26. CENOZOIC CALCAREOUS NANNOFOSSILS FROM DEEP SEA DRILLING PROJECT LEG 77: BIOSTRATIGRAPHY AND DELINEATION OF HIATUSES[1]

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ABSTRACT

Three of the six DSDP Leg 77 sites drilled in the western approaches to the Straits of Florida yielded thick sequences of Cenozoic sediment rich in calcareous nannofossils. Hiatuses are prominent in each of these continuously cored intervals. A prominent upper Oligocene hiatus, observed at each of these three sites, can be correlated to a large-scale "global" regression event. Other disconformable horizons present in the study area cannot be positively related to sea-level fluctuations and may be caused by a number of factors including local tectonic activity. Paleogene sections are generally marked by thick accumulations within the upper Oligocene *Sphenolithus ciperoensis* Zone and by a pronounced braarudosphaerid-holococcolith bloom recorded in the lower Oligocene and upper Eocene. This bloom is particularly well developed at Site 540. All samples examined contain abundant nannofossils. Preservation fluctuates throughout the sections from good to poor.

INTRODUCTION

During DSDP Leg 77 (December 1980 to January 1981), 238 cores were recovered from six sites in the western approaches to the Straits of Florida (Fig. 1). The calcareous nannofossils in samples from these cores have been examined in order to provide an initial description of the abundance, diversity, preservation, and biostratigraphy of the assemblages. In addition, a special effort was made to detect and determine the extent of hiatuses in the sections. This phase of the investigation was stimulated by the recent assertion by Vail and others (1980) that they have been able to detect seismically in deep-marine Mesozoic and Cenozoic sequences of the North Atlantic a suite of 28 major and minor unconformities previously identified in nearshore sections. This was an extension of previous work along the continental margins where the principal authors had concluded that lowstands of sea level produce interregional or "global" unconformities (Vail et al., 1977).

Major Cenozoic unconformities identified in the North Atlantic by Vail and others (1980) are basal Thanetian, basal upper Ypresian, basal middle Chattian, basal Burdigalian, basal middle Tortonian, and basal Messinian. The authors suggest that the identification and seismic correlation of these unconformities are useful for building a stratigraphic framework for paleoenvironmental studies and for correlating deep-sea stratigraphy with the stratigraphy of continental shelves and interior basins. By this reasoning, it is worthwhile to look for these disconformities in other ocean basins and to attempt paleontologic verification of the dating of these surfaces. Because Leg 77 was able to continuously core a number of long Cenozoic sections, the material recovered seems particularly useful for carrying out such an investigation in the Gulf of Mexico.

At three of the six sites drilled on this leg (Sites 536, 538, and 540), holes were continuously cored and yielded significant Cenozoic sedimentary sections. Nannofossils in these sections are consistently abundant, whereas preservation fluctuates from poor to very good. The recovered sections at these three sites illustrate a history of discontinuous sedimentation from the early Paleocene to the Holocene. Many hiatuses were observed. Several are long enough to effectively package the recovered sections into sequences of distinct units (Fig. 2).

The other three sites drilled on Leg 77 (Sites 535, 537, and 539) did not yield significant Cenozoic sections. Drilling operations at the first of these (Site 535) recovered 17 cores of Cenozoic nannofossil-rich sediments, all of which are assigned to the *Emiliania huxleyi* Zone of the uppermost Quarternary. The sediments examined from Site 537 also contain abundant nannofossils. However, the discontinuous coring program at this site prevents a coherent biostratigraphic study. At Site 539, two attempts to spud the drill bit were unsuccessful because of the firm nature of the substratum. Three cores of Miocene to Oligocene nannofossil mud, nannofossil ooze, and nannofossil-foraminiferal ooze were recovered. These cores, as well as sediments from Sites 535 and 537, are discussed only briefly.

Three sites drilled on DSDP Leg 10 were located near the study area (Bukry, 1973; and Fig. 1). Unfortunately, discontinuous coring at two of these sites coupled with mechanical difficulties at the third prevent precise stratigraphic correlation between these and the Leg 77 sites.

Many nannofossil species identified in the sections discontinuously cored on Leg 10 also occur in Leg 77 samples. The abundance of these taxa, however, were not reported. Thus, detailed correlation of zonal boundaries and disconformities between these earlier drilled holes and holes drilled on Leg 77 are not possible at a scale necessary to further delineate disconformities in the section.

Zonal determinations for the Cenozoic core samples from Leg 77 are summarized in Figure 3. Citations for

[1] Buffler, R. T., Schlager, W., et al., *Init. Repts. DSDP*, 77: Washington (U.S. Govt. Printing Office).

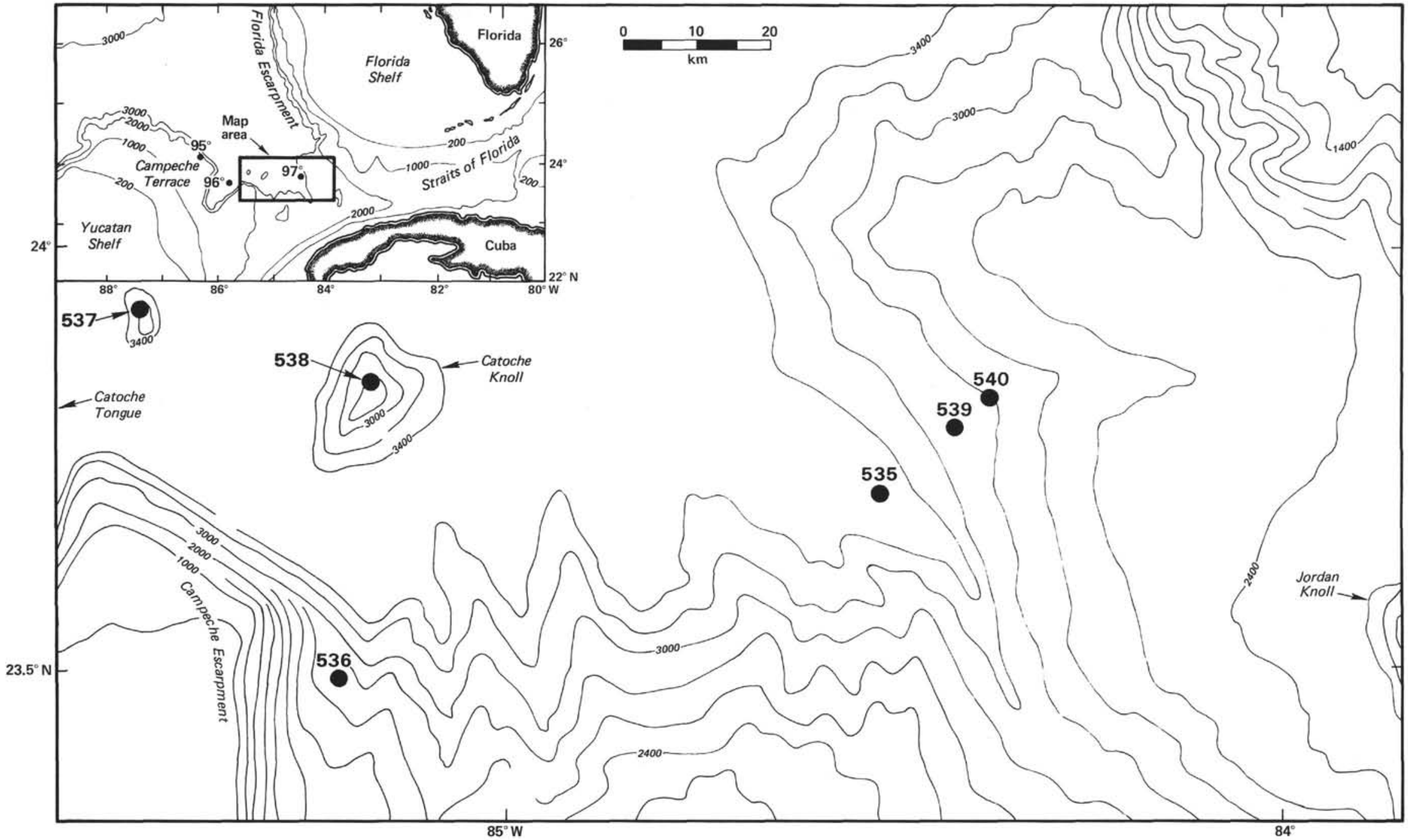

Figure 1. Location of Leg 77 drill sites and Sites 95, 96, and 97 from DSDP Leg 10.

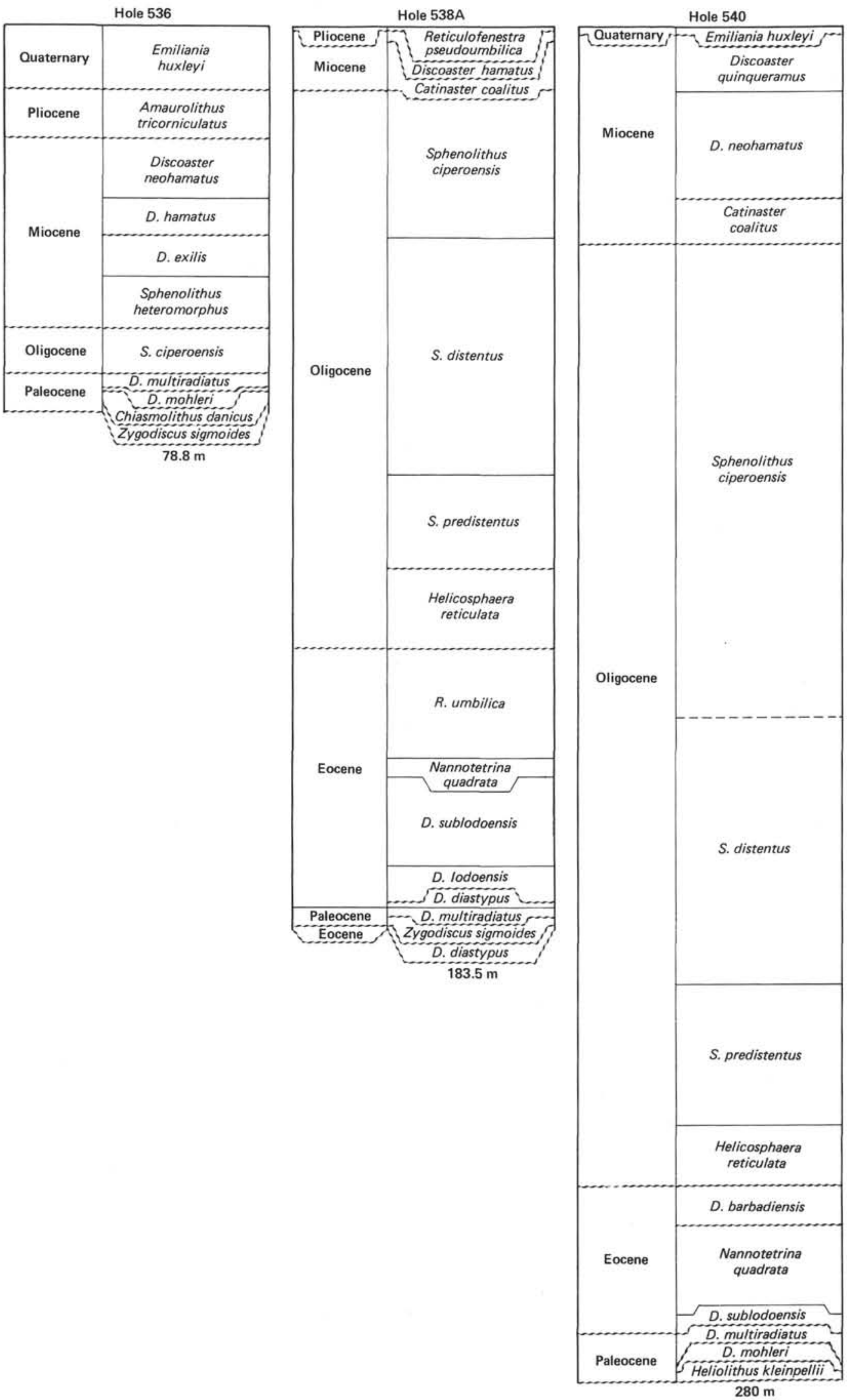

Figure 2. Generalized columnar sections for Holes 536, 538A, and 540. Note "packages" of middle Miocene sediment bounded by unconformities. Vertical scale: 1 cm = 4 m.

