27. PHYTOPLANKTON STRATIGRAPHY, OFFSHORE EAST AFRICA, DEEP SEA DRILLING PROJECT LEG 25[1]

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INTRODUCTION

Leg 25 of the Deep Sea Drilling Project, June to August 1972, through the western Indian Ocean from Port Louis, Mauritius, to Durban, South Africa, recovered 171 cores at 11 drilling sites (Figure 1). Light-microscope techniques were used to study the coccoliths and silicoflagellates of 264 samples from these cores. Coccolith zonation, based on Bukry (1973a), is summarized (Figure 2), and some phytoplankton assemblages at Leg 25 sites are described.

EOCENE PALEOENVIRONMENT INDICATED BY *DISCOASTER* TO *CHIASMOLITHUS* RATIO

The premise of a paleotemperature method based on the *Discoaster* to *Chiasmolithus* ratio is the general observation that *Discoaster* is rare or absent at high-latitude localities and that *Chiasmolithus* is especially abundant there (Bukry, in press). It could be hypothesized, therefore, that during the time when these groups flourished—late Paleocene through late Eocene—a fairly equal mix of these two genera in a coccolith assemblage would indicate intermediate or temperate conditions.

Previous study of the southernmost Eocene Deep Sea Drilling Project sample in the Pacific (DSDP 207A-14-2, 35-36 cm, lat 37°S), which is considered cool-temperate, shows a 31% *Discoaster* to 69% *Chiasmolithus* ratio for a count of 500 specimens of these genera. This contrasts sharply with an Eocene assemblage in DSDP 44-4-5, 145-150 cm, lat 19°N, which is considered tropical (Lonsdale et al., 1972). A count of 500 specimens there reveals 98% *Discoaster* to 2% *Chiasmolithus.*

The ratio of the relative abundances of *Discoaster* and *Chiasmolithus* is described for Leg 25 Eocene coccolith assemblages at Sites 242 and 245. The ratios between these two solution-resistant genera indicate a tropical environment at DSDP 242 during the late Eocene and a warm to temperate environment at DSDP 245 through the early Eocene. Hence, the sites of Leg 25 are likely to have lain during the Eocene at latitudes similar to those they now occupy.

SITE SUMMARIES

Site DSDP 239
(lat 21°17.67'S, long 51°40.73'E; depth 4971 m)

Site 239, on the abyssal plain of the Mascarene Basin 290 km east of Madagascar, sampled sediment of Late Cretaceous to late Pleistocene age. The 19 sediment cores were cut discontinuously through a 314-meter section above basalt.

Cores 1 to 3 were cut consecutively between 0 and 27 meters and contain the *Gephyrocapsa oceanica* Zone. Sample 239-1-4, 90-91 cm (5 m) contains common reworked coccoliths of Late Cretaceous and many Tertiary ages, including the species: *Cribrosphaera ehrenbergii, Lophodolithus nascens, Chiasmolithus grandis, Dictyococcites bisectus, Discoaster neohamatus, D. surculus, D. asymmetricus.* The assemblage from the lower part of the *G. oceanica* Zone in Sample 239-3-2, 90-91 cm (20 m) contains common *Gephyrocapsa caribbeanica* and *Emiliania annula* with a few *Gephyrocapsa oceanica* and rare reworked early Tertiary species such as *Cyclococcolithina formosa* and *Dictyococcites bisectus.*

Cores 4 to 6 were cut consecutively between 66 and 93 meters and contain mixtures of species indicating middle Miocene (*Discoaster hamatus*) to late Miocene (*Ceratolithus primus*) age. Preservation and species composition for specific samples are variable. For example, Sample 239-4-4, 71-72 cm (70 m) is preserved in etching stage -2 and contains a diverse mixture of discoasters, including *Catinaster calyculus, Discoaster bellus, D. berggrenii, D. hamatus, D. intercalaris, D. loeblichii, D. neohamatus, D. pentaradiatus, D. quinqueramus, D. rutellus, D. surculus,* and *D. variabilis.* Other taxa present include *Ceratolithus primus* and *Minylitha convallis.* The species *D. hamatus, D. loeblichii,* and *C. primus* are stratigraphically disjunct elsewhere. Their cooccurrence here probably indicates mixing, but locally extended ranges also could be suggested by the similar preservation stage of these species. In Sample 239-5-5, 20-21 cm (81 m) species are in a thickly overgrown +3 stage of preservation, and both *C. primus* and *D. hamatus* occur. In samples from Cores 6 to 8, *D. hamatus* and *C. calyculus* are present in assemblages lacking younger taxa such as *C. primus, D. quinqueramus,* or *D. surculus.* Eocene and Cretaceous species are mixed into these assemblages of the upper *Discoaster hamatus* Zone.

Placoliths are rare and etched in samples from the lower part of Core 8 to the upper part of Core 15. Solution-resistant placoliths such as *Cyclicargolithus floridanus* occur with *Sphenolithus moriformis* and ?*Discoaster deflandrei* in Cores 9 to 12 (140-215 m). A more stratigraphically diagnostic species, *Helicopontosphaera kamptneri,* occurs in Samples 239-9-1, 83-84 cm (141 m) and 239-11-2, 75-76 cm (160 m) and suggests an early or middle Miocene age here. Rare reworked Cretaceous taxa such as *Tetralithus trifidus* and *Watznaueria barnesae* are present.

Beginning with Sample 239-15-3, 79-80 cm (275 m), a thick section of the lower Paleocene *Cruciplacolithus tenuis* Zone is present in the interval of Cores 15 to 18 (275-304 m). The coccolith species range from rare to abundant, and the assemblages all show moderate to strong etching. Typical species include *Fasciculithus magnus,* which is

