15. COCCOLITH STRATIGRAPHY – LEG 14, DEEP SEA DRILLING PROJECT[1]

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Leg 14 of the Deep Sea Drilling Project, October-December 1970, through the Atlantic Ocean from Lisbon to San Juan, recovered 98 cores at ten drilling sites near the continental-shelf margins of Africa and South America (Figure 1). Light-microscope techniques were used to study the coccoliths of 188 samples from these cores. Zonal assignment of cores is summarized in Table 1. The coccolith assemblages at each site are related to those from previously cored Deep Sea Drilling Project sites.

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

SITE 135
(lat 35° 20.80′N., long 10° 25.46′W., depth 4152 meters)

Site 135 is on a topographic high about 750 meters above the surrounding abyssal plain. Nine spot cores were cut between the sea floor and a subbottom depth of 687 meters to investigate the nature of sonic-reflector horizons. Coccolith ooze of late Pleistocene to middle Miocene age is present in the upper four cores, 0 to 268 meters. A lower Pliocene assemblage in Core 2 (80 to 89 meters) is characterized throughout by the overlapping ranges of *Ceratolithus rugosus* and *C. tricorniculatus*, by small specimens of *Discoaster* spp., and by sparse *Discolithina* spp.,

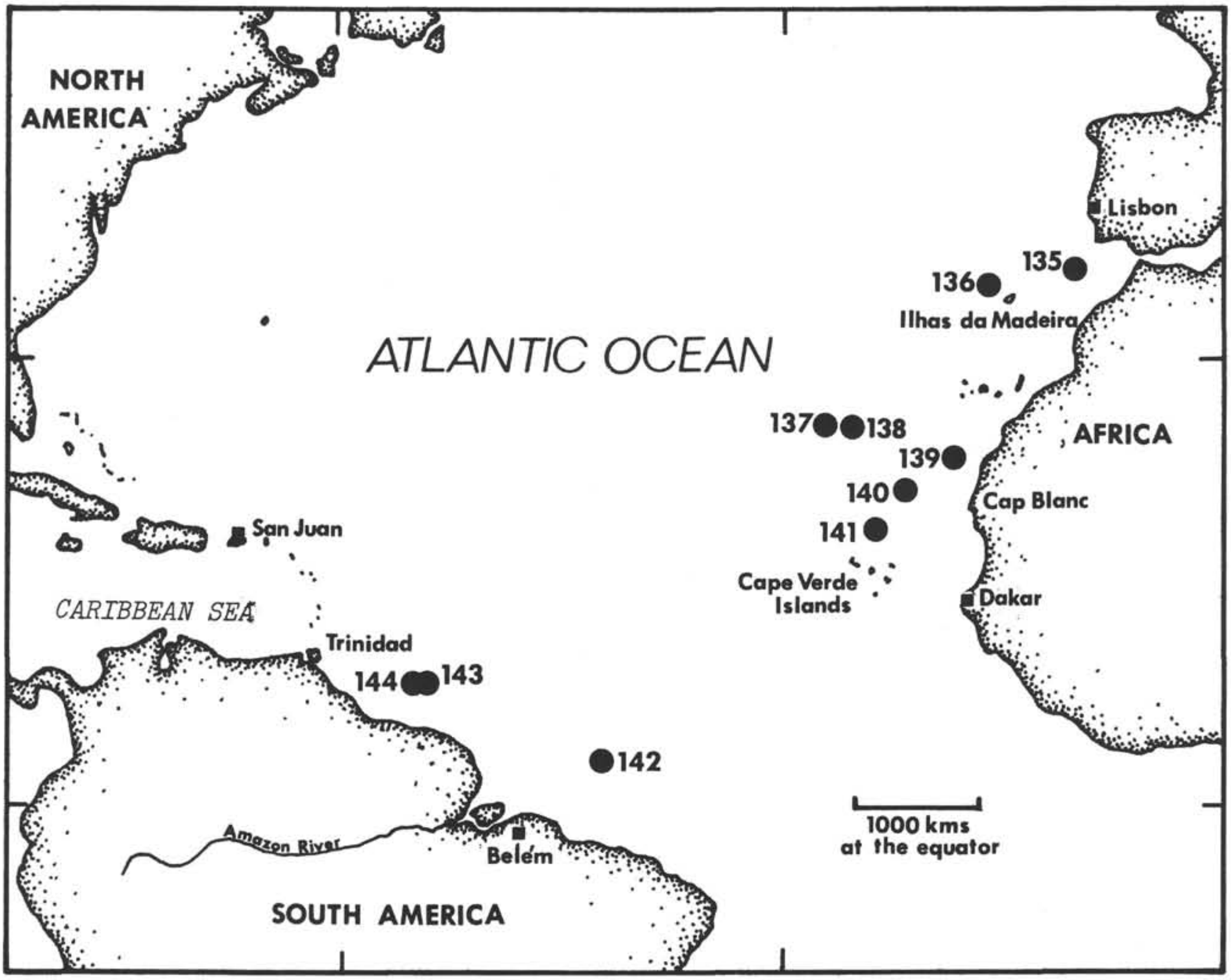

Figure 1. *Location of coring sites for Leg 14, Deep Sea Drilling Project.*

TABLE 1
Geologic Age and Zone or Stage Assignment of Cores from Leg 14 Based on Coccoliths in Samples Examined

