20. CALCAREOUS NANNOPLANKTON FROM DEEP SEA DRILLING PROJECT LEG 78A: EVIDENCE FOR IMBRICATE UNDERTHRUSTING AT THE LESSER ANTILLIAN ACTIVE MARGIN[1]

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ABSTRACT

During Leg 78A of the Deep Sea Drilling Project, six holes were drilled at three sites in the fore-arc region of the Lesser Antilles. Samples taken from sediments recovered west of the deformation front of the Barbados Ridge at Sites 541 and 542 contain upper Miocene through upper Pleistocene nannofossil assemblages. Comparable states of preservation in age-equivalent sediments indicate similar depositional histories at these two sites. Samples recovered from Site 543, an oceanic reference site east of the deformation front, contain poorly preserved nannofossils dated as early Pliocene through early Pleistocene. The sequence of nannofossil zones in the continuously cored sections at Sites 541 and 543 is similar. Differences in preservation of the calcareous nannoplankton in age-equivalent sediments at these two sites indicate that since the Miocene, sediments at Site 543 have been deposited at greater depths.

A major stratigraphic inversion is present in Hole 541 at a depth of 276 m below the seafloor. At this horizon, upper Miocene muds of the *Amaurolithus primus* Subzone (CN9b) overlie upper Pliocene marly nannofossil oozes of the *Discoaster tamalis* Subzone (CN12a). About 117 m of section are repeated above this level, as determined by the calcareous nannoplankton. This horizon is thought to be a reverse fault formed by imbricate underthrusting during the formation of an accretionary prism at the active margin. This is the first time this type of structure has been dated biostratigraphically at a modern convergent margin drilled by the Deep Sea Drilling Project. Three smaller repetitions of section occur above this fault in Hole 541. They begin at 262, 172, and 77 m sub-bottom. Strong evidence of faulting was also observed in sediments recovered at Site 542, as the last occurrence of *Amaurolithus tricorniculatus* lies at 180 m sub-bottom in Hole 542 and 211.5 m in Hole 542A. Poorly preserved nannofossil assemblages of the *Discoaster berggrenii* Subzone (CN9a) in a very thick section in the bottom of Hole 542A also suggest faulting of these upper Miocene muds.

INTRODUCTION

Leg 78A of the Deep Sea Drilling Project sailed to the fore-arc region of the Lesser Antilles in February and March of 1981 to investigate subduction processes at this convergent margin. Interpretations from previous drilling at other active margins were handicapped by low core recovery, unstable hole conditions, and poor biostratigraphic resolution resulting from high sedimentation rates and dissolution of calcareous microfossils.

The Lesser Antilles is unique among the active margins drilled by DSDP in that it is the only one located in the Atlantic Ocean. This is advantageous because the calcium compensation depth is much deeper in the equatorial Atlantic than it is in the Pacific. Thus the calcareous microfossils should be more useful for age determinations at this margin than they have been at convergent margins in the Pacific.

During Leg 78A, six holes were drilled at three sites near the toe of the Barbados Ridge (Fig. 1). Two of these, Sites 541 and 542, were drilled west of the deformation front of the Barbados Ridge in an attempt to penetrate the prism of supposed accreted sediment. This had never been accomplished at any other active margin prior to Leg 78A. Site 543 serves as an oceanic reference site and is located 3.5 km east of the toe of the Barbados Ridge.

Nannofossils were recovered from samples at all three sites and range in age from early Campanian to Pleistocene. Upper Cretaceous nannofossil assemblages were observed only in a short, discontinuous section at the bottom of Hole 543A. The remainder of the nannofossils occur in upper Miocene through upper Pleistocene sediments at the three sites. Pliocene and Pleistocene assemblages exhibit better preservation than do Miocene assemblages.

ZONATION SCHEMES

The zonation used for Cenozoic determinations in this report (Fig. 2) is a modification of those proposed by Gartner (1977), Okada and Bukry (1980), and Bukry (1973b, 1975).

The low-latitude zonation of Bukry (1973b, 1975) and Okada and Bukry (1980) works well for pre-Pleistocene assemblages, but is somewhat less useful for the Pleistocene because the gephyrocapsids do not provide reliable datums. In its place, the zonation proposed by Gartner (1977) is used for this part of the column, for it provides better resolution. Because both these schemes use the last occurrence of *Discoaster brouweri* to date the Pliocene/Pleistocene boundary, the zonation adopted in this paper is continuous. A slight amount of confusion may arise when these zonations are used in conjunction with each other because *Calcidiscus macintyrei* is utilized as a zone name by Gartner (1977), but as a subzone for a different interval by Okada and Bukry (1980).

During the course of this study, it became necessary to modify the adopted zonal scheme. The small *Gephy-*

[1] Biju-Duval, B., Moore, J. C., et al., *Init. Repts. DSDP*, 78A: Washington (U.S. Govt. Printing Office).

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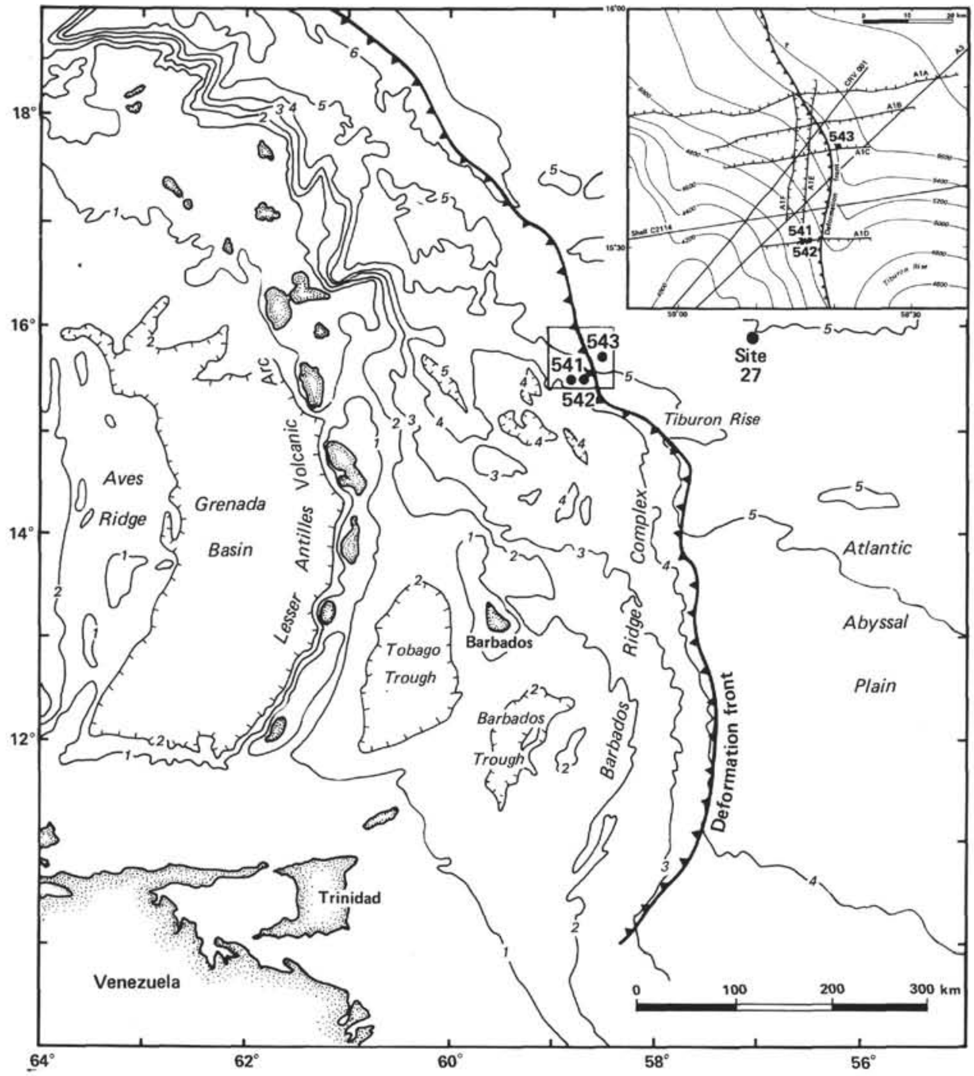

Figure 1. Leg 78A site location map (from Moore, Biju-Duval, et al., 1981).

rocapsa Zone of Gartner (1977) could not be recognized, because the abundance of these forms fluctuated with the preservation of the sample. *Triquetrorhabdulus rugosus*, the last occurrence of which marks the upper boundary of the *Triquetrorhabdulus rugosus* Subzone (CN10a), is not used as a datum, because its extinction is not consistent throughout the sections examined.

Two emendations of the Okada and Bukry (1980) scheme are recommended. One is that the last occurrence of *Amaurolithus primus* not be used as a datum for interoceanic correlation. In the sections examined, this datum is found just below the first occurrence of *Ceratolithus acutus*. Other reported last occurrences of this species lie much higher and usually occur at the extinctions of either *Amaurolithus delicatus* (Haq and Berggren, 1978; Ellis and Lohman, 1979) or *Amaurolithus tricorniculatus* (Ellis, 1979; Bukry, 1973b, 1975; Okada and Bukry, 1980). Confusion may also develop in the identification of this species by various authors, especially in samples in which overgrowths are a problem.

A second recommendation is in regard to the first occurrence of *Ceratolithus rugosus*. This datum is often used in conjunction with the last occurrence of *Ceratolithus acutus* as a zonal boundary marker in the lower Pliocene. In my samples, this same relationship is seen between *Ceratolithus cristatus* and *Ceratolithus acutus*. *Ceratolithus rugosus* is scarce in these sections, but *Ceratolithus cristatus* is not. Therefore, it is quite possible that *Ceratolithus rugosus* is an overgrown form of *Ceratolithus cristatus*, and its first appearance datum is replaced here with that of *Ceratolithus cristatus*.

The Appendix presents the methods used to examine and evaluate the samples.

SITE SUMMARIES

Site 543

Site 543 was drilled as an oceanic reference for the other two sites and is discussed first. It was drilled in 5637 m of water approximately 3.5 km east of the toe of the accretionary prism (Fig. 1). Two holes had to be drilled at this site in order to obtain a continuous section to basement and thus provide a record of the sedimentary sequence entering the subduction zone. Hole 543 was

Age		Nannofossil zone or subzone		Boundary species
Pleistocene	late	*Emiliania huxleyi* Acme Zone		Acme of *Emiliania huxleyi*
Pleistocene	late	*Emiliania huxleyi* Zone		FAD *Emiliania huxleyi*
Pleistocene	late	*Gephyrocapsa oceanica* Zone		LAD *Pseudoemiliania lacunosa*
Pleistocene	early	*Pseudoemiliania lacunosa* Zone		LAD *Helicosphaera sellii*
Pleistocene	early	*Helicosphaera sellii* Zone		LAD *Calcidiscus macintyrei*
Pleistocene	early	*Calcidiscus macintyrei* Zone		LAD *Discoaster brouweri*
Pliocene	late	*Discoaster brouweri* Zone	*Calcidiscus macintyrei* Subzone	LAD *Discoaster pentaradiatus*
Pliocene	late	*Discoaster brouweri* Zone	*Discoaster pentaradiatus* Subzone	LAD *Discoaster surculus*
Pliocene	late	*Discoaster brouweri* Zone	*Discoaster surclus* Subzone	LAD *Discoaster tamalis*
Pliocene	late	*Discoaster brouweri* Zone	*Discoaster tamalis* Subzone	LAD *Reticulofenestra pseudoumbilica*; LAD *Sphenolithus neoabies*
Pliocene	early	*Reticulofenestra pseudoumbilica* Zone	*Discoaster asymmetricus* Subzone	Beginning of the acme of *Discoaster asymmetricus*
Pliocene	early	*Reticulofenestra pseudoumbilica* Zone	*Sphenolithus neoabies* Subzone	LAD *Amaurolithus tricorniculatus*
Pliocene	early	*Amaurolithus tricorniculatus* Zone	*Ceratolithus rugosus* Subzone	LAD *Ceratolithus acutus*; FAD *Ceratolithus cristatus*
Pliocene	early	*Amaurolithus tricorniculatus* Zone	*Ceratolithus acutus* Subzone	FAD *Ceratolithus acutus*
Pliocene–Miocene	early–late	*Amaurolithus tricorniculatus* Zone	*Triquetrorhabdulus rugosus* Subzone	LAD *Discoaster quinqueramus*
Miocene	late	*Discoaster quinqueramus* Zone	*Amaurolithus primus* Subzone	FAD *Amaurolithus primus*
Miocene	late	*Discoaster quinqueramus* Zone	*Discoaster berggrenii* Subzone	FAD *Discoaster berggrenii*; FAD *Discoaster surculus*

Figure 2. Nannofossil zonation adopted for this study (from Bukry, 1973b, 1975; Gartner, 1977). FAD = first appearance datum; LAD = last appearance datum.

continuously cored to a depth of 324 m before a jammed core barrel forced the hole to be abandoned. A second hole, Hole 543A, was continuously cored below a depth of 332 m and hit basement at approximately 408.5 m sub-bottom.

Nannoplankton were observed in samples from two intervals at Site 543. The first is an incomplete section containing poorly preserved Upper Cretaceous assemblages in Cores 7 through 10 in Hole 543A (Table 1). Several samples from Core 7 contain common nannofossils, but they are very poorly preserved. The presence of large *Prediscosphaera cretacea* and the absence of several species restricted to the Campanian suggest that this core is lower Maestrichtian. The next occurrence of nannofossils downhole is in Section 543A-9-1. Samples from this section contain *Ceratolithoides aculeus* and *Uniplanarius gothicus*, but no other age-diagnostic species. The sediments in this section are probably middle Campanian. The sediments in contact with basement in Section 543A-10-1 contain common, but poorly preserved nannoplankton. *Marthasterites furcatus* and *Broinsonia parca* with greatly reduced central areas occur in samples from this section, and these basal sediments are dated as early Campanian.

A second, more complete section occurs in lower Pliocene to Pleistocene sediments in the top seven cores of Hole 543; all the samples taken below Sample 543-8-1, 65–66 cm are barren (Table 2). Nannoplankton are often poorly preserved in these samples, but preservation is still good enough to allow reliable age assignments to be made. This section was not deposited continuously as the *Discoaster pentaradiatus* Subzone, and most of the *Discoaster surculus* Subzone is missing. A small number of reworked forms, consisting mostly of discoasters, are found in most of the samples throughout this interval.

Site 542

Site 542 is located about 1.5 km west of the deformation front of the Barbados Ridge (Fig. 1). The first hole drilled at this site (Hole 542) penetrated to a depth of

Table 1. Cretaceous nannofossil species present in Cores 7 to 10 in Hole 543A.

Age	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Ceratolithoides aculeus*	*Watznaueria barnesae*	*Micula concava*	*Cretarhabdus conicus*	*Prediscosphaera cretacea*	*Microrhabdulus decoratus*	*Micula decussata*	*Cribrosphaerella ehrenbergi*	*Marthasterites furcatus*	*Uniplanarius gothicus*	*Lithastrinus grillii*	*Rucinolithus hayi*	*Kamptnerius magnificus*	*Broinsonia parca*	*Manivitella pemmatoidea*	*Cylindralithus serratus*	*Cretarhabdus surirellus*	*Eiffellithus turriseiffeli*	*Arkhangelskiella* sp.
		7-1, 3–4	B																				
		7-1, 89–90	B																				
		7-1, 134–135	B																				
		7-2, 23–24	B																				
		7-2, 99–100	C	P		A	C		F	R	C	F								F	F		F
		7-2, 136–137	C	P		C	R		F	R	C	F								F	F		F
Maes-trich-tian		7-3, 1–2	C	P		A	F	R	F	R	C	F								F	C		F
		7-3, 7–8	A	P		A	F	R	F	R	C	C					R		R	F	C	F	F
		7-3, 96–97	C	P		C	F		F		C	R								C	F		F
		7-3, 119–120	C	P		C	R		R	P	C	R								C	R		
		7-4, 22–23	B																				
	389.0	7,CC	R	P		R			R	P	R									P			
		8-1, 72–73	B																				
		8-1, 127–128	B																				
	398.5	8,CC	B																				
—?—		9-1, 4–5	C	P	R	C	F				F			C					R	R			
		9-1, 41–42	C	P	P	C	F				C			F					P	R	R		
	408.0	9,CC	B																				
Cam-panian		10-1, 9–10	A	P		A	R		F		C	R	C		P	P		R	F	F	C		
		10-1, 34–35	C	P		C			R		C		F			P		F	F	F	F		
	417.5	10,CC	C	P		A			R		F	R	R			P		R	F	C	F		

Note: See the Appendix for an explanation of the symbols.

240 m below the seafloor. Three spot cores were taken from this hole between 0 and 202 m sub-bottom, and the hole was continuously cored below that interval.

Hole 542A was continuously cored between 240 and 325.5 m sub-bottom, forming with Hole 542 a continuous sequence below a depth of 202 m. A single core was recovered above this interval at 173.5 to 183.0 m sub-bottom. Two washed cores, one above and below this first core, were also recovered. Unstable hole conditions ended the drilling of this hole at 325.5 m sub-bottom.

A third hole, Hole 542B, was begun with the hope of emplacing casing in the unstable portion of the hole to prevent its collapse. This attempt was unsuccessful, and no sediment was recovered from this hole.

Between Holes 542 and 542A, the section is continuous from 202 to 325.5 m sub-bottom and contains upper Miocene through lower Pliocene sediments. Most of the upper Miocene sediments are muds with occasional interbeds of marly nannofossil ooze or ash. There is an increase in the amount of biogenic carbonate in these upper Miocene sediments at a depth of 230 m, and above this are nannofossil muds and marly nannofossil oozes dated as late Miocene to early Pleistocene.

The nannofossil assemblages in the bottom of Hole 542 (Core 4) and the top of the continuously cored sequence in Hole 542A (Core 2) are presented in Tables 3 and 4, and show that sediments from Hole 542 dated in the *Amaurolithus primus* Subzone are above those dated in the *Discoaster berggrenii* Subzone from the top of the continuous section in Hole 542A. This means that there is no overlap in age between the two holes and that a small gap may exist in the section formed by these two holes.

There is strong evidence for a stratigraphic repetition in the section at this site. In Hole 542A, the last occurrence of *Amaurolithus tricorniculatus* (Table 5) occurs between Samples 542A-1-5, 58–59 cm and 542A-1-4, 58–59 cm at 180 m sub-bottom. In Hole 542, this same datum is placed between Cores 1 and 2 at a depth of 211.5 m (Table 3). This 31.5-m difference in the placement of this datum can be explained by repetition of section; it is too large to be attributed to an error in drilling (for which, in any event, there is no evidence). This conclusion is supported by a repetition of section in sediments of the same age at Hole 541.

Hole 542

The three washed cores recovered from Hole 542 are only important because they are in normal stratigraphic order (Table 6) and may be compared to age-equivalent sediments at the other two sites. The preservation of the nannoplankton in these cores is about the same as that seen in age-equivalent sediments at Site 541, but is far better than at Site 543.

The four cores recovered between 202 and 240 m below the seafloor in Hole 542 contain muds and nannofossil muds (Table 3). The preservation and abundance of the nannofossils in these samples is similar to that seen in samples of equivalent age at Site 541.

Hole 542A

Core 542A-1 is a spot core taken from 173.5 to 183.0 m sub-bottom (Table 5) and contains the boundary between the *Ceratolithus rugosus* Subzone and the *Sphenolithus neoabies* Subzone. A washed core (Core H1) taken above this spot core contains upper Pliocene assemblages from the *Discoaster tamalis* Subzone. The washed core (Core H2) recovered below Core 1 has a good succession of ceratoliths from the *Ceratolithus acutus* and *Ceratolithus rugosus* Subzones (Table 5).

The nine continuous cores (Cores 2–10) recovered from the bottom of Hole 542A contain upper Miocene muds.

Table 2. Nannofossil species present in the Pliocene and Pleistocene in Hole 543.

Age		Nannofossil zone or subzone	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Ceratolithus cristatus*	*C. rugosus*	*C. separatus*	*Triquetrorhabdulus rugosus*	*Discoaster asymmetricus*	*D. braarudii*	*D. brouweri*	*D. challengeri*	*D. pentaradiatus*	*D. quinqueramus*	*D. surculus*	*D. tamalis*	*D. variabilis*	*Sphenolithus abies*	*S. neoabies*	*Coccolithus pelagicus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Umbilicosphaera cricota*	*U. mirabilis*	*Pseudoemiliania lacunosa*	*Crenalithus doronicoides*	*Reticulofenestra pseudoumbilica*	*Gephyrocapsa caribbeanica*	*G. oceanica*	*G. omega*	*Gephyrocapsa* sp.	*Hayaster perplexus*	*Scapholithus fossilis*	*Thoracosphaera albatrosiana*	*T. heimi*	*Helicosphaera carteri*	*H. sellii*	*Rhabdosphaera clavigera*	*Pontosphaera* sp.	*Scyphosphaera ampla*	*S. apsteini*	*S. globulosa*	*S. pulcherrima*	*S. recta*	*S. recurvata*	*Syracosphaera pulchra*
Pleistocene	early	*Pseudoemiliania lacunosa* Zone		1-1, 60-61	F	M	P																C		P	R	F	C		R	F	C	A			R		F		R								R
				1-2, 60-61	B																																											
				1-3, 61-61	R	P																	R				R	F																				
				1-4, 120-121	B																																											
		?		1-5, 63-64	F	P	R						P		P											R	F	A		R	C	F	C					F	P							P		F
		Helicosphaera sellii Zone		1-6, 63-64	A	M	R						r		r								C		R	F	C	A		P	A	C	A	R		R		F	F	C		P					P	F
			10.5	1,CC	C	P	P						p		r								F	p	p	F	C	C		P	C	F	C			R		F	R	R								F
				2-1, 51-52	C	P	R													p			C			C	F	A					A			P		C	R	C								C
				2-2, 51-52	B								p				p		p																													
				2-3, 51-52	A	M	R						p		p							R	C		R	F	A	A					E		R	F		C		C	R	P			R		P	F
				2-4, 51-52	R	P																	R			P	F	F										R										
				2-5, 51-52	B																																											
			20.0	2,CC	C	P	R									p	p		p			P	C			C	C	A		R			A			R		C	P	F					P			R
		Calcidiscus macintyrei Zone		3-1, 62-63	F	P	R															R	F			P	A	C		F	C							F		P								
				3-2, 62-63	F	P	F						p		p							R	F	P	R	R	C	A		F	F		C			R		C	R	R					P			F
				3-3, 62-63	C	M	R						p		p							R	C	R	R	F	A	A		C	F		A			R		C	R	F					P			C
				3-4, 62-63	C	M	F						p		p				p			R	C	F		F	A	A					C			F		C	R	F	R			R	R		R	C
				3-5, 62-63	A	M	F															F	C	F		F	A	A					A			R		C	R	C	R		P		R			C
				3-6, 62-63	A	M	F		P				p		p	p						R	C	F		F	A	A					A			R		C	F	C		R						F
				3-7, 16-17	A	P	R		P			p	p		p		p	p				R	C	F		F	C	A					C			F		C	F	F	R				P			C
			29.5	3,CC	A	P	F		R				r		p		r		p			R	C	C	R	C	A	A					C		R	F	R	C	F	C	R							C
Pliocene	late	*Calcidiscus macintyrei* Subzone (CN12d)		4-1, 54-55	F	P	F		R			F	C		r		p					R	C	C		R	C	C					F			R		R	R		P				P			C
				4-2, 54-55	B																																											
				4-3, 54-55	F	P	F		R			C	F									F	C	C		F	C	C										P										
				4-4, 54-55	F	P	R					F	C		p		r					R	C	F			R	F																				
				4-5, 54-55	F	P	R					F	F									F	F	F		C	C	C										F	R									R
				4-6, 54-55	F	P	R					C	C		p		p					F	C	F		C	C	A					C					F	R									C
				4-7, 44-45	F	P	F	P				F	R		p		r					R	C	F		R	F	C										F										R
			39.0	4,CC	F	P	R					C	F		p		p	p				R	F	F		R	F	C										R	R									F
		? *D. surculus* Subzone (CN12b)		5-1, 100-101	R	P							R		p							P	P				F	R										P										
				5-2, 100-101	A	P	R					F	C		A		F					F	C	C	P	R	A	A					C			R		C	F									C
				5-3, 100-101	C	P	F				R	C	C		C		F	R	P			R	C	C			C	A					F					R	R									F
				5-4, 100-101	A	M	F				F	C	C		A		C	F					C	C	C	R	C	E					C			R		C	F									F
			48.5	5,CC	C	P	F				R	C	C		C		F	F				R	C	C	F	F	C	A					C			P		F	R	P								C
		Discoaster tamalis Subzone (CN12a)		6-1, 94-95	C	P	F				R	C	C		C		F	R	P			F	C	C	R		F	A					F															R
				6-2, 94-95	A	P	F				R	F	F		A		F	F	R			F	C	C	C		C	A					A					F	F									C
				6-3, 94-95	C	P	R				F	C	F		C		C	F	R			F	C	F	F	R	C	A					C			R		F	R									R
				6-4, 94-95	A	P	F				R	F	C		C		C	F	R			F	C	C	F	F	C	A					C					F	R		P							R
				6-5, 94-95	A	P	R				C	R	C		C		C	F	R			F	F	F	F		C	A					C					R	R						P			R
				6-6, 94-95	A	M	C	R			F	C	F	R	C		F	F	R			F	C	C	C		C	E					A			P		C	F						P			C
			58.0	6,CC	F	P	R				F	C	F		C		F	F	R			F	C	F	F		F	A					F					R	R									R
				7-1, 55-56	C	P	R	R			C	C	F	R	C		F	F	R		P	R	C	F	R		R	A					C					R	F									
				7-2, 55-56	C	M	R				C	C	C	P	C		C	F	R	C	F	R	C	C	R	F	F	E					C			P		C	F					P				C
	early	*R. pseudoumbilica* Zone		7-3, 55-56	F	P	R			p	C	C	F	R	C		F	R	R	F	R		F				F	C	R				F						P									R
				7-4, 55-56	C	P	F	R		p	R	F	F		A		C		R	C	F		C	R					C																			
			67.5	7,CC	A	P	F	R			R	R	C	R	A		C	R	F	C	F		C	P	R			R	C																			
				8-1, 65-66	F	P	P					R	F		F		C		R										R																			

Note: See the Appendix for an explanation of symbols.

