

19. CENOZOIC CALCAREOUS NANNOFOSSILS FROM THE GALICIA MARGIN, OCEAN DRILLING PROGRAM LEG 103¹

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ABSTRACT

Ocean Drilling Program Leg 103 occupied five sites on the Galicia margin, northwest of the Iberian Peninsula. Two holes (Holes 637A and 638B) yielded significant Cenozoic sedimentary sections ranging from late Miocene to late Pleistocene in age. From the nannofossil stratigraphy, one hiatus is recognized in Hole 637A (2.35–2.4 Ma), whereas two hiatuses (one at 1.9–2.6 Ma and another at 3.5–3.7 Ma) are recognized in Hole 638B. Sediment-accumulation rates for the Cenozoic portions of these two holes have been calculated based on the nannofossil datums. The abundance ratios of *Coccolithus pelagicus* to *Discoaster brouweri* for Hole 637A show relatively low values and small fluctuations from 2.5 to 6.5 Ma but sharply increase and then widely fluctuate beginning at about 2.5 Ma. This may indicate relatively warmer, more stable surface-water temperatures from 2.5 to 6.5 Ma and cooler, variable surface-water temperatures after 2.5 Ma at Site 637. *C. pelagicus*/*D. brouweri* ratios from Hole 638B also show a trend of increasing values with time from late Miocene to late Pliocene, but with more fluctuations and a different pattern from that of Hole 637A.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 103 cored the Galicia margin (April–June 1985), 150 km west of the northern Iberian Peninsula (Fig. 1), to investigate the deep structure and the history of rifting, subsidence, and sedimentation during the progressive opening of this portion of the North Atlantic. The results from Leg 103 were intended to build on previous drilling results from this margin at nearby Deep Sea Drilling Project (DSDP) Site 398 (Leg 47B; Sibuet, Ryan, et al., 1979), where the deeper portion of the syn-rift sequence was not successfully penetrated.

The Galicia margin is a starved passive ocean margin with a thin sedimentary cover. The continental basement is broken by normal faults into tilted blocks trending north and dipping gently east, forming a series of half-grabens. On the uplifted western sides of some of these blocks, basement and pre-rift sedimentary rocks were believed to crop out, presumably making it possible to drill through the oldest sedimentary strata and into basement on Leg 103.

Five sites were occupied and 14 holes were drilled during Leg 103. The sediments recovered range from Late Jurassic to late Pleistocene in age, and the analysis of the calcareous nannofossil biostratigraphy has been divided into two parts. The Mesozoic section is presented by Applegate and Bergen (this volume), whereas the Cenozoic is discussed in this paper.

Two continuously cored holes (637A and 638B) yielded significant Neogene sedimentary sections. Nannofossils are abundant in these sections, and preservation ranges from poor to good. Range charts and sediment-accumulation rate curves have been prepared for these two holes and the extent of the hiatuses estimated from the curves. In addition, the abundance ratios of *Coccolithus pelagicus* (cool-water species) to *Discoaster brouweri* (warm-water species) have been plotted in an attempt to identify possible surface-water temperature changes with time.

Of the twelve other Leg 103 holes: Holes 638A and 641B were operational holes where no cores were taken; Holes 638C, 640A, and 641C recovered only Cretaceous sediments; two of the six holes at Site 639 (639E and 639F) recovered sediment

barren of nannofossils; the other four holes at Site 639 (639A–639D) and Hole 641A yielded only minor amounts of Cenozoic sediment and are discussed briefly in this paper.

Methods and Procedures

The occurrence of abundant nannofossils in the Cenozoic sediments recovered on Leg 103 permitted the preparation of smear slides directly from raw sediment samples. Smear slides were examined using the light microscope, and the distribution of nannofossils was recorded on the range charts. Nannofossil abundances were estimated using the criteria defined by Hay (1970), except that the slides were here examined at 1560× rather than at 1000×. These criteria are as follows:

- 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×

The abundance ratios of *Coccolithus pelagicus* to *Discoaster brouweri* from Holes 637A and 638B were determined by counting at least 100 specimens of *C. pelagicus* and *D. brouweri* on random tracks across the slides. If *D. brouweri* was not observed in the first 200 specimens, the *C. pelagicus*/*D. brouweri* ratio was recorded as 200.

The state of the preservation in a sample was estimated based on the following criteria:

- 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

Species considered in this study are listed in the Appendix, arranged alphabetically by generic epithets. Most of the bibliographic references for these taxa are presented by Loeblich and Tappan (1966, 1968, 1970a, 1970b, 1971, 1973), van Heck (1979a, 1979b, 1980a, 1980b, 1981a, 1981b, 1982a, 1982b, 1983), and Steinmetz (1984, 1984b, 1985a, 1985b, 1986). Any references not included in the above are listed in the references of this paper.

CALCAREOUS NANNOFOSSIL ZONATION

The Cenozoic calcareous nannofossil zonation applied in this study (Fig. 2) results from a combination of those proposed by Bukry (1973, 1985), Okada and Bukry (1980), and Gartner

¹ Boillot, G., Winterer, E. L., et al., 1988. *Proc. ODP, Sci. Results*, 103: College Station, TX (Ocean Drilling Program).

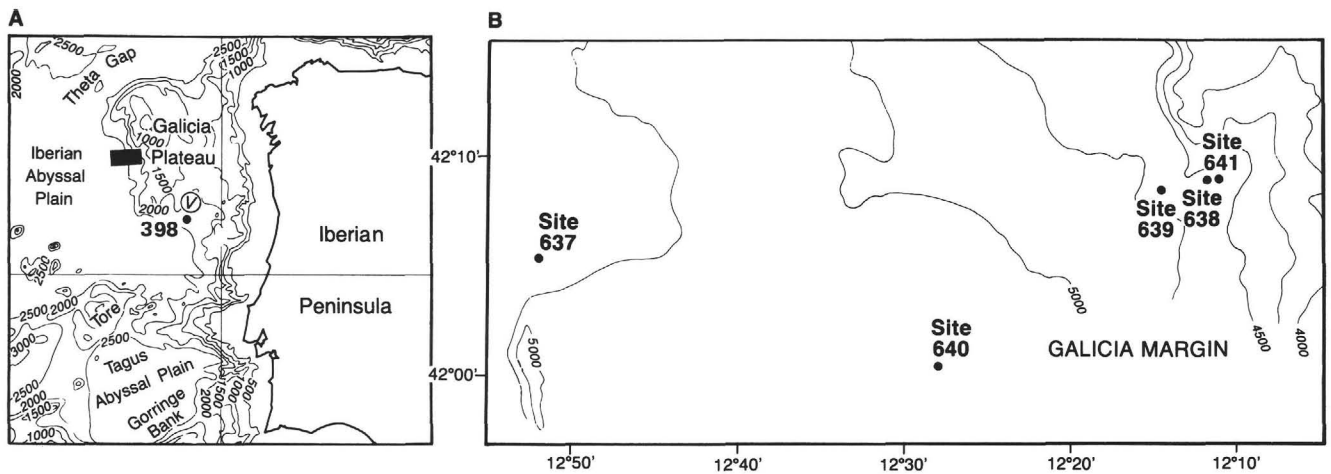


Figure 1. **A.** General location map of Iberian Peninsula and Galicia margin. Rectangle shows location of Figure 1B. **B.** Bathymetric map showing location of Leg 103 drill sites.