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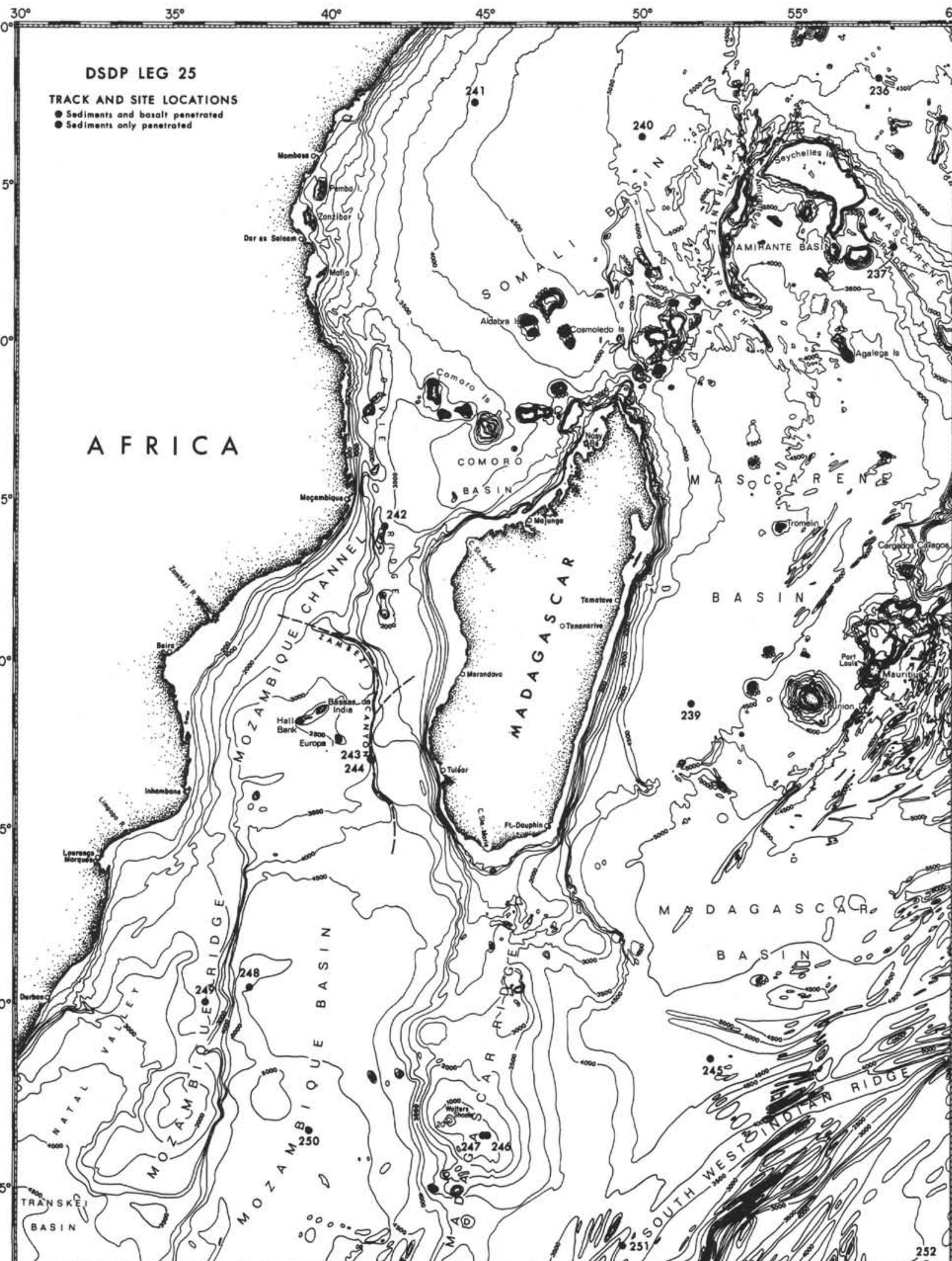

Figure 1. *Location of Deep Sea Drilling Project Leg 25 sites in the western Indian Ocean.*

especially prominent in Samples 239-17-1, 50-51 cm (291 m) and 239-16-1, 80-81 cm (282 m). *Coccolithus pelagicus* s. ampl., *Cruciplacolithus tenuis*, and *Zygodiscus sigmoides* are especially abundant in Sample 239-15-3, 79-80 cm (275 m).

Although apparently reworked Cretaceous species are conspicuous in Paleocene Sample 239-18-1, 70-71 cm (300 m), only the deepest sample available, 239-19-2, 95-96 cm (314 m), contains an exclusively Cretaceous assemblage. Sample 239-18-1 contains only rare specimens of species indicating a Paleocene age such as *Coccolithus pelagicus* s. ampl., *Cruciplacolithus tenuis*, and *Biantholithus sparsus*. The Cretaceous assemblage of 239-19-2 contains *Apertapetra gronosa*, *Arkhangelskiella cymbiformis*, *Micula decussata*, *M. mura*, *Prediscosphaera cretacea*, *Tetralithus praemurus*, *Watznaueria barnesae*, and *W. biporta*. The etched specimens and the dominance of solution-resistant species in this assemblage indicate the -3 stage of intensive solution, even though these coccoliths are abundant.

Site DSDP 240
(lat 03°29.24′S, long 50°03.22′E; depth 5082 m)

Site DSDP 240 in the abyssal plain of the Somali Basin, 800 km east of Africa, penetrated sediment of late Paleocene to late Pleistocene age. The 12 cores were cut intermittently through a 195-meter section above basalt.

Sample 240-1-3, 90-91 cm (3 m) contains abundant coccoliths and diatoms and common silicoflagellates. The warm-water assemblages of all three groups indicate a late Quaternary age. The coccolith assemblage is dominated by small placoliths, ?*Emiliania huxleyi*; other species present include *Cyclococcolithina leptopora*, *Emiliania annula*, *Gephyrocapsa oceanica*, *Helicopontosphaera kamptneri*, and some rare reworked *Discoaster brouweri* and *D. variabilis*. The assemblage is provisionally assigned to the *Emiliania huxleyi* Zone. The associated silicoflagellate assemblage is assigned to the *Dictyocha epiodon* Zone on the basis of a count of 100 specimens that produced the following species and percentages: 76% *Dictyocha fibula*, 19% *D. epiodon*, 3% *Octactis pulchra*, 1% *Mesocena elliptica*, and 1% *Dictyocha* sp. cf. *D. aspera*. The abundant diatom population is dominated by large specimens of *Hemidiscus cuneiformis* and by *Thalassiothrix longissima*. Stratigraphically diagnostic species *Pseudoeunotia doliolus*, *Roperia tessellata*, and *Thalassiosira oestrupii* are present. Other species in the assemblage include: *Actinoptychus* sp. cf. *A. vulgaris monicae*, *Asteromphalus imbricatus*, *Bacteriastrum* sp., *Coscinodisus excentricus*, *C.* sp. cf. *C. gigas diorama*, *C. nodulifer*, *Ethmodiscus rex*, *Liostephania* sp. (*Asteromphalus arachne* form), *Nitzschia marina*, *Rhizosolenia bergonii*, *R. styliformis*, *Triceratium cinnamomeum minor*. This assemblage is assigned to the *Pseudoeunotia doliolus* Zone (Burckle, 1972). The *Roperia tessellata* Zone (Bukry and Foster, 1973) may represent the upper part of the *P. doliolus* Zone. Sample 240-1-6, 80-81 cm (6 m) contains a similar though less diverse phytoplankton assemblage, and the sediment is predominantly zooplankton foraminifera. Ascidian spicules are also present, suggesting shallow-marine deposition or slumping from carbonate banks (Hekel, in press).

