27. COCCOLITH AND SILICOFLAGELLATE STRATIGRAPHY, EASTERN INDIAN OCEAN, DEEP SEA DRILLING PROJECT LEG 22¹

David Bukry, United States Geological Survey, La Jolla, California

INTRODUCTION

Leg 22 of the Deep Sea Drilling Project, January to March 1972, which began at Darwin, Australia, and ended at Colombo, Ceylon, investigated the eastern Indian Ocean, recovering 275 cores at eight drilling sites (Figure 1). Light-microscope techniques were used to study the coccoliths and silicoflagellates in 312 samples from these cores and to indicate the presence of diatoms. Of these phytoplankton groups, coccoliths are present most consistently. The zonation employed in coccolith zonal assignments of core samples (summarized in Figure 2) is based on Bukry, in press (a). Late Cretaceous silicoflagellates from Site 216 are shown (Plate 1).

SITE SUMMARIES

SITE 211

(lat 9°46.53'S, long 102°41.95'E, depth 5535 m)

The only samples available from Site 211, Cores 1 to 6 (0 to 190 m), are barren of coccoliths. The sediment is rich in siliceous phytoplankton and Radiolaria. Silicoflagellates and diatoms are most abundant in the upper two cores, where tropical Pleistocene assemblages are present. Radiolarians are dominant in the lower cores as a result of solution of silicoflagellates and diatoms. Phytoplankton assemblages of Sample 211-1-1, 75-76 cm (1 m) are assigned to the tropical *Dictyocha epidon* Zone of silicoflagellates (Bukry and Foster, 1973) and the *Pseudoeunotia doliolus* Zone of diatoms (Burckle, 1972). Only two silicoflagellate species were found; a count of 100 specimens gave the following percentages: *Dictyocha epidon* (41%); *D. fibula* (59%). The diatom assemblage is numerically dominated by abundant fragments of *Ethmodiscus rex* and *Thalassiothrix longissima*. The next most common species are *Coscinodiscus nodulifer*, *Hemidiscus cuneiformis*, *Pseudoeunotia doliolus*, and *Rhizosolenia styliformis*. A relatively rare occurrence of *Actinopteryx senarius*, *Asteromphalus arachne*, *A. imbricatus*, *Coscinodiscus excentricus*, *Nitzschia marina*, *Rhizosolenia bergonii*, and *Triceratium cinnamomeum minor* probably reflects differential dissolution, as these taxa are relatively common at shallower oceanic sites (DSDP 157). In Sample 211-2-1, 75-76 (10 m), the same zones are present, although the species proportions differ. A count of 150 silicoflagellates shows 71% *Dictyocha fibula*, 21% *D. epidon*, 1% *Mesocena elliptica*, 1% *Octactis pulchra*, and <1% *Distephanus speculum*. Among diatoms, *Asteromphalus imbricatus* and *Pseudoeunotia doliolus* are common, and *Ethmodiscus rex* fragments are meager.

SITE 212

(lat 19°11.34'S, long 99°17.84'E, depth 6243 m)

Coccolith assemblages are typically overgrown and contain reworked specimens. For example, the Miocene *Sphenolithus heteromorphus* Zone of Sample 212-10-1, 75-76 cm (165 m) has Eocene taxa such as *Chiasmolithus grandis* and *Isthmolithus recurvus*. The middle Eocene *Discoaster bifax* Subzone of Sample 212-18-3, 34-45 cm (329 m) contains Paleocene or lower Eocene taxa such as *Discoaster multiradiatus*, *D. lodoensis*, and *Tribrachiatus orthostylus*. Indigenous species permitting subzonal assignment include *Chiasmolithus grandis*, *Coccolithus eopelagicus* s. str., *Discoaster bifax*, and *Reticulofenestra umbilica*.

Nephrolithus frequens, a shallow-water indicator for the late Maastrichtian, is present in well-diversified coccolith assemblages of Cores 31 to 35 (440 to 488 m). *Markalius astroporus* and *Kamptnerius magnificus* also occur in the assemblages that are excellent correlatives with those at coeval European localities.

SITE 213

(lat 10°12.71'S, long 93°53.77'E, depth 5611 m)

Samples available from Cores 1 to 8 (0 to 76 m) contain few silicoflagellates, abundant diatoms, and no coccoliths. Samples from Cores 15 and 16 (133 to 152 m) contain an upper Paleocene and lower Eocene coccolith sequence.