Age	Zone	Subzone	Hole 535	Hole 536	Hole 537	Hole 538	Hole 538A	Hole 539	Hole 539A	Hole 540
Quaternary	*Emiliania huxleyi*		1-1/17-2	1-1/2-2				1-1/1,CC	1-1/1-2, 90–92cm	1-1
	Gephyrocapsa oceanica	*Ceratolithus cristatus*								
		Emiliania ovata								
	Crenalithus doronicoides	*Gephyrocapsa caribbeanica*								
		E. annula								
Pliocene	*Discoaster brouweri*	*Calcidiscus macintyrei*				Core 1 (reworked)				
		Discoaster pentaradiatus						2-2/2,CC		
		Discoaster surculus								
		Discoaster tamalis								
	Reticulofenestra pseudoumbilica	*Discoaster asymmetricus*			1-1/1-4		1-1, 0–1 cm			
		Sphenolithus neoabies								
	Amaurolithus tricorniculatus	*Ceratolithus rugosus*								
		Ceratolithus acutus		3-1/3-6	1-5/1,CC					
Miocene		*Triquetrorhabdulus rugosus*								
	D. quinqueramus	*Amaurolithus primus*							1-2, 94 cm/1-3	1-2/2-6
		Discoaster berggrenii								
	D. neohamatus	*Disocaster neorectus*		4-1/4-6						3-1/5-1
		Discoaster bellus		5-1						
	D. hamatus	*Catinaster calyculus*		5-2			1-1 144-145 cm/1-2, 62–63 cm			
		Helicosphaera carteri								
	Catinaster coalitus						2-1			5-2/6-1
	D. exilis	*Discoaster kugleri*		6-1						
		Coccolithus miopelagicus								
	Sphenolithus heteromorphus			7-1/8-1, 1–3 cm						
	Helicosphaera ampliaperta									
	S. belemnos									
	Triquetrorhabdulus carinatus	*Discoaster druggii*								
		Discoaster deflandrei								
Oligocene		*Cyclicargolithus abisectus*								
	S. ciperoensis	*Dictyococcites bisectus*		8-1, 7-9 cm/8-5			3-1/6-2		1-4/1,CC	7-1/14-5
		Cyclicargolithus floridanus								
	S. distentus						6-3/11-2			15-1/21-2
	S. predistentus						12-1/13-2			22-1/24-5
	Helicosphaera reticulata	*Reticulofenestra hillae*								25-1/25-3
		Coccolithus formosus					14-1			26-1/26-2
		Coccolithus subdistichus								
Eocene	*D. barbadiensis*	*Isthmolithus recurvus*								26-3
		Chiasmolithus oamaruensis								
	R. umbilica	*Discoaster saipanensis*					15-1/17-3			
		Discoaster bifax								
	Nannotetrina quadrata	*Coccolithus staurion*					17-4/17-5			27-1/28-2
		Chiasmolithus gigas								
		Discoaster strictus								
	D. sublodoensis	*Rhabdosphaera inflata*		9-1, 0–10 cm	2-1		17-6/18-6			29-1
		Discoasteroides kuepperi					19-1/19-4			29-2
	D. lodoensis				2,CC		19-5/20-1			
	Tribrachiatus orthostylus									
	D. diastypus	*Discoaster binodosus*			3-1, 27–28 cm		20-2 and 21-1, 39–41 cm			
		Tribrachiatus contortus								
Paleocene	*D. multiradiatus*	*Campylosphaera eodela*		9-1, 11–13 cm/9-3, 1–2 cm	3-1, 40 cm/3-1, 95 cm		20-4			30-1
		Chiasmolithus bidens								
	D. nobilis									
	D. mohleri			9-3, 10–12 cm	3-1, 128 cm/3-2, 5 cm					30-2, 28–32 cm
	Heliolithus kleinpellii									
	Fasciculithus tympaniformis									30-2, 81–83 cm/30,CC
	Ellipsolithus macellus			9-3, 56–58 cm/9-4						
	Chiasmolithus danicus									
	Zygodiscus sigmoides	*Cruciplacolithus tenuis*		9-5 50 cm/9-5, 70 cm			20-6			
		Cruciplacolithus primus								

Figure 3. Summary of the nannofossil zonation of core samples from the Cenozoic sections recovered on Leg 77. Sample numbers designate core-section; core-section, depth in section in cm; or core section, interval in cm. Where more than one core and section are assigned to a single zone, the numbers corresponding to the highest and lowest samples in that zone are separated by a slash (/). CC = core catcher.

the species listed in the Appendix at the end of the chapter were taken from the *Annotated Index and Bibliography of the Calcareous Nannoplankton, I–VII* (Loeblich and Tappan, 1966; 1968; 1969; 1970a; 1970b; 1971; 1973) and from the *Bibliography* and *Taxa of Calcareous Nannoplankton* (van Heck, 1979a; 1979b; 1980a; 1980b; 1981a; 1981b; 1982a; 1982b; 1983).

METHODS AND PROCEDURES

The abundance of nannofossils in the Cenozoic sediment recovered on Leg 77 permitted preparation of 301 smear slides directly from raw sediment samples. A simple settling technique was used to concentrate nannofossils in samples from the Quaternary of Sites 535, 536, and 540. These samples were then examined with a Cambridge IV Stereoscan scanning electron microscope (SEM) to confirm the presence of the tiny upper Pleistocene zonal species, *Emiliania huxleyi*. Older sediment samples were examined primarily by light microscope. Abundances were calculated using a method similar to that described by Hay (1970). The one difference is in the use, here, of a higher magnification of 1560 instead of the 1000 used by Hay. The higher magnification allowed better resolution in the examination of particularly small species. Letters on the range charts indicating abundances are keyed to the number of specimens as follows:

V = very abundant; more than 10 specimens per field of view at 1560×; A = abundant; 1–10 specimens per field of view at 1560 ; C = common; 1 specimen per 2–10 fields of view at 1560×; F = few; 1 specimen per 11–100 fields of view at 1560×; R = rare; 1 specimen per 101–1000 fields of view at 1560×.

Estimates of the preservation in a sample were made using the following outline:

G = good, little evidence of secondary alteration via etching and/or overgrowth, identification of species not impaired; M = moderate, significant evidence of secondary alteration via etching and/or overgrowth, identification of species not impaired; P = poor; specimens typically heavily overgrown or severely etched; identification of some species significantly impaired.

The zonation scheme used in this study (Table 1) is that of Okada and Bukry (1980). The high degree of resolution gained from this scheme made it most suitable for the nannofossil-rich sediments encountered. Earlier zonation schemes, such as that by Martini (1971), are not as applicable as the one used here (Gartner, 1977).

SITE SUMMARIES

Site 535 (23°42.48′N; 84°30.97′W; 3450 m water depth)

Drilling at Site 535 was intended to penetrate the sedimentary column beneath a seismically prominent mid-Cretaceous unconformity (see site chapter, Site 535, this volume). Drilling at this site was primarily concerned with penetration of the older portion of the sequence below this mid-Cretaceous unconformity (MCU), whereas operations at Site 540 to the northeast were intended to penetrate the younger part above the MCU. Cenozoic sediments at Site 535 are restricted to the first 17 cores recovered, all of which contain the Quaternary species *Emiliania huxleyi*. Lithologies encountered included slightly calcareous muds and clays with small scattered stringers of marly clay and foraminiferal ooze. These stringers as well as light-colored burrows were selectively sampled because they showed a dramatic rise in the numbers of calcareous nannofossils within otherwise nannofossil-poor intervals. These nannofossil-rich zones are typically dominated by abundant Tertiary forms but also contain a few reworked Cretaceous species. The sparse assemblages in the surrounding nannofossil-poor intervals on the other hand are dominated by solution-resistant Cretaceous taxa.

A nannofossil-pteropod ooze in Section 535-1-1 and in Sample 535-5-4, 107–109 cm contains abundant, well-preserved nannofossils. The assemblages include *E. huxleyi, Gephyrocapsa oceanica, Helicosphaera carteri, Syracosphaera pulchra*, and *Ceratolithus cristatus*. Reworked species include the Pliocene forms *Discoaster pentaradiatus* and *Reticulofenestra pseudoumbilica* as well as several Cretaceous taxa including *Micula decussata, Broinsonia parca, Eiffelithus eximius, E. turriseiffeli*, and *Prediscosphaera cretacea*. Another interval with abundant nannofossils occurs at 535-12-2, 63–65 cm. This sample, like the aforementioned ones, contains abundant Quaternary species with reworked Cretaceous and Tertiary taxa. Nannofossils are also common in Samples 535-14-1, 104–106 cm and 535-17-2, 30–32 cm, both of which contain *Emiliania huxleyi* as determined by SEM observation.

Site 536 (23°29.39′N; 85°12.58′W; 2790 m water depth)

Site 536 is located in an area of the southeastern Gulf where seismic profiles show that the sedimentary cover over basement fault blocks is relatively thin. The main objective at this site was to penetrate the sedimentary cover, reach basement, and attempt to document the nature, origin, and age of the rifted basement. The site lies topographically higher than the floor of the abyssal Gulf. Sediments from this site include a Tertiary suite of gray and gray-to-yellow nannofossil oozes interrupted by numerous hiatuses. Preservation in this nannofossil-rich sequence is typically moderate to good (Fig. 4).

Of the 213 m of sediment penetrated at this site, the first nine cores contain Cenozoic sediment. The first two cores down to 536-2-2, 29–31 cm contain *Emiliania huxleyi, Gephyrocapsa oceanica, G. caribbeanica, Syracosphaera pulchra, Rhabdosphaera clavigera, R. stylifera, Scapholithus fossils, Calcidiscus leptoporus, Helicosphaera carteri*, and others. These samples are assigned to the *E. huxleyi* Zone. Samples 536-3-1, 20–22 cm to 536-3-6, 20–22 cm correspond to the *Ceratolithus acutus* Subzone based on the occurrence of *C. acutus, Reticulofenestra pseudoumbilica, Sphenolithus abies*, and an abundance of discoasters including *Discoaster brouweri, D. surculus, D. pentaradiatus*, and *D. variabilis*. These Quaternary and Pliocene sections are therefore separated by a substantial hiatus; the entire lower and middle part of the Quaternary as well as the upper Pliocene are missing. Using the absolute age assignments of Okada and Bukry (1980) (Table 1), the least possible amount of missing time represented by this hiatus can be estimated. The top of the *C. acutus* Subzone is at 4.4 Ma, and the base of the *E. huxleyi* Zone is dated at 0.2 Ma. If, as a result of this hiatus, the only sediment missing is sediment from between these two zones and not from within either, then approximately 4.2 Ma of section would not be represented. However, part of the section assigned to the upper and lower zones is almost certainly missing as well, so somewhat more than 4.2 Ma

Table 1. Nannofossil zonation scheme used in this study (from Okada and Bukry, 1980).

Age	Zone		Subzone		Martini (1971) zone	Duration (Ma)	Boundary (Ma)
	CN15	*Emiliania huxleyi*			NN21	0.2	0.2
	CN14	*Gephyrocapsa oceanica*	CN14b	*Ceratolithus cristatus*	NN20	0.1	0.3
Quat.			CN14a	*Emiliania ovata*		0.6	0.9
	CN13	*Crenalithus doronicoides*	CN13b	*Gephyrocapsa caribbeanica*	NN19	0.7	1.6
			CN13a	*Emiliania annula*		0.2	1.8
	CN12	*Discoaster brouweri*	CN12d	*Calcidiscus macintyrei*	NN18	0.2	2.0
			CN12c	*Discoaster pentaradiatus*	NN17	0.1	2.1
			CN12b	*D. surculus*	NN16	0.4	2.5
			CN12a	*D. tamalis*		0.5	3.0
Plio.	CN11	*Reticulofenestra pseudoumbilica*	CN11b	*D. asymmetricus*	NN15	0.5	3.5
			CN11a	*Sphenolithus neoabies*		0.5	4.0
	CN10	*Amaurolithus tricorniculatus*	CN10c	*Ceratolithus rugosus*	13/14	0.4	4.4
			CN10b	*Ceratolithus acutus*	NN12	0.6	5.0
			CN10a	*Triquetrorhabdulus rugosus*		0.6	5.6
	CN9	*Discoaster quinqueramus*	CN9b	*Amaurolithus primus*	NN11	1.0	6.6
			CN9a	*D. berggrenii*		0.4	7.0
	CN8	*Discoaster neohamatus*	CN8b	*D. neorectus*	NN10	0.5	7.5
			CN8a	*D. bellus*		3.5	11.0
	CN7	*Discoaster hamatus*	CN7b	*Catinaster calyculus*	NN9	1.0	12.0
			CN7a	*Helicosphaera carteri*		1.0	13.0
Mio.	CN6	*Catinaster coalitus*			NN8	0.2	13.2
	CN5	*Discoaster exilis*	CN5b	*D. kugleri*	NN7	0.2	13.4
			CN5a	*Coccolithus miopelagicus*	NN6	0.6	14.0
	CN4	*Sphenolithus hetermorphus*			NN5	1.0	15.0
	CN3	*Helicosphaera ampliaperta*			—	2.0	17.0
	CN2	*S. belemnos*			NN2	1.0	18.0
	CN1	*Triquetrorhabdulus carinatus*	CN1c	*D. druggii*		3.0	21.0
			CN1b	*D. deflandrei*	NN1	2.0	23.0
			CN1a	*Cyclicargolithus abisectus*	—	1.0	24.0
	CP19	*Sphenolithus ciperoensis*	CP19b	*Dictyococcites bisectus*	NP25	1.0	25.0
			CP19a	*Cyclicargolithus floridanus*	NP24	1.5	26.5
Oligo.	CP18	*S. distentus*			NP23	3.5	30.0
	CP17	*S. predistentus*				4.0	34.0
	CP16	*Helicosphaera reticulata*	CP16c	*Reticulofenestra hillae*	NP22	0.5	34.5
			CP16b	*Coccolithus formosus*	NP21	2.5	37.0
			CP16a	*Coccolithus subdistichus*		1.0	38.0
	CP15	*D. barbadiensis*	CP15b	*Isthmolithus recurvus*	19/20	3.0	41.0
			CP15a	*Chiasmolithus oamaruensis*	NP18	1.0	42.0
	CP14	*Reticulofenestra umbilica*	CP14b	*D. saipanensis*	NP17	2.0	44.0
			CP14a	*D. bifax*	NP16	1.0	45.0
	CP13	*Nannotetrina quadrata*	CP13c	*Coccolithus staurion*		1.5	46.5
			CP13b	*Chiasmolithus gigas*	NP15	0.5	47.0
Eoc.			CP13a	*D. strictus*		1.0	48.0
	CP12	*D. sublodoensis*	CP12b	*Rhabdosphaera inflata*	NP14	1.0	49 0
			CP12a	*Discoasteroides kuepperi*		0.5	49.5
	CP11	*D. lodoensis*			12/13	0.5	50.0
	CP10	*Tribrachiatus orthostylus*				2.0	52.0
	CP9	*D. diastypus*	CP9b	*Discoaster binodosus*	NP11	0.8	52.8
			CP9a	*Tribrachiatus contortus*	NP10	0.7	53.5
	CP8	*D. multiradiatus*	CP8b	*Campylosphaera eodela*	NP9	0.5	54.0
			CP8a	*Chiasmolithus bidens*		1.0	55.0
	CP7	*D. nobilis*			7/8	0.5	55.5
	CP6	*D. mohleri*				1.5	57.0
Paleoc.	CP5	*Heliolithus kleinpellii*			NP6	1.0	58.0
	CP4	*Fasciculithus tympaniformis*			NP5	2.0	60.0
	CP3	*Ellipsolithus macellus*			NP4		
	CP2	*Chiasmolithus danicus*			NP3		
	CP1	*Zygodiscus sigmoides*	CP1b	*Cruciplacolithus tenuis*	NP2		
			CP1a	*Cruciplacolithus orimus*	NP1		65.0

of section is missing. The interval from below 536-3-6, 20-22 cm to 536-4-1, 60-62 cm is assigned to the *Triquetrorhabdulus rugosus* Subzone.

