

13. CENOZOIC SILICOFAGELLATE AND COCCOLITH STRATIGRAPHY, SOUTHEASTERN ATLANTIC OCEAN, DEEP SEA DRILLING PROJECT LEG 40

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INTRODUCTION

Leg 40 of the Deep Sea Drilling Project, December 1974 to February 1975, which began at Cape Town, South Africa, and ended at Abidjan, Ivory Coast (Figure 1), recovered 248 cores at six drilling sites, 360-365. Light-microscope techniques were used to study the Cenozoic silicoflagellates and coccoliths of 212 samples from these cores. Coccolith zonation of the samples, summarized in Figure 2, follows Bukry (1975c).

SITE SUMMARIES

Site 360

(lat 35°50.75'S, long 18°05.79'E, depth 2949 m)

Site 360, on the continental rise of southwest Africa, was cored to obtain a continuous stratigraphic section of the younger portion of the continental rise sediment prism. Coccoliths in the 50 sediment cores (80 to 840 m subbottom) range from lowermost Pliocene or upper Miocene to middle Eocene. Etching and overgrowth of specimens is moderate. The assemblages are temperate in character, and contain cool-water indicators such as persistent *Chiasmolithus* in the Paleogene, abundant *Isthmolithus* near the Eocene-Oligocene boundary, and *Discoaster challengeri* in the Miocene. Low-latitude zonal markers such as *Discoaster bifax*, *D. hamatus*, and *Sphenolithus ciperensis* are present in small numbers, however, and permit relatively fine zonation.

The *Amaurolithus tricorniculatus* Zone assemblages of Cores 1 to 4 (80 to 118 m) are dominated by placoliths, and contain ceratoliths of only two species—*Amaurolithus delicatus* and *A. primus*. Discoasters and sphenoliths are sparse and species of *Ceratolithus* are missing, suggesting a cool-temperate assemblage.

The lower part of the *Discoaster berggrenii* Subzone in Sample 360-12-3, 49-50 cm (187 m), has *Discoaster loeblichii* and *Minylitha convallis* overlapping with *Discoaster berggrenii* and *D. surculus*.

Discoasters are scarce or absent in many Oligocene assemblages, such as those of Samples 360-31-3, 49-50 cm (492 m) and 360-34-3, 49-50 cm (549 m). In Sample 360-30-3, 9-11 cm (472 m), the low ratio of *Discoaster* to *Chiasmolithus* (17/83) suggests cool-water conditions (Bukry, 1973). This ratio shows a substantial cooling trend through the late Eocene into the Oligocene at Site 360 (Figure 3) which corresponds to that identified by oxygen isotope determinations from the Pacific (Savin et al., 1975).

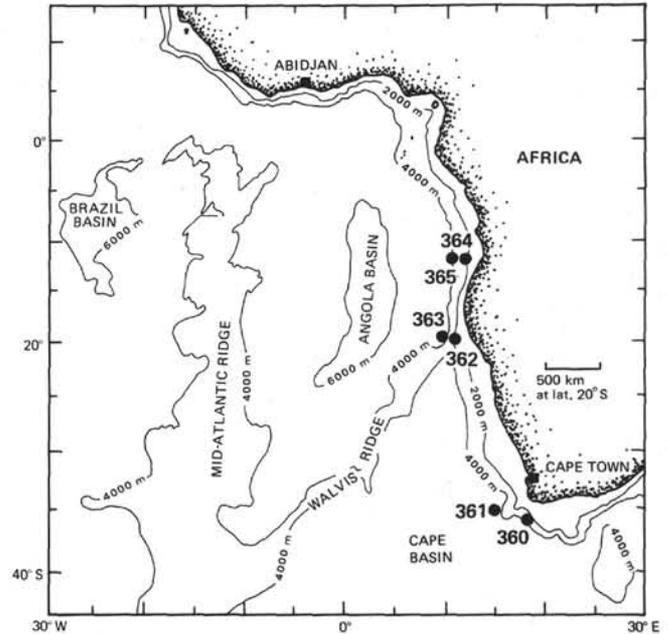


Figure 1. Sketch map of sites drilled on Deep Sea Drilling Project Leg 40.

Chiasmolithus oamaruensis overlaps with *C. grandis* in Samples 360-39-3, 49-50 cm (633 m) and 360-40-2, 49-50 cm (651 m), which are assigned to the lower upper Eocene *Chiasmolithus oamaruensis* Subzone. The deepest samples examined, 360-49-2, 50-52 cm (812 m) and 360-50-2, 49-50 cm (832 m), contain the short-ranged middle Eocene guide fossil *Chiasmolithus gigas*.

Site 361

(lat 35°03.97'S, long 15°26.91'E, depth 4549 m)

Site 361, near the base of the southwest African continental rise west of Cape Town, was cored from upper Eocene at 32 meters subbottom into the Lower Cretaceous at 1314 meters. Coccolith-rich lower Cenozoic sediment was cored discontinuously in the interval 32 to 279 meters (Cores 1 to 10). Upper Eocene and Paleocene specimens are strongly etched; middle and lower Eocene specimens are moderately etched and overgrown.

Upper Eocene assemblages identified by the overlapping ranges of solution-resistant *Discoaster saipanensis* and *Isthmolithus recurvus* in Samples 361-1-6, 49-50 cm (35 m) and 361-2-2, 49-50 cm (61 m) contain placoliths and placolith remnants that are