Samples 240-3-1, 80-81 cm (77 m) and 240-3-5, 66-67 cm (79 m) are barren. Sample 240-5-3, 75-80 cm (161 m) is almost barren, containing only rare and apparently reworked coccoliths of probable Miocene age.

Sample 240A-3-1, 95-96 cm (186-195 m) contains an abundance of overgrown +3 coccoliths, but only a few resistant species occur: *Coccolithus pelagicus* s. ampl., *Discoaster barbadiensis*, *D. diastypus*, *D. lodoensis*, *Discoasteroides kuepperi*, *Sphenolithus radians*, and *Tribrachiatus orthostylus*. This assemblage is assigned to the lower Eocene *Tribrachiatus orthostylus* Zone.

Sample 240A-3, CC (195 m) is less overgrown (+2) and much more diverse. The coccolith assemblage contains several species, the first occurrences of which are diagnostic for the uppermost Paleocene *Campylosphaera eodela* Subzone such as *Campylosphaera eodela*, *Lophodolithus nascens*, and *Rhomboaster cuspis*. Other species include: *Chiasmolithus bidens*, *C. consuetus*, *Coccolithus pelagicus* s. ampl., *Discoaster lenticularis*, *D. multiradiatus*, *D. nobilis*, *Neochiastozygus distentus*, *N. junctus*, *Sphenolithus anarrhopus*, and *Zygolithus* sp. cf. *Z. dubius*.

Site DSDP 241
(lat 02°22.24′S, long 44°40.77′E; depth 4054 m)

Site 241 is on the continental rise of East Africa at the shoreward margin of the Somali Basin about 270 km from the coast. A penetration of 1174 meters was achieved at this site in sediment ranging in age from late Quaternary to Late Cretaceous. Warm-water coccolith assemblages characterize the samples examined from the intermittently cut Cores 1 to 25 (0-844 m). Tropical silicoflagellates and diatoms are also common in late Quaternary Cores 1 to 4 (0-65 m) signifying elevated nutrient supply and phytoplankton production then. In Sample 241-2-5, 131-132 cm (16 m), belonging to the *Dictyocha epiodon* Zone, a count of 73 silicoflagellates shows only two species—55% *Dictyocha fibula* and 45% *D. epiodon*. The *Dictyocha fibula* population is dominated by the large inflated tropical form (see Bukry and Foster 1973, pl. 3, fig. 1). A diverse diatom assemblage is similar to those recorded at DSDP 240 to the south and DSDP 157 in the Panama Basin. Key tropical stratigraphic indicators present include *Pseudoeunotia doliolus*, *Roperia tessellata*, and *Thalassiosira oestrupii*; the upper *Pseudoeunotia doliolus* Zone is indicated. In Sample 241-3-5, 60-61 cm (54 m), the silicoflagellate assemblage is assigned to the *Mesocena elliptica* Zone; species present in a count of 100 specimens include 90% *Mesocena elliptica*, 9% *Dictyocha fibula*, and 1% *Mesocena triangula*. The *D. fibula* specimens are mainly the small variety with I-shaped apical structure. In Sample 241-4-2, 70-71 cm (57 m), silicoflagellates are scarcer; the inflated form of *D. fibula* is most common, and only a few specimens of *M. elliptica* and *D. aspera* were noted. Below this level, siliceous phytoplankton are missing, but coccoliths provide a basis for stratigraphic determinations. Silicoflagellate zonation is presently in an early phase of development and as yet provides relatively broad stratigraphic subdivisions having tenuous boundaries (Table 1). The diversity of silicoflagellates through time generally parallels that of discoasters, being relatively higher in the

Series or Subseries	Zone	Subzone	239	240	241	242	245	249
Holocene								
Pleistocene	*Emiliania huxleyi*			1-3/1-6				
	Gephyrocapsa oceanica		1-4/3-2		1-5/4-2	1-3		
	Crenalithus doronicoides	*Gephyrocapsa caribbeanica*			4-5			
		Emiliania annula			5-5			
Upper Pliocene	*Discoaster brouweri*	*Cyclococcolithina macintyrei*			6-1/6-6	2-4		
		Discoaster pentaradiatus						
		Discoaster tamalis						
Lower Pliocene	*Reticulofenestra pseudoumbilica*	*Discoaster asymmetricus*			7-1/7-3			
		Sphenolithus neoabies				3-1		
	Ceratolithus tricorniculatus	*Ceratolithus rugosus*			7-5	3-6		1-2/2-1
		Ceratolithus acutus			8-1	4-1/4-6		
Upper Miocene		*Triquetrorhabdulus rugosus*				5-1		2-4/3-2
	Discoaster quinqueramus	*Ceratolithus primus*	4-1/5-5		8-3/10-4			3-5/8-5
		Discoaster berggrenii			11-4	5-4/6-3		9-5/10-4
	Discoaster neohamatus	*Discoaster neorectus*						10-6/14-5
		Discoaster bellus						
Middle Miocene	*Discoaster hamatus*		6-2/8-2		12-2			
	Catinaster coalitus							
	Discoaster exilis	*Discoaster kugleri*				7-1/7-3		15-1/16-2
		Coccolithus miopelagicus						
	Sphenolithus heteromorphus		9-1/11-2			7-6		
Lower Miocene	*Helicopontosphaera ampliaperta*							
	Sphenolithus belemnos					8-2		
	Triquetrorhabdulus carinatus	*Discoaster druggii*						
		Discoaster deflandrei				? 8-5		
Oligocene		*Cyclicargolithus abisectus*						
	Sphenolithus ciperoensis					9-6		
	Sphenolithus distentus					10-1		
	Sphenolithus predistentus					?10-6/13-4		
	Helicopontosphaera reticulata	*Reticulofenestra hillae*						
		Cyclococcolithina formosa				13-5/14-4	?2A-3/?5A-4	
		Coccolithus subdistichus				15-3/16-1		
Upper Eocene	*Discoaster barbadiensis*					17-1/19-3		

