

14. TERTIARY AND QUATERNARY CALCAREOUS NANNOPLANKTON BIOSTRATIGRAPHY OFF PERU (ODP LEG 112)¹

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ABSTRACT

Positions of all cores recovered during Ocean Drilling Program (ODP) Leg 112 off Peru are shown in the standard calcareous nannoplankton zonation. Stratigraphic and regional occurrences and preservation of calcareous nannoplankton are discussed for all sites, and fossil lists are presented for selected samples. Late Miocene to Holocene nannoplankton assemblages in the upwelling systems off Peru and scattered blooms, especially of *Gephyrocapsa* species and *Helicosphaera carteri*, are described. *Scyphosphaera* assemblages found in late Miocene Zone NN9 (*Discoaster hamatus* Zone) at Site 684 are compared with similar assemblages from Gabon on the west coast of Africa. Remarkable subsidence is indicated by early and middle Eocene nearshore and shallow-water nannoplankton assemblages for Sites 682, 683, and 688. Besides several local hiatuses, major regional hiatuses were noted at Site 682 (upper Eocene, uppermost middle Eocene, and part of the lower and middle Oligocene missing), Site 683 (uppermost middle Eocene to lower part of the middle Miocene missing), and Site 688 (part of the middle Eocene, uppermost middle Eocene to upper Oligocene, and parts of the lower and middle Miocene missing).

INTRODUCTION

During ODP Leg 112, 10 sites (679 through 688) were occupied and 27 holes drilled in the forearc basins and continental slope of the convergent margin off Peru (Fig. 1). The main objectives of Leg 112 were (1) investigation of the paleoceanographic conditions of the upper-slope basin deposits in connection with fluctuations of the upwelling systems, (2) reconstruction of the vertical movement of the continental margin, (3) study of the nature and age of the transition zone that lies between the lower-slope accretionary complex and the metamorphic basement, and (4) evaluation of the geochemical processes connected with the upwelling system and diagenesis in organic carbon-rich sediments. Most sites were aligned along two transects at 9°S (Sites 684, 683, and 685) and near 11°S (Sites 681, 680, 679, 688, and 682). Two additional sites were occupied in the Pisco Basin (Sites 686 and 687).

All holes yielded calcareous nannoplankton, although barren intervals occurred frequently in the late Miocene to Holocene sequences in the upwelling areas. Paleogene sediments were recovered only in the deeper Sites 682, 683, and 688 (Table 1). The observed calcareous nannoplankton assemblages are discussed below, and fossil lists of selected samples for all sites are represented in Tables 2 through 8 and Tables 10 through 12.

CALCAREOUS NANNOPLANKTON ZONATION

For Tertiary and Quaternary sediments, the standard calcareous nannoplankton zonation (Martini, 1971; Martini and Müller, 1986) is used. However, because sphenoliths are poorly preserved or missing in the nannoplankton assemblages of middle to late Oligocene age at Site 682, the following deviation has been necessary:

¹ Suess, E., von Huene, R., et al., 1990. *Proc. ODP, Sci. Results*, 112: College Station, TX (Ocean Drilling Program).

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³ Superscript asterisk indicates that top marker has been changed, subscript asterisk, that base marker has been changed.

NP24/NP25 *³

(combined *Sphenolithus distentus*/*S. ciproensis* Zone)³

Substitute definition. Interval from the first occurrence of *Cycli-cargolithus abisectus* (Müller) to the last occurrences of *Zygrhablithus bijugatus* (Deflandre) and *Dictyococcites dictyodus* (Deflandre).

Remarks. Similar difficulties exist in high latitudes, where sphenoliths are frequently missing in the middle and late Oligocene interval, and *Helicosphaera recta* (Haq) is not represented in most of the calcareous nannoplankton assemblages. In these areas, *C. abisectus* and *Z. bijugatus* are taken as substitute species (Müller, 1976, 1979; Martini, 1979, 1986).

Correlations between the low-latitude coccolith zonation of Okada and Bukry (1980) and standard nannoplankton zonation are outlined in Tables 4 and 5 of Martini and Müller's study (1986) of current Tertiary and Quaternary calcareous nannoplankton stratigraphy.

Data for calibration of Tertiary and Quaternary zonal boundaries to absolute ages were taken from Backman and Shackleton (1983), Berggren et al. (1985), and Martini (1986). Concerning the misleading version of the Oligocene in Berggren et al. (1985), the reader is referred to Martini et al.'s discussion (1986) of the threefold subdivision of the Oligocene.

SITE SUMMARIES

**Site 679 (11°03.52'S, 78°15.92'W;
water depth, 439.5 m)**

Five holes were drilled at Site 679, located on the outer continental shelf of Peru, to sample sediments beneath a modern upwelling plume. The youngest sediments are present in Cores 112-679C-1H and -679D-1H, where a *Gephyrocapsa* spp./*Helicosphaera carteri* Assemblage also contains *Emiliana huxleyi*, indicating the Holocene calcareous nannoplankton Zone NN21 (*Emiliana huxleyi* Zone), which is younger than 0.275 Ma.

The *Gephyrocapsa* spp./*Helicosphaera carteri* Assemblage was found in Samples 112-679A-1H, CC, -679B-1H, CC, -2H, CC, -3H, CC, and in Core 112-679D-2H. Because *E. huxleyi* could not be found, these samples are placed in the late Pleistocene nannoplankton Zone NN20 (*Gephyrocapsa oce-*

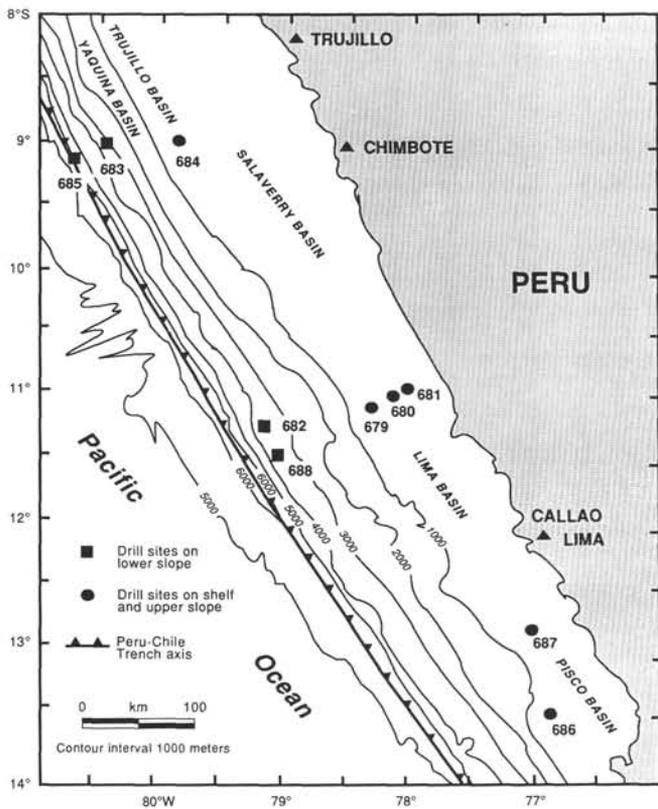


Figure 1. Location of sites drilled during Leg 112 in the eastern South Pacific off Peru. Contours in meters.

onica Zone), above the last occurrence of *Pseudoemiliana lacunosa* (0.47 Ma). An assemblage dominated by *Coccolithus pelagicus* is present in Samples 112-679B-4H, CC, -679C-2H, CC, -4H, CC, -5H, CC, and -679D-4H, CC, indicating cold-water conditions. A few *Gephyrocapsa* specimens, *Cyclococcolithus leptoporus*, and rare *Helicosphaera sellii* also occur in some of these samples. As *Pseudoemiliana lacunosa* probably is missing in this particular assemblage, these samples are placed only tentatively in nannoplankton Zone NN19 (*Pseudoemiliana lacunosa* Zone).

Several samples between the *Coccolithus pelagicus* Assemblage and the underlying *Reticulofenestra pseudoumbilicalis/Coccolithus pelagicus* Assemblage were barren. These included Samples 112-679D-5H, CC, -6H, CC, and -7H, CC, as well as Samples 112-679C-3H, CC, and -6H, CC. Cores 112-679D-9H, -10H, -12H to -18X, and -20X within the *Reticulofenestra pseudoumbilicalis/Coccolithus pelagicus* Assemblage also were barren. The *R. pseudoumbilicalis/C. pelagicus* Assemblage was observed in Samples 112-679B-8H, CC, -9H, CC, -12H, CC, -13H, CC, 112-679C-7H, CC, -8H, CC, and in Cores 112-679D-8H, -11H, and Sample 112-679D-12H-1, 61–62 cm. This assemblage is not younger than 3.5 Ma because the last occurrence of *R. pseudoumbilicalis* marks the top of calcareous nannoplankton Zone NN15 (*Reticulofenestra pseudoumbilicalis* Zone). These samples are tentatively placed in the early Pliocene nannoplankton Zone NN15, although owing to the low diversity they may be older, indicating a possible hiatus just above this level. In Core 112-679D-19X, a sudden occurrence of well-preserved *R. pseudoumbilicalis*, together with *Sphenolithus abies*, *Cyclococcolithus leptoporus*, and *C. pelagicus* in an otherwise barren sequence between Cores 112-679D-12H and -679D-27X again was noted (Table 2).

Samples from Hole 679E (245.3 to 359.3 mbsf) are barren of calcareous nannoplankton, with the exception of some levels within Cores 112-679E-11X and -12X. This meager assemblage contains some discoasters besides *Reticulofenestra pseudoumbilicalis*, *Coccolithus pelagicus*, and *Helicosphaera carteri*. These include *Discoaster exilis* and *Discoaster variabilis*. In Sample 112-679E-12X, CC, *Cyclicargolithus cf. floridanus* was observed, and this assemblage is tentatively placed in the middle Miocene calcareous nannoplankton Zone NN6 (*Discoaster exilis* Zone).

**Site 680 (11°03.90'S, 78°04.67'W;
water depth, 252.5 m)**

Three holes were drilled at Site 680, which is centered on an east-west transect of three sites across the coastal upwelling deposits off Peru. The deepest hole (680B) terminated at 195.5 mbsf.

In Hole 680A, calcareous nannoplankton was found only in the upper five cores in rather monotonous assemblages at various levels. Assemblages in Cores 112-680A-1H to -4H include *Gephyrocapsa oceanica*, *Gephyrocapsa aperta*, *Helicosphaera carteri*, *Cyclococcolithus leptoporus*, and others (Table 3), and belong to nannoplankton Zone NN20 (*Gephyrocapsa oceanica* Zone). However, Sample 112-680A-1H-4, 98–99 cm, in which some specimens of *Emiliana huxleyi* were noted, should be placed in nannoplankton Zone NN21 (*Emiliana huxleyi* Zone). In Sample 112-680A-5H-4, 22–23 cm, a few specimens of *Pseudoemiliana lacunosa* were found, indicating that this level is not younger than nannoplankton Zone NN19 (*Pseudoemiliana lacunosa* Zone). Cores 112-680A-6H to -10H are barren of calcareous nannoplankton.

A similar distribution pattern was found in Hole 680B. Quaternary calcareous nannoplankton is present in the upper five cores. The lowest occurrence of nannoplankton was noted in Sample 112-680B-7H, CC, but in this case, may represent downhole contamination. All other cores down to the terminal Core 112-680B-22X are barren of calcareous nannoplankton. A mass occurrence of calcareous nannoplankton was found in a pale, 4-mm-thick layer at 112-680B-2H-1, 105–106 cm, and represents a bloom of *Helicosphaera carteri* and *Gephyrocapsa oceanica*, of which coccospheres also are preserved. Because rare *Emiliana huxleyi* also were noted, this assemblage still belongs to nannoplankton Zone NN21 (*Emiliana huxleyi* Zone) and is documented in Pl. 1, Figs. 1 through 3.

Dolomite rhombs are seen frequently in several samples from both holes, and a relationship between these and the abundance of calcareous nannoplankton was noted. With an increase of dolomite rhombs, nannoplankton assemblages become scarce and finally disappear (Table 3). Core-catcher Samples 112-680C-1H to -4H were barren of calcareous nannoplankton, with Sample 112-680C-3H-CC showing abundant dolomite rhombs.

