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14. QUATERNARY AND PALEOGENE CALCAREOUS NANNOFOSSILS, LEG 115[1]

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ABSTRACT

The occurrences of ten datum events for the Quaternary and top Pliocene nannofossils are identified at nine Leg 115 sites. A quantitative investigation of Paleogene nannofossils in 470 samples selected from 11 holes at 9 sites yielded 197 taxa, including one new species and 10 unidentified taxa that are likely to be new species. Regional differences in the timing of some biostratigraphically important events are recognized, and a set of datum events useful for biostratigraphy in the tropical Indian Ocean is presented.

Biogeographical differences are minor for Paleogene cores from the tropical sites (Sites 707–716); however, the Quaternary and late early Oligocene floras observed at the two subtropical sites (Sites 705 and 706) differ significantly from the corresponding floras of the tropical sites. Bathymetrically controlled dissolution is recognized by the reduction of species diversity in the Paleogene flora. Selective dissolution of nannofossils is also evidenced by the percentage reduction of three holococcolith taxa, *Lanternithus minutus, Zygrhablithus bijugatus*, and Holococcolith type A as well as by the increase of *Coccolithus pelagicus* and *Cribrocentrum reticulatum* in the deeper sites.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 115 drilled 22 holes at 12 sites in the tropical and subtropical Indian Ocean (Fig. 1). This was the first leg to recover advanced hydraulic piston core (APC) and extended core barrel (XCB) materials from the Indian Ocean. The main paleontological objectives of the leg were (1) to study the selective dissolution of calcareous fossils in a carbonate bathymetric transect, (2) to investigate detailed biostratigraphy in the tropical Indian Ocean, and (3) to study biogeographic differences between the tropical and subtropical water masses.

The sediments we initially expected to recover on Leg 115 were mainly Neogene and Quaternary sequences, and these objectives were aimed for late Cenozoic biota. The actual operation of Leg 115, however, retrieved Paleogene sediments at nine sites. At Sites 707, 709, and 711, the recovered cores contain unexpectedly long Paleogene records, and the oldest core at the first site goes back to the late early Paleocene. Moreover, the Carbonate Bathymetric Transect (CBT) sites (707 through 715), located east and southeast of the Seychelles Bank, all recovered Oligocene sediments. It is possible, therefore, to pursue these three objectives for the late Paleogene also.

The purposes of this investigation are to investigate quantitatively the Quaternary and Paleogene flora of calcareous nannofossils and to delineate the nature of selective preservation recorded as the percentage change in the flora among the CBT sites. Improving nannofossil biostratigraphy as well as biogeographical distribution of Paleogene flora were also attempted. The stratigraphy of selected Quaternary datum events and short comments about floral characteristics will be presented for the Quaternary nannofossils.

METHODS AND PROCEDURES

Approximately 1,000 smear slides of the unprocessed Quaternary samples were examined with a light microscope in cross-polarized light for occurrences of biostratigraphically important taxa. During this procedure, general characteristics of the Quaternary flora were also recorded.

Smear slides of more than 600 Paleogene samples were preliminarily examined for the state of preservation as well as the occurrence of reworked taxa. Heavily reworked samples and closely spaced samples with less desirable preservation were eliminated, and 470 samples were selected for quantitative investigation of calcareous nannofossils. Smear slides of these selected samples were quantitatively examined for the full assemblages of calcareous nannofossils under a light microscope. Because of limitations in optical resolution, very small nannofossils (<4 μm in maximum diameter) were excluded from the species identification and counting. These small forms that were excluded from the counting generally constitute less than 10% of the total flora, except in the lower Oligocene flora of Site 706, where their abundance reaches to the maximum level of 30%–40%.

Throughout this report, relative abundances of Paleogene taxa in the nannofossil flora are defined as follows:

Dominant: >50% of the total assemblage;
Abundant: 10%–50% of the total assemblage;
Common: 1%–10% of the total assemblage;
Few: 0.1%–1% of the total assemblage; and
Rare: <0.1% of the total assemblage.

The actual procedure of the investigation was as follows:

1. I prepared smear slides from unprocessed samples with the mounting medium "Entellan New." For samples that showed a tendency to coagulate during the drying process, a small amount of carbonate-free clays were added to assure even distribution of nannofossils on the cover glass.
2. The first 200 specimens encountered under a cross-polarized light microscope with 1250× magnification were identified and counted for each smear slide. Additional observations were conducted under a phase-contrast image as needed. Major species encountered more than twice during this process are expressed in percentages on the range charts. Specimens not identifiable to the 197 taxa listed in Appendix B were excluded from the range charts, but their occurrences were used for the calculation of species diversity.
3. Observations were continued until approximately 1,000 nannofossils were scanned. Additional taxa showing up during this procedure were generally recorded as "few." Taxa that were

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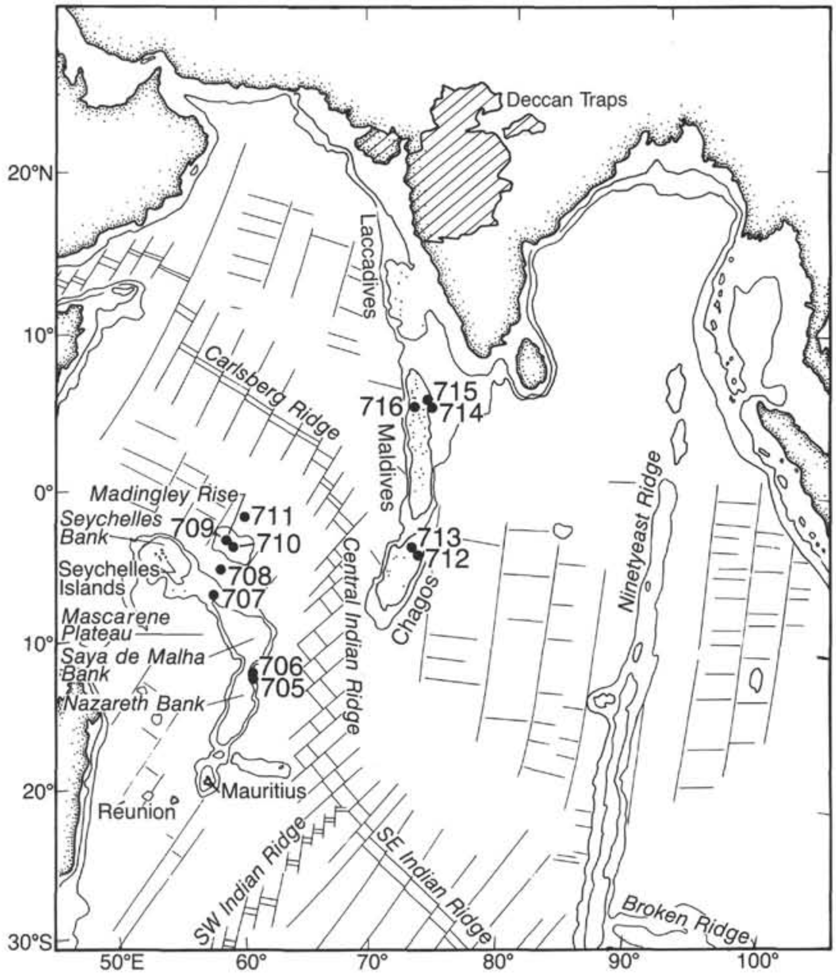

Figure 1. Location of Leg 115 sites.

encountered only once during the initial count of 200 specimens were also recorded into the "few" category. The general state of preservation and the severeness of etching and overgrowth on nannofossils were also recorded at this stage.

4. I continued scanning the slides until a reasonably large number of nannofossils were observed. Additional taxa encountered during this observation were generally recorded as "rare," but the ranking of "few" or "rare" categories may be altered by subsequent reexamination of the flora.

5. Reworked specimens were counted separately and categorized by the same procedure with the indigenous specimens. Abundances of the reworked taxa are expressed as categories in range charts. All of the reworked specimens are Paleogene forms, and no Mesozoic forms were observed throughout this investigation.

6. The species compositions measured during the first procedure were converted to a species diversity (Shannon-Wiener Function) and to the averaged composition of major species for each time interval to examine the geographic and bathymetric differences of the flora.

BIOSTRATIGRAPHY AND FLORA OF QUATERNARY NANNOFOSSILS

Biostratigraphy of Quaternary Nannofossils

Recent biometric studies of nannofossils provided revisions and subdivisions for the standard Quaternary zonation of Gartner (1977), and many new biostratigraphic datum events were presented (Pujos, 1985a, 1985b; Takayama and Sato, 1987; Matsuoka and Okada, 1989; Rio et al., in press). Although proposed biostratigraphic events are numerous in some reports and differ from each other, some events are commonly cited in these recent reports. Ten biostratigraphic datum events were selected from these recent compilations and the stratigraphic occurrences were determined for all Leg 115 sites except for Sites 712 and 713, where no significant Quaternary sequences were recovered (Table 1).

Characteristics of Quaternary Flora

Complete Quaternary sequences were recovered by APC coring at seven sites. A detailed investigation for the floral change is currently underway, and only general characters of the flora at selected holes are briefly described here.

Site 705

Although the Quaternary sequence was cored with the APC, the upper parts of Cores 115-705A-1H and -2H are disturbed, and prospects for a high-resolution study of the flora are limited. Nannofossils, however, are well preserved and highly diversified in the upper part of the Quaternary sequence, and the flora is significantly different from the corresponding flora of Leg 115 tropical sites. Many delicately constructed species, such as *Syracosphaera* spp., *Umbellosphaera* spp., and *Neosphaera coccolithomorpha*, are present. Since this is the southernmost

Table 1. The latest Pliocene and Quaternary datum events observed at each site. The estimated age is adopted from Matsuoka and Okada (1989) for the upper five events and from Rio et al. (in press) for the lower four Quaternary events.

Datum events (estimated age)	705A	707A	708A	709A	710B	711A	714A	715A	716B
FO *Emiliania huxleyi*	1H-1, 130	1H-1, 90	1H-3, 42	1H-2, 140	1H-2, 80	1H-2, 60	2H-4, 110	2R-6, 44	2H-4, 5
(0.27 Ma)	1H-2, 130	1H-1, 130	1H-3, 120	1H-3, 42	1H-2, 110	1H-2, 80	2H-5, 40	2R-CC	2H-4, 75
LO *Pseudoemiliania lacunosa*	1H-2, 130	1H-2, 30	1H-4, 110	1H-4, 42	1H-4, 60	1H-3, 90	3H-4, 70	5R-2, 119	2H-CC
(0.46 Ma)	1H-3, 130	1H-2, 50	1H-6, 90	1H-4, 90	1H-4, 90	1H-3, 100	3H-4, 150	5R-3, 44	3H-1, 75
LO *Reticulofenestra* sp. A (L)		1H-3, 50	2H-5, 42	1H-7, 90	2H-2, 70	1H-5, 100	5H-CC		4H-1, 75
(0.81 Ma)		1H-3, 60	2H-5, 130	1H-CC	2H-2, 100	1H-5, 110			4H-1, 145
Rejuvenation of *G. oceanica*	1H-3, 130	1H-3, 130	2H-6, 42	2H-1, 42	2H-2, 130	1H-6, 30		5R-CC	
(0.92 Ma)	1H-4, 130	1H-4, 10	2H-6, 120	2H-1, 90	2H-2, 150	1H-6, 40			
LO Large *Gephyrocapsa oceanica*	1H-4, 130	1H-4, 120	2H-CC	2H-2, 140	2H-3, 150	1H-CC			4H-CC
(1.10 Ma)	1H-5, 130	1H-4, 130	3H-5, 10	2H-3, 42	2H-4, 30	2H-1, 40			5H-2, 15
LO *Helicosphaera sellii*	1H-CC	2H-1, 25	3H-CC	2H-5, 42	2H-5, 40	1H-CC			
(1.20 Ma)	2H-1, 130	2H-1, 45	4H-2, 110	2H-5, 90	2H-5, 70	2H-1, 40			
FO Large *Gephyrocapsa oceanica*	1H-CC								5H-CC
(1.29–1.36 Ma)	2H-1, 130								6H-1, 75
LO *Calcidiscus macintyrei*	1H-CC	2H-3, 5	4H-2, 110	2H-6, 42	2H-6, 10				6H-6, 75
(1.45–1.46 Ma)	2H-1, 130	2H-3, 25	4H-3, 80	2H-6, 90	2H-6, 40				6H-7, 75
FO *Gephyrocapsa oceanica*	2H-1, 130	2H-3, 95	4H-3, 117	2H-CC	2H-6, 120	2H-1, 40			
(1.55–1.62 Ma)	2H-2, 130	2H-3, 105	4H-3, 140	3H-1, 1	2H-6, 140	2H-2, 40			
FO *Gephyrocapsa caribbeanica*	2H-1, 130	2H-3, 125	4H-3, 140	2H-CC	2H-6, 120	2H-1, 40			7H-CC
	2H-2, 130	2H-3, 145	4H-4, 10	3H-1, 1	2H-6, 140	2H-2, 40			8H-CC

site for Leg 115, the recovered flora is important for the biogeographical study of the late Quaternary in the Indian Ocean.

Site 707

The Quaternary sequence is almost pure foraminifer sand, and calcareous nannofossils occur only as a minor constituent of the lithology. Although the preparation of smear slides is fairly easy when samples are wet, this task becomes more difficult once the samples have dried. Nannofossils are generally well preserved, but overgrowth is evident for some species in the lower sequence. The diversity of the flora is significantly lower than was observed at Site 705. Reworking is consistent and moderately heavy in certain intervals, making detection of some biostratigraphic events difficult. Although winnowing probably affected the flora, very small forms of nannofossils are commonly found. This site, located in 1552 m water depths, is the shallowest among the CBT sites, and this shallow end-member flora should provide important data to compare with the dissolved flora observed at deeper sites.

Site 708

Nannofossils suffered slight to moderate dissolution at Site 708. Although turbidites occur repeatedly, the sediment between turbidites is fairly free of reworked fossils. This is the next deepest site (4109 m) among the CBT sites. Because the Quaternary floras recovered from the deepest site (711; 4430 m) are heavily contaminated by reworked specimens, the recovered floras from this site provided valuable information regarding the bathymetric changes in preservation of the flora. Because of the advanced dissolution, the floras are low in diversity and are generally dominated by *Florisphaera profunda.*

Site 709

Nannofossils are generally well preserved in the upper sequence except during some short intervals where weak dissolution is evident. Dissolution is more pronounced in the lower sequence. Reworking is minimal throughout the entire sequence, and the flora recovered here is ideal for biostratigraphic studies. A quantitative time-progressive trend for the morphometry of the genus *Gephyrocapsa* observed at Hole 709C is presented elsewhere (Matsuoka and Okada, this volume).

Site 710

Holocene and top Pleistocene materials were not recovered at Hole 710A. The upper two cores of Hole 710B recovered a complete sequence of Quaternary sediments. Core 115-710B-3H accidentally recovered a repeated sequence of Pleistocene and should be disregarded for biostratigraphy. Nannofossils are moderately preserved throughout the sequence with slight to moderate dissolution. No reworking is observed in the upper sequence, but slight reworking is evident in portions of the lower sequence.

Site 711

The preservation of nannofossils varies from wholly dissolved to moderate at Site 711, the deepest of the CBT sites. Several layers of turbidites that are full of Neogene discoasters were recognized, and reworked nannofossils frequently occur in the nonturbidite intervals. Because of the common reworking as well as the advanced dissolution, this sequence is not ideal for biostratigraphy; it will give good returns, however, for the study of bathymetry-controlled dissolution effects. Although the base of the Pleistocene is not clear for Hole 711A, it is located between Samples 115-711B-2H-5, 30 cm, and 115-711B-2H-5, 100 cm, at Hole 711B. The presence of a turbidite between these samples obscures the precise location of the boundary.

Site 716

Coring at Site 716 was aimed to recover a complete late Neogene and Quaternary sequence of aragonite-bearing periplatform ooze, and an approximately 60-m-thick Quaternary sequence was recovered. Because this site is very shallow (554 m), no dissolution was detected on nannofossils, but severe overgrowth hinders a detailed biostratigraphy in the lower Quaternary sequence. Preservation is excellent to good for the upper two cores of Hole 716B. Although the species diversity is not particularly high, the upper Quaternary flora differs from that of other Leg 115 sites. *Umbilicosphaera sibogae, Syracosphaera* spp., and small *Gephyrocapsa* are noticeably abundant members of the flora. Reflecting the shallow water depth, *Florisphaera profunda* is less abundant than at the other Leg 115 sites. Okada (1983) demonstrated its potential as an indicator of paleodepth, and a quantitative investigation of *F. profunda* at this site may provide important data for the Quaternary sea-level change.

PALEOGENE ZONATION

The biostratigraphic zonations proposed by Martini (1971) and Bukry (1973, 1975) are the current standards for Cenozoic calcareous nannofossils. Bukry's zonation, which was slightly modified to employ code numbers (Okada and Bukry, 1980), is more suitable for the biostratigraphy of tropical pelagic assemblages, and it was used throughout this investigation. Bukry's original zonation employs double criteria for some boundaries to ensure wider applicability. Some of these double criteria, however, occur at widely separated levels in this investigation, and the assignment of Leg 115 cores to zones and subzones is based upon the primary (first cited) criteria Bukry (1975) proposed (Table 2).

The first occurrence (FO) of *Sphenolithus distentus* marks the base of the upper lower Oligocene Zone CP18. Throughout this investigation, however, a form similar to *S. distentus* was commonly observed in the lower lower Oligocene sequences. This form, which was initially identified as *S. distentus*, is now regarded as distinct and is tentatively designated as *Sphenolithus* aff. *distentus* in this report. Zonal assignments for Zones CP18 and CP17 presented in this report, therefore, differ from the results shown in Volume 115 of *Proceedings of the Ocean Drilling Program, Initial Reports. Reticulofenestra umbilica*, the last occurrence (LO) of which defines the base of Zone CP17, occurs inconsistently in Leg 115 cores, and this boundary is not identifiable at Sites 706 and 707. The unreliability of this event was already demonstrated in the south Atlantic Ocean (Backman, 1987). The end of the acme of *Ericsonia subdisticha*, which defines the base of Subzone CP16b, is not identifiable in Leg 115 cores, and Subzones CP16a and CP16b are not differentiated throughout this report.

PALEOGENE NANNOFOSSIL RESULTS AT EACH SITE

Site 706

This site is located on the Nazareth Bank, Mascarene Plateau at a water depth of 2504 m (Table 3). Three holes were drilled and lower Oligocene sediments were recovered directly below a 3.8-m-thick upper Quaternary calcareous sand. Slight to moderately overgrown nannofossils are abundant throughout the recovered sequence. Hole 706C was washed down to basement, and small pieces of baked-in sediment were retrieved between basalt layers in Core 115-706C-9R. Heavily overgrown nannofossils were common in this sediment.

The LO of *Ericsonia formosa* observed in Sample 115-706A-5H-5, 130–131 cm, marks the top of Subzone CP16b; and, because of the absences of *Discoaster barbadiensis* and *Discoaster saipanensis*, the lowest sequence recovered at Hole 706A was assigned to the lower lower Oligocene (CP16a–CP16b). *Sphenolithus distentus* is also absent in this Oligocene sequence and the interval between Samples 115-706A-2H-2, 13–14 cm, and 115-706A-5H-4, 130–131 cm, is assignable to either Subzone CP16c or Zone CP17. The occurrence of *Reticulofenestra umbilica* is sporadic in the Oligocene cores of Leg 115, and its LO (base of CP17) was found to be an unreliable marker. The absence of *R. umbilica* at this site, therefore, was excluded from the age assignment. *Sphenolithus* aff. *distentus* is a consistent member throughout the recovered Oligocene sequence.

The Oligocene flora at this site is also highly diversified. *Quinquerhabdus colossicus*, which is absent in other Leg 115 sites, occurs commonly or even abundantly in Sample 115-706A-5H-4, 130–131 cm. Many species of *Helicosphaera* and *Pontosphaera* also characterize the flora. Holococcoliths, such as *Lanternithus minutus, Zygrhablithus bijugatus*, and Holococcolith type A in addition to *Cruciplacolithus tarquinius* and *Syracosphaera* sp. 1, are much more common than at the other Leg 115 sites. Moreover, many unidentified taxa also are present; no doubt some of them have never been described. Because they are not common members of the flora or are very small, a detailed taxonomic study was not attempted for this report.

The uniqueness of the flora at this site clearly reflects differences in water-mass influence between this site and the more northern sites of Leg 115. The abundance of *Braarudosphaera bigelowii, Micrantholithus* spp., and *Q. colossicus* probably indicates the closeness to land and the rather shallow water depth.

Site 707

This site is located between the Seychelles and Saya de Malha banks on the Mascarene Plateau. The Paleogene flora retrieved from the three holes of this site ranges from the latest Oligocene to possibly late early Paleocene in age (Table 2). The floral record is continuous down to the middle Eocene, but a hiatus separates between the late early and early middle Eocene. Below this hiatus the record is apparently continuous down to the upper upper Paleocene. The poor recovery, however, prevents a detailed biostratigraphy for this lower Paleogene sequence.

Oligocene

Moderately overgrown nannofossils occur abundantly throughout the Oligocene sequence (Tables 4 and 5). A slight reworking is observed in the upper Oligocene but is unrecognizable in the lower Oligocene. Rare *Sphenolithus* aff. *distentus* coexists with *Sphenolithus distentus* at the basal part of the latter's stratigraphic range, and the FO of the former morphotype precedes the LO of *Ericsonia formosa*. Although the latter observation is consistent at all sites of Leg 115, the former observation contradicts the trend observed in other sites. These two sphenolith taxa usually occur in different stratigraphic intervals. Their co-occurrence observed here, therefore, is probably a result of reworking. Another sphenolith taxon, tentatively named *Sphenolithus* aff. *ciperoensis*, co-occurs with the type species in the upper Oligocene cores. These two taxa are probably related, and the former may be an end member of the morphologically diverse *S. ciperoensis*.

A previously undescribed form occurs only in Sample 115-707A-16H-3, 65–66 cm, and this taxon is described as *Crassidiscus backmanii* in this report. The consistent occurrence of this new species within the short stratigraphic interval in the upper Oligocene was confirmed throughout this investigation as well as at DSDP Site 445 in the Philippine Sea (see remarks in Appendix A). This new species, *C. backmanii*, can be a useful biostratigraphic marker, therefore, for the upper Oligocene of the tropical and subtropical oceans. *Ericsonia obruta* was observed to disappear during the early Oligocene in the South Atlantic (Backman, 1987). This species, however, is a persistent member of the late Oligocene flora at Leg 115 sites as well as at the DSDP Site 445 (H. Okada, unpubl. data). The sharp increase of *E. obruta* at the basal Oligocene observed in the Atlantic Ocean (Backman, 1987) and at Italian land sections (e.g., Coccioni et al., 1988) is also not recognized at the Leg 115 sites. The geographic and biostratigraphic distribution of the first abundant occurrence as well as the LO of this species, therefore, needs further investigation for global applicability.

Ericsonia subdisticha cannot be used as a key species for the lower Oligocene cores of Leg 115. *Bramletteius serraculoides* is a consistent member of the lower Oligocene flora, and its disappearance within Subzone CP16c or Zone CP17 is a distinctive event. The LOs of *Hayella situliformis* or *Chiasmolithus titus* can be used as biostratigraphic markers between the LOs of *Discoaster saipanensis* (base, CP16a) and *Ericsonia formosa* (base,

Table 2. Geologic age and zonal assignment of Leg 115 Paleogene cores based on calcareous nannofossils.

Age	Zone	706A	706C	707A	707C	708A	709C	710A	711A	712A	713A	714A
Oligocene	CP19b			16H-1/16H-6		20X-2/21X-CC	22X-2/23X-4	16X-1/17X-6	9H-6/11H-4			22X-4/23X-6
	CP19a			16H-7/18H-CC		22X-1/23X-CC	23X-5/25X-CC	17X-CC/20X-2	11H-5/13X-4	10R-CC/11R-1		23X-CC/25X-CC
	CP18			20X-1/20X-2		24X-3/25X-CC	26X-1/26X-5	20X-3/21X-1	13X-5/14X-2			
	CP17	2H-2/5H-4		20X-3/21X-5			26X-6/29X-2	21X-2/22X-CC	14X-3/15X-4			
	CP16c						29X-3/29X-6		15X-5/16X-4			
	CP16ab	5H-5/6H-3	9R-1	21X-6/22X-6	3R-1/3R-6		29X-CC/30X-5		16X-6/17X-3			
Eocene	CP15b			22X-7/23X-6	3R-CC		30X-6/31X-4		17X-4/18X-1			
	CP15a			23X-CC	5R-1/6R-CC		31X-5/33X-3		18X-2/19X-3			
	CP14b				7R-1/9R-CC		33X-6/35X-2		19X-4/21X-4	12R-1/12R-CC	5R-1/7R-2	
	CP14a				10R-1/10R-2		35X-3		21X-5		7R-3/8R-3	
	CP13c				10R-3/11R-CC		35X-4/37X-4		21X-CC/23X-6		8R-4/17R-1	
	CP13b				12R-1/12R-CC		37X-5/37X-CC		23X-CC/25X-1		17R-2/21R-2	
	CP13a								25X-2/25X-CC			
	CP12ab								26X-CC			
	CP11				13R-1/13R-CC							
	CP10				14R-1/14R-CC							
	CP9b				15R-1							
	CP9a				15R-2/15R-CC							
Paleocene	CP8b				16R-2/16R-CC							
	CP8a											
	CP7				17R-CC							
	CP6-5											
	CP4-3				19R-CC/21R-CC							

Table 3. Percentage occurrences of calcareous nannofossils observed in the Oligocene samples from Holes 706A and 706C.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Blackites spinosus*	*Braarudosphaera bigelowii*	*Bramletteius serraculoides*	*Calcidiscus kingii*	*Coccolithus eopelagicus*	*Coccolithus fuscus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coccolithus* sp. 1	*Coronocyclus nitescens*	*Cruciplacolithus tarquinius*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster adamanteus*	*Discoaster deflandrei*	*Discoaster tanii*	*Ericsonia formosa*	*Ericsonia obruta*	*Helicosphaera bramlettei*
CP16c–CP17	4.13	2H-2, 13–14	A	M		O-2			3		R	F		R	6	F	1	3	46	3	2		1	R		2	R
	5.30	2H-2, 130–131	A	M		O-1			1			F		R	10	R	F	3	50	1	F		F	R		2	R
	6.80	2H-3, 130–131	A	M		O-2			2			F			7	R	F	5	40	2	F		F	R		1	F
	8.30	2H-4, 130–131	A	M		O-1			2			R		R	6	R	1	2	45	2	1		1	R		3	F
	9.80	2H-5, 130–131	A	M		O-1			2		R	F			7	F	F	3	39	1	1		1	R		1	F
	10.53	2H-CC	A	M		O-2			F			F			10	R	F	4	42	F	F		1	F		1	F
	13.50	3H-1, 130–131	A	M		O-1			F			R			8	R	F	2	47	4	F		1	R		1	F
	15.00	3H-2, 130–131	A	G					F	R		F			9	R	F	5	46	1	R		F	R		F	R
	16.50	3H-3, 130–131	A	G					F	R		R			7	R	F	2	54	2	1	R	1	R		F	F
	18.00	3H-4, 130–131	A	M		O-1		R	1	F		R	R		7	R	1	4	42	F	F		F	R		F	F
	19.50	3H-5, 130–131	A	M		O-1		F	2	F		R	R	R	4	R	2	3	36	1	R		F			1	F
	20.68	3H-CC	A	M		O-2		F	F	F		R			5	1	1	2	37	1			1			1	F
	23.20	4H-1, 130–131	A	M		O-2		F	1	F		R	R		10	1	F	2	24	F			1			1	R
	24.70	4H-2, 130–131	A	M		O-2		F	F	F		R	F		9	1	F	3	27	3			1			2	F
	26.20	4H-3, 130–131	A	M		O-2		R	F	1		R			8	R	F	1	37	1			1	R		1	F
	27.70	4H-4, 130–131	A	M		O-2		R	F	F		R			9	R	1	2	28	1			F			1	F
	29.32	4H-CC	A	M		O-2		R	1	F		R			7	F	F	1	31	1			2	R		F	F
	32.80	5H-1, 130–131	A	M		O-2			F	1		R			11	F	F	1	30	F			F	R		F	F
	34.30	5H-2, 130–131	A	M		O-2			1	1		F	R		11	1	R	1	29	2			F	F		F	F
	35.80	5H-3, 130–131	A	M		O-2			1	2	R	R			6	F	R	1	28	1			F	F		1	F
	37.30	5H-4, 130–131	A	M		O-2		R	F	2	R	R			10	F	F	F	30	F	F		F	F		F	F
CP16ab	38.80	5H-5, 130–131	A	M		O-2		R	F	1	R	F			8	F	F	F	25	1	F		F	R	F	F	1
	40.30	5H-6, 130–131	A	M		O-2		R	F	2		F			11	F	F	F	34	F	F		F	R	F	1	F
	40.88	5H-CC	A	M		O-2			F	F	F	R			7	F	F	1	32	1	1		F	R	R	F	F
	42.38	6H-1, 128–129	A	M		O-2			F	1	F	F			6	F	1	F	41	5	3	R	F	F	R	F	F
	44.21	6H-3, 11–12	A	M		O-2		R	1	1	F	F			3	F	F	F	45	1	2		1	1	1	F	F
	112.73	9R-1, 73	C	P		O-3			1	F		1			6				65	4	6				1		

Note: Specimens not identifiable to known species are excluded. Distribution chart: Numbers = calculated percentage in the indigenous flora, figures below the decimals are omitted; F = few (>0.1% and <1% of indigenous forms); R = rare (<0.1% of indigenous forms); c = common reworked occurrence (>1% and <10% of the total flora), f = few reworked occurrence (>0.1% and <1% of the total flora); r = rare reworked occurrence (<0.1% of the total flora). Abundance: A = abundant, C = common, and F = few. Preservation: G = good, M = moderate, and P = poor. Etching: E-3 = heavy dissolution, E-2 = moderate dissolution, and E-1 = weak dissolution. Overgrowth: O-3 = heavy overgrowth, O-2 = moderate overgrowth, and O-1 = weak overgrowth. Reworking: 3 = heavy, 2 = moderate, and 1 = slight.

CP16c). *Reticulofenestra umbilica* is scarce in the lower Oligocene sequence, and its LO coincides with that of *E. formosa. Lanternithus minutus* is common to abundant in Zone CP17 and Subzone CP16c, and its disappearance at the upper part of this interval is similar to the data presented in Martini (1971). The abrupt increase of *L. minutus* observed in Core 115-707A-21X is a clear sign of the paleoenvironmental change that occurred during the early early Oligocene at this site.

Upper and Middle Eocene

Core recovery was good for the lowest Oligocene and top Eocene sediments at Hole 707A, but it was poor for the top Eocene at Hole 707C (Tables 4 and 5). Observations of downcore trends, therefore, can be continuous by combining the data from Holes 707A and 707C at the base of Subzone CP15b. Preservation of nannofossils is similar to the Oligocene sequence and reworking is minimal. *Isthmolithus recurvus*, the key species of Subzone CP15b, was considered to be absent at tropical regions (Bukry, 1975). Rare specimens of this species, however, are observed at three tropical sites of Leg 115. Since they are rare and occur sporadically, the FO of *Isthmolithus recurvus* located at Section 115-707A-23X-6 may not be a reliable datum. The downward sequential disappearances of *Discoaster saipanensis, Discoaster barbadiensis*, and *Cribrocentrum reticulatum* are distinct.

The two criteria for the base of Zone CP14b, the LOs of *Chiasmolithus solitus* and *Discoaster bifax*, are not synchronous, but they do occur in the samples next to each other. The interval assignable to Zone CP14a is unexpectedly thin if the primary criterion for the base, the FO of *Reticulofenestra umbilica* (defined as larger than 14 μm), is adopted. However, it becomes much thicker when the secondary criterion, the FO of *Discoaster bifax*, is used.

Lower Eocene and Paleocene

Core 115-707C-12R is assignable to the middle middle Eocene Subzone CP13b, and Core 115-707C-13R yields abundant nannofossils of upper lower Eocene Zone CP11 (Table 6). A hiatus representing at least 4 m.y. of late early and early middle Eocene exists at this site. Although rotary drilling caused poor recovery, all the zones and subzones of the middle lower Eocene through the top of the Paleocene are recognized.