Middle Eocene	*Reticulofenestra umbilica*	*Discoaster saipanensis*						
		Discoaster bifax					6A-1/6A-3	
	Nannotetrina quadrata	*Coccolithus staurion*						
		Chiasmolithus gigas					3-4	
		Discoaster strictus					3-5/3-6	
	Discoaster sublodoensis	*Rhabdosphaera inflata*					7A-2/7A-6	
Lower Eocene		*Discoasteroides kuepperi*					4-1/4-6	
	Discoaster lodoensis						5-1/6-2	
	Tribrachiatus orthostylus			3A-1				
	Discoaster diastypus						7-1/8-2	
Paleocene	*Discoaster multiradiatus*	*Campylosphaera eodela*		3A-CC				
		Chiasmolithus bidens					9-1/9-2	
	Discoaster nobilis						9-3	
	Discoaster mohleri						10-1/10-3	
	Heliolithus kleinpellii						11-1/11-5	
	Fasciculithus tympaniformis						12-2/13-4	
	Cruciplacolithus tenuis		15-3/18-2				13-5/16-1	
Upper Cretaceous	*Micula mura*		19-2					17-1/17-3
	Lithraphidities quadratus							
	Tetralithus trifidus				22-1/25-2			17-4/21-3
	Broinsonia parca							
	Eiffellithus augustus							21-5/23-3
Lower Cretaceous	*Chiastozygus litterarius*							28-1/31-2

Figure 2. *Coccolith zonation of DSDP Leg 25. The numbers assigned to zonal intervals are core and section numbers of samples examined. A core is typically 9 meters long, and a section is a sixth part of a core, 1.5 meters, both numbered from the top. Where a zone or subzone is represented in samples from two or more core sections, the highest and lowest sections are listed.*

TABLE 1
Preliminary Correlation of Coccolith and Silicoflagellate Low-Latitude Zonations with Extrapolated Boundary Ages

Series or Subseries	Coccolith Zone or Subzone	Boundary (m.y.)	Silicoflagellate Zone	Boundary (m.y.)
Holocene	*Emiliania huxleyi*	0.2	*Dictyocha epiodon*	
Pleistocene	*Gephyrocapsa oceanica*	0.9		0.6
	Gephyrocapsa caribbeanica	1.6	*Mesocena elliptica*	
	Emiliania annula	1.8		
Pliocene	*Cyclococcolithina macintyrei*	2.1		2.0
	Discoaster pentaradiatus	2.5	*Distephanus boliviensis*	2.5
	Discoaster tamalis	3.0	*Cannopilus major*	
	Discoaster asymmetricus	3.4		3.5
	Sphenolithus neoabies	4.0	*Dictyocha fibula*	
	Ceratolithus rugosus	4.3		
	Ceratolithus acutus	5.1		
Upper Miocene	*Triquetrorhabdulus rugosus*	5.2		
	Ceratolithus primus	6.0		
	Discoaster berggrenii	6.8		6.8
	Discoaster neorectus	7.3	*Dictyocha aspera*	
	Discoaster bellus	11.0		11.0
Middle Miocene	*Discoaster hamatus*	13.0	*Distephanus longispinus*	
	Catinaster coalitus	13.2		13.2
	Discoaster kugleri	13.4	*Corbisema triacantha*	
	Coccolithus miopelagicus	14		
	Sphenolithus heteromorphus	15		15
Lower Miocene	*Helicopontosphaera ampliaperta*	17	*Distephanus octacanthus*	17
	Sphenolithus belemnos	18	*Naviculopsis quadrata*	
	Triquetrorhabdulus carinatus	24		22
Oligocene	*Sphenolithus ciperoensis*	27	*Rocella gemma*	
	Sphenolithus distentus	30		28
	Sphenolithus predistentus	34	*Dictyocha deflandrei*	
	Helicopontosphaera reticulata	38		38
Upper Eocene	*Discoaster barbadiensis*	42	*Dictyocha hexacantha*	
Middle Eocene	*Reticulofenestra umbilica*	45		
	Nannotetrina quadrata	48		48
Lower Eocene	*Discoaster sublodoensis*	50	*Naviculopsis constricta*	
	Discoaster lodoensis	51		
	Tribrachiatus orthostylus	52		
	Discoaster diastypus	53		53
Paleocene	*Discoaster multiradiatus*	55	*Corbisema hastata*	
	Discoaster nobilis	56		
	Discoaster mohleri	57		
	Heliolithus kleinpellii	58		
	Fasciculithus tympaniformis	60		
	Cruciplacolithus tenuis	63		63
Upper Cretaceous	*Micula mura*	66	*Lyramula furcula*	
	Lithraphidites quadratus	70	?	?

Note: Coccolith zonation and ages from Bukry (1973b). Silicoflagellate zonation and ages from Bukry and Foster (1973; in press) which also incorporates data from Glezer (1966), Mandra (1968), Martini (1971), and Ling (1972).

Eocene and Miocene than in the Oligocene or Pleistocene (Figure 3).

The silicoflagellate and diatom assemblages of Cores 1 to 4 all fall within the *Gephyrocapsa oceanica* Zone of coccoliths. In the lower part of Core 4, *Cyclococcolithina leptopora, Gephyrocapsa caribbeanica,* and *Helicopontosphaera sellii* are common. Rare reworked discoasters occur in this and all other Quaternary cores examined from this site. The *Emiliania annula* Subzone assemblage of Sample 241-5-5, 67-68 cm (72 m) is distinct from the much deeper Sample 241-6-1, 74-75 cm (105 m), which is in the next older *Cyclococcolithina macintyrei* Subzone. *Emiliania annula* and *E. ovata* are conspicuous, and only a rare discoaster *D. pentaradiatus* is recorded for 241-5-5, whereas, 241-6-1 contains common *D. brouweri* (5- and 6-rayed) and *D. triradiatus, Coccolithus pelagicus, Crenalithus doronicoides,* and *Ceratolithus rugosus.* Therefore, the Pliocene-Pleistocene boundary is within the uncored interval.

