

## 25. CALCAREOUS NANNOFOSSILS FROM THE NORTH ATLANTIC (LEG 48)

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### INTRODUCTION

During IPOD Leg 48 (Bay of Biscay and Rockall Plateau) nine holes were drilled at eight sites. Sites 399 to 402 are located in the Bay of Biscay and Sites 403 to 406 on the margins of the Rockall Plateau. Calcareous nannofossils are generally abundant in the sediments recovered in both areas.

Age determinations for the Lower Cretaceous sediments (only in the Bay of Biscay) are based on the nannoplankton zonation proposed by Thierstein (1971, 1973); for the Upper Cretaceous, that proposed by Roth (1973), which combined zones proposed by Bukry and Bramlette (1970), Čepek and Hay (1969), and Martini (1969), was used. Martini's (1971) nannoplankton zonation is used for Tertiary and Quaternary sediments (Table 1). Paleogene nannoplankton zones can be recognized without difficulty, whereas, for the Neogene it becomes complicated or impossible because of the scarcity or absence of most of the index fossils in regions of lower water temperatures. For the Pliocene section it was necessary to use combined zones. Water temperatures began to decline in late Eocene time, continuing to do so during the Neogene.

Location of the sites (Figure 1) at different latitudes and in different water depths allows some ecological interpretations.

The results of this investigation are based on about 1500 samples, only several of which were studied with the stereoscan.

Fossil lists are given for all sites; only selected samples are listed.

### NANNOFOSSIL ZONES IDENTIFIED AT LEG 48 SITES

#### HOLE 400A

(lat 47°22.90'N; long 09°11.90'W; water depth: 4399 m)

Hole 400A was drilled at the foot of the Meriadzek Escarpment near the ocean-continent boundary on the northern continental margin of the Bay of Biscay. It was washed down to 74.5 meters sub-bottom after the upper part of the Pleistocene (Zones NN 21 and NN 20) was recovered from the nearby located Site 399.

The *Pseudoemiliania lacunosa* Zone (NN 19) of the lower Pleistocene is present at Hole 400A from Core 1 to Core 3, Section 2, 100 to 101 cm (74.5 to 95.0 m) (Table 2). The assemblage of this zone is marked by the abundance of *Discolithina japonica* and *Pontosphaera pacifica*. The Pliocene/Pleistocene boundary is marked by the extinction of *Cyclococcolithus macintyreai* in Core 3; discoasters are missing or extremely rare in upper Pliocene rocks. Some layers of the upper Pliocene sequence are distinguished by high content of terrigenous material and reworked Cretaceous species, indicating that the first ice rafted material occurred in late Pliocene time, approximately in the upper-

most part of the *Discoaster surculus* Zone (NN 16) at about 3 to 2.7 m.y. B.P.

Subdivision of the Pliocene section is difficult even though the sediments are rich in well-preserved nannofossils, because index fossils are missing or are scarce; the last discoasters are present within the *D. surculus* Zone (NN 16), the base of which is determined in Core 8, Section 1.

Lower Pliocene sediments occur from Core 8, Section 2 to Core 15, Section 5, where it is necessary to use combined zones. The stratigraphic interval of the *D. asymmetricus/Reticulofenestra pseudoumbilica* Zone (NN 14/NN 15) is present from Core 8, Section 2 to Core 13, Section 4. *R. pseudoumbilica* specimens are smaller in the upper part of the nannoplankton Zone NN 15, where a short overlapping of *R. pseudoumbilica* and *P. lacunosa* can be observed.

The *Ceratolithus tricorniculatus/Ceratolithus rugosus* Zone (NN 12/NN 13) was recovered from Core 13, Section 5 to Core 15, Section 5; the sediments are rich in well-preserved nannoplankton. Slightly warmer water temperatures are inferred for the lowermost part of Zone NN 12 by the increasing number of discoasters and *C. tricorniculatus*. The *Discoaster quinqueramus* Zone (NN 11) of the upper Miocene (Table 3) is determined from Core 16, Section 1 to Core 21 (218.0 to 274.0 m sub-bottom). *D. quinqueramus* is restricted to a few samples. Fluctuations of water temperature can be assumed from the variable abundance of discoasters therein. Nannofossils are abundant but, in several layers, are broken and etched. The assemblage is of low diversity. Core 22 to Core 26 probably belong to the stratigraphic interval of the *Discoaster hamatus/Discoaster calcaris* Zone (NN 9/NN 10). One specimen of *Catinaster coalitus* was found in Core 27, Section 1, indicating the *C. coalitus* Zone (NN 8) of the middle Miocene. Cores 29 and 30 belong to the *Discoaster kugleri* Zone (NN 7), with *D. kugleri*, *Discoaster exilis*, and the large variety of *Coccolithus pelagicus* (= *C. miopelagicus*). The *D. exilis* Zone (NN 6) is present in Cores 31 and 32 where the species is abundant. The *Sphenolithus heteromorphus* Zone (NN 5) is determined from Sample 34, CC to Sample 36, CC. Nannofossils are abundant, coccoliths are strongly etched and broken, discoasters are overgrown. The sequence from Core 37, Section 1, to Core 37, Section 4, probably belongs to the *Helicosphaera ampliaperta* Zone (NN 4) of the lower Miocene although *H. ampliaperta* was not observed. *Sphenolithus belemnios* was found from Sample 37, CC to Sample 38, CC indicating the *Discoaster druggii/S. belemnios* Zone (NN 2/NN 3); subdivision is not possible. The interval from Core 42 (435.5 to 473.5 m) probably is lowermost Miocene in age.

The Oligocene/Miocene boundary is determined to lie between Core 42 and Core 43; *Dictyococcites dictyodus* does not occur above Core 43 (Table 4).

**TABLE I**  
Nannofossil Zonation for Tertiary and Quaternary Stratigraphy

Nannoplankton Zones		Site 399	Hole 400A	Site 401	Site 402	Hole 402A	Site 403	Site 404	Site 405	Site 406
NN 21	<i>Emiliana huxleyi</i>	1-1 to 2, CC		1-1 to 1, CC	1-1 to 1, CC		1-1 to 2-3	1-1 to 1, CC	1-1 to 1-2	1-1 to 1, CC
NN 20	<i>Gephyrocapsa oceanica</i>				2-1 to 3-1		2-3 to 2, CC		2-3 to 2, CC	
NN 19	<i>Pseudemiliania lacunosa</i>	1-1 to 3-2			3-1 to 3, CC		3-1 to 4-1	2-1 to 2, CC	2-4 to 5, CC	2-1 to 2, CC
NN 18	<i>Discoaster brouweri</i>	3-2 to 6-1					4, CC to 6, CC			
NN 17	<i>Discoaster pentaradiatus</i>									
NN 16	<i>Discoaster surculus</i>	6-2 to 8-1								
NN 15	<i>Reticulofenestra pseudoumbilica</i>	8-2 to 13-4					7-1 to 8-3			3-1 to 3, CC
NN 14	<i>Discoaster asymmetricus</i>						8-4 to 8, CC?			
NN 13	<i>Ceratolithus rugosus</i>	13-5 to 15, CC						3-1 to 3, CC	6-1 to 6, CC	4-1 to 4, CC
NN 12	<i>Ceratolithus tricorniculatus</i>							4-1 to 4, CC	7-1	5-1 to 11, CC
NN 11	<i>Discoaster quinqueramus</i>	16-1 to 21, CC					9-1 to 21, CC			
NN 10	<i>Discoaster calcaris</i>	22-1 to 26, CC?						5-1 to 6, CC?		
NN 9	<i>Discoaster hamatus</i>									
NN 8	<i>Catinaster coalitus</i>	27-1 to 28, CC								12-1 to 15, CC?
NN 7	<i>Discoaster kugleri</i>	29-1 to 30, CC								16-1 to 19, CC
NN 6	<i>Discoaster exilis</i>	31-1 to 32, CC								20-1 to 23, CC
NN 5	<i>Sphenolithus heteromorphus</i>	34-1 to 36, CC								24-1 to 24, CC
NN 4	<i>Helicosphaera ampliaperta</i>	37-?								
NN 3	<i>Sphenolithus belemnos</i>	37, CC to 38, CC								24, CC to 27, CC
NN 2	<i>Discoaster druggii</i>									28-1 to 32-2
NN 1	<i>Triquetrorhabdulus carinatus</i>	39-1 to 41, CC					25-1 to 26-3			32-4 to 36, CC
NP 25	<i>Sphenolithus ciperoensis</i>	43-1 to 45-3								
NP 24	<i>Sphenolithus distentus</i>									
NP 23	<i>Sphenolithus predistentus</i>	45-3 to 45-5								
NP 22	<i>Helicosphaera reticulata</i>	45, CC								
NP 21	<i>Ericsonia subdisticha</i>	46-3 to 47-1		2, CC						
NP 20	<i>Sphenolithus pseudoradians</i>				3, CC	4-1 to 5-1	1-1			36-2 to 42-1
NP 19	<i>Isthmolithus recurvus</i>				4, CC	5-2 to 5-1, CC	1-2 to 2-1			42-2 to 45, CC
NP 18	<i>Chiasmolithus oamaruensis</i>						2, CC to 4, CC			
NP 17	<i>Discoaster saipanensis</i>						26-3 to 27, CC			
NP 16	<i>Discoaster tani nodifer</i>	47-6 to 52-1			5-1 to 6, CC					
NP 15	<i>Chitramalithus alatus</i>				7-1 to 11-1					
NP 14	<i>Discoaster sublodoensis</i>	52-1 to 53-1			11-2 to 11-3					
NP 13	<i>Discoaster lodoensis</i>	53-1 to 54, CC			11-3 to 11-5					
NP 12	<i>Marthasterites tribriachiatus</i>	55-1 to 56-2			11, CC to 12, CC					
NP 11	<i>Discoaster binodosus</i>	56, CC			13-1 to 13-3					
NP 10	<i>Marthasterites contortus</i>	57-1			13-3 to 13, CC					
NP 9	<i>Discoaster multiradiatus</i>	57, CC to 58, CC			14-1 to 15, CC					
NP 8	<i>Heliolithus riedeli</i>	59-1 to 59, CC			16-1 to 16-3					
NP 7	<i>Discoaster gemmeus</i>									
NP 6	<i>Heliolithus kleinpelli</i>									
NP 5	<i>Fasciculithus tympaniformis</i>									
NP 4	<i>Ellipsolithus macellus</i>									
NP 3	<i>Chiasmolithus danicus</i>				16, CC to 17, CC					
NP 2	<i>Cruciplacolithus tenuis</i>									
NP 1	<i>Markalius inversus</i>									
	<i>Tetralithus murus</i>				18-1					
	<i>Lithraphidites quadratus</i>	60, CC		18-1						
	<i>Teralithus trifidus</i>	61, CC		18-1 to 18, CC						
	<i>Brownsonia parca</i>			19-1						
	<i>Eiffellithus eximus</i>									
	<i>Gartnerago obliquum</i>									
	<i>Marthasterites furcatus</i>									
	<i>Tetralithus pyramidalis</i>									
	<i>Corollithion exiguum</i>									
	<i>Lithraphidites alatus</i>									
	<i>Eiffellithus turris eiffeli</i>	62-1 to 64-1								
	<i>Prediscophara cretacea</i>	63-2 to 65-1								
	<i>Parhabdolithus angustus</i>	65-2 to 67, CC		19-1		5-1 to 33-2				
	<i>Chiastozygus littoralis</i>						34-1 to 35, CC			

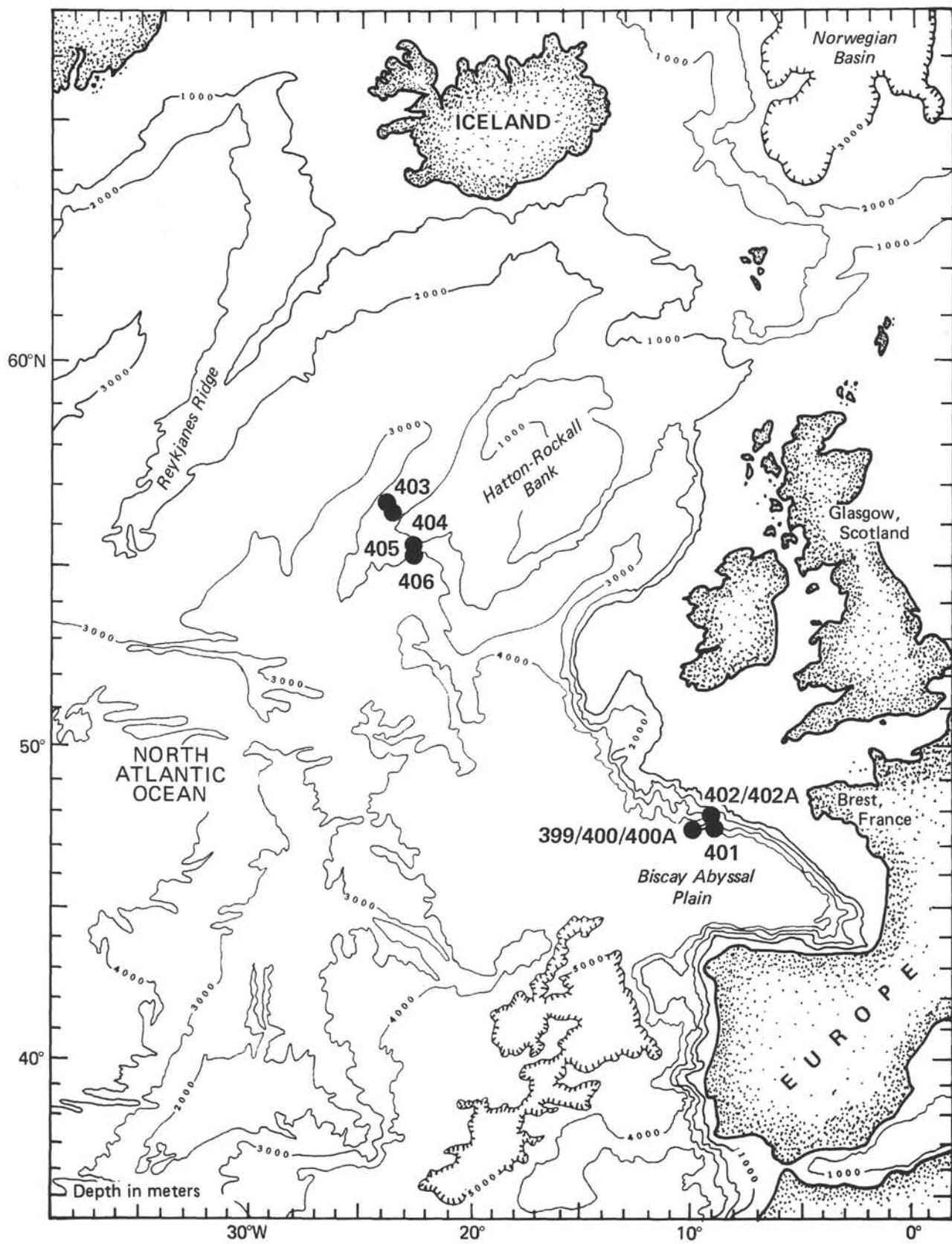


Figure 1. Location of sites drilled during Leg 48.

TABLE 2  
Calcareous Nannofossils From the Pliocene to Quaternary Sediments of Hole 400A

Age	Zone	Sample (Interval in cm)	<i>C. pelagicus</i>	<i>H. carteri</i>	<i>C. leptoporus</i>	<i>R. pseudoumbilica</i>	<i>C. rotula</i>	<i>C. macintyreai</i>	<i>S. aries</i>	<i>C. tricorniculatus</i>	<i>S. recurvata</i>	<i>S. pulcherima</i>	<i>S. intermedia</i>	<i>S. conica</i>	<i>L. perdurum</i>	<i>D. pentaradiatus</i>	<i>D. challengerii</i>	<i>D. brouweri</i>	<i>C. rugosus</i>	<i>D. asymmetricus</i>	<i>D. tamalis</i>	<i>S. apsteini</i>	<i>H. sellii</i>	<i>P. pacifica</i>	<i>D. japonica</i>	<i>P. lacunosa</i>	<i>R. stylifera</i>	<i>R. clarigera</i>	<i>C. doronicoides</i>	<i>S. fossilis</i>	<i>S. pulchra</i>	<i>G. oceanica</i>	<i>Gephyrocapsa</i> sp.	Preservation	Abundance	Reworked species
Quaternary	NN 19	1-1, 80-81	○	○	●																										M	A	X			
		2-1, 30-31	○	○	○																									M	F	X				
		2-2, 100-101	●	●	●	○																							M	A	X					
		2-3, 80-81	●	●	●	○																							G	A	X					
		2-4, 15-16	●	●	●	○																							M	A	X					
		2-5, 90-91	●	●	●	○																							M	A	X					
		2, CC	●	●	●	○																							M	C	X					
		3-1, 90-91	●	●	●	○																							M	A	X					
		3-2, 100-101	●	●	●	○																							P	A	X					
Late Pliocene	NN 17/NN 18	3-3, 50-51	●	○	○																								G	A						
		3-4, 90-91	●	●	○																								M	C						
		3, CC	●	●	○																								M	A	X					
		4-1, 75-76	○	○																									P	F	X					
		4-3, 145-146	●	●	●	○																							M	A						
		4-4, 90-91	●	●	●	○																							P	A						
		4, CC	●	●	●	○																							P	C						
		5-1, 30-31	●	●	●	○	X																						M	A						
		5-1, 140-141	●	●	●	○																							G	A						
		6-1, 130-131	●	●	●	○																							G	A						
Early Pliocene	NN 16	6-2, 30-31	●	●	●	○																							G	A						
		6-3, 100-101	●	●	●	○																							G	A						
		7-1, 50-51	●	●	●	○																							G	A						
		7-2, 110-111	●	●	●	○																							G	A	X					
		7-3, 40-41	●	●	●	○																							G	A						
		8-1, 100-101	●	●	●	○																							G	A						
NN 14/NN 15	NN 14/NN 15	8-2, 90-91	●	●	●	○																							G	A						
		8-3, 40-41	●	●	●	○																							M	A						
		8-4, 35-36	●	●	●	○																							G	A	X					
		8-6, 50-51	●	●	●	○																							G	A						
		9-1, 30-31	●	●	●	○																							G	A						
		9-3, 30-31	●	●	●	○																							G	A						
		9-4, 140-141	●	●	●	○																							G	A						
		9-6, 100-101	●	●	●	○																							G	A						
		10-1, 100-101	●	●	●	○																							G	A						
		10-2, 30-31	●	●	●	○																							G	A						
NN 12/NN 13	NN 12/NN 13	10-3, 60-61	●	●	●	○																							M	A						
		11-1, 70-71	●	●	●	○																							G	A						
		11, CC	●	●	●	○																							G	A						
		12-1, 110-111	●	●	●	○																							G	A						
		12-3, 60-61	●	●	●	○																							G	A						
		12-4, 20-21	●	●	●	○																							M	A						
		12-5, 75-76	○	○	○	●																							M	A						
		12, CC	●	●	●	○																							G	A						
		13-1, 80-81	●	●	●	○																							G	A						
		13-3, 130-131	●	●	●	○																							G	A						
		13-4, 96-97	●	●	●	●																							G	A						
		13, CC	●	●	●	●																							G	A						
		14-1, 140-141	●	●	●	●																							M	A						
		14-2, 30-31	●	●	●	●																							M	A						
		14, CC	●	●	●	●																							G	A						
		15-1, 48-49	●	●	●	●																							G	A						
		15-3, 70-71	●	●	●	●																							G	A						
		15-5, 23-24	●	●	●	●																							G	A						

Oligocene is recorded in the interval from Sample 45, CC to Sample 47-1, 79-80 cm. Nannofossils are abundant, strongly etched and broken. Some specimens of *Chiasmolithus oamaruensis* were recovered from this unit.

Lower Oligocene sediments are underlain by the middle Eocene *Discoaster tani nodifer* Zone (NP 16) and the *Chiasmolithus alatus* Zone (NP 15). Precise determination of

TABLE 3  
Calcareous Nannofossils From the Miocene Sediments of Hole 400A

Age	Zone	Sample (Interval in cm)	<i>S. moriformis</i>	<i>C. floridanus</i>	<i>C. pelagicus</i>	<i>C. abiectus</i>	<i>C. nitescens</i>	<i>D. deflandrei</i>	<i>H. carteri</i>	<i>C. leptoporus</i>	<i>S. belémnos</i>	<i>S. abies</i>	<i>R. pseudoumbilica</i>	<i>H. ampliaperta</i>	<i>C. rotula</i>	<i>C. macintyreii</i>	<i>S. heteromorphus</i>	<i>D. exilis</i>	<i>C. cf. nitescens</i>	<i>C. pelagicus</i> (large)	<i>T. rugosus</i>	<i>D. kugleri</i>	<i>C. coolidus</i>	<i>D. variabilis</i>	<i>D. pentaradiatus</i>	<i>D. brouweri</i>	<i>D. calcarius</i>	<i>D. sirculus</i>	<i>D. quinqueramus</i>	<i>C. tricornutulus</i>	Preservation	Abundance	Reworked species
Late Miocene	NN 11	16-1, 87-88											●	●															M	A			
		16, CC		●																									P	A			
		17-3, 60-61		○	○																								G	A			
		17-5, 60-61		○	○																								P	C			
		18-1, 80-81		●	●																								M	A			
		18-3, 50-51		○	○																								M	C	X		
		18-5, 60-61																											G	A			
		18, CC		●																									M	A			
		19-1, 60-61		○	○																								P	C			
		19-3, 6-7		○	○																								G	A			
		19-5, 20-21		○	○																								M	A			
		20-1, 70-71		○	○																								P	A			
		20-3, 85-86		○	○																								G	A			
		20-5, 142-143																											P	A			
		20, CC		○	○																								P	A			
		21-2, 90-91		○	○																								P	A			
		21-4, 106-107																											M	A			
		21, CC																											P	A			
Middle Miocene	NN 9/NN 10	22, CC		○																								P	A	X			
		23, CC																										P	A				
		24-6, 54-55		●																								P	C				
		24, CC		○	○																							P	C	X			
		25-4, 126-127		○	○																							M	C				
		25-6, 125-126		●																								M	C				
		25, CC		○																								P	C				
		26-1, 90-91		○																								M	C				
		26-3, 62-63		○																								P	C	X			
		27-1, 18-19																										M	C				
Early Miocene	NN 7	28, CC		○	○																							P	A				
		29-1, 50-51		○																								P	C				
		29-1, 136-137		○																								P	C				
		29, CC		○																								P	C				
		30-1, 125-126		●	○																							M	A				
Early Miocene	NN 6	30, CC		●																								P	C				
		31-1, 50-51		○	○																							M	A				
		32-2, 39-40		○	○																							P	A				
		32, CC		●	○																							P	A				
		34, CC		●	○	X																						P	C				
Early Miocene	NN 5	35-1, 6-7		●	●																							P	A				
		35, CC		○	●	●																						P	A				
		36-2, 76-77		○	○	○																						P	C				
		36, CC		○	○	○																						P	A				
		37-1, 48-49		○	●	○	○																					P	A				
Early Miocene	NN 4?	37-2, 110-111		○	○	○	○	○	○									●	X								P	A					
		37-4, 13-14		○	○	●	○	○	○	○								●									P	C					
		37, CC		●	●	○		●		○																	M	C					
Early Miocene	NN 3	38-1, 90-91		○	○	○	○	○	○	○																	M	C					
		38, CC		○	○	○	○	○	○	○									●								P	C					
Early Miocene	NN 2/NN 1?	39-2, 70-71		○	○	○	○	○	○	○																	M	F					
		39-3, 65-66		○	○	○	○	●	○	○																	P	C					
		39, CC		○	○	○	○	○	○	○																	P	C					
		40-2, 63-64		○	●	○	●	○	○	○																	M	C					
Early Miocene		40, CC		○	○	○	○	○	○	○																	P	C					
		41-1, 25-26		○	○	○	○	○	○	○																	P	C					
		42, CC		○	○	○	○	○	○	○																	P	C					

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. ●=abundant, ○=common, ○=rare, X=trace.