The Paleocene/Eocene boundary was approximated at the CP8b/CP9a and at the NP9/NP1O boundary, and was estimated at 57.8 Ma (Berggren et al., 1985). This epoch boundary is now given a younger age (57.0 Ma) and is identified at slightly below the CP8b/CP9a boundary (56.8 Ma) (Aubry et al., 1988). The primary criterion of the CP8b/CP9a boundary, the FO of *Discoaster diastypus*, was recognized in Sample 115-707C-15R-CC, and the secondary criterion of the boundary, the FO of *Tribrachiatus contortus*, occurs at the next higher sample. The base of NP1O, the FO of *Tribrachiatus bramlettei*, was recognized in two samples below the base of CP9a. This observation is concordant with the new time scale of Aubry et al. (1988), but the poor recovery of cores at Hole 707C prevents precise age calibrations for these two boundaries.

As usual for the warm-water flora of this period, many short-ranged species belonging to the genera *Discoaster, Fasciculithus, Rhomboaster, Tribrachiatus*, and *Zygodiscus* occur, resulting in a high species diversity. Cores 115-707C-19R through -21R yield moderately preserved floras dominated by *Prinsius martinii* and small forms of *Prinsius bisulcus*. Because of the consistent presence of *Cruciplacolithus subrotundus*, this flora is tentatively identified with Zone CP3 or CP4 of the upper lower to lower upper Paleocene.

Table 3 (continued).

Helicosphaera compacta	*Helicosphaera euphratis*	*Helicosphaera intermedia*	*Helicosphaera obliqua*	*Helicosphaera perch-nielseniae*	*Helicosphaera reticulata*	*Helicosphaera wilcoxonii*	*Ilselithina fusa*	*Lanternithus minutus*	*Markalius* sp. 1	*Micrantholithus altus*	*Micrantholithus flos*	*Micrantholithus procerus*	*Pedinocyclus larvaris*	*Peritrachelina joidesa*	*Pontosphaera formosa*	*Pontosphaera latoculata*	*Pontosphaera ocellata*	*Pontosphaera plana*	*Pontosphaera punctosa*	*Pontosphaera rimosa*	*Pontosphaera versa*	*Quinquerhabdus colossicus*	*Rhabdosphaera procera*	*Sphenolithus* aff. *distentus*	*Sphenolithus moriformis*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Syracosphaera* sp. 1	*Transversopontis rectipons*	*Umbilicosphaera* sp. 1	*Zygrhablithus bijugatus*	Holococcolith type A
1	F	F	R	1	F		F	2			1		F	R				R			R	2	R	F	4	6		2		3	3	1
2	F	F	F	1	1		F	1			F	R	F	R			R	R		R	F	1	R	F	4	9		2		2	2	F
3	1	F	F	1	F		F	2			F	R	1	R				R			F	7	R	F	4	5		1		7	4	1
2	1	F	F	F	F		R	7			F	R	1	R		R			R		R	3	R	F	3	8		2		2	F	F
4	1	F	F	F	1		R	10			F		F	F							R	5		F	4	6		1		2	1	F
3	F	F	F	F	F		F	10			F		F	R							R	4	R	R	4	6		2		2	1	F
1	F	R	1	F	F		F	5			R		1	R			F				R	3		F	6	8		1		4	1	F
1	1	1	R	F	F		R	3			R		F	R							F	1	R	F	5	8		2		10	1	F
2	F	F	F	F	F	R	F	6				R	F	F		R		R	1		F	1	R	R	3	4		1		3	3	F
1	F	F	R	F	F		F	11			R		1	R				R	R		F	2	R	R	2	4		F	R	12	5	F
2	F	F		1	F		R	10		R			F	R	R	R	R	R	F		F	3	R	R	5	10		1		10	2	F
2	F	F		F	F		F	18					F	R		R		R	F	R	F	4	1	R	2	4		F	R	9	3	2
3	1	F		1	1		F	15			R		F	R	R	R		R	F		F	1	F	F	4	7		1		5	5	6
1	F	F		F	1		F	10			R		1	F				R	1		F	3	R	1	1	10		1		7	2	5
2	F	R		F	2		1	11					1	F				F	F		F	2		1	5	7		F		4	1	6
3	1	R		F	1	R	F	15		R	R		1	R		R		R	1		R	4	R	1	5	7		1		7	2	4
2	F			R	1		F	21			F	R	1	R	R	F			F	R	R	2		F	7	5		1		2	F	7
4	F			R	3		R	14		R	R		1	R					F		F	1		F	3	15	R	F		F	E	8
2	1	R			2	R		16			F		F	F	R	R			F	R	F	7		1	2	6	R	1		2	E	7
2	F				1		R	31		R	1		F	R	R				F		F	4		2	3	4	R	1		F	F	5
2	F	R			1		R	18	R	R	F		F	F		R			F		1	10		4	3	3	R	1	R	F	F	8
2	1				3		F	33			R	R	F	R					R		F	F		2	2	9	F	F		F	F	3
1	1				F		F	27			R	R	F	R	R				R		R	1		5	2	4	F	F	R	1	F	2
F	3				2			24	F	R	R		1	R	R				F		F	1		2	3	6	R	1	R	4	F	4
F	F	R			2			12	1		R	R	F	R	R				1		R	1		3	2	8	F	1	R	2	F	3
1	1	F			2			16	1	R	R	R	F	R					R		R	F		2	5	4	R	1	F	F	F	3
F	2				2																				3	1					1	

Site 708

This site is located on an abyssal plain at a water depth of 4097 m. Approximately 54 m of the Oligocene sequence yielded abundant nannofossils, which are moderately well preserved except at the basal part where advanced etching is evident (Table 7). Repeated turbidites contain frequent reworked specimens, but nonturbidite intervals are fairly free of reworking. *Crassidiscus backmanii* occurs again within Subzone CP19b at this site. Although it occurs in the lowest sample of the subzone, Sample 115-708A-21X-CC, the true base of the subzone, is likely to be located well below this sample within an unrecovered interval.

Ericsonia obruta is a common member of the flora through the upper Oligocene. *Sphenolithus ciperoensis* and *Sphenolithus* aff. *ciperoensis* again co-occur in the upper Oligocene sequence. Unlike at Hole 707A, however, the latter appears earlier than the former, and it is a common member of the flora in the upper part of Zone CP18. Compared with the flora at Site 707, the Oligocene floras at Site 708 are significantly lower in diversity.

Site 709

This site is located in a small basin near the summit of the Madingley Rise at a water depth of 3038 m. A continuous Paleogene sedimentary sequence was recovered down to the middle middle Eocene in Hole 709C. Although upper Oligocene sediment was also cored at Hole 709B, Paleogene nannofossils were studied only for Hole 709C materials.

Oligocene

Moderately well-preserved nannofossils are abundant in the entire Oligocene sequence and reworking is minimal, except in Core 115-709C-23X where weak but continuous reworking was detected (Table 8). All zones and subzones of the Oligocene are identifiable except the CP16a/CP16b boundary. The very short but distinctive occurrence of *Crassidiscus backmanii* in the lower part of Subzone CP19b, as well as the continuous common occurrence of *Ericsonia obruta* beyond the top of the Oligocene, are again confirmed. The FO of *Sphenolithus distentus* is above the LO of *Sphenolithus* aff. *distentus*. As mentioned earlier, the co-occurrence of these two at Site 707 is considered because of the reworking. The LO of *Bramletteius serraculoides* is distinct, occurring one sample above the LO of *Reticulofenestra umbilica*. The LO of *Hayella situliformis*, occurring slightly below the LO of *Ericsonia formosa*, is also distinct. The LO of *Chiasmolithus titus* is a bit ambiguous at this site, but it is known to be below the LO of *E. formosa*.

Eocene

Nannofossils are also abundant in the recovered Eocene sediments (Table 9). Overgrowth, which was minor in the Oligocene sequence, becomes more severe in the entire Eocene sequence; and this effect, combined with the weak dissolution, degrades nannofossil preservation within some intervals of the middle Eocene. Reworking is severe in the lower sections of Cores 115-709C-32X and -33X, but it is minimal in the other cores.

Rare *Isthmolithus recurvus* occur sporadically down to Section 115-709C-31X-4, but the boundary assignment of Subzone CP15b in this core is tentative. The evolutionary succession in the upper Eocene is identical to that observed in Site 707. Occurrences of *Reticulofenestra umbilica* and *Reticulofenestra samodurovii* are inconsistent, and these species are absent in two short intervals. The middle Eocene Subzone CP14a is again very short compared with that of CP14b, and the stratigraphic succession of the four boundary criteria for the top and base of this subzone are also the same as at Site 707. It is now evident that the occurrence of *R. umbilica*, and consequently its FO and LO, are highly unreliable datum events in the tropical Indian Ocean. On the other hand, *Discoaster bifax* can be a reliable biostratigraphic marker in the tropical Indian Ocean, although the exact age of its stratigraphic range needs to be calculated.

Table 4. Percentage occurrences of calcareous nannofossils observed in the Oligocene and upper Eocene samples from Hole 707A.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Braarudosphaera bigelowii*	*Bramletteius serraculoides*	*Calcidiscus kingii*	*Calcidiscus protoannulus*	*Catinaster? umbrellus*	*Chiasmolithus titus*	*Coccolithus eopelagicus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coccolithus* sp. 1	*Coronocyclus nitescens*	*Crassidiscus backmanii*	*Cribrocentrum reticulatum*	*Cruciplacolithus tarquinius*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster adamanteus*	*Discoaster barbadiensis*	*Discoaster deflandrei*	*Discoaster nodifer*	*Discoaster saipanensis*	*Discoaster tanii*	*Ericsonia formosa*	*Ericsonia obruta*	*Ericsonia subdisticha*	*Hayaster perplexus*
CP19b	141.95	16H-1, 65–66	A	M		O-2	1					F			R	4		F		r		F	48	F		F		5					2		
	143.45	16H-2, 65–66	A	M		O-2	1					F		R	R	8		F				F	50	F		F		2					1		
	144.95	16H-3, 65–66	A	M		O-2	1					F		R	R	4		F	F			F	51	3	F	F		3					1		
	146.45	16H-4, 65–66	A	M		O-2	1					1		1	F	9	R	F				F	41	F		1		5			R		3		
	147.95	16H-5, 65–66	A	M		O-2	1					1		F	R	9		F		r		F	46	2		F		3			R		1		
	149.45	16H-6, 65–66	A	M		O-2	1			R		F		R	F	7		F			R	1	55	1		F		5			R		6		
CP19a	150.95	16H-7, 65–66	A	M		O-2	1			R				R	R	8		1			R	F	59	1		F		3			R		1		
	151.65	17H-1, 65–66	A	M		O-2	1			F				R	F	5		F			R	F	57	1		1		4			R		3		
	152.51	17H-CC	A	M		O-2				R				F	F	8		F			R	1	52	1	1	F		2			R		1		
	160.70	18H-CC	A	M	E-1	O-2				F				R	R	3		F				F	48	1	F	F		F			R		1		
CP18	174.35	20X-1, 65–66	A	M	E-1	O-2	1			F				R	R	11		R				F	48	5	1	F		F			1		3	F	
	175.85	20X-2, 65–66	A	M		O-2	1	F		R				F	R	8		F				R	53	2	1	F		F			2	r	2	1	
CP17-CP16c	177.35	20X-3, 65–66	A	M		O-2		F		R				F		7		F				R	63	F	F	F		2			1		1	F	
	178.51	20X-CC	A	M		O-2		F		F				F		8	F	R				R	44	3	2	F		F			F		2	1	
	184.05	21X-1, 65–66	A	M		O-2	1	F	F					R		9	F	F		r			59	4	F	F		1			F		1	R	
	185.55	21X-2, 65–66	A	M		O-2		F	F					R		6	F	F					55	5	1	F		1			F		F		
	187.05	21X-3, 65–66	A	M		O-2		F	F					R		19	F	F					38	4	F	F		F			F		F		
	188.55	21X-4, 65–66	A	M		O-2		F	1					R		16	F	F					34	5	F	F		F			E		1	F	
	190.05	21X-5, 65–66	A	M		O-2		2	2					F		20	F	F					40	4	1	R		1			R	R	F	2	
CP16ab	191.55	21X-6, 65–66	A	M		O-2		1	6					1		18	F	F					31	4	1			2			F	F	F	4	
	192.52	21X-CC	A	M		O-2		F	8					1		15	F	F					37	7	3			F			1	1	F	3	
	193.75	22X-1, 65–66	A	M		O-2		1	7					F		11	F	F					46	14	1	R		F			1	F	F	3	
	195.25	22X-2, 65–66	A	M		O-2			4					F		17	F	R					33	21	1	R		F			1	2	F	1	
	196.75	22X-3, 65–66	A	M		O-2		R	8					F		7	F	1					39	18	3			F			F	1	F	4	
	198.25	22X-4, 65–66	A	M		O-2		F	7	R			F	R		25	1	F					23	20	4			2			1	1		3	
	199.20	22X-5, 10	A	M	E-1	O-2		F	10	F			F	R		24	2	F					14	17	4			2	R	r	1	4		3	
	199.75	22X-5, 65	A	M	E-1	O-2		F	5	F			F	R		17	F	F					16	27	4			2			1	F		1	
	200.70	22X-6, 10	A	M		O-2		1	9	F			F	R		15	2	F					39	17	2			1			2	F		F	
	201.25	22X-6, 65–66	A	M		O-2		F	8	1			F	R		17	F	F					37	14	2			F			1	F		2	R
CP15b	202.15	22X-7, 5	A	M		O-2			8	1			F			22	1	F					25	17	1			F	R	F	2	F	R	F	R
	202.71	23X-1, 1	A	M		O-2		R	4	F			F			20	2	F					4	8	1		5	F	R	2	3	2			R
	203.05	23X-1, 35	A	M		O-2		R	4	F			F	F		20	1	F					7	5	1		7		R	8	F	3			
	203.35	23X-1, 65	A	M		O-2			11	F			F			20	1	1					2	F	F		4			2	2	5			
	203.70	23X-1, 100	A	M		O-2			5	F			F			21	1	R					1	1	F		8			7	F	5		R	
	204.20	23X-1, 150	A	M		O-2		R	6	F	R		1	R		21	1	R		R			9	1	1		10			10	F	7			
	204.85	23X-2, 65–66	A	M		O-2			6	R			1	F		23	F	R		4			11	2	1		5			11	1	6		R	
	206.35	23X-3, 65–66	A	M		O-2			5	R			F	R		21	F	R		12			14	1	1		8			9	2	2			
	207.85	23X-4, 65–66	A	M		O-2		R	10	R			R	R		20	F			22			27				3			2	1	3			R
	209.35	23X-5, 65–66	A	M		O-2			10	F			R	R		21	F			25			13	7	2		3			4	F	2			
	210.85	23X-6, 65–66	A	M		O-2			5	F			R	F		13	1			16			11	15	4		5		R	11	1	3			
CP15a	212.05	23X-CC	A	M	E-1	O-2		R	3	7	F		R	1		14	1	F		5			3	14	12		2		R	13	1	3		1	

Note: See Table 3 for an explanation of the symbols used.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Hayella situliformis*	*Helicosphaera compacta*	*Helicosphaera euphratis*	*Helicosphaera intermedia*	*Helicosphaera reticulata*	*Isthmolithus recurvus*	*Lanternithus minutus*	*Micrantholithus altus*	*Micrantholithus flos*	*Pedinocyclus larvaris*	*Peritrachelina joidesa*	*Pontosphaera segmenta*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilica*	*Sphenolithus ciperoensis*	*Sphenolithus* aff. *ciperoensis*	*Sphenolithus dissimilis*	*Sphenolithus distentus*	*Sphenolithus* aff. *distentus*	*Sphenolithus furcatolithoides*	*Sphenolithus moriformis*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Sphenolithus radians*	*Triquetrorhabdulus carinatus*	*Triquetrorhabdulus milowii*	*Zygrhablithus bijugatus*	Holococcolith type A
CP19b	141.95	16H-1, 65-66	A	M		O-2	1		r	F	F											5	1	8				19	f			4		F	F
	143.45	16H-2, 65-66	A	M		O-2	1			F	F								R	r		6	2	6				19	f			2		F	F
	144.95	16H-3, 65-66	A	M		O-2	1		r	F	R											7	2	3				18	f			3	F	F	F
	146.45	16H-4, 65-66	A	M		O-2	1		r	F	R											14	F	2				19	f			1	F	F	F
	147.95	16H-5, 65-66	A	M		O-2	1			F									R		r	14	2	F				15				1	R	F	F
	149.45	16H-6, 65-66	A	M		O-2	1			F	R											6	F		r			15	F			1	R	F	F
CP19a	150.95	16H-7, 65-66	A	M		O-2	1		r	R	R						R					9	1		F			13	F			F	R	F	R
	151.65	17H-1, 65-66	A	M		O-2	1			R		r					R					F	1		1			11	11			F		F	R
	152.51	17H-CC	A	M		O-2			F	R							R					F	1		2			16	9			F		F	R
	160.70	18H-CC	A	M	E-1	O-2			2	R							R		R			1	1		1			8	30	R				F	R
CP18	174.35	20X-1, 65-66	A	M	E-1	O-2	1		F								R		R						F	R		14	12	R	r			F	1
	175.85	20X-2, 65-66	A	M		O-2	1		1	R							R		R		r				F	R		9	15	F	r			1	1
CP17-CP16c	177.35	20X-3, 65-66	A	M		O-2			1								R		R							F		6	11	R				F	2
	178.51	20X-CC	A	M		O-2			F					F		R	R									F		16	16	R				1	2
	184.05	21X-1, 65-66	A	M		O-2	1		F			r		1			R		R		r					F		8	9	F				2	1
	185.55	21X-2, 65-66	A	M		O-2			1	R				2			R	R								F		7	11	R				1	3
	187.05	21X-3, 65-66	A	M		O-2			2					3			F	R								F		4	15	R				4	5
	188.55	21X-4, 65-66	A	M		O-2			F					11			F	R	R							1		5	9	R				6	5
	190.05	21X-5, 65-66	A	M		O-2			2					5			R	R	R							F		5	6	F				1	4
CP16ab	191.55	21X-6, 65-66	A	M		O-2			1			F		1		R	R	F	R		R					F		7	10	F				1	3
	192.52	21X-CC	A	M		O-2			F			F		1	R	R	F	F			F					F		8	5	F				2	1
	193.75	22X-1, 65-66	A	M		O-2			F			1			R	F	R	R	R		R					R		5	2	R				3	1
	195.25	22X-2, 65-66	A	M		O-2		1	F			F					R	R			R					R		2	10	F				1	1
	196.75	22X-3, 65-66	A	M		O-2		1	F			F					R	F	R		F							6	5	R				1	2
	198.25	22X-4, 65-66	A	M		O-2		1	F	R		R		F			R	R	R		F							6	R	F				F	2
	199.20	22X-5, 10	A	M	E-1	O-2		4	F			R		R			R		F		R							9		F				1	1
	199.75	22X-5, 65	A	M	E-1	O-2		2	F			F	R			R	F		F		F							14		1				F	1
	200.70	22X-6, 10	A	M		O-2		1	F			F		R			F		F		1							3		F				1	1
	201.25	22X-6, 65-66	A	M		O-2		1	F			F					1		F	F	2							2		F				1	3
CP15b	202.15	22X-7, 5	A	M		O-2		2	F			F	R				F		F	F	5							1		1				1	2
	202.71	23X-1, 1	A	M		O-2		F	R			R	R				F		F	7	25							1		F				2	4
	203.05	23X-1, 35	A	M		O-2		F	R			R	R				1			6	14							4		F				3	3
	203.35	23X-1, 65	A	M		O-2		1	R			R					F		R	9	18							7		1				3	2
	203.70	23X-1, 100	A	M		O-2		3	F			R	R				R			3	20							7		F				2	1
	204.20	23X-1, 150	A	M		O-2		2	R								F			1	8							5		F				1	1
	204.85	23X-2, 65-66	A	M		O-2		2	R				R				F		R	2	7							3		F				3	2
	206.35	23X-3, 65-66	A	M		O-2		F	R			R					F			1	4							3		F				4	1
	207.85	23X-4, 65-66	A	M		O-2		R	R			R		F			1			R	R							2		F				3	F
	209.35	23X-5, 65-66	A	M		O-2		F	R			R					1				R							1		F				3	1
	210.85	23X-6, 65-66	A	M		O-2		1	R			R	R				F		R		R							2		1				2	1
CP15a	212.05	23X-CC	A	M	E-1	O-2		R	F			F		1			1			R	F						F	5		1	F			F	1

Table 5. Percentage occurrences of calcareous nannofossils observed in the upper to middle Eocene samples from Hole 707C.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Braarudosphaera bigelowii*	*Bramletteius serraculoides*	*Calcidiscus kingii*	*Calcidiscus protoannulus*	*Campylosphaera dela*	*Chiasmolithus consuetus*	*Chiasmolithus expansus*	*Chiasmolithus gigas*	*Chiasmolithus grandis*	*Chiasmolithus solitus*	*Chiasmolithus titus*	*Coccolithus eopelagicus*	*Coccolithus pelagicus*	*Coccolithus* sp. 1	*Coronocyclus nitescens*	*Cribrocentrum reticulatum*	*Cruciplacolithus cribellum*	*Cruciplacolithus staurion*	*Cruciplacolithus vanheckae*	*Cruciplacolithus* spp.
CP16a	194.00	3R-1, 50-51	A	M		O-1		2	6										F	14	1	F					
	195.50	3R-2, 50-51	A	M		O-1		1	3	R									F	15	F	F					
	197.00	3R-3, 50-51	A	M		O-2		F	1										F	19	F	F					
	198.50	3R-4, 50-51	A	P	E-1	O-3		R	9	R									R	12	F	F					
	200.00	3R-5, 50-51	A	P	E-1	O-3		R	6	F								R	R	16	1	F					
	201.50	3R-6, 50-51	A	P	E-1	O-3		R	7	F								1		12	2	F					
CP15b	203.24	3R-CC	A	M	E-1	O-2			5	3	F							F		21	1	1					
CP15a	213.30	5R-1, 50-51	A	M		O-2			12	3	F									9	F	F	10				
	213.45	5R-CC	A	M		O-2			6	4								R	1	6	F	F	3				
	223.00	6R-1, 50-51	A	M		O-2		R	7	4								R	F	10	F	F	1				
	224.50	6R-2, 50-51	A	M		O-2			1	3									2	11	1	F	2				
	226.00	6R-3, 50-51	A	M		O-2			6	3									F	13	F	F	15				
	226.87	6R-CC	A	M		O-2		R	4	1									F	10	1	F	26				R
CP14b	232.60	7R-1, 50-51	A	M	E-1	O-2			2	3		R				R		R	1	18	2	F	2				R
	234.10	7R-2, 50-51	A	M		O-2		R	3	2		2				F		F	3	7	1	1	F				
	235.60	7R-3, 50-51	A	M	E-1	O-2			4	3		1				F		F	F	1	2	F	F				R
	237.10	7R-4, 50-51	A	M	E-1	O-2			5	1		1				F		R	R	4	1	F					F
	238.51	7R-CC	A	M		O-2			2	1	F	2				R		R	F	6	F	R	F				F
	242.30	8R-1, 50-51	A	M		O-2	1	R	3	1	F	F				R		F	F	6	F		R				F
	243.02	8R-CC	A	M		O-2	1		1	1	1	1				F		F	F	9	1		F				F
	251.59	9R-1, 19-20	A	M		O-2			F	F	F	1				1		1	1	17	F		F			R	F
	253.18	9R-2, 28-29	A	M	E-1	O-2			2	1	F	1		R		F		F	F	16	F		F				F
	254.68	9R-3, 28-29	A	M		O-2		R	5	F	1	1				F		1	F	15	F					R	F
	255.18	9R-CC	A	M		O-2		R	1	F	1	4				1		F	F	19	2						F
CP14a	261.57	10R-1, 57-58	A	M	E-1	O-2			F	R	F	2	R			F	F	F	F	18	1					R	F
	263.12	10R-2, 62-63	A	M	E-1	O-2		F	2	R	F	3	R			F	R	1	1	8	R					F	F
CP13c	264.55	10R-3, 55-56	A	M	E-1	O-2		R	F	R	F	1	R	R		R	R	F	F	6	R				R	R	F
	266.42	10R-4, 92-93	A	M	E-1	O-2		R	F	F	F	3	R			F	R	F	F	8	F				F	R	F
	267.18	10R,CC	A	M		O-2		R	F	R	F	3	F	R		F	F	F	1	6	R				F	R	F
	271.10	11R-1, 50-51	A	M		O-2		F	2	R	F	F	R			F	F	F	1	4	F				2	F	F
	271.76	11R-CC	A	M	E-1	O-2		F	1		1	2				F	1	1	2	8					F	F	F
CP13b	280.60	12R-1, 30-31	A	M		O-2		F	F	R	1	1	R		R	1	1	F	F	12				R	1	R	F
	280.99	12R-CC	C	M	E-1	O-2		F	F		F	F	F		R	1	F	F	F	5					1	F	F

Note: See Table 3 for an explanation of the symbols used.

Site 710

Two holes were drilled at this site located on the central Madingley Rise in a water depth of 3812 m. Paleogene sediment was recovered only from Hole 710A. Nannofossils are abundant throughout the recovered Oligocene sequence, and reworking is minimal (Table 10). The preservation of nannofossils is moderate, except in the top sequence where nannofossils are well preserved. Occurrences of *Crassidiscus backmanii, Ericsonia obruta*, and *Sphenolithus* aff. *distentus* are similar to those observed at Site 709.

Coccolithus fuscus and *Catinaster*? *umbrellus* are characteristic members of the uppermost Oligocene flora. The identification of *Sphenolithus ciperoensis* is difficult in the early stage of its evolution at this site, and rare questionable specimens were observed in Sample 115-710A-21X-3, 43–44 cm, located far below the base of an interval in which *S. ciperoensis* occurs continuously. *Sphenolithus* aff. *ciperoensis* occurs more commonly than the true *S. ciperoensis* in the early evolutionary stage of this lineage.

Site 711

This site is located at a water depth of 4428 m on the northern edge of the Madingley Rise. Two holes were drilled at this deep CBT site, and a continuous sequence from the upper Oligocene through the middle Eocene was recovered. Although upper Oligocene sediment was retrieved from Hole 711B, nannofossils were investigated only for the materials recovered at Hole 711A.

Oligocene

Nannofossils are abundant and are moderately well preserved within the Oligocene cores (Table 11). The effect of overgrowth is weak and persistent, and moderately severe dissolution is evident in Core 115-711A-13X. Reworked specimens are frequent throughout the sequence, and reworking becomes moderately heavy in some cores. All zones and subzones are recognizable except the CP16a/CP16b boundary. All the biostratigraphically significant events noticed at the previous sites occur in a similar manner. Rare *Crassidiscus backmanii*, observed in Sample 115-711A-10H-2, 40–41 cm, at the upper part of Subzone CP19b, are probably reworked. The LO of *Hayella situliformis* is a good substitute biostratigraphic marker for the hard-to-detect end of the acme of *Ericsonia subdisticha* in the lower lower Oligocene.

Eocene

Moderate to poorly preserved nannofossils are abundant throughout the recovered Eocene sequence (Table 12). Despite the presently great water depth, dissolution is not a major factor for nannofossil preservation; severe overgrowth is noticed in two middle Eocene intervals. Because reworking is minimal and the retrieved sediments represent the most complete record of the

Table 5 (continued).

Cyclicargolithus floridanus	*Cyclolithella kalianata*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster barbadiensis*	*Discoaster bifax*	*Discoaster deflandrei*	*Discoaster nodifer*	*Discoaster saipanensis*	*Discoaster tanii*	*Ericsonia formosa*	*Ericsonia obruta*	*Ericsonia pacifica*	*Ericsonia subdisticha*	*Hayella situliformis*	*Helicosphaera compacta*	*Helicosphaera heezenii*	*Helicosphaera lophota*	*Helicosphaera reticulata*	*Helicosphaera seminulum*	*Isthmolithus recurvus*	*Lanternithus minutus*	*Lophodolithus acutus*	*Markalius inversus*	*Markalius* sp. 1	*Markalius* sp. 2	*Micrantholithus altus*	*Nannotetrina alata*	*Nannotetrina* sp. (small)	*Pedinocyclus larvaris*	*Peritrachelina joidesa*	*Pontosphaera bicaveata*
47		10	4			F			F	1	R		2	F	F			F		R	1					R				F	
37		19	1			F			1	1	R		3	F	F			R			R								F	R	
40		14	3			F	R		F	2	F	R	4	1	F			R			F								F	1	
27		21	3			F	R		1	F			5	F	F			R		R										F	
22		25	4			1	R		1	3			3	1	F					R										F	
21		25	4			F	R		1	1		R	1	2	F			R													
29		10	1			F	R	F	1	F	1	F	1	F	1					R	1										
37		8	1	2		F		1	1	1		R	F	1	F			R			F								R		
26		22	3	5				8	2	1		R		F	F	R					F								R		
19		26	3	5			R	5	2	2		F		F	R	F		F			F								1		
22		23	8	2		R	R	2	1	2		F		F	R	R		F			F			R					F		
12		13	4	10			R	5	F	1		F		F	R	R					F			R					F		
7		8	3	12			F	5	F	4		R		F	R						F			R	R				R		
14		17	7	9			R	6	F	3				F	F	F					1			F		R			F		
26		21	5	8				5	F	2		R		F	F	F			R		F			F					F		
44		15	6	5				2	F	F		R		F	R	R					F			F					F		
22		27	7	10			R	4	F	1		R		F	F	1					F			F					F		
31		23	5	3			F	2	F	2		R		R	F	F	F				F			F		R			1		
32		18	8	6	r		F	3		1		F			F	1	F	R			F			F	R				1		
50		3	1	3	r	R	R	4		2	R	R			F	1		R	R		F		F	2	R				F		
22	F			17		R	R	1		7		R				F					F		F	3	F				F		
21	1			12				1		6		R				F			R		1		R	1	R				F		
13	F			22			R	1		10		R				1	R		F		F		R	2	R				F		
9	F			12			F	1	R	2		R				1	R		F		F		F	3	R				1		
25	F			7		R		1		5		2				F	F		R		3		F	1	R			R	F		
17	F			12	1		R	2		3	R	F				F	R		R		1		F	3	F				F		
40	R			5	1			1	R	3	R	F				F	F		F		1		F	5	R		R		1		
33				10	F			2		4		1				F	F		R		F	R	F	5	F	R	R	R	F		
44				6	2	R		1		1		1				1	F		F		F		F	1	F		R	R	F		R
46	F			5	R	F		F		F	R	F				1	F		R		F		1	F	F		R	R	1		
30	R			12	R	F		F		2		R				F	1		R		F		1	F	F	R	R	F	1		R
31				9		F		F		3		R				R	F		F		F		R	1	R		R	F	5		
53	R			7		F		1		4		F												F	R		R	F	1		

middle Eocene among Leg 115 sites, this sequence can serve as a standard for an improved biostratigraphy of the middle and late Eocene in the tropical Indian Ocean.

The time-progressive floral change is similar to that observed at adjacent Sites 707 and 709. The downward sequential LOs of *Discoaster saipanensis, Discoaster barbadiensis*, and *Cribrocentrum reticulatum* are distinct within the uppermost Eocene. *Isthmolithus recurvus* occurs sporadically, and the identification of the CP15a/CP15b boundary is not reliable. The FOs of *Hayella situliformis* and *C. reticulatum* are difficult to detect. The four datum events marked by species of *Chiasmolithus*—the LOs of *Chiasmolithus grandis, Chiasmolithus solitus*, and *Chiasmolithus gigas* and the FO of *C. gigas*—are all distinct and occur in the stratigraphic positions where they are expected. The synchronous occurrence for the two basal boundary criteria of Subzone CP14, the LOs of *C. solitus* and *D. bifax*, is also confirmed. *Dictyococcites bisectus* fluctuates widely in abundance, but its FO within Subzone CP14a is a clear-cut event.