The Miocene-Pliocene boundary lies within the cored interval of Core 8 (180-189 m). The contrasting coccolith assemblages of Core 8, Sections 1 and 3 and the void in the core recovery at the position of Core 8, Section 2 suggest a possible lithologic contact for the boundary. Traces of sand near the void led the shipboard sedimentologists to speculate that a sand layer at this point may have been washed out during coring. Coccolith evidence for the boundary position includes, in *Ceratolithus acutus* Subzone Sample 241-8-1, 90-91 cm (180 m), the occurrence of *Ceratolithus acutus* and the absence of *Discoaster quinqueramus* and *Triquetrorhabdus rugosus.* In Sample 241-8-3, 72-73 cm (181 m), *Discoaster quinqueramus, Triquetrorhabdulus rugosus* and *Ceratolithus primus* indicate the *Ceratolithus primus* Subzone. This subzone extends to Core 10, Sample 241-10-4, 71-72 cm (222 m), where well-preserved assemblages with *Ceratolithus amplificus* emend., *C. primus,* and *D. quinqueramus* occur.

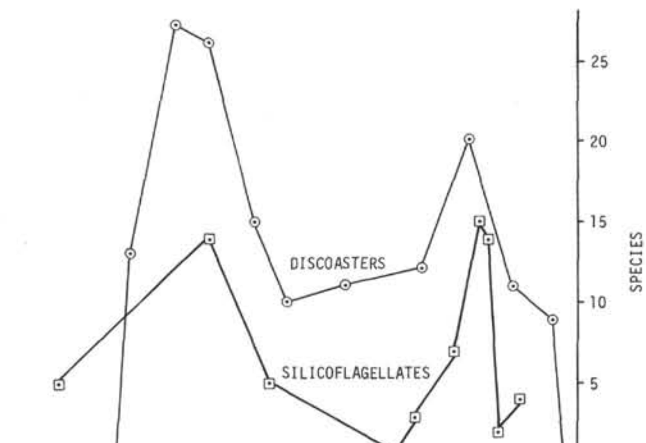

Figure 3. *Diversity of Silicoflagellate and Discoaster species from Late Cretaceous to Holocene. Silicoflagellate data from Ling (1972) shown as square and heavy lines. Discoaster data from Haq (1971) shown as circles and light lines.*

The boundary between the middle and upper Miocene lies in the uncored interval between the common occurrence of *Discoaster berggrenii* in Sample 241-11-4, 70-71 cm (260 m) and the cooccurrence of *Catinaster calyculus* and *Discoaster hamatus* in Sample 241-12-2, 90-91 cm (295 m).

Late Cretaceous (Campanian) coccolith assemblages of the *Tetralithus trifidus* Zone are common in claystone samples from Cores 22 and 25 (626-844 m). Sample 241-22-1, 100-101 cm (627 m) contains abundant *Tetralithus aculeus, T. gothicus, T. trifidus,* and *Watznaueria barnesae;* other species present include *Broinsonia parca, Cretarhabdus crenulatus, Micula decussata,* and *Prediscosphaera cretacea.* This is an assemblage of the Late Cretaceous species most resistant to alteration by solution or overgrowth. Sample 241-25-2, 95-96 cm (836 m) is less diverse, containing *B. parca, M. decussata, T. aculeus, T. trifidus,* and *W. barnesae* (predominant).

Site DSDP 242
(lat 15°50.65′S, long 41°49.23′E; depth 2275 m)

Site 242 is on the Davie Ridge in the Mozambique Channel between Africa and Madagascar. The site was intermittently cored to a depth of 676 meters in coccolith-rich sediment ranging in age from late Eocene to Holocene. Warm-water coccolith assemblages characterize the entire section.

The late Pleistocene *Gephyrocapsa oceanica* Zone of Sample 242-1-3, 40-41 cm (2 m) contains abundant *Gephyrocapsa oceanica* and rare reworked *Discoaster quinqueramus, D. surculus,* and *Sphenolithus neoabies* in an assemblage also composed of *Ceratolithus cristatus, Cyclococcolithina leptopora, Helicopontosphaera kamptneri, H. wallichii, Pontosphaera discopora, Rhabdosphaera clavigera,* and *Scyphosphaera* spp.

Reworking is also evident in the uppermost Pliocene *Cyclococcolithina macintyrei* Subzone where the older species *Cyclicargolithus floridanus, Discoaster hamatus, D. surculus,* and *Sphenolithus neoabies* occur in an assemblage dominated by *Discoaster brouweri.* Other species present in Sample 242-2-4, 60-61 cm (57 m) include *Ceratolithus rugosus, Coccolithus pelagicus, Cyclococcolithina leptopora, Discolithina japonica, Emiliania annula, E. ovata, Helicopontosphaera kamptneri, Rhabdosphaera stylifera,* and *Thoracosphaera saxea.*

A thick and well-characterized basal Pliocene sequence is indicated by coccoliths from Cores 3 to 4 (128-156 m). The overlapping ranges of *Ceratolithus acutus, C. primus,* and *C.* sp. cf. *C. rugosus* in Sample 242-3-6, 70-71 cm (136 m) indicate the *Ceratolithus rugosus* Subzone. In Samples 242-4-1, 70-71 cm (147 m) and 242-4-6, 70-71 cm (155 m), *C. acutus,* with equant and inequant horns, and *C. primus* occur indicating the *Ceratolithus acutus* Subzone. The uppermost Miocene *Triquetrorhabdulus rugosus* Subzone is identified in the top of Core 5 (233-241 m) by the cooccurrence of *C. primus* and *Triquetrorhabdulus rugosus,* in the absence of *Discoaster quinqueramus* and *C. acutus.* Other species characterizing Sample 242-5-1, 90-92 cm (233 m) include common to abundant *Discoaster surculus, D. variabilis, Scyphosphaera globulata,* and *Sphenolithus neoabies.* The next lower sample 242-5-4, 70-71 cm

(238 m) contains the *Discoaster berggrenii* Subzone suggesting a gap in the paleontologic sequence because the usually extensive *Ceratolithus primus* Subzone is missing. A break in the lithologic sequence is also indicated at the top of Section 4 where the sediment is reported to be much stiffer and semilithified in contrast to shallower sediment. A pyrite burrow cast was also noted near the top of Section 4.

An early assemblage of the *Discoaster berggrenii* Subzone is present in Sample 242-6-3, 70-71 cm (311 m); species include *Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster bellus, D. berggrenii, D. brouweri* s. ampl., *D. neohamatus, D. pansus, D. pentaradiatus, D.* sp. cf. *D. quinqueramus* (transitional from *D. bellus*), *D. variabilis, Discolithina multipora, Helicopontosphaera kamptneri* (especially abundant), *Minylitha convallis, Scyphosphaera pulchra, Sphenolithus neoabies,* and *Triquetrorhabdulus rugosus.*

Lower Miocene Sample 242-8-5, 70-71 cm (485 m) contains what appear to be coccosphere-like aggregations of the species *Triquetrorhabdulus carinatus.*

An excellent upper Eocene and lower Oligocene coccolith-rich sediment occurs in Cores 10 to 19 (602-676 m). Several shallow-marine species such as *Braarudosphaera rosa, Ceratolithina*? *vesca, Cyclococcolithina kingii, Helicopontosphaera reticulata, Isthmolithus recurvus, Peritrachelina joidesa,* and *Reticulofenestra reticulata* are present.