(1977). The zonation of Bukry (1973, 1985) is used only for pre-Pleistocene sections. Gartner's (1977) zonation provides better resolution for the Pleistocene and is used for this part of the column. Because both zonal schemes recognize the Pliocene/Pleistocene boundary on the basis of the last occurrence (LO) of *Discoaster brouweri*, there is no discontinuity in the combined zonation adopted in this paper. *Calcidiscus macintyreii* is used as the earliest Pleistocene zonal name by Gartner (1977), as well as the latest Pliocene subzonal name by Bukry (1973) and Okada and Bukry (1980). This confusion has been subsequently avoided since Bukry renamed the latter as the *Discoaster triradiatus* Subzone (Bukry, 1985).

Two emendations of the Okada and Bukry (1980) scheme were necessary in studying the Leg 103 samples. One is that the first occurrence datum (FOD) of *Pseudoemiliania lacunosa* is substituted for the datum level marked elsewhere by the beginning of the acme of *Discoaster asymmetricus*; a *Discoaster asymmetricus* acme was not observed in the Leg 103 material. Moreover, environmental control of acmes also greatly hinders their use in biostratigraphic zonations (Bukry, 1981). *Pseudoemiliania lacunosa* has a distinct FOD near the middle of the *Reticulofenestra pseudoumbilica* Zone and approximates the *Discoaster asymmetricus* acme (see Bergen, 1984; Perch-Nielsen, 1985; Lohman, 1986). We also recommend that the FOD of *P. lacunosa* be considered in other areas, especially in mid- to high-latitude areas where *D. asymmetricus* is rare or absent. *Pseudoemiliania lacunosa* is relatively dissolution resistant and is usually in high abundance where present, thus making its datum level easily recognizable.

The second emendation is that the FOD of *Amaurolithus primus* be used with that of *Amaurolithus delicatus*. Many investigators have reported these datums as coincident (Haq and Berggren, 1978; Ellis and Lohman, 1979; Perch-Nielsen, 1985; Lohman, 1986). *Amaurolithus primus* is scarce in the Leg 103 material and could not be used.

Because the Leg 103 sites are at midlatitudes, some of the marker species of Okada and Bukry's (1980) low-latitude zonation are scarce or absent. The Leg 103 holes were drilled in deep water, especially Site 637 (5307 m). According to the calculation proposed by Sclater et al. (1985), the paleodepth of the oldest Cenozoic sediments (upper Miocene) at this site was near 5200 m. Dissolution may have reduced or removed some of the less dissolution-resistant marker species. In addition, trace amounts of reworked material are present in most of the samples examined. All of these factors limit the biostratigraphic resolution, and some zones and/or subzones cannot be reliably discrimi-

nated. Dashed lines are used on the range charts to indicate problems in discerning these boundaries. Reasons for the uncertainty about the positions of these boundaries at each site are subsequently discussed. A summary of the calcareous nannofossil biostratigraphy of the Cenozoic sections recovered on Leg 103 is presented in Figure 3.

HOLE SUMMARIES

Hole 637A (Table 1)

Hole 637A was drilled east of a north-trending basement ridge near the Galicia continental margin (42°05.3'N, 12°51.8'W) in a water depth of 5307 m. Approximately 212 m of sediment overlying serpentinized peridotite basement were cored. Three lithostratigraphic units are recognized (see "Site 637" chapter; Shipboard Scientific Party, 1987a):

Unit I: 135 m of Pleistocene and upper Pliocene gray clay and nannofossil marl interbedded with clayey silt layers. This unit shows many coarse- to fine-grained thin cycles (less than 25 cm), characteristic of turbidites.

Unit II: 45 m of lower Pliocene and upper Miocene brown clay and nannofossil marl. Several slump structures are present.

Unit III: 32 m of reddish brown and grayish brown clay overlying the serpentinized peridotite basement. Unit III is barren of calcareous nannofossils.

The sedimentary section from this hole yielded calcareous nannofossils ranging from late Miocene to late Pleistocene in age (Table 1). Nannofossils are abundant or common in most of the samples examined and preservation is mostly moderate. All of the nannofossil zones of Okada and Bukry (1980) and Gartner (1977) for this part of the column are recognized, and only one minor hiatus in the Pliocene section is apparent from the stratigraphic sequence. The nannofossil biostratigraphy of Hole 637A presented here is basically a refinement of the initial biostratigraphy completed aboard ship and presented in the "Site 637" chapter (Shipboard Scientific Party, 1987a).

Recovery was poor in the first five cores of Hole 637A. A single sample was available from each of these core catchers.

Section 103-637A-1R, CC, is placed in the *Emiliania huxleyi* Zone based on the presence of *E. huxleyi*, which was confirmed by scanning electron microscopy. *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Gephyrocapsa oceanica*, *Gephyrocapsa* spp. (small), and *Reticulofenestra* spp. (smaller than 5 μm) are common to abundant. *Helicosphaera carteri* and *Rhabdosphaera claviger* are few to rare. The *Emiliania huxleyi* acme Zone (Gartner, 1977) was not detected.

Age	Zone	Subzone	Nannofossil datums	Ma	
late Pleistocene	<i>Emiliana huxleyi</i> acme		FOD <i>E. huxleyi</i> acme	0.085	
			FOD <i>E. huxleyi</i>	0.275	
			LOD <i>P. lacunosa</i>	0.474	
			highest level of dominantly small <i>Gephyrocapsa</i>	0.92	
	early Pleistocene	small <i>Gephyrocapsa</i>		LOD <i>H. sellii</i>	1.37
				LOD <i>C. macintyreii</i>	1.45
				LOD <i>D. brouweri</i>	1.9
late Pliocene	<i>Discoaster brouweri</i> (CN12)	CB12d <i>D. triradiatus</i>	LOD <i>D. pentaradiatus</i>	2.35	
		CN12c <i>D. pentaradiatus</i>	LOD <i>D. surculus</i>	2.4	
		CN12b <i>D. surculus</i>	LOD <i>D. tamalis</i>	2.6	
		CN12a <i>D. tamalis</i>	LOD <i>R. pseudumbilica</i> or LOD <i>Sphenolithus</i> spp	3.5	
	<i>Reticulofenestra pseudumbilica</i> (CN11)	CN11b <i>D. asymmetricus</i>	FAD FOD <i>P. lacunosa</i>		
		CN11a <i>S. neoabies</i>	LOD <i>A. delicatus</i> or LOD <i>A. tricorniculatus</i>	3.7	
	early Pliocene	<i>Amaurolithus tricorniculatus</i> (CN10)	CN10c <i>C. rugosus</i>	FOD <i>C. rugosus</i> or LOD <i>C. acutus</i>	4.57
			CN10b <i>C. acutus</i>	FOD <i>C. acutus</i> or LOD <i>T. rugosus</i>	5.0
			CN10a <i>T. rugosus</i>	LOD <i>D. quinquaramus</i>	5.6
	late Miocene	<i>Discoaster quinquaramus</i> (CN9)	CN9b <i>A. primus</i>	FOD <i>A. delicatus</i>	6.5
CN9a <i>D. berggrenii</i>			FOD <i>D. berggrenii</i> or FOD <i>D. surculus</i>	8.2	

Figure 2. Nannofossil zonation adopted for this study (from Bukry, 1973, 1985; Okada and Bukry, 1980; Gartner, 1977). Datum ages are taken from Berggren et al. (1985) and Backman and Shackleton (1983). FOD = first occurrence datum; LOD = last occurrence datum.