Silicoflagellates in Sample 213-1-1, 20-21 cm (0 m), indicate the late Quaternary *Dictyocha epidon* Zone. A sparse assemblage of 27 specimens includes 60% *Dictyocha fibula*, 30% *D. epidon*, 7% *Mesocena elliptica*, and 3%

Figure 1. Location of Leg 22 sites in the eastern Indian Ocean.

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

Series or Subseries	Zone	Subzone	DSDP Hole							
			212	213	214	215	216	216A	217	218
Holocene	<i>Emiliania huxleyi</i>									
Pleistocene	<i>Gephyrocapsa oceanica</i>						1-6		1-1/14	2-2/6-2
	<i>Coccolithus doronicoides</i>	<i>Gephyrocapsa caribbeanica</i>								
		<i>Emiliania annula</i>			3-1					8-2
Upper Pliocene	<i>Discoaster brouweri</i>	<i>Cyclococcolithina macintyreii</i>			3-3/4-1					
		<i>Discoaster pentaradiatus</i>			4-3/4-5					10-1
		<i>Discoaster tamalis</i>			5-3/5-6					
Lower Pliocene	<i>Reticulofenestra pseudumbilica</i>	<i>Discoaster asymmetricus</i>			6-2/6-3					
		<i>Sphenolithus neoabies</i>			6-4/7-3		2-2/2-4		2-2/2-4	
	<i>Ceratolithus tricorniculatus</i>	<i>Ceratolithus rugosus</i>	1-1/2-4		8-2					
Upper Miocene		<i>Ceratolithus acutus</i>			? 9-2					
		<i>Triquetrorhabdulus rugosus</i>	3-1/?4-1		10-2/10-5					
	<i>Discoaster quinquerramus</i>	<i>Ceratolithus primus</i>	?5-1/8-2		10-6/13-2		3-2			
		<i>Discoaster berggrenii</i>			14-2			1A-6	3-1	13-2/19-2
	<i>Discoaster neohamatus</i>	<i>Discoaster neorectus</i>						2A-6		
		<i>Discoaster bellus</i>	9-1		15-2/16-5			2A-6	4-2/4-6	23-2
Middle Miocene	<i>Discoaster hamatus</i>				17-1/17-5					? 25-2
	<i>Catinaster coalitus</i>				?18-2					
	<i>Discoaster exilis</i>	<i>Discoaster kugleri</i>			?19-2					
		<i>Coccolithus miopelagicus</i>	10-1/15-1		20-2		4-2/4-5	3A-6/4A-6		
	<i>Sphenolithus heteromorphus</i>				21-2			5A-6		
Lower Miocene	<i>Helicopontosphaera ampliaperta</i>				22-1			6A-6		
	<i>Sphenolithus belemnus</i>				22-2/22-5		5-2			
	<i>Triquetrorhabdulus carinatus</i>	<i>Discoaster druggii</i>								
		<i>Discoaster deflandrei</i>			22-6/24-2		6-1/8-2		6-1	
		<i>Cyclacargolithus abisectus</i>							6-6	
Oligocene	<i>Sphenolithus ciperoensis</i>				24-3/25-2		9-2/10-2		7-2/7-6	
	<i>Sphenolithus distentus</i>						12-2		8-1	
	<i>Sphenolithus predistentus</i>				26-2		14-2		9-1	
	<i>Helicopontosphaera reticulata</i>	<i>Reticulofenestra hillaie</i>								
		<i>Cyclococcolithina formosa</i>			27-2/27-6		15-2/15-3		9-5	
		<i>Coccolithus subdistichus</i>								
Upper Eocene	<i>Discoaster barbadiensis</i>				28-2/28-6		16-1-16-3			
Middle Eocene	<i>Reticulofenestra umbilica</i>	<i>Discoaster saipanensis</i>					? 17-1/17-2			
		<i>Discoaster bifax</i>	18-3/26-6		29-2/30-5					
	<i>Nannotetrina quadrata</i>	<i>Coccolithus staurion</i>			31-2/31-5				10-2/10-6	
		<i>Chiasmolithus gigas</i>			32-2/32-6					
		<i>Discoaster strictus</i>								

these cores are similar, containing *Chiasmolithus danicus* (and varieties), *Coccolithus pelagicus* s. ampl., *Prinsius bisulcus*, and rare *Cruciplacolithus tenuis*.