The relative abundances of *Chiasmolithus* and *Discoaster* in the upper Eocene of Cores 17 to 19 (668-676 m) suggest warm-water deposition. In general, cool-water Eocene assemblages from high-latitude localities have abundant specimens of *Chiasmolithus* but rare or no rosette *Discoaster.* Temperate assemblages have a balanced mixture, and warm-water assemblages have abundant specimens of rosette *Discoaster* but rare or no *Chiasmolithus.* Sample 242-18-1, 80-82 cm (673 m) demonstrates the abundance relation of a warm-water assemblage. A count of 500 *Discoaster* and *Chiasmolithus* specimens shows 435 rosette forms, *Discoaster barbadiensis* and *D. saipanensis;* 64 free-rayed forms, *D. deflandrei, D. nodifer,* and *D. tani;* and only one *Chiasmolithus titus.* Similarly, a middle Eocene assemblage in Sample 44-4-5, 145-150 cm (73 m) from Horizon Guyot in the Pacific (assumed to be a warm-water site at lat 7°N in the late Eocene; Lonsdale et al., 1972) contains 423 *D. barbadiensis* and *D. saipanensis;* 64 *D. nodifer* and *D.* sp. cf. *D. tani;* and 13 *Chiasmolithus grandis.* These examples contrast sharply with middle Eocene Sample 207A-14-2, 35-36 cm (171 m) from the Lord Howe Rise, presently at lat 37°S, which is considered to represent an Eocene cool-temperate locality. Abundances here are practically the reverse of the two warm-water sites, as a count of 500 specimens of *Chiasmolithus* and *Discoaster* shows 344 *Chiasmolithus expansus, C. grandis,* and *C. solitus;* 96 free-rayed forms, *Discoaster deflandrei, D. nodifer* and *D. strictus;* but only 60 rosette forms, *Discoaster barbadiensis* and *D. wemmelensis.* Because both *Chiasmolithus* and *Discoaster* are solution resistant, their relative abundances provide a convenient guide for the paleoenvironmental interpretation of Paleogene coccolith assemblages.

Site DSDP 243
(lat 22°54.49'S, long 41°23.99'E; depth 3879 m)

No samples available; see reports of shipboard scientists.

Site DSDP 244
(lat 22°55.87'S, long 41°25.98'E; depth 3768 m)

A single sample from Site 244 in the Zambesi Canyon of the Mozambique Channel, 244-1, CC (0-3 m) contains rare late Pleistocene coccoliths, *Coccolithus pelagicus, Cyclococcolithina leptopora, Gephyrocapsa* sp. cf. *G. lumina, G. oceanica,* and *Helicopontosphaera kamptneri.*

Site DSDP 245
(lat 31°32.02'S, long 52°18.11'E; depth 4857 m)

Site 245, located southeast of Madagascar, penetrated 397 meters of sediment ranging in age from early Paleocene to early Oligocene. Moderate to strong etching (−3 to −4.5) characterizes the middle Eocene to early Oligocene coccolith assemblages of Cores 3 (121-130 m) and 2A to 6A (54-109 m), whereas most of the early Paleocene to early Eocene assemblages of Cores 7A (140-149 m) and 4 to 16 (159-385 m) are overgrown (+2 or +3) and fragmented as a result of diagenesis. This preservation change corresponds to a distinct lithologic change from brown silty clay above to pale orange and pink coccolithic chalk below at approximately 123 meters subbottom in Hole 245. These two lithologies are interbedded through most of the cored interval (26-149 m) in Hole 245A, but Core 7A (140-149 m) is entirely within a chalk unit. The two lithologies can be distinguished paleontologically by the reduced abundance and greater etching and reworking evident in the brown silty clay. Basalt and diabase were cored in Cores 17 to 19 (389-397 m).

Reworked Eocene species such as *Chiasmolithus grandis, Discoaster barbadiensis,* and *D. lodoensis* in Sample 245A-2-5, 60-62 cm (61 m) make discrimination of Eocene from Oligocene assemblages difficult because the extinction of *D. barbadiensis* (or the similar species *D. saipanensis*) is the criterion used. *Isthmolithus recurvus,* a species most common in the latest Eocene and earliest Oligocene, is recorded from four samples: 245A-2-3, 70-72 cm (56 m); 245A-3-2, 80-82 cm (65 m); 245A-4-2, 50-52 cm (73 m); and 245A-4-3, 80-82 cm (75 m). Of these samples, only 245A-2-3 and 245A-4-2 contain *D. barbadiensis* (?reworked).

Middle Eocene Sample 245A-6-1, 90-92 cm (101 m) and deeper samples contain more definitive coccolith assemblages. Although the coccoliths of Core 6A (100-109 m) are all etched (−4), exhibiting incised and narrow placolith rims and centerless discoasters, the overlapping occurrences of *Chiasmolithus grandis, Discoaster bifax, Nannotetrina cristata,* and *Reticulofenestra umbilica* allow stratigraphic assignment to the *Discoaster bifax* Subzone.

All samples examined from Core 3 (121-130 m) contain common and diverse populations of *Nannotetrina. Discoaster sublodoensis* is common at the bottom in Sample 245-3-6, 130-132 cm (122 m); other species present include *Discoaster lodoensis, Reticulofenestra dictyoda, Tribrachiatus orthostylus,* and *Triquetrorhabdulus inversus.* The natural occurrence of *T. orthostylus* as high as the *N. quadrata* Zone also has been noted at several localities on the west coast of North America.

The lower Eocene of Cores 7A (140-149 m) and 4 to 8 (159-292 m) is characterized by diagnostic coccolith assemblages (Figure 4).