Age	Zone or Stage	Hole 135	136	137	139	140	141	142	144	144A	144B
PLEISTOCENE AND HOLOCENE	*Emiliania huxleyi*										
	Gephyrocapsa oceanica	1						1			
	Coccolithus doronicoides						1	2–3			
PLIOCENE	*Discoaster brouweri*					1	2–4				
	Reticulofenestra pseudoumbilica				1		5	4–5			
	Ceratolithus rugosus	2					5				
	Ceratolithus tricorniculatus		1		2		6				
MIOCENE	*Discoaster quinqueramus*							7			
	Discoaster neohamatus	3						8			
	Discoaster hamatus						7				
	Catinaster coalitus										
	Discoaster exilis	4			5?						
	Sphenolithus heteromorphus	4	2					9			
	Helicopontosphaera ampliaperta		2			2					
	Sphenolithus belemnos		3			2					
	Triquetrorhabdulus carinatus		3, 4?		7						
OLIGOCENE	*Sphenolithus ciperoensis*										
	Sphenolithus distentus										
	Sphenolithus predistentus									1A	1B–3B
	Helicopontosphaera reticulata									2A	3B
EOCENE	*Discoaster barbadiensis*									2A?	
	Reticulofenestra umbilica								1		
	Nannotetrina quadrata										
	Discoaster sublodoensis										
	Discoaster lodoensis										
	Tribrachiatus orthostylus										
	Discoaster diastypus										
PALEOCENE	*Discoaster multiradiatus*								2		
	Discoaster mohleri									3A	
	Heliolithus kleinpellii									3A	
	Fasciculithus tympaniformis									3A	
	Cruciplacolithus tenuis										
CRETACEOUS	*Tetralithus murus*										
	Lithraphidites quadratus										
	Tetralithus gothicus trifidus	7							3	4A	
	SANTONIAN AND CONIACIAN									5A	
	TURONIAN								4?	6A?	
	CENOMANIAN			7–16							
	ALBIAN AND APTIAN		8								

Rhabdosphaera spp., *Scyphosphaera* spp., and *Sphenolithus* spp. An upper Miocene assemblage in Core 3 (173 to 182 meters) is dominated by *Discoaster* species and *Reticulofenestra pseudoumbilica*. In Core 3 the occurrence together of *Discoaster bellus, D. brouweri, D. neohamatus, D. perclarus,* and *D. variabilis variabilis* indicates the *Discoaster neohamatus* Zone. Middle Miocene coccoliths from Core 4 (259 to 268 meters) are abundant but poorly preserved. *Discoasters* have irregular secondary overgrowths. The assemblage which contains rare *Sphenolithus heteromorphus* and abundant *Coccolithus eopelagicus* is assigned a position at or near the boundary between the *Sphenolithus heteromorphus* Zone and the *Discoaster exilis* Zone. One sample from Core 5 (336 meters) contains carbonate rhombs and only a few coccoliths: *Discoaster deflandrei, Watznaueria barnesae*, and *?Cyclococcolithina neogammation*. In Core 7 (431 to 435 meters) a few Upper Cretaceous coccoliths occur in a turbidite-like sediment. The presence of *Arkhangelskiella cymbiformis, Broinsonia parca, Tetralithus gothicus trifidus,* and *Tetralithus pyramidus* indicates a probable late Campanian or early Maestrichtian age. Lower Cretaceous assemblages, along with carbonaceous plant debris, occur in Core 9 (685 to 687 meters).

SITE 136
(lat 34° 10.13′N., long 16° 18.19′W., depth 4169 meters)

Site 136 is in an area of abyssal hills about 160 kilometers northwest of Ilhas da Madeira. Nine cores were cut to a depth of 313 meters to sample basement and to date the sediment directly above basement. The interval of Cores 3 to 8, cut continuously between 244 and 289 meters, contains a slightly dissolved lower Miocene coccolith ooze at the top (Cores 3 to 4), a barren clay with carbonate rhombs (Cores 5 to 6), and at the base an Albian or Aptian coccolith ooze (Core 8). Core 9 is basalt.

Upper Miocene assemblages of the *Ceratolithus tricorniculatus* Zone, *Triquetrorhabdulus rugosus* Subzone, occur throughout Core 1 (130 to 139 meters). The assemblages are characterized by the presence of *Ceratolithus primus, C. tricorniculatus, Reticulofenestra pseudoumbilica* and *Triquetrorhabdulus rugosus*, and by the absence of *Discoaster surculus, Discolithina, Helicopontosphaera, Rhabdosphaera, Scyphosphaera* and *Sphenolithus*. Placoliths predominate at the top of the core and ceratoliths at the bottom, where the coccolith specimens are exceptionally large. Core 2 (216 to 225 meters) contains assemblages assigned to the lower part of the middle Miocene *Sphenolithus heteromorphus* Zone (the lower two sections of the core may represent the lower Miocene *Helicopontosphaera ampliaperta* Zone). Assemblages from the upper part of the core contain common large specimens of *Coccolithus eopelagicus, Cyclococcolithina macintyrei*, and *C. neogammation.* Long-rayed discoasters such as *D. exilis, D. signus,* and *D. variabilis variabilis* predominate over *D. deflandrei.* In the lower part of the core *D. deflandrei* predominates over the long-rayed *D. exilis,* and *C. macintyrei* is less common than in the upper part. The preservation is poorer in the lower part owing to dissolution. *Sphenolithus heteromorphus* occurs throughout the core, but *Coronocyclus, Discolithina, Helicopontosphaera, Rhabdosphaera* and *Scyphosphaera* are absent.