AGE	ZONE	SUBZONE	360	361	362	363	364	
QUATERNARY	<i>Emiliana huxleyi</i>				1-1		1-3	
	<i>Gephyrocapsa oceanica</i>	<i>Ceratolithus cristatus</i>			1-3/2-3			
		<i>Emiliana ovata</i>						
	<i>Crenolithus doronicoides</i>	<i>Gephyrocapsa caribbeanica</i>						
PLIOCENE	<i>Discoaster brouweri</i>	<i>Cyclococcolithina macintyreii</i>						
		<i>Discoaster pentaradiatus</i>			5-3/10-3			
		<i>Discoaster surculus</i>						
		<i>Discoaster tamalis</i>						
	<i>Reticulofenestra pseudoumbilica</i>	<i>Discoaster asymmetricus</i>				11-3/12-3		
		<i>Sphenolithus neobabies</i>						3-1/3-2
	<i>Amaurolithus tricorniculatus</i>	<i>Ceratolithus rugosus</i>				13-3		3-6
		<i>Ceratolithus acutus</i>	1-1/4-3					
		<i>Triquetrorhabdulus rugosus</i>				14-3/19-3		
	MIOCENE	<i>Discoaster quinquerramus</i>	<i>Amaurolithus primus</i>	5-3/7-3		20-3/23-3		
<i>Discoaster berggrenii</i>			8-3/12-3		24-3/26-3		4-2	
<i>Discoaster neohamatus</i>		<i>Discoaster neorectus</i>			27-3		74-6	
		<i>Discoaster bellus</i>	13-3/15-2		29-3			
<i>Discoaster hamatus</i>		<i>Catinaster calyculus</i>	16-3					
		<i>Helicosphaera carteri</i>			30-3			
<i>Catinaster coalitus</i>			17-2		31-3, 732-3			
<i>Discoaster exilis</i>		<i>Discoaster kugleri</i>	718-2		33-3			
		<i>Coccolithus miopelagicus</i>	19-3/21-3		34-3	1-1/1-3		
		<i>Sphenolithus heteromorphus</i>	22-6		35-3/36-3			
		<i>Helicosphaera ampliaperta</i>	23-3		37-3		5-3	
		<i>Sphenolithus belemnus</i>						
OLIGOCENE		<i>Triquetrorhabdulus carinatus</i>	<i>Discoaster druggii</i>	24-2		738-3		
	<i>Discoaster defandrei</i>				39-3	1-5		
	<i>Cyclicargolithus abisectus</i>		25-2		41-3			
	<i>Sphenolithus ciperoensis</i>	<i>Dictyococcites bisectus</i>	26-2/28-3		2A-3	2-3		
		<i>Cyclicargolithus floridanus</i>	29-3/30-3		3A-3/4A-1	3-2/4-3		
	<i>Sphenolithus distentus</i>	31-3/33-3		4A-3/5A-3	5-3/7-1			
	<i>Sphenolithus predistentus</i>							
EOCENE	<i>Helicosphaera reticulata</i>	<i>Reticulofenestra hillae</i>			5A-5	8-2		
		<i>Coccolithus formosus</i>			6A-2, 6A-5			
		<i>Coccolithus subdistichus</i>	34-3/35-3		77A-2	9-2		
	<i>Discoaster barbadiensis</i>	<i>Isthmolithus recurvus</i>	36-1/39-2	1-6/2-2	7A-5/8A-3	9-4		
		<i>Chiasmolithus oamaruensis</i>	39-3/40-2					
	<i>Reticulofenestra umbilica</i>	<i>Discoaster saipanensis</i>	41/2-43-2		9A-1/9A-4	10-5		
		<i>Discoaster bifax</i>	46-2/48-2		10A-1	11-1		
	<i>Nannotetrina quadrata</i>	<i>Coccolithus staurion</i>	48-4		10A-3	11-2		
		<i>Chiasmolithus gigas</i>	49-2/50-2		11A-1	11-5		
	<i>Discoaster subloedenis</i>	<i>Discoaster strictus</i>		5-1				
		<i>Rhabdosphaera inflata</i>		5-4 & 7-1		12-2		
	<i>Discoasteroides kuepperi</i>				12-5	8-1		
	<i>Discoaster lodoensis</i>		5-6/6-2	12A-1	13-2/13-5	8-3		
	<i>Tribrachiatus orthostylus</i>					8-5		
PALEOCENE	<i>Discoaster diastypus</i>	<i>Discoaster binodosus</i>		8-1				
		<i>Tribrachiatus contortus</i>				14-2	9-1	
	<i>Discoaster multiradiatus</i>	<i>Campylosphaera eodela</i>		8-6/9-2		14-5/15-3	9-3	
		<i>Chiasmolithus bidens</i>						
	<i>Discoaster nobilis</i>							
	<i>Discoaster mohleri</i>							
	<i>Heliolithus kleinpellii</i>				16-2			
	<i>Fasciculithus tympaniformis</i>					10-2		
	<i>Cruciplacolithus tenuis</i>		10-2		17-1/18-2	10-5		

Figure 2. Cenozoic coccolith zonation of core samples from Deep Sea Drilling Project Leg 40. The numbers assigned to zonal intervals are core and section numbers of samples examined. Where a zone or subzone is represented in samples from two or more core sections, the highest and lowest are given.

fragmented and solution-thinned. Samples from Cores 3 and 4 (98 to 146 m) are barren or nondiagnostic.

Core 5 (174 to 184 m) contains several Eocene coccolith zones. A diverse lower *Nannotetrina quadrata* Zone assemblage in Sample 361-5-1, 20-21 cm (174 m), contains *Rhabdosphaera gladius*, a middle Eocene marker species generally missing in deep-sea cores. Other species present include *Chiasmolithus grandis*, *C. solitus*, *Coccolithus staurion*, *Cyclicargolithus pseudo-*

gammation, *Discoaster mirus*, *D. nonradiatus*, *D. saipanensis*, *Ellipsolithus lajollaensis*, *Helicosphaera lophota*, *Nannotetrina quadrata*, *Reticulofenestra dictyoda*, *Sphenolithus radians*, and *Zygodolithus dubius*. The *Rhabdosphaera inflata* Subzone of Sample 361-5-4, 49-50 cm (176 m), contains exceptionally large numbers of both *Chiasmolithus solitus* and *Discoaster subloedenis*; *Rhabdosphaera inflata* is scarce. Similar domination of an *R. inflata* Subzone assemblage occurs

Site 360 Sample	Depth (m)	<i>Discoaster</i> / <i>Chiasmolithus</i> Ratio	Age
30-3, 9-11 cm	472	17/83	Oligocene
31-3, 49-50 cm	492	1/99	
35-1, 70-71 cm	564	36/64	
35-3, 49-50 cm	567	44/56	
36-1, 49-50 cm	574	48/52	Late Eocene
37-2, 49-50 cm	593	77/23	
38-1, 49-50 cm	612	89/11	
40-2, 49-50 cm	651	86/14	

Figure 3. Decrease in the *Discoaster/Chiasmolithus* ratio in dicates cooling conditions from the late Eocene to Oligocene at Site 360.

in Sample 264A-4-5, 60-61 cm (155 m), from a site at lat 34°58.13'S off southwestern Australia (Bukry, 1975b). The lowest sample, 361-5-6, 49-50 cm (179 m), is assigned to the *Discoaster lodoensis* Zone; *Chiasmolithus grandis* and *Discoaster lodoensis* are common; *Coccolithus crassus* is scarce; and there are no *Discoaster sublodoensis*. The same assemblage occurs in Sample 361-6-2, 49-50 cm (205 m), but the topmost sample of Core 7, 361-7-1, 78-79 cm (231 m), contains the younger *R. inflata* Subzone. The small recovery (less than one m) in junction with a skip-coring program suggests a probable in-hole slump.

Solution-resistant *Fasciculithus involutus* dominates the strongly dissolved upper Paleocene assemblage in Sample 361-9-2, 9-10 cm (260 m). The next most common species are *Discoaster mohleri* and *D. multi-radiatus*; placoliths are scarce.

The Danian age of the oldest sample examined, 361-10-2, 49-50 cm (270 m), is indicated by the occurrence of *Chiasmolithus* sp. cf. *C. danicus*, *Coccolithus pelagicus* s. ampl., *Cruciplacolithus tenuis*, *Markalius inversus*, and *Zygodiscus sigmoides*.

Site 362

(lat 19°45.45'S, long 10°31.95'E, depth 1325 m)

Site 362, on the Frio Ridge where the Walvis Ridge joins the continental margin of southwest Africa, was cored to date significant regional acoustic reflector horizons. Cenozoic coccolith assemblages, including an Oligocene *Braarudosphaera* chalk sequence, range from lower Eocene to Holocene. Silicoflagellates are prominent in upper Miocene to Holocene samples, and are distinctly similar to North Atlantic (Leg 37) and North Pacific (Leg 32) associations.

Discoasters are generally sparse through the Pliocene of Cores 5 to 13 (74 to 158 m), which impedes application of low-latitude zonations. This indication of cool-water conditions is supported by the high percentages of *Distephanus* (26% to 64%) among the silicoflagellates. Discoasters are more common in the Miocene, and this aids in recognition of numerous subzones. The appearance of *Discoaster berggrenii* in Core 26 and *Amaurolithus delicatus* in Core 23, and the disappearance of *Discoaster quinqueramus* in Core 20,

were used to identify the two subzones of the *Discoaster quinqueramus* Zone. *Discoaster loeblichii* in Sample 362-27-3, 49-51 cm (410 m), was used to indicate the upper part of the *Discoaster neohamatus* Zone.

A sparse occurrence of *Cyclococcolithina macintyreii* in Sample 362-37-3, 49-50 cm (619 m), may indicate the lower *Sphenolithus heteromorphus* Zone, but the dominance of *Discoaster deflandrei* among the discoasters is more typical of the *Helicosphaera ampli-aperta* Zone. The name-giving species *Helicosphaera ampli-aperta* also outnumbers *C. macintyreii*, an indication that the upper part of the *H. ampli-aperta* Zone was sampled.