TABLE 4  
Calcareous Nannofossils From the Paleogene Sediments of Hole 400A

L. Paleoc.	Early Eocene	Middle Eocene	E. Olig.	Middle Oligocene	Age	Zone	Sample (Interval in cm)
							<i>C. reticulatus</i>
							<i>C. evanescens</i>
							<i>Z. sigmoides</i>
							<i>M. interversus</i>
							<i>F. tympaniformis</i>
							<i>D. gemmeus</i>
							<i>H. riedeli</i>
							<i>D. multiradiatus</i>
							<i>C. bidentata</i>
							<i>E. distictcha</i>
							<i>E. macellus</i>
							<i>Z. dubius</i>
							<i>T. eminiensis</i>
							<i>T. craticulus</i>
							<i>T. defflandrei</i>
							<i>N. junctus</i>
							<i>L. nascentis</i>
							<i>K. fimbriata</i>
							<i>D. kuepperi</i>
							<i>D. digitipus</i>
							<i>D. binodosus</i>
							<i>M. tribrachiatus</i>
							<i>H. seminudum</i>
							<i>C. formosus</i>
							<i>C. pelagicus</i>
							<i>Z. biguttatus</i>
							<i>S. racians</i>
							<i>S. moriformis</i>
							<i>C. solitus</i>
							<i>D. loddensis</i>
							<i>D. ericiformis</i>
							<i>D. septentrionalis</i>
							<i>D. nonradiatus</i>
							<i>D. subbiodensis</i>
							<i>D. leitertularis</i>
							<i>D. distinctus</i>
							<i>D. horbidiensis</i>
							<i>R. inflata</i>
							<i>R. umbilica</i>
							<i>C. grandis</i>
							<i>C. stauron</i>
							<i>C. copelagicus</i>
							<i>C. gigas</i>
							<i>C. cristatus</i>
							<i>C. daturus</i>
							<i>D. marinii</i>
							<i>D. tamnoides</i>
							<i>D. distyliodus</i>
							<i>C. floridanus</i>
							<i>C. obovatus</i>
							<i>I. recurvatus</i>
							<i>E. subdistictcha</i>
							<i>S. predistinctus</i>
							<i>S. distictus</i>
							<i>H. euphratis</i>
							<i>C. alatus</i>
							<i>R. elatioria</i>
							<i>H. pritchettensis</i>
							Preservation
							Abundance
							Reworked species

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant, ●=abundant, ○=common, ◇=rare, X=trace.

the boundary between these two zones is not possible because *Rhabdosphaera gladius* is missing. Nannofossils are dissolved and/or diluted by the high amount of siliceous microfossils. In some samples discoasters are enriched by selective dissolution of the more fragile coccoliths. The hiatus between the lower Oligocene and the middle Eocene represents an interval of about 7 m.y. The *Discoaster sublodoensis* Zone (NP 14) is determined to lie between Core 52, Section 1, and Core 53, Section 1. The *D. lodoensis* Zone (NP 13) is represented in the sediments from Core 53, Section 1, to Core 54, and the *Marthasterites tribrachiatus* Zone (NP 12)/*Tribrachiatus orthostylus* Zone (Bukry, 1973) in Core 55, Section 1, to Core 56, Section 2. Sample 56, CC belongs to the *Discoaster binodosus* Zone (NP 11) and Sample 57-1, 148-149 cm to the *Marthasterites contortus* Zone (NP 10).

Upper Paleocene sediments are recovered between Sample 57, CC and Sample 59, CC representing the *Discoaster multiradiatus* Zone (NP 9) and the *Heliolithus riedeli* Zone (NP 8). Well preserved nannofossils are abundant, with few reworked Cretaceous species.

The Cretaceous/Tertiary boundary lies between Core 59 and Core 60 (Table 5); the thickness of the Upper Cretaceous sequence is extremely reduced. The uppermost Maestrichtian (*Tetralithus murus* Zone) is not represented. The *Lithraphidites quadratus* Zone is recorded in Sample 60,

CC, and the *Tetralithus trifidus* Zone of the upper Campanian/lowest Maestrichtian in Sample 61, CC. Nannofossils are abundant but severely broken. A hiatus of about 22 m.y. lies between Cores 61 and 62. The *Eiffelithus turriseiffeli* Zone of the upper Albian/lowest Cenomanian is recognized from Core 62, Section 1, to Core 63, Section 1, and the *Prediscosphaera cretacea* Zone of the middle Albian from Core 63, Section 2, to Core 65, Section 1. The *Parhabdolithus angustus* Zone of the upper Aptian/lower Albian is present from Core 65, Section 2, to Core 74. These sediments are rich in nannofossils and show more or less strong signs of dissolution. The Aptian/Albian boundary is determined at the first occurrence of *Hayesites albiensis* between Cores 68 and 69.

#### SITE 401

(lat 47°25.65'N; long 08°48.62'W; water depth: 2495 m)

Hole 401 was located on top of a horst at the edge of the Meriadzek Terrace on the northern Biscay continental margin.

Pleistocene sediments (NN 21) were recovered in Core 1 (Table 6). The hole was washed down to 85.0 meters and core taken from this interval contained Oligocene sediments (NP 24). Lower Oligocene sediments of the *Ericsonia subdisticha* Zone (NP 21) are present in Core 2. Nannofossils are abundant, they are slightly etched and

TABLE 5  
Calcareous Nannofossils From the Cretaceous Sediments of Hole 400A

Age	Zone	Sample (Interval in cm)	<i>Z. diplogrammus</i>	<i>Z. crax</i>	<i>W. communis</i>	<i>W. britannica</i>	<i>W. bipora</i>	<i>W. barnesae</i>	<i>P. splendens</i>	<i>P. infinitus</i>	<i>P. embbergeri</i>	<i>P. angustus</i>	<i>P. asper</i>	<i>M. pennatoides</i>	<i>L. carniolicensis</i>	<i>L. floralis</i>	<i>N. truitii</i>	<i>N. minutus</i>	<i>N. kamptheri</i>	<i>N. elongatus</i>	<i>S. leffittei</i>	<i>S. fossils</i>	<i>C. signum</i>	<i>C. acylosus</i>	<i>C. fornicatus</i>	<i>C. coronadensis</i>	<i>C. littoralis</i>	<i>H. albiensis</i>	<i>C. conicus</i>	<i>C. serratus</i>	<i>P. cretacea</i>	<i>E. turriseiffeli</i>	<i>B. parca</i>	<i>T. pyramidalis</i>	<i>M. staurophora</i>	<i>K. magnificus</i>	<i>C. ethenhergi</i>	<i>T. trifidus</i>	<i>M. decoratus</i>	<i>A. cymbiformis</i>	<i>L. quadratus</i>	Preservation	Abundance
L. Cret	<i>L. quadratus</i>	60, CC						○				○																							P A	P C							
	<i>T. trifidus</i>	61, CC						○				X																						M C	P C								
	<i>Eiffelithus turriseiffeli</i>	62-1, 61-62	○	○	○	○	○	●	○	○	○	○	○	○	○	○															M C	M C											
		62-2, 131-132	○	○	○	○	○	●	○	○	○	○	○	○	○	○	X														M C	M C											
		62-3, 56-57	○	○	○	○	○	●	○	○	○	○	○	○	○	○															M C	M C											
		62-5, 17-18	○	○	○	○	○	●	○	○	○	○	○	○	○	○															M C	M C											
		62, CC	○	○	○	○	○	●	○	○	○	○	○	○	○	○															M C	P C											
	<i>Prediscosphaera cretacea</i>	63-1, 41-42	○	○	○	○	○	○	○	○	○	○	○	○	○	○															M C	P C											
		63-2, 4-5	○	○	○	○	○	○	○	○	○	○	●	○	○	○	X														M C	M A											
		63-4, 30-31	○	○	○	○	○	○	○	○	○	○	○	○	○	○															M A	M A											
		64-2, 59-60	○	○	○	○	○	○	○	○	○	○	○	○	○	○															G A	M A											
		64-4, 36-37	○	○	○	○	○	○	○	○	○	○	○	○	○	○	X														M A	G A											
		64; CC	○	○	○	○	○	●	○	○	○	○	○	○	○	○															M A	M A											
		65-1, 39-40	○	○	○	○	●	○	○	○	○	○	○	○	○	○															M A	M A											
Early Cretaceous	<i>Parhabdolithus angustus</i>	65-2, 23-24	○	○	●	●	●	●	○	○	○	○	●	●	●	●	X	X													M A	M C											
		65, CC	○	○	○	○	○	○	○	○	○	○	○	○	○	○															M C	M C											
		66-1, 81-82	○	○	○	○	○	○	○	○	○	○	○	○	○	○															M A	M A											
		66-2, 66-67	○	○	○	○	○	○	●	○	○	○	○	○	○	○															M A	M A											
		66-3, 149-150	○	○	○	○	○	●	○	○	○	○	○	○	○	○															M A	M A											
		67, CC	X	○	○	○	○	○	○	○	○	○	○	○	○	○															P F	G A											
		68-1, 85-86	○	○	○	○	○	○	○	○	○	○	○	○	○	○															G A	G A											
		68-2, 115-116	○	○	○	○	○	○	●	○	○	○	○	○	○	○															G A	G A											
		68, CC	○	○	○	○	○	●	○	○	○	○	○	○	○	○															M A	M A											
		69-1, 90-91	○	○	○	○	○	●	●	●	●	●	●	●	●	●															G A	M A											
	<i>Parhabdolithus angustus</i>	69, CC	○	○	○	○	○	●	●	●	●	●	●	●	●	●															G A	M A											
		70-2, 101-102	○	○	○	○	○	●	○	○	○	○	○	○	○	○															G C	M C											
		70, CC	○	○	○	○	○	●	○	○	○	○	○	○	○	○															G C	M A											
		71-1, 21-22	○	○	○	○	○	●	●	●	●	●	●	●	●	●															G A	M C											
		71, CC	○	○	○	○	○	●	●	●	●	●	●	●	●	●															M A	M A											
		72-1, 44-45	○	○	○	○	○	●	●	●	●	●	●	●	●	●															M A	G C											
		72-3, 59-60	○	○	○	○	○	●	●	●	●	●	●	●	●	●															G A	M A											
		72, CC	○	○	○	○	○	●	●	●	●	●	●	●	●	●															M A	M C											
		73, CC	○	○	○	○	○	●	●	●	●	●	●	●	●	●															P R												
		74-1, 4-5	○	○	○	○	○	●	●	●	●	●	●	●	●	●																											

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant, ●=abundant, ○=common, □=rare, X=trace.

**TABLE 6**  
Calcareous Nannofossils From the Middle Eocene to Quaternary Sediments of Site 401

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. •=abundant, ◦=common, □=rare, X=trace.

broken. The *Isthmolithus recurvus/Sphenolithus pseudoradians* Zone (NP 19/NP 20) of the upper Eocene is recognized in Core 3 (94.0 to 103.0 m). A hiatus which represents an interval of about 1 m.y., includes the *D. saipanensis* Zone (NP 17); it lies between Cores 4 and 5.

The *Discoaster tani nodifer* Zone (NP 16) and *Chiphagmalithus alatus* Zone (NP 15) are present from Core 5 to Core 11, Section 1 (113.0 to 170.50 m); the sediments are rich in siliceous and calcareous microfossils. The boundary between the nannoplankton Zones NP 16 and NP 15 lies between Cores 6 and 7, Section 1; it is defined by the last occurrence of *Rhabdosphaera gladius*. The *D. sublodoensis* Zone (NP 14) is represented in Core 11, Sections 2 and 3 (Table 7). Core 11, Section 3, to Core 11, Section 5, belong to the *D. lodoensis* Zone (NP 13). The sediments are rich in nannofossils; coccoliths are etched and broken whereas the discoasters are overgrown.

The *Marthasterites tribrachiatus* Zone (NP 12) is present from Sample 11, CC to Sample 12, CC, the *D. binodosus* Zone (NP 11) from Core 13, Section 1, to Core 13, Section 3, and the *M. contortus* Zone (NP 10) from Core 13, Section 3, to Sample 13, CC.

The Paleocene/Eocene boundary lies between Core 13 and Core 14. The upper Paleocene (*D. multiradiatus* Zone, NP 9 and *Heliolithus riedeli* Zone, NP 8) are present from Core 14 to Core 16, Section 3. The sediments contain well-preserved to slightly overgrown nannofossils. A hiatus, which represents an interval of about 4 m.y., lies between Core 16, Section 3, and Sample 16, CC. Cores 16 and 17 belong to the *Chiasmolithus danicus* Zone (NP 3) of the lower Paleocene. Another hiatus, which represents an interval of about 2 m.y. exists between the Late Cretaceous of Core 18 and the early Paleocene. The *Tetralithus murus* Zone is present from Sample 18.1, 11-12 cm to Sample 18.1, 27-28 cm (Table 8). Sample 18.1, 85-86 cm belongs to the *Lithraphidites quadratus* Zone. The sediments are rich in strongly etched and broken nannofossils. The *Broinsonia parca/Tetralithus trifidus* Zone of the upper Campanian/lowermost Maestrichtian is recognized in Sample 18.1, 120-121 cm to Sample 19.1, 98-99 cm. *T. trifidus* is missing, but *Lucianorhabdus cayeuxii* becomes very abundant in Sample 18.1, 120-121 cm to Sample 18, CC. Sample 19.1, 127-128 cm, just above the reddish limestone, contains a nannoplankton assemblage which consists mainly of nannoconids of late Aptian age. The hiatus between the late Aptian and the Campanian represents an interval of about 38 m.y. The limestones recovered at Site 401 from 247.5 to 341.0 meters are barren of nannofossils.

#### HOLES 402/402A

(lat 47°52.48'N; long 08°50.44'W; water depth: 2339.5 m)

Holes 402/402A are located on a spur of the northern continental margin of the Bay of Biscay north of the Meriazdek Escarpment. Pleistocene sediments (NN 21 to NN 19) were recovered in Core 1 to Core 3 of Site 402 and the sediments are rich in well-preserved nannofossils.

Pliocene and middle Miocene sediments are present in the washed down core, taken between 89.5 and 108.0 meters. The upper Eocene is present from Core 4 to Core 5 of Site 402. The *Isthmolithus recurvus/Sphenolithus pseudoradians*

Zone (NP 19/NP 20) is present from Sample 4, CC to Sample 5, Section 1, the *Chiasmolithus oamaruensis* Zone (NP 18) from Core 5, Section 2, to Sample 5, CC. The sediments have abundant siliceous microfossils and well-preserved to slightly etched nannofossils.

The hole was washed down to 137.0 meters. The *I. recurvus/S. pseudoradians* Zone (NP 19/NP 20) occurs in Core 1, Section 1 of Hole 402A (Table 9). Core 1, Section 2, and Core 2, Section 1, belong to the *C. oamaruensis* Zone (NP 18) and Sample 2, CC to Sample 4, CC to the *Discoaster saipanensis* Zone (NP 17) of the upper Eocene. Upper Eocene sediments are separated from Cretaceous sediments by a hiatus representing an interval of at least 56 m.y. In Cores 5 and 6 (Table 10) few nannofossils are present; an exact age determination is not possible.

The *Parhabdolithus angustus* Zone of late Aptian to early Albian age occurs from Core 11 to Core 13. This sequence is distinguished by the occurrence of nannoconids, which are abundant in several layers, whereas other nannofossils are less so. The *Chiastozygus litterarius* Zone of the lower Aptian is present in Cores 34 and 35 (Table 11). Nannoconids are abundant, indicating marginal conditions.

#### SITE 403

(lat 56°08.31'N; long 23°17.64'W; water depth: 2301 m)

Site 403 was drilled on the southwest margin of the Rockall Plateau. Pleistocene sediments (nannoplankton Zones NN21 to NN 19) were recovered in Core 1 to Core 4 (0 to 33.0 m) (Table 12). The sediments are rich in well-preserved nannofossils; reworked species of Cretaceous age are present in several samples.

The Pliocene/Pleistocene boundary is determined by the extinction of *Cyclococcolithus macintyrei* between Sample 4-1, 98-99 cm and Sample 4, CC. The upper Pliocene (NN 16 to NN 18) is recognized from Sample 4, CC to Sample 6, CC. Subdivision of this sequence is not possible due to the scarcity or absence of discoasters, but the sediments are rich in slightly etched nannofossils. Slightly warmer water temperatures can be assumed for the *Reticulofenestra pseudoumbilica* Zone (NN 15) by the slight increase of discoasters and scyphospheres. The *Ceratolithus rugosus* Zone (NN 13) is represented in the lower part of Core 8. The *D. quinqueramus* Zone (NN 11) of the upper Miocene (Core 9 to Core 24) is extremely thick (71.0 to 223.0 m). Fluctuations of the water temperature are believed to have occurred during the deposition of this sequence on the basis of the variable abundance of discoasters and the differences in the degree of dissolution. *C. tricorniculatus*, *S. abies* and discoasters in general are rare due to low water temperatures.

A hiatus, which represents an interval of about 18 m.y., lies between Core 24 and 25. The upper Miocene is underlain by middle/upper Oligocene sediments (NP 24/NP 25) in Core 25 to Core 26, Section 3. In turn, they are underlain by middle Eocene deposits (nannoplankton Zone NP 16) from 236.0 to 251.5 meters. This indicates a hiatus which includes an interval of about 3 m.y. Another hiatus, representing an interval of about 5 m.y., is present between the middle Eocene (NP 16) and the underlying lower Eocene (NP 12) in Core 28 (Table 13).

The sediments from Cores 29 to 42 (261.0 to 294.0 m) are poor in nannofossils; they belong to the *M. contortus/D.*

TABLE 7  
Calcareous Nannofossils From the Lower Paleocene to Middle Eocene Sediments of Site 401

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. ●=abundant, ○=common, △=rare, X=trace.

**TABLE 8**  
Calcareous Nannofossils From the Cretaceous Sediments of Site 401

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. ●=abundant, ○=common, ◇=rare, ×=trace

**TABLE 9**  
**Calcareous Nannofossils From the Upper Eocene Sediments of Hole 402A**

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. ●=abundant, ○=common, △=rare, X=trace.

*binodosus* Zone (NP 10/NP 11) of the lower Eocene. Few specimens of *M. bramlettei*, which are typical for the nanoplankton Zone NP 10, occur in several samples from Core 34 to Core 42. The sediments of Core 42 to Core 52 (384.0 to 489.0 m) are barren of nannofossils.

## SITE 404

(lat 56°03'.13'N; long 23°14'.95'W; water depth: 2306 m)

Site 404 is located on the southwest margin of the Rockall

Pleistocene sediments were recovered in Core 1 (NN 21) and Core 2 (NN 19) from 0 to 28.0 meters (Table 14). Core 3 (104.0 to 113.0 m) belongs to the lower Pliocene (nanoplankton Zone NN 12). The *D. quinqueramus* Zone (NN 11) occurs in Core 4 (170.5 to 180.0 m). Core 5 probably belongs to the stratigraphic interval of the *D. hamatus/D. calcaris* Zone (NN 9/NN 10), but a precise age determination is not possible, due to the scarcity of discoasters and

their poor preservation. Core 6 (189.0 to 199.0 m) probably belongs to the middle Miocene as indicated by the presence of the large variety of *Coccolithus pelagicus* (= *C. miopelagicus*), which seems to be typical for the nannoplankton Zones NN 6 and NN 7. This miocene sequence is underlain by lower Eocene sediments of the *D. lodoensis* Zone (NP 13) in Core 7 to Core 9 (Table 15). The hiatus represents an interval of about 36 m.y. Discoasters are rare in this section; few specimens of *Imperiaster obscurus* have been observed.

The *Marthasterites tribrachiatus* Zone (NP 12) is present from Core 10 to Core 16, Section 1; *D. lodoensis* and *M. tribrachiatus* are scarce. Poorly preserved nannofossils are abundant from Core 11 downwards. The sequence from Core 11, Section 2, to at least Core 21 (286.0 to 341.5 m) belongs to the *M. contortus/D. binodosus* Zone (NP 10/NP 11); *M. bramlettei* was found only in Sample 21-4, 47-48 cm. Nannofossils are rare from Core 17 downwards, which is probably due to the high amount of terrigenous material.