The lower Miocene lower *Sphenolithus belemnos* Zone in Section 1 of Core 3 is characterized by an overwhelming abundance of *Discoaster deflandrei* and *Cyclococcolithina neogammation* which shows central-area dissolution. Other diagnostic species that occur less commonly are short forms of *Triquetrorhabdulus carinatus,* and *Sphenolithus belemnos, S. dissimilis,* and *Discoaster* sp. cf. *D. calculosus.* Absent from this assemblage are the genera missing in Core 2. The abundance of fine calcareous debris derived from coccoliths, the presence of specimens with etched margins and missing central-area structures, and the lack of more readily dissolved coccolith genera suggest moderately strong dissolution. The association here of carbonate rhombs and coccoliths showing dissolution is representative of a general relation that occurs in other DSDP cores from this and other legs. In the lower part of Core 3, evidence of solution is even more pervasive. The samples contain small carbonate rhombs (5 to 30 microns) and small calcite crystallites from disaggregated coccoliths. Even the generally solution-resistant discoasters are affected, as discoasters with dissolved centers are present. The identifiable coccoliths are those most resistant to dissolution–discoasters, placoliths, and rare compacct sphenoliths. Stratigraphic assignment to the lower Miocene *Triquetrorhabdulus carinatus* Zone, *Discoaster druggii* Subzone, is based on the presence of abundant *Coccolithus eopelagicus, Cyclococcolithina neogammation* and *Discoaster deflandrei*, with few to common *Dictyococcites abisectus, Discoaster calculosus, D. druggii, Sphenolithus dissimilis* and *Triquetrorhabdulus carinatus.*

One aspect shared by some of the most solution-resistant coccoliths is a seemingly similar relation between the calcite-crystallite surface area and the crystallographic-axis orientation. The crystallites forming the upper rims of *Coccolithus* and *Cyclococcolithina* and the rays of *Discoaster* have the optic axis oriented approximately perpendicular to the largest face of the crystallite. The superior resistance of this relation is demonstrated by *Cyclococcolithina leptopora*, which has an upper shield constructed of crystallites whose optic axes are almost perpendicular, and a smaller lower shield constructed of crystallites whose optic axes are oriented almost parallel to the shield surface. (This is why, under the microscope only the lower shield is bright in cross-polarized light.) In slightly dissolved samples, the lower shield and connecting tube are removed, and *C. leptopora* is represented by only the upper shields, which are dark in cross-polarized light. These dissolution fragments were at one time falsely designated as the genus *Calcidiscus*. Although the difference in rates of solution along the different calcite crystallographic axes may be too small to totally account for the empirically observed solution sequence of coccoliths, other additive factors, such as, variation in crystallite thickness, in imbrication in rims, and in organic coating could contribute to the effect (M. N. Bramlette, verbal communication, 1971). *Cyclococcolithina* specimens at Site 136 help show the degree of dissolution, as only the upper shields are preserved in specimens from both Core 1 and 2.

All samples except the uppermost sample from Core 4 (244 meters) are barren. An apparent mixture of lower and middle Miocene taxa in this sample suggests in-hole slumping. The next deeper coccolith assemblage in Core 8

(280 to 289 meters) is Aptian or early Albian in age, as indicated by the common occurrence of *Rhagodiscus asper* and *Watznaueria britannica* and by the absence of the cosmopolitan species *Cretarhabdus decorus, Eiffellithus turriseiffeli, Lithastrinus floralis* and *Prediscosphaera*, which characterize late Albian to early Cenomanian assemblages. Cosmopolitan *Discolithus cuvilleri*, which characterizes Neocomian assemblages, is also missing.

SITE 137
(lat 25° 55.53′N., long 27° 03.64′W., depth 5361 meters)

Site 137 is about 1000 kilometers west of Cap Blanc, near the base of the continental rise. Cores 1 to 6 (52 to 225 meters) are reported to be a brown zeolitic clay barren of coccoliths. Cenomanian coccolith assemblages occur in all the samples examined from Core 7 to 16 (256 to 383 meters). The assemblages are similar throughout, although they range in specimen size and species-composition percentage. Typical species include: *Apertapetra gronosa, Cretarhabdus crenulatus, Eiffellithus turriseiffeli, Lithastrinus floralis, Lithraphidites carniolensis, Parhabdolithus angustus, P. embergeri, Prediscosphaera cretacea cretacea, Watznaueria actionosa*, and *W. barnesae*. Of taxa characteristically assigned to the Albian or lower Cenomanian, such as *Cretarhabdus decorus, C. decussatus, Prediscosphaera columnatus* [basionym: *Deflandrius columnatus* Stover, 1966, *Micropaleontology* v. 12, no. 2, p. 141, pl. 6, figs. 6-10; pl. 9, fig. 16], *Rhagodiscus asper*, and *Watznaueria britannica*, only a few specimens are present in the lower part of the section. For example, in Sample 137-13-3, 114-115 cm, the joint occurrence of *C. decorus, Coccolithus matalosus*, and *P. columnatus*, along with such taxa as *Biscutum* sp. cf. *B. blackii, Corollithion signum, Cribrosphaera ehrenbergii, E. turriseiffeli, L. floralis, P. embergeri*, and *Podorhabdus dietzmannii* indicates the lower Cenomanian (Stover, 1966). *Gartnerago concavum* and *Zygodiscus phacelosus*, which occur in the uppermost Cenomanian and Turonian of Texas and England, were not found in this section; and, therefore a Cenomanian assignment for this section is indicated. A general contrast between the upper and lower parts of the section is a greater abundance (up-section) of *L. floralis* and *P. cretacea cretacea*, and lesser abundance of *B.* sp. cf. *B. blackii* and *p. embergeri*. Electron-microscope study of the diversified small coccoliths in this interval could help in establishing an effective subdivision of the Cenomanian.

Shipboard scientists report that the core-catcher sample of Core 16 and a deeper sidewall-core sample from 393 meters both contain late Albian assemblages.

