58. BIOSTRATIGRAPHY OF CALCAREOUS NANNOFOSSILS: LEG 34, DEEP SEA DRILLING PROJECT

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ABSTRACT

Forty-four cores were recovered from three drill sites during Leg 34 of the Deep Sea Drilling Project in the southeastern Pacific. Calcareous nannofossils ranging in age from late Eocene to Quaternary were found in 24 of these cores. The Neogene is well represented at Site 319 and partially represented at Site 320. For the most part, calcareous nannofossils are absent or poorly preserved in the Plio-Pleistocene interval at all three sites. The Miocene interval was continuously cored at Site 319, and calcareous nannofossils are fairly well preserved in this interval. Site 320 was intermittently cored in three holes, penetrating primarily lower Miocene sediments. The Neogene interval at Site 321 is barren of calcareous nannofossils, except for a fairly diverse, well-preserved upper Oligocene/lower Miocene flora at a depth of about 58 meters. The only Paleogene sediments found on Leg 34 were recovered at Site 321, where a nearly complete Oligocene section extending into the upper Eocene was cored.

INTRODUCTION

Three sites were drilled in the southeastern Pacific during Leg 34 (Figure 1). These are: Site 319, located in the Bauer Deep between the Galapagos Rise and the East Pacific Rise; Site 320, located about 200 miles off the western coast of Peru; and Site 321, also located off the western coast of Peru. Calcareous nannofossils were found at all three sites which presently lie below the carbonate compensation depth. (CCD). The presence of carbonates in the sediments probably reflects a combination of factors including subsidence, which has brought these sites below the CCD, and large-scale fluctuations of the CCD through geologic time (van Andel et al., in preparation). These factors and their influence on the geologic history of the area are discussed in detail by Quilty et al. (this volume). The purpose of this study is threefold: (1) to determine the biostratigraphic relationships of the calcareous nannofossils recovered during Leg 34; (2) to record and present data on the preservation of the nannofossils; and (3) to provide data to aid in the reconstruction of the geologic history of the area.

