33. CALCAREOUS NANNOFOSSILS

33.1. COCCOLITH STRATIGRAPHY LEG 13, DEEP SEA DRILLING PROJECT[1]

David Bukry, U. S. Geological Survey, La Jolla, California

INTRODUCTION

Leg 13 of the Deep Sea Drilling Project, August-October 1970, which began and ended at Lisbon, investigated the Mediterranean Sea and adjacent Atlantic Ocean, recovering 183 cores at 15 drilling sites (Figure 1). Light-microscope techniques were used to study the coccoliths of 192 samples from these cores. Zonal assignments of cores from Leg 13 are summarized in Tables 1 and 2.

The majority of samples from the Mediterranean Sea are of Pleistocene or late Pliocene age. None of the Mediterranean samples examined are definitely older than middle Miocene, but a few late Jurassic and early Cretaceous samples were obtained from Site DSDP 120, Cores 2 to 7, west of the Straits of Gibraltar in the Atlantic Ocean. Many of the Mediterranean samples are turbidite-like sediments, rich in detritus, that contain reworked late Cretaceous and early Tertiary coccoliths.

The occurrence of *Braarudosphaera bigelowi* (Gran and Braarud) in Pliocene and Pleistocene samples distinguishes the Mediterranean assemblages from coeval assemblages recovered on previous open-ocean DSDP legs, and it suggests lower than normal oceanic salinities ($<35°/_{\circ\circ}$).

OPEN-OCEAN ZONATION OF THE PLIOCENE AND PLEISTOCENE COMPARED WITH THE ZONATION AT MEDITERRANEAN SITE DSDP 132

Hole DSDP 132 was drilled on an isolated rise in the Tyrrhenian Basin west of Naples (latitude 40° 15.67'N., longitude 11° 26.46'E., depth 2835 m) in pelagic carbonate ooze of Holocene, Pleistocene, Pliocene, and late Miocene age. As this may provide a useful reference for late Cenozoic stratigraphy, owing to its proximity to classic stage localities in Italy, the ranges of selected coccolith taxa, as compared with the zonation used for open-ocean coccolith-rich sediments, are illustrated in Table 3.

The Pliocene to Pleistocene interval has been cored repeatedly in pelagic biogenic sediment by the Deep Sea Drilling Project during the 12 legs prior to coring in the Mediterranean Sea. Study of these open-ocean cores has shown that a series of seven generally defined coccolith zones can be consistently identified. Further, in areas of high biogenic productivity and high diversity, many of these zones can be divided into subzones. Publications pertinent to the development of open-ocean upper Cenozoic coccolith zonation include: Boudreaux and Hay, 1969; Bramlette and Riedel, 1954; Bukry, 1971; Bukry and Bramlette, 1970; Gartner, 1969; Gartner, 1970; Hay and others, 1967; Martini and Bramlette, 1963; and Riedel and others, 1963. With light-microscope study, up to eleven biostratigraphic units can be identified in the Pliocene to Pleistocene interval, based on certain changes in coccolith assemblages (such as, specimen size and generic composition) and on the restricted ranges of key species (Table 4). The general characteristics of the biostratigraphic units, beginning with early Pliocene, are as follows:

Ceratolithus tricorniculatus Zone

Ceratolithus amplificus Subzone

This subzone is characterized throughout by the presence of cosmopolitan *Ceratolithus tricorniculatus*. The species *Ceratolithus amplificus* is typically restricted to this subzone; its first occurrence approximates the last occurrence of *Triquetrorhabdulus rugosus*, and its last occurrence approximates the first occurrence of *Ceratolithus rugosus*. This stratigraphic sequence is demonstrated in Hole DSDP 72, Core 2, and in Hole DSDP 83A, Cores 9A to 11A. In Hole DSDP 82A, Core 9A, a bizarre form of *C. tricorniculatus* (having the horn extended into a rod), that occurs in the lower Pliocene of Italy, is associated with *C. amplificus*. Typical species of the subzone assemblage include: *Ceratolithus amplificus, C. tricorniculatus, Cyclococcolithina leptopora, C. macintyrei, Discoaster brouweri, D. pentaradiatus, D. surculus, D. variabilis variabilis, Discolithina japonica, D. multipora, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica, Scyphosphaera globulata, Sphenolithus abies,* and *S. neoabies*. The *C. amplificus* Subzone is distinguished from the underlying *Triquetrorhabdulus rugosus* Subzone by first occurrence of *C. amplificus* and last occurrence of *T. rugosus*.

