29. CRETACEOUS AND PALEOGENE COCCOLITH STRATIGRAPHY, DEEP SEA DRILLING PROJECT, LEG 26[1]

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INTRODUCTION

Drilling on Leg 26 of the Deep Sea Drilling Project, Sept. to Oct. 1972, through the southern Indian Ocean from Durban, South Africa, to Fremantle, Australia (Figure 1), recovered 239 cores at nine drilling sites, Sites 250-258. Light-microscope techniques were used to study the Cretaceous and Paleogene coccoliths of 99 samples from these cores. Cretaceous coccolith zonation is based primarily on Thierstein (1971) and Roth (1973) with supporting data from Cepek and Hay (1969) and Manivit (1971). Paleogene coccolith zonation is based on Bukry (in press).

SITE SUMMARIES

SITE 250
(lat 33°27.74'S, long 39°22.15'E, depth 5119 m)

Coccoliths occur in only 3 of the 13 samples examined from Site 250, which was cored to determine the basement age in the southeastern Mozambique Basin. This region is devoid of prominent magnetic anomalies. The coccoliths are Late Cretaceous (Santonian) in age (Figure 2) and are present in sediment 10 to 20 meters above basement. All assemblages are strongly etched and are dominated by a few solution-resistant species. In Core 22A (691-701 m), *Marthasterites furcatus* and *Micula decussata* predominate, whereas in Core 23A (701-711 m), *Watznaueria barnesae* and *Micula decussata* predominate.

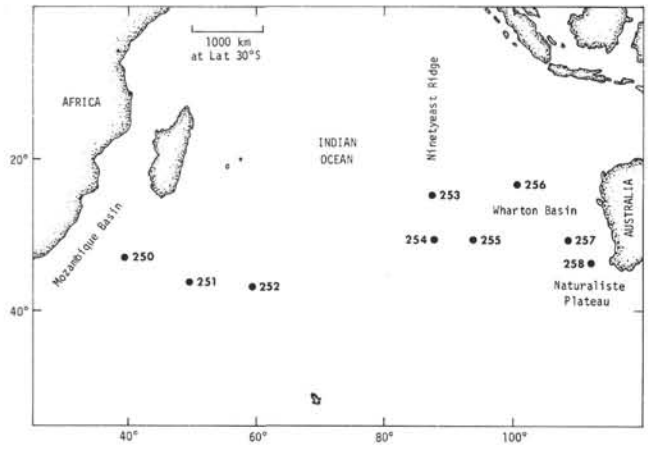

Figure 1. *Location of Deep Sea Drilling Project Leg 26 drilling sites.*

Sample (Interval in cm)	Quantity and Preservation	Zone	Stage
18A-2, 80	–		
19A-2, 78	–		
20A-1, 66	–		
20A-2, 62-63	–		
21A-2, 108	–		
22A-1, 90	–		
22A-2, 92	–		
22A-3, 37	Cp (-3.5)		
22A-4, 3	Rp (-4.0)	*Marthasterites furcatus*	Santonian
23A-1, 25	Ap (-3.0)		
23A-2, 18	–		
24A-1, 97	–	?	?
24A-2, 30	–		
25A-1, 16	–		

Figure 2. *Quantity, preservation, zone, and stage designations of samples from Hole 250A based on coccoliths. Quantity indicated as* A, *abundant;* C, *common;* R, *rare; or* –, *absent. Poor preservation throughout indicated by* p *and further refined by numerical preservation code in which -4.0 = almost all specimens fragmented by etching, and -3.0 = many major structures removed by etching (Bukry, 1973).*

An age of 83 ±6 m.y. is assigned to these assemblages. This age is derived by the error-estimate technique of van Andel and Bukry (1973) using the age indicated for the Mesozoic coccolith zone (Figure 3). As noted by Lambert (1971) and by Douglas and Bukry (1973), the age determinations of Mesozoic stage boundaries are interpolations of sparse and often poorly correlated radiometric data. Below the Cenomanian stage much of the radiometric data are based on determinations from glauconite and cannot be considered highly accurate. The ages of zone boundaries, within the stages, are then further extrapolations. Until more radiometric determinations are available, such extrapolated ages should be viewed only as the best current estimates. The relative ages between zones may be improved more rapidly of drilling of Mesozoic magnetic anomaly sequences in the ocean basins is successful.