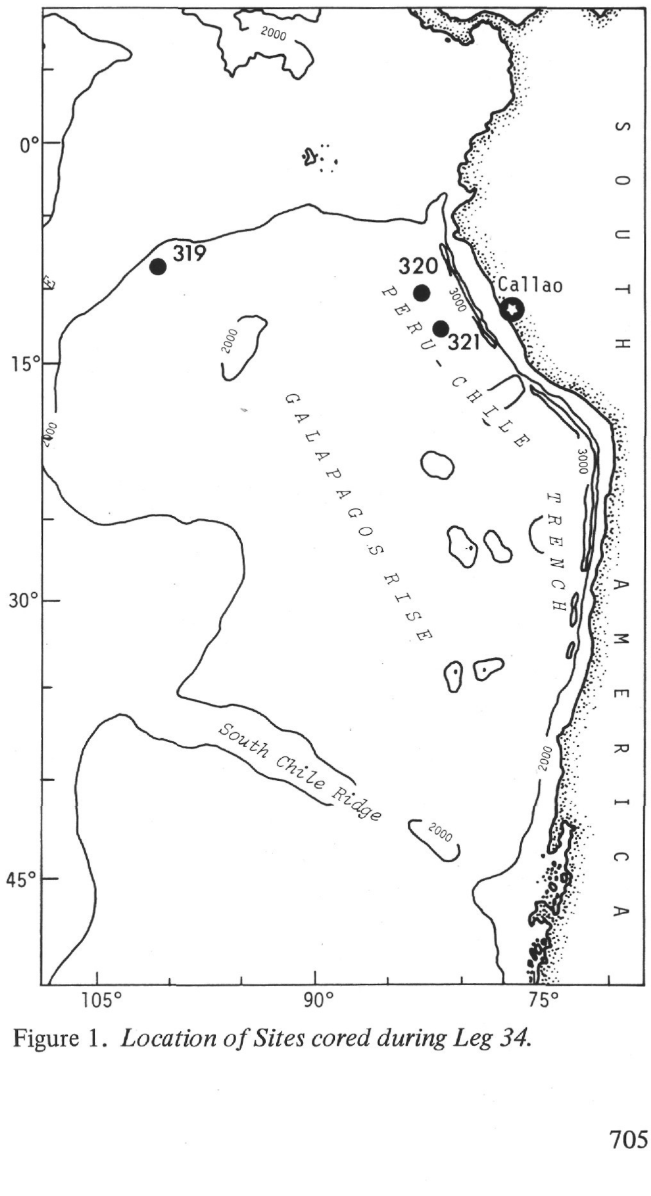

Figure 1. *Location of Sites cored during Leg 34.*

BIOSTRATIGRAPHY

Cenozoic calcareous nannoplankton zonations have been established by a number of investigators, primarily based on land or epicontinental sections (Bramlette and Sullivan, 1961; Bramlette and Wilcoxon, 1967; Hay et al., 1967; Gartner, 1969; Martini, 1971; Edwards, 1971; and Bukry, 1973). With the increase in data available from the deep sea, it has become apparent that land-based zonation schemes are not always applicable in the deep sea. This probably is the result of several factors, the most obvious of which is selective dissolution of solution-susceptible taxa in deep water sections and the shelf restricted habitat of many species. For the most part, the standard calcareous nannofossil zonation notation established by Martini (1971) has been used in this report, although in some cases zonal boundaries have been defined more in accordance with those proposed by Bukry (1973) for low latitude deep-sea sections. This system employs the use of one or more datum (highest or lowest occurrence of a taxon) to define zonal boundaries. Because of selective solution of taxa and provincialism among the calcareous nannofossils, this proves to be a more practical approach to deep-sea biostratigraphy, although it involves some sacrifice of precision. In general, Martini's zones were recognizable in the Neogene sections examined from Leg 34 and for most of the Paleogene section recovered at Site 321. Figure 2 summarizes the biostratigraphic criteria used in zonal determinations for this report.

PRESERVATION

Selective dissolution and overcalcification of calcareous nannofossils are important factors in species identification and species composition in deep-sea sediments. As previously stated, this may have a considerable effect on biostratigraphic results.

Frequently placoliths show dissolution features, with destruction of fine structures and central area enlargement, while discoasters show overcalcification. This phenomenon has been discussed in detail by Wise and Kelts (1972) and Adelseck et al. (1973). Because of this differential preservation, placolith and discoaster preservation have been recorded separately in this study. A modified preservation scale similar to that described by Bukry (1973) was used here. Briefly this scale may be described as follows:

+5 = Complete recrystallization and secondary calcification—coccoliths unrecognizable—essentially a micrite.
+4 = Marked recrystallization and secondary calcification—few identifiable coccoliths.
+3 = Marked recrystallization and secondary calcification—some problem in identification, fine structures obscured.
+2 = Moderate recrystallization and secondary calcification—almost all taxa recognizable—fine structures mostly obliterated.
+1 = Mild recrystallization and secondary calcification—some thickening of discoasters, fine structures visible.
−1 = Mild etching—no difficulty in species identification—most fine structures intact.
−2 = Solution more marked—holococcoliths and solution-susceptible taxa absent.
−3 = Marked dissolution—central areas of placoliths affected—all fine.
−4 = Marked dissolution—only most resistant taxa remaining—much fragmentation.
−5 = Barren of coccoliths and other calcareous material.

METHOD

Light microscopy was used entirely in the examination of approximately 140 samples. Calcareous nannofossil taxa preselected for consideration are listed in Table 1. As no new species are described in this report,

	ZONE NAME	NUMBER	DATUM INDICATOR	
Quat.	*Emiliania huxleyi*	NN21	HOS	*Emiliania huxleyi*
	Gephyrocapsa oceanica	NN20	HOS	*Pseudoemiliania lacunosa*, LOS *Gephyrocapsa oceanica*
	Pseudoemiliania lacunosa	NN19	HOS	*Discoaster brouweri*
Pliocene	*Discoaster brouweri*	NN18	HOS	*Discoaster pentaradiatus*
	Discoaster pentaradiatus	NN17	HOS	*Discoaster surculus*
	Discoaster surculus	NN16	HOS	*Reticulofenestra pseudoumbilica*
	Reticulofenestra pseudoumbilica	NN15	HOS	*Ceratolithus tricorniculatus*
	Discoaster asymmetricus	NN14	LOS	*Discoaster asymmetricus*
	Ceratolithus rugosus	NN13	LOS	*Ceratolithus rugosus*
Miocene	*Ceratolithus tricorniculatus*	NN12	HOS	*Discoaster quinqueramus*
	Discoaster quinqueramus	NN11	LOS	*Discoaster quinqueramus*
	Discoaster calcaris	NN10	HOS	*Discoaster hamatus*
	Discoaster hamatus	NN9	LOS	*Discoaster hamatus*
	Catinaster coalitus	NN8	LOS	*Catinaster coalitus*
	Discoaster kugleri	NN7	LOS	*Discoaster kugleri*
	Discoaster exilis	NN6	HOS	*Sphenolithus heteromorphus*
	Sphenolithus heteromorphus	NN5	HOS	*Helicopontosphaera ampliaperta*
	Helicopontosphaera ampliaperta	NN4	LOS	*Sphenolithus heteromorphus*, HOS *Sphenolithus belemnos*
	Sphenolithus belemnos	NN3	HOS	*Discoaster druggi*, HOS *Triquetrorhabdulus carinatus*
	Discoaster druggi	NN2	LOS	*Discoaster druggi*
	Triquetrorhabdulus carinatus	NN1	HOS	*Sphenolithus ciperoensis*, HOS *Reticulofenestra bisecta*
Oligocene	*Sphenolithus ciperoensis*	NP25	HOS	*Sphenolithus distentus*
	Sphenolithus distentus	NP24	LOS	*Sphenolithus ciperoensis*
	Sphenolithus predistentus	NP23	HOS	*Reticulofenestra umbilica*, LOS *Sphenolithus distentus*
	Reticulofenestra umbilica	NP22	HOS	*Cyclococcolithus formosa*
	Helicopontosphaera reticulata	NP21	HOS	*Discoaster barbadiensis*, HOS *Discoaster saipanensis*
Eo.	*Sphenolithus pseudoradians*	NP20	LOS	*Sphenolithus pseudoradians*