Nannofossils in Sample 536-4-1, 60-62 cm and all samples down to 536-4-6, 60-62 cm are characteristic of the *Discoaster neorectus* Subzone. Sample 536-5-1, 120-122 cm is assigned to the *D. bellus* Subzone. This upper Miocene interval is marked by a very diverse discoaster assemblage that includes *D.neohamatus, D. brouweri, D. quinqueramus, D. loeblichii, D. variabilis, D. asymmetricus, D. challengeri*, and others. Other taxa present include *Catinaster mexicanus, Triquetrorhabdulus rugosus, Helicosphaera carteri, Coccolithus pelagicus, Calcidiscus macintyrei, C. leptoporus*, and several species of *Scyphosphaera*. The underlying sample (536-5-2, 120-122 cm) has an assemblage somewhat similar to that seen in samples from the *D. neohamatus* Zone, but with a few important differences. *D. loeblichii*, fairly prominent in the younger sediments, is absent, whereas *D. hamatus* and *D. bollii*, not seen in the younger samples, occur in substantial numbers. These differences serve to distinguish between these two assemblages, and the lower is thus assigned to the *D. hamatus* Zone. The upper boundary of the *D. neohamatus* Zone at this site is marked by a hiatus that, according to the rationale stated earlier, involves at least 1.4 Ma of section. Sample 536-6-1, 137-139 cm contains *D. exilis, D. kugleri, R. pseudoumbilica*, and *T. rugosus*. It is here assigned to the *D. exilis* Zone. Thus another hiatus involving at least 0.2 Ma of section occurs between these and overlying sediments assigned to the *D. hamatus* Zone. Samples 536-7-1, 110-112 cm through 536-8-1, 1-3 cm contain *Cyclicargolithus floridanus, Sphenolithus heteromorphus*, and *Coccolithus pelagicus*. These forms are characteristic of the *S. heteromorphus* Zone of the middle Miocene, and the age is assigned accordingly. The boundary between these and the underlying Oligocene sediments is also marked by a hiatus (at least 9.0 Ma). Sample 536-8-1, 7-9 cm contains *D. deflandrei, S. ciperoensis, S. moriformis, H. recta, H. euphratis, H. intermedia, H. wilcoxonii, Cyclicargolithus abisectus, C. floridanus, Pontosphaera segmenta, R. bisecta, R. scrippsae*, and *Zygrhablithus bijugatus*. This assemblage persists through Sample 536-8-5, 90-92 cm. All the sediment within this interval is assigned to the *Dictyococcites bisectus* Subzone of the late Oligocene. The only Eocene recovered at this site was in three clasts from the top 10 cm of Section 536-9-1. These contained an assemblage assignable to the *Discoaster sublodoensis* Zone. The underlying samples, 536-9-1, 11-13 cm through 536-9-3, 1-2 cm, are assigned to the *Campylosphaera eodela* Subzone of the late Paleocene. Another hiatus is apparent between these and the overlying Eocene sediments. Important species present in this Paleocene interval include *D. multiradiatus, Fasciculithus tympaniformis, D. nobilis, D. mohleri, Chiasmolithus californicus, D. consuetus*, and *Toweius eminens*. Sample 536-9-3, 10-12 cm has a similar assemblage but lacks *D. multiradiatus* and *D. nobilis*, which are prominent in samples above this level. This sample is assigned to the *D. mohleri* Zone and is offset both above and below by unconformities. The interval below this (from 536-9-3, 56-58 cm to 536-9-4, 134-136 cm) contains an assemblage characteristic of the early Paleocene. Species present include *C. danicus, Cruciplacolithus tenuis, Braarudosphaera bigelowii, B. discula, Neochiastozygus concinnis, Coccolithus cavus*, and *Zygodiscus sigmoides*. This interval is assigned to the *Chiasmolithus danicus* Zone. Sample 536-9-5, 50 cm contains an assemblage that includes *Z. sigmoides, Cruciplacolithus tenuis, Markalius astroporus*, and *Coccolithus cavus* and is assigned to the *Z. sigmoides* Zone of the earliest Paleocene. Detailed shipboard nannofossil and foraminiferal work identified the Cretaceous/Tertiary boundary at 536-9-5, 70 cm, where a poorly delineated burrowed zone occurs with the foraminifers, *"Globigerina" eugubina* in the burrows (see Premoli Silva and McNulty, this volume).

Site 537 (23°56.01′N; 85°27.62′W; 2820 m water depth)

A small knoll just north of the Campeche Escarpment near the mouth of the Catoche Tongue was chosen as the location for Site 537. This knoll stands about 300 m above the level of the flat-lying abyssal Gulf and was chosen because seismic data showed a relatively thin sediment cover overlying basement. The knoll is thought to represent the uplifted end of one of several tilted basement blocks located in the area. As at Site 536, the main objective was to investigate the nature, age, and origin of the basement rocks.

Cenozoic sediments are predominantly Pliocene to Paleocene nannofossil and foraminiferal oozes; ash and zeolitic layers are interspersed in the lower part of the section. Preservation in samples from this discontinuously cored sequence fluctuates from good to poor. Neogene samples usually show moderate preservation but several Eocene samples exhibited pronounced secondary alteration particularly by overgrowths on characteristic discoaster species. Hiatuses are also inferred for this site, though discontinuous coring does not allow us to make precise determinations.

Three cores of Cenozoic sediment were recovered from this site. Core 1 contains lower Pliocene nannofossils of the *Reticulofenestra pseudoumbilica* Zone and the *Amaurolithus tricorniculatus* Zone. Species in the upper four sections of the core include *R. pseudoumbilica, Discoaster pentaradiatus, D. brouweri, D. surculus, Calcidiscus macintyrei, Helicosphaera carteri*, and *Ceratolithus cristatus*. This interval is assigned to the *R. pseudoumbilica* Zone. Section 537-1-5 and the core catcher contain a similar assemblage with the addition of *A. tricorniculatus*. This short interval is assigned to the *A. tricorniculatus* Zone. After recovery of Core 1, the hole was washed to 54 m, where Core 2 was cut. The interval above the core catcher contains species typical of the *D. sublodoensis* Zone of the middle Eocene. A sample from the core catcher contains a poorly preserved assemblage of the lower Eocene *D. lodoensis* Zone. A few five-rayed discoasters were found, but their size (20^+ microns) was deemed too large for *D. sublodoensis*. Also, the common occurrence of *D. lodoensis* suggested placement in the zone of the same name. Other forms

Age	Zone or subzone		Core-Section (interval in cm)	Preservation	*Amaurolithus delicatus*	*A. primus*	*A. tricorniculatus*	*Biantholithus sparsus*	*Braarudosphaera bigelowii*	*B. discula*	*Calcidiscus leptoporus*	*C. macintyrei*	*Campylosphaera eodela*	*Catinaster mexicanus*	*Ceratolithus acutus*	*C. cristatus*	*C. rugosus*	*C. helesmus*	*Chiasmolithus bidens*	*C. californicus*	*C. consuetus*	*C. danicus*	*C. expansus*	*C. staurion*	*Clausicoccus cribellum*	*C. fenestratus*	*Coccolithus cavus*	*C. eopelagicus*	*C. pelagicus*	*Coronocyclus nitescens*	*Cruciplacolithus tenuis*	*Cyclicargolithus abisectus*	*C. floridanus*	*Discoaster asymmetricus*	*D. barbadiensis*	*D. bollii*	*D. brouweri*	*D. calcaris*	*D. challengeri*	*D. deflandrei*	*D. exilis*	*D. hamatus*	*D. intercalaris*
Quaternary	*Emiliania huxleyi*		1-1, 84–86	G					R		F					F													F														
			1-2, 6	G							F					F		R											F														
			1-3, 8–10	G							F																		F														
			2-1, 105–107	MG							C					R		R											F														
			2-2, 29–31	G							F					R													F														
Pliocene	*Amaurolithus tricorniculatus*	*Ceratolithus acutus* Subzone	3-1, 20–22	MP							C	C			F		R												F					R			C		R				
			3-2, 20–22	MP		R					F	C			R														C							?	C		C				
			3-4, 20–22	G	R	R					F	C			R														C					R			C		C				
		T. rugosus Subzone	3-5, 20–22	MP		R					F	C			R														R					R			C		C				
			3-6, 20–22	MP	R	F	R					C																	C								C		C				
Miocene	*Discoaster neohamatus*	*Discoaster neorectus* Subzone	4-1, 60–62	MG							F	C		F															C					R			C		F			?	
			4-3, 60–62	MG								C		F															C					R			C	R	F				
			4-5, 60–62	MG							F	C		F															F					R			F						F
		D. bellus Subzone	4-6, 60–62	MG							F	C		R															F			?					F			?			F
			5-1, 120–122	MG							F	C																	C					R			C		F				R
	Discoaster hamatus		5-2, 120–122	MG							C	C																	C			?				FC	C	F		?		FC	
	Discoaster exilis		6-1, 137–139	MG								C																	C'				F			R			F		C		
	Sphenolithus heteromorphus		7-1, 110–112	G								F																	C			?	C								C		
			7-3, 110–112	G								F																	C	F		?	C								C		R
			8-1, 1–3	G								F																	C	R			C							R	C		R
Oligocene	*Sphenolithus ciperoensis*	*Dictyococcites bisectus* Subzone	8-1, 7–9	G																						F		C	C	R		F	C							A			
			8-1, 90–92	G																						F		C	F	R		F	C							A			
			8-2, 90–92	G																						F		C	C	R		C	C							A			
			8-3, 90–92	MG																						C		C	F	F		C	C							C			
			8-4, 90–92	MG																						C		C	R	R		C	A							A			
			8-5, 90–92	MG																						C		C	F			C	C							C			
Paleocene	*Discoaster multiradiatus*	*Campylosphaera eodela* Subzone	9-1, 11–13	MG									C							F	R			R	F				C														
			9-1, 111–113	MG									C							F	F		?	R	R				C		?				?								
			9-1, 140–142	MG					R				C						F		F			R	R				C														
			9-1, 147–149	M				R					C							F	F			R	F				C		?				?								
			9-2, 7–8	G				R		R			C							F	C			R	R				C														
			9-2, 76–78	G									C								C			R	F				C														
			9-2, 111–113	M																F	F				R				C														
			9-2, 134–136	M									C							F	F	?		R					C														
			9-3, 1–2	G						R			C							F	F				F				F														
	Discoaster mohleri		9-3, 10–12	M																F	F			R					C														
	Chiasmolithus danicus		9-3, 56–58	MP																	F	F																					
			9-3, 93–95	M					A	A											F	F					C				C												
			9-4, 134–136	M					C	C											F	F					C				C												
	Zygodiscus sigmoides		9-5, 50	M					C	C																	C				C												

V = very abundant; A = abundant; C = common; F = few; R = rare; ? = presence is questionable; G = good;
M = moderate; P = poor; MP = poor to moderate; MG = moderate to good.

Figure 4. Ranges of Cenozoic calcareous nannofossil species observed at Hole 536. Wavy lines in age and zone columns represent hiatuses.

present include *Campylosphaera dela, Discoasteroides kuepperi, Ericsonia formosa, Discoaster barbadiensis, Chiasmolithus grandis, Coccolithus pelagicus*, and *Pontosphaera rimosa*.