Reticulofenestra umbilica varies greatly in abundance, although it shows up more consistently at Site 711 than at Site 709. Its FO again occurs at a much higher level than the FO of *D. bifax*. *Nannotetrina alata* is more common than *Nannotetrina austriacus*, and its consistent occurrence ends in the basal part of Subzone CP14b. *Sphenolithus* sp. 1, which has four distinctive apical spines, is a noticeable member of the lower CP13 flora. *Zygrhablithus bijugatus* is rare and sporadic in the upper part of the recovered Eocene sequence, but its abundance increases significantly in the lower cores. Another holococcolith, Holococcolith type A, also has a similar trend.

The last core of the hole was empty except for small pieces of sediment recovered in the core catcher. Smear slides prepared from two pieces of sediment revealed a significantly different flora. One of these samples, which has been designated Sample 115-711A-26X-CC (A), yields abundant *Discoaster sublodoensis* and common *Rhabdolithus inflata* but no large *Nannotetrina.* This clearly indicates the lower middle Eocene Subzone CP12b. The other, Sample 115-711A-26X-CC (B), contains common *D. sublodoensis* but no *D. inflata* is observed. This assemblage is referred to the upper lower Eocene Subzone CP12a.

Site 712

A single hole was drilled at this site located on the northern margin of the Chagos Bank at a water depth of 2904 m (Table 13). Very little Paleogene material was recovered at this site. Nannofossils are common and are heavily overgrown in the Oligocene, which is represented by limestone. The co-occurrence of *Sphenolithus ciperoensis* and *S. distentus* indicates upper Oligocene Subzone CP19a for Samples 115-712A-10R-CC and 115-712A-11R-1, 1 cm. The Eocene sequence recovered in Core 115-712A-12R contains abundant nannofossils. The assemblage is assignable to the middle Eocene Subzone CP14b, and the notable absence of *Dictyococcites bisectus* indicates the lower part of this subzone.

Table 5 (continued).

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Pontosphaera formosa*	*Pontosphaera scissura*	*Pontosphaera segmenta*	*Pseudotriquetrorhabdulus inversus*	*Reticulofenestra dictyoda*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilica*	*Rhabdosphaera tenuis*	*Sphenolithus furcatolithoides*	*Sphenolithus intercalaris*	*Sphenolithus moriformis*	*Sphenolithus obtusus*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Sphenolithus radians*	*Sphenolithus spiniger*	*Toweius*? sp. 1	*Zygrhablithus bijugatus*	Holococcolith type A
CP16a	194.00	3R-1, 50–51	A	M		O-1								R				4		1	F				F	1
	195.50	3R-2, 50–51	A	M		O-1								R				6		5	1				F	2
	197.00	3R-3, 50–51	A	M		O-2				R				R				3		3	F				F	1
	198.50	3R-4, 50–51	A	P	E-1	O-3								R				16		F	F				1	
	200.00	3R-5, 50–51	A	P	E-1	O-3							R	R				5		F	F				4	
	201.50	3R-6, 50–51	A	P	E-1	O-3				R			R	F				12			1	R			3	2
CP15b	203.24	3R-CC	A	M	E-1	O-2				R			F	4				3			F				5	4
CP15a	213.30	5R-1, 50–51	A	M		O-2				R			R	F				1			F				1	2
	213.45	5R-CC	A	M		O-2				R				R				6			F				1	1
	223.00	6R-1, 50–51	A	M		O-2				R								5			F				2	1
	224.50	6R-2, 50–51	A	M		O-2							R	F				8			F				1	1
	226.00	6R-3, 50–51	A	M		O-2				R		F	F					4			1				3	2
	226.87	6R-CC	A	M		O-2				R			1	2				5			2				1	1
CP14b	232.60	7R-1, 50–51	A	M	E-1	O-2				R			F	F				2			F				4	F
	234.10	7R-2, 50–51	A	M		O-2								F	R			5			F				2	F
	235.60	7R-3, 50–51	A	M	E-1	O-2				R	R		1	F			F	2	3		F				1	2
	237.10	7R-4, 50–51	A	M	E-1	O-2				R	F		R	R			1	1	3		F				2	1
	238.51	7R-CC	A	M		O-2		R		R	F		F	R			1	3	5		1				F	F
	242.30	8R-1, 50–51	A	M		O-2	1				1		F	F			3	2	6		F				1	F
	243.02	8R-CC	A	M		O-2	1				F	F	2	F	R		2	2	1		F		2		1	F
	251.59	9R-1, 19–20	A	M		O-2					F	F	2	1		5		2			1	1	2		3	F
	253.18	9R-2, 28–29	A	M	E-1	O-2				R	F	1	2	1		13		4			1	1	5		2	1
	254.68	9R-3, 28–29	A	M		O-2			R	F	F	1	3	4		5		2			F	F	2		2	1
	255.18	9R-CC	A	M		O-2				R	1	1	2	1		10		1			F	F	12		3	1
CP14a	261.57	10R-1, 57–58	A	M	E-1	O-2					F	F	3	1		7		2			F	F	6		4	1
	263.12	10R-2, 62–63	A	M	E-1	O-2		R	1		1	1	3	R		8		4				1	7		9	1
CP13c	264.55	10R-3, 55–56	A	M	E-1	O-2		R	F		F	1	2			6		4				F	7	1	5	F
	266.42	10R-4, 92–93	A	M	E-1	O-2		R	F	R	1	2	R			3		3				F	7	1	6	F
	267.18	10R,CC	A	M		O-2		F	F	R	3	2	F			6		1				F	5	1	4	F
	271.10	11R-1, 50–51	A	M		O-2		R	F		3	1				7		4			R	1	3	F	6	F
	271.76	11R-CC	A	M	E-1	O-2		R	F	R	5	2	F			3		6				F	9	F	5	F
CP13b	280.60	12R-1, 30–31	A	M		O-2		R	F	R	6	2	F		R	6		2			R	F	3		4	F
	280.99	12R-CC	C	M	E-1	O-2					7	3	1			1		2				F	3		2	1

Site 713

Drilling at Site 713, situated 1.6 nmi north of Site 712 at 2915 m water depth, recovered a middle Eocene nannofossil chalk directly below a thin Neogene sequence. Nannofossils are abundant throughout the recovered interval with minimal signs of reworking. Preservation is mostly moderate (Table 14).

The interval assignable to Subzone CP14a is much thicker at this site than at Sites 707, 709, and 711 located in the western Indian Ocean. It is increased further if the dubious rare specimens of *Reticulofenestra umbilica* observed in Sample 115-713A-13R-2, 143–144 cm, are taken as the real FO of the species. One factor contributing to the unusually thick Subzone CP14a (in a regional sense) is that the sedimentation rate is at least four times greater for the middle Eocene sequence of Site 713 than that for the CBT sites.

The LO of *Discoaster bifax* almost coincides with the LO of *Chiasmolithus solitus*, confirming the synchroneity of the two events. The FO of *D. bifax* occurs slightly above the LO of *Chiasmolithus gigas*, which is the basal criteria of Subzone CP13c. If the base of Subzone CP14a is determined by the FO of *D. bifax*, the stratigraphic range of Subzone CP13c would be very short. The same is true at the CBT sites and is certain to be consistent in the tropical Indian Ocean. In addition to the biostratigraphic similarity, the character of the flora is also similar to that of the corresponding floras observed in the CBT sites.

Site 714

Site 714 is located on the eastern shoulder of the Maldive Ridge at a water depth of 2032 m. Two holes were drilled, and upper Oligocene sediment was retrieved from Hole 714A (Table 15). Moderately well-preserved nannofossils are abundant, and the consistent occurrence of *Sphenolithus ciperoensis* indicates the upper Oligocene. The short interval with *Crassidiscus backmanii* observed in the CBT sites is also present here. The occurrence of this species at this site, however, is at the top of Subzone CP19a instead of in the lower part of Subzone CP19b.

Because this site is located far away from the CBT sites, the time discrepancy observed here may indicate a diachronous occurrence of *C. backmanii*. Another possibility is that the *Sphenolithus distentus* observed in Cores 115-714A-23X and -24X are reworked specimens and the CP19a/CP19b boundary actually is located lower than the level indicated in Table 15. Because of the poor recovery for the latter core, the reason for the observed time difference for the stratigraphic range of *C. backmanii* cannot be determined.

Site 715

This single-hole site is located on the eastern margin of the Maldives Ridge at a water depth of 2266 m. Recovery of Paleogene sediment was poor, and the only two samples yielded poorly preserved and rare nannofossils. Taxa observed in Sample 115-

715A-12R-CC consists of *Cyclicargolithus floridanus, Dictyococcites* sp., and *Sphenolithus moriformis.* In addition to these, a piece of limestone found in the upper part of Section 115-715A-13R-1 yielded *Coccolithus pelagicus, Dictyococcites bisectus, Discoaster barbadiensis, Ericsonia obruta, Helicosphaera euphratis*, and *Sphenolithus predistentus.* The latter assemblage is assignable to the upper Eocene Zone CP15 or to the upper part of Subzone CP14b.

BIOSTRATIGRAPHY OF PALEOGENE NANNOFOSSILS

The age estimates of some biohorizons observed in this study is significantly different from the estimates of Berggren et al. (1985) and Aubry et al. (1988). The observed stratigraphic succession for these events is generally consistent among the studied sites and, therefore, accurately reflects the sequence of events that occurred in this part of the Indian Ocean. The time differences observed in this investigation vs. previous publications may reflect the diachronous nature of corresponding events. Moreover, biostratigraphically useful events that have not been used for the standard zonations of Bukry (1973, 1975) or Martini (1971) were also demonstrated. These biostratigraphic events will be summarized here to clarify the new findings.

To avoid the influences of reworking as much as possible, Oligocene and Eocene cores were selected from Holes 709C and 711A, respectively, and the observed stratigraphic ranges for biostratigraphically important species are illustrated in Figure 2. The approximate ages for the biostratigraphically significant events were also extrapolated from age-depth curves, which were drawn by plotting the biostratigraphic ages that I consider to be more reliable than the rest of the proposed ages (Table 16). Unfortunately, an examination of the ages of these anchor events is not possible because no paleomagnetic data were available from Leg 115 sediments.

Oligocene Biostratigraphy

The greatest age difference among the Oligocene events between this study and Berggren et al. (1985) is the age of the FO of *Sphenolithus distentus.* The extrapolated age of this event at Hole 707C is 31.2 Ma, whereas Berggren et al. (1985) indicated this age to be 34.2 Ma. A sphenolith similar to *S. distentus, Sphenolithus* aff. *distentus*, occurs in the lower Oligocene cores of Leg 115, and its FO (35.1 Ma) is rather close to 34.2 Ma, the FO age of *S. distentus* reported by Berggren et al. (1985). It is possible that these two FOs are actually the same event. Because the earlier-evolved *S.* aff. *distentus* is bigger than the latter-evolved true *S. distentus*, and because their stratigraphic ranges do not overlap, I have concluded that they are separate taxa.

The lower range of *S.* aff. *distentus* overlaps with the upper range of *Ericsonia formosa* at Leg 115 sites. If these two sphenoliths are the same species, Zone CP17 cannot exist in the tropical Indian Ocean. Stratigraphic occurrences are also similar for *S. ciperoensis* and *S.* aff. *ciperoensis*, although their stratigraphic ranges overlap for the most part. The taxonomy and ranges of these four sphenoliths and of the other related forms need to be further examined in the Indian Ocean as well as in other world oceans. Backman (1987) reported a detailed biochronology for the middle Eocene through Oligocene period in the South Atlantic. His conclusion that the LO of *Reticulofenestra umbilica* is an unreliable datum was confirmed in this investigation. The LO of *Ericsonia obruta* in the lower Oligocene was reported as a distinct, but possibly, diachronous event by Backman, and the diachroneity was proven to be true to a large extent. This species is common through the entire Oligocene at all sites of Leg 115, and its disappearance was surely postponed until the Neogene in the tropical Indian Ocean (Tables 3, 4, 7, 8, 10, 11, and 15).

The sharp increase of *E. obruta* in the lower lower Oligocene reported by Backman (1987) was not observed; *E. obruta* generally increases within the basal Oligocene, but the increase is neither sharp nor consistent in Leg 115 cores. *Ericsonia subdisticha* does not decrease sharply in the lower lower Oligocene sequence of Leg 115 sites either. As Backman (1987) reported, the top of its acme, used for the CP16a/CP16b boundary in Bukry's zonation, is certainly not a globally recognizable event. In the tropical Indian Ocean, *E. subdisticha* gradually decreases in the higher part of Zone CP17.

Beside the four well-known datum events considered here as reliable—the LOs of *Dictyococcites bisectus, Ericsonia formosa*, and *Discoaster saipanensis* and the FO of *Sphenolithus ciperoensis*—five additional events are recognized as useful for the Oligocene biostratigraphy in the tropical Indian Ocean. These are the LO and FO of *Crassidiscus backmanii*, and the LOs of *Bramletteius serraculoides, Hayella situliformis*, and *Chiasmolithus titus*, in descending order (Fig. 2 and Table 16).

Eocene Biostratigraphy

No additional or local biostratigraphic events were observed for the upper Eocene cores of Leg 115. The LOs of *Discoaster saipanensis* and *Discoaster barbadiensis* are synchronous in a Mediterranean coastal sequence (Nocchi et al., 1986), but the former LO, following a drastic abundance decline, occurred shortly after the latter event in the South Atlantic Ocean (Backman, 1987). The occurrence of these two LOs are consistent with Backman's findings throughout this investigation, and the downward succession within the top Eocene sequence, the LOs of *D. saipanensis, D. barbadiensis*, and *Cribrocentrum reticulatum*, are confirmed to be good age markers in the tropical Indian Ocean. Although the FO of *Isthmolithus recurvus* is detectable, its rare and inconsistent occurrence lowers the biostratigraphic reliability. The occurrence of *H. situliformis* is also sporadic in the lower portion of its stratigraphic range, and its FO in the upper middle Eocene is not a reliable event for biostratigraphy.

Bukry (1975) employed four events from the evolution of the genus *Chiasmolithus* in his middle Eocene zonation. All of these biohorizons—the LOs of *Chiasmolithus grandis, Chiasmolithus solitus*, and *Chiasmolithus gigas* and the FO of *Chiasmolithus gigas*—are easy to detect and are useful events for the biostratigraphy of Leg 115 cores.

The duration of Subzone CP14a is the most notable difference between the results of this investigation and that of Aubry et al. (1988). The criteria for the top of Subzone CP14a, the LOs of *C. solitus* and *Discoaster bifax*, are synchronous at Leg 115 sites. The two basal criteria of the subzone, however, occur as widely spaced events. The primary basal event, the FO of *R. umbilica*, takes place just below the top events of the subzone, whereas the secondary basal event, the FO of *D. bifax*, occurs at a much lower level. The time gap between these supposedly synchronous basal events is estimated to be 3 m.y. (Table 16). As mentioned earlier, I have adopted the smallest size (14 μm) suggested by Backman (1987) to use in recognizing *R. umbilica.* Decreasing this lower size limit will no doubt narrow the time difference. Obviously, the time-progressive size increase of the species needs to be investigated quantitatively in the Indian Ocean. Because the occurrence of *R. umbilica* is proved to be unreliable, however, its evolutionary size increase has limited potential for the biostratigraphy of the tropical Indian Ocean, and the FO of *D. bifax* would be a more appropriate criterion for the boundary of Subzone CP14a. The FO of *D. bifax*, which

Table 6. Percentage occurrences of calcareous nannofossils observed in the lower Eocene and Paleocene samples from Hole 707C.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Biscutum* sp.	*Braarudosphaera bigelowii*	*Campylosphaera dela*	*Campyrosphaera eodela*	*Chiasmolithus bidens*	*Chiasmolithus californicus*	*Chiasmolithus consuetus*	*Chiasmolithus danicus*	*Chiasmolithus eograndis*	*Chiasmolithus grandis*	*Chiasmolithus solitus*	*Coccolithus pelagicus*	*Coronocyclus prionion*	*Cruciplacolithus cribellum*	*Cruciplacolithus frequens*	*Cruciplacolithus primus* (small)	*Cruciplacolithus primus* (large)	*Cruciplacolithus subrotundus*	*Cruciplacolithus tenuis*	*Cruciplacolithus* spp.
CP11	290.00	13R-1, 20–21	A	M	E-1	O-1		F	F	12			F	F		R		R	14	2	2						
	290.38	13R-1, 58	A	M	E-1	O-2			F	15			F	F				R	17	1	F						
	291.08	13R-CC	A	M	E-1	O-2			F	21			F	R					15	F	1						
CP10	299.53	14R-1, 23–24	A	M		O-2				11			1	R		R			19	5	F						R
	299.85	14R-CC	A	M	E-1	O-1	1			11	F		1	F					14	2	F						
CP9b	309.40	15R-1, 50–51	A	M	E-1		1			5	F	R	R	F		R			26	2	R						
CP9a	310.90	15R-2, 50–51	A	M	E-1		1		R	3	1	R	1	F		R	R		16	1	F						R
	312.40	15R-3, 50–51	A	M	E-1					4	1	R	R	F		F			25	1	R						R
	312.87	15R-CC	A	M		O-1				5	3	R	F	R		R		R	18	1							
CP8b	318.21	16R-1, 1	A	M		O-1				1	9		F	R					19	R						R	
	318.70	16R-1, 50–51	A	M		O-1				F	3	R	F	R					22	R						R	
	319.20	16R-1, 100	A	M		O-1				F	4		F	R	R	R			16	R	R		R				R
	319.71	16R-2, 1	A	M		O-1					3	R	F	F	R				17	R							
	320.20	16R-2, 50	A	M		O-1					6		F	R	R				22	1	R		R	R			
	320.70	16R-2, 100	A	M		O-1		F			6	R	R	F	R				28	R	R	R				R	
	321.18	16R-2, 148	A	M		O-1		R			4	F	F	F	R				20	F	R	F				R	
	321.39	16R-CC	A	M		O-1		F			2	F	1	F	R				24	R	R	R		R		R	
CP7	327.99	17R-CC	F	M		O-2						F		F	F				15				1	1		F	
CP4-3	348.78	19R-CC	F	M		O-2													1				3	F	F	F	
	358.52	20R-CC	F	M		O-2													2				2	1	F	F	
	368.20	21R-2, 70	F	M		O-2									F				3				1	1	F	F	
	368.55	21R-CC	F	M		O-2													5					F	F		

Note: See Table 3 for an explanation of the symbols used.

Table 6 (continued).

Cyclolithella kalianata	*Discoaster barbadiensis*	*Discoaster binodosus*	*Discoaster delicatus*	*Discoaster diastypus*	*Discoaster elegans*	*Discoaster falcatus*	*Discoaster kuepperi*	*Discoaster limbatus*	*Discoaster lodoensis*	*Discoaster mahmoudii*	*Discoaster megastypus*	*Discoaster mohleri*	*Discoaster multiradiatus*	*Discoaster nobilis*	*Discoaster salisburgensis*	*Ellipsolithus distichus*	*Ellipsolithus macellus*	*Ericsonia formosa*	*Ericsonia pacifica*	*Ericsonia robusta*	*Ericsonia subpertusa*	*Fasciculithus bobii*	*Fasciculithus clinatus*	*Fasciculithus hayi*	*Fasciculithus involutus*	*Fasciculithus richardii*	*Fasciculithus schaubii*	*Fasciculithus tympaniformis*	*Helicosphaera lophota*	*Helicosphaera seminulum*	*Heliolithus riedelii*	*Hornibrookina australis*
F	7						F		1									15	R										2	F		
1	10						F		13									10											1	1		
F	12			F			1		11									8											1	1		
	1	R		1	R		1		1						R		1	10	R													
	3	R		1	F	F	F		F				R		1	R	2	17					r					r				
	1	F		F	1	F							R	R	F		3	7						R				r				
	F	1		1		R							R		1		F	4										r				
	F	F		F		R							F		F		F	1														
	F	1		F									F	R	1		1	1										F				R
		R											F		F	R	F	6			F							F				
						R						R	1	R	1	R	R	9			F		R					F				
										F		F	F	F	F	F	R	6		R	1							1				
			R			R				F		F	2	F	F	F	R	4			F							1				6
						R				F		F	4	F	R	F	F	1			F	R						1				F
			R			R		R			R	F	4	F	R	1	R	1		R	1		R	F	F	R	R	3				
								R				F	5	R	F	F	R	2			1			F	F	F	F	5				
												F	1	R	F	F	R	3			F			1	F	R	R	4			R	
														F			F			R	1							F				
																	F				F							F				
																	F				1							F				
																					2											

Table 6 (continued).

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Lophodolithus nascens*	*Markalius inversus*	*Micrantholithus flos*	*Neochiastozygus chiastus*	*Neochiastozygus concinnus*	*Neochiastozygus distentus*	*Neochiastozygus junctus*	*Neochiastozygus rosenkrantzii*	*Neococcolithus dubius*	*Neochiastozygus protenus*	*Neocrepidolithus* sp.	*Pedinocyclus larvaris*	*Pontosphaera pectinata*	*Pontosphaera plana*	*Pontosphaera punctosa*	*Pontosphaera rimosa*	*Prinsius bisulcus*	*Prinsius martinii*	*Prinsius* spp.
CP11	290.00	13R-1, 20–21	A	M	E-1	O-1			F							R	R		2							
	290.38	13R-1, 58	A	M	E-1	O-2		F	F							R	R		1							
	291.08	13R-CC	A	M	E-1	O-2		F	F	F						R	R		F							
CP10	299.53	14R-1, 23–24	A	M		O-2		2	F				R	F	R	R	1	R	F	F						
	299.85	14R-CC	A	M	E-1	O-1	1	F	F				R	2	R		1	R	R	F						
CP9b	309.40	15R-1, 50–51	A	M	E-1		1	F	F				R	1	R		F	F	F							F
CP9a	310.90	15R-2, 50–51	A	M	E-1		1	F	R				F	1	R		F	F	R							F
	312.40	15R-3, 50–51	A	M	E-1			F	R				F	1	R		F	1				F				F
	312.87	15R-CC	A	M		O-1		R	R				F	1	F		1	1			F	R				F
CP8b	318.21	16R-1, 1	A	M		O-1		R	F				1	3	F		1	F			2	F				1
	318.70	16R-1, 50–51	A	M		O-1		R	R		F		F	F	F		F	F			F	F		5		10
	319.20	16R-1, 100	A	M		O-1		R	F		2		F	3	1		1	1			F	1	R	5		11
	319.71	16R-2, 1	A	M		O-1		R	R		1		F	5	F		F	F			F	F		2		7
	320.20	16R-2, 50	A	M		O-1		R	R		F		R	1	F		F	F			F	F		3		9
	320.70	16R-2, 100	A	M		O-1		R	R		F		F	F	F		F	R			F		R	1		10
	321.18	16R-2, 148	A	M		O-1		R	R		F		F				1	R					R	3		4
	321.39	16R-CC	A	M		O-1		F	F		F		R	R			F							4		5
CP7	327.99	17R-CC	F	M		O-2			F		F			F			F	2						7	55	
CP4-3	348.78	19R-CC	F	M		O-2												3						11	65	
	358.52	20R-CC	F	M		O-2												2						12	69	
	368.20	21R-2, 70	F	M		O-2						F						6						6	67	
	368.55	21R-CC	F	M		O-2					1	F						2						8	75	

Table 6 (continued).

Rhomboaster bitrifida	*Rhomboaster calcitrapa*	*Rhomboaster cuspis*	*Scapholithus fossilis*	*Scapholithus rhombiformis*	*Semihololithus biscayae*	*Semihololithus kerabyi*	*Sphenolithus anarrhopus*	*Sphenolithus conspicuus*	*Sphenolithus editus*	*Sphenolithus moriformis*	*Sphenolithus orphanknolli*	*Sphenolithus radians*	*Sphenolithus* sp. 1	*Toweius callosus*	*Toweius? crassus*	*Toweius eminens*	*Toweius gammation*	*Toweius occultatus*	*Toweius pertutus*	*Toweius tovae*	*Transversopontis exilis*	*Transversopontis pax*	*Transversopontis pulcher*	*Transversopontis pulcheroides*	*Transversopontis rectipons*	*Tribrachiatus bramlettei*	*Tribrachiatus contortus*	*Tribrachiatus orthostylus*	*Zygodiscus adamus*	*Zygodiscus herlynii*	*Zygodiscus sigmoides*	*Zygrhablithus bijugatus*
									F	4	F	7			F		14															F
									1	1	1	5		F	1		6															1
								F	F	2	1	6		F	R		4															1
								2	F	2		1		F		R	5	8	8						1			R	R		R	F
								3	F	2		3		2		R	4	4	7						1			R			R	F
								2	F	4	2	1	3	4				5	17						R			F			R	F
			R						1	4	2	1	2	2		R		9	42		R		F		R		F		R		R	R
R									F	1	5		2	1				5	39				F		R	1	R				R	R
R			R	R						F	8		F	2		F		4	39				F			F			R		R	R
F							1			F	3			F		1		2	36				F			F			1		F	
R							3			F	4			F		2			31				R						F	R	F	
R		R	R				F			F	1					F			30		R		F						F	R	F	
R			R			R					3					1			37	R		R	F		R				F	F	F	
R	R	R	R			F					5					1			35	R			F	F					R	F	F	
R				3	R	R					1					4			28	R		R	F	F	R				R	F	1	
		R		3		R					1					3			42	F			R	R					R	F	1	
				F	R	R					1					F			44	F			R						R	1	1	
							F				1					F			2											R	1	
																			1												F	
																			3												F	
																			3												F	
																			4												F	

Table 7. Percentage occurrences of calcareous nannofossils observed in the Oligocene samples from Hole 708A.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Braarudosphaera bigelowii*	*Bramletteius serraculoides*	*Calcidiscus kingii*	*Catinaster? umbrellus*	*Coccolithus eopelagicus*	*Coccolithus fuscus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coronocyclus nitescens*	*Crassidiscus backmanii*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster adamanteus*
CP19b	180.75	20X-2, 105-106	A	M		O-1							F	F	9	F			62	R		F
	182.19	20X-3, 99-100	A	M		O-1							F	R	16	R			44	F		F
	183.88	20X-4, 118-119	A	M		O-1					F		F	R	12	R		F	48	1		F
	184.67	20X-5, 47-48	A	M		O-1					F		F	1	15	R		2	34	F		F
	185.64	20X-CC	A	M		O-1					F		F	R	8	F		F	37	F		R
	188.32	21X-1, 42-43	A	M		O-1					F		F	F	11	F		1	44	F		R
	189.82	21X-2, 42-43	A	M		O-1					F	R	F	R	11	F		F	52	R		R
	191.40	21X-CC	A	M		O-1	1			F	F	F	F		10	F	F	F	55	F		F
CP19a	197.92	22X-1, 42-43	A	M		O-1	1			F		F			15	1		1	48	F		R
	200.92	22X-3, 42-43	A	M		O-1				F		F		R	11	F		1	70			R
	202.42	22X-4, 42-43	A	M		O-1				R		R			11	1		1	52	F		1
	205.42	22X-6, 42-43	A	M		O-1				R		R			13	1		1	54	1		F
	206.68	22X-CC	A	M		O-1				R		R			7	F		2	67	F		F
	207.52	23X-1, 42-43	A	M		O-2	2			F		F			9	F		F	55	1	F	R
	212.02	23X-4, 42-43	A	M		O-1	1			R		F			9	R		1	66	1	R	
	213.52	23X-5, 42-43	A	M		O-2	2	F	f	F		F			8	R		R	64	1	R	
	215.88	23X-CC	A	M		O-1				F		F			4	F		F	69	1	1	
CP18	220.22	24X-3, 42-43	A	M	E-1	O-1	1			R		R			5	F			63	F	R	
	224.73	24X-CC	A	M	E-1	O-1						R		R	5	F			55	1	R	
	227.55	25X-1, 105-106	A	M	E-1	O-1				R		R			6	F			62	1	R	
	229.24	25X-2, 124-125	A	M	E-1	O-1						F			7	F			50	F	R	
	230.74	25X-3, 124-125	A	M	E-1	O-1	1					F			4	F			50	2	R	
	232.24	25X-4, 124-125	A	M	E-1	O-1	1			R		R			3	F			80	F	F	
	233.74	25X-5, 124-125	A	M	E-1	O-1						F			10	F			59	4	3	R
	234.42	25X-6, 42-43	A	P	E-2	O-1	1					F			5	F			60	2	1	
	234.77	25X-CC	A	P	E-2	O-1						1			7				64	1	1	

Note: See Table 3 for an explanation of the symbols used.

is calibrated as 46.6 Ma at Hole 711A, is older than the FO of *R. umbilica* observed elsewhere (44.38 Ma by Backman, 1987, and 46.0 by Berggren et al., 1985). The acceptance of *D. bifax* as a true basal marker for Subzone CP14a, therefore, results in a very short duration of Subzone CP13c.

Other datum events that have not been used for the standard zonations but are observed to be useful for the biostratigraphy of the middle Eocene are, the LOs of *Campylosphaera dela, Sphenolithus spiniger*, and *Sphenolithus furcatolithoides* and the FO of *Dictyococcites bisectus*. Because one sample from Section 115-711A-20X-3 is missing and was not examined, the latter three events are recognized within the same interval at Hole 711A. At Sites 707 and 709, the LO of *S. spiniger* occurs at slightly higher level than the FO of *D. bisectus* and the LO of *S. furcatolithoides. Nannotetrina alata*, which shows up more frequently than *Nannotetrina austriacus*, disappears together with *C. solitus*. Another easy-to-detect event is the LO of *Cruciplacolithus staurion* at just below the CP14a/CP14b boundary (Fig. 2). Other potentially useful datum events, such as the FOs of *Bramletteius serraculoides, C. titus*, and *S. furcatolithoides* and the LO of *Sphenolithus* sp. 1, are observed only at Hole 711A, and their reliability can not be confirmed.

BATHYMETRIC CHANGE AND GEOGRAPHIC DIFFERENCE IN PALEOGENE ASSEMBLAGE

Sites 707 through 711 were drilled to examine the bathymetric change of carbonate dissolution. Because the basement ages and tectonic settings differ between these sites, the bottom topography during the Oligocene and Eocene would be much different from the present one. Differences in present water depths, therefore, may not accurately represent the Paleogene paleodepth at each site. Compared with their Neogene counterparts, Paleogene nannofossils recovered at these sites are much less affected by dissolution. Nevertheless, minor differences in species diversity and relative abundances are detectable in the Paleogene floras observed at these sites. Some of these differences may be controlled by paleodepth.

Time-progressive Change in Species Diversity

Time-progressive changes in species diversity, expressed as the Shannon-Wiener Function, are illustrated for the three CBT sites where long Paleogene sequences were recovered (Fig. 3). Values fluctuate, but the general trends are similar between Sites 707 and 709; the diversity was generally high (ranging between 2.6 and 2.2) during the middle and late Eocene, started to decline during the early early Oligocene, and dropped to a low level of 1.8–1.4 through the rest of the Oligocene. Although the time-progressive pattern is similar to the shallower sites, the diversity is generally lower in the deep Site 711. Diversity during the Eocene and late Oligocene is lowered to the levels of 2.5–2.0 and 1.7–1.0, respectively. The magnitude of fluctuation is also greater during the late early and late Oligocene at deep Site 711, and three short intervals are recognizable in which the diversity measurements are significantly lower (Fig. 3). These low diversities are not so clear in the shallower sites, except for the oldest decrease observed in the upper lower Oligocene sequence of Site 709. These lower values may indicate repeated short occurrences of increased dissolution.

Although there are some irregularities, a similar trend is also observed in the mean species diversity calculated for all the Pa-

Table 7 (continued).