Sphenolithus ciperoensis occurs with *Dictyococcites bisectus* and *Helicosphaera recta* in Sample 362A-2A-3, 49-50 cm (800 m), an association of the upper *Sphenolithus ciperoensis* Zone. The presence of *S. ciperoensis* and *S. distentus* in Sample 362A-3A-3, 49-50 cm (838 m) indicates the lower *S. ciperoensis* Zone. This sample is further distinguished by the frequent occurrence of *Rhabdosphaera procera*, as rhabdolithid coccoliths are generally missing from upper Oligocene oceanic assemblages.

Large, thick pentoliths of *Braarudosphaera* sp. cf. *B. bigelowii* and *B. rosa* are frequent to abundant in several samples from Cores 4A and 5A (872 to 920 m). The greatest abundances are in beds termed *Braarudosphaera* chalks, which contain Oligocene *Sphenolithus distentus* Zone coccolith assemblages. *Braarudosphaera* are sparser in other Oligocene zones, however; even within the *S. distentus* Zone, some levels lack *Braarudosphaera*, as for example Sample 362A-4A-5, 43-44 cm (878 m). In the core logs of the Initial Core Description for Leg 40, shipboard scientists illustrate 18 distinct *Braarudosphaera* beds of bluish white limestone in Core 4A and 16 in Core 5A. The *Braarudosphaera* beds, which range from 10 to 150 cm thick, are separated by drab gray marls of similar thickness.

Coccolith assemblages through the chalk and marl intervals are rather uniform. The only paleontologically significant difference between the two units is dilution of the normal assemblage by pentoliths and pentolith fragments of *Braarudosphaera* in the chalk beds (Plates 2 and 3). Pentoliths of a related genus, *Micrantholithus*, occur commonly only in Sample 362A-5A-1, 82-83 cm (911 m), which is further distinguished by having more than half of the *Braarudosphaera* specimens intact, rather than in the typical largely disaggregated state.

The general coccolith assemblage differs from those typical of open ocean only by the slightly more common occurrence of *Helicosphaera*. A representative assemblage, disregarding the pentolith species, includes *Chiasmolithus altus*, *Coccolithus eopelagicus*, *C. pelagicus*, *Cyclicargolithus abisectus*, *C. floridanus*, *Dictyococcites bisectus*, *D. scrippsae*, *Discoaster deflandrei*, *D. tanii*, *Helicosphaera compacta*, *H. euphratis*, *H. intermedia*, *H. perch-nielsenasae*, *H. wilcoxonii*, *Reticulofenestra* sp. cf. *R. gartneri*, *Sphenolithus distentus*, *S. moriformis*, *S. predistentus*, and *Zygrhablithus bijugatus*.

The distribution of *Braarudosphaera* chalk beds at DSDP Sites 14, 17, 19, 20, 22, and 362 suggests an essentially regional aberration of surface water

conditions during the late Oligocene in the South Atlantic Ocean. The episode at Site 362 was prolonged through the *Sphenolithus distentus* Zone. It was cyclical; at least 34 *Braarudosphaera* chalk beds, representing a maximum interbed period of 100,000 years or less, are recorded at Site 362. Other isolated *Braarudosphaera* chalks are at Oceanographer Canyon (*Alvin*-2698; lat 40°15'N, long 68°06'W) in the North Atlantic, at Site 209 in the western Pacific, and at Site 363 in the South Atlantic.

Of the various conditions that might account for the great abundance of a typical nearshore fossil in the open ocean (Roth, 1974), salinity and nutrient supply seem more important than temperature. Modern *Braarudosphaera* occur in significant numbers off Maine and Panama in marine waters of lower than normal salinity (Gran and Braarud, 1935; Smayda, 1966). A sessile life phase (Takayama, 1972; Bybell and Gartner, 1972) might explain its high relative abundance in nearshore areas and the thicker *Braarudosphaera* beds at nearshore sites in the South Atlantic. But this would not directly account for the cyclic mode of deposition and the lack of reworked specimens in deeper water deposits of the South Atlantic.

Inadequate knowledge of the true nature of the organism that produces *Braarudosphaera* skeletons hampers understanding of the anomalous oceanic *Braarudosphaera* beds. Is it a coccolithophore which blooms only when certain nutrients are optimal, or, is the reverse true—that it is an encystment life stage of an organism that normally lacks a mineralized skeleton, producing a *Braarudosphaera* skeleton only in response to the withdrawal of some essential nutrient? Although living *B. bigelowii* has been collected for biological study, long-term cultures have not been achieved (Lefort, 1972). Until laboratory-culture studies are done on the life cycle and nutrition of modern *Braarudosphaera*, interpretations of the Oligocene *Braarudosphaera* chalk beds are speculative.

The long geological range and conservative, compact skeletal form of *Braarudosphaera* (Fischer et al., 1967) suggest that it probably is an encystment. Because its greatest modern concentrations are found in marine areas of lower than normal ocean salinity (areas of high coastal runoff, or upwelled water), short-termed lowering of near-surface salinity, or some related factor, may account for the blooms of *Braarudosphaera* in the South Atlantic (Bukry, 1974). Periodic influx of near surface waters diluted by glacial meltwaters might have contributed to the low salinity pulses (Hsü, personal communication, 1977).

Isthmolithus recurvus is more common in the lower *Helicosphaera reticulata* Zone than in the underlying *Discoaster barbadiensis* Zone, but nowhere in such large numbers of specimens as were recorded at Site 360, which is 16 degrees farther south.

Eocene coccolith specimens of Cores 9A to 12A (996 to 1081 m) are poorly preserved, owing to diagenetic overgrowth and fragmentation. Coccolith debris is common. The top sample of Core 9A, 362A-9A-1, 107-108 cm (997 m), is assigned to the upper *Reticulo-*

fenestra umbilica Zone; but the presence of *Dictyococcites bisectus* and the scarcity of *Chiasmolithus grandis*, *Reticulofenestra umbilica*, *Sphenolithus furcatorolithoides*, and *Triquetrorhabdulus inversus* suggest a possible lower *Discoaster barbadiensis* Zone assemblage with reworking.

Triquetrorhabdulus inversus, missing at Site 360, is present through the middle Eocene at Site 362, indicating relatively warm conditions.

The oldest Cenozoic sample available from Site 362 is lower Eocene. Sample 362A-12A-1, 107-108 cm (1073 m), contains a thickly overgrown assemblage dominated by *Zygrhablithus bijugatus* and *Discoaster barbadiensis*. The most common placoliths are *Coccolithus crassus* and *C. magnicrassus*. Other taxa present include *Campylosphaera dela*, *Chiasmolithus* sp. cf. *C. grandis*, *Coccolithus pelagicus*, *Discoaster lodoensis*, *D. sp. cf. D. mirus*, and *Sphenolithus radians*. This is a *Discoaster lodoensis* Zone assemblage.

Site 363

(lat 19°38.75'S, long 9°02.80'E, depth 2248 m)

Site 363, on the north side of the Frio Ridge segment of the Walvis Ridge, was cored to obtain a Mesozoic reference section for this region. Drilling at nearby Site 362 was terminated in the lower Cenozoic because of bit failure. Cenozoic coccolith assemblages recovered at Site 363 range from lower Paleocene to middle Miocene. Coccoliths are abundant, but moderately to heavily etched and overgrown through the Cenozoic interval of Cores 1 to 18 (31 to 335 m).