Section 103-637A-2R, CC, contains neither *Emiliana huxleyi* nor *Pseudoemiliana lacunosa* but rather *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Gephyrocapsa oceanica*, *Gephyrocapsa* spp. (small), *Helicosphaera carteri*, *Reticulofenestra* spp. (small), and rare *Umbilicosphaera sibogae*. The preservation is moderate, and the nannofossils are abundant; the sample is assigned to the *Gephyrocapsa oceanica* Zone (Gartner, 1977).

Section 103-637A-3R, CC, through Sample 103-637A-8R-3, 60–61 cm, are placed in the combined *Pseudoemiliana lacunosa* Zone/small *Gephyrocapsa* Zone (Gartner, 1977) based on the presence of *Pseudoemiliana lacunosa* and the absence of *Helicosphaera sellii*. The differentiation of these two zones is difficult because of the presence of many turbidite cycles, and the small *Gephyrocapsa* acme datum level could not be reliably discerned. Nannofossil preservation ranges from good to poor. *Pseudoemiliana lacunosa* occurs consistently in this interval, as do *Calcidiscus leptoporus* and *Reticulofenestra* spp. (small). *Coccolithus pelagicus* is absent or rare in the lower part of the interval and common in the upper part. Other species within this interval include common *Gephyrocapsa* spp. (small), *Helicosphaera carteri*, *Rhabdosphaera claviger*, few *Gephyrocapsa oceanica*, and rare *Ceratolithus cristatus*, *Pontosphaera japonica*, and *Scaenolites fossilis*.

The highest stratigraphic occurrence of *Helicosphaera sellii* is in Section 103-637A-8R, CC. The interval that includes this sample down to Sample 103-637A-10R-1, 6–7 cm, is assigned to the *Helicosphaera sellii* Zone (Gartner, 1977). The nannofossil flora present in this interval is the same as that in the above zone, except that the abundance of *Coccolithus pelagicus* is common, *Gephyrocapsa caribbeanica* is few, and *Rhabdosphaera claviger* is absent. Within this interval, Sample 103-637A-9R-1, 51–52 cm, is barren of nannofossils.

The lower Pleistocene *Calcidiscus macintyreii* Zone (Gartner, 1977) is defined by the extinction of *Discoaster brouweri* at the base and that of *Calcidiscus macintyreii* at the top; Sections 103-637A-10R, CC, through 103-637A-11R, CC, are placed in this zone. Because the preservation in this interval is poor, the lower zonal boundary determination is not very reliable. It is possible that the absence of *Discoaster brouweri* is due to poor preservation rather than its true extinction. In this interval, *Coccolithus pelagicus*, *Gephyrocapsa* spp. (small), *Helicosphaera carteri*, *H. sellii*, *Pseudoemiliana lacunosa*, and *Reticulofenestra* spp. (small) are also represented.

Samples 103-637A-12R-1, 43–45 cm, through 103-637A-13R-1, 72–73 cm, are assigned to the *Discoaster triradiatus* Subzone (CN12d) based on the absence of *Discoaster pentaradiatus* and *D. surculus* and the presence of *D. brouweri*. Rare *D. triradiatus* are also present. Sample 103-637A-12R-1, 43–45 cm, is distinct in that it contains abundant *Rhabdosphaera claviger*, one of the least solution-resistant species (Bergen, 1984).

Samples 103-637A-13R-2, 46–47 cm, to 103-637A-15R-2, 82–83 cm, are placed in the *Discoaster surculus* Subzone (CN12b). The highest stratigraphic occurrences of both *Discoaster surculus* and *D. pentaradiatus* were observed in Sample 103-637A-13R-2, 46–47 cm; thus, an unconformity may be present between Samples 103-637A-13R-1, 72–73 cm, and 103-637A-13R-2, 46–47 cm, where the entire *Discoaster pentaradiatus* Subzone (CN12c) and possibly parts of the two adjacent subzones are missing. *Discoaster intercalaris* is present in most of the samples in this interval, but *D. tamalis* is absent.

Samples 103-637A-15R-4, 48–49 cm, through 103-637A-16R-1, 23–24 cm, are assigned to the *Discoaster tamalis* Subzone (CN12a). *Discoaster tamalis* has a very sparse occurrence in this interval; thus, the upper boundary is tentative. The lower boundary is

Age	Zone/subzone	Hole 637A	Hole 638B	Hole 639A	Hole 639B	Hole 639C	Hole 639D	Hole 641A	
Pleistocene	late	<i>E. huxleyi</i>	1R, CC		1R-1		1R, CC		
		<i>G. oceanica</i>	2R, CC		1R, CC/3R-1	1R, CC			
		<i>P. lacunosa</i>	3R, CC 8R-3		3R-2/3R-3				1R-1
		small <i>Gephyrocapsa</i>							
		<i>H. sellii</i>	8R, CC/10R-1						
early	<i>C. macintyreii</i>	10R, CC/11R, CC	1R-2/2R-1						
Pliocene	late	CN12d <i>D. triradiatus</i>	12R-1/13R-1						
		CN12c <i>D. pentaradiatus</i>							
		CN12b <i>D. surculus</i>	13R-2/15R-2						
		CN12a <i>D. tamalis</i>	15R-4/16R-1	2R-1/4R-7					
		CN11b <i>D. asymmetricus</i>	16R-1/17R-1				1R, CC		
		CN11a <i>S. neoabies</i>	17R-2/17R-3						
	early	CN10c <i>C. rugosus</i>	17R-4	4R, CC/8R-7					
		CN10b <i>C. acutus</i>	17R, CC/18R-2	10R-1/11R-2					
late Miocene		CN10a <i>T. rugosus</i>	18R-2/19R-2	11R-3/17R-1					
		CN9b <i>A. primus</i>							
		CN9a <i>D. berggrenii</i>	19R-2/20R, CC	17R-2/19R, CC					

Figure 3. Summary of nannofossil biostratigraphy of the Cenozoic sections recovered on Leg 103. Where more than one core is assigned to a single zone/subzone, the highest and lowest sections are listed with a slash between them. CC = core catcher.

placed at the last occurrence datum (LOD) of *Reticulofenestra pseudoumbilica*. The assemblage is similar to that of the overlying subzone, but includes rare *Discoaster tamalis*. Rare *Sphenolithus* spp. (small) were found in the bottommost sample (*Sphenolithus* spp. (small), as used in this report, includes *Sphenolithus abies*, *S. compactus*, *S. moriformis*, and *S. neoabies*, because consistent differentiation between these species is difficult; Backman, 1980; Perch-Nielsen, 1985). The LOD of *Sphenolithus* spp. in Hole 637A is observed at a slightly higher level than the LOD of *Reticulofenestra pseudoumbilica*.

The highest stratigraphic occurrence of *Reticulofenestra pseudoumbilica* is in Sample 103-637A-16R-1, 147–148 cm, and the interval from this sample down to Sample 103-637A-17R-3, 39–40 cm, is placed in the *Reticulofenestra pseudoumbilica* Zone (CN11).

Samples 103-637A-16R-1, 147–148 cm, to 103-637A-17R-1, 44–45 cm, are placed in the *Discoaster asymmetricus* Subzone (CN11b). This interval contains similar assemblages to that of the above subzone (CN12a), plus *Reticulofenestra pseudoumbilica*, *Discoaster variabilis*, *Syracosphaera pulchra*, and *Umbilicosphaera sibogae*.