TABLE 10  
Calcareous Nannofossils From the Cretaceous Sediments of Hole 402A

Age	Zone	Sample Interval in cm)	<i>Z. diplogrammus</i>	<i>V. crux</i>	<i>W. communis</i>	<i>W. britannica</i>	<i>W. bipora</i>	<i>W. barnesae</i>	<i>S. laffitei</i>	<i>S. fossilis</i>	<i>P. splendens</i>	<i>P. infinitus</i>	<i>P. embriigeri</i>	<i>P. asper</i>	<i>P. angustus</i>	<i>N. truitii</i>	<i>N. minutus</i>	<i>N. elongatus</i>	<i>M. pennaroides</i>	<i>L. cornioidensis</i>	<i>L. floralis</i>	<i>C. crenulatus</i>	<i>C. conicus</i>	<i>C. acutulus</i>	<i>C. littoralis</i>	<i>B. bigelowi</i>	Preservation Abundance	Reworked species
Early Cretaceous	<i>Parhabdolithus angustus</i>	5-1, 14-15																									M T	
		5-2, 5-6																									M T	
		6-1, 145-146																									M C	
		11-1, 4-5	X	o																							M F	
		11-1, 87-88			o																						M C	
		11-2, 144-145	X		o				X																		M C	
		11-3, 14-16		X																							M F	
		11-4, 22-23			o	X																					M C	
		11, CC				o																					M F	
		12-1, 83-84	X	X																							M F	
		12-2, 9-10			o																						M F	
		12-2, 83-84			o																						M F	
		12, CC	X		o																						M R	
		13-1, 90-91	X	X	X																						M R	
		13-2, 45-47			o																						M F	
		13-2, 134-135			o																						M F	
		13, CC	X		o																						M F	
		14-1, 47-48	X		o			X																			M F	
		14-2, 40-41			o			o																			M F	
		14-3, 36-37			o			o																			P F	
		14-3, 106-107			o			o																			M F	
		14, CC	X		o			o																			M F	
		15-2, 121-123			o			o				X															M F	
		15-3, 41-42			o			o				o															M F	
		15-3, 102-103			o			o				o															M C	
		15-4, 135-136			o			o				o															M C	
		15-5, 52-53			o			o				o															M F	
		15, CC			o			o				X															M F	
		16-1, 44-45			X			o				X															G C	
		16-2, 19-21			o			o				o															G C	
		16-2, 98-100			o			o				X															M C	
		16, CC			o			o				X															G C	
		17-1, 44-46			X			o				X															G C	
		17-1, 117-118			o			o				X															G C	
		17-2, 30-32			o			o				X															G C	
		17, CC			o			o				X															G F	
		18-1, 105-106			o			o				X															M R	
		18-2, 46-48			o			o				X															G C	
		18-3, 18-20			o			o				X															G F	
		18-4, 20-22			o			o				X															G F	
		18, CC			o			o				X															M R	
		19-1, 92-93			o			o				X															M C	
		19-2, 34-35			o			o				X															G C	
		19-2, 124-125			o			o				X															G C	
		19-3, 14-15			o			o				X															G C	
		19-3, 121-122			o			o				X															M C	
		19-4, 119-120			o			o				X															M F	
		20-1, 52-53			o			o				X															G F	
		20-3, 31-32			o			o				X															G C	
		20-3, 28-29			o			o				X															G F	
		20-3, 130-131			o			o				X															G F	
		20-4, 20-22			●			o				X															G C	
		21-1, 124-126			o			X				X															G C	
		21-2, 36-38			o			o				X															G F	
		21-2, 117-118			o			X				X															G C	
		21-3, 91-93			o			o				X															G F	
		21-3, 111-112			X			o				X															G R	
		21-4, 32-33			o			o				X															G C	
		21-4, 91-92			o			o				X															G C	
		21-5, 32-33			o			o				X															G F	
		21-6, 124-125			o			o				X															G C	
		21, CC			o			o				X															G C	

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant, ●=abundant, ○=common, ◇=rare, X=trace.

TABLE 11  
Calcareous Nannofossils From the Cretaceous Sediments of Hole 402A

Age	Zone	Sample (Interval in cm)	<i>C. mexicana</i>	<i>M. hischueri</i>	<i>N. wasadi</i>	<i>N. truitii</i>	<i>N. minutus</i>	<i>N. kampfneri</i>	<i>N. globulus</i>	<i>N. elongata</i>	<i>N. bucheri</i>	<i>Z. diploplasmus</i>	<i>Z. crux</i>	<i>W. communis</i>	<i>W. britannica</i>	<i>W. bipora</i>	<i>W. barnesae</i>	<i>S. laefftitei</i>	<i>S. fossilis</i>	<i>P. splendens</i>	<i>P. infinitus</i>	<i>P. embergeri</i>	<i>P. asper</i>	<i>P. angustus</i>	<i>M. pennatoides</i>	<i>L. canoniensis</i>	<i>L. floralis</i>	<i>C. crenulatus</i>	<i>C. conticus</i>	<i>C. litterarius</i>	<i>C. achlyosus</i>	<i>B. bigelowi</i>	Preservation	Abundance	Reworked species
Early Cretaceous	<i>Parhabdolithus angustus</i>	22-1, 14-16																														M F			
		22-1, 111-112																														M R			
		22-2, 45-46																														M C			
		22-2, 140-141																														M R			
		22-3, 137-138	X X																													M T			
		22-4, 53-54																														G F			
		22-4, 136-137											X																			G C			
		22-5, 15-16																														G F			
		22-5, 100-102																														G F			
		22-6, 7-8																														G T			
		23-1, 24-25																														G T			
		23-2, 46-47																														G R			
		23-3, 11-13																														G F			
		23-4, 46-48												X X																		M F			
		23-5, 38-40																														M F			
		23-6, 25-26																														M C			
		23, CC																														M C			
		24-1, 86-87													X																	M F			
		24-2, 56-57																														G C			
		24-3, 44-46																														G C			
		24-4, 16-18													X X																	G C			
		24, CC																														G F			
		25-1, 124-125																														G C			
		25-2, 17-18																														G A			
		25-3, 22-23																														G C			
		25-4, 35-36													X																	G C			
		23, CC																														G C			
		26-1, 36-38																														G C			
		26, CC																														G C			
		27, CC																														G C			
		29, CC																														M C			
		30-1, 76-78																														G A			
		30-3, 19-20																														G C			
		30-5, 18-20																														G C			
		31-1, 44-46																														G A			
		31-3, 17-18																														G A			
		31-5, 21-23																														G C			
		31, CC																														G C			
		32-1, 24-25																														G C			
		32-3, 16-19																														G C			
		32-5, 40-42																														G C			
		32, CC													X																	G A			
		33-1, 131-132																														G A			
		33-2, 88-90	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	M A				
		33-3, 143-146	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	M C				
		33-5, 24-27	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	P F				
Chiastozygus litterarius	Chiastozygus litterarius	34-1, 30-32	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	M C				
		34-2, 112-114	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	G C				
		34-4, 8-11	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	P C				
		35-1, 58-60	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	P C				
		35-3, 71-72	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	G C				
		35-5, 14-16	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	P A				
		35, CC	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	C A				

Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. ●=abundant, ○=common, ◊=rare, X=trace.

**TABLE 12**  
Calcareous Nannofossils From the Oligocene to Quaternary Sediments of Site 403

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. ●=abundant, ○=common, △=rare, ×=trace.

**TABLE 13**  
**Calcareous Nannofossils From the Lower to Middle Eocene Sediments of Site 403**

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. •=abundant, ◊=common, ◇=rare, X=trace.

TABLE 14  
Calcareous Nannofossils From the Middle Miocene to Quaternary Sediments of Site 404

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. ●=abundant, ○=common, △=rare, ✕=trace.

TABLE 15

Calcareous Nannofossils From the Lower Eocene Sediments of Site 404

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. ●=abundant, ○=common, ◇=rare, ✕=trace.

Sediments of Core 22 to Core 26 (341.5 to 389.0 m) are barren of nannofossils.

SITE 405

(lat 55°20.18'N; long 22°03.49'W; water depth: 2958 m)

Site 405 was drilled at the foot of the east-west-trending transform fault marking the transform part of the northwest margin of the Rockall Plateau. Pleistocene sediments (NN 21 to NN 19) rich in nannofossils were recovered in Core 1 to Core 5 (0 to 46.0 m) (Table 16), but in several samples the content of nannofossils is diluted by the high input of terrigenous material containing reworked Cretaceous and Eocene species. A hiatus, which represents an interval of about 3.2 m.y., lies between Core 5 and Core 6; the entire Pliocene sequence is missing and only a part of the lower-most Pliocene (NN 12) is represented in Core 6.

The upper Miocene (*D. quinqueramus* Zone, NN 11) in Core 7 is underlain by sediments of the middle Eocene *D. sublodoensis* Zone (NP 14) determined from Core 8 to Core 11, Section 1. The hiatus between Cores 7 and 8 represents an interval of about 43 m.y.; well-preserved nannofossils are abundant. The lower Eocene (Table 17) is represented from Sample 11, CC to Sample 43, CC, the *D. lodoensis* Zone, NP 13 from Sample 11, CC to Sample 31-3, 105-106 cm and the *M. tribrachiatus* Zone, NP 12 from Core 32 to Core 43). The nannofossils from Zone NP 13 are well preserved; few specimens of *Imperiaster obscurus* were ob-

served within it. Preservation is poor in the nannoplankton Zone NP 12, where they are overgrown and broken.

SITE 406

(lat 55°15.50'N; long 22°05.41'W; water depth: 2907 m)

Site 406 is situated south of the east-west scarp forming part of the southwest margin of the Rockall Plateau. Pleistocene sediments are recovered in Core 1 (NN 21) and in Core 2 (NN 19) (Table 18). Well-preserved nannofossils are abundant.

The lower Pliocene is represented in Core 3 (NN 14/NN 15) and Core 4 (NN 12) from 138.0 to 223.5 meters. The *D. quinqueramus* Zone (NN 11) of the upper Miocene is determined from Core 5 to Core 11 (318.5 to 442.0 m). Sediments are rich in slightly etched and broken nannofossils, but discoasters are scarce. A precise age determination is not possible. It probably belongs to the middle Miocene as suggested by the presence of the large variety of *C. pelagicus*. Broken and etched nannofossils are abundant; discoasters are scarce or missing.

The *D. exilis* Zone (NN6) was recovered from Core 16 to Core 19 (480.5 to 518.0 m) with *Cyclicargolithus abisectus* and *D. exilis*. From Core 20 to Core 23, Section 4, the *Sphenolithus heteromorphus* Zone (NN 5) is represented. Nannofossils are abundant, but they are severely broken and etched. The lower Miocene is encountered from Core 24 to

**TABLE 16**  
**Calcareous Nannofossils From the Lower Eocene to the Quaternary Sediments of Site 405**

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. ●=abundant, ○=common, △=rare, ✕=trace.

**TABLE 17**  
Calcareous Nannofossils From the Lower Eocene Sediments of Site 405

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. •=abundant, ◦=common, ◻=rare, X=trace.

Core 27 (556.0 to 594.0 m). The sediments belong to the *Triquetrorhabdulus carinatus* Zone (NN 1).

The Oligocene/Miocene boundary is drawn between Core 27 and Core 28 on the basis of the extinction of *Helicosphaera recta*. Sphenoliths are absent. The *Sphenolithus ciperoensis* Zone (NP 25) of the upper Oligocene is determined from Sample 28-1, 34-35 cm to Sample 32-2, 15-17 cm by the presence of *T. carinatus*.

The sequence between Sample 32-4, 95-96 cm and Sample 36-1, 107-108 cm belongs to the *Sphenolithus distentus* Zone (NP 24) of the middle Oligocene. The nannoplankton assemblage with *Discoaster deflandrei* and *Chiasmolithus altus* is comparable to the middle Oligocene assemblages from the Norwegian-Greenland Sea and the North Atlantic (Leg 12). A hiatus which represents an interval of about 8 m.y. lies between the middle Oligocene and the underlying

upper Eocene (NP 19/NP 20) (Table 19). This combined zone is determined from Sample 36-2, 27-28 cm to Core 42, Section 1. Nannofossils are abundant but poorly preserved. In several layers nannofossils are rare due to recrystallization; discoasters and *Isthmolithus recurvus* are scarce. *Cribrocentrum reticulatum*, *Reticulofenestra umbilica*, and *Dictyococcites dictyodus* are the most abundant species. Reworked species from the middle Eocene occur in several samples. A slump of middle Eocene sediments (NP 14) is intercalated in the upper Eocene sequence of Core 45, Section 5. The *Chiasmolithus oamaruensis* Zone (NP 18) is recognized from Sample 42-2, 15-16 cm to Sample 45, CC (730.0 to 765.0 m).

The upper Eocene (NP 18) is underlain by middle Eocene (NP 14); this hiatus represents an interval of about 6.5 m.y. The *Discoaster sublodoensis* Zone (NP 14) was recovered.

TABLE 18

Calcareous Nannofossils From the Oligocene to the Quaternary Sediments of Site 406

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. •=abundant, □=common, ◻=rare, X=trace;

TABLE 19  
Calcareous Nannofossils From the Middle to Upper Eocene Sediments of Site 406

Age	Zone	Sample (Interval in cm)	<i>Z. dubius</i>	<i>Z. huijgeni</i>	<i>T. pulcher</i>	<i>S. radians</i>	<i>S. moriformis</i>	<i>R. umbilicata</i>	<i>M. inversum</i>	<i>H. seminalum</i>	<i>D. kuepperi</i>	<i>D. sublodoensis</i>	<i>D. septentrionalis</i>	<i>D. nonradiatus</i>	<i>D. lodoensis</i>	<i>D. lenticularis</i>	<i>D. distinctus</i>	<i>D. barbadensis</i>	<i>C. laminis</i>	<i>C. formosus</i>	<i>C. pelagicus</i>	<i>C. helis</i>	<i>C. pappi</i>	<i>C. cristatus</i>	<i>C. solitus</i>	<i>C. grandis</i>	<i>B. creber</i>	<i>L. minutus</i>	<i>H. compacta</i>	<i>E. fenestrata</i>	<i>D. dictyodus</i>	<i>C. reticulatum</i>	<i>C. ornariensis</i>	<i>D. saipanensis</i>	Preservation	Abundance	Worked species
L. Olig.	NP 21?	36-2, 27-29			○	○	○																								P	C					
Late Eocene	NP 19/NP 20	36-3, 82-83						●																							P	A					
		37-2, 101-102						○																							M	F					
		37, CC						○	○																					P	F						
		38-2, 117-118						○																							P	F					
		38, CC						○	○	X																				G	F						
		39-1, 35-36						○	○																					P	F						
		39-5, 36-38						○	○	X																				P	F						
		40-3, 95-96						○	○																					P	F						
		41-1, 24-25						○	○																					P	F						
		41-4, 142-143						○																						P	F						
		42-1, 103-103						○	X																					P	F						
Middle Eocene	NP 18	42-2, 15-16	X	○																										M	C						
		42, CC	○	○																										P	C						
		43, CC	○																											P	F	X					
		44, CC	○																											P	F	X					
		45-3, 85-86	○	○	○																								P	C							
		45-5, 25-26	○	○	○																								M	C	X						
		46-1, 3-5		○	X		○																								M	C					
		46-2, 141-143	○	X	X		○	X		●	X		X	○	○	X	○	○	○	○	○	○	○	○	○	○	○	○	○	○	M	C					
		46, CC	X	○	X		○	○		○	X		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	M	C					
		47-1, 19-20	○				○	○	○	●	X		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	M	A						
NP 14	NP 14	47-4, 133-134	○	○		○	○	X			X		X	X	X	X	○	○	○	○	●	●	●	●	●	●	●	●	●	M	A						
		48-1, 3-4	○		X		○	X	X	X	X		X	X	X	X	○	○	○	○	●	●	●	●	●	●	●	●	●	M	C						
		18-4, 61-63	○	○	X		○	○	X	○							○	○	○	○	X	○	○	○	○	○	○	○	○	M	C						
		49-2, 24-26	○	○	○			○	○								○	○	○	○	○	○	○	○	○	○	○	○	○	M	C						
		50, CC	○	○	○			○	○								○	○	○	○	○	○	○	○	○	○	○	○	○	M	C						
		51, CC	○	○	○			○	○								○	○	○	○	○	○	○	○	○	○	○	○	○	M	C						
		52, CC	○	○	○			○	○								X	○	○	○	○	○	●	●	●	●	●	●	●	M	C						
		46-1, 3-5																																			
		46-2, 141-143																																			
		46, CC																																			
		47-1, 19-20																																			
		47-4, 133-134																																			
		48-1, 3-4																																			
		18-4, 61-63																																			
		49-2, 24-26																																			
		50, CC																																			
		51, CC																																			
		52, CC																																			

Note: Preservation: P=poor, G=good, M=moderate. Abundance: T=trace, R=rare, C=common, A=abundant. ●=abundant, ○=common, ◇=rare, X=trace.

from Sample 45, CC to Sample 52, CC (765.0 to 831.0 m). Nannofossils are abundant but show signs of dissolution; *D. sublodoensis* is abundant in the upper part of this zone whereas *D. lodoensis* is rare throughout the sequence. The zones determined at each site are given in Table 1 and the distribution of the most important nannofossils in the Paleogene of the North Atlantic and other areas is shown in Table 20.

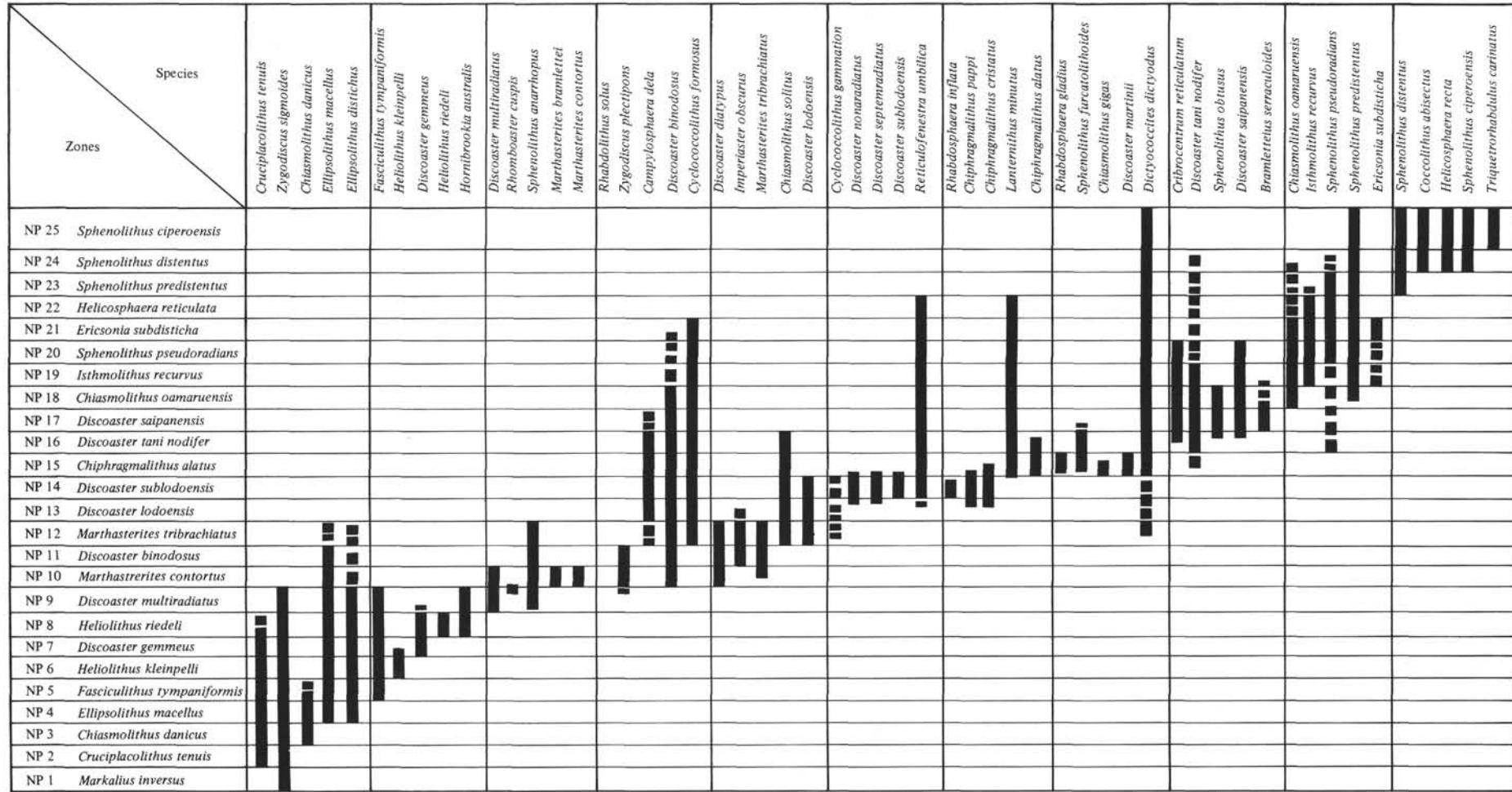
**CRETACEOUS**  
**Biostratigraphy**

Cretaceous sediments were recovered in the Bay of Biscay at Hole 400A, Site 401, and Hole 402A. Oldest nannofossil-bearing sediments are of early Aptian age (*Chiastozygus litterarius* Zone) in Hole 402A (cores 34 and 35). The Upper Jurassic/Lower Cretaceous limestones drilled at Site 401 are barren of nannofossils.

The calcareous marls to limestones of the *C. litterarius* Zone are rich in nannoconids, characteristic of marginal conditions (Thierstein, 1976). The most frequent species are *Nannoconus truitti*, *N. wassilli*, *N. minutus*, whereas *N. kamptneri*, *N. bucheri*, and *N. elongatus* are rare; they are accompanied by *Micrantholithus obtusus*, *M. hoschulzi*, *Braarudosphaera bigelowi*, and *Conusphaera mexicana*, all of which are considered to be typical of a near-shore environment. *B. bigelowi* becomes abundant in Sample 34-1,

30-32 cm. Coccoliths and related nannofossils are less abundant in these nannoconid-rich layers and often smaller compared with their normal size in open-ocean sediments. The *P. angustus* Zone of the upper Aptian-lower Albian is encountered at Hole 400A, Site 401, and Hole 402A. In it the nannoplankton assemblages are distinguished by remarkable differences because they were deposited in different environments (see following section on paleoenvironment). The *P. angustus* Zone is defined from the first occurrence of this species or *Lithastrinus floralis* to the first occurrence of *Prediscosphaera cretacea* (Thierstein, 1971, 1973). In Hole 400A it is possible to determine the Aptian/Albian boundary between Core 68 and Core 69 by the first occurrence of *Hayesites albiensis*, which is scarce throughout the Albian at this site; the species has been recognized only from the Albian (Manivit, 1971; Wilcoxon, 1972; Thierstein, 1973, 1976). *H. albiensis* was not observed at Hole 402A, which may be due to deposition in a different environment. The nannoplankton assemblages of the *P. angustus* Zone at Hole 400A are well diversified. The sediments are rich in nannofossils which, in almost all samples, show signs of dissolution and fragmentation. In general the dissolution is stronger in the dark layers which have a higher content of organic material and pyrite, than in the gray sediment where they are only slightly etched. It is assumed that this phenomenon is caused partially by

TABLE 20  
Distribution of the Most Important Nannofossils in the Paleogene of the North Atlantic and Other Areas



different physicochemical conditions in the surface sediments and the bottom water and by deposition of these sediments near the CCD. The amount of detrital material is often slightly higher in the black layers.