The overlapping ranges of *Coccolithus miopelagicus*, *Cyclicargolithus floridanus* (abundant), *Discoaster deflandrei*, *D. exilis*, *Reticulofenestra pseudoumbilica*, *Sphenolithus* sp. cf. *S. abies*, and *Triquetrorhabdulus rugosus* in Sample 363-1-1, 49-50 cm (32 m) indicate the middle Miocene *Coccolithus miopelagicus* Subzone of the *Discoaster exilis* Zone.

Sample 363-1-5, 48-50 cm (38 m) contains the youngest known occurrence of the *Braarudosphaera* chalk in the South Atlantic. Pentaliths and pentalith fragments constitute about half of coccoliths present. *Braarudosphaera rosa* is more abundant than *B. bigelowii*, and populations of both are roughly 75 per cent fragmented specimens. The coccolith assemblage is assigned to the basal Miocene *Discoaster deflandrei* Subzone of the *Triquetrorhabdulus carinatus* Zone. Members of the assemblage include *Coccolithus miopelagicus* (unusually small centers), *C. pelagicus*, *Coronocyclus* sp., *Cyclicargolithus floridanus* (abundant), *Discoaster deflandrei* (common), *Helicosphaera euphratis*, *H. intermedia* (common), *Micrantholithus* sp. cf. *M. vesper*, *Sphenolithus moriformis*, *Triquetrorhabdulus carinatus*, and *T. milowii*.

Large but more meager *Braarudosphaera* in the basal *Sphenolithus distentus* Zone of Samples 363-6-2, 49-50 cm (127 m) and 363-7-1, 49-50 cm (145 m) occur with *Peritrichelina joidesa* and common *Zygrhablithus bijugatus*, suggesting shallow-marine conditions. *Sphenolithus distentus* is the most prominent sphenolith in Section 7-1, but a few giant specimens of *Sphenolithus pseudoradians* are present.

Etching of coccoliths increases slightly downward through Core 9. The lower sample, 363-9-4, 49-50 cm (187 m), contains a great abundance of solution-resistant *Isthmolithus recurvus* and *Discoaster nodifer*, but lacks any rosette discoasters. It is tentatively assigned to the uppermost Eocene because of the flood of *Isthmolithus*; the defining species for the *Discoaster barbadiensis* Zone are not present.

Ortholithid coccolith taxa, such as *Zygrhablithus bijugatus*, *Triquetrorhabdulus inversus*, and species of *Discoaster* are common to abundant through the Eocene. Rarely reported four-rayed specimens of *Discoaster martinii* occur in Sample 363-11-1, 49-50 cm (222 m), in an assemblage that also contains scarce *Discoaster* sp. cf. *D. bifax* and *Reticulofenestra umbilica*, and common *Chiasmolithus grandis* and *Sphenolithus furcatolithoides*.

The deepest Cenozoic sample, 363-18-2, 49-50 cm (327 m), has a moderately etched lower Paleocene assemblage including *Biantholithus sparsus*, *Braarudospaera* sp. cf. *B. bigelowii*, *Coccolithus pelagicus* s. ampl., *Cruciplacolithus tenuis*, *Markalius inversus*, *Thoracosphaera operculata*, and *Zygodiscus sigmoides*.

Site 364

(lat 11°34.32'S, long 11°58.30'E, depth 2448 m)

Site 364 is on the continental rise flanking the Angola Basin. The Cenozoic section of Cores 1 to 10 (8 to 359 m) was discontinuously cored, and lower Paleocene to Holocene coccolith assemblages were recovered.

Helicosphaera carteri and *Gephyrocapsa oceanica* are common in Holocene Sample 364-1-3, 49-50 cm (11 m). Samples from Core 2 (36 to 46 m) are barren.

Tropical lower Pliocene assemblages, as indicated by a great abundance of *Discoaster brouweri* and *D. pentaradiatus*, occur through Core 3 (65 to 73 m). Some solution thinning of placoliths and fragmentation of discoasters into individual rays are evident. A general lack of *Sphenolithus*, a tropical indicator, and of siliceous phytoplankton suggests that unusual paleoecologic conditions, not simply temperature, were operating to create the flood of discoasters relative to other coccoliths.

Helicosphaera ampliapertura is scarce and *Sphenolithus heteromorphus* abundant in the upper lower Miocene *Helicosphaera ampliapertura* Zone of Sample 364-5-3, 49-50 (152 m). Samples from Cores 6 and 7 (197 to 255 m) are barren.

A compressed sequence of lower Eocene and Paleocene zones occurs in Cores 8 to 10 (283 to 359 m). The *Discoaster lodoensis* Zone of Sample 364-8-3, 49-50 cm (287 m), contains *Campylosphaera dela*, *Chiasmolithus grandis*, *Coccolithus crassus*, *C. cribellum*, *C. sp. cf. C. formosus*, *C. magnicrassus*, *Cyclococcolithina?* sp. cf. *C. gammation*, *Discoaster barbadiensis*, *D. lodoensis*, *D. sp. cf. D. mirus*, *Discoasteroides kuepperi*, and *Sphenolithus radians*. It lacks abundant *Zygrhablithus bijugatus*, a shallow-water indicator dominant at Site 362. The upper Paleocene *Campylosphaera eodela* Subzone is characterized by *Campylosphaera eodela*

(common), *Chiasmolithus bidens*, *C. consuetus*, *Discoaster multiradiatus*, *D. nobilis*, *Ellipsolithus macellus*, *Neochiastozygus chiastus*, *N. distentus*, and *Toweius craticulus*. Lower Paleocene assemblages are more strongly etched than those just described. For example, the *Fasciculithus tympaniformis* Zone of Sample 364-10-2, 49-50 cm (351 m), is characterized by resistant placolith rims and species of *Fasciculithus* including *F. involutus*, *F. janii*, *F. pileatus*, and *F. tympaniformis*.

Site 365

(lat 11°39.10'S, long 11°53.72'E, depth 3018 m)

No Cenozoic samples were available from this site on the continental rise of the Angola Basin. Coring between 225 and 687 meters subbottom was part of an attempt to directly sample the Aptian salt layer presumed to underlie the basin. See report of shipboard scientists.

NEOGENE SILICOFLAGELLATE CORRELATION

Silicoflagellates are scarce to common in upper Miocene to Holocene samples from Site 362 on the Frio Ridge. Specimen counts for 14 samples through the 133-meter interval of Cores 1 to 14 indicate the relative abundance and range of stratigraphic and paleoecologic guide fossils (Figure 4).

Several similarities in ranges and abundances of species exist between Site 362 and other Deep Sea Drilling Project sites in the North Atlantic and Pacific oceans. The disappearances of *Mesocena circulus*, *Dictyocha brevispina*, and *Distephanus boliviensis jimlingii* or *D. boliviensis major*, and the first, consistent, common to abundant occurrence of *Dictyocha stapedia stapedia* are noted in the upper Pliocene to lower Pleistocene at Site 362 and at Site 333 (lat 37°N) in the North Atlantic, Site 310 (lat 37°N) in the North Pacific (Figure 5), and Site 321 (lat 12°S) in the South Pacific.

Another distinctive feature common to the two Atlantic sites is an upper Pliocene acme horizon of *Dictyocha perlaevis ornata*—38% in Core 7 at Site 362 and 52% in Core 2 at Site 333 (Bukry, in press). In regional settings of similar ecology, horizons of short-termed taxa, such as *D. perlaevis ornata*, may provide useful guides for correlation.