At Site DSDP 132 the interval from the lower part of Core 16 to Core 21 contains *C. tricorniculatus* or *C. amplificus* and lacks *Discoaster quinqueramus*, a relation indicating assignment of the cores to the *Ceratolithus tricorniculatus* Zone. In Pacific Ocean cores, the extinction of *C. amplificus*, an intermediate species considered a progenitor of *C. rugosus* and appearing between the first occurrences of *C. tricorniculatus* and *C. rugosus*, has formerly been considered to be a convenient guide to the Miocene-Pliocene boundary as lower Pliocene samples examined from the Pasquasia-Capodarso and Tabiano sections of Italy show no *C. amplificus*, only *C. tricorniculatus*. In the context of the ranges of these species in Site DSDP 132, however, the absence of *C. amplificus* in the terrestrial Italian samples is evidently local, and the formerly Miocene upper *C. tricorniculatus* Zone–the new *C. amplificus* Subzone–is now considered lower Pliocene. This designation yields a coccolith identification of the Miocene-Pliocene boundary in open-ocean sediment that is more consistent with the type and reference sections of Italy and Site DSDP 132 in the Tyrrhenian Basin. In the absence of subzonal indicators for the *C. tricorniculatus* Zone, such as *C. amplificus* or *Triquetrorhabdulus rugosus*, this designation results in the placement of the Miocene-Pliocene boundary within the *C. tricorniculatus* Zone.

[1]Publication authorized by the Director, U. S. Geological Survey.