Figure 2. *Zones used in this study. (HOS = highest occurrence surface; LOS = lowest occurence surface).*

TABLE 1
Nannofossil Species Considered in This Report, Listed Alphabetically According to Species Name

Sphenolithus abies	Deflandre in Deflandre and Fert
Reticulofenestra abisecta	(Muller) Roth and Thierstein
Chiasmolithus altus	Bukry and Percival
Helicopontosphaera ampliaperta	(Bramlette and Wilcoxon) Hay
Oolithus antillarium	(Cohen) Reinhardt *in* Cohen and Reinhardt
Discoaster asymmetricus	Gartner
Discoaster aulakos	Hay
Discoaster barbadiensis	Tan Sin Hok
Sphenolithus belemnos	Bramlette and Wilcoxon
Braarudosphaera bigelowi	(Gan and Braarud) Deflandre
Zygrhablithus bijugatus	(Deflandre) Deflandre
Discoaster binodosus	Martini
Reticulofenestra bisecta	(Hay, Mohler, and Wade) Roth
Discoaster bollii	Martini and Bramlette
Discoaster brouweri	Tan Sin Hok
Discoaster calcaris	Gartner
Catinaster calyculus	Martini and Bramlette
Sphenolithus capricornutus	Bukry and Percival
Triquetrorhabdulus carinatus	Martini
Discoaster challengeri	Bramlette and Riedel
Sphenolithus ciperoensis	Bramlette and Wilcoxon
Syracosphaera clathrata	Roth and Hay *in* Hay et al.
Rhabdosphaera clavigera	Murray and Blackman
Catinaster coalitus	Martini and Bramlette
Quinquerhabdus colossicus	Bukry and Bramlette
Helicopontosphaera compacta	(Bramlette and Sullivan) Hay
Sphenolithus conicus	Bukry
Ceratolithus cristatus	Kamptner
Sphenolithus distentus	Bramlette and Wilcoxon
Coccolithus doronicoides	Black and Barnes
Discoaster druggi	Bramlette and Wilcoxon
Zygolithus dubius	Deflandre *in* Deflandre and Fert
Coccolithus eopelagicus	(Bramlette and Riedel) Bramlette & Sullivan
Discoaster exilis	Martini and Bramlette
Ericsonia fenestrata	(Deflandre) Stradner
Cyclicargolithus floridanus	Roth and Hay *in* Hay et al.
Cyclococcolithus formosa	(Kamptner) Wilcoxon
Chiasmolithus grandis	(Bramlette and Riedel) Gartner
Discoaster hamatus	Martini and Bramlette
Sphenolithus heteromorphus	Deflandre
Reticulofenestra hillae	Bukry and Percival
Emiliania huxleyi	Lohmann
Reticulofenestra insignata	Roth and Hay *in* Hay et al.
Helicopontosphaera intermedia	(Martini) Hay and Mohler
Markalius inversus	(Deflandre) Bramlette and Martini
Discolithina japonica	Takayama
Helicopontosphaera kamptneri	Hay and Mohler
Cyclococcolithus kingi	Roth
Discoaster kugleri	Martini and Bramlette
Pseudoemiliania lacunosa	(Kamptner) Gartner
Discoaster lautus	Hay
Reticulofenestra laevis	Roth and Hay *in* Hay et al.
Cyclococcolithus leptopora	(Murray and Blackmann) Wilcoxon
Discoaster lidzi	Hay
Cyclococcolithus macintyrei	(Bukry and Bramlette) Wilcoxon
Discolithina millepuncta	Gartner
Lanternithus minutus	Stradner
Umbellosphaera mirabilis	Lohmann
Sphenolithus moriformis	(Bronnimann and Stradner) Bramlette & Wilcoxon
Discolithina multipora	(Kamptner) Martini
Discoaster neohamatus	Bukry and Bramlette
Discoaster nephados	Hay
Chiasmolithus oamaruensis	(Deflandre) Hay, Mohler, and Wade
Reticulofenestra oamaruensis	(Deflandre) Stradner
Helicopontosphaera obliqua	(Bramlette and Wilcoxon) Roth and Thierstein
Transversopontis obliquipons	(Deflandre) Hay, Mohler, and Wade
Gephyrocapsa oceanica	Kamptner
Sphenolithus pacificus	Martini