Biostratigraphically, the presence of *Dictyocha aculeata* in Sample 362-1-4, 49-51 cm (41 m), indicates the Quaternary *Dictyocha aculeata* Zone. The Pliocene/Pleistocene boundary based on silicoflagellate evidence is not well established for various locations. Coccolith evidence shows this boundary to be within the lower part of Core 4 or the upper part of Core 5 at Site 362. Several changes in silicoflagellate assemblages occur in or near this interval, including a marked increase in the numbers of *Dictyocha stapedia stapedia* and the disappearance of *Distephanus boliviensis major* group. A persistence of *Distephanus boliviensis boliviensis* from the Pliocene into the Pleistocene here suggests that the first common occurrence of *D. stapedia stapedia* at middle latitudes in the Atlantic is a

SYSTEMATIC PALEONTOLOGY

Genus DICTYOGCHA Ehrenberg, 1837

Dictyocha hessii n. sp.

Dictyocha sp. cf. *D. aspera* Lemmermann, Dumitrica, 1973 (in part), Deep Sea Drilling Proj. Initial Repts., v. 13, p. 907, pl. 7, fig. 4-7.

Dictyocha lingi Dumitrica, Dumitrica, 1973 (in part), Deep Sea Drilling Proj. Initial Repts., v. 21, p. 848, pl. 3, fig. 4.

Description: *Dictyocha hessii* has a small to moderate basal ring that is finely apiculate along the periphery. The apical bar is moderate and oriented perpendicular to the major axis. Spines are moderate and the basal ring is slightly elongate and scalloped. Basal pikes are small and located at or beside the strut-ring junctions.

Remarks: *Dictyocha hessii* is distinguished from *D. lingii* by a more scalloped outline instead of a more continuous ellipse, also by the apical structure which is of regular thickness. *D. hessii* is distinguished from *D. perlaevis ornata* by the apical bar orientation and by the irregular and more abundant apiculation of the basal ring. *D. hessii* is distinguished from other small to moderate asperoid taxa, such as *D. pulchella*, *D. varia*, and *D. vexativa*, by its apiculate periphery.

Occurrence: The holotype and isotypes of *Dictyocha hessii* are from the lower Quaternary of Site 128 in the Mediterranean Sea. Other specimens occur in the Quaternary at Sites 206, 310, and 412 which extends the range of *D. hessii* through the Atlantic and Pacific Oceans. It is sparse to common at these sites.

Size: Maximum internal diameter 25 to 45 μm ; holotype (28 μm).

Holotype: Plate 7, figure 6 of Dumitrica, 1973, DSDP Volume 13.

Isotypes: Plate 7, figures 4, 5, 7 of Dumitrica, 1973, DSDP Volume 13.

Type locality: Mediterranean Sea, Sample 128-11-3, 148-150 cm (475 m).

Dictyocha pumila (Ciesielski) n. comb.

Dictyocha fibula var. *pumila* Ciesielski, 1975, v. 28, p. 656, pl. 5, fig. 5-10; pl. 6, fig. 1, ?2.

Remarks: *Dictyocha pumila* is a distinctive fibuloid species from Antarctic waters (Ciesielski, 1975). It has a basal ring that is slightly and unevenly, convexly flexed. *D. pumila* is distinguished from the *D. fibula* group by its asymmetric strut placement and canted apical bar. It is distinguished from the *D. perlaevis* and *D. stapedia* groups by irregular outline and curved spines. In terms of size and proportions, *D. pumila* is most similar to *D. stapedia aspinosa*; it is distinguished by its irregular flexed outline. And Pliocene populations of *D. stapedia aspinosa* have a propensity to develop strut pikes.

Dictyocha vexativa n. sp.

(Plate 1, Figures 10-14)

Description: *Dictyocha vexativa* has a small, very slightly elongate and rounded, rhomboid basal ring. Spines are straight and short to moderate in length. Four basal pikes are slightly offset from the strut junctures, clockwise in apical view. The apical bar is short, axially aligned and the strut-bar-strut outline is rounded. The struts appear to narrow slightly away from the bar, toward the basal ring. One or more of the struts are usually curved in apical view. Asperoid and fibuloid forms occur.

Remarks: *Dictyocha vexativa* is distinguished from *D. pulchella* by its more elongate and less rounded basal ring. It is distinguished from *D. brevispina* by its smaller size, and from *D. aspera* by its more nearly H-shaped apical structure. The tapering, slightly curved struts and short apical bar help distinguish *D. vexativa* from other taxa.

Occurrence: *Dictyocha vexativa* was first recorded in the Quaternary of DSDP Site 310 in the North Pacific. It was thought to be a local phenotype because substantial Quaternary populations of small asperoid *Dictyocha* spp. were unknown. However, the occurrence of the same form in the Quaternary at Site 362 suggested a potential value for this species in Quaternary stratigraphy and paleoecology of middle latitude sites.

Size: Maximum internal diameter 22 to 28 μm ; holotype 22 μm .

Holotype: USNM 240292 (Plate 1, Figures 12, 13).

Isotypes: USNM 240293 and 240294.

Type locality: Southeastern Atlantic Ocean, Sample 362-4-1, 49-51 cm (65 m).

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D. aspera clinata Bukry—Bukry, 1975c
D. brevispina (Lemmermann)—Bukry, 1976b
D. fibula fibula Ehrenberg—Ling, 1972
D. lingii Dumitrica—Dumitrica, 1973
D. perlaevis delicata Bukry—Bukry, 1976b
D. perlaevis ornata Bukry—Bukry, in press
D. perlaevis perlaevis Frenguelli—Bukry, 1976b
D. pulchella Bukry—Bukry, 1975a
D. stapedia aspinosa Bukry—Bukry, 1976b
D. stapedia stapedia Haeckel—Bukry, 1976b
D. subarctios Ling—Ling, 1970
D. varia Locker—Locker, 1975
Distephanus boliviensis boliviensis (Frenguelli)—Bukry and Foster, 1973
D. boliviensis frugalis Bukry—Bukry, 1975c
D. boliviensis jimlingii Bukry—Bukry, 1975c
D. boliviensis major (Frenguelli)—Bukry and Foster, 1973
D. crux (Ehrenberg)—Ling, 1972
D. speculum elongatus Bukry—Bukry, 1975c
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D. speculum pentagonus Lemmermann—Ling, 1972
D. speculum quintus (Bukry and Foster)—Bukry and Foster, 1973
D. speculum speculum (Ehrenberg)—Martini, 1971
D. varians (Gran and Braarud)—Bukry, 1976a
Mesocena circulus (Ehrenberg)—Bukry, 1975a
M. diodon Ehrenberg—Bukry, 1975a
M. elliptica (Ehrenberg)—Bukry and Foster, 1973
Naviculopsis quadrata (Ehrenberg)—Ling, 1972
Octactis pulchra Schiller—Bukry and Foster, 1973

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PLATE 1
Silicoflagellates from DSDP Leg 40

Figure 1, magnification 500×; scale bar equals 10 μm; Figures 2-16, magnification 800×; scale bar equals 10 μm.