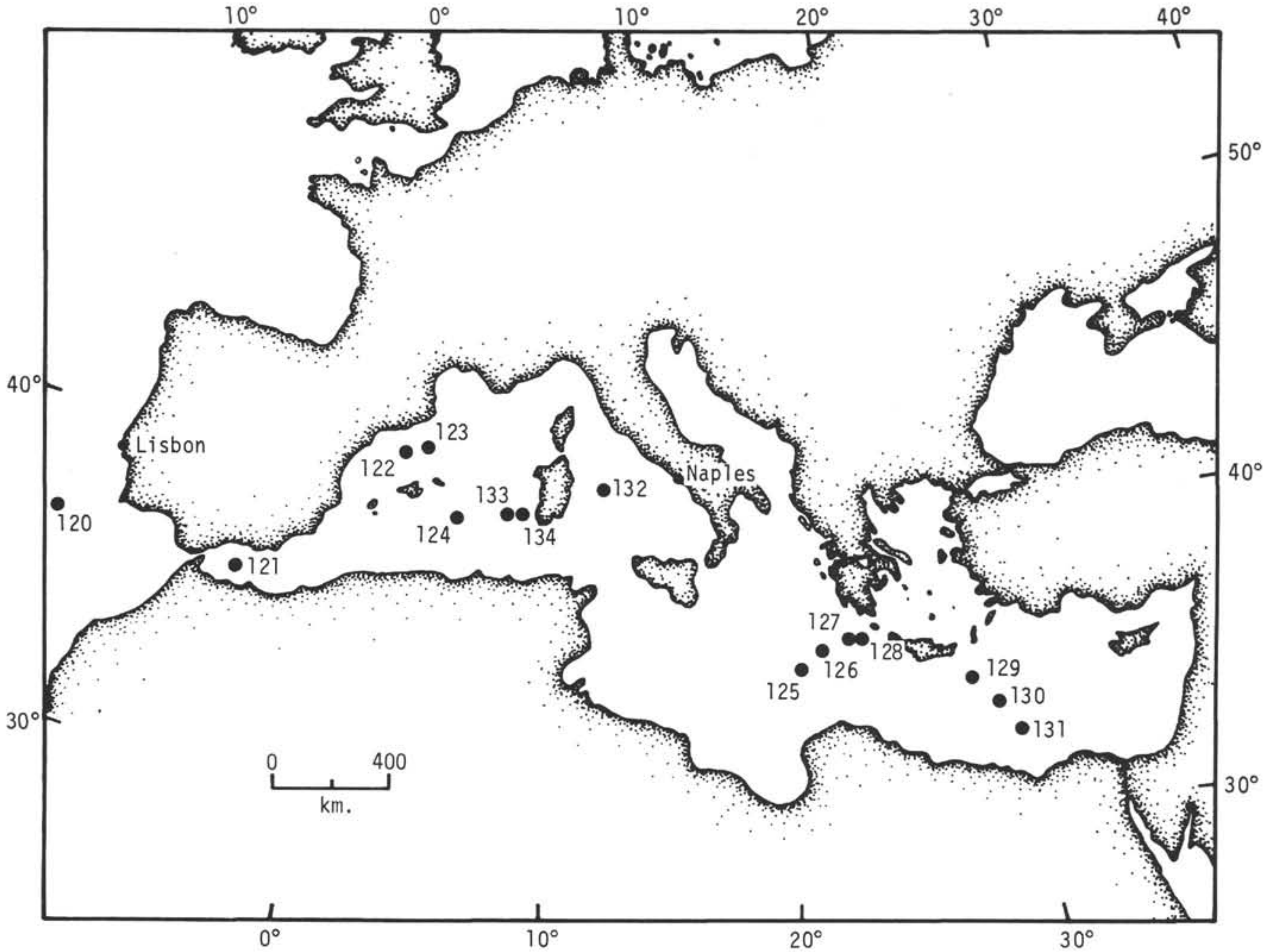

Figure 1. *Locations of sites cored during DSDP Leg 13 in the Mediterranean Sea and eastern North Atlantic Ocean.*

TABLE 1
Geologic Age and Zone Assignment of Cores from Holes 120-127A Based on Coccoliths in Samples Examined

Age	Zone	Subzone	DSDP Hole										
			120	121	122	123	124	125	125A	126	126A	127	127A
Pleistocene and Holocene	*Emiliania huxleyi*							1-3		1			
	Gephyrocapsa oceanica			1-3	1		1					1-10	
	Coccolithus doronicoides	*Gephyrocapsa caribbeanica*	bit			2				1		14-15	2-4
		Emiliania annula		4, 7?			2	4	1				
Pliocene	*Discoaster brouweri*	*Cyclococcolithina macintyrei*		7?, 8-9			2	4	1				
		Discoaster pentaradiatus		10-14	1	3-5	3	5-7	2-4			18	
	Reticulofenestra pseudoumbilica						3		5				
	Ceratolithus rugosus			19-24	2-3	6	4-5						
	Ceratolithus tricorniculatus								5				
Miocene	*Discoaster quinqueramus*												
	Discoaster neohamatus												
	Discoaster hamatus												
	Catinaster coalitus												
	Discoaster exilis									1?			
	Sphenolithus heteromorphus												

TABLE 2
Geologic Age and Zone Assignment of Cores from Holes 128-134A Based on Coccoliths in Samples Examined

Age	Zone	Subzone	DSDP Hole 128	129	129A	130	130A	131A	132	133	134	134A
Pleistocene and Holocene	*Emiliania huxleyi*								1?			1
	Gephyrocapsa oceanica		1			1-2			2-7	1?		
	Coccolithus	*Gephyrocapsa caribbeanica*	2-3			3-6	1	4-5	7			
		Emiliania annula	7-11						8			
Pliocene	*Discoaster*	*Cyclococcolithina macintyrei*							8-10		3-5	
		Discoaster pentaradiatus							11-14			
	Reticulofenestra pseudoumbilica								15		7	
	Ceratolithus rugosus			2-3?	3?				15-16			
	Ceratolithus tricorniculatus								16-26			
Miocene	*Discoaster quinqueramus*											
	Discoaster neohamatus											
	Discoaster hamatus											
	Catinaster coalitus											
	Discoaster exilis											
	Sphenolithus heteromorphus											

Ceratolithus rugosus Zone

This zone is widely identified as the interval from the first occurrence of *Ceratolithus rugosus* tc the last occurrence of *C. tricorniculatus. C. amplificus* is usually missing from this interval, and in tropical areas *Oolithotus antillarum* first occurs at the top of this interval. The assemblage of long-ranging coccoliths is the same as in adjacent zones, but particularly robust specimens of several genera, probably reflecting a general ocean warming, help to distinguish assemblages of this zone, even at high latitudes (DSDP Leg 12).