Samples taken from these cores are either barren or contain few, poorly preserved nannoplankton (Table 4). It was difficult to delineate any successions in this hole for this reason. However, the occurrence of nannofossils in this section suggests that there are repetitions of section in these cores.

Amaurolithus delicatus and *A. primus* are not present in any of the samples from Cores 2 to 10. This is not the result of poor preservation throughout this interval, because several samples contain placoliths that are less solution-resistant than the amauroliths. Most of the samples from these cores contain either *Discoaster surculus* or *D. berggrenii*, and may be placed in the *Discoaster berggrenii* Subzone on the basis of these species being present and the amauroliths being absent. Some samples, however, do not contain any of these species. No other age-diagnostic species other than *D. neohamatus* are present in these samples, and they may be slightly older than the *Discoaster berggrenii* Subzone. Thus, the 75 m of section between Cores 2 and 10 in Hole 542A shown no change in age, indicated by the nannofossils.

Further evidence of a repetition in section in Cores 2 to 10 (Table 4) can be seen by examining nannofossil occurrences in these sediments. The sequence found in Samples 542A-10-1, 49–50 cm through 542A-7-4, 64–65 cm is very similar to the one from Samples 542A-6-1, 121–122 cm to 542A-4-2, 60–61 cm. In both instances, *D. surculus* occurs in the bottom three samples, is followed first by an interval in which *D. surculus* and *Discoaster* sp. cf. *D. Berggrenii* are absent, and then by samples in which only *Discoaster* sp. cf. *D. berggrenii* is present. In the upper part of the section, *D. berggrenii* and *D. quinqueramus* are also present in the topmost samples of this sequence and indicate a slightly younger age for these samples. Evidence from Site 541 shows that the first occurrence of *Discoaster* sp. cf. *D. berggrenii* is before that of *D. surculus.* If this is so, two additional repetitions of section in the bottom of this hole

Table 3. Nannofossil species present in Cores 1 to 4 in Hole 542.

Age	Nannofossil zone or subzone	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Amaurolithus amplificus*	*A. delicatus*	*A. primus*	*A. tricorniculatus*	*Ceratolithus acutus*	*C. armatus*	*C. atlanticus*	*C. cristatus*	*C. rugosus*	*Triquetrorhabdulus rugosus*	*Discoaster asymmetricus*	*D. berggrenii*	*D. braarudii*	*D. brouweri*	*D. challengeri*	*D. pentaradiatus*	*D. quinqueramus*	*D. surculus*	*D. variabilis*	*Sphenolithus abies*	*S. moriformis*	*S. neoabies*	*Coccolithus pelagicus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Umbilicosphaera cricota*	*Crenalithus doronicoides*	*Reticulofenestra pseudoumbilica*	*Thoracosphaera albatrosiana*	*Helicosphaera carteri*	*H. sellii*	*Pontosphaera* sp.	*Scyphosphaera ampla*	*S. globulosa*	*S. pulcherrima*	*S. recta*	*S. recurvata*	*Syracosphaera pulchra*
	Sphenolithus neoabies Subzone (CN11a)		1-1, 97–98	C	M								R	R				C	R	R	C		C	R	C		C	R	C	F	R	A	C	F	C	R	P		P			P	R
			1-2, 97–98	A	M								R	P	r			C	F		C	F	F	C		C	R	C	F	F	A	F	F	C	R	P			R		P	P	
			1-3, 97–98	A	M								P	R		R		C	F	R	C		C	F	C		C	R	C	C	F	A	C	F	C	R	P	P		P		P	
			1-4, 97–98	A	M								R					C	F	R	C		C	F	C		F	F	A		F	A	C		C	R	P	P					P
			1-5, 97–98	A	M								R	R				C	R	F	C		C	C	C		F	R	A	F	C	A	F	R	F								
			1-6, 97–98	A	M								R		r	R		C	R	F	C		C	C	C		C	F	C		F	C	C		C	R						P	R
		211.5	1,CC	A	P								P	P				C	F		C		C	F	C		C	R	C	F	R	A	C	R	F	R	P			P	P		R
	Ceratolithus rugosus Subzone (CN10c)		2-1, 61–62	A	M				R				R					A	F	R	C		C	R	F		C	R	C	F	F	E	C	R	C	P	P						
Plio-cene early			2-2, 61–62	A	M				P				R	R	r			C	C	R	C	p	F	R	C		C	F	C	F	C	E	C		F					P	P		R
			2-3, 61–62	A	M				F				R	P				C	F		C		F	R	R		F	R	C	F	F	C	C	R	F								R
			2-4, 61–62	C	M				F				R					C		R	C		A				F	R	C	R	F	A	C		F								R
			2-5, 96–97	C	P		R		R				R					C	F	R	C		A	F	R		R		C		R	F	A		R								
		221.0	2,CC	C	P		F		R		R		R		p	P		C	F	F	F		C		R		F	F	C	R	F	F	C		R								P
	Ceratolithus acutus Subzone (CN10b)		3-1, 40–41	A	M		F		R	R	P	P						C	C	R	C		A	C	A		C	C	C	R	R	A	F	R	F	R			P				
			3-1, 113–114	A	M		F	p		R		R						C	F	R	F		C	C	C		R	C	C		R	A	C		R								
			3-2, 40–41	C	M		F		P	R	P	R			P			C	F	R	F		C	F	F		C	C	C		F	A	F		F	P							
			3-3, 40–41	C	M		R			R	R			R		F	F	R	F		C	C	F		R	C	C			A	R												
			3-3, 113–114	A	M		F			R		R			P			C	C	F	R		A	C	C		F	C	C		R	A	F		F								
	T. rugosus Subzone (CN10a)		3-4, 40–41	C	P		F			R					R		F	F	F	F		C	C	F			C	F			C	F											
			3-4, 113–114	A	M		F								F			C	F	R	C		C	F	F		R	C	C			A	F		F	R							
			3-5, 40–41	F	P		R	R										F				R	F	F				R	R				P										
			3-5, 113–114	C	P		F	R							R		C	R		C	R	C	C		F		C	F			A	F											
			3-6, 40–41	C	M		F	R							F			F	F		C	R	F	F	F	F	R	F	C			A	F		R								
	Amaurolithus primus Subzone (CN9b)	230.5	3,CC	C	P		F								F			C	F	C			F	F					F		C	F		R									
			4-1, 27–28	A	M		F	R							F		P	F	R			F	C	F	F	C	R	C	C		F	A	F		F	R							
Miocene late			4-2, 27–28	C	M		R	R							F		R			C	F	F	C		F	F	R	F	C		F	C	F		C	R	R					P	
			4-3, 46–47	A	M		R	F							F			F	P	R		F	C	F	F	F	F	C	C		F	A	C										
			4-4, 46–47	C	P		R	R							R		R	F		F	R	C	F	C				F	F				F										
			4-5, 93–94	F	P			P														F	C	C																			
			4-6, 93–94	C	P	R	F	R										F		R	R	C	C	C	F		R	F	F			F	C										
		240.0	4,CC	B																																							

Note: See the Appendix for explanation of symbols.

may exist because the first appearance of *Discoaster* sp. cf. *D. berggrenii* occurs after that of *D. surculus* in the two sequences discussed earlier.

Site 541

Site 541, drilled in 4940 m of water, is the shallowest of the three sites drilled. It is located about 3 km west of the toe of the accretionary prism (Fig. 1). High core recovery in a continuously cored section provide an excellent record of the sediments in this part of the Barbados Ridge. Unstable hole conditions eventually caused the collapse of the bottom of this hole after 460 m of section had been drilled.

The most significant outcome at this site was the location of a large repetition of section beginning at 276 m sub-bottom in Core 30, Section 6. At this horizon, upper Miocene mud of the *Amaurolithus primus* Subzone overlie an upper Pliocene nannofossil mud of the *Discoaster tamalis* Subzone (Fig. 3; Tables 7, 8). This contact is interpreted as a large-scale reverse fault. About 117 m of section are repeated above this contact, as determined from the nannofossils.

In the sediments overlying this contact, a second fault occurs in the middle of Core 29 as sediments placed in the *Discoaster berggrenii* Subzone overlie those assigned to the *Amauroliths primus* Subzone (Table 8). This indicates that 12 m of section have been faulted into the section above the major reverse fault.

Figure 3 illustrates the important nannoplankton species in samples on both sides of this small fault. In the bottom half of Core 29 and Core 30, *D. surculus*, *D. quinqueramus*, and typical *D. berggrenii* (see taxonomic notes) are present in samples that contain amauroliths. Above this, in the top part of Core 29 and in Core 28, the amauroliths are not present and the sediments are older. *Discoaster* sp. cf. *D. berggrenii* (see the systematic paleontology) is the only age-diagnostic species present throughout this interval. Typical *D. berggrenii*, with buttons that are equal in length to the central area and arms that are equal in length to the central area, do not appear in this interval until Sample 541-28-5, 54–55 cm.

If the occurrence of these species in the sediments above the major fault is interpreted correctly and is not a consequence of preservation, it can provide important information that may be used in similar-age sediments at the other sections examined in this study. One inference is that there is an evolutionary trend from *Discoaster* sp. cf. *D. berggrenii* to *D. berggrenii* to *D. quinqueramus* through the reduction in size of the central knob and lengthening of the arms. This was first suggested by Bukry (1971b). A second inference that can be drawn is that *Discoaster* sp. cf. *D. berggrenii* has its true first occurrence before that of *D. surculus* in these sections. This is important when examining sediments from the *Discoaster berggrenii* Subzone in the bottom of this hole and at Site 542 (Tables 4 and 7). The occurrence of nan-

Table 4. Nannofossil species present in Cores 2 to 10 in Hole 542A.

Age	Nannofossil zone or subzone	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Triquetrorhabdulus rugosus*	*Discoaster asymmetricus*	*D. berggrenii*	*Discoaster* sp. cf. *D. berggrenii*	*D. braarudii*	*D. brouweri*	*D. challengeri*	*D. neohamatus*	*D. pentaradiatus*	*D. surculus*	*D. variabilis*	*D. hamatus*	*Sphenolithus abies*	*S. moriformis*	*S. neoabies*	*Coccolithus pelagicus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Umbilicosphaera cricota*	*Crenalithus doronicoides*	*Reticulofenestra pseudoumbilica*	*Thoracosphaera albatrosiana*	*Helicosphaera carteri*	*H. sellii*	*Pontosphaera* sp.
			2-1, 69–70	B																										
			2-2, 94–95	B																										
			2-3, 110–111	B																										
			2-4, 85–86	B																										
			2-5, 101–102	B																										
			2-6, 93–94	B																										
		249.5	2,CC	B																										
			3-1, 104–105	B																										
			3-2, 104–105	R	P					P						R														
			3-3, 104–105	B																										
			3-4, 104–105	F	P					F					R	C														
			3-5, 86–87	F	P			R	C	F		C			R	F														
			3-6, 86–87	B																										
		259.0	3,CC	B																										
			4-1, 90–91	B																										
			4-2, 60–61	C	P	F		F	C	C	F	C	P			C		F	F	R	C	F	R	R	F	R		F		
			4-3, 58–59	C	P	F		C	F	C	R	R	P	R	P	C		R	F	F	C	C			R	R				
			4-4, 91–92	B																										
			4-5, 97–98	B																										
		268.5	4,CC	B																										
			5-1, 55–56	B																										
			5-2, 125–126	C	P	R				C	F		R	R		C			R	R	C	F	F			F				
			5-3, 77–78	C	P	R				F	F	R		R		C			R	F	C	F	F	R		F		R	P	
			5-4, 85–86	C	P				R	C	R	C		R		C			R	R	C	F	F	R	R	F		R		
Miocene late	*Discoaster berggrenii* Subzone (CN9a)		5-5, 101–102	C	M	R				C	R	F	R	F		C		R	F	F	C	C	R	R	C	C		R		
			5-6, 91–92	C	P	R				C	F	F	R	R	F	C		R	R	F	C	F	R		C	C		R		
		278.0	5,CC	F	P					F		R		R	R	C										F				
			6-1, 121–122	C	P					A	R	C	P	R	F	C					R	R				F				
			6-3, 114–115	B																										
			6-4, 92–93	R	P										C															
			6-5, 92–93	B																										
			6-6, 92–93	B																										
		287.5	6,CC	R	P							R			R	F														
			7-1, 11–12	B																										
			7-1, 113–114	B																										
			7-4, 64–65	F	P				R	F						F														
		297.0	7,CC	R	P					R						F														
			8-1, 87–88	C	P				P	C	R	F	R	R		A				F	F	C	F			R				
			8-2, 87–88	B																										
			8-4, 98–99	B																										
			8-5, 40–41	F	P	R				C	R	F	R	R		C					F	F	R			F				
		306.5	8,CC	F	P	R	P			C		R		R		C						R	R							
			9-1, 63–64	C	P	R				C	F	F	R	F		C	R	R	R	F	F	C	F			C	R	C		P
			9-2, 35–36	F	P					F						C														
			9-3, 15–16	C	P					C		F	P	F	F	C					C	F				C				
		316.0	9,CC	F	P					C			P	R	R	C					P					R				
			10-1, 49–50	C	P	R	R		P	C	F	F	R	F	F	C		R	R		F					C		F		
			10-2, 147–148	B																										
			10-3, 95–96	B																										
			10-4, 49–50	B																										
			10-5, 51–52	B																										

Note: See the Appendix for an explanation of symbols.

Table 5. Nannofossil species present in Core 1 and washed cores from Hole 542A.

Age	Nannofossil zone or subzone	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Amaurolithus delicatus*	*A. primus*	*A. tricorniculatus*	*Ceratolithus acutus*	*C. armatus*	*C. atlanticus*	*C. cristatus*	*C. rugosus*	*Triquetrorhabdulus rugosus*	*Discoaster asymmetricus*	*D. berggrenii*	*D. braarudii*	*D. brouweri*	*D. challengeri*	*D. pentaradiatus*	*D. quinqueramus*	*D. surculus*	*D. tamalis*	*D. variabilis*	*Sphenolithus abies*	*S. moriformis*	*S. neoabies*	*Coccolithus pelagicus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Umbilicosphaera cricota*	*U. mirabilis*	*Pseudoemiliania lacunosa*	*Crenalithus doronicoides*	*Reticulofenestra pseudoumbilica*	*Scapholithus fossilis*	*Thoracosphaera albatrosiana*	*T. heimi*	*Helicosphaera carteri*	*Helicosphaera sellii*	*Rhabdosphaera clavigera*	*Pontosphaera* sp.	*Scyphosphaera ampla*	*S. apsteini*	*S. globulosa*	*S. pulcherrima*	*S. recurvata*	*Syracosphaera pulchra*
Pliocene, late	*Discoaster tamalis* Subzone (CN12a)		H1-2, 103–104	C	M							R					F	C		C		F	R						C	C	F		R	A			F		F	R								C
			H1-3, 80–81	A	M							R	R		F		F	C		C		F	R	R				R	C	F	C		C	A		P	R	R	C	F	R	R		P	P	R		C
			H1-4, 80–81	A	M							R			R		F	F		C		F	R					R	C	F	C		C	E			F	R	C	R		R				P		C
			H1-5, 80–81	A	M							F	R		F		C	F	R	F		C	F	R				R	F	F	C		C	A			F		C	F	R	R				R	R	F
	Reticulofenestra pseudoumbilica Zone (CN11)	173.5	H1,CC	A	M							R	P	p	R		F	C	R	C		F	P	R	C		C		C	R	F	R		E	F		F		C	R		R				P		
			1-1, 58–59	A	M							R					F	F		C				F	C		C		C	F	C			C	C		R		C	R		R				R	R	R
			1-2, 58–59	A	M							R					C	C	R	C		C		R	C		C	R	C		F			A	F				F	R								
Pliocene, early			1-3, 58–58	A	M							R	R				C	F	F	C		C		R	R		C	R	C	F	F			C	C				C	R		P	P	P			P	
			1-4, 58–59	C	M							R			P	r	F	F	F	C		C			F		C	R	C	F	C			A	C		R		C			P	P				P	R
	C. rugosus Subzone (CN10c)		1-5, 58–59	A	M			R				R	P			P	C	F		C		F		R	C		F		C	P				C	C				C								P	R
		183.0	1,CC	C	M			F				P	R				F	R		C	p	F		F	F		C	R	C	R	R			C	C				R									
	Ceratolithus rugosus Subzone (CN10c)	183.0	H2-1, 55–56	A	M			R				R					C	R		C		C		R	F		R	R	C	R	R			A	F				R	R		P						
			H2-2, 67–68	C	P	R		F				R					C	R		C		C		R	R		R		F						C	F												
			H2-3, 46–47	A	P	F		R		R		R	R			p	C	F		R		A			F		R		C	R				A	C				R									
			H2-4, 27–28	A	M	R		R		R							F	F	R	F	p	C		R	F	R	F	F	C		R			A	C				F	R								
	Ceratolithus acutus Subzone (CN10b)		H2-5, 27–28	C	M	R		R	R	R							C	R	F	F		C		F	C		R	F	C	P	F			A	F				F	R								
			H2-6, 69–70	A	M	R	P	R	R								C	R	R	F	p	F		F	F		R	C	C		C			A	C				F									
		240.0	H2,CC	R	P												F							R																								

Note: See the Appendix for an explanation of symbols.

Table 6. Nannofossil species present in washed cores from Hole 542.

Age	Nannofossil zone or subzone	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Ceratolithus cristatus*	*C. rugosus*	*C. separatus*	*Triquetrorhabdulus rugosus*	*Discoaster asymmetricus*	*D. braarudii*	*D. brouweri*	*D. challengeri*	*D. pentaradiatus*	*D. quinqueramus*	*D. surculus*	*D. tamalis*	*D. variabilis*	*Sphenolithus abies*	*S. moriformis*	*S. neoabies*	*Coccolithus pelagicus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Umbilicosphaera cricota*	*U. mirabilis*	*Pseudoemiliania lacunosa*	*Crenalithus doronicoides*	*Reticulofenestra pseudoumbilica*	*Gephyrocapsa* sp.	*Scapholithus fossilis*	*Thoracosphaera albatrosiana*	*T. heimi*	*Helicosphaera carteri*	*H. sellii*	*Rhabdosphaera clavigera*	*Pontosphaera* sp.	*P. japonica*	*Scyphosphaera ampla*	*S. globulosa*	*S. piriformis*	*S. pulcherrima*	*S. recurvata*	*Syracosphaera pulchra*
Pleistocene, early	*Calcidiscus macintyrei* Zone		H1-1, 69–70	A	M	R								r				r				R	C		R	F	C	C		F	R	F		C	R	A	R					R		C
			H1-2, 43–44	A	M	R		F				r		r	p			p				F	C	C		F	C	A			R	F	R	C	R	C	R	R		P	P	R	R	C
			H1-3, 15–16	C	P	F		R				f										R	C	C	R	F	C	A				R		F	F	F				P				C
			H1-4, 22–23	C	M	R		R				p		p		p						F	C	C		R	C	A		R	R	F		C	F	C	R	R	P			R		C
		88.0	H1,CC	C	M	R		F				p						p				R	C	C		C	C	A			R	F	P	C	R	P	R	P	P			P		C
Pliocene, late	*Discoaster tamalis* Subzone (CN12a)	88.0	H2-2, 68–69	C	M	R				R	C	C		C		C	R					F	C	C	F		F	A	p	R		F		C								P		F
			H2-3, 68–69	C	P	F				R	C	F		C		F	R					R	F	F	F		R	A				R		F										F
			H2-4, 68–69	C	M	F			r	F	C	C		C		C	F					F	C	C	F		C	A		F	R	R	P	C								R		C
			H2-7, 87–88	C	P	R				R	C	F		C		F	R	R			p	F	C	F	F		F	A		F		R		C								P		
		154.5	H2,CC	C	P	R				F	C	F		C		F	R	F					C	F	F		F	A		R	F	F		C								P		F
Pliocene, early	*Reticulofenestra pseudoumbilica* Zone	154.5	H3-1, 67–68	A	M	F				C	C	C	F	F		C	P	R	C		C	R	C	F	C	C	F	E	F	F				C	R							R	R	F
			H3-2, 67–68	C	P	F				F	F	C	R	F		C		R	C		C	R	C	R	F	R	F	A	F		P	R		C			P					P	P	R
			H3-3, 67–68	C	M	F	P		r	F	C	F		C		C		R	C		A	R	C	F	F		R	C	C		P	R		C	P		P					P		
			H3-4, 67–68	A	M	R	P		p	R	C	F	R	C		C	P		C	r	C	F	C	C	C	R		A	F			F		C	F		P					R	R	
		202.0	H3,CC	A	M	R	P		r		F	C		A		C		R	C		A		C	F	F	R		A	C			F		C	R		R			P		R	P	

Note: See the Appendix for an explanation of the symbols.

noplankton in those samples is different from the sequence in Section 541-30-6 through Core 28. In those samples, *D. surculus* is found in samples below *Discoaster* sp. cf. *D. berggrenii* and *D. berggrenii*, which is the reverse of the situation seen just above the major fault (Table 8). This suggests that the sediments from the *Discoaster berggrenii* Subzone in the bottom half of Hole 541 and at Site 542 are inverted.