The *Prediscosphaera cretacea* Zone of the middle Albian and the *Eiffellithus turriseiffeli* Zone of the upper Albian-lower Cenomanian are recognized from Core 65, Section 1, to Core 62 at Hole 400A. The boundary between the two zones is defined by the first occurrence of *E. turriseiffeli* (Thierstein, 1971). The abundant nannofossils are fragile and strongly affected by dissolution, mainly in the uppermost part of the interval; often only the outer rims are preserved, whereas the central areas of the shields are broken. In general, an enrichment of dissolution-resistant species can be observed. *P. cretacea* and *E. turriseiffeli* are only scarce. The extensive dissolution of nannofossils in the uppermost part of the Albian sediments indicates a rise of the CCD, which may be due to further subsidence of Site 400 or a drop in temperatures brought on by the influx of cold-water currents. Penetration of boreal dinoflagellates far to the south in late Albian-Cenomanian time is reported by Norris and Dörhöfer (1977). The Aptio-Albian assemblages are dominated by species of the genera *Watznaueria*, *Parhabdolithus*, and *Cretarhabdulus*. *Lithraphidites carniolensis*, *Manivitella pemmatoides*, and *Corollithion achylosum* are abundant in several samples.

Between the Lower and Upper Cretaceous recovered at Hole 400A and Site 401 lies a hiatus of at least 28 to 30 m.y. The thickness of the Upper Cretaceous sequence is extremely reduced, the zones being represented by a few centimeters of sediments. They are rich in nannofossils strongly affected by dissolution and fragmentation mainly in Hole 400A where the Late Cretaceous sediments were deposited in a deep basin.

The *Broinsonia parca* Zone of the upper Campanian is encountered at Site 401 in the uppermost part of Core 19. The *Tetralithus trifidus* Zone of the uppermost Campanian and lowermost Maestrichtian is present in Hole 400A in Sample 61, CC and at Site 401 in Core 18. *T. trifidus* is abundant in Hole 400A, whereas it was not found at Site 401 where the stratigraphic interval is marked by abundant *Lucianorhabdus cayeuxii*. The latter species is regarded to be typical of boreal, marginal conditions (Thierstein, 1976). The results from Leg 48 suggest that the presence or absence of *L. cayeuxii* seem to be more controlled by water depth or distance from the continent than by water temperature. This suggestion is confirmed by the occurrence of *T. murus*, a tropical-subtropical species (Worsley and Martini, 1970) in the uppermost Maestrichtian at Site 401. Its presence indicates warm water temperatures in the Bay of Biscay during this time.

The *Lithraphidites quadratus* Zone of the lower Maestrichtian is present in Hole 400A and at Site 401; *L. quadratus* is very abundant at Site 401, but rare in Hole 400A; this scarcity is not attributed to dissolution only.

In Hole 400A the *L. quadratus* Zone is overlain by the *Heliolithus riedeli* Zone (NP 8) of the upper Paleocene. In Hole 401 the *T. murus* Zone is overlain by the *Chiasmolithus danicus* Zone (NP 3) of the Danian. The Cretaceous/Tertiary boundary is not recorded in the Bay of Biscay.

## Paleoenvironment

Hole 400A is located in the Bay of Biscay at the foot of the Meriadzek escarpment near the ocean-continent boundary (present water depth: 4399 m). Site 401 is located on top of a horst at the edge of the Meriadzek Terrace (present water depth: 2495 m) and Hole 402A on a spur of the northern continental margin of the Bay of Biscay (present water depth: 2339 m). The nannoplankton assemblages of the Lower and Upper Cretaceous recovered from these holes show that, during that time, water depths are different. Lower Cretaceous sediments recovered from Site 401 and Hole 402A were deposited in marginal, near-shore conditions, as indicated by the abundance of nannoconids. They are more abundant and of larger size in the limestones from the lower Aptian (*Chiastozygus litterarius* Zone) in Hole 402A, Cores 34 and 35. They occur with *Conusphaera mexicana*, *Micrantholithus obtusus*, and *M. holschulzi*; *Braarudosphaera bigelowi* is abundant in Sample 34-1, 30-31 cm. This assemblage is typical for marginal conditions (Thierstein, 1976). It is also described from Lower Cretaceous sediments of France by Bouché (1965). In contrast, coccoliths are generally less abundant and smaller, an observation made by Noël (1968) in describing an alternation of limestones and marls. The limestones are characterized by abundant nannoconids and few coccoliths, whereas coccoliths are more abundant and dominant in the marls. It is considered that the nannoconids prefer clean water without an input of terrigenous material. That nannoconids are typical of marginal environments is confirmed by investigations of several samples from Hole 398D (Leg 47, Müller, unpublished data) where nannoconids are absent. They occur only in layers that were displaced from the shelf and upper slope.

Major differences exist between the nannoplankton assemblages of the *Parhabdolithus angustus* Zone recovered in Hole 400A on one hand and Site 401 and Hole 402A on the other. The nannoplankton assemblage in Hole 400A (located in deeper water further from the continent) contains abundant coccoliths and related nannofossils; it is dominated by species of *Watznaueria* and *Parhabdolithus*. Nannoconids are essentially absent; only in one or two samples were few specimens of *Nannoconus truitti* and *N. minutus* observed. In contrast, the assemblage of the *P. angustus* Zone at Site 401 and Hole 402A, located on the margins, is distinguished by the occurrence of nannoconids. At Site 401 only a few centimeters of limestone (Sample 19-1, 128 cm) represent this stratigraphic interval.

The assemblage and the size of the nannoconids in the limestone at Site 401 are comparable with those of the limestones from Hole 402A, but the nannoconids in the marls of the *P. angustus* Zone at Hole 402A, which are in general rich in detrital material, are smaller and are represented only by *N. truitti* and *N. minutus*. These species are abundant in several layers, but are present in all samples of this sequence. This observation may confirm the assumption (Noël, 1968) that nannoconids find optimal conditions in clean water without an input of terrigenous material. Coccoliths are more abundant in the lower part of the *P. angustus* Zone at Hole 402A, decreasing towards the top of this sequence. They also become smaller and more fragile in

the upper part, which is typical for deposits in a very shallow environment (Müller, unpublished). In several layers of this sequence the content of nannofossils is diluted by the high input of terrigenous material.

A different environment for Hole 400A and Site 401 can be assumed also for the deposition of the Upper Cretaceous sediments. *T. trifidus* is typical of the *T. trifidus* Zone of the uppermost Campanian-lowermost Maestrichtian. It is abundant in Hole 400A but was not found at Site 401. The corresponding stratigraphic interval at Site 401 is distinguished by the abundance of *Lucianorhabdus cayeuxii*, which was not observed at Hole 400A. This species is considered to be typical for marginal, boreal conditions (Thierstein, 1976). However, the presence of *T. murus* in the upper Maestrichtian (a species of tropical-subtropical regions) at Site 401 indicates warmer water temperatures for the Upper Cretaceous. According to this observation the marginal conditions seem to be the more important factor in controlling the absence or presence of *L. cayeuxii*. A shallower environment for the deposition of the Upper Cretaceous sediments at Site 401 may be also confirmed by the abundance of *Lithraphidites quadratus* in the Maestrichtian. This species is rare at Hole 400A, but its scarcity cannot be explained only by dissolution. It is considered to be a near-shore, shallow-water species (Roth, in press).

## TERTIARY

### Biostratigraphy

Lower Paleocene sediments encompassing *Chiasmolithus danicus* Zone NP 3 were recovered only at Site 401 (Sample 16, CC and Sample 17, CC) in the Bay of Biscay. They are underlain by deposits of the upper Maestrichtian (*T. murus* Zone); the lower part of the Danian is not represented. The marly chalk of Zone NP 3 is rich in poorly preserved calcareous nannofossils. The assemblage is distinguished by the abundance of *Braarudosphaera bigelovi*, *B. discula*, and *Thoracosphaera deflandrei*, and is very similar to the assemblage described by Hay and Mohler (1967) from the early Paleocene of Pont Labau (France). It is overlain by the upper Paleocene *H. riedeli* Zone (NP 8) and *D. multiradiatus* Zone (NP 9). This hiatus, which represents an interval of about 3 m.y., is known from many parts of North Europe (France, North Germany, England, North Sea). The hiatus is marked further by a lithologic change from marly chalks to siliceous nannofossil oozes. The same sedimentological change at the end of the Danian is also known from the North Sea and North Europe.

Nannoplankton Zones NP 8 and NP 9 were recovered at Hole 400A. Here the sediments contain abundant, well-preserved to slightly etched nannofossils. The assemblages are highly diverse; discoasters are abundant, mainly in the *D. multiradiatus* Zone. Besides the typical nannoplankton assemblages of the *H. riedeli* Zone and *D. multiradiatus* Zone, other species occur which may be of stratigraphic value. *Hornbrookina australis* seems to be restricted to the upper Paleocene nannoplankton Zones NP 8 and NP 9. This species is described by Edwards and Perch-Nielsen (1975) in the same stratigraphic interval from the Southwest Pacific, and by Edwards (1973) as *Hornbrookina* sp. from the Tasmanian Sea. The

northernmost occurrence of *H. australis* is mentioned by Edwards and Perch-Nielsen (1975) from the upper Paleocene of the Crimea. *H. australis* was also observed in the *Heliolithus riedeli* Zone (NP 8) of North Germany (Müller, unpublished data), and it is also present in the *D. multiradiatus* Zone (NP 9) in Hole 400A. *Rhomboaster cuspidis* was found in several samples of Core 41 at Site 401 (*D. multiradiatus* Zone, NP 9), but it was not observed in Hole 400A. This species is described by Bramlette and Sullivan (1961) from the *D. multiradiatus* Zone of the Lodo Formation of California and by Bukry and Bramlette (1970) from the northwestern Pacific (Site 47). It is also mentioned by Bukry (1972) from Site 118 (Bay of Biscay) in a mixed assemblage of Eocene and Paleocene nannofossils. *R. cuspidis* (= *R. calcitrapa*) is also described by Gartner (1971) from the *D. multiradiatus* Zone from the Blake Plateau. Locker (1968) mentioned this species from the lower Eocene, but the illustration given in his paper does not allow a precise identification. It seems that *R. cuspidis* is restricted to the *D. multiradiatus* Zone. Edwards (1971) established the *R. cuspidis* Zone in New Zealand, which according to its definition (interval from the first occurrence of *R. cuspidis* to the first occurrence of *Marthasterites tribrachiatus*) would correspond to the uppermost Paleocene and lowermost part of the *M. contortus* Zone (NP 10) of the lower Eocene. It seems that *R. cuspidis* is restricted to a very short time interval, at the Paleocene/Eocene boundary. *Sphenolithus anarrhopus* (= *S. conspicuus* Martini, 1976) is described by Bukry and Bramlette (1969) from the upper Paleocene, and by Martini (1976) from the lower Eocene (nannoplankton Zones NP 11 and 12). This species was found in the Bay of Biscay in the *D. multiradiatus* Zone (NP 9) to the *M. tribrachiatus* Zone (NP 12). It is also known from lower Eocene sediments (NP 11 and NP 12) in North Germany and Italy (Müller, unpublished data). The upper Paleocene sediments, determined by dinoflagellates (see: Costa and Downie, this volume) at Sites 403 and 404 from the Rockall Plateau, are barren of nannofossils. The lower Eocene sequence recovered in the Bay of Biscay is condensed as compared with those from the margins of the Rockall Plateau where the lower Eocene is very thick. At Sites 403 and 404 the high amount of terrigenous and volcaniclastic material and at Site 405 the high production of siliceous and calcareous microfossils account for this. The nannoplankton assemblages of the lowermost Eocene (*M. contortus* Zone, NP 10) from the Bay of Biscay and the Rockall Plateau are not comparable due to the different environments of deposition. *M. contortus*, the index fossil for the zone, was not found although a few specimens of *M. bramlettei* occur at Sites 403 and 404; this species is not present in the lowermost Eocene sediments of the Bay of Biscay.

The upper Paleocene-lower Eocene ash layers encountered in the holes drilled on the margin of the Rockall Plateau (Site 403 and 404) probably correspond to those known from the same stratigraphic interval in northwestern Europe and the North Sea. Until now it has not been possible to determine the *M. contortus* Zone (NP 10) in northwestern Europe where sediments of this age are characterized by the occurrence of ash layers and the absence of calcareous microfossils (Bettenstaedt et al., 1962). Moorkens (1976) suggested that the absence of

calcareous microfossils was due to dissolution. The sediments of the *M. contortus* Zone (NP 10) and the *D. binodosus* Zone (NP 11) at Sites 403 and 404 are poor in nannofossils. They are slightly more abundant in the sediments at Site 404 where the sediments appear to have been deposited in a slightly deeper environment (Peypouquet, this volume). The nannoplankton assemblages consist mainly of *Koczyia fimbriata*, *Transversopontis pulcher*, *Toweius eminens*, *T. craticulus*, *Zygoolithus dubius*, *C. bidens*, *Zygodiscus plectopons*, *Ellipsolithus macellus*, *Discoasteroides kuepperi*, *M. tribrachiatus*, *Imperiaster obscurus*, and *Neochiastozygus junctus*. Discoasters are rare. *I. obscurus*, which becomes abundant in several samples of the lower Eocene in Holes 403 and 404, was not found in the sediments of the same age in the Bay of Biscay. Few specimens of this species are present in the *Discoaster lodoensis* Zone (NP 13) at Site 405. This was also observed in North Germany (Müller, unpublished). *I. obscurus* is described by Martini (1970) only from the *D. binodosus* Zone (NP 11) and the *M. tribrachiatus* Zone (NP 12). According to the results from Leg 48 and North Germany, this species seems to have a longer range in several areas, which may be controlled by ecological factors. However, further investigations are necessary to confirm this assumption. The reddish brown calcareous marls recovered in the Bay of Biscay in the lower Eocene (nannoplankton Zones NP 11 and NP 12) have a wide geographic distribution. They are also known from North Germany, England, Denmark, France, and the North Sea in the same stratigraphic interval (Bettenstaedt et al., 1967; Perch-Nielsen, 1967). *Rhabdolithus solus* is described by Perch-Nielsen (1971) from the lower Eocene of Denmark. This species also occurs within this zone in the Bay of Biscay and the Rockall Plateau as well as in North Germany and Austria (Müller, unpublished data). According to results from Hole 400A, it first occurs in the uppermost Paleocene.

*Cyclococcolithus gammation*, described by Bramlette and Sullivan (1961), appears to be restricted to the *D. lodoensis* Zone (NP 13) and the *D. sublodoensis* Zone (NP 14). Martini (1976) also records it only from the nannoplankton Zone NP 14. In the material from Leg 48 the species occurs in nannoplankton Zones NP 13 and NP 14, but is never abundant. *Rhabdosphaera inflata* was found only in the *D. sublodoensis* Zone (NP 14) in the Bay of Biscay and the Rockall Plateau. It is present also in the nannoplankton Zone NP 14 of Pakistan and Columbia (Müller, unpublished), and is described by Bramlette and Sullivan (1961) from Unit 5 (= Zone NP 14) of the Lodo Formation of California. Bukry and Kennedy (1969) described *R. inflata* from the Rose Canyon Shale Member of the La Jolla Formation, which also belongs to Zone NP 14; Bukry (1972) reports it from the Zone NP 14 of the Bay of Biscay. According to these results *R. inflata* has a restricted occurrence within the lowermost middle Eocene and is of considerable stratigraphic value. It was not observed in sediments of the *D. sublodoensis* Zone (NP 14) in Site 406 on the Rockall Plateau and in North Germany. Its presence within the *D. tani nodifer* Zone (NP 16) of the middle Eocene in Italy reported by Proto Decima et al. (1975) is probably caused by reworking. This is also observed in the uppermost middle

Eocene/lowest upper Eocene of Austria (Müller, unpublished data), where a few specimens of it occur along with many reworked species of Paleocene to middle Eocene ages.

Large specimens of *Reticulofenestra umbilica* are present in the *D. sublodoensis* Zone (NP 14). Its first occurrence is in the *Chiphragmalithus alatus* Zone (NP 15), and smaller, round specimens similar to *R. umbilica* are found as low as the *D. lodoensis* Zone (NP 13).

A few specimens of *D. septemradiatus* and *D. nonaradiatus*, which have a range from the upper part of the *D. lodoensis* Zone (NP 13) to the lower part of the *C. alatus* Zone (NP 15) are present in almost all samples of the *D. sublodoensis* Zone (NP 14).

Complexly structured nannofossils (Plate 8, Figures 1 to 6) are present in Section 404-7-1. Comparable specimens are described by Perch-Nielsen (1971) from the lower Eocene of Denmark; they have been also observed in several samples of this stratigraphic interval in north Germany (Müller, unpublished data).

A few specimens of *D. martini* are present in almost all samples of the *C. alatus* Zone (NP 15). It appears to be typical of the zone, but is never abundant. *D. martini* is reported by Martini (1958) as "*D. pentaradiatus*" from sediments from the nannoplankton Zone NP 15 in North Germany, and it is known in the same stratigraphic interval from several wells of North Germany (Müller, unpublished data). It is also described by Bramlette and Sullivan (1961) and by Bukry (1972) from the same zone. *Chiasmolithus gigas* appears restricted to the lower part of the *Chiphragmalithus alatus* Zone (NP 15). The boundary between the *C. alatus* Zone and the *D. tani nodifer* Zone (NP 15/NP 16) is sometimes not possible to establish because of the absence of *Rhabdosphaera gladius*; this species seems to be absent in pelagic sediments. It is proposed to use the first appearance of *D. tani nodifer* for the determination of Zone NP 16.

*Cribrocentrum reticulatum* first occurs in the upper part of Zone NP 16 and becomes abundant in the upper Eocene. It has not been reported in lower Oligocene sediments, and its disappearance can be used to determine the Eocene/Oligocene boundary in regions where discoasters are rare or missing in the uppermost Eocene such as North Germany, Austria, northern and southern high latitudes (Müller, unpublished data).

*S. obtusus*, as described by Bukry (1971), has its first occurrence in the upper part of the *D. tani nodifer* Zone (NP 16) and is present in the *D. saipanensis* (NP 17) and *Chiasmolithus oamaruensis* (NP 18) Zones. It is also reported by Martini (1976) from the Pacific Ocean within this stratigraphic interval. *Helicosphaera dinesenii* (= *H. heezeni* Bukry, 1971) is present mainly in Zones NP 16 and NP 17. *S. orphanknolli* (= *S. spiniger* Bukry, 1971) has its maximum development in the middle Eocene (NP 15/NP 16). *Corannulus germanicus*, *Clathrolithus ellipticus*, and *Bramletteius serraculoides* seem to be typical of the upper Eocene, mainly in the *D. saipanensis* Zone. These species were found along with *Braarudosphaera bigelowi*, *Pemma rotundum*, and *Micrantholithus basquensis* in the upper Eocene sediments of Hole 402A in the Bay of Biscay, which are deposited in marginal conditions. The range of *S.*

*pseudoradians* is known from tropical areas from the middle Eocene (NP 16) to the middle Oligocene (NP 24). It was not found in the material of Leg 48, but it is reported by Perch-Nielsen (1972) from the North Atlantic.

A significant transgression can be assumed during the upper part of the middle Oligocene (*S. distentus* Zone, NP 24). Sediments of this stratigraphic interval have a wide geographic distribution and in general are rich in nannofossils, the assemblages being distinguished by low species diversity. It is the only time during which nannofossil ooze is deposited in the Norwegian-Greenland Sea (north and south of the Faeroe-Iceland Ridge and on the Vøring Plateau), and is interpreted as a northward penetration of Atlantic water masses (Müller, 1976); nannoplankton assemblages of this zone are the same in both the Rockall Plateau area and the North Atlantic (Perch-Nielsen, 1972; Bukry, 1972). The nannofossils of the upper part of the middle Oligocene are remarkably larger than those of upper Oligocene to lower Miocene sediments, where they are often extremely small; this also has been observed in the Mediterranean (Bizon and Müller, 1978).

*Isthmolithus recurvus* is generally considered to have its last occurrence in the early Oligocene, but a few specimens have been found in the lower part of the middle Oligocene in North Germany and in the Netherlands (Benedek and Müller, 1976). It is also described by Edwards and Perch-Nielsen (1975) from southern high latitudes. The same is true for *Chiasmolithus oamaruensis*, which persists into middle Oligocene sediments on the margin of the Rockall Plateau.

Subdivision of the middle/upper Oligocene (*S. distentus*/*S. ciperoensis* zones, NP 24/NP 25) is often impossible because of the absence or scarcity of sphenoliths. In addition, *T. carinatus*, which can be a useful zone marker, was observed only at Site 406; few specimens occur at Site 403.

Determination of the Oligocene/Miocene boundary is difficult. The boundary is defined by the extinction of *H. recta* which is absent or rare in the upper Oligocene sediments recovered during Leg 48. Dissolution, which was significant at this time, may be a partial cause. The Oligocene/Miocene boundary is herein determined by the last occurrence of *Dictyococcites dictyodus* and *Zygrhablithus bijugatus*; *D. dictyodus* is rare in the uppermost Oligocene. The range of the most important species is given in Table 20.

## NEOGENE

It is difficult to distinguish the Neogene nannofossil zones according to the standard zonation of Martini (1971) because some index fossils are absent or scarce. This paucity reflects decreasing water temperatures that began in late Eocene time in the high latitudes, and continued into the Neogene.

The lower Miocene zones in Hole 400A and at Site 406 are obscure, particularly the *T. carinatus* Zone (NN 1) and the *Discoaster druggii* Zone (NN 2). The *S. belemnos* Zone (NN 3) is determined in Hole 400A by the presence of that species. *H. ampliaperta*, which is normally present in high

latitudes, is absent or, at Hole 400A and Site 406, rare. This may be due to dissolution of calcareous microfossils in lower Miocene sediments; helicospheres are not very resistant to dissolution. *S. heteromorphus* is present in both regions, possibly as a result of widespread transgression and northward penetration of Atlantic water masses. The interval of the *H. ampliaperta* Zone (NN 4) and *S. heteromorphus* Zone (NN 5) is the only one that can be determined in northern Europe (Martini and Müller, 1973). The interval corresponds to the Hemmoor transgression in North Germany.