After recovery of Core 2, the hole was washed to a depth of 88 m, where Core 3 was cut. Sample 537-3-1, 27–29 cm contains *D. diastypus, D. barbadiensis, D. lenticularis, D. multiradiatus*, and *Sphenolithus anarrhopus*, but it lacks *D. lodoensis*. This sample is assigned to the basal Eocene *D. diastypus* Zone. A firm brown ooze from 537-3-1, 40 cm to 537-3-1, 95 cm contains *D. multiradiatus, D. mohleri, Coccolithus pelagicus, Ellipsolithus macellus*, and *Toweius eminens*; it is assigned to the *D. multiradiatus* Zone of the upper Paleocene. Samples from 537-3-1, 128 cm to 537-3-2, 5 cm contain *D. mohleri, Fasciculithus tympaniformis*, and *Ellipsolithus macellus* but lack *D. multiradiatus*; they are assigned to the *D. mohleri* Zone. The interval from 537-3-2, 18 cm to 537-3-2, 43 cm contains a heavily reworked lower Tertiary and Upper Cretaceous flora and is underlain by a white chalk interval assigned to the *Chiastozygus litterarius* Zone (see Watkins and Bowdler, this volume). Thus the Cretaceous/Tertiary boundary at this site lies within this reworked interval.

Site 538 (23°50.98′N; 85°10.26′W; 2820 m water depth)

Site 538 was drilled on top of Catoche Knoll, a large topographic high approximately 25 km northeast of the Campeche Escarpment. This site was originally an alternate site but the decision to drill here was made when drilling at the first two sites went faster than expected. The objective at this site was to test the basement inferred from seismic data. These data suggest that the knoll is an uplifted basement block.

Hole 538 was drilled on the northwestern flank of the Catoche Knoll. A single core of reworked Pliocene to Oligocene sediment was recovered from this hole before relocation.

Hole 538A was drilled on top of a northwest-trending ridge near the crest of the Catoche Knoll. The Cenozoic section recovered included sediments from each epoch of the Tertiary. Sediments younger than middle Pliocene were absent. Only the first sample examined (538A-1-1,

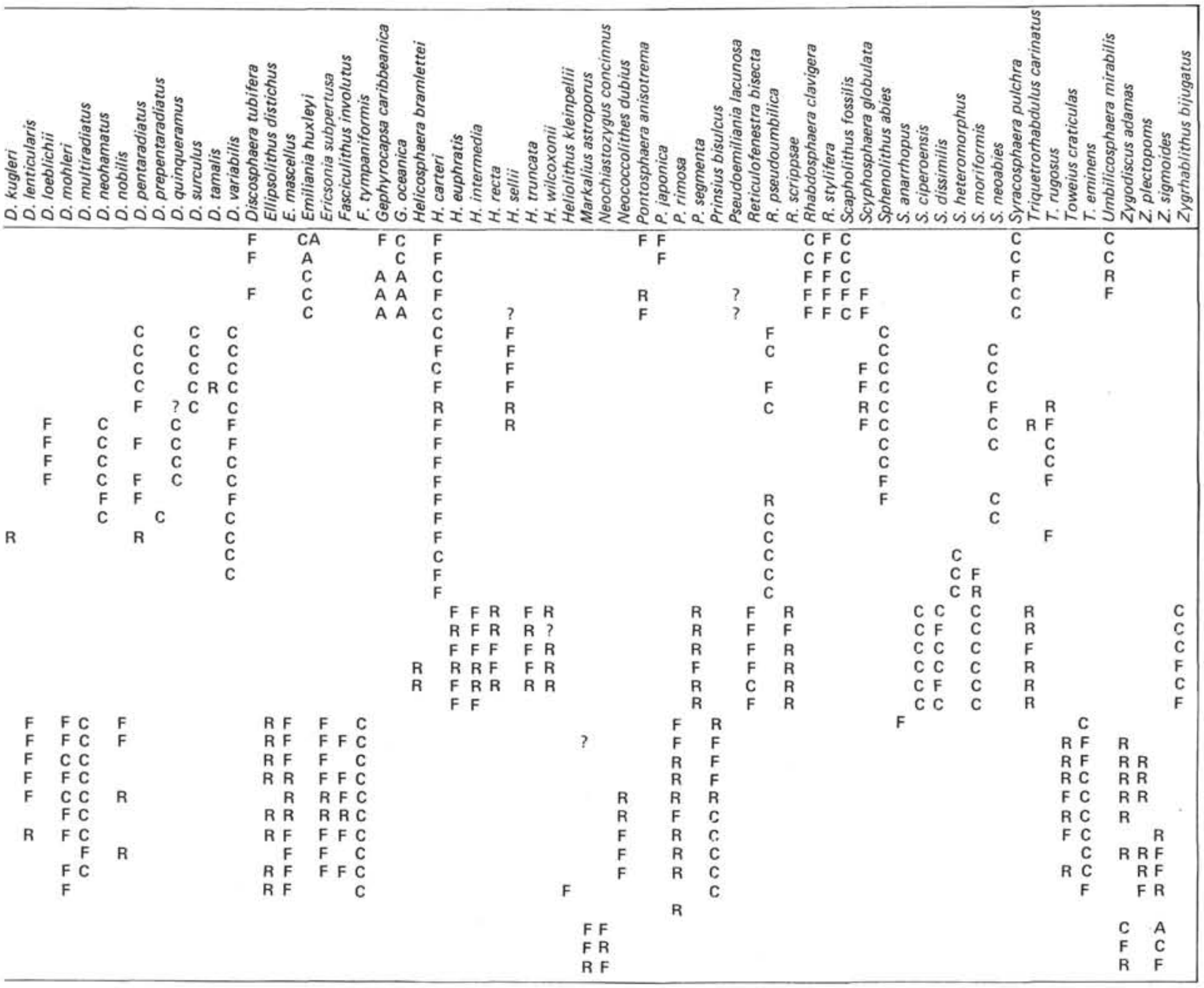

Figure 4. (Continued).

0–1 cm) contains Pliocene species including *Discoaster brouweri, D. surculus, D. pentaradiatus, Reticulofenestra pseudoumbilica, Helicosphaera carteri*, and *Coccolithus pelagicus*. The presence of these forms in the absence of older taxa such as the species of *Amaurolithus* places this sample within the *Reticulofenestra pseudoumbilica* Zone. The five samples immediately downhole are Miocene in age indicating a hiatus between these and the overlying sediments involving at least 7.0 Ma of section. Three samples from Core 1 (538A-1-1, 144–145 cm through 538A-1-2, 62–63 cm) contain *D. hamatus, D. neohamatus, Catinaster coalitus*, and *D. bollii*, which indicate an age equivalent to that of the *D. hamatus* Zone of the middle Miocene. Samples 538A-2-1, 19–20 cm and 538A-2-1, 94–95 cm have assemblages similar to those found in the previous interval but lacking the distinctive *D. hamatus*, which implies an older age. These are placed in the *C. coalitus* Zone (Fig. 5).

Samples from 538A-3-1, 121–122 cm through 538A-6-3, 56–57 cm are placed in the upper Oligocene *Sphenolithus ciperoensis* Zone. The assemblage includes the characteristic upper Oligocene species *S. ciperoensis, Cyclicargolithus abisectus, H. euphratis*, and *Triquetrorhabdulus carinatus*. A hiatus of at least 10.8 Ma is evident between these samples and those from the overlying Core 2. Samples 538A-6-3, 100–102 cm to 538A-11-2, 100–102 cm show a lack of *S. ciperoensis* and an abundance of *S. distentus*. This interval is assigned to the *S. distentus* Zone. The boundary between the *S. distentus* Zone and the underlying *S. predistentus* Zone is difficult to delineate precisely because of a number of sphenoliths with intermediate construction. The boundary has been placed above 538A-12-1, 90–92 cm. Samples below this boundary down to 538A-13-2, 90–92 cm are placed within the *S. predistentus* Zone. Species commonly in the assemblage include *H. compacta, Bramletteius serraculoides, Zygrhablithus bijugatus, Braarudosphaera bigelowii*, and *Peritrachelina joidesa*. Sample 538A-14-1, 74–76 cm was placed in the *H. reticulata* Zone based on the absence of any Eocene discoasters and the presence of *R. umbilica, R. hillae*, and *Ericsonia formosa*.

The youngest Eocene sediment was encountered in the interval from 538A-15-1, 34–35 cm to 538A-17-3, 69–71 cm. Samples from this interval are assigned to the *R. umbilica* Zone. Another hiatus (at least 4.0 Ma) oc-

Age	Zone or subzone	Core-Section (interval in cm)	Preservation	Braarudosphaera bigelowii	B. discula	Bramletteius serraculoides	Calcidiscus leptoporus	C. macintyrei	Campylosphaera dela	C. eodela	Catinaster calyculus	C. coalitus	C. mexicanus	Catinaster sp.	Chiasmolithus altus	C. californicus	C. consuetus	C. expansus	C. gigas	C. grandis	C. solitus	C. staurion	C. titus	Clausicoccus cribellum	C. fenestratus	Coccolithus cavus	C. eopelagicus	C. pelagicus	Coranocyclus nitescens	Cruciplacolithus tenuis	Cyclicargolithus abisectus	C. floridanus	Discoaster asymmetricus	D. barbadiensis	D. bellus	D. bollii	D. brouweri	D. calcaris	D. challengeri	D. cruciformis	D. deflandrei	D. diastypus	D. exilis	D. hamatus	D. lenticularis	D. lodoensis
Pliocene	Reticulofenestra pseudoumbilica	1-1, 0–1	P				F	C																				F					R				F									
		1-1, 144–145	G				F	C			F	R																C					R		C	C	C	F	C					F		
Miocene	Discoaster hamatus	1-2, 19–21	G				F	C			F	R		R														C							F	C	C	F	C		?			F		
		1-2, 62–63	G				F	C			F	F		F														A								C	F	F	F					F		
	Catinaster coalitus	2-1, 19–20	G				F	C				C	R	C														C								F	C	C					F			
		2-1, 94–95	G				F	C																				C	F							R		F	F				F			
Oligocene	Sphenolithus ciperoensis	3-1, 121–122	MP																						C		F	C	F		C	A									A					
		3-2, 90–91	MP																						C		F	C	R		A	A									A					
		4-1, 100–101	MG																						C		C	F			C	A									A					
		4-2, 100–101	MG																						C		F	C	R		C	A									C					
		4-3, 100–102	MG																						C		F	C	R		A	A									C					
		5-1, 40–42	MG																						F		F	C			C	A									C					
		5-2, 40–42	MG																						C		F	C	R		C	A									A					
		6-1, 100–102	G																						F		F	C	R		C	A									A					
		6-2, 100–102	G																						F		F	C	R		F	A									A					
		6-3, 56–57	G																						F		C	C			F	A									A					
	S. distentus	6-3, 100–102	G																						C		F	C	R		C	A									C					
		6-3, 130–132	MG	F	F																				F		C	C	R		A	C									A					
		7-1, 100–102	MG																						F		C	C	R		A	A									C					
		7-3, 100–102	MG																						F		F	C			C	C									A					
		7-4, 100–102	G																						C		F	F	F		A	A									C					
		8-1, 73–74	G																						F		C	C	F		F	A									C					
		8-2, 13–15	G	R																					F		A	F	R		C	C									A					
		8-2, 117–119	G																						F		C	C			C	A									A					
		8-3, 47–49	G																						F		C	C	F		F	C									A					
		9-1, 90–92	G																						C		C	F	F		F	C									A					
		9-2, 90–92	G																						C		C	C	F		C	A									C					
		9-3, 90–92	MG																						C		C	F			C	A									C					
		9-4, 90–92	G																						C		C	C			C	A									C					
		10-1, 98–100	M																						C		F	A	F		C	A									C					
		10-2, 101–103	M																						F		R	C	R		C	A									C					
		10-3, 90–92	M																						F		F	F			F	A									C					
		10-4, 98–100	M																						F		C	F	F		F	A									C					
		10-5, 67–69	M																						F		F	F	F		F	A									C					
		11-1, 100–102	M																						C		C	C	F		F	A									C					
		11-2, 100–102	M																						F		C	F			C	A									F					
	S. predistentus	12-1, 90–92	M																						C		C	F			C	A									F					
		12-2, 90–92	M																						F		F	F	R		C	A									F					
		12-3, 90–92	M																						F		F	F	R		C	A									C					
		12-4, 90–92	M																						C		F	C	R		F	A									C					
		13-1, 90–92	M	C	F																				R		C	C			R	A									F					
		13-2, 90–92	M	C	F	R									R												A	C	F			A									C					
	Helicosphaera reticulata	14-1, 74–76	M	F		A									R												C	C				C									C					
Eocene	R. umbilica	15-1, 34–35	M		F	C			C											R			R				C	C	R			C		C							F					
		16-1, 109–110	MP	C	C	C			C											F			R				F	C	F			A		C							F					
		16-2, 115–117	MP	R	F	C			C											F			R					C	F			C		C							F					
		16-3, 116–117	M	F	F	C			C											F			F	F			C	C				C		C							F					
		16-4, 111–113	M		R	C			C														F	F			C	C				C		C							F					
		16-5, 102–104	M		R	C			C											F	R		F	F			A	C				A		A							F					
		16-6, 92–94	M		R	C			C											F	R	R	F	R				C				C		A							F					
		17-1, 38–40	M		R	F			C											F			F	R	R		F	C				C		C							F					
		17-2, 25–27	M	F	F	C			C											F			F	R	F		F	F				C		C							C					
		17-3, 69–71	M	A	A	C			C											F			F	F	F		C	F				C		C							F					
	Nannotetrina quadrata	17-4, 111–113	MP	A	A	F			C									R	F	R								C	C					A							F				C	
		17-5, 75–77	M	A	A				C									F	F						R				F					C							C				F	
	D. sublodoensis / R. inflata Subzone	17-6, 44–46	MP						F									F				F	R	R		F				F						C							R	F				C	
		17-7, 15–17	MP		C				F								F			F	R			F				F						C						R	F				C	
		18-1, 102–104	MP						F								R			R					?			F						A						R					F	R
		18-2, 38–40	MP						F								R			R	R							F						C						R					R	R
		18-3, 71–73	M						C								C			F		R		F	?			F						C						R	R				F	R
		18-4, 134–136	M	C	C				F								F	R		C		R			?			F						C						R	R				F	A
		18-5, 129–131	M						F									R		F	F			R				F						A											F	F
		18-6, 52–54	M						F								C											C						C						R					C	R
	D. sublodoensis / Discoasteroides kuepperi Subzone	19-1, 51–53	M						F								F			F								F						C							R				C	
		19-2, 117–119	M						C											F	F			R				F						A						R					R	R
		19-3, 16–18	M						C											F	F			R				C						A											C	F
		19-4, 50–52	MG						C								F			F	F	R		F				C						A											F	R
	Discoaster lodoensis	19-5, 112–114	M						F																			C						A											F	A
		20-1, 14–16	P						F								R			R								R						C											F	C
	D. diastypus	20-2, 9–12	MP						F	R							R				R					F		F						C								F			F	
Paleocene	D. multiradiatus	20-4, 97–99	MG							C						F	C									A																			F	
	Zygodiscus sigmoides	20-6, 7–9	G																							A				F																
Eocene	D. diastypus	21-1, 39–41	MP	F	R				F	F							R																	C								F				

