16. LOW-LATITUDE COCCOLITH BIOSTRATIGRAPHIC ZONATION[1]

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INTRODUCTION

Leg 15 of the Deep Sea Drilling Project, conducted December 1970 through February 1971, in the Caribbean Sea from San Juan, Puerto Rico, to San Cristobal, Panama, recovered 264 cores at nine drilling sites (Figure 1). Light-microscope techniques were used to study the coccoliths of 197 cores from which samples were available. Zonal assignment of cores from Leg 15 is summarized in Table 1. Following an explanation of coccolith zonation developed from cores of this and other low-latitude DSDP legs are summaries of the coccolith stratigraphy at DSDP Leg 15 sites.

COCCOLITH ZONATION

Relative dating of Deep Sea Drilling Project sediment cores containing calcareous microfossils has been facilitated by the identification of sequences of coccolith zones. These zones are identified by assemblages of species and are separated by specified boundary criteria (Figure 2). The first, last, or acme occurrences of one or more species are generally used as boundary criteria. As species concepts and the relative stratigraphic ranges of species are refined, and the effects of solution, diagenesis, and paleoecological exclusion are understood, new definitions and criteria will evolve. Variation in definitions of zonal systems, already evident in the literature, suggests that individual authors' concepts of species and relative ranges depend on the facies and locations of the sedimentary strata they have studied. As taxonomy is improved and species ranges become more accurate, the use of acme zones and last-occurrence zones may be phased out of interregional zonation in favor of first-occurrence assemblage zones, thus eliminating some of the ambiguity of present systems.

On a regional basis, the appearance, acme, and extinction of paleogeographically limited species can be sufficiently reproducible to provide a more detailed zonation than that based solely on cosmopolitan species (Milow, 1970; Roth, et al., 1971; Bukry, 1971c). Establishing the chronostratigraphic relations between subzonal sequences of various regions will be difficult because middle- and high-latitude coccolith assemblages contain restricted species and generally fewer total species than do low-latitude assemblages (Edwards, 1968; Bukry and Bramlette, 1970a; Hornibrook and Edwards, 1971). Similarly, marine shelf and nearshore basin areas possess additional taxa not available for zonation in deep-ocean areas. For example, the Paleogene coccolith zonation for the Blake Plateau (Gartner, 1971) makes use of taxa that, while not available for use in deep-ocean sediment, do permit a fine division for low-latitude nearshore areas. Depending on where zonations were described and whether cosmopolitan or only regional taxa were used, composite zonal scales can contain a mixture of cosmopolitan and regional units (Hay et al., 1967; Martini, 1971). Although all current zonations suffer from these problems to some extent, the continuing recovery of deep-ocean sediment sections by the *Glomar Challenger* at various latitudes will provide the material needed to thoroughly evaluate the stratigraphic and geographic ranges of coccolith species. This will permit more consistent zonation.

The zonal summary presented below is not intended to be exhaustive but simply illustrates the basis of a low-latitude open-ocean coccolith zonation that is currently employed in reports of our laboratory. The assemblages listed for each zonal unit are a composite of the most representative species recognized at Deep Sea Drilling Project sites. If more than one species is used for a boundary, the first listed is considered the more diagnostic. Symbols are used to indicate appearance (*), disappearance (†), beginning of acme (A*), and end of acme (A†).

Eiffellithus augustus Zone

Boundary species: Top – *Eiffellithus augustus* †; bottom – *Broinsonia parca**.

Assemblage: *Apertapetra gronosa, Arkhangelskiella cymbiformis, Broinsonia parca, Cretarhabdus crenulatus, Cribrosphaera ehrenbergii, Eiffellithus augustus, E. turriseiffeli, Microrhabdulus decoratus, Micula decussata, Prediscosphaera cretacea, Tetralithus aculeus, Watznaueria barnesae, Zygodiscus bicrescenticus.*

Selected references: Bukry and Bramlette, 1970a; Cita and Gartner, 1971; Roth and Thierstein, 1972.

Broinsonia parca Zone

Boundary species: Top – *Tetralithus trifidus* *; bottom – *Eiffellithus augustus* †.

Assemblage: *Apertapetra gronosa, Arkhangelskiella cymbiformis, Broinsonia parca, Cretarhabdus crenulatus, Cribrosphaera ehrenbergii, Eiffellithus turriseiffeli, Micula decussata, Prediscosphaera cretacea, Tetralithus gothicus, T. pyramidus, Watznaueria barnesae, Zygodiscus lacunatus.*

Selected references: Bukry, in press[a].

Tetralithus trifidus Zone

Boundary species: Top - *Tetralithus trifidus* †; bottom – *Tetralithus trifidus* *.

Assemblage: *Apertapetra gronosa, Arkhangelskiella cymbiformis, Broinsonia parca, Cretarhabdus crenulatus, Cribrosphaera ehrenbergii, Eiffellithus turriseiffeli, Microrhabdulus decoratus, Micula decussata, Prediscosphaera cretacea, P. lata, Tetralithus aculeus, T. pyramidus, T. trifidus, Watznaueria barnesae, Zygodiscus meudini.*

Comment: *Cylindralithus gallicus* usually appears near the end of this zone.

Selected references: Bukry and Bramlette, 1970a; Cita and Gartner, 1971; Bukry, in press[a].

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

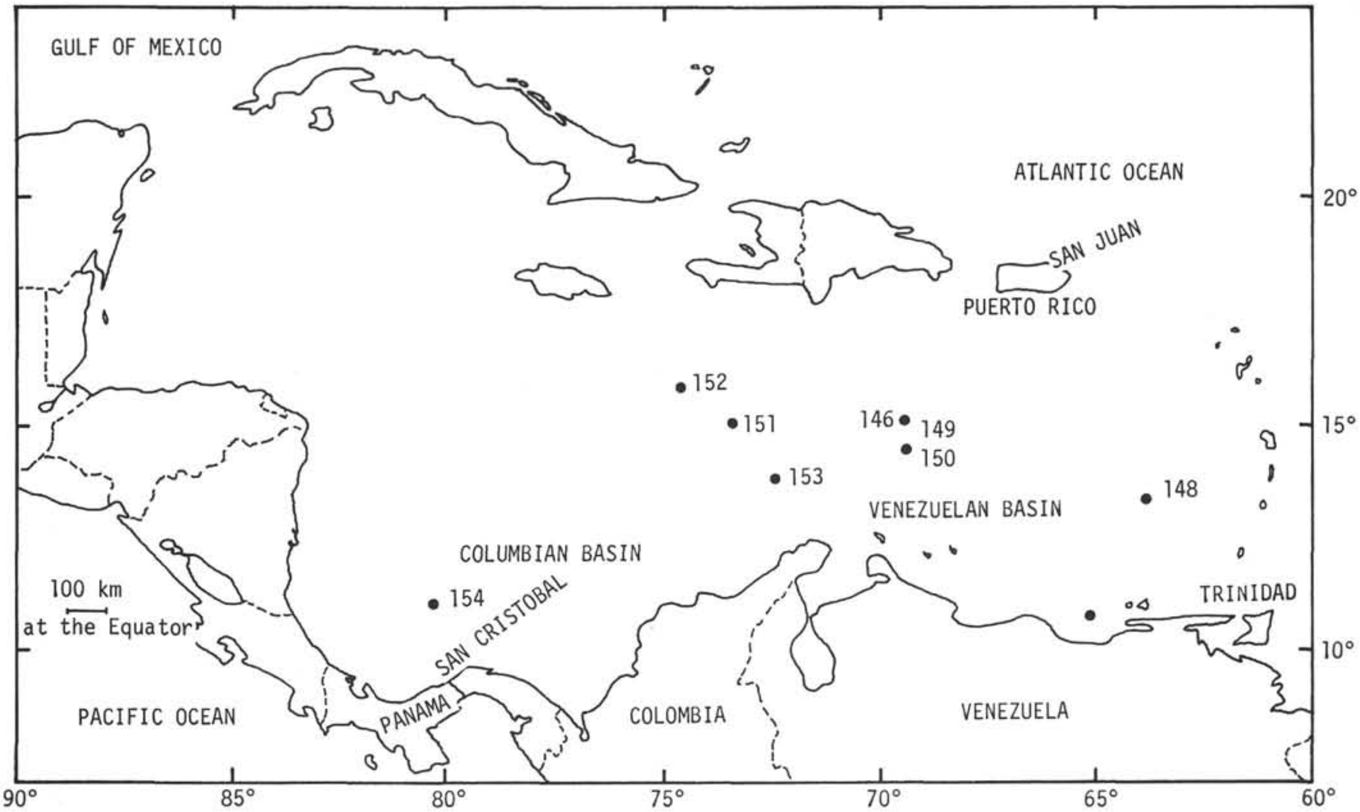

Figure 1. *Sites cored in the Caribbean Sea during Deep Sea Drilling Project Leg 15.*

Lithraphidites quadratus Zone

Boundary species: Top – *Micula mura* *; bottom – *Tetralithus trifidus* †.

Assemblage: *Apertapetra gronosa, Arkhangelskiella cymbiformis, Cretarhabdus conicus, C. crenulatus, Cribrosphaera ehrenbergii, Cylindralithus gallicus, Eiffellithus turriseiffeli, Micula decussata, Prediscosphaera cretacea, Watznaueria barnesae, Zygodiscus lacunatus.*

Comment: In open-ocean warm-water assemblages, *Nephrolithus frequens* and *Lithraphidites quadratus* are not commonly observed. The original zonal interval was indicated between the first occurrence of these species. *Micula mura* and *Tetralithus trifidus* are more consistent stratigraphic indicators for the same general interval in low-latitude oceanic assemblages.

Selected references: Čepek and Hay, 1969; Bukry and Bramlette, 1970a; Cita and Gartner, 1971.

Micula mura Zone

Boundary species: Top – *Cruciplacolithus tenuis* *; bottom – *Micula mura* *.

Assemblage: *Apertapetra gronosa, Arkhangelskiella cymbiformis, Cretarhabdus crenulatus, Cribrosphaera ehrenbergii, Cylindralithus gallicus, Eiffellithus turriseiffeli, Microrhabdulus decoratus, Micula decussata, M. mura, Prediscosphaera cretacea, Watznaueria barnesae, Zygodiscus sigmoides.*

Comment: This zone approximates the range of *Micula mura*. The disappearance of almost all members of the zonal assemblage near the top of the zone has been discussed in relation to the Cretaceous-Tertiary boundary event in the oceans (Bramlette and Martini, 1964; Worsley, in press).

Selected references: Martini, 1969; Bukry and Bramlette, 1970a; Worsley and Martini, 1970.

Cruciplacolithus tenuis Zone

Boundary species: Top – *Fasciculithus tympaniformis* *; bottom – *Cruciplacolithus tenuis* *.

Assemblage: *Coccolithus pelagicus, Coccolithus* spp. [small], *Cruciplacolithus tenuis, Markalius astroporus, Zygodiscus sigmoides.*

Comment: Shallow marine assemblages are enriched by the preservation of species such as *Biantholithus sparsus, Braarudosphaera bigelowi, Chiasmolithus danicus,* and *Thoracosphaera* spp. (see Bramlette and Martini, 1964; Perch-Nielsen, 1969).

Selected references: Mohler and Hay, 1967; Bukry and others, 1971.

Fasciculithus tympaniformis Zone

Boundary species: Top – *Heliolithus kleinpellii* *; bottom – *Fasciculithus tympaniformis* *.

Assemblage: *Chiasmolithus* sp. cf. *C. bidens, C. californicus, C. consuetus, Coccolithus pelagicus, Cruciplacolithus tenuis, Cyclolithella? robusta, Fasciculithus tympaniformis, Toweius eminens, Zygodiscus sigmoides.*

Selected references: Mohler and Hay, 1967; Gartner, 1971.

Heliolithus kleinpellii Zone

Boundary species: Top – *Discoaster mohleri* *; bottom – *Heliolithus kleinpellii* *.

Assemblage: *Chiasmolithus californicus, C. consuetus, Coccolithus pelagicus, Cruciplacolithus tenuis, Cyclolithella? robusta, Ellipsolithus macellus, Fasciculithus clinatus, F. involutus, F. tympaniformis, Heliolithus kleinpellii, Neochiastozygus chiastus, Zygodiscus sigmoides, Zygrhablithus simplex.*

Selected references: Mohler and Hay, 1967; Bukry, 1971c; Gartner, 1971.

Discoaster mohleri Zone

Boundary species: Top – *Discoaster nobilis* *; bottom – *Discoaster mohleri* *.

Assemblage: *Chiasmolithus bidens, C. californicus, C. consuetus, Coccolithus pelagicus, Discoaster mohleri, Ellipsolithus distichus, E. macellus, Fasciculithus clinatus, F. involutus, F. tympaniformis, Heliolithus kleinpellii, Neochiastozygus chiastus, Toweius craticulus, T. eminens, Zygodiscus plectopons.*

TABLE 1

Geologic Age and Zone or Stage Assignment of Cores from Leg 15 Based on Coccoliths in Samples Examined

Age	Zone or Stage	DSDP Hole									
		146	147	148	149	150	151	152	153	154	154A
Pleistocene and Holocene	*Emiliania huxleyi*									1?	
	Gephyrocapsa oceanica		2-18	1-9	2						1A-3A
	Gephyrocapsa doronicoides			10-16	3-5		1				4A-8A
Pliocene	*Discoaster brouweri*			17-26	6-8	1			1	2	8A-14A
	Reticulofenestra pseudoumbilica			27							15A
	Ceratolithus rugosus									3-12?	16A-18A ?
	Ceratolithus tricorniculatus						2				
Miocene	*Discoaster quinqueramus*				11				2-3	13	
	Discoaster neohamatus				12-13						
	Discoaster hamatus										
	Catinaster coalitus				15,16						
	Discoaster exilis				15,16		3				
	Sphenolithus heteromorphus				16-19				4		
	Helicopontosphaera ampliaperta				20				5		
	Sphenolithus belemnos				21?		4				
	Triquetrorhabdulus carinatus				21-27	5			6		
Oligocene	*Sphenolithus ciperoensis*	2			27		6-7				
	Sphenolithus distentus				28		9				
	Sphenolithus predistentus				29-30				7		
	Helicopontosphaera reticulata										
Eocene	*Discoaster barbadiensis*										
	Reticulofenestra umbilica				32-35						
	Nannotetrina quadrata				37-42						
	Discoaster sublodoensis										
	Discoaster lodoensis										
	Tribrachiatus orthostylus										
	Discoaster diastypus							1			
Paleocene	*Discoaster multiradiatus*	7						2-4			
	Discoaster nobilis										
	Discoaster mohleri	8							10		
	Heliolithus kleinpellii										
	Fasciculithus tympaniformis							6-7?			
	Cruciplacolithus tenuis						10-11?	9-10?			
Cretaceous	*Micule murus*										
	Lithraphidites quadratus	11-14						14	12-13?		
	Tetralithus trifidus	15-24						16-21			
	Eiffellithus augustus	25-39?					12	22?			
	Santonian					9-10			18		

Comment: A group of *Discoaster* ranges was first used to indicate this zone. It was later revised (Mohler and Hay, 1967) to be the interval from the first *Discoaster mohleri* to the first *Heliolithus riedelii*. Because of the rare and sporadic occurrence of *H. riedelii* in oceanic assemblages, and because the first occurrence of *Discoaster nobilis* has been suggested for the top of the zone (K. Perch-Nielsen, personal commun., 1971), *H. riedelii* is not used as a boundary marker. The name of the zone was changed from *Discoaster gemmeus* Zone to *Discoaster mohleri* Zone because of a taxonomic revision (Bukry and Percival, 1971).