The *D. exilis* Zone (NN 6) of the middle Miocene is recognized by the presence of *D. exilis* and *Cyclicargolithus abisectus*; *D. exilis* is generally abundant. Another species in this zone is *Coronocyclus cf. C. nitescens* (oval) which is present in the same stratigraphic interval from the Paratethys and the Mediterranean (Müller, 1974b, 1977). *T. rugosus* is abundant in several samples of the *D. exilis* Zone (NN 6). A few specimens of *S. heteromorphus* exist in the *D. exilis* Zone and *D. kugleri* Zone (NN 7), as they do in the Paratethys (Rögl and Müller, 1976). *D. kugleri* is rare in the middle Miocene sediments at Hole 400A, and only one specimen of *Catinaster coalitus* was found in Core 27 at this site.

The determination of the upper middle Miocene nannoplankton Zones NN 8, NN 9 and lower NN 10 is not possible because index fossils are missing. Discoasters are few in the interval or are strongly overgrown. The same holds true for the Mediterranean (Bizon and Müller, 1977). Inability to determine the zones of this stratigraphic interval does not necessarily imply a hiatus. The large variety of *Coccolithus pelagicus* (= *C. miopelagicus* Bukry, 1971) is common in nannoplankton Zones NN 6 and NN 7, and seems to be a useful indicator for the middle Miocene, at least in the North Atlantic.

The *D. quinqueramus* Zone (NN 11) of the upper Miocene is generally thick, being about 60 meters in Hole 400A, about 160 meters at Site 403, about 90 meters at Site 404, and about 200 meters at Site 406. *D. quinqueramus* is scarce in almost all samples; in some layers it is missing. The species is mainly represented by the smaller variety of *D. quinqueramus* with the shorter arms (= *D. berggrenii* Bukry, 1971). *D. calcaris* is more abundant and seems to have been less sensitive to changing water temperatures. Fluctuations of water temperature during late Miocene is evidenced by variable abundance of discoasters and variable degrees of dissolution. *Ceratolithus tricorniculatus* occurs in almost all samples of the *D. quinqueramus* Zone and in the lower part of the *C. tricorniculatus* Zone (NN 12) in the Bay of Biscay, whereas it and *S. abies* are less frequent further north.

Pliocene nannoplankton zones are also difficult to determine for lack of index fossils. Decreasing water temperatures continued into the Pliocene, becoming most evident in the upper Pliocene where discoasters are absent. Slightly warmer water temperatures are suggested at the base of the Pliocene and in nannoplankton Zone NN 15 (lower part). The *C. tricorniculatus* Zone (NN 12) is combined with the *C. rugosus* Zone (NN 13) because *C. rugosus* occurs only sporadically or is missing. The base of the *D. asymmetricus* Zone (NN 14) is determined by the

first occurrence of *D. asymmetricus*. Discoasters are rare to absent in the lower Pliocene sediments. The *D. asymmetricus* Zone (NN 14) and the *Reticulofenestra umbilica* Zone (NN 15) are combined because *C. tricorniculatus*, the extinction of which is used to distinguish the boundary between these zones, is missing in the upper part of the lower Pliocene; *C. tricorniculatus* has an earlier extinction in high latitudes. Small specimens of *R. pseudoumbilica* occur in the upper part of Zone NN 15, although they are larger further down in the zone. This also occurs in the Mediterranean (Müller, 1978), and may be related to decreasing water temperatures after a slight warming in the lower part of the *R. pseudoumbilica* Zone. An overlap of *R. pseudoumbilica* and *Pseudoemiliania lacunosa* (smaller, oval) can be observed in the uppermost part of this zone. It too is reported from the Mediterranean (Müller, 1978). *S. abies* is uncommon throughout the lower Pliocene.

Subdivision of the upper Pliocene is impossible because discoasters are absent, probably from the uppermost part of the *D. surculus* Zone (NN 16) to the top of the Pliocene (*D. brouweri* Zone, NN 18). The *D. pentaradiatus* Zone (NN 17) and the *D. brouweri* Zone (NN 18) are therefore combined and include the interval from the last occurrence of *D. surculus* to the last occurrence of *Cyclococcolithus macintyrei*.

The Pliocene/Pleistocene boundary is marked by the extinction of *C. macintyrei*, which occurs near the top of the Olduvai event according to paleomagnetic measurements at Hole 400A (Hailwood, this volume). The extinction of *C. macintyrei* coincides with the extinction level of *D. brouweri*, also near the top of the Olduvai event as determined in several areas (Berggren et al., 1969; Gartner, 1971; Cita et al., 1973; Ryan et al., 1974; Gartner, 1971). The extinction of *C. macintyrei* was also used in the western Mediterranean to determine the Pliocene/Pleistocene boundary (Müller, 1978; Bizon and Müller, 1977, 1978). A small and primitive species of *Gephyrocapsa* (probably *G. aperta*) is present in the uppermost Pliocene. The lower Pleistocene (*P. lacunosa* Zone, NN 19) is distinguished by the abundance of *Discolithina japonica* and *P. pacifica*. Both species are rare or absent in both upper Pliocene and upper Pleistocene. *Pseudoemiliania lacunosa* is a somewhat smaller form than specimens from subtropical regions. *G. oceanica* is represented by a smaller variety which is abundant in the Pleistocene sediments of the Bay of Biscay and the Rockall Plateau. In some layers it and *Coccolithus pelagicus* are the only nannoplankton species. Large specimens of *Emiliania huxleyi*, which is typical of cooler water masses (McIntyre and Bé, 1967) are abundant in the *E. huxleyi* Zone (NN 21) at Site 406.

The nannoplankton assemblage of the Quaternary (typical for the transitional zone [McIntyre and Bé, 1967]) contains abundant *C. pelagicus*, *Cyclococcolithus leptoporus*, *Gephyrocapsa* sp. (small), *E. huxleyi*, *Syracospaera pulchra*, and *H. carteri*.

Ice rafted material first appears in the upper Pliocene; it contains reworked species of Cretaceous and Eocene ages. Autochthonous nannofossils are rare in these beds, which is typical for the North Atlantic (Perch-Nielsen, 1972;

Martini, in press) and the Norwegian-Greenland Sea (Müller, 1976).

## PALEOECOLOGY

The location of Leg 48 drilling sites in different water depths and in different latitudes permits some paleoecological interpretations for the distribution of several nannofossils. The marginal conditions assumed for the deposition of the Upper Cretaceous sediments at Site 401 continued into early Paleocene time (*Chiasmolithus danicus* Zone, NP 3). The nannoplankton assemblage is distinguished by the abundance of *Braarudosphaera bigelowi* and *B. discula*, *Micrantholithus pinguis* is less abundant, but the sediments are rich in *Thoracosphaera deflandrei*. Thierstein and Haq (1977) described *B. bigelowi* and *B. discula* as typical near-shore species, whereas thoracospheres are considered to be open-ocean indicators. This conclusion is not confirmed by the results obtained from Site 401. Thoracospheres seem to be more influenced by water temperatures; they are abundant in tropical and subtropical regions, and almost absent in temperate and high latitude areas. The presence of *Rhomboaster cuspis* in the upper Paleocene (*Discoaster multiradiatus* Zone, NP 9) at Site 401 and its absence in the sediments in Hole 400A, which were deposited in an open-ocean deep-water environment, may indicate that this species prefers marginal conditions. *R. cuspis* is described from only a few regions and it is difficult to recognize the factors which control its absence or presence. It is described by Bramlette and Sullivan (1961) from the Lodo Formation, California, considered by Sullivan (1965) to be littoral deposits. This can also be assumed for the lower part of the Wanstead Formation, New Zealand (Edwards, 1971). Bukry (1972) found *R. cuspis* in a mixed assemblage of Paleocene and lower Eocene nannofossils in the Bay of Biscay (Site 118). It is possible that the Paleocene species are reworked from the slope.

*Hornbrookina australis* of the upper Paleocene (nannoplankton Zones NP 8 and NP 9) is known from southern and northern high latitudes, the Bay of Biscay, and North Germany, but is not reported from tropical and subtropical regions; probably this species prefers lower water temperatures, but it is a small species and easy to overlook.

Early Eocene assemblages from the Bay of Biscay and the margins of Rockall Plateau are different due to the position of the sediments in totally different environments. Their scarcity and their smaller size in the lowermost Eocene (*Marthasterites contortus* Zone, NP 10) at Sites 403 and 404 indicate deposition in very shallow water, which is confirmed by ostracodes (Peypouquet, this volume) and benthic foraminifers (Murray, this volume). Investigation of Pleistocene sediments from cores which were taken in shallow water (0 to 50 m) has shown that nannofossils therein are either absent or extremely rare, of smaller size, and more fragile than in sediments deposited in deeper water. In water depths of 60 meters and deeper, nannofossils are abundant (Müller, unpublished data). The maximal distribution in modern temperate to tropical areas lies between 50 and 100 meters depth, and in the uppermost

50 meters of the water column in subarctic regions (Honjo, 1976).

The assemblage of the *M. contortus* Zone at Sites 403 and 404 is distinguished by the occurrence of *Zygodiscus plectopons* and *M. bramlettei*. *M. bramlettei* seems to prefer a near-shore, shallow environment. Nannofossils are more abundant and the assemblages more diversified in the sediments of the *D. binodosus* Zone (NP 11) and *M. tribrachiatus* Zone (NP 12) at both sites, indicating subsidence during the Eocene. The assemblages are typical of an epicontinental environment and they are comparable with those described from the Norwegian-Greenland Sea (Müller, 1976) and northwest Europe (Martini, 1958; Locker, 1968; Perch-Nielsen, 1972; Müller, unpublished). *Imperiaster obscurus*, *Koczyia fimbriata*, *Micrantholithus mirabilis*, and abundant *Zygolithus dubius* are characteristic for this assemblage. *I. obscurus* is known from North Germany, Belgium, Denmark, Siberia, and England (Martini, 1970; Perch-Nielsen, 1968; Bukry, 1972). It is also described from Hole 117A on the Rockall Plateau (Bukry, 1972) and from the Norwegian-Greenland Sea (Müller, 1976). *M. mirabilis* is known from north Germany (Locker, 1968); Denmark (Perch-Nielsen, 1968); and from the Norwegian-Greenland Sea (Müller, 1976). Neither species was observed in the sediments of the Bay of Biscay, which were deposited in a deeper environment (Peypouquet, this volume, and Schnitker, this volume). From these results it seems very likely that the presence or absence of *I. obscurus* and *M. mirabilis* are more controlled by depth than by water temperatures.

The presence of *I. obscurus* and the abundance of *Zygrhablithus bijugatus*, *Zygolithus dubius*, and *Transversopontis pulcher* in the lower Eocene sediments (nannoplankton Zone NP 12) indicate marginal, near-shore conditions; the ostracodes in this zone support an upper bathyal to middle bathyal environment of about 300 to 1000 meters (Peypouquet, this volume).

*Rhabdosphaera gladius* in the middle Eocene sediments, Zone NP 15, seems also to be controlled by ecological factors. This species is present in the epicontinental sediments of northwest Europe where it is abundant in several layers along with other species of *Rhabdosphaera*. It is missing, however, in the middle Eocene sediments recovered in the Bay of Biscay at Hole 400A. Bukry (1972) did not report it from the Bay of Biscay, and it is also absent in the pelagic middle Eocene sediments from the central Pacific Ocean (Martini, 1976) and from the Indian Ocean (Müller, 1974).

A few specimens of *R. gladius* occur at Site 401 and some reworked specimens in the upper Eocene sediments from Hole 402A. The scarcity or absence of *R. gladius* due to ecological conditions diminish the value of this species as an index fossil. In contrast *Chiphragmeliithus alatus* occurs in almost all samples from this stratigraphic interval.

Marginal conditions for the deposition of the upper Eocene sediments (Zone NP 19) at Hole 402A are shown by the presence of *Bramletteius serraculoides* along with numerous *Braarudosphaera bigelowi*, *M. basquensis*, *Pemma rotundum*, *M. procerus*, *R. tenuis*, and *R. spinula* and few specimens of *Corannulus germanicus* and *Clathrolithus ellipticus*.

Latitudinal differentiation of the nannoplankton assemblages existed through Eocene time. They are less distinct or not recognizable during the Neogene when the assemblages found in the Bay of Biscay were comparable with those from the margins of the Rockall Plateau. Several groups of nannofossils, such as discoasters, sphenoliths, scyphosphere, thoracospheres, and ceratoliths, are considered to indicate warmer water temperatures. Based on this, an attempt was made to recognize changing water temperatures during the Tertiary in the North Atlantic. Varying degrees of dissolution caused by fluctuations of the CCD were taken also into consideration.

The abundance of *D. multiradiatus* in the upper Paleocene/lowest Eocene of the Bay of Biscay indicates warmer water temperatures. Discoasters are less frequent at Sites 403 and 404 drilled on the margins of the Rockall Plateau. This may be due to latitudinal differentiation or to the deposition of these sediments in a shallow environment. However, discoasters were also rare in North Germany at this time (Müller, unpublished). Cooler water temperatures can be discerned for Zone NP 11 and the lower part of NP 12 by the paucity of discoasters. This interval was followed by a short warming period, represented by the upper part of Zone NP 12 and in Zone NP 13, which is more distinct in the Bay of Biscay. Rarity of discoasters in the sediments of this interval on Rockall Plateau indicates cooler water temperatures there.

A slight decrease of water temperature in the lower part of the *D. subledoensis* Zone (NP 14) was followed by an increase in the upper part of the zone. The middle Eocene NP 15 and NP 16 zones indicate slightly lower water temperature which again increased in Zone NP 17 of the upper Eocene. Lower temperatures can be observed again towards the top of the Eocene (Zones NP 19 and NP 20); this decrease is more distinct in higher latitudes (Rockall Plateau, Site 406, and northern Europe), where discoasters are rare or missing in the uppermost Eocene. They are common in the sediments of the same stratigraphic interval in the Bay of Biscay.

Latitudinal differentiation of the nannoplankton assemblages continued during Oligocene time. *Sphenolithus distentus* and *S. predistentus* are present in middle Oligocene sediments from the Bay of Biscay (washed interval at Site 401), but are missing or extremely rare in the middle Oligocene sediments from the margin of the Rockall Plateau, as they are from land sections. Sphenoliths are present in the middle Oligocene of the Mediterranean area, southwest France, and the Rhinegraben (Müller, 1971), but they are absent in North Germany and Belgium. A general characteristic of the Oligocene nannoplankton assemblage is a species diversity lower than that from the middle-late Eocene. This is not restricted to the North Atlantic, but is also known from the Indian Ocean and the Pacific, and suggests a worldwide cooling during Oligocene time.

Nannoplankton assemblages of the middle Oligocene (Zone NP 23 and mainly, Zone 24) are comparable with those described from other sites drilled in the North Atlantic (DSDP Leg 12) and from the Norwegian-Greenland Sea (DSDP Leg 38). The interval is characterized by the occurrence of *Chiasmolithus altus* and *D. deflandrei* both of which are missing in the middle Oligocene from North

Germany. Coccoliths of this interval are large compared to those from upper Oligocene and lower Miocene sediments, a phenomenon also observed in North Germany (Müller, unpublished) and in the Mediterranean area (Bizon and Müller, 1977). The interval nannoplankton Zone NP 24/NP 25 is the only one during which nannofossil ooze was deposited in the Norwegian-Greenland Sea (south and north of the Iceland-Faeroe Ridge and on the Vøring Plateau). This is explained by a northward penetration of Atlantic water masses (Müller, 1976) with coincides with a significant transgression in northwest Europe.

The great abundance of *Reticulofenestra* in the Norwegian-Greenland Sea and northwest Europe can probably be explained by cold water. These species are less abundant in several parts of the North Atlantic, which were influenced during the middle Oligocene by warmer currents, much like the modern Gulf Stream. *S. ciperoensis* of the upper Oligocene was not found in the Bay of Biscay or on the Rockall Plateau, but is reported by Bukry (1972) from Site 117 drilled in the Hatton-Rockall Basin. *Triquetrorhabdulus carinatus* is missing in the Bay of Biscay, and also in the Mediterranean area (Müller, 1978) but is present at Site 406 and few specimens at Site 403. The presence of these species, which prefer warmer water temperatures in several areas of the North Atlantic, may confirm the assumption of warmer water masses penetrating at this time further to the north.

Cooling water temperatures can be interpreted for the lowermost Miocene (Zones NN 1 to NN 2/3). The assemblages of this interval are dominated by small specimens of *Coccolithus pelagicus*. Index fossils used in tropical and subtropical areas for the determination of zone boundaries occur only sporadically or are missing. It is thus difficult to make a precise age determination for the lower Miocene.

*S. belemnos* is present at Hole 400A in the Bay of Biscay, indicating Zone NN 3; this interval was not recovered on the margin of the Rockall Plateau. Warmer water temperatures are assumed for the nannoplankton Zones NN 4 to NN 6, followed by a pronounced cooling, mainly in Zones NN 8 to lower NN 10. This warming in the lower-middle Miocene is again related to a transgression corresponding to the Hemmoor transgression in North Germany; it is the only stratigraphic interval in northern Europe that can be dated precisely by nannofossils (Martini and Müller, 1973) and is based on the occurrence of *Helicosphaera ampliaperta* and *S. heteromorphus*.

*D. exilis* is in general abundant within Zone NN 6. The species seems to have been less sensitive to changing water temperatures. Discoasters are fewer in the *D. kugleri* Zone (NN 7) and are rare to absent in Zones NN 8 and NN 9. *Catinaster coalitus*, the index fossil of Zone NN 8 is absent. The determination of these zones is thus almost impossible, as is the case in the Mediterranean area (Bizon and Müller, 1978, Müller, 1978); a hiatus is not necessarily implied. Pronounced cooling, with a maximum at about 11 m.y. (Bizon and Müller, 1977), is confirmed by isotopic measurements (Grazzini et al., this volume). Slightly increased water temperatures are assumed for the middle

part of the *D. calcaris* Zone (NN 10), but they decreased, with several fluctuations, during the upper Miocene (*D. quinqueramus* Zone, NN 11). These fluctuations are interpreted on the presence or absence of discoasters, *Ceratolithus tricorniculatus* and differences in the degree of dissolution.

*D. calcaris* appears to have been less sensitive to changing water temperatures than was *D. quinqueramus*. The latter species is rare or missing in several layers in which *D. calcaris* is still present. In general the nannoplankton assemblages of the upper Miocene are distinguished by low species diversity. The assemblage consists mainly of long ranging species like *Coccolithus pelagicus*, *R. pseudoumbilica*, *C. macintyrei* and *C. leptoporus*. The scarcity of *H. carteri* is probably due to dissolution, because helicospheres are not dissolution resistant.

Discoasters and *Ceratolithus tricorniculatus* become more abundant in the lower part of the *C. tricorniculatus* Zone (NN 12) at the Miocene/Pliocene boundary and in the lowermost Pliocene, indicating a slight warming at this time, which is confirmed by isotopic measurements (Grazzini et al., this volume). Specimens of *D. pentaradiatus* are represented by the smaller variety with small bifurcations at the end of the rays. This variety occurs also in the lowermost Pliocene of the western Mediterranean, whereas in the eastern Mediterranean the large variety is present (Müller, 1978). Another slight warming is interpreted in the *R. pseudoumbilica* Zone (NN 15) of the uppermost lower Pliocene, as is indicated by the presence of some scyphospheres and a larger number of discoasters.

Lower water temperatures dominate again during the upper Pliocene with a major drop in the uppermost part of the *D. surculus* Zone (NN 16) to the *D. brouweri* Zone (NN 18). This lowering, at about 2.7-2.5 m.y., relates in the North Atlantic with the first occurrence of ice-rafted material (Berggren, 1972; Müller, this volume) and is indicated by the almost complete disappearance of discoasters; the Pliocene/Pleistocene boundary is determined by the extinction of *Cyclococcolithus macintyrei* (Müller, 1978; Bizon and Müller, 1977, 1978). In the Mediterranean, mainly in the western part, the scarcity or absence of discoasters at the same level (Bukry, 1973; Müller, 1978), records a coincident cooling.

Fluctuations of water temperatures during the Quaternary (mainly in the upper part, Zones NN 20 and NN 21) are indicated by alternation of sediments rich in nannofossils and with those containing abundant reworked Cretaceous and Eocene species. Intercalations of sediments rich in reworked species and ice-rafted material were also mentioned by Perch-Nielsen (1972) and Martini (in press) from other sites drilled in the North Atlantic, and by Müller (1976) from the Norwegian-Greenland Sea. The abundance of *Discolithina japonica* and *Pontosphaera pacifica* in the *Pseudoemiliania lacunosa* Zone (NN 19) in the North Atlantic may be typical of cooler water temperatures but their abundance was not observed from other regions by the author.

## SYSTEMATIC PALEONTOLOGY

Genus SCYPHOSPHAERA sp. Lohmann, 1902

**Scyphosphaera sp.**

(Plate 8, Figures 10-12; Plate 9, Figure 15)

**Remarks:** *Scyphosphaera* sp. has a conical, flat dish-like shape, with a circular proximal plate without pores. The wall consists of about 40 slightly turned elements, which form a rim on the distal side. Several specimens were found in the lower Eocene (*Discoaster lodoensis* Zone, NP 13) at Site 405.

**Incertae sedis**

Genus NANNOTURBA n. gen.

**Definition:** Forms consisting of several sticks or plates of rectangular to quadratic shape.

**Nannoturba robusta** n. sp.

(Plate 8, Figures 4-6)

**Description:** This species is constructed of rectangular to quadratic sticks which are combined at an angle of 90°.

**Diameter:** 8.5-9.0  $\mu\text{m}$ .

**Holotype:** Plate 8, Figure 4, S.MB 13017.

**Paratype:** Plate 8, Figure 5, S.MB 13018.

**Type locality:** DSDP Site 404, Core 7-1, 13-14 cm.

**Type level:** *Discoaster lodoensis* Zone (NP 13), lower Eocene.

**Distribution:** These forms are described by Perch-Nielsen (1971) from the lower Eocene of Denmark as calcite crystals. They are also observed in lower Eocene sediments of north Germany (Müller, unpublished data) and Poland (Martini, personal communication).

**Nannoturba spinosa** n. sp.

(Plate 8, Figures 1-3)

**Description:** *Nannoturba spinosa* is hexagonal in shape, constructed of rectangular plates which are combined at an angle of 120°. Four of these elements are interlaced at the ends.