**Site 681 (10°58.60'S, 77°57.46'W;
water depth, 150.5 m)**

Three holes were drilled at Site 681, which is the most landward site of a transect across the coastal upwelling system off Peru at 11°S. Hole 681A (the deepest hole) was terminated at 187.0 mbsf.

Calcareous nannoplankton was found in meager assemblages at various levels in the Quaternary part of Site 681. The most common species observed are *Gephyrocapsa aperta*, *Gephyrocapsa oceanica*, *Helicosphaera carteri*, and *Cyclococcolithus leptoporus*. The cold-water species *Coccolithus pelagicus* was observed in only a few samples (Table 4). This

Table 1. Calcareous nannoplankton stratigraphy of Sites 679 to 688.

		679B	679C	679D	679E	680A	680B	681A	681B	681C	682A	683A	683B	684A	684B	684C	685A	686A	686B	687A	687B	688A	688E
Quaternary	NN 21	1	1	1		1	1-2	1	1	1	1	1											1
	NN 20	1-3	1	2		1-4	2-4	1-7	1-7	1-8	1-3	1-7		1-2	1		3-7	8		1 6-7			1-4
	NN 19	4	2-5	3-5		5	5	9-14	9-15	10		7-9 (14-15)					8-21	10, 12 16-22	25	14 17-22	9, 16 19-22		5-22
Upper Pliocene	NN 18											19											
	NN 17																						
	NN 16													4-6	(3-4)	4, 6							
Lower Pliocene	NN 15	8-13	7-8	8, 11				(197)			8												
	NN 14			12, 19 7																			
	NN 13																						
	NN 12																						
Upper Miocene	NN 11																						23-25
	NN 10																						26 38
Middle Miocene	NN 9													7-14		8-13							
	NN 8																						
	NN 7																						
	NN 6				11-13																		
	NN 5										32-33	40-45	1-5										
Lower Miocene	NN 4										34												
	NN 3										35												
	NN 2										35												
	NN 1										36												22-25
Upper Oligocene	NP 25										37-41												
	NP 24																						
Middle Oligocene	NP 23																						
Lower Oligocene	NP 22																						
	NP 21										44												
Upper Eocene	NP19/20																						
	NP 18																						
Middle Eocene	NP 17												7										
	NP 16										45-48		7-9										27-36
	NP 15																						
Lower Eocene	NP 14																						36
	NP 13																						36-45

Note: Numbers refer to cores. Hiatuses based on calcareous nannoplankton striped. Zones = standard nannoplankton zones.

species is much more common at the offshore Site 679 than at either Sites 680 or 681.

Minor blooms of *Gephyrocapsa* species, including well-preserved coccospheres, were found in Samples 112-681A-1H-4, 125 cm, -681A-4H-3, 117 cm, and -681B-4H-2, 98-99 cm (Pl. 1, Fig. 4). Calcareous nannoplankton is present only in low diversity and in low individual numbers and is further diminished by the carbonate uptake during dolomite formation, which was already noted at Site 680.

Stratigraphically, Cores 112-681A-1H to -14X, Cores 112-681B-1H to -15X, and all 10 cores of Hole 681C can be placed in the Quaternary. In Sample 112-681A-1H-1, 89-90 cm, rare *Emiliania huxleyi* were noted, indicating that this level belongs to nannoplankton Zone NN21 (*Emiliania huxleyi* Zone). The remaining samples from Core 112-681A-1H down to the upper part of Core 112-681-7H can be placed in nannoplankton Zone NN20 (*Gephyrocapsa oceanica* Zone). Samples 112-681A-9H, CC, -681A-10H-3, 50-51 cm, -681B-9H, CC, and -681B-10H, CC, contain *Pseudoemiliania lacunosa*, and thus are no younger than nannoplankton Zone NN19 (*Pseudo-*

emiliania lacunosa Zone). *Cyclococcolithus macintyreii* was found in Sample 112-681B-14X, CC, indicating that this level is no younger than the lowest part of Zone NN19 (= top of Subzone NN19a = last occurrence of *Cyclococcolithus macintyreii*, 1.45 Ma). This seems in good agreement with the silicoflagellate data for this hole (Martini, this volume) because the earliest occurrence of the silicoflagellate *Distephanus bioctonarius bioctonarius* was noted in Sample 112-681B-13X, CC. Several intervals barren of calcareous nannoplankton were found in all holes, including Cores 112-681A-15X to -18X and -20X (Table 4).

Near the bottom of Hole 681A, rare displaced *Reticulofenestra pseudoumbilica*, *Dictyococcites dictyodus*, and *Cyclicargolithus floridanus* were observed in an otherwise Quaternary nannoplankton assemblage in Sample 112-681A-19X, CC. However, the presence of *Reticulofenestra pseudoumbilica* also may indicate that this level represents the early Pliocene with displaced Eocene or Oligocene nannoplankton and with downhole contamination from the Quaternary resulting from drilling difficulties.

Table 2. Distribution of calcareous nannoplankton in selected samples from Holes 679D and 679E and indication of standard nannoplankton zones.

	<i>Coccolithus pelagicus</i>	<i>Cyclargolithus floridanus</i>	<i>Cyclococcolithus leptoporus</i>	<i>Cyclococcolithus macintyreii</i>	<i>Discoaster exilis</i>	<i>Discoaster variabilis</i>	<i>Emiliana huxleyi</i>	<i>Gephyrocapsa aperta</i>	<i>Gephyrocapsa oceanica</i>	<i>Helicosphaera carteri</i>	<i>Helicosphaera sellii</i>	<i>Helicosphaera</i> sp.	<i>Reticulofenestra pseudumbilica</i>	<i>Reticulofenestra</i> (small)	<i>Rhabdosphaera</i> sp.	<i>Sphenolithus abies</i>	Preservation	Nannoplankton Zones	
D 1H-2, 102-104 cm	barren																		
1H, cc								F	C	C	F					R	H/G	NN 21	
2H-6, 89-91 cm	R							R	R									M	NN 20
2H, cc	R							R	R									M	
3H-4, 34-35 cm	F	R	R					F			R							H/G	
3H, cc	R	R	R					R										M	
4H-3, 109-110 cm	F							R	R									M	-NN 19
4H, cc	F							R	R									H/G	
5H-1, 85-86 cm	C	R	R					F	R		F							M/G	
5H-3, 94-95 cm	C		R															G	
5H, cc to 7H, cc	barren																		
8H-2, 105-106 cm	R											R	R					G	-NN 15
8H-4, 108-109 cm	R											F	F			R	G		
8H, cc	R											C	F					G	
9H-2 to 10H, cc	barren																		
11H-2, 98-99 cm	R									R		F	R		R	G			NN 15 or older
11H, cc	R														R	G			
12H-1, 61-62 cm	F																	G	
12H, cc to 18X, cc	barren																		
19X-1, 88-90 cm	R											R	R					M	NN 15 or older
19X, cc	R	R										F	R		R	G			
20X-1, 63-64 cm	barren																		
20X, cc to 27X, cc	barren																		
E 1X, cc to 10X, cc	barren																		
11X-2, 127-128 cm	R											R						M	-NN 6
11X, cc	R											F	R					M	
12X-1, 114-115 cm	R			R	R			R		R	R	R	R					M	
12X-2, 26-27 cm	R			R						R	R	R						M	
12X, cc	F	R	R	R	R			R		R	R	F	R		R	H			
13X, cc	R											R						P/M	

Note: R = rare, F = few, C = common, A = abundant. Preservation: P = poor, M = moderate, G = good.

Site 682 (11°15.99'S, 79°03.73'W; water depth, 3788.5 m)

One hole was drilled at this site to establish the history of vertical tectonism and to sample distal material from upwelling on the shelf area. Hole 682A terminated at 436.7 mbsf in middle Eocene sediments.

Quaternary calcareous nannoplankton was found in rather monotonous assemblages in Cores 112-682A-1H to -3H. Species identified include *Emiliana huxleyi* in Sample 112-682A-1H-2, 95-96 cm, indicating the presence of nannoplankton Zone NN-21 (*Emiliana huxleyi* Zone) in the upper part of Core 112-682A-1H. The nannoplankton assemblages of the remaining part of this interval are dominated by *Gephyrocapsa oceanica* and *Gephyrocapsa aperta*, as well as *Cyclococcolithus leptoporus* (in Sample 112-682A-2H-6, 62-63 cm), whereas *Helicosphaera carteri* and *Coccolithus pelagicus* are rare. Because *Pseudoemiliana lacunosa* is missing, the above interval represents nannoplankton Zone NN20 (*Gephyrocapsa oceanica* Zone), which is confirmed by cross-correlation with silicoflagellates.

Cores 112-682A-4H to -6H and -9X to -14X are barren of calcareous nannoplankton.

Table 3. Distribution of calcareous nannoplankton in selected samples from Holes 680A and 680B and indication of standard nannoplankton zones.

	<i>Braarudosphaera bigelowii</i>	<i>Coccolithus pelagicus</i>	<i>Cyclococcolithus leptoporus</i>	<i>Emiliana huxleyi</i>	<i>Gephyrocapsa aperta</i>	<i>Gephyrocapsa oceanica</i>	<i>Helicosphaera carteri</i>	<i>Pseudoemiliana lacunosa</i>	<i>Syracosphaera pulchra</i>	Dolomite rhombs	Preservation	Nannoplankton Zones
1H-4, 98-99 cm		F	R	F	F	C	R				G/M	NN 21
1H, cc	R		C		A	A	C		R		G	NN 20
Core 2H	barren											?
3H-2, 98-99 cm			R		F	R						G/M
3H, cc			R		A	C	C					G/M
4H-2, 119-120 cm			F		C	R	R					G/M
4H, cc					F	R				◆		P/M
5H-4, 22-23 cm			R		F	F	R	R		◆		P/M
5H, cc			R		F	F	R			◆		P/M
Cores 6H to 10H	barren											◆
Cores B11H to B22X	barren											?

Note: Dolomite rhombs are not present in all samples from the interval between Cores 112-680A-6H to -10H.

In Samples 112-682A-7X-2, 89-90 cm, and -682A-7X, CC, several *Discoaster brouweri* were noted in an otherwise nondiagnostic nannoplankton assemblage. Because of the unknown occurrence of index species in the late Pliocene of this region, these samples are placed in the combined interval between Zones NN16 (*Discoaster surculus* Zone) to NN18 (*Discoaster brouweri* Zone) above the last occurrence of *Reticulofenestra pseudumbilica*. This species, together with *Sphenolithus abies* and others, is present in Sample 112-682A-8X, 44-45 cm, which belongs in the early Pliocene nannoplankton Zone NN5 (*Reticulofenestra pseudumbilica* Zone).

Nannoplankton assemblages of Cores 112-682A-15X to -20X and -22X to -29X are nondiagnostic. These include *Discoaster variabilis* in most samples, with *Discoaster brouweri* and *Discoaster exilis* present at some levels (Table 5). These samples seem to represent the upper part of the middle Miocene, but cannot be definitely assigned to certain nannoplankton zones because of low diversity and lack of index species. Dolomite rhombs were noted in varying abundance in many samples. The growth of authigenic dolomite seems to diminish calcareous nannoplankton during diagenesis, if the total carbonate content in the sediments is low. This "scavenging" of carbonate should lead to a poorly preserved, impoverished assemblage, or even result in a total loss of calcareous nannoplankton. In Cores 112-682A-30X and -31X, only gravels were recovered, and no calcareous nannoplankton data are available. In Core 112-682A-32X (bottom), *Sphenolithus heteromorphus* is present, and the interval between this sample and the level above Sample 112-682A-34X-1, 87-88 cm, with *Helicosphaera ampliapertura* placed in nannoplankton Zone NN5 (*Sphenolithus heteromorphus* Zone).

The lower Miocene sequence seems to be complete, and calcareous nannoplankton Zones NN4 (*Helicosphaera ampliapertura* Zone) to NN1 (*Triquetrorhabdulus carinatus* Zone)

Table 4. Distribution of calcareous nannoplankton in selected samples from Hole 681A and indication of standard nannoplankton zones.