Samples 103-637-17A-2R, 10–11 cm, and 103-637A-17R-3, 39–40 cm, are tentatively assigned to the *Sphenolithus neoabies* Subzone (CN11a) because both *Pseudoemiliana lacunosa* and *Amaurolithus delicatus* are absent.

The highest stratigraphic occurrence of *Amaurolithus delicatus* is in Sample 103-637A-17R-4, 39–40 cm, and the highest stratigraphic occurrence of *Ceratolithus acutus* is in Section 103-637A-17R, CC; thus, Sample 103-637A-17R-4, 39–40 cm, is placed in the *Ceratolithus rugosus* Subzone (CN10c).

Section 103-637A-17R, CC, through Sample 103-637A-18R-2, 27–28 cm, are placed in the *C. acutus* Subzone (CN10b) based on the presence of *C. acutus*. Both *Discoaster asymmetricus* and *Triquetrorhabdulus rugosus* are absent in this interval. The preservation of the assemblages is moderate to good.

The highest stratigraphic occurrence of *Triquetrorhabdulus rugosus* was found in Sample 103-637A-18R-2, 86–87 cm, and

the lowest stratigraphic occurrence of *A. delicatus* was observed in Sample 103-637A-19-2, 45–46 cm. This interval is assigned to the *T. rugosus* Subzone (CN10a)/*Amaurolithus primus* Subzone (CN9b). *Discoaster quinqueramus* is very scarce in Leg 103 material, and its LOD could not be used to mark the boundary between Subzones CN10a and CN9b. *Minylitha convallis* and *Discoaster loeblichii* were found in this interval.

Sample 103-637A-19R-2, 80–81 cm, to Section 103-637A-20R, CC, are assigned to the *Discoaster berggrenii* Subzone (CN9a) based on the absence of *Amaurolithus delicatus* and the presence of *Discoaster surculus* and *D. quinqueramus*. Section 103-637A-19R, CC, within this interval is barren of nannofossils. Section 103-637A-20R, CC, contains few and poorly preserved nannofossils.

Samples taken from the red-brown clays of lithologic Unit III at the base of the sedimentary section are barren of nannofossils (Sample 103-637A-21R-1, 8–9 cm, through Section 1103-637A-23R, CC). The only nannofossils recovered from this interval came from isolated sedimentary clasts of calcareous ooze (Sections 103-637A-20R, CC, and 103-637A-21R, CC, and Sample 103-637A-21R-6, 14 cm). These clasts contain well-preserved assemblages of early Pliocene age. However, the reliability of the age determinations from these clasts is questionable, because two of these age determinations are from core-catcher samples, which might include downhole cavings. The third sample (103-637A-21R-6, 14 cm) came from an interval of drilling breccia at the base of Core 103-637A-21R.

Several aspects of the nannofossil assemblages in Hole 637 are noteworthy. First, there are very few discoasters in the upper Pliocene sediment samples. This made age determinations difficult because all datums used for this interval are based on last occurrences of discoasters. Second, sphenoliths are rare to absent in most upper Miocene and lower Pliocene samples examined, though they are typically common in low-latitude deep-sea coeval sediment. Third, high abundance of *Coccolithus pelagicus* was observed throughout the section (except in the upper lower Pleistocene). In present-day oceans, this form has a pref-

erence for cooler water (McIntyre et al., 1970). The low abundance of discoasters and sphenoliths at Site 637 would also be explained by cooler water, because discoasters and sphenoliths are believed to thrive in warmer low-latitude waters (Haq, 1980). Finally, trace amounts of reworked nannofossils are present in every sample. The amount of reworked nannofossils is constant and never exceeds 1% of the total assemblage. Common solution-resistant Late Cretaceous forms such as *Micula staurophora*, *Eiffellithus turiseiffeli*, *Cribrosphaerella ehrenbergii*, *Zygodithus diplogrammus*, and *Prediscosphaera cretacea* are the most common. *Ceratolithoides aculeus*, *Arkhangelskiella cymbiformis*, *Rhagodiscus asper*, and *Eiffellithus eximus* were also encountered. Many samples also contain reworked Eocene species such as *Discoaster saipanensis* and *D. barbadiensis*. *Dictyocites bisectus*, *Reticulofenestra umbilica*, and *Ericsonia formosa* were found in many samples. Pliocene sediments at this site contain reworked nannofossils of mostly Miocene forms. Similarly, Pliocene forms were found most frequently in Pleistocene samples. The persistent trace amounts of reworked nannofossils are indicative of erosion and resuspension of material by bottom currents throughout deposition at Site 637.

Nannofossil flora from the nearby DSDP Site 398 also shows the first three aspects as discussed in the preceding, though Blechschmidt (1979) did not report the reworked species and reworking patterns.

Hole 638B (Table 2)

Hole 638B was drilled on a valley floor that runs roughly parallel to and east of the cuesta formed by resistant carbonate beds at the western edge of a tilted fault block (42°09.2' N, 12°11.8' W; water depth, 4661 m). The objectives were to obtain reliable data on the very early history of the margin, on the timing of rifting, and on the timing of paleoenvironmental changes in this region of the North Atlantic. A 431-m sedimentary section was drilled at Hole 638B. It includes 184 m of Cenozoic pelagic ooze overlying 245 m of Lower Cretaceous marls, limestones, and turbidites. The Cenozoic section yields abundant calcareous nannofossils and is from late Miocene to early Pleistocene in age. Nannofossils are abundant and moderately well preserved in most samples. Assemblages indicate that two unconformities are present in this section. As compared with the initial shipboard results presented in the "Site 638" chapter (Shipboard Scientific Party, 1987b), the results presented here include adjustments to some zonal/subzonal boundaries in the lower Pliocene and upper Miocene sections of this hole.

The first core and the highest sample in the second core (103-638B-2R-1, 34–35 cm) are assigned to the *Calcidiscus macintyrei* Zone based on the presence of *C. macintyrei* and the absence of discoasters. Nannofossils are abundant in all of the samples, and preservation is good to moderate.

Underlying the *Calcidiscus macintyrei* Zone is an interval (Samples 103-638B-2R-1, 125–126 cm, through 103-638B-4R-7, 11–12 cm) with a markedly different nannofossil assemblage. *Gephyrocapsa caribbeanica* and *G. oceanica* are absent, and a diverse assemblage of discoasters (*D. asymmetricus*, *D. brouweri*, *D. intercalaris*, *D. pentaradiatus*, *D. surculus*, *D. tamalis*, *D. triradiatus*, and *D. variabilis*) is present. Rare *Sphenolithus* spp. (small), *Scyphosphaera lagena*, *S. penna*, and few *Syrocosphaera pulchra* were also found. Because *Reticulofenestra pseudoumbilica* is absent, this interval is placed in the *Discoaster tamalis* Subzone (CN12a). Nannofossils are abundant in all samples and preservation is moderate to good, except for Samples 103-638B-2R-5, 121–122 cm, 103-638B-2R-6, 82–83 cm, in which nannofossils are common to abundant and poorly preserved. As the *Discoaster tamalis* Subzone (CN12d) and *Calcidiscus macintyrei* Zone (Gartner, 1977) are determined for subadjacent samples, a major unconformity is present in this hole.