**Remarks:** The species differs from *Nannoturba robusta* by its shape and arrangement of the elements.

**Diameter:** 10-12  $\mu\text{m}$ .

**Holotype:** Plate 8, Figure 3, S.MB 13019.

**Paratype:** Plate 8, Figure 1, S.MB 13020.

**Type locality:** DSDP Site 404, Core 7-1, 13-14 cm.

**Type level:** *Discoaster lodoensis* Zone (NP 13), lower Eocene.

**Distribution:** *Nannoturba spinosa* was found until now only in the lower Eocene of the North Atlantic.

LIST OF SPECIES MENTIONED IN THIS REPORT

*Blackites creber* (Deflandre) Roth, 1970

*Braarudosphaera bigelowi* (Gran and Braarud) Deflandre, 1947

*Braarudosphaera discula* Bramlette and Riedel, 1954

*Bramletteius serraculoides* Gartner, 1969

*Campylosphaera dela* (Bramlette and Sullivan) Hay and Mohler, 1967

*Catinaster coalitus* Martini and Bramlette, 1963

*Ceratolithus rugosus* Bukry and Bramlette, 1968

*Ceratolithus tricorniculatus* Gartner, 1967

*Chiasmolithus altus* Bukry and Percival, 1971

*Chiasmolithus bidens* (Bramlette and Sullivan) Hay and Mohler, 1967

*Chiasmolithus danicus* (Brotzen) Hay and Mohler, 1967

*Chiasmolithus gigas* (Bramlette and Sullivan) Radomski, 1968

*Chiasmolithus grandis* (Bramlette and Riedel) Radomski, 1968

*Chiasmolithus titus* Gartner, 1970

*Chiasmolithus oamaruensis* (Deflandre) Hay, Mohler, and Wade, 1966

*Chiasmolithus solitus* (Bramlette and Sullivan) Locker, 1968

*Chiphragmalithus alatus* (Martini) Martini, 1969

*Chiphragmalithus cristatus* (Martini) Bramlette and Sullivan, 1961

*Clathrolithus ellipticus* Deflandre, 1954

*Coccolithus eopelagicus* (Bramlette and Riedel) Bramlette and Sullivan, 1961

*Coccolithus helis* Stradner, 1963

*Coccolithus miopelagicus* Bukry, 1971

*Coccolithus pelagicus* (Wallich) Schiller, 1930

*Coccolithus staurion* (Bramlette and Sullivan) Gartner, 1971

*Corannulus germanicus* Stradner, 1962

*Coronocyclus nitescens* (Kamptner) Bramlette and Wilcoxon, 1967

*Coronocyclus serratus* Hay, Mohler and Wade, 1966

*Crenalithus doronicoides* (Black and Barnes)

*Cribrocentrum reticulatum* (Gartner and Smith) Perch-Nielsen, 1971

*Cruciplacolithus tenuis* (Stradner) Hay and Mohler, 1967

*Cyclcargolithus floridanus* (Roth and Hay) Bukry, 1971

*Cyclococcolithus formosus* Kamptner, 1963

*Cyclococcolithus gammation* (Bramlette and Sullivan) Sullivan, 1964

*Cyclococcolithus leptoporos* (Murray and Blackman) Kamptner, 1954

*Cyclococcolithus luminis* Sullivan, 1965

*Cyclococcolithus macintyrei* Bukry and Bramlette, 1969

*Cyclococcolithus rotula* Kamptner, 1956

*Dictyococcites dictyodus* (Deflandre and Fert) Martini, 1969

*Discoaster asymmetricus* Gartner, 1969

*Discoaster barbadiensis* Tan Sin Hok, 1927

*Discoaster binodosus* Martini, 1958

*Discoaster brouweri* Tan Sin Hok, 1927

*Discoaster calcaris* Gartner, 1967

*Discoaster challengeri* Bramlette and Riedel, 1954

*Discoaster cruciformis* Martini, 1958

*Discoaster deflandrei* Bramlette and Riedel, 1954

*Discoaster diatypus* Bramlette and Sullivan, 1961

*Discoaster distinctus* Martini, 1958

*Discoaster elegans* Bramlette and Sullivan, 1961

*Discoaster exilis* Martini and Bramlette, 1963

*Discoaster gemmeus* Stradner, 1959

*Discoaster icarus* Stradner, 1973

*Discoaster kugleri* Martini and Bramlette, 1963

*Discoaster lenticularis* Bramlette and Sullivan, 1961

*Discoaster lodoensis* Bramlette and Riedel, 1954

*Discoaster martinii* Stradner, 1959

*Discoaster mediosus* Bramlette and Sullivan, 1961

*Discoaster multiradiatus* Bramlette and Riedel, 1954

*Discoaster nobilis* Martini, 1961

*Discoaster nonaradiatus* Klumpp, 1953

*Discoaster pentaradiatus* Tan Sin Hok, 1927

*Discoaster quinqueramus* Gartner, 1969

*Discoaster saipanensis*, Bramlette and Riedel, 1954

*Discoaster septemradiatus* (Klumpp) Martini, 1958

*Discoaster sublodoensis* Bramlette and Sullivan, 1961

*Discoaster surculus* Martini and Bramlette, 1963

*Discoaster talis* Kamptner, 1967

*Discoaster tani nodifer* Bramlette and Riedel, 1954

*Discoaster variabilis* Martini and Bramlette, 1963

*Discoaster wemmelensis* Achutus and Stradner, 1969

*Discoasteroides kuepperi* (Stradner) Bramlette and Sullivan, 1961

*Discolithina desueta* Müller, 1970

*Discolithina distincta* (Bramlette and Sullivan) Levin and Joerger, 1967

*Discolithina exilis* (Bramlette and Sullivan) Bukry and Kennedy, 1969

*Discolithina japonica* Takayama, 1967

*Discolithina multipora* (Kamptner) Martini, 1965

*Discolithina ocellata* (Bramlette and Sullivan) Perch-Nielsen, 1971

*Discolithina plana* (Bramlette and Sullivan) Perch-Nielsen, 1971

*Emiliania huxleyi* (Lohmann) Hay and Mohler, 1967

*Ericsonia cava* (Hay and Mohler) Perch-Nielsen, 1969

*Ericsonia fenestrata* (Deflandre and Fert) Stradner, 1968

*Ericsonia subpertusa* Hay and Mohler, 1967

*Ellipsolithus distichus* (Bramlette and Sullivan) Hay and Mohler, 1967

*Ellipsolithus macellus* (Bramlette and Sullivan) Sullivan, 1964

*Fasciculithus billii* Perch-Nielsen, 1971

*Fasciculithus tympaniformis* Hay and Mohler, 1967

*Gephyrocapsa oceanica* Kamptner, 1943

*Gephyrocapsa* sp.

*Goniolithus fluckigeri* Deflandre, 1957

*Helicosphaera ampliapertura* Bramlette and Wilcoxon, 1967

*Helicosphaera carteri* (Wallich) Kamptner, 1954

*Helicosphaera compacta* Bramlette and Wilcoxon, 1967

- Helicosphaera dinesenii* (Perch-Nielsen) Jafar and Martini, 1975  
*Helicosphaera euphratis* (Haq) Jafar and Martini, 1975  
*Helicosphaera heezeni* (Bukry) Jafar and Martini, 1975  
*Helicosphaera lophota* (Bramlette and Sullivan) Jafar and Martini, 1975  
*Helicosphaera perch-nielsenasae* (Haq) Jafar and Martini, 1975  
*Helicosphaera recta* (Haq) Jafar and Martini, 1975  
*Helicosphaera reticulata* Bramlette and Wilcoxon, 1967  
*Helicosphaera sellii* (Bukry and Bramlette) Jafar and Martini, 1975  
*Helicosphaera seminulum* (Bramlette and Sullivan) Jafar and Martini, 1975  
*Heliolithus riedeli* Bramlette and Sullivan, 1961  
*Hornbrookina australis* Edwards and Perch-Nielsen, 1975  
*Imperiaster obscurus* (Martini) Martini, 1970  
*Isthmolithus recurvus* Deflandre, 1954  
*Koczyia fimbriata* (Bramlette and Sullivan) Perch-Nielsen, 1971  
*Lanternithus minutus* Stradner, 1962  
*Lithostromation perdurum* Deflandre, 1942  
*Lophodolithus nascens* Bramlette and Sullivan, 1961  
*Markalius inversus* (Deflandre) Bramlette and Martini, 1964  
*Marthasterites bramlettei* Brönnimann and Stradner, 1960  
*Marthasterites tribrachiatus* (Bramlette and Riedel) Deflandre, 1959  
*Micrantholithus basquensis* Martini, 1959  
*Micrantholithus mirabilis* Locker, 1965  
*Micrantholithus pinguis* Bramlette and Sullivan, 1961  
*Micrantholithus procerus* Bukry and Bramlette, 1969  
*Micrantholithus vesper* Deflandre, 1954  
*Naninfla deflandrei* Perch-Nielsen, 1968  
*Nannotetrastr pappi* (Stradner) Perch-Nielsen, 1972  
*Neochiastozygus concinnus* (Martini) Perch-Nielsen, 1971  
*Neochiastozygus junctus* (Bramlette and Sullivan) Perch-Nielsen, 1971  
*Neococcilithes protensus* (Bramlette and Sullivan) Hay and Mohler, 1967  
*Oolithotus fragilis* (Lohmann) Martini and Müller, 1972  
*Pemma rotundum* Klumpp, 1953  
*Pontosphaera pacifica* Burns, 1973  
*Pontosphaera syracusana* Lohmann, 1902  
*Pseudoemiliania lacunosa* (Kamptner) Gartner, 1969  
*Reticulofenestra clatrata* Müller, 1970  
*Reticulofenestra insignita* Roth and Hay, 1967  
*Reticulofenestra lockeri* Müller, 1970  
*Reticulofenestra pseudoumbilica* (Gartner) Gartner, 1969  
*Reticulofenestra umbilica* (Levin) Martini and Ritzkowski, 1968  
*Rhabdolithus solus* Perch-Nielsen, 1971  
*Rhabdosphaera clavigera* Murray and Blackman, 1898  
*Rhabdosphaera gladius* Locker, 1967  
*Rhabdosphaera inflata* Bramlette and Sullivan, 1961  
*Rhabdosphaera scabrosa* (Deflandre) Bramlette and Sullivan, 1961  
*Rhabdosphaera spinula* Levin, 1965  
*Rhabdosphaera stylifera* Lohmann, 1902  
*Rhabdosphaera tenuis* Bramlette and Sullivan, 1961  
*Rhabdosphaera vitrea* (Deflandre) Bramlette and Sullivan, 1961  
*Rhomboaster cuspis* Bramlette and Sullivan, 1961  
*Scapholithus fossilis* Deflandre, 1954  
*Scyphosphaera apsteinii* Lohmann, 1902  
*Scyphosphaera conica* Kamptner, 1955  
*Scyphosphaera intermedia* Deflandre, 1942  
*Scyphosphaera pulcherima* Deflandre, 1942  
*Scyphosphaera recurvata* Deflandre, 1942  
*Sphenolithus abies* Deflandre, 1954  
*Sphenolithus anarrhopus* Bukry and Bramlette, 1969  
*Sphenolithus belemnos* Bramlette and Wilcoxon, 1967  
*Sphenolithus furcatolithoides* Locker, 1967  
*Sphenolithus heteromorphus* Deflandre, 1953  
*Sphenolithus moriformis* (Brönnimann and Stradner) Bramlette and Wilcoxon, 1967  
*Sphenolithus obtusus* Bukry, 1971  
*Sphenolithus orphanknollii* Perch-Nielsen, 1971  
*Sphenolithus predistentus* Bramlette and Wilcoxon, 1967  
*Sphenolithus pseudoradians* Bramlette and Wilcoxon, 1967  
*Sphenolithus spiniger* Bukry, 1971  
*Sphenolithus radians* Deflandre, 1954  
*Syracosphaera pulchra* Lohmann, 1902
- Thoracosphaera deflandrei* Kamptner, 1956  
*Toweius callosus* Perch-Nielsen, 1971  
*Toweius craticulus* Hay and Mohler, 1967  
*Toweius eminens* (Bramlette and Sullivan) Perch-Nielsen, 1971  
*Transversopontis pulcher* (Deflandre) Hay, Mohler, and Wade, 1966  
*Transversopontis pulcheroides* (Sullivan) Perch-Nielsen, 1971  
*Triquetrorhabdulus carinatus* Martini, 1965  
*Triquetrorhabdulus rugosus* Bramlette and Wilcoxon, 1967  
*Umbilicosphaera mirabilis* Lohmann, 1902  
*Zygodiscus plectopons* Bramlette and Sullivan, 1961  
*Zygodiscus sigmoides* Bramlette and Sullivan, 1961  
*Zyglithus dubius* Deflandre, 1954  
*Zygrhablithus bijugatus* (Deflandre) Deflandre, 1959
- Cretaceous:
- Arkhangelskiella cymbiformis* Vekshina, 1959  
*Braarudosphaera bigelowi* (Gran and Braarud) Deflandre, 1947  
*Broinarius parca* (Stradner) Bukry, 1969  
*Chiastozygus literarius* (Gorka) Manivit, 1971  
*Corollithion achylosum* (Stover) Thierstein, 1971  
*Corollithion signum* Stradner, 1963  
*Cretarhabdus conicus* Bramlette and Martini, 1964  
*Cretarhabdus coronadensis* Reinhardt, 1966  
*Cretarhabdus crenulatus* Bramlette and Martini, 1964  
*Cretarhabdus loriei* Gartner, 1968  
*Cretarhabdus unicornis* Stover, 1966  
*Cretaturbella mexicana* Trejo, 1969  
*Cribrosphaerella ehrenbergi* Archangelsky, 1912  
*Cylindralithus serratus* Bramlette and Sullivan, 1964  
*Diazomatolithus lehmani* Noël, 1965  
*Eiffellithus turrisceiffeli* (Deflandre) Reinhardt, 1965  
*Hayesites albiensis* Manivit, 1971  
*Kamptnerius magnificus* Deflandre, 1959  
*Lithastrinus floralis* Stradner, 1962  
*Lithraphidites carniolensis* Deflandre, 1963  
*Lithraphidites quadratus* Bramlette and Martini, 1964  
*Lucianorhabdus cayeuxii* Deflandre, 1959  
*Manivitella pemmatoides* (Deflandre) Thierstein, 1971  
*Markalius circumradius* (Stover) Perch-Nielsen, 1968  
*Micrantholithus hoschulzi* (Reinhardt) Thierstein, 1971  
*Microrhabdulus decoratus* Deflandre, 1959  
*Micula staurophora* (Gardet) Stradner, 1963  
*Nannoconus bucheri* Brönnimann, 1955  
*Nannoconus elongatus* Brönnimann, 1955  
*Nannoconus globulus* Brönnimann, 1955  
*Nannoconus kampnieri* Brönnimann, 1955  
*Nannoconus minutus* Brönnimann, 1955  
*Nannoconus truitii* Brönnimann, 1955  
*Nannoconus wasalli* Brönnimann, 1955  
*Nephrolithus frequens* Gorka, 1957  
*Parhabdolithus angustus* (Stradner) Stradner, Adamiker, and Maresch, 1968  
*Parhabdolithus asper* (Stradner) Manivit, 1971  
*Parhabdolithus embergeri* (Noël) Stradner, 1963  
*Parhabdolithus infinitus* (Worsley) Thierstein, 1972  
*Parhabdolithus splendens* (Deflandre) Noël, 1969  
*Prediscosphaera cretacea* (Archangelsky) Gartner, 1968  
*Reinhardtites anthophorus* (Deflandre) Perch-Nielsen, 1968  
*Scapholithus fossilis* Deflandre and Fert, 1954  
*Stephanolithion laffitei* Noël, 1956  
*Tetralithus aculeus* (Stradner) Gartner, 1968  
*Tetralithus gothicus* Deflandre, 1959  
*Tetralithus obscurus* Deflandre, 1959  
*Tetralithus pyramidus* Gardet, 1955  
*Tetralithus trifidus* (Stradner) Bukry, 1973  
*Watznaueria barnesae* (Black) Perch-Nielsen, 1968  
*Watznaueria biporta* Bukry, 1969  
*Watznaueria britannica* (Stradner) Reinhardt, 1964  
*Watznaueria communis* Reinhardt, 1966  
*Zygodiscus diplogrammus* (Deflandre and Fert) Gartner, 1968  
*Zygodiscus sigmoides* Bramlette and Sullivan, 1961

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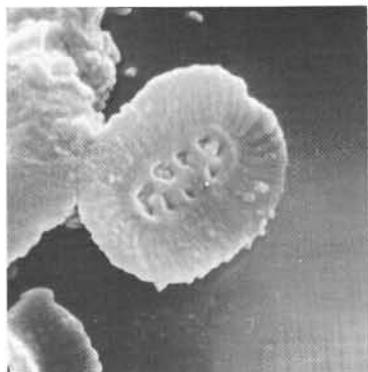
## PLATE 1

- Figure 1      *Markalius inversus* (Deflandre) Bramlette and Martini, 1964.  
                   5000  $\times$ , distal view.  
                   Sample 405-9-2, 114-115 cm.
- Figure 2      *Ellipsolithus distichus* (Bramlette and Sullivan) Hay and Mohler, 1967.  
                   5000  $\times$ , distal view.  
                   Sample 405-14-1, 124-125 cm.
- Figure 3      *Neococcolithes protenus* (Bramlette and Sullivan) Hay and Mohler, 1967.  
                   4500  $\times$ . Sample 401-14-1, 26-27 cm.
- Figure 4      *Ericsonia cava* (Hay and Mohler) Perch-Nielsen, 1969.  
                   5000  $\times$ , distal view.  
                   Sample 401-14-3, 64-65 cm.
- Figures 5, 6    *Discoaster mediosus* Bramlette and Sullivan, 1961.  
                   Sample 401-14-3, 64-65 cm.  
                   5. 2300  $\times$ .  
                   6. 2800  $\times$ .
- Figure 7      *Nannoconus truitti* Brönnimann, 1955.  
                   3500  $\times$ .  
                   Sample 402A-35-2, 25-26 cm.
- Figure 8      *Nannoconus kampfneri* Brönnimann, 1955.  
                   2500  $\times$ .  
                   Sample 402A-35-2, 25-26 cm.
- Figure 9      *Nannoconus wassilli* Brönnimann, 1955.  
                   2500  $\times$ .  
                   Sample 402A-35-2, 25-26 cm.
- Figure 10     *Nannoconus* sp.  
                   4250  $\times$ .  
                   Sample 402A-35-2, 25-26 cm.
- Figure 11, 12   *Conosphaera mexicana* Trejo, 1969.  
                   5000  $\times$ .  
                   Sample 402A-35-2, 25-26 cm.

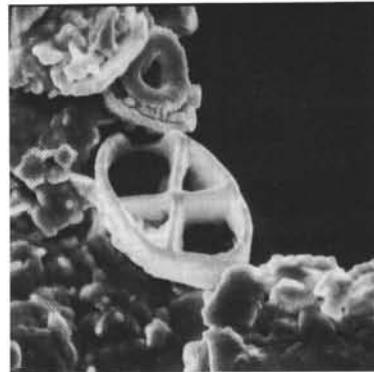
## PLATE 1



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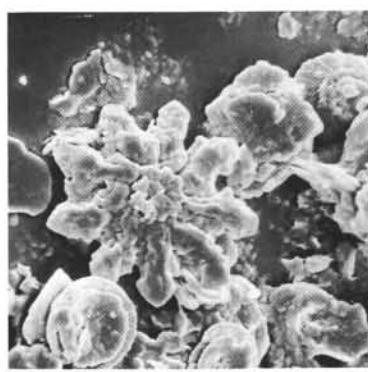
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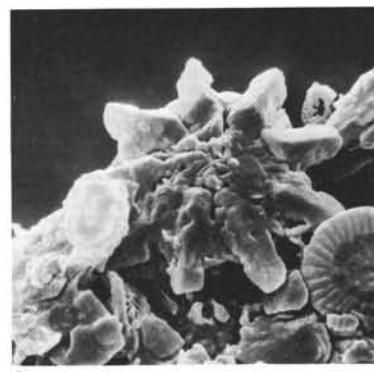
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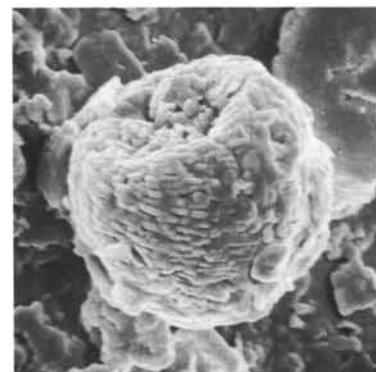
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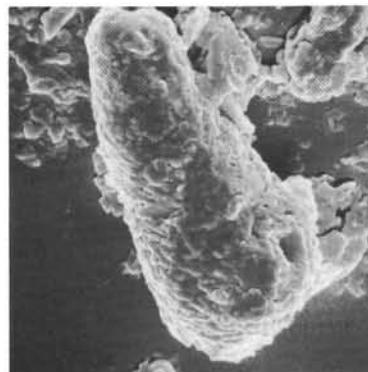
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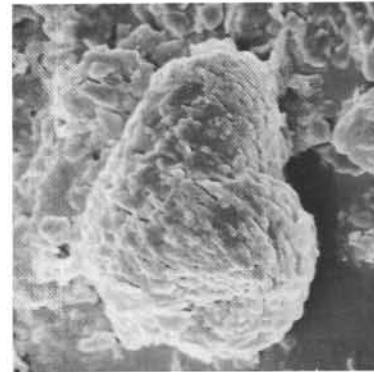
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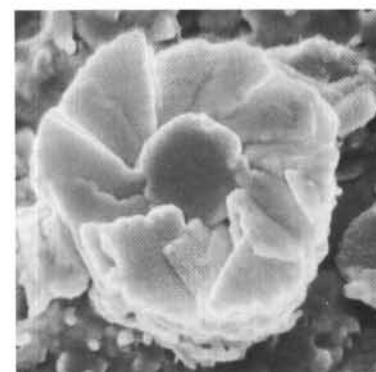
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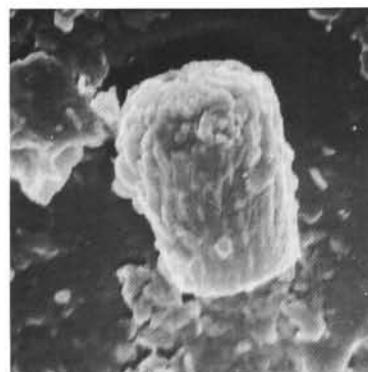
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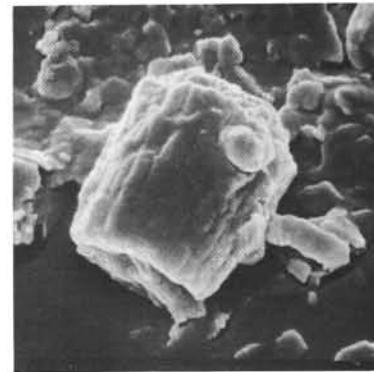
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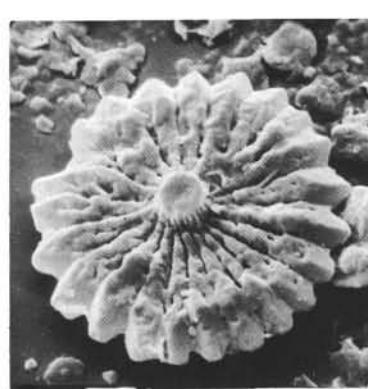
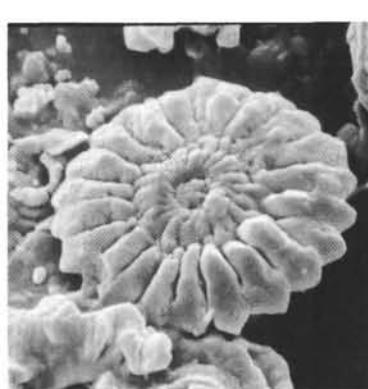
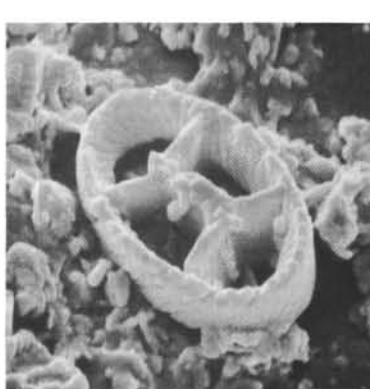
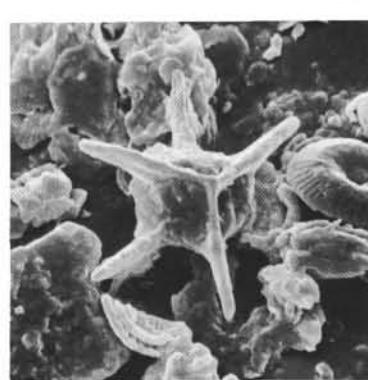
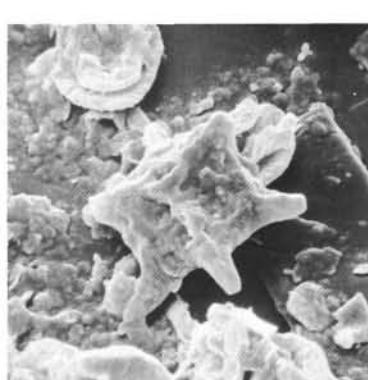
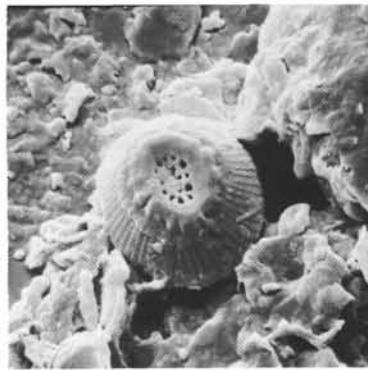