Discoaster barbadiensis	*Discoaster deflandrei*	*Discoaster nodifer*	*Discoaster saipanensis*	*Discoaster tanii*	*Ericsonia formosa*	*Ericsonia obruta*	*Ericsonia subdisticha*	*Helicosphaera compacta*	*Helicosphaera euphratis*	*Helicosphaera perch-nielseniae*	*Helicosphaera reticulata*	*Markalius inversus*	*Pedinocyclus larvaris*	*Reticulofenestra umbilica*	*Sphenolithus ciperoensis*	*Sphenolithus* aff. *ciperoensis*	*Sphenolithus dissimilis*	*Sphenolithus distentus*	*Sphenolithus* aff. *distentus*	*Sphenolithus moriformis*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Triquetrorhabdulus carinatus*	*Triquetrorhabdulus milowii*	*Zygrhablithus bijugatus*	Holococcolith type A
	5					4			F						1		2			12			2			
	9					6			F						1		3			18			1			R
	6					3			R						1		3			22			1	F		
	13					3			R						2		2			20			2	F		
	7					5			F						5		2			27			3	F		
	9					3			F						1		1			23			3			
	4					2			R						5		F			20			4			R
	11					1									1	1				15	f		2	F		
	8	R				F									10	F		F		11	c			F	R	
	4					1									4	F		1		6				R		
	2					1									F	F		4		12	11			R		
	7					1									5	F		2		11	1			F		
	4					1									R	1		1		10	4			1		
c	3	R	f			1		F		F	f	f		f		R		5		6	11			F	R	F
	1					F							f			R		1		4	11		F	F		
c	2		f		f	F	c								R	R		1	f	6	8	F		F		F
	F					F									R	1		4		5	10		R	R		R
	3	R		R		1										2		5		2	13	1		R		R
	1	R				1	f							r		2		7		13	10	F				R
	2					2										1		3		5	12	F				R
	F					F		R								2		10		9	15	F				F
	5	R		R		F		F								F		5		5	20	F				F
	3	F		R		F	f	1								1		1		4	3	F				R
	1	F		R		F	f	1								R		R		11	7	F			R	F
	1			R		1		1						r		R		F		7	17	R				F
r	1			F		F		F				r		r		R		R		11	11	F				F

leogene flora recovered at the five CBT sites (Fig. 4). The mean values of measured diversity do not strictly correspond to the present water depths, but they are generally lower at the presently deeper sites (711, 708, and 710) than at the two shallower Sites 709 and 707. The exact numbers and horizons where these data sets are measured vary between sites and different biostratigraphic zones, but the general trend observed here is likely to reflect advanced dissolution in the presently deeper sites.

Selective Dissolution and Geographic Differences in Paleogene Assemblage

The percentage occurrence of major species in each sample were averaged for five time intervals of the Oligocene and Eocene to investigate (1) the selective dissolution of calcareous nannofossils, (2) bathymetric change in the floral composition, and (3) biogeographic provincialism.

Good late Oligocene assemblages were recovered from all five CBT sites, and the averaged flora between approximately 25–27 Ma (part of Zone CP19) are compared (Table 17). The number of major species is higher at the shallower sites than at the deeper sites, and the species diversity is reduced with increasing water depth except at Site 708. The unproportionately high value may indicate the shallow paleodepth for Site 708. A robustly constructed *Coccolithus pelagicus* clearly increases in abundance at the deeper sites, reflecting its resistance to dissolution. On the other hand, delicately constructed species such as *Helicosphaera euphratis* or Holococcolith type A suggest the opposite trend. *Sphenolithus ciperoensis* and *Sphenolithus predistentus* also are reduced with increasing depth, but the trend is not clear for other similarly constructed sphenolith taxa (Table 17). The flora at Site 714, which are located away from the CBT sites and further north, are similar to the flora of Sites 707 and 709, which are from similar water depths.

The early Oligocene assemblages of approximately 34–35 Ma (parts of Zone CP17 and Subzone CP16c) are compared among the three CBT sites and Site 706, which is located in the subtropic area (Table 18). The number of major species are not much different among the CBT sites, but the species diversity is clearly lower at deepest Site 711. *Coccolithus pelagicus* or *Sphenolithus predistentus*, which show a bathymetric trend in the upper Oligocene flora, do not indicate any clear trend at this older level. On the other hand, two holococcolith taxa, *Lanternithus minutus* and *Zygrhablithus bijugatus*, are numerically reduced at the deeper sites. This agrees with the trend observed for Holococcolith type A in the upper sequence.

Floral differences observed between the CBT sites are minor compared with the big differences between the CBT sites and Site 706, in which the number of major species as well as the species diversity is high (Table 18). *Cruciplacolithus tarquinius, Quinquerhabdus colossicus, Syracosphaera* sp. 1, and *Umbilicosphaera* sp. 1 commonly occur only at the subtropical site, whereas *Ericsonia subdisticha* is restricted to the tropical CBT sites. As mentioned earlier, the Quaternary assemblage was also significantly different between Site 705, located adjacent to Site 706, and the CBT sites. This clear difference in the nannofossil flora observed in the upper Oligocene as well as in the Quaternary sequences indicates a persistent difference of water masses between the two subtropical sites and the tropical CBT sites.

Differences in the number of major species as well as in the species diversity is again obvious between the two shallower sites (Sites 707 and 709) and deepest Site 711 during two Eocene intervals (Table 19). The disappearance of the three holococcolith

Table 8. Percentage occurrences of calcareous nannofossils observed in the Oligocene samples from Hole 709C.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Bramletteius serraculoides*	*Calcidiscus kingii*	*Calcidiscus protoannulus*	*Catinaster? umbrellus*	*Chiasmolithus titus*	*Coccolithus eopelagicus*	*Coccolithus fuscus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coccolithus* sp. 1	*Coronocyclus nitescens*	*Crassidiscus backmanii*	*Cruciplacolithus tarquinius*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster adamanteus*	*Discoaster deflandrei*	*Discoaster nodifer*	*Discoaster tanii*
CP19b	200.80	22X-2, 60–65	A	M		O-1					F			1	F	14		F				40			F	9		
	202.30	22X-3, 60–65	A	M		O-1					F			1	F	7		F				51	R		1	6		
	203.80	22X-4, 60–65	A	M		O-1					F			1	F	6		F			F	55	F		F	3		
	205.30	22X-5, 60–65	A	M		O-1					F			F	F	11		F			F	32	F		F	12		
	206.52	22-CC	A	M		O-1					F		R	F	F	5		F			F	52	1		F	4		
	208.80	23X-1, 40–41	A	M		O-1	1				R		F	1	1	6		F	1		1	45	F		F	5		
	210.30	23X-2, 40–41	A	M		O-1	1				R		R	F	R	13		F		R	1	43	1		F	5		
	212.20	23X-3, 80	A	M		O-1	1				R		F	F	R	9		F			F	46	1		F	9		
	213.30	23X-4, 40–41	A	M		O-1	1		R		R		F	F	F	11	R	F		R	F	55	F		F	8		R
CP19a	214.80	23X-5, 40–41	A	M		O-1	1		F		R		R	F	F	9		F		R	1	58	F		F	2		
	216.09	23X-CC	A	M		O-1	1		F				F		F	8		F		R	1	61	1		R	2		
	218.40	24X-1, 40–41	A	M		O-1			F				F		F	5		F		R	F	61	R			4		
	219.90	24X-2, 40–41	A	M		O-1			F	R			F		R	10		F			1	51	R			2		F
	221.80	24X-3, 80	A	M		O-1			R				F		R	10		F			F	52	F			3		F
	222.90	24X-4, 40–41	A	M		O-1			R				1		R	10		F			R	51	1			1		
	224.40	24X-5, 40–41	A	M		O-1	1		R				F		R	6		F				60	1			3	R	
	226.04	24X-CC	A	M		O-1			F	R			F			6		F		R		61	1			3		R
	228.10	25X-1, 40–41	A	M		O-1			F				F			9		F		R		48	F	R		2		
	229.60	25X-2, 40–41	A	M		O-1			F				R			5		F				53	F	R		2	R	
	231.50	25X-3, 80	A	M		O-1							R		R	8		F				60	F		R	2	R	
	232.60	25X-4, 40–41	A	M		O-1			R				R			6		F				45	F			3		R
	234.10	25X-5, 40–41	A	M		O-1			R							6		F		F	F	48	F			2	R	
	235.54	25X-CC	A	M		O-1			R				R			7		F		R	F	46	1	F		1	R	R
CP18	237.83	26X-1, 43–44	A	M		O-1							F			5		R		R		55	F	R		2	R	F
	239.33	26X-2, 43–44	A	M		O-1							F			2		R				46	2	F		3	R	R
	240.83	26X-3, 43–44	A	M		O-1							R			5		F		R		54	2	F		F		R
	242.33	26X-4, 43–44	A	M		O-1							R			5		F		R		63	1	F	R	F		R
	243.83	26X-5, 43–44	A	M		O-1							R			8		F				53	F	F	R	4	R	R
CP17	245.33	26X-6, 43–44	A	M		O-1							R			3		F		R		70	1		R	1		R
	246.67	26X-CC	A	M		O-1							R			4		F				64	1			1		R
	247.43	27X-1, 43–44	A	M		O-1							R			7		R				66	F			F		R
	248.93	27X-2, 43–44	A	M		O-1							R			8		R				61	F			1	R	R
	250.43	27X-3, 43–44	A	M		O-1							R			12						54	F			F		1
	251.93	27X-4, 43–44	A	M		O-1							R			6						55	2			F		F
	253.61	27X-CC	A	M		O-2							R			9						47	7	F		1	R	F
	257.13	28X-1, 43–44	A	M		O-2							R			10	R					46	5	F		2		F
	258.63	28X-2, 43–44	A	M		O-2							F			7					R	50	3	F		F		F
	260.13	28X-3, 43–44	A	M		O-2							F			10		R				42	5	1		1	R	F
	261.44	28X-CC	A	M	E-1	O-2							R			9					F	47	4	1		1		F
	266.83	29X-1, 43–44	A	M		O-2			R				R			6	R	R				40	4	1	R	1		F
	268.33	29X-2, 43–44	A	M		O-2		R					R			12	R	R				49	6	F	R	1		F
CP16c	269.83	29X-3, 43–44	A	M		O-2		F					R			16	F	R				43	5	F		F		F
	271.33	29X-4, 43–44	A	M		O-2		1					R			16	F			R		34	10	1		F		F
	272.83	29X-5, 43–44	A	M	E-1	O-2		2					F			13	F	R				29	4	2		1	R	F
	274.33	29X-6, 43–44	A	M	E-1	O-2		3					F			9	F					34	8	5		F		F
CP16ab	275.91	29X-CC	A	M	E-1	O-2		7	R				F			13	1			R		33	8	5		F		R
	276.53	30X-1, 43–44	A	M		O-2		8	R				F			10	F	R				51	6	3		F		R
	278.03	30X-2, 43–44	A	M		O-2		3	1				R			12	F	F				29	11	7		F	R	F
	279.53	30X-3, 43–44	A	M		O-2		5	3	R		F	F			4	1	R		R		49	10	5		F		F
	281.03	30X-4, 43–44	A	M		O-2		5	F				F			15	1	R		R		45	7	2		F	R	F
	282.53	30X-5, 43–44	A	M		O-2		3	3			F	F			17	1	R				32	15	5		F		F

Note: See Table 3 for an explanation of the symbols used.

taxa, *L. minutus, Z. bijugatus*, and Holococcolith type A, is clear in Site 711. *Pedinocyclus larvalis* also disappears at the deepest site, and *Bramletteius serraculoides* is reduced in abundance progressively in the deeper sites. On the other hand, two robustly constructed species, *C. pelagicus* and *Cribrocentrum reticulatum*, demonstrate an opposite trend. These observations clearly indicate a bathymetrically advanced dissolution of nannofossils.

The relationship between present water depth and the diversity of flora is less clear in the middle middle Eocene time interval equivalent to Subzone CP13c (Table 20). In accordance with the trend observed in the younger intervals, the abundance of *Coccolithus pelagicus* is greater at the deeper sites, but another robustly constructed species, *Cylicargolithus floridanus*, shows an opposite trend. The depth-progressive change between two similarly constructed species, *Discoaster barbadiensis* and *Discoaster saipanensis*, also shows that they have trends opposite each other.

Among the three holococcolith taxa that show a clear bathymetric trend in the upper intervals, *Z. bijugatus* is the only species that occurs as a major element of the flora in this time interval, and its absence at the deepest Site 711 is conspicuous compared with its common occurrence in the two shallower sites. Actually, holococcoliths are scarce except in the lower middle Eocene (Subzone CP13a) at Site 711 (Tables 11 and 12). Their scarceness, therefore, may partly reflect provincialism rather than selective dissolution. Even if this speculation is true, the bathymetrically controlled reduction in abundance of holococcoliths is evident at all the other intervals examined.

In summary, bathymetric control is apparent in the species diversity and in the preservation of some major species, but it is not too obvious in the relative abundances of most the major

Table 8 (continued).

Ericsonia formosa	*Ericsonia obruta*	*Ericsonia subdisticha*	*Hayaster perplexus*	*Hayella situliformis*	*Helicosphaera bramlettei*	*Helicosphaera compacta*	*Helicosphaera euphratis*	*Helicosphaera intermedia*	*Helicosphaera perch-nielseniae*	*Helicosphaera recta*	*Helicosphaera reticulata*	*Isthmolithus recurvus*	*Lanternithus minutus*	*Markalius* sp. 1	*Pedinocyclus larvaris*	*Pedinocyclus* sp.	*Peritrachelina joidesa*	*Pontosphaera segmenta*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilica*	*Sphenolithus ciperoensis*	*Sphenolithus* aff. *ciperoensis*	*Sphenolithus dissimilis*	*Sphenolithus distentus*	*Sphenolithus* aff. *distentus*	*Sphenolithus moriformis*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Syracosphaera* sp. 1	*Triquetrorhabdulus carinatus*	*Triquetrorhabdulus milowii*	*Zygrhablithus bijugatus*	Holococcolith type A
	3						R											R			1	F	4			21			R	5		R	R
	5						F											R			3	F	5			15				4		R	R
	5		R				F											R			4	F	3			13			R	6	R	R	
	2						F			R								R			4	1	6			28				3			
	2						F	R		r								1			5	F	F			25			R	3	R		R
	1						F											R			7	F	F	r		24				3	R		
	1		R				F											R			7	R	F	r		25				F	F	F	R
	1		R				F											R			14	F	F	r		14	f			1	F	R	R
	2						F											R			7	F	F	f		13	f			F	F	R	R
	5		R				F									R		R		r	8	2	F	1		10	f			1	F	R	R
	2						F	R								F		R			8	1		2		10	1			R	F	F	R
	1						R	R								F		R			F	F		5		12	8				R	R	
	3						R	R								R		R			F	F		4		10	13				F	F	R
	3		R				R			R						R		R			F	F		4		7	16				R	R	R
	1		R				R			R						F		R			F	F		2		11	16			R	R	R	
	1						R	R								1		R		r	F	1		2		9	10				R	R	
	F						F	R		R						F					F	1		3		11	7				F	R	
	F						R	F								1		R			F	3		5		9	14	R		R	F	F	
	1						R			R						F					2	1		2		8	14	F			F	F	
	F	F				R	R									R					1	2		2		9	9	F		R	F	R	
	1	F					R	R								F		R			F	4		2		16	14	F		R	F	R	
	4					R	R		R							F		R			1	4		1		11	13	F			R	F	
	2					R	F									R		R			F	1		3		10	19	F		R	F	F	
	3	1				2	F									R		R				F		2		10	15	F				F	
	1	1				1	F																	F		17	22	F				F	
	F	1				2	R	R								R								F		12	20	R				F	R
	1	F				3	R									R		R				R		F		11	11	1				1	R
	1	1				2												R				R		F		13	12	F				1	R
	1	1				1										R										8	10	F				F	
	F	F				F			R							R										11	15	F				F	
	1	F					F																			10	13	R				F	
	1	F				F				R						R		R								8	16	F				F	R
	1	1				2	R	R	R							R										8	19	R				F	
	F	2				F										R										13	14	F				1	R
	1	1				1										R										7	21	R				F	R
	F	1				F	R		R		R				1	R		R							R	9	19					2	R
	2	1				2			R						R	R									R	9	19	R				F	F
	1	1				F			R		R				R	R									F	9	22					F	F
	F	1				F					R		R		R	R									F	11	20	R				F	
	F	1				1					R				R	F		R							1	12	25					F	R
	1	F				1	R	R	R		R		R		R	R									F	6	15	R				4	R
	F	F				2			R		R		4		F	R	R	R		R					F	9	11					5	1
	4	F				1	F	F	R		F		1		F	F		F		R					1	7	13					1	3
r	F	F			R	1	F		R		F		5		F	R		F		R					1	7	16	R				1	8
	F	F			R	2	F		R		1		2	F	F	R		F		R					1	9	8					1	9
1	F	1			F	1	1	R			2		1	F	F		R	F		R					1	7	5					F	2
F	F	3		F		F	F				F		R	R	F	R		R		F						3	9					F	F
1	F	7		1		1	R				F	F	1	R	F	R			F	F						7	7	R				F	F
F	F	3		F		F	F	R			F	R		R	F	R		R		F						8	2	F				1	F
F	F	1		F		F	R	R			1	R		F	R					F						5	13	F				R	F
1	1	6		F		F	R				F	R	F	F	F			F		F						4	3					F	F

species in the Paleogene sequences studied. Aside from the depth-progressive decreases in holococcoliths, increases in *C. pelagicus* and *C. reticulatum* provide the major evidence that clearly demonstrated bathymetrically controlled changes in the Paleogene flora.

SUMMARY

Biostratigraphy and floral characteristics were quantitatively investigated for the Quaternary and Paleogene nannofossils recovered by Leg 115 drilling in the tropical and subtropical Indian Ocean. The observations can be summarized as follows:

1. Nannofossils are very abundant in most of the Paleogene sections studied, and the observed flora were identified to standard zones and subzones of the late early Paleocene through the latest Oligocene.

2. The commonly used datum event, the FO of *Sphenolithus distentus*, is easily confused with other events; and some other markers, such as the FO of *Reticulofenestra umbilica* and the LO of *Ericsonia obruta*, are either unreliable or are diachronous. Extra care is necessary in applying these events to the age calibrations and regional biostratigraphy.

3. Eleven previously undescribed taxa were noted, and a new species *Crassidiscus backmanii* was described. This new species as well as several other species that included some of the undescribed taxa show good potentials for regional biostratigraphy.

4. A set of datum events considered useful for the biostratigraphy of the tropical Indian Ocean was selected for the middle

Table 9. Percentage occurrences of calcareous nannofossils observed in the Eocene sample from Hole 709C.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Braarudosphaera bigelowii*	*Bramletteius serraculoides*	*Calcidiscus kingii*	*Calcidiscus protoannulus*	*Campylosphaera dela*	*Chiasmolithus consuetus*	*Chiasmolithus expansus*	*Chiasmolithus gigas*	*Chiasmolithus grandis*	*Chiasmolithus medius*	*Chiasmolithus solitus*	*Chiasmolithus titus*	*Coccolithus eopelagicus*	*Coccolithus pelagicus*	*Coccolithus* sp. 1	*Coronocyclus nitescens*	*Cribrocentrum reticulatum*	*Cruciplacolithus cruciformis*	*Cruciplacolithus staurion*	*Cruciplacolithus* cf. *tarquinius*
CP15b	284.03	30X-6, 43–44	A	M		O-2			5	3	F								F	R	13	F					
	284.78	30X-CC	A	M		O-2			5	2	F								F		9	F		R			
	286.23	31X-1, 43–44	A	M		O-1			11	2	F								F		12	F		22			
	287.73	31X-2, 43–44	A	M		O-1			3	1	R										16	F		36			
	289.23	31X-3, 43–44	A	M		O-2			10	3									F		9	F		30			
	290.73	31X-4, 43–44	A	M		O-2			4	5	R								1		13	F	R	19			
CP15a	292.23	31X-5, 43–44	A	M		O-2			2	6	F								F		9	F		23			
	294.32	31X-CC	A	M		O-2			4	3	F	R							R	R	4	F	R	26			
	295.83	32X-1, 43–44	A	M		O-2			5	5									R	F	11	F	R	6			
	297.33	32X-2, 43–44	A	M		O-2			3	4									F	F	5	F	R	8			
	298.83	32X-3, 43–44	A	M		O-2			3	8									R	F	6	F		13			
	300.33	32X-4, 43–44	A	M		O-2	1		4	F				R		r			R	F	6	R	R	33			
	301.83	32X-5, 43–44	A	M		O-2	2		5	1		F		R		r			R	1	5	F	R	5			
	303.33	32X-6, 43–44	A	M		O-2	2		3	2		F		R		f			F	F	8	F	F	2			
	305.06	32X-CC	A	M		O-2			2	9									F	F	5	1	F	3			
	305.53	33X-1, 43–44	A	M		O-2			6	9									F	F	6	F	F	1			
	307.03	33X-2, 43–44	A	M		O-2			4	6									R	F	6	R	F	9			
	308.53	33X-3, 43–44	A	M		O-2			4	6									R	1	4	F	F	10			
?	310.03	33X-4, 43–44	A	M		O-2	2		3	2	F	F				F			F	F	10	R		1			
	311.53	33X-5, 43–44	A	M		O-2	3		1	1	1	1				F			F	1	12	1		2			
CP14b	313.03	33X-6, 43–44	A	P		O-3			5	2		F				F			F	1	6	F	R	3			
	313.51	33X-CC	A	P	E-3	O-3			2	1		F				R		r	F	F	11	F		4			
	315.23	34X-1, 43–44	A	M		O-2			F	1	R	F				F			1	F	20	F		1			
	316.73	34X-2, 43–44	A	M		O-2			2	F	F	F		R		R			F	F	12	F		1			
	318.23	34X-3, 43–44	A	M		O-2			2	F	2	F				F			1	F	10	F		F			
	319.73	34X-4, 43–44	A	M		O-2			1	F	1	1				F			1	F	11	1		F			
	321.23	34X-5, 43–44	A	M		O-2		2	F	F	1					F			1	F	17	1		F			
	322.73	34X-6, 43–44	A	M		O-2			1	R	R	F				R			2	1	16	1		3			
	323.95	34X-CC	A	M	E-1	O-2		R	1	R	1	F				R			F	1	16	F		F			R
	324.83	35X-1, 43–44	A	M	E-1	O-2			F	R	R	1		R		F			1	1	9	F					
	326.33	35X-2, 43–44	A	P	E-1	O-3		R	1	R	R	1				F			1	F	10	F					
CP14a	327.83	35X-3, 43–44	A	P	E-1	O-3			1		R	F				F		R	F	1	7	F				R	R
CP13c	329.33	35X-4, 43–44	A	P	E-1	O-3			1		R	F				R		F	F	F	10	F					
	330.83	35X-5, 43–44	A	P	E-1	O-3			2	R	1	F	R			F		R	F	F	8	F				R	
	332.33	35X-6, 43–44	A	M	E-1	O-2			4		F	1	R			R		F	2	F	5	1				R	
	334.03	35X-CC	A	M	E-1	O-2			4		R	1				F		F	F	1	10	F				R	R
	334.53	36X-1, 43–44	A	M	E-1	O-2			2		R	F				R		R	1	F	9	F				R	
	336.03	36X-2, 43–44	A	M	E-1	O-2			2	F		1				R		F	R	F	7	R				R	
	337.53	36X-3, 43–44	A	M	E-1	O-2			F	F	R	F	R			R		1	R	F	9	R					
	339.03	36X-4, 43–44	A	M	E-1	O-2			1	R	R	F	R			F		1	F	F	8	F				R	
	339.78	36X-CC	A	P	E-1	O-3			1		F	1	R			F		F	1	F	15	F				R	
	344.33	37X-1, 43–44	A	P	E-1	O-3			F	R	1	F	F	R		F	F	F	1	R	12	F				R	
	345.83	37X-2, 43–44	A	P	E-1	O-3			F		1	1	F			F		R	F		9	F				R	
	347.33	37X-3, 43–44	A	M	E-1	O-2			F		F	1	R			F		R	F		13	F				F	
	348.83	37X-4, 43–44	A	M		O-2			2		2	2	R			R	R	R	F	F	9	F			R	R	
CP13b	350.33	37X-5, 43–44	A	M		O-2			F		1	F			R	R		R	F	F	11	F				F	
	351.83	37X-6, 43–44	A	M		O-2			F		2	1			F	F		R	1	F	8	F			R	F	
	353.56	37X-CC	A	M		O-2			1		F	F			R	F		R	F	R	6	1				F	

Note: See Table 3 for an explanation of the symbols used.

Eocene through late Oligocene time intervals, and the ages for these events were estimated.

5. Species diversity is lower at the deeper sites along the Carbonate Bathymetric Transect (CBT), and selective dissolution related to the paleodepth is likely to be the main cause.

6. As a result of selective dissolution in deeper waters, holococcoliths are reduced in abundance at the deeper sites, whereas the abundance of *Coccolithus pelagicus* and *Cribrocentrum reticulatum* increases. Some other species also show depth-controlled changes, but the trends are either unconfirmed or are inconsistent among the observed sites.

7. Paleogene and Quaternary flora are similar among the tropical sites, but they are significantly different among the tropical sites and the two subtropical sites.

8. Ten datum events were identified in the Quaternary and top Pliocene cores at the nine sites.

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Table 9 (continued).

Cruciplacolithus vanheckae	*Cruciplacolithus* spp.	*Cyclicargolithus floridanus*	*Cyclolithella kalianata*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster barbadiensis*	*Discoaster bifax*	*Discoaster deflandrei*	*Discoaster nodifer*	*Discoaster saipanensis*	*Discoaster tanii*	*Ericsonia formosa*	*Ericsonia pacifica*	*Ericsonia subdisticha*	*Hayella situliformis*	*Helicosphaera compacta*	*Helicosphaera euphratis*	*Helicosphaera heezenii*	*Helicosphaera intermedia*	*Helicosphaera lophota*	*Helicosphaera reticulata*	*Helicosphaera seminulum*	*Isthmolithus recurvus*	*Lanternithus minutus*	*Markalius inversus*	*Markalius* sp. 1	*Markalius* sp. 2	*Nannotetrina alata*	*Nannotetrina austriacus*	*Nannotetrina* sp. (small)
		30		10	4			F	R	R	F	2		2	R	1	R		R		F		R	8						
		41		13	1	R		F	F	F	F	2		1	F	1					F		R	6						
		26		F	1	2		F	F	3	F	4	R	F	F	F	R				F			1						
		9		F	1	11		F		4	2	3			R	F					F		R							
		8		3	2	7				9	3	4			R	F			R		F									
	R	19		3	8	7			R	6	1	2				1	R				F		R	R						
	R	29		5	4	6				3	1	2			R	F			R		F									
		31		8	2	4		F		3	1	2				F	R	R	R		R			F						
		11		7	25	5		F	F	2	F	1				F		F			F			1						
		15		14	18	4		F	R	2	F	1	R		R	1	F	R	R		F			F						
		6		9	18	5			R	3	F	1	R			1	R	1			F			F						
		13		3	5	6			R	5	1	3			R	R		F			F			F		R				
		28		18	10	4			R	3	F	F				F		1			F			F		R				
R		28	R	12	16	6			R	6	R	F				R		F			R			F		F				
		21	R	25	8	6			F	6	R	F				R		F			F			R						
		16	R	25	16	7			R	4	F	F				R		1			F			R		R				
		8		23	15	7			R	4	F	1				R		F			F			R		R				
		8		22	17	3			R	3	F	2			R	F		1	R		F			F		R				
		38		11	5	3			R	9	R	1				F		1		R	F			F		F				
	F	31				10			R	10		2				F		1		R	F			F	R	F				
	F	30		14	13	7			R	F	R	F				F		1		F	F			F	R	F				
	R	35		2	3	7			R	2		1	R			F		2		F	F	R		1	R	F				
R	F	15	R		R	9				13		2	F			F		1		F	R	R		1	R	F				
R		47				2				6		1	F			F		1		F	R	R		1	R	1				
		43				5				7		2	F			R		F		F		R			R	F				
		17				17				4		2	F			R		1		F				F	R	F				
	R	10	R			11				F		6	F							1	R	R			R	2				
		22	R			10				1		2	F					F		F		R			F	2				
		18	R			14				1		3	F					F		F		R		F	R	1				
	R	50				6				1		3	R					F		F		R		F	F	1	F			
	R	30				11				2		8						F		F		R		F	R	6	F			
	F	23	R			16	F			F		5						F		F		R		F	F	5	F	R		
R	F	40				7	2			F		3	R					F		F	R	F		F	F	2	F	R		
	F	47	R		R	5	F			F		2						F		F		R		R	F	2	F	F		
R	F	29				12	1			R		4	R					F		1		R			F	2	F	F		F
F	F	12				12	2		R	1		7						F		F		R		R	1	2	R	F		F
	F	18	R		R	17	1			1		2						F		R		R		F	R	1	R	F		F
	F	29				14	1	F	R	1		3						F		F		R			F	F	F	R		F
	F	36				8	1			F		3	R					F		1		R			F	2	F	R		F
	F	31			R	13	2			F		7	R					F		F		R			F	1	F	R		F
R	F	33				7	F			R		6						F		1		R			F	F	F	F		F
F	F	20	R			6	F					4						F		1		F			F	2	F	F	R	F
F	F	21				5	F					5						F		F		F			F	1	F	1		1
F	F	23				8	1				R	1						F		3		F			F	3	F	F		F
F	1	24	R			6		F		R		5						1		F		F			F	2	R	R	R	F
R	F	39				11				R	R	4	R					F		F		F			F	1	R	R	R	F
R	F	41				11			R	R		2								F		F		R	R	2		R	R	1
F	R	19				11				F		3								F		F		R	R	1				2

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Table 9 (continued).

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Pedinocyclus larvaris*	*Pontosphaera formosa*	*Pontosphaera scissura*	*Pontosphaera segmenta*	*Pseudotriquetrorhabdulus inversus*	*Reticulofenestra dictyoda*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilica*	*Sphenolithus furcatolithoides*	*Sphenolithus intercalaris*	*Sphenolithus moriformis*	*Sphenolithus obtusus*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Sphenolithus radians*	*Sphenolithus spiniger*	*Toweius*? sp. 1	*Zygrhablithus bijugatus*	Holococcolith type A
CP15b	284.03	30X-6, 43–44	A	M		O-2		F			F			1	5			3		2	1				2	2
	284.78	30X-CC	A	M		O-2		F			F			F	3			2		F	1				1	1
	286.23	31X-1, 43–44	A	M		O-1		R			F			F	F			4		1	F				1	2
	287.73	31X-2, 43–44	A	M		O-1					1				F			3		F	F				1	1
	289.23	31X-3, 43–44	A	M		O-2					R							4		F	F				1	1
	290.73	31X-4, 43–44	A	M		O-2		R			R							2		1	F				F	1
CP15a	292.23	31X-5, 43–44	A	M		O-2		F			F			R	R			2		F	1				F	F
	294.32	31X-CC	A	M		O-2		F	R		R				R			3		1	R				1	1
	295.83	32X-1, 43–44	A	M		O-2		F			F			R	R			8			1				F	1
	297.33	32X-2, 43–44	A	M		O-2		F			F			F	F			7			1		r		1	1
	298.83	32X-3, 43–44	A	M		O-2		F			F			F	1			5		R	F				1	1
	300.33	32X-4, 43–44	A	M		O-2	1	F			R	F		R	F			7			1				1	1
	301.83	32X-5, 43–44	A	M		O-2	2	F			R	F						3	5		F				2	1
	303.33	32X-6, 43–44	A	M		O-2	2	1			R	F						2	1		F				1	F
	305.06	32X-CC	A	M		O-2		1			R							4	R		F				1	F
	305.53	33X-1, 43–44	A	M		O-2		F			R							4	R		F				F	F
	307.03	33X-2, 43–44	A	M		O-2		F	R		R				R			6			1				5	R
	308.53	33X-3, 43–44	A	M		O-2		F					R	F	F			4			1	R			1	3
?	310.03	33X-4, 43–44	A	M		O-2	2	1			R	F			R		F	F	4	R	F				2	F
	311.53	33X-5, 43–44	A	M		O-2	3	F			R	F		3	F	2		7			F		2		2	F
CP14b	313.03	33X-6, 43–44	A	P		O-3		1	R		R	F					F	2	4		F	R			1	2
	313.51	33X-CC	A	P	E-3	O-3		F			R	F		F	F		6	3		F	F	R	6		4	1
	315.23	34X-1, 43–44	A	M		O-2		F			R	1	F	1	F	F	2	6		F	F	R	15		F	F
	316.73	34X-2, 43–44	A	M		O-2		F			R	F	F	2	1	2	F	3			F	R	5		1	F
	318.23	34X-3, 43–44	A	M		O-2		F			R	F	F	F	F	4		4			F	R	5		7	1
	319.73	34X-4, 43–44	A	M		O-2		F				F		12	2	7	R	5			F	R	4		5	F
	321.23	34X-5, 43–44	A	M		O-2		1			R	F		7	3	15		2			F	R	12		2	F
	322.73	34X-6, 43–44	A	M		O-2		F	R		R	F		5	4	8		7			1	R	3		3	1
	323.95	34X-CC	A	M	E-1	O-2		F			R	F	F	9	9	6		2			1	R	3		7	1
	324.83	35X-1, 43–44	A	M	E-1	O-2		1	R		R	F	1	6	2	3		1			F		3		5	F
	326.33	35X-2, 43–44	A	P	E-1	O-3		1				F	F	3	1	6		3			F		5		4	1
CP14a	327.83	35X-3, 43–44	A	P	E-1	O-3		F		R		2	F	4	R	11		3			F		9		8	F
CP13c	329.33	35X-4, 43–44	A	P	E-1	O-3		1	R	R	R	2	F			13		3			R	R	7	R	1	F
	330.83	35X-5, 43–44	A	P	E-1	O-3		1		R		4	F			6		2				F	9	F	F	F
	332.33	35X-6, 43–44	A	M	E-1	O-2		F	R	R	F	5	F			5		2				F	12	F	3	R
	334.03	35X-CC	A	M	E-1	O-2		1	R		F	1	F	4		5		3				2	10	F	13	1
	334.53	36X-1, 43–44	A	M	E-1	O-2		F	R	R		2	F	1		11		5				F	10	7	4	F
	336.03	36X-2, 43–44	A	M	E-1	O-2		F	R	R		1	F	R		8		2				F	7	3	10	F
	337.53	36X-3, 43–44	A	M	E-1	O-2		F	R			5	1	F		10		3				F	9	1	4	F
	339.03	36X-4, 43–44	A	M	E-1	O-2		F	R		R	2	F			9		1				F	7	1	8	1
	339.78	36X-CC	A	P	E-1	O-3		1	R		R	2	F			8		2				F	8	F	3	1
	344.33	37X-1, 43–44	A	P	E-1	O-3		1	F	R	R	4	F	2		7		3			F	2	13	F	10	R
	345.83	37X-2, 43–44	A	P	E-1	O-3		1	F	F	R	4	F	4		8		4			F	1	16		3	R
	347.33	37X-3, 43–44	A	M	E-1	O-2		F	R	F	F	3	F	4		9		8			R	F	10		3	R
	348.83	37X-4, 43–44	A	M		O-2		1	F	R	F	6	F	4		7		2			R	F	10	R	5	1
CP13b	350.33	37X-5, 43–44	A	M		O-2		F	R	R	F	4	1	2		3		3			F	1	6		1	F
	351.83	37X-6, 43–44	A	M		O-2		F	R		F	8	2	F		1		2			F	F	8		2	F
	353.56	37X-CC	A	M		O-2		4	R		F	5	2	1		6		4				F	8		16	F

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APPENDIX A

Systematic Paleontology and Remarks on Selected Taxa

Coccolithus sp. 1
(Plate 1, Figs. 3 and 4)

Remarks. This is an elliptical placolith with a medium-sized central area that is covered by plates. The placolith size ranges from approximately 7 to 10 μm. This species resembles *Coccolithus pelagicus*, but it is easily identified from the latter species by the dark appearance of its proximal disc under cross-polarized light as well as by the covered central area, which is a notch brighter than the discs under a cross-polarized light. It also appears darker under a phase-contrast light, and the elements making up the two discs are wider and fewer than those of *C. pelagicus*. This species commonly occurs in the lower Oligocene through middle Eocene, and its LO is observed within Zone CP17.