	<i>Braarudosphaera bigelowi</i>	<i>Coccolithus pelagicus</i>	<i>Cyclococcolithus leptoporus</i>	<i>Discolithina japonica</i>	<i>Emiliania huxleyi</i>	<i>Gephyrocapsa aperta</i>	<i>Gephyrocapsa oceanica</i>	<i>Helicosphaera carteri</i>	<i>Pseudoemiliania lacunosa</i>	<i>Reticulofenestra pseudoumbilica</i>	<i>Reticulofenestra</i> (small)	Reworked	Dolomite rhombs	Preservation	Nannoplankton Zones
1H-1, 89-90 cm	R	R			R	C	C	C						G	NN 21
1H-4, 125 cm			R			F	A							G/M	NN 20
1H, cc						R	R							P/M	
2H-2, 38-39 cm		R	R			F	F	R						G/M	
2H, cc						R	F	R						M	
3H-2, 47-48 cm			R			F	C	R						M	
3H, cc	b a r r e n												◆	?	
4H-3, 117 cm			F			A	F							G/M	NN 20
4H, cc	b a r r e n													?	
5H-2, 26-27 cm			cf.			C	F	F						M	NN 20
5H, cc		R				R	R							P/M	
6H, cc	b a r r e n												◆	?	
7H-1, 101-102 cm		F				R	F	R						M	NN 20
7H, cc	b a r r e n													?	
8H, cc	b a r r e n													?	
9H, cc						R	R	R	R					P/M	NN 19
10H-3, 50-51 cm			R			R	R	cf.						P/M	
10H, cc						R	R							◆	
11H, cc		R				R	R							◆	
12H, cc		R				F	R							M	
13X, cc		R				F	R							M	
14X, cc		F	R			F	R							M	
Cores 15X to 18X	b a r r e n													?	
19X, cc		F	R			R	R		R	R	T			M	?
20X, cc	b a r r e n													?	

Note: R = rare, F = few, C = common, A = abundant. Preservation: P = poor, M = moderate, G = good.

were identified in Cores 112-682A-34X to -36X, despite the absence of *Sphenolithus belemnus*. *Triquetrorhabdulus carinatus* is present in well-preserved specimens, and rare *Discoaster druggii* also were noted. Because the abundance of siliceous components declines markedly in the early Miocene at this site, the sedimentation rate is low and the lower Miocene sequence seems to be much less thicker, compared with the middle and upper Miocene sequence.

The Oligocene is represented by Cores 112-682A-37X to -44X, but this interval is difficult to subdivide because in the middle and late Oligocene, sphenoliths are not preserved or are missing in the poorly preserved nannoplankton assemblages. On the basis of the presence of *Cyclicargolithus abisectus*, which has its first occurrence near the base of nannoplankton Zone NP24 (*Sphenolithus distentus* Zone) and *Dictyococcites dictyodus*, which just crosses the Oligocene/Miocene boundary elsewhere, Samples 112-682A-37X-2, 39-40 cm, to -40X-2, 100-101 cm, have been placed in the combined Zone NP24/25* (*Sphenolithus distentus*/*S. ciperensis* Zone). The remaining part of Core 112-682A-40X and -682A-42X to -43X are barren of calcareous nannoplankton. In Core 112-682A-41X, a meager nannoplankton assemblage containing rare *Cyclicargolithus abisectus* and *Triquetrorhab-*

dulus carinatus was noted. This assemblage has been tentatively assigned to the late Oligocene nannoplankton Zone NP24/25*, but also could represent downhole contamination. In Core 112-682A-44X, a moderately preserved nannoplankton assemblage with frequent *Reticulofenestra umbilica*, *Isthmolithus recurvus*, and *Cyclococcolithus formosus* was found, indicating the presence of the early Oligocene nannoplankton Zone NP21 (*Ericsonia subdisticha* Zone) at this level.

The remaining cores (from Core 112-682A-45X down to the terminal Core 112-682A-48X at 436.7 mbsf) are of middle Eocene age. An uppermost Eocene sequence was not recovered, and a hiatus has been postulated between the early Oligocene and middle Eocene. *Discoaster saipanensis*, which has its first occurrence near the top of Zone NP16 (*Discoaster tani nodifer* Zone), is found throughout Cores 112-682A-45X to -48X, together with rare *Chiasmolithus solitus*, indicating the upper part of Zone NP16. The occurrence of the nearshore and shallow-water genera *Braarudosphaera* and *Discolithina* in the early Oligocene Core 112-682A-44X and in middle Eocene Cores 112-682A-45X to -48X (in the latter cores associated with representatives of the genus *Micrantholithus*) indicates a shallower paleodepth for Site 682 during the early Oligocene and late middle Eocene than their paleodepth from the late Oligocene to Holocene interval (Core 112-682A-41X to -1H).

Reworked calcareous nannoplankton were observed at two intervals. The most obvious reworking took place in the early Oligocene because in samples from Core 112-682A-44X, Upper Cretaceous species occur frequently. These include *Watznaueria barnesae*, *Cretarhabdus crenulatus*, and *Tetralithus trifidus* (the latter primarily occurring only in the upper Campanian and lower Maestrichtian). The other interval includes at least Cores 112-682A-15X to -23X, where lower Miocene species, such as *Helicosphaera ampliaperta* and *Discoaster deflandrei*, were scattered in late middle Miocene to early upper Miocene nannoplankton assemblages.

Site 683 (9°01.69'S, 80°24.40'W; water depth, 3071.8 m)

Site 683 was chosen to investigate the vertical tectonic movement of the Peruvian continental margin. Two holes were drilled, with an overlap between 402.5 and 419.2 mbsf. Hole 683B was terminated at 488.0 mbsf in middle Eocene sediments.

Quaternary calcareous nannoplankton was found in Hole 683A in monotonous assemblages down to Core 112-683A-9H, with boundaries between Zones NN20 (*Gephyrocapsa oceanica* Zone) and NN21 (*Emiliania huxleyi* Zone) within Core 112-683A-1H and between Zone NN19 (*Pseudoemiliania lacunosa* Zone) and NN20 (*G. oceanica* Zone) in Core 112-683A-7X (Table 6). These assemblages are dominated by *Gephyrocapsa* species; all other species, such as *Helicosphaera carteri*, *Coccolithus pelagicus*, and *Cyclococcolithus leptoporus*, forming only minor constituents. Scattered blooms were noted, with the most obvious blooms occurring in Samples 112-683A-9H-5, 2 cm (74.7 mbsf) and -15X-1, 2 cm (125.7 mbsf), with the latter probably of Pliocene age.

The interval between Cores 112-683A-10X and -26X is barren of calcareous nannoplankton, with the exception of the above-mentioned bloom in Core 112-683A-15X and part of Core 112-683A-19X, where an insignificant nannoplankton assemblage was observed. This assemblage includes, besides common *Gephyrocapsa* species, rare to few *Coccolithus pelagicus*, *C. miopelagicus*, *Cyclococcolithus leptoporus*, and

Table 5. Distribution of calcareous nannoplankton in selected samples from Hole 682A and indication of standard nannoplankton zones.

	<i>Ceratolithus rugosus</i>	<i>Coccolithus miopelagicus</i>	<i>Coccolithus pelagicus</i>	<i>Cyclococcolithus leptopus</i>	<i>Cyclococcolithus macintyreii</i>	<i>Cyclococcolithus rotula</i>	<i>Discoaster brouweri</i>	<i>Discoaster exilis</i>	<i>Discoaster variabilis</i>	<i>Discoaster VI sec. calc.</i>	<i>Emiliania huxleyi</i>	<i>Gephyrocapsa aperta</i>	<i>Gephyrocapsa oceanica</i>	<i>Gephyrocapsa sp.</i>	<i>Helicosphaera carteri</i>	<i>Lithothamnion perdurum</i>	<i>Reticulofenestra pseudumbilica</i>	<i>Reticulofenestra (small)</i>	<i>Scyphosphaera sp. (base)</i>	<i>Sphenolithus abies</i>	<i>Umbilicosphaera mirabilis</i>	Dolomite rhombs	Reworking	Preservation	Nannoplankton Zones	
1H-2, 95-96 cm			C	R							F	C	F	F										G	NN 21	
1H-4, 65-66 cm			R									F	F	R											P/M	NN 20
2H-3, 7-8 cm			F	R								A	F	F							R				M	
2H, cc			R	C								A	F	F											M	
3H-3, 69-70 cm			R	F								A	F	R										M	M	
3H, cc	barren																							?		
Cores 4H to 6H	barren																									
7X-2, 89-90 cm			R				R						F							R					P/M	NN 16/18
7X, cc			R	R			R						F	R											P/M	
8X-1, 44-45 cm	R	C	F	R									F			F	F			R					M	NN 15
8X, cc	barren																							?		
Cores 9X to 14X	barren																									
15X, cc		F	F				R	cf	R	R				R		F	F		R					M	M	-NN 6 to -NN 10
16X-1, 21-22 cm		R	R	R	R			R	R							R	F								M	
17X, cc		R	F				cf	R	R					R		F	C		R		◇	M	P/M			
18X, cc		R	F				R		R					R		C	C		R		◇	M	P/M			
19X, cc		R	F				R	R	R					R	R	F	C		F				M	P/M		
20X, cc		R	F			R	R	R						R		F	C		R		◇	M	P/M			
Core 21X	barren																							?		
22X, cc		R	R	R			R	R	R							R	F				◇	M	P/M		-NN 6 to -NN 10	
23X-1, 107-112 cm		F		R	R		R	R						R		R	F		R		◇	M	P			
24X, cc			R				R		R					R		R	R		R		◇		P			
25X, cc																R					◇		P			
26X, cc			R				R	R	R							F	R				◇		P			
27X, cc			R						R							R	R				◇		P			
28X, cc		R	R				R	R								F	C		R				M	P/M		
29X, cc			R													R	R						M	P/M		
Core 30X	barren																							?		
31X, cc	barren																									

Note: R = rare, F = few, C = common, A = abundant. Preservation: P = poor, M = moderate, G = good. Reworking: C = Cretaceous, E = Eocene, M = Miocene.

rare specimens of *Cyclococcolithus macintyreii* and *Discoaster brouweri*. Because *Reticulofenestra pseudumbilica* could not be found, this assemblage is of late Pliocene age and may represent nannoplankton Zone NN18 (*Discoaster brouweri* Zone).

From Core 112-683A-27X down to terminal Core 112-683A-45X at 419.2 mbsf, calcareous nannoplankton is present in slumped material from middle Miocene strata, except in a barren interval between Cores 112-683A-34X and -38X. Upper Miocene sediments were not found. Even though most samples represent slumped material, nannoplankton assemblages seem to be in normal and descending order (Table 6), which was ascertained on the basis of silicoflagellates (Martini, this volume). Within this sequence, one core containing a younger nannoplankton assemblage was identified; this assemblage is intercalated in a part that probably represents nannoplankton Zone NN6 (*D. exilis* Zone). Core 112-863A-30X can be placed with certainty in the middle Miocene nannoplankton Zone NN8 (*Catinaster coalitus* Zone), based

on the presence of the nominate species in several samples (Pl. 2, Figs 19-21) within this core. Core 112-683A-39X represents nannoplankton Zone NN6 (*D. exilis* Zone), with common *Cyclicargolithus floridanus* and few *Discoaster exilis*. In Cores 112-683A-40X to -45X, nannoplankton Zone NN5 (*Sphenolithus heteromorphus* Zone) was ascertained on the basis of the frequent presence of *Sphenolithus heteromorphus* and the absence of *Helicosphaera ampliaperta* throughout the cores.

Preservation is good to moderate in the Quaternary part of the sequence and only moderate to poor in the slumped material, depending on the amount of disturbance and sorting of the assemblages. A nearly pure, discoaster-bearing layer was found in Sample 112-683A-42X, CC (381.9 mbsf), associated with abundant and concentrated diatoms of the genus *Thalassiothrix* and a flood of slightly rounded dolomite rhombs.

In Hole 683B, Cores 112-683B-1X to-6X contain middle Miocene calcareous nannoplankton assemblages that belong

to nannoplankton Zone NN5 (*Sphenolithus heteromorphus* Zone), based on the presence of *Sphenolithus heteromorphus* and the absence of *Helicosphaera ampliaperta*. Cores 112-683B-1X and -2X are from the same level as Cores 112-683A-44X and -45X.