SITE 251
(lat 36°30.26'S, long 49°29.08'E, depth 3489 m)

No Cretaceous or Paleogene sediment was recovered at this site.

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

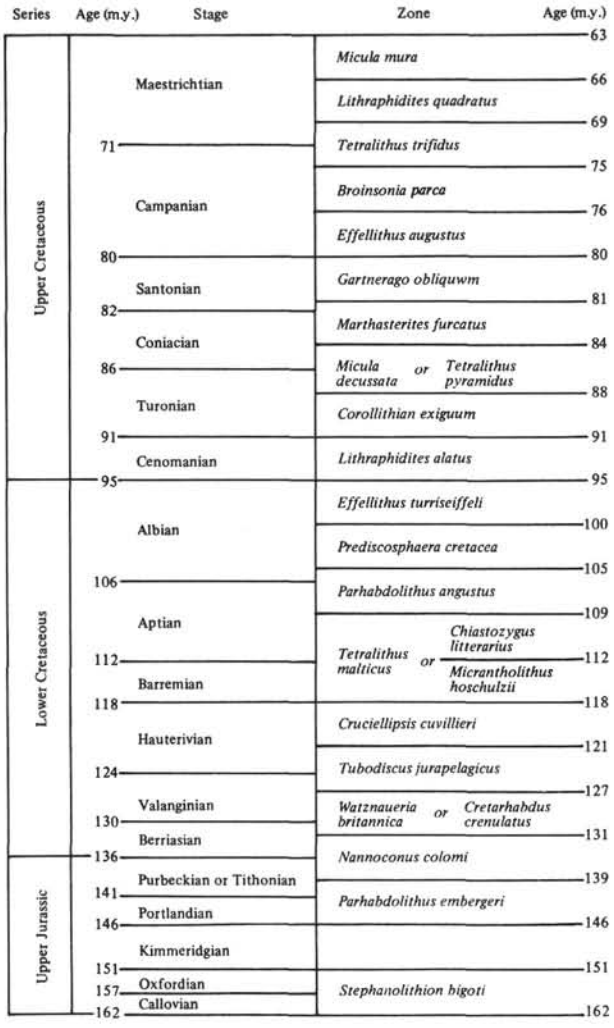

Figure 3. *Estimated ages of Mesozoic coccolith zone and universal stage boundaries. Ages in m.y. obtained from the Phanerozoic Time Scale of Harland et al. (1964), Lambert (1971), and Izett et al. (1971). Coccolith zonation based on Stradner (1964), Cepek and Hay (1969), Thierstein (1971), Bukry (in press), and Roth (1973).*

SITE 252
(lat 37°02.44'S, long 59°14.33'E, depth 5032 m)

No Cretaceous or Paleogene sediment was recovered at this site.

SITE 253
(lat 24°52.65'S, long 87°21.97'E, depth 1962 m)

Of the 57 cores cut at Site 253 on the Ninetyeast Ridge, 44 are assigned to the Eocene on the basis of coccoliths (Figure 4). Unfortunately, extensive solution of coccoliths (preservation -3 to -5) and dilution in rapidly accumulated volcanic ash make most of the lower section, in Cores 17 to 57 (152-555 m), useless as a biostratigraphic reference. The age range of the rare cosmopolitan coccoliths in the lowest sample, 253-57-3, 115-116 cm (548 m), yields an estimated age of 50 ±3 m.y.