- Figure 1 *Dictyocha* sp. cf. *D. brevispina* (Lemmerman).
Aberrant mimic of *Mesocena elliptica*.
Sample 362-14-3, 49-51 cm (163 m).
- Figure 2, 3 *Dictyocha* sp. cf. *D. brevispina* (Lemmermann).
Aberrant mimic of Paleocene *Corbisema disymmetrica disymmetrica*.
Sample 362-14-1, 49-51 cm (160 m).
- Figure 4 *Dictyocha* sp. cf. *D. perlaevis* Frenguelli.
Small form.
Sample 362-10-3, 49-51 cm (125 m).
- Figures 5, 6 *Dictyocha* sp. cf. *D. perlaevis* Frenguelli.
Lopsided form.
5. Sample 362-6-2, 49-51 cm (86 m).
6. Sample 362-7-3, 49-51 cm (96 m).
- Figures 7, 8 *Dictyocha perlaevis ornata* Bukry.
Sample 362-6-2, 49-51 cm (86 m).
- Figure 9 *Dictyocha* sp. cf. *D. stapedia aspinosa* Bukry.
Less H-shaped apical structure than *Dictyocha vexativa*.
Sample 362-4-1, 49-51 cm (65 m).
- Figures 10-14 *Dictyocha vexativa* n. sp.
10, 11. USNM 240293, Sample 362-4-1, 49-51 cm (65 m).
12, 13. Holotype, USNM 240292, Sample 362-4-1, 49-51 cm (65 m).
14. USNM 240294, Sample 362-2-5, 49-51 cm (52 m).
- Figure 15 *Distephanus boliviensis boliviensis* (Frenguelli).
Aberrant specimen; apical ring unjoined by three struts.
Sample 362-5-4, 49-51 cm (79 m).
- Figure 16 *Mesocena circulus* (Ehrenberg).
Recurved form.
Sample 362-6-2, 49-51 cm (86 m).

PLATE 1

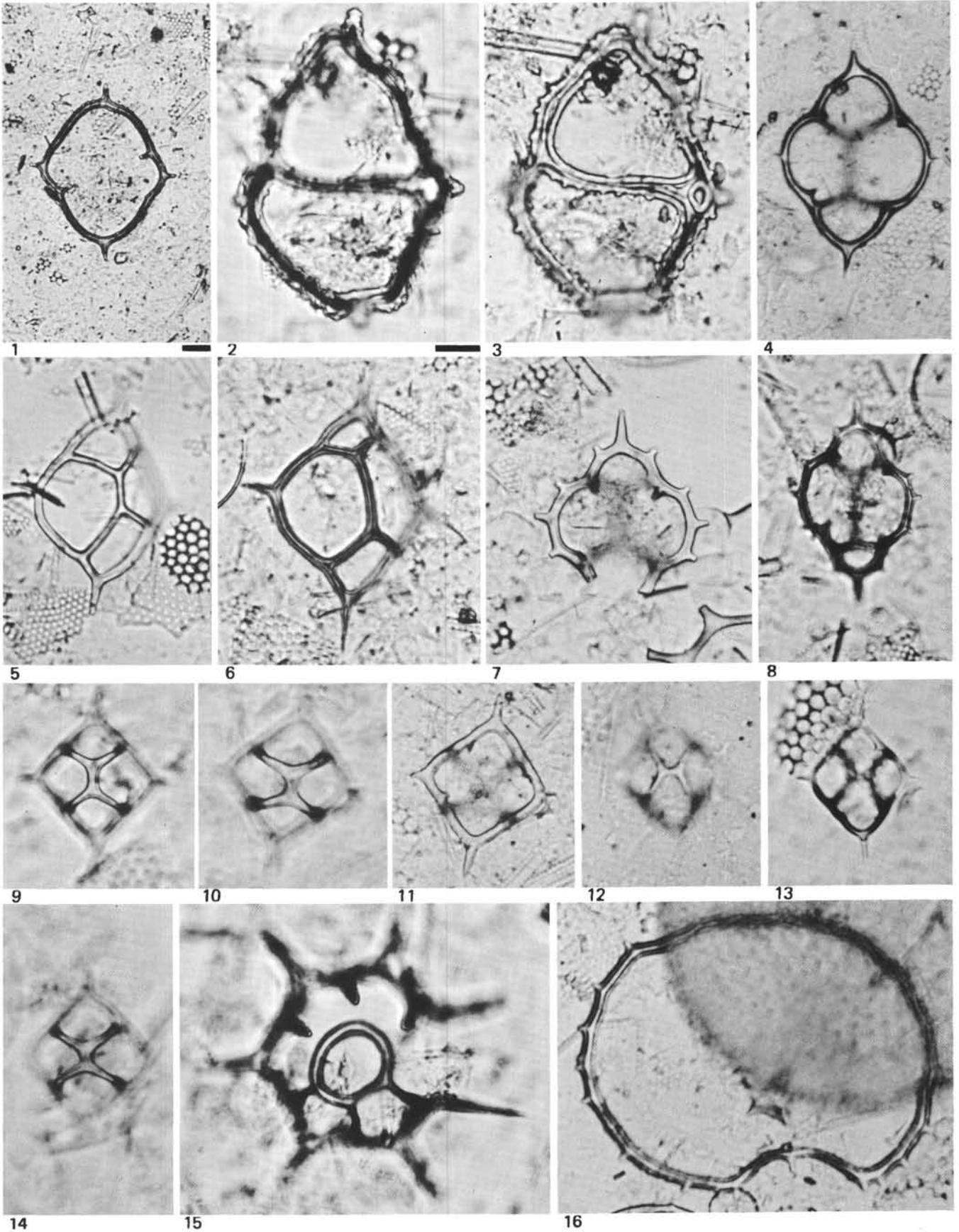


PLATE 2

Braarudosphaera-rich, deep-sea sediment from DSDP Sites 22, 362, 363, and *Alvin*-2698 in the Atlantic Ocean.

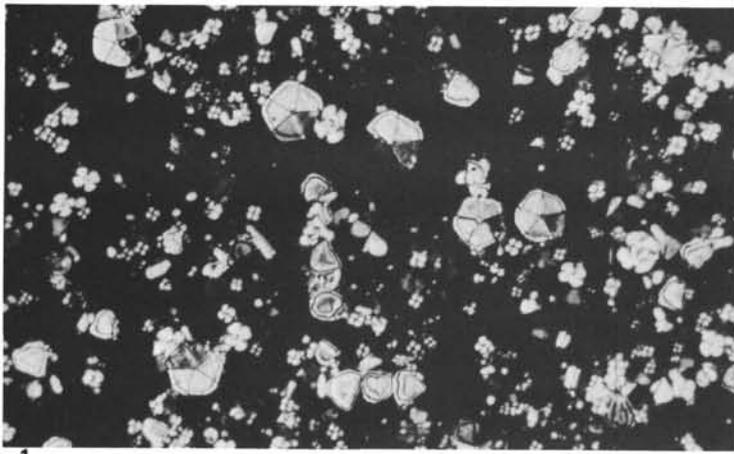
Figures 1-3, magnification 500 ×; scale bar equals 10 μm;

Figure 4, magnification 2500 ×; scale bar equals 5 μm;

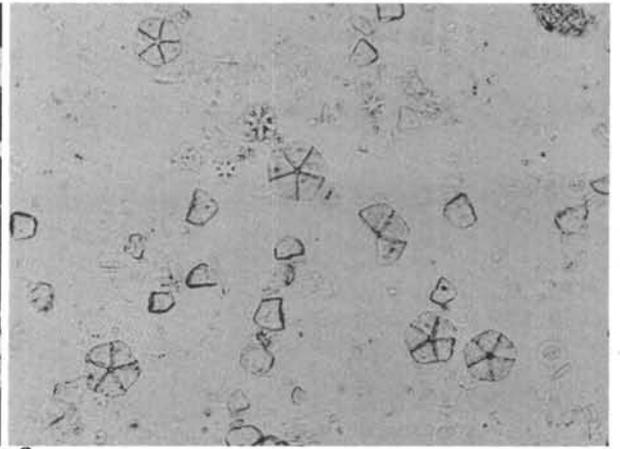
Figures 5-8, magnification 800 ×; scale bar equals 10 μm.