Paleocene assemblages of Cores 9 to 16 (311-385 m) are commonly dominated by one or two species. *Discoaster multiradiatus* is common in the *Chiasmolithus bidens* Subzone, but discoasters are sparse in the underlying *Discoaster nobilis* Zone where *Cyclolithella*? *robusta* and *Fasciculithus involutus* are especially common. *Discoaster mohleri* is rare in the lower part of the *Discoaster mohleri* Zone, but is common in the upper part. *Heliolithus kleinpellii* is unusually common in the interval from Sample 245-11-5, 70-72 cm (336 m) to Sample 245-10-3, 98-100 cm (324 m). Sample 245-11-3, 70-72 cm (333 m) is essentially a two-species ooze of giant *H. kleinpellii* and *F. involutus*.

Samples from the lower two zones of the Paleocene in Cores 12 to 16 (338-385 m) are distinctive mainly in the occurrence of *Chiasmolithus danicus* and *Markalius astroporus* in the lower part of the *Cruciplacolithus tenuis* Zone, Samples 245-15-3, 123-124 cm (372 m) and 245-16-1, 80-82 cm (377 m).

Site DSDP 246
(lat 33°37.21′S, long 45°09.60′E; depth 1030 m)

No samples available; see reports of shipboard scientists.

Site DSDP 247
(lat 33°37.53′S, long 45°00.68′E; depth 944 m)

No samples available; see reports of shipboard scientists.

Site DSDP 248
(lat 29°31.78′S, long 37°28.48′E; depth 4994 m)

Only one of four samples examined from Site 248 in the Mozambique Basin contains coccoliths. Sample 248-4-2, 75-76 cm (122 m) contains rare strongly etched specimens in preservation stage −4. Discoasters are centerless, and ray tips are etched. The species present, *Discoaster asymmetricus, D. braarudii, D. brouweri, D. neohamatus, D.* sp. aff. *D. tamalis, D. variabilis,* and *Reticulofenestra* sp., suggest a Pliocene age with reworked Miocene.

Site DSDP 249
(lat 29°56.99′S, long 36°04.62′E; depth 2088 m)

Site 249 east of Durban penetrated 412 meters of coccolith-rich sediment ranging in age from Early Cretaceous to early Pliocene.

Typical warm-water marker species are abundant in the nearly continuous upper Miocene to lower Miocene sediment of Cores 1 to 15 (0-159 m). Preservation is at overgrowth stage +2 and is generally good throughout. Although the relative species proportions vary, the *Discoaster neohamatus* Zone assemblages of Samples 249-12-5, 80-82 cm (110 m); 249-13-5, 80-82 cm (119 m); and 249-14-5, 68-70 cm (138 m) are characterized by the occurrences of *Discoaster bellus, D. braarudii, D. neohamatus, D. pentaradiatus, D. prepentaradiatus, D. variabilis, Minylitha convallis* (exceptionally abundant in 14-5), and *Triquetrorhabdulus rugosus.*

The upper part of the *Discoaster neohamatus* Zone is indicated in Samples 249-10-6, 80-82 cm (92 m) and 249-11-5, 80-81 cm (100 m) by the occurrence of *Discoaster loeblichii* in both samples and by the transitional form of some *Discoaster bellus* specimens in 10-6.

The first *Discoaster berggrenii* s. str. possessing the diagnostic large central stem occurs in Sample 249-10-4, 80-82 cm (89 m). *Discoaster neohamatus* specimens in this sample are the late variety having short and only slightly bent ray tips. Rare *Discoaster neorectus* occurs in Sample 249-10-3, 80-81 cm (88 m), but *D. berggrenii* s. str. is absent. *Discoaster berggrenii* is first common in Sample 249-10-1, 80-81 cm (85 m). This sample also contains the highest definite occurrence of *Minylitha convallis.*

Ceratolithus primus and *Discoaster berggrenii* or *D. quinqueramus* occur throughout the interval from Sample 249-8-5, 70-71 cm (71 m) to 249-3-5, 90-92 cm (23 m). The abundance of *Discoaster quinqueramus* diminishes progressively from common in Sample 249-4-6, 80-82 cm (35 m) to sparse in 249-3-5, 90-92 cm (23 m). *Discoaster berggrenii* is last recorded from Sample 249-5-5, 40-42 cm (42 m), a point nearly midway through the *Ceratolithus primus* Subzone.

The base of the Pliocene is suggested by the earliest occurrences of both *Ceratolithus acutus* and *C. rugosus* in Sample 249-2-1, 110-112 cm (8 m).

Cretaceous coccolith assemblages of Campanian and Maestrichtian age are present in the interval from Cores 17 to 24 (178-303 m). Coccoliths are abundant and only slightly to moderately etched through most of the interval in and above Sample 249-23-3, 80-81 cm (287 m). Both Samples 249-24-1, 106-108 cm (295 m) and 249-23-4, 135-136 cm (289 m) reflect a distinct lithologic contact between coccolith chalk above and silty claystone and tuffaceous siltstone below in Core 23. Although coccoliths are common in two samples from below the contact, only four species are identified, and *Watznaueria barnesae* predominates as expected. Other rare species include *Cretarhabdus crenulatus, Zygodiscus* sp. cf. *Z. lacunatus,* and *Zygodiscus* sp.

Three coccolith zones are identified in the chalk interval. The youngest Cretaceous samples available are from the Maestrichtian ?*Nephrolithus frequens* Zone of upper Core 17 in the interval from Sample 249-17-3, 100-102 cm (182 m) to 249-17-1, 80-81 cm (179 m). The presence of only a single specimen of late Maestrichtian *Nephrolithus frequens* in 17-3 leaves some measure of doubt in the zonal assignment of the interval. Other species present are compatible with a Maestrichtian age, but definitive populations of marker species such as *Lithraphidites quadratus, Tetralithus praemurus, Micula mura,* and *Nephrolithus frequens* are lacking. But even the single specimen provides evidence that the *Nephrolithus frequens* Zone is present at Site 249 either here or in Core 16 from which no samples were available to me.