Sample (Interval in cm)	Quantity and Preservation	Zone or Subzone	Subseries
12-3, 59-60	Ap	*Reticulofenestra hillae*	
13-1, 80-81	Am		Lower Oligocene
13-3, 80-81	Am	*Cyclococcolithina formosa*	
14-1, 80-81	Am		Upper Eocene
14-3, 75-77	Am	*Discoaster barbadiensis*	
16-4, 141-142	Am	*Discoaster saipanensis*	
17-3, 31-32	–	?	
18-2, 80-81	Cm		Middle Eocene
19-2, 28-29	Rp		
20-2, 80-81	Cm	*Rhabdosphaera inflata*	
21-2, 85-86	Am		
25-1, 100-101	Cp		
30-1, 94-95	Rp		
31-3, 40-41	Cm		
36-2, 24-25	–		
38-1, 136-137	Rp		
40-3, 66-67	–		Lower Middle Eocene or Upper lower Eocene
42-2, 37-38	–		
43-2, 131-132	Rp		
46-2, 113-114	Rp		
46-6, 122-123	Rp	?	
48-2, 33-34	–		
49-2, 116-117	–		
49-3, 36-37	–		
51-3, 108-109	Cm		
51-4, 122-123	Rp		
55-2, 135-136	Cp		
56-1, 124-125	Cp		
57-3, 115-116	Rp		

Figure 4. *Quantity, preservation, zone or subzone, and subseries designations of samples from Site 253 based on coccoliths. Quantity indicated as* A, *abundant;* C, *common;* R, *rare; or* –, *absent. Preservation indicated as* g, *good;* m, *moderate; or* p, *poor.*

The best Paleogene assemblages are late middle Eocene to early Oligocene in Cores 12 to 16 (104-152 m). The early Oligocene *Reticulofenestra hillae* Subzone is identified in Sample 253-12-3, 59-60 cm (108 m), which contains *Chiasmolithus altus, C. oamaruensis, Coccolithus eopelagicus, Cyclicargolithus floridanus, Dictyococcites bisectus, Discoaster* sp. cf. *D. deflandrei, D.* sp. cf. *D. nodifer, D.* sp. cf. *D. tanii, Reticulofenestra hillae,* and *Sphenolithus moriformis.* The slightly older early Oligocene assemblages of Core 13 are distinguished by the occurrence of *Cyclococcolithina formosa* and *Reticulofenestra umbilica.* A temperate paleoenvironment is suggested by the scarcity of *Sphenolithus.*

Late Eocene *Discoaster barbadiensis* Zone assemblages occur in Core 14 and are noteworthy for the great abundance of *Reticulofenestra umbilica.* Sample 253-14-1, 80-81 cm (124 m) contains *Bramletteius serraculoides, Coccolithus eopelagicus, Cyclicargolithus* sp. cf. *C. floridanus, Cyclococcolithina formosa, Dictyococcites scrippsae, Discoaster nodifer, D. saipanensis, D. tanii, Reticulofenestra umbilica, Sphenolithus moriformis,* and *Zygrhablithus bijugatus.*

A late middle Eocene *Discoaster saipanensis* Subzone assemblage occurs in Sample 253-16-4, 141-142 cm (148 m), which is a coccolith ooze. The ratio of *Discoaster* to *Chiasmolithus,* 82% to 18% based on a count of 300 individuals, ordinarily indicates a warm-water assemblage. In the volcanogenic-rich sediment of subjacent