The assemblages of both this zone and the *C. tricorniculatus* Zone at Site DSDP 132 are characterized by the common occurrence of a plexus of *Scyphosphaera* forms and by the sparse occurrence of true ceratoliths. Throughout the lower Pliocene section, *Ceratolithus rugosus* is rare, but a species of *Scyphosphaera* with heavily calcified, closely spaced walls that mimics the form of *C. rugosus* is present. Similarly, tilted and broken rims of some discoliths mimic the form of unornamented *C. tricorniculatus*; the highest occurrence of true *C. tricorniculatus* is recorded in Sample 132-15-5, 100 cm. Therefore, the *C. rugosus* Zone, indicated here by the overlapping ranges of *C. rugosus* and *C. tricorniculatus*, is restricted to Cores 15 to 16.

Reticulofenestra pseudoumbilica Zone

Sphenolithus neoabies Subzone

The base of this zone and subzone is recognized by the disappearance of cosmopolitan *Ceratolithus tricorniculatus.* The subzone is recognized in tropical areas by the abundance of *Sphenolithus neoabies* and by the lowest common occurrences of *Oolithotus antillarum, Discoaster asymmetricus,* and small *Helicopontosphaera sellii.* The latter three species become more common in overlying zonal units.

Reticulofenestra pseudoumbilica Zone

Discoaster asymmetricus Subzone

The top of this zone and subzone is recognized by a closely spaced disappearance of *Sphenolithus abies, S. neoabies,* and large *Reticulofenestra pseudoumbilica.* The subzone is characterized by a marked increase in abundance of *Discoaster asymmetricus* and small *Helicopontosphaera sellii* compared to the underlying *Sphenolithus neoabies* Subzone. The lowest sparse occurrence of *Discoaster tamalis* is noted in this subzone. In the upper part of this subzone and in the overlying *Discoaster tamalis* Subzone, the last period of *Discoaster* development is recorded, wherein the common to abundant occurrences of *D. asymmetricus, D. tamalis,* and *D. variabilis decorus* serve to distinguish these two subzonal units from other Pliocene intervals.

As *Discoaster asymmetricus* is rare throughout DSDP 132, no subdivision of the short *Reticulofenestra pseudoumbilica* Zone is indicated. The last occurrences of *Reticulofenestra pseudoumbilica, Sphenolithus abies,* and *S. neoabies* in the top of Core 15, combined with the last occurrence of *C. tricorniculatus* in the bottom of the same core, delimit this zonal interval. The assemblage contains few *D. asymmetricus, D. brouweri,* and tiny *H. sellii,* and common *Coccolithus pelagicus, Cyclococcolithina,* and *Scyphosphaera.*

Discoaster brouweri Zone

This zone can be divided into several subzones on the basis of sequential extinctions of species of *Discoaster.* In tropical areas the first common occurrences of *Emiliania annula* and *Rhabdosphaera clavigera* are recorded in this zone.

TABLE 3
Occurrence of Selected Coccolith Species in Samples from Site DSDP 132, with Geologic Age and Zonal Assignment[a]