The highest stratigraphic occurrence of *Amaurolithus delicatus* was found in Section 103-638B-4R, CC. The interval from this section to Sample 103-638B-8R-7, 45–46 cm, is placed in the *Ceratolithus rugosus* Subzone (CN10c). The lower boundary is tentative because *Ceratolithus rugosus* is extremely rare in Hole 638B, and the FOD of this species is difficult to recognize. *Amaurolithus primus* is rare in this interval whereas *A. delicatus* is rare to few and consistently present. The species present in this interval are quite different from those in the overlying zone: *Amaurolithus amplificus*, *A. ninae*, *Sphenolithus* spp. (including *S. abies*, *S. moriformis*, and *S. compactus*), and *Reticulofenestra pseudoumbilica*. *Pseudoemiliania lacunosa* is absent. Within this interval recovery was poor in both Cores 103-638B-5R and 103-638B-6R, and only one sample could be taken from the core catcher of Core 103-638B-6R. Nannofossils are abundant throughout this interval, and the preservation is moderate. The *Reticulofenestra pseudoumbilica* Zone (CN11) is not recognized, and a lower Pliocene unconformity is present in this hole.

Samples 103-638B-10R-1, 71–72 cm, through 103-638B-11R-2, 41–42 cm, are assigned to the *Ceratolithus acutus* Subzone (CN10b) because *Ceratolithus rugosus* and *Triquetrorhabdulus rugosus* are absent. Core 103-638B-9R recovered little sediment (1% core recovery), and a sample from the core catcher yielded only poorly preserved Cretaceous nannofossils.

The highest stratigraphic occurrence of *Triquetrorhabdulus rugosus* was observed in Sample 103-638B-11R-3, 25–26 cm, and the lowest stratigraphic occurrence of *Amaurolithus delicatus* was observed in Sample 103-638B-17R, 20–21 cm. This interval is placed in the combined *T. rugosus* Subzone (CN10a)/*Amaurolithus primus* Subzone (CN9b). Differentiation of the two subzones is not possible because *Discoaster quinqueramus* is absent in Hole 638B. The lower boundary of *A. primus* Subzone (CN9b) is tentatively drawn below Sample 103-638B-17R-1, 20–21 cm, as amaurooliths are scarce in this hole.

Sample 103-638B-17R-2, 96–97 cm, to Section 103-638B-19R, CC, are assigned to the *Discoaster berggrenii* Subzone (CN9a) because *Discoaster surculus* is present in this interval. *Discoaster loeblichii* and *Minylitha convallis* are present in the lower part of the interval.

As in Hole 637A, sediments from Hole 638B contain very few discoasters. Sphenoliths are also rare to absent. *Coccolithus pelagicus* is abundant throughout the Cenozoic section. Reworked nannofossils were observed only in one-third of the samples from Hole 638B, but the reworked assemblages are similar to those in Hole 637A.

Hole 639A

Hole 639A (42°08.6' N, 12°14.9' W; water depth, 4720 m) is one of six holes drilled at Site 639 in an attempt to recover a composite section through the Mesozoic carbonate rocks and penetrate into the basement.

Pleistocene and middle Miocene nannofossil assemblages are present in the 22 m of Cenozoic sediment of Hole 639A. Sample 103-639A-1R-1, 115–116 cm, contains *Emiliania huxleyi* and is assigned to the *Emiliania huxleyi* Zone (Gartner, 1977). Section 103-639A-1R, CC, through Sample 103-639A-3R-1, 17–18 cm, contain *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Gephyrocapsa caribbeanica*, *G. oceanica*, and *Helicosphaera sellii*. *Pseudoemiliania lacunosa* is absent. This interval is placed in the *Gephyrocapsa oceanica* Zone (Gartner, 1977). Samples 103-639A-3R-2, 115–116 cm, and 103-639A-3R-3, 102–104 cm, contain *P. lacunosa*, *G. caribbeanica*, and *G. oceanica*, but no discoasters, and are early Pleistocene in age. Samples 103-639A-3R-4, 19–20 cm, through 103-639A-4R-1, 1–2 cm, contain *Reticulofenestra pseudoumbilica*, *Triquetrorhabdulus rugosus*, and some overgrown discoasters. This interval represents an age older than

Table 1. Distribution of calcareous nannofossils, Hole 637A. Dashed lines indicate tentative zonal/subzonal boundaries; wavy line indicates hiatus.

Lithologic unit	Age	Zone/Subzone	Depth (mbsf)	Hole 637A (core, section, interval in cm)	Abundance	Preservation	Amaurolithus		Coccolithus pelagicus	Discoaster asymmetricus	Discoaster blackstockae	Discoaster brouweri	Discoaster decorus	Discoaster intercalaris	Discoaster loeblichii	
							amplificus	delicatus								
I	Pleistocene	<i>Emiliana huxleyi</i>	3.0	1R, CC	A	M			C							
		<i>Gephyrocapsa oceanica</i>	15.7	2R, CC	A	M			C							
		<i>Pseudoemiliana lacunosa/</i> <i>small Gephyrocapsa</i>	25.4	3R, CC	A	G			C							
			35.1	4R, CC	C	M			F							
			44.9	5R, CC	C	M			F							
			45.4	6R-1, 50-51	A	M			C					F		
			46.9	6R-2, 49-50	A	M			C					F		
			48.4	6R-3, 50-51	C	P			C							
			54.6	6R, CC	A	G			A					F		
			55.1	7R-1, 50-51	A	P			C					F		
			56.6	7R-2, 50-51	A	G			C							
			58.1	7R-3, 47-48	R	P										
	60.0	7R-4, 91-92	A	G			C					F				
	64.4	7R, CC	A	M			A					F				
	65.1	8R-1, 69-70	F	P			C					F				
	66.7	8R-1, 76-77	A	M			C					R				
	68.0	8R-3, 60-61	A	M			C									
	<i>Helicosphaera sellii</i>	74.0	8R, CC	A	M			C					C			
74.5		9R-1, 51-52	B													
76.0		9R-2, 51-52	A	M			A					C				
83.7		9R, CC	A	M			A					C				
83.8		10R-1, 6-7	A	M			C					C				
<i>Calcidiscus macintyreii</i>	93.3	10R, CC	A	P			C				R	C				
	99.8	11R-1, 53-54	C	P			F				F	C				
	102.7	11R, CC	C	P			F				F	C				
II	Pliocene	<i>Discoaster triradiatus</i> (CN12d)	103.1	12R-1, 43-45	A	G			F		F			F		
			103.5	12R-1, 82-84	A	M			C		F		R		R	
			103.6	12R-1, 86-87	C	P			R		R		R		F	
			104.4	12R-2, 20-22	F	P			R		R		R			
			104.5	12R-2, 36-37	A	P			C		F		A		F	
			104.9	12R-2, 64-66	F	P			R		F		F		F	
		<i>Discoaster brouweri</i> (CN12)	112.4	12R, CC	A	M			F		F		A		F	
			113.1	13R-1, 72-73	A	M			F		F		A		R	
			<i>Discoaster surculus</i> (CN12b)	113.9	13R-2, 46-47	A	M			F		C		A		F
				122.0	13R, CC	A	M			C		C		A		F
				122.5	14R-1, 53-54	A	M			C		C		A		R
				131.7	14R, CC	A	M			C		C		A		R
	<i>Discoaster tamalis</i> (CN12a)	132.3	15R-1, 64-65	A	M			C		C		R		A		
		134.0	15R-2, 82-83	A	M			C		C		R		A		
	early	<i>Discoaster fenestra pseudoumbilica</i> (CN11)	135.2	15R-4, 48-49	A	M			F		C		R		F	
			141.3	15R, CC	A	M			F		C		R		F	
		141.5	16R-1, 23-24	A	M			F		C		R		F		
		<i>Reticulofenestra pseudoumbilica</i> (CN11)	142.8	16R-1, 147-148	A	M			C		C		A		R	
143.4			16R-2, 65-66	A	M			C		C		R		A		
143.8			16R-3, 54-55	A	M			C		C		A		C		
151.0	16R, CC		A	M			F		F		A		F			
<i>Sphenolithus neobies</i> (CN11a)	151.4	17R-1, 44-45	C	P			F		F		C		F			
	152.6	17R-2, 10-11	A	M			F		C		A		R			
early	<i>Ceratolithus rugosus</i> (CN10c)	154.4	17R-3, 39-40	A	M			F		C		A		F		
		154.9	17R-4, 39-40	A	M			R		F		C		R		
	<i>Amaurolithus tricorniculatus</i> (CN10)	160.7	17R, CC	A	M			R		R		F		C		
		160.9	18R-1, 20-21	A	M			F		F		C		R		
		161.1	18R-1, 37-38	A	M			R		C		C		F		
		161.8	18R-1, 96-97	A	M			F		R		C		R		
	162.6	18R-2, 27-28	A	G			F		F		R		C			
	<i>Triquetrorhabdulus rugosus</i> (CN10a)/ <i>Amaurolithus primus</i> (CN9b)	163.0	18R-2, 86-87	A	G			R		R		R		A		
		163.2	18R-2, 104-105	A	M			R		R		F		C		
		170.4	18R, CC	C	M			R		R		F		R		
		170.9	19R-1, 45-46	C	M			R		R		F		R		
	<i>Discoaster quinqueramus</i> (CN9)	171.3	19R-1, 96-97	A	M			C		C		A		C		
171.4		19R-1, 101-102	C	M			R		R		F		R			
172.4		19R-2, 45-46	C	M			R		R		C		R			
172.8		19R-2, 80-81	A	M			C		C		A		R			
<i>Discoaster berggrenii</i> (CN9a)	173.8	19R-3, 40-41	A	M			C		C		A		C			
	179.9	19R, CC	B													
	180.2	20R-1, 26-27	A	M			F		F		A		C			
	180.2	20R-1, 30-31	A	M			F		C		A		C			
	180.5	20R-1, 57-58	A	M			F		C		A		F			
	189.5	20R, CC	F	P			R		C		A		R			
III	?	?	?	189.6	21R-1, 8-9	B										