Selected references: Hay, 1964; Mohler and Hay, 1967; Bukry, 1971c.

Series or Subseries	Zone	Subzone	Boundary Species
HOLOCENE	*Emiliania huxleyi*		*E. huxleyi**
PLEISTOCENE	*Gephyrocapsa oceanica*		*G. oceanica**
	Gephyrocapsa doronicoides	*Gephyrocapsa caribbeanica*	*G. caribbeanica**
		Emiliania annula	*D. brouweri*†
UPPER PLIOCENE	*Discoaster brouweri*	*Cyclococcolithina macintyrei*	*D. pentaradiatus* †, *D. surculus* †
		Discoaster pentaradiatus	*D. tamalis* †
		Discoaster tamalis	*R. pseudoumbilica* †, *Sphenolithus* spp. †
LOWER PLIOCENE	*Reticulofenestra pseudoumbilica*	*Discoaster asymmetricus*	*D. asymmetricus A**
		Sphenolithus neoabies	*C. primus* †, *C. tricorniculatus* †
	Ceratolithus tricorniculatus	*Ceratolithus rugosus*	*C. rugosus**, *C. acutus* †
		Ceratolithus acutus	*C. acutus**, *T. rugosus* †
UPPER MIOCENE		*Triquetrorhabdulus rugosus*	*D. quinqueramus* †
	Discoaster quinqueramus	*Ceratolithus primus*	*C. primus**
		Discoaster berggrenii	*D. berggrenii**, *D. neorectus* †
	Discoaster neohamatus	*Discoaster neorectus*	*D. neorectus**
		Discoaster bellus	*D. hamatus* †
MIDDLE MIOCENE	*Discoaster hamatus*		*D. hamatus**
	Catinaster coalitus		*C. coalitus**, *D. kugleri* †
	Discoaster exilis	*Discoaster kugleri*	*D. kugleri**
		Coccolithus miopelagicus	*S. heteromorphus* †
	Sphenolithus heteromorphus		*D. deflandrei A* †, *H. ampliaperta* †
LOWER MIOCENE	*Helicopontosphaera ampliaperta*		*S. heteromorphus**, *S. belemnos* †
	Sphenolithus belemnos		*S. belemnos**
	Triquetrorhabdulus carinatus	*Discoaster druggii*	*D. druggii**, *O. serratus**
		Discoaster deflandrei	*C. abisectus* A†
OLIGOCENE		*Cyclicargolithus abisectus*	*S. ciperoensis*†, *D. bisectus* †, *D. scrippsae* †
	Sphenolithus ciperoensis		*S. ciperoensis**
	Sphenolithus distentus		*S. distentus**
	Sphenolithus predistentus		*R. hillae* †, *R. umbilica* †
	Helicopontosphaera reticulata	*Reticulofenestra hillae*	*C. formosa* †
		Cyclococcolithina formosa	*C. subdistichus* s. l. A†
		Coccolithus subdistichus	*D. barbadiensis* †, *D. saipanensis* †
UPPER EOCENE	*Discoaster barbadiensis*		*C. grandis* †
MIDDLE EOCENE	*Reticulofenestra umbilica*	*Discoaster saipanensis*	*D. bifax* †, *C. solitus* †
		Discoaster bifax	*R. umbilica**, *D. bifax**
	Nannotetrina quadrata	*Coccolithus staurion*	*C. gigas* †
		Chiasmolithus gigas	*C. gigas**
		Discoaster strictus	*N. quadrata**, *R. inflata* †
	Discoaster sublodoensis	*Rhabdosphaera inflata*	*R. inflata**
LOWER EOCENE		*Discoasteroides kuepperi*	*D. sublodoensis**
	Discoaster lodoensis		*C. crassus**
	Tribrachiatus orthostylus		*D. lodoensis**
	Discoaster diastypus		*D. diastypus**, *T. contortus**
PALEOCENE	*Discoaster multiradiatus*	*Campylosphaera eodela*	*C. eodela**, *Rhomboaster* spp.*
		Chiasmolithus bidens	*D. multiradiatus**
	Discoaster nobilis		*D. nobilis**
	Discoaster mohleri		*D. mohleri**
	Heliolithus kleinpellii		*H. kelinpellii**
	Fasciculithus tympaniformis		*F. tympaniformis**
	Cruciplacolithus tenuis		*C. tenuis**
UPPER CRETACEOUS	*Micula mura*		*M. mura**
	Lithraphidites quadratus		*T. trifidus* †
	Tetralithus trifidus		*T. trifidus**
	Broinsonia parca		*E. augustus* †
	Eiffellithus augustus		*B. parca**

Figure 2. *Summary of low-latitude coccolith zones, subzones, and boundary species for Late Cretaceous through Quaternary. * = Appearance, † = Disappearance, A* = Beginning of acme, A† = End of acme.*

Discoaster nobilis Zone

Boundary species: Top – *Discoaster multiradiatus* *; bottom – *Discoaster nobilis* *.

Assemblage: *Chiasmolithus bidens, C. californicus, C. consuetus, Coccolithus pelagicus, Discoaster mohleri, D. nobilis, Ellipsolithus distichus, E. macellus, Fasciculithus clinatus, F. involutus, F. tympaniformis, Neochiastozygus chiastus, N. distentus, Toweius craticulus, T. eminens, Zygodiscus plectopons.*

Comment: A first occurrence sequence of the many new species of *Discoaster* appearing in the late Paleocene could be codified to form a large number of "zones." But much new data must be evaluated because of numerous changes in recognized ranges and taxa. Comparison of studies done even five years apart is difficult in many parts of the coccolith sequence.

Selected references: Perch-Nielsen, 1972.

Discoaster multiradiatus Zone

Boundary species: Top – *Discoaster diastypus* *, *Tribrachiatus contortus**; bottom – *Discoaster multiradiatus* *.

Assemblage: *Campylosphaera eodela, Chiasmolithus bidens, C. consuetus, Coccolithus pelagicus, Discoaster lenticularis, D. multiradiatus, D. nobilis, Ellipsolithus distichus, E. macellus, Fasciculithus clinatus, F. tympaniformis, Lophodolithus nascens, Rhomboaster cuspis, Sphenolithus radians, Toweius craticulus, T. eminens, Zygrhablithus simplex.*

Comment: This zone can be generally recognized by the range of *Discoaster multiradiatus* which is common through the interval. The upper part of the zone can be distinguished by the first appearance of *Campylosphaera eodela*, the *Campylosphaera eodela* Subzone, in deep-ocean areas and by *C. eodela, Rhomboaster cuspis*, and related taxa such as *R. calcitrapa* in shallow-ocean areas (Bukry and Percival, 1971; Gartner, 1971). The lower part of the zone, *Chiasmolithus bidens* Subzone, lacks *C. eodela.*

Selected references: Bronnimann and Stradner, 1960; Bramlette and Sullivan, 1961; Hay, 1964; Mohler and Hay, 1967; Moshkovitz, 1967; Bukry and others, 1971.

Discoaster diastypus Zone

Boundary species: Top – *Discoaster lodoensis* *; bottom – *Discoaster diastypus* *, *Tribrachiatus contortus* *.

Assemblage: *Campylosphaera dela, C. eodela, Chiasmolithus* sp. cf. *C. bidens, Chiasmolithus consuetus, Coccolithus pelagicus, Discoaster barbadiensis, D. diastypus, D. lenticularis, D. nobilis, Ellipsolithus macellus, Lophodolithus nascens, Sphenolithus radians, Tribrachiatus contortus, T. orthostylus, Zygrhablithus bijugatus, Z. dispar.*

Comment: Zonation of the lower Eocene section in deep-ocean facies is still tentative. Owing to poor, often mixed, recovery and poor preservation, consistent relative ranges of most species are not yet established. The deep-ocean zonation used here employs the first occurrences of *Discoaster diastypus, D. lodoensis, Coccolithus crassus*, and *Discoaster sublodoensis*. But many alternatives are possible. In a study of lower Eocene sections from the Santa Ynez Mountains of California (Bukry, unpub.), the most effective zonation was based on a sequence of first occurrences of *Discoaster diastypus, Tribrachiatus orthostylus, Discoaster lodoensis, Coccolithus crassus*, and *Discoaster sublodoensis.*

Selected references: Hay, 1964; Hekel, 1968; Bukry and Bramlette, 1970a, b; Milow, 1970; Bukry, 1971a.

Tribrachiatus orthostylus Zone

Boundary species: Top – *Coccolithus crassus* *; bottom – *Discoaster lodoensis* *.

Assemblage: *Campylosphaera dela, Chiasmolithus consuetus, C. grandis, Coccolithus magnicrassus, C. pelagicus, Discoaster barbadiensis, Discoaster* cf. *D. deflandrei, D. lodoensis, Discoasteroides kuepperi, Ellipsolithus macellus, Helicopontosphaera seminulum, Lophodolithus nascens, Reticulofenestra* sp. cf. *R. dictyoda, Sphenolithus radians, Tribrachiatus orthostylus, Zygrhablithus bijugatus.*

Comment: Although this zone has generally been distinguished by an overlap of the ranges *Discoaster lodoensis* and *Tribrachiatus orthostylus*, the last occurrence of *T. orthostylus* may range higher than previously indicated. A preliminary study of the Arroyo El Bulito section in California shows it ranging as high as the middle Eocene *Nannotetrina quadrata* Zone which is several zones above its presumed level of disappearance.

Selected references: Bronnimann and Stradner, 1960; Bramlette and Sullivan, 1961; Bronnimann and Rigassi, 1963; Hay, 1964; Mohler and Hay, 1967; Gartner, 1971.

Discoaster lodoensis Zone

Boundary species: Top – *Discoaster sublodoensis* *; bottom – *Coccolithus crassus* *.

Assemblage: *Campylosphaera dela, Chiasmolithus consuetus, C. grandis, Coccolithus crassus, C. magnicrassus, C. pelagicus, Cyclicargolithus pseudogammation, Cyclococcolithina formosa, Discoaster barbadiensis, D. gemmifer, D. germanicus, D. lodoensis, D. nonaradiatus, Discoasteroides kuepperi, Helicopontosphaera* sp. cf. *H. lophota, H. seminulum, Lophodolithus nascens, Reticulofenestra dictyoda, Sphenolithus radians, Tribrachiatus orthostylus, Zygolithus dubius, Zygrhablithus bijugatus.*

Selected references: Bronnimann and Stradner, 1960; Hay, 1964; Hay and Mohler, 1965; Mohler and Hay, 1967.

Discoasteroides kuepperi Subzone

Boundary species: Top – *Rhabdosphaera inflata* *; bottom – *Discoaster sublodoensis* *.

Assemblage: *Campylosphaera dela, Chiasmolithus grandis, C. solitus, Coccolithus crassus, C. cribellum, C. pelagicus, Cyclicargolithus pseudogammation, Cyclococcolithina formosa, C. gammation, Discoaster barbadiensis, D. cruciformis, D. lodoensis, D. mirus, D. sublodoensis, Discoasteroides kuepperi, Ellipsolithus lajollaensis, Helicopontosphaera lophota, H. seminulum, Lophodolithus mochlophorus, Sphenolithus radians, Triquetrorhabdulus inversus, Zygolithus dubius, Zygrhablithus bijugatus.*

Comment: Recognition of the *Discoasteroides kuepperi* Zone (Bukry, 1971c) restricted previous limits of the *Discoaster sublodoensis* Zone (Hay, 1967). The zonation is modified here to reinstitute the *D. sublodoensis* Zone of Hay (1967) by use of a lower *Discoasteroides kuepperi* Subzone and an upper *Rhabdosphaera inflata* Subzone.

Selected references: Bramlette and Sullivan, 1961; Hay, 1967; Bystricka, 1971; Bukry, in press[a].

Rhabdosphaera inflata Subzone

Boundary species: Top – *Nannotetrina quadrata* *, *Rhabdosphaera inflata* †; bottom – *Rhabdosphaera inflata* *.

Assemblage: *Campylosphaera dela, Chiasmolithus grandis, C. solitus, Coccolithus pelagicus, C. staurion, Cyclicargolithus pseudogammation, Cyclococcolithina formosa, Discoaster barbadiensis, D. germanicus, D. lodoensis, D. mirus, D. strictus, D. sublodoensis, D. wemmelensis, Ellipsolithus lajollaensis, Lophodolithus mochlophorus, Helicopontosphaera lophota, H. seminulum, Reticulofenestra dictyoda, R. samodurovi, Rhabdosphaera inflata, Sphenolithus radians, Zygolithus dubius, Zygrhablithus bijugatus.*

Comment: The *Rhabdosphaera inflata* Subzone, named here, corresponds with Unit 5 of Bramlette and Sullivan (1961) and *Discoaster sublodoensis* Zone of Bukry (1971c).

Selected reference: Sullivan, 1965.

Discoaster strictus Subzone

Boundary species: Top – *Chiasmolithus gigas* *; bottom – *Nannotetrina quadrata* *; *Rhabdosphaera inflata* †.

Assemblage: *Campylosphaera dela, Chiasmolithus grandis, C. solitus, Coccolithus pelagicus, C. staurion, Cyclicargolithus pseudogammation, Cyclococcolithina formosa, Discoaster barbadiensis, D. gemmifer, D. mirus, D. nodifer, D. nonaradiatus, D. saipanensis, D. strictus, D. wemmelensis, Helicopontosphaera seminulum, Nannotetrina quadrata, N. mexicana, Reticulofenestra samodurovi, Sphenolithus radians, S. spiniger, Triquetrorhabdulus inversus, Zygolithus dubius, Zygrhablithus bijugatus.*

Comment: The name *Discoaster strictus* Subzone is a substitute name for the *Discoaster mirus* Subzone of Bukry (1971c; in press[a])not the *D. mirus* Subzone of Roth and others (1971). *Discoaster strictus* is common within the lower subzone of the *Nannotetrina quadrata* Zone. *Nannotetrina quadrata, Nannotetrina mexicana,* and *Nannotetrina* spp. range through the whole zone, although their occurrence is sporadic.