TABLE 1 – *Continued*

Helicopontosphaera parallela	(Bramlette and Wilcoxon) Bukry
Discoaster pentaradiatus	Tan Sin Hok
Discoaster perplexus	Bramlette and Riedel
Sphenolithus predistentus	Bramlette and Wilcoxon
Coccolithus productus	Kamptner
Sphenolithus pseudoradians	Bramlette and Wilcoxon
Reticulofenestra pseudoumbilica	Gartner
Discolithina pygmaea	Locker
Discoaster quinqueramus	Gartner
Helicopontosphaera recta	(Bramlette and Wilcoxon) Muller
Isthmolithus recurvus	Deflandre *in* Deflandre and Fert
Helicopontosphaera reticulata	(Bramlette and Wilcoxon) Roth
Braarudosphaera rosa	Levin and Jorger
Ceratolithus rugosa	Bukry and Bramlette
Triquetrorhabdulus rugosus	Bramlette and Wilcoxon
Discoaster saipanensis	Bramlette and Sullivan
Discoaster saundersi	Hay
Reticulofenestra scissura	Hay, Mohler, and Wade
Reticulofenestra scrippsae	Bukry and Percival
Discolithina segmenta	Bukry and Percival
Helicopontosphaera sellii	Bukry and Bramlette
Helicopontosphaera seminulum	(Bramlette and Sullivan) Stradner
Bramlettius serraculoides	Gartner
Coronocyclus serratus	Hay, Mohler, and Wade
Ericsonia subdisticha	(Roth and Hay) Roth *in* Baumann and Roth
Discoaster surculus	Martini and Bramlette
Discoaster tani	Bramlette and Riedel
Rhabdosphaera tenuis	Bramlette and Sullivan
Ceratolithus tricorniculatus	Gartner
Sphenolithus tribulosus	Roth
Discoaster trinidadensis	Hay
Reticulofenestra umbilica	(Levin) Martini and Ritzkowski
Discoaster variabilis	Martini and Bramlette
Micrantholithus vesper	Deflandre and Fert

no discussion or taxonomic description is included here. Detailed descriptions of taxa may be found by consulting Loeblich and Tappan (1966, 1968, 1969, 1970a, 1970b, and 1971). Data were collected using the optical scanning technique described by Blechschmidt and Worsley (in preparation). Briefly, this technique involves recording data on abundance and presence of taxa on a specially designed "mark sense" sheet similar to those used in machine graded testing. Using this technique, data are recorded by the investigator while examining a sample in a format allowing direct computer input. This technique allows rapid recording of data and direct input onto a magnetic tape for computer storage and processing.

Abundance estimates were tabulated according to a logarithmic scale and are shown in Figures 3, 4, and 5 using the more traditional letter symbols. The abundance catagories are as follows:

- A = Abundant: 10^1—ten or more specimens of a taxa per field of view at 640× magnification.
- C = Common: 10^0—One to zero specimens per field of view at 640× magnification.
- F = Few: 10^{-1}—0.1 to 0.9 specimens per field of view at 640× magnification.
- R = Rare: 10^{-2}—0.01 to 0.09 specimens per field of view at 640× magnification.
- V = Very rare: 10^{-3}—0.001 to 0.009 specimens per field of view at 640× magnification.

Preservation data have been tabulated and are shown on the accompanying range charts as previously described. Reworking, downworking, or contamination of