^a A = abundant; C = common; F = few; R = rare; B = barren.
^b P = poor; M = moderate; G = good.

Table 1 (continued).

<i>Discoaster pentaradiatus</i>	<i>Discoaster quinqueramus</i>	<i>Discoaster surculus</i>	<i>Discoaster lamalis</i>	<i>Discoaster triradiatus</i>	<i>Discoaster variabilis</i>	<i>Emiliana huxleyi</i>	<i>Gephyrocapsa caribbeanica</i>	<i>Gephyrocapsa oceanica</i>	<i>Gephyrocapsa</i> spp. (small)	<i>Helicosphaera carteri</i>	<i>Helicosphaera sellii</i>	<i>Mnylitha convalis</i>	<i>Pontosphaera japonica</i>	<i>Pontosphaera</i> sp.	<i>Pseudoemiliana lacunosa</i>	<i>Reiculofenestra pseudourbilica</i>	<i>Reiculofenestra</i> spp. (small)	<i>Rhabdosphaera claviger</i>	<i>Rhabdosphaera procera</i>	<i>Scapholithus fossilis</i>	<i>Sphenolithus</i> spp. (small)	<i>Syracosphaera pulchra</i>	<i>Triquetrorhabdulus rugosus</i>	<i>Umbilicosphaera sibogae</i>
					C	C	C	C	F							A	R							
							F	C	F							A							R	
								C	F						C	A	F							
								F	F					F	C	C	R	F						
								C	A					R	C	A	A	R						
								F	F					R	C	A	A	F						
								R	C					R	C	A	A	C						
								C	C					F	C	A	A	C		R				
								R	C					C	A	A	A	F						
								C	C					A	A	A	A	C						
								F	A					C	A	A	C							
								F	A					C	A	A	C							
								F	A					C	A	A	C							
								F	A					C	A	A	C							
								F	A					C	A	A	C							
								F	A					C	A	A	C							
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								F	A					C	A	A	C							
								F	A					C	A	A	C							
								F	A					C	A	A	C	</						

Table 2. Distribution of calcareous nannofossils, Hole 638B. Dashed lines indicate tentative zonal/subzonal boundaries; wavy lines indicate hiatuses.