Chiasmolithus gigas Subzone

Boundary species: Top – *Chiasmolithus gigas* †; bottom – *Chiasmolithus gigas* *.

Assemblage: *Bramletteius serraculoides, Campylosphaera dela, Chiasmolithus gigas, C. grandis, C. solitus, Coccolithus eopelagicus, C. pelagicus, C. staurion, Cyclicargolithus pseudogammation, Cyclococcolithina formosa, Discoaster barbadiensis, D. gemmifer, D. mirus, D. nodifer, D. nonaradiatus, D. saipanensis, D. strictus, D. wemmelensis, Helicopontosphaera compacta, H. seminulum, Nannotetrina mexicana, N. quadrata, Reticulofenestra samodurovi, Sphenolithus furcatolithoides, S. radians, S. spiniger, Triquetrorhabdulus inversus, Zygrhablithus bijugatus.*

Comment: The name for this subzone was suggested by Milow (1970) and defined by the range of *Chiasmolithus gigas* in Bukry (1971c). This interval, in the middle of the *Nannotetrina quadrata* Zone, has been recognized in Sections 149-37-4 to 149-40-1, 162-13-3 to 162-14-4, and 165A-12A-5 to 165A-12A-6. In shallow oceanic areas, *Braarudosphaera discula* is common in this and the next higher subzone, for example, in Sections 94-18-3 to 94-20-4 for the *C. gigas* Subzone and Sections 94-17-1 to 94-18-1 for the *Coccolithus staurion* Subzone.

Coccolithus staurion Subzone

Boundary species: Top – *Reticulofenestra umbilica* *, *Discoaster bifax* *; bottom – *Chiasmolithus gigas* †.

Assemblage: *Bramletteius serraculoides, Campylosphaera dela, Chiasmolithus grandis, C. solitus, Coccolithus eopelagicus, C. pelagicus, C. staurion, Cyclicargolithus pseudogammation, C. floridanus, Cyclococcolithina formosa, Discoaster barbadiensis, D. deflandrei, D. gemmeus, D. martinii, D. nodifer, D. saipanensis, D. strictus, D. wemmelensis, Helicopontosphaera compacta, Nannotetrina mexicana, N. quadrata, Reticulofenestra samodurovi, Sphenolithus furcatolithoides, S. radians, Triquetrorhabdulus inversus, Zygolithus dubius, Zygrhablithus bijugatus.*

Comment: This is the uppermost of three subzones in the *Nannotetrina quadrata* Zone that are keyed to the range of *Chiasmolithus gigas* in the middle of the zone. The appearance of large *Reticulofenestra umbilica* is the principal guide to the top of the *Coccolithus staurion* Subzone, with the first *Discoaster bifax* and latest species of *Nannotetrina* occurring near that level.

Selected reference: Bukry, 1971c.

Discoaster bifax Subzone

Boundary species: Top – *Discoaster bifax* †, *Chiasmolithus solitus* †; bottom - *Reticulofenestra umbilica* *, *Discoaster bifax* *.

Assemblage: *Bramletteius serraculoides, Campylosphaera dela, Chiasmolithus grandis, C. solitus, Coccolithus eopelagicus, C. pelagicus, C. staurion, Cyclicargolithus floridanus, C. pseudogammation, Cyclococcolithina formosa, Dictyococcites scrippsae, Discoaster barbadiensis, D. bifax, D. deflandrei, D. nodifer, D. saipanensis, D. strictus, Helicopontosphaera compacta, H. heezenii, Reticulofenestra samodurovi, R. umbilica, Sphenolithus furcatolithoides, S. obtusus, S. pseudoradians, S. radians, Triquetrorhabdulus inversus, Zygrhablithus bijugatus.*

Comment: The lower subzone, *Discoaster bifax* Subzone, of the *Reticulofenestra umbilica* Zone is recognized by the range of *D. bifax* above the first occurrence of *R. umbilica. Nannotetrina* is typically extinct at this interval, rare specimens are noted at a few localities.

Selected references: Bukry, 1971c, in press[a]; Roth and others, 1971.

Discoaster saipanensis Subzone

Boundary species: Top – *Chiasmolithus grandis* †; bottom – *Discoaster bifax* †, *Chiasmolithus solitus* †.

Assemblage: *Bramletteius serraculoides, Campylosphaera dela, Chiasmolithus grandis, Coccolithus eopelagicus, C. pelagicus, Cyclicargolithus floridanus, Cyclococcolithina formosa, Dictyococcites bisectus, D. scrippsae, Discoaster barbadiensis, D. deflandrei, D. nodifer, D. saipanensis, D. strictus, D. tani* [rare], *Helicopontosphaera compacta, H. reticulata* [rare], *Reticulofenestra samodurovi, R. umbilica, Sphenolithus obtusus, S. predistentus, S. pseudoradians, Triquetrorhabdulus inversus, Zygrhablithus bijugatus.*

Comment: The *Discoaster saipanensis* Subzone is the upper interval of the *Reticulofenestra umbilica* Zone. The original criteria for this subzone (Roth and others, 1971) included the last occurrence of *Chiasmolithus solitus* and the first of *C. oamaruensis.* In low-latitude assemblages, the last occurrence of *C. grandis* has proved to be more widely recognized than the first of *C. oamaruensis.* The disappearance of *C. grandis* closely approximates the appearance of *C. oamaruensis.* Care must be exercised in identifying *C. oamaruensis* owing to its superficial resemblance to *C. altus* and *C. expansus* (see Gartner, 1970; Bukry and Percival, 1971).

The *Dictyococcites bisectus* – *D. scrippsae* group becomes established in this subzone, although *D. bisectus* is generally rare. Diversity in the subzone is generally high both in open-ocean and nearshore settings.

Selected references: Bukry, in press[a]; Roth and others, 1971.

Discoaster barbadiensis Zone

Boundary species: Top – *Discoaster barbadiensis* †, *Discoaster saipanensis* †; bottom – *Chiasmolithus grandis* †.

Assemblage: *Bramletteius serraculoides, Chiasmolithus altus, Coccolithus eopelagicus, C. pelagicus, C. subdistichus* s. l., *Cyclicargolithus floridanus, Cyclococcolithina formosa, Dictyococcites bisectus, D. scrippsae, Discoaster barbadiensis, D. deflandrei, D. nodifer, D. saipanensis, D. tani, Helicopontosphaera compacta, Isthmolithus recurvus* [rare], *Pontosphaera vadosa, Reticulofenestra hillae, R. reticulata* [rare], *R. samodurovi, R. umbilica, Sphenolithus moriformis, S. predistentus, S. pseudoradians.*

Comment: Subdivision of the upper Eocene interval, represented by the *Discoaster barbadiensis* Zone, has been inconclusive for open-ocean assemblages, even though its duration has been estimated at an excessively long 4 to 5 million years. There is little evolution in the warm-water genus *Discoaster* which developed the greatest number of new species during intervals of warmest temperature in the lower to middle Eocene and middle Miocene. The reduced *Discoaster* speciation and the generally longer zones in the upper Eocene and Oligocene indicate a cool-temperature interval. Variation in ranges and sporadic occurrences of other inshore or cool-water markers such as *Isthmolithus recurvus, Sphenolithus pseudoradians, Reticulofenestra reticulata, Chiasmolithus oamaruensis,* and *Hayella situliformis*, and the strong dissolution evident in many upper Eocene open-ocean sections have prevented effective subzonation. Although *Chiasmolithus oamaruensis* appears at the end of the range of *C. grandis,* near the lower boundary of the zone, its occurrence in open-ocean sediment is sporadic. *Discoaster tani* first becomes common in the lower part of the zone following the extinction of *C. grandis.*

Selected references: Bronnimann and Stradner, 1960; Radomski, 1968; Bukry and Bramlette, 1970a.

Coccolithus subdistichus Subzone

Boundary species: Top – *Coccolithus subdistichus* s. l. A†; bottom – *Discoaster barbadiensis* †, *Discoaster saipanensis* †.

Assemblage: *Bramletteius serraculoides, Chiasmolithus altus, Coccolithus eopelagicus, C. fenestratus, C. pelagicus, C. subdistichus* s. l. [common], *Cyclicargolithus floridanus, Cyclococcolithina formosa, Dictyococcites bisectus, D. scrippsae, Discoaster deflandrei, D. nodifer, D. tani, Helicopontosphaera compacta, Isthmolithus recurvus* [rare], *Pontosphaera vadosa, Reticulofenestra hillae, R. umbilica, Sphenolithus moriformis, S. predistentus, S. pseudoradians.*

Comment: Original boundary criteria for the *Coccolithus subdistichus* Subzone were the last *Discoaster barbadiensis* and the first *Cyclococcolithina margaritae* (Roth and Hay, 1967). But *C. margaritae* has not been easily identified in light microscopy. Martini (1970) suggested that the interval from the last *D. barbadiensis* to the last *Coccolithus subdistichus* be used. The definition was later emended by Roth and others (1971) to the interval from the last *Discoaster saipanensis* to the last *Cyclococcolithina formosa*. The definition used here keys the unit to a shorter interval that can be distinguished in some sections as a subzone based on the acme of *Coccolithus subdistichus* s. l. The subzonal assemblage at the base of the tripartite *Helicopontosphaera reticulata* Zone may be missing as a result of ecological factors or the widespread unconformity present near the base of the zone. A lack of distinction between overgrown specimens of *C. subdistichus, C. obrutus* and *C. fenestratus* in open-ocean sediment may accentuate the acme where it is preserved.

Selected references: Martini and Ritzkowski, 1968; Martini and Moorkens, 1969; Roth 1970; Martini, 1971.

Cyclococcolithina formosa Subzone

Boundary species: Top – *Cyclococcolithina formosa* †; bottom – *Coccolithus subdistichus* A†.

Assemblage: Similar to the underlying *Coccolithus subdistichus* Subzone, except *C. subdistichus* s. l. is less prominent and *Isthmolithus recurvus* is extinct.

Comment: The *Cyclococcolithina formosa* Subzone is the middle of three subzones in the *Helicopontosphaera reticulata* Zone. In open-ocean sections this subzone composes most of the zone. The disappearance of cosmopolitan, easily identified *Cyclococcolithina formosa* marks the top of the subzone.

Selected references: Roth, 1970; Martini, 1971; Bukry, in press[a].

Reticulofenestra hillae Subzone

Boundary species: Top – *Reticulofenestra hillae* †, *Reticulofenestra umbilica* †; bottom – *Cyclococcolithina formosa* †.

Assemblage: Similar to the underlying *Cyclococcolithina formosa* Subzone, except *C. formosa* is extinct.

Comment: This interval is small in open-ocean sections (Bukry, in press [a]).

Sphenolithus predistentus Zone

Boundary species: Top – *Sphenolithus distentus* *; bottom – *Reticulofenestra hillae* †, *Reticulofenestra umbilica* †.

Assemblage: *Bramletteius serraculoides* [rare], *Chiasmolithus altus, Coccolithus eopelagicus, C. pelagicus, Cyclicargolithus floridanus* [abundant], *Dictyococcites bisectus, D. scrippsae, Discoaster deflandrei, D. nodifer, D. tani, Helicopontosphaera compacta, Pontosphaera vadosa, Reticulofenestra gartneri, Sphenolithus moriformis, S. predistentus, S. pseudoradians.*

Comment: The first definition of this zone (Bramlette and Wilcoxon, 1967) used the extinctions of *Helicopontosphaera reticulata* and *Reticulofenestra umbilica* at the bottom and the extinctions of *Discoaster* sp. aff. *D. nodifer, Discoaster gartneri* (name substituted herein for *Discoaster tani ornatus* Bramlette and Wilcoxon, 1967, Tulane Studies Geology, v. 5, p. 112, pl. 7, fig. 8 which cannot be raised to species rank because the name *Discoaster ornatus* Stradner, 1958, has been previously used), and *Sphenolithus pseudoradians,* and the appearances of *Helicopontosphaera bramlettei* and *Cyclicargolithus abisectus* at the top. Numerous modifications by later workers have been suggested as more sections have been studied.

Selected references: Roth, 1970; Bukry, 1971b; Martini, 1971.

Sphenolithus distentus Zone

Boundary species: Top - *Sphenolithus ciperoensis* *; bottom – *Sphenolithus distentus* *.

Assemblage: *Chiasmolithus altus, Coccolithus eopelagicus, C. pelagicus, Cyclicargolithus* sp. cf. *C. abisectus* [rare], *C. floridanus* [abundant], *Dictyococcites bisectus* [few], *D. scrippsae, Discoaster deflandrei, D. nodifer, D. tani* [rare], *Helicopontosphaera compacta, Reticulofenestra gartneri, Sphenolithus distentus, S. moriformis, S. predistentus, S. pseudoradians* [rare], *Triquetrorhabdulus carinatus* [rare].

Comment: Among the original criteria for this zone (Bramlette and Wilcoxon, 1967), the earliest evolutionary occurrence of *Sphenolithus distentus* has proved most useful in open-ocean sections. *Cyclicargolithus abisectus* first occurs within the zone and the earliest evolutionary occurrence of *Sphenolithus ciperoensis* marks the top of the zone most effectively in low-latitude oceanic sections. The *Sphenolithus* lineage is difficult to apply at high latitude owing to the rarity of specimens (Edwards, 1971). Auxiliary marker species such as *Triquetrorhabdulus carinatus* or *Cyclicargolithus abisectus* appear to have first occurrences that are more stratigraphically variable. This may result partially from identification ambiguity in overgrown preservation states and low abundance levels. The sequence of first *C. abisectus*, first *T. carinatus* only approximates the evolutionary sequence of first *S. distentus*, first *S. ciperoensis* at low-latitude.

Sphenolithus ciperoensis Zone

Boundary species: Top – *Sphenolithus ciperoensis* †, *Dictyococcites bisectus* †, *Dictyococcites scrippsae* †; bottom – *Sphenolithus ciperoensis* *.

Assemblage: *Chiasmolithus altus, Coccolithus eopelagicus, C.* sp. aff. *C. fenestratus, C. miopelagicus* [rare], *C. pelagicus, Cyclicargolithus abisectus, C. floridanus, Dictyococcites bisectus, D. scrippsae, Discoaster deflandrei, D. nodifer* [rare], *Discolithina segmenta, Helicopontosphaera intermedia* [rare], *H. recta* [rare], *Reticulofenestra gartneri, Sphenolithus ciperoensis, S. dissimilis, S. distentus, S. moriformis, Triquetrorhabdulus carinatus.*

Comment: The close-spaced disappearance of *Dictyococcites bisectus* and *D. scrippsae* with *Sphenolithus ciperoensis* at the top of the zone at low-latitude provides a coordinate basis to recognize the top of the zone at high-latitude. (Bukry and Bramlette, 1970b; Bukry, 1972a; Edwards, A. R., personal commun., 1972). There, *Dictyococcites bisectus* or *D. scrippsae* are used.