Sample 253-18-2, 80-81 cm (163 m); however, the ratio is reversed to 2% *Discoaster* to 98% *Chiasmolithus* based on a count of 300 individuals. Such an extreme ratio suggests a cool-temperate assemblage. This lower middle Eocene sample, assigned to the *Rhabdosphaera inflata* Subzone, is chronostratigraphically about 4 m.y. older than the overlying sample, which accounts, in part, for the apparent abruptness of the shift. Possible contributing to the effect is the evolutionary extinction of *Chiasmolithus solitus* just below the *Discoaster saipanensis* Subzone and hence between the samples. The change from coccolith-rich to volcanic-rich sediment also suggests a stratigraphic break. Coccoliths present in Sample 253-18-2, 80-81 cm include *Braarudosphaera bigelowii, B. discula, Chiasmolithus expansus, C. grandis, C. solitus, Coccolithus jugatus, C. pelagicus, Cyclicargolithus pseudogammation, Discoaster barbadiensis, Ellipsolithus lajollaensis, Helicopontosphaera lophota, H. seminulum, Markalius inversus, Reticulofenestra dictyoda, Rhabdosphaera inflata* s. str., *R. tenuis, R. truncata, Transversopontis pulcher, T. pulcheroides, Zygolithus dubius,* and *Zygrhablithus bijugatus.* The presence of *Braarudosphaera, Ellipsolithus, Rhabdosphaera,* and *Transversopontis* suggests fairly shallow deposition. Diatoms are common; silicoflagellates and ebridians are rare. Silicoflagellates are represented only by predominant *Naviculopsis constricta* and fragments of *Corbisema* probably derived from *C. geometrica* and *C. triacantha.* The absence of *Naviculopsis foliacea* and *Dictyocha hexacantha* suggests early middle Eocene age (Bukry and Foster, in press), particularly in view of the good preservation of *N. constricta.* The ebridians *Ebriopsis crenulata* and *Ammodochium* sp. support only a general Eocene age.

Sample 253-20-2, 80-81 cm (182 m) contains *Braarudosphaera discula, Chiasmolithus expansus, C. grandis, C. solitus, Coccolithus jugatus, C. pelagicus, Cyclicargolithus floridanus, Cyclococcolithina formosa, Discoaster barbadiensis, Ellipsolithus lajollaensis, Helicopontosphaera lophota, Micrantholithus crenulatus, Reticulofenestra dictyoda, R.* sp. cf. *R. samodurovi, Transversopontis pulcher, T. pulcheroides, Zygolithus dubius, Zygrhablithus bijugatus.* Downhole contamination by Neogene sediment is indicated by the presence of *Cyclococcolithina macintyrei, Discoaster* sp. cf. *D. brouweri,* and *D. pentaradiatus.*

In Sample 253-21-2, 85-86 cm (191 m), the lowest assemblage assigned to the *Rhabdosphaera inflata* Subzone contains 11% *Discoaster* and 89% *Chiasmolithus* in a count of 300 specimens of these genera. This temperate-water assemblage contains *Braarudosphaera bigelowii, Chiasmolithus expansus, C. grandis, C. solitus, Coccolithus pelagicus, Cyclicargolithus pseudogammation, Cyclolithella bramlettei, Discoaster barbadiensis, D. nonaradiatus, D. sublodoensis, D. wemmelensis, Ellipsolithus lajollaensis, Helicopontosphaera lophota, Koczyia wechesensis, Micrantholithus crenulatus, Reticulofenestra dictyoda, Transversopontis pulcher, T. pulcheroides, Zygolithus dubius,* and *Zygrhablithus bijugatus.*