Silicoflagellates of the early Paleocene *Corbisema hastata* Zone (Bukry and Foster, in press) are most common in Sample 214-38-3, Top (354 m). A count of 50 specimens shows 48% *Corbisema hastata*, 26% *C. triacantha*, 24% *C. geometrica*, and 2% *C. schulzii*. The dominance of *C. hastata*, *C. geometrica*, and *C. triacantha* is similar to determinations for the early Paleocene at DSDP 208 in the Tasman Sea where these species compose 83% to 100% of the assemblages (Bukry, in press b).

SITE 215

(lat 8°07.30'S, long 86°47.50'E, depth 5319 m)

Diatom assemblages from Cores 1 to 7 (0 to 65 m) are being studied by H. J. Schrader. Initial determinations show an excellent sequence of late Miocene to Pleistocene warm-water assemblages ranging from the *Thalassiosira convexa* Zone to *Pseudoeunotia dolioles* Zone.

Silicoflagellates are rare in Core 1, but the sparse occurrence of *Dictyocha epidon* and *Mesocena elliptica* in Sample 215-1-4, 25-27 cm (5 m) indicates middle or late Quaternary. In Core 7, silicoflagellates are abundant. A count of 300 specimens for Sample 215-7-2, 50-52 cm (56 m) shows 54% *Dictyocha fibula*, 40% *Dictyocha aspera* s. ampl., 5% *Distephanus* sp. cf. *D. speculum* (lacks apical ring and struts), <1% each of *Distephanus speculum* s. str., *Dictyocha pseudofibula*, and *Corbisema triacantha*. The abundance level of *D. aspera* relative to *D. fibula* suggests the early part of *Dictyocha fibula* Subzone, which is late late Miocene in age.

Coccolith-bearing samples were available only from Cores 10 to 16 (84 to 150 m), which range in age from early Paleocene to early Eocene. Preservation and diversity are good, providing an excellent late Paleocene section. Noteworthy in the section are a prominent occurrence of *Cyclolithella? robusta* in the *Fasciculithus tympaniformis* Zone of lower Core 16; a great abundance of *Heliolithus kleinpellii* near the top of Core 15; and the exceptionally large size of specimens in the *Chiasmolithus bidens* Subzone of the *Discoaster multiradiatus* Zone of Core 12.

SITE 216

(lat 1°27.73'N, long 90°12.48'E, depth 2247 m)

Coccolith samples from Holes 216 and 216A indicate a continuous pelagic record from late Maastrichtian to late Pleistocene. The assemblages are unusual in the great dominance of some species and the absence of others at various levels. Silicoflagellates are exceptionally abundant in the late Maastrichtian of Cores 30 to 32 (396 to 425 m), where the rarely reported species *Vallacerta hortonii*, *V. tumidula*, and *Lyrarula furcula* are present.

Examples of noteworthy coccolith occurrences include a *Discoaster quinqueramus* ooze in Sample 216-3-2, 75-76 cm (84 m). Large *Cyclicargolithus abisectus* occurs in the lower *Sphenolithus ciperoensis* Zone of Sample 216-10-2, Top (207 m). Upper Eocene assemblages of Core 16 (263 to 273 m) are unusual in the absence of *Reticulofenestra umbilica* and in the great abundance of *Reticulofenestra reticulata* instead. In the *Discoaster mohleri* Zone of Sample

216-20-3, 75-76 cm (304 m), *Fasciculithus tympaniformis* predominates. The upper Maastrichtian in Cores 27 to 34 contains assemblages characterized by *Arkhangelskiella cymbiformis*, *Kamptnerius magnificus*, and *Nephrolithus frequens*. Such assemblages are more comparable to coeval shallow-marine assemblages from northern Europe than to those from previous deep-water, low-latitude Deep Sea Drilling Project sites.