Two other repetitions of section were dated in this hole and both are above the major fault. The lower of the two occurs between Cores 19 and 20 (Fig. 4). The *Ceratolithus acutus* Subzone is recognized in the base of Core 19, but samples in Core 20 are zoned in the younger *Sphenolithus neoabies* Subzone (Table 9). This contact was not recovered, and about 23 m of section are repeated above Core 20.

A final repetition of section is seen in Samples 541-9-5, 75–76 cm through 541-9-2, 75–76 cm and is equivalent to 6 m of section in Core 10 (Table 10).

Two unconformities are present in Hole 541. One occurs in the top part of the hole, as Sample 541-13-1, 30–31 cm is the only sample from the *Discoaster pentaradiatus* Subzone. A hiatus was observed at a similar stratigraphic interval at Site 543 where *D. pentaradiatus* is absent from sediments. A second unconformity in Hole 541 occurs between Samples 541-37-1, 35–36 cm and 541-36,CC. The *Triquetrorhabdulus rugosus* Subzone represents this missing interval.

CORRELATIONS

Site 541 is crucial in the correlation of nannofossil-bearing sediments at these sites because Sites 542 and

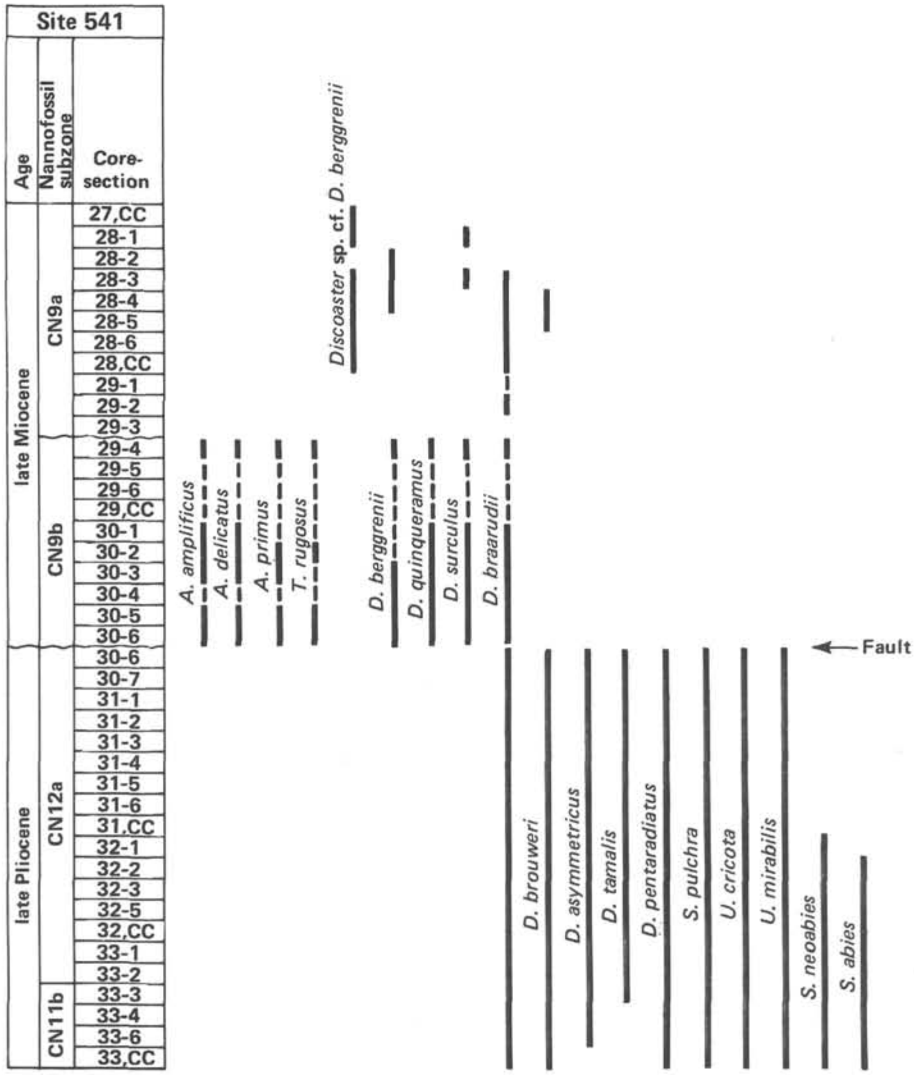

Figure 3. Distribution of selected nannofossil species across the fault at 276 m sub-bottom in Hole 541.

543 have no age-equivalent nannofossil sediments in common. For this reason, correlations between Site 541 and the other two sites are discussed separately.

Sites 541 and 542

Sediments cored at Site 542 form a continuous section from the *Discoaster berggrenii* Subzone to the *Sphenolithus neoabies* Subzone. The succession of nannofossil subzones, sedimentation rates, and the preservational characteristics in the upper part of this section from Cores 1 through 4 in Hole 542 are very similar to that in Cores 20 through 23 in Hole 541. A fault occurs above Core 20 in Hole 541, and the *Ceratolithus acutus* through the *Sphenolithus neoabies* Subzones are repeated above that horizon. Evidence from Site 542 also demonstrates that faulting occurs there in sediments of similar age inasmuch as the last occurrence of *Amaurolithus tricorniculatus* is at 211.5 m sub-bottom in Hole 542 and at 180 m in a spot core from Hole 542A. This fault may be located anywhere between 183.5 and 202 m sub-bottom in an interval that was not cored and is deeper than the fault at Site 541.

Comparisons between the two sites are difficult to make in sediments of the *Discoaster berggrenii* Subzone. These correlations are hampered by poor preservation of the nannofossil assemblages and barren intervals in sediments of these ages, but may also be complicated by faulting in these two sections. One very obvious difference is that 70 m of section of the *Discoaster berggrenii* Subzone are present in Hole 542A, but only 13 m and 14 m of sediments of this same age are present above and below the major fault at Site 541. There are several possible explanations.

One is that the sedimentation rates at Sites 541 and 542 were different. This explanation is not likely because of thicknesses that are different by a factor of five in lithologically similar sediments. A second explanation could be that Site 542 was above the carbonate compensation depth for a longer period of time than was Site 541. If this were true, the 40 m of barren section (Core 541-43 to Section 541-47-1) between the radiolarian mudstone and the first nannofossil-bearing sediments in Hole 541 would be upper Miocene muds. Thus no middle Miocene sediments would be present at that site and upper

Table 7. Nannofossil species present below the major fault in Hole 541.

Age		Nannofossil zone or subzone	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Amaurolithus amplificus*	*A. delicatus*	*A. primus*	*A. tricorniculatus*	*Ceratolithus acutus*	*C. armatus*	*C. atlanticus*	*C. cristatus*	*C. rugosus*	*Triquetrorhabdulus rugosus*	*Discoaster asymmetricus*	*D. berggrenii*	*Discoaster* sp. cf. *D. berggrenii*	*D. bollii*
Pliocene	late	*Discoaster tamalis* Subzone (CN12a)		30-6, 135–136	C	M								R			R			
				30-7, 60–61	C	M								R			R			
			276.5	30,CC	C	M								P			F			
				31-1, 89–90	C	M								R	P		C			
				31-2, 89–90	A	M								R			F			
				31-3, 89–90	A	M								R			F			
				31-4, 89–90	C	M								R			F			
				31-5, 89–90	A	M								R			F			
				31-6, 89–90	A	M								F			F			
			286.0	31,CC	A	M								R			R			
				32-1, 45–46	C	M								P			F			
				32-2, 69–70	A	M								R			C			
				32-3, 45–46	A	M								R	P		C			
				32-5, 45–46	C	M								R			F			
			295.5	32,CC	A	M								R	P		F			
				33-1, 58–59	C	M								R			C			
				33-2, 58–59	A	M								R			C			
	early	*Discoaster asymmetricus* Subzone (CN11b)		33-3, 58–59	C	M								R	P		F			
				33-4, 58–59	A	M								R	R		F			
				33-6, 39–40	C	M									P		F			
			305.0	33,CC	F	M								P	R					
		Sphenolithus neoabies Subzone (CN11a)		34-1, 101–102	C	M									R		R			
				34-2, 89–90	A	M								P	R		R			
				34-3, 74–75	C	P								R			R			
				34-4, 101–102	C	M								R	R	p				
				34-5, 48–49	C	M								P	R		R			
				34-6, 101–102	C	M								R	R					
			314.5	34,CC	C	M								R	P					
				35-1, 75–76	C	M								R			R			
				35-2, 64–65	A	M								R	P					
				35-3, 69–70	C	M								R	P					
		Ceratolithus rugosus Subzone (CN10c)		35-4, 64–65	C	P				F				R						
				35-5, 80–81	A	M				F				R			P			
				35-6, 64–65	C	M		R		F				R						
			324.0	35,CC	C	M		R		R		R		P			P			
Miocene	late	*Ceratolithus acutus* Subzone (CN10b)		36-1, 35–36	C	P		R	P	R	R	R								
				36-2, 35–36	A	M		R		R	R	R								
			335.5	36,CC	C	P		R			R		R				P			
		Amaurolithus primus Subzone (CN9b)		37-1, 35–36	C	P		F								R		P		
				37-2, 75–76	C	P		R	F							R		R		
				37-3, 35–36	C	P		R	F							F				
				37-4, 25–26	C	M		F	R							F		R		
				37-5, 20–21	C	P	P	R	R							R	P	R		
			343.0	37,CC	C	M	P	R	P											
				38-1, 75–76	R	P												R		
				38-3, 75–76	C	P	P	R	P											
				38-5, 75–76	B															
			352.5	38,CC	B															
				39-1, 95–96	R	P														
				39-3, 21–22	C	P		R	R							R		R		
		?		39-5, 12–13	R	P												P	P	
		Non-diagnostic	362.0	39,CC	R	P														
				40-2, 64–65	B															
				40-3, 40–41	B															
				40-4, 99–100	R	P														
				40-5, 97–98	B															
				40-6, 55–56	B															
			371.5	40,CC	B															
				41-1, 101–102	B															
				41-2, 96–97	B													F	C	
		? *Discoaster berggrenii* Subzone (CN9a)		41-4, 34–35	C	P										F		F	C	
				41-4, 121–122	C	P										R				
				41-6, 57–58	R	P														
			381.0	41,CC	B															
				42-2, 44–45	F	P										P				
				42-3, 83–86	R	P														r
				42-4, 83–86	C	M										R				r
				42-5, 69–70	F	P														
				42-7, 54–55	B															
			390.5	42,CC	R	P														

Note: See the Appendix for an explanation of symbols.

Table 7. (Continued).

D. braarudii	D. brouweri	D. challengeri	D. hamatus	D. neohamatus	D. pentaradiatus	D. quinqueramus	D. surculus	D. tamalis	D. variabilis	Sphenolithus abies	S. moriformis	S. neoabies	Coccolithus pelagicus	Calcidiscus leptoporus	C. macintyrei	Umbilicosphaera cricota	U. mirabilis	Pseudoemiliania lacunosa	Crenalithus doronicoides	Reticulofenestra pseudoumbilica	Thoracosphaera albatrosiana	T. heimi	Helicosphaera carteri	H. sellii	Rhabdosphaera clavigera	Pontosphaera sp.	Scyphosphaera ampla	S. apsteini	S. cylindrica	S. globulosa	S. piriformis	S. pulcherrima	S. recta	S. recurvata	Syracosphaera pulchra
F	F	R			F		C	R					F	C	C	F		C	A		R		C			R									F
F	F				F		F	F					F	F	F	R		C	A		R	P	F			F						R			R
C	C	R			F		F	R	P				F	C	F	F		C	A		R		F				P	P			R		P		F
C	C				F		F	F					R	C	F	C		F	A		F	R	C		P	F						R	P		C
F	F	P			C		F	R					F	C	C	F		F	E		F		C	R		R				P				R	F
R	C				F		F	F					F	C	F	C		C	A		R	R	C	R		F	P		P			P			F
C	F	P			F		F	F					F	C	F	F		C	A				F	P		P						P			R
F	F	R			R		F	R					R	C	F	F		F	E		R	R	C	R		R									R
R	C	R			F		F	F						C	F	F		C	A		R		F												F
F	F	F			C		C	R	R				R	C	C	C		F	A				C			R	P					P		R	F
F	C	F			R		F	F	R			R	R	C	C	C		F	A		R	R	C			P						P			
F	F	F			F		C	F		R		F		C	F	F		C	A		R	R	F	R		R						P			R
C	C	F			R		C	F	R	F		C		C	F	F		R	A		R		C	R		P									F
F	F	R			F		C	F		R		F	R	C	C	F		R	A		R	P	F	R											F
F	C	F			F		C	R	R	F		F	R	C	R	R	R	C	A		R	R	C	F	P		P					R			F
F	F	F			R		F	R	R	C		F	R	C	F	R		F	A		R		F												R
F	C	F			F		C	R	R	C		F		C	F	R	F	F	A				F	R											R
C	C	F			F		F	R		C		C	R	C	F	F	F	R	C	F	R	P	F	R		R						R			R
R	C	F			F		C			C		A	P	C	F	F	R	F	A	F	R		C	R		R		R							R
R	C	R			F		F		R	C		A	R	C		R	R	R	A	F	F		F			R								P	
C	R				F		F		R	F		F	R	C	F	F			C	F			F	P										P	
C	F	R			F		F		R	F		C	R	F	F	R			F	F	F		F	R										P	
F	C	F			F		C	P	F	C		C		C	F	F	R		A	F	F	R	C	P			P					P		P	
F	C	P			C		F		R	F		C	R	F	R	C	R	F	F	F	F		F	R				P		P					
C	F	F			C		F		R	C		C	R	C	F	F	R	C	C	F			C								P		P		
F	F	F			C		F		R	C		C		C	F	F	R		C	C	R	R	C		P	R				P		P			P
F	F	R			C		F		F	C		R		C	F	C			C	C	F	P	F												
F	R				C		C			A		F	R	C	R	R			F	C			F												
F	F	F			F		F		F	C		F	R	C		F			C	C			F												
C	F	R			C		F		R	F		C	R	A		C			C	C	R		C	F	P							R	R		
F	R	C			F		F		F	F	P	C	R	C	F				C	C			F							P					
F	R	R			C		C		R	F		R	R	C	R				C	C				R											
F	R				C		C			C		F		C	F				C	C			F												
C	F				F		C			R		R	R	C	R				A	C			R												
C	R				F		C		R			F	R	C					A	F			R												
C	F	R			F		C			C		F	F	C	F	R			C	C	R		F	R											
C	R	R			R		C		F	F	P	R	C	C	R	R			A	C			R	R											
F	R	R			R		C		F	R			F	F					C	R															
F	P	F			R	F	C		F			R	C	F	R	R			A	F															
F	P	F				F	F		C	R			F	C	R	F			C	F			R												
F		R			P	R	C		C	C		R	C	F					C	F			R												
F		F				F	C		C	C	P	R	F	C					A	F															
R		R				C	F		F	F			C	C					C	C															
F	R	F					A		F	F	R	F	C	C					C	F			R												
									F																										
R						C	C		F		R		F	F						R															
							R		P																										
						F	C		F	R	P			F						F		R	R	P											
							F		R																										
									R																										
									R																										
C	R	F		P					C	R	F		C	F																					
C	F	F		R					C		F		F	F	R					R															
									R																										
F	F	R			R		R		C				F	R	F					F															
R									F											R															
F	R	C	p				R		R	P			C	F	F					C			P	R		P									
F							R		F											R															
P									R																										

Table 8. Nannofossil species present in Cores 23 to 30 in Hole 541.

Age	Nannofossil zone or subzone	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Amaurolithus amplificus*	*A. delicatus*	*A. primus*	*Triquetrorhabdulus rugosus*	*Discoaster asymmetricus*	*D. berggrenii*	*Discoaster* sp. cf. *D. berggrenii*	*D. braarudii*	*D. brouweri*	*D. challengeri*	*D. neohamatus*	*D. pentaradiatus*	*D. quinqueramus*	*D. surculus*	*D. variabilis*	*Sphenolithus abies*	*S. moriformis*	*Coccolithus pelagicus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Umbilicosphaera cricota*	*Crenalithus doronicoides*	*Reticulofenestra pseudoumbilica*	*Helicosphaera carteri*
	Amaurolithus primus Subzone (CN9b)		23-1, 64–65	C	P		R	F	R		R		F	R	C		P	C	C	C	F	R	F	C	R		C	F	
			23-2, 64–65	A	M		F	R	R				R	P	F		R	F	C	C	C	R	C	C	R	F	A	F	F
			23-3, 64–65	C	P		R		F				R				R	R	C	C	F	R	F	F	R	R	C	F	
			23-4, 64–65	C	P		F				R				F			C	C	C			F	F				C	
			23-5, 64–65	C	M		R	R	R		R		R		R			F	C	A			P						
			23-6, 64–65	B																									
		210.0	23,CC	F	P													R	R	F			P						
			24-1, 58–59	R	P																								
			24-2, 58–59	F	P						R							F	F	C									
			24-3, 58–59	F	P						R	R	P		P			F	F	F									
			24-4, 58–59	F	P	P					R							R	C	F									
			24-5, 58–59	F	P						R		R					F	C	C									
			24-6, 58–59	C	P	R	F		P		R		F					C	C	C			F	F				C	
		219.5	24,CC	C	P	R	F		R				F					C	C	C	F	F	C	C			R	C	
	? Nondiagnostic ?		25-1, 58–59 to 27-7, 4–6	Barren																									
		248.0	27,CC	R	P							F	R							F									
	Discoaster berggrenii Subzone (CN9a)		28-1, 54–55	F	P							F							F	C									
			28-2, 54–55	B																									
Miocene late			28-3, 54–55	C	P				P		C	C	C		C	P			R	F			R						
			28-4, 54–55	C	P				R		C	C	C	R	F	R				A		R	F	F					
			28-5, 54–55	C	P				P		F	C	C	R	C					A			C	F	R				
			28-5, 97–98	F	P							F	R		F					C									
			28-6, 54–55	C	P				P			C	C		F					C			F						
		257.5	28,CC	F	P							R	R		F					C									
			29-1, 75–76	B																									
			29-2, 75–76	C	M								A		C					A									
			29-3, 75–76	B																									
	Amaurolithus primus Subzone (CN9b)		29-4, 75–76	C	M	R	R	P	R		R		R		R			C	F	C									
			29-5, 75–76	R	P															R									
			29-6, 75–76	R	P															R									
		267.0	29,CC	R	P															F									
			30-1, 28–29	F	P	P	R						R		R			F	C	F		R	F	F				F	
			30-2, 89–90	C	P	R	F	R	P	P			R		R			C	C			R	R	F				F	
			30-3, 89–90	C	P	P	F	R			F		F					C	C	F			F	F				C	
			30-4, 90–91	F	P						P		R					F	C	F									
			30-5, 90–91	F	P	R	R	R	P		R		F		R			F	C	C			F	F				F	
			30-6, 90–91	F	P								R					R	F	F			R	R					
		275.8	30-6, 130–131	C	P	R	R		R		F		R					F		C			F	F	R			C	

Note: See the Appendix for an explanation of symbols. From about 220 m to 247 m sub-bottom the section is barren.

Miocene muds would directly overlie lower Miocene radiolarian mudstones. This situation is entirely possible, because the top of the radiolarian mudstone may be a surface of décollement. It is unlikely, however, because a large amount of barren section is also found above radiolarian mudstones at the reference site. A third explanation is that the section at Site 542 is faulted. Faulting is not unexpected considering the tectonic setting of this site. Nannofossil distributions in Hole 542A are somewhat supportive of this explanation (see the discussion in the site report). A fault in Hole 541 in these same upper Miocene muds also demonstrates the succeptability of these sediments to faulting. The inability to correlate these faults between sites that are only a kilometer apart means that they are small-scale inversions, and it is entirely possible that there are many more of them than can be recognized from the nannofossil data. Therefore, one should be very cautious when trying to determine sedimentation rates in these sediments.

Sites 541 and 543

Comparison of the continuously cored sequences at Sites 541 and 543 can determine whether the sediments at Site 541 are oceanic sediments that have been accreted

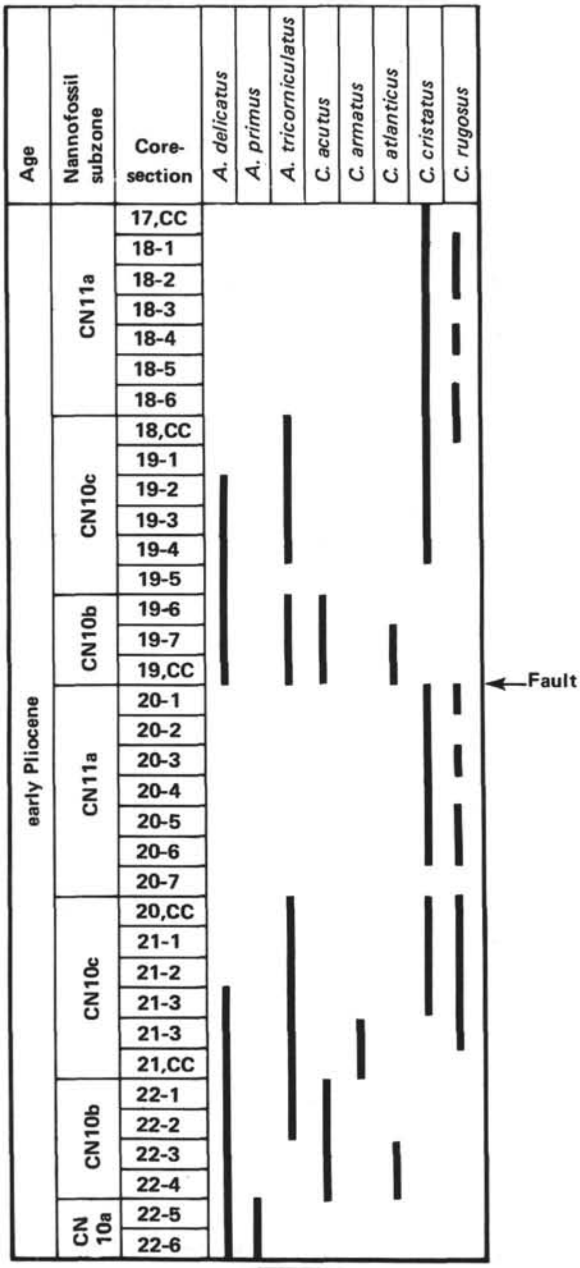

Figure 4. Occurrences of ceratoliths across the stratigraphic repetition at 172 m sub-bottom in Hole 541.

onto the Caribbean Plate. Site 541 is also important because four stratigraphic repetitions have been dated at that site. The largest of these occurs at a sub-bottom depth of 276 m in Hole 541 and is interpreted as a reverse fault that formed by imbricate-thrusting. The three stratigraphic repetitions above the fault may have formed by the same process and may be related to its formation. As expected, there are no stratigraphic repetitions in the section at Site 543.

The stratigraphic sections at these two sites, exclusive of the repetitions at Site 541, are similar. A lower Miocene radiolarian mud found in the bottom 30 m of Hole 541 was also cored at Site 543. The top of the radiolarian mud is probably equivalent to the seismic reflector that separates the underthrust sedimentary sequence from the offscraped material above.

Sediments at both these sites immediately overlying the radiolarian muds do not contain any microfossils and could not be age-dated. About 74 m of barren section were recovered at Site 543, but only 37 m at Site 541. This difference in thickness exists because the first nannofossils occur in upper Miocene sediments at Site 541 and are not preserved until the latter part of the early Pliocene at Site 543. Thus Site 541 was above the carbonate compensation depth during most of the late Miocene and all of the early Pliocene, and Site 543 was not.

