.	.	.	.	.	.	r
		5H-1, 40	A	M	.	C	.	A	.	.	.	.	.	.	.	.	.
		5H-3, 40	R	M	.	.	.	.	.	.	R	.	.	.	.	R	.
		5H-5, 40	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		5H-CC	R	M	.	.	.	.	.	.	R	.	.	.	.	.	.
		6H-1, 10	C	M	.	.	.	.	.	.	F	.	.	.	.	.	.
		6H-3, 101	C	M	.	.	.	.	.	.	F	.	.	.	.	.	.
		6H-5, 105	C	M	.	R	.	R	.	.	C	.	.	.	.	.	.
		6H-CC	R	M	.	.	.	.	.	.	R	.	.	.	.	.	.
		7H-1, 60	F	M	r	.	.	.	.	.	F	.	r	.	.	.	.
		7H-3, 64	B		.	.	.	.	.	.	.	.	r	.	.	.	.
		7H-5, 67	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		7H-CC	R	P	.	R	.	.	.	.	R	.	.	.	R	.	.
		8H-1, 136	R	P	.	.	.	R	r	.	.	r	r	.	.	.	r
		8H-3, 68	B		.	.	.	.	.	.	.	r	.	.	.	.	.
		8H-5, 62	C	P	.	.	.	C	.	.	.	.	.	.	.	R	.
		8H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		9H-3, 30	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		9H-5, 85	R	P	.	.	.	.	.	.	R	.	.	.	.	.	.
		9H-7, 24	R	P	.	.	.	.	.	.	R	.	.	.	.	.	.
		9H-CC	R	P	.	.	.	.	.	.	R	.	.	.	.	.	.
		10H-1, 107	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		10H-3, 131	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		10H-5, 143	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		10H-CC	R	P	.	.	.	.	.	.	R	.	.	.	.	.	.
		11H-1, 145	R	P	.	.	.	.	.	.	R	.	.	.	R	.	.
		11H-3, 145	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		11H-5, 146	B		.	.	.	.	.	.	.	.	.	.	.	.	.
		11H-CC	C	P	.	R	?	.	.	.	.	.	.	R	.	.	.

Age	Zone	Core, section interval (cm)	Abundance	Preservation	*Calcidiscus leptoporus*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*Gephyrocapsa* spp. >4 µm	*Pseudoemiliania lacunosa*
Pleistocene	CN13-CN14	**152-918A**							
		12H-1, 22	B		.	.	.	.	.
		12H-3, 22	B		.	.	.	.	.
		12H-5, 47	B		.	.	.	.	.
		12H-CC	B		.	.	.	.	.
		13H-4, 41	B		.	.	.	.	.
		13H-5, 25	B		.	.	.	.	.
		13H-CC	R	P	R	.	r	R	.
		14H-CC	B		.	.	.	.	.
		15H-CC	B		.	.	.	.	.
		16H-CC	R	P	R	.	.	R	R
		17H-CC	B		.	.	.	.	.
		18H-CC	B		.	.	.	.	.
		19H-CC	R	P	R	.	.	R	.
		20X-CC	R	P	R	.	.	R	.
		21X-CC	R	P	R	.	.	.	.
		22X-CC	B		.	.	.	.	.
		23X-CC	R	P	.	.	.	R	.
		24X-CC	R	P	.	.	.	R	.
?	?								
late Pliocene	CN12	25X-CC	B		.	.	.	.	.
		26X-CC	B		.	.	.	.	.
		27X-CC	B		.	.	.	.	.
		28X-CC	R	P	R	.	.	.	.
		29X-CC	R	P	R	.	.	.	.
		31X-CC	C	P	R	F	.	.	R
?	?	32X-CC	B		.	.	.	.	.
		33X-CC	B		.	.	.	.	.
		35X-CC	B		.	.	.	.	.
		37X-CC	B		.	.	.	.	.
		38X-CC	B		.	.	.	.	.

Note: A = abundant, C = common, F = few, R = rare, B = barren, M = moderate, and P = poor.

than indicated in Table 5. Similarly, as *D. quinqueramus* is rare at this high latitude and its stratigraphic range is almost certainly shorter than at lower latitudes, the precise location of the lower boundary of Zone CN9 is not known but is at least below Sample 152-918D-24R-CC (Table 5).

The highest occurrence of *Coccolithus miopelagicus* is in Sample 152-918D-37R-5, 25 cm. This suggests that the sample is about 11 Ma in age. The highest occurrence of *Cyclicargolithus floridanus* is in Sample 152-918D-38R-6, 25 cm. This datum has an age of about 11.6 Ma (Young et al., 1994). Another useful datum slightly below is the highest occurrence of *Calcidiscus premacintyrei* in Sample 152-918D-39R-4, 18 cm (Pl. 2, Figs. 3, 4), which can be assigned an age of 12.1 Ma (Young et al., 1994). The lowest occurrence of *Reticulofenestra gelida* (>7 µm) is in Sample 152-918D-40R-3, 33 cm (Table 5). This level is considered to be equivalent to the first occurrence of *Reticulofenestra pseudoumbilicus* (>7 µm), which has been correlated with Chron C5AA at 13 Ma (Young et al., 1994).

The next important marker is the highest occurrence of *Sphenolithus heteromorphus* in Sample 152-918D-42R-CC. This datum has been correlated with magnetostratigraphy at low to middle latitudes with an age of about 13.6 Ma (Young et al., 1994). As sphenoliths generally preferred relatively warm waters, the stratigraphic range of *S. heteromorphus* is most likely to be shorter at this high latitude, that is, the highest occurrence of this species at Site 918 should be older than 13.6 Ma. The lowest occurrence of *Calcidiscus premacintyrei* is in Sample 152-918D-52R-5, 79 cm, and suggests an age of about 17.4 Ma based on biomagnetostratigraphic correlation in the mid-latitude North Atlantic (Gartner, 1992).

Table 5. Distribution of calcareous nannofossils, Hole 918D.