Late Maastrichtian samples from Cores 30 to 32 are further distinguished by the common occurrence of diatoms and silicoflagellates, but samples from Core 34 (434 to 444 m) contain abundant volcanic ash, and no siliceous phytoplankters were seen. Of the silicoflagellates present in Cores 30 to 32, *Vallacerta tumidula* is reported for only the second time since its original description in the Late Cretaceous of western Siberia (Glezer, 1959). *Vallacerta hortonii* has been noted previously only from western Siberia (Glezer, 1966), northern Germany (Mandra, 1968), and the Moreno Shale of California (Hanna, 1928; Mandra, 1968; Ling, 1972). Both species occur together in Cores 31 and 32 (Figure 3). *Lyrarula furcula* and related forms dominate the assemblages, which are assigned to the *Lyrarula furcula* Zone (Bukry and Foster, in press). A remarkably similar assemblage of silicoflagellates has been found on the Campbell Plateau (lat 50°S) at Site 275. Preservation is superior at the Campbell Plateau site, although species diversity and abundance are only slightly different. For example, a count of 300 specimens from Sample 275-1-2, 75-76 cm shows 83% *Lyrarula furcula*, 11% *Corbisema geometrica*, 3% *Vallacerta tumidula*, 2% *Lyrarula simplex*, <1% *Vallacerta hortonii*, and <1% *Cornua trifurcata*.

SITE 217

(lat 8°55.57'N, long 90°32.33'E, depth 3020 m)

Tropical coccolith assemblages of late Quaternary to Late Cretaceous age occur in the upper 30 cores from Site 217. Both *Gephyrocapsa oceanica* and *G. omega* occur in the *Gephyrocapsa oceanica* Zone assemblages of Core 1 (0

Sample (Depth)	Species						Total
	<i>Corbisema geometrica</i>	<i>Lyrarula furcula</i>	<i>Cornua</i> sp. cf. <i>C. trifurcata</i>	<i>Vallacerta hortonii</i>	<i>Vallacerta tumidula</i>	<i>Corbisema archangeliskiana</i>	
216-30-1, 70-71 cm (397 m)	5	90	4		2		266
216-31-1, 90-91 cm (406 m)	3	89	4	1	2	<1	325
216-32-1, 116-117 cm (415 m)	3	88	<1	1	1	5	216
216-32-4, Top (417 m)	2	94	2	1	<1		340

Figure 3. Occurrence of silicoflagellates as percentages in upper Maastrichtian samples of the *Lyrarula furcula* Zone.

to 9 m). *Dictyocha aspera* dominates the sparse late Miocene silicoflagellate population of Sample 217-4-2, 75-76 cm (120 m). A late variety of *Discoaster bellus* dominates the discoaster population assigned to the *Discoaster neohamatus* Zone.

Middle Eocene *Sphenolithus obtusus* and *Discoaster bifax* in the upper part of Core 10 (344 to 353 m) suggest an assemblage near the *Nannotetrina quadrata* Zone/*Reticulofenestra umbilica* Zone boundary; however, *Reticulofenestra umbilica* is missing.

In Core 16 (412 to 421 m) a basal Paleocene coccolith assemblage transitional to the Upper Cretaceous is present. Late Cretaceous *Micula mura* Zone assemblages occur in Cores 17 and 18 (421 to 440 m), assemblages of the early Paleocene *Fasciculithus tympaniformis* Zone and *Cruciplacolithus tenuis* Zone in Cores 14 and 15 (393 to 412 m). The mixing of Cretaceous and Tertiary species is probably largely the result of moderate to strong bioturbation (described in shipboard core logs). Sample 217-16-6, 75-76 cm (420 m) contains a great variety of species, including *Arkhangelskiella cymbiformis*, *Biantholithus sparsus*, *Broinsonia parca*, *Chiasmolithus* sp. cf. *C. danicus*, *Coccolithus pelagicus* s. ampl., *Cruciplacolithus tenuis*, *Markalius astroporus*, *Micula mura*, *Prediscosphaera cretacea*, *Thora-cosphaera operculata*, *Watznaueria barnesae*, *W. biporta*. Similar mixing near the Cretaceous-Tertiary boundary has been described by Bramlette and Martini (1964), Perch-Nielsen (1969), and Hekel (in press).

SITE 218

(lat 8°00.42'N, long 86°16.9'E, depth 3759 m)

Intermittent coring through 735 meters and the only partially biogenic silty sediment recovered limit the utility of this site as a biostratigraphic reference. Below the *Discoaster quinqueramus* Zone of Cores 13 to 19 (374 to 498 m), samples contain poorly diagnostic assemblages or are barren.