Moderately preserved middle Eocene calcareous nannoplankton was observed in Core 112-683B-7X. This observation signifies a prominent hiatus between Cores 112-683B-6X and -7X, with part of the middle Eocene, upper Eocene, Oligocene, and lower Miocene missing. Thus, this hiatus covers a time interval of approximately 28 m.y. The upper part of Core 112-683B-7X down to Sample 112-683B-7X-2, 98–99 cm (462 mbsf) can be placed in nannoplankton Zone NP17 (*Discoaster saipanensis* Zone), with the nominate species present in fair numbers. In Sample 112-683B-7X-3, 30 cm, and in samples below, *Chiasmolithus solitus* was found, the last occurrence of which indicates the top of nannoplankton Zone NP16 (*Discoaster tani nodifer* Zone). Accordingly, this sample marks Zone NP6, which extends down to terminal Core 112-683B-9X (total depth, 488.0 mbsf). However, Samples 112-683B-7X, CC, and -8X, CC (30 cm), contain nannoplankton Zone NP17 and may represent downhole contamination.

Cores 112-683B-8X and -9X were greatly disturbed by drilling and contain Eocene sediments, together with displaced Miocene material from above. Miocene contamination was recognized in Samples 112-683B-8X, CC (10 cm), -683B-8X, CC, -683B-9X, CC (2 cm), and -683B-9X, CC. Shallow-water species, such as *Zygrhablithus bijugatus*, *Braarudosphaera bigelowi*, *Micrantholithus* sp., and *Discolithina* species, were found in the Eocene part of Hole 683B, but in lesser numbers than at Site 682.

**Site 684 (8°59.59'S, 79°54.35'W;
water depth, 426.0 m)**

This site is the northern point of a transect of three north-south directed sites along the upper-slope deposits of the Peruvian margin. One Leg 112 objective was to investigate the latitudinal variability of upwelling parameters. Three holes were drilled at this site; however, only Hole 684A was investigated in detail for calcareous nannoplankton, which was found with distinct assemblages in three different intervals.

Core-112 684A-1H and part of -2H contain a monotonous nannoplankton assemblage of the late Quaternary. *Gephyrocapsa oceanica* and *Gephyrocapsa aperta* are always present and are accompanied by rare *Cyclococcolithus leptoporus* and abundant *Helicosphaera carteri* (Table 7). Some reworked specimens from the Neogene were observed in Sample 112-684A-1H-2, 84–86 cm (2.3 mbsf).

The lowest part of Core 112-684A-3H and the upper part of Core 112-684A-4H are barren of calcareous nannoplankton.

In Samples 112-684A-4H, CC (33.6 mbsf), and -5H, CC, rare *Discoaster surculus* were noted. *Discoaster brouweri* was found in several samples from Cores 112-684A-5H and -6H, together with *Discoaster tamalis* in Sample 112-684A-6H-3, 98 cm (47.3 mbsf). Because *Reticulofenestra pseudumbilica* is absent in all samples, this interval is placed in the late Pliocene nannoplankton Zone NN16 (*Discoaster surculus* Zone).

In the interval between Samples 112-684A-6H, CC, and -7H-5, 57–58 cm (51–59.4 mbsf), an assemblage dominated by *Reticulofenestra pseudumbilica* and related species is present. Rare *Discoaster hamatus* in Samples 112-684A-7H-6, 80–81 cm, and -8H-1, 9–10 cm (61.1 and 62.4 mbsf, respectively), down to -13X, CC (107.9 mbsf), allow one to place the interval in nannoplankton Zone NN9 (*Discoaster hamatus* Zone). Sample 112-684A-14X, CC, probably also belongs in Zone NN9 because *Catinaster coalitus*, a species indicative of

the next lower Zone NN8, was not found, even though it was observed at nearby Site 683. *Braarudosphaera bigelowi* was observed frequently in Sections 112-684A-8H-2 and 8H-3, as well as in Sample 112-684C-8X, CC (60.4 mbsf). Together with *Discolithina* species in Cores 112-684A-8X to -14X (Table 7), *Braarudosphaera bigelowi* indicates nearshore and shallow-water conditions for the area during deposition of this late middle Miocene sequence. Blooms of *Reticulofenestra* species were noted at several levels. Preliminary study of selected light-colored thin layers in equivalent strata of Hole 684C indicates the presence of many *Reticulofenestra* blooms. Complete spheres are frequent in these layers (resulting from blooms) and indicate rapid accumulation and undisturbed settlement. *Scyphosphaera* species (Pl. 2, Figs. 1–8) occur frequently in Cores 112-684A-13X and -684C-13X at the same level near the bottom of the drilled sequence (at approximately 107 mbsf in both cases) and also are found above this level. A nearly identical assemblage is present in the slightly younger sequence (nannoplankton Zone NN10, *Discoaster calcaris* Zone) from Gabon on the west coast of Africa (Martini, 1969), deposited under similar conditions but that assemblage is associated with *Coccolithus pelagicus*, which commonly indicates cold-water influences in marine sediments. This species is missing in the assemblages of late middle Miocene age at Site 684.

According to these nannoplankton data, two hiatuses divide the assemblages. One hiatus is present in the lowest part of Core 112-684A-2H at approximately 15 mbsf, with the lower part of the Quaternary and the uppermost Pliocene (equivalent to 2.0 m.y.) missing. The other hiatus is between Core 112-684A-6H and -7H at approximately 52 mbsf, where the lower Pliocene and most of the upper Miocene (equivalent to 5.4 m.y.) is missing.

Samples from Hole 684B and from the upper part of Hole 684C were not investigated because of the meager nannoplankton assemblages encountered in Hole 684A at these levels.

**Site 685 (9°06.78'S, 80°35.01'W;
water depth, 5070.8 m)**

Site 685 was located so as to sample the oldest part of the sediment accreted to the Peru Trench during the Andean orogeny. Only one hole was drilled.

Cores 112-685A-1H to -22X (199.8 mbsf) contain meager Quaternary nannoplankton assemblages at some levels, but are frequently barren or yield only a few poorly preserved *Gephyrocapsa* specimens. Some better preserved assemblages occur in Samples 112-685A-3H-2, 19–20 cm, -685A-4H, CC, and between 112-685A-6X, CC, and -685A-10X-4, 98–99 cm. These include *Gephyrocapsa oceanica*, *G. aperta*, *Helicosphaera carteri*, *Coccolithus pelagicus*, and *Cyclococcolithus leptoporus* (Table 8). Samples between Cores 112-685A-3H and -7X may represent nannoplankton Zone NN20 (*Gephyrocapsa oceanica* Zone) of the late Quaternary. Samples below this and down to Core 112-685A-22X may belong to Zone NN19 (*Pseudoemiliania lacunosa* Zone) because rare *Pseudoemiliania lacunosa* were found in Samples 112-685A-8X-4, 24–25 cm, and -12X-2, 98–99 cm.

A hiatus of 4.3 m.y. duration was noted between Cores 112-685A-22X and -23X at 200 mbsf, dividing the Quaternary from the late Miocene. In Samples 112-685A-23X, CC (203.6 mbsf) and -25X-1, 3 cm (222.6 mbsf), *Discoaster quinqueramus* was found frequently with *Reticulofenestra pseudumbilica*, *Reticulofenestra* sp. (small), rare *Sphenolithus abies*, *Coccolithus pelagicus*, *Cyclococcolithus leptoporus*, and a few unidentifiable six-rayed discoasters having calcite overgrowth (Table 8). In Sample 112-685A-25X, CC, only a few

Discoaster quinquerramus were observed. Based on calcareous nannoplankton, the interval between Cores 112-685A-23X and -25X (Nothing was recovered from Core 112-685A-24X) can be placed in the late Miocene nannoplankton Zone NN11 (*Discoaster quinquerramus* Zone). Sample 112-685A-26X, CC (232.1 mbsf), contained only a few well-preserved *Discoaster calcaris*, but as *D. quinquerramus* was not found, this sample is assigned to the late Miocene nannoplankton Zone NN10 (*Discoaster calcaris* Zone).

Cores 112-685A-27X through -51X (235.2–459.1 mbsf) are barren of calcareous nannoplankton, with the exception of Cores 112-685A-38X, -44X, -48X, and -50X. In Cores 112-685A-38X and -48X, a poorly preserved, partially recrystallized nannoplankton assemblage was observed in a snowflake-like background of tiny calcite particles. A single specimen of *Discoaster calcaris* was noted among frequent *Reticulofenestra* sp. and rare *Sphenolithus abies*, as well as *Coccolithus pelagicus* in Sample 112-685A-38X-1, 36 cm (338.6 mbsf), indicating that this level may still belong to nannoplankton Zone NN10.

In Cores 112-685A-44X (392.6–396.1 mbsf) and -50X (449.6–450.6 mbsf), slumped material was recovered that contains a mixture of lower Miocene and middle to upper Eocene nannoplankton. Oligocene nannoplankton was not found. Nannoplankton in selected clasts from Core 112-685A-44X reveals that besides purely lower Miocene and Eocene clasts, a number of lower Miocene ones are present that also contain Eocene nannoplankton, obviously reworked in early Miocene time from older strata. Nannoplankton assemblages in some of the clasts in Cores 112-685A-44X and -50X were identified and are shown in Table 9.

According to the occurrence of only discoaster-bearing samples, poorly preserved coccolith assemblages, and barren samples, most of the sequence was deposited well below the local carbonate compensation depth (CCD). The interval between Cores 112-685A-23X and -26X (203.6–232.1 mbsf), however, was deposited approximately at the local CCD, with Samples 112-685A-25X, CC (223 mbsf) and -26X, CC (232.1 mbsf) just below this level. The same may apply for Cores 112-685A-38X (338.1–338.6 mbsf) and -48X (430.6–440.5 mbsf).

Based on nannoplankton data, the sedimentation rate in the Quaternary sediments (NN19 to NN21) may exceed 107 m/m.y. (interval at 0 to 199.8 mbsf) and in the late Miocene (NN10) may exceed 168 m/m.y. (interval at 232.1 to 459.1 mbsf) at this site. Dip of the sediments was not considered for these calculations.

**Site 686 (13°28.81'S, 76°53.49'W;
water depth, 446.8 m)**

At Site 686, which also was selected to study the upwelling system off Peru, most samples from the two holes drilled are barren in calcareous nannoplankton. From approximately 60 mbsf down to approximately 284 mbsf, calcareous nannoplankton was scattered in impoverished and poorly preserved assemblages containing *Gephyrocapsa* species and rare *Helicosphaera carteri* (Table 10). Rare *Pseudoemiliania lacunosa* were found in Samples 112-686A-10X-2, 68–69 cm (74.9 mbsf) and -21X, CC (186.6 mbsf), indicating the presence of nannoplankton Zone NN19 (*Pseudoemiliania lacunosa* Zone) in the lower part of the sequence. *Cyclococcolithus macintyreii* is present in Samples 112-686A-19X, CC (167.5 mbsf), and -686A-22X, CC (187.1 mbsf), which can be used to identify the lower part of the *Pseudoemiliania lacunosa* Zone (Zone NN19a, last occurrence of *Discoaster brouweri* to last occurrence of *Cyclococcolithus macintyreii*) and the lowest part of the Quaternary.

In most cases, the meager Quaternary nannoplankton assemblages are associated with displaced lower to middle

Miocene and middle to late Eocene nannoplankton species. These displaced species are especially frequent in the shell-bed interval at about 190 mbsf that contains common *Calyptraea* sp. and some other gastropods (Hagn and Martini, this volume) and where in Sample 112-686A-22X, CC, *Discoaster deflandrei*, *Cyclicargolithus floridanus*, *Reticulofenestra pseudoumbilica*, *Dictyococcites dictyodus*, and *Reticulofenestra umbilica* were identified.

Sedimentation rates are at least 160 m/m.y., if one considers the whole sequence as representing the Quaternary calcareous nannoplankton Zones NN19 (*Pseudoemiliania lacunosa* Zone) to NN21 (*Emiliania huxleyi* Zone).

The upper part of Hole 686B is more or less identical with the sequence previously described for Hole 686A. Below 205.7 mbsf, where Hole 686A was terminated, samples from Core 112-686B-24X to -32X contain scattered, poorly preserved nannoplankton or were barren (Table 10). Sample 112-686B-25X, CC, may belong in nannoplankton Zone NN19 (*P. lacunosa* Zone). The remaining samples could not be assigned to a certain nannoplankton zone.