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PLATE 2

- Figures 1, 2      *Toweius eminens* (Bramlette and Sullivan)  
Perch-Nielsen, 1971.  
Sample 401-14-3, 64-65 cm. Distal views.  
1. 4500  $\times$ .  
2. 5100  $\times$ .
- Figure 3      *Toweius craticulus* Hay and Mohler, 1967.  
5700  $\times$ , distal view.  
Sample 401-14-2, 111-112 cm.
- Figure 4      *Toweius callosus* Perch-Nielsen, 1971.  
5000  $\times$ , distal view.  
Sample 401-14-1, 26-27 cm.
- Figures 5, 6      *Hornibrookina australis* Edwards and Perch-Nielsen,  
1975.  
5000  $\times$ , distal views.  
Sample 401-14-3, 64-66 cm.
- Figures 7-9      *Rhomboaster cuspis* Bramlette and Sullivan, 1961.  
2600  $\times$ .  
Sample 401-14-3, 64-65 cm.
- Figure 10      *Zygolithus dubius* Deflandre, 1954.  
5000  $\times$ .  
Sample 405-14-1, 124-125 cm.
- Figures 11, 12      *Discoaster multiradiatus* Bramlette and Riedel, 1954.  
2700  $\times$ .  
Sample 401-14-3, 64-65 cm.

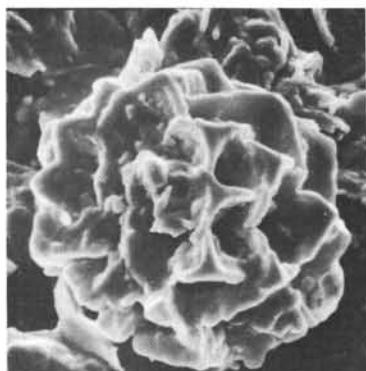
## PLATE 2



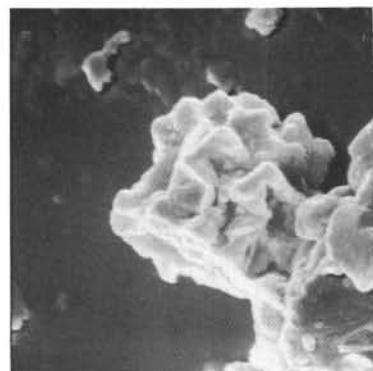
## PLATE 3

- Figure 1 *Sphenolithus* sp.  
4500 ×.  
Sample 401-14-1, 26-27 cm.
- Figure 2 *Sphenolithus primus* Perch-Nielsen, 1971.  
5000 ×.  
Sample 400A-57-2, 148-149 cm.
- Figure 3 *Sphenolithus furcatolithoides* Locker, 1967.  
4000 ×.  
Sample 401-5-1, 105-106 cm.
- Figure 4 *Sphenolithus moriformis* (Brönnimann and Stradner)  
Bramlette and Wilcoxon, 1967.  
5000 ×.  
Sample 402A-5-2, 9-10 cm.
- Figure 5 *Chiasmolithus grandis* (Bramlette and Riedel)  
Radomski, 1968 and *Chiasmolithus solitus* (Bramlette  
and Sullivan) Locker, 1968.  
2000 ×.  
Sample 405-14-1, 124-125 cm.
- Figure 6 *Chiasmolithus grandis* (Bramlette and Riedel)  
Radomski, 1968.  
2750 ×, distal view.  
Sample 405-9-2, 24-25 cm.
- Figure 7 *Chiasmolithus solitus* (Bramlette and Sullivan)  
Locker, 1968.  
3000 ×, distal view.  
Sample 404-7-1, 13-14 cm.
- Figure 8 *Chiasmolithus titus* Gartner, 1970.  
5000 ×, distal view.  
Sample 404-7-1, 13-14 cm.
- Figure 9 *Campylosphaera dela* (Bramlette and Sullivan) Hay  
and Mohler, 1967.  
5250 ×, distal view.  
Sample 401-14-3, 131-132 cm.
- Figure 10 *Cruciplacolithus crux* (Deflandre and Fert) Roth,  
1970.  
4600 ×, distal view.  
Sample 401-10-4, 131-132 cm.
- Figures 11, 12 *Coccolithus staurion* (Bramlette and Sullivan)  
Gartner, 1971.  
5000 ×, distal views.  
Sample 405-14-2, 36-37 cm.

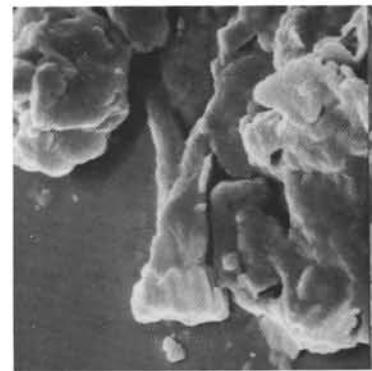
## PLATE 3



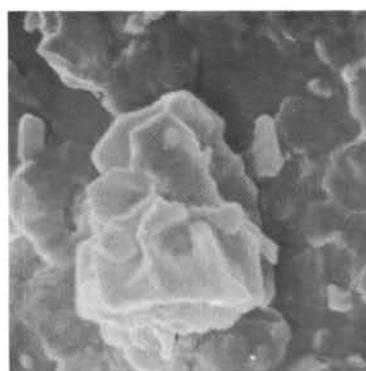
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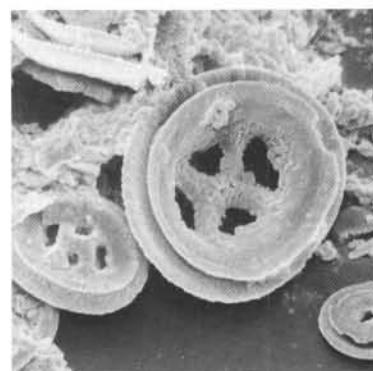
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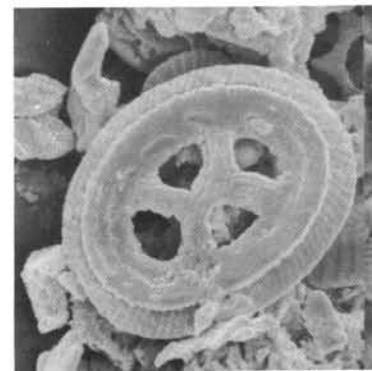
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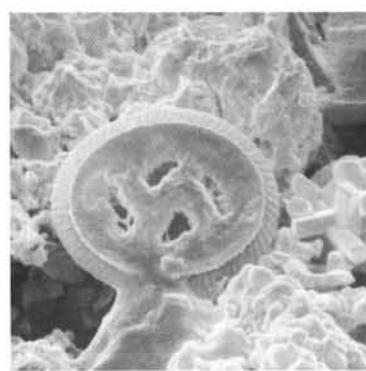
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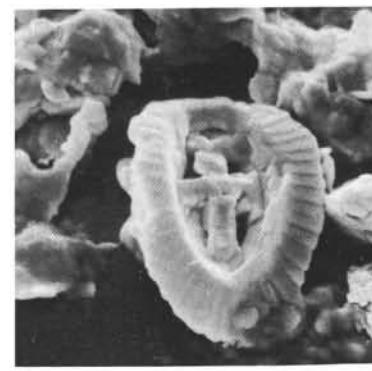
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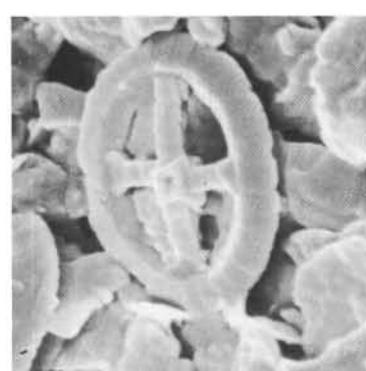
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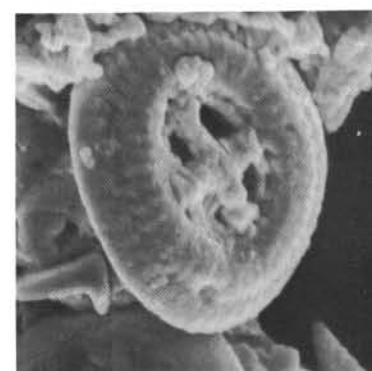
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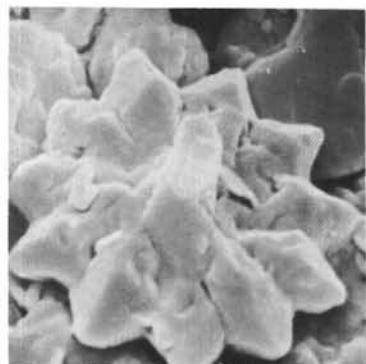


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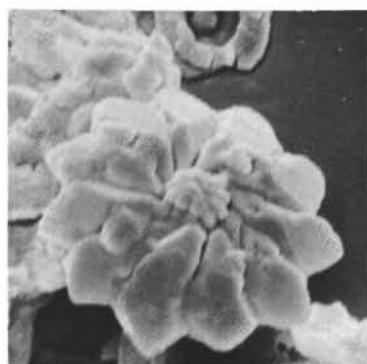
PLATE 4

- Figures 1, 2     *Discoaster barbadiensis* Tan Sin Hok, 1927.  
4600 ×.  
Sample 401-10-4, 131-132 cm.
- Figures 3, 4, 6     *Discoaster elegans* Bramlette and Sullivan, 1961.  
Sample 405-14-1, 124-125 cm.  
3. 4200 ×.  
4, 6. 3200 ×.
- Figure 5     *Discoaster* sp.  
3700 ×.  
Sample 405-14-1, 124-125 cm.
- Figures 7-9     *Discoaster lodoensis* Bramlette and Sullivan, 1961.  
Sample 405-14-1, 124-125 cm.  
7. 1900 ×.  
8, 9. 5000 ×.
- Figures 10, 11     *Discoaster mirus* Deflandre, 1954. Sample 405-14-1,  
124-125 cm.  
10. 5000 × (?*Discoaster brönnimanni* Stradner,  
1961).  
11. 4000 ×.
- Figure 12     *Discoaster distinctus* Martini, 1958.  
5000 ×.  
Sample 405-14-1, 124-125 cm.

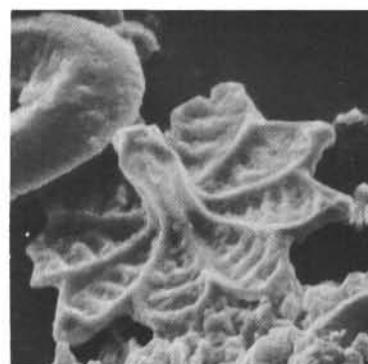
## PLATE 4



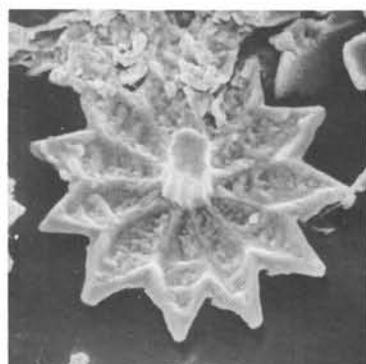
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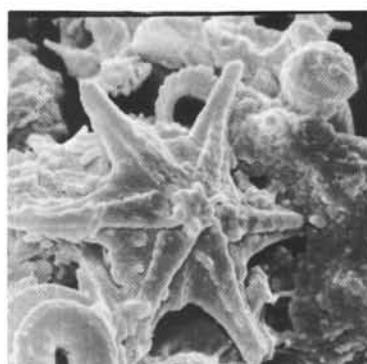
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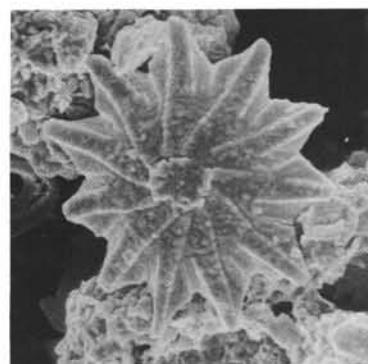
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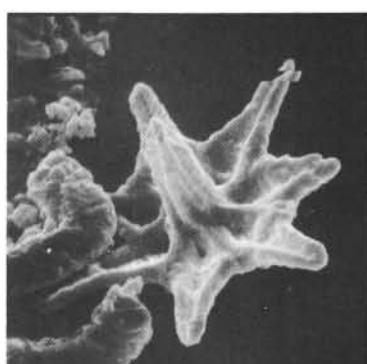
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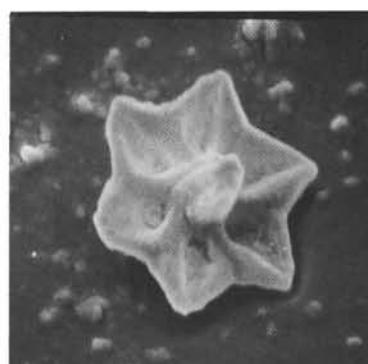
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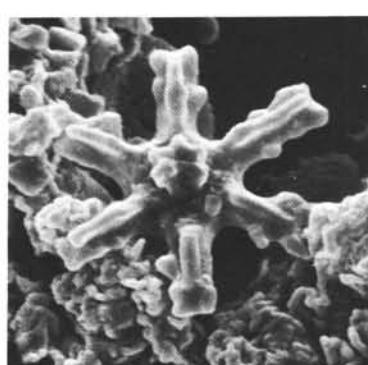
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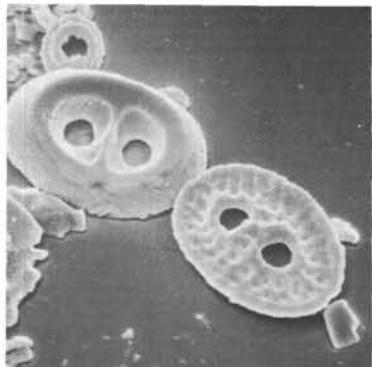


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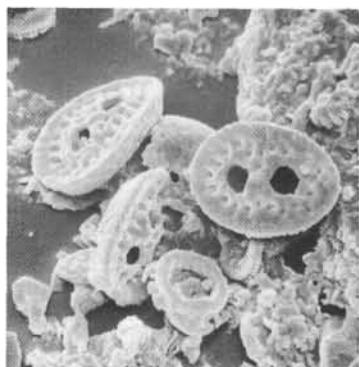
## PLATE 5

- Figure 1      *Transversopontis pulcher* (Deflandre) Hay, Mohler, and Wade, 1966.  
                 2500  $\times$ , distal and proximal view.  
                 Sample 405-14-1, 124-125 cm.
- Figure 2      *Transversopontis pulcher* (Deflandre) Hay, Mohler, and Wade, 1966.  
                 2500  $\times$ .  
                 Sample 405-14-1, 124-125 cm.
- Figure 3      *Discolithina plana* (Bramlette and Sullivan)  
                 Perch-Nielsen, 1971.  
                 4500  $\times$ , proximal view.  
                 Sample 405-14-2, 36-37 cm.
- Figure 4      *Discolithina ocellata* (Bramlette and Sullivan)  
                 Perch-Nielsen, 1971.  
                 3800  $\times$ , distal view.  
                 Sample 405-25-1, 58-59 cm.
- Figure 5      *Koczyia fimbriata* (Bramlette and Sullivan)  
                 Perch-Nielsen, 1971.  
                 2500  $\times$ , distal view.  
                 Sample 402A-5-2, 9-10 cm.
- Figure 6      *Transversopontis panarium* (Deflandre) Locker, 1968.  
                 5000  $\times$ , proximal view.  
                 Sample 405-14-1, 124-125 cm.
- Figure 7      *Discolithina* sp.  
                 5000  $\times$ , distal view.  
                 Sample 403-36-3, 8-9 cm.
- Figure 8      *Discolithina punctosa* (Bramlette and Sullivan)  
                 Perch-Nielsen, 1971.  
                 4500  $\times$ , distal view.  
                 Sample 405-14-2, 36-37 cm.
- Figure 9      *Transversopontis* sp.  
                 4000  $\times$ , proximal view.  
                 Sample 404-7-1, 13-14 cm.
- Figure 10     *Discolithina ocellata* (Bramlette and Sullivan)  
                 Perch-Nielsen, 1971.  
                 4000  $\times$ , proximal view.  
                 Sample 404-7-1, 13-14 cm.
- Figure 11     *Thoracosphaera prolata* Bukry and Bramlette, 1969.  
                 900  $\times$ .  
                 Sample 401-14-1, 26-27 cm.
- Figure 12     *Thoracosphaera deflandrei* Kamptner, 1956.  
                 1100  $\times$ .  
                 Sample 401-14-3, 64-65 cm.