Selected reference: Bramlette and Wilcoxon, 1967.

Cyclicargolithus abisectus Subzone

Boundary species: Top – *Cyclicargolithus abisectus* A†; bottom – *Sphenolithus ciperoensis* †, *Dictyococcites bisectus* †, *Dictyococcites scrippsae* †.

Assemblage: *Coccolithus eopelagicus, C.* sp. aff. *C. fenestratus, C. miopelagicus, C. pelagicus, Coronocyclus* sp., *Cyclicargolithus abisectus* [common], *C. floridanus, Discoaster deflandrei, D. lidzii, Discolithina segmenta, Helicopontosphaera euphratis, H. intermedia, Reticulofenestra gartneri, Sphenolithus dissimilis, S. moriformis, Triquetrorhabdulus carinatus.*

Comment: The original *Triquetrorhabdulus carinatus* Zone of Bramlette and Wilcoxon (1967) was defined by the range of *Triquetrorhabdulus carinatus* above the last occurrence of *Helicopontosphaera recta.* This zonal definition was modified for open-ocean assemblages by Bukry and Bramlette (1970a) to include the interval above the last *Sphenolithus ciperoensis* and *Dictyococcites bisectus* to the last *T. carinatus* and the first *Sphenolithus belemnos* s. s. The acme of *Discoaster druggii* occurs in the upper part of the zone. The lower part of the zone at low-latitude contains the acme of *Cyclicargolithus abisectus* (Bukry, 1971a). These two subintervals and the intervening transition have been indicated as three low-latitude subzones (Bukry, 1971c). From bottom to top these are the *Cyclicargolithus abisectus* Subzone, *Discoaster deflandrei* Subzone, and *Discoaster druggii* Subzone.

Discoaster deflandrei Subzone

Boundary species: Top – *Discoaster druggii* *, *Orthorhabdus serratus* *; bottom – *Cyclicargolithus abisectus* A†.

Assemblage: *Coccolithus eopelagicus, C.* sp. aff. *C. fenestratus, C. miopelagicus, C. pelagicus, Coronocyclus* sp., *Cyclicargolithus floridanus* [abundant], *Discoaster deflandrei* [abundant], *Helicopontosphaera euphratis, H. intermedia, Reticulofenestra gartneri, Sphenolithus conicus, S. dissimilis, S. moriformis, Triquetrorhabdulus carinatus* [abundant].

Comment: Variously defined *Discoaster deflandrei* biostratigraphic intervals have been indicated for the Eocene to lower Miocene where the name-giving species and its overgrowth variants are abundant (Bronnimann and Stradner, 1960; Bronnimann and Rigassi, 1963; Hay, 1964; Edwards, 1971). The subzone used here was first indicated in the western Pacific as a transitional interval between the *Cyclicargolithus abisectus* Subzone below, and the *Discoaster druggii* Subzone above (Bukry et al., 1971). The later recognition of the same transitional assemblages in cores from the Caribbean (DSDP Leg 15) and eastern equatorial Pacific (DSDP Leg 16) prompted naming of the subzone. The assemblage is characterized by low diversity with *Discoaster deflandrei* and *Triquetrorhabdus carinatus* being especially abundant; *Cyclicargolithus floridanus* dominates among the placoliths. The top of the interval is indicated by the first occurrence of *Discoaster druggii* and *Orthorhabdus serratus.* The bottom is indicated by the end of the regional acme of *Cyclicargolithus abisectus.*

Discoaster druggii Subzone

Boundary species: Top - *Sphenolithus belemnos**; bottom - *Discoaster druggii**, *Orthorhabdus serratus**.

Assemblage: *Coccolithus miopelagicus, C. pelagicus, Coronocyclus* sp., *Cyclicargolithus floridanus, Discoaster deflandrei, D. druggii, D. lidzii, D.* sp. cf. *D. variabilis, Helicopontosphaera euphratis, H. intermedia, Orthorhabdus serratus, Reticulofenestra gartneri, Sphenolithus dissimilis, S. moriformis, Triquetrorhabdulus carinatus, T. milowii.*

Comment: The range of *Discoaster druggii* or *Orthorhabdus serratus* was suggested as a convenient guide to the upper part of the *Triquetrorhabdulus carinatus* Zone (Bukry and Bramlette, 1970a). The *Discoaster druggii* Subzone (Bukry, 1971a) has proved to be a widely recognized interval in low-latitude cores of the Deep Sea Drilling Project. *D. druggii* is more cosmopolitan than *O. serratus.*

Selected references: Martini and Worsley, 1970; Roth and Thierstein, 1972.

Sphenolithus belemnos Zone

Boundary species: Top - *Sphenolithus heteromorphus**, *Sphenolithus belemnos* †; bottom - *Sphenolithus belemnos**.

Assemblage: *Coccolithus miopelagicus, C. pelagicus, Coronocyclus* sp., *Cyclicargolithus floridanus, Discoaster aulakos, D. deflandrei, D. druggii* [rare], *Reticulofenestra gartneri, Sphenolithus belemnos, S. moriformis, Triquetrorhabdulus carinatus* [rare], *T. milowii.*

Comment: The distinctive guide species of this zone, *Sphenolithus belemnos,* occurs sporadically in open-ocean sections. Large and small *Helicopontosphaera ampliaperta,* used as another marker for the zone in the original definition of Bramlette and Wilcoxon (1967), are rare. Cosmopolitan *Sphenolithus heteromorphus* is now utilized for the top of the zone (Bukry, 1972b).

Helicopontosphaera ampliaperta Zone

Boundary species: Top - *Discoaster deflandrei* A†, *Helicopontosphaera ampliaperta* †; bottom - *Sphenolithus heteromorphus** *Sphenolithus belemnos* †.

Assemblage: *Coccolithus miopelagicus, C. pelagicus, Coronocyclus* sp., *Cyclicargolithus floridanus, Cyclococcolithina macintyrei* [rare], *Discoaster aulakos, D deflandrei, D.* sp. cf. *D. exilis, D. variabilis, Helicopontosphaera ampliaperta* [rare], *H. granulata, H.* sp. cf. *H. kamptneri, Reticulofenestra* sp. cf. *R. gartneri, Sphenolithus heteromorphus, S. moriformis, Triquetrorhabdulus milowii.*

Comment: The upper boundary of this zone was originally determined (Bramlette and Wilcoxon, 1967) as the extinction of *Helicopontosphaera ampliaperta* in the Cipero section of Trinidad and the lower boundary as the appearance of *Sphenolithus heteromorphus* or the extinction of *S. belemnos.* On the basis of the co-occurrence of these two species at DSDP Site 140, the first occurrence of more cosmopolitan *S. heteromorphus* has been selected as the principal indicator (Bukry, 1972b). The last occurrences of *S. belemnos* and *Triquetrorhabdulus milowii* in the lower part of the zone and the first rare occurrences of *Cyclococcolithina macintyrei* s. l. and *Discoaster exilis* near the top help in identifying this interval. A reduction in the dominance of *Discoaster deflandrei* among the discoasters at the top of the zone in favor of long-rayed discoasters such as *D. exilis, D. signus,* and *D. variabilis* is distinctive in low-latitude areas. Characteristically, heavy overgrowth on discoaster rays in this part of the section makes distinguishing species of long-rayed discoasters from each other difficult, but the contrast between *D. deflandrei* and long-rayed discoasters is evident even in advanced stages of overgrowth.

Sphenolithus heteromorphus Zone

Boundary species: Top - *Sphenolithus heteromorphus* †; bottom - *Discoaster deflandrei* A†, *Helicopontosphaera ampliaperta* †.

Assemblage: *Coccolithus miopelagicus, C. pelagicus, Coronocyclus* sp., *Cyclicargolithus floridanus, Cyclococcolithina leptopora, C. macintyrei, Discoaster aulakos, D. deflandrei, D. exilis, D. moorei, D. signus, D. variabilis, Discolithina* sp. [large], *Helicopontosphaera granulata, H. kamptneri, Reticulofenestra pseudoumbilica, Sphenolithus abies, S. heteromorphus, S. moriformis, Triquetrorhabdulus rugosus.*

Comment: Overgrowth on discoasters is often moderate to heavy in the interval of this zone, making species distinction among long-rayed discoasters difficult. However, even in overgrown condition, the change in the relative abundance of short-rayed *Discoaster deflandrei* can be determined at the base of the zone. From a dominant numerical position in underlying zones, it falls to equal or less than equal numbers with respect to newer long-rayed species. The appearance of populations of *Cyclococcolithina macintyrei* (elliptic central areas), *Discoaster exilis,* and large *Reticulofenestra pseudoumbilica* near the base of the zone and *Sphenolithus abies* and *Triquetrorhabdulus rugosus* near the top aid in distinguishing the interval. There may be a gradation from *Reticulofenestra* sp. cf. *R. gartneri* of lower zones to larger more oval *R. pseudoumbilica* in this zone. Distinguishing the two species in this part of the range is difficult, suggesting that the two names refer to the same lineage.

Coccolithus miopelagicus Subzone

Boundary species: Top – *Discoaster kugleri**; bottom – *Sphenolithus heteromorphus*†.

Assemblage: *Coccolithus miopelagicus, C. pelagicus, Coronocyclus* sp., *Cyclicargolithus floridanus, Cyclococcolithina leptopora, C. macintyrei, Discoaster aulakos, D. braarudii, D. deflandrei, D. exilis, D. moorei, D. signus, D. variabilis, Discolithina* sp. [large], *Helicopontosphaera granulata, H. kamptneri, Reticulofenestra pseudoumbilica, Sphenolithus abies, S. moriformis, Triquetrorhabdulus rugosus.*

Comment: The original name for this interval, *Discoaster exilis* Zone (Hay, 1970), was applied to the interval from the first *Discoaster exilis* to the first *D. kugleri.* This was intended to fill an unnamed stratigraphic interval in the zonal scheme of Bramlette and Wilcoxon (1967). But the first *D. exilis* occurs prior to the extinction of cosmopolitan, easily identified *Sphenolithus heteromorphus* which was indicated as the criteria for the top of the *Sphenolithus heteromorphus* Zone or the base of the unnamed interval by Bramlette and Wilcoxon. Later workers (Martini and Worsley, 1970; Bukry, 1971c) used the last *S. heteromorphus* to define the base of the *D. exilis* Zone. The top of the *D. exilis* Zone was extended upward to the first *Catinaster coalitus* so the *Discoaster kugleri* Zone of Bramlette and Wilcoxon (1967) could be included as a subzone (Bukry, 1971c). This usage was prompted to avoid seeming stratigraphic hiatuses where the sporadic, tropical species, *D. kugleri* was not present. Aside from *D. kugleri* there are no other significant first occurrences to serve as auxiliary markers. The first occurrence of

Discoaster bollii might prove useful, but it generally occurs in higher intervals. The last occurrence of *Cyclicargolithus floridanus* is generally near this level, but that species has also been recorded as common in the *Discoaster kugleri* Subzone of some areas (Roth and Thierstein, 1972). Because the occurrence of *D. kugleri* provided the only criterion to separate the assemblages of the *D. exilis* and *D. kugleri* Zones, recognition of the *D. kugleri* Zone as a subzone was recommended. The lower companion subzone was named the *Coccolithus eopelagicus* Subzone. A taxonomic revision changed the name to the *Coccolithus miopelagicus* Subzone (Bukry, 1971c).

Discoaster kugleri Subzone

Boundary species: Top - *Catinaster coalitus**, *Discoaster kugleri* †; bottom - *Discoaster kugleri**.

Assemblage: *Coccolithus miopelagicus, C. pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster aulakos, D. bollii, D. braarudii, D. challengeri, D. exilis, D. kugleri, D. moorei, D.* sp. cf. *D. variabilis, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica, Sphenolithus abies, S. neoabies, Triquetrorhabdulus rugosus.*

Comment: Only the occurrence of *Discoaster kugleri* permits definite recognition of the upper assemblages of the *Discoaster exilis* Zone (Bukry, 1971b). The appearance of *D. bollii* also suggests the upper part of the zone.

Selected references: Bramlette and Wilcoxon, 1967; Martini, 1971; Roth and Thierstein, 1972.

Catinaster coalitus Zone

Boundary species: Top - *Discoaster hamatus**; bottom - *Catinaster coalitus**, *Discoaster kugleri* †.

Assemblage: *Catinaster coalitus, Coccolithus miopelagicus, C. pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster bollii, D. braarudii, D. challengeri, D.* sp. cf. *D. exilis, D. pseudovariabilis, D. variabilis, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica, Sphenolithus abies, S. neoabies, Triquetrorhabdulus rugosus.*

Comment: This zone was originally defined using the range of *Catinaster coalitus* below the first occurrence of *Discoaster hamatus* by Bramlette and Wilcoxon (1967). This usage has proved reliable for low-latitude assemblages. Additionally, it has been noted that *Discoaster bellus* and *D. calcaris* may occur rarely near the top of the zone; however, these species are characteristic of the *Discoaster hamatus* Zone or the *Discoaster neohamatus* Zone. The disappearance, within the zone, of *Coccolithus miopelagicus* and *Discoaster exilis*, and the appearance of *D. pseudovariabilis* are also useful guides.

Selected references: Bukry, 1971b; Martini, 1971.

Discoaster hamatus Zone

Boundary species: Top - *Discoaster hamatus* †; bottom - *Discoaster hamatus**.

Assemblage: *Catinaster calyculus, C. coalitus, Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster bellus, D. bollii, D. braarudii, D. brouweri* [rare], *D. calcaris, D. challengeri, D. hamatus, D. neohamatus, D. prepentaradiatus, D. pseudovariabilis, D. variabilis, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica, Sphenolithus abies, S. neoabies, Triquetrorhabdulus rugosus.*

Comment: This zone was originally defined as the range zone of *Discoaster hamatus* by Bramlette and Wilcoxon (1967). The beginning of a distinctive Neogene five-rayed discoaster lineage marks the base of the zone as *Discoaster bellus* and *D. hamatus* appear approximately together. *Catinaster calyculus* and *Discoaster neohamatus* first occur within this zone. The appearance of *Catinaster calyculus* marks the upper part of the zone (M. N. Bramlette, personal commun., 1968). Therefore, where *C. calyculus* is present, its first appearance could be used to indicate an upper, *Catinaster calyculus* Subzone and a lower interval, nominally the *Helicopontosphaera kamptneri* Subzone. *Discoaster hamatus* Zone assemblages, showing one or both of the divisions, occur at sections 62.1-31-6 to 62.1-33-2, 158-24-1 to 158-28-2, and 200-6 to 200-7.

Selected references: Martini and Bramlette, 1963; Bukry, 1971b; Martini and Worsley, 1971.