Age	Zone	Sample (Interval in cm)	Placolith Preservation	Discoaster Preservation	Reworking, downworking, contamination	*Discoaster asymmetricus*	*Discoaster brouweri*	*Discoaster calcaris*	*Discoaster challengeri*	*Coccolithus doronicoides*	*Discoaster druggi*	*Discoaster exilis*	*Cyclicargolithus floridanus*	*Sphenolithus heteromorphus*	*Helicopontosphaera kamptneri*	*Discoaster kugleri*	*Cyclococcolithus leptopora*	*Cyclococcolithus macintyrei*	*Sphenolithus moriformis*	*Discoaster neohematus*	*Discoaster nephados*	*Discoaster pentaradiatus*	*Discoaster perplexus*	*Coccolithus productus*	*Reticulofenestra pseudoumbilica*	*Helicopontosphaera recta*	*Triquetrorhabdulus rugosus*	*Discoaster surculus*	*Ceratolithus tricorniculatus*	*Discoaster trinidadensis*	*Discoaster variabilis*	*Helicopontosphaera parallela*	*Coccolithus eopelagicus*	*Discoaster aulakos*
		1-1, 115	–5																															
		1-2, 115	–5																															
Miocene	NN12	1-3, 120	–2	+1		V	F			F							F	F				R		F	F			F	F		R			
		1-4, 110	–2	+1			C		R	F							F					F		F				F	C		F			
		1-5, 110	–2	+2			C										C	F				F		F				F	F		F			
		1-6, 111	–3	+2			F			C							F	R				R		F	R			F	F		R			
		2-1, 61	–2	+2			F			C							C	F				R		F	R			F	R		R			
		2-2, 81	–2	+2			F		F								C	F											R		F			
	NN 11-12	2-3, 120	–2	+2			F		F								C	F				F		F							C			
		2-4, 4	–2	+2			F		F								C	F				R			R						C			
	NN10	3-2, 2	–3	+2			F	R	F						V		F	C		R		F			R		R				C			
		3-3, 120	–2	+2			C	R	F								F	F		R		F			R		R					C		
	NN6	4-1, 139	–2	+3			F					F				R	C	F				F			F		F				C			
		4-2, 120	–3	+3			R					F					F	F							F						C		F	
		4-3, 107	–2	+3			R					F		V		V	F	F	R						C		F				C		C	
		4-4, 107	–2	+3					R			F					R	C							C		F				C		F	
		4-5, 80	–2	+3								F						F							C		F				F		F	
		4-6, 129	–2	+3			F					F			R		F	F						F	C		F				C		F	
		5-1, 140	–2	+3	X		F					C	R	R	R		R	F	R		R				C		F				C		C	
		5-2, 110	–2	+3	X		F					F	F	C	R		F	F	F		R				F		F				C		F	
		5-3, 110	–2	+3			R					F	C	C	R		F	F	F						F		F				F		F	
		5-4, 110	–2	+3			F					F	F		R		F	F			R				C		C				F		F	
		5-5, 110	–2	+3			R					F	R		F		F	F	R				R		F		F				F		C	
		5-6, 110	–2	+3	X		R					C	F	C	R		R	R	F		R				F		F				C		F	
		6-1, 106	–2	+3	X		R					F	F	C	R		F	F	R						F		F				C		F	
		6-3, 126	–2	+2			R					F	R		R		F	F	R		R				F		F				F		F	
		6-4, 11	–2	+3			R					C	F				F	F	R						C		F				F		F	
		6-5, 130	–2	+3	X		R					C	R	F			F	R	F		R				F		F				F		F	
		6-6, 125	–2	+3			R					C	F	F	R		F	F							F		C				F		F	
		7-1, 37	–2	+3			R					F	F	R			F	F	F						F		F				F	R		
		7-2, 52	–2	+3	X							F	F	F				R	R						C		F				F	R	F	
		7-3, 112	–2	+3								C	R				F	F			R				F		F				C	R	F	
		7-4, 105	–2	+3								F	F		R		R	F	F						F		C				F	R	F	R
		7-5, 105	–2	+3	X							F	F				R	F	C						F	V	C				F	R		
		7-6, 94	–2	+3								F	F		R		R	F	F						F						F	R	F	R
	NN5	8-1, 52	–2	+3								F	F	C				R	C		R				F						F		F	F
		8-4, 118	–2	+3								C	F	C				R	A						R						F		F	R
		8-6, 60	–2	+3								F	F	A			R	F	C				R								F	R	F	R
		9-3, 61	–2	+3								F	F	A			R	R	C		R										F	R	F	
		10-3, 62	–2	+3								F	F	C			R		F												C	R	F	R
		10-5, 50	–2	+3	X							C	C	A	R			R	C							R				V	F		F	R
		11-1, 3	–3	+3								F	C	A				R	F												C		F	R
		11-3, 30	–3	+3								C	C	A	R				F												F		F	R
		11-6 60	–2	+3							R	F	C		R		R		F											R	F		R	R
		12-1, 128	–2	+3							R	F	C	A			R		F		R										F		F	F
		12-3, 35	–2	+3							R	C	C	A				R	C												F	R		F