Age	Zone	Core, section interval (cm)	Abundance	Preservation	*Amaurolithus delicatus*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pelagicus*	*Discoaster brouweri*	*Discoaster druggii*	*Discoaster intercalaris*	*Discoaster quinqueramus*	*Discoaster* spp.	*Discoaster surculus*	*Discoaster variabilis*	*Helicosphaera carteri*	*Lithostramation perdurum*	*Pontosphaera multipora*	*Reticulofenestra gelida*	*Reticulofenestra perplexa*	*Reticulofenestra producta*	*Sphenolithus moriformis*
		152-918D																				
Pliocene	?	4R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		5R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		8R-CC	R	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		9R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		11R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		13R-1, 93	R	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	R	.
		13R-CC	R	P	.	.	.	R	.	.	.	.	.	.	.	R	.	.	.	.	R	.
early Pliocene	CN10-CN11	14R-1, 109	F	P	.	R	.	F	.	.	.	.	.	.	.	.	.	.	R	.	R	.
		14R-2, 65	C	P	.	R	.	C	.	.	.	.	R	.	.	R	.	.	F	.	R	.
		14R-CC	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.
		15R-1, 37	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.
		15R-1, 82	R	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		18R-1, 61	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		18R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		19R-CC	A	P	.	R	.	A	.	.	.	.	.	.	.	.	.	.	.	.	F	.
		21R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		22R-2, 75	C	P	.	R	.	C	.	.	.	.	R	.	.	.	.	.	C	.	R	.
		22R-3, 65	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		22R-CC	C	P	.	R	.	C	.	.	.	.	.	.	.	.	.	R	C	.	R	.
		23R-CC	F	P	.	R	.	F	.	.	.	.	.	.	.	.	.	.	F	.	.	.
		24R-1, 61	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.
		24R-2, 29	C	P	.	R	R	C	.	.	.	.	.	.	.	.	.	.	R	.	C	.
late Miocene	CN9	24R-3, 49	C	P	.	.	.	.	.	.	R	R	.	.	R	.	.	.	C	.	.	.
		24R-CC	A	P	.	.	.	C	R	?	R	R	.	R	R	.	.	.	C	.	F	.
	CN7-CN9	25R-1, 63	F	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	F	.
		25R-2, 27	F	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	F	.
		25R-3, 16	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		25R-4, 30	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		25R-5, 50	C	P	.	R	.	C	.	.	.	.	.	.	.	R	.	R	C	.	.	.
		25R-CC	R	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.
		27R-1, 66	F	P	.	R	.	F	.	.	.	.	R	.	.	.	.	.	F	.	.	.
		27R-2, 67	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		27R-3, 67	F	P	.	R	.	F	.	.	.	.	.	.	.	.	.	.	F	.	.	.
		27R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		28R-1, 67	R	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		28R-2, 60	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		28R-3, 63	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		28R-4, 6	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		28R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		29R-1, 67	F	P	.	.	.	F	.	.	.	.	.	.	.	.	.	.	F	.	.	.
		29R-2, 66	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		29R-CC	R	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.
		30R-CC	C	P	.	.	.	C	.	.	.	.	.	.	.	.	.	.	F	.	.	.
		31R-1, 64	R	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.
		31R-CC	R	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.
		32R-1, 65	C	P	.	.	.	C	.	.	.	.	.	.	.	.	.	.	F	.	.	.
		32R-CC	R	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.
		33R-1, 59	A	P	.	.	.	C	.	.	.	.	.	.	.	.	.	.	F	.	.	.
		33R-CC	C	P	.	.	.	F	.	.	.	.	.	.	.	.	.	.	F	.	.	.
		34R-1, 38	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		34R-CC	F	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.
		35R-1, 33	C	M	.	R	.	R	.	.	.	.	.	.	.	R	.	.	R	.	.	.
		35R-2, 23	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		35R-3, 21	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		35R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		36R-1, 74	A	M	?	R	R	F	.	.	.	.	.	.	.	.	.	.	R	F	.	.
		36R-2, 74	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.
		36R-3, 58	A	M	.	F	F	C	.	.	.	.	.	.	R	.	.	.	F	F	A	.
		36R-CC	A	P	.	F	R	C	.	.	.	.	.	.	R	R	R	.	R	F	A	.
		37R-1, 34	C	M	.	R	R	C	.	.	.	.	.	.	.	.	.	.	R	F	C	R
		37R-2, 22	A	M	.	R	R	C	.	.	.	.	.	.	.	.	.	.	F	C	A	R
		37R-2, 37	A	M	.	R	.	F	.	.	.	.	.	.	.	.	.	.	C	F	C	.
		37R-2, 46	A	M	.	R	.	C	.	.	.	.	.	.	R	.	.	.	C	C	C	R
		37R-2, 49	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		37R-2, 50	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		37R-2, 79	V	P	.	R	R	A	.	.	.	.	.	.	.	.	.	.	A	A	C	R
		37R-3, 36	V	P	.	R	.	A	.	.	.	.	.	.	.	.	.	.	F	A	A	.