SITE 138
(lat 25° 55.37′N., long 25° 33.79′W., depth 5288 meters)

Seven spot cores were cut between 52 and 442 meters at Site 138, which is about 130 kilometers east of Site 137 and about 850 kilometers west of Cap Blanc, at the base of the continental rise. Tertiary clay, some of it sandy, occurs in Cores 1 to 3 (52 to 190 meters). Samples available to the author from this interval are barren of coccoliths, as are samples from Core 5 (332 to 341 meters) and Core 6 (425 to 431 meters). Shipboard scientists report sparse Late Cretaceous radiolarians and coccoliths from these two cores. Basalt is present in Core 7 from a depth of 437 meters to the base at 442 meters.

SITE 139
(lat 23° 31.14′N., long 18° 42.26′W., depth 3047 meters)

Site 139 was drilled 250 kilometers northwest of Cap Blanc, on the middle continental rise, in an effort to compare the geologic history of this area with that of eastern North America. Eight spot cores, including one sidewall core, were cut from 114 to 665 meters. Pliocene and Miocene coccolith ooze is present in Cores 1 to 4 (114 to 463 meters). Miocene diatom-coccolith sediment that is locally sandy occurs in Cores 5 to 7 (570 to 665 meters).

Core 1 (114 to 123 meters) contains a coccolith assemblage that is characteristic of the upper lower Pliocene *Reticulofenestra pseudoumbilica* Zone, *Discoaster asymmetricus* Subzone. Taxa present include: *Ceratolithus rugosus, Coccolithus doronicoides, C. pelagicus, Cyclococcolithina leptopora, C. macintyrei, Discoaster asymmetricus, D. brouweri, D. surculus, D. tamalis, D. variabilis decorus, Discolithina japonica, Helicopontosphaera kamptneri, H. sellii* [small], *Reticulofenestra pseudoumbilica* [small], and *Rhabdosphaera procera*. Among the most common taxa are *C. pelagicus, D. asymmetricus, D. brouweri, D. surculus, H. sellii*, and *R. pseudoumbilica*. The specimens of *R. pseudoumbilica* are smaller than normal and this, together with the abundance of cool-water *C. pelagicus* and the absence of *Sphenolithus* indicates the beginning of the widespread late Pliocene cooling of the oceans. An abundance of ribbon diatoms in this core likewise indicates a cool-water deposit. Core 2 (225 to 234 meters) contains an assemblage characteristic of the upper Miocene *Ceratolithus tricorniculatus* Zone, *Triquetrorhabdulus rugosus* Subzone. The most common placoliths are *C. pelagicus, C. macintyrei*, and *R. pseudoumbilica*; the most common discoasters are *D. pentaradiatus, D. surculus*, and *D. variabilis variabilis*. Guide species include *Ceratolithus tricorniculatus, Triquetrorhabdulus rugosus*, and small *Scyphosphaera globulata*. In DSDP open-ocean cores, this association is characteristic of the stratigraphic interval below the first appearance of *C. rugosus*. Although *C. rugosus* and *Ceratolithus amplificus* were searched for to help in the determination of zonal boundaries, no specimens of either were found. However, in a slide from Section 4, owing to some coarse debris in the sample, a tilted specimen of *C. tricorniculatus* was observed which appears somewhat bright like *C. rugosus* in cross-polarized light. Because of the crystallographic orientation of the optic axis of the calcite in *C. tricorniculatus*, any tilted specimen will produce a slightly bright figure in cross-polarized light. Another, though less likely, kind of fossil material that could be misidentified as *C. rugosus* is curved, disaggregated rays of certain discoasters. In plan view, all discoasters are dark in cross-polarized light because the optic axis is oriented vertically, but in side view the rays appear blade-like and bright because in this view the optic axis is not vertical and is perpendicular to the optic path of the microscope. Because of the structural simplicity of *Ceratolithus* and the stratigraphic utility of this genus, particular care in identification is indicated.

A single sample from the interval of Cores 3 to 6 (345 to 612 meters), DSDP 139-5-1, 145-146 cm, is a diatom ooze containing rare coccoliths, including *Reticulofenestra pseudoumbilica* and *Discoaster* sp. cf. *D. aulakos*, that suggest the middle Miocene. Silicoflagellates observed in the coccolith smear slide for this sample include *Dictyocha quadrata, D. fibula brevispina, D. crux longispina*, and *?Pseudorocella corona*, which also suggest the middle Miocene or higher (Loeblich and others, 1968).

In the diatom ooze of Core 7 (656 to 665 meters), sparse coccoliths, such as *Cyclococcolithina neogammation, Dictyococcites abisectus, Discoaster deflandrei, Helicopontosphaera parallela, Sphenolithus dissimilis* and *Triquetrorhabdulus carinatus*, indicate the lower Miocene *Triquetrorhabdulus carinatus* Zone. Eocene reworking is indicated by *Discoaster lodoensis, D. septemradiatus, D. tani nodifer, Transversopontis pulchra*, and possibly by the only silicoflagellate recorded, *Corbisema tricantha flexuosa*, which ranges from Eocene to lower Miocene.