Age	Zone/Subzone	DSDP Sample	*Sphenolithus abies*	*Ceratolithus tricorniculatus*	*Reticulofenestra pseudoumbilica*	*Discoaster surculus*	*Scyphosphaera* cf. *intermedia*	*Discoaster brouweri*	*Cyclococcolithina macintyrei*	*Helicopontosphaera kamptneri*	*Sphenolithus neoabies*	*Discoaster pentaradiatus*	*Ceratolithus amplificus*	*Discoaster variabilis variabilis*	*Discoaster asymmetricus*	*Ceratolithus rugosus*	*Helicopontosphaera sellii*	*Discoaster tamalis*	*Coccolithus doronicoides*	*Emiliania annula*	*Braarudosphaera bigelowi*	*Rhabdosphaera clavigera*	*Syracosphaera histrica*	*Gephyrocapsa* cf. *caribbeanica*	*Rhabdosphaera stylifera*	*Gephyrocapsa oceanica*	*Emiliania huxleyi*
Holocene	*E. huxleyi* (?)	132-1-1, 142 cm								X							X				X						X
	G. oceanica	132-2-1, 149 cm								X									X						X	X	
		132-3-1, 144 cm								X							X		X		X		X		X	X	
Pleistocene		132-4-1, 143 cm								X									X	X	X	X	X		X		
		132-5-1, 140 cm								X										X	X		X	X			
		132-6-1, 120 cm								X							X		X	X	X	X			X		
		132-7-1, 140 cm								X							X			X	X	X	X	X	X	X	
	C. doronicoides	132-7-4, 138 cm								X							X			X	X		X	X	X		
	G. caribbeanica	132-7-5, 140 cm							X	X							X		X	X	X			X			
	E. annula	132-8-3, 140 cm							X	X							X		X	X		X	X				
Late Pliocene	*D. brouweri* *C. macintyrei*	132-8-6, 140 cm						X	X	X							X		X	X		X	X				
		132-9-2, 140 cm					X	X	X	X									X	X		X	X				
		132-10-1, 140 cm						X	X	X									X	X	X	X					
	D. pentaradiatus	132-11-1, 140 cm				X		X	X	X		X			X		X		X								
	D. tamalis	132-12-1, 140 cm				X	X	X	X	X		X		X	X		X	X	X	X	X						
		132-13-1, 140 cm				X	X	X	X	X					X		X	X	X								
		132-14-2, 83 cm				X	X	X	X	X					X	X		X									
Early Pliocene	*R. pseudoumbilica*	132-15-1, 140 cm			X		X	X	X	X					X	X	X										
		132-15-4, 100 cm			X		X		X	X	X	X				X	X										
	C. rugosus	132-15-5, 100 cm		X	X	X	X		X	X	X	X				X	X										
		132-16-1, 140 cm			X		X	X	X	X	X	X		X													
		132-16-3, 100 cm	X		X		X	X	X	X	X	X		X		X											
	C. tricorniculatus *C. amplificus*	132-16-5, 100 cm	X	X	X		X		X	X	X	X		X													
		132-17-3, 100 cm	X	X	X	X		X	X	X		X	X														
		132-18-4, 100 cm	X	X	X		X	X	X	X		X	X														
		132-19-1, 140 cm	X	X	X	X		X	X	X	X	X															
		132-20-4, 100 cm	X	X	X	X	X	X	X	X	X	X	X	X	X												
		132-21-1, 100 cm	X	X	X	X	X	X	X	X																	

[a]Taxa are arranged by first occurrence; those occurring in the deepest sample are arranged by last occurrence in this hole.

Discoaster tamalis Subzone

This subzone is defined at the base by the last occurrences of *Reticulofenestra pseudoumbilica, Sphenolithus abies,* and *S. neoabies.* The top can be recognized by the last occurrence of *Discoaster variabilis decorus* in tropical areas, or by the last common occurrence of *D. tamalis* in tropical and temperate areas. Assemblages of this subzone are characterized in many areas by the restricted occurrence of *D. variabilis decorus* and the common occurrence of *D. tamalis* and *D. asymmetricus.*

In the absence of the tropical guide species *Discoaster variabilis decorus,* the last common occurrence of *Discoaster tamalis* in Sample 132-11-2, 140 cm is used to determine the top of the *D. tamalis* Subzone. The assemblages are dominated by placoliths with only few *Ceratolithus rugosus, D. asymmetricus, D. brouweri, D. pentaradiatus, D. surculus,* and *D. tamalis.*

Discoaster brouweri Zone

Discoaster pentaradiatus Subzone

The top of this subzone is determined by the last occurrence of *Discoaster pentaradiatus. Discoaster surculus* generally becomes extinct at or just below this level. The bottom of the subzone is determined by the highest occurrence of *D. variabilis decorus* or by the highest common occurrence of *D. tamalis.* The occurrence of *Ceratolithus rugosus, Coccolithus doronicoides, Cyclococcolithina leptopora, C. macintyrei, Discoaster brouweri, D. pentaradiatus, D. surculus, Helicopontosphaera kamptneri,* and *H. sellii* with early forms of *Emiliania annula* and *Rhabdosphaera clavigera* is characteristic.