		37R-3, 86	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		37R-3, 88	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Age	Zone	Core, section interval (cm)	Abundance	Preservation	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Calcidiscus premacintyrei*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Discoaster deflandrei*	*Discoaster intercalaris*	*Discoaster* spp.	*Discoaster variabilis*	*Helicosphaera carteri*	*Lithostramation perdurum*	*Pontosphaera multipora*	*Reticulofenestra gelida*	*Reticulofenestra producta*	*Reticulofenestra pseudoumbilicus*	*Sphenolithus conicus*	*Sphenolithus heteromorphus*	*Sphenolithus moriformis*
		152-918D																						
middle Miocene	CN5-CN6	37R-5, 25	A	P	.	.	.	R	A	.	.	.	.	.	.	R	.	.	F	F	C	.	.	R
		37R-5, 93	V	P	.	.	.	R	C	.	.	.	.	R	R	R	.	.	R	.	R	.	.	.
		38R-1, 59	C	P	.	.	.	C	F	.	.	.	.	.	.	R	.	.	F	.	.	.	.	R
		38R-2, 61	C	P	.	.	.	C	F	.	.	.	R	.	.	R	.	.	C	.	.	.	.	.
		38R-3, 62	A	P	.	.	.	C	C	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.
		38R-4, 17	A	P	.	.	.	C	C	.	.	.	R	.	.	.	.	.	A	.	.	.	.	.
		38R-4, 54	A	P	.	R	.	C	C	.	.	.	.	.	.	.	.	.	A	.	.	.	.	R
		38R-5, 15	A	P	.	.	.	C	C	.	.	.	.	R	.	R	.	.	C	.	.	.	.	R
		38R-6, 25	A	P	.	.	.	C	C	R	R	.	.	.	.	R	.	.	C	.	.	.	.	R
		38R-CC	C	P	.	.	.	C	C	.	R	.	.	.	.	.	.	.	C	.	.	.	.	.
		39R-1, 78	A	M	.	.	.	F	C	.	R	.	.	.	.	.	.	.	C	.	.	.	.	.
		39R-2, 95	A	M	.	R	.	F	C	R	R	.	.	.	.	.	.	.	F	.	.	.	.	R
		39R-3, 93	A	P	.	R	.	F	C	.	R	.	C	R	R	.	.	.	F	.	.	.	.	.
		39R-4, 18	V	M	.	.	R	F	A	R	R	.	F	.	R	R	.	.	F	.	.	.	.	.
		39R-5, 80	V	M	.	R	R	R	A	R	R	.	R	.	R	R	.	R	C	.	.	.	.	R
		39R-6, 60	V	M	.	.	R	R	A	R	R	.	R	R	R	F	.	.	A	.	.	.	.	F
		39R-CC	V	M	.	.	F	R	A	F	R	.	R	R	.	R	.	.	C	.	.	.	.	R
		40R-2, 41	A	P	.	R	R	F	A	R	R	.	R	.	.	F	.	.	F	.	.	.	.	.
		40R-3, 33	V	M	.	.	R	F	A	F	R	.	R	R	.	R	.	R	F	.	.	.	.	.
		40R-4, 50	V	M	R	.	R	F	A	C	F	.	F	.	.	R	.	.	.	.	.	.	.	.
		40R-6, 16	V	P	.	.	R	F	A	R	R	.	R	.	.	F	.	.	.	.	.	.	.	.
		40R-CC	V	P	.	R	R	F	A	R	R	.	F	.	.	R	.	R	.	.	.	.	.	R
		41R-1, 91	V	M	R	R	R	F	A	R	F	.	R	R	.	R	.	R	.	.	.	.	.	R
		41R-2, 9	V	M	.	.	.	F	A	F	C	.	.	R	.	R	.	.	.	.	.	.	.	.
		41R-3, 120	V	M	.	.	.	C	A	R	F	.	.	R	.	F	.	R	.	.	.	.	.	R
		41R-4, 109	V	M	.	.	R	C	A	F	C	.	R	.	R	F	.	R	.	.	.	.	.	.
		41R-5, 70	A	M	.	.	.	C	A	R	R	.	R	.	.	R	.	R	.	.	.	.	.	R
		41R-CC	V	M	.	R	R	F	A	R	R	.	R	.	.	R	.	R	.	.	.	.	.	R
		42R-1, 71	V	M	.	.	.	F	A	R	R	.	R	.	.	F	.	.	.	.	.	.	.	F
		42R-2, 65	V	M	.	.	.	R	A	R	R	.	R	.	R	F	.	R	.	.	.	.	.	.
		42R-3, 54	V	M	.	.	.	R	A	.	R	.	R	R	R	F	.	R	.	.	.	.	.	.
		42R-4, 63	V	M	.	.	R	R	A	R	R	.	R	R	.	R	.	R	.	.	.	.	.	.
		42R-5, 96	V	M	.	.	.	R	A	R	R	.	R	.	.	F	.	R	.	.	.	.	.	.
		42R-6, 68	V	M	.	.	R	F	A	R	F	.	R	.	.	R	.	.	.	.	.	.	.	.
	CN3-CN4	42R-CC	V	M	.	.	.	R	A	R	C	.	.	.	R	R	.	.	.	.	.	.	R	.
		43R-1, 72	V	M	.	.	R	.	A	.	C	.	.	R	.	F	.	R	.	.	.	.	R	R
		43R-2, 52	V	M	.	.	.	R	A	.	R	.	.	.	.	R	.	.	.	.	.	.	R	R
		43R-CC	V	M	.	.	.	.	A	.	.	.	.	R	.	R	.	.	.	.	.	.	R	R
		44R-1, 61	V	M	.	.	.	F	A	.	R	.	.	R	.	.	.	.	.	.	.	.	R	R
		44R-2, 67	V	M	R	.	R	F	V	.	C	.	.	R	.	.	R	.	.	.	.	.	R	R
		44R-3, 64	V	M	.	.	.	R	A	.	C	.	.	R	.	R	.	.	.	.	.	.	R	.
		44R-4, 66	V	M	.	.	.	R	A	.	C	.	.	R	.	R	.	.	.	.	.	.	.	R
early Miocene		44R-5, 65	V	M	.	.	R	F	A	.	R	.	.	R	.	R	R	.	.	.	.	.	.	.
		44R-CC	V	M	.	R	R	R	A	.	C	.	R	R	.	.	.	.	.	.	.	.	R	.
		47R-1, 49	C	P	.	.	.	R	C	.	F	.	R	R	R	.	.	.	.	.	.	.	.	.
		47R-2, 66	A	P	.	.	.	R	A	.	F	.	R	R	R	.	.	.	.	.	.	.	R	R
		51R-1, 69	A	P	.	.	.	.	A	.	R	.	.	R	.	.	R	.	.	.	.	.	R	.
		51R-2, 51	V	M	.	.	R	.	V	.	F	.	R	R	R	R	.	.	.	.	.	.	F	.
		51R-3, 75	A	M	.	R	.	R	A	.	R	.	R	F	.	F	.	.	.	.	.	.	R	.
		51R-4, 28	A	M	.	.	R	R	C	.	F	.	.	F	R	.	.	.	.	.	.	.	F	R
		52R-5, 79	V	M	.	.	R	.	V	.	C	.	.	R	R	F	.	R	.	.	.	.	F	R
		53R-1, 57	V	M	.	.	.	.	A	.	C	.	.	R	.	F	.	.	.	.	.	.	R	.
		53R-2, 62	A	M	.	.	.	.	C	.	C	.	.	R	.	.	.	.	.	.	.	.	R	R
		53R-3, 77	V	M	.	.	.	.	V	.	C	.	.	R	.	F	.	.	.	.	.	.	R	R
	CN1-CN2	53R-4, 77	V	M	.	.	.	.	V	.	A	.	.	F	.	.	.	.	.	.	.	.	.	.
		53R-5, 62	A	M	.	.	.	.	A	.	C	.	.	R	.	F	.	.	.	.	.	.	.	R
		53R-6, 71	A	M	.	.	.	.	A	.	C	.	.	R	R	R	.	.	.	.	.	.	.	R
		53R-CC	A	M	.	.	.	.	A	.	C	.	.	F	.	.	.	.	.	.	.	.	.	.
		54R-CC	A	M	.	.	.	.	A	.	C	.	.	F	.	.	.	.	.	.	.	.	.	R
		55R-1, 38	V	M	.	.	.	.	A	.	C	.	.	F	.	.	.	.	.	.	.	R	.	.
		55R-2, 62	V	M	.	.	.	.	V	.	R	.	.	F	.	.	.	.	.	.	.	R	.	.
		55R-3, 111	V	M	.	.	.	.	V	.	F	.	.	F	.	.	.	.	.	.	.	.	.	.
		55R-4, 74	V	M	.	.	.	.	V	.	R	R	.	C	.	R	.	.	.	.	.	.	.	R
		55R-5, 78	V	M	.	.	.	.	V	.	R	R	.	C	.	.	.	.	.	.	.	.	.	R
		55R-6, 24	V	M	.	.	.	.	V	.	.	R	.	F	.	.	.	.	.	.	.	.	.	.
		55R-CC	F	P	.	.	.	.	F	.	F	.	.	.	.	.	.	.	.	.	.	.	.	R
		57R-1, 87	V	M	.	.	.	.	V	F	A	R	.	F	.	.	.	.	.	.	.	.	.	R
		57R-2, 86	V	M	.	.	.	.	V	F	A	.	.	.	.	.	.	.	.	.	.	.	.	.
		57R-3, 34	A	P	.	.	.	.	A	R	R	.	.	R	.	.	.	.	.	.	.	.	.	.