Figure 3. *Distribution of calcareous nannofossils at Site 319.*

Age	Zone	Sample (Depth in Section in cm)	Placolith Preservation	Discoaster Preservation	Reworking, Downworking Contamination	*Triquetrorhabdulus carinatus*	*Rhabdosphaera clavigera*	*Sphenolithus conicus*	*Coccolithus doronicoides*	*Discoaster druggi*	*Discoaster exilis*	*Cyclicargolithus floridanus*	*Sphenolithus heteromorphus*	*Helicopontosphaera kamptneri*	*Cyclococcolithina leptopora*	*Discoaster lidzi*	*Cyclococcolithus macintyrei*	*Sphenolithus moriformis*	*Discoaster nephados*	*Gephyrocapsa oceanica*	*Coccolithus productus*	*Discoaster saundersi*	*Discoaster trinidadensis*	*Helicopontosphaera parallela*	*Coccolithus eopelagicus*	*Discoaster aulakos*
?		1-1, 5	–5																							
		1-2, 61	–5																							
		1-3, 6	–5																							
		1-4, 9	–5																							
		1A-0, 20	–5																							
Quaternary	NN20?	1-5, 85	–5						R																	
		1A-1, 60	–5						R																	
		1A-2, 89	–5						R																	
		1A-3, 98	–2				R		F					R	F		R			F	C					
		1A-4, 18	–5				R																			
		1A-5, 110	–4						R					R	R					R						
		1A-6, 4	–4											R	R					R	F					
	NN5	2A-1, 75	–2	+2							C	F	C		F			C							F	R
		2A-2, 96	–3	+3						R	C	F	C					F	R							
Miocene	NN2	3A-1, 99	–2	+3				R		R		C		R		R	R	C							R	F
		3A-2, 3	–1	+3				R		R		C		R		R	V	C							R	R
		3A-6, 9	–3	+3				F		R		C						C								F
		1B-0, 45	–2	+3		C		F		F		C				R		F								R
		1B-1, 106	–2	+2		C		F		F		C				R		F				R	R		R	F
		1B-2, 13	–2	+3		C		R		F		C				R		F						R		R
Oligocene	NN1	1B-3, 9	–2	+3		F						F						C				R			R	R
		1B-6, 20	–2	+3		C		F				C						A							R	R
		2B-1, 64	–2	+3		C		R				C						C								F
		2B-3, 82	–3	+3		C		F				F						C				R			R	F
		2B-5, 31	–2	+3		F		F				C						C				R				R

Figure 4. *Distribution of calcareous nannofossils at Site 320.*

a sample is denoted by an X in the appropriate space shown in Figures 3, 4, and 5.

SITE 319—LATITUDE 13°01.04′S, LONGITUDE 101°31.46′W

Site 319 was drilled in 4290 meters of water in the Bauer Deep; 116.5 meters of metalliferous nanno ooze were drilled and 84.8 meters of sediment recovered. Sediments recovered at this site range in age from Quaternary to early Miocene.

Sections 1 and 2 of Core 1 are barren of calcareous nannofossils, containing much siliceous material (primarily diatoms fragments and silicoflagellates). Section 3 of Core 1 contains a moderately well preserved upper Miocene assemblage belonging to the *Ceratolithus tricorniculatus* Zone dominated by *Discoaster brouweri* and *Ceratolithus tricorniculatus*. Species diversity in this section and the remainder of Core 1 is quite low. Core 2 also recovered the *Ceratolithus tricorniculatus* Zone. The lower part of this core (Sections 3 and 4) is also tentatively assigned to the *C. tricorniculatus* Zone, but it may also represent the *Discoaster quinqueramus* Zone. Overcalcification of discoasters makes differentiation difficult. *C. tricorniculatus* is not found in Sections 3 and 4. *Discoaster brouweri, Discoaster variabilis,* and *Cyclococcolithus leptoporus* dominate the assemblage. A portion of Core 3 was lost in coring. An assemblage belongs to the *Discoaster calcaris* Zone with common *Triquetrorhabdulus rugosus, D. brouweri, D. variabilis, C. leptoporus,* and *Cyclococcolithus macintyrei. Discoaster calcaris* was found in Section 3. Tentative age assignment of Core 4 placed it in the *Discoaster exilis* Zone. *Discoaster kugleri* appears very sparsely in Section 1 of this core. *Triquetrorhabdulus rugosus, D. exilis, D. variabilis,* and *C. leptoporus* are common in this core. *Helicopontosphaera kamptneri* also appears rarely throughout this core. Some reworking was apparent in Core 5 with a dominant assemblage characteristic of the *D. exilis* Zone. Reworked *Sphenolithus heteromorphus* was detected in Sections 1, 2, and 5. This reworking was also apparent in Core 6 and to some extent in Core 7, both of which contain a dominant floral assemblage