Genus *Crassidiscus* n. gen.
Type species *Crassidiscus backmanii* n. sp.

Description. Elliptical coccolith constructed of more than four overlapping layers of shields. The distal shield consists of imbricating elements radially disposed around the small elliptical central area. The stacking layer of proximal shields has a large central area that is covered with a complicated arrangement of elements.

Remarks. The new species *Crassidiscus backmanii* is unique among Cenozoic taxa in having multilayered shields. Because no genus was available to comprise this species, the new genus was introduced.

Crassidiscus backmanii n. sp.
(Plate 1, Figs. 15 and 16; Plate 3, Figs. 5–9)

Description. This elliptical species is constructed from a single distal shield layer and three proximal shield layers. The distal shield has 30–35 radiating elements and appears similar to such ordinary placoliths as *Coccolithus pelagicus*. The proximal shields consist of the same numbers of elements as the distal shields. The three layers of proximal shields are identical in the outer periphery, but they are narrower than the distal shield. The upper two layers of the proximal shields are narrower than the proximally concaved basal layer. The proximal side of the central area is large and consists of a peripheral circle surrounding a pack of central elements. The peripheral circle is formed by radially arranged laths. Because of the severe overgrowth, the structure of the distal side of the central area is not clear, but a prominent collarlike structure protrudes from the periphery of the central area. This protruding structure varies in overall shape and number of elements. It is probably an original structure, like the wall structure of extant subspecies *Emiliania huxleyi corona*, but the possibility that this structure is an array of strongly overgrown elements cannot be excluded. The shields are rather bright, and the central part is dark under cross-polarized light except for the projected collarlike structures.

Remarks. This species occurs in a narrow stratigraphic range of the upper Oligocene at Sites 707, 709, 710, 711, and 714; moreover, a subsequent examination of DSDP Leg 58 materials revealed the occurrence of this species at Site 445 (25°31.36′N, 133°12.49′E). The sequence between Samples 58-445-45R-CC and 58-445-47R-3, 48–49 cm, was identified to CP19b (Okada, 1980), and this species occurs commonly in Samples 58-445-46R-2, 94–95 cm, and 58-445-46R-3, 94–95 cm, whereas it is absent at the higher (Sample 58-445-46R-1, 94–95 cm, and above) and lower (Sample 58-445-46R-4, 94–95 cm, and below) intervals. Its identical occurrence in the northwest Pacific Ocean and in the tropical Indian Ocean confirmed its high potential for a detailed biostratigraphy. The presence of multilayered proximal shields is unique among Cenozoic species and creates an optical character that is similar to some Mesozoic taxa. Since no other Mesozoic forms coexists and its narrow-ranged occurrence is identical between the six sites, it is very unlikely that this species was reworked from Mesozoic sediments.

Occurrence. *Crassidiscus backmanii* occurs in a very narrow stratigraphic range of the upper Oligocene (the lower or middle parts of Subzone CP19b) in the tropical Indian Ocean and in the Philippine Sea.

Size. 6.5–8.5 μm, maximum diameter; holotype, 7.4 μm.

Holotype. YGUES 1001 (Plate 3, Fig. 5).

Paratype. YGUES 1002 through 1005 (Plate 3, Figs. 6–9) and YGUES 1006 (Plate 1, Figs. 15 and 16).

Type locality. Tropical Indian Ocean, Sample 115-709C-23X-1, 40—41 cm (208.8 m).

Cruciplacolithus tarquinius Roth and Hay, 1967
(Plate 1, Figs. 5 and 6)

Cruciplacolithus tarquinius Roth and Hay in Hay et al., 1967, p. 446, pl. 6, fig. 8.

Remarks. This is a medium-sized placolith with a large central area that is spanned by a delicate cross structure. Both discs and the cross structure are faintly bright under cross-polarized light. The cross structure is easily broken off, and many specimens show no sign of the structure even in a well-preserved sample. The placolith size measures from 5.0 to 6.5 μm. This species was originally described from the lowest Oligocene in JOIDES Core 5 (Hay et al., 1967), but Perch-Nielsen (1985) indicated its occurrence in the middle Eocene Zone CP13b. Small *Cruciplacolithus* identifiable to this species occur commonly in the lower Oligocene sequence at Site 706, and rare occurrences are also recognized in the Oligocene sequences at the other Leg 115 sites. Rare specimens looking similar to this species (see Perch-Nielsen, 1988) also occur in the middle Eocene at Sites 709 and 711. The Oligocene form is generally more abundant than the Eocene form in Leg 115 materials, and the former's occurrence fits well with the original description. Since these two forms occur in isolated intervals, the identification of the Eocene form into this species needs further examination.

Cruciplacolithus spp.

Remarks. All small *Cruciplacolithus* that are not readily identifiable to existing species are included in this entity. This group is mostly observed in the middle Eocene sequences, and undoubtedly contains several different taxa, but their relative abundance as a whole is not significant in most of the examined samples.

Markalius sp. 1
(Plate 1, Figs. 7 and 8)

Remarks. This is a round placolith with a small central area. Both discs are dark, and a thin collar surrounding the central area appears bright under a cross-polarized light. The placolith size measures from 5 to 8 μm. A set of laths radially project toward the center of the disc from the periphery of the central area. Because of the lack of a bright central area under a cross-polarized light, this taxon was separated from *Markalius inversus*. There is, however, a certain possibility that this is actually a partly dissolved *M. inversus*. Gartner (1971) identified three groups within the placoliths that have been assigned to *M. inversus* by various authors. Because of the overgrowth, the number of elements are not easily determined for the specimens studied. Because of the small size, however, many of these specimens are likely to belong to the hitherto undescribed "third group" mentioned by Gartner. This taxon occurs in the middle Eocene through the lower Oligocene sediments.

Markalius sp.
(Plate 1, Figs. 9 and 10)

Remarks. This is a large circular placolith with a small closed central area. Both discs are bright under a cross-polarized light, and the central area is a notch brighter than the discs. The overall size ranges from 10 to 12 μm. Because of its totally bright appearance under cross-polarized light, it is readily distinguishable from *Markalius inversus*. Moreover,

Table 10. Percentage occurrences of calcareous nannofossils observed in the Oligocene samples from Hole 710A.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Calcidiscus kingii*	*Catinaster? umbrellus*	*Coccolithus eopelagicus*	*Coccolithus fuscus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coccolithus* sp. 1	*Coronocyclus nitescens*	*Crassidiscus backmanii*	*Cruciplacolithus tarquinius*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster adamanteus*
CP19b	142.53	16X-1, 43–44	A	G					R		F	F	9		F				54			R
	144.03	16X-2, 43–44	A	G					F		1	R	7		F			F	49	R		R
	145.53	16X-3, 43–44	A	G					F		1	R	15		F			R	39	F		R
	146.03	16-4, 43–44	A	G					F		1		7		R			F	42	F		R
	147.53	16X-5, 43–44	A	G					1		F	R	4		R			R	41	F		R
	149.46	16X-CC	A	M		O-1			1		F	R	4		F			1	54	R		R
	152.23	17X-1, 43–44	A	M		O-1			1	R	F		7		F			R	65	1		R
	153.73	17X-2, 43–44	A	M		O-1			F	R	F		8		R			R	48	F		R
	155.23	17X-3, 43–44	A	M		O-1			F	F	F	R	12		F	1		F	50	F		R
	156.73	17X-4, 43–44	A	M		O-1			1	F	F	R	19		F	F		F	31	F		R
	158.23	17X-5, 43–44	A	M		O-1			F	R	1		16		F			F	44	1		R
	159.73	17X-6, 43–44	A	M		O-1			R	F	F		9		F			1	45	1		R
CP19a	160.80	17X-CC	A	M		O-1				F	F		10		F			1	42	F		R
	161.83	18X-1, 43–44	A	M		O-1		R		F	F	R	9		1		R	1	62	F		R
	163.33	18X-2, 43–44	A	M		O-1				F	F	R	11		F		R	3	60	R		R
	164.83	18X-3, 43–44	A	M		O-1	1			F		R	8		F		R	2	54	F		R
	166.33	18X-4, 43–44	A	M		O-1		R	R	F		R	9		F			3	62	F		R
	167.83	18X-5, 43–44	A	M		O-1		F		F		F	8		F			1	55	F		R
	168.65	18X-CC	A	M		O-1		F		F		R	12		F			F	56	1		R
	171.53	19X-1, 43–44	A	M		O-1		F		R		R	10		F		R	1	54	F		R
	173.03	19X-2, 43–44	A	M		O-1		F		F			10	R	F			1	55	3		R
	174.53	19X-3, 43–44	A	M		O-1		F		R			7		F		R	1	66	1		R
	176.03	19X-4, 43–44	A	M		O-1		F		R			11		F			F	61	F		R
	177.53	19X-5, 43–44	A	M		O-1		1		R			10		F				61			R
	179.03	19X-6, 43–44	A	M		O-1		F		R			5		F		R		57	F		
	180.45	19X-CC	A	M		O-1		F		R			8		F		1		56	F		R
	181.23	20X-1, 43–44	A	M		O-1		F		R			6		F		F		64	F		
	182.73	20X-2, 43–44	A	M		O-1		R		F			3		F		R	F	47	F		R
CP18	184.23	20X-3, 43–44	A	M		O-1				R			5		F		R	1	51	F		
	185.73	20X-4, 43–44	A	M		O-1				R			1		F		F		62	F	F	
	187.73	20X-5, 43–44	A	M		O-1				R			3		F		F		43	F	F	R
	188.73	20X-6, 43–44	A	M		O-1	1			R			8		F				45	F	2	R
	189.55	20X-CC	A	M		O-1				R			7		F				48	F	F	
	190.83	21X-1, 43–44	A	M		O-1				R			2		F				79	F		
CP17	192.33	21X-2, 43–44	A	M		O-1				R			7		R		R		69	F		
	193.83	21X-3, 43–44	A	M		O-1		R		R			6		R				70	F		
	195.33	21X-4, 43–44	A	M		O-1				R			8		R				68	F		
	196.83	21X-5, 43–44	A	M		O-1				R			10		R				46	F	1	
	198.33	21X-6, 43–44	A	M		O-1				R			6		F			1	53	1	F	
	199.14	21X-CC	A	M		O-1				R			7				R	F	48	2	2	R
	200.53	22X-1, 43–44	A	M		O-1				R			6					F	55	2	F	
	202.03	22X-2, 43–44	A	M		O-1		F		F			9					F	49	3	F	
	203.53	22X-3, 43–44	A	M		O-1				F			8					R	51	7	2	
	205.03	22X-4, 43–44	A	M		O-1				F			9		F			F	45	10	1	
	206.53	22X-5, 43–44	A	M		O-1				R			7		F				47	8	2	
	206.85	22X-CC	A	M		O-1		R		F			12	R	F				54	F	R	

Note: See Table 3 for an explanation of the symbols used.

the number of elements commonly exceeds 40, whereas the number for the "three groups of *M. inversus*" mentioned by Gartner (1971) ranges from 19 to 36; this taxon, therefore, is distinguished from *M. inversus*.

Nannotetrina alata (Martini, 1960) Haq and Lohmann, 1976
(Plate 3, Fig. 2)

Nannotetraster alatus Martini in Martini and Stradner, 1960, p. 268, figs. 9 and 15.

Nannotetrina alata (Martini, 1960) Haq and Lohmann, 1976, p. 183.

Nannotetraster fulgens Stradner in Martini and Stradner, 1960, p. 268, figs. 10 and 16.

Nannotetrina fulgens (Stradner, 1960), Achuthan and Stradner, 1969, p. 7.

Chiphragmarithus(?) *quadratus* Bramlette and Sullivan, 1961, p. 157, pl. 10, figs. 14a, 14b, and 15.

Nannotetraster quadratus (Bramlette and Sullivan, 1961) Bystricka, 1964, p. 222, p. 18, fig. 12.

Nannotetrina quadrata (Bramlette and Sullivan, 1961) Bukry 1973, p. 703.

Remarks. The three large *Nannotetrina* species, *N. alata, N. fulgens*, and *N. quadrata*, are considered to be the same species by many researchers (i.e., Perch-Nielsen, 1985). The former two taxa were originally introduced in the same year, but Haq and Lohmann (1976) had identified that *N. alata* has priority over *N. fulgens*. All large *Nannotetrina* with four tapered or straight arms, therefore, are identified as *N. alata* in this study.

Table 10 (continued).

Discoaster deflandrei	*Discoaster nodifer*	*Discoaster tanii*	*Ericsonia obruta*	*Ericsonia subdisticha*	*Hayaster perplexus*	*Helicosphaera bramlettei*	*Helicosphaera compacta*	*Helicosphaera euphratis*	*Helicosphaera intermedia*	*Helicosphaera perch-nielseniae*	*Helicosphaera recta*	*Helicosphaera reticulata*	*Pedinocyclus larvaris*	*Pontosphaera segmenta*	*Reticulofenestra umbilica*	*Sphenolithus ciperoensis*	*Sphenolithus* aff. *ciperoensis*	*Sphenolithus dissimilis*	*Sphenolithus distentus*	*Sphenolithus* aff. *distentus*	*Sphenolithus moriformis*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Syracosphaera* sp. 1	*Triquetrorhabdulus carinatus*	*Triquetrorhabdulus milowii*	*Zygrhablithus bijugatus*
6			6					R								2		4			14				1		
2			5					F						R		3		5			22				3		
4			3					F						F		5		8			21				1		
5			3					F								3		3			28				5		
3			5		R			F						R		9	F	2			32				F		
6			3					F	R							2	F	1			24				1		
4			1					F	R							3	F				14				F	R	
1			F					R	R					R		11	F				27				1	R	
6			1					F	R							4	F				22			R	F	F	
9			F					R						R		12	F				25				F	R	
4			2					R								10	F				17				1	R	
10			1					R						R		12	F				17				F	F	
11			1					R	R				R	R		8	F		F		22					R	
3			1		R			R						R		8	1		1		8	R				R	
6			1										R			7	F		F		9					R	
4			1					R	R					R	r	6	1		2		20					R	
3			F					R	R				R	R		F	F		2		11	6		R	R	F	
4			2					F	R				R			1	F		4		16	4				F	
5			F					R	R				R	R		F	F		3		12	5				F	
3	R		3				r	R			R		R			F	1		4		8	13				F	
5	R		4					R	R				R	R		F	F		1		4	10				R	
2	R		1					R					R	R		F	F		3		3	10				R	
2	R		F					R					R			F	F		4		11	6	R			F	
5	R		1					R					R			F	1		7		5	4	R			F	R
3	R		F	1				F	R				R			F	2		6	r	10	8	F			R	
2	R	R	2	F				R								R	3		4		9	8	F			R	
2	R	R	3	F									R			R	2		5		5	7	F			R	
6	F	R	1	F									R	R		R	3		7		8	15	F				R
5	F	R	1	1				R	R								3		4		9	13	F			R	
1	R	R	F	1			1						R				3		1		8	16	F				
2	R	R	1	F			1												F		19	24	F				
4	R	R	F	F			1		R						r				2		17	17	F				
F	R	R	1	1			1												F		18	20	F				
F		R	F	F			F							R					R		5	11	F				R
F	R	R	F	F			F														9	11	F				
F		R	F	F			F	R	R				R	R		R					11	10	F				
F		F	1	F			F	R	R				R	R							7	13	F				
2	R	F	2	1			1	R	F			R		R						R	7	24	F				R
1	R	F	F	1			F		R			R								R	19	13	F				
1		R	4	1			F		R				R	R						F	10	18	F				
F	R	R	1	2		R	F					R								F	13	11	F				
2		R	F	3		R	F		R			R								F	10	15	F				
F		R	F	3		R	F					R								F	8	16	F				
2	R	F	F	1			F					R								R	9	16	F				
2	F	1	2	F			2			R		F	R	R						R	8	17	F				R
1	R	F	F	1			2					R	F							R	9	14	F				

Nannotetrina austriacus (Stradner, 1959) n. comb.
(Plate 3, Fig. 3)

Trochoaster austriacus Stradner, 1959, p. 1088, fig. 11.
Nannotetraster austriacus (Stradner, 1959) Martini and Stradner, 1960, p. 266, fig. 4.

Remarks. This species resembles *Nannotetrina fulgens*, but the presence of a pointed projection between each of the four arms clearly differentiates these two species.

Nannotetrina spinosus (Stradner in Martini and Stradner, 1960)
n. comb.
(Plate 3, Fig. 4)

Nannotetraster spinosus Stradner in Martini and Stradner, 1960, p. 269, figs. 11 and 17.

Remarks. This species somewhat resembles such eight-rayed discoasters as *D. saipanensis*. The extremely thick rays of this species, however, show characteristic birefringence under cross-polarized light, and it is easily separated from any *Discoaster* of the middle Eocene.

Nannotetrina sp. (small)
(Plate 3, Fig. 1)

Remarks. The most common *Nannotetrina* observed in this study shows severe overgrowth, and the identification to species is particularly difficult for the small specimens. Small *Nannotetrina* that show no morphological features identifiable to any existing species, therefore, are lumped together under this name.

Sphenolithus sp. aff. *S. ciperoensis*
(Plate 2, Figs. 3 and 4)

Remarks. This is a small sphenolith with approximately the same height and width, which measure between 3.5 and 4.5 μm. It resembles *Sphenolithus ciperoensis* (Plate 2, Figs. 1 and 2), but the apical spine is shorter and wider than the type species. The spines making up the basal

Table 11. Percentage occurrences of calcareous nannofossils observed in the Oligocene samples from Hole 711A.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Braarudosphaera bigelowii*	*Bramletteius serraculoides*	*Calcidiscus kingii*	*Catinaster? umbrellus*	*Chiasmolithus altus*	*Chiasmolithus titius*	*Coccolithus eopelagicus*	*Coccolithus fuscus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coccolithus* sp. 1	*Coronocyclus nitescens*	*Crassidiscus backmanii*	*Cribrocentrum reticulatum*	*Cruciplacolithus tarquinius*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster adamanteus*	*Discoaster barbadiensis*
CP19b	83.50	9H-6, 40-41	A	M		O-1					F				F	F	13		R				F	64	F	F	F	
	85.19	9H-CC	A	M		O-1	1				F			R	F	F	17		R				1	33	F	F	F	
	85.60	10H-1, 40-41	A	M		O-1	1				1				R	F	13		F				F	47	F	R	R	
	87.10	10H-2, 40-41	A	M		O-1	1				F			F	F	R	8		F	R			F	52	F	1	R	
	88.60	10H-3, 40-41	A	M		O-1					F			R	F	F	9		F				F	52	F	R	F	
	90.10	10H-4, 40-41	A	M		O-1					F			F	R		10		F				F	58	F	F	F	
	91.60	10H-5, 40-41	A	M		O-1	1				F			F	F	R	10		F	1			F	51	1	F	F	
	93.10	10H-6, 40-41	A	M	E-1	O-1	1				R			F	R		13		R	F			F	49	2	F	F	r
	94.60	10H-7, 40-41	A	M		O-1	1				R			F	F	R	17		F				1	46	3	F	F	
	95.20	11H-1, 40-41	A	M		O-1	1	F				R		F	F	R	10		F				F	62	2	F	F	r
	96.70	11H-2, 40-41	A	M		O-1	1							F	R	R	13		F				F	61	F	R	F	
	98.20	11H-3, 40-41	A	M		O-1								F			16		F				1	54	F	R	F	
	99.70	11H-4, 40-41	A	M	E-1	O-1	1			F				F		R	15		F				1	71	F	R	F	
CP19a	101.20	11H-5, 40-41	A	M		O-1	1							F		R	9		F				F	60	1	R	F	r
	102.70	11H-6, 40-41	A	M		O-1								R			12		F				F	54	F	F	R	
	104.20	11H-7, 40-41	A	M		O-1								F		R	11		F				F	53	F	F		
	104.90	12X-1, 40-41	A	M		O-1								R		R	10		F				1	67	F	F		
	106.40	12X-2, 40-41	A	M		O-1								R			8		1				F	44	F	F	R	
	107.90	12X-3, 40-41	A	M		O-1	2	R	f	R				R			11	R	F		f		F	55	F	1		c
	109.18	12X-CC	A	M		O-1	2		c	R				R			5		F		f		F	59	2	F		r
	114.60	13X-1, 40-41	A	M	E-2		1							R			4		F				F	84	F	F		r
	116.10	13X-2, 40-41	A	M	E-1	O-1	1		r	R				F			10		F				F	53	5	F		r
	117.60	13X-3, 40-41	A	M	E-2	O-1								1			9		F				F	66	F	F	R	
	119.10	13X-4, 40-41	A	M	E-2	O-1	1			R				F			4		F		r		F	60	3	1	R	
CP18	120.60	13X-5, 40-41	A	M	E-1		1							R			4		1				R	66	1	1		
	122.10	13X-6, 40-41	A	M	E-2	O-1	1		r					F			7		F		r			62	3	6		
	124.30	14X-1, 40-41	A	M		O-1	1							R			2		F					78	F	R		
	125.80	14X-2, 40-41	A	M		O-1	2		f	R				R			4		R		f		R	66	1	1		f
CP17	127.30	14X-3, 40-41	A	M		O-1								R			4		F					76	F		R	
	128.80	14X-4, 40-41	A	M		O-1								R			4		F					72	F			
	130.30	14X-5, 40-41	A	M		O-1								R			7		R					69	1	F		
	131.80	14X-6, 40-41	A	M		O-1								R			9		R					70	1	F		
	132.38	14X-CC	A	M		O-1								R			14		R					51	1	F		
	134.00	15X-1, 40-41	A	M		O-1								R			10		F				F	58	1	F		
	135.50	15X-2, 40-41	A	M		O-1			r					R			9		R				F	52	2	F		
	137.00	15X-3, 40-41	A	M		O-1								R			7	R	R			R	4	47	3	F		
	138.50	15X-4, 40-41	A	M		O-1								R			16		R				F	47	2	F		
CP16c	140.00	15X-5, 40-41	A	M		O-1	1							R			10		R		r			48	2	1	R	
	141.50	15X-6, 40-41	A	M		O-1	1			R				R			6	R	R		r			48	4	1		
	143.70	16X-1, 40-41	A	M		O-1			R					F			15	F	F					49	5	F		
	145.20	16X-2, 40-41	A	M		O-1			R	R		R		F			18	F	F					47	6	1		
	146.70	16X-3, 40-41	A	M		O-1			F					F			22	F	F			R		36	6	F	R	
	148.20	16X-4, 40-41	A	M		O-1			3	F				F			14	F	F		r			41	5	2		
CP16ab	151.20	16X-6, 40-41	A	M		O-1			2					F			17	F	F					38	9	4	R	
	152.35	16X-CC	A	M		O-1			1					R			4	F	R					45	11	3		
	153.40	17X-1, 40-41	A	M		O-1	2		F	R			R	F			12	F	R		c			46	14	2		f
	154.00	17X-1, 100	A	M		O-1			1	R			R	F			17	F	F					40	19	3		
	154.90	17X-2, 40-41	A	M		O-1	1		F	R				R			12	F	F					37	21	7		
	155.50	17X-2, 100	A	M		O-1	1		F	R			R	R			11	F	F		r			25	25	10		r
	156.40	17X-3, 40-41	A	M	E-1	O-1	1		F	R			R	F			15	2	F		r	R		37	22	3		r
	157.00	17X-3, 100	A	M	E-1	O-1	1		R	F			R				14	F	R					45	13	1		r

Note: See Table 3 for an explanation of the symbols used.

area are thinner and are arranged to form a more widely spread base than true *S. ciperoensis*. This taxon seems to belong to the same lineage as *S. ciperoensis*, and there are some specimens that show a transitional morphology between these two taxa. This taxon appeared slightly earlier than true *S. ciperoensis* during the late early Oligocene, but their stratigraphic occurrence mostly overlaps.

Sphenolithus aff. *distentus*
(Plate 2, Figs. 7 and 8)

Remarks. This is a robustly constructed tall sphenolith with a big apical spine and a small basal part. The V-shaped basal line of the apical spine is similar to the typical *Sphenolithus distentus* (Plate 2, Figs. 5 and 6), but the apical spine and overall size of sphenolith is larger than true *S. distentus*. As usual, *S. distentus* gradually increases in size during the early late Oligocene, but even the late form does not reach the size of this taxon. The height without the bifurcating spines measures from 7 to 12 μm. This taxon occurs in the lower lower to middle lower Oligocene, whereas the true *S. distentus* first occurs within the upper lower Oligocene; their stratigraphic range does not overlap. The phylogenetic relationship between these two taxa is presently unclear.

Sphenolithus sp. 1
(Plate 2, Figs. 9–12)

Remarks. This rather short sphenolith has four radiating apical spines that can be seen as a cross from a top view. The length of the apical spines varies greatly, and specimens with a pair of long and another pair of short spines are commonly found. The diverting angle of these spines varies, but it is generally larger than 120° and is readily distinguished from the acute-angled *Sphenolithus furcatolithoides*, which incidentally has only one pair of apical spines. The morphological similarity between this taxon and the late Miocene species *Sphenolithus quadrispinatus* is striking, and it is a good example of iterative homeomorphy. This taxon is observed only in middle Eocene (Subzones CP13a and CP13b) samples from Site 711.

Table 11 (continued).

Discoaster deflandrei	*Discoaster nodifer*	*Discoaster saipanensis*	*Discoaster tanii*	*Ericsonia formosa*	*Ericsonia obruta*	*Ericsonia subdisticha*	*Hayella situliformis*	*Helicosphaera bramlettei*	*Helicosphaera compacta*	*Helicosphaera euphratis*	*Helicosphaera intermedia*	*Helicosphaera perch-nielseniae*	*Helicosphaera reticulata*	*Helicosphaera wilcoxonii*	*Isthmolithus recurvus*	*Lanternithus minutus*	*Pedinocyclus larvaris*	*Pontosphaera segmenta*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilica*	*Sphenolithus ciperoensis*	*Sphenolithus* aff. *ciperoensis*	*Sphenolithus dissimilis*	*Sphenolithus distentus*	*Sphenolithus* aff. *distentus*	*Sphenolithus moriformis*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Triquetrorhabdulus carinatus*	*Triquetrorhabdulus milowii*	*Zygrhablithus bijugatus*	Holococcolith type A
3					F																F		2			10			4	R		
6					2					R								R			4		2			29			1	R		
6		r			3					R								R			2	R	3			20			2	R		
11					2				r	R							R	R		r	2	F	2			17	c		1	R		
5					2					R								R			3	F	2			14			6	R		
1					F					R								R			5	F	F			20			1	R	R	
4					F					R								R		r	F	1	F			26			F	F		
10		r			F					R										r	1	F				18	f		1	R		
4			R		F				r											r	3	F		f		22	f		F	F	R	
6			R		1				r										r	r	5	F		c		8	c	r	F	F	R	F
3		r		r	F													R			5	2		c		13	c	r	F	R	R	
6					1																3	F		f		11	f		R	F		
3					F													R		r	F	R		r		6	f	f	R	R		
2					F																5	R		1		17	f		R	F		
3					F																2	F		F		19	5		R	R		
3					R																1	R		1		15	12		R	R		
2					1																F	R		F		15	1		R	R		
4					F																1	1		2		17	18		R	R	R	
1		f		r	2	F	r		R				r					R	f	f	F	1		4		8	10	F		R	1	F
1	R		R		1	F		F	F	F	R		r					R	r	r	F	F		2		10	10	F		R	1	F
3		r			F	F			R											r		F		F		2	3	F		R	F	R
5		r	R		2	F			F											f		2		5		6	8	F		R	F	R
3	R				2	F			F												F	1		2		5	1	1		R		
2	R		R		F																F	F		4		2	15	F				
2	R		R		1	F			F											r		F		5		1	13	1	R			
2		r	R		F	R			F															F		4	12	F			R	R
F			R		F	F			F															F		8	9	F				
1		r	F		F	F			F			r							f	r				F		7	13	F			F	F
F	R		F		F				F																	4	11	2				
F	R		R		F				F																	5	16	F			R	
F			R		F	F			F									R								11	9	1				
1			1		3	F			1				R													5	6	1				
F	R		1		1	2			1				R					R								15	10	F				
F			R		1	1			F																R	11	11	R				
1			R		3	F			R				R				R	R							R	14	15	R				
1			F		2	3			R				R												R	9	21	F				
F			R		2	4	r		R				F												R	11	12	R				
1			1		2	2		R	F				F							R						8	21	R				
1	R	r	F		1	4			1					R						R					F	12	16	R				
1			F		F	3			F	F			F				R			R					F	6	13	R			F	
1			F		1	1		R	F	F	R	R	F				F	R		R					1	7	13	R				
1			F	r	2	2			1	F	R	R	F	R			F	F		R					1	8	14	F				
F			F	r	F	3			3	F		R	2	F			F	R		R					1	11	8	F			F	
1			F	1	F	2			F	F	F		2	F			R			F					1	7	8	F				
F			F	3	1	6			1	R	R		1	R			R			F					F	6	10	R				
F		f	F	1	1	2	1		F				1				R		R	F					R	5	7	F			F	R
F	R		1	F	1	4	1		F				F	R			R	R	R	F					R	3	3	R			R	
F	R	r	F	F	F	5	F		F		R		F						F	1						4	2	R				
F	R		F	1		7	1		F				F	R	R			R	F	1						8	2	R			R	
R	R		F	F		5	F		F				R		R				F	1						5	F	R			R	R
1	R		F	3		2	F		F	R			R		R	R		R	1	9						3	2	F				

Syracosphaera sp. 1
(Plate 1, Figs. 13 and 14)

Remarks. This elliptical taxon has a thin outer rim and a wide central area. The central area shows a complicated structure, and a central process is observed in some specimens. The thin rim is bright with a distinctive suture line and a central area, except the process appears dark under a cross-polarized light. The long sides of the elliptical outline are straight or dented in some specimens. The maximum length measures from 5 to 7 μm. This species is common in the upper lower Oligocene sequence at Site 706, but it is rare in the other Leg 115 sites, occurring only sporadically in the upper Oligocene samples.