Table 5 (continued).

Age	Zone	Core, section interval (cm)	Aundance	Preservation	*Chiasmolithus altus*	*Chiasmolithus eograndis*	*Chiasmolithus expansus*	*Chiasmolithus solitus*	*Coccolithus formosus*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Discoaster barbadiensis*	*Discoaster deflandrei*	*Discoaster distinctus*	*Discoaster kuepperi*	*Discoaster lodoensis*	*Discoaster* spp.	*Imperiaster obscurus*	*Markalius apertus*	*Markalius inversus*	*Nannotetrina cristatus*	*Neococcolithes dubius*	*Pontosphaera multipora*	*Reticulofenestra bisecta*	*Reticulofenestra daviesii*	*Reticulofenestra hillae*	*Reticulofenestra reticulata*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilicus*	*Sphenolithus moriformis*	*Toweius callosus*	*Transversopontis pulcher*	*Tribrachiatus orthostylus*	*Zygrhablithus bijugatus*
		152-918D																																	
late Oligocene	CP17-CP19	58R-CC	V	P	.	.	.	.	.	A	R	C	.	R	.	.	.	F	.	.	.	.	.	.	F	F	.	.	.	.	R	.	.	.	.
		60R-CC	V	M	.	.	.	.	.	V	R	A	.	R	.	.	.	R	.	.	.	.	.	R	R	R	.	.	.	.	.	.	.	.	.
		62R-1, 67	V	M	.	.	.	.	.	V	R	A	.	.	.	.	.	R	.	.	.	.	.	.	R	R	.	.	.	.	R	.	.	.	.
		62R-2, 65	V	M	.	.	.	.	.	V	.	C	.	.	.	.	.	.	.	.	.	.	.	R	R	R	.	.	.	.	.	.	.	.	.
		62R-CC	V	P	.	.	.	.	.	V	.	A	.	R	.	.	.	F	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.
		63R-1, 62	A	P	.	.	.	.	.	A	.	A	.	R	.	.	.	R	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.
		63R-2, 63	V	M	.	.	.	.	.	A	.	A	.	.	.	.	.	.	.	.	.	.	.	.	F	F	.	.	.	.	.	.	.	.	.
		63R-CC	C	P	.	.	.	.	.	C	.	C	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.
		64R-CC	R	P	.	.	.	.	.	R	.	R	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.
		66R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		68R-1, 33	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		68R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		71R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		72R-1, 37	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		72R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		74R-1, 57	V	M	.	.	.	.	.	A	C	F	.	.	.	.	.	.	.	.	.	.	.	.	C	C	.	.	.	.	F	.	.	.	.
		74R-1, 110	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	.
		75R-1, 56	V	M	C	.	.	.	.	A	C	C	.	R	.	.	.	.	.	.	.	.	.	.	C	A	.	.	.	.	R	.	.	.	.
		75R-2, 106	V	M	C	.	.	.	.	A	F	C	.	R	.	.	.	R	.	.	.	.	.	.	A	C	.	.	.	.	R	.	.	.	.
		75R-CC	V	M	C	.	.	.	.	A	F	C	.	.	.	.	.	R	.	.	.	.	.	.	A	.	.	.	.	.	R	.	.	.	.
		76R-1, 30	A	M	A	.	.	.	.	A	F	F	.	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	R	.	.	.	C
		76R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		77R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		78R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		79R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		80R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		83R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		84R-1, 90	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		84R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		86R-1, 17	C	P	R	.	.	.	.	C	R	F	.	R	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.
		86R-1, 30	F	P	R	.	.	.	.	C	R	F	.	.	.	.	.	.	.	.	.	.	.	.	F	R	.	.	F	.	.	.	.	.	.
		86R-1, 86	C	P	.	.	.	.	.	C	R	C	.	R	.	.	.	R	.	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	.
		86R-2, 64	A	P	.	.	.	.	.	A	R	F	.	.	.	.	.	F	.	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	.
middle Eocene	CP14a	88R-1, 2	A	M	.	.	.	R	R	A	.	.	1	.	.	.	.	.	.	.	.	.	R	.	R	C	R	F	C	R	.	.	.	.	R
	?	88R-1, 5	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		88R-1, 42	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	CP11-CP13	88R-1, 49	V	M	.	.	.	C	R	A	.	.	1	.	.	.	.	.	.	.	.	.	R	.	.	C	.	.	C	.	.	.	.	.	.
		88R-CC	V	M	.	.	.	C	R	A	.	.	.	.	.	.	.	.	.	.	.	1	R	.	.	A	.	.	C	.	.	.	.	.	A
		89R-CC	A	P	.	.	.	A	.	A	.	.	.	.	.	.	R	R	.	.	.	.	.	.	.	C	.	.	C	.	.	.	A	.	C
		90R-2, 39	A	M	.	.	.	A	.	A	.	.	.	.	1	R	F	.	.	.	R	.	R	.	.	R	.	.	A	.	.	.	A	.	R
		90R-3, 39	A	M	.	.	R	A	.	A	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	F	.	.	A	.	.	.	A	.	R
		90R-CC	A	P	.	.	R	A	.	A	.	.	.	.	.	R	R	.	.	R	.	.	R	.	.	C	.	.	F	.	.	.	A	.	R
		91R-1, 117	A	M	.	.	R	A	.	A	.	.	.	.	1	R	R	R	.	.	R	.	R	.	.	C	.	.	C	.	.	.	C	.	.
		91R-CC	C	P	.	.	.	C	.	C	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	F	.	.	C	.	.	.	C	.	.
early Eocene	CP10	92R-1, 57	R	P	.	.	.	R	.	R	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	R	.
		92R-CC	F	P	.	.	R	F	.	R	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	R	R	.
		93R-1, 40	R	P	.	.	.	R	.	R	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.
		93R-2, 9	R	M	.	.	.	R	.	R	.	.	.	.	.	R	R	.	R	.	.	.	R	.	.	.	.	.	.	.	.	.	R	R	.
	CP9b	93R-CC	F	P	.	R	.	C	.	F	.	.	.	.	.	F	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	R	R	F	.
?	?	95R-1, 23	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		95R-CC	R	P	.	.	.	R	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		96R-2, 65	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		96R-3, 64	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		96R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		97R-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Note: V = very abundant, A = abundant, C = common, F = few, R = rare, B = barren, M = moderate, and P = poor.

The CN2/CN3 zonal boundary, which is defined by the lowest occurrence of *Sphenolithus heteromorphus,* is drawn between Samples 152-918D-53R-3, 77 cm, and 53R-4, 77 cm. This boundary has an age of about 18.2 Ma according to biomagnetostratigraphic calibration at Deep Sea Drilling Project (DSDP) Site 609 (Gartner, 1992). The occurrence of *Sphenolithus conicus* in Samples 152-918D-55R-1, 38 cm, and 55R-2, 62 cm, suggests that the samples may belong to Zone CN1 (Perch-Nielsen, 1985; Gartner, 1992).

Upper Oligocene assemblages were encountered in the interval between Samples 152-918D-58R-CC and 86R-2, 64 cm. This is recognized by the presence of *Reticulofenestra bisecta* and *R. daviesii* in the absence of *R. umbilicus* and *Isthmolithus recurvus.* The highest occurrence of *Chiasmolithus altus* in Sample 152-918D-75R-1, 56 cm (Pl. 2, Fig. 11), may suggest an age around 27 Ma assuming that this datum has about the same age as in the southern high latitudes (Wei and Wise, 1992). The intervals from Cores 152-918D-66R through 72R and 76R through 84R are barren of calcareous nannofossils and were interpreted as turbidite deposits (see Larsen, Saunders, Clift, et al., 1994).

Chiasmolithus solitus, Reticulofenestra reticulata (Pl. 2, Fig. 12), and *R. umbilicus* are present in Sample 152-918D-88R-1, 2 cm. This indicates a Subzone of CP14a (middle Eocene) for the sample. Thus, a significant hiatus (8–10 m.y.) exists above this sample. Samples 152-918D-88R-1, 5 cm, and 88R-1, 42 cm, are barren of nannofossils. This interval contains volcanic ash, glauconites, and manganese oxides (Larsen, Saunders, Clift, et al., 1994), and may represent additional hiatuses.

The interval between Samples 152-918D-88R-1, 49 cm, and 91R-CC can be placed in Zones CP11–CP13 based on the absence of *Reticulofenestra umbilicus* and *Tribrachiatus orthostylus.* This age assignment is supported by the presence of *Nannotetrina cristata* in Sample 152-918D-88R-CC (Table 5; Pl. 3, Fig. 8), the highest occurrence of *Discoaster lodoensis* in Sample 152-918D-89R-CC, and the highest occurrence of *Discoaster kuepperi* in Sample 152-918D-90R-2, 39 cm (Pl. 3, Fig. 7).

The highest occurrence of *Tribrachiatus orthostylus* is in Sample 152-918D-92R-1, 57 cm, and this datum defines the top of Zone CP10. The base of this zone is placed below Sample 152-918D-93R-2, 9 cm, where the lowest occurrence of *D. lodoensis* is located. Sample 152-918D-93R-CC contains *T. orthostylus* and no *D. lodoensis,* and thus can be assigned to Subzone CP9b. *Imperiaster obscurus* occurs in Samples 152-918D-93R-2, 9 cm, and 93R-CC (Table 5). Müller (1976) previously proposed a zone defined by the range of this species. Her correlation of this zone with the early Eocene is confirmed by the standard nannofossil zones recognized here.

Site 919

Two holes were drilled at this site. Core 152-919A-10H overlaps with Core 152-919B-3H. A nannofossil range chart for the entire hole 152-919A and Cores 152-919B-3H through 8H is presented in Table 6.

Emiliania huxleyi occurs downhole to Sample 152-919A-4H-5, 72 cm, and suggests an age of 0.26 Ma, or oxygen isotope Stage 8, as confirmed by the oxygen isotope stratigraphy of Flower (this volume). The next useful datum is the highest occurrence of *Pseudoemiliania lacunosa* in Sample 152-919A-7H-5, 65 cm. This datum defines the CN14a/CN14b boundary with an age of 0.45 Ma.