The first nannofossil-bearing sediments at Site 543 are from the *Reticulofenestra pseudoumbilica* Zone. Nannofossils occur in most samples above this except for 10 m of barren sediments at the top of Hole 543A. Nannofossils of the upper Miocene *Discoaster berggrenii* Subzone are the earliest datable assemblages recovered from Site 541. Miocene sequences at this site are not continuous, as there are several barren intervals. All Pliocene and Pleistocene samples from Site 541 contain nannofossils.

The succession of nannofossil subzones in the section at Site 543 is the same as the one at Site 541, although deposition of nannofossil sediments began at an earlier time at Site 541 (Tables 2, 9, 10, and 11). A hiatus is present in both sections below the sediments of the *Calcidiscus macintyrei* Subzone. At Site 541, this hiatus occurs above Sample 541-13-1, 30–31 cm, which is from the *Discoaster pentaradiatus* Subzone. This hiatus also occurs above Sample 543-5-2, 100–101 cm at Site 543, which is placed in the *Discoaster surculus* Subzone.

Sediments from the top of Hole 541 contain upper Pleistocene assemblages from the *Gephyrocapsa oceanica* Zone (Table 11). The youngest datable sediments at Site 543, however, are from the lower Pleistocene *Pseudoemiliania lacunosa* Zone.

In summary, the sections at these two sites have similar successions of lithologies and nannofossil zones. Therefore, it is likely that the sediments at Site 541 have been emplaced by accretion. Several differences in the two sections, however, do exist. These are: (1) the relation of the two sites to the carbonate compensation depth since the late Miocene, (2) the abundance and preservation of nannofossils throughout the sections, and (3) the sediment rates. As pointed out earlier, Site 543 had been below the CCD during the late Miocene and much of the early Pliocene, as well as all of the late Pleistocene. This is not true for Site 541. Also, the nannofossils are not as common, nor as well preserved in samples from Site 543 as they are at Site 541. And finally, sedimentation rates are much higher at Site 541, especially in Pleistocene sediments. Deposition of the sediments at a shallower depth at Site 541 (on the Tiburon Rise) than at Site 543 (north of the Tiburon Rise) could account for all of these differences. It is also possible that tectonic thickening of the sediments at Site 541 resulting from folding, faulting, and layer-parallel shortening could

Table 9. Nannofossil species present in Section 541-15-6 through Core 22 in Hole 541.

Age	Nannofossil zone or subzone	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Amaurolithus delicatus*	*A. primus*	*A. tricorniculatus*	*Ceratolithus acutus*	*C. armatus*	*C. atlanticus*	*C. cristatus*	*C. rugosus*	*Triquetrorhabdulus rugosus*	*Discoaster asymmetricus*	*D. braarudii*	*D. brouweri*	*D. challengeri*	*D. pentaradiatus*	*D. quinqueramus*
Pliocene, late	*Discoaster tamalis* Subzone (CN12a)		15-6, 20–21	A	M							R	R		F	F	C	F	C	
		134.0	15,CC	A	M							R			F	R	F		C	
			16-1, 13–14	A	M							R	P		F	F	C	F	C	
			16-2, 13–14	A	M							R	P		C	R	C		F	
			16-3, 13–14	A	M							R	R		F	C	F	F	F	
			16-4, 13–14	A	M							R	R		C	F	C	F	F	
Pliocene, early	*Discoaster asymmetricus* Subzone (CN11b)		16-5, 13–14	A	M							R	P		F		C		F	
			16-6, 13–14	A	M							R	P		F	R	C	R	C	
			16,CC	C	M							R			R	R	C	F	C	
			17-1, 40–41	C	M		p			p		R		p	F	F	C	F	C	
			17-2, 40–41	C	M							R			F	F	C	R	F	
	Sphenolithus neoabies Subzone (CN11a)		17-3, 75–76	A	M							F			P	C	C	R	C	
			17-4, 80–81	A	G							R			R	C	F		C	
			17-5, 75–76	A	G							R			R	F	C	F	C	
			17-6, 75–76	A	M							F	R			C	F	R	C	
		153.0	17,CC	A	G							F				C	F		C	
			18-1, 49–50	C	M							R	P			R	F	R	C	
			18-2, 49–50	A	M							R	R			F	C	R	C	
			18-3, 75–76	C	M							F				F	F	F	C	
			18-4, 99–100	A	M							R	R		R	C	C	R	C	
			18-5, 75–76	A	M							R				C	C	F	C	
			18-6, 43–44	A	M							R	R			C	C	R	C	
	Ceratolithus rugosus Subzone (CN10c)	162.5	18,CC	A	M			R				R	P			C	F	F	C	
			19-1, 60–61	C	G			R				R				R	F		C	
			19-2, 60–61	C	P	R		F				P				C	F		C	
			19-3, 60–61	A	M	R		F		P		R				C	F		F	
			19-4, 60–61	A	M	R		R		R		P				F	C		F	
			19-5, 60–61	F	P	F				P						F	R		R	
	Ceratolithus acutus Subzone (CN10b)		19-6, 79–80	C	M	F		R	P	P						R	F	R	F	
			19-7, 27–28	A	M	F		R	R	P	R					C	F	R	F	
		172.0	19,CC	A	M	F		P	R		R					C	F	F	F	
	Sphenolithus neoabies Subzone (CN11a)		20-1, 45–46	C	M							R	R			R	F	R	C	
			20-2, 45–46	C	M							R				F	F	R	C	
			20-3, 45–46	A	M							R	R			C	C	F	C	
			20-4, 45–46	A	M							P				F	C	F	C	
			20-5, 45–46	A	M		p					R	P		P	F	F	C	C	
			20-6, 45–46	A	M							R	R		R	F	C		C	
			20-7, 4–5	F	M											R	F	R	F	
	Ceratolithus rugosus Subzone (CN10c)	181.5	20,CC	C	P			F				R	P			C	C	R	C	
			21-1, 9–10	A	M			F				R	P			C	F	R	C	
			21-2, 9–10	A	M			F				R	P			F	F		F	
			21-3, 9–10	A	M	R		R				R	P			C	C		F	
			21-3, 119–120	C	M	R		R		R			R			C	C		F	
		191.0	21,CC	C	P	R		R		R						F	C	F	C	
	Ceratolithus acutus Subzone (CN10b)		22-1, 22–23	C	M	R		R	P							F	F	F	F	
			22-2, 22–23	A	M	F		P	R							F	R	C	F	
			22-3, 22–23	A	M	F			P		P			R		F	R	F		
			22-3, 49–50	A	M	F			R		R			R		R	F	F	F	
			22-4, 22–23	A	M	F			R		R			P		F	F	F	R	
Miocene, late	*T. rugosus* Subzone (CN10a)		22-5, 22–23	A	P	F	P							R		C	F	C	R	
			22-6, 22–23	C	P	F	R							P		F	R	C	R	
	A. primus	200.5	22,CC	F	P	P	F									F		C		R

Table 9. (Continued).

D. surculus	*D. tamalis*	*D. variabilis*	*Sphenolithus abies*	*S. moriformis*	*S. neoabies*	*Coccolithus pelagicus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Umbilicosphaera cricota*	*U. mirabilis*	*Pseudoemiliania lacunosa*	*Crenalithus doronicoides*	*Reticulofenestra pseudoumbilica*	*Scopholithus fossilis*	*Thoracosphaera albatrosiana*	*T. heimi*	*Helicosphaera carteri*	*H. sellii*	*Rhabdosphaera clavigera*	*Pontosphaera* sp.	*Scyphosphaera ampla*	*S. apsteini*	*S. conica*	*S. globulosa*	*S. piriformis*	*S. pulcherrima*	*S. recta*	*S. recurvata*	*Syracosphaera pulchra*
F	F	R	P		R	R	C	F	F		F	A			R		C			P							P		R
C	F	R			R	R	C	F	F		C	A			R		F	R	R	R	P					P		P	R
F	R				R		C	F	F		C	A		P	R	R	C			R						P		P	F
F	F	R	F		R		C	F	F	R	C	A					C	R								P	P		C
F	R		C		F	R	C	F	F	F	C	A			R	P	F							P					F
F	R	R	C		C	R	C	C	R		F	A			R		F												R
F	R	R	C		F	R	C	R	C	R	R	A	F		R		C	R						P		P	P		R
F	R		C		C	R	C	F	F	C	F	A	F				C	R		R					P	R		P	F
F	P		C		C	R	C	F	C	F	F	A	F		R		C	R		R	P								R
F	R	R	C		F		C	F	C		R	A	F				F			R						R			R
F	P	F	C		C	R	C	R	C	R	R	A	F		R		C	R		R				P		P			R
F		F	C		C		C	R	C	F		A	F		R		C			R						R		P	R
F		R	C		C	R	C	F	F	R	P	A	F		R		F		P	R	P					P	R	R	
F		R	C		A	R	C	R	F	F		A	C		F		C			R						R		R	P
C	P	R	F		C	R	C	F	C	R		A	F	R	F	R	C			R					P			R	R
F		F	C		C	R	C	R	F	F		A	C	P	F		C	R		P						R		R	R
F		F	C		C	R	C	R	F	R		C	C		R		F									P		P	
F		F	C		C	R	C	R	F			A	C		R		C	R		R						R		P	R
C		R	C		C	R	C	R	C	R		A	F				F												
C		F	C		F	R	C	F	F			C	C				F	R					P						
F		F	C		F	P	C	R	C			A	C		R		C				P				P	P			
C			F		F		C	R	C	R		C	C		R		C			P	P	P	P		P	P		P	R
F			C		C		C	R	C	R		A	C		R		F			P							P		R
F		R	F		R	R	C	F	F	R		C	F				C	R											R
C		F	R		R		C		R			C	C																
C		R	R		R		C	F	C			A	C				F	R											
A		F	R		R		C	F	R			A	C				R												
C		C				R	F					C	R																
C		F	C		R	C	C		F			C	C				R												
C		C	C		R	C	C		F			A	F		R		F				P								
C		C	C		C	C	C	R	R			A	C		R		F	R											
C			F		C		F		F	R		C	F		R		F	R							P				
F		R	C		F	R	C	F	F			A	F		F		C												
F		F	C		C	R	C		F	R		A	F		R		F				P							P	
C		R	C		C	R	C	F	F	R		C	C		R		F	P											
C		F	C		F	R	A	F	F	R		C	C		R		C											P	
C		R	C		C	P	C	R	F	R		A	C		R		C			P						P		P	
F	P	R	R		R		C		R			C	F				R												
F		F	F		C	R	C	R	F			F	C				F												
C		F	R		C	P	C	F	F			C	C		R		F					P							
A		R	R		F	P	C	F	R			A	C											P					R
C		R	F		F	F	C	R	F			C	C		R		F	R											
C		R	C		R	F	C	R	R			A	C									P							
A		R	F		R	F	C	F	R			C	R																
C		F	F		R	F	F		F			C	F				R												
C		F	F	r	P	C	C		R			A	C																
C		C	C			C	C	R	R			A	C					P											
C		C	C		F	C	C		R			A	C																
A		F	C		R	C	C	R	F			A	F				F	R											
C		C	F	p		C	C		R			A	F																
F		C				F	F					F	F																
C		F				R																							

Table 10. Nannofossil species present in Core 8, Section 5 to Core 15, Section 5, Hole 541.

Age	Nannofossil zone or subzone	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Ceratolithus cristatus*	*C. rugosus*	*C. separatus*	*Triquetrorhabdulus rugosus*	*Discoaster asymmetricus*	*D. berggrenii*	*D. braarudii*	*D. brouweri*	*D. challengeri*	*D. pentaradiatus*	*D. quinqueramus*	*D. surculus*	*D. tamalis*	*D. variabilis*	*Sphenolithus abies*	*S. neoabies*	*Coccolithus pelagicus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Umbilicosphaera cricota*	*U. mirabilis*	*Pseudoemiliania lacunosa*	*Crenalithus doronicoides*	*Reticulofenestra pseudoumbilica*	*Gephyrocapsa caribbeanica*	*G. oceanica*	*Gephyrocapsa* sp.	*Hayaster perplexus*	*Scapholithus fossilis*	*Thoracosphaera albatrosiana*	*T. heimii*	*Helicosphaera carteri*	*H. sellii*	*Rhabdosphaera clavigera*	*Pontosphaera* sp.	*Scyphosphaera ampla*	*S. apsteinii*	*S. globulosa*	*S. piriformis*	*S. pulcherrima*	*S. recta*	*S. recurvata*	*Syracosphaera pulchra*
	Helicosphaera sellii Zone		8-5, 75-76	C	P	R									p				p			F	F		P	F	C	C		C	C	C			R		C	R	F				P					F
			8-6, 75-76	C	M	R													p			F	C			R	C	C		F	C	A		R	F		C	R	C	R	P							C
		67.5	8,CC	C	P	F							p		p							F	C	R		F	C	C		F	F	R			R		C	P	C		P		P					R
			9-1, 75-76	A	M	F					p		p		r				p			F	C			R	C	A		C	C	F			C	R	C	P	C	F					R			C
	Calcidiscus macintyrei Zone		9-2, 75-76	C	M	F									p				p				C	F		R	C	A		C	F	C			F		C	R	C	R	P				P			C
			9-3, 75-76	C	P	F							p		p				p			R	F	F		R	C	A		R		F			F		C	R	C	R	P							C
			9-4, 75-76	C	M	F							p		p				p			R	C	F		F	C	A		R	P	F	P		F		C	R	C	R	P				P			C
			9-5, 75-76	C	M	F									p				p			R	C	F		F	C	A				F			F		C	R	C	R			P		R			C
	Helicosphaera sellii Zone		9-6, 75-76	A	M	R							p						p			F	C		R		C	C		C	R	C		P	R	R	C	R	C	F					P		P	C
			9-7, 40-41	C	M	F							p						p			F	C			F	C	C		C	C	F			F		C	R	C	R	P				P			F
Pleistocene early		77.0	9,CC	C	M	F							p		p	p			p			R	C	F		F	C	A		F	R	F			F		C	R	F	F					R	P		C
			10-1, 75-76	A	M	R							p				p	p	p			F	C			R	C	A		F	C	C			F		C	P	C	R				P	R			C
	Calcidiscus macintyrei Zone		10-2, 75-76	A	M	F							p		p				p			F	C			F	C	A		F	C			R	F		C	R	C	F					R		P	C
			10-3, 75-76	A	M	F							p		p				p			F	C	P	P	F	C	C	p	C	F	F		P	F		C	R	C	R					P		P	C
			10-4, 75-76	A	M	F							p				p	p	p			P	C	F		F	C	A	p	C	R	F		R	F		C	R	F	F		P	P		R			C
			10-5, 75-76	C	M	R								r								R	C	C		R	C	A		F	P	F			F	P	C		C	R	P		P		P		R	C
			10-6, 75-76	C	M	R							p				p		p			R	C	F		R	C	A		F		R		P	R	P	C	R	F	F					P		P	C
			10-7, 35-36	C	M	R			p													R	C	F		F	C	A				F			F	P	C	R	C	F					R		P	C
		86.5	10,CC	C	M	R								p	p							F	C	C		R	C	A	p					R	F	P	C	R	C	F	P				P		P	C
	Calcidiscus macintyrei Subzone (CN12d)		11-1, 75-76	C	M	R																F	F	F	R	R	A	A							F		F		F			P			R			C
			11-2, 75-76	C	M	R		F														R	F	C	R	R	C	A				F		R	F	P	C	R	C	R		P			R			C
			11-3, 75-76	C	M			R	p				R		p				r			F	C	F		F	C	C							F		C	R	C	R		P			R			F
			11-3, 131-132	C	M	P		F				P	R									R	C	F		F	C	A				P		R	F	R	C		C	F	R				R			C
			11-4, 8-9	C	P	R		F				R	C									R	F	F	R	F	C	C				C			F		F	R	C		P				P			C
			11-4, 75-76	C	P	R		F				R	F									R	C	F		C	C	C							F		F	R	C		P				P	P		C
			11-5, 6-7	C	M	F		F	p			F	C									R	F	F		F	C	A				C		P	F		F	R	C	F	P				R	P		C
		96.0	11,CC	C	M	F		R				F	F						p	p		F	F	F		F	C	A						R	F	P	F	R	C	R		P			R			C
			12-1, 75-76	C	P	F		R				R	F									F	C	F	R	F	C	A							R		F		C						P			C
			12-2, 75-76	C	M	R		F					F									F	F	C		C	C	C							R		C		C	P					P		P	C
			12-3, 75-76	C	P	R		R				R	F									F	F	F		F	C	A							R		F		F				P		P			C
			12-4, 75-76	A	M	F		F				F	R									F	F	C		F	C	A				P			R		F	R	C	P	P				R			F
			12-5, 75-76	C	M	F		R				F	F		p				r			F	F	F		F	C	A	p			P		R	R		C	R	C	R	P				R			C
			12-6, 75-76	C	M	F		R					F									R	C	F	R	F	C	A				P			R		C		C	R					R			F
			12-7, 17-18	C	M	F		R					F							p			C	F	R	F	C	A						R	R	P	C	P	C	P					R		R	F
	Discoaster pentaradiatus	105.5	12,CC	C	P	R						R	C				p					C	F	F		R	C	C						R	R	R	C		F	R	P				R			C
	Discoaster surculus Subzone (CN12b)		13-1, 30-31	C	M	R	P						C	p	F							F	C	F	R	F	C	A									C	R	F	R	P				P			C
			13-2, 30-31	C	M	R				P		R	F		C		F	p		r		F	F	C		R	C	A							R		C	P	F	R	P							C
Pliocene late			13-3, 30-31	C	M	R						C	C		C		F					R	C	C	R	R	C	A									F	R										C
			13-4, 30-31	C	P	R						R	C		C		F					F	F	F	F	F	C	C									F											
			13-5, 30-31	C	P	R						F	F		F		F					R	C	F	F	F	C	C							R		C	R	F	R					P			C
			13-6, 30-31	C	M	R				P		F	C		C		F	R				F	C	C	F	P	C	A							R		C	R	C									F
			13-7, 30-31	A	M	R	P					C	C		C		F	R				F	C	F	C		F	A							R		C	R	R	R								C
		115.0	13,CC	C	M	R				R		F	C		F		F	R				F	C	C	F	P	C	A							R		C	R	R		P							C
	Discoaster tamalis Subzone (CN12a)		14-1, 25-26	A	M	R				R		C	C		C		R	R			p	F	C	C	F		C	A							F	P	C	R	P	P	P				P			C
			14-2, 25-26	C	M	R	R			R		F	F	R	C		F	R				F	C	F	F		C	A							R		C			P	P				P			F
			14-3, 25-26	A	M	R	P			R		F	C	R	C		F	R	R			F	C	F	F		C	A							R		C	R							P			F
			14-4, 25-26	A	M	R	P			F		F	C	F	F		C	R	R			F	C	F	F	R	C	A							R		C	P		F					P			F
			14-5, 25-26	C	M	R						C	F	R	F		F	R				F	C	F	R	F	F	A							R		C	R		R					R			F
			14-6, 25-26	C	P	R				F		R	F		C		F	R	R			R	C	F	F		F	C						R	R		C	R		F					P			F
			14-7, 25-26	C	M	R						F	C	P	C		F	F				F	C	C	F		C	A					P		R	P	C	R		R					R		R	C
		124.5	14,CC	C	M	R				C		R	C		F		F	F	r			R	C	F	C		C	A							R		C	F		R					R			C
			15-1, 20-21	C	M	R	R			C		F	C	R	F		F	F				R	C	F	C		C	A							R	R	C		R	F	P		P		P		P	F
			15-2, 20-21	A	M	R				R		F	F		C		F	F				R	C	F	F		C	A					P		F	R	C		R	F	P	P			P			C
			15-3, 20-21	A	M	R				F		F	C		F		F	F				R	C	F	C		C	A							R		F											R
			15-4, 20-21	C	M	R				C		R	C	R	F		F	F				R	C	F	F	P	F	A							R	P	C	R		R					P	P	P	F
			15-5, 20-21	A	M	R				R		C	F	R	C		C	F					C	F	C		C	A							R		F	R		P						P		R

have contributed to the apparently higher sedimentation rates at that site (Wright, sediment accumulation rates chapter, this volume).

PRESERVATION

The carbonate compensation depth in this region is about 5500 m (Wright, sediment distribution and depositional processes chapter, this volume). Sites 541 and 542 were drilled above the carbonate compensation depth, but still below the foraminiferal lysocline. Site 543 was drilled well below the present-day carbonate compensation depth in 5600 m of water.

Foraminifers recovered from samples at these sites indicate that all the calcareous sediments were deposited below the foraminiferal lysocline with the exception of an occasional foraminiferal gravity flow (Hemleben and Auras, this volume). Nannofossils in almost every sample examined show some signs of etching. The degree of etching varies widely upsection and among species. Overgrowths are commonly seen only on large discoasters in poorly preserved samples, but never obscure the identity of these species. The nannofossil content in these sediments never exceeds 45%.

The preservation of the calcareous nannoplankton in these samples fluctuates with species diversities. Both of these parameters are probably controlled by the amount of dissolution, as overgrown specimens are uncommon. A ranking of the resistance to solution of the various Cenozoic genera follows. The ranking is qualitative and is based on the relationship of the nannofossil occurrences to preservational trends upsection. Genera of com-

Table 11. Nannofossil species present in Core 1 to Core 8, Section 4 in Hole 541.