Toweius? sp. 1
(Plate 1, Figs. 11 and 12)

Remarks. This is a circular to subcircular placolith with a large and clearly defined central opening. The two discs are dark, but the thin distinctive central tube appears bright under cross-polarized light. The extinction cross strongly swirls, but unlike *Toweius*? *gammation*, the extinction pattern is smooth for the entire length. The placolith size measures between 7 and 9 μm, and its occurrence is limited to the middle middle Eocene (Subzones CP13b and CP13c).

Umbilicosphaera sp. 1
(Plate 1, Figs. 1 and 2)

Remarks. This is a circular placolith with a large central opening. Both discs are dark, and only the central tube is bright under cross-polarized light. The placolith size measures from approximately 3 to 6 μm. The central opening varies in proportion to the overall size of the placolith and reaches one half of the placolith size in extreme cases. This species resembles *Geminilithella rotula*, but well-preserved specimens clearly show a dome-shaped configuration. It occurs commonly or even abundantly in the lower Oligocene sequence of Site 706, but it is totally absent in the tropical sites of Leg 115, except for rare and sporadic occurrences observed in the upper Oligocene of Site 714.

Table 12. Percentage occurrences of calcareous nannofossils observed in the Eocene samples from Hole 711A.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Braarudosphaera bigelowii*	*Bramletteius serraculoides*	*Calcidiscus kingii*	*Calcidiscus protoannulus*	*Campylosphaera dela*	*Chiasmolithus consuetus*	*Chiasmolithus expansus*	*Chiasmolithus gigas*	*Chiasmolithus grandis*	*Chiasmolithus medius*	*Chiasmolithus solitus*	*Chiasmolithus titus*	*Coccolithus eopelagicus*	*Coccolithus pelagicus*	*Coccolithus* sp. 1	*Coronocyclus nitescens*	*Cribrocentrum reticulatum*	*Cruciplacolithus cruciformis*	*Cruciplacolithus staurion*	*Cruciplacolithus* cf. *tarquinius*	*Cruciplacolithus vanheckae*	*Cruciplacolithus* spp.
CP15b	157.90	17X-4, 40–41	A	M	E-1	O-1			1	2	R								R	R	23	1	1						
	158.50	17X-4, 100	A	M		O-1			F	R									R	R	17	F	1						
	159.40	17X-5, 40–41	A	M		O-1			1	1									F	R	20	F		2					
	160.00	17X-5, 100	A	M		O-1			F	1	R								F	R	19	1		9					
	160.90	17X-6, 40–41	A	M		O-1			F	F	R									R	14	F	R	15					
	161.50	17X-6, 100	A	M		O-1		R	F	F										R	15	F		33					
	162.24	17X-7, 24	A	M		O-1			F	4	R									R	16	F		36					
	163.12	18X-1, 42–43	A	M		O-1			F	2	R									R	15	F		43					
CP15a	164.62	18X-2, 42–43	A	M	E-1	O-1			1	F										F	9	R	R	39					
	166.04	18X-3, 34–35	A	M		O-1	1		4	4						r				F	5	R	R	14					
	167.49	18X-4, 29–30	A	M	E-1	O-1			R	2										F	6	R	R	13					
	168.72	18X-CC	A	M		O-1			F	2										F	4	F	R	17					
	172.78	19X-1, 38–39	A	M	E-1	O-1			F	3										2	7	F	R	7					
	174.97	19X-2, 107–10	A	M		O-1			F	3										2	11	F		12					
	176.15	19X-3, 75	A	M		O-1			F	1										1	14	F		30					
CP14b	177.28	19X-4, 38–39	A	M		O-1			F	F						R				F	8	F	R	47					
	178.78	19X-5, 38–39	A	M		O-1	1		1	1		R		R		F				1	9	F	F	24					
	180.28	19X-6, 38–39	A	M		O-1			F	2						F				F	17	F	F	4					
	181.62	19X-CC	A	M	E-1	O-1			F	1		1		R		F			F	F	5	1	F	4					
	182.85	20X-1, 75	A	M	E-1	O-1			F	1		2				R			F	F	10	R							
	184.35	20X-2, 75	A	M	E-1	O-1			F	F		2				1			F	F	6	F							
	186.99	20X-4, 39–40	A	M	E-1	O-1			1	R	F	F				F			1	1	19	1		F					
	188.49	20X-5, 39–40	A	M	E-1	O-1			F	F	1	1				F			F	F	15	F		F					
	188.75	20X-CC	A	M		O-1			1	F	F	2		R		F			F	1	19	F							
	192.10	21X-1, 40–41	A	M		O-1				F	1	1				F		r	1	F	21	R						R	
	193.60	21X-2, 40–41	A	M		O-1			1	F	F	F	R			R			F	R	20	F		F					
	195.10	21X-3, 40–41	A	M	E-1	O-1			F	F	F	F	R			R			1	F	19	F		R					
	196.60	21X-4, 40–41	A	M	E-1	O-2			F	1	F	1	R			R			F	1	15	R					R		
CP14a	198.10	21X-5, 40–41	A	M	E-1	O-2			F	F	R	1	R	R		1		R	F	F	18	F							R
CP13c	199.18	21X-CC	A	M		O-2			F	F	F	2	F			R		F	2	1	15	1			R	R		F	1
	201.80	22X-1, 40–41	A	M		O-2			F	F	1	F	F			F		F	F	F	15	F				R		F	F
	203.30	22X-2, 40–41	A	M		O-1			1	1	R	F	R			R		F	1	R	4	F				R			F
	204.80	22X-3, 40–41	A	M		O-1			F	R	F	F		R		R		R	F	F	8	F							F
	206.30	22X-4, 40–41	A	M		O-1			F		R	F	F			R		R	2	R	8	F				R			F
	207.07	22X-CC	A	P		O-3			2		F	F	1			R		R	2	R	11	F				R			F
	211.50	23X-1, 40–41	A	P		O-3			1		1	F	R			R			F	F	5	F				F	R		F
	213.00	23X-2, 40–41	A	P		O-3			1		F	1	R			R		R	F	F	15	R				F			F
	214.50	23X-3, 40–41	A	P		O-3			F	R	F	1	F			F		F	F	F	17	R				F			F
	216.00	23X-4, 40–41	A	M		O-2			R		F	F	R			R		F	1	R	12					F			R
	217.50	23X-5, 40–41	A	P		O-3			1		F	1	R	R		R		R	F	R	14	R		r		F			R
	219.00	23X-6, 40–41	A	M		O-2			1		F	F	R			F		R	F	F	12	R				F			F
CP13b	220.27	23X-CC	A	M		O-2			F		1	1	R		R	F	R	F	1	R	13					F	R		R
	221.10	24X-1, 40–41	A	M		O-2			F		1	F	F		R	R	2	F	R	R	10	R				F			
	222.60	24X-2, 40–41	A	M		O-2					F	F	R		R	F	2	F	R	R	11	F				F		R	R
	224.10	24X-3, 40–41	A	M		O-2			R		F	F			F	F	2	F	R	R	1	F				F			R
	225.60	24X-4, 40–41	A	M		O-2			R		F	F		R	R	F	1	F	F	R	4	R				F			R
	227.10	24X-5, 40–41	A	M		O-2					F	F			R	F	1	F		R	3	R				R		R	F
	227.78	24X-CC	A	M		O-2					F	1	R		R	F	1	2		R	3					R		R	F
	230.70	25X-1, 40–41	A	M		O-2					F	F	R		R	F	F	F	R	R	4					R			F
CP13a	232.20	25X-2, 40–41	A	M		O-2					F	F				F	F	1		R	3					R		R	R
	233.70	25X-3, 40–41	A	M		O-2					F	F				F	R	1		R	4					R		R	F
	235.20	25X-4, 40–41	A	M		O-2					R	F	R	R		F	R	R		R	5					R	R	F	F
	236.70	25X-5, 40–41	A	M		O-2					R	F		R		F	R	R		R	4					R			R
	237.26	25X-CC	A	M		O-2					1	F	R			1	R	F		R	6	F				R			
CP12b	240.33	26X-CC (A)	A	P	E-1	O-3						F				F		1		R	5								R
CP12a	240.33	26X-CC (B)	A	P	E-1	O-3						2				F		F			4							R	

Note: See Table 3 for an explanation of the symbols used.

Holococcolith type A
(Plate 2, Figs. 13–16)

Remarks. This is possibly a group of holococcoliths consisting of several different taxa belonging to the family Calyptrosphaeraceae. Some specimens included in this group are possibly small overgrown *Zygrhablithus bijugatus*, especially that of *Z. bijugatus crassus* described by Locker (1967). Because typical *Z. bijugatus* is easily distinguishable from this group in most samples, and because some of the small specimens included in this group are likely to belong to different taxa, I have distinguished this group from larger and typical *Z. bijugatus*. However, transitional forms are commonly found in some samples, and I set an arbitrary cut-off point of 7 µm in identifying *Z. bijugatus*. Because most of the holococcoliths are severely overgrown in Leg 115 materials, it is very difficult to identify these small holococcoliths into respective species. They are generally shaped like a short cylinder with a tapering end or like a compressed pear. Their overall sizes range from 4 to 6 µm in width and from 4 to 7 µm in height. This group occurs from all sequences of the middle Eocene through the upper Oligocene at the Leg 115 sites.

APPENDIX B

List of Calcareous Nannofossils Identified to Known Taxa

Blackites spinosus (Deflandre and Fert, 1954) Hay and Towe, 1962
Braarudosphaera bigelowii (Gran and Braarud, 1935) Deflandre, 1947
Bramletteius serraculoides Gartner, 1969
Calcidiscus kingii (Roth, 1970) Loeblich and Tappan, 1978
Calcidiscus protoannulus (Gartner, 1971) Loeblich and Tappan, 1978
Campylosphaera dela (Bramlette and Sullivan, 1961) Hay and Mohler, 1976
Campylosphaera eodela Bukry and Percival, 1971

Table 12 (continued).

Cyclicargolithus floridanus	*Cyclolithella kalianata*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster barbadiensis*	*Discoaster bifax*	*Discoaster deflandrei*	*Discoaster lodoensis*	*Discoaster kuepperi*	*Discoaster nodifer*	*Discoaster saipanensis*	*Discoaster sublodoensis*	*Discoaster tanii*	*Ericsonia formosa*	*Ericsonia obruta*	*Ericsonia pacifica*	*Ericsonia subdisticha*	*Hayella situliformis*	*Helicosphaera compacta*	*Helicosphaera heezenii*	*Helicosphaera lophota*	*Helicosphaera reticulata*	*Helicosphaera seminulum*	*Isthmolithus recurvus*	*Lophodolithus acutus*	*Lophodolithus mochloporus*	*Markalius inversus*	*Markalius* sp. 1	*Markalius* sp. 2	*Nannotetrina alata*	*Nannotetrina austriacus*	*Nannotetrina* sp. (small)	*Neocrepidolithus* sp.	*Pedinocyclus larvaris*
23		11	5			R			F	4		1	3			1	F	F			F		R										
3		10	F	10		F			R	9		F	3			F	R	1			R												
22		6	1	13					F	9		1	5	R			R	F			F		R										
33		F	F	13					F	9		1	2				R	F			R												R
44		1	F	10		R			R	2		F	4			F	F	F			F												
28		1	F	3					R	3		1	4				F	F			F												R
12		1	F	9					R	4		2	7			R	F	F			R												
11		3	1	5					R	6		1	4				F	F			R		R										
16		10	4	8					R	6		F	3					R			R												
27		20	5	6					F	2		1	3					F			R												
18		17	3	15		R			R	10		1	2					F															
24		22	3	7					F	8		1	3					F	R														
40		2	14	10		R			F	3		1	1					F															
21		4	13	10					F	6		F	6				R	F															
9		6	11	6					F	5		F	6				F	F	R		R												
13		4	3	6					F	4		F	2					F	R														
13		17	9	6		R			F	8		R	2		R			F	R								R						
19		21	7	11					F	7		F	1		R			F	R								F						
42		15	10	4					F	3		R	F		R			F	R								F						R
21	R	25	8	5					F	4		R	5		R			F	R								F						R
19		21	7	8					F	6			4		R			F	R								F						
18			F	22					R	1		R	5		F			F	1							R	F						R
24	R			14					R	R		R	5		R			F	1	R		R				R	1						
13				17					R	F		R	7		R			R	F	R		R				R	F						R
10	R			19					R	F		R	6					R	F	R		R				R	1						R
18	R			23					R	F			3						F	F		R				F	1	R					F
32	R			14					R	F			5					R	F	R		R				F	2						F
35				5						F		R	5						R	R						F	1	R					F
38	R			7	F	R				F			5						R	F		R				F	1	F	R				F
39				11	F					F			2						1	1		R				F	F	1	R		R		F
24				14	F					F			4						1	1		R				F	1	1	R		R		1
38				8	1					R			F		R				F	F		R				F	3	1	R				R
38				8	2					R			2						F	F		R				F	1	F			R		R
23				15	3					R			3		R				F	F						F	3	1	R		R		R
37				16	F								2		R				F	F		R				F	3	1	F		F		F
41	R			15	F								4						F	F		R				R	2	R	F	R	F		1
20	R			16	F								3		R				1	F		R				F	2	R	F	R	F		R
16	R			14	F				R	R			8						F	F		R				F	F	F	1	R	1		R
9	R			21	F					R		R	6						1	1		F				F	F	1	R		F		R
24	R			5									9						F	F		R				R	1	R	F	R	F		R
34				8						R			6						R	F		F				R	2		F	R	1		R
30	R			17						R			3						F	F		F				R	1		F		F		F
26	R			8						F			1							F		F					1		R	R	1		2
22	F			10						F			3							F		F				R	1	R	R		R		2
64	R			8						1			1		R					F		F					F	F	R		F		F
37	R			21						1		R	1							F		R		R			F	R	R		1		F
59	R			7						F			5							F		R		R		R	F	R	R		F		1
44	R			10			f			F			3							F		F		R	R	R	F	R	F		1	R	F
54	F			5						F			4							F		F		F	R	R	F		R		1		1
40	R			10						F			6							F		F		R		F	F	R	R		F		F
37	F			12				R		1	R		5							1		F		F	R	R	F		R		F		F
9				25			F			1	F		5							F		R		F		R	F		R		F	R	1
15				18			F			1	1		5							F		F		R	R		F		R		F		5
21				23			R			F	R		8		R					1		F		R	R		1		R		F	R	3
12				20			F				12		4							F		R		F			1				F		3
1				30			5	1			1		13							F							3					F	1

Catinaster? *umbrellus* Bukry, 1971
Chiasmolithus altus Bukry and Percival, 1971
Chiasmolithus bidens (Bramlette and Sullivan, 1961) Hay and Mohler, 1976
Chiasmolithus californicus (Sullivan, 1964) Hay and Mohler, 1967
Chiasmolithus consuetus (Bramlette and Sullivan, 1961) Hay and Mohler, 1967
Chiasmolithus danicus (Brotzen, 1959) Hay and Mohler, 1967
Chiasmolithus eograndis Perch-Nielsen, 1971
Chiasmolithus expansus (Bramlette and Sullivan, 1961) Gartner, 1970
Chiasmolithus gigas (Bramlette and Sullivan, 1961) Radomski, 1968
Chiasmolithus grandis (Bramlette and Riedel, 1954) Radomski, 1968
Chiasmolithus medius Perch-Nielsen, 1971
Chiasmolithus solitus (Bramlette and Sullivan, 1961) Locker, 1968
Chiasmolithus titus Gartner, 1970
Coccolithus eopelagicus (Bramlette and Riedel, 1954) Bramlette and Sullivan, 1961
Coccolithus fuscus Backman, 1980
Coccolithus miopelagicus Bukry, 1971
Coccolithus pelagicus (Wallich, 1877) Schiller, 1930
Coronocyclus nitescens (Kamptner, 1963) Bramlette and Wilcoxon, 1967
Coronocyclus prionion (Deflandre and Fert, 1954) Stradner in Stradner and Edwards, 1968
Crassidiscus backmanii Okada, n. sp.
Cribrocentrum reticulatum (Gartner and Smith, 1967) Perch-Nielsen, 1971
Cruciplacolithus cribellum (Bramlette and Sullivan, 1961) Romein, 1979
Cruciplacolithus cruciformis (Hay and Towe, 1962) Roth, 1970
Cruciplacolithus frequens (Perch-Nielsen, 1977) Romein, 1979
Cruciplacolithus primus Perch-Nielsen, 1977

Table 12 (continued).

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Pontosphaera formosa*	*Pontosphaera scissura*	*Pontosphaera segmenta*	*Pseudotriquetrorhabdulus inversus*	*Reticulofenestra dictyoda*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilica*	*Rhabdosphaera inflata*	*Sphenolithus furcatolithoides*	*Sphenolithus intercalaris*	*Sphenolithus moriformis*	*Sphenolithus obtusus*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Sphenolithus radians*	*Sphenolithus spiniger*	*Sphenolithus stellatus*	*Sphenolithus* sp. 1	*Toweius gammation*	*Toweius* ? sp. 1	*Zygrhablithus bijugatus*	Holococcolith type A
CP15b	157.90	17X-4, 40–41	A	M	E-1	O-1							1	12				2		2	F								
	158.50	17X-4, 100	A	M		O-1							4	29				6		F	F								
	159.40	17X-5, 40–41	A	M		O-1							2	10				1			R							R	
	160.00	17X-5, 100	A	M		O-1				R			F	2				6			F								
	160.90	17X-6, 40–41	A	M		O-1							R	1				4		R	F								
	161.50	17X-6, 100	A	M		O-1							R	1				3		2	F							R	
	162.24	17X-7, 24	A	M		O-1							R	F				2		1	R								
	163.12	18X-1, 42–43	A	M		O-1				R			R	F				3		3	R								
CP15a	164.62	18X-2, 42–43	A	M	E-1	O-1							R	F				1		1	F								
	166.04	18X-3, 34–35	A	M		O-1	1				r		R	R				2	R	2	F							F	R
	167.49	18X-4, 29–30	A	M	E-1	O-1				R				R				8		2	F								
	168.72	18X-CC	A	M		O-1							F	R				3		F	F	R							
	172.78	19X-1, 38–39	A	M	E-1	O-1							F	F				2		1	F	R							
	174.97	19X-2, 107–10	A	M		O-1				R								5		F	F	R							
	176.15	19X-3, 75	A	M		O-1				R			R	1				4	R	F	F	F							
CP14b	177.28	19X-4, 38–39	A	M		O-1							F	1				4		F	F	F							
	178.78	19X-5, 38–39	A	M		O-1	1				f		R	R			F	3	1	F	F	F						F	R
	180.28	19X-6, 38–39	A	M		O-1							F	F				3			R	F							F
	181.62	19X-CC	A	M	E-1	O-1							R				F	2	F		R	1							
	182.85	20X-1, 75	A	M	E-1	O-1					F		F	4			2	F	6		R	F							
	184.35	20X-2, 75	A	M	E-1	O-1					F		F	1			16	1	2		R	F							
	186.99	20X-4, 39–40	A	M	E-1	O-1					F		2	5		12		2			R	1	3					R	
	188.49	20X-5, 39–40	A	M	E-1	O-1					F	1	5	5		12		3			R	1	4					R	
	188.75	20X-CC	A	M		O-1				R	R	2	4	F		19		5				F	5					F	
	192.10	21X-1, 40–41	A	M		O-1					R	2	3	5		16		2				F	8						R
	193.60	21X-2, 40–41	A	M		O-1				R	R	1	3	F		13		3			R	F	5						
	195.10	21X-3, 40–41	A	M	E-1	O-1					R	2	5	F		10		4				F	1						
	196.60	21X-4, 40–41	A	M	E-1	O-2			R		F	5	3	F		9		7			R	F	8					R	
CP14a	198.10	21X-5, 40–41	A	M	E-1	O-2					F	F	3	F		8		4				1	8				F		
CP13c	199.18	21X-CC	A	M		O-2		R	F	R	3	F	F			7		3				F	3						
	201.80	22X-1, 40–41	A	M		O-2		F	F	R	F	2	R			8		3				1	14				F		
	203.30	22X-2, 40–41	A	M		O-1		R	R		3	F	R			14		5				F	12				4		
	204.80	22X-3, 40–41	A	M		O-1		R	R		F	1	2			11		6				F	14				F	R	
	206.30	22X-4, 40–41	A	M		O-1		R			1	1	1			10		3				1	13				4	F	
	207.07	22X-CC	A	P		O-3		R	R		5	F				4		1				F	6				F	F	R
	211.50	23X-1, 40–41	A	P		O-3		R	R		5	3	11			1		2				1	4				R	R	
	213.00	23X-2, 40–41	A	P		O-3		R	R	R	4	4	5			6		6				2	7					R	
	214.50	23X-3, 40–41	A	P		O-3		F	R		5	1	F			5		6				1	17					R	
	216.00	23X-4, 40–41	A	M		O-2		R	R	R	6	2	2			14		7				F	8					R	
	217.50	23X-5, 40–41	A	P		O-3		R	R	R	5	2	8			8		5				F	6				R	R	
	219.00	23X-6, 40–41	A	M		O-2		R	R	R	5	F	5			6		8			R	F	3					R	
CP13b	220.27	23X-CC	A	M		O-2		F	R	R	6	2	5			3		3				1	6				R	R	
	221.10	24X-1, 40–41	A	M		O-2		R		R	15	F	7			3		9				F	4	1				F	
	222.60	24X-2, 40–41	A	M		O-2				R	11	2	8			6		5			R	1	8					F	
	224.10	24X-3, 40–41	A	M		O-2				F	8	1	3			1		2			R	R	2					R	
	225.60	24X-4, 40–41	A	M		O-2				R	6	1	1			F		18			R	1	2	R				R	
	227.10	24X-5, 40–41	A	M		O-2				R	4	3	F					11			R	2	1	F				F	
	227.78	24X-CC	A	M		O-2				F	7	2	R					9			R	6	F	2	R			2	F
	230.70	25X-1, 40–41	A	M		O-2				F	5	3	1					11			R	F	1	1	F	R		3	R
CP13a	232.20	25X-2, 40–41	A	M		O-2				F	5	2	F					16			R	2	1	2	1			2	F
	233.70	25X-3, 40–41	A	M		O-2				R	10	6	1					10				F	1	F	3			1	R
	235.20	25X-4, 40–41	A	M		O-2				F	8	3	F					9				6	F	1	1			16	F
	236.70	25X-5, 40–41	A	M		O-2				F	9	8	F					5				6	F		2			12	F
	237.26	25X-CC	A	M		O-2				F	4	4	F		R			5				6	F	R				7	F
CP12b	240.33	26X-CC (A)	A	P	E-1	O-3					7	6	F		1			13				7	F	F				F	R
CP12a	240.33	26X-CC (B)	A	P	E-1	O-3				R	2	1						10				7	F			3		7	R

Cruciplacolithus staurion (Bramlette and Sullivan, 1961) Gartner, 1971
Cruciplacolithus subrotundus Perch-Nielsen, 1969
Cruciplacolithus tarquinius Roth and Hay in Hay et al., 1967
Cruciplacolithus tenuis (Stradner, 1961) Hay and Mohler in Hay et al., 1967
Cruciplacolithus vanheckae Perch-Nielsen, 1984
Cyclicargolithus abisectus (Müller, 1970) Wise, 1973
Cyclicargolithus floridanus (Roth and Hay in Hay et al., 1967) Bukry, 1971
Cyclolithella kalianata Bukry, 1971
Dictyococcites bisectus (Hay, Mohler and Wade, 1966) Bukry and Percival, 1971
Dictyococcites scrippsae Bukry and Percival, 1971
Discoaster adamanteus Bramlette and Wilcoxon, 1967
Discoaster barbadiensis Tan, 1927
Discoaster bifax Bukry, 1971
Discoaster binodosus Martini, 1958
Discoaster deflandrei Bramlette and Riedel, 1954
Discoaster delicatus Bramlette and Sullivan, 1961
Discoaster diastypus Bramlette and Sullivan, 1961
Discoaster distinctus Martini, 1958
Discoaster elegans Bramlette and Sullivan, 1961
Discoaster falcatus Bramlette and Sullivan, 1961
Discoaster germanicus Martini, 1958
Discoaster kuepperi Stradner, 1959
Discoaster limbatus Bramlette and Sullivan, 1961
Discoaster lodoensis Bramlette and Riedel, 1954
Discoaster mahmoudii Perch-Nielsen, 1981

Discoaster megastypus (Bramlette and Sullivan, 1961) Perch-Nielsen, 1985
Discoaster mohleri Bukry and Percival, 1971
Discoaster multiradiatus Bramlette and Riedel, 1954
Discoaster nobilis Martini, 1961
Discoaster nodifer (Bramlette and Riedel, 1954) Bukry, 1973
Discoaster saipanensis Bramlette and Riedel, 1954
Discoaster salisburgensis Stradner, 1961
Discoaster tanii Bramlette and Riedel, 1954
Ellipsolithus distichus (Bramlette and Sullivan, 1961) Sullivan, 1964
Ellipsolithus macellus (Bramlette and Sullivan, 1961) Sullivan, 1964
Ericsonia obruta Perch-Nielsen, 1971
Ericsonia pacifica (Bukry, 1971) Romein, 1979
Ericsonia robusta (Bramlette and Sullivan, 1961) Perch-Nielsen, 1977
Ericsonia subdisticha (Roth and Hay in Hay et al., 1967) Roth in Baumann and Roth, 1969
Ericsonia subpertusa Hay and Mohler, 1967
Fasciculithus bobii Perch-Nielsen, 1971
Fasciculithus clinatus Bukry, 1971
Fasciculithus hayi Haq, 1971
Fasciculithus involutus Bramlette and Sullivan, 1961
Fasciculithus richardii Perch-Nielsen, 1971
Fasciculithus schaubii Hay and Mohler, 1967
Fasciculithus tympaniformis Hay and Mohler in Hay et al., 1967
Hayaster perplexus (Bramlette and Riedel, 1954) Bukry, 1973
Hayella situliformis Gartner, 1969
Helicosphaera bramlettei Müller, 1970
Helicosphaera compacta Bramlette and Wilcoxon, 1967
Helicosphaera euphratis Haq, 1966
Helicosphaera heezenii Bukry, 1971
Helicosphaera intermedia Martini, 1965
Helicosphaera lophota Bramlette and Sullivan, 1961
Helicosphaera obliqua Bramlette and Wilcoxon, 1967
Helicosphaera perch-nielseniae Haq, 1971
Helicosphaera recta Haq, 1966
Helicosphaera reticulata Bramlette and Wilcoxon, 1967
Helicosphaera seminulum Bramlette and Sullivan, 1961
Helicosphaera wilcoxonii Gartner, 1971
Heliolithus riedelii Bramlette and Sullivan, 1961
Hornibrookina australis Edwards and Perch-Nielsen, 1971
Ilselithina fusa Roth, 1970
Isthmolithus recurvus Deflandre, 1954
Lanternithus minutus Stradner, 1962
Lophodolithus acutus Bukry and Percival, 1971
Lophodolithus mochlophorus Deflandre and Fert, 1954
Lophodolithus nascens Bramlette and Sullivan, 1961
Markalius inversus (Deflandre in Deflandre and Fert, 1954) Bramlette and Martini, 1964
Micrantholithus altus Bybell and Gartner, 1972
Micrantholithus flos Deflandre in Deflandre and Fert, 1954
Micrantholithus procerus Bukry and Bramlette, 1969
Nannotetrina alata (Martini, 1960) Haq and Lohmann, 1976
Nannotetrina austriacus (Stradner, 1959) n. comb.
Nannotetrina spinosus (Stradner in Martini and Stradner, 1960) n. comb.
Neochiastozygus chiastus (Bramlette and Sullivan, 1961) Perch-Nielsen, 1971
Neochiastozygus concinnus (Martini, 1961) Perch-Nielsen, 1971
Neochiastozygus distentus (Bramlette and Sullivan, 1961) Perch-Nielsen, 1971
Neochiastozygus junctus (Bramlette and Sullivan, 1961) Perch-Nielsen, 1971
Neochiastozygus rosenkrantzii Perch-Nielsen, 1971
Neococcolithus dubius (Deflandre, 1954) Black, 1967
Neococcolithus protenus (Bramlette and Sullivan, 1961) Black, 1967
Pedinocyclus larvalis (Bukry and Bramlette, 1969b) Loeblich and Tappan, 1973
Pemma basquensis (Martini, 1959) Baldi-Beke, 1971
Pemma papillatum Martini, 1959
Pemma rotundum Klumpp, 1953
Peritrachelina joidesa Bukry and Bramlette, 1968
Pontosphaera bicaveata (Perch-Nielsen, 1967) Romein, 1979
Pontosphaera formosa (Bukry and Bramlette, 1969b) Romein, 1979
Pontosphaera latoculata (Bukry and Percival, 1971) Perch-Nielsen, 1984
Pontosphaera ocellata (Bramlette and Sullivan, 1961) Perch-Nielsen, 1984
Pontosphaera pectinata (Bramlette and Sullivan, 1961) Sherwood, 1974
Pontosphaera plana (Bramlette and Sullivan, 1961) Haq, 1971
Pontosphaera punctosa (Bramlette and Sullivan, 1961) Perch-Nielsen, 1984
Pontosphaera rimosa (Bramlette and Sullivan, 1961) Roth and Thierstein, 1972
Pontosphaera scissura (Perch-Nielsen, 1971d) Romein, 1979
Pontosphaera segmenta Bukry and Percival, 1971
Pontosphaera versa (Bramlette and Sullivan, 1961) Sherwood, 1974
Prinsius bisulcus (Stradner, 1963) Hay and Mohler, 1967
Prinsius martinii (Perch-Nielsen, 1969) Haq, 1971
Pseudotriquetrorhabdulus inversus (Bukry and Bramlette, 1969) Wise in Wise and Constans, 1976
Quinquerhabdus colossicus Bukry and Bramlette, 1969
Reticulofenestra dictyoda (Deflandre in Deflandre and Fert, 1954) Stradner in Stradner and Edwards, 1968
Reticulofenestra samodurovii (Hay, Mohler and Wade, 1966) Roth, 1970
Reticulofenestra umbilica (Levin, 1965) Martini and Ritzkowski, 1968
Rhabdosphaera inflata Bramlette and Sullivan, 1961
Rhabdosphaera procera Martini, 1969
Rhabdosphaera tenuis Bramlette and Sullivan, 1961
Rhomboaster bitrifida Romein, 1979
Rhomboaster calcitrapa Gartner, 1971
Rhomboaster cuspis Bramlette and Sullivan, 1961
Scapholithus fossilis Deflandre in Deflandre and Fert, 1954
Scapholithus rhombiformis Hay and Mohler, 1967
Semihololithus biskayae Perch-Nielsen, 1971
Semihololithus kerabyi Perch-Nielsen, 1971
Sphenolithus anarrhopus Bukry and Bramlette, 1969
Sphenolithus ciperoensis Bramlette and Wilcoxon, 1967
Sphenolithus conspicuus Martini, 1976
Sphenolithus dissimilis Bukry and Percival, 1971
Sphenolithus distentus (Martini, 1965) Bramlette and Wilcoxon, 1967
Sphenolithus editus Perch-Nielsen in Perch-Nielsen et al., 1978
Sphenolithus furcatolithoides Locker, 1967
Sphenolithus intercalaris Martini, 1976
Sphenolithus moriformis (Brönnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967
Sphenolithus obtusus Bukry, 1971
Sphenolithus orphanknolli Perch-Nielsen, 1971
Sphenolithus predistentus Bramlette and Wilcoxon, 1967
Sphenolithus pseudoradians Bramlette and Wilcoxon, 1967
Sphenolithus radians Deflandre in Grasse, 1952
Sphenolithus spiniger Bukry, 1971
Sphenolithus stellatus Gartner, 1971
Striatococcolithus pacificanus Bukry, 1971
Toweius callosus Perch-Nielsen, 1971
Toweius? crassus (Bramlette and Sullivan, 1961) Perch-Nielsen, 1984
Toweius eminens (Bramlette and Sullivan, 1961) Perch-Nielsen, 1971
Toweius gammation (Bramlette and Sullivan, 1961) Romein, 1979
Toweius occultatus (Locker, 1967) Perch-Nielsen, 1971
Toweius pertusus (Sullivan, 1965) Romein, 1979
Toweius tovae Perch-Nielsen, 1971
Transversopontis exilis (Bramlette and Sullivan, 1961) Perch-Nielsen, 1971
Transversopontis fimbriatus (Bramlette and Sullivan, 1961) Locker, 1969
Transversopontis pax Stradner and Seifert, 1980
Transversopontis pulcher (Deflandre in Deflandre and Fert, 1954) Perch-Nielsen, 1967
Transversopontis pulcheroides (Sullivan, 1964) Baldi-Beke, 1971
Transversopontis rectipons (Haq, 1968) Roth, 1970
Tribrachiatus bramlettei (Brönnimann and Stradner, 1960) Proto Decima et al., 1975
Tribrachiatus contortus (Stradner, 1958) Bukry, 1972
Tribrachiatus orthostylus Shamrai, 1963
Triquetrorhabdulus carinatus Martini, 1965
Triquetrorhabdulus milowii Bukry, 1971
Zygodiscus adamus Bramlette and Sullivan, 1961
Zygodiscus herlynii Sullivan, 1964

Table 13. Percentage occurrences of calcareous nannofossils observed in the Oligocene and Eocene samples from Hole 712A.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Braarudosphaera bigelowii*	*Bramletteius serraculoides*	*Calcidiscus kingii*	*Calcidiscus protoannulus*	*Campylosphaera dela*	*Chiasmolithus grandis*	*Chiasmolithus titus*	*Coccolithus eopelagicus*	*Coccolithus fuscus*	*Coccolithus pelagicus*	*Coccolithus* sp. 1	*Coronocyclus nitescens*	*Cribrocentrum reticulatum*	*Cruciplacolithus tarquinius*	*Cyclicargolithus floridanus*	*Cyclolithella kalianata*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster barbadiensis*	*Discoaster deflandrei*
CP19a	86.53	10R-CC	C	P		O-3	1								R	1	4		1			72		F	F		2
	96.11	11R-1, 1	C	P		O-3	2			R						F	8		F	f		68		1	F	f	3
?	98.42	11R-CC	C	P		O-3	1	2							1		16		F			44		7	5	r	
CP14b	105.76	12R-1, 6–7	A	M		O-2			3	R	1	3	F	F	F		13	F		1	F	20				10	
	107.52	12R-2, 32–33	A	P	E-1	O-3			3	R	F	3	R	1	F		11	1		F	1	39				13	R
	109.46	12R-3, 76–77	A	P		O-3		R	1	F	F	2	F	F	F		15	1		F	F	18	R			17	R
	110.22	12R-CC	A	P	E-1	O-3			6	F	F	3	F	1	F		13	F		F	F	17	R			17	F

Note: See Table 3 for an explanation of the symbols used.