Gephyrocapsa spp. (>4 µm) occurs sporadically down to the last core in Hole 919B and may suggest that the oldest sediment is still of Pleistocene age. Shipboard identification of *Calcidiscus macintyrei* in one sample (152-919B-6H-CC) led to the placement of Pliocene/Pleistocene boundary near this level. However, those specimens of "*C. macintyrei*" are problematic because they are actually smaller than 10 µm (Pl. 1, Fig. 4), and thus should be better placed in *Calcidiscus leptoporus.* This nannofossil stratigraphic interpretation is consistent with the strontium isotope stratigraphy (Israelson and Spezzaferri, this volume) and magnetostratigraphy (Ali and Vandamme, this volume), which suggests an age between the Brunhes and the Jaramillo (~0.9 Ma) for the bottom of Hole 918B.

SOME PALEOCLIMATIC AND PALEOCEANOGRAPHIC REMARKS

Eocene nannofossil assemblages from the Leg 152 sites are relatively diverse and contain a number of warm water taxa, such as several species of discoasters and *Coccolithus formosus.* The abundance of cool water taxa, such as species of *Chiasmolithus,* is relatively low. These assemblages closely resemble those in the middle and even low latitudes. The relatively low biogeographic gradients suggest that the thermal gradients between the high northern latitudes and the low latitudes during the Eocene were considerably lower than today. The high northern latitudes apparently cooled significantly by the early Oligocene, as most warm water taxa had disappeared from the area, and cool water taxa (*Chiasmolithus altus* and *Reticulofenestra daviesii*) had become prominent.

A comparison of the nannofossil assemblages from the northern high latitudes with those in the southern high latitudes (Pospichal and Wise, 1990; Wei and Wise, 1990) shows a relatively symmetric bipolar biogeographic distribution during the early and middle Eocene. By the late Eocene, warm water taxa, such as discoasters, virtually disappeared from the southern high latitudes, whereas they were still present in the northern high latitudes. This may suggest that a protocircumpolar current had been established around Antarctica by the late Eocene. Since this time, differences in nannofossil assemblages between the northern high latitudes and southern high latitudes progressively increased. Warm-water taxa were totally absent, and cool water taxa dominated the southern high latitudes in the Oligocene and Miocene, whereas warm-water taxa were present, although sporadically, through the Pliocene in the northern high latitudes. Nannofossils were virtually absent from the southern high latitudes in the Neogene whereas they persisted to the present in the northern high latitudes. All this clearly reflects the progressive intensification of the cold circum-polar current around Antarctica, a condition that did not exist in the northern high latitudes.

Discoasters are consistently present from Sample 152-918D-39R-3, 93 cm, downhole in the Miocene (Table 5). Above this sample, discoasters are virtually absent. This level is interpreted as the time when the cold East Greenland Current began to flow through the Denmark Strait, abruptly cooling the southeast Greenland Margin and driving warm-water dwelling discoasters away from the region. This event is dated as about 12 Ma based on the highest occurrences of *Cyclicargolithus floridanus* and *Calcidiscus premacintyrei* in the lower part of this core.

The onset of North Atlantic Deep Water (NADW) flow through the Irminger Basin, as identified by glauconitic hardgrounds in Cores 152-918D-37R and 38R (Larsen, Saunders, Clift, et al., 1994), occurred about 0.5 m.y. later than the interpreted onset of East Greenland Current, that is, 11.5 Ma based on the highest occurrence of *Coccolithus miopelagicus* in Core 152-918D-37R. This is in contrast to previous studies with estimates for the onset of NADW from ~34 Ma to 12.5 Ma based largely on carbon isotope data from middle to low latitudes (Schnitker, 1980; Blanc et al., 1980; Miller and Fairbanks, 1985; Wright et al., 1992).

The first indication of extensive glaciation on Greenland was identified by the lowest occurrence of dropstones in Core 152-918D-28R (Larsen, Saunders, Clift, et al., 1994). Shipboard nannofossil and planktonic foraminiferal biostratigraphy suggested an age of about 7 Ma or older for this core. This age is consistent with the present nannofossil data. The maximum age for Core 152-918D-28R is not well constrained as the next available datum downhole is the last occurrence of *Coccolithus mipelagicus* (11 Ma) in Core 152-918D-37R. It

Table 6. Distribution of calcareous nannofossils, Site 919.

Age	Zone	Core, section interval (cm)	Abundance	Preservation	*Arkhangelskiella cymbiformis*	*Chiasmolithus solitus*	*Calcidiscus leptoporus*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*Eiffellithus turriseiffelii*	*Emiliania huxleyi*	*Gephyrocapsa* spp. >4 µm	*Helicosphaera carteri*	*Micula decussata*	*Prediscosphaera cretacea*	*Pontosphaera multipora*	*Prinsius dimorphusus*	*Pseudoemiliania lacunosa*	*Reticulofenestra bisecta*	*Reticulofenestra daviesi*	*Stephanolithion bigotii*	*Watznaueria barnesae*	*Zygrhablithus bijugatus*
Pleistocene	CN15	**Hole 919A**																					
		1H-1, 67	C	G	.	.	R	.	.	.	C	R	.	.	.	.	.	.	.	.	.	.	.
		1H-3, 67	F	P	.	.	.	R	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.
		1H-5, 66	R	P	.	.	.	.	.	.	R	R	.	.	r	.	.	.	.	.	.	r	.
		1H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		2H-1, 66	C	M	.	.	.	.	.	.	C	R	.	.	.	.	.	.	.	.	.	.	.
		2H-3, 66	A	M	.	.	.	R	.	.	A	R	R	.	.	.	.	.	.	.	.	.	.
		2H-CC	A	M	.	.	R	R	.	.	C	A	.	.	.	.	.	.	.	.	.	.	.
		3H-1, 65	A	M	.	.	R	R	.	.	C	A	.	.	.	.	.	.	.	.	.	.	.
		3H-3, 65	C	M	.	.	.	R	.	.	F	C	.	.	.	.	.	.	.	.	.	.	.
		3H-5, 64	C	M	.	.	R	R	.	.	F	C	.	.	.	.	.	.	.	.	.	.	.
		3H-7, 64	R	P	.	.	.	R	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.
		3H-CC	R	P	.	.	.	R	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.
		4H-1, 65	R	P	.	.	.	R	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.
		4H-3, 65	C	P	.	.	R	C	.	r	R	F	R	.	.	.	.	.	.	.	.	.	.
		4H-5, 72	F	P	.	.	R	F	.	.	R	R	.	.	.	.	.	.	.	.	.	r	.
	CN14b	4H-CC	F	P	.	.	R	R	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
		5H-1, 65	F	P	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.
		5H-3, 64	R	P	r	.	.	.	.	.	.	R	.	.	r	.	r	.	r	.	.	r	.
		5H-5, 65	R	P	.	.	R	R	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
		5H-CC	F	P	.	.	R	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
		6H-1, 65	C	P	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.
		6H-3, 65	R	P	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
		6H-5, 65	A	M	.	.	.	C	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
		6H-CC	R	P	.	.	.	R	.	.	.	R	.	.	.	.	.	.	.	.	.	r	.
		7H-1, 65	A	M	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	.	r	.
		7H-3, 66	F	P	.	.	.	R	.	r	.	F	.	.	r	.	.	.	.	.	.	.	.
	CN13-CN14a	7H-5, 65	A	M	.	.	.	.	.	.	.	C	.	.	.	R	.	R	.	.	.	r	.
		7H-CC	A	M	.	.	.	.	.	.	.	A	.	.	.	.	.	R	.	.	.	.	.
		8H-1, 67	A	M	.	.	R	R	.	.	.	C	R	.	.	.	.	R	.	.	.	.	.
		8H-3, 67	C	M	.	.	.	.	.	.	.	C	.	.	.	.	.	R	.	.	.	.	.
		8H-5, 67	C	M	.	.	R	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.
		8H-CC	A	M	.	.	R	F	.	.	.	A	R	.	.	.	.	R	.	.	.	.	.
		9H-1, 65	A	M	.	.	R	R	.	.	.	A	.	.	r	.	.	R	.	.	.	.	.
		9H-3, 63	C	P	.	.	.	.	.	.	.	C	.	.	.	.	.	R	.	.	.	.	.
		9H-5, 63	F	P	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.
		9H-CC	A	M	.	.	.	.	.	.	.	A	.	.	.	.	.	R	.	.	.	r	.
		10H-1, 69	F	M	.	.	.	.	.	.	.	F	.	.	.	.	.	R	.	.	.	.	.
		10H-3, 29	C	M	.	.	R	.	.	.	.	C	R	.	.	.	.	R	.	.	.	.	.
		10H-5, 78	C	M	.	.	R	.	.	.	.	C	R	.	.	.	.	R	.	.	.	.	.
		10H-CC	R	P	.	.	.	.	.	.	.	R	R	.	.	.	.	R	.	.	.	.	.
		Hole 919B																					
		3H-1, 64	A	M	.	.	R	.	.	.	.	R	.	.	.	.	.	R	.	.	.	.	.
		3H-3, 66	C	M	.	.	R	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
		3H-5, 66	R	P	.	r	R	.	.	r	.	.	.	.	.	.	.	.	.	.	.	r	.
		4H-1, 65	R	P	r	.	.	R	.	.	.	.	.	r	r	.	.	.	.	r	r	r	.
		4H-3, 65	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		4H-5, 66	V	M	.	.	R	R	.	.	.	.	F	.	.	R	.	F	.	.	.	.	.
		4H-CC	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		5H-1, 64	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		5H-3, 66	F	M	.	.	R	.	.	.	.	F	R	.	.	.	.	F	.	.	.	.	.
		5H-5, 65	R	P	.	.	R	R	.	.	.	R	R	.	.	.	.	R	.	.	.	.	.
		5H-CC	R	P	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
		6H-1, 64	R	P	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	r	.
		6H-3, 67	B		.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	r	r
		6H-5, 63	A	M	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.
		6H-7, 65	A	M	.	.	F	R	.	.	.	.	R	.	.	.	.	.	.	.	.	r	.
		6H-CC	A	M	.	.	F	R	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.
		7H-1, 66	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		7H-3, 66	B		.	.	.	.	.	r	.	.	.	.	.	.	r	.	.	.	.	r	.
		7H-5, 66	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		7H-CC	F	M	.	.	R	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
		8H-1, 107	R		.	.	R	.	.	.	.	R	.	.	.	.	.	R	.	.	.	.	.
		8H-3, 44	B		r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		8H-5, 60	R	P	.	.	.	R	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
		8H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Note: V = very abundant, A = abundant, C = common, F = few, R = rare, B = barren, M = moderate, and P = poor.