Age	Zone	Sample (Depth in Section in cm)	Placolith Preservation	Discoaster Preservation	Reworking, Downworking Contamination	*Reticulofenestra abisecta*	*Discoaster aulakos*	*Discoaster barbadiensis*	*Braarudosphaera bigelowi*	*Zygrhablithus bijugatus*	*Reticulofenestra bisecta*	*Sphenolithus capricornutus*	*Triquetrorhabdulus carinatus*	*Sphenolithus ciperoensis*	*Quinquerhabdus colossicus*	*Helicopontosphaera compacta*	*Sphenolithus conicus*	*Sphenolithus distentus*	*Coccolithus doronicoides*	*Cyclicargolithus floridanus*	*Cyclococcolithus formosa*	*Reticulofenestra hillae*	*Discoaster lautus*	*Reticulofenestra laevis*	*Cyclococcolithus leptopora*	*Sphenolithus moriformis*	*Sphenolithus predistentus*	*Coccolithus productus*	*Sphenolithus pseudoradians*	*Discoaster saipanensis*	*Discoaster saundersi*	*Reticulofenestra scissura*	*Discolithina segmenta*	*Bramlettius serraculoides*	*Discoaster tani*	*Sphenolithus tribulosus*	*Reticulofenestra umbilica*
Undifferentiated		1-1, 110	-5																V																		
		2-1, 120	-5																V																		
		2-2, 120	-4																V									V									
		2-3, 68	-4																V									V									
		2-4, 78	-5																									V									
		3-1, 30	-4																V						V												
		3-2, 80	-5																V																		
		3-2, 110	-5																									V									
		3-4, 80	-5																V																		
		3-5, 62	-5																V																		
		3-6, 115	-5																V																		
		4-2, 112	-5																V																		
		4-3, 123	-5																V																		
		4-4, 111	-5																V																		
		5-2, 93	-5																V																		
		5-3, 124	-5																									V									
		5-4, 115	-5																									V									
		5-5, 101	-5																									V									
		5-6, 102	-5																V																		
		6-2, 122	-5																V																		
		6-3, 83	-5																																		
		6-4, 126	-5																																		
		6-5, 117	-5																																		
		6-6, 97	-5																																		
		7-2, 93	-5																																		
		7-3, 89	-5																																		
		7-4, 91	-5																																		
		7-5, 87	-5																																		
Oligocene	NP1?	7-6, 144	-1	+3	X		R			R	F		C		R		F			A			C	R		C	F							R			V
		8-1, 131	-1	+3	X	F	R			F	F		F	R	F		F	F		A	R	R	C			C	F		F			C		F	R		R
	NP 24-25	8-2, 51	-1	+3	X	C	F	F		F	F		F	F	F	R	F	R					F	F		C	F		R			F	R	F	F		R
		8-3, 55	+1	+3	X	F	R	F		C	C		F	F	F		F	F		R	R	F	C			C	C		F			F		C	F		F
		8-4, 89	+1	+3	X	F	R	R		C	C	R	F	F			F	F		C		F	C			C	V		R	R		F		F	F		F
		8-5, 63	+1	+3	X	F		F		C	F		F	F			F	F		C		F	C			C	C		F	R		F		F	F		F
		8-6, 105	+1	+3	X	F		F	R	C	C		R	F		R	F	F		A	R	R	C			C	C		F			C	R	C	F		F
	NP24	9-1, 81	-2	+3	X						F			R			F	F		C		F	C			C	F				R	F			R		
		9-2, 181	-2	+3	X						F			R				F		A			F			C	C		R			F		R			
		9-3, 106	-2	+3	X					F	F						C	F		A		F	F			R	C		R			F			F		
		9-4, 129	-2	+3	X			V			F							F		C		F	F			C	C		F			F			R		
		9-5, 24	-1	+3	X						F							F		C		F	F			C	C		R			F			F		R
		9-6, 62	-1	+3	X			R			F							C		C						C	C		F			F		F	F	R	R
	NP23	10-2, 82	-1	+3							C							R		C		F	F			C	C					F		F	C		
		10-3, 70	-1	+3							C							F		C		R	F			A	C					C			C		
		11-1, 10	-1	+3							F							C		C			F			C	C					F			R		
		11-2, 70	-1	+3							C							F		A			F			C	C		F			F			R		
		11-3, 66	-1	+3							C							F		C		F				A	C		R			F			C		R
		11-4, 80	+1	+3							C							F		C		F	F			A	C		F			C		F	C		R
Eocene	NP20	13-1, 117	-3	+2				C			C									F		F				F	F			C		C			C		F
		13-2, 75	-2	+2				C			C									F						F	R			C		C		F	C		C
		13-3, 118	-1	+2				C			C									F						C				C		A		C	C		F

Figure 5. *Distribution of calcareous nannofossils at Site 321.*

characteristic of the *D. exilis* Zone. Common species present are *T. rugosus, D. variabilis, D. exilis, C. leptoporus,* and *C. macintyrei.* Cores 8, 9, 10, 11, and 12 all recovered nanno ooze with a flora characteristic of the *Sphenolithus heteromorphus* Zone. *S. heteromorphus, C. macintyrei, Discoaster aulakos,* and *D. variabilis* are common in this assemblage. *D. exilis* disappears in Core 12, in which discoasters of the *Discoaster deflandre* group become more dominant.

Preservation: Calcareous nannofossils in all sections show some effects of dissolution. This is particularly marked in the upper Miocene sediments recovered at this site. The less solution-resistant genera such as *Discolithus* and *Braarudosphaera* are not preserved at all. Discoasters showed marked overcalcification in almost all samples examined, making identification quite difficult in many cases. This factor is much more prominent in the lower Miocene sediments recovered. Preservation of placoliths is generally fairly good with general destruction of fine structures. For the most part, this did not hamper identification.

SITE 320—LATITUDE 9°00.40'S, LONGITUDE 83°31.80'W

At Site 320, located approximately 200 miles from the west coast of South America, 155 meters of sediment were cored. Four holes were drilled in which 84.5 meters of sediment were recovered ranging in age from Quaternary to early Miocene. The Quaternary interval at this site is a siliceous clay. Lower Miocene sediments are a nanno-foram ooze.