SITE 140
(lat 21° 44.97′N., long 21° 47.52′W., depth 4483 meters)

Site 140 is about 450 kilometers west of Cap Blanc at the base of the continental rise. Eight cores were cut in Hole 140 and two cores in Hole 140A to determine the nature of the sediments in relation to nearby sites and to date the basement at the "magnetic quiet zone boundary." Aside from Cores 1 and 2 of Hole 140, samples from this site are barren of coccoliths. Core 1 (89 to 98 meters) contains a lower upper Pliocene, *Discoaster brouweri* Zone, *Discoaster tamalis* Subzone, assemblage that is only slightly higher than the Core 1 assemblage in Hole 139. Coccoliths present include large abundant *Coccolithus doronicoides, C. pelagicus, Cyclococcolithina leptopora* and *C. macintyrei*, with common *Ceratolithus rugosus, Discoaster asymmetricus, D. brouweri, D. pentaradiatus, D. surculus, D. tamalis, Discolithina japonica, Helicopontosphaera kamptneri* and *H. sellii*. A few specimens of *Scapholithus, Rhabdosphaera procera* and two small forms with faint rims, probably referable to terminal *Reticulofenestra* sp. cf. *R. pseudoumbilica* and to early *Emiliania* sp. cf. *E. annula*, are also present. Core 2 (201 to 210 meters) contains a diatom-coccolith ooze of the lower Miocene *Helicopontosphaera ampliaperta* Zone and *Sphenolithus belemnos* Zone. The occurrence of *Helicopontosphaera ampliaperta, Sphenolithus belemnos* and *S. heteromorphus* in the upper part of the core, and *H. ampliaperta, H. intermedia, S. belemnos* and short *Triquetrorhabdulus carinatus* in the bottom part provides the basis for distinguishing these zones here. In Trinidad, where the *H. ampliaperta* Zone and *S. belemnos* Zone were first identified, the sample interval available was such that an overlap of the ranges of *S. belemnos* and *S. heteromorphus* was not indicated (Bramlette and Wilcoxon, 1967). Their co-occurrence in the upper part of Core 2, if not the result of mixing, indicates that *S. belemnos* may range upward—particularly in view of the presence of *Discoaster exilis* and *D.* sp. cf. *D. variabilis variabilis* that have middle Miocene affinities. Therefore the base of the *H. ampliaperta* Zone is based on the first occurrence of cosmopolitan *S. heteromorphus. S. belemnos* has lower Miocene affinities, as it appears to be developed by lengthening of the base and coalescing and lengthening of the apical spines from *S. dissimilis* [*S.* sp. aff. *S. belemnos* of my earlier Deep Sea Drilling Project reports].

Silicoflagellates are most common in the upper part of the core, where *Corbisema tricantha flexuosa, Dictyocha crux, D. fibula brevispina, D. ponticulus*, and *Distephanus speculum minuta* with six- and seven-fold symmetry occur. Only *D. crux* and *D. ponticulus* are noted from the bottom of the core.

SITE 141
(lat 19° 25.16′N., long 23° 59.91′W., depth 4148 meters)

Site 141 is at a submarine piercement structure about 200 kilometers north of the Cape Verde Islands, on the lower continental rise. Coring was conducted to determine whether the piercement material is of igneous or sedimentary origin. Basalt is present in Core 10 (295 to 298 meters). Sediment in Cores 1 to 6 (5 to 68 meters) provides an excellent sequence of lower Pleistocene to lower Pliocene coccolith assemblages. Core 7 (79 to 88 meters) contains an unusual assemblage of the upper Miocene *Discoaster hamatus* Zone. Samples available from Cores 8 and 9 (117 to 123 meters, and 191 to 200 meters) are barren of coccoliths.

Lower Pleistocene *Coccolithus doronicoides* Zone, *Emiliania annula* Subzone, assemblages of Core 1 are characterized by a common occurrence of *Coccolithus doronicoides, C. pelagicus, Cyclococcolithina leptopora, Emiliania annula, Helicopontosphaera kamptneri, H. sellii*, and *Rhabdosphaera* sp. cf. *R. stylifera*. Also present are a few specimens of *Ceratolithus cristatus, C. rugosus, Cyclococcolithina macintyrei, Discolithina japonica, Scapholithus, Scyphosphaera pulcherrima, Syracosphaera histrica*, and *Thoracosphaera saxea*. The bottom sample of the core contains rare, possibly reworked *Discoaster brouweri*. In Core 2, assigned to the upper Pliocene *Discoaster brouweri* Zone, *Cyclococcolithina macintyrei* Subzone, *Discoaster brouweri* and *D. triradiatus* are common at the top and abundant at the bottom. Large *C. pelagicus, C. doronicoides, C. macintyrei*, large *H. kamptneri*, and *H. sellii* are common throughout. *C. rugosus, Rhabdosphaera, Scapholithus*, and *Scyphosphaera* are uncommon. In Core 3, the *Discoaster pentaradiatus* Subzone is recognized throughout by the occurrence of *D. brouweri, D. pentaradiatus*, and *D. surculus. C. rugosus* is more common in this core than above. Coccoliths indicating the *Discoaster tamalis* Subzone occur in two samples available from Core 4. Small thin-rayed discoasters are abundant, especially *D. pentaradiatus* and *D. tamalis*, with lesser numbers of *D. asymmetricus, D. brouweri*, and rare *D. triradiatus. C. pelagicus* is quite abundant; species that occur commonly are *C. rugosus*, small *H. sellii*, and small *Emiliania* sp. cf. *E. annula*. In contrast with Core 4, the discoasters of Core 5 are large and relatively thick rayed, suggesting deposition under warmer water conditions than for those above. Other marked differences in the Core 5 assemblages are larger, more abundant *C. rugosus* and a common occurrence of older taxa that are missing from Core 4, such as *Discoaster variabilis variabilis, Reticulofenestra pseudoumbilica, Sphenolithus abies*, and *S. neoabies*. Only rare *D. tamalis* and *H. sellii* are noted in Core 5. On the basis of the occurrence of common *D. asymmetricus* and a few *D. variabilis decorus,* along with those taxa already cited, the upper half of Core 5 is assigned to the lower Pliocene *Reticulofenestra pseudoumbilica* Zone, *Discoaster asymmetricus* Subzone. The lowest sample available from Core 5 (DSDP 141-5-6, 114-115 cm) contains common *C. rugosus* and a few *C. tricorniculatus* and *Scyphosphaera globulata*, indicating the lower Pliocene *Ceratolithus rugosus* Zone. DSDP sample 141-6-3, 114-115 cm, contains a basal Pliocene assemblage of the *Ceratolithus tricorniculatus* Zone, *Ceratolithus amplificus* Subzone, as indicated by the occurrence of *Ceratolithus amplificus s.s.* and *C. tricorniculatus,* with *S. globulata*. This same association occurs in tropical Pacific Ocean cores from DSDP Legs 8 and 9. The absence of *C. rugosus* and the occurrence of rare specimens of *Triquetrorhabdulus rugosus,* usually restricted to the lower *C. tricorniculatus* Zone and deeper intervals, point to a stratigraphic position at the base of the *C. amplificus* Subzone.