Discoaster bellus Subzone

Boundary species: Top - *Discoaster neorectus**; bottom - *Discoaster hamatus* †.

Assemblage: *Catinaster calyculus, C. coalitus, Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus* [rare, possibly variants of *D. bellus*], *D. bellus, D. bollii, D. braarudii, D. brouweri* s. 1., *D. intercalaris* [rare], *D.* sp. cf. *D. leoblichii, D. neohamatus, D. pentaradiatus, D. perclarus, D. prepentaradiatus, D. pseudovariabilis, D. variabilis, Helicopontosphaera kamptneri, Minylitha convallis, Reticulofenestra pseudoumbilica, Sphenolithus abies, S. neoabies, Triquetrorhabdulus rugosus.*

Comment: This interval is fairly long but contains several appearances and extinctions such that further subdivision is possible when the ranges of several newly described species are more fully determined. The appearances of *Discoaster loeblichii, D. pentaradiatus,* and *Minylitha convallis* and disappearances of *Catinaster calyculus, C. coalitus, Discoaster prepentaradiatus,* and *D. pseudovariabilis* are noted in this zone.

Selected reference: Bukry, in press [a].

Discoaster neorectus Subzone

Boundary species: Top - *Discoaster berggrennii**, *Discoaster neorectus*†; bottom - *Discoaster neorectus.**

Assemblage: *Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus* [rare], *D. bellus, D. brouweri, D. challengeri, D. intercalaris, D. loeblichii, D. neohamatus, D. neorectus, D. pentaradiatus* [rare], *D. perclarus, D. quinqueramus* [transitional from *D. bellus*], *D. variabilis, Discolithina japonica, D. multipora, Helicopontosphaera kamptneri, Minylitha convallis, Reticulofenestra pseudoumbilica, Sphenolithus abies, S. neoabies, Triquetrorhabdulus rugosus.*

Comment: This short interval at the top of the *Discoaster neohamatus* Zone is characterized by relatively diverse discoaster assemblages owing to many overlapping ranges. Short-ranging *Discoaster loeblichii* and *D. neorectus* occur with late *D. bellus* and transitional forms related to *D. quinqueramus.* A late variety of *D. neohamatus,* having only a slight twist of the ray tips, is also present. *D. surculus* which may have developed from *D. pseudovariabilis* is only rarely noted, being most typical in the overlying *Discoaster quinqueramus* Zone.

Discoaster berggrenii Subzone

Boundary species: Top - *Ceratolithus primus**; bottom - *Discoaster berggrenii**, *Discoaster neorectus*†.

Assemblage: *Coccolithus pelagicus, Cyclococcolithina liptopora, C. macintyrei, Discoaster asymmetricus* [rare], *D. berggrenii, D. brouweri, D. challengeri, D. intercalaris, D. pentaradiatus, D. quinqueramus, D. surculus, D. variabilis, Discolithina japonica, Helicopontosphaera kamptneri, Minylitha convallis* [rare], *Reticulofenestra pseudoumbilica, Sphenolithus abies, S. neoabies, Triquetrorhabdulus rugosus.*

Comment: Several changes in discoaster populations occur near the bottom of this subzone. *Discoaster neohamatus, D. loeblichii,* and *D. bellus*, characterizing underlying intervals, disappear. *D. surculus, D. quinqueramus*, and *D. berggrenii* appear within a short interval and become common in the *Discoaster quinqueramus* Zone. The appearance of large *D. surculus* provides an alternate means to the *D. berggrenii* appearance to recognize the base of the *Discoaster berggrenii* Subzone. *D. berggrenii* is most common in the lower *D. quinqueramus* Zone and this acme aids in recognizing the *D. berggrenii* Subzone. *Minylitha convallis* may range up into this subzone, although it is most typical of the *Discoaster neohamatus* Zone. The top of the *D. berggrenii* Subzone is recognized by the first *Ceratolithus primus*, a simple horseshoe-shaped fossil lacking ornamentation.

Selected references: Perch-Nielsen, 1972; Roth and Thierstein, 1972; Bukry, in press[a].

Ceratolithus primus Subzone

Boundary species: Top - *Discoaster quinqueramus* †; bottom - *Ceratolithus primus**.

Assemblage: *Ceratolithus dentatus, C. primus, Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus* [rare], *D. berggrenii, D. brouweri, D. challengeri, D. intercalaris, D. pentaradiatus, D. quinqueramus, D. surculus, D. variabilis, Discolithina japonica, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica, Scyphosphaera globulata, S. pulcherrima, Sphenolithus abies, S. neoabies, Triquetrorhabdulus rugosus.*

Comment: Genus *Ceratolithus* first occurs in the *Ceratolithus primus* Subzone which is readily distinguished by the occurrence together of *Ceratolithus dentatus* or *C. primus*, and *Discoaster quinqueramus* and *D. surculus. Scyphosphaera globulata* appears within this interval.

Selected reference: Bukry, 1971c.

Triquetrorhabdulus rugosus Subzone

Boundary species: Top - *Ceratolithus acutus**, *Triquetrorhabdulus rugosus*†; bottom - *Discoaster quinqueramus*†.

Assemblage: *Angulolithina arca, Ceratolithus dentatus, C. primus* [after Bukry, in press (a)], *C. tricorniculatus* [after Bukry, in press (a)], *Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus* [rare], *D. brouweri, D. challengeri, D. intercalaris, D. pentaradiatus, D. surculus, D. variabilis, Discolithina japonica, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica, Rhabdosphaera procera, Scyphosphaera globulata, S. pulcherrima, Sphenolithus abies, S. neoabies, Triquetrorhabdulus rugosus.*

Comment: The *Triquetrorhabdulus rugosus* interval between the extinctions of *Discoaster quinqueramus* and *Triquetrorhabdulus rugosus* occurs at the bottom of the *Ceratolithus tricorniculatus* Zone (Bukry, 1971c). This subzone is so short that it falls within the margin of standard error for most zones. It may prove too variable, owing to local variation of key species ranges, in all but expanded sections. The *T. rugosus* Subzone is not equivalent to the *T. rugosus* Zone of Bukry and Bramlette (1970a) which was defined by the assemblages developed between the last *Discoaster hamatus* and the first *Ceratolithus tricorniculatus* Gartner, emended Bukry and Bramlette (1968). Owing to the manner in which *C. tricorniculatus* has been recorded in the past, there is some uncertainty as to its typical first occurrence. The situation is complicated by the occurrence together of both nonbirefringent and partially birefringent specimens of *C. tricorniculatus* s. s. morphology in samples from the type core at 5 cm above and below the type level. As no crystallographic data accompanied the original description (Gartner, 1967), the emendation of this species to only nonbirefringent specimens (Bukry and Bramlette, 1968) has been used. But in the future, a revision may be desirable to combine both crystallographic types (Gartner and Bukry, in prep.).

Ceratolithus acutus Subzone

Boundary species: Top - *Ceratolithus rugosus**, *Ceratolithus acutus*†; bottom - *Ceratolithus acutus**, *Triquetrorhabdulus rugosus*†.

Assemblage: *Angulolithina arca, Ceratolithus acutus, C. primus, C. tricorniculatus, Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus* [rare], *D. brouweri, D. challengeri, D. pentaradiatus, D. surculus, D. variabilis, Discolithina japonica, D. multipora, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica, Scyphosphaera globulata, S. intermedia, S. pulcherrima, Sphenolithus abies. S. neoabies.*

Comment: Recognition of the *Ceratolithus acutus* Subzone is aided by the short range of the name giving species (Gartner and Bukry, in prep.) prior to the appearance of *C. rugosus*. Paired extinctions or appearances, such as those used here for boundary species, are not intended to indicate identical age, but instead, to indicate closely spaced events in the geologic record that allow alternate means of quickly sequencing assemblages in a variety of preservation stages and from different geographic areas.

Selected references: Bukry, in press [a]; Gartner, in press; Gartner and Bukry, in prep.

Ceratolithus rugosus Subzone

Boundary species: Top - *Ceratolithus primus*†, *Ceratolithus tricorniculatus* †; bottom - *Ceratolithus rugosus* *, *Ceratolithus acutus* †.

Assemblage: *Ceratolithus bizzarus* [rare], *C. rugosus, C. tricorniculatus, Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus, D. brouweri, D. challengeri, D. pentaradiatus, D. surculus, D. variabilis, Discolithina japonica, D. multipora, Helicopontosphaera kamptneri, H. sellii* [rare, small], *Reticulofenestra pseudoumbilica, Scyphosphaera globulata, S. intermedia, S. pulcherrima, Sphenolithus abies, S. neoabies.*

Comment: Originally established as a zone distinguished by the overlapping ranges of *Ceratolithus rugosus* and *C. primus* or *C. tricorniculatus*, this interval is now designated a subzone because the geographic range of *C. rugosus* is more restricted than that of *C. tricorniculatus* (Bukry and Bramlette, 1970b). *C. rugosus* is most consistently present at low latitude.

Selected references: Gartner, 1969; Bukry and Bramlette, 1970a; Roth and Thierstein, 1972; Gartner, in press.

Sphenolithus neoabies Subzone

Boundary species: Top - *Discoaster asymmetricus* A*; bottom - *Ceratolithus primus*†, *Ceratolithus tricorniculatus*†.

Assemblage: *Ceratolithus rugosus, Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus, D. brouweri, D. challengeri, D. pentaradiatus, D. surculus, D. variabilis, Discolithina japonica, Helicopontosphaera kamptneri, H. sellii, Reticulofenestra pseudoumbilica, Scyphosphaera globulata, S. intermedia, S. pulcherrima, Sphenolithus abies, S. neoabies* [abundant], *Thoracosphaera saxea.*

Comment: The *Sphenolithus neoabies* Subzone, the lower part of the *Reticulofenestra pseudoumbilica* Zone, lacks *Discoaster tamalis* and *D. decorus*, and contains only sporadic *D. asymmetricus*. This subzone (Bukry, 1971b) is not equivalent to the *Sphenolithus abies* Zone (Boudreaux and Hay, 1969) which was locally defined in a Caribbean core as the interval from the last *Discoaster surculus* to the last *Sphenolithus abies.*

Discoaster asymmetricus Subzone

Boundary species: Top - *Reticulofenestra pseudoubmilica*†, *Sphenolithus* spp. †; bottom - *Discoaster asymmetricus* A*.

Assemblage: *Ceratolithus rugosus, Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus* [common], *D. brouweri, D. challengeri, D. decorus, D. pentaradiatus, D. surculus, D. tamalis, D. variabilis, Discolithina japonica, Helicopontosphaera kamptneri, H. sellii, Reticulofenestra pseudoumbilica, Scyphosphaera intermedia, S. pulcherrima, Sphenolithus abies, S. neoabies, Thoracosphaera saxea.*

Comment: The *Reticulofenestra pseudoumbilica* Zone, between the extinction of nonbirefringent *Ceratolithus primus* and *C. tricorniculatus*, and the extinction of *Reticulofenestra pseudoumbilica* and *Sphenolithus* spp., is relatively short. Only the regional acme of *D. asymmetricus* in the upper part of the interval indicates a subdivision in low-latitude areas. Within this upper subzonal interval, *Discoaster tamalis* and *D. decorus* first appear and *Helicopontosphaera sellii* becomes more abundant. The *Discoaster asymmetricus* Subzone is not equivalent to the *Discoaster asymmetricus* Zone of Gartner (1969) which is defined as the interval between the first *D. asymmetricus* and the last *C. tricorniculatus*. Discoasters indistinguishable from *D. asymmetricus* have since been recognized to occur sporadically in preceding zones (Bukry, 1971b). At low latitude, the first common occurrence of *D. asymmetricus* is above the extinction of *C. tricorniculatus* (Gartner, 1972; Roth and Thierstein, 1972; Bukry, in press [a]).

Discoaster tamalis Subzone

Boundary species: Top - *Discoaster tamalis*†; bottom - *Reticulofenestra pseudoumbilica*†, *Sphenolithus* spp. †.

Assemblage: *Ceratolithus rugosus, Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus, D. brouweri, D. decorus, D. pentaradiatus, D. surculus, D. variabilis* [rare], *Discolithina japonica, Helicopontosphaera kamptneri, H. sellii, Rhabdosphaera procera* [rare], *Scyphosphaera pulcherrima, Thoracosphaera saxea.*

Comment: The occurrence together of *Discoaster asymmetricus* and *D. tamalis* in the absence of both *Reticulofenestra pseudoumbilica* and *Sphenolithus* spp. is a practical distinction for the lower subzone of the *Discoaster brouweri* Zone in low-latitude assemblages. *Discoaster decorus* does not range above this interval.

Selected references: Hay, 1970; Bukry, 1971c; Roth and Thierstein, 1972.

Discoaster pentaradiatus Subzone

Boundary species: Top - *Discoaster pentaradiatus*†, *Discoaster surculus*†; bottom - *Discoaster tamalis*†.

Assemblage: *Ceratolithus rugosus, Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus, D. brouweri, D. pentaradiatus, D. surculus, D. triradiatus, Discolithina japonica, Emiliania* sp. cf. *E. annula, Gephyrocapsa doronicoides, Helicopontosphaera kamptneri, H. sellii, Rhabdosphaera clavigera, R. procera, Scyphosphaera pulcherrima, Thoracosphaera saxea.*

Selected references: Gartner, 1969; Martini and Worsley, 1970; Bukry, 1971b, 1973.

Cyclococcolithina macintyrei Subzone

Boundary species: Top - *Discoaster brouweri*†; bottom - *Discoaster pentaradiatus*†, *Discoaster surculus*†.

Assemblage: *Ceratolithus cristatus, C. rugosus, Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei* [common], *D. brouweri, D. triradiatus, Discolithina japonica, Emiliania* sp. cf. *E. annula, Gephyrocapsa doronicoides, Helicopontosphaera kamptneri, H. sellii, Rhabdosphaera clavigera, Scyphosphaera pulcherrima, Syracosphaera* sp., *Thoracosphaera saxea.*

Comment: The base of the *Cyclococcolithina macintyrei* Subzone is indicated by the disappearances of *Discoaster pentaradiatus* and *D. surculus* which are closely spaced. The disappearance of *D. surculus* typically precedes *D. pentaradiatus*, but the interval is short and *D. surculus* survives diagenetic changes and reworking better than *D. pentaradiatus*. Therefore, for practical application their disappearances are considered similar.