**Site 687 (12°51.78' W, 76°59.43'W;
water depth, 306.8 m)**

Two holes were drilled at Site 687, which was selected to study the Peru coastal upwelling regime. As in the previous site, most of the samples are barren in calcareous nannoplankton. However, Sample 112-687A-1H, CC (7.4 mbsf) contains a well-preserved but poorly diversified late Quaternary nannoplankton assemblage (Table 11). Scattered impoverished and poorly preserved assemblages having *Gephyrocapsa* sp., *Coccolithus pelagicus*, and rare *Helicosphaera carteri* were encountered. *Helicosphaera sellii* was found in Samples 112-687A-14X, CC (127.9 mbsf), -687B-9X, CC (81.0 mbsf), -687B-16X, CC (130.0 mbsf), and -687B-22X, CC (185.8 mbsf). Together with the highest occurrence of *Cyclococcolithus macintyreii* in Sample 112-687B-9X, CC (81.0 mbsf), these species may indicate the presence of the early Quaternary nannoplankton Zone NN19 (*Pseudoemiliania lacunosa* Zone) in this interval.

In some cases, these meager nannoplankton assemblages were associated with rare reworked lower to middle Miocene and middle to upper Eocene nannoplankton species. The displaced species found in Samples 112-687A-19X, CC (175.0 mbsf), -687A-22X, CC (202.0 mbsf), -687B-20X, CC (167.9 mbsf), and -687B-22X, CC (185.8 mbsf) include *Discoaster deflandrei*, *Cyclococcolithus floridanus*, *Reticulofenestra pseudoumbilica*, *Dictyococcites dictyodus*, *Discoaster tani*, and *Reticulofenestra umbilica*.

Between Cores 112-687A-6H and -7X, dolomite rhombs are frequent at several levels, as also indicated in Table 11, and samples are barren or contain only poorly preserved and impoverished nannoplankton assemblages. Sample 112-687B-9X, CC (81.0 mbsf), containing *Cyclococcolithus macintyreii*, has an age of at least 1.45 Ma, which Backman and Shackleton (1983) assigned for the last occurrence of *C. macintyreii*. Thus, the sedimentation rate in the Quaternary at Site 687 is at least 56 m/m.y.

**Site 688 (11°32.26'S, 78°56.57'W;
water depth, 3819.8 m)**

Objectives of this site were similar to those at Site 682 for establishing the history of vertical tectonism and the oceanic or continental origin of the crystalline basement in a location near the trench. Five holes were drilled at this site, but only Holes 688A and 688E were successful. Hole 688C yielded only one core, and Holes 688B and 688D were abandoned after drilling failed.

The first four cores of Hole 688A contain a moderately well-preserved late Quaternary nannoplankton assemblage with common *Gephyrocapsa oceanica* and *Gephyrocapsa aperta*, few *Coccolithus pelagicus*, *Cyclococcolithus leptoporus*, and *Helicosphaera carteri* (Table 12). Sample 112-688A-1H-4, 91–92 cm, can be placed in nannoplankton Zone NN21 (*Emiliania huxleyi* Zone). The lower part of Core 112-688A-1H down to -688A-4H does not contain *Emiliania huxleyi* and belongs to nannoplankton Zone NN20 (*Gephyrocapsa oceanica* Zone). Below this level, *Pseudoemiliania lacunosa* was scattered, indicating that most of the sequence belongs to the Quaternary nannoplankton Zone NN9 (*Pseudoemiliania lacunosa* Zone).

From Core 112-688A-14X (12.3 mbsf) downward, barren intervals are frequent and include part of Cores 112-688A-14X to -16X (12.3–57.7 mbsf), Cores 112-688A-23X, -25X to -27X (226.8–253.4 mbsf), part of Cores 112-688A-30X, -31X, and -32X (283.3–304.6 mbsf), as well as -35X to -37X (321.3–343.4 mbsf).

Cyclococcolithus macintyreii in single, poorly preserved specimens was found in Samples 112-688A-6H, CC, and -9X, CC; these are regarded as reworked. This species can be observed more frequently and in better preservation in Core 112-688A-19X (169.8 mbsf), indicating the lower part of nannoplankton Zone NN19 (= NN19a) at this level. Cores 112-688A-24X, -28X, -29X, and part of -32X to -34X contain only rare and, in most cases, also poorly preserved *Gephyrocapsa* species and *Coccolithus pelagicus*, and may represent displaced material from upslope. Because of impoverished nannoplankton assemblages and barren intervals, no zonal or age assignment is possible for the sequence below Core 112-688A-22X (198.7 mbsf) to the terminal depth of Hole 688A at 350.3 mbsf.

Two samples from Hole 688C at 351.0 (112-688C-1R-1, 75 cm) and 351.5 mbsf (112-688C-1R-1, bottom) are barren of calcareous nannoplankton.

In Hole 688E, Cores 112-688E-1R to -11R (350.0–441.0 mbsf), -19R (517.0–521.8 mbsf), and -26R (583.5–584.6 mbsf) also are barren of calcareous nannoplankton. Between Cores 112-688E-12R and -21R, middle Miocene calcareous nannoplankton were observed; these cores contain varying numbers of moderately preserved *Discoaster exilis*, *D. variabilis*, *Reticulofenestra pseudoumbilica*, *Cyclicargolithus floridanus*, and other species. Because *Sphenolithus heteromorphus* was not found, the nannoplankton assemblages of Cores 112-688E-12R to -16R can be placed with certainty in nannoplankton Zone NN6 (*Discoaster exilis* Zone). Cores 112-688E-17R, -18R, and -21R may contain only caved-in middle Miocene material from above. Between Samples 112-688E-22R-1, 2–3 cm (545.5 mbsf) and -24R-1, 86–87 cm, and also in Sample 112-688E-25R, CC (576.7 mbsf) below a barren interval, a nannoplankton assemblage dominated by *Discoaster deflandrei*, *Cyclicargolithus floridanus*, and *Reticulofenestra* sp. (small) is present. *Coccolithus miopelagicus*, *C. pelagicus*, *Cyclicargolithus abisectus*, rare *Sphenolithus dissimilis*, and *Triquetrorhabdulus carinatus* also were found. As neither *Sphenolithus belemnos* and *Sphenolithus heteromorphus* nor *Dictyococcites dictyodus* and other species having their last occurrence at or near the Oligocene/Miocene boundary were encountered, the above interval is believed to represent the early Miocene nannoplankton Zone NN1 (*Triquetrorhabdulus carinatus* Zone) and probably Zone NN2 (*Discoaster druggii* Zone).

A major hiatus was found between Cores 112-688E-26R and -27R. In Core 112-688E-27R, a middle Eocene nannoplankton assemblage is present in Sample 112-688E-27R-1,

Table 6. Distribution of calcareous nannoplankton in selected samples from Holes 683A and 683B and indications of standard nannoplankton zones.

	<i>Coccolithus miopelagicus</i>	<i>Coccolithus pelagicus</i>	<i>Cyclococcolithus leptoporus</i>	<i>Cyclococcolithus macintyreii</i>	<i>Discoaster braueri</i>	<i>Emiliania huxleyi</i>	<i>Gephyrocapsa aperta</i>	<i>Gephyrocapsa oceanica</i>	<i>Helicosphaera carteri</i>	<i>Helicosphaera sellii</i>	<i>Pseudoemiliania lacunosa</i>	<i>Syracosphaera pulchra</i>	Reworking	Preservation	Nannoplankton Zones
1H-1, 112-113 cm		R				R	F	C	F					G/M	NN 21
1H, cc		F	R				C	C	R					G/M	NN 20
2H, cc		R					C	F	F					M	
3H-4, 103-104 cm							C	R	A					G/M	
3H, cc		R	R				C	F	F					M	
4H, cc		R	R				C	F	R			R		G/M	
5H, cc			R				A	F	R					G/M	
6H-4, 20-21 cm			R				A	R	F					G/M	
6H, cc			R				A	F	R					G/M	
7H-4, 95-96 cm		R	R				A	F	F					M	
7H, cc		R	R				C	F	R		R			M	
8H, cc			cf.				R	R						P	NN 19
9H-5, 2 cm							R	C	R		A			G/M	?
9H, cc	b a r r e n														
Cores 10X to 13X	b a r r e n														
14X, cc		R					F	R	R	R				M	
15X-1, 2 cm			R				A	C	C					G	?
15X, cc	b a r r e n														
Cores 16X to 18X	b a r r e n														
19X, cc	F	R	R	R	R		C	F	R					M	NN18
Cores 20X to 26X	b a r r e n													?	

Note: R = rare, F = few, C = common, A = abundant. Preservation: P = poor, M = moderate, G = good.

120 cm (594.2 mbsf), that includes *Chiasmolithus solitus*, *Reticulofenestra umbilica*, *Cyclococcolithus formosus*, *Criboecentrum reticulatum*, *Discoaster saipanensis*, *Discoaster barbadiensis*, and *Neococcolithes dubius* (Table 12). This assemblage can be placed in nannoplankton Zone NP16 (*Discoaster tani nodifer* Zone) and can be followed down to Sample 112-688E-36R-1, 60–61 cm (679.1 mbsf), although several intervals between these cores are barren or contain only rare, poorly preserved nannoplankton species. A change in the nannoplankton assemblage was noted between Samples 112-688E-36R-1, 60–61 cm, and -36R-2, 18–19 cm; this change is related to another hiatus. In the latter sample, *Discoaster saipanensis*, *Criboecentrum reticulatum*, and *Reticulofenestra umbilica* are missing, but rare *Discoaster sublodoensis* are present, indicating nannoplankton Zone NP14 (*Discoaster sublodoensis* Zone). Below this sample, *Discolithina* and *Transversopontis* species show a significant increase, and *Braarudosphaera bigelowi* also was found, indicating a shallower water depth in the middle Eocene. In Sample 112-688E-36R-2, 140–141 cm, and below, *Discoaster sublodoensis* is missing, but *Discoaster lodoensis*, *Discoaster distinctus*, *Discoasteroides kuepperi*, *Cyclococcolithus formosus*, and *Chiasmolithus solitus* are present, and these samples are placed in the early Eocene nannoplankton Zone NP13 (*Discoaster lodoensis* Zone). The remaining cores, down to terminal Core 112-688E-45R (769.0 mbsf), also

Table 6 (continued).

	<i>Catinaster coalitus</i>	<i>Coccolithus miopelagicus</i>	<i>Coccolithus pelagicus</i>	<i>Cyclitargolithus abisectus</i>	<i>Cyclitargolithus floridanus</i>	<i>Cyclitargolithus leptopus</i>	<i>Cyclitargolithus macintyreii</i>	<i>Cyclitargolithus rotula</i>	<i>Discoaster braueri</i>	<i>Discoaster deflandrei</i>	<i>Discoaster exilis</i>	<i>Discoaster kugleri</i>	<i>Discoaster surculus</i>	<i>Discoaster variabilis</i>	<i>Discoaster</i> sp. sec. calc.	<i>Discolithina multipora</i>	<i>Helicosphaera ampliapertura</i>	<i>Helicosphaera carteri</i>	<i>Helicosphaera euphratis</i>	<i>Reticulofenestra pseudumbilica</i>	<i>Reticulofenestra</i> (small)	<i>Sphenolithus abies</i>	<i>Sphenolithus heteromorphus</i>	<i>Sphenolithus mariformis</i>	Reworking	Dolomite rhombs	Preservation	Nannoplankton Zones
27X-1, 116-117 cm		R	F						R		F									F	F						P/M	(-NN 6/7)
27X, cc, 12-13 cm		R	F								F	cf.					R			C	F						P/M	
28X-1, 56-57 cm		C	R			R					R									A	A	F					M	
28X, cc		C	F						R	R	R									C	C	F					P/M	(-NN 6)
29X-1, 17-18 cm		R	R							F	R		cf.	F						C	C	F					P/M	
29X, cc		R												R						C	C	R					P/M	
30X-1, 112-113 cm	R	F	F					R			R						R	R	C	C	F						M	NN 8
30X, cc	R	R	F							R								F		C	F	F					M	
31X-2, 10-11 cm		F	C			R			R	R			cf.				F			C	C	F		R			P/M	(-NN 6)
31X, cc		F	R							cf.	R			cf.			R			C	C	F					M	
32X, cc			R																	R	R						P	
33X, cc		R	F	R							R			cf.				R		C	C	F					P/M	NN 6
Cores 34X to 38X	barren																										?	
39X-2, 106-107 cm		F	F	F	C						R									C	C	R					M	NN 6
39X, cc		R	F	F	C						F			R						F	C	R					P/M	
40X-1, 104-105 cm			F	F			R			R				R	R		F			C	R	R	R				P/M	NN 5
40X-3, 121-122 cm		R	F	R						R				R	R	R		R		R	C		R				P/M	
40X, cc		F	C	F	F						F					R		F		F	C		R				P/M	
41X, cc		C	F	F	F				R	F				R	F			C		F	C		R				P/M	
42X, cc									cf.	C				F	F											◆	P/M	?
43X, cc		R	F	R							F			F	F	R		R		F			R			◇	P/M	NN 5
44X-4, 115-116 cm		C	F	R	R				R	F				R	F	R		F			C	F	F				P/M	
44X, cc	barren																										?	
45X-2, 112-113 cm	barren																										?	
45X, cc	R	R		R							F			F	R			R								◇	P/M	NN 5

contain the nannoplankton assemblage of Zone NP13, with the exception of Cores 112-688E-40R and -41R (716.6-735.5 mbsf), which are barren of calcareous nannoplankton.