Figure 5. Distribution of Cenozoic calcareous nannofossils in samples from Hole 538A. Wavy lines in age and zone columns represent hiatuses. See Figure 4 for key.

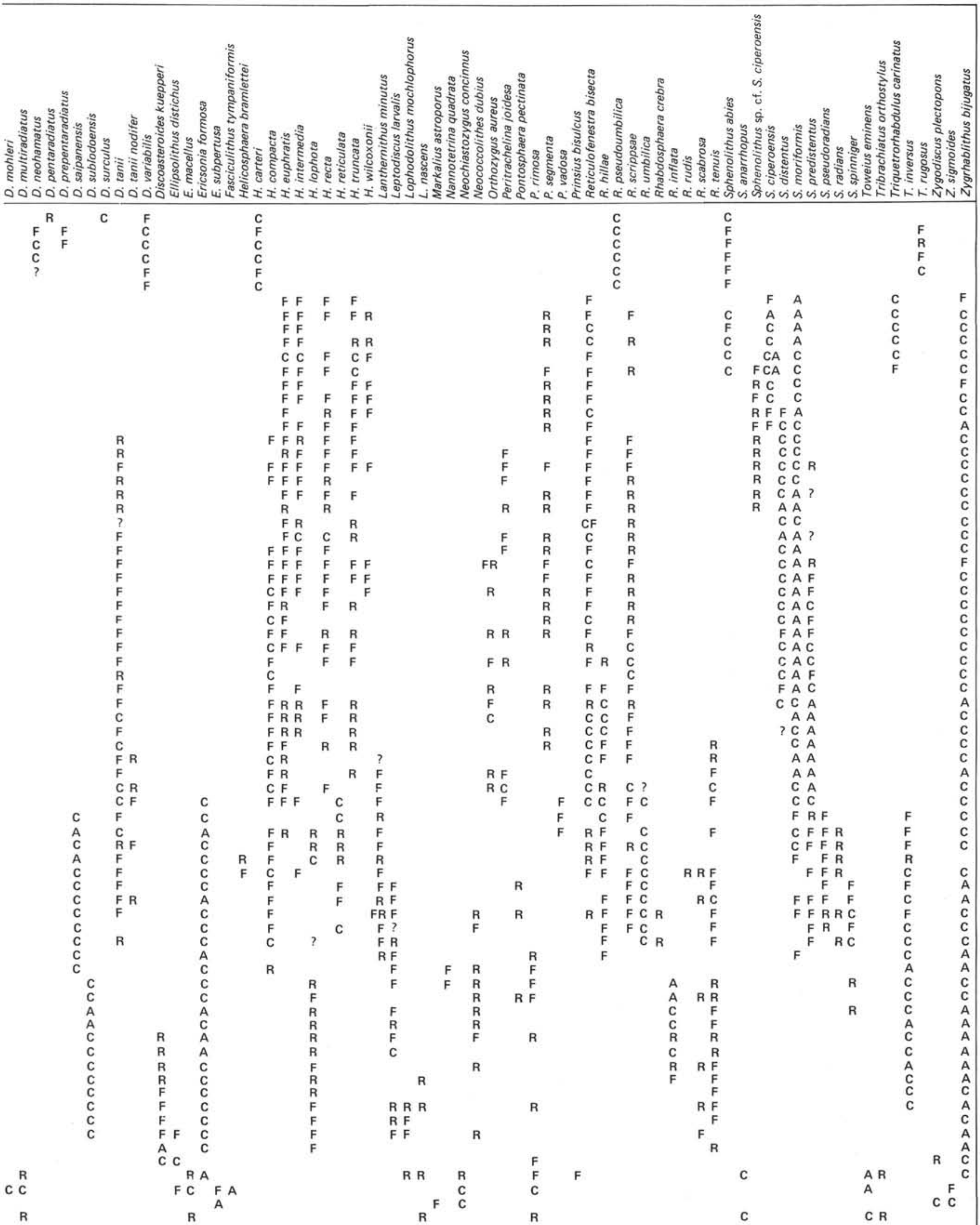

Figure 5. (Continued).

curs in the section at the upper boundary of this interval. Samples assigned to this zone contain some of the most diverse assemblages encountered at this site. Forms usually present include *D. barbadiensis, D. saipanensis, R. bisecta, R. umbilica, Chiasmolithus grandis*, and *Rhabdisphaera tenuis*. *B. bigelowii, B. discula*, and debris derived from these become very abundant in this interval as well. Samples 538A-17-4, 111–113 cm and 538A-17-5, 75–77 cm contain a similar assemblage but lack *Reticulofenestra umbilica* and are assigned the *Nannotetrina quadrata* Zone.

The *D. sublodoensis* Zone encompasses Samples 538A-17-6, 44–46 cm to 538A-19-4, 50–52 cm. This assemblage is composed, in part, of *D. sublodoensis, D. barbadiensis, E. formosa*, and *Campylosphaera dela*. The presence of *Rhabdosphaera inflata* in samples from the top of this interval down to 538A-18-6, 52–54 cm places these within the *Rhabdosphaera inflata* Subzone. The lowest four samples in the interval lack *R. inflata* but otherwise contain the same assemblage, which clearly delimits a second subzone, the *Discoasteroides kuepperi* Subzone. Two underlying samples (538A-19-5, 112–114 cm and 538A-20-1, 14–16 cm) contain nannofossils characteristic of the *Discoaster lodoensis* Zone. Species present include *D. lodoensis, D. lenticularis, D. barbadiensis*, and *R. tenuis*. A hiatus (at least 2 Ma) separates this interval from the underlying sample (538A-20-2, 9–12 cm), which is assigned to the *D. diastypus* Zone on the basis of the presence of *D. multiradiatus, D. diastypus*, and *Tribrachiatus orthostylus*. *D. lodoensis* is conspicuously absent from this sample.

Sample 538A-20-4, 97–99 cm is assigned to the upper Paleocene *Campylosphaera eodela* Subzone of the *D. multiradiatus* Zone, because it contains *C. eodela* and lacks *D. diastypus, T. orthostylus*, and any other species characteristic of younger Eocene sediments. Sample 538A-20-6, 7–9 cm is the only sample assigned to the lower Paleocene *Zygodiscus sigmoides* Zone. The sample contains *Z. sigmoides, Markalius astroporus, Cruciplacolithus tenuis*, and other forms common to sediments of that age. Beneath this lower Paleocene section occurs a short interval in which the sediments show a pronounced age reversal. Sample 538A-21-1, 39–41 cm, contains an assemblage virtually identical to that found in samples assigned to the Eocene *D. diastypus* Zone. This reversal was interpreted by shipboard scientists as a small slump deposit generated sometime in the early to early middle Eocene. All samples below this interval contain typical Cretaceous species, including *Cribrosphaerella ehrenbergi, Micula decussata, Watznaueria barnesae, Prediscosphaera cretacea*, and *Lithraphidites carniolensis* (see Watkins and Bowdles, this volume).

Site 539 (23°47.34N; 84°25.19′W; 3089 m water depth)

Hydrocarbon shows at nearby Site 535 prevented drilling at the original location planned for Site 539. After consultation with DSDP, the scientific party proposed and won approval for a new site along seismic Line SF-15 (see site chapter, Site 539, this volume). The principal objectives for this site were: (1) to date the MCU, (2) to study the section between the MCU and the underlying Unconformity 1, (3) to date Unconformity 1, and (4) to study the hummocky sequence below Unconformity 1 as seen on seismic records. The first of two holes drilled at this site recovered two cores before an extremely firm substratum was encountered. Further penetration would have required rotary drilling, and the hole was abandoned. Drilling in the second hole recovered a single core before hitting the same firm substratum, after which the site was abandoned. The Holocene to Oligocene sediments recovered from this site consist of brown or gray nannofossil muds and marls, and white nannofossil oozes. Preservation in this interval is typically moderate.

The entire first core recovered from Hole 539 contains typical upper Quaternary taxa, including *Emiliania huxleyi, Gephyrocapsa oceanica, G. caribbeanica*, and *Ceratolithus cristatus*. All samples from this core fall within the *E. huxleyi* Zone. At 539-2-2, 132 cm, Pliocene discoasters occur, including *Discoaster brouweri, D. pentaradiatus*, and others. Also present are other Pliocene species: *Calcidiscus macintyrei, C. leptoporus*, and *Helicosphaera carteri*. Samples below this level down to the termination of drilling are placed in the upper Pliocene *D. brouweri* Zone.

Drilling in Hole 539A recovered a single core. This single core contains sediments that range in age from the Holocene to the Oligocene. Sediment from 539A-1-1, 0–2 cm through 539A-1-2, 90–92 cm contains *E. huxleyi* and the upper Quaternary assemblage typically found with that species. These sediments are placed in the *E. huxleyi* Zone. Samples 539A-1-2, 94 cm through 539A-1-3, 92 cm contain a Miocene assemblage that includes both *D. quinqueramus* and *Amaurolithus primus*, limiting the interval to the upper Miocene *A. primus* Subzone. The rest of the core contains typical Oligocene forms found at the other sites, including *Sphenolithus ciperoensis, Cyclicargolithus abisectus, C. floridanus, Reticulofenestra bisecta*, and *S. moriformis*.

Site 540 (23°49.73′N; 84°22.25′W; 2926 m water depth)

Site 540 was drilled about 20 km northeast of Site 535 and on the flank of a prominent erosional valley. The main objectives at this site were to determine the nature and age of the prominent mid-Cretaceous? unconformity (MCU) seen on seismic records and to determine the nature and age of the sedimentary section between this MCU and an underlying horizon, Unconformity 1. The Cenozoic sequence recovered from this site consisted in part of gray marls and light-colored oozes and chalks of Quaternary to Paleocene age. The sequence here, as at the other sites, is cut by numerous hiatuses. Preservation of nannofossils is generally moderate to good in samples from this site (Figs. 6–7).

Pliocene sediments are missing from the section recovered at this site, but all other epochs of the Tertiary are represented. Samples 540-1-1, 4–6 cm through 540-1-1, 145–147 cm contain *Emiliania huxleyi* plus species of *Gephyrocapsa* and are placed in the upper Quaternary *E. huxleyi* Zone.

Samples 540-1-2, 75–77 cm through 540-2-6, 90–92 cm contain discoasters including *Discoaster quinqueramus, D. variabilis, D. brouweri, D. surculus, D. challengeri*, and other taxa such as *Amaurolithus primus* and *A. amplificus*. Sediments in this interval are assigned to the *A. primus* Subzone (Fig. 6). Thus, a hiatus involving at least 5.4 Ma of section separates these Miocene sediments from the overlying Holocene sediments.

Samples 540-3-1, 90–92 cm through 540-5-1, 101–103 cm are assigned to the *D. neohamatus* Zone. The assemblage in this interval characteristically contains a wide variety of discoasters including *D. neohamatus, D. variabilis, D. pentaradiatus, D. surculus,* and *D. loeblichii*. The base of this interval is marked by a hiatus (at least 2 Ma); the older *D. hamatus* Zone is completely missing.

Samples 540-5-2, 118–120 cm through 540-6-1, 110–112 cm are assigned to the *Catinaster coalitus* Zone of the middle Miocene. The nominative species shows a remarkable propensity for overgrowth, rendering identification rather difficult. In the same interval *Discoaster exilis* is also present in substantial numbers and also shows the effects of overgrowths, although identification of this species is still fairly easy.