Age	Nannofossil zone or subzone	Depth below seafloor (m)	Sample (core-section, interval in cm)	Abundance	Preservation	*Ceratolithus cristatus*	*Discoaster asymmetricus*	*D. berggrenii*	*D. brouweri*	*D. pentaradiatus*	*D. surculus*	*D. variabilis*	*Sphenolithus abies*	*S. moriformis*	*Coccolithus pelagicus*	*Calcidiscus leptoporus*	*Umbilicosphaera cricota*	*U. mirabilis*	*Crenalithus doronicoides*	*Pseudoemiliania lacunosa*	*Reticulofenestra psuedoumbilica*	*Gephyrocapsa caribbeanica*	*G. oceanica*	*G. omega*	*Gephyrocapsa* sp.	*Scapholithus fossilis*	*Thoracosphaera albatrosiana*	*T. heimi*	*Helicosphaera carteri*	*H. sellii*	*Rhabdosphaera clavigera*	*Pontosphaera* sp.	*P. japonica*	*Scyphosphaera ampla*	*S. conica*	*S. globulosa*	*S. pulcherrima*	*S. recta*	*S. recurvata*	*Syracosphaera pulchra*
late	*Gephyrocapsa oceanica* Zone		1-1, 18–19	A	M	F				p						C		F	C			R	A		A		F	R	C		C									R
		1.0	1,CC	C	M	F		p	p						R	C		F	C		p	R	A		C	R	F	R	C		C									R
	Pseudoemiliania lacunosa Zone		2-1, 70–72	A	M	R			p	p		p			R	C		R	A	F		F	A		E	R	R		F		R									R
			2-2, 63–64	F	P											F		R	C	F		R	A		C				R											R
			2-3, 99–100	F	P	F				p		p			R	C		R	C	R			C		F		R		F											
			2-4, 144–145	C	P	R			p	p		p			R	F		R	A	C	p		F	F	F				R											
			2-5, 76–77	F	P	P				p		p			R	F			C	R			F	F																
			2-6, 83–84	F	P	R									R	F		R	C	F		R	F	F					R											
		10.5	2,CC	C	P	R			p	p		p				C		R	C	C			C	F	F			P	F		F									R
			3-1, 75–76	C	M	R				p						C		R	A	C	p	P	C		C	R	R		F		F								P	F
			3-2, 75–76	A	M	R				p						C	R	F	A	C		P			C	R	F		C		C	R							R	C
			3-3, 75–76	C	P	F			p	p						F	R	R	A	C					C				C		F					P				F
			3-4, 75–76	A	M	R			p	p		p				C		F	A	C		R			C	R	F	R	C		F	R	R				R		P	R
		20.0	3,CC	A	M	R			p	p		p			R	C	R	F	A	C					C		F		C		C	R		P			P		P	R
			4-1, 75–76	A	M	R				p	p		p		R	F		R	A	C		P	P		A	R	F	F	C		C	R	R						P	F
			4-2, 75–76	A	M	R			p	p		p			R	C	R	F	A	C		R	R		C	R	F	R			C	R	R						P	C
			4-3, 75–76	F	P											F			F	C		R	F						R											
			4-4, 75–76	F	P	R				p	p				R	C	P	R	C	F		R	F				R		F		R									F
			4-5, 75–76	C	M	R						p			R	C		F	C	C		C	F				R		F		C									F
Pleistocene early			4-6, 75–76	A	M	R				p	p				R	C		F	C	C		C	R		A		F	R	C	R	C	F	R	P			P	P		C
		29.5	4,CC	C	P	R			p	p		p			R	C		F	C	F		P	F	C	C	R			F		F									R
			5-1, 75–76	R	P														F			P	R	R																
			5-2, 13–14	A	M	R			p	p						C		R	A	C			A	C	A	R	F	F	C		F	F	R					P		F
			5-2, 75–76	F	P	R										F		R	C	F		R	F	F																R
			5-3, 75–76	F	P	R					p	p			R	C		R	C	C			C	C	F		R		F		R									R
		39.0	5,CC	C	M	R			p	p		r				C		R	C	C		R	C	C	C		R		F			R								R
			6-1, 75–76	F	P	R										F		F	C	F			F	F	F				F											R
		48.5	6,CC	B																																				
			7-1, 75–76	F	P	R			p							F			C	C		R	F	R	F				F											
			7-2, 75–76	B																																				R
			7-3, 75–76	A	M	R	p		p	p		r				C		F	A	C			C	C	C		R		F											F
			7-4, 75–76	R	P											R			F	R		P	F	F					P											
			7-5, 75–76	F	P											C		F	C	F			C	C	F				R											
			7-6, 75–76	A	M	F			p			p			R	C		F	A	C	p		C	C	A	R	R		C		F	R		P						R
			7-7, 40–41	F	P	F			p	p		p		p	R	C			C	C		P	R	F	R				F											
		58.0	7,CC	F	P		p	p		p		r			R	C		R	C	C			R	R	F		R		F											
			8-1, 75–76	C	M	R			p		p	p			R	C		F	A	C	p	P			C	R	F	R	C		F	R			P		P			F
			8-2, 75–76	F	P	R				p		r			R	F		F	C	C		F	R				R		F											R
	?— *Helicosphaera sellii* Zone		8-3, 75–76	C	P	R				p		r			R	C	R	F	C	C		F	F		F		R		C	R	F									R
			8-4, 75–76	A	M	R						r			F	C		F	C	C		F	F		F	R	F	R	C		C	F					P		P	F

Note: See the Appendix for an explanation of symbols.

parable solution resistance have been grouped together. The order in decreasing resistance to solution is:

Discoaster

Coccolithus
Calcidiscus
Reticulofenestra
Gephyrocapsa
Amaurolithus
Pseudoemiliania
Ceratolithus

Sphenolithus
Helicosphaera
Umbilicosphaera

Syracosphaera
Rhabdosphaera
Thoracosphaera
Pontosphaera
Scyphosphaera

Scapholithus

The ranking was helpful in assessing the reliability of age assignments in poorly preserved assemblages and in providing an additional guide to preservation trends. Identification of preservation trends in these sections is important in recognizing possible tectonic effects at Sites 541 and 542. Although changes in preservation at Site 543 may largely be the result of fluctuations in the carbonate compensation depth, it is likely that vertical movements at the two sites on the Barbados Ridge would result in different trends. The island of Barbados, located on the western part of the Barbados Ridge, was uplifted almost 300 m during the Pleistocene.

Information about trends in preservation at the two tectonics sites comes mostly from the continuously cored sequence at Site 541. Evidence from Site 542 is fragmentary, because only upper Miocene sediments were continuously cored at that site. Preservation and species diversities of nannofossil assemblages in age-equivalent samples from these two sites are alike. This is evidence that the depositional histories of these sites are similar, although both stratigraphic sections have been changed by faulting.

Samples from upper Miocene sediments at Sites 541 and 542 contain poorly preserved assemblages separated by barren intervals. These poorly preserved samples are characterized by low species diversities because scyphosphaerids, pontosphaerids, and rhabdosphaerids are absent, and sphenoliths and helicosphaerids are present only in isolated samples. As the Miocene/Pliocene boundary is approached, there is an increase in the quality of preservation, and barren samples are no longer encountered. The number of species present also increased as the ceratoliths diversified, and the sphenoliths and helicosphaerids are present in every sample.

Most Pliocene samples at Site 541 contain moderately preserved assemblages. All age determinations throughout this interval are highly reliable. A slight decrease in preservation is observed in the few samples from the *Discoaster surculus* and *Calcidiscus macintyrei* Subzones.

Nannofossil assemblages are moderately preserved up to and including Sample 541-9-1, 75–76 cm. At this point, there begin fluctuations in preservation and species diversities. These fluctuations continue to the top of the section.

The first Cenozoic sediments at Site 543 that contain nannofossils were dated in the *Reticulofenestra pseudoumbilica* Zone. Therefore, while Sites 541 and 542 were above the carbonate compensation depth throughout most of the late Miocene and all the early Pliocene, Site 543 was below the carbonate compensation depth until the latter part of the early Pliocene.

Sediments recovered at Site 543 mostly contain poorly preserved nannofossil assemblages, with the exception of a series of samples just above the Pliocene/Pleistocene boundary in Core 3. Fluctuations in species diversities occur throughout this section except for the interval above the Pliocene/Pleistocene boundary. Another interval of constant preservation and species diversities is seen in lower Pleistocene sediments at Site 541. In both instances, this interval occurs before the last occurrence of *Calcidiscus macintyrei.* A significant decrease in abundance and preservation is seen in Sample 543-5-1, 100–101 cm. These sediments unconformably overlie sediments of the *Discoaster surculus* Subzone.

Preservational trends at Sites 543 and 541 were often difficult to compare because of the large contrast in preservation. No gross differences, however, were noticed in the trends at these sites. It appears that tectonism has not severely affected the depth relationships between these two sites since the middle of the Pliocene.

CONCLUSIONS

Six holes were drilled at three sites during Leg 78A. Site 543, an oceanic reference site 3.5 km east of the deformation front of the Barbados Ridge, was continuously cored from the ocean floor to basement. High core recoveries throughout this section provided a complete record of the sedimentary pile entering the subduction zone. Sites 541 and 542 are located west of the deformation front and were drilled into the accretionary prism.

The succession of lithologies and nannofossil zones in the continuously cored hole at Site 541 is similar to that seen in the section at Site 543, and indicates that the sediments in this portion of the Barbados Ridge have been derived from an oceanic section. Information from Site 542 is fragmentary, because the holes drilled at this site were not continuously cored throughout their length. However, the sediments that were recovered from this site are similar to those at Site 541.

The preservation and abundance of age-equivalent nannofossil assemblages at Sites 541 and 542 are also the same. Thus the sediments at these two sites were deposited at about the same water depth. Such is not the case at Site 543. Nannofossils recovered from sediments at that site are less abundant and more poorly preserved than those in age-equivalent sediments at Site 541. In addition to this, the first Cenozoic nannofossil-bearing sediments at Site 543 were deposited in the late early Pliocene, whereas the first nannofossils at Site 541 occur in upper Miocene sediments. These differences can be explained if the sediments at Sites 541 and 542 were deposited in shallower water than those at Site 543. Thus if the sediments at Sites 541 and 542 have been accreted, they were scraped off a topographic high (the Tiburon Rise).

The most significant outcome of this study was finding several stratigraphic repetitions of section at Sites 541 and 542 that were not found at the reference site. These stratigraphic inversions were dated solely by the nannofossils, because siliceous microfossils are not present in sediments of those ages, and the foraminifers are too poorly preserved to provide age estimates. The largest of these repetitions begins at 276 m sub-bottom in Hole 541. Here, an upper Miocene mud dated in the *Amaurolithus primus* Subzone overlies a marly nannofossil ooze of the *Discoaster tamalis* Subzone. Deformational features such as scaly foliations, stratal disruption, and fracturing are restricted to the upper Miocene muds as the sediments below the horizon are unaffected (Cowan et al., this volume). This horizon is interpreted as a reverse fault that has formed by imbricate-thrusting, and it is likely that the other stratigraphic inversions have been formed the same way. It is the first time structures of this type have been dated biostratigraphically at a modern convergent margin. The findings lend strong support to the existence of an accretionary prism along the fore-arc region of the Lesser Antilles.

Nannofossils recovered from sediments immediately overlying basement at the bottom of Hole 543A are dated as early Campanian. The oceanic crust entering the subduction zone, therefore, is about that age.

SYSTEMATIC PALEONTOLOGY

Species considered in this study are listed in Table 12. Those groups given special consideration are discussed next.

Table 12. List of species used in this study.

Cenozoic

Sphenolithus abies Deflandre, 1953
Ceratolithus acutus Gartner and Bukry, 1974
Thoracosphaera albatrosiana Kamptner, 1963
Scyphosphaera ampla Kamptner, 1955
Amaurolithus amplificus (Bukry and Percivil) Gartner and Bukry, 1975
Scyphosphaera apsteini Lohmann, 1902
Ceratolithus armatus Müller, 1974
Discoaster asymmetricus Gartner, 1969
Ceratolithus atlanticus Perch-Nielsen, 1977
Discoaster berggrenii Bukry, 1971
Discoaster bollii Martini and Bramlette, 1963
Discoaster braarudii Bukry 1971
Discoaster brouweri Tan Sin Hok, 1927
Gephyrocapsa caribbeanica Boudreaux and Hay, 1969
Helicosphaera carteri (Wallich) Kamptner, 1954
Discoaster challengeri Bramlette and Riedel, 1954
Rhabdosphaera clavigera Murray and Blackman, 1898
Scyphosphaera conica Kamptner, 1955
Umbilicosphaera cricota (Gartner) Cohen and Reinhardt, 1968
Ceratolithus cristatus Kamptner, 1950
Scyphosphaera cylindrica Kamptner, 1955
Amaurolithus delicatus Gartner and Bukry, 1975
Crenolithus doronicoides (Black and Barnes) Roth, 1973
Scapholithus fossilis Deflandre, 1954
Gephyrocapsa sp. (small)
Scyphosphaera globulosa Kamptner, 1955
Thoracosphaera heimi (Lohmann) Kamptner, 1941
Pontosphaera japonica (Takayama) Burns, 1973
Pseudoemiliania lacunosa (Kamptner) Gartner, 1969
Calcidiscus leptoporus (Murray and Blackman) and Loeblich and Tappen, 1978
Calcidiscus macintyrei (Bukry and Bramlette) and Loeblich and Tappen, 1978
Umbilicosphaera mirabilis Lohmann, 1902
Sphenolithus moriformis (Bronnimann and Stradner) Bramlette and Wilcoxon 1967
Sphenolithus neoabies Bukry and Bramlette, 1969
Discoaster neohamatus Bukry and Bramlette, 1969
Gephyrocapsa oceanica Kamptner, 1943
Gephyrocapsa omega Bukry, 1973
Coccolithus pelagicus (Wallich) Schiller, 1930
Discoaster pentaradiatus Tan Sin Hok, 1927
Hayaster perplexus (Bramlette and Riedel) Bukry, 1973
Scyphosphaera piriformis Kamptner, 1955
Pontosphaera sp.
Amaurolithus primus (Bukry and Percivil) Gartner and Bukry, 1975
Reticulofenestra pseudoumbilica (Gartner) Gartner, 1969
Syracosphaera pulchra Lohmann, 1902
Scyphosphaera pulcherrima Deflandre, 1942
Discoaster quinqueramus Gartner, 1969
Scyphosphaera recta (Deflandre) Kamptner, 1955
Scyphosphaera recurvata Deflandre, 1942
Ceratolithus rugosus Bukry and Bramlette, 1968
Triquetrorhabdulus rugosus Bramlette and Wilcoxon, 1967
Helicosphaera sellii (Bukry and Bramlette) and Jafar and Martini, 1975
Ceratolithus separatus Bukry, 1979
Discoaster surculus Martini and Bramlette, 1963
Discoaster tamalis Kamptner, 1967
Amaurolithus tricorniculatus (Gartner) Gartner and Bukry, 1975
Discoaster variabilis Martini and Bramlette, 1963

Mesozoic

Ceratolithoides aculeus (Stradner) Prins and Sissingh, 1977
Arkhangelskiella sp.
Micula concava (Stradner) Bukry, 1969
Prediscosphaera cretacea (Arkhangelsky) Gartner, 1969
Watznaueria barnesae (Black) Perch-Nielsen, 1968
Cretarhabdus conicus Bramlette and Martini, 1964
Microrhabdulus decoratus Deflandre, 1959
Micula decussata Vekshina, 1959
Cribrosphaerella ehrenbergi (Arkhangelsky) Deflandre, 1952
Marthasterites furcatus (Deflandre) Deflandre, 1959
Uniplanarius gothicus (Deflandre) Hattner and Wise, 1980
Lithastrinus grilli Stradner 1962
Rucinolithus hayi Stover, 1966
Kamptnerius magnificus Deflandre, 1959
Broinsonia parca (Stradner) Bukry, 1969
Manivitella pemmatoidea (Deflandre ex Manivit) Thierstein, 1971
Cylindralithus serratus Bramlette and Martini, 1964
Cretarhabdus surirellus (Deflandre) Reinhardt, 1970
Eiffellithus turriseiffeli (Deflandre) Reinhart 1965

References for citations in this systematic paleontology that are not cited in the reference list may be found in Loeblich and Tappan (1966, 1968, 1969, 1970a, 1970b, 1971, and 1973).

Kingdom PLANTAE
Division CHRYSOPHYTA
Class COCCOLITHOPHYCEAE Rothmaler, 1951
Order DISCOASTERACEAE Tan Sin Hok, 1927
Family CERATOLITHACEAE Norris, 1965

A very complete succession of ceratoliths was observed at Sites 541 and 542. Faulting of sediments in Hole 541 allowed this succession to be seen three times in that hole alone. Ceratoliths that occurred in samples from these sites were exceptional in that many species are represented in these sections and most of these forms were beautifully preserved (which is unusual, as ceratoliths are commonly overgrown).

Poor preservation and barren intervals in upper Miocene sediments obscured the early relationships among *Amaurolithus amplificus, A. delicatus*, and *A. primus*. However, it is clear that *A. delicatus* and *A. primus* are the first forms to enter these sections and it appears that their first occurrences are coincident. *A. amplificus* is the next species seen in these samples. It is very scarce and restricted to the *Amaurolithus primus* Subzone.

The next event, is the extinction of *A. primus*, which occurs just prior to the appearance of *Ceratolithus acutus*. This extinction occurs much earlier than expected. In other low-latitude sections, the last occurrence of this species is after the extinction of *C. acutus* and is often at the same level as the extinctions of either *A. tricorniculatus* or *A. delicatus*. Some confusion could arise in the placement of this datum because of different species concepts used among the various authors or because problems imposed by overgrowths.

The first occurrence of *C. acutus* marks the appearance of the birefringent forms. Its entire range defines the *Ceratolithus acutus* Subzone, and provides a framework by which the other ceratoliths may be compared. *C. atlanticus*, a very distinctive species described by Perch-Nielsen (1977), is restricted to this subzone in the samples studied. This is the first reported occurrence of this species outside its type area in the South Atlantic.

The first *C. acutus* observed possesses a very thick apical region with a high spire (Plate 3, Figs. 5–6). In subsequent samples, the apical region is reduced and the horns are longer and begin to curve. This trend manifests itself in *C. armatus*, which is first seen in the middle of the *C. acutus* Subzone and becomes extinct shortly after the last occurrence of *C. acutus*. This may then lead to *C. cristatus* by reduction and flattening of the apical region. *C. cristatus* appears in these sections either at or slightly above the last occurrence of *C. acutus*. In these samples, its appearance is used in conjunction with the extinction of *C. acutus* to mark the upper boundary of the *Ceratolithus acutus* Subzone.

C. rugosus, which has been used in other studies to mark this boundary, is scarce in the sections examined. It is not seen above the Pliocene/Pleistocene boundary.

A. tricorniculatus has its first occurrence in the *Ceratolithus acutus* Subzone. The last occurrence of this species defines the top of the *Ceratolithus rugosus* Subzone and is the last amaurolith to occur in these sections. *A. delicatus* becomes extinct in this subzone.

C. separatus is found much higher up in the section than most of the other ceratoliths. It occurs in uppermost Pliocene and lowermost Pleistocene sediments at Sites 541 and 543 along with *C. cristatus*.

The succession of ceratoliths seen in these samples is exceptional because many species are represented and identification is facilitated by the lack of overgrowths. A series of consistent appearances and extinctions is recognized in these sections:

(1) FAD: *Amaurolithus delicatus, Amaurolithus primus*
(2) LAD: *Amaurolithus primus*
(3) FAD: *Ceratolithus acutus*
(4) FAD: *Amaurolithus tricorniculatus*
(5) FAD: *Ceratolithus cristatus and* LAD: *Ceratolithus acutus*
(6) LAD: *Ceratolithus armatus*
(7) LAD: *Amaurolithus delicatus*
(8) LAD: *Amaurolithus tricorniculatus.*

Genus *AMAUROLITHUS* Gartner and Bukry, 1975

Amaurolithus amplificus (Bukry and Percivil) Gartner and Bukry, 1975
(Plate 2, Fig. 8)

Ceratolithus tricorniculatus Gartner. Gartner, 1969, partim, p. 596, pl. 2, fig. 1 (non-figs. 2, 3).
Ceratolithus amplificus Bukry and Percivil, 1971, partim, p. 125, pl. 1, fig. 11 (non-figs. 9, 10).
Ceratolithus dentatus Bukry, 1973a, p. 676, pl. 2, figs. 1-3.
Amaurolithus amplificus (Bukry and Percivil) Gartner and Bukry, 1975, partim, p. 454, fig. 6g, k, i, l, (non-figs. 6h, j).

Remarks. Specimens of *A. amplificus* are much more robust than any of the other ceratoliths. The small apical spur and the distinct row of nodes on the shorter of the two horns, characteristic of more well-preserved specimens, are not observed on any of the specimens in these samples. However, a prominent thick ridge on the short horn is present on every specimen. This feature, along with the straight, shorter horn and the hooked projection at the end of the longer horn, are used to separate this species from all other ceratolith species. Forms that do not possess these three features (such as Gartner and Bukry, 1975, fig. 6h, j) are not placed in this species.

Occurrence. *A. amplificus* was rare in samples from the *Amaurolithus primus* Subzone.

Amaurolithus delicatus Gartner and Bukry, 1975
(Plate 2, Figs. 4-5)

Ceratolithus tricorniculatus Gartner. Bukry and Bramlette, 1968, partim, p. 152, pl. 2, fig. 1.
Ceratolithus primus Bukry and Percivil. Bukry, 1973a, p. 676, pl. 1, fig. 11.
Amaurolithus delicatus Gartner and Bukry, 1975, p. 456, figs. 7a-f.
Amaurolithus ninnae Perch-Nielsen, 1977, partim, pl. 5, fig. 13.

Remarks. The species concept of Gartner and Bukry (1975) is followed. *A. delicatus* is distinguished from *A. primus* by its greater height relative to width and the uniform thickness of the horns, as well as by its having more inwardly directed horns.

Occurrence. The first occurrences of *A. primus* and *A. delicatus* are coincident in Holes 541 and 542, and these datums are used to define the base of the *Amaurolithus primus* Subzone. The last occurrence of *A. delicatus* in Holes 541 and 542 is above the last occurrence of *Ceratolithus acutus* and just below the last occurrence of *A. tricorniculatus.*

Amaurolithus primus (Bukry and Percivil) Gartner and Bukry, 1975
(Plate 2, Fig. 9)

Ceratolithus primus Bukry and Percivil, 1971, p. 126, pl. 1, figs. 12-14.
Amaurolithus primus (Bukry and Percivil) Gartner and Bukry, 1975, p. 457, figs. 7g-l.

Remarks. The species concept of Gartner and Bukry (1975) is followed. None of the specimens of *A. primus* are heavily calcified (as in Bukry and Gartner, 1975, fig. 7g, i; Haq and Berggren, 1978, pl. 5, fig. 4), and the specimen illustrated in Plate 2 is typical of those seen.

Occurrence. The last occurrence of this species in Holes 541 and 542 is just below the first occurrence of *Ceratolithus acutus*, and is much lower than the last occurrences of both *A. delicatus* and *A. tricorniculatus*. This is considerably earlier than reported elsewhere. Ellis (1979) and Bukry (1973b, 1975) both use the last occurrences of *A. tricorniculatus* and *A. primus* to mark the same zonal boundary. Haq and Berggren (1978) and Ellis and Lohman (1979) both show the last occurrences of *A. primus* and *A. delicatus* to be coincident and higher than the last occurrence of *A. tricorniculatus*. All four of these papers place the *A. primus* extinction above that of *Ceratolithus acutus*. Therefore, the last occurrence of *A. primus* is diachronous and should not be used as a datum.

Amaurolithus tricorniculatus (Gartner) Gartner and Bukry, 1975
(Plate 2, Figs. 3, 6, 7)

Ceratolithus tricorniculatus Gartner, 1967, p. 5, pl. 10, figs. 4-6.
Amaurolithus tricorniculatus (Gartner) Gartner and Bukry, 1975, p. 457, figs. 8c-h.

Remarks. *A. tricorniculatus* is a species possessing a distinct, delicate apical spine and thin legs of uniform thickness. The size and position of the spine and the curvature and length of the legs is highly variable (see plate illustrations).

Occurrence. The last occurrence of *A. tricorniculatus* is a reliable datum (Haq and Berggren, 1978), and has the highest occurrence of all the amauroliths in the sediments recovered during Leg 78A.

Genus *CERATOLITHUS* Kamptner, 1950

Ceratolithus acutus Gartner and Bukry, 1974
(Plate 3, Figs. 1-6)

Ceratolithus acutus Gartner and Bukry, 1974, p. 115, pl. 1, figs. 1-4; Gartner and Bukry, 1975, p. 458, figs. 6a-f.

Remarks. This species, although very distinctive, shows considerable variation in the curvature and relative lengths of the horns and in the size and shape of the apical region. All specimens possess a row of nodes along the lower part of each horn and a centrally located suture that bisects the specimen. Typical *C. acutus* has a pronounced apical spine and horns that are unequal in length and slightly curved.

Occurrence. The first and last occurrence of this species is used to delineate the *Ceratolithus acutus* Subzone in Holes 541 and 542.

Ceratolithus armatus Müller, 1974
(Plate 2, Figs. 10-11)

Ceratolithus armatus Müller, 1974, p. 591, pl. 11, figs. 4-6, pl. 19, figs. 3-4; Gartner and Bukry, 1975, p. 458, figs. 5f-i.

Remarks. Observed specimens of *C. armatus* have a pointed apical region that is reduced in size. Otherwise, all specimens conform to the descriptions of Gartner and Bukry (1975).

Occurrence. *C. armatus* has its first occurrence just below the last occurrence of *C. acutus* and its last occurrence just after the appearance of *C. cristatus*. It may represent a transitional form between *C. acutus* and *C. cristatus*. It is very rare in the samples in which it is found.

Ceratolithus atlanticus Perch-Nielsen, 1977
(Plate 4, Figs. 4, 5, 7, 8)

Ceratolithus atlanticus Perch-Nielsen, 1977, p. 745, pl. 3, figs. 1-14; pl. 5, figs. 1-7, 10; pl. 49, figs. 2-4.

Remarks. This very distinctive species occurs with *C. acutus* in the lower part of that species range in Hole 541 and throughout most of its range in Hole 542.