is clear though that the ice-rafted detritus from Site 918 represents the oldest Greenland glacial record ever observed.

Cretaceous nannofossils are sporadically present in the Pleistocene sediments (see Table 6) but are absent in older sediments. There was no Cretaceous nannofossil deposition in the Canadian Arctic, Greenland, Greenland-Norwegian Sea, or the Arctic Ocean. The Cretaceous nannofossils most likely were ice-rafted from northwest Europe. Indeed, significantly more Cretaceous nannofossils (up to 100% of the nannofossil assemblages) have been found in the Pleistocene sediments of Leg 104 sites in the Norwegian Sea, whereas Cretaceous nannofossils are virtually absent in older sediments in these sites (Donnally, 1989; Henrich and Baumann, 1994; Wei, unpubl. data). The reworked nannofossils are most abundant in the glacial/deglacial intervals (Henrich and Baumann, 1994). Furthermore, Cretaceous nannofossils have been found in the Heinrich layers at DSDP Site 609 (50°N; 24°W) in the North Atlantic Ocean (Wei, unpubl. data). The Heinrich layers are generally believed to have been the results of massive discharges of icebergs during colder episodes of glacial periods (Broecker et al., 1992; Bond et al., 1992; Fronval et al., 1995). All of this suggests that the reworked Cretaceous nannofossils were transported by icebergs. Such icebergs most likely originated from the North Sea-Denmark area, where nannofossil-rich chalk facies are present and extensively exposed.

The presence of Cretaceous nannofossils in the Pleistocene (<0.9 Ma) and their virtual absence in older sediments both on the East Greenland Margin and in the Norwegian Sea may suggest that extensive discharge of icebergs from the North Sea-Denmark area began in the middle Pleistocene, around 0.9 Ma. This is the time of the so called "Mid-Pleistocene Climate Revolution" (Berger et al., 1993; Berger and Jansen, 1994), when climate changed from prominently 41-k.y. cycles (obliquity-related forcing) to prominently 100-k.y. cycles (eccentricity-related forcing). This change in climate cyclicity could be due to an increase of marine-based ice sheets like the one grounded in the North Sea area. The increased instability of the marine-based ice sheets and the fluctuations of the albedos could amplify the eccentricity forcing, causing the prominently 100-k.y. climate cycles.

SUMMARY

The distribution of calcareous nannofossils in Leg 152 sites has been documented in range charts, which forms the basis for biostratigraphic interpretations. The nannofossil biostratigraphy provides the primary means of dating the sediments. The commencement of marine sedimentation at Site 918 in the Irminger Basin is dated as the early Eocene (52–53 Ma), shortly (<3 m.y.) after the youngest basalt sequence was formed above sea level (Larsen, Saunders, Clift, et al., 1994). Marine sedimentation at Site 917 on the continental shelf began later, in the middle Eocene (~40–42 Ma), even though the basalts here were formed earlier than those at Site 918. Nannofossil biostratigraphy reveals a number of hiatuses, including a long one (middle Eocene–late Oligocene) in the Irminger Basin Site 918 that may be caused by strong local tectonic activities.

Nannofossil assemblages of the Eocene are similar to those in the lower latitudes as well as those in the southern high latitudes. This suggests significant warmth in the high latitudes during the Eocene. Species diversity generally decreased through the later part of the Cenozoic, in response to a cooling trend. Discoasters, which are considered as warm water taxa, persisted to the Pliocene at these northern high latitudes, in contrast to southern high latitudes, where discoasters totally disappeared by the late Eocene. The last consistent occurrence of discoasters at about 12 Ma in the Irminger Basin may suggest that the cold East Greenland Current began to flow through the Denmark Strait. Other important events dated by the nannofossil biostratigraphy include the onset of NADW at about 11.5 Ma and the earliest dropstones in the Irminger Basin at about 7 Ma or older.

The stratigraphic distribution of reworked Cretaceous nannofossils in the Irminger Basin is similar to that in the Norwegian Sea and may suggest that extensive discharge of icebergs from the North Sea-Denmark area began in the middle Pleistocene, and that the icebergs not only drifted to the Norwegian Sea but also reached the Irminger Basin during glacial periods.