- Figures 1, 2 Upper Oligocene sediment having abundant intact pentoliths and wedge-shaped fragments of the coccolith species *Braarudosphaera rosa*. Sample 363-6-2, 49-50 cm (127 m).
1. Cross-polarized photomicrograph (XP).
2. Bright-field photomicrograph (BF).
- Figure 3 Abundant *Braarudosphaera bigelowii* s. ampl. and *B. rosa* and fragments from a *Braarudosphaera* chalk bed (BF).
Sample 362A-5A-1, 82-83 cm (911 m).
- Figure 4 *Braarudosphaera rosa* from the upper Oligocene of the North Atlantic. Transmission electron-micrograph. Sample *Alvin*-2698.
- Figures 5, 6 Sediment rich in *Braarudosphaera* fragments. Sample *Alvin*-2698.
5. (BF).
6. (XP).
- Figures 7, 8 *Braarudosphaera rosa* specimens and fragments are distinctly larger and thicker than associated coccoliths. Sample 363-6-2, 49-50 cm (127 m).
7. (XP).
8. (BF).

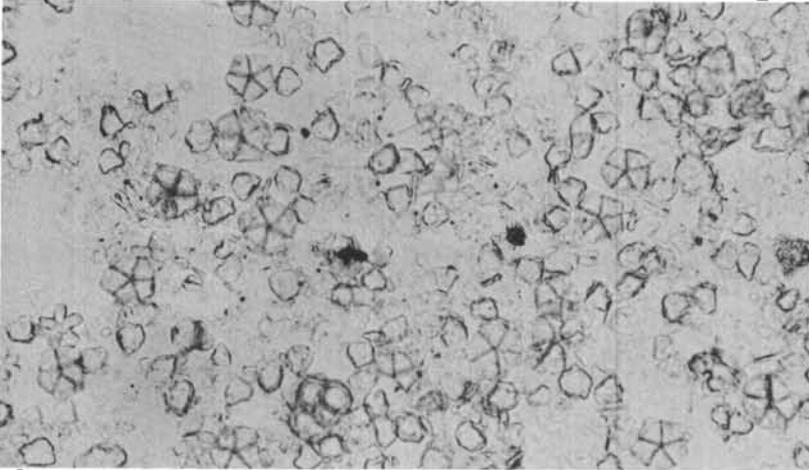
PLATE 2



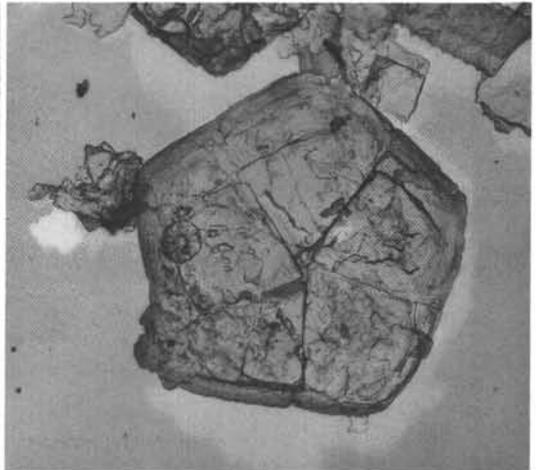
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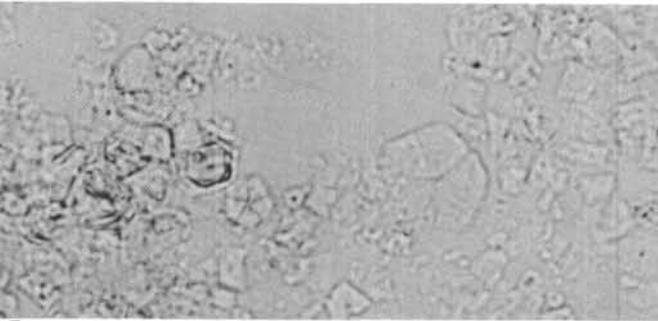
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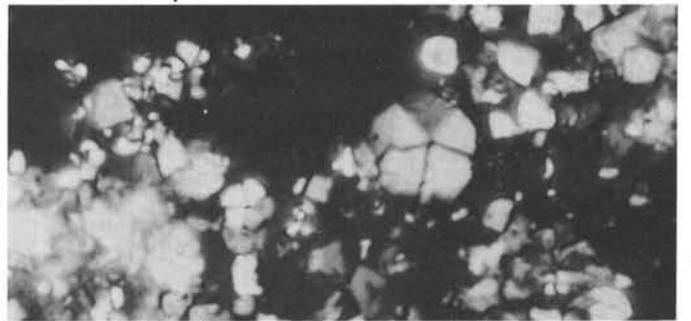
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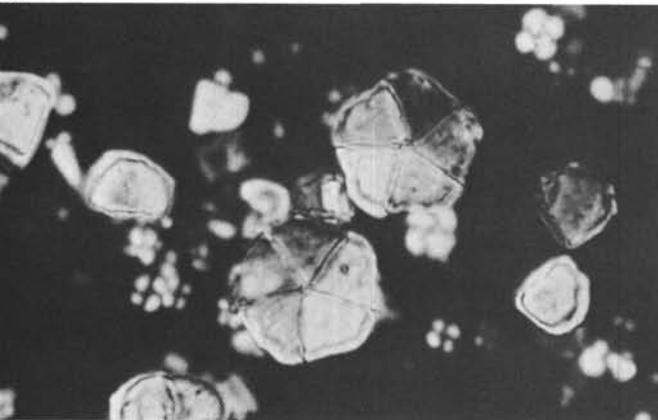
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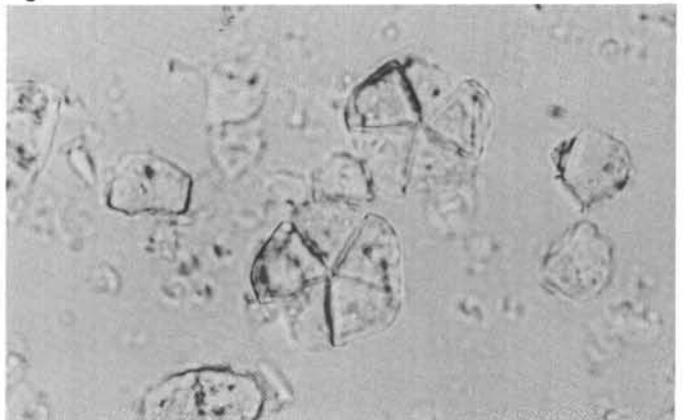
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PLATE 3

Braarudosphaera-bearing, deep-sea sediment from DSDP Sites 22, 362, 363, in the Atlantic Ocean, and WHOI Core 1443G, 6 cm, in the Black Sea.

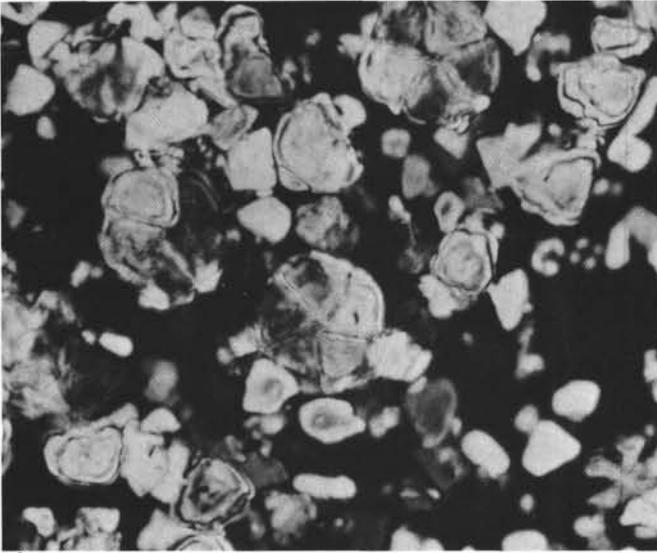
Figures 1, 2, 5, 6, magnification 800 ×; scale bar equals 10 μm;