The top of the subzone is generally indicated by the disappearance of *Discoaster brouweri*. This disappearance is determined by a dramatic reduction in the abundance of *D. brouweri* from percentages of 1 percent or greater in the coccolith assemblage to percentages of 0.01 percent or less. In higher strata, *D. brouweri* is absent or percentages are so small that *D. brouweri* may not be detected in routine biostratigraphic dating. At such small percentages, indigenous specimens could not be discriminated from reworked specimens. Warm-water sites such as 88 and 203 show that where small percentages of *D. brouweri* occur at higher levels they are associated with other species of *Discoaster* that disappeared at much deeper horizons, indicating reworking and an ambiguous origin of the rare *D. brouweri* specimens. Other criteria used to indicate levels near the top of the subzone are reduced abundances of *Cyclococcolithina macintyrei* and *Ceratolithus rugosus* and increased abundances for *Coccolithus pelagicus* and *Helicopontosphaera sellii.*

Selected references: Bukry and Bramlette, 1971a; Roth and Thierstein, 1972.

Emiliania annula Subzone

Boundary species: Top - *Gephyrocapsa caribbeanica**; bottom - *Discoaster brouweri*†.

Assemblage: *Ceratolithus cristatus, C. rugosus* [rare], *Coccolithus pelagicus, Cyclococcolithina leptopora, C. macintyrei* [rare], *Discolithina japonica, Emiliania annula, E. ovata, Gephyrocapsa doronicoides, Helicopontosphaera kamptneri, H. sellii, Rhabdosphaera clavigera, R. procera, R. stylifera, Scyphosphaera pulcherrima, Syracosphaera* sp., *Thoracosphaera saxea.*

Comment: The *Emiliania annula* Subzone is a short interval between the extinction of discoasters and the appearance of barred *Gephyrocapsa* species (Bukry, 1971c).

Gephyrocapsa caribbeanica Subzone

Boundary species: Top - *Gephyrocapsa oceanica**; bottom - *Gephyrocapsa caribbeanica**.

Assemblage: *Ceratolithus cristatus, Coccolithus pelagicus, Cyclococcolithina leptopora, Discolithina japonica, Emiliania annula, E. ovata, Gephyrocapsa caribbeanica, G. doronicoides, Helicopontosphaera kamptneri, H. sellii, Pontosphaera discopora, Rhabdosphaera clavigera, R. stylifera, Scyphosphaera apsteinii, S. pulcherrima, Syracosphaera* sp., *Thoracosphaera saxea.*

Comment: The *Gephyrocapsa caribbeanica* Subzone was originally described as zone by Boudreaux and Hay (1967); their definition has been modified. Both units employ the first *G. oceanica* to indicate the top boundary. But instead of using their *Discoaster brouweri* criteria for the bottom (see comment for *Cyclococcolithina macintyrei* Subzone), the first occurrence of *Gephyrocapsa caribbeanica* is used for the subzone definition (Bukry, 1971c). Recognition of this interval requires discrimination of species within the genus *Gephyrocapsa* (Boudreaux and Hay, 1969; McIntyre et al., 1970; Bukry, in press[a]).

Gephyrocapsa oceanica Zone

Boundary species: Top - *Emiliania huxleyi**; bottom - *Gephyrocapsa oceanica**.

Assemblage: *Ceratolithus cristatus, Coccolithus pelagicus, Cyclococcolithina leptopora, Emiliania annula, E. ovata, Gephyrocapsa caribbeanica, G. oceanica. G. omega, Helicopontosphaera kamptneri, H. sellii, Pontosphaera discopora, Rhabdosphaera clavigera, R. stylifera, Syracosphaera* sp., *Thoracosphaera saxea.*

Comment: The definition of the *Gephyrocapsa oceanica* Zone indicated here is the original definition of Boudreaux and Hay (1967). From the viewpoint of light microscopy, a fairly large population of *Emiliania huxleyi* is needed to distinguish the top of the zone because individual specimens are small and similar to the earlier *Gephyrocapsa protohuxleyi*. The possibility of using the last *Emiliania annula* to indicate the top of the zone (see Gartner, in press) would be a practical improvement for light-microscope zonation.

Selected references: Boudreaux and Hay, 1969; Gartner, 1969; Roth and Thierstein, 1972; Bukry, in press[b], Gartner, in press.

Emiliania huxleyi Zone

Boundary species: Bottom - *Emiliania huxleyi**.

Assemblage: Similar to underlying *Gephyrocapsa oceanica* Zone, except *Emiliania huxleyi* and *Gephyrocapsa ericsonii* are added and *Emiliania annula* is missing.

Selected references: Boudreaux and Hay, 1967, 1969; Gartner, 1969; Bukry, 1971b; Gartner, in press.

SUMMARY OF COCCOLITH STRATIGRAPHY

Site 146
(lat. 15°06.99′N., long. 69°22.67′W., depth 3949 m)

Site 146, in the central part of the Venezuelan Basin, was selected to investigate the early geologic hsitory of the Caribbean Sea. All but two of the forty-four cores taken at Site 146 were intended to sample the interval between the shallow seismic reflecting Horizon A″ (406 m) and the basement (762 m). Coring of the section above 406 meters was done at Site 149, located less than 2 kilometers away. Coccolith samples available from the continuously cored lower interval of Site 146 begin at Core 7 (440 m), which has an abundant uppermost Paleocene assemblage of the *Discoaster multiradiatus* Zone, *Campylosphaera eodela* Subzone. Strong dissolution has reduced the slightly older *Discoaster mohleri* Zone assemblage in Core 8 (449 m) to only resistant taxa such as *Coccolithus pelagicus* s. l., *Discoaster mohleri* and *Fasciculithus tympaniformis*. The deeper samples from Cores 11 through 14 (476 to 512 m) are characterized by abundant Maestrichtian assemblages of the *Lithraphidites quadratus* Zone. *Arkhangelskiella cymbiformis* is large and common through the interval, and *Kamptnerius magnificus* is common in the lower part, suggesting relatively shallow deposition. An abundance of *Micula* and broken rim fragments, however, indicates moderate dissolution. Good assemblages of the upper Campanian or lower Maestrichtian *Tetralithus trifidus* Zone occur through Cores 15 to 24 (512 to 602 m) and are characterized by *Apertapetra gronosa, Arkhangelskiella cymbiformis, Broinsonia parca*, and *Tetralithus trifidus*. Samples from Cores 25 through 39 (602 to 728 m) have little coccolith diversity and are poorly preserved; calcareous debris is abundant. Long-ranging Cretaceous taxa such as *Watznaueria barnesae* and *Cretarhabdus crenulatus* are generally present in small numbers.

Site 147
(lat. 10°42.48′N., long. 65°10.48′W., depth 892 m)

Site 147 was drilled in the Cariaco Basin, an elongate structural depression on the continental shelf of Venezuela, to sample a sequence of sediment formed during Pleistocene glacial and interglacial times. The available samples from Cores 2 through 18 (4 to 162 m) are all assigned to the *Gephyrocapsa oceanica* Zone of late Pleistocene age. *Gephyrocapsa oceanica* is present throughout, but is especially abundant and large in Cores 2 through 6 (4 to 51 m). Though abundant, the size decreases downward through Cores 7 through 10 (51 to 88 m). In Cores 11 through 17 (88 to 153 m), *G. oceanica* is uncommon, whereas the smaller more temperature-tolerant species *G. caribbeanica* is abundant. In the deepest sample, Core 18 (162 m), *G. oceanica* is abundant.

Notably absent from most of the section are the fully oceanic, tropical genera *Ceratolithus* and *Rhabdosphaera*. Other taxa generally missing st Site 147 are *Braarudosphaera, Coccolithus pelagicus, Discolithina, Pontosphaera, Scyphosphaera* and *Syracosphaera*. The most prominent species in these restricted assemblages are *Cyclococcolithina leptopora, Helicopontosphaera kamptneri, Gephyrocapsa caribbeanica, G. oceanica*, and *G. omega*. Specimens of *Ceratolithus, Rhabdosphaera* and *Scyphosphaera* have been recorded together in only a single sample from Core 12 (106 m), where *G. caribbeanica* dominates small *Gephyrocapsa* sp. cf. *G. oceanica*.

Site 148
(lat. 13°25.12′N., long. 63°43.25′W., depth 1232 m)

Cores 1 through 27 (sea floor to 249 m) from Site 148, located on the western crest of the Aves Ridge, have a continuous sequence of upper Pleistocene to lower Pliocene coccolith marl. Although the assemblages are fairly diverse, they are in places dispersed in abundant clay. In contrast with Site 147, the Pleistocene and Pliocene assemblages here represent a fully oceanic setting, reflected by the common occurrence of such taxa as *Ceratolithus, Discolithina*, and *Rhabdosphaera*, in addition to those taxa occurring at Site 147. A single sample from below the Pliocene section, Core 31 (267 m), contains rare specimens of *Braarudosphaera bigelowi, Coccolithus pelagicus, Cruciplacolithus tenuis, Micula decussata*, and *Watznaueria barnesae*—a mixture of Upper Cretaceous and Paleocene that could be of early Paleocene age if later reworking has not occurred.

Site 149
(lat. 14°06.25′N., long. 69°21.85′W., depth 3972)

Site 149 is located in the central part of the Venezuelan Basin, less than 2 km away from Site 146. Whereas Site 146 was continuously cored from 406 to 762 meters, Site 149 investigated the upper section by continuously coring from the sea floor to 406 meters. Samples available for thirty-seven of the forty-three cores recovered range from the late Pleistocene *Gephyrocapsa oceanica* Zone to the middle Eocene *Nannotetrina quadrata* Zone. The coccolith stratigraphy of the section is commonly nonsequential; this supports the observations of the shipboard sedimentologists that flow-in and drilling disturbance of the sediment was common (Nahum Schneidermann, verbal commun., 1971). Stratigraphy may be reversed from one core sample to the next, as flow-in or slumping has extended ranges of species both upward and downward. Even though the interzonal stratigraphic detail has commonly been obliterated by mixing during coring, the mixing is localized and the specimens are well preserved, so that a general sequence of coccolith stratigraphic units is recognizable in the samples that follow:

Pleistocene
(*Gephyrocapsa oceanica* Zone)

Sample 149-2-6(78-79cm); depth 9 meters:
Ceratolithus cristatus, Gephyrocapsa caribbeanica, Gephyrocapsa sp. cf. *G. oceanica, Helicopontosphaera kamptneri, H. sellii, Rhabdosphaera clavigera, R. stylifera, Scapholithus* sp., *Syracosphaera histrica.*

This sample is practically a *Gephyrocapsa* ooze in which no specimens of *Cyclococcolithina* or *Scyphosphaera* were noted.

Pleistocene
(*Gephyrocapsa doronicoides* Zone,
***Emiliania annula* Subzone)**

Sample 149-3-6(80-81cm); depth 18 meters:
Ceratolithus cristatus, Cyclococcolithina leptopora, Discolithina japonica, Emiliania annula, Gephyrocapsa doronicoides, Helicopontosphaera kamptneri, H. sellii, Rhabdosphaera procera, Scyphosphaera pulcherrima, Syracosphaera histrica, Thoracosphaera saxea, Umbilicosphaera sibogae.

Sample 149-5-5(73-74cm); depth 35 meters:
Ceratolithus cristatus, C. rugosus, Cyclococcolithina macintyrei, Discolithina japonica, Emiliania annula, Gephyrocapsa doronicoides, Helicopontosphaera kamptneri, Rhabdosphaera clavigera, R. procera, Scapholithus sp., *Scyphosphaera apsteinii, S. pulcherrima, S.* spp., *Syracosphaera histrica, Thoracosphaera saxea.*

The abundance of *Ceratolithus, Emiliania, Rhabdosphaera* and *Thoracosphaera*, the dominance of *H. kamptneri* over *H. sellii*, and the lack of *Coccolithus pelagicus* all indicate a distinctly warm-water aspect for the early Pleistocene assemblages of Cores 4 and 5 (19 to 37 m).

Sample 149-6-6(77-78 cm); depth 45 meters:

The assemblage of this sample is similar to that generally characteristic of the lower Pleistocene but contains abundant *Discoaster brouweri* and *D. triradiatus* and a few specimens of *Coccolithus pelagicus* indicating the upper Pliocene *Discoaster brouweri* Zone, *Cyclococcolithina macintyrei* Subzone. A lower Pleistocene assemblage, lacking any discoasters, was obtained from Core 7 (50 m). Shipboard sedimentologists noted that Core 7 was unreliable owing to severe drilling disturbance and flow-in.

Upper Pliocene
(*Discoaster brouweri* Zone, *Discoaster pentaradiatus* Subzone)

Sample 149-8-6(77-78cm); depth 64 meters:
Ceratolithus cristatus, C. rugosus, Coccolithus pelagicus, Cyclococcolithina macintyrei, Discoaster asymmetricus, D. brouweri, D. pentaradiatus, Discolithina japonica, Gephyrocapsa doronicoides, Helicopontosphaera kamptneri, H. sellii, Rhabdosphaera procera, Scyphosphaera pulcherrima, Thoracosphaera saxea.

Upper Miocene
(*Discoaster quinqueramus* Zone)

Sample 149-11-6(73-74cm); depth 92 meters:
Ceratolithus primus, Coccolithus pelagicus, Discoaster brouweri s. l., *Discoaster* sp. aff. *D. calcaris, D. pentaradiatus, D. quinqueramus, D. surculus, D. variabilis, Triquetrorhabdulus rugosus.*

This sample is a solution residuum dominated by the orthlithid genus *Discoaster*. Only rare upper-rim cycles of *C. pelagicus* are preserved from the heliolithids. Discoasters are well preserved; only few specimens show etching or central-area dissolution. The disparity in preservation between ortholithid and heliolithid coccoliths (Bukry and others, 1971) is not particularly critical in upper Miocene assemblages, because present stratigraphic assignment is based chiefly on evolutionary sequences within the ortholithid genera alone.

Upper Miocene
(Upper *Discoaster neohamatus* Zone)

Sample 149-12-6(106-107cm); depth 102 meters:
Coccolithus pelagicus, Cyclococcolithina macintyrei, Discoaster bellus, Discoaster sp. cf. *D. berggrenii, D. brouweri* s. l., *D. neohamatus, D. pansus, D. pentaradiatus, D. perclarus, D. variabilis, Helicopontosphaera kamptneri, Sphenolithus abies, Triquetrorhabdulus rugosus.*

Upper Miocene
(Lower *Discoaster neohamatus* Zone)

Sample 149-13-5(76-77cm); depth 109 meters:
Coccolithus pelagicus, Cyclococcolithina macintyrei, Discoaster bellus, D. bollii, D. braarudii, D. brouweri s. l., *D. hamatus, D. neohamatus, D. prepentaradiatus, D. variabilis, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica, Triquetrorhabdulus rugosus.*

As in Cores 11 and 12 above, the coccolith assemblages of this core contain abundant discoasters. A single specimen of *Discoaster hamatus* was noted; in the absence of any *Catinaster* specimens, the sample is assigned to the basal *Discoaster neohamatus* Zone.

Upper Miocene
(*Catinaster coalitus* Zone)

Sample 149-15-2(76-77cm); depth 123 meters:
Catinaster coalitus, Discoaster braarudii, D. variabilis.