The Oligocene at this site, like the Oligocene in Hole 538A, contains an extensive section through the *Sphenolithus ciperoensis* Zone and the *S. distentus* Zone (Fig. 7). The interval from 540-7-1, 44–46 cm to 540-14-5, 100–102 cm is placed within the *S. ciperoensis* Zone. The nominative species is present within this interval, as are abundant *Cyclicargolithus abisectus, C. floridanus, Reticulofenestra bisecta*, and *D. deflandrei*. This interval also contains a relatively diverse *Helicosphaera* population.

The interval from 540-15-1, 100–102 cm to 540-21-1, 133–135 cm, is placed within the *S. distentus* Zone. Samples in this interval show a lack of *S. ciperoensis* and an abundance of *S. distentus*. This interval is also marked by an abundance of braarudosphaerids. Species present in this zone are similar to those from the overlying *S. ciperoensis* Zone, but *S. ciperoensis* is absent. The boundary between this zone and the underlying *S. predistentus* Zone is more difficult to place because of the presence of specimens of intermediate construction. The boundary has been placed between Samples 540-21-2, 133–135 cm and 540-22-1, 10–12 cm. The *S. predistentus* Zone includes samples from this level down to 540-24-5, 96–98 cm.

In the lower Oligocene, the distinctive *Reticulofenestra umbilica* is observed in Samples 540-25-1, 67–69 cm through 540-26-2, 124–126 cm. This interval is assigned to the *H. reticulata* Zone on this basis. The cosmopolitan *Ericsonia formosa* is observed in Sample 540-26-1, 12–14 cm. These two extinction datums, that of *R. umbilica* and that of *E. formosa*, permit further subdivision of the *H. reticulata* Zone at this site into at least two subzones, the upper *R. hillae* Subzone and the lower *E. formosa* Subzone. The lowermost subzone, the *Coccolithus subdistichus* Subzone, cannot be definitively identified at this site because the original description of the subzone utilizes an acme that was not observed here.

Populations within the *H. reticulata* Zone show a slight change in character from the younger overlying intervals. The sequential extinction datums of *R. umbilica*

Age	Zone or subzone	Core-Section (interval in cm)	Preservation	*Amaurolithus amplificus*	*A. primus*	*Braarudosphaera bigelowii*	*B. discula*	*Calcidiscus leptoporus*	*C. macintyrei*	*Catinaster coalitus*	*Ceratolithus cristatus*	*Coccolithus pelagicus*	*Discoaster asymmetricus*	*D. berggrenii*	*D. brouweri*	*D. calcaris*	*D. challengeri*	*D. exilis*	*D. intercalcaris*	*D. loeblichii*	*D. neohamatus*	*D. pentaradiatus*	*D. quinqueramus*	*D. surculus*	*D. variabilis*	*Discosphaera tubifera*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*G. oceanica*	*Helicosphaera carteri*	*H. sellii*	*Pontosphaera anisotrema*	*P. japonica*	*Pseudoemiliania lacunosa*	*Reticulofenestra pseudoumbilica*	*Rhabdosphaera clavigera*	*R. stylifera*	*Scapholithus fossilis*	*Sphenolithus abies*	*Syracosphaera pulchra*	*Triquetrorhabdulus rugosus*	*Umbilicosphaera mirabilis*
Quaternary	*Emiliania huxleyi*	1-1, 4–6	M			R		C			F															F	A	F	A	F		R	F			F	C	A		A		A
		1-1, 70–72	M			R		C			F															F	A	F	A	F		R	F			F	C	A		A		A
		1-1, 145–147	M					C			F															A	A	C	A	A			F	?		A		A		A		A
Miocene	*Discoaster quinqueramus* / *Amaurolithus primus* Subzone	1-2, 75–77	M	F	F	R		A	A			A		F	C		C		C			F	A	F	A					C					F						F	
		2-1, 90–92	M		R			F	F			C	R				C		F			F	A	C	C					F					F						F	
		2-2, 90–92	MP		R			C	C			F	R	F	C		C		R			C	A	C	C					F					F				C		F	
		2-3, 90–92	MP		R			F	A			C	R		C		C		F			F	A	C	A					F					F				C		F	
		2-4, 90–92	MP		R			C	C			F			F		C		F			F	A	C	C					C					F				F		F	
		2-5, 90–92	M		?			C	C			F	R		C		A		F			F	A	A	A					C					F				C		F	
		2-6, 90–92	M		?			C	C			C			F		C		R			F	C	C	A					C					F				C		F	
	D. neohamatus	3-1, 90–92	M					C	C			C	R		F		C			R	C	F	?	F	C					C					R				C		F	
		3-2, 90–92	M					A	C			C			F		F		R	C	A	F	?		A					A					R				C		F	
		3-3, 90–92	MP					A	C			C	R		C	R	C			C	C	R	?		C					C					R				C		F	
		4-1, 102–104	MG					C	A			C	R			R	C			R	C				C					A					R				C		R	
		4-2, 119–121	MP					A	F			C	R		R	C	F			R	C				A					A					F				C		F	
		4-3, 100–102	MP					C	C			F				C	C			R	C				C					C					A				C		F	
		4-4, 87–89	M					C	C			F				C	C			R	C				C					C					C				C		F	
		5-1, 101–103	MG					F	C			C				R	F			R	A				C					A					C				C		F	
	Catinaster coalitus	5-2, 118–120	M				R	F	C	F		F					F	C							F					C					A				C		R	
		5-3, 48–50	M			R	R		C	F		C					C	C							C					C					A				C		R	
		6-1, 110–112	M				R		C	F		C					C	C							F					F					C				C			

Figure 6. Distribution of Neogene calcareous nannofossils in samples from Hole 540. Wavy lines in Age and Zone columns represent hiatuses. See Figure 4 for key. See Figure 7 for Paleogene calcareous nannofossils, Hole 540.

Age	Zone or subzone	Core-Section (interval in cm)	Preservation	Braarudosphaera bigelowii	B. discula	Bramletteius serraculoides	Campylosphaera dela	C. eodela	Chiasmolithus altus	C. bidens	C. californicus	C. consuetus	C. gigas	C. grandis	C. staurion	C. titus	Clausicoccus cribellum	C. fenestratus	Coccolithus cavus	C. eopelagicus	C. pelagicus	Coranocyclus nitescens	Cruciplacolithus tenuis	Cyclicargolithus abisectus	C. floridanus	Discoaster barbadiensis	D. deflandrei	D. lenticularis	D. lodoensis	D. mohleri	D. multiradiatus
		7-1, 44–46	M	F	F													F		C	F	F		A	A		C				
Oligocene	Sphenolithus ciperoensis	7-1, 99–101	M	R	R													C		F	F	R		C	A		A				
		7-2, 110–112	G	R	R													C		A	F	R		A	A		A				
		7-3, 95–97	MG		R													C		C	C	F		A	A		A				
		7-4, 86–88	M		R													C		C	C	F		A	A		A				
		7-5, 53–55	M	R	R													C		C	C	F		A	A		A				
		8-1, 60–62	M															C		C	C			A	A		A				
		8-2, 60–62	MG															C		A	A	R		A	A		A				
		8-3, 60–62	MG															C		A	F	R		A	A		A				
		8-4, 60–62	MG															C		A	F	R		A	A		A				
		8-5, 60–62	M															C		A	A	F		A	A		A				
		8-6, 60–62	M															C		A	C			C	A		A				
		8-7, 60–62	MG															C		A	C	R		C	A		A				
		9-2, 60–62	MG		R													C		A	C	R		A	A		A				
		9-4, 60–62	MG	R														C		A	C			A	A		A				
		9-6, 10–12	M															C		A	C	R		A	A		A				
		10-1, 55–57	M															C		A	F			A	A		A				
		10-2, 55–57	M															C		A	C	R		A	A		A				
		10-3, 55–57	M															C		A	C	R		A	A		C				
		10-4, 55–57	M															C		A	F	F		A	A		A				
		10-5, 34–36	M	R														C		C	F	F		A	A		A				
		11-1, 60–62	M	R														C		A	C	R		A	A		A				
		11-3, 60–62	M	C	F													C		A	C	F		A	A		A				
		11-6, 56–58	M	R														C		A	F	F		A	A		A				
		12-1, 60–62	M															C		A	F	F		A	A		A				
		12-2, 60–62	M	C	F													F		C	F			A	A		A				
		12-5, 60–62	M	F														C		A	A	F		A	A		A				
		13-1, 80–82	M	R														F		A	C	R		A	A		A				
		13-3, 80–82	M	R														C		A	C	F		A	A		A				
		13-5, 80–82	MP															F		C	A	R		A	A		A				
		14-1, 100–102	M	C	F													C		F	C	F		A	A		A				
		14-3, 100–102	M	C	F													C		F	F	F		C	A		A				
		14-5, 100–102	M	C	R													C		A	C	F		C	A		A				
	S. distentus	15-1, 100–102	MP	C	F													F		C	F	R		C	A		C				
		15-3, 100–102	M	F	R													F		A	F	R		A	A		A				
		15-4, 100–102	M	F	R													F		C	F	R		A	A		A				
		16-1, 100–102	M	C	R·													F		A	C	F		A	A		A				
		16-3, 100–102	M	C	R													C		A	F	R		A	A		A				
		17-1, 100–102	M	C	R													C		C	F	F		A	A		A				
		17-2, 100–102	M	F	R															A	C	F		A	A		A				
		17-4, 100–102	M	F	R													F		A	F	F		A	A		A				
		17-6, 100–102	M	F	F													F		C	C			A	A		A				
		18-1, 100–102	M	F	R													F		C	F			A	A		A				
		18-3, 100–102	M	C	F															C	F	R		A	A		C				
		19-1, 106–108	M	C	R													F		C	F			A	A		C				
		19-3, 106–108	M	A	F															C	C	R		A	A		A				
		19-5, 106–108	M	F	R															C	F	R		A	A		C				
		20-1, 121–123	M															F		C	A	R		A	A		F				
		20-3, 121–123	M	R														R		C	C			F	A		C				
		21-1, 109–110	M															R		C	F			R	A		C				
		21-2, 133–135	M																	C	R			C	A		F				
	S. predistentus	22-1, 10–12	M	A	R													R		F	R			F	A		F				
		23-1, 106–108	M	A	F													R		F	C			F	A		F				
		23-3, 91–92	M	C	F													R		F	C			R	A		C				
		24-1, 129–131	M	A	F													F		C	F				A		F				
		24-3, 117–119	M	A	A													F		C	F				A		C				
		24-5, 96–98	M	A	C															F	F				A		F				
	Helicosphaera reticulata: Reticulofenestra hillae Subzone	25-1, 67–69	M	A	C	C												F		C	C				A		F				
		25-2, 117–118	M	A	C	C			R									F		C	C				A		C				
		25-3, 86–88	M	A	A	C			F									C			C				A		C				
	Helicosphaera reticulata: Ericsonia formosa Subzone	26-1, 12–14	M	A	C	C			R											F	F				A		F				
		26-2, 124–126	M	A	C	A			R									R		C	C				A		F				
Eocene	Discoaster barbadiensis	26-3, 101–103	MP	A	C	A										R				C	F				A	C	F				
	Nannotetrina quadrata	27-1, 140–142	P	A	C		F						R	R	R					R	F				C	C	C				
		28-1, 13–15	M	C	C		F						F	F						R	R				A	C	F				
		28-2, 10–12	MP	F			F						R	F			F			R	F				A	C	F				
	D. sublodoensis	29-1, 38–40	P	C	F		R							R							R					F		R	F		
		29-2, 19–21	P				F							R							F					C		R	F		
Paleocene	D. multiradiatus	30-1, 14–16	M					F		F									A		F							R			C
		30-1, 114–116	M	R				F		F	F	F							A		C							R			C
	D. mohleri	30-2, 28–30	M	R						R	F	F							A		F		R							F	
		30-2, 31–32	M	R						R	F	F							A		F		R							F	
	Heliolithus kleinpelli	30-2, 81–83	M	R						R									A				R								

Figure 7. Distribution of Paleogene calcareous nannofossils in samples from Hole 540. Wavy lines in Age and Zone columns represent hiatuses. See Figure 4 for key. See Figure 6 for Neogene calcareous nannofossils, Hole 540.