Three cores were recovered at Hole 320. Sections 1 and 2 of Core 1 are barren of calcareous nannofossils. Section 3 contains a fairly well preserved Pleistocene assemblage belonging to the *Gephyrocapsa oceanica* Zone. This assemblage includes *C. leptoporus, G. oceanica, H. kamptneri, Rhabdosphaera clavigera,* and *Coccolithus doronicoides.* Section 4 is barren of calcareous nannofossils and Sections 5 and 6 contain an assemblage similar to that found in Section 3. Preservation in these two sections is poor with only more resistant taxa remaining. Core 2 recovered lower Miocene sediments at a subbottom depth of 73.5 meters. The nannofossil assemblage in this core is representative of the *S. heteromorphus* and common *C. leptoporus* and *C. floridanus.* Core 3 recovered sediment from 103.5 to 111.5 meters. The nanno-foram ooze of this core contains a floral assemblage representative of the *Discoaster druggi* Zone. *Reticulofenestra abisecta, Sphenolithus moriformis, D. druggi,* and *D. aulakos* are among the taxa found in samples from this core.

Hole 320A: All samples from the only core recovered are barren of calcareous nannofossils.

Hole 320B: Two cores were recovered at a depth below mudline of 136.0 to 155.0 meters. Both penetrated lower Miocene sediments. Sections 1 and 2 of Core 1 contain nannofossils characteristic of the *D. druggi* Zone with common *Cyclicargolithus floridanus, S. moriformis, Triquetrorhabdulus carinatus,* and *D. druggi.* Sections 3 through 6 are assigned to the *T. carinatus* Zone including *T. carinatus, Reticulofenestra scrippsae, S. moriformis,* and *C. floridanus.* Core 2 contains a similar assemblage and is also assigned to the *T. carinatus* Zone.

Preservation: Nannofossils recovered at Site 320 are generally poorly preserved in the Pleistocene interval. The successive appearance and disappearance of calcareous nannofossils in Core 1 of Hole 320 may represent Pleistocene fluctuations in the CCD. Nannofossils in the lower Miocene interval of the cores collected are relatively well preserved. Discoasters are frequently badly overcalcified making identification impossible. Fine structures of placoliths were destroyed, but identification of taxa was not impaired.

SITE 321—LATITUDE 12°01.29', LONGITUDE 81°54.24'

Site 321 was drilled in 4827 meters of water on the eastern edge of the Nazca plate about 200 miles west of the coast of Peru. Of the 125 meters of sediment drilled at this site, 81.3 meters were recovered. The lower 67 meters contain calcareous nannofossils ranging in age from early Miocene/late Oligocene to late Eocene.

Cores 1 through 6, recovered at Site 321, are barren of calcareous nannofossils. Sections 1 through 5 of Core 7 are also barren of nannofossils. Section 6 of Core 7 shows the sudden appearance of a fairly well preserved and diverse nannoflora assemblage probably belonging to the *Triquetrorhabdulus carinatus* Zone. Reworking is prominent in this section with lower Oligocene and Eocene taxa forming a minor component of most of the assemblages observed. This reworking makes it necessary to base zonal definitions on lowest occurrences when possible. Core 8 has been assigned to the *Sphenolithus distentus/Sphenolithus ciperoensis* zones with common *T. carinatus, S. ciperoensis, R. abisecta, C. floridanus, Reticulofenestra bisecta,* and *Reticulofenestra scissura.* Considerable reworking is apparent in all sections of this core. Surprisingly a few specimens of *Braarudosphaera bigelowi* are present in Section 6 of Core 8. Core 9 contains an assemblage similar to that seen in Core 8, characteristic of the *S. distentus* Zone. Reworking is also pronounced in this core. *S. ciperoensis, S. distentus, R. bisecta,* and *C. floridanus* are among the more common taxa recognized in this core. Core 10 recovered a nannofossil assemblage characteristic of the *Sphenolithus predistentus* Zone with *S. predistentus, S. distentus, R. bisecta, Reticulofenestra hillae, C. floridanus,* and *Discoaster tani* among the taxa found at this level. The nannofossil assemblage found in Core 11 is similar to that found in Core 10. Some reworking is apparent, but it is less pronounced than in the upper cores. Core 13 contains an upper Eocene assemblage including *Discoaster barbadiensis, Discoaster saipanensis, Bramlettius serraculoides, Cyclococcolithus formosus,* and *Reticulofenestra umbilica.* This core has been assigned to the *Sphenolithus pseudoradians* Zone.

Preservation: Complete dissolution of calcite is seen in the upper cores at Site 321. Preservation of the calcareous nannofossils in the Oligocene-Eocene sediments recovered is generally good with destruction of most of the fine structure in placoliths and a general lack of solution-susceptible taxa. An exception to this is the appearance of *Braarudosphaera bigelowi* in Core 8. Dissolution is more marked in the Eocene sediments of Core 13.

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