Owing to strong dissolution of less resistant fossils, discoasters are more prominent in the Core 7 sediment, with placoliths represented mainly by a few rims of the solution-resistant *Coccolithus pelagicus, Cyclococcolithina macintyrei,* and even rarer *Reticulofenestra pseudoumbilica*. The discoasters, including *Discoaster bellus, D. bollii, D. braarudii, D. brouweri, D. calcaris, D. challengeri, D. hamatus, D. neohamatus, D. perclarus, D. prepentaradiatus,* and *D. variabilis variabilis,* indicate the lower upper Miocene. On the basis of rare presence of *D. hamatus s.s.* and a few specimens indicating a possible transition between *D. hamatus* and *D. bellus*, the assemblage is assigned a position in the upper *Discoaster hamatus* Zone. The presence of a few specimens of three-rayed and asymmetric five-rayed discoaster variants, in combination with the general dominance of discoasters in this assemblage, is a relation that has been observed previously in lower upper Miocene samples from DSDP Hole 97, Core 3 (23° 53′N., 84° 27′W., water depth 2930 meters, core depth 142 to 145 meters) in the Gulf of Mexico and DSDP Hole 29B, Core 3B (14° 47′N., 69° 19′W., water depth 4247 meters, core depth 78 to 87 meters) in the Caribbean Sea. The larger size of the discoasters in these samples suggests warm-water deposition; the lack of siliceous microfossils suggests relatively nutrient-deficient waters; the lack of secondary overgrowths on discoasters and the dissolution of placoliths point to bottom conditions undersaturated with respect to calcite.

SITE 142
(lat 03° 22.15′N., long 42° 23.49′W., depth 4372 meters)

Site 142 is just south of the Ceara Rise on the Ceara Abyssal Plain about 700 kilometers east-northeast of the Amazon River mouth. Nine cores were cut in the 626 meters penetrated in order to determine the age and lithologic character of various reflective zones of the abyssal-plain sediment. Sandy Pleistocene sediment from Cores 1 to 3 (98 to 106 meters, 200 to 209 meters, and 293 to 301 meters) is dominated by warm-water coccoliths. Upper Pleistocene *Gephyrocapsa oceanica* Zone assemblages of Core 1 contain abundant *Gephyrocapsa oceanica*, common *Gephyrocapsa* sp. cf. *G. aperta, Cyclococcolithina leptopora, Umbilicosphaera mirabilis,* and few *Emiliania annula, Helicopontosphaera kamptneri, Syracosphaera histrica*, and fragments of *Thoracosphaera*. Cores 2 and 3, which contain assemblages assigned to the lower Pleistocene *Coccolithus doronicoides* Zone, *Emiliania annula* Subzone, are dominated by *E. annula*, with common *Coccolithus doronicoides, C. leptopora, H. kamptneri, U. mirabilis,* and a few *Ceratolithus cristatus, Scyphosphaera pulcherrima,* and *Thoracosphaera*. Conspicuously missing from Core 2 are the cool-water indicators *Coccolithus pelagicus* and *Helicopontosphaera sellii*. A dominance of the exactly-circular form of *E. annula* in Core 2 also indicates warm-water conditions. Core 3 differs slightly by having a few *H. sellii* and more common *C. doronicoides.*

Lower Pliocene *Reticulofenestra pseudoumbilica* Zone, *Discoaster asymmetricus* Subzone, assemblages occur throughout Core 4 (367 to 376 meters). *Coccolithus* sp. cf. *C. doronicoides, Discoaster brouweri, Helicopontosphaera kamptneri, Reticulofenestra pseudoumbilica,* and *Sphenolithus abies* are the most abundant taxa. Other typical members of the assemblage are: *Ceratolithus rugosus, Cyclococcolithina macintyrei, Discoaster asymmetricus, D. pentaradiatus, D. surculus, D. variabilis pansus, D. variabilis variabilis, Discolithina japonica, Scyphosphaera globulata, S. pulcherrima,* and *Thoracosphaera saxea.* A few specimens of small *Helicopontosphaera sellii, Rhabdosphaera procera* and *Scyphosphaera recurvata* are present. In Core 5 (423 to 429 meters) a slightly older but similar assemblage is assigned to the *Sphenolithus neoabies* Subzone. The absence of *Coccolithus pelagicus* in all samples examined here from the Pliocene and Pleistocene interval contrasts strongly with the dominance of this species in coeval high-latitude intervals cored during DSDP Legs 5 and 12. The species is present, though not dominant, at DSDP Site 141, sixteen degrees farther north. Therefore, the cool-water range (6 to 14°C) of living members of *C. pelagicus* (McIntyre and Bé, 1967; McIntyre and others, 1970) is characteristic at least as far back as early Pliocene. As all deeper Miocene cores at this site contain *C. pelagicus* as a typical member of coccolith assemblages, a cooler temperature is thereby indicated, although we are less certain of the temperature sensitivity of the species at this earlier time.