D. nobilis	D. saipanensis	D. sublodoensis	D. tanii	Discoasteroides kuepperi	Ellipsolithus distichus	E. macellus	Ericsonia formosa	E. subpertusa	Fasciculithus tympaniformis	Helicosphaera bramlettei	H. compacta	H. euphratis	H. intermedia	H. recta	H. reticulata	H. truncata	H. wilcoxonii	Heliolithus kleinpellii	Isthmolithus recurvus	Lanthernithus minutus	Leptodiscus larvalis	Lophodolithus nascens	Markalius astroporus	Micrantholithus flos	M. vesper	Nannotetrina quadrata	Neochiastozygus concinnus	Orthozygus aureus	Peritrachelina joidesa	Pontosphaera rimosa	P. segmenta	Prinsius bisulcus	Reticulofenestra bisecta	R. hillae	R. scrippsae	R. umbilica	Rhabdosphaera inflata	R. tenuis	Sphenolithus anarrhopus	S. ciperoensis	S. distentus	S. moriformis	S. predistentus	S. pseudoradians	S. radians	Sphenolithus sp. cf. S. ciperoensis	S. spinniger	Toweius eminens	Triquetrorhabdulus carinatus	T. inversus	Zygodiscus plectopons	Z. sigmoides	Zygrhabdolithus bijugatus
												F	F	R		F	F							R				F	R		F		F							C		A							F				F
												F	F	F		F	R											F	R		F		F							F		A							F				F
												F	R	F		F	R											F			R		F		R					F		A							F				C
												F	F	R		R	R											F			R		C		R					C		A							R				C
												F	F	R		R	R											F			F		C		R					C		A							R				C
												F	F	R		R												R	R		F		F							C		A							F				C
												F	R	F		R												F			R		F							C		A							R				A
												F	R	F		R												R			R		R							C		A							F				C
												F		F		R	R											R			R		F		R					C		A							R				C
												F	R	F		R															R		F		R					C		C							F				C
												C		R		F	F											R			R		C		R					C		A							R				A
												F	F	F		F												F			F		F		R					F		C											C
												F	C	F		F												F			R		C		R					A		A											A
												C	C	F		C	C														R		C		R					C		A											C
												C	F	F		F	F							R							F		F		R					C		A											C
												C	R	F		F	F														R		C		R					C		A											C
												F	R	F		F												R			F		C		F					C		A											C
												C	C	F		C	F														R		F		F					C		A											C
												F	F	F		F	F														R		F		F					C		C				R							A
												F		F		F	F				R										R		R		R					C		A											C
												F		F		R					R							R	R				F		R					C		A											C
												R	R	R		R					R								R		R		F							C		A											C
										R		R	R	R							F										R		R		R					C		A											C
										R		R	F	R		R					F										R		R		R					C		A				R							C
										R		F	R	F		R					C												R							C		A				R							C
												R		R		R					F			R									R							C	R	A				R							C
												R	R	R		F					C												F		R					C	F	A											C
												R		R		R					F												R		R					F	C	A											C
												F	R			R					R								R		R		R		R					R	A	A				?							C
			R									R	R	R		R					R										R		F		R					F	C	A											C
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			F								R	C	F	C		F					F								R		R		R								A	A				R							A
			F									F	F	F		F					R								F		R		R		R						C	A				R							A
			F							F		R	F	R		R					F			R					R				F		R						A	A				R							A
			F								R	F	R	R		R					R			R					F				R		R						C	A				R							F
			F								R	F	R	F		F					F												F		R						C	A											C
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			F								C	R		R						R				F					F				C	R	R			F				A	C										C
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			F								C	F		R	R					R	R								F				C	R		?		C				A	A										C
			F								C	F		R	R					FC	C								F				C		F	F		R				A	C										A
			C								C	R	R	R	F					C	C			F									C	R	R	F		F				A	C	?									A
			F								C	F	F		F					C	F			F									C	R	F	F		F				A	A										A
			C				C				C				F					F	F			R					F				C			C		F				A	C	R									CA
			F				C				C				F				R	F					F				F				C	F	F	C		F				A	C	R									CA
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Figure 7. (Continued).

and *E. formosa* are prominent, as are the extinction levels of *Bramletteius serraculoides* and *H. reticulata*. However, the braarudosphaerids that are prominent in the earlier samples are abundant throughout this interval as well.

Eocene discoasters are encountered in Sample 540-26-3, 101–103 cm, which is assigned to the upper Eocene *D. barbadiensis* Zone. The boundary between this sample and the overlying Oligocene section may be marked by an unconformity, as is common in all the Cenozoic sections drilled on Leg 77. However, the uncertainty concerning the presence of the lowermost subzone of the *H. reticulata* Zone precludes unequivocal identification of the boundary as a hiatus, though one is strongly suspected. This highest Eocene sample, 540-26-3, 101–103 cm, has an assemblage composed of *D. barbadiensis, D. saipanensis, B. serraculoides, H. compacta, S. pseudoradians*, and others. Samples 540-27-1, 140–142 cm to 540-28-2, 10–12 cm contain species characteristic of the *Nannotetrina quadrata* Zone of the middle Eocene. A disconformity involving at least 3.0 Ma of section separates this interval from the overlying one. A striking feature of the assemblage is the presence of a tremendous number of *N. quadrata*. Included in this assemblage are common *D. barbadiensis, D. saipanensis, E. formosa*, and *Braarudosphaera bigelowii*. Eocene sediments in this hole, as in Hole 538A, show the highest diversity of any interval in the Cenozoic section at this site.

Samples 540-29-1, 38–40 cm and 540-29-2, 19–21 cm are placed in the *D. sublodoensis* Zone. Both samples contain *D. barbadiensis, D. sublodoensis, Chiasmolithus grandis, Rhabdosphaera tenuis*, and *Campylosphaera dela*. Only the upper sample of the two contains *R. inflata* and rare *D. lodoensis*, whereas the lower lacks the former and has common *D. lodoensis*. This may support the separation of the two samples into the *R. inflata* Subzone and the *Discoasteroides kuepperi* Subzone.

A disconformity (at least 4.0 Ma) lies between the above samples and Sample 540-30-1, 14–16 cm, which contains *Discoaster multiradiatus, Toweius eminens, C. eodela, Chiasmolithus bidens, C. californicus, C. consuetus*, and *Zygodiscus sigmoides* and is assigned to the upper Paleocene *D. multiradiatus* Zone. Samples 540-30-2, 28–30 cm and 540-30-2, 31–32 cm have similar assemblages but lack the distinctive *D. multiradiatus*, placing them in the *D. mohleri* Zone. *D. nobilis* was not observed, so another hiatus is inferred between these two samples and the overlying sample. These samples also contain well-preserved *Fasciculithus tympaniformis* and *S. anarrhopus*. Other forms present include *Ellipsolithus macellus, Cruciplacolithus tenuis*, and *Coccolithus cavus*.

Sample 540-30-2, 81–83 cm, lacks discoasters of any kind but contains *Heliolithus kleinpellii, F. tympaniformis, C. tenuis*, and *E. subpertusa*. There also occur a few reworked Cretaceous species such as *Micula decussata* and *Microrhabdulus decoratus*. This sample is placed within the lower Paleocene *H. kleinpellii* Zone. All samples examined below Core 31 contain a thoroughly reworked Tertiary and Cretaceous assemblage, which is underlain by definite Cretaceous sediments. Thus the Cretaceous/Tertiary boundary at this site is obscured by this intensively reworked interval.

SUMMARY AND CONCLUSIONS

Two significant features (one paleontologic, the other depositional) have been observed through study of the nannofossils in the Cenozoic sediment recovered on Leg 77. The first is the occurrence of anomalous braarudosphaerid accumulations in the lower Oligocene and upper Eocene at Site 540. The second, and most important, is the detection of numerous disconformities, the most prominent of which is related to a widespread Oligocene regressive interval.

Braarudosphaerids

Sections 540-22-1 to 540-28-2 span the upper Eocene to lower Oligocene at Site 540. Braarudosphaerids are common to abundant in this interval. This abundance is anomalously high in relation to the rest of the Oligocene section, where braarudosphaerids are generally few to rare. The isolated rhomb-shaped laths that in union compose the braarudosphaerids are also extremely abundant in this interval, a fact that is not reflected in the abundances plotted on the range charts. This abundance of pentaliths and pentalith debris is notable in itself but becomes more intriguing when one considers the relation that appears to exist between this group and certain holococcoliths. The well-known forms *Peritrachelina joidesa, Lanthernithus minutus*, and *Zygrhablithus bijugatus* are also found in the lower Oligocene and upper Eocene portions of the section drilled at Site 540. The abundance of these holococcoliths seems to parallel the fluctuating abundances of the braarudosphaerids. *P. joidesa*, in particular becomes much more prominent in the samples with the highest numbers of braarudosphaerids.

At least three mechanisms could explain this anomalous accumulation of braarudosphaerids: (1) shallowing of the seaway, (2) selective dissolution of other nannofossil species, or (3) an increase in productivity of these taxa.

The presence of holococcoliths implies a departure from normal pelagic sedimentation to more shallow-pelagic conditions (Bukry, 1970; Roth, 1970), so the cause of this braarudosphaerid accumulation could lie in a decrease in water depth. This shoaling effect could be generated by a prolonged sea-level drop or by local tectonic uplift of the sea floor. However, the sea-level fluctuation curve of Vail and Hardenbol (1979) for the Tertiary (Fig. 8) shows no such prolonged drop in sea level at the time of the deposition of these early Oligocene braarudosphaerid concentrations. Unfortunately, tectonic uplift of the area, on the other hand, cannot be independently confirmed.

If selective dissolution of other nannofossil taxa were the cause, the highly solution-susceptible holococcoliths would not remain intact. In this interval, however, they not only remain intact, but their numbers increase as well.

An increase in productivity among braarudosphaerids, on the other hand, has been logically invoked to

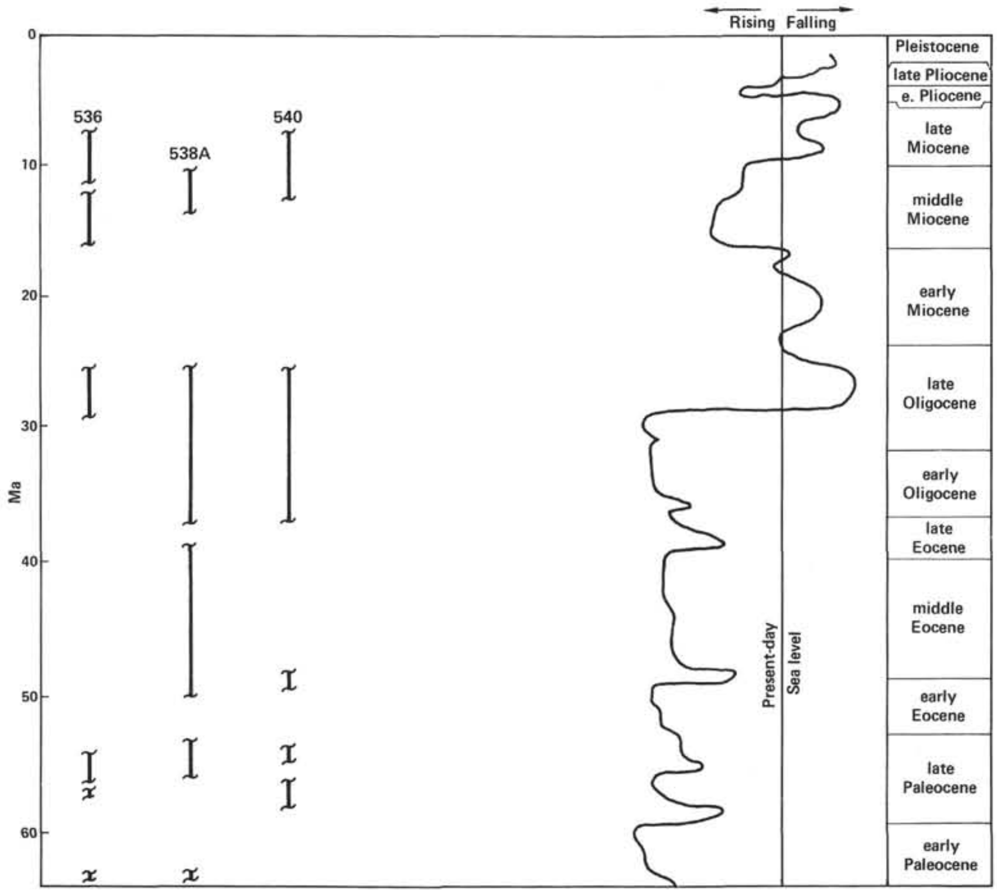

Figure 8. Comparison of sea-level fluctuation curve (Vail and Hardenbol, 1979) and hiatuses in the Cenozoic sections from Holes 536, 538A, and 540.

explain similar accumulations elsewhere (Maxwell, von Herzen, et al., 1970; Fischer and Arthur, 1977). This same mechanism is invoked for the Gulf of Mexico. Another work on sediments from the Gulf (Bukry, 1973) describes the same braarudosphaerid and holococcolith species in the same stratigraphic interval as those in Leg 77 sediments. Although the abundances of these taxa are not reported in the Bukry (1973) report, their presence is significant.

Thus, of the three mechanisms proposed, the most reasonable seems to be that a productivity increase among braarudosphaerids in the southeastern Gulf of Mexico during the Oligocene is responsible for the generation of this braarudosphaerid-holococcolith concentration.

Hiatuses

The most obvious depositional features of the Cenozoic sections at these sites are the numerous hiatuses, which essentially package the sections into sequences of distinct units. The extent of these hiatuses represented by missing nannofossil zones is sometimes very large, as in the case of Site 536. Here, the only Eocene found was in a few clasts in the top 10 cm of one core, whereas both Holes 538A and 540 contain ample Eocene sediment. Similarly, the Pliocene interval, represented in both Holes 536 and 538A, is completely missing from the Site 540. In general, hiatuses were found throughout the Cenozoic of every hole drilled on Leg 77.