Zygrhablithus bijugatus (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959

List of Tentatively Named Calcareous Nannofossils That Are Not Identified to Known Taxa

Coccolithus sp. 1
Holococcolith type A
Markalius sp. 1
Markalius sp. 2
Sphenolithus aff. *ciperoensis*
Sphenolithus aff. *distentus*
Sphenolithus sp. 1
Syracosphaera sp. 1
Toweius? sp. 1
Umbilicosphaera sp. 1

Table 13 (continued).

Discoaster nodifer	*Discoaster saipanensis*	*Discoaster tanii*	*Ericsonia formosa*	*Ericsonia obruta*	*Ericsonia pacifica*	*Helicosphaera euphratis*	*Helicosphaera heezenii*	*Helicosphaera reticulata*	*Lanternithus minutus*	*Markalius inversus*	*Markalius* sp. 1	*Markalius* sp. 2	*Micrantholithus flos*	*Pedinocyclus larvaris*	*Pemma rotundum*	*Pontosphaera segmenta*	*Pseudotriquetrorhabdulus inversus*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilica*	*Sphenolithus ciperoensis*	*Sphenolithus dissimilis*	*Sphenolithus distentus*	*Sphenolithus furcatolithoides*	*Sphenolithus moriformis*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Sphenolithus spiniger*	*Triquetrorhabdulus carinatus*	*Zygrhablithus bijugatus*	Holococcolith type A
				F																F	F	F		14	2	f		F	F	F
	f			F														f	f	R		F	f	8	2			F	F	
		R				F		1					F						r					6	F				3	3
R	1		1		R		1		R	R	8	R		R	R	R	3	4	2				6	3		2	6		3	F
R	1	R	4		R		F		R	F	1			R	R		F	1	1				3	4		F	1		4	2
1	F		7		R		1			R	2			R	R		R	8	2				10	1		1	1		1	1
	F		7		R		1		R	F	1	R		F			R	5	1				10	5		1	3		F	2

Table 14. Percentage occurrences of calcareous nannofossils observed in the Eocene samples from Hole 713A.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Braarudosphaera bigelowii*	*Bramletteius serraculoides*	*Calcidiscus kingii*	*Calcidiscus protoannulus*	*Campylosphaera dela*	*Chiasmolithus consuetus*	*Chiasmolithus expansus*	*Chiasmolithus gigas*	*Chiasmolithus grandis*	*Chiasmolithus medius*	*Chiasmolithus solitus*	*Chiasmolithus titus*	*Coccolithus eopelagicus*	*Coccolithus pelagicus*	*Coccolithus* sp. 1	*Cribrocentrum reticulatum*	*Cruciplacolithus cruciformis*	*Cruciplacolithus staurion*	*Cruciplacolithus vanheckae*	*Cruciplacolithus* spp.
CP14b	30.90	5R-1, 40–41	A	M		O-2			F	R	1	3				F			F	F	14	F	2			R	F
	32.40	5R-2, 40–41	A	M		O-2		R	1	R	2	3				F			F	F	13	1	1			F	F
	33.90	5R-3, 40–41	A	M		O-2			F	R	2	1				F			F	F	16	1	1	R			F
	35.03	5R-CC	A	G					F	R	F	F				F			1	F	11	F	F				F
	40.50	6R-1, 40–41	A	M		O-1			3	F	1	2				F			F	F	7	F	F				F
	41.89	6R-2, 29–30	A	M		O-2			1	F	2	4				F			1	1	13	F	R				F
	43.50	6R-3, 40–41	A	M		O-2		R	2	F	3	2	R			F			F	F	21	1	F				F
	45.22	6R-4, 62–63	A	M		O-2			1	F	1	1				R			1	F	14	F	F				F
	46.50	6R-5, 40–41	A	M		O-2		R	1	F	F	3				F			F	F	8	F					F
	47.05	6R-CC	A	M		O-2			3	F	F	4				F			F	F	10	F					F
	49.93	7R-1, 23–24	A	P		O-3			F	F	1	1	R			F			F	1	10	F					F
	51.70	7R-2, 50–51	A	M		O-2		R	1	F		2				F			F		8	R				R	F
CP14a	53.25	7R-3, 55–56	A	M		O-2			2	F	R	4	R			F		R	F	R	10						1
	55.34	7R-4, 114–115	A	M		O-2			1	F	R	2				F		1	1	F	11	F	R			R	R
	56.52	7R-5, 82–83	A	M		O-2		F	2	R		2				F		R	F	F	11	F				R	R
	57.53	7R-6, 33–34	A	M		O-2			2	R	R	3				F		R	1	F	6	1					
	58.20	7R-CC	A	M		O-2		R	2	R		4				F		F	2	F	5	F				F	
	59.80	8R-1, 40–41	A	M		O-2			2	R	R	6				F		F	F	F	6	F				R	R
	61.30	8R-2, 40–41	A	M		O-2		F	1	F	R	4				F		F	F	F	6	F					F
	62.80	8R-3, 40–41	A	M		O-2			1	F	F	2				F		F	F	F	9	F					F
CP13c	64.30	8R-4, 40–41	A	M		O-2			1	F	F	1		R		F		F	F	F	7	F			R	R	1
	64.61	8R-CC	A	M		O-2		R	3	R	F	1				R		F	F	F	8	F			1		F
	69.51	9R-1, 40–41	A	M		O-2			2	R	F	2	R			F		F	F	F	7	F			F	R	F
	71.00	9R-2, 40–41	A	M		O-2			2	F	F	2	R			F		F	F	F	7	F			1		R
	72.73	9R-CC	A	M		O-2			2	F	F	1	R			F	R	F	F	F	4	R			1	R	R
	79.07	10R-1, 37–38	A	M		O-2		R	6	F	R	F				R		F	F	F	5				F	R	R
	80.28	10R-2, 8–9	A	M		O-2		R	5	F		F				R		F	F	R	5	R			F		F
	81.02	10R-CC	A	M	E-1	O-2	1	R	4	F	R	1	R			F		F	F	F	3	F			F		
	88.80	11R-1, 40–41	A	P		O-3			3	F	R	F				F	R	F	F	F	7	F			R	R	
	90.30	11R-2, 40–41	A	P		O-3			2	R	R	1	R			F		F	F	F	6	F			F	R	R
	91.80	11R-3, 40–41	A	M		O-2			3	R	F	1	R			F	R	F	1	F	3	F			F	R	F
	98.50	12R-1, 40–41	A	M		O-2		R	2	F	F	F				1	F	F	1	1	5	F				R	F
	100.00	12R-2, 40–41	A	P		O-3		R	1	F	1	2				F		1	1	F	4	F			R	R	1
	110.63	13R-2, 143–144	A	M		O-2			2		F	F				F		F	F	2	6	F			R	R	R
	134.00	15R-5, 130	C	M		O-2	1		1	F	F	1				F		F	F	F	4	F		R	F	F	
	134.46	15R-CC	A	M		O-2	1	R	1		F	F				1	R	F	1	F	8	F			F	R	R
	136.37	16R-1, 17–18	A	M		O-2			2	F	F	2				1		F	F	F	12	F			F	F	
	138.10	16R-2, 40–41	A	M		O-2		R	1	1	F	1				F	R	R	1	R	7	F			F	R	
	139.29	16R-3, 9–10	A	M		O-2		R	1	F	F	F				R			F	R	8	F			F	F	
	140.93	16R-4, 23–24	A	M		O-2			1	R	F	1				F			1	F	5	F			F	F	F
	142.44	16R-5, 24–25	A	M		O-2		F	1	R	F	1				R			F	F	4	F			F	F	F
	143.85	16R-6, 15–16	A	M		O-2		F	3	R	R	F				F	R		F	F	6	F			F	R	F
	145.72	17R-1, 2–3	A	M		O-1		1	2	F	2	1				F		R	F	F	5	F		R	F	1	F
CP13b	147.71	17R-2, 51–52	A	M		O-1		F	2	1	1	4		R	R	F			R	F	3	F			F	F	1
	149.25	17R-3, 55–56	A	M		O-1		F	1	F	1	3			R	F			F	F	4	F		R	F	1	F
	150.81	17R-4, 61–62	A	M		O-1		1	F	2	F	1			F	F		R	F	F	5	F			F	R	F
	186.23	21R-2, 143	C	P		O-3		1	F	1	1	2	R		R	F		R		F	3						F

Note: See Table 3 for an explanation of the symbols used.

Table 14 (continued).

Cyclicargolithus floridanus	*Cyclolithella kalianata*	*Discoaster barbadiensis*	*Discoaster bifax*	*Discoaster deflandrei*	*Discoaster distinctus*	*Discoaster germanicus*	*Discoaster nodifer*	*Discoaster saipanensis*	*Discoaster tanii*	*Ericsonia formosa*	*Ericsonia pacifica*	*Helicosphaera compacta*	*Helicosphaera heezenii*	*Helicosphaera lophota*	*Helicosphaera seminulum*	*Lanternithus minutus*	*Lophodolithus acutus*	*Lophodolithus mochloporus*	*Markalius inversus*	*Markalius* sp. 1	*Markalius* sp. 2	*Micrantholithus altus*	*Micrantholithus procerus*	*Nannotetrina alata*	*Nannotetrina austriacus*	*Nannotetrina spinosus*	*Nannotetrina* sp. (small)	*Pedinocyclus larvaris*	*Pemma basquensis*	*Pemma papillatum*
36		10						F		1		F	1	R	R	R			R	2		R						F		
22	R	15					R	1		1		R	2	F	R				F	3								F		R
25		17					F	F		3		R	F	F	F				F	3	R	R						F		
44		16		F			F	2	R	1			1	F	F				R	1								R		R
22		11					F	1		2	R	R	F	R		R			R	1			R					F		R
19		15					F	F		2	R	R	F	R	R	R			F	2								F		R
11		12		R			R	1		2			F	R		R			F	1		R	R					F		
33		9					R	1		4	R		F	R		R			1	1	R							R		
45	R	8					R	F		3	R		F	R	R	R			F	1	F							R	R	
30	R	8		R				1	F	5	R		F	R	R	R			F	1	F							F		
53	R	5						F		3		R	F	R	R	R			F	2	1							F		
48		5		R				1		4	R		F	R	F	F			F	F	2							F		R
44		2		R				F		5	R		F	F	F	F			F	3	1							F		R
34	R	4	F	F				F		3			F	F	F	F			F	4	1							F		
32		5	1	F			R	F		4			1	1	F	F			F	3	1							F		
27		10	1	F			F	F		1			F	F	F	F			F	2	1							F		
46	R	12	4	F				F		1			F	F	R	F			F	3	F	R						1		
33		8	2				R	F		4			F	F	F	F			F	2	1							1	R	
37		7	1				R	1		3	R		R	R	F	F			1	1	F							F		
29		10	1				R	F		3			F	R	R	F			1	1	F			R				1		
35		7	2				R	F		4			F	F	R	F			F	3	F						R	1		
33		14	1				R	3		2			F	F	R	F			1	1	F			R				F		R
48	R	8	F			R	R	1		3	R		R	F	R	F			F	2	F			R			R	F		
46	R	8	F					2		1	R		F	R	R	F			F	5	F			R			R	F		
45	F	4	F				R	F		2			F	F	R	F			F	3	F						R	F		
53	R	6	F					R		1	R		1	R		1			F	F	F			R			F	F		
44	R	8	F					1		F			F	F	R	F			R	5	F			R			R	F		
49		10	F	R				1		5	R		F	1	R	R			R	1	F	R					R	R		
56		8	F	R				F		2	R		F	F	R	F			F	2	R			R			R	R		R
51		8	F					F		3			F	F	R	R			F	1	R						R	F		
50		7	F	F				F		3			1	F	R	F			F	F	1	R		R	R		R	R		
46	F	9		F			R	R		F			1	F	R	R			1	1	2			F			R	F		
44		12	R					1		3			F	F	F	F	R		F	2	F	R		F	R			F		
47		7					R	1		2			F	F	F	F			F	F	F							R		
59		4	R			R				1			F	1	F	F	F		F	1	F						R	F		
38		8	R	R	R			F		5			F	F	1				F	1	1				F	R	F	F		
40	R	13	R	F				F		3			F	F	F		R		F	F	1			R	R	R	F	F	R	
41	F	13	F	F	R	R		F		3			F	F	F	R			F	F	1			R	R		F	R		
45	F	15				R				8			F	F	F				F	F	F	R		F	R		F	R		
40	F	12								4			F	F	F				F	2	F				R		F	F		
61	F	5		R		R				1			F	F	F				F	F	1				R		F	1		
59	R	8		F		R				2			F	F	F	R			F	1	F				R		F	F		
60	R	2		F						1			1	F	F		F		F	F	F						F	F		
56	F	6		F			R			5			F	F	F			R	F	1	F	R		R			F	F		
47	F	10		F			R	R		4			F	F	F		R	R	2	1	1			R			F	F	1	
45	F	5		F	R	R		F		10	R		F	1	1	R		R	F	1							F	F	R	
64		1		R				F		4			F	F	F		R			1	F						F	F		

Table 14 (continued).

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Pontosphaera formosa*	*Pontosphaera latoculata*	*Pontosphaera ocellata*	*Pontosphaera pectinata*	*Pontosphaera scissura*	*Pontosphaera segmenta*	*Pseudotriquetrorhabdulus inversus*	*Reticulofenestra dictyoda*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilica*	*Scapholithus rhombiformis*	*Sphenolithus furcatolithoides*	*Sphenolithus moriformis*	*Sphenolithus pseudoradians*	*Sphenolithus radians*	*Sphenolithus spiniger*	*Toweius*? sp. 1	*Transversopontis fimbriatus*	*Transversopontis pax*	*Zygrhablithus bijugatus*	Holococcolith type A
CP14b	30.90	5R-1, 40–41	A	M		O-2							F	F		6	5		4	1	F	F	5				2	F
	32.40	5R-2, 40–41	A	M		O-2							F	1		2	1		9	3	F	F	8				2	1
	33.90	5R-3, 40–41	A	M		O-2							F	F		F	F		8	3	F	R	7				2	2
	35.03	5R-CC	A	G									R	F		1	1		2	4	1	F	3				2	2
	40.50	6R-1, 40–41	A	M		O-1							F	F		2	2		13	5	F	F	14				4	1
	41.89	6R-2, 29–30	A	M		O-2		R					R			2	2		13	5	F	F	9				1	3
	43.50	6R-3, 40–41	A	M		O-2								R		3	2		8	9	2	F	7				4	2
	45.22	6R-4, 62–63	A	M		O-2							R	R		5	R		9	4	F	F	1				4	3
	46.50	6R-5, 40–41	A	M		O-2									1	10	F		4	4	R	R	2				2	2
	47.05	6R-CC	A	M		O-2							R	R	F	6	R		7	6			8				1	1
	49.93	7R-1, 23–24	A	P		O-3										1	R		5	4			5				1	1
	51.70	7R-2, 50–51	A	M		O-2		R							F	3	1		6	3	R	R	7				2	2
CP14a	53.25	7R-3, 55–56	A	M		O-2		R					R			2	1		3	2	R		8	F			3	1
	55.34	7R-4, 114–115	A	M		O-2		R							F	5	R		8	4	R	R	7	1			2	F
	56.52	7R-5, 82–83	A	M		O-2		R						R	R	6	F		6	6	F	1	6				4	1
	57.53	7R-6, 33–34	A	M		O-2		R							R	11	1		6	7	F	1	3				7	F
	58.20	7R-CC	A	M		O-2		R							R	F	F		F	2	F	1	4	F			5	F
	59.80	8R-1, 40–41	A	M		O-2						R		R	F	1	R		6	5	F	2	3	1			9	F
	61.30	8R-2, 40–41	A	M		O-2									F	F	R		5	6	F	F	6	9			2	F
	62.80	8R-3, 40–41	A	M		O-2						R	R	R	F	1	R		8	4	R	F	5	11	R		4	1
CP13c	64.30	8R-4, 40–41	A	M		O-2		R						F	F	F			12	3	R	R	8	6			F	F
	64.61	8R-CC	A	M		O-2								F	1	1			6	2	R	R	2	4			7	F
	69.51	9R-1, 40–41	A	M		O-2							R	F	F	F			5	1	F	F	4	7			2	F
	71.00	9R-2, 40–41	A	M		O-2						R		F	F	1			5	1	R	F	5	3			2	F
	72.73	9R-CC	A	M		O-2		R						1	1	1			13	3		F	2	5			6	F
	79.07	10R-1, 37–38	A	M		O-2								1	F	F			2	3		1	5	1			7	1
	80.28	10R-2, 8–9	A	M		O-2						R		F	F	1			8	4		1	5	4			1	1
	81.02	10R-CC	A	M	E-1	O-2	1					R		2		F			7	3	R	F	2	1			3	F
	88.80	11R-1, 40–41	A	P		O-3						R		F	R	2			1	5	R	F	5	2			1	F
	90.30	11R-2, 40–41	A	P		O-3						R		2	F	1		R	1	5	R	F	3	1			5	1
	91.80	11R-3, 40–41	A	M		O-2							R	2	F	7			1	2	F	F	1	2			5	1
	98.50	12R-1, 40–41	A	M		O-2						R		1	F	8			1	6		F	4	F			4	F
	100.00	12R-2, 40–41	A	P		O-3		R				R	R	F	F	2			4	3	R	F	5	3			2	F
	110.63	13R-2, 143–144	A	M		O-2								F	2	9	R		6	2	R	F	3	F	R		1	F
	134.00	15R-5, 130	C	M		O-2	1	R			R	R		F	F	F			2	9		F	4	3			1	
	134.46	15R-CC	A	M		O-2	1				R	R	R	2	F	4			2	9		F	2	F	R		2	
	136.37	16R-1, 17–18	A	M		O-2						F	R	2	F	3			6	3		F	1	F			2	F
	138.10	16R-2, 40–41	A	M		O-2						R	R	F	F	6			3	6		F	2	F			4	F
	139.29	16R-3, 9–10	A	M		O-2		R			R	R		1	2	6			1	2			F	1			1	F
	140.93	16R-4, 23–24	A	M		O-2		R						2	6	6			5	4			5	1			F	F
	142.44	16R-5, 24–25	A	M		O-2		R				R		2	2	2			3	4		F	1	1			1	F
	143.85	16R-6, 15–16	A	M		O-2		R		R				2	F	1			6	1		R	1	F			F	F
	145.72	17R-1, 2–3	A	M		O-1		R		R				1	1	2			1	6	R	R	3	F			F	R
CP13b	147.71	17R-2, 51–52	A	M		O-1				R			R	1	1	2			F	3	R	F	2	1			1	F
	149.25	17R-3, 55–56	A	M		O-1			R		R	R		F	1	3			2	3		F	3			R	3	F
	150.81	17R-4, 61–62	A	M		O-1		R	F			R		2	1	7		R	1	2		1	5				1	F
	186.23	21R-2, 143	C	P		O-3			2			F		F	F	F		F	4	5		F	2	F			F	

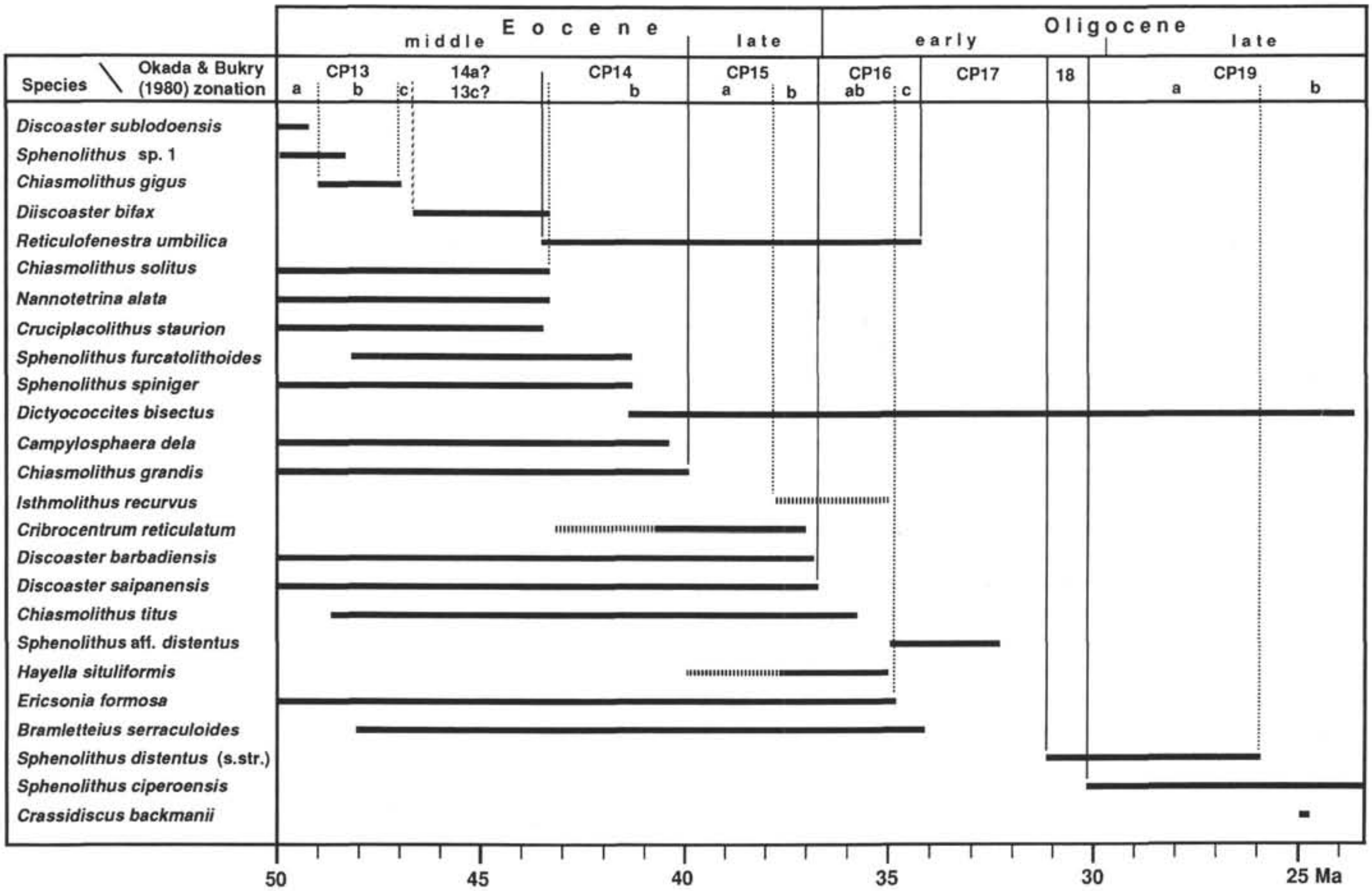


Figure 2. Range chart of important species for Paleogene biostratigraphy. The FOs and LOs are expressed in approximate ages calibrated in the same manner with that explained in Table 16. The solid lines indicate consistent occurrences, and the dashed lines indicate sporadic occurrences.

Table 15. Percentage occurrences of calcareous nannofossils observed in the Oligocene samples from Hole 714A.

Zonation (Okada and Bukry, 1980)	Depth (mbsf)	Core, section, interval (cm)	Abundance	Preservation	Etching	Overgrowth	Reworking	*Braarudosphaera bigelowii*	*Calcidiscus kingii*	*Catinaster? umbrellus*	*Coccolithus eopelagicus*	*Coccolithus fuscus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coronocyclus nitescens*	*Crassidiscus backmanii*	*Cruciplacolithus tarquinius*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster adamanteus*
CP19b	199.30	22X-4, 40–41	A	M		O-1				F		F	R	10				F	51			F
	200.80	22X-5, 40–41	A	M		O-1				F		F	F	11				F	51			R
	201.44	22X-CC	A	M		O-1				F		F	F	11				1	52	F		R
	204.50	23X-1, 40–41	A	M		O-1			R	1		F	1	5	R			F	58	R		F
	206.00	23X-2, 40–41	A	M		O-1				1		F	F	8	R		R	F	55	R		F
	207.50	23X-3, 40–41	A	M		O-1			R	F		F	1	5	R		F	F	56	R		F
	209.00	23X-4, 40–41	A	M		O-1				2	F	F	R	11	R		F	F	56	F		F
	210.50	23X-5, 40–41	A	M		O-1			R	1	F	F	F	8	R		F	F	56	1		F
	212.00	23X-6, 40–41	A	M		O-1			R	F	R	F	R	6	R		F	F	61	F	F	F
CP19a	213.87	23X-CC	A	M		O-1				R	F	F		6	F	F	R	1	47	F		1
	214.20	24X-1, 40–41	A	M		O-1			R	R	R	1	R	6	F	1	R	F	57	1		F
	215.83	24X-CC	A	M		O-1		R	F		R	F		4	F		F	F	56	R	F	
	223.70	25X-1, 40–41	A	M		O-1		R	F		R	R		8	F		F	1	68	F	1	
	225.04	25X-2, 24–25	A	M		O-2	1		R					6	F		R	F	45	F	3	R
	226.72	25X-CC	A	M		O-2	1							5	F				44	R	1	

Note: See Table 3 for an explanation of the symbols used.

Table 15 (continued).

Discoaster deflandrei	*Discoaster nodifer*	*Discoaster tanii*	*Ericsonia obruta*	*Helicosphaera euphratis*	*Helicosphaera intermedia*	*Helicosphaera obliqua*	*Helicosphaera perch-nielseniae*	*Helicosphaera recta*	*Helicosphaera wilcoxonii*	*Ilselithina fusa*	*Pedinocyclus larvaris*	*Pontosphaera latoculata*	*Pontosphaera segmenta*	*Scapholithus fossilis*	*Sphenolithus ciperoensis*	*Sphenolithus* aff. *ciperoensis*	*Sphenolithus dissimilis*	*Sphenolithus distentus*	*Sphenolithus moriformis*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Syracosphaera* sp. 1	*Triquetrorhabdulus carinatus*	*Triquetrorhabdulus milowii*	*Umbilicosphaera* sp. 1	*Zygrhablithus bijugatus*	Holococcolith type A
4			6	F	F		F			F					2		4		17			F	1			F	1
2			9	1	F		F	F		F			R		2		3		16			F	1	F			1
2			2	1	F		R	F		R			R		1		5		20			R	F	F			F
8			7	1	F		R	F		R			R		2		4		9			F	F	R		R	1
2			5	1	F	R	F	1		R			R		2		3		17			R	1	R		R	F
2			7	3	1		F	1		F			R		1		3		13	R		R	1	F	R	R	1
3			2	2	F	R	F	F		F		R	R		1		4		13	R		F	F	R			1
4			4	4	1		F	F		R			R		F	F	1		12			R	F	R			F
1			5	1	F	R	F	F		R					2	F			19	R		F	F	R			F
6			4	3	R	R	R	1		R					2	F		1	22			R	F	R			F
2			4	2	F		R	F		R					4	F		1	19			R	F				F
1			3	F	R		R	R		R	R				F	R		2	13	14			F		R	R	F
3			1	F	R	R	R	R		R	R	R		R	F	R		3	3	9		R	F		R	F	F
3	F		1	F	R		R		R	R	R				F	1		5	11	18	r					F	1
1	F	F	1	R	R										F	R		7	12	21						F	1

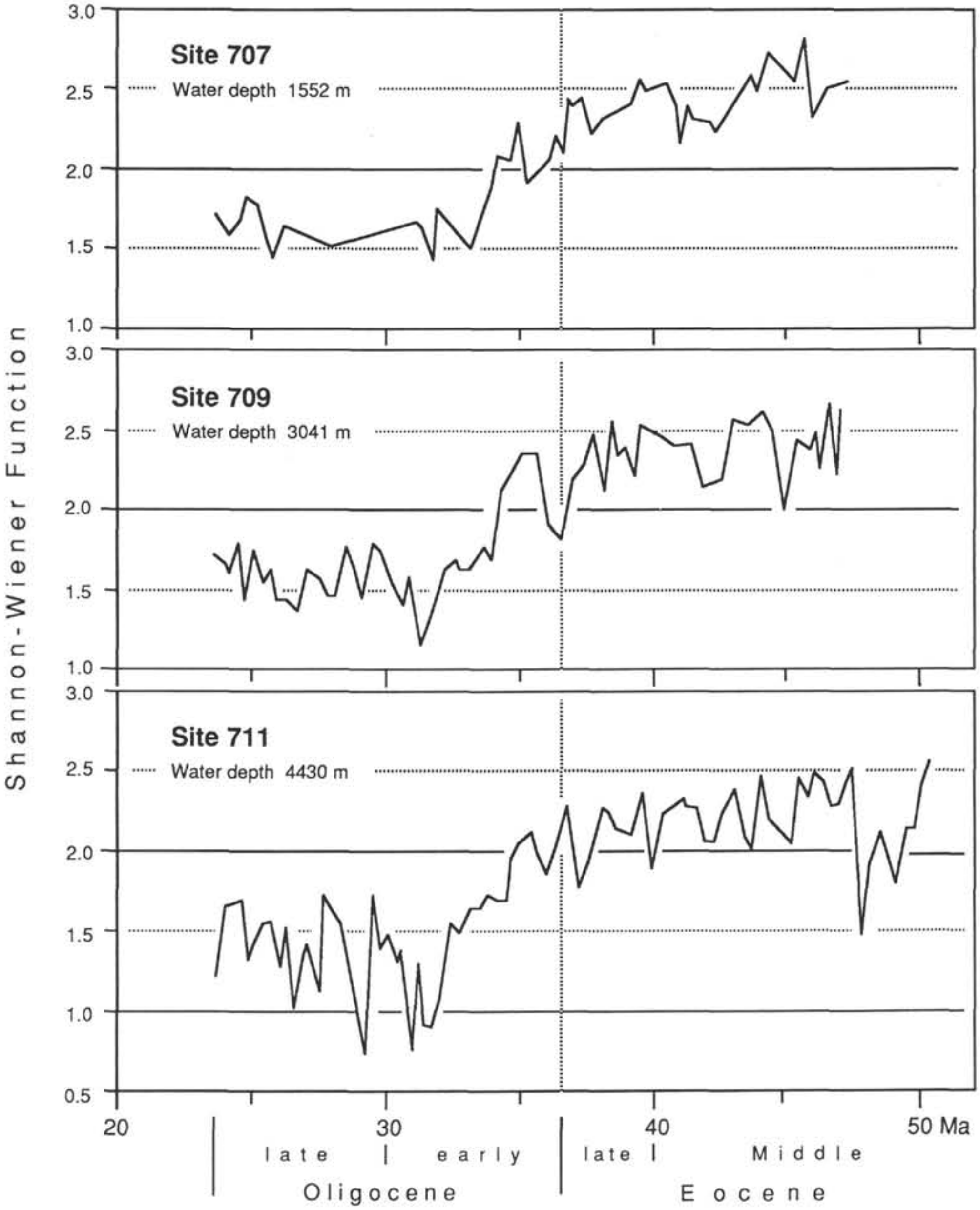


Figure 3. Temporal change in the species diversity measured by Shannon-Wiener Function at the three CBT sites.