Assemblages from deeper cores are similar but are stratigraphically less diagnostic. The *Discoaster* to *Chiasmolithus* ratio in two of the better samples is similar to that for Core 21. Sample 253-31-3, 40-41 cm (282 m) has 8% *Discoaster* to 92% *Chiasmolithus; Sample 253-51-3, 108-109 cm (472 m), 10% Discoaster to 90% Chiasmolithus,* based on counts of 300 individuals. *Micrantholithus* and *Braarudosphaera,* suggesting a shallower depositional environment, are more common in Sample 253-31-3 than in higher samples. Coccoliths present in Sample 253-31-3 include *Braarudosphaera discula, Chiasmolithus grandis, C. solitus, Coccolithus pelagicus, Cyclicargolithus pseudogammation, Cyclococcolithina gammation, Discoaster barbadiensis, D. distinctus, D.* sp. cf. *D. mirus, D.* sp. cf. *D. sublodoensis, Helicopontosphaera lophota, H. seminulum, Micrantholithus crenulatus, Reticulofenestra dictyoda, Sphenolithus radians,* and *Zygolithus dubius.* Sample 253-51-3 contains *Chiasmolithus expansus, C. grandis, C. solitus, Coccolithus pelagicus, Cyclicargolithus pseudogammation, Discoaster barbadiensis, D. distinctus, D. lodoensis, D.* sp. cf. *D. mirus, Lophodolithus mochlophorus, Micrantholithus crenulatus, M.* sp. cf. *M. flos, M.* sp. cf. *M. attenuatus, Reticulofenestra dictyoda, Rhabdosphaera* sp., *Transversopontis pulcher, T. pulcheroides, Zygolithus dubius,* and *Zygrhablithus bijugatus.*

SITE 254
(lat 30°58.15′S, 87°53.72′E, depth 1253 m)

No Cretaceous or Paleogene sediment was recovered at this site.

SITE 255
(lat 31°07.87′S, long 93°43.72′E, depth 1144 m)

No Cretaceous or Paleogene sediment samples were available from this site.

SITE 256
(lat 23°27.35′S, long 100°46.46′E, depth 5361 m)

Cretaceous coccoliths occur in Cores 8 and 9 (238-257 m) from Site 256 in the Wharton Basin, west of Australia.

The assemblage is Albian in age and is similar in species composition to the Albian of Site 258 on the Naturaliste Plateau. The deepest sample available, 256-9-1, 111-112 cm (247 m), contains the most diverse assemblage; it includes *Cretarhabdus crenulatus, Cribrosphaera ehrenbergii, C.* sp. (two-piece diagonal central-area crossbar), *Cyclagelosphaera margerelii, Eiffellithus turriseiffeli, Lithastrinus floralis, Manivitella pemmatoidea, Parhabdolithus embergeri, Prediscosphaera cretacea, Watznaueria barnesae, W.* sp. cf. *W bayackii, W. biporta, W. britannica, W. ovata, Zygodiscus bicrescenticus, Z.* sp. cf. *Z. deflandrei.* The assemblage of Sample 256-8-1, 95-96 cm (239 m) is more etched, but differs mainly by the absence of *Cribrosphaera* and *Cyclagelosphaera.* No species suggesting Cenomanian, such as *Lithraphidites alatus, Gartnerago obliquum,* or *Eiffellithus augustus,* were observed from this site (Figure 5).

SITE 257
(lat 30°59.16′S, long 108°20.99′E, depth 5278 m)

Coccoliths of Early Cretaceous (Albian) age occur in four of the eight samples examined from Site 257 in the southeastern Wharton Basin near the Naturaliste

Sample (Interval in cm)	Quantity and Preservation	Zone	Stage
1-2, 99-100	–	?	?
6-4, 93-94	–		
7-3, 85-86	–		
8-1, 95-96	Ap	*Eiffellithus turriseiffeli*	Albian
8-3, 90-91	Am		
8-6, 81-82	Am		
9-1, 111-112	Am		

Figure 5. *Quantity, preservation, zone, and stage designations of samples from Site 256 based on coccoliths. See Figure 4 for key to abbreviations.*

Plateau. The diagnostic fossil for the zonal assignment *Prediscosphaera cretacea* is rare, but is present in the highest and lowest coccolith samples (Figure 6). The lower sample, 257-8-2, 3-4 cm (239 m), is most diverse, containing *Biscutum* sp., *Cretarhabdus crenulatus, C. loriei, Cribrosphaera* sp. (two-piece diagonal central-area crossbar), *Cyclagelosphaera margerelii, Lithastrinus floralis, Parhabdolithus angustus, P. asper, P. embergeri, Prediscosphaera cretacea, Vagalapilla matalosa, Watznaueria barnesae, W. britannica, W. ovata, Zygodiscus bicrescenticus, Zygodiscus* sp. The assemblage of Sample 257-7-2, 81-82 cm (201 m) is more etched, but the species composition is similar; *C. margerelii* and *P. asper* are absent.