The coccolith assemblage of Core 6 (451 to 457 meters) has been reduced by dissolution to resistant taxa, such as *Coccolithus pelagicus, Discoaster brouweri, D. pentaradiatus, D. surculus, D. variabilis variabilis* and *Reticulofenestra pseudoumbilica*. This assemblage could be upper Miocene or lower Pliocene. A more complete assemblage is present in Core 7 (479 to 487 meters), where the upper Miocene *Discoaster quinqueramus* Zone, *Ceratolithus primus* Subzone, occurs throughout. Similar assemblages have been found in tropical Pacific Ocean cores of DSDP Leg 9. The general sequence of taxa in the tropics used in correlation includes the earlier association of common *Discoaster berggrenii* and *D. quinqueramus* in the lower part of the *D. quinqueramus* Zone (*Discoaster berggrenii* Subzone) followed by the association, in the upper part of the zone, of common *D. quinqueramus*, with the earliest *Ceratolithus primus* and *C. tricorniculatus, D. berggrenii* being rare or absent. The distribution of these earliest ceratoliths was apparently patchy, as samples through this stratigraphic interval at various sites show a similar assemblage, with *D. quinqueramus* and *D. surculus* abundant but with a sporadic occurrence of ceratoliths. The lower *Ceratolithus tricorniculatus* Zone, or *Triquetrorhabdulus rugosus* Subzone, is recognized by the association of *Discoaster surculus, Triquetrorhabdulus rugosus* and *C. tricorniculatus* without *D. quinqueramus*. The morphologic varieties that characterize *C. primus* in the Pacific are present in Core 7. Specimens without secondary overgrowth show short, robust, toothed arms connected by a thin wide planar arch. Typical assemblages from Core 7 contain: *C. primus, C. tricorniculatus, C. pelagicus, D. brouweri, D. quinqueramus, D. surculus, D. variabilis pansus, D. variabilis variabilis, Helicopontosphaera kamptneri, R. pseudoumbilica, Sphenolithus abies* and *T. rugosus.*

A poorly preserved assemblage from Core 8 (529 to 538 meters) represents the upper Miocene *Discoaster neohamatus* Zone. Taxa present include: *Coccolithus pelagicus, Cyclococcolithina macintyrei, Discoaster bellus, D. brouweri s.l., D. challengeri, C. neohamatus, D. variabilis variabilis, Reticulofenestra pseudoumbilica* and *Triquetrorhabdulus rugosus*. A middle Miocene assemblage is present in Core 9 (575 to 584 meters). Characteristic species include abundant *Coccolithus eopelagicus, Discoaster deflandrei* and *Sphenolithus heteromorphus*, with common *Coronocyclus* sp. cf. *C. nitescens, Cyclococcolithina leptopora, C. neogammation, Discoaster aulakos, D. exilis, Helicopontosphaera kamptneri* and *R. pseudoumbilica.*

SITE 143
(lat 09° 28.45′N., long 54° 18.71′W., depth 3493 meters)

Site 143 was cored about 400 kilometers north of Surinam, on the northern flank of the Demerara Rise, in an attempt to sample Mesozoic sediment of the early Atlantic Ocean basin. The single sample (DSDP 143-1-2, 66-67 cm) from Core 1 (0 to 9 meters) is barren of coccoliths. Shipboard scientists report recovery of Cretaceous and Pleistocene or Holocene microfossils from other samples in the core. Lack of drill penetration forced the operation to be shifted upslope to DSDP Site 144.

SITE 144
(lat 09° 27.23′N., long 54° 20.52′W., depth 2957 meters)

Site 144 was cored in the same area as Site 143 but in shallower water. Three holes were drilled at this site–DSDP Holes 144, 144A, and 144B–recovering a total of 17 cores ranging in age from middle Oligocene to Early Cretaceous. Coccolith assemblages from the three holes are discussed together in stratigraphic sequence from youngest to oldest. Core 1A (20 to 29 meters) and Cores 1B to 3B (0 to 27 meters) contain the lower middle Oligocene *Sphenolithus predistentus* Zone. *Discoaster* varies in abundance, but is generally common. *Helicopontosphaera* species are common to abundant and, in conjunction with the presence of such taxa as *Lanternithus minutus, Pedinocyclus larvalis* and a few *Discolithina*, indicate deposition at moderately shallow ocean depth. Of taxa that indicate shallow Oligocene marine environments, only rare specimens of *Rhabdosphaera* and *Transversopontis* are present, and *Braarudosphaera* and *Micrantholithus* are absent. The zonal assemblage at this locality, nevertheless, is fairly diverse, typically containing: *Coccolithus eopelagicus, C. fenestratus, C. pelagicus, Dictyococcites bisectus, D. scrippsae, Discoaster deflandrei, D. tani nodifer* (six-rayed), *D. tani tani* (five-rayed), *Helicopontosphaera compacta, H. parallela, H.* sp. cf. *H. bramlettei, Reticulofenestra gartneri, Sphenolithus predistentus,* and *S. moriformis*. Few to rare occurrences of *Bramletteius serraculoides, Chiasmolithus altus, Cyclococcolithina formosa, Helicopontosphaera reticulata, Isthmolithus recurvus, Reticulofenestra hillae, Sphenolithus distentus,* and *Zygrhablithus bijugatus* are in part reworked from Eocene or lower Oligocene. A lower Oligocene *Helicopontosphaera reticulata* Zone assemblage is identified from the upper part of Core 2A (38 to 47 meters) and from the lower part of Core 3B (18 to 27 meters). Typical *H. reticulata* Zone species that serve to distinguish this assemblage from overlying *S. predistentus* Zone are *Coccolithus subdistichus, C. formosa, H. reticulata, Reticulofenestra umbilica,* and *Syracosphaera labrosa*. Rare *Discoaster saipanensis* in the bottom of Core 3B probably indicate Eocene reworking. The only sample available that might be assigned to the upper Eocene *Discoaster barbadiensis* Zone is from the bottom of Core 2A (DSDP 144A-2A-6, 114-115 cm). Whereas the assemblage is similar to the overlying one, rare specimens of both *Discoaster barbadiensis* and *D. saipanensis* are present and *H. reticulata* is common in this sample.