REFERENCES

- Bramlette, M. N. and Martini, E., 1964. The great change in calcareous nannoplankton fossils between the Maestrichtian and Danian: *Micropaleontology*, v. 10, p. 291.
- Bukry, D., in press (a). Low-latitude coccolith biostratigraphic zonation. In Edgar, N. T., Saunders, J. B., et al., Initial Reports of the Deep Sea Drilling Project, Volume XV: Washington (U. S. Government Printing Office).
- , in press (b). Coccolith and silicoflagellate stratigraphy, Tasman Sea and southwestern Pacific Ocean, Deep Sea Drilling Project Leg 21, In Burns, R. E., Andrews, J.E., et al., Deep Sea Drilling Project, Volume XXI; Washington (U. S. Government Printing Office).
- Bukry, D., and Foster, J. H., 1973. Silicoflagellate and diatom stratigraphy, Leg 16, Deep Sea Drilling Project. In Van Andel, T. H., Heath, G. R., et al., Initial Reports of the Deep Sea Drilling Project, Volume XVI: Washington (U. S. Government Printing Office), p. 815.
- , In press. Silicoflagellate zonation of Late Cretaceous to early Miocene deep-sea sediment: U.S. Geol. Survey J. Res.
- Burckle, L. H., 1972. Late Cenozoic planktonic diatom zones from the Eastern Equatorial Pacific: *Nova Hedwigia Beihefte*, v. 39, p. 217.
- Glezer, Z. I., 1959. Nekotorye novye dannye o semeistve Vallacertaceae Deflandre (Silicoflagellatae) (Some new data on the Family Vallacertaceae Deflandre [Silicoflagellatae]): *Vses. Nauchno-Issled. Geol. Inst. Inform. Sbornik*, v. 10, p. 103.
- , 1966. Silicoflagellatophyceae, In Gollerbakh, M. M., (ed.), *Cryptogamic plants of the U.S.S.R.*: Akad. Nauk SSSR, V. A. Komarova Bot. Inst. (Translated from Russian by Israel Program for Scientific Translations Ltd., Jerusalem, 1970, v. 7, p. 1.
- Hanna, G. D., 1928. Silicoflagellata from the Cretaceous of California: *J. Paleontol.*, v. 1, p. 259.
- Hekel, H., in press. Nannofossil biostratigraphy, Leg 20, Deep Sea Drilling Project. In Heezen, B.C., MacGregor, I., et al., Initial Reports of the Deep Sea Drilling Project, Volume XX: Washington (U. S. Government Printing Office).
- Ling, H. Y., 1972. Upper Cretaceous and Cenozoic silicoflagellates and ebridians: *Am. Paleontol. Bull.*, v. 62, p. 135.
- Mandra, Y. T., 1968. Silicoflagellates from the Cretaceous, Eocene, and Miocene of California, U.S.A.: *California Acad. Sci. Proc.*, v. 36, p. 231.
- , 1969. Silicoflagellates: A new tool for the study of Antarctic Tertiary climates: *U. S. Antarctic J.*, v. 4, p. 172.
- Perch-Nielsen, K., 1969. Die Coccolithen einiger Dänischer Maestrichtien- und Danienlokalitäten: *Geol. Soc. Denmark Bull.*, v. 19, p. 51.

PLATE 1

Late Cretaceous Silicoflagellates DSDP 216
Photomicrographs Magnified 1000X
Scale bar = 10 μ

- Figure 1 *Corbisema archangelskiana* (Schulz)
Sample 216-32-1, 116-117 cm (415 m).
- Figure 2 *Corbisema geometrica* Hanna
Sample 216-32-1, 116-117 cm (415 m).
- Figure 3 *Corbisema geometrica* Hanna, central plate
Sample 216-32-1, 116-117 cm (415 m).
- Figure 4 *Cornua* sp. cf. *C. trifurcata* Schulz
Sample 216-31-1, 90-91 cm (406 m).
- Figure 5 *Vallacerta hortonii* Hanna
Sample 216-31-1, 90-91 cm (406 m).
- Figure 6 *Vallacerta* sp., spine
Sample 216-32-1, 116-117 cm (415 m).
- Figures 7-8 *Vallacerta tumidula* Glezer
Sample 216-31-1, 90-91 cm (406 m).
7. High focus.
8. Low focus.

PLATE 1