Figures 3, 4 magnification 1000 ×; scale bar equals 10 μm;

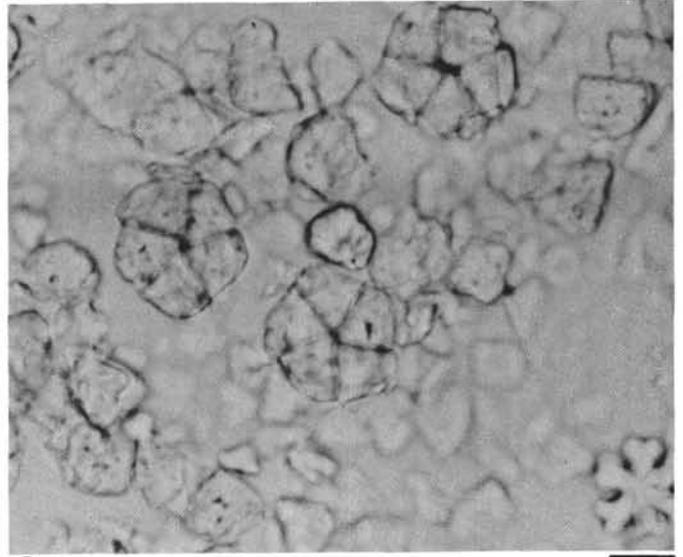
Figures 7, 8, magnification 500 ×; scale bar equals 10 μm.

- Figures 1, 2 Abundant intact pentoliths and wedge-shaped fragments of the coccolith species *Braarudosphaera rosa* from an upper Oligocene *Braarudosphaera* chalk bed. *Discoaster deflandrei* at lower right. Sample 22-4-1, 74-75 cm (134 m).
1. Cross-polarized photomicrograph (XP).
2. Bright-field photomicrograph (BF).
- Figures 3, 4 *Braarudosphaera bigelowii* in a Holocene coccolith ooze from the Black Sea. *B. bigelowii*, although physically prominent, is much less abundant than the associated oval coccoliths (XP). Sample 1443 G, 6 cm.
- Figures 5, 6 Irregularly overgrown and fragmented upper Oligocene *Braarudosphaera rosa*. Sample 362A-4A-3, 21-23 cm (875 m).
5. (XP).
6. (BF).
- Figures 7, 8 *Braarudosphaera rosa* and fragments, top and side views, in upper Oligocene coccolith assemblage. Sample 363-6-2, 49-50 cm (127 m).
7. (XP).
8. (BF).

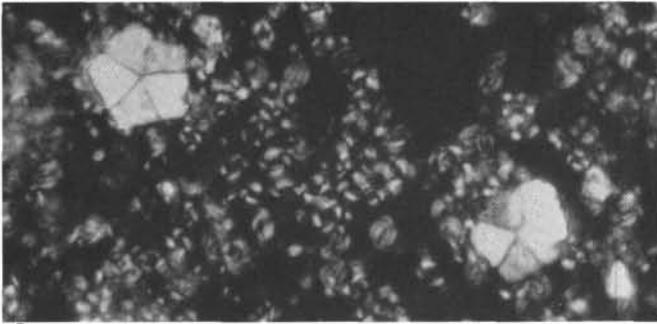
PLATE 3



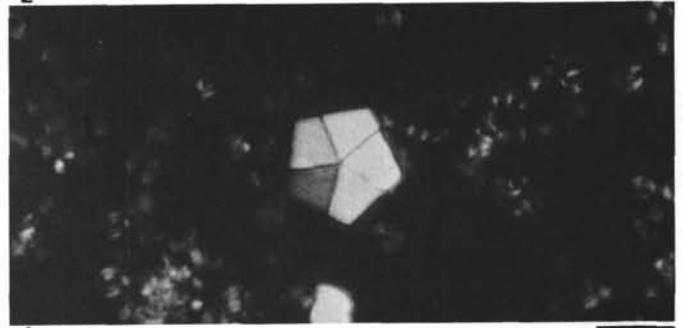
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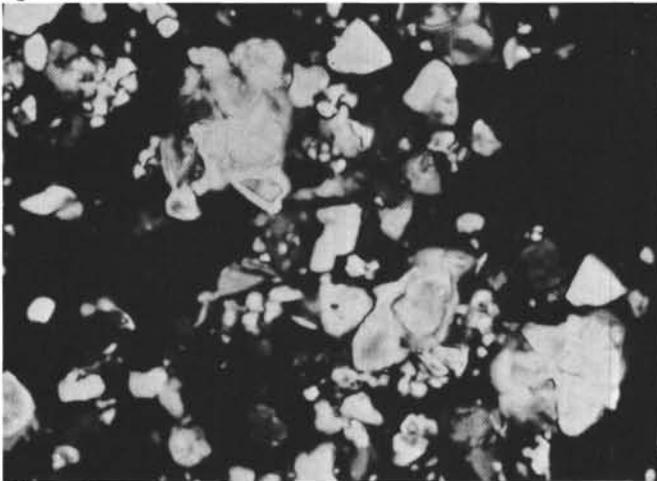
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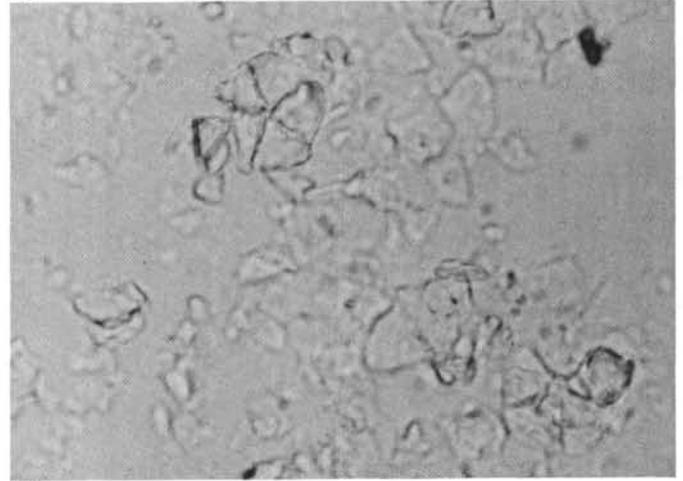
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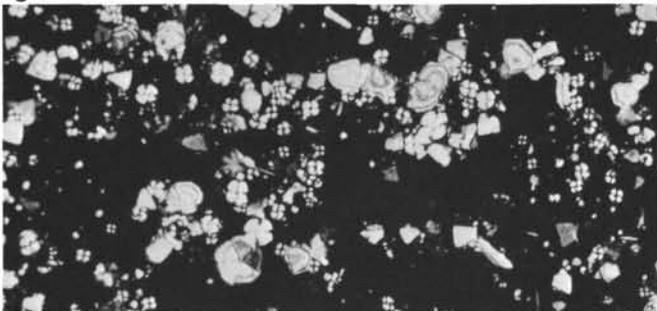
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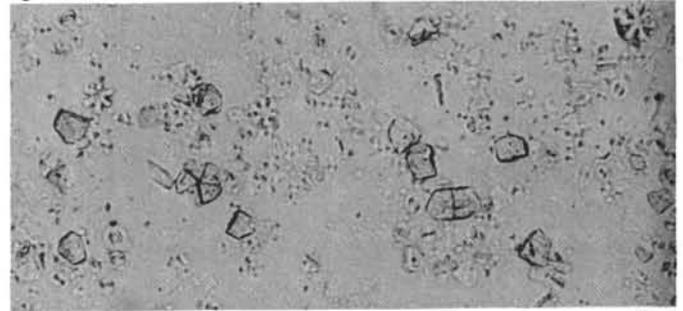
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