The coccolith assemblage in this sample is a residuum of intense dissolution. Centerless six-rayed discoasters having little remaining specific character are predominant.

Sample 149-15-3(77-78cm); depth 125 meters:
Catinaster coalitus, Coccolithus miopelagicus, Discoaster sp. aff. *D. exilis, D. variabilis, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica, Sphenolithus abies, Triquetrorhabdulus* sp.

Middle Miocene
(*Discoaster exilis* Zone)

Sample 149-15-5(65-66cm); depth 128 meters:
Coccolithus miopelagicus, Coronocyclus nitescens, Cyclococcolithina leptopora, Discoaster sp. cf. *D. bollii, D. braarudii, D. exilis, D. moorei, D. variabilis, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica, Sphenolithus abies.*

Specimens in this sample are large; *Discoaster* and *Reticulofenestra* are the most abundant. The absence of *Discoaster kugleri* precludes division of the *Discoaster exilis* Zone into subzones.

Upper Miocene
(*Catinaster coalitus* Zone)

Sample 149-16-2(83-84cm); depth 132 meters:
Catinaster coalitus, Coccolithus miopelagicus, C. pelagicus, Coronocyclus nitescens, Cyclococcolithina macintyrei, Discoaster sp. cf. *D. bollii, D. variabilis, Helicopontosphaera granulata, Reticulofenestra pseudoumbilica.*

Mixed Upper and Middle Miocene

Sample 149-16-3(73-74cm); depth 134 meters:
Catinaster coalitus, Catinaster sp. cf. *C. mexicanus, Coccolithus miopelagicus, C. pelagicus, Cyclicargolithus floridanus, Cyclococcolithina macintyrei, Discoaster bollii* s. s., *D. moorei, D. variabilis, Reticulofenestra pseudoumbilica, Sphenolithus heteromorphus.*

The occurrence of abundant *Cyclicargolithus floridanus*, and *Sphenolithus heteromorphus* with *Catinaster coalitus* and *Discoaster bollii* in this section must be a drilling artifact, as examination of land cores and outcrops (Bramlette and Wilcoxon, 1967) and cores from the 154 Deep Sea Drilling Project sites drilled to date has consistently shown the extinction of *C. floridanus* and *S. heteromorphus* prior to the appearance of *C. coalitus* and *D. bollii.*

Samples from Sections 2 and 3 show a wide variety of forms of *Catinaster coalitus* and *Discoaster bollii* that suggests possible derivation of *C. coalitus*, as well as *C. mexicanus*, from *D. bollii* by reduction of the rays.

Middle Miocene
(*Sphenolithus heteromorphus* Zone)

Sample 149-16-4(76-77cm); depth 135 meters:
Coccolithus miopelagicus, Coronocyclus nitescens, Cyclicargolithus floridanus, Cyclococcolithina macintyrei, Discoaster signus, D. variabilis, Discolithina sp., *Helicopontosphaera* sp. cf. *H. granulata, H. kamptneri, Scyphosphaera recurvata, Scyphosphaera* spp., *Sphenolithus heteromorphus.*

The only significant occurrences of *Scyphosphaera* and *Discolithina* in the Miocene section of Site 149 are found together in this core. This occurrence in the fossil record supports the recent discovery by Gaarder (1970) that skeletal parts attributed to these genera may be produced simultaneously by the same organism.

Sample 149-17-3(77-78cm); depth 143 meters:
Coccolithus miopelagicus, Cyclicargolithus floridanus, Discoaster braarudii, D. deflandrei, D. exilis, D. moorei, D. signus, D. variabilis, Helicopontosphaera granulata, Sphenolithus heteromorphus.

The abundance of *Sphenolithus heteromorphus* and long slender-rayed discoasters in this sample and the one above indicate the lower middle Miocene.

Middle Miocene
(Lower? *Sphenolithus heteromorphus* Zone)

Sample 149-18-3(74-75cm); depth 153 meters:
Coccolithus miopelagicus, C. pelagicus, Coronocyclus nitescens, Cyclicargolithus floridanus, Cyclococcolithina macintyrei, Discoaster aulakos, D. braarudii, D. deflandrei, Discoaster sp. cf. *D. dilatus, D. exilis, D. moorei, D. perplexus, D. signus, D. variabilis, ?Helicopontosphaera ampliaperta, H. granulata, Sphenolithus heteromorphus, Triquetrorhabdulus milowii.*

Sample 149-19-2(98-99cm); depth 160 meters:
Coccolithus miopelagicus, Coronocyclus nitescens, Cyclicargolithus floridanus, Cyclococcolithina macintyrei, Discoaster aulakos, D. calculosus, D. deflandrei, D. exilis, D. lidzii, D. moorei, ?Helicopontosphaera ampliaperta, H. granulata, H. kamptneri, Sphenolithus heteromorphus, Triquetrorhabdulus milowii.

Although the natural range of *Helicopontosphaera ampliaperta* in a particular area might include the lower *Sphenolithus heteromorphus* Zone (Bukry 1971b), the occurrence here of *Triquetrorhabdulus milowii. Discoaster calculosus*, and *D. lidzii* suggests some reworking or mixing from lower Miocene strata, at least as old as the *Sphenolithus belemnos* Zone. Any specimen of *H. granulata* with secondarily subdued rim flare and dissolved central area would closely resemble *H. ampliaperta*, the general distinctions between these taxa being the smaller rim flare, more oval shape, and the open-centered construction of *H. ampliaperta*. Dominant species in the assemblages are *C. floridanus, D. deflandrei, D. exilis*, and *S. heteromorphus.*

Lower Miocene
(*Helicopontosphaera ampliaperta* Zone)

Sample 149-20-2(77-78cm); depth 169 meters:
Coccolithus pelagicus, Coronocyclus nitescens, Cyclicargolithus floridanus, Discoaster deflandrei, Helicopontosphaera ampliaperta s. s., *H. granulata* s. s., *Helicopontosphaera* sp. cf. *H. kamptneri, Sphenolithus heteromorphus.*

Sample 149-20-5(71-72cm); depth 174 meters:
Coccolithus miopelagicus, Coronocyclus sp. cf. *C. nitescens* [large], *Cyclicargolithus floridanus, Discoaster calculosus, D. deflandrei, Helicopontosphaera ampliaperta* [small], *H. granulata, Reticulofenestra gartneri, Sphenolithus* sp. cf. *S. belemnos, S. heteromorphus, S. moriformis, Triquetrorhabdulus milowii.*

Short, moderately thick rayed *Discoaster deflandrei* and typical *Cyclicargolithus floridanus* dominate these assemblages.

Lower Miocene
(*Triquetrorhabdulus carinatus* Zone, *Discoaster druggii* Subzone)

Sample 149-21-5(68-69cm); depth 183 meters:
Coccolithus miopelagicus, C. pelagicus, Coronocyclus nitescens, Cyclicargolithus floridanus, Discoaster deflandrei, D. druggii, D. moorei, Helicopontosphaera intermedia, Orthorhabdus serratus, Sphenolithus belemnos, S. moriformis, Triquetrorhabdulus carinatus.

Sample 149-22-6(122-123cm); depth 194 meters:
Coccolithus miopelagicus, Coronocyclus nitescens, Cyclicargolithus floridanus, Discoaster deflandrei, D. druggii, Reticulofenestra gartneri, Sphenolithus moriformis, Triquetrorhabdulus carinatus.

Sample 149-23-4(59-60cm); depth 200 meters:
Bramletteius serraculoides, Coccolithus pelagicus, Cyclicargolithus abisectus, C. floridanus, Discoaster deflandrei, D. druggii, Helicopontosphaera euphratis, H. recta s. s., *Reticulofenestra gartneri, Sphenolithus dissimilis, S. moriformis, Triquetrorhabdulus carinatus.*

The common occurrence of *Sphenolithus belemnos* and the rare occurrence of *Discoaster druggii* and *Orthorhabdus* sp. in the first of these three samples (Core 21) indicates that the sample could be assigned to the *Sphenolithus belemnos* Zone, in view of the mixing in this section. In the next sample from Core 22, both *D. druggii* and *Triquetrorhabdulus carinatus* are common. The occurrence of common *Helicopontosphaera recta* and *Cyclicargolithus abisectus* in the third sample from Core 23 is unusual, as a few specimens of *D. druggii* and a late variety of *Sphenolithus dissimilis* (with elongate basal spines similar to *S. belemnos*) are also present. *H. recta* and *C. abisectus* are characteristic of the older *Sphenolithus ciperoensis* Zone, but no specimens of *Sphenolithus ciperoensis* are present. The probable mixing or reworking is further complicated by the rare occurrence of *Bramletteius serraculoides* a species typical of upper Eocene to lower Oligocene strata.

Lower Miocene
(*Triquetrorhabdulus carinatus* Zone, *Discoaster deflandrei* Subzone)

Sample 149-24-1(90-91cm); depth 205 meters:
Coccolithus miopelagicus, C. pelagicus, Cyclicargolithus floridanus, Discoaster deflandrei, Sphenolithus moriformis, Triquetrorhabdulus carinatus.

Sample 149-26-1(90-91cm); depth 224 meters:
Coccolithus miopelagicus, C. pelagicus, Cyclicargolithus floridanus, Discoaster deflandrei, ?Helicopontosphaera intermedia, Reticulofenestra gartneri, Sphenolithus dissimilis, S. moriformis, Triquetrorhabdulus carinatus.

Samples from this interval have common radiolarians and poorly preserved coccoliths. *Triquetrorhabdulus carinatus* is long and abundant. The *Discoaster deflandrei* Subzone extends through the interval above the acme of *Cyclicargolithus abisectus* and below the appearance of *Discoaster druggii* and *Orthorhabdus serratus.* This interval was recorded as a transition between the *Cyclicargolithus abisectus* Subzone and *Discoaster druggii* Subzone in the coccolith report for DSDP Leg 6.

Lower Miocene
(*Triquetrorhabdulus carinatus* Zone, *Cyclicargolithus abisectus* Subzone)

Sample 149-27-2(66-67cm); depth 234 meters:
Coccolithus eopelagicus, C. pelagicus, Cyclicargolithus abisectus [common], *C. floridanus, Discoaster deflandrei, Discoaster* sp. cf. *D. lidzii, Reticulofenestra gartneri, Sphenolithus dissimilis* [early, short variety], *S. moriformis, Triquetrorhabdulus carinatus.*

Upper Oligocene
(*Sphenolithus ciperoensis Zone*)

Sample 149-27-3(73-74cm); depth 236 meters:
Coccolithus eopelagicus, C. pelagicus, Cyclicargolithus abisectus, C. floridanus, Dictyococcites bisectus, Discoaster deflandrei, Reticulofenestra gartneri, Sphenolithus ciperoensis, S. moriformis, Triquetrorhabdulus carinatus s.l.

Radiolarians are common in this sample, and the coccolith assemblage has undergone moderate dissolution.

Middle Oligocene
(*Sphenolithus distentus* Zone)

Sample 149-28-2(78-79cm); depth 243 meters:
Coccolithus eopelagicus, C. sp. aff. *C. fenestratus, C. pelagicus, Cyclicargolithus abisectus, Discoaster deflandrei, Reticulofenestra gartneri, Sphenolithus distentus* s. s., *S. moriformis.*

Sample 149-28-4(69-70cm); depth 246 meters:
Cyclicargolithus floridanus, Discoaster deflandrei, D. nodifer, Reticulofenestra gartneri, Sphenolithus distentus, S. moriformis, S. predistentus, S. pseudoradians.

Middle Oligocene
(*Sphenolithus predistentus* Zone)

Sample 149-29-3(72-73cm); depth 254 meters:
Coccolithus eopelagicus, Cyclicargolithus floridanus, Dictyococcites bisectus, Discoaster deflandrei, D. nodifer, D. tani, Sphenolithus moriformis, S. predistentus, Zygrhablithus bijugatus.

Middle Eocene
(*Reticulofenestra umbilica* Zone)

Sample 149-32-4(79-80cm); depth 284 meters:
Chiasmolithus grandis, Coccolithus eopelagicus, Cyclococcolithina formosa, Dictyococcites bisectus [rare], *D. scrippsae, Discoaster barbadiensis, D. nodifer, D. saipanensis, Discoaster* sp. cf. *D. tani, Reticulofenestra umbilica.*

Sample 149-34-3(77-78cm); depth 302 meters:
Campylosphaera dela, Chiasmolithus grandis, Coccolithus eopelagicus, Cyclococcolithina formosa, Discoaster barbadiensis [abundant], *D. nodifer, Reticulofenestra samodurovi, R. umbilica, Sphenolithus pseudoradians.*

This interval is dominated by solution-resistant taxa, indicating deposition in an area that was calcite undersaturated.

Middle Eocene
(*Nannotetrina quadrata* Zone)

Sample 149-37-4(77-78cm); depth 330 meters:
Chiasmolithus gigas, C. grandis, C. titus, Coccolithus eopelagicus, Coccolithus sp. cf. *C. staurion, Discoaster barbadiensis, D. nodifer, Helicopontosphaera* sp. cf. *H. compacta* [rims], *Pemma rotundum* [fragment], *Reticulofenestra samodurovi, Sphenolithus furcatolithoides, S. radians, Triquetrorhabdulus inversus.*

Sample 149-38-3(75-76cm); depth 337 meters:
Chiasmolithus grandis, C. solitus, Coccolithus staurion, Cyclococcolithinia sp. cf. *C. formosa* [small], *Discoaster barbadiensis, D. deflandrei, D. strictus, Nannotetrina quadrata, Triquetrorhabdulus inversus.*

Sample 149-40-1(53-54cm); depth 354 meters:
Chiasmolithus gigas, C. grandis, Coccolithus staurion, discoaster barbadiensis, D. mirus [rare], *D. strictus, Helicopontosphaera* sp. [rim], *Nannotetrina spinosa, Reticulofenestra samodurovi, Triquetrorhadbulus inversus.*

Sample 149-41-6(79-80cm); depth 370 meters:
Chiasmolithus grandis, C. solitus, Cyclococcolithina sp. cf. *C. formosa, Cyclolithella? bramlettei, Discoaster barbadiensis, D. nodifer, D. nonaradiatus, D. wemmelensis, Nannotetrina cristata, N. mexicana, Reticulofenestra samodurovi, Sphenolithus radians* [abundant], *Triquetrorhabdulus inversus.*

Sample 149-42-4(77-78cm); depth 376 meters:
Chiasmolithus grandis, Coccolithus staurion, Cyclococcolithina sp. cf. *C. formosa, Cyclolithella? bramlettei, Discoaster barbadiensis, D. deflandrei, D. gemmeus, D. nodifer, D. wemmelensis, Nannotetrina mexicana, Nannotetrina* sp. cf. *N. quadrata, Reticulofenestra dictyoda, R. samodurovi, Sphenolithus radians, Triquetrorhabdulus inversus.*

The samples from this middle Eocene interval contain abundant radiolarians and elongate diatoms, indicating a silica-rich watermass. Coccolith assemblages are typical of an oceanic deposit that has been subjected to calcite remobilization, probably about the time of deposition. This effect is indicated by secondary overgrowths of calcite on discoasters and by etching of the placoliths (Bukry and others, 1971). The open-ocean character of the assemblages is emphasized by the absence or rarity of *Braarudosphaera, Discolithina, Helicopontosphaera, Lophodolithus, Micrantholithus, Rhabdosphaera,* and *Syracosphaera*, which are typical in shallow-marine Eocene deposits (see coccolith reports for DSDP Legs 2, 10, and 11).