Lithologic unit	Age	Zone/Subzone	Depth (mbsf)	Hole 638B (core, section, interval in cm)			<i>Amaurolithus amplifolius</i>	<i>Amaurolithus delicatus</i>	<i>Amaurolithus niinae</i>	<i>Amaurolithus primus</i>	<i>Calcidiscus leotoporius</i>	<i>Calcidiscus macintyreii</i>	<i>Ceratolithus cristatus</i>	<i>Ceratolithus rugosus</i>	<i>Coccolithus pelagicus</i>	<i>Discoaster asymmetricus</i>	<i>Discoaster brouweri</i>	<i>Discoaster decorus</i>	<i>Discoaster intercalaris</i>	<i>Discoaster loeblichii</i>	<i>Discoaster pansus</i>	<i>Discoaster pentaradiatus</i>	<i>Discoaster surculus</i>	<i>Discoaster tamalis</i>	<i>Discoaster triadriatus</i>	<i>Discoaster variabilis</i>						
I	early Pleistocene	<i>Calcidiscus macintyreii</i>	2.5	1R-2, 100-101	A	G																										
			5.1	1R-4, 56-57	A	G																										
			6.3	1R-5, 28-29	A	M																										
			6.7	2R-1, 34-35	A	G																										
			7.7	2R-1, 125-126	A	G																										
	late Pliocene	<i>Discoaster brouweri</i> (CN12)	<i>Discoaster tamalis</i> (CN12a)	8.2	2R-2, 47-48	A	G																									
				9.0	2R-2, 125-126	A	G																									
				10.1	2R-3, 66-67	A	M																									
				11.2	2R-4, 29-30	A	M																									
				12.1	2R-4, 119-120	A	M																									
				13.0	2R-5, 38-39	A	M																									
				13.6	2R-5, 121-122	C	P																									
				14.7	2R-6, 82-83	A	P																									
				16.0	2R, CC	A	M																									
				16.4	3R-1, 40-41	A	M																									
				16.9	3R-1, 93-94	A	M																									
				17.6	3R-2, 5-6	A	M																									
				25.5	3R, CC	A	M																									
				26.1	4R-1, 55-56	A	M																									
				27.2	4R-2, 20-21	A	M																									
				28.0	4R-2, 108-109	A	G																									
				29.4	4R-3, 92-93	A	M																									
				30.4	4R-4, 36-37	A	M																									
				31.1	4R-4, 108-109	A	M																									
				31.7	4R-5, 18-19	A	M																									
				33.6	4R-6, 61-62	A	M																									
				34.6	4R-7, 11-12	A	M																									
				early Miocene	<i>Ceratolithus rugosus</i> (CN10c)		35.2	4R, CC	A	M	R	R																				
							54.4	6R, CC	A	M																						
							54.8	7R-1, 39-40	A	M																						
							55.3	7R-2, 39-40	A	M	R	R	R	R																		
							60.6	7R-5, 15-16	A	M																						
							65.1	8R-1, 103-104	A	M																						
							70.9	8R-5, 76-77	A	M																						
							72.0	8R-6, 42-43	A	M																						
	73.6	8R-7, 45-46	A				M																									
	late Miocene	<i>Amaurolithus tricorniculatus</i> (CN10)	<i>Ceratolithus acutus</i> (CN10b)				84.1	9R, CC	B																							
							84.8	10R-1, 71-72	A	M	R	R	R																			
							85.7	10R-2, 14-15	A	M																						
							86.5	10R-2, 91-92	F	P																						
							87.3	10R-3, 17-18	A	M																						
							94.0	11R-1, 31-32	A	M																						
	late Miocene	<i>Discoaster quinqueramus</i> (CN9)	<i>Triquetrorhabdulus rugosus</i> (CN10a)/ <i>Amaurolithus primus</i> (CN9b)	97.0	11R-3, 25-26	A	M																									
				103.4	11R, CC	A	M	R	R																							
				104.4	12R-1, 103-104	A	G																									
				113.1	12R, CC	A	M																									
				113.9	13R-1, 75-76	A	M	R	R	R																						
				115.1	13R-2, 53-54	A	M																									
				116.3	13R-3, 17-18	A	M																									
				122.9	13R, CC	A	M																									
				123.3	14R-1, 37-38	A	P																									
				132.6	14R, CC	A	M																									
				133.0	15R-1, 35-36	A	M																									
				234.8	15R-2, 66-67	A	M	R																								
				137.8	15R-4, 65-66	A	M																									
				142.2	15R, CC	A	M	R																								
				142.6	16R-1, 38-39	A	M																									
				144.5	16R-2, 28-29	A	P																									
				147.7	16R-3, 21-22	A	M																									
				151.8	16R, CC	A	M	R	R	R	R																					
				152.0	17R-1, 20-21	A	M																									
				early Miocene	<i>Discoaster berggrenii</i> (CN9a)		154.3	17R-2, 96-97	A	M																						
	154.8	17R-2, 149-150	A				M																									
	161.5	18R-1, 0-1	R				P																									
	161.5	18R-1, 2-3	B																													
	162.1	18R-1, 55-56	B																													
	163.8	18R-2, 75-76	A				M																									
	165.1	18R-3, 57-59	A				M																									
	166.6	18R-4, 57-59	A				M																									
	168.2	18R-5, 67-68	A				M																									
	171.1	18R, CC	A				M																									
	171.2	19R-1, 13-14	A	G																												
	180.6	19R, CC	A	M																												

^a A = abundant; C = common; F = few; R = rare; B = barren.
^b P = poor; M = moderate; G = good.

ment of different ages, as indicated by the nannofossils and the variety of sediment types encountered. Section 103-641A-3R-1 through Sample 103-641A-6X-7, 27 cm, is barren of nannofossils.

SEDIMENT-ACCUMULATION RATES AND HIATUSES

Sediment-accumulation rate curves for Holes 637A and 638B are presented in Figures 4 and 5. The sediment-accumulation rates, uncorrected for compaction, were calculated by dividing the thickness of the sediment by time, as indicated by the nannofossil datums.

This study adopts the following ages for the calcareous nannofossil datum levels from the newly adjusted Neogene time scale of Berggren et al. (1985): FOD of *Amaurolithus delicatus*, 6.5 Ma; LOD of *Discoaster quinquerramus*, 5.6 Ma; LOD of *Triquetrorhabdulus rugosus*, 5.0 Ma; FOD of *Ceratolithus acutus*, 5.0 Ma; LOD of *C. acutus*, 4.57 Ma; FOD of *Ceratolithus rugosus*, 4.57 Ma; LOD of *Amaurolithus delicatus*, 3.7 Ma; LOD of *Reticulofenestra pseudoumbilica*, 3.5 Ma; LOD of *Discoaster tamalis*, 2.6 Ma; LOD of *Discoaster surculus*, 2.4 Ma; LOD of *Discoaster brouweri*, 1.9 Ma; LOD of *Calcidiscus macintyreii*, 1.45 Ma; LOD of *Helicosphaera sellii*, 1.37 Ma; highest level of dominantly small gephyrocapsids, 0.92 Ma; LOD of *Pseudo-*

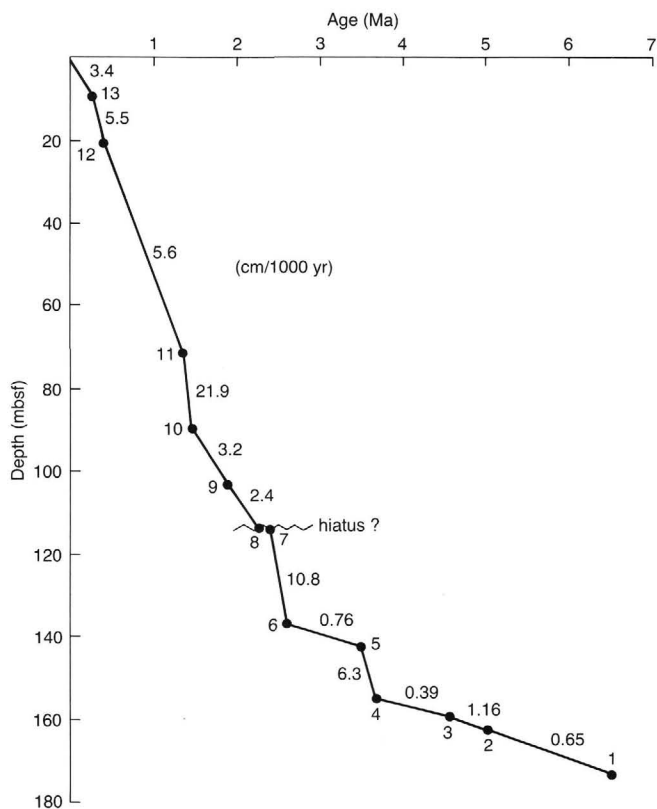


Figure 4. Sediment-accumulation rate diagram for Hole 637A based on nannofossil datums. 1 = FO *Amaurolithus delicatus*; 2 = LO *Triquetrorhabdulus rugosus*; 3 = FO *Ceratolithus acutus*; 4 = LO *Amaurolithus delicatus*; 5 = LO *Reticulofenestra pseudoumbilica*; 6 = LO *Discoaster tamalis*; 7 = LO *D. surculus*; 8 = LO *D. pentaradiatus*; 9 = LO *D. brouweri*; 10 = LO *Calcidiscus macintyreii*; 11 = LO *Helicosphaera sellii*; 12 = LO *Pseudoemiliania lacunosa*; 13 = FO *Emiliania huxleyi*. All of the datum ages are from Berggren et al. (1985) except that of LO *D. pentaradiatus*, which is taken from Backman and Shackleton (1983). Hiatus is denoted by a wavy line.