SITE 258
(lat 33°47.69'S, long 112°28.42'E, depth 2793 m)

Coccoliths of Early and Late Cretaceous age occur in Cores 5 to 22 (124-445 m) from Site 258 on the Naturaliste Plateau. The uppermost assemblages of Santonian age in Cores 5 to 7 (124-162 m) are well preserved and differ from each other only in the relative abundance of species. *Chiastozygus disgregatus*, a species common in the lower Santonian of Texas (Bukry, 1969), is most common here in Samples 258A-9-3, 28 cm (116 m) and 258-6-4, 93-94 cm (147 m). A typical assemblage of the *Gartnerago obliquum* Zone at this site from Sample 258-7-2,

Sample (Interval in cm)	Quantity and Preservation	Zone	Stage
7-2, 81-82	Am	*Prediscosphaera cretacea*	Albian
7-5, 80-81	Ag		
8-1, 86-87	Ag		
8-2, 3-4	Ag		
9-1, 145-146	–	?	?
9-2, 146-147	–		
9-3, 67-68	–		
10-1, 8-9	–		

Figure 6. *Quantity, preservation, zone, and stage designations of samples from Site 257 based on coccoliths. See Figure 4 for key to abbreviations.*

80-81 cm (154 m) contains *Biscutum* sp., *Broinsonia brevieri, Cretarhabdus crenulatus, Effellithus augustus, E. turriseiffeli, Gartnerago obliquum, Kamptnerius magnificus, Lithastrinus floralis, Micula decussata, Prediscosphaera cretacea, Stephanolithion laffitei, Watznaueria barnesae, Zygodiscus deflandrei,* and *Zygodiscus* spp.

A single sample of the Coniacian or Santonian *Marthasterites furcatus* Zone occurs at the top of Core 9 in Sample 258-9-1,145-146 cm (182 m). The assemblage is much more diverse than that recovered at the deep-water Site 250. Species present include *Biscutum* sp., *Broinsonia bevieri, Cretarhabdus crenulatus, Eiffellithus augustus, E. turriseiffeli, Gartnerago obliquum, Lithastrinus floralis, Marthasterites furcatus, Micula decussata, Parhabdolithus angustus, Prediscosphaera cretacea, Watznaueria barnesae, W. biporta, W. ovata, Zygodiscus deflandrei,* and *Zygodiscus* spp.

The presence of *Tetralithus pyramidus* without *Marthasterites furcatus* in Cores 10 and 11 (200-225 m) suggests a Coniacian assignment. The relative ranges of key species in the Cenomanian to Campanian are still not established. For example, at some localities in France, *M. furcatus* appears before *T. pyramidus* (Manivit, 1971). The assemblage of Sample 258-11-2, 78-79 cm (217 m) includes *Cylindralithus coronatus, Eiffellithus augustus, E. turriseiffeli, Gartnerago costatum, G. obliquum, Lithastrinus floralis, Lithraphidites carniolensis, Prediscoaphaera cretacea, Tetralithus pyramidus, Watznaueria barnesae, W. coronata, W. ovata, Zygodiscus deflandrei,* and *Zygodiscus* spp.