Ceratolithus cristatus Kamptner, 1950
(Plate 2, Figs. 12-13; Plate 3, Figs. 7-9; Plate 4, Fig. 3; Plate 13, Figs. 3, 6)

Ceratolithus cristatus Kamptner, 1950, p. 154; Bukry and Bramlette, 1968, p. 150, pl. 1, figs. 1-2, 4; Gartner and Bukry, 1975, p. 458, figs. 4a-c.

Remarks. This species shows a considerable variation in its morphology. Specimens range from a more robust form, with a flattened apical region connecting horns that are unequal in length and taper to sharp points (Plate 3, Figs. 7-8), to a more delicate form with a rounded apical region (Plate 2, Figs. 12-13). The more robust form is common.

All specimens possess horns that are directed inward toward each other and are more strongly curved near the apical region. Well-preserved specimens have a high row of nodes on both horns that are found on the same side of the specimen (Plate 3, Fig. 9; Plate 4, Fig. 3). In poorly preserved samples, specimens are thinner and commonly broken into pieces.

C. separatus and *C. rugosus* are similar to *C. cristatus. C. separatus* has a thicker apical region, an apical spur above each horn, numerous spines projecting from the horns, and is much more robut than *C. cristatus. C. rugosus* is more heavily calcified and has horns that do no bend inward or possess sharp points.

Occurrence. The first occurrence of *C. cristatus* in these samples is at approximately the same level as the last occurrence of *C. acutus*. Perch-Nielsen (1977) also found the first occurrence of *C. cristatus* to be near the last occurrence of *C. acutus* in Hole 354. This same relationship is seen between *C. acutus* and *C. rugosus* at several other locations (Bukry, 1973b, 1975; Haq and Berggren, 1978; Ellis, 1979; and Ellis and Lohman, 1979). This suggests that *C. rugosus* is only an overgrown form of *C. cristatus.*

***Ceratolithus rugosus* Bukry and Bramlette, 1968**
(Plate 2, Figs. 14–15)

Ceratolithus rugosus Bukry and Bramlette, 1968, p. 157, pl. 1, figs. 5–9; Gartner and Bukry, 1975, p. 459, figs. 5a–e.

Remarks. *C. rugosus* has a rough surface and horns that are nearly parallel along their inner margin. Forms vary in shape from short, wide specimens (Plate 2, Figs. 14–15) to long, thin types (Bukry and Bramlette, 1968, pl. 1, fig. 8). The same variation in shape is seen in *C. cristatus* in these samples.

Occurrence. *C. rugosus* occurs sporadically in lower Pliocene sediments at all three sites and is usually rare when found. Similar ranges of both *C. rugosus* and *C. cristatus* suggest that the two species are conspecific.

***Ceratolithus separatus* Bukry, 1975**
(Plate 4, Figs. 1–2; Plate 11, Figs. 1–3)

Ceratolithus separatus Bukry, 1975, p. 310, pl. 1, figs. 1–16.

Remarks. Typical *C. separatus* are robust, short and wide, and have a thickened apical region and numerous spines projecting from the horns. Rare specimens have a centrally located apical spur and an apical region that is convex along the outer margin.

Occurrence. *C. separatus* is found in uppermost Pliocene and lowermost Pleistocene sediments in Holes 541 and 543.

Family DISCOASTERACEAE Tan Sin Hok, 1927
Genus *DISCOASTER* Tan Sin Hok, 1927

***Discoaster berggrenii* Bukry, 1971**
(Plate 1, Figs. 7–8)

Discoaster berggrenii Bukry, 1971b, pl. 2, figs. 4–6.

Remarks. When describing *D. berggrenii*, Bukry restricted this species to five-rayed asteroliths with a knob that nearly fills the central area and a free arm length that is equal to or less than the size of the central area. These criteria distinguish *D. berggrenii* from *D. quinqueramus.* In this paper, *D. berggrenii* is restricted to forms similar to the type specimens illustrated by Bukry. Such forms have a free arm length equal to the central area and a knob that nearly fills the central area. Specimens with very short arms and a knob that entirely fills or extends outside the central area are placed in *Discoaster* sp. cf. *D. berggrenii.*

Occurrence. *D. berggrenii* is found with both *D. quinqueramus* and *Discoaster* sp. cf. *D. berggrenii* and may be a transitional form between these other two forms. The last occurrence of *D. berggrenii* in my samples is just below the extinction of *D. quinqueramus;* its first occurrence is above that of *Discoaster* sp. cf. *D. berggrenii.*

Discoaster* sp. cf. *D. berggrenii
(Plate 1, Fig. 6)

Description. *Discoaster* sp. cf. *D. berggrenii* is a small, five-rayed asterolith with arms less than half the length of the central area and a distinct stellate knob that entirely fills or extends beyond the central area.

Occurrence. This form occurs only in samples from the *Discoaster berggrenii* Subzone. It is never found with *Amaurolithus delicatus* or *D. quinqueramus. Discoaster* sp. cf. *D. berggrenii* and *D. berggrenii* are found together in the same samples from Holes 541 and 542. It appears that *Discoaster* sp. cf. *D. berggrenii* occurs before *D. berggrenii,* although it is difficult to discern because of poor preservation and possible stratigraphic repetitions in sediments of that age.

***Discoaster quinqueramus* Gartner, 1969**
(Plate 1, Fig. 9)

Discoaster quinqueramus Gartner, 1969, partim, p. 598, pl. 1, fig. 6 (non-fig. 7).

Discoaster quintatus Bukry and Bramlette, 1969, partim, p. 133, pl. 1, figs. 7–8 (non-fig. 6).

Remarks. The species concept of Bukry (1971b) is followed.

Occurrence. *D. quinqueramus* is found only in sediments from the *Amaurolithus primus* Subzone. Its last occurrence is used to mark the upper boundary of the subzone.

***Discoaster asymmetricus* Gartner, 1969**
(Plate 1, Fig. 1)

Discoaster asymmetricus Gartner, 1969, p. 598, pl. 1, figs. 1–3.

Occurrence. The first stratigraphic occurrence of *Discoaster asymmetricus* could not be used as a datum because of rare and sporadic occurrences of this species in upper Miocene and lowermost Pliocene sediments. The *Discoaster asymmetricus* Subzone (Bukry, 1973b, 1975; Okada and Bukry, 1980), which is based on the first common occurrence of that species, is applicable to the samples examined.

***Discoaster bollii* Martini and Bramlette, 1963**
(Plate 1, Fig. 4)

Discoaster bollii Martini and Bramlette, 1963, p. 851, pl. 105, figs. 1–4, 7.

Occurrence. Rare, poorly preserved specimens of *D. bollii* are present in Samples 541-42-5, 69–70 cm and 541-42-4, 85–86 cm. It is likely that these are reworked.

***Discoaster pentaradiatus* Tan Sin Hok, 1927**

Discoaster pentaradiatus Tan Sin Hok, 1927, p. 416, fig. 14; Bramlette and Riedel, 1954, p. 401, pl. 39, fig. 11, text-fig. 2a–b.

Remarks. *D. pentaradiatus* from upper Miocene sediments tend to have larger central areas, and many possess a small, stellate knob. Specimens from poorly preserved samples are missing the normal bifurcated tips.

***Discoaster tamalis* Kamptner, 1967**
(Plate 2, Fig. 2)

Discoaster brouweri (Tan Sin Hok) Martini and Bramlette, 1963, pl. 102, fig. 10.

Discoaster tamalis Kamptner, 1967, p. 166, text-fig. 29.

Remarks. The species concept used in this paper includes all slender, four-rayed discoasters with arms that are perpendicular to each other. They may or may not have curved rays like those of *D. brouweri.*

Occurrence. The last occurrence of *D. tamalis* is utilized as a datum in these samples. The first occurrence of *D. tamalis* lies at approximately the same level as the first common occurrence of *D. asymmetricus.* Ellis (1979) used this datum in sediments from the eastern Mediterranean, and it may prove useful as a datum in the deep sea.

Order COCCOLITHALES Rood et al., 1971
Family GEPHYROCAPSACEAE Hay, 1977

Genus *GEPHYROCAPSA* Kamptner, 1943

Members of the genus *Gephyrocapsa* show more variation in morphology than any other group of nannofossils examined. Three species are recognized in this study: *G. caribbeanica, G. oceanica,* and *G. omega.* Forms under 3 μm in size are too small to be discernible under the light microscope and are noted as *Gephyrocapsa* spp. (small). This group includes over a dozen species cited in the literature.

The size of the central opening is used to discriminate between *G. caribbeanica* and *G. oceanica.* Both species showed a wide range in bar angles (between 0–55° with the minor axis of the ellipse). *G. omega*, a species with an open central region and a bar that lies in the minor axis of the ellipse, is retained as a separate species because this form has a distinct first occurrence in Pleistocene sections at Holes 541 and 543.

Bukry (1973b, 1975), Okada and Bukry (1980), and Ellis (1979) use the first occurrences of *G. caribbeanica* and *G. oceanica* as successive datums in the lower Pleistocene. Gartner (1977) warns that climatically induced variations in these two species make them useless for biostratigraphic purposes. The range charts presented by Gartner (1977) at Hole 154A and Sites 206 and 289 show that the first occurrences of *G. caribbeanica* and *G. oceanica* are not consistent. In this study, both species have their first occurrence at the same level. A further complication in working with this group is the different species concepts that may be employed by various authors. Because of all these discrepancies, it seems that this group should not be used in biostratigraphic correlations.

Gephyrocapsids are found in samples from Holes 541 and 543. The information derived from Hole 543 is fragmentary because of poor preservation and barren intervals. The section in Hole 541 is much more complete, as *Gephyrocapsa* are present in each of the top ten cores. Two observations are made about the occurrence of geophyrocapsid species in these samples. One is that *G. caribbeanica* is very rare or absent in samples that contain *G. omega*, probably because of an environmental influence. Gartner (1977) believes that *G. omega* is the warm-cycle member of the *Gephyrocapsa oceanica* group, whereas the more closed-center forms such as *G. lumina* (included here under *G. caribbeanica*) are the cold-cycle variant. A second interesting observation is that *Gephyrocapsa* over 3 μm in length are absent from samples just below the appearance of *G. omega*. This is not the result of preservation, as these samples are as well preserved as the samples that contain *G. omega*.

Gephyrocapsa caribbeanica **Boudreaux and Hay, 1969**
(Plate 7, Figs. 3, 16)

Gephyrocapsa caribbeanica Boudreaux and Hay, in Hay et al., 1969, p. 447, pl. 12, figs. 1–4; pl 13, figs. 1–4; Boudreaux and Hay, 1969, partim, p. 262, pl. 2, figs. 4–9 (non-fig. 2–3); Gartner, 1977, pl. 2, figs. 2–3.

Gephyrocapsa lumina Bukry, 1973a, p. 678, pl. 3, figs. 1–4.

Remarks. Forms with a closed central area are included in *G. caribbeanica*. The angle the bridge makes with the minor axis varies, and a collar of variable width may surround the central area. The first *G. caribbeanica* are small (3 to 4 μm) and have bridges that are at a high angle to the minor axis. Forms with lower bar angles are more dominant in higher parts of the section.

Occurrence. The first occurrence of *G. caribbeanica* in Holes 541 and 543 is just below the last occurrence of *Calcidiscus macintyrei* and is coincident with the first occurrence of *G. oceanica. G. caribbeanica* is either rare or absent in samples that contain *G. omega*.

Gephyrocapsa oceanica **Kamptner, 1943**
(Plate 7, Figs. 11–15)

Gephyrocapsa oceanica Kamptner, 1943, pp. 43–49; Cohen, 1964, p. 240, pl. 3, fig. 3a–e; pl. 4, fig. 3a–b; Hay et al., 1967, pl. 12–13, figs. 5–6; Boudreaux and Hay, 1969, p. 258, pl. 1, figs. 18–25; pl. 2 fig. 1.

Gephyrocapsa oceanica Kamptner var. *typica* Kamptner, 1956, p. 179, pl. 16, fig. 4–5.

Gephyrocapsa oceanica var. *californiensis* Kampter, 1956, p. 179.

Gephyrocapsa kamptneri Deflandre and Fert, 1954. Hay and Beaudry, 1973, p. 679, pl. 1, figs. 8–9.

Gephyrocapsa margereli Breheret, 1978, p. 447, pl. 1, figs. 1–2; pl. 2, figs. 1–2.

Remarks. The first *G. oceanica* in these samples are small (3–4 μm) and have bridges that are at a high angle to the small axis of the ellipse. Forms with bridge angles greater than 30° to the minor axis of the ellipse are not seen in samples that contain *G. omega*.

Occurrence. The first occurrence of *G. oceanica* is coincident with that of *G. caribbeanica* in these samples.

Gephyrocapsa omega **Bukry, 1973**
(Plate 7, Fig. 17)

Gephyrocapsa omega Bukry, 1973a, p. 679, pl. 3, figs. 5–11.

Gephyrocapsa parallela Hay and Beaudry, 1973, p. 672, pl. 2, figs. 10–12.

Remarks. *G. omega* is retained as a separate species because its first occurrence is higher than both *G. oceanica* and *G. caribbeanica*, and it is easy to identify. Gartner (1977) mentions that *G. omega* is a warm-water variant of *G. oceanica*.

Occurrence. *G. omega* is found at three intervals: Core 1 in Hole 543, Samples 541-7,CC to 541-4,CC, and Samples 541-3-1, 75–76 cm to 541-2-4, 144–145 cm. Just below each of these three intervals are one or more samples in which the larger *Gephyrocapsa* species (greater than 3 μm) are absent or very rare.

Gephyrocapsa **spp. (small)**

Many small species of *Gephyrocapsa* have been described in the literature. It is impractical, and often impossible, to distinguish between these species with the light microscope. Therefore, the following species could possibly be included under the category of *Gephyrocapsa* spp. (small:

Gephyrocapsa aperta Kamptner, 1963
Gephyrocapsa ericsonii McIntyre and Bé, 1967
Gephyrocapsa kamptneri Deflandre and Fert, 1954
Gephyrocapsa pelta Samtleben, 1980
Gephyrocapsa protohuxleyi McIntyre, 1970
Gephyrocapsa rota Samtleben, 1980
Gephyrocapsa sinuosa Hay and Beaudry, 1973
Gephyrocapsa undulatus Lecal, 1967

Genus *RETICULOFENESTRA* Hay et al., 1967

Reticulofenestra pseudoumbilica **(Gartner) Gartner, 1969**
(Plate 7, Fig. 18)

Coccolithus pseudoumbilica Gartner, 1967, p. 4 pl. 6, figs. 1–4.

Reticulofenestra pseudoumbilica (Gartner) Gartner, 1969, p. 198, pl. 2, figs. 1–2.

Remarks. Backman (1978), in studying Miocene-Pliocene nannofossil assemblages from the northeast Atlantic Ocean, defined a lower size limit of 5 μm in length for *R. pseudoumbilica*. This same lower size limit is used in this study.

Occurrence. The last occurrence of *R. pseudoumbilica* occurs just below the last occurrences of *Sphenolithus abies* and *Sphenolithus neoabies*.

Genus CRENALITHUS **Roth, 1973**

Crenalithus doronicoides **(Black and Barnes), 1961**

Coccolithus doronicoides Black and Barnes, 1961, p. 142, pl. 25, fig. 3.

Gephyrocapsa doronicoides (Black and Barnes) Bukry, 1973a, p. 678.

Crenalithus doronicoides (Black and Barnes) Roth, 1973, p. 731, pl. 3, fig. 3.

Cyclicargolithus doronicoides (Black and Barnes) Wise, 1973, pg. 594.

Remarks. *Crenalithus doronicoides* is retained as a species name for forms with open centers that are less than 5 μm in length.

Genus *PSEUDOEMILIANIA* Gartner, 1969

Pseudoemiliania lacunosa **(Kamptner) Gartner, 1969**
(Plate 7, Figs. 6–8)

Ellipsoplacolithus lacunosa Kamptner, 1963, p. 172, pl. 9, fig. 50.

Umbilicosphaera cricota (Gartner) Cohen and Reinhardt, 1968, p. 296, pl. 19, figs. 1–2, pl. 21, fig. 3.

Pseudoemiliania lacunosa (Kamptner) Gartner, 1969, p. 598, pl. 2, figs. 9–10.

Emiliania ovata Bukry, 1973a, p. 678, pl. 2, figs. 10–12.

Remarks. Elliptical and circular forms have the same stratigraphic range in these sediments, and both are included in this species.

Occurrence. The first occurrence of *P. lacunosa* is at the base of the *Discoaster asymmetricus* Subzone in Holes 541 and 543.

Order SYRACOSPHAERALES Hay, 1977
Family PONTOSPHAERACEAE Lemmermann, 1908

Genus *PONTOSPHAERA* Lohmann, 1902

The pontosphaerids form an insignificant part of the nannofossil assemblages in sequences at all three sites. Their occurrence is very sporadic because they are not very resistant to solution.

P. japonica, by virtue of its distinct appearance, is the only species identified in these samples. All other pontosphaerids show a wide variation in the arrangement and number of pores, and are collectively referred to in the range charts as *Pontosphaera* sp. In general, smaller forms from 7 to 9 μm in length (Plate 6, Figs. 4–5; Plate 11, Fig. 4) are entirely perforate, containing three to four cycles of perforations. Specimens of intermediate size (Plate 10, Fig. 1) commonly have only the outer row of pores preserved with a few randomly arranged pores in the central region. Specimens greater than 12 μm in length are mostly imperforate with two longitudinal slits or have a series of randomly arranged pores in the central area. These are more common in poorly preserved samples.

Pontosphaera japonica **(Takayama) Burns, 1973**

Discolithina jaonica Takayama, 1967, p. 189, pl. 9, pl. 10, figs. 1, 2a–d; text-fig. 7.

Discolithina millepuncta Gartner, 1967, p. 5, pl. 8, figs. 1, 2, 3a-c, 4a-d.
Pontosphaera japonica (Takayama) Burns, 1973, p. 154, 157, pl. 2, figs. 8-13.

Remarks. *Pontosphaera japonica* is very distinctive because of the numerous fine perforations that are barely visible on the light microscope. These pores are far more numerous than on other forms of *Pontosphaera.*

Occurrence. This species is scarce in a few samples from Site 543.

ACKNOWLEDGMENTS

I thank Dr. S. W. Wise for encouraging me to participate in Leg 78A of the Deep Sea Drilling Project and for his guidance and advice on this project, which formed the basis for a M.Sc. thesis at Florida State. I am grateful as well to the other members of my committee, Dr. G. Osmond and Dr. P. Ragland, for their review of this manuscript. In addition, I thank C. H. Ellis, who also reviewed the manuscript. Very special thanks to Rosemarie Raymond for her patience in drafting all the figures and tables for this manuscript. I would also like to thank Dennis Cassidy for his concern and advice on several aspects of this project and the opportunity to work at the Antarctic Research Facility. The assistance and helpful suggestions of George Wiegand and Amrisar Kaharoeddin are also greatly appreciated.

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Date of Initial Receipt: October 5, 1982
Date of Acceptance: September 30, 1983

APPENDIX
Methods

A smear slide preparation was made for each of the 634 samples taken. All biostratigraphic work and estimates of abundance and preservation were made from these slides. Five traverses of each slide were routinely made at a magnification of ×625. It was necessary to examine Pleistocene assemblages at ×1560 and adjust the abundances accordingly. The following scale was used to estimate the abundances of the individual species:

E (extremely abundant)	100 specimens/field of view
A (abundant)	10–100 specimens/field of view
C (common)	1–10 specimens/field of view
F (few)	1 specimen/1–10 fields of view
R (rare)	1 specimen/1–100 fields of view
P (present)	a few specimens per slide

Occurrences of reworked species are indicated by lower-case letters on the range charts.

Estimates of the percentage of nannofossils present in the sediment were made from the following scale:

A (abundant)	>50%
C (common)	between 10 and 50%
F (few)	between 1 and 10%
R (rare)	<1%
B (barren)	none

Samples were then selected for photomicrography on the scanning electron microscope and the light microscope. The excessive amounts of clay in these samples made it necessary to centrifuge the samples in order to concentrate the nannofossils.

Elvacite was utilized as the mounting medium for light micrography because it provided greater relief than other mediums. However, it also adversely affected the quality of photographs in phase contrast light. Scanning electron micrographs were taken on both AMR-1000 and Cambridge Mark IV microscopes.

Assessments of preservation were based on the condition of the placoliths in the sample, because the discoasters and ceratoliths did not show a great range of preservational characteristics. Assemblages with good preservation (G) contained placoliths that showed no signs of etching. Delicate forms such as lopadoliths and rhabdosphaerids were intact in these samples. Samples with moderate preservation (M) had placoliths that were slightly etched and the number of delicate forms was reduced. These delicate forms were also frequently broken. When all the placoliths were noticeably etched and many isolated shields remained, the sample was considered to be poorly preserved (P). Delicate forms were not present in these samples, and some of the discoasters and ceratoliths were broken and fragmented.

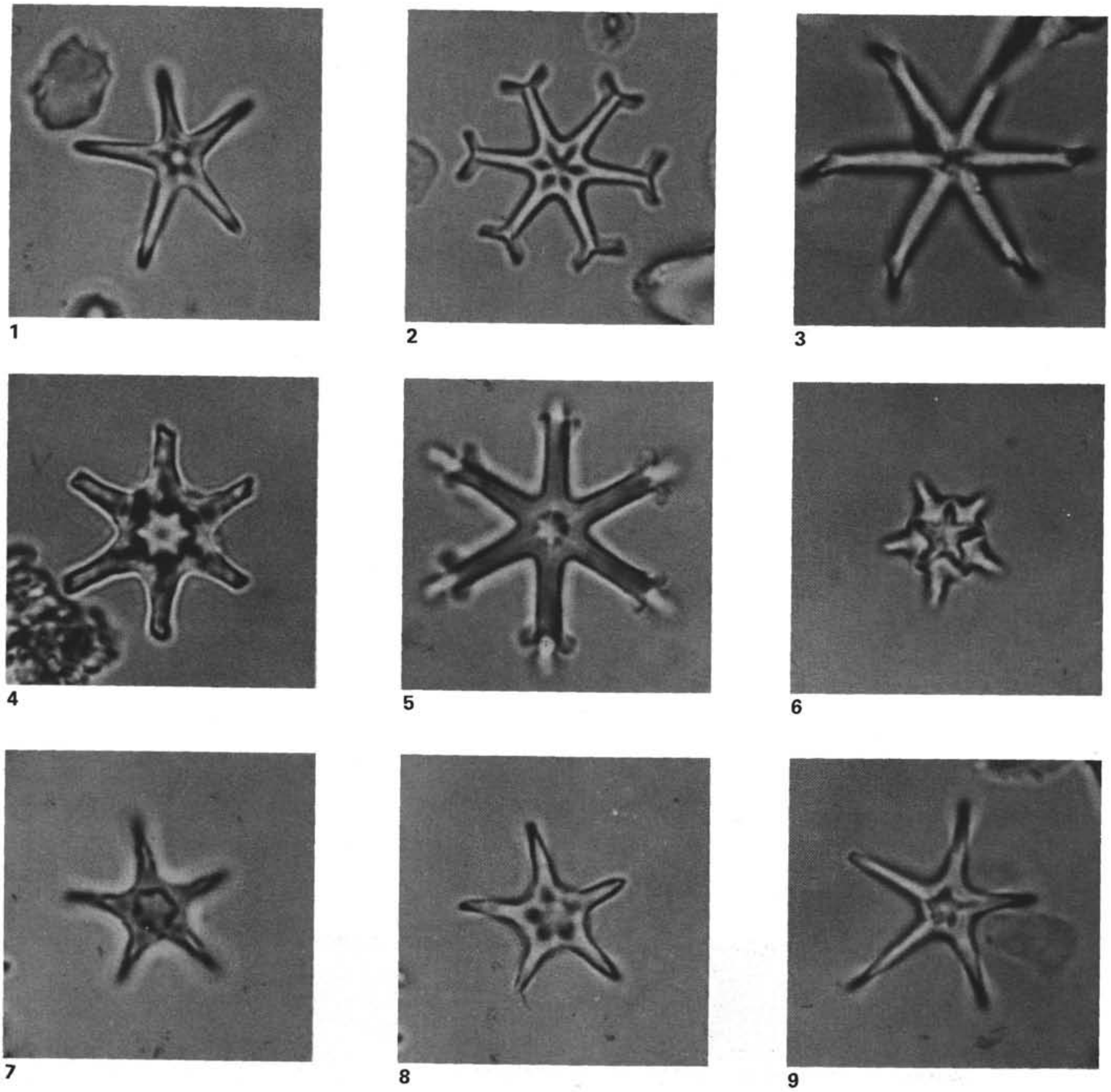

Plate 1. (All specimens magnified ×3000.) **1.** *Discoaster asymmetricus* Gartner, Sample 543-6-6, 94–95 cm, transmitted light. **2.** *Discoaster variabilis* Martini and Bramlette, Sample 543-6-6, 94–95 cm, transmitted light. **3.** *Discoaster hamatus* Martini and Bramlette, Sample 541-42-4, 85–86 cm, transmitted light. **4.** *Discoaster bollii* Martini and Bramlette, Sample 541-42-4, 85–86 cm, transmitted light. **5.** *Discoaster surculus* Martini and Bramlette, Sample 541-23-1, 64–65 cm, transmitted light. **6.** *Discoaster* sp. cf. *D. berggrenii* Bukry, Sample 541-28-6, 54–55 cm, transmitted light. **7–8.** *Discoaster berggrenii* Bukry, Sample 541-41-4, 121–122 cm (**7**) transmitted light, (**8**) same specimen at different focus. **9.** *Discoaster quinqueramus* Gartner, Sample 542-4-1, 27–78 cm, transmitted light.