Site 150
(lat. 14°30.69′N., long. 69°21.35′W., depth 4545 m)

Site 150 is located in the central part of the Venezuelan Basin. Twelve cores were cut between 49 and 180 meters below the sea floor to sample sediment at and near seismic Horizons A″ and B″, which are relatively shallow here. The section ranges from the late Pliocene *Discoaster brouweri* Zone, *Discoaster pentaradiatus* Subzone, in Core 1 (49 to 58 m) to the Late Cretaceous (Santonian) in Cores 9 to 10 (150 to 168 m). Diabase was recovered in deeper cores. The only significant coccolith-rich samples available, in addition to those from Cores 1, 9, and 10, are from Core 5 (105 to 114 m), which is assigned to the *Triquetrorhabdulus carinatus* Zone, *Discoaster druggii* Subzone.

Site 151
(lat. 15°01.02′N., long. 73°24-58′W., depth 2029 m)

Site 151 is located on the Beata Ridge in the middle of the Caribbean Sea. Cores 1 to 4 were discontinuous at 61, 117, 181, and 237 meters. Continuous coring was begun with Core 5 at 302 meters and terminated in diabase with Core 15 at 381 meters. The coccolith samples available indicate that the section ranges in age from late Pleistocene to Late Cretaceous.

A sample from Core 1, Section 6 (69 m), contains the basal Pleistocene *Gephyrocapsa doronicoides* Zone, *Emiliania annula* Subzone, characterized by the presence of *Emiliania annula, Ceratolithus cristatus,* rare *Ceratolithus rugosus, Cyclococcolithina macintyrei*, and *Gephyrocapsa doronicoides*, and by the absence of both *Discoaster* and barred *Gephyrocapsa* species. In Core 2, Section 3 (121 m), the basal Pliocene is represented by the *Ceratolithus tricorniculatus* Zone, *Ceratolithus acutus* Subzone, with *Ceratolithus acutus* s. s., *C. tricorniculatus, Discoaster brouweri, D. pentaradiatus, D. surculus, Reticulofenestra pseudoumbilica, Scyphosphaera globulata*, and *Sphenolithus abies*. Discoasters of Core 3 at 188 meters in the middle Miocene *Discoaster exilis* Zone include *D. aulakos, D. exilis, D. moorei, D. perplexus, D. signus*, and *D. variabilis*; whereas in Core 4 at 238 meters (*Sphenolithus belemnos* Zone), *D. deflandrei* is predominant and *D. druggii* rare.

The upper Oligocene upper *Sphenolithus ciperoensis* Zone assemblage from Cores 6 and 7 (311 to 329 m) contains *Cyclicargolithus abisectus, Discolithina segmenta, Helicopontosphaera* sp. cf. *H. recta*, and *Sphenolithus ciperoensis*. Sample 15-151-8-1(100-101cm) (330 m) is from a zone of reworking or is mislabelled. Its poorly preserved assemblage, which includes *Chiasmolithus bidens, C. consuetus, Cruciplacolithus tenuis, Cyclolithella*? *robusta*, and *Zygolithus chiastus*, is Paleocene. Fine calcareous debris is common in this and deeper samples. Whereas a sample from Core 9, Section 2 (341 m), has a typical middle Oligocene assemblage, Core 10, Section 2 (350 m), contains only a few rare coccoliths of probable early or middle Paleocene age (*Coccolithus pelagicus* s. l., *Cruciplacolithus tenuis*, and *Cyclolithella*? *robusta*). The bottom section of Core 11 (363 m) contains a chaotic mixture of Paleocene, Eocene, and Oligocene taxa. Late Cretaceous (Campanian?) coccoliths occur in the deepest sample from Core 12, in Section 3 (371 m); the presence of a few *Coccolithus pelagicus* indicates some Tertiary admixing.

Site 152
(lat. 15°52.72′N., long. 74°36.47′W., depth 3899 m)

Site 152 is located on the Nicaragua Rise in the north-central Caribbean Sea. Continuous coring was carried out between 153 and 295 meters below the sea floor in an attempt to obtain core from the Cretaceous-Tertiary boundary. The twenty-four cores range in age from the earliest Eocene *Discoaster diastypus* Zone to the Late Cretaceous (late Campanian) *Tetralithus trifidus* Zone. A coccolith-radiolarian ooze in Core 1 is assigned to the lower Eocene. The common occurrence of some species generally considered upper Paleocene may be due to a natural transition or to slight mixing of the coccoliths owing to their potential mobility within the large interstices of radiolarian skeletons. Species present include *Campylosphaera eodela, Chiasmolithus bidens, C. consuetus, Coccolithus pelagicus, Discoaster diastypus, D. multiradiatus, D. nobilis, Lophodolithus nascens*, and small *Sphenolithus* sp. Assemblages of the upper Paleocene *Discoaster multiradiatus* Zone, *Campylosphaera eodela* Subzone, occur in Cores 2 and 3 (162 to 182 m). The assemblage in Core 2 is larger and more diverse, containing such species as *Campylosphaera eodela, Chiasmolithus bidens, C. californicus, C. consuetus, Coccolithus pelagicus, Discoaster lenticularis, D. mohleri, D. multiradiatus, D. nobilis, Ellipsolithus macellus, Heliolithus* sp. aff. *H. kleinpellii, Toweius eminens*, and *Zygolithus chiastus*. Deeper Paleocene cores contain sparse assemblages. Rare *Arkhangelskiella cymbiformis, Prediscosphaera cretacea, Watznaueria barnesae*, and *Coccolithus pelagicus* are present in Core 10 (239 to 248 m), which could represent a Cretaceous-Tertiary transition or reworking. *Tetralithus trifidus*, as well as upper Campanian and lower Maestrichtian species, is also present. No samples were available from Cores 11 to 13 (248 to 276 m), an interval of poor recovery. In Core 14 (276 to 286 m), a lower Maestrichtian coccolith assemblage with large (*Arkhangelskiella cymbiformis* and common *Kamptnerius magnificus* is assigned to the *Lithraphidites quadratus* Zone. The interval of Cores 16 through 21 (342 to 462 m) contains the upper Campanian or lower Maestrichtian *Tetralithus trifidus* Zone. Assemblages are all similar, having *Arkhangelskiella cymbiformis, Broinsonia parca, Cretarhabdus decorus, Cribrosphaera ehrenbergii, Lucianorhabdus cayeuxi, Microrhabdulus decoratus, Tetralithus pyramidus, T. trifidus, Zygodiscus lacunatus, Z. meudini,* and *Z. spiralis*. The deepest sample available, from Core 22 (465 m), has only a few species, including *Tetralithus aculeus*, a Campanian to Maestrichtian guide species.

Site 153
(lat. 13°58.33′N, long. 72°26.08′W., depth 3932 m)

Site 153 is located at the southern end of the Beata Ridge in the Caribbean Sea north of the Goajira Peninsula of Columbia. Twenty spot cores were cut between 102 and 776 meters. Samples available from the section range from the upper Pliocene *Discoaster brouweri* Zone, *Discoaster pentaradiatus* Subzone, in Core 1 (102 to 111 m) to the Upper Cretaceous (Santonian) in Core 18 (749 to 759 m).

Upper Miocene assemblages from Cores 2 and 3 (198 to 216 m) are sparse but can be assigned to the *Discoaster quinqueramus* Zone because of the occurrence of *Discoaster quinqueramus* and *D. surculus* throughout the cores, with *D. berggrenii* in the lower sample from Core 3 (211 m). Middle Miocene to middle Oligocene assemblages are identified from Cores 4 to 7 (300 to 508 m). The *Sphenolithus heteromorphus* Zone of Core 4 contains *Coccolithus miopelagicus, Cyclicargolithus floridanus, Cyclococcolithina leptopora, Discoaster aulakos, D. deflandrei, D. exilis, D. moorei, D. signus, D. variabilis, Helicopontosphaera kamptneri*, and *Sphenolithus heteromorphus*. The *Helicopontosphaera ampliaperta* Zone of Core 5 (403 to 412 m) is dominated by *Cyclicargolithus floridanus, Discoaster deflandrei*, and *Sphenolithus heteromorphus*, but also contains a few *Discoaster exilis, Helicopontosphaera ampliaperta*, and *Helicopontosphaera* sp. aff. *H. granulata*. In Core 6 (412 to 421 m), the *Triquetrorhabdulus carinatus* Zone, *Discoaster druggii* Subzone, has a few *Discoaster druggii* and short *Triquetrorhabdulus milowii*. In Core 7 (499 to 508 m), the *Sphenolithus predistentus* Zone contains *Coccolithus eopelagicus, Cyclicargolithus floridanus, Dictyococcites scrippsae, Discoaster deflandrei, Helicopontosphaera compacta, Reticulofenestra gartneri, Sphenolithus moriformis*, and *S. predistentus*. Specimens in this assemblage have ragged and broken rims indicating moderate dissolution.

Poorly preserved Paleocene assemblages of low diversity occur in samples from Cores 8 to 11 (563 to 609 m). The occurrence of *Discoaster mohleri* and *Heliolithus kleinpellii* together with *Chiasmolithus californicus* and *Fasciculithus tympaniformis* in Core 10 (591 to 600 m) indicates the lower *Discoaster mohleri* Zone of late Paleocene age. Most coccoliths from this core are broken and strongly etched by solution. Other Paleocene assemblages examined are less distinctive.

Upper Cretaceous samples from Cores 12 to 18 (609 to 758 m) are generally poorly preserved and have little diversity. A questionable identification of several species of *Tetralithus* in Cores 12 to 13 (609 to 656 m) together with *Arkhangelskiella cymbiformis* and *Kamptnerius magnificus* suggests upper Campanian or lower Maestrichtian. Only long-ranging *Watznaueria barnesae* and *Micula decussata* are identified from Cores 14 to 16 (656 to 740 m). The deepest samples available, from Core 18 (749 to 758 m), contain a more abundant assemblage that, although dominated by *Watznaueria barnesae* shows more diversity by the presence of such taxa as *Apertapetra gronosa, Chiastozygus amphipons, Eiffellithus augustus, E. turriseiffeli, Kamptnerius magnificus, Microrhabdulus decoratus, Prediscosphaera cretacea, Zygodiscus deflandrei*, and *Z. lacunatus*. These are all long-ranging taxa that can occur together in strata throughout most of the Upper Cretaceous, but the occurrence of several specimens of *Marthasterites furcatus furcatus* and *Marthasterites furcatus crassus* in Section 2 of Core 18 (751 m) probably indicates the Santonian (Deflandre, 1959).

Site 154
(lat. 11°05.11′N., long. 80°22.75′W., depth 3338 m)

Site 154 is located at a topographic high on the Colombian Basin abyssal plain in the western Caribbean Sea about 210 kilometers north of San Cristobal, Panama. Fourteen cores were taken from Hole 154 to a depth of 278 meters and eighteen from Hole 154A, which terminated at 172 meters. Samples available range from Pleistocene to upper Miocene. A distinct lithologic change at 170 meters from a pelagic ooze above to a volcanic-rich sediment below is responsible for poorly preserved sparse lower Pliocene and upper Miocene assemblages at this site.

The Pliocene-Pleistocene boundary in Core 8A (68 to 78 m) is partially obscured by mixing. Abundant *Emiliania annula, Gephyrocapsa doronicoides, Helicopontosphaera kamptneri*, and *Rhabdosphaera clavigera*, few *Coccolithus pelagicus, Cyclococcolithina leptopora*, and *C. macintyrei*, and rare *Gephyrocapsa caribbeanica* characterize the upper two sections. Rare *Discoaster brouweri* and *D. triradiatus* occur with this same assemblage in the third section. This overlap of *Discoaster* with barred *Gephyrocapsa* species is stratigraphically unusual and likely results from mixing. Section 4 has common *D. brouweri* and *D. triradiatus* with no *G. caribbeanica*. Of these guide species, only rare *D. brouweri* occurs in Sections 5 and 6. Core 9A (78 to 87 m) has common *Coccolithus pelagicus, Cyclococcolithina macintyrei, Discoaster brouweri*, and *Emiliania annula* and is more readily assigned to the upper Pliocene *Discoaster brouweri* Zone, *Cyclococcolithina macintyrei* Subzone. A predominance of *Helicopontosphaera kamptneri* over *H. sellii* and a consistent presence of *Ceratolithus, Discolithina, Scapholithus, Scyphosphaera*, and *Syracosaphera* indicate open-ocean deposition where the bottom water was not significantly undersaturated with respect to calcite. In Cores 11A (97 to 106 m) and 13A (116 to 125 m) respectively, the upper limits of the *Discoaster pentaradiatus* Subzone and *Discoaster tamalis* Subzone of the *Discoaster brouweri* Zone are identified. The upper part of the lower Pliocene, the *Reticulofenestra pseudoumbilica* Zone, occurs in Core 15A (134 to 144 m), but below this level the coccoliths deteriorate in terms of preservation, abundance, and diversity, and zonal assignments therefore are only approximate. The assemblage for Core 13 (258 to 268 m) contains only rare resistant species, such as *Discoaster brouweri* and *D. surculus*; this indicates that the sediment is no older than late Miocene.

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APPENDIX
TAXONOMIC RECOMBINATIONS OF COCCOLITH SPECIES

Cyclicargolithus abisectus (Müller)
Basionym:
Coccolithus? *abisectus* Müller, 1970, N. Jb. Geol. Paläont. Abh. 135, p. 92, pl. 9, figs. 9-10; pl. 12, fig. 1.

Nannotetrina mexicana (Stradner)
Basionym:
Trochoaster mexicanus Stradner, 1959, Erdoel-Z. 75, p. 480, fig. 55.

Nannotetrina quadrata (Bramlette and Sullivan)
Basionym:
Chiphragmalithus(?) *quadratus* Bramlette and Sullivan, 1961, Micropaleontology. 7 (2), p. 157, pl. 10, figs. 14ab, 15.

Nannotetrina spinosa (Stradner)
Basionym:
Nannotetraster spinosus Strander, in Martini and Stradner 1960, Erdoel-Z. 76, p. 269. figs. 11, 17.