Samples from Cores 12 and 13 (235-263 m) contain poorly diagnostic assemblages. They are possibly of Turonian age based on rare specimens of *Kamptnerius magnificus*. Sample 258-12-5, 64-65 cm (242 m) contains *Biscutum* sp., *Broinsonia bevieri, Eiffellithus turriseiffeli, Gartnerago costatum, G. obliquum, Kamptnerius magnificus, Lithastrinus floralis, L. grillii, Lithraphidites carniolensis, Manivitella pemmatoidea, Podorhabdus dietzmannii, Prediscosphaera cretacea, Watznaueria barnesae, W. biporta, Zygodiscus bicrescenticus, Z. deflandrei,* and *Zygodiscus* spp. No specimens of *Cribrosphaera* are present in this or higher samples, but a new species of *Cribrosphaera* is present in Core 14 and all deeper coccolith-bearing cores. Questionable *Cribrosphaera ehrenbergii* was noted only in Sample 258-16-2, 85 cm (302 m).

No specimens of *Lithraphidites alatus* or *Eiffellithus augustus,* which would suggest Cenomanian, were observed in Cores 14 to 18 (263-273 m). The initial appearance of *Gartnerago obliquum* also may suggest Cenomanian; it appears first in Sample 258-14-1, 139-140 cm (264 m). On the basis ofthe co-occurrence of *Eiffellithus turriseiffeli* and *Prediscosphaera cretacea* through the interval of Cores 14 to 18, an Albian or Cenomanian age is indicated (Figure 7).

The oldest coccolith-bearing cores, 20 and 21 (377-415 m), contain diverse moderately etched assemblages of the lower Albian *Prediscosphaera cretacea* Zone. Sample 258-20-1, 108-109 cm (377 m) contains *Cretarhabdus crenulatus, C. loriei, Cribrosphaera* sp. (two-piece diagonal central-area crossbar), *Cyclagelosphaera*

Sample (Interval in cm)	Quantity and Preservation	Zone	Stage
5-1, 75-76	Ag		
5-3, 81	Ag		
9A-3, 28	Ag	*Gartnerago obliquum*	Santonian
6-4, 93-94	Ag		
7-2, 80-81	Ag		
9-1, 145-146	Am	*Marthasterites furcatus*	
10-2, 43-44	Am		Coniacian (?)
11-2, 78-79	Am	*Tetralithus pyramidus*	
12-2, 44-45	Am		
12-5, 64-65	Ag	?	Turonian (?)
13-3, 148-149	Cm		
14-1, 139-140	Am		
15-2, 138-139	Am		
15-5, 100-101	Rp		Cenomanian
16-2, 85	Cm		
16-5, 30-31	Cp	*Eiffellithus turriseiffeli*	or
17-2, 80-81	Rp		
17-4, 147-148	Am		Albian
18-2, 80-81	Cm		
18-4, 144-145	Am		
20-1, 108-109	Cm		
21-1, 80-81	Cg	*Prediscosphaera cretacea*	Albian
21-3, 100-101	Cm		
22-3, 111-112	Rp		
23-2, 121-122	–		
24-3, 53-54	–	?	?
24-5, 120-121	–		
25-3, 85-86	–		

Figure 7. *Quantity, preservation, zone, and stage designations of samples from Site 258 based on coccoliths. See Figure 4 for key to abbreviations.*

margerelii, Lithastrinus floralis, Manivitella pemmatoidea, Parhabdolithus angustus, Podorhabdus dietzmannii, P. reinhardtii, Prediscosphaera cretacea, Stephanolithion laffitei, Vagalapilla matalosa, Watznaueria barnesae, W. sp. cf. *W. britannica,* and *Zygodiscus* spp. The lowest sample, 258-21-3, 100-101 cm (410 m), is more etched and less diverse. Species present include *Biscutum* sp., *Cretarhabdus crenulatus, Cribrosphaera* sp., *Cyclagelosphaera margerelii, Lithastrinus floralis, Manivitella pemmatoidea, Parhabdolithus angustus, Podorhabdus dietzmannii, Prediscosphaera cretacea, Vagalapilla* sp., *Watznaueria barnesae, W. britannica, W. ovata,* and *Zygodiscus* spp.

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