Based on calcareous nannoplankton and silicoflagellates (Martini, this volume), sedimentation rates at Site 688 are increasing downward from approximately 98 m/m.y. in the late Quaternary (0-46 mbsf), to approximately 135 m/m.y. in the late early Quaternary (46-179 mbsf), and to approximately 350 m/m.y. in the earliest Quaternary (179-340 mbsf), if the lowest occurrence of *Mesocena quadrangula* at this site really is near the Pliocene/Pleistocene boundary. Sedimentation rates for the upper part of Hole 688E down to Core 112-688E-11R at present cannot be evaluated because of suspected hiatuses and the, as yet unknown, time involved. In the middle Miocene (450 to 528 mbsf), sedimentation rates may exceed 43 m/m.y., based on the occurrence of nannoplankton Zone NN6 in this interval. In the lower Miocene (545-593 mbsf), a rate of at least 9.4 m/m.y. is indicated by the calcareous nannoplankton, but this may be considerably higher because the interval between Cores 112-688E-22R and -26R may represent only part of nannoplankton Zone

NN1/NN2. The middle Eocene is represented by nannoplankton Zone NP16 in Cores 112-688E-27R to -35R, and a sedimentation rate of more than 47.5 m/m.y. may be expected between 593 and 678 mbsf. In the lower Eocene, a sedimentation rate up to 125 m/m.y. may be calculated (678-775 mbsf). Note that the sedimentation rates are not adjusted to dipping values.

DISCUSSION

Calcareous nannoplankton in the Quaternary and late Neogene upwelling areas off Peru, which were sampled in a north-south transect (Sites 684, 679, 687, 686) between 9°S and 13°30'S at a water depth of approximately 400 m and in a west-east transect at 11°S (Site 679 at a water depth of 450 m, Site 680 at 253 m, and Site 681 at 151 m) exhibit a low diversity in species. The more common ones include *Gephyrocapsa oceanica*, *Helicosphaera carteri*, in the youngest sediments, *Ericsonia huxleyi* (Pl. 1, Fig. 5), and in levels older than late Pliocene, *Reticulofenestra pseudumbilica*. Scattered blooms, especially of *Gephyrocapsa oceanica* (Pl. 1, Fig. 4) and smaller *Gephyrocapsa* species, were noted. These were

Table 8. Distribution of calcareous nannoplankton in selected samples from Hole 685A and indication of standard nannoplankton zones.

	<i>Coccolithus pelagicus</i>	<i>Cyclococcolithus leptoporus</i>	<i>Discoaster calcaris</i>	<i>Discoaster quinqueramus</i>	<i>Discoaster</i> sp.	<i>Gephyrocapsa aperta</i>	<i>Gephyrocapsa oceanica</i>	<i>Gephyrocapsa</i> sp.	<i>Helicosphaera carteri</i>	<i>Pseudoemiliania lacunosa</i>	<i>Reticulofenestra pseudumbilica</i>	<i>Reticulofenestra</i> (small)	<i>Sphenolithus abies</i>	<i>Syracosphaera pulchra</i>	<i>Trochaaster</i> sp.	Reworking	Preservation	Nannoplankton Zones
1H, cc	b a r r e n																	?
3H-2, 19-20 cm	R	R				A	C	C						R			G/M	NN 20
3H, cc	b a r r e n																	?
4H, cc	R	R				C	C		F								M	NN 20
5X, cc	b a r r e n																	?
6X, cc						F											M	NN 20
7X-2, 99-100 cm	R					C	R		F								M	
8X-4, 24-25 cm	R	F				A	F		F	R							M	NN 19
9X, cc						C			cf.								M	
10X-4, 98-99 cm		R				C	R										M	
11X, cc	R					C	R		R								P/M	
12X-2, 98-99 cm						C	R		R	R								
13X, cc	b a r r e n																	?
14X, cc						F											P/M	~NN 19
15X, cc	R	R				C	F		R								P/M	
16X, cc		R				C	F		F								P/M	
17X, cc	b a r r e n																	?
18X, cc	b a r r e n																	?
19X, cc	R					R											P/M	~NN 19
20X, cc	b a r r e n																	?
21X, cc						F	R		R								P	~NN 19
22X, cc	b a r r e n																	?
23X, cc		R	cf.	R	R			R			F		R		R		M	NN 11
25X-1, 3 cm	R			F							R	F	R				M	
25X, cc				R													P/M	
26X, cc			R								R	R					P/M	NN 10
Cores 27X to 37X	b a r r e n																	?
38X-1, 36 cm	R		R								R	C	R				P/M	NN 10
38X, cc											F	C	cf.				P	
Cores 39X to 43X	b a r r e n																	?
Core 44X																M	M	?
Cores 45X to 47X	b a r r e n																	?
48X-1, 27 cm	R								R		R	C					P	?
48X, cc, 23 cm											R	R					P	
Core 49X	b a r r e n																	?
Core 50X																M	M	
Core 51X	b a r r e n																	?

Note: R = rare, F = few, C = common, A = abundant. Preservation: P = poor, M = moderate, G = good. Reworking: C = Cretaceous, E = Eocene, M = Miocene.

Table 9. Stratigraphic position of calcareous nannoplankton assemblages in selected clasts found in slumped material of late Miocene age in Cores 112-685A-44R and -50R.

Core, section, interval (cm)	Zonation
112-685A-44R-1, 28	Lower Miocene (NN1/NN2) and reworked Eocene
-2, 6	Lower Miocene and reworked Eocene
-2, 63	Lower Miocene (NN1/NN2) and reworked Eocene
-2, 82	Eocene (NP17/NP20)
-2, 127	Lower Miocene (NN1/NN2)
-3, 4	Lower Miocene ?
-CC, 16-18	Lower Miocene (NN4)
-CC, 27	Lower Miocene (NN1/NN2) and reworked Eocene
112-685A-50R-1, 15	Lower Miocene ?
-1, 53	Lower Miocene (NN1/NN2)
-1, 73	Lower Miocene ?
-1, 81,5	Eocene (NP17/NP20)
-CC, 11	Lower Miocene (~NN2)
-CC, 24	Eocene (NP17/NP20)

Table 10. Distribution of calcareous nannoplankton in selected samples from Holes 686A and 686B and indication of standard nannoplankton zones.

	<i>Coccolithus pelagicus</i>	<i>Cyclaccolithus leptopus</i>	<i>Cyclaccolithus macintyreii</i>	<i>Discolithina japonica</i>	<i>Gephyrocapsa aperta</i>	<i>Gephyrocapsa oceanica</i>	<i>Helicosphaera carteri</i>	<i>Helicosphaera sellii</i>	<i>Pseudoemiliania lacunosa</i>	Reworking	Dolomite rhombs	Preservation	Nannoplankton Zones
A Cores 1H to 7H	barren												?
8H-2, 8-9 cm					C	F	R					M	NN20
Core 9X	barren												?
10X-2, 68-69 cm	R	F			C	F			R	M		M	NN19
Core 11X	barren												?
12X-2, 80-81 cm	R	R			C	C	R			M		M	NN19
Cores 13X to 15X	barren												?
16X-2, 31-32 cm	R	R			F	R						M	NN19
17X-4, 93-94 cm	R				F	R						P/M	
18X, cc	R	R			R					M		P/M	
19X, cc			R	cf.	F	R				E		P/M	
20X, cc		R			R					E		P	
21X, cc	R				R		R		R	M		P/M	
22X, cc	R	R	R		R		R			M		P/M	
Core 23X	barren												?
B Core 24X	barren												?
25X, cc		R	R		R		R		R	M		P/M	NN19
26X, cc	barren												?
27X, cc	R				cf.					M		P	?
28X-4, 94-95 cm	R				cf.					M		P	
29X, cc	R				cf.		R			M		P	
30X-2, 89-90 cm					cf.		R			M		P	
Core 31X	barren												?
32X-2, 59-60 cm					cf.					M		P	?
32X, cc	barren												?

Note: R = rare, F = few, C = common, A = abundant. Preservation: P = poor, M = moderate, G = good. Reworking: C = Cretaceous, E = Eocene, M = Miocene.

(late middle Eocene to early middle Miocene, approximately 26 m.y.). At the southern Site 688, the missing interval included part of nannoplankton Zone NP16, to a level within Zones NN1/NN2 (late middle Eocene to early Miocene, approximately 21.5 m.y.). At Site 682, the hiatus is between the upper part of Zone NP16 and Zone NP21 (late middle Eocene to early Oligocene, approximately 8 m.y.). Another hiatus is suspected in the Oligocene at this site, but because of poor recovery and a barren interval cannot be ascertained. This major hiatus also was observed during DSDP Leg 90 at Site 588 on the Lord Howe Rise (Martini, 1986), where it includes part of the combined nannoplankton Zones NP15/ NP16 to Zone NP24 (middle Eocene to early late Oligocene, approximately 19 m.y.). Similar hiatuses were reported by Edwards (1973) from DSDP Sites 206, 207, and 208.

Kennett and von der Borch (1986) discussed the causes for this major regional hiatus in the southwest Pacific and related it to erosional bottom currents flowing northward. These probably were triggered by the separation of Antarctica and Australia about 50 m.y. ago and by the newly developed current system in the southern Pacific. This may also apply to the Leg 112 sites off Peru. Another possibility is the lowering of sea level at the end of the middle and late Eocene, as shown by the Vail curve in Harland et al. (1982). A large-scale erosional change was already announced in the highest levels of the preserved middle Eocene sequences by the presence of reworked Cretaceous nannoplankton at Sites 682 and 688, unknown in the lower middle Eocene sequence, which exhibits an increase in abundance in the basal Oligocene of Site 682. In addition, the calcareous nannoplankton in the middle Eocene seem to indicate a shallow depositional level for these sites at that particular time.