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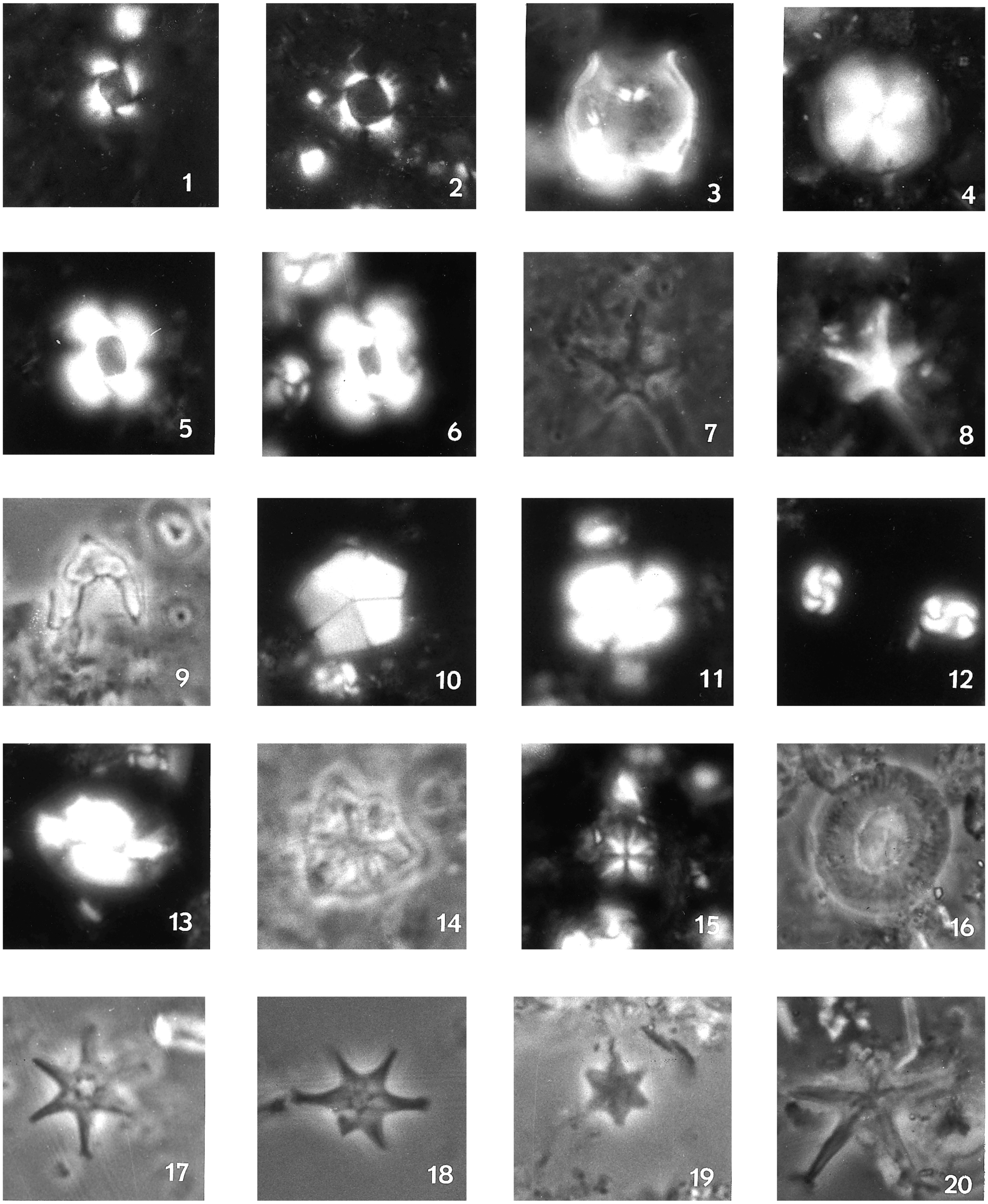

Plate 1. **1, 2.** *Pseudoemiliania lacunosa,* 2000×, Sample 152-919A-7H-5, 65 cm. **3.** *Scyphosphaera* sp., 2000×, Sample 152-919A-8H-1, 67 cm. **4.** *Calcidiscus leptoporus,* 2700×, Sample 152-919B-6H-CC. **5, 6.** *Reticulofenestra gelida,* 2700×, Sample 152-918D-14R-1, 109 cm. **7, 8.** *Discoaster quinqueramus,* 2700×, Sample 152-918D-24R-3, 49 cm. **9.** *Amaurolithus delicatus*? 2700×, Sample 152-918D-24R-CC. **10.** *Braarudosphaera bigelowii,* 2700×, Sample 152-918D-36R-CC. **11.** *Reticulofenestra perplexa,* 2700×, Sample 152-918D-36R-CC. **12.** *Reticulofenestra producta,* 2700×, Sample 152-918D-36R-CC. **13.** *Helicosphaera carteri,* 2700×, Sample 152-918D-36R-CC. **14.** *Lithostramation perdurum,* 2700×, Sample 152-918D-36R-CC. **15.** *Sphenolithus moriformis,* 2700×, Sample 152-918D-36R-CC. **16.** *Coccolithus miopelagicus,* 1500×, Sample 152-918D-38R-4, 54 cm. **17, 18.** *Discoaster intercalaris,* 2700×, Sample 152-918D-38R-2, 61 cm. **19.** *Discoaster* sp. 1, 2700×, Sample 152-918D-37R-5, 93 cm. **20.** *Discoaster* sp. 2, 2700×, Sample 152-918D-39R-3, 93 cm.