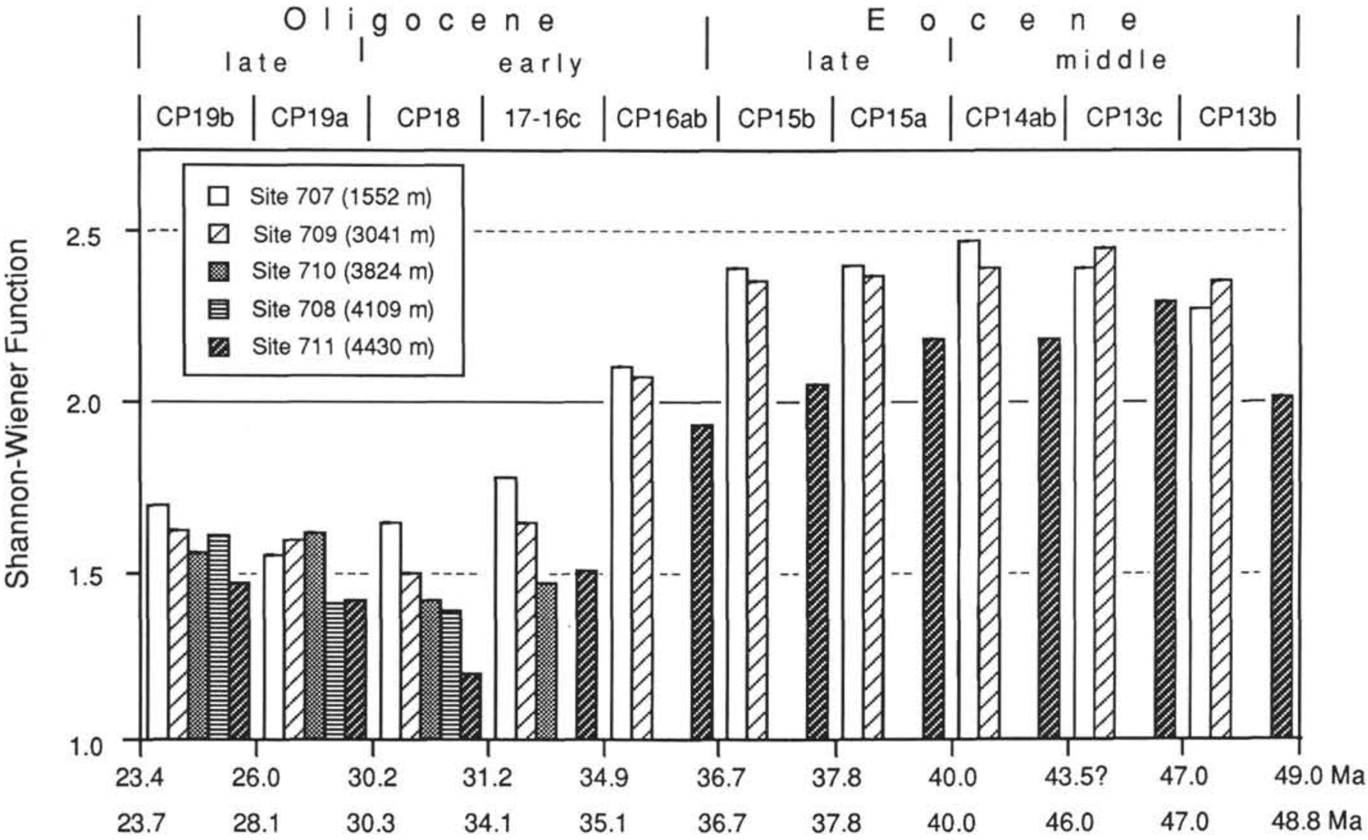


Figure 4. Average value of the species diversity measured by Shannon-Wiener Function at the five CBT sites. The Shannon-Wiener Function was calculated for all examined samples and averaged for corresponding zones and subzones. The boundary ages shown in the upper row are the calibrated ages for the tropical Indian Ocean (see explanation of Table 16), whereas the ages in the lower row are that of Berggren et al. (1985) and Aubry et al. (1988).

Table 16. Occurrence of Oligocene to middle Eocene events and their ages observed in the Oligocene cores of Hole 709C and in the Eocene cores of Hole 711A.

Datum event	Core, section, interval (cm)	Depth (mbsf)	Age (Ma)
Hole 709C:			
Sphenolithus ciperoensis top	22X-1, 60/22X-2, 60	199.30–200.80	23.4
Dictyococcites bisectus top	22X-2, 60/22X-3, 60	200.80–202.30	**23.7**
Crassidiscus backmanii top	22X-CC/23X-1, 40	206.52–208.80	24.8
Crassidiscus backmanii base	23X-1, 40/23X-2, 40	208.08–210.30	25.0
Sphenolithus distentus top	23X-4, 60/23X-5, 60	213.30–214.80	26.0
Sphenolithus ciperoensis base	25X-CC/26X-1, 43	235.54–237.83	**30.2**
Sphenolithus distentus base	26X-5, 43/26X-6, 43	243.83–245.33	31.2
Sphenolithus aff. *distentus* top	27X-CC/28X-1, 43	253.61–257.13	32.4
Bramletteius serraculoides top	29X-2, 43/29X-3, 43	268.33–269.83	34.2
Reticulofenestra umbilica top	29X-2, 43/29X-3, 43	268.33–269.83	34.2
Ericsonia formosa top	29X-6, 43/29X-CC	274.33–275.91	**34.9**
Hayella situriformis top	29X-CC/30X-1, 43	275.91–276.53	35.1
Sphenolithus aff. *distentus* base	29X-CC/30X-1, 43	275.91–276.53	35.1
Chiasmolithus titus top	30X-2, 43–30X-3, 43	278.03–279.53	35.8
Dicoasater saipanensis top	30X-5, 43/30X-6, 43	282.53–284.03	**36.7**
Hole 711A:			
Discoaster saipanensis top	17X-3, 100/17X-4, 40	156.40–157.90	**36.7**
Discoaster barbadiensis top	17X-4, 40/17X-4, 100	157.90–158.50	36.8
Cribrocentrum reticulatum top	17X-4, 100/17X-5, 40	158.50–159.40	37.0
Isthmolithus recurvus base	18X-1, 42/18X-2, 42	163.12–164.62	37.8
Chiasmolithus grandis top	19X-3, 75/19X-4, 38	176.15–177.28	**40.0**
Campylosphaera dela top	19X-6, 38/19X-CC	180.28–181.62	40.6
Sphenolithus spiniger top	20X-2, 75/20X-4, 39	184.35–186.99	41.4
Sphenolithus furcatolithoides top	20X-2, 75/20X-4, 39	184.35–186.99	41.4
Dictyococcites bisectus base	20X-2, 75/20X-4, 39	184.35–186.99	41.4
Chiasmolithus solitus top	21X-4, 40/21X-5, 40	196.60–198.10	43.4
Discoaster bifax top	21X-4, 40/21X-5, 40	196.60–198.10	43.4
Nannotetrina alata top	21X-4, 40/21X-5, 40	196.60–198.10	43.4
Reticulofenestra umbilica base	21X-5, 40/21X-CC	198.10–199.18	43.5
Cruciplacolithus staurion top	21X-5, 40/21X-CC	198.10–199.18	43.5
Discoaster bifax base	23X-4, 40/23X-5, 40	216.00–217.50	46.6
Chiasmolithus gigas top	23X-6, 40/23X-CC	219.00–220.27	**47.0**
Sphenolithus furcatolithoides base	24X-4, 40/24X-5, 40	225.60–227.10	48.2
Chiasmolithus gigas base	25X-1, 40/25X-2, 40	230.70–232.20	49.0

Note: The ages presented in bold typeface are taken from Berggren et al. (1985), Backman (1987), and Aubry et al. (1988). The ages shown in normal type face are estimated ages observed in the respective holes. The estimated ages were obtained from the sediment accumulation rates, which was plotted by adopting the anchor ages expressed in bold typeface.

Table 17. Species diversity and average composition of calcareous nannofossil flora at the five CBT sites and at Site 714 during the late Oligocene (25–27 Ma).

Site	707	709	710	708	711	714
Latitude	07°33S	03°55S	04°19S	05°28S	02°45S	05°04N
Water depth (m)	1552	3041	3824	4109	4430	2038
*Coccolithus pelagicus***	7.9	9.2	11.6	12.0	12.9	6.9
Cyclicargolithus abisectus	0.7	0.7	1.0	0.8	0.7	0.2
Cyclicargolithus floridanus	51.9	53.0	50.1	49.9	57.0	54.8
Dictyococcites bisectus	1.1	0.6	0.4	0.3	1.3	0.2
Dictyococcites scrippsae	0.2	0.2	—	—	0.1	0.5
Discoaster deflandrei	3.9	5.1	6.3	8.3	5.0	2.8
Ericsonia obruta	2.5	2.1	1.2	1.9	0.5	3.6
*Helicosphaera euphratis**	0.2	0.1	—	—	—	1.6
*Sphenolithus ciperoensis**	7.4	7.7	8.5	4.5	2.9	1.2
Sphenolithus aff. *ciperoensis*	1.1	0.6	0.4	0.4	0.6	0.1
Sphenolithus dissimilis	0.4	0.1	—	0.4	0.1	1.1
Sphenolithus distentus	—	1.4	0.2	0.1	0.1	1.9
Sphenolithus moriformis	15.1	15.7	18.1	17.6	15.4	14.2
*Sphenolithus predistentus**	3.7	1.3	—	—	—	5.8
Triquetrorhabdulus carinatus	0.8	0.9	0.4	2.4	0.3	0.2
Holococcolith type A*	0.2	—	—	—	—	0.5
Number of species ($\geq$0.1% of flora)	23	21	17	17	17	23
Shannon-Wiener Function	1.65	1.53	1.49	1.54	1.38	1.57

Note: Taxa with single asterisks are considered to show a decreasing trend in deeper sites, and the taxon with double asterisks the inverse trend.

Table 18. Species diversity and average composition of calcareous nannofossil flora at the three CBT sites and at Site 714 during the early Oligocene (approximately between 34 and 35 Ma).

Site Latitude Water depth (m)	706 13°07S 2504	707 07°33S 1552	709 03°55S 3041	711 02°45S 4430
Braarudosphaera bigelowii	1.1	0.3	—	—
Bramletteius serraculoides	0.4	0.7	0.7	0.5
*Cruciplacolithus tarquinius***	2.5	—	—	—
Coccolithus pelagicus	8.2	13.3	11.0	13.5
Coronocyclus nitescens	0.6	0.1	—	0.1
Cyclicargolithus floridanus	37.7	45.4	41.7	46.6
Dictyococcites bisectus	1.5	4.6	5.7	4.4
Dictyococcites scrippsae	0.3	0.8	1.4	1.0
Discoaster deflandrei	0.8	0.7	0.9	1.0
Ericsonia obruta	1.2	1.0	1.1	1.5
*Ericsonia subdisticha***	—	0.6	0.8	2.4
Helicosphaera compacta	2.3	1.0	1.2	0.6
Helicosphaera euphratis	0.6	—	0.2	0.1
Helicosphaera reticulata	0.8	—	0.2	0.4
*Lanternithus minutus**	11.5	3.9	1.3	—
Pedinocyclus larvarlis	0.7	0.1	0.2	—
*Quinquerhabdus colossicus***	3.6	—	—	—
Umbilicosphaera sp. 1**	4.6	—	—	—
Sphenolithus moriformis	3.9	7.6	9.0	9.7
Sphenolithus predistentus	7.0	11.5	17.1	14.0
Sphenolithus aff. *distentus*	0.7	0.4	0.6	0.4
Syracosphaera sp. 1**	1.3	—	—	—
*Zygrhablithus bijugatus**	2.0	2.8	1.6	—
Number of species (≥0.1% of flora)	35	22	20	20
Shannon-Wiener Function	2.27	1.83	1.86	1.72

Note: Taxa with single asterisks are considered to show a decreasing trend in deeper sites. Taxa with double asterisks show a geographic provincialism.

Table 19. Species diversity and average composition of calcareous nannofossil flora at the three CBT sites during the early late Eocene (38–40 Ma) and late middle Eocene (40–42 Ma).

Age Zone (approx. age)	Early late Eocene CP15a (38–40 Ma)			Late middle Eocene CP14b (40–42 Ma)		
Site Water depth (m)	707 1552	709 3041	711 4430	707 1552	709 3041	711 4430
*Bramletteius serraculoides**	6.3	4.0	0.4	2.8	1.7	0.5
Calcidiscus kingii	3.2	5.2	1.4	1.5	0.4	0.7
Calcidiscus protoannulus	—	—	—	0.4	0.4	0.4
Campylosphaera dela	—	—	—	1.6	0.4	0.9
Chiasmolithus titus	—	—	—	0.3	0.8	0.3
Coccolithus eopelagicus	—	—	—	0.6	0.4	0.5
*Coccolithus pelagicus***	9.8	6.5	16.8	11.0	12.8	14.3
Coccolithus sp. 1	—	—	—	0.9	0.3	0.3
*Cribrocentrum reticulatum***	9.8	11.8	19.9	0.3	1.2	6.2
Cyclicargolithus floridanus	20.8	18.8	22.2	26.0	29.0	21.6
Dictyococcites bisectus	16.9	14.6	3.4	11.4	1.5	8.0
Dictyococcites scrippsae	3.8	13.1	0.6	3.7	1.5	3.6
Discoaster barbadiensis	6.2	5.5	9.2	10.0	9.2	12.1
Discoaster saipanensis	4.6	4.0	6.4	2.9	3.5	2.8
Ericsonia formosa	2.2	1.2	4.2	3.5	2.8	4.1
*Lanternithus minutus**	—	—	—	0.5	0.3	—
Markalius sp. 1	—	—	—	1.1	1.4	0.6
*Pedinocyclus larvarlis**	—	—	—	0.4	0.4	—
Reticulofenestra dictyoda	—	—	—	0.3	0.1	1.2
Reticulofenestra samodurovii	—	—	—	1.3	4.2	2.2
Reticulofenestra umbilica	—	—	—	0.9	2.1	1.9
Sphenolithus furcatolithoides	—	—	—	3.1	4.9	7.1
Sphenolithus intercalaris	—	—	—	0.7	0.8	1.5
Sphenolithus moriformis	5.2	4.8	3.9	2.5	3.6	3.3
Sphenolithus obtusus	—	—	—	1.7	0.4	1.2
Sphenolithus pseudoradians	—	—	—	0.6	0.2	—
Sphenolithus spiniger	—	—	—	2.2	5.8	2.8
*Zygrhablithus bijugatus**	1.7	1.3	—	2.2	3.8	—
Holococcolith type A*	1.7	0.9	—	0.9	0.7	—
Number of species (≥0.1% of flora)	25	26	22	39	32	30
Shannon-Wiener Function	2.40	2.37	2.23	2.43	2.39	2.19

Note: Taxa with single asterisk are considered to show a decreasing trend in deeper sites, and taxa with double asterisks the inverse trend.

Table 20. Species diversity and average composition of calcareous nannofossil flora at the three CBT sites and at Site 713 during the middle Eocene (46–47 Ma).

Site Latitude Water depth (m)	707 07°33S 1552	709 03°55S 3041	711 02°45S 4430	713 04°12S 2915
Bramletteius serraculoides	1.1	1.8	0.8	2.5
Calcidiscus protoannulus	0.5	0.6	0.5	0.3
Campylosphaera dela	2.0	0.8	0.7	1.1
Chiasmolithus titus	0.6	0.5	0.9	0.5
Coccolithus eopelagicus	0.6	0.4	0.5	0.3
*Coccolithus pelagicus***	6.7	11.0	11.7	6.2
Cruciplacolithus staurion	0.5	—	—	0.2
Cyclicargolithus floridanus	38.8	31.8	28.8	47.5
Discoaster barbadiensis	7.9	10.9	12.8	8.8
Discoaster bifax	0.7	1.0	0.7	0.2
Discoaster saipanensis	0.9	0.3	—	0.6
Ericsonia formosa	2.3	4.9	4.3	2.7
Helicosphaera heezenii	0.8	0.1	0.4	0.3
Helicosphaera lophota	0.5	0.7	0.5	0.3
Markalius inversus	0.7	0.1	—	0.3
Markalius sp. 1	2.6	1.9	1.9	1.6
Markalius sp. 2	—	—	0.6	0.6
*Pedinocyclus larvarlis**	1.1	0.7	0.2	0.2
Pseudotriquetrorhabdulus inversus	2.4	3.7	3.8	1.3
Reticulofenestra dictyoda	1.8	0.1	1.6	0.8
Reticulofenestra samodurovii	0.5	1.7	3.1	3.0
Reticulofenestra umbilica	0.9	2.1	1.9	1.3
Sphenolithus furcatolithoides	5.2	9.6	8.0	4.6
Sphenolithus moriformis	3.7	3.8	4.8	4.0
Sphenolithus radians	0.4	0.4	0.7	0.3
Sphenolithus spiniger	6.6	11.4	9.2	3.4
Toweius? sp. 1	0.7	1.1	0.8	2.2
*Zygrhablithus bnijugatus**	5.4	6.0	—	2.8
Number of species (≥0.1% of flora)	36	29	31	39
Shannon-Wiener Function	2.38	2.45	2.29	2.07

Note: Taxa with single asterisk are considered to show a decreasing trend in deeper sites and the taxon with double asterisks, the inverse trend.

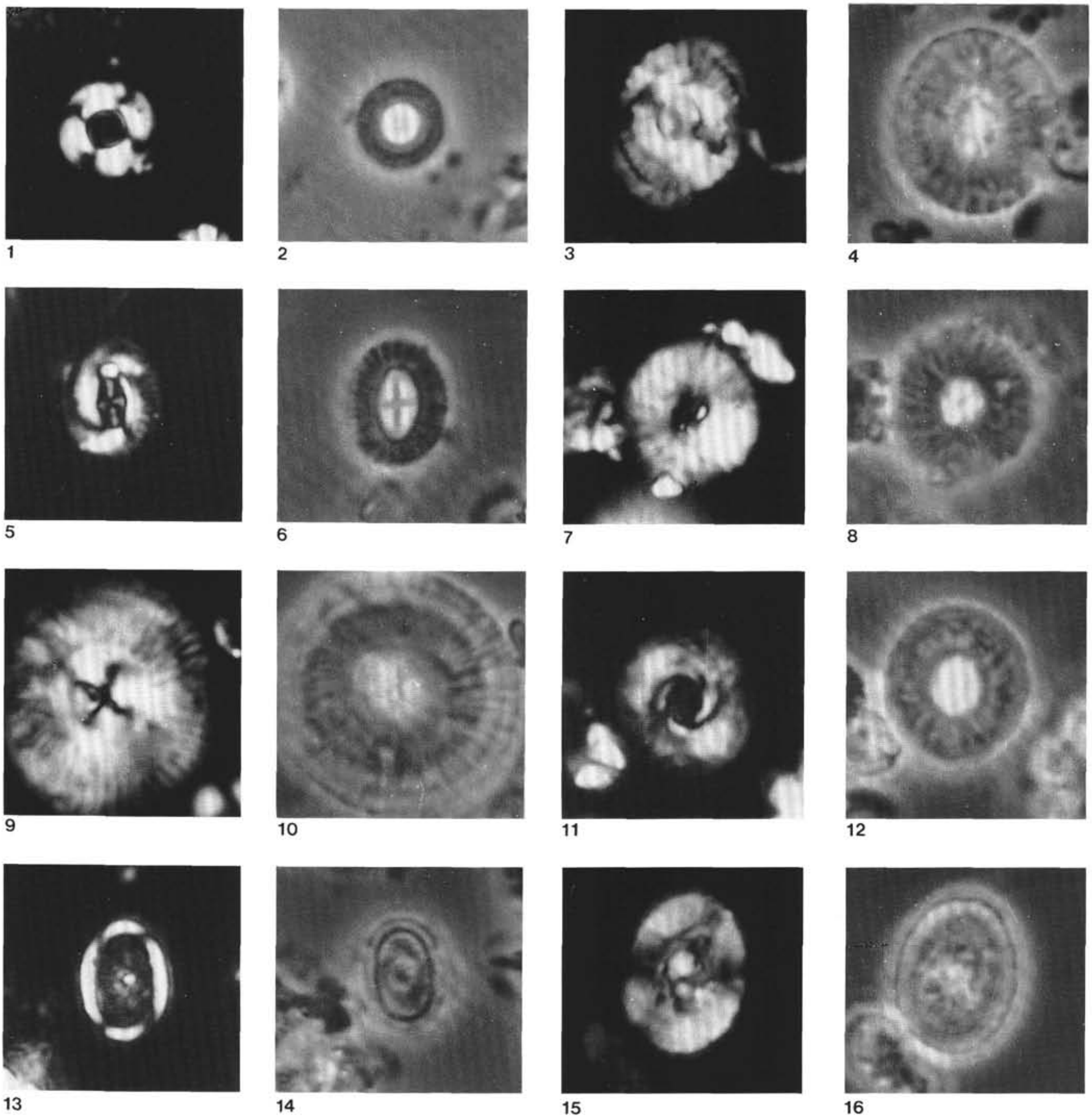
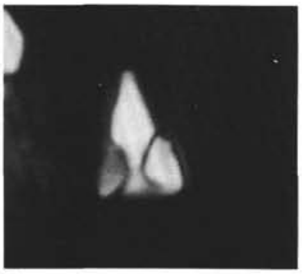


Plate 1. Optical micrographs of selected Paleogene taxa. Odd-numbered figures are micrographs under a cross-polarized light, and even numbered figures are phase-contrast images. All figures have same magnification. Scale bar in the lower right corner represents 5 μm. **1, 2.** *Umbilicosphaera* sp. 1, Sample 115-706A-3H-2, 130–131 cm. **3, 4.** *Coccolithus* sp. 1, Sample 115-709C-30X-CC. **5, 6.** *Cruciplacolithus tarquinius* Roth and Hay in Hay et al., 1967, Sample 115-706A-3H-2, 130–131 cm. **7, 8.** *Markalius* sp. 1, Sample 115-711A-21X-3, 40–41 cm. **9, 10.** *Markalius* sp. 2, Sample 115-713A-7R-2, 50–51 cm. **11, 12.** *Toweius*? sp. 1, Sample 115-711A-22X-2, 40–41 cm. **13, 14.** *Syracosphaera* sp. 1, Sample 115-706A-3H-2, 130–131 cm. **15, 16.** *Crassidiscus backmanii* n. sp., Sample 115-710A-17X-3, 43–44 cm.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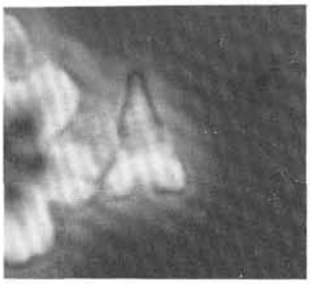
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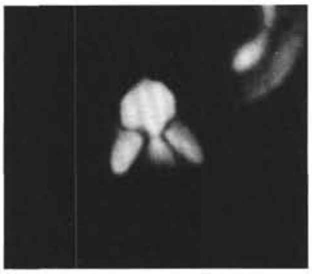
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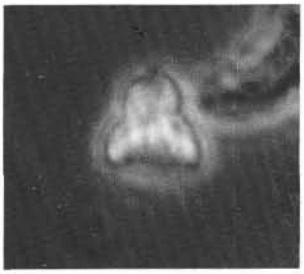
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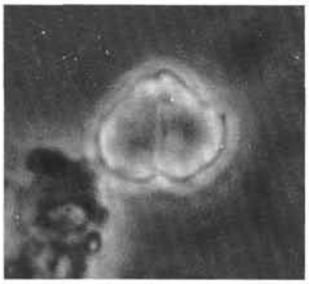
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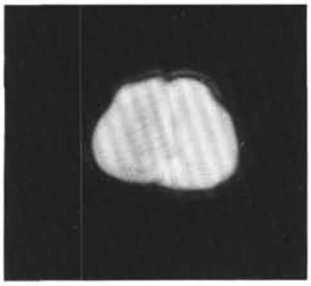
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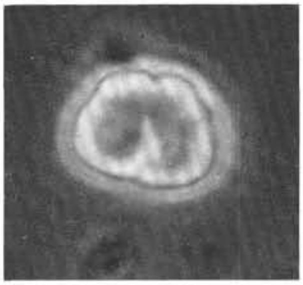
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Plate 2. Optical micrographs of Paleogene taxa that are not identifiable to known taxa. Odd numbered figures are micrographs under a cross-polarized light and even numbered figures are phase-contrast images. All figures same magnification. Scale bar in the lower right corner represents 5 μm. **1, 2.** *Sphenolithus ciperoensis* Bramlette and Wilcoxon, Sample 115-709C-23X-5, 40–41 cm. **3, 4.** *Sphenolithus* sp. aff. *S. ciperoensis*, Sample 115-711A-12X-2, 40–41 cm. **5, 6.** *Sphenolithus distentus* (Martini) Bramlette and Wilcoxon, Sample 115-711A-13X-4, 40–41 cm. **7, 8.** *Sphenolithus* sp. aff. S. *distentus*, Sample 115-711A-16X-3, 40–41 cm. **9, 10.** *Sphenolithus* sp. 1 (side view), Sample 115-711A-25X-1, 40–41 cm. **11, 12.** *Sphenolithus* sp. 1 (top view), Sample 115-711A-25X-1, 40–41 cm. **13–16.** Holococcolith type A, Sample 115-709C-30X-CC.

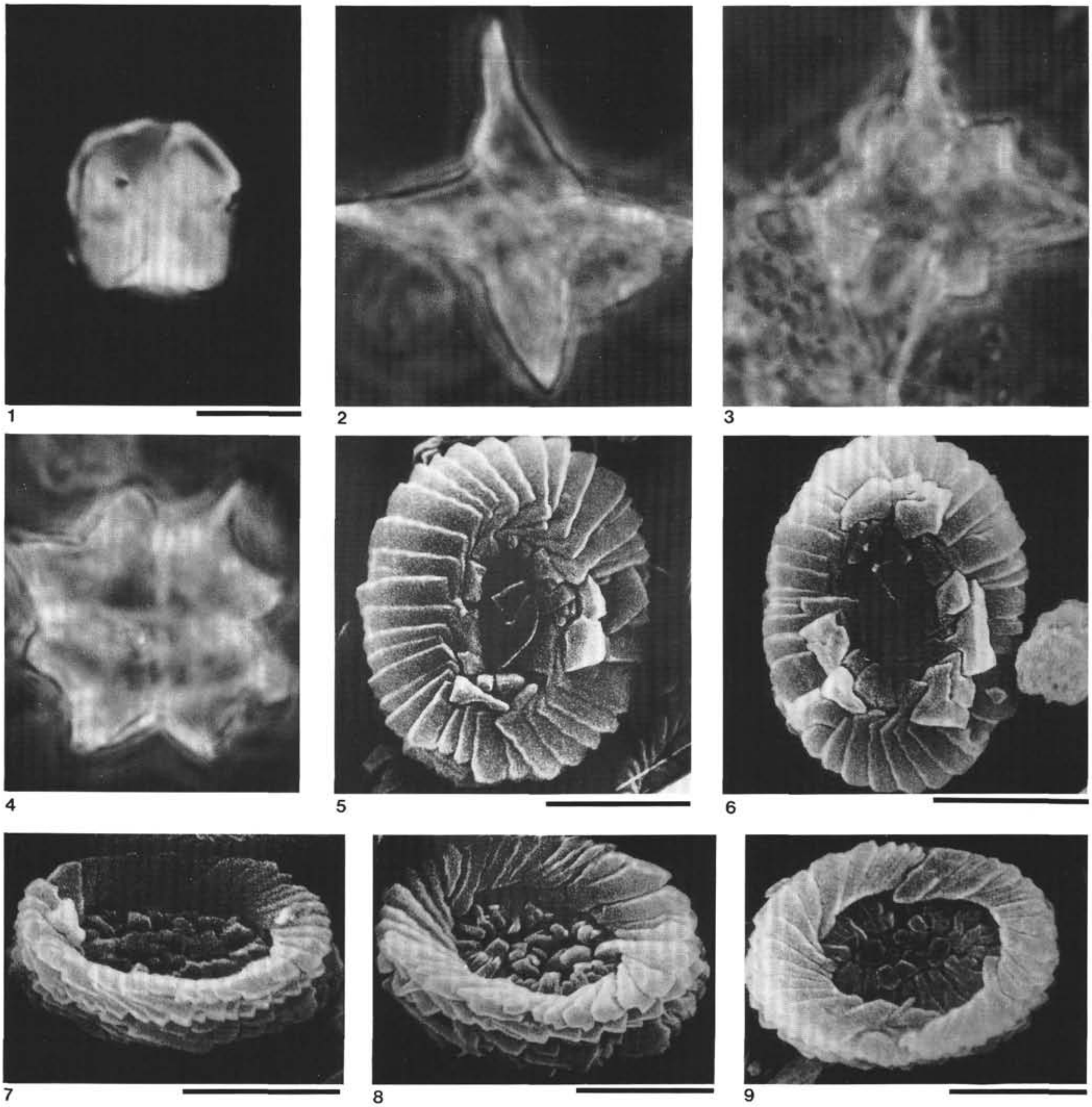

Plate 3. Optical micrographs of *Nannotetrina* species and SEM micrograph of *Crassidiscus backmanii* n. sp. Figures 1 through 4 have same magnification, and the scale bar in Figure 1 represents 5 μm. Figures 5 through 9 are SEM micrographs, and the scale bars in the lower right corner of each figure represent 3 μm. **1.** *Nannotetrina* sp. (small), cross-polarized light micrograph, Sample 115-711A-24X-1, 40–41 cm. **2.** *Nannotetrina alata* (Martini, 1960) Haq and Lohmann, 1976, phase-contrast micrograph, Sample 115-713A-16R-1, 17–18 cm. **3.** *Nannotetrina austriacus* (Stradner, 1959) n. comb., phase-contrast micrograph, Sample 115-713A-16R-1, 17 cm. **4.** *Nannotetrina spinosus* (Stradner in Martini and Stradner, 1960) n. comb., phase-contrast micrograph, Sample 115-713A-16R-1, 17–18 cm. **5–9.** *Crassidiscus backmanii* n. sp., SEM micrographs, Sample 115-709C-23X-1, 40–41 cm, (5 and 6) distal plan view, (7 and 8) oblique view of the proximal side, (9) proximal plan view.