The *Tetralithus trifidus* Zone of late Campanian and early Maestrichtian age is present through the interval from Sample 249-21-3, 60-61 cm (260 m) to 249-17-4, 130-131

Zone or Subzone	Sample	Depth (m)	Discoaster/ Chiasmolithus (%)	Chiasmolithus bidens	Heliolithus kleinpellii (reworked)	Tribrachiatus contortus	Campylosphaera eodela	Discoaster multiradiatus	D. nobilis	D. lenticularis	Ellipsolithus macellus	Discoaster diastypus	Zygrhablithus bijugatus s. ampl.	Chiasmolithus grandis	Tribrachiatus orthostylus	Discoaster mirus	Coccolithus magnicrassus	Discoaster barbadiensis	Coccolithus crassus	Discoasteroides kuepperi	Campylosphaera dela	Cyclococcolithina gammation	Discoaster lodoensis	D. cruciformis	Zygolithus dubius	Discoaster sublodoensis	Reticulofenestra dictyoda	Chiasmolithus solitus	Triquetrorhabdulus inversus	Chiphragmalithus calathus	Ellipsolithus lajollaensis
Discoasteroides kuepperi	245A-7-2, 100-101 cm	141	53/47											X		X	X	X			X	X	X		X	X	X	X	X	X	X
	245A-7-6, 90-92 cm	146	67/33											X			X	X	X	X	X	X	X	X		X		X	X		
	245-4-1, 93-94 cm	160	79/21											X	X	X	X	X	X	X	X		X	X		X		X		X	
	245-4-2, 60-62 cm	161	82/18											X		X	X	X	X	X	X		X	X		X	X	X		X	
	245-4-3, 120-121 cm	163	74/26											X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	
	245-4-6, 80-82 cm	167	70/30											X		X	X	X			X	X	X	X	X	X	X	X	X		
Discoaster lodoensis	245-5-1, 80-82 cm	208	82/18										X	X		X	X	X	X	X	X	X	X	X	X						
	245-6-2, 70-72 cm	246	76/24									?	X	X		X	X	X	X	X	X	X	X								
Discoaster diastypus	245-7-1, 110-112 cm	255	72/28							X	X	X	X	X	X	X	X	X													
	245-8-1, 65-67 cm	284	79/21				X	X	X	X	X	X	X	X	X	?															
	245-8-2, 70-72 cm	285	69/31	X	X	X	X	X	X	X	X	X	X	X																	

Figure 4. *Distribution and zonation of lower Eocene coccoliths at Site 245. A warm-temperate open-ocean deposit is suggested by the absence of* Braarudosphaera, Clathrolithus, Helicopontosphaera, Imperiaster, *and* Rhabdosphaera, *and by a moderate to high* Discoaster/Chiasmolithus *ratio, based on a count of 300* Discoaster, Discoasteroides, *and* Chiasmolithus *specimens for each sample.*

cm (184 m). Abundant, diverse, and only slightly etched coccolith assemblages characterize the interval. For example, Sample 249-20-5, 60-61 cm (244 m) includes *Amphizygus brooksii brooksii, Apertapetra gronosa, Arkhangelskiella cymbiformis, Broinsonia parca, Cretarhabdus decorus, Eiffellithus turriseiffeli, Kamptnerius magnificus, Micula decussata, Prediscosphaera cretacea, Tetralithus aculeus, T. trifidus, Watznaueria barnesae, Zygodiscus lacunatus, Z. meudini.* Sample 249-17-4, 130-131 cm (184 m) at the top of the zone contains *Arkhangelskiella cymbiformis, Biscutum testudinarium, Broinsonia parca, Cretarhabdus crenulatus, C. decorus, Cribrosphaera ehrenbergii, Eiffellithus turriseiffeli, Kamptnerius magnificus, Microrhabdulus decoratus, Micula decussata, Parhabdolithus angustus, Prediscosphaera cretacea, P. lata, P. spinosa, Tetralithus trifidus, Vagalapilla* sp., *Watznaueria barnesae, Zygodiscus bicrescenticus, Z. meudini, Z. spiralis.*

The Campanian *Eiffellithus augustus* Zone extends from Core 23 into Core 21 and is represented by a similar assemblage throughout. The highest assemblage in Sample 249-21-5, 60-61 cm (263 m) contains *Broinsonia parca, Cretarhabdus crenulatus, Eiffellithus augustus, E. turriseiffeli, Kamptnerius magnificus, Lucianorhabdus cayeuxi, Micula decussata, Prediscosphaera cretacea, Tetralithus pyramidus, Watznaueria barnesae, Zygodiscus bicrescenticus, Z. lacunatus, Z. meudini, Z. spiralis.*

Cretaceous coccoliths of probable early Aptian age are present in the interval of Cores 28 to 31 (332-398 m). Coccoliths are sparse to common in the silty claystone. Predominant species in the samples examined are *Micrantholithus obtusus, Vagalapilla matalosa,* and *Watznaueria barnesae.* The only previously known cooccurrence of *M. obtusus* and *V. matalosa* is in France in the early Aptian *Chiastozygus litterarius* Zone (Thierstein, 1971). *M. obtusus* is the older of the two species, having been recorded from the Hauterivian of Europe by Stradner (1964) and Reinhardt (1966) and from Berriasian to Aptian by Thierstein (1971). Although *M. obtusus* might be expected to occur in later stages, because as a pentalith-producing species it is more a facies fossil than *Watznaueria*, for example, this has not yet proved true. Manivit (1971), in a detailed stratigraphic study of the Aptian to Maestrichtian in France, does not record *M. obtusus.* The earliest known occurrences of *V. matalosa* are Aptian (Stover, 1966; Thierstein, 1971; Roth and Thierstein, 1972).

Although the absence of species is an insecure biostratigraphic criterion, several generally dominant, cosmopolitan, solution-resistant, Late Cretaceous taxa are missing. The absence of the genera *Cribrosphaera, Eiffellithus, Micula,* and *Prediscosphaera* in samples from Cores 28 to 31 suggests pre-Albian deposition. Post-Hauterivian deposition is suggested by the absence of *Cruciellipsis cuvillieri,* a conspicuous species in the early part of the Early Cretaceous (Bukry and Bramlette, 1969; Thierstein, 1971) that has recently been recognized as a marker species for the oceanic *Cruciellipsis cuvillieri* Zone (Roth, 1973).

Sample 249-31-2, 44-45 cm (390 m) contains the most common and diverse coccolith assemblage. *Watznaueria barnesae* is abundant, and *Micrantholithus obtusus* and *Vagalapilla matalosa* are common. Other species present include *Bidiscus* sp., *Cretarhabdus crenulatus, ?Cretaturbella rothii, Micrantholithus hoschulzii, Parhabdolithus asper, P. embergeri, Vagalapilla stradneri, Watznaueria ovata, Zygodiscus* spp. Shallower samples are sparser. For example, Sample 249-28-1, 77-78 cm (333 m) contains meager *Micrantholithus hoschulzii, M. obtusus,* and *Vagalapilla matalosa* and rare *Watznaueria barnesae* and *Zygodiscus* sp.

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