This unit is limited at DSDP 132 by the last occurrence of *Discoaster pentaradiatus* in Sample 132-10-5, 140 cm; the last *D. surculus* is in 132-10-6, 140 cm, and the last *D.*

TABLE 4
Typical Ranges of Zonal Guide Fossils in Open-Ocean Sediment

Coccoliths			*Triquetrorhabdulus rugosus*	*Ceratolithus amplificus*	*Ceratolithus rugosus*	*Ceratolithus tricorniculatus*	*Discoaster asymmetricus*	*Reticulofenestra pseudoumbilica*	*Sphenolithus neoabies*	*Discoaster tamalis*	*Discoaster variabilis decorus*	*Discoaster surculus*	*Discoaster pentaradiatus*	*Discoaster brouweri*	*Cyclococcolithina macintyrei*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Emiliania huxleyi*
Age	Zone	Subzone																
Holocene	*Emiliania huxleyi*																	
	Gephyrocapsa oceanica																	
Pleistocene	*Coccolithus doronicoides*	*Gephyrocapsa caribbeanica*																
		Emiliania annula																
Late Pliocene	*Discoaster brouweri*	*Cyclococcolithina macintyrei*																
		Discoaster pentaradiatus																
		Discoaster tamalis																
Early Pliocene	*Reticulofenestra pseudoumbilica*	*Discoaster asymmetricus*																
		Sphenolithus neoabies																
	Ceratolithus rugosus																	
Late Miocene	*Ceratolithus tricorniculatus*	*Ceratolithus amplificus*																
		Triquetrorhabdulus rugosus																

tamalis in 132-11-2, 140 cm. The assemblage contains *Coccolithus doronicoides, C. pelagicus, Cyclococcolithina macintyrei, Discolithina japonica, Helicopontosphaera kamptneri, H. sellii, Rhabdosphaera clavigera, R. procera,* and *Scyphosphaera apsteinii.*

Discoaster brouweri Zone

Cyclococcolithina macintyrei Subzone

This unit is defined at the base by the absence of *Discoaster pentaradiatus* and *D. surculus,* which occur below. *Discoaster brouweri,* showing maximum down-bending of rays, and *Discoaster triradiatus* are the only common discoasters. *Discoaster asymmetricus* may occur rarely. The most prominent coccoliths in tropical areas are *Ceratolithus rugosus, Coccolithus doronicoides, Cyclococcolithina macintyrei, Emiliania annula,* and *Helicopontosphaera sellii.* The appearance or increased abundance of *Coccolithus pelagicus* near the top of this subzone is typical. In most areas, the top can be recognized by an abrupt reduction in the abundance of *D. brouweri, C. macintyrei,* and *C. rugosus.*

The upper Pliocene *Cyclococcolithina macintyrei* Subzone of DSDP 132 (Cores 8 to 10) is characterized by sparse *Discoaster brouweri* and *D. triradiatus;* common *Coccolithus pelagicus, Cyclococcolithina macintyrei, Rhabdosphaera clavigera, Discolithina,* and *Scyphosphaera. Emiliana annula* and *Helicopontosphaera sellii* are sparse in the lower part of the interval but become more common toward the top. *Braarudosphaera bigelowi* is sparsely present through the interval.

In the upper part of the interval, *Discoaster* occurrence is discontinuous; none are noted in Sample 132-8-5, 140 cm and above. The sparse occurrence of *Discoaster* in the upper Pliocene of DSDP 132 is similar to the relation encountered at high latitudes in the Atlantic Ocean (DSDP Leg 12), where discoasters, though common in the warm-water lower Pliocene, are rare in the cool-water upper Pliocene. In tropical open-ocean sediment (DSDP Leg 7), discoasters are abundant through the entire Pliocene.

Coccolithus doronicoides Zone

Emiliania annula Subzone

This unit is characterized by the common occurrences of *Coccolithus doronicoides, C. pelagicus, Cyclococcolithina leptopora, Emiliania annula,* and *Helicopontosphaera sellii,* and by the absence of species of *Discoaster* and *Gephyrocapsa. Ceratolithus rugosus* is replaced by *C. cristatus* in this interval, and *Cyclococcolithina macintyrei* is replaced by small *C. leptopora,* although in some areas *C. macintyrei* persists through this interval in small numbers. The base of the subzone is defined by an abrupt reduction in the abundances of *D. brouweri, C. macintyrei,* and *C. rugosus.* The first occurrence of *Gephyrocapsa caribbeanica* is used to distinguish the top of this subzone.