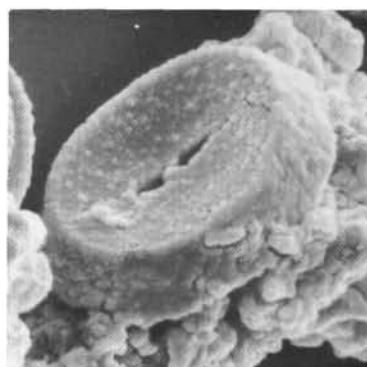
## PLATE 5



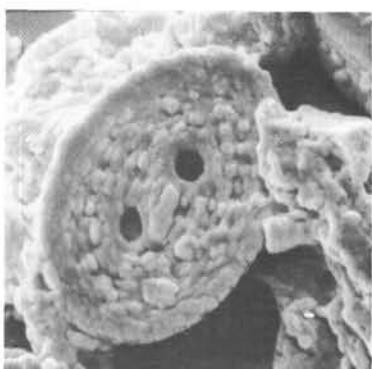
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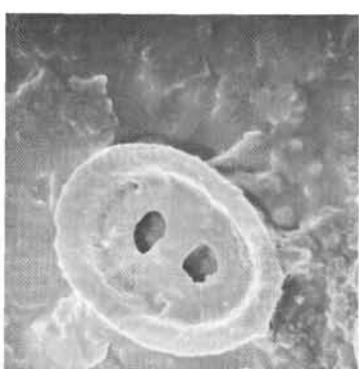
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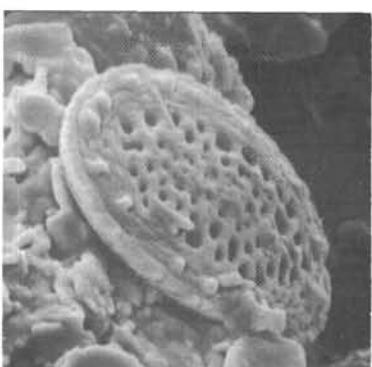
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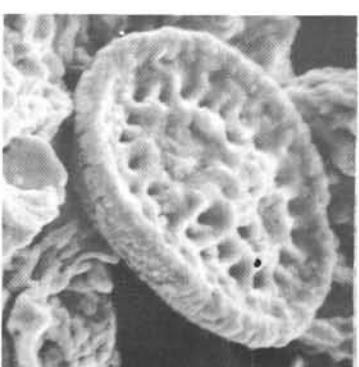
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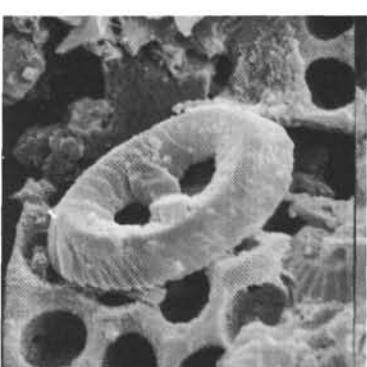
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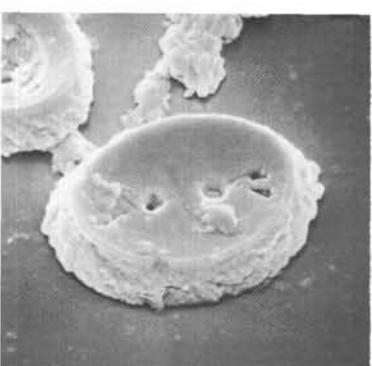
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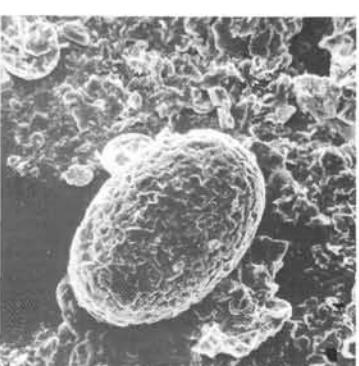
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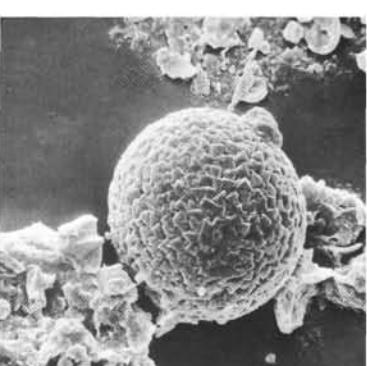
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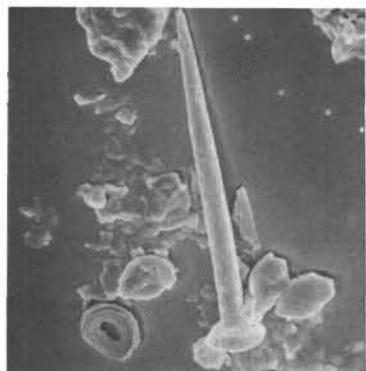


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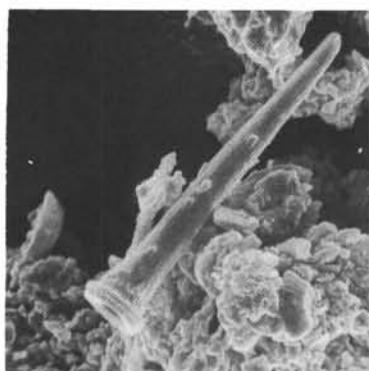
## PLATE 6

- Figure 1      *Rhabdosphaera tenuis* Bramlette and Sullivan, 1961.  
2300  $\times$ .  
Sample 402A-5-1, 106-107 cm.
- Figure 2      *Rhabdosphaera spinula* Levin, 1965.  
2500  $\times$ .  
Sample 405-14-1, 124-125 cm.
- Figure 3      *Blackites creber* (Deflandre) Roth, 1970.  
5000  $\times$ . proximal view.  
Sample 402A-5-1, 106-107 cm.
- Figure 4      *Naninfula deflandrei* Perch-Nielsen, 1968.  
5000  $\times$ .  
Sample 402A-3-4, 129-130 cm.
- Figures 5, 6    *Rhabdolithus solus* Perch-Nielsen, 1971. Sample  
401-14-1, 26-27 cm.  
5. 2500  $\times$ .  
6. 5000  $\times$ .
- Figure 7      *Blackites* cf. *B. creber* (Deflandre) Roth, 1970.  
5000  $\times$ .  
Sample 402A-3-4, 129-130 cm.
- Figure 8      *Blackites creber* (Deflandre) Roth, 1970.  
5000  $\times$ .  
Sample 404-8-2, 23-24 cm.
- Figure 9      *Rhabdosphaera inflata* Bramlette and Sullivan, 1961.  
3300  $\times$ .  
Sample 405-9-2, 114-115 cm.
- Figure 10     *Blackites* cf. *B. creber* (Deflandre) Roth, 1970.  
4500  $\times$ .  
Sample 402A-5-1, 106-107 cm.
- Figure 11     *Rhabdolith* gen. indet. sp. indet.  
5000  $\times$ .  
Sample 404-8-2, 23-24 cm.
- Figure 12     *Rhabdolith* gen. indet.  
3500  $\times$ .  
Sample 404-8-2, 23-24 cm.

## PLATE 6



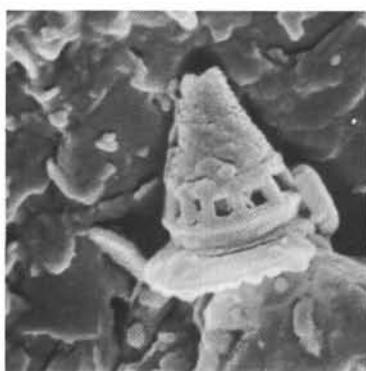
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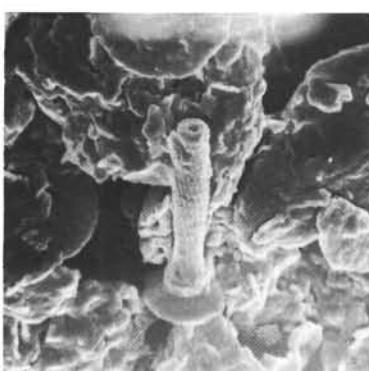
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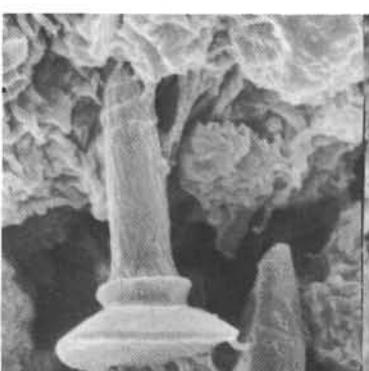
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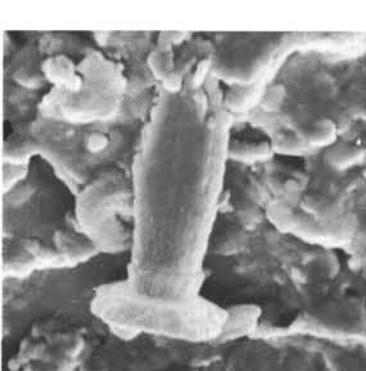
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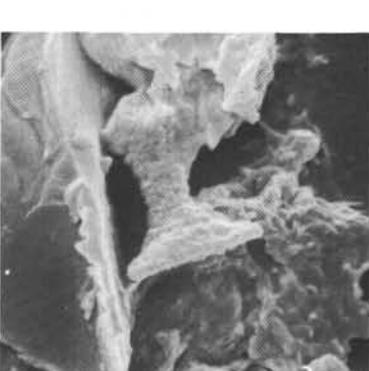
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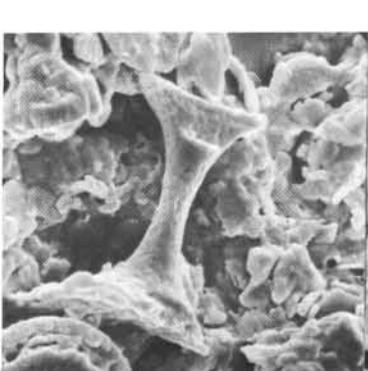
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## PLATE 7

- Figures 1, 2     *Reticulofenestra umbilica* (Levin) Martini and Ritzkowski, 1968. Sample 405-25-1, 58-59 cm.  
2500  $\times$ .  
1. Distal view.  
2. Proximal view.
- Figures 3, 4     *Cribrocentrum reticulatum* (Gartner and Smith) Perch-Nielsen, 1971. Sample 402A-3-4, 129-130 cm.  
5000  $\times$ .  
3. Distal view.  
4. Proximal view.
- Figure 5        *Coccolithus pelagicus* (Wallich) Schiller, 1930.  
4000  $\times$ , distal view.  
Sample 406-2-3, 8-9 cm.
- Figure 6        *Ericsonia fenestrata* (Deflandre) Stradner, 1968.  
5000  $\times$ , distal view.  
Sample 405-14-2, 36-37 cm.
- Figure 7        *Cyclococcolithus formosus* Kamptner, 1963.  
4200  $\times$ , distal view.  
Sample 402A-5-2, 9-10 cm.
- Figure 8        *Cyclolithella aprica* Roth, 1973.  
4500  $\times$ , distal view.  
Sample 402A-5-1, 106-107 cm.
- Figure 9        *Cyclolithella pakistanica* Haq, 1971.  
5000  $\times$ , distal view.  
Sample 402A-3-4, 129-130 cm.
- Figure 10       *Cyclococcolithus* sp.  
3250  $\times$ , distal view.  
Sample 405-14-2, 36-37 cm.
- Figure 11       *Cyclolithus bramlettei* Hay and Towe, 1962.  
5000  $\times$ , proximal view.  
Sample 401-14-1, 26-27 cm.
- Figure 12       *Cyclococcolithina kingi* Roth, 1970.  
5000  $\times$ , distal view.  
Sample 405-14-2, 36-37 cm.

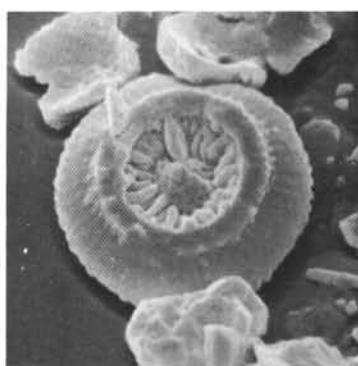
## PLATE 7



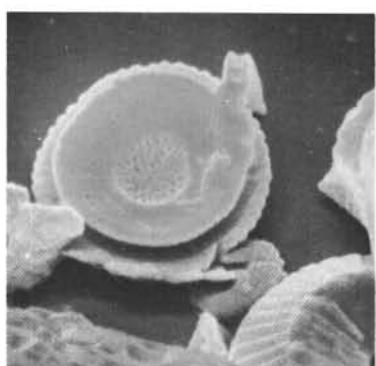
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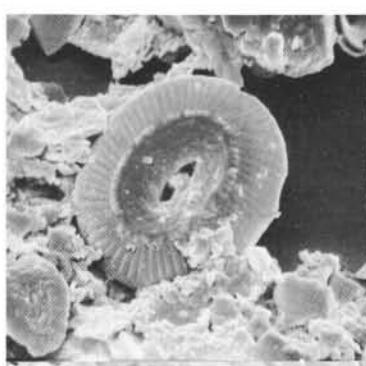
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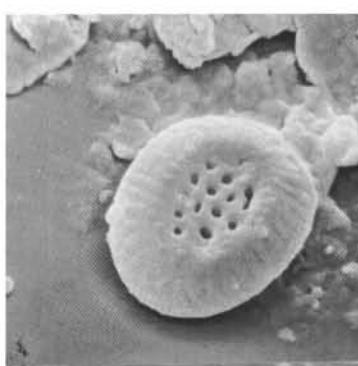
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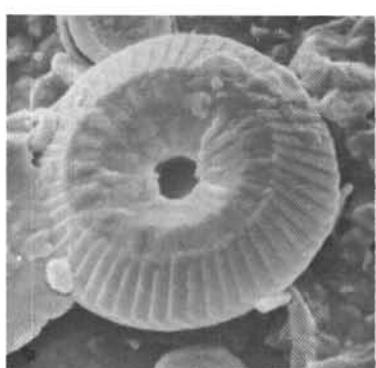
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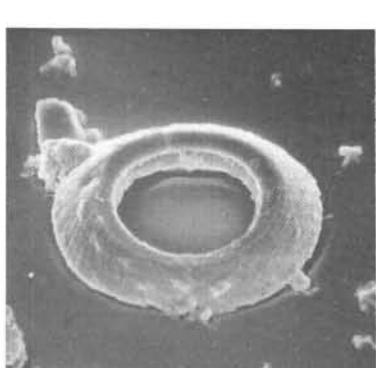
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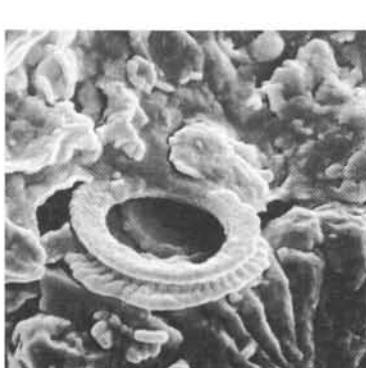
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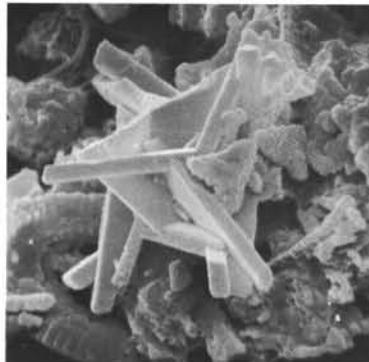


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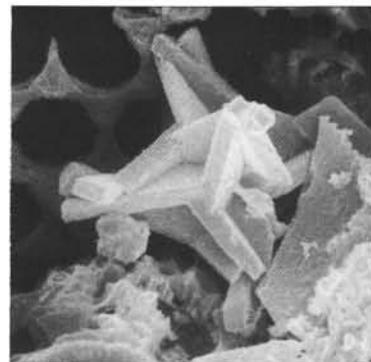
PLATE 8

- Figures 1-3      *Nannoturba spinosa* nov. gen. n. sp.  
Holotype: Figure 3, SM.B 13019  
3200 ×.  
Sample 404-7-1, 13-14 cm.
- Figures 4-6      *Nannoturba robusta* nov. gen. n. sp.  
Holotype: Figure 4, SM.B. 13017  
4000 ×.  
Sample 404-7-1, 13-14 cm.
- Figure 7      *Helicosphaera seminulum* Bramlette and Sullivan,  
1961.  
3500 ×, proximal view.  
Sample 405-14-1, 124-125 cm.
- Figure 8      *Helicosphaera dinesenii* (Perch-Nielsen) Jafar and  
Martini, 1975.  
3250 ×, proximal view.  
Sample 405-9-2, 24-25 cm.
- Figure 9      *Pontosphaera* sp.  
3250 ×, distal view.  
Sample 405-14-1, 124-125 cm.
- Figures 10-12    *Scyphosphaera* sp. Sample 405-14-1, 124-125 cm.  
10. Distal view.  
11, 12. Side view.

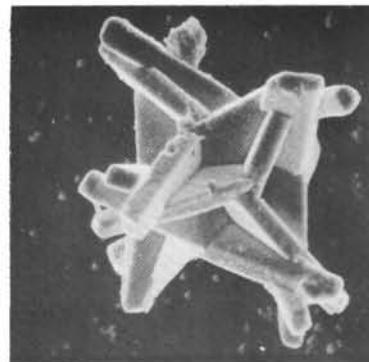
## PLATE 8



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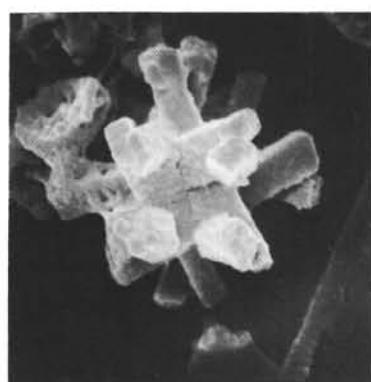
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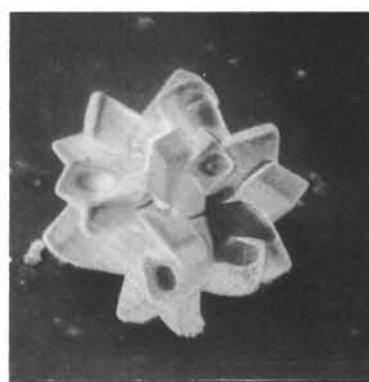
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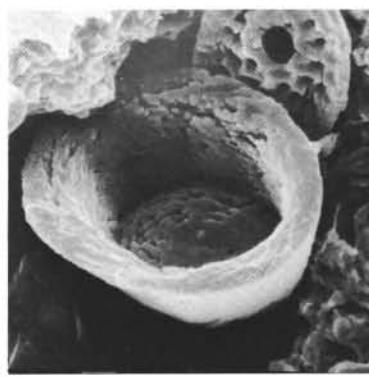
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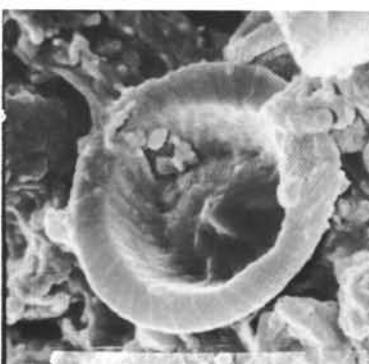
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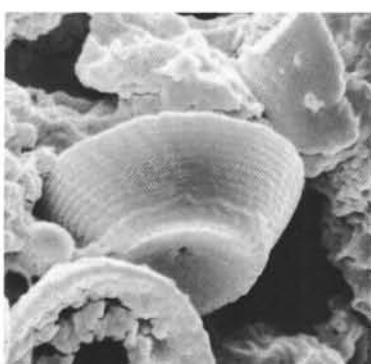
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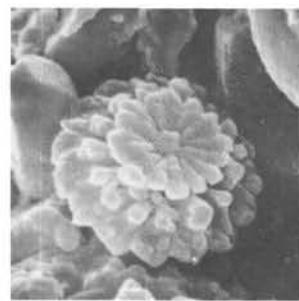


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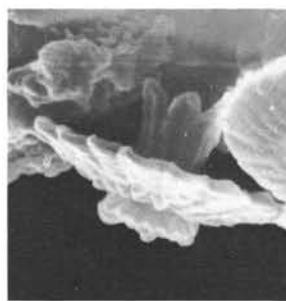
## PLATE 9

- Figure 1 *Discoaster lenticularis* Bramlette and Sullivan, 1961.  
6500  $\times$ . Sample 405-14-1, 124-125 cm.
- Figure 2 *Discoasteroides kuepperi* (Stradner) Bramlette and Sullivan, 1961.  
4400  $\times$ . Sample 405-14-1, 124-125 cm.
- Figure 3 *Conococcolithus minutus* Hay and Mohler, 1967.  
5000  $\times$ . Sample 401-14-3, 64-66 cm.
- Figure 4 *Rhabdosphaera vitrea* (Deflandre) Bramlette and Sullivan, 1961.  
4800  $\times$ . Sample 402A-5-1, 24-25 cm.
- Figures 5, 9, 10 *Pontosphaera pacifica* Burns, 1973. Sample 406-2-3, 111-113 cm.  
5. 1900  $\times$ , proximal view.  
9. 2000  $\times$ , proximal view.  
10. 2000  $\times$ , distal view.
- Figure 6 *Koczyia wechesensis* (Bukry and Percival) Sherwood, 1974.  
3000  $\times$ . Sample 405-14-1, 124-125 cm.
- Figure 7 *Ellipsolithus macellus* (Bramlette and Sullivan) Sullivan, 1964.  
2200  $\times$ , distal view. Sample 401-14-3, 64-65 cm.
- Figure 8 *Thoracosphaera operculata* Bramlette and Martini, 1964.  
800  $\times$ . Sample 401-14-1, 26-27 cm.
- Figures 11, 12 *Helicosphaera carteri* (Wallich) Kamptner, 1954. Sample 406-2-3, 111-113 cm.  
11. 2000  $\times$ , distal view.  
12. 2000  $\times$ , proximal view.
- Figure 13 *Helicosphaera dinesenii* (Perch-Nielsen) Jafar and Martini, 1975.  
2800  $\times$ , proximal view. Sample 405-9-2, 24-25 cm.
- Figure 14 *Helicosphaera seminulum* Bramlette and Sullivan, 1961.  
3400  $\times$ , distal view. Sample 405-14-2, 36-37 cm.
- Figure 15 *Scyphosphaera* sp.  
5000  $\times$ . Sample 405-14-1, 124-125 cm.
- Figure 16 *Cyclococcolithus leptoporus* (Murray and Blackman) Kamptner, 1954.  
1300  $\times$ . Sample 403-3-3, 8-9 cm.
- Figure 17 *Umbilicosphaera mirabilis* Lohmann, 1902.  
3700  $\times$ , distal view. Sample 406-2-3, 111-113 cm.
- Figure 18 *Pseudoemiliania lacunosa* (Kamptner) Gartner, 1969.  
5000  $\times$ . Sample 406-2-3, 111-113 cm.
- Figure 19 *Gephyrocapsa ornata* Heimdal, 1973.  
6800  $\times$ . Sample 403-3-3, 8-9 cm.
- Figure 20 *Discolithina japonica* Takayama, 1967.  
5000  $\times$ , proximal view. Sample 406-2-3, 111-113 cm.

## PLATE 9



1



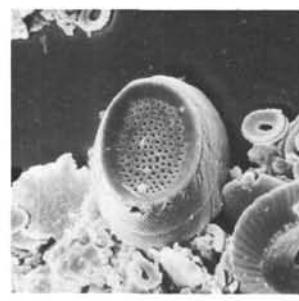
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3



4



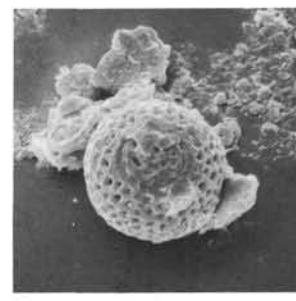
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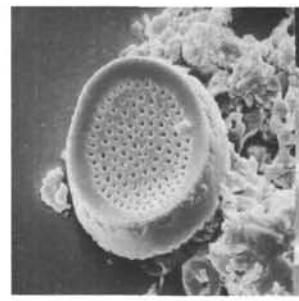
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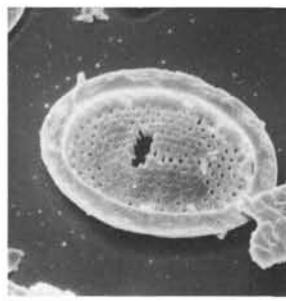
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8



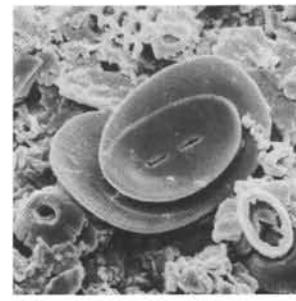
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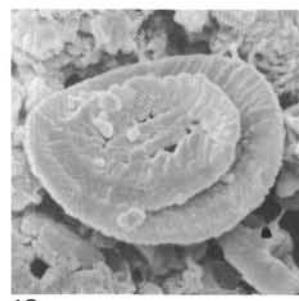
10



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