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- Chiphragmalithus cristatus* (Martini) Bramlette and Sullivan, 1961
- Coccolithus eopelagicus* (Bramlette and Riedel) Bramlette and Sullivan, 1961
- Coccolithus miopelagicus* Bukry, 1971
- Coccolithus pelagicus* (Wallich) Schiller, 1930
- Coronocyclus nitescens* (Kamptner) Bramlette and Wilcoxon, 1967
- Cribricentrum reticulatum* (Gartner and Smith) Perch-Nielsen, 1971
- Cruciplacolithus staurion* (Bramlette and Sullivan) Gartner, 1971
- Cyclicargolithus abisectus* (Müller) Wise, 1973
- Cyclicargolithus floridanus* (Roth and Hay) Bukry, 1971
- Cyclococcolithus formosus* Kamptner, 1963
- Cyclococcolithus gammation* (Bramlette and Sullivan) Sullivan, 1964
- Cyclococcolithus leptoporus* (Murray and Blackman) Kamptner, 1954 ex 1956
- Cyclococcolithus luminis* Sullivan, 1965
- Cyclococcolithus macintyreii* Bukry and Bramlette, 1969
- Cyclococcolithus rotula* (Kamptner) Kamptner, 1956
- Dictyococcites dictyodus* (Deflandre and Fert) Martini, 1969
- Discoaster barbadiensis* Tan Sin Hok, 1927
- Discoaster binodosus* Martini, 1958
- Discoaster brouweri* Tan Sin Hok, 1927
- Discoaster calcaris* Gartner, 1967
- Discoaster deflandrei* Bramlette and Riedel, 1954
- Discoaster distinctus* Martini, 1958
- Discoaster druggii* Bramlette and Wilcoxon, 1967
- Discoaster elegans* Bramlette and Sullivan, 1961
- Discoaster exilis* Martini and Bramlette, 1963
- Discoaster germanicus* Martini, 1958
- Discoaster hamatus* Martini and Bramlette, 1963
- Discoaster kugleri* Martini and Bramlette, 1963
- Discoaster lodoensis* Bramlette and Riedel, 1954
- Discoaster neohamatus* Bukry and Bramlette, 1969
- Discoaster quinquerramus* Gartner, 1969
- Discoaster saipanensis* Bramlette and Riedel, 1954
- Discoaster septemradiatus* (Klump) Martini, 1958
- Discoaster sublodoensis* Bramlette and Sullivan, 1961
- Discoaster surculus* Martini and Bramlette, 1963
- Discoaster tani* Bramlette and Riedel, 1954
- Discoaster tamalis* Kamptner, 1967
- Discoaster variabilis* Martini and Bramlette, 1963
- Discoaster wemmelensis* Achutan and Stradner, 1969
- Discoasteroides kuepperi* (Stradner) Bramlette and Sullivan, 1961
- Discolithina callosa* Martini, 1969
- Discolithina desueta* Müller, 1970
- Discolithina distincta* (Bramlette and Sullivan) Levin and Joerger, 1967
- Discolithina duocava* (Bramlette and Sullivan) Perch-Nielsen, 1971
- Discolithina enormis* Locker, 1967
- Discolithina japonica* Takayama, 1967
- Discolithina multimora* (Kamptner ex Deflandre) Martini, 1965
- Discolithina plana* (Bramlette and Sullivan) Levin, 1965
- Ellipsolithus macellus* (Bramlette and Sullivan) Sullivan, 1964
- Emiliana huxleyi* (Lohmann) Hay and Mohler, 1967
- Gephyrocapsa aperta* Kamptner, 1963
- Gephyrocapsa oceanica* Kamptner, 1943
- Helicosphaera ampliaperia* Bramlette and Wilcoxon, 1967
- Helicosphaera carteri* (Wallich) Kamptner, 1954
- Helicosphaera commacta* Bramlette and Wilcoxon, 1967
- Helicosphaera euphratis* Haq, 1966
- Helicosphaera lophota* (Bramlette and Sullivan) Locker, 1972
- Helicosphaera sellii* (Bukry and Bramlette) Jafar and Martini, 1975
- Helicosphaera seminulum* Bramlette and Sullivan, 1961
- Isthmolithus recurvus* Deflandre, 1954
- Koczyia fimbriata* (Bramlette and Sullivan) Perch-Nielsen, 1971
- Lanternithus minutus* Stradner, 1962
- Lithostromation perdurum* Deflandre, 1942
- Markalius inversus* (Deflandre) Bramlette and Martini, 1964
- Micrantholithus vesper* Deflandre, 1950
- Neococcolithes dubius* (Deflandre) Black, 1967
- Pseudoemiliana lacunosa* (Kamptner) Gartner, 1969
- Reticulofenestra insignita* Roth and Hay, 1967

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Ms 112B-180

APPENDIX

Eocene to Holocene calcareous nannoplankton from the eastern Pacific off Peru.

- Blackites tenuis* (Bramlette and Sullivan) Sherwood, 1974
- Braarudosphaera bigelowi* (Gran and Braarud) Deflandre, 1947
- Campylosphaera dela* (Bramlette and Sullivan) Hay and Mohler, 1967
- Catinaster coalitus* Martini and Bramlette, 1963
- Ceratolithus rugosus* Bukry and Bramlette, 1968
- Chiasmolithus altus* Bukry and Percival, 1971
- Chiasmolithus consuetus* (Bramlette and Sullivan) Hay and Mohler, 1967
- Chiasmolithus grandis* (Bramlette and Riedel) Radomski, 1968

- Reticulofenestra oamaruensis* (Deflandre) Stradner and Edwards, 1968
Reticulofenestra pseudoumbilica (Gartner) Gartner, 1969
Reticulofenestra umbilica (Levin) Martini and Ritzkowski, 1968
Reticulofenestra aff. *umbilica* (Levin) Martini and Ritzkowski, 1968
Rhabdosphaera procera Martini, 1969
Rhabdosphaera rudis Bramlette and Sullivan, 1961
Scyphosphaera amphora Deflandre, 1942
Scyphosphaera apsteini Lohmann, 1902
Scyphosphaera campanula Deflandre, 1942
Scyphosphaera intermedia Deflandre, 1942
Sphenolithus abies Deflandre, 1954
Sphenolithus dissimilis Bukry and Percival, 1971
Sphenolithus furcatolithoides Locker, 1967
Sphenolithus heteromorphus Deflandre, 1953
Sphenolithus moriformis (Brönnimann and Stradner) Bramlette and Wilcoxon, 1967
Sphenolithus orphanknolli Perch-Nielsen, 1971
Sphenolithus predistentus Bramlette and Wilcoxon, 1967
Sphenolithus radians Deflandre, 1954
Syracosphaera pulchra Lohmann, 1902
Transversopontis panarium (Deflandre) Locker, 1967
Transversomontis pulcher (Deflandre) Hay, Mohler and Wade, 1966
Transversopontis pulcheroides (Sullivan) Perch-Nielsen, 1971
Triquetrorhabdulus carinatus Martini, 1965
Trochoaster operosus (Deflandre) Martini and Stradner, 1960
Umbilicosphaera jafari Müller, 1974
Umbilicosphaera mirabilis Lohmann, 1902
Zygrhablithus bijugatus (Deflandre) Deflandre, 1959

Table 11. Distribution of calcareous nanoplankton in selected samples from Hole 687A and indication of standard nanoplankton zones.

	<i>Coccolithus pelagicus</i>	<i>Cyclacoccolithus leptoporus</i>	<i>Gephyrocapsa aperta</i>	<i>Gephyrocapsa oceanica</i>	<i>Helicosphaera carteri</i>	<i>Helicosphaera sellii</i>	Reworking	Dolomite rhombs	Preservation	Nannoplankton Zones
1H-1, 109-111 cm	R		F	R				P/M	NN 20	
1H, cc	F	F	C	C	F			G/M		
Cores 2H to 5H	barren								?	
6H, cc	R	R	R	R		T	◆	P/M	NN 20	
7X-1, 133-134 cm	R		R				◆	P/M		
7X, cc	barren								◆	?
Cores 8X to 13X	p.p.									
14X-4, 96-97 cm	R	R	F	R	R			P/M	NN 19	
14X, cc	R	F	R		R			P/M		
Cores 15X to 16X	barren								?	
17X-4, 101-102 cm	R		F	F				P/M	NN 19	
17X, cc	barren									?
18X-1, 25-26 cm	F	R	F	R				P/M	NN 19	
18X, cc	R		F	R				P/M		
19X-4, 82-83 cm	R		F	R				P/M		
19X, cc	barren								T	?
20X, cc	barren									
21X-2, 94-95 cm	R		C	C	R	R	T	M	NN 19	
21X, cc	R	R	R					P/M		
22X, cc	R		R	R			T	P/M		

Note: R = rare, F = few, C = common, A = abundant. Preservation: P = poor, M = moderate, G = good.

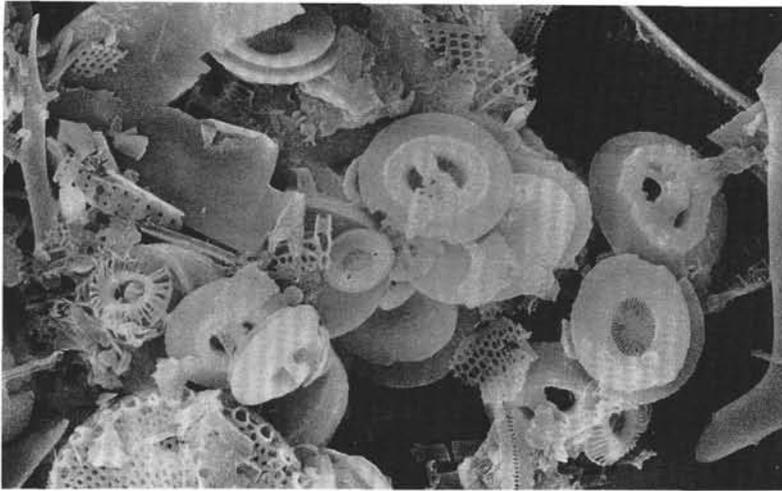
Table 12. Distribution of calcareous nanoplankton in selected samples from Holes 688A and 688E and indication of standard nanoplankton zones.

	<i>Coccolithus pelagicus</i>	<i>Cyclacoccolithus leptoporus</i>	<i>Cyclacoccolithus macintyreii</i>	<i>Discolithina japonica</i>	<i>Emiliania huxleyi</i>	<i>Gephyrocapsa aperta</i>	<i>Gephyrocapsa oceanica</i>	<i>Helicosphaera carteri</i>	<i>Helicosphaera sellii</i>	<i>Pseudoemiliania lacunosa</i>	Reworking	Dolomite rhombs	Preservation	Nannoplankton Zones
1H-4, 91-92 cm	F	R			cf.	F	R	R					H	NN 21?
1H, cc	R	R				R	R							P
2H, cc	F	F				C	F	C	R		M			NN 20
3H, cc	R	F				A	C	C	R					
4H, cc		F				C	F	F				◇		M
5H, cc	R	F				A	F	F	C					M
6H, cc	R	R	cf.			F	F	R				◇		P/M
7H, cc	F	R				F	F	R	R					P/M
8X, cc	R	cf.				F	R	R				◆		P/M
9X, cc		R	cf.			F	R	R			M			P
10X, cc		R				F	R		R			◇		P
11X, cc	barren													?
12X, cc		R	R			F	R							P
13X, cc	R	F				C	C	F	C					P/M
14X, cc to 16X, cc	barren													?
17X, cc		R				F	R	R						P
18X, cc				R		F	R							P
19X, cc		F	R			C	C		R					P/M
20X, cc	R	R				F	F		R					P
21X, cc	R	R				R	R							P
22X, cc	R	R				F	F	R	R					P
23X, cc	barren													?
24X, cc		R				R	R							P
25X, cc to 27X, cc	barren													?
28X, cc	R	R				R								P
29X, cc	F					F	R		R					P
30X, cc to 31X, cc	barren													?
32X, cc	R					R						◇		P
33X, cc	R					R						◇		P
34X, cc		R				F						◇		P
35X, cc to 37X, cc	barren													?

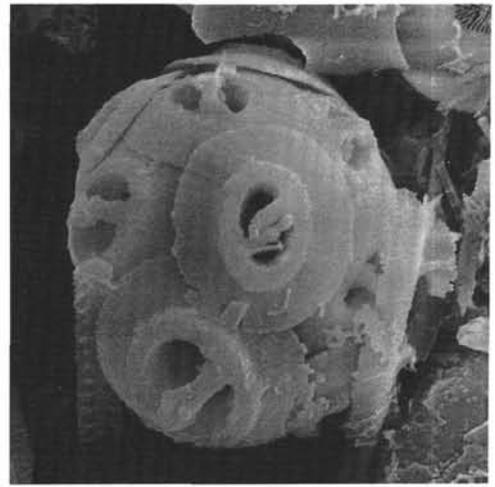
Note: R = rare, F = few, C = common, A = abundant. Preservation: P = poor, M = moderate, G = good. Reworking: C = Cretaceous, E = Eocene, M = Miocene.

Table 12 (continued).