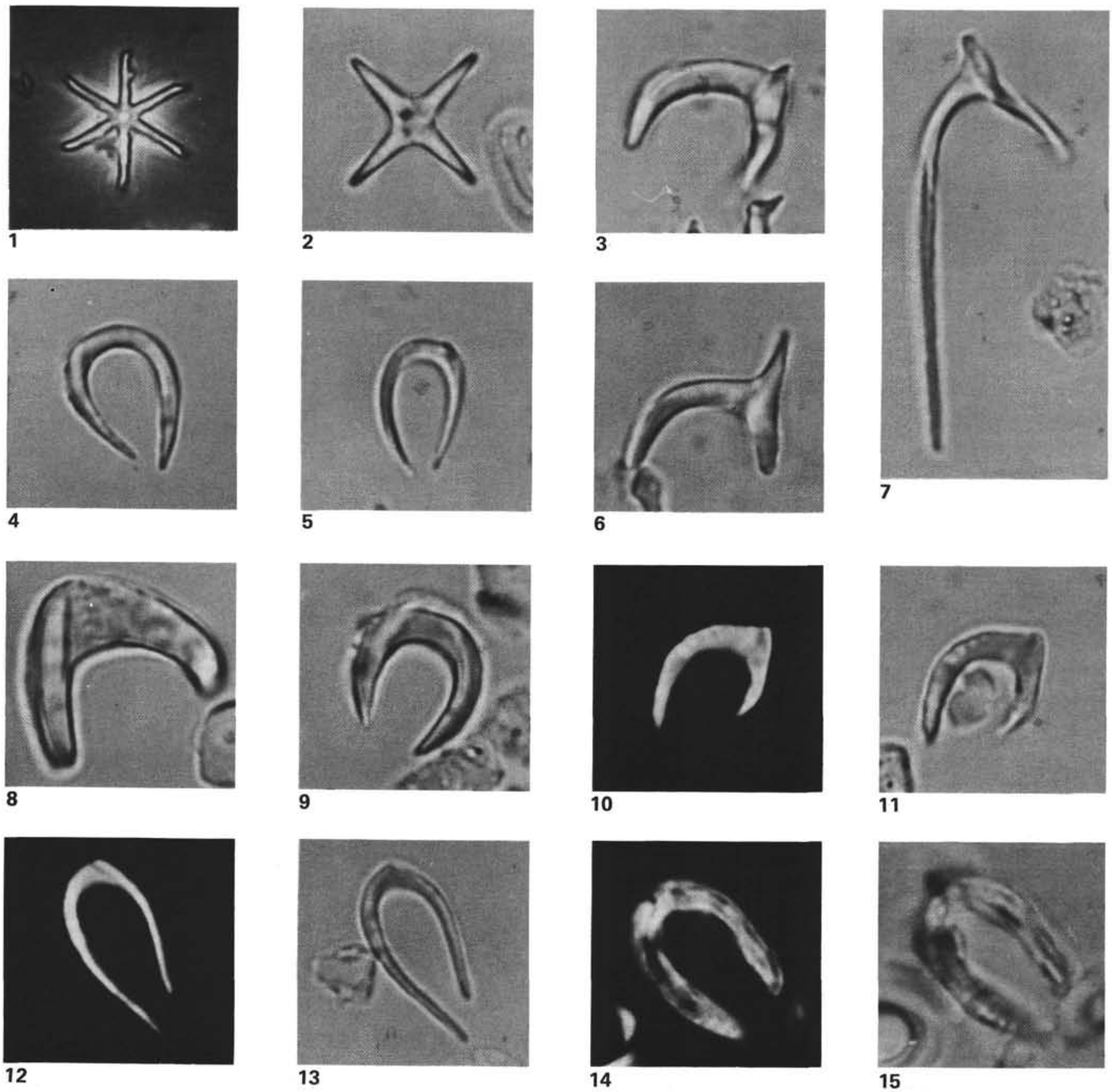

Plate 2. (All specimens magnified ×3000 unless otherwise specified.) **1.** *Discoaster neohamatus* Bukry and Bramlette, Sample 541-42-4, 85–86 cm, phase contrast (×1750). **2.** *Discoaster tamalis* Kamptner, Sample 543-6-6, 94–95 cm, transmitted light. **3.** *Amaurolithus tricorniculatus* (Gartner) Gartner and Bukry, Sample 541-21-3, 119–120 cm, transmitted light. **4–5.** *Amaurolithus delicatus* Gartner and Bukry, **(4)** Sample 541-19-7, 27–28 cm, transmitted light, **(5)** Sample 541-21-3, 119–120 cm, transmitted light. **6–7.** *Amaurolithus tricorniculatus* (Gartner) Gartner and Bukry, **(6)** Sample 541-36-2, 35–36 cm, transmitted light, **(7)** Sample 541-19-7, 27–28 cm; transmitted light. **8.** *Amaurolithus amplificus* (Bukry and Percivil) Gartner and Bukry, Sample 541-29-4, 75–76 cm, transmitted light. **9.** *Amaurolithus primus* (Bukry and Percivil) Gartner and Bukry, Sample 542-4-3, 46–47 cm, transmitted light. **10–11.** *Ceratolithus armatus* Müller, Sample 541-36-2, 35–36 cm, **(10)** cross-polarized light, **(11)** transmitted light. **12–13.** *Ceratolithus cristatus* Kamptner, Sample 543-6-2, 94–95 cm, **(12)** cross-polarized light, **(13)** transmitted light. **14–15.** *Ceratolithus rugosus* Bukry and Bramlette, Sample 541-20-6, 45–46 cm, **(14)** cross-polarized light, **(15)** transmitted light.

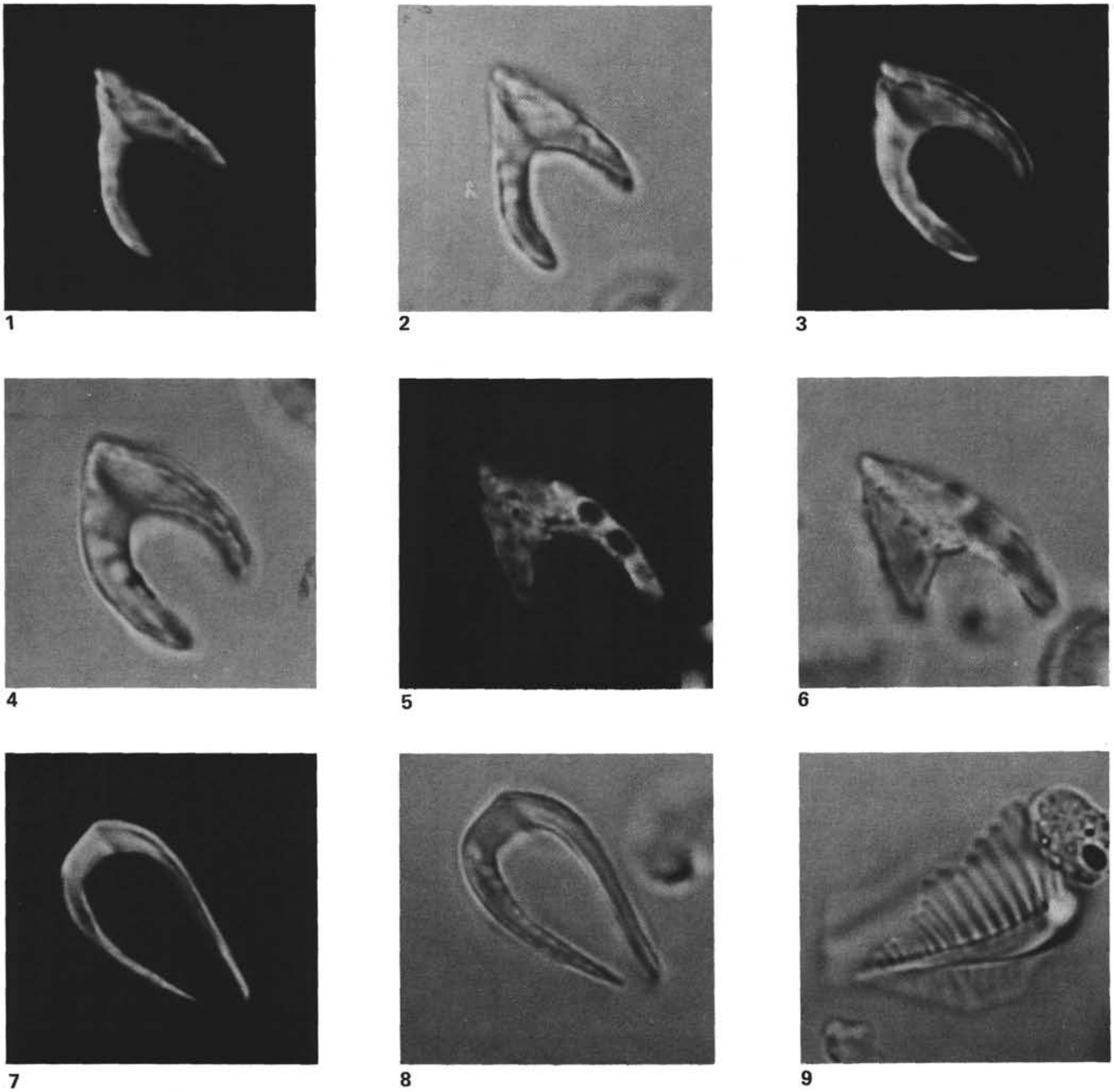

Plate 3. (All specimens magnified ×3000.) **1–6.** *Ceratolithus acutus* Gartner and Bukry, **(1–2)** Sample 541-19-7, 27–28 cm (**1**, cross-polarized light; **2**, transmitted light), **(3–4)** Sample 541-19-7, 27–28 cm (**3**, cross-polarized light; **4**, transmitted light), **(5–6)** Sample 541-36-2, 35–36 cm (**5**, cross-polarized light; **6**, transmitted light). **7–9.** *Ceratolithus cristatus* Kamptner, **(7–8)** Sample 543-6-2, 94–95 cm (**7**, cross-polarized; **8**, transmitted light), **(9)** Sample 543-6-2, 94–95 cm, side view in transmitted light.


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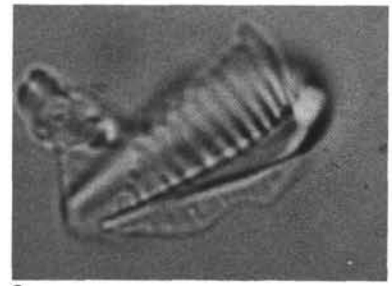
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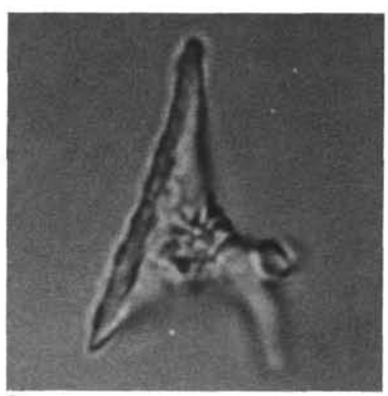
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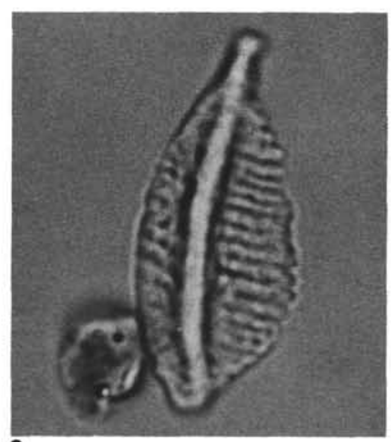
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Plate 4. (All specimens magnified ×3000.) **1–2.** *Ceratolithus separatus* Bukry, Sample 541-12-2, 75–76 cm, **(1)** cross-polarized light, **(2)** transmitted light. **3.** *Ceratolithus cristatus* Kamptner, Sample 543-6-2, 94–95 cm, side view in transmitted light. **4–5.** *Ceratolithus atlanticus* Perch-Nielsen, Sample 541-19-7, 27–28 cm, **(4)** cross-polarized light, **(5)** transmitted light. **6, 9.** *Triquetrorhabdulus rugosus* Bramlette and Wilcoxon, Sample 541-42-4, 85–86 cm, **(6)** phase contrast; **(9)** transmitted light. **7–8.** *Ceratolithus atlanticus* Perch-Nielsen, Sample 541-22-4, 22–23 cm, **(7)** cross-polarized light, **(8)** transmitted light.

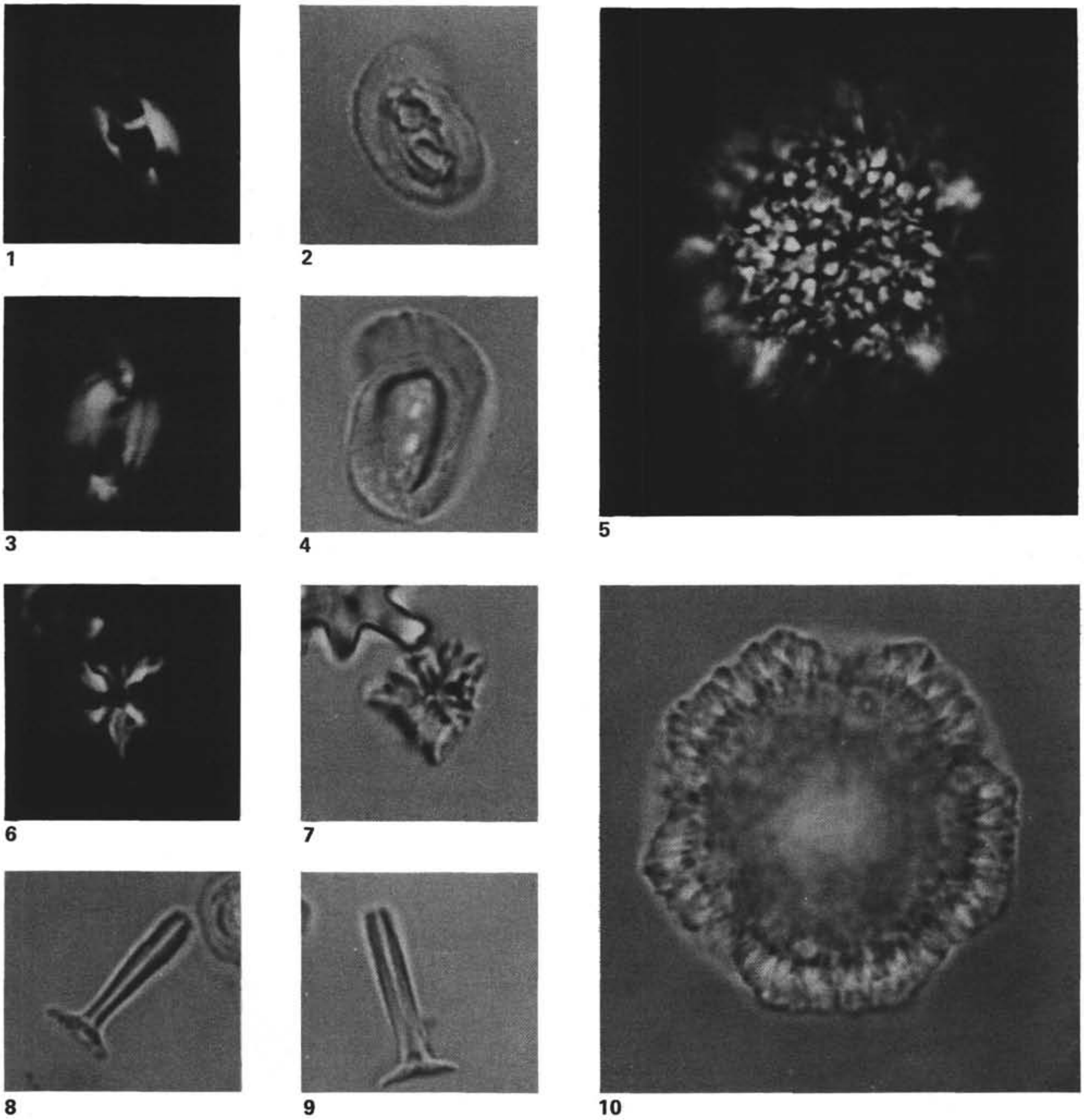

Plate 5. (All specimens magnified ×3000.) 1–2. *Helicosphaera sellii* (Bukry and Bramlette) Jafar and Martini. Sample 543-6-2, 94–95 cm, (1) cross-polarized light, (2) transmitted light. 3–4. *Helicosphaera carteri* (Wallich) Kamptner, Sample 541-10-4, 75–76 cm, (3) cross-polarized light, (4) transmitted light. 5, 10. *Thoracosphaera albatrosiana* Kamptner, Sample 541-4-6, 75–76 cm, (5) cross-polarized light, (10) transmitted light. 6–7. *Sphenolithus moriformis* (Bronnimann and Stradner) Bramlette and Wilcoxon, Sample 541-41-4, 121–122 cm, (6) cross-polarized light, (7) transmitted light. 8–9. *Rhabdosphaera clavigera* Murray and Blackman, Sample 541-4-6, 75–76 cm; different specimens in transmitted light.

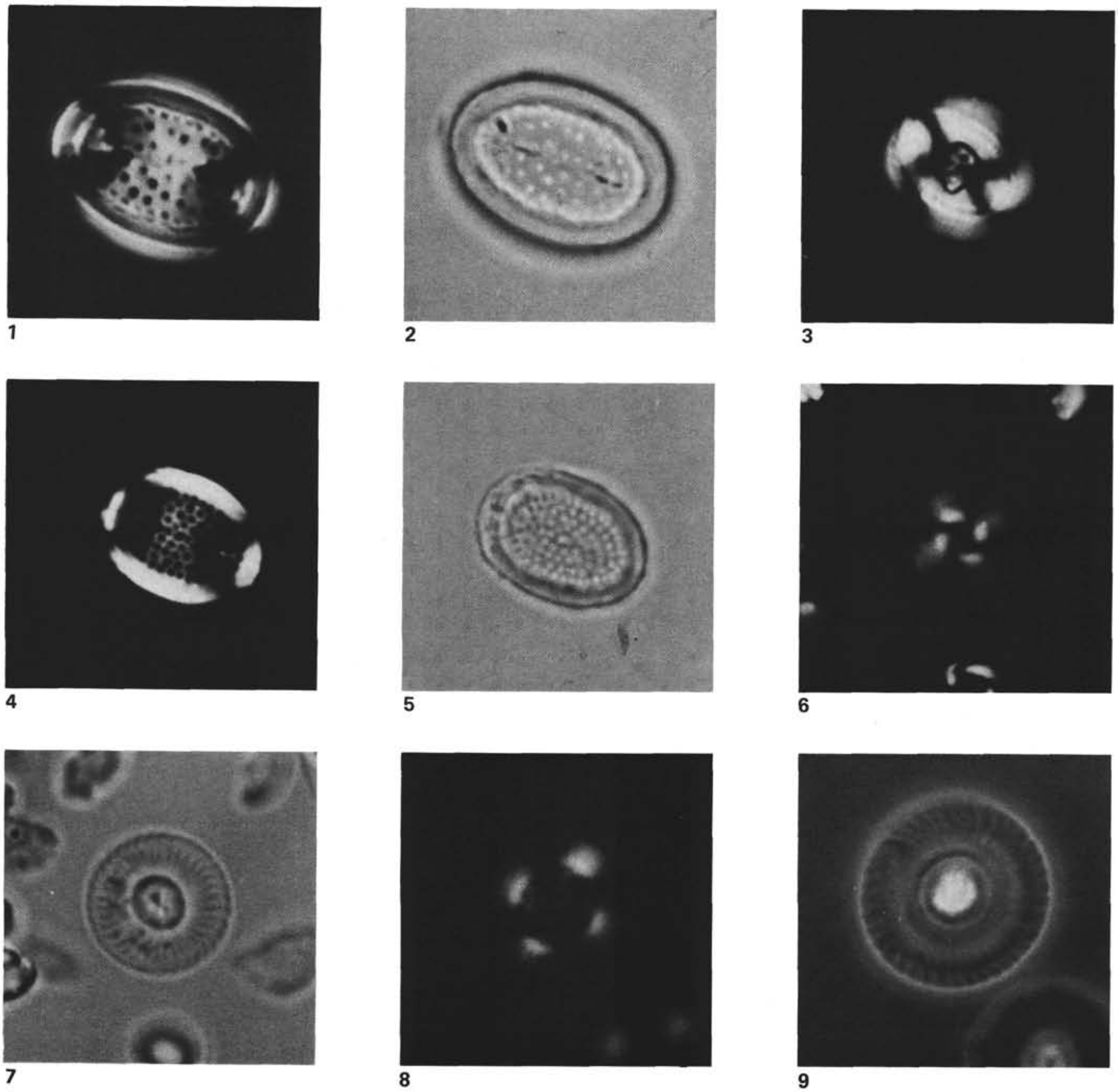

Plate 6. (All specimens magnified ×3000.) **1–2.** *Pontosphaera* sp., Sample 541-15-1, 20–21 cm, **(1)** cross-polarized light, **(2)** transmitted light. **3.** *Coccolithus pelagicus* (Wallich) Schiller, Sample 541-4-6, 75–76, cross-polarized light. **4–5.** *Pontosphaera* sp., Sample 541-9-1, 75–76 cm, **(4)** cross-polarized light, **(5)** transmitted light. **6–7.** *Calcidiscus leptoporus* (Murray and Blackman) Loeblich and Tappen, Sample 541-4-6, 75–76 cm, **(6)** cross-polarized light, **(7)** transmitted light. **8–9.** *Calcidiscus macintyrei* (Bukry and Bramlette) Loeblich and Tappen, Sample 543-6-2, 94–95 cm, **(8)** cross-polarized light, **(9)** phase contrast.