A coccolith-diatom ooze of the middle Eocene *Reticulofenestra umbilica* Zone is present in Core 1 (57 to 65 meters). The assemblage throughout the core is fairly consistent except for a general upward increase in *Helicopontosphaera* abundance. Typical species include *Campylosphaera dela, Chiasmolithus grandis, C. solitus, Coccolithus staurion, Cyclococcolithina formosa, C. neogammation, C. protoannula, Discoaster barbadiensis, D. saipanensis, D. tani nodifer, Helicopontosphaera compacta, H. reticulata, Reticulofenestra samodurovi, R. umbilica, Sphenolithus predistentus* and *S. pseudoradians*. A few specimens of *Bramletteius serraculoides* and *Micrantholithus stradneri* also occur. Specimens of *D. tani nodifer* occurring here have, in addition to the six-rayed forms, seven- and eight-rayed forms. This is typical of the middle Eocene fossils of this subspecies in many areas. Higher representatives from upper Eocene and Oligocene deposits are mainly six-rayed.

The next deeper stratigraphic interval cored is the upper Paleocene in Core 2 (104 to 112 meters) and Core 3A (140 to 149 meters). Core 2 contains the uppermost Paleocene *Discoaster multiradiatus* Zone, *Campylosphaera eodela* Subzone, indicated by the occurrence of such species as *Campylosphaera eodela, Chiasmolithus bidens, Discoaster multiradiatus, D. nobilis, Ellipsolithus distichus, E. macellus, Fasciculithus tympaniformis*, and *Toweius eminens*. In Core 3A, the upper two core sections have *Discoaster mohleri* Zonal assemblages containing: *Chiasmolithus californicus, C. consuetus, Cruciplacolithus tenuis,. Cyclolithella? robusta, Discoaster mohleri, E. distichus, E. macellus, F. tympaniformis, T. eminens, Zygodiscus plectopons, Z. sigmoides* and *Zygrhablithus? simplex.* In Section 3, an upper *Heliolithus kleinpellii* Zonal assemblage contains both *Heliolithus kleinpellii* and *H. riedelii*, and lacks discoasters. Sections 4 and 5 are assigned to the *Fasciculithus tympaniformis* Zone on the basis of the occurrence of *Chiasmolithus* sp. cf. *C. bidens, C. californicus, C. consuetus, C.? robusta, F. tympaniformis, T. eminens,* and *Z. sigmoides*. The lowermost sample for Core 3A, Section 6, contains abundant fine calcareous debris, with rare resistant Cretaceous coccoliths (*Apertapetra gronosa, Cretarhabdus crenulatus, Micula decussata*, and *Watznaueria barnesae)*.

Core 3 (162 to 166 meters) and Core 4A (173 to 182 meters) contain assemblages of the upper Campanian or lower Maestrichtian *Tetralithus gothicus trifidus* Zone. The assemblage from Core 4A is the most diverse, containing: *Arkhangelskiella cymbiformis, Cretarhabdus crenulatus, C. decorus, C. lorei, Cribrosphaera ehrenbergii, Eiffellithus turriseiffeli, Kampterius magnificus, Lithraphidites carniolensis, Microrhabdulus decoratus, M. stradneri, Micula decussata, Prediscosphaera cretacea cretacea, P. spinosa, Tetralithus gothicus gothicus, T. gothicus trifidus, Vagalapilla* spp., *Watznaueria barnesae, W. biporta* and *Zygodiscus lacunatus.* Typical guide taxa to earlier Late Cretaceous assemblages, such as *Marthasterities furcatus furcatus* and *Micula*, are missing from deeper cores. On the basis of the co-occurrence of *Amphizygus brooksii brooksii, Gartnerago concavum* and *Lithastrinus floralis,* with a few *Corollithion signum, Eiffellithus augustus, Kamptnerius magnificus* and *Watznaueria biporta,* the Santonian or Coniacian is indicated for Core 5A (182 to 191 meters). Core 6A (191 to 200 meters) contains a similar but less diverse assemblage, lacking *Amphizygus* and *Kamptnerius.* The Core 4 (213 to 219 meters) samples lack characteristic Albian taxa; the presence of *Arkhangelskiella* sp. cf. *A. erratica, Chiastozygus amphipons, Coccolithus*? *matalosus, E. turriseiffeli, G. concavum, L. floralis, P. cretacea cretacea, Rucinolithus planus*, and *Zygolithus*? *tractus* suggests the upper Cenomanian or Turonian.

Samples from Cores 5 to 8 (264 to 327 meters) contain only rare coccoliths. The Cretaceous taxon *Watznaueria barnesae* is present, and questionably *Lithastrinus floralis.* Shipboard scientists report the occurrence of Early Cretaceous *Braarudosphaera* and *Nannoconus* in their samples from these cores.

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