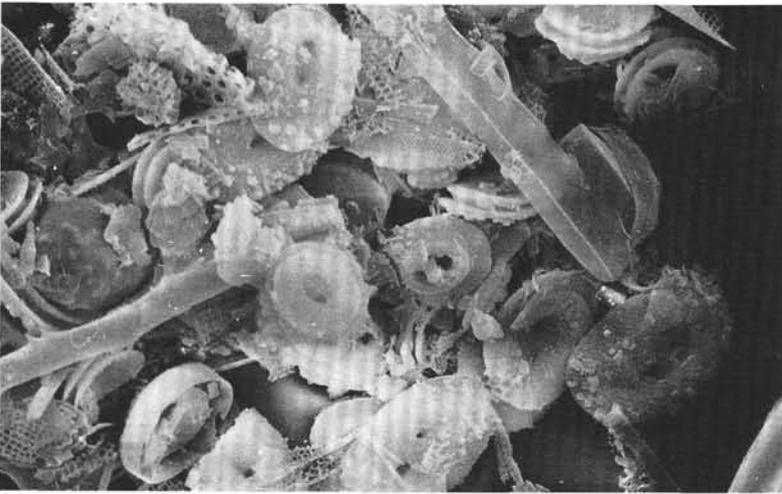
	<i>Coccolithus miopelagicus</i>	<i>Coccolithus pelagicus</i>	<i>Cyclargolithus abisechus</i>	<i>Cyclargolithus floridanus</i>	<i>Cyclococcolithus leptopus</i>	<i>Cyclococcolithus macintyreii</i>	<i>Cyclococcolithus rotula</i>	<i>Discoaster brouweri</i>	<i>Discoaster deflandrei</i>	<i>Discoaster exilis</i>	<i>Discoaster variabilis</i>	<i>Discoaster</i> VI sec. calc.	<i>Discolithina multipora</i>	<i>Helicosphaera carteri</i>	<i>Helicosphaera euphratis</i>	<i>Reticulofenestra pseudumbilica</i>	<i>Reticulofenestra</i> (small)	<i>Sphenolithus abies</i>	<i>Sphenolithus dissimilis</i>	<i>Sphenolithus mariformis</i>	<i>Triquetrorhabdulus carinatus</i>	Reworking	Dolomite rhombs	Preservation	Nannoplankton Zones
Cores 1R to 11R	b a r r e n																						?		
12R-2, 93-94 cm	C	F	R	R	R		R		R	R	R		R		C	C	F							P/M	NN 6
12R, cc		R	R		R						R				R	F	R							P	
13R, cc		R		R	R	R					R	R		R		R	F						◇	P/M	
14R, cc	F	F		R						R	F	F		R		C	C	R						P/M	
15R, cc	F	F		R	R					R	R		F		C	C	R							P/M	
16R, cc				R						cf.	R					R								P	
17R, cc	F	C		R		R	R			R			R	R		C	C	R						P/M	
18R, cc	F	F			R	R				F		F		R		C	C	R						P/M	
19R, cc	b a r r e n																						?		
20R-1, 20-21 cm	R	R	R	F							R	R				F	C							P/M	[NN 6]
20R, cc	b a r r e n																						?		
21R, cc	F	F	R	F			R			R				R		C	C	F						P/M	[NN 6]
22R-1, 2-3 cm	F	F	R	F					C			R			cf.	C							◇	P/M	NN 1/2
22R, cc	R	R							F			R	R			F							◆	P/M	
23R-2, 130-131 cm	R	F	R	C					F			F				C		R	R				◆	P/M	
23R, cc	F	F	F	C					F			F				C		R	R	R			◆	P/M	
24R-2, 2-3 cm	R	F	F	C					F			R			R		C		R	F			◆	P/M	
24R, cc	b a r r e n																						?		
25R, cc	R	F	R	C					F							C			R	R		◇	P/M	NN 1/2	
Core 26R	b a r r e n																						?		



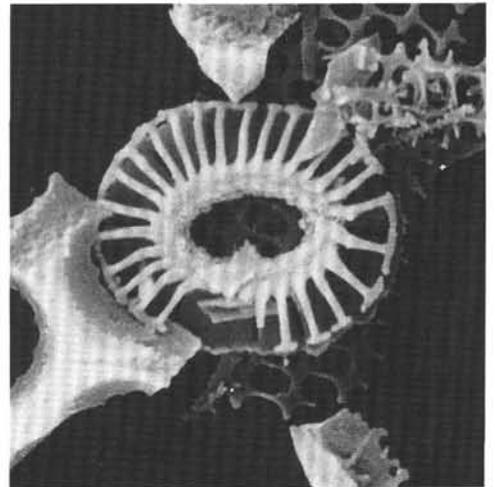
1



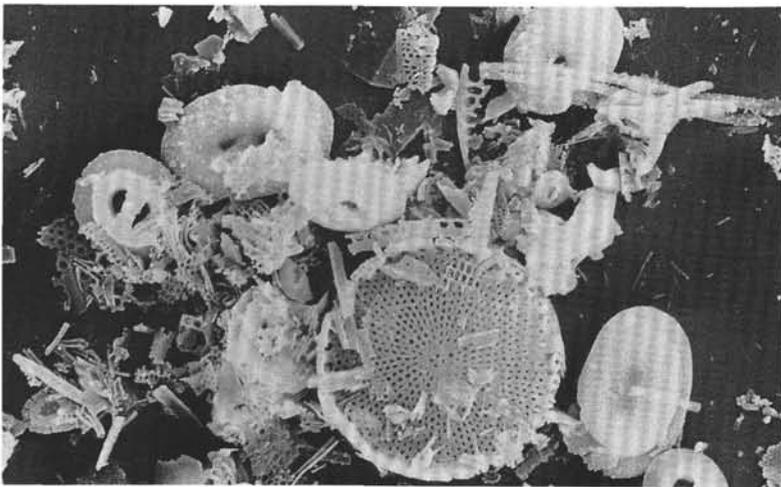
4



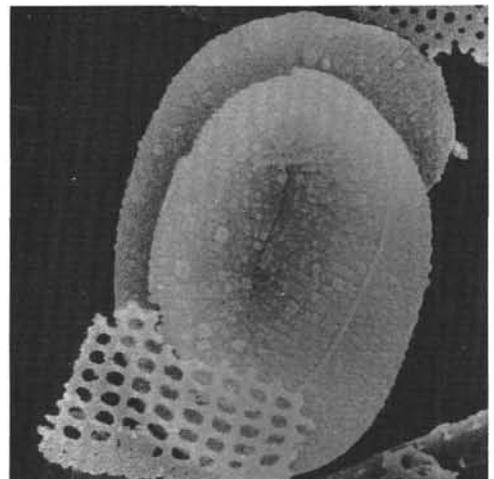
2



5



3



6

Plate 1. Holocene calcareous nannoplankton from a bloom horizon at 112-680B-2H-1, 105-106 cm, in otherwise diatomaceous muds (nannoplankton Zone NN21). 1-3. Different concentrations of the *Gephyrocapsa oceanica*/*Helicosphaera carteri* bloom containing *Emiliana huxleyi* (magnification 3650 \times , SEM). 4. Complete sphere of *Gephyrocapsa oceanica* Kamptner, SEM 5650 \times . 5. *Emiliana huxleyi* (Lohmann), SEM 12,000 \times . 6. *Helicosphaera carteri* (Wallich), SEM 8000 \times .

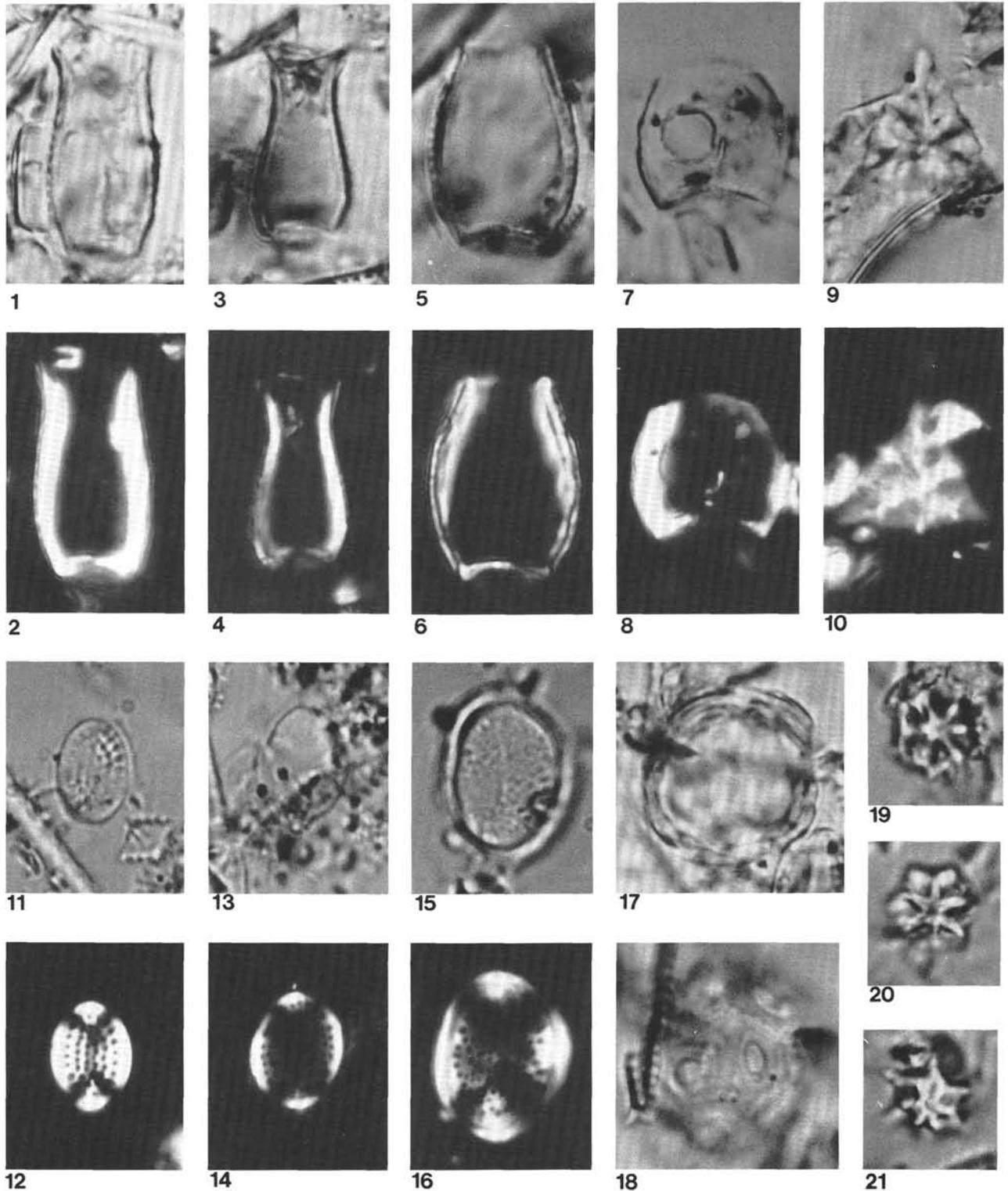


Plate 2. Miocene calcareous nannoplankton (All specimens magnified 2000×). 1, 2. *Scyphosphaera amphora* Deflandre, Sample 112-684A-14X, CC. 3, 4. *Scyphosphaera intermedia* Deflandre, Sample 112-684A-13X, CC. 5, 6. *Scyphosphaera apsteini* Lohmann, Sample 112-684A-13X, CC. 7, 8. *Scyphosphaera apsteini* Lohmann, Sample 112-684A-14X, CC. 9, 10. *Lithostromation perdurum* Deflandre, Sample 684A-14X, CC. 11, 12. *Discolithina multipora* (Kamptner ex Deflandre), Sample 112-684A-14X, CC. 13, 14. *Discolithina callosa* Martini, Sample 112-684A-14X, CC. 15, 16. *Scyphosphaera* sp. (base), Sample 112-684A-14X, CC. 17, 18. *Reticulofenestra pseudoumbilica* (Gartner), coccosphere, Sample 112-684A-14X, CC. 19–21. *Catinaster coalitus* Martini and Bramlette, Sample 112-683A-30X-2, 41–42 cm. 1–18. Nannoplankton Zone NN9. 19–21. Nannoplankton Zone NN8.