Accelerated bottom-current activity during periods of global cooling and/or marine regression has been used to explain hiatuses in other deep-sea sections (Johnson, 1972; Rona, 1973; Davies, et al., 1975; Moore, et al., 1978; Barron and Keller, 1982). In this study, the same mechanism is invoked for the generation of at least the major upper Oligocene unconformity observed in the southeastern Gulf of Mexico. This upper Oligocene horizon correlates fairly well with the Chattian hiatus observed by Vail and others (1980) in sections from both the continental shelf off West Africa and the Blake continental slope off the southeastern United States. Those authors relate the horizon to the pronounced sea-level drop shown on their curves.

A slight discrepancy exists, however, between the age placed on this regression (Vail et al., 1980) and the apparent age of the late Oligocene hiatus in Leg 77 Cenozoic sections. The hiatus seen in Holes 536, 538A, and 540 (Figs. 2 and 8) is slightly younger. The precise dating of this horizon in the southeastern Gulf would be best achieved at some point where the disconformity approaches conformity. Unfortunately, that would require more precise correlation of regional seismic reflection lines and biostratigraphic work on a reasonable number of other sections, all of which is therefore beyond the scope of this initial report. For gross correlation purposes, however, the disconformity and the large scale sea-level drop become tantalizingly coincident.

Most other hiatuses in the Leg 77 Cenozoic sections do not correlate well with the unconformities identified elsewhere by Vail and his co-authors (1980). A possible exception is the minor disconformity in the basal Serravalian dated at 15.5 Ma. The disconformity at the bottom of the *Sphenolithus heteromorphus* Zone in Hole 536 is of a similar age and could conceivably be tied to that minor event. However, because of the lack of correlation between the major unconformities, a correlation between this minor Serravalian horizon and a horizon of similar age at the Leg 77 sites is highly tenuous.

If intensified bottom-current activity during marine regressions can explain hiatuses, then the fading effects of these currents during a subsequent transgression should allow normal accumulation of sediments. Vail and Hardenbol (1979) depict a middle Miocene transgression after the pronounced late Oligocene regression (Fig. 8). Lowered current velocities during this transgression should have allowed deposition of sediments at that time and preservation of these deposits. This, then, can explain the presence of the only Miocene sediment found on Leg 77 and its age, which is middle Miocene.

Future studies may show that factors other than sea-level oscillations caused disconformities in the Cenozoic section of the southeastern Gulf of Mexico. At this point, however, the remarkable concurrences of "global" regressions with hiatuses and of transgressions with preserved sections cannot be ignored.

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APPENDIX

Nannofossil Species Considered (alphabetic by species name)

Sphenolithus abies Deflandre, 1953
Cyclicargolithus abisectus (Müller) Wise, 1973
Chiphragmalithus acanthodes Bramlette and Sullivan, 1961
Ceratolithus acutus (Bukry) Gartner and Bukry, 1974

Discoaster adamanteus Bramlette and Wilcoxon, 1967
Zygodiscus adamas Bramlette and Sullivan, 1961
Chiasmolithus altus Bukry and Percival, 1967
Amaurolithus amplificus (Bukry and Percival) Gartner and Bukry, 1975
Sphenolithus anarrhopus Bukry and Bramlette, 1969
Pontosphaera anisotrema (Kamptner) Backman, 1980
Markalius astroporus (Stradner) Hay and Mohler, 1967
Discoaster asymmetricus Gartner, 1969
Micrantholithus attenuatus Bramlette and Sullivan, 1961
Orthozygus aureus (Stradner) Bramlette and Wilcoxon, 1967
Discoaster barbadiensis Tan, 1927
Sphenolithus belemnos Bramlette and Wilcoxon, 1967
Discoaster bellus Bukry and Percival, 1971
Discoaster berggrenii Bukry, 1971
Chiasmolithus bidens (Bramlette and Sullivan) Hay and Mohler, 1967
Braarudosphaera bigelowii (Gran and Braarud) Deflandre, 1947
Zygrhablithus bijugatus (Deflandre) Deflandre, 1959
Reticulofenestra bisecta (Hay, Mohler, and Wade) Roth, 1970
Prinsius bisulcus (Stradner) Hay and Mohler, 1967
Discoaster bollii Martini and Bramlette, 1963
Helicosphaera bramlettei (Müller) Jafar and Martini, 1975
Discoaster brouweri Tan, 1927
Discoaster calcaris Gartner, 1967
Chiasmolithus californicus (Bramlette and Sullivan) Hay and Mohler, 1967
Catinaster calyculus Martini and Bramlette, 1963
Gephyrocapsa caribbeanica Boudreaux and Hay, 1967
Triquetrorhabdulus carinatus Martini, 1965
Helicosphaera carteri (Wallich) Kamptner, 1954
Coccolithus cavus Hay and Mohler, 1967
Discoaster challengeri Bramlette and Riedel, 1954
Sphenolithus ciperoensis Bramlette and Wilcoxon, 1967
Catinaster coalitus Martini and Bramlette, 1963
Helicosphaera compacta Haq, 1966
Neochiastozygus concinnus (Martini) Perch-Nielsen, 1971
Sphenolithus conicus Bukry, 1971
Chiasmolithus consuetus (Bramlette and Sullivan) Hay and Mohler, 1967
Toweius craticulus Hay and Mohler, 1967
Rhabdosphaera crebra (Deflandre) Bramlette and Sullivan, 1961
Clausicoccus cribellum (Bramlette and Sullivan) Prins, 1979
Nannotetrina cristata (Martini)
Ceratolithus cristatus Kamptner, 1950
Discoaster cruciformis Martini, 1958
Chiasmolithus danicus (Brotzen) Hay and Mohler, 1967
Discoaster deflandrei Bramlette and Riedel, 1954
Campylosphaera dela (Bramlette and Sullivan) Hay and Mohler, 1967
Amaurolithus delicatus Gartner and Bukry, 1975
Discoaster diastypus Bramlette and Sullivan, 1961
Braarudosphaera discula Bramlette and Riedel, 1954
Sphenolithus distentus (Martini) Bramlette and Wilcoxon, 1967
Ellipsolithus distichus (Bramlette and Sullivan) Sullivan, 1964
Discoaster distinctus Martini, 1958
Neococcolithes dubius (Deflandre) Black, 1967
Discoaster elegans Bramlette and Sullivan, 1961
Campylosphaera eodela Bukry and Percival, 1971
Coccolithus eopelagicus (Bramlette and Riedel) Bramlette and Sullivan, 1961
Toweius eminens (Bramlette and Sullivan) Perch-Nielsen, 1971
Helicosphaera euphratis Haq, 1966
Discoaster exilis Martini and Bramlette, 1963
Chiasmolithus expansus (Bramlette and Sullivan) Gartner, 1970
Clausicoccus fenestratus (Deflandre and Fert) Prins, 1979
Cyclicargolithus floridanus (Roth and Hay) Bukry, 1971
Micrantholithus flos Deflandre, 1950
Ericsonia formosa (Kamptner) Romein, 1979
Scapholithus fossilis Deflandre, 1954
Chiasmolithus gigas (Bramlette and Sullivan) Gartner, 1970
Scyphosphaera globulata Bukry and Percival, 1971
Chiasmolithus grandis (Bramlette and Riedel) Gartner, 1970
Helicosphaera granulata (Bukry and Percival) Jafar and Martini, 1975
Discoaster hamatus Martini and Bramlette, 1963
Helicosphaera heezenii (Bukry) Jafar and Martini, 1975
Sphenolithus heteromorphus Deflandre, 1953
Reticulofenestra hillae Bukry and Percival, 1971
Emiliania huxleyi (Lohmann) Hay and Mohler *in* Hay, Mohler, Roth, Schmidt, and Boudreaux, 1967
Braarudosphaera imbricata Manivit, 1966
Rhabdosphaera inflata Bramlette and Sullivan, 1961
Discoaster intercalaris Bukry, 1971
Helicosphaera intermedia Martini, 1965
Triquetrorhabdulus inversus Bukry and Bramlette, 1969
Fasciculithus involutus Bramlette and Sullivan, 1961
Pontosphaera japonica (Takayama)
Peritrachelina joidesa Bukry and Bramlette, 1969
Calcidiscus kingii (Roth) Loeblich and Tappan, 1978
Heliolithus kleinpellii Sullivan, 1964
Discoasteroides kuepperi (Stradner) Bramlette and Sullivan, 1961
Discoaster kugleri Martini and Bramlette, 1963
Pseudoemiliania lacunosa (Kamptner) Gartner, 1969
Leptodiscus larvalis Bukry and Bramlette, 1969
Discoaster lenticularis Bramlette and Sullivan, 1961
Calcidiscus leptoporus (Murray and Blackman) Loeblich and Tappan, 1978
Discoaster lodoensis Bramlette and Riedel, 1954
Discoaster loeblichii Bukry, 1971
Helicosphaera lophota (Bramlette and Sullivan) Jafar and Martini, 1975
Ellipsolithus macellus (Bramlette and Sullivan) Sullivan, 1964
Calcidiscus macintyrei (Bukry and Bramlette) Loeblich and Tappan, 1978
Catinaster mexicanus Bukry, 1971
Lanthernithus minutus Stradner, 1962
Umbilicosphaera mirabilis Lohmann, 1902
Lophodolithus mochlophorus Deflandre *in* Deflandre and Fert, 1954
Discoaster mohleri Bukry and Percival, 1971
Sphenolithus moriformis (Brönnimann and Stradner) Bramlette and Wilcoxon, 1967
Discoaster multiradiatus Bramlette and Riedel, 1954
Lophodolithus nascens Bramlette and Sullivan, 1961
Sphenolithus neoabies Bukry and Bramlette, 1969
Discoaster neohamatus Bukry and Bramlette, 1969
Coranocyclus nitescens (Kamptner) Bramlette and Wilcoxon, 1967
Discoaster nobilis Martini, 1961
Gephyrocapsa oceanica Kamptner, 1943
Pyrocyclus orangensis (Bukry) Backman, 1980
Tribrachiatus orthostylus (Bramlette and Riedel) Shamrai, 1963
Pontosphaera pectinata (Bramlette and Sullivan)
Coccolithus pelagicus (Wallich) Schiller, 1930
Discoaster pentaradiatus Tan, 1927
Pontosphaera plana (Bramlette and Sullivan) Romien, 1979
Zygodiscus plectopons Bramlette and Sullivan, 1961
Sphenolithus predistentus Bramlette and Wilcoxon, 1967
Discoaster prepentaradiatus Bukry and Percival, 1971
Amaurolithus primus (Bukry and Percival) Gartner and Bukry, 1975
Cyclicargolithus pseudogammation (Bouche) Bukry, 1973
Sphenolithus pseudoradians Bramlette and Wilcoxon, 1967
Syrachosphaera pulchra Lohmann, 1902
Nannotetrina quadrata (Bramlette and Sullivan) Bukry, 1973
Discoaster quinqueramus Gartner, 1969
Sphenolithus radians Deflandre, 1952
Helicosphaera recta (Haq) Jafar and Martini, 1975
Isthmolithus recurvus Deflandre *in* Deflandre and Fert, 1954
Helicosphaera reticulata Bramlette and Wilcoxon, 1967
Pontosphaera rimosa (Bramlette and Sullivan)
Rhabdosphaera rudis (Bramlette and Sullivan) Sullivan, 1964
Triquetrorhabdulus rugosus Bramlette and Wilcoxon, 1967
Discoaster saipanensis Bramlette and Riedel, 1954
Rhabdosphaera scabrosa (Deflandre) Bramlette and Sullivan, 1961
Reticulofenestra scrippsae (Bukry and Percival) Shafik, 1981
Pontosphaera segmenta (Bukry and Bramlette) Jafar and Martini, 1975
Helicosphaera sellii (Bukry and Bramlette) Jafar and Martini, 1975
Helicosphaera seminulum (Bramlette and Sullivan) Jafar and Martini, 1975
Bramletteius serraculoides Gartner, 1969
Zygodiscus sigmoides Bramlette and Sullivan, 1961
Chiasmolithus solitus (Bramlette and Sullivan) Locker, 1968
Biantholithus sparsus Bramlette and Martini, 1964
Sphenolithus spinniger Bukry, 1971

Chiasmolithus staurion (Bramlette and Sullivan)
Rhabdosphaera stylifera Lohmann, 1902
Discoaster sublodoensis Bramlette and Sullivan, 1961
Ericsonia subpertusa Hay and Mohler, 1967
Discoaster surculus Bramlette and Martini, 1963
Discoaster tamalis Kamptner, 1967
Discoaster tanii Bramlette and Riedel, 1954
Discoaster tanii nodifer Bramlette and Riedel, 1954
Ceratolithus telesmus Norris, 1965
Cruciplacolithus tenuis Bramlette and Sullivan, 1961
Rhabdosphaera tenuis Bramlette and Sullivan, 1961
Chiasmolithus titus (Bramlette and Sullivan) Gartner, 1970
Amaurolithus tricorniculatus (Gartner) Gartner and Bukry, 1975
Helicosphaera truncata Bramlette and Wilcoxon, 1967
Discosphaera tubifera (Murray and Blackman) Kamptner, 1944
Fasciculithus tympaniformis Hay and Mohler, 1967
Reticulofenestra umbilica (Levin) Martini and Ritzkowski, 1968
Discoaster variabilis Bramlette and Martini, 1963
Micrantholithus vesper Deflandre, 1950
Helicosphaera wilcoxonii (Gartner) Jafar and Martini, 1975