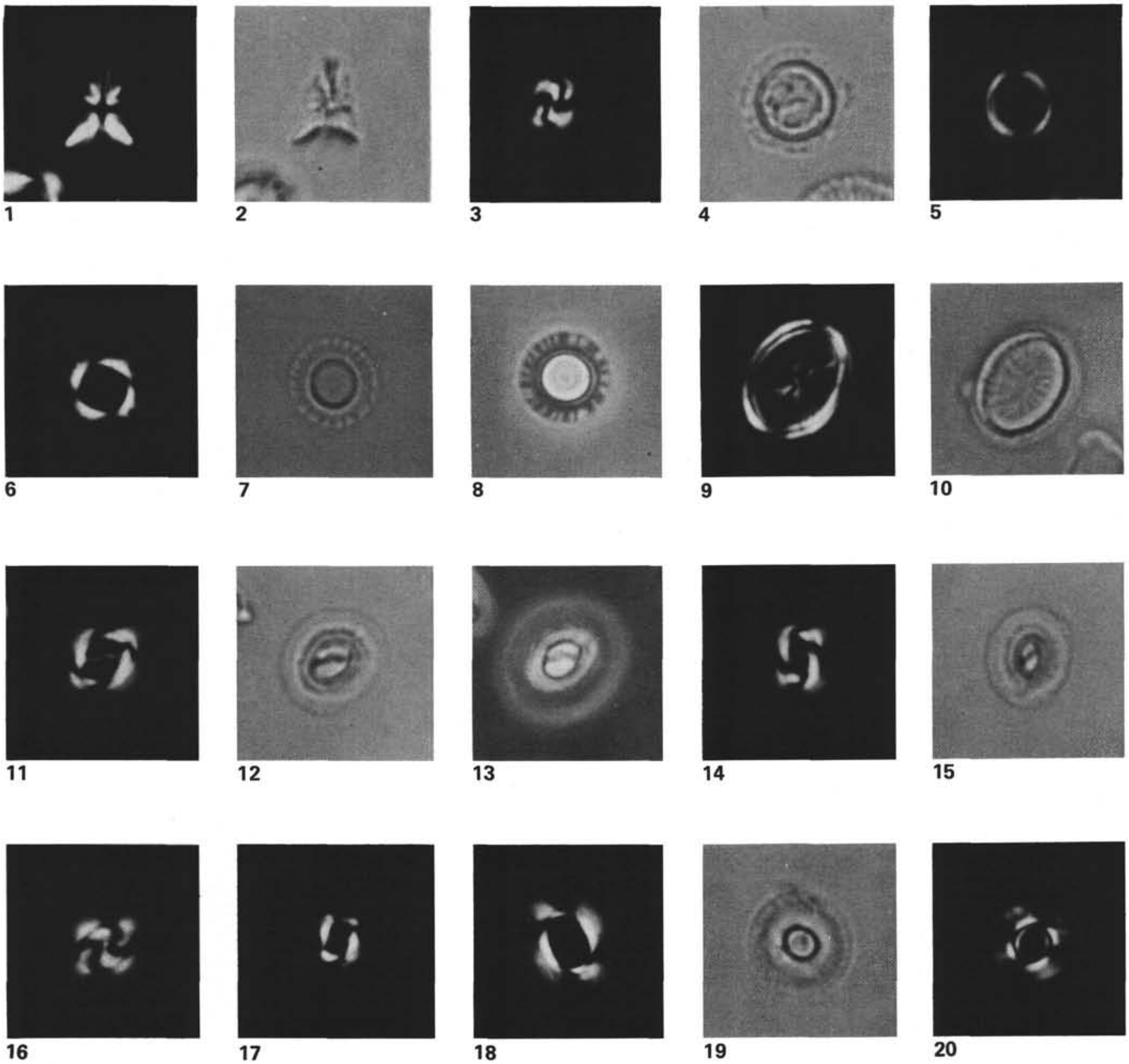

Plate 7. (All specimens magnified ×3000.) **1–2.** *Sphenolithus abies* Deflandre, Sample 541-19-7, 27–28 cm, **(1)** cross-polarized light, **(2)** transmitted light. **3.** *Gephyrocapsa caribbeanica* Boudreaux and Hay, Sample 541-10-4, 75–76 cm, cross-polarized light. **4–5.** *Umbilicosphaera cricota* (Gartner) Cohen and Reinhardt, Sample 541-18-6, 43–44 cm, **(4)** transmitted light, **(5)** cross-polarized light. **6–8.** *Pseudoemiliania lacunosa* (Kamptner) Gartner, Sample 541-10-4, 75–76 cm, **(6)** cross-polarized light,**(7)** transmitted light, **(8)** phase contrast. **9–10.** *Syracosapharea pulchra* Lohmann, Sample 541-10-4, 75–76 cm, **(9)** cross-polarized light, **(10)** transmitted light. **11–15.** *Gephyrocapsa oceanica* Kamptner, **(11–13)** Sample 541-10-4, 75–76 cm **(11,** cross-polarized light; **12,** transmitted light; **13,** phase contrast), **(14–15)** Sample 541-10-4, 75–76 cm **(14,** cross-polarized light; **15,** transmitted light). **16..** *Gephyrocaspa caribbeanica* Boudreaux and Hay, Sample 541-4-6, 75–76 cm, cross-polarized light. **17.** *Gephyrocapsa omega* Bukry, Sample 541-7-6, 75–76 cm, cross-polarized light. **18.** *Reticulofenestra pseudoumbilica* (Gartner) Gartner, Sample 541-20-5, 45–46 cm, cross-polarized light. **19–20.** *Umbilicosphaera mirabilis* Lohmann, Sample 541-4-6, 75–76 cm, **(19)** transmitted light, **(20)** cross-polarized light.

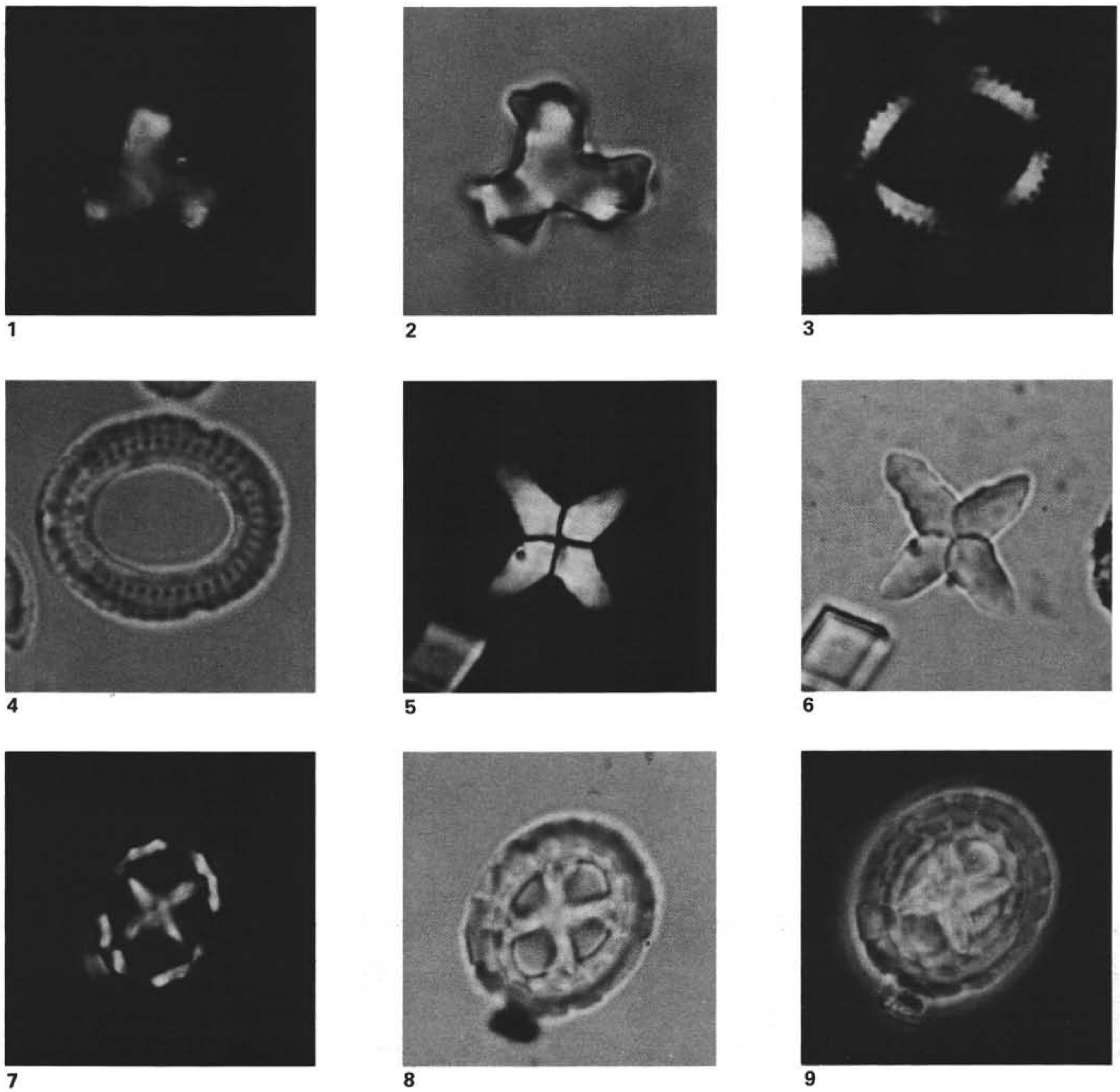

Plate 8. (All specimens magnified ×3000.) **1–2.** *Marthasterites furcatus* (Deflandre) Deflandre, Sample 543A-10-1, 9–10 cm, **(1)** cross-polarized light, **(2)** transmitted light. **3–4.** *Manivitella pemmatoidea* (Deflandre ex Manivit) Thierstein, Sample 543A-10-1, 9–10 cm, **(3)** cross-polarized light, **(4)** transmitted light. **5–6.** *Uniplanarius gothicus* (Deflandre) Hattner and Wise, Sample 543A-9-1, 41–42 cm, **(5)** cross-polarized light, **(6)** transmitted light. **7–9.** *Prediscosphaera cretacea* (Arkhangelsky) Gartner, Sample 543A-7-3, 7–8 cm, **(7)** cross-polarized light, **(8)** transmitted light, **(9)** phase contrast.

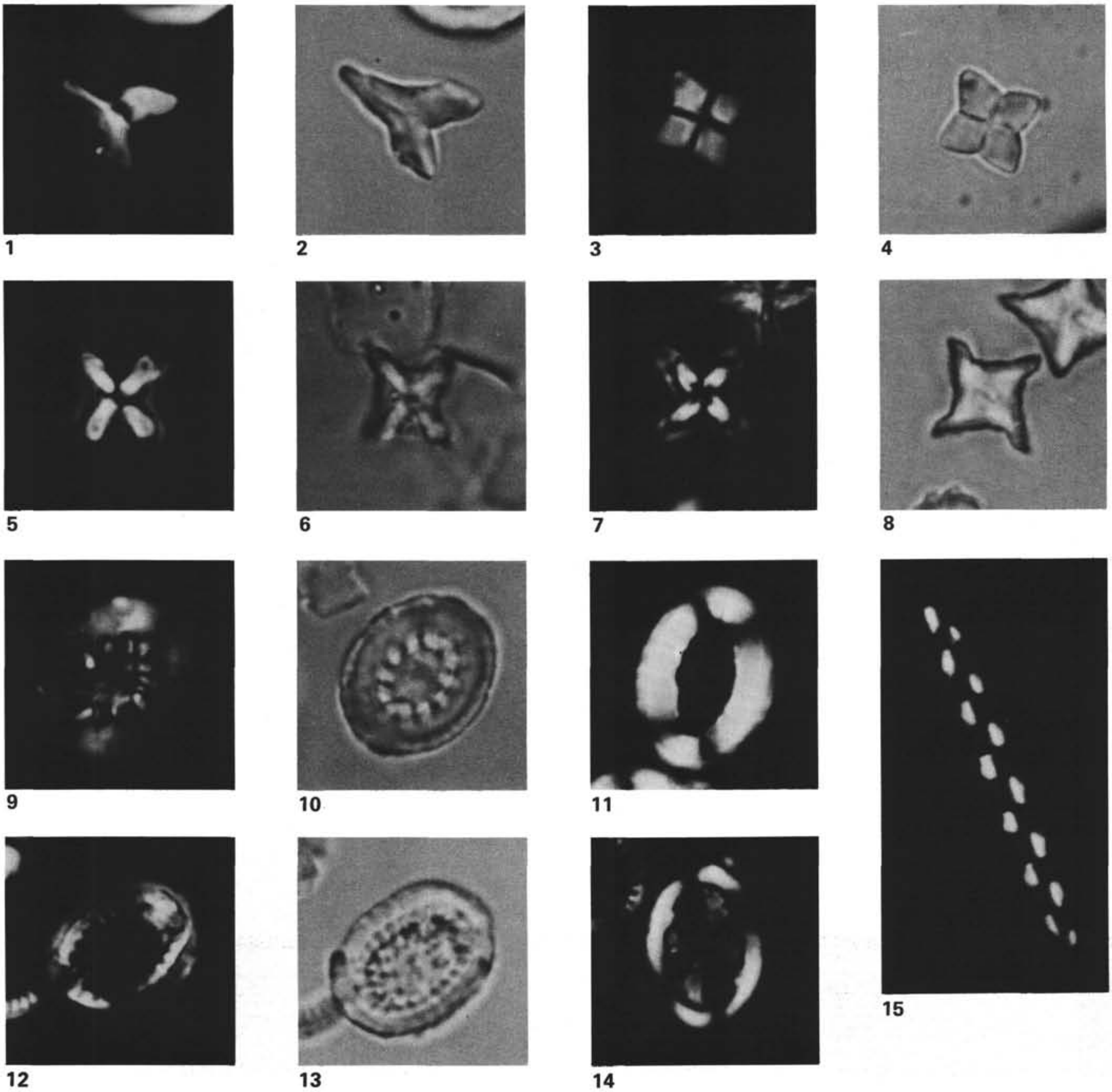

Plate 9. (All specimens magnified ×3000.) **1–2.** *Ceratolithoides aculeus* (Stradner) Prins and Sissingh, Sample 543A-7-3, 7–8 cm, **(1)** cross-polarized light, **(2)** transmitted light. **3–4.** *Uniplanarius gothicus* (Deflandre) Hattner and Wise, Sample 543A-9-1, 41–42 cm, **(3)** cross-polarized light, **(4)** transmitted light. **5–8.** *Micula decussata Vekshina*, **(5–6)** Sample 543A-7-3, 7–8 cm **(5**, cross-polarized light; **6**, transmitted light.). **(7–8)** Sample 543A-9-1, 41–42 cm **(7**, cross-polarized light; **8**, transmitted light). **9–10.** *Cretarhabdus surirellus* (Deflandre) Reinhardt, Sample 543A-7-3, 7–8 cm, **(9)** cross-polarized light, **(10)** transmitted light. **11.** *Broinsonia parca* (Stradner) Bukry, Sample 543A-10-1, 9–10 cm, cross-polarized light. **12–13.** *Cribrosphaerella ehrenbergi* (Arkhangelsky) Deflandre, Sample 543A-7-3, 7–8 cm, **(12)** cross-polarized light, **(13)** transmitted light. **14.** *Arkhangelskiella* sp., Sample 543A-7-3, 7–8 cm, cross-polarized light. **15.** *Microrhabdulus decoratus* Deflandre, Sample 543A-7-3, 7–8 cm, cross-polarized light.

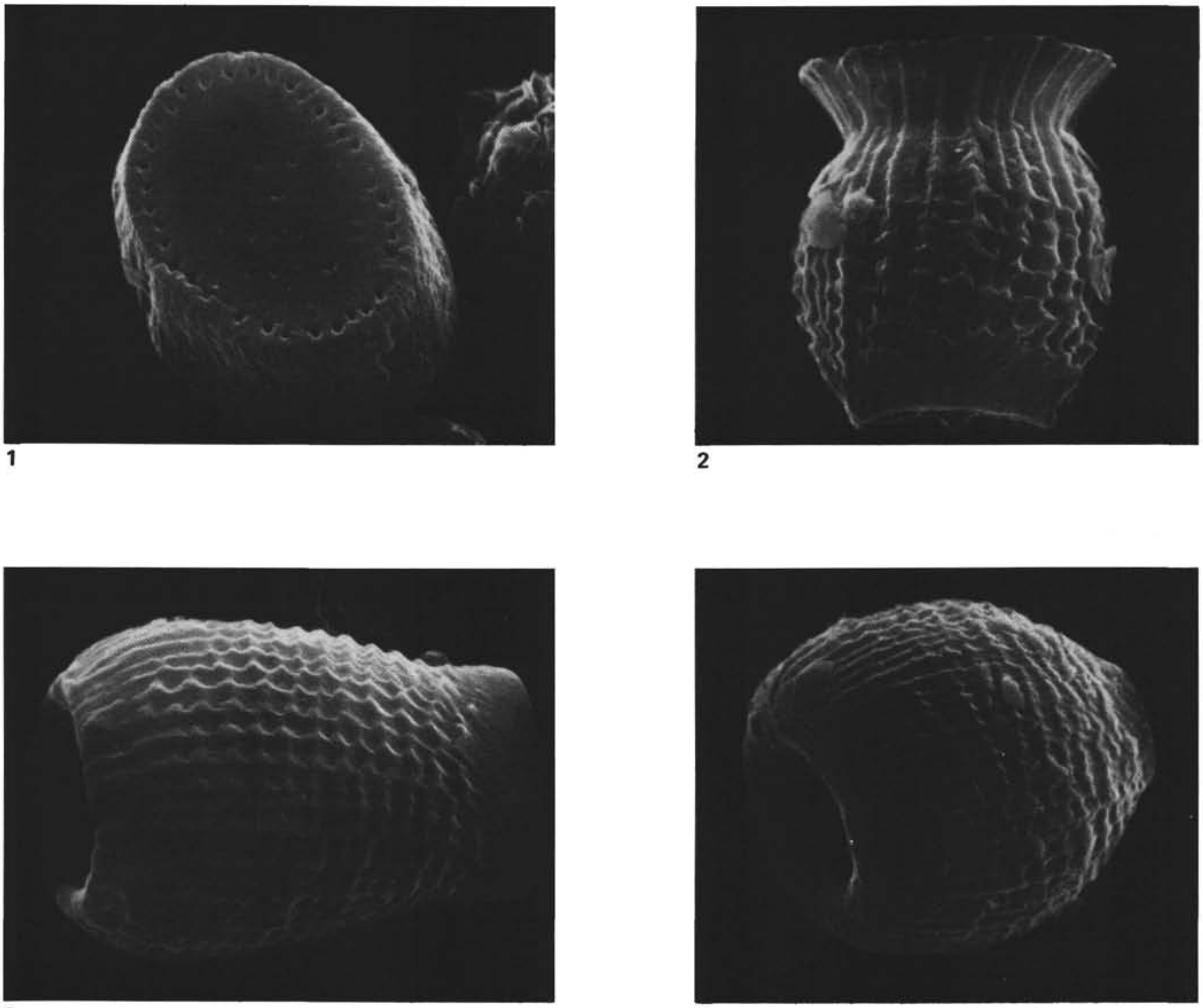

Plate 10. **1.** *Pontosphaera* sp., Sample 541-14-7, 25–26 cm, ×5500. **2.** *Scyphosphaera pulcherrima* Deflandre, Sample 541-14-7, 25–26 cm, ×4730. **3.** *Scyphosphaera recurvata* Deflandre, Sample 541-10-5, 75–76 cm, ×6600. **4.** *Scyphosphaera ampla* Kamptner, Sample 541-10-4, 75–76 cm, ×3625.

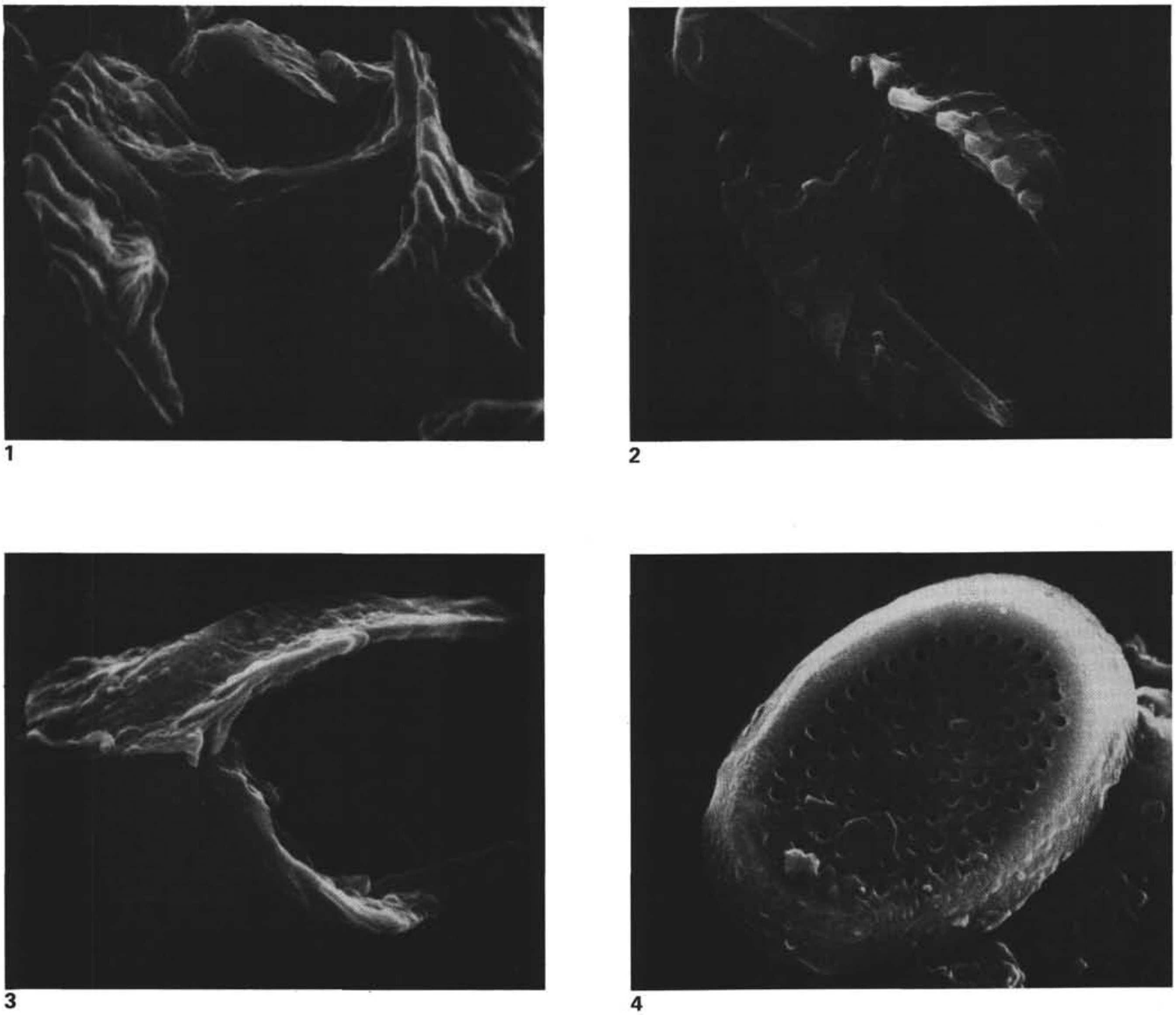

Plate 11. **1–3.** *Ceratolithus separatus* Bukry, **(1–2)** Sample 541-10-4, 75–76 cm, two views of same specimen (**1,** end view, ×7000; **2,** proximal view, ×4300), **(3)** Sample 541-10-4, 75–76 cm, distal view, ×7100. **4.** *Pontosphaera* sp., Sample 541-10-5, 75–76 cm, proximal view, ×8250.