The last common occurrence of *Discoaster brouweri* is in DSDP 132, Core 9. Rare specimens occur in the lower part of Core 8. The interval in Core 8 above the last occurrence of discoasters contains common *Cyclococcolithina macintyrei* but no ceratoliths and is assigned to the *Coccolithus doronicoides* Zone. The common occurrence of *Helicopontosphaera sellii* through the *C. doronicoides* Zone and the dominance of this species over *H. kamptneri* are characteristic of oceanic assemblages. This relation occurs here in Cores 7 and 8. *Emiliania annula* abundance is variable, being greatest in Sample 132-8-1, 137 to 140 cm. Small *Gephyrocapsa* sp. cf. *G. caribbeanica* occur through

Core 7 and allow division of the *Coccolithus doronicoides* Zone into lower and upper subzones at DSDP 132.

Coccolithus doronicoides Zone

Gephyrocapsa caribbeanica Subzone

The assemblage of the upper subzone of the *C. doronicoides* Zone is similar to that of the *E. annula* Subzone, but the first appearance and common occurrence of *Gephyrocapsa caribbeanica* below the first appearance of *G. oceanica* is used to define this unit.

Gephyrocapsa oceanica Zone

This unit is defined at the base by the first occurrence of *G. oceanica.* Assemblages of the zone are characterized by *Ceratolithus cristatus, Cyclococcolithina leptopora, Gephyrocapsa aperta, G. caribbeanica, G. oceanica, Helicopontosphaera kamptneri* [*H. sellii* absent or rare], *Rhabdosphaera clavigera,* and *Scapholithus* sp. The top of this unit is based, in light-microscope study, on the occurrence above of a great abundance of *Emiliania huxleyi,* a small (2 to 3 micron) faint oval coccolith.

The Pleistocene zonal assemblages of DSDP 132, in this and adjacent zones, are distinguished from open-ocean assemblages by the presence throughout of *Braarudosphaera bigelowi,* a marginal-marine species, and by the absence of *Ceratolithus cristatus,* a fully marine species. *Gephyrocapsa caribbeanica,* the most temperature-tolerant species of *Gephyrocapsa,* occurs commonly through the Pleistocene cores. The warm-water species *G. oceanica* occurs most commonly at the top of Core 7, considered the lower part of the *Gephyrocapsa oceanica* Zone. Occurrences in higher cores are sparse and discontinuous.

Emiliania huxleyi Zone

This zone, the highest coccolith zone recognized, is characterized by the overwhelming dominance of *Emiliania huxleyi.* This species cannot be definitely identified by light microscopy, but dominance of small coccoliths at the top of oceanic-sediment sections in conjunction with narrow-rimmed specimens of *Helicopontosphaera kamptneri* generally results in the identification of *E. huxleyi* when electron-microscope study is carried out.

Sample 132-1-1, 142 to 143 cm contains abundant ?*Emiliania huxleyi* and some small, narrow-rimmed *Helicopontosphaera kamptneri,* with *Coccolithus pelagicus, Cyclococcolithina leptopora,* and *Gephyrocapsa* sp. cf. *G. caribbeanica.*

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33.2. CALCAREOUS NANNOFOSSIL AGE DETERMINATIONS, DEEP SEA DRILLING PROJECT, LEG 13

Stefan Gartner, Jr., Rosenstiel School of Marine and Atmospheric Science,
University of Miami, Miami, Florida

This paper contains age determinations made on a suite of samples from the cores collected during Leg 13 of the Deep Sea Drilling Project. With the exception of Site 120 in the eastern North Atlantic, all samples containing nannofossils are Neogene in age. The samples from Site 120 were dated approximately, based on meager literature available for the Jurassic and lower Cretaceous calcareous nannofossils. Inconsistency in the results obtained by the several workers who have studied this interval, lack of rigorous nomenclature, and the absence of nannoconids in the samples, make the ages assigned to Samples 13-120-2-1; 70 cm and 13-120-7-1; 33-34 cm mere estimates.