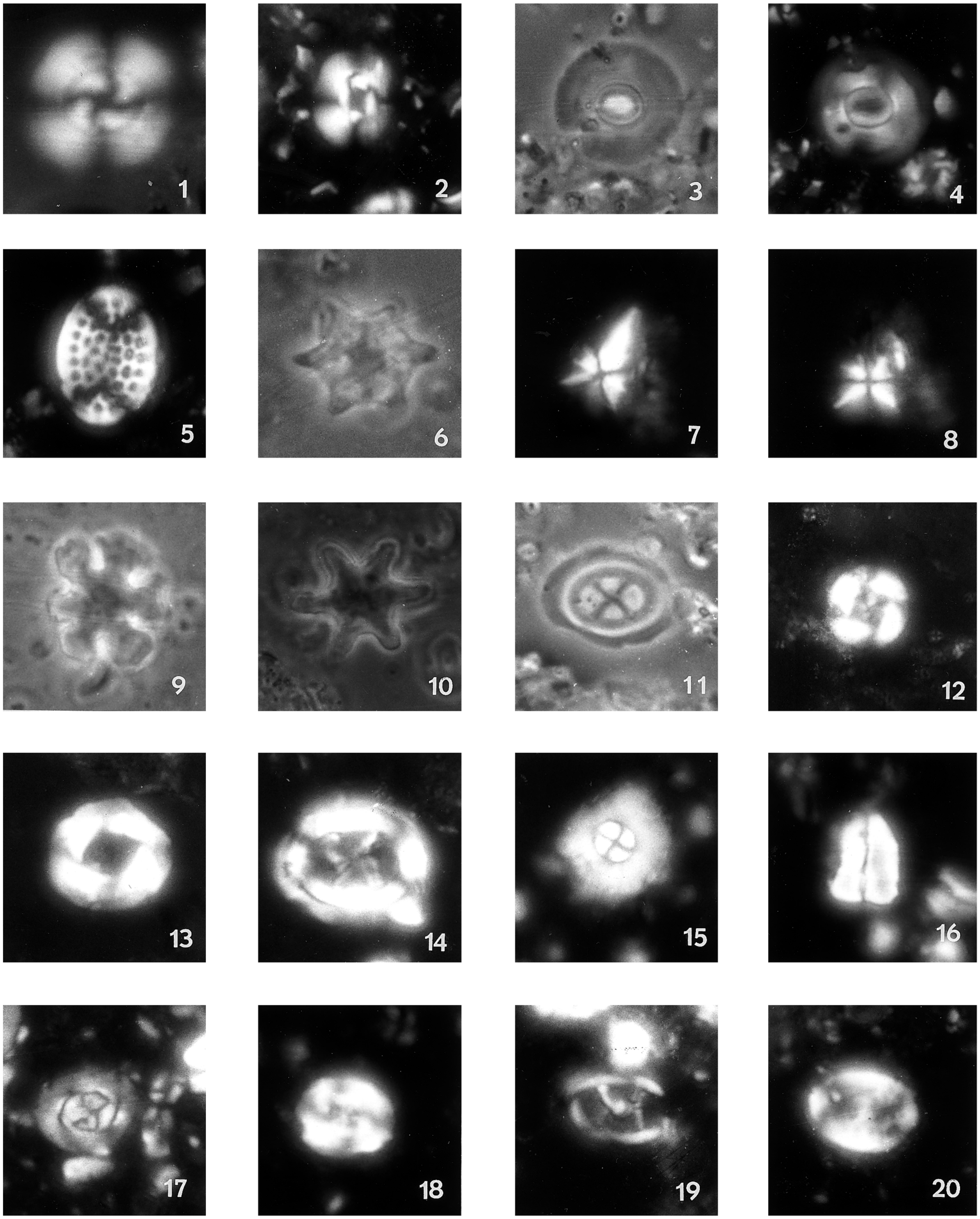

Plate 2. **1.** *Cyclicargolithus abisectus,* 2300×, Sample 152-918D-39R-2, 95 cm. **2.** *Cycllicargolithus floridanus,* 2300×, Sample 152-918D-39R-5, 80 cm. **3, 4.** *Calcidiscus premacintyrei,* 2300×, Sample 152-918D-39R-4, 18 cm. **5.** *Pontosphaera multipora,* 2300×, Sample 152-918D-39R-4, 18 cm. **6.** ?*Catinaster* sp., 2300×, Sample 152-918D-43R-2, 52 cm. **7, 8.** *Sphenolithus heteromorphus,* 2300×, Sample 152-918D-43R-1, 72 cm. **9.** *Discoaster* sp. 3., 2300×, Sample 152-918D-54R-CC. **10.** *Discoaster druggii*? 1500×, Sample 152-918D-24R-CC. **11.** *Chiasmolithus altus,* 2000×, Sample 152-918D-75R-1, 56 cm. **12.** *Reticulofenestra reticulata,* 2300×, Sample 152-918D-88R-1, 2 cm. **13.** *Reticulofenestra samodurovii,* 2300×, Sample 152-918D-88R-1, 2 cm. **14.** *Chiasmolithus solitus,* 2300×, Sample 152-918D-88R-1, 2 cm. **15.** *Markalius inversus,* 2700×, Sample 152-918D-88R-CC. **16.** *Zygrhablithus bijugatus,* 2300×, Sample 152-918D-88R-CC. **17.** *Clausicoccus fenestratus,* 2700×, Sample 152-918D-88R-CC. **18.** *Reticulofenestra daviesii,* 2700×, Sample 152-918D-88R-CC. **19.** *Neococcolithes dubius,* 2700×, Sample 152-918D-89R-CC. **20.** *Transversopontis pulcher,* 2700×, Sample 152-918D-89R-CC.

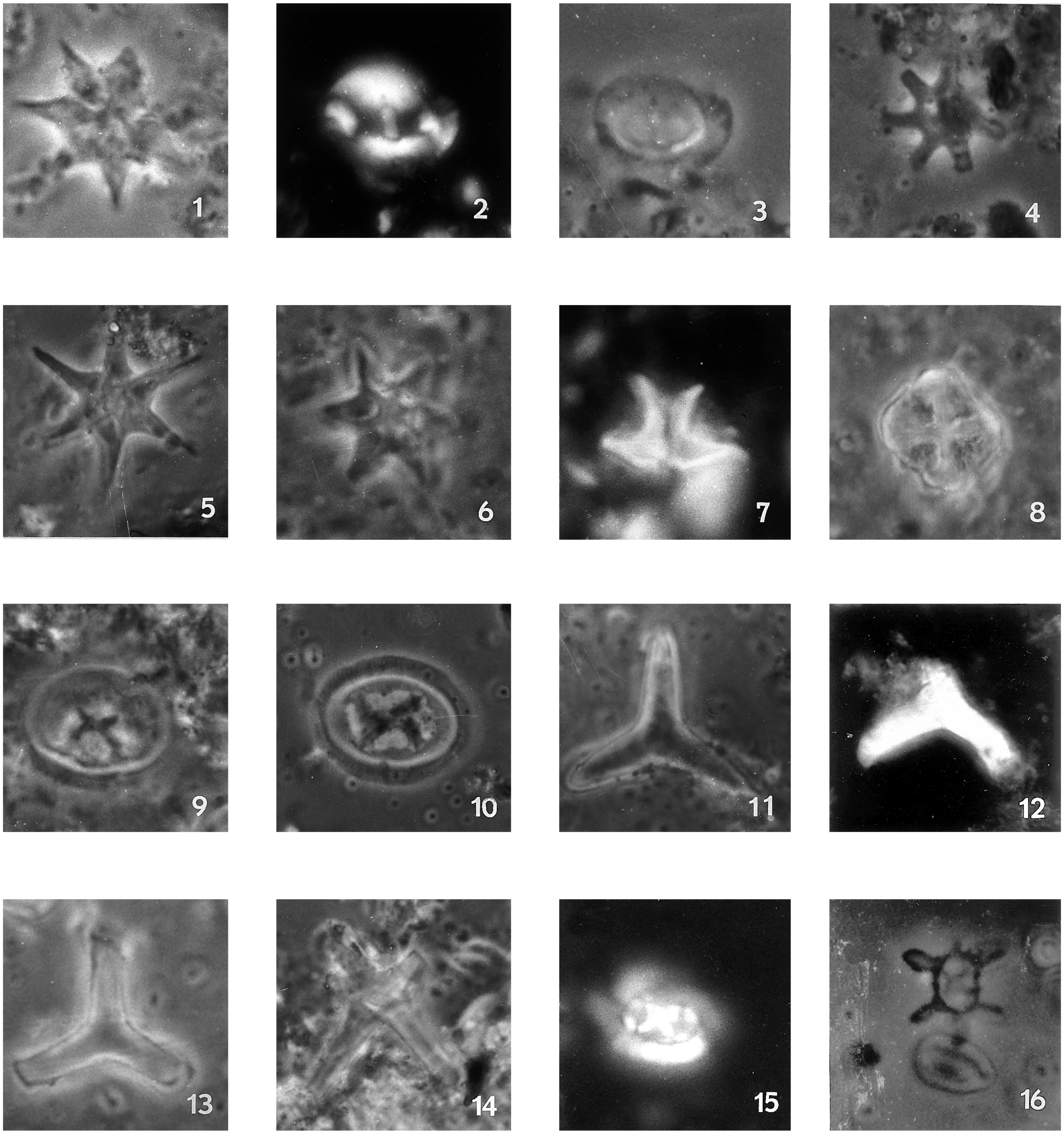

Plate 3. **1.** *Discoaster saipanensis,* 2300×, Sample 152-915A-15R-CC. **2, 3.** *Helicosphaera seminulum,* 2300×, Sample 152-918D-89R-CC. **4.** *Discoaster* sp. 4, 2300×, Sample 152-918D-89R-CC. **5, 6.** *Discoaster lodoensis,* 1500×, Sample 152-918D-90R-CC. **7.** *Discoaster kuepperi,* 2300×, Sample 152-918D-90R-2, 39 cm. **8.** *Nannotetrina cristata,* 2300×, Sample 152-918D-88R-CC. **9.** *Chiasmolithus expansus,* 2000×, Sample 152-918D-90R-3, 39 cm. **10.** *Chiasmolithus eograndis,* 2000×, Sample 152-918D-93R-CC. **11, 12, 13.** *Tribrachiatus orthostylus,* 1500×. (11, 12) Sample 152-92R-1, 57 cm, and (13) Sample 152-918D-93R-CC. **14.** *Imperiaster obscurus,* 1500×, Sample 152-918D-93R-CC. **15.** *Prediscosphaera cretacea* (reworked Cretaceous species), 2300×, Sample 152-919B-6H-3, 67 cm. **16.** *Stephanolithion bigotii* (the only reworked Jurassic species observed in this study), 2300×, Sample 152-919B-4H-1, 65 cm.

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