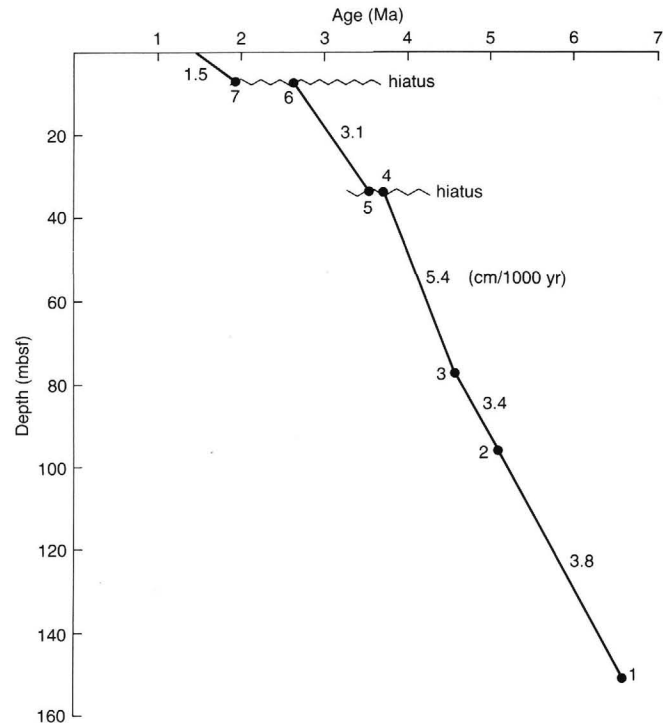


Figure 5. Sediment-accumulation rate diagram for Hole 638B based on nannofossil datums. 1 = FO *Amaurolithus delicatus*; 2 = LO *Triquetrorhabdulus rugosus*; 3 = FO *Discoaster asymmetricus*; 4 = LO *Amaurolithus delicatus*; 5 = *Reticulofenestra pseudoumbilica*; 6 = LO *Discoaster tamalis*; 7 = LO *D. brouweri*. All of the datum ages are from Berggren et al. (1985). Hiatuses are denoted by wavy lines.

emiliania lacunosa, 0.474 Ma; FOD of *Emiliania huxleyi*, 0.275 Ma; and FOD of *E. huxleyi* acme, 0.085 Ma (see Fig. 3). The age of the LOD of *Discoaster pentaradiatus* was taken from Backman and Shackleton (1983) because Berggren et al. (1985) gave it the same age as that of the LOD of *Discoaster surculus* (2.35 Ma), apparently not in agreement with the zonal concepts of Okada and Bukry (1980), which are followed in this paper.

The average sediment-accumulation rate for Hole 637A is 2.6 cm/1000 yr. The highest sediment-accumulation rate (21.9 cm/1000 yr) was observed for the *Helicosphaera sellii* Zone, which has a time span of 0.08 m.y. An unconformity may be present at a depth of about 114 m below seafloor (mbsf) because the *Discoaster pentaradiatus* Subzone (CN12c) was not observed. Lang and Wise (1987) recognized a similar hiatus at DSDP Site 604 (continental rise off New Jersey). The time represented by this hiatus coincides with the onset of Northern Hemisphere continental glaciation, which Backman (1979) and Shackleton and Kennett (1975) dated at about 2.4 to 2.5 Ma. It is also possible that the *D. pentaradiatus* Subzone was not sampled because this subzone represents a very short time period (0.05 m.y.), whereas the sampling interval here is 1.25 m.

The sediment-accumulation rate curve for Hole 638B is presented in Figure 5. The average sediment-accumulation rate for the post-Miocene section at this site is 1.9 cm/1000 yr. The sediment-accumulation rates for each of the nannofossil zones are close to the average rate at this site. As discussed in "Site 638" chapter (Shipboard Scientific Party, 1987b), the missing upper Pleistocene section in Hole 638B could be present in the 6 m that was not cored. However, even if the 6 m of sediment were added to the sediment-accumulation rate calculation for the Pleistocene, the rate would still be low (0.7 cm/1000 yr). This is in contrast with that in Hole 637A, where the sediment-accumulation rate is high for the entire Pleistocene section (average 5.4

cm/1000 yr). Therefore, a large part of Pleistocene section at Site 638 could be missing. This may indicate strong bottom currents in this valley during the Pleistocene, and nondeposition and removal of sediment must have occurred.

A major hiatus is recognized at and below the Pliocene/Pleistocene boundary at a depth between 6.7 and 7.7 mbsf. The minimum time represented by this hiatus is 0.77 m.y. Another hiatus in Hole 638B is present at a depth of about 35 mbsf, where the *Reticulofenestra pseudoumbilica* Zone (CN11) is missing. The time span of the nannofossil zone is from 3.7 to 3.5 Ma. The hiatus may include parts of both the zones above and below the *R. pseudoumbilica* Zone. This hiatus coincides in time with the event when the Gulf Stream increased its intensity due to the uplifting of the Isthmus of Panama, thereby closing the marine connection between the Atlantic and Pacific oceans (Berggren and Hollister, 1974; Saito, 1976; Keigwin, 1982).

COCCOLITHUS PELAGICUS/DISCOASTER BROUWERI RATIOS AND THEIR IMPLICATIONS

Coccolithus pelagicus prefers cool waters, whereas *Discoaster brouweri* thrived in warmer waters (McIntyre et al., 1970; Bukry, 1971, 1973; Siesser, 1975; Haq, 1980). The abundance ratio of *Coccolithus pelagicus* abundance to that of *D. brouweri* may therefore provide an estimate of the relative paleotemperature changes of the surface water.

The use of this ratio has the following advantages:

1. Both *C. pelagicus* and *D. brouweri* have long stratigraphic ranges. *C. pelagicus* ranges from the Paleocene to the present and *D. brouweri* from the early late Miocene through the Pliocene, which enables observation of their abundance changes over a relatively long time span.
2. *C. pelagicus* is among the most common species present in most oceanic sediment, whereas *D. brouweri* is usually one of the most common warm-water species in most deep-sea sediment. Therefore, observation of them is easy and consistent.
3. Both species are among the most dissolution-resistant forms (Bukry, 1973; Wise, 1973; Roth et al., 1975). Thus, they are less subject to diagenetic effects and better represent the original environment.
4. The use of the abundance ratio of *C. pelagicus* to *D. brouweri* instead of their absolute abundance in the sediment filters out variation in sediment-accumulation rates, variation in slide thickness, dissolution bias, and other factors so that the ratio values are a better reflection of the paleotemperature of the surface waters.

The *C. pelagicus/D. brouweri* ratios for Holes 637A and 638B have been plotted in Figures 6 and 7.

It is interesting to note from Figure 6 that between 6.5 and 2.5 Ma, *C. pelagicus/D. brouweri* ratio values are low, fluctuate little, and are quite similar in trend to the stable isotopic records from the North Pacific (Keigwin, 1979), equatorial Pacific (Keigwin, 1979, 1982), South Atlantic (Leonard et al., 1983), Caribbean (Keigwin, 1982), and Mediterranean (Thunell and Williams, 1983), which suggests a relatively higher and stable surface-water temperature at Site 637 for that time.

After about 2.5 Ma, *C. pelagicus/D. brouweri* ratio values increase sharply and fluctuate widely. This change coincides in time with the deposition of the oldest ice-rafted debris in the northern Atlantic Ocean (Backman, 1979) and the oldest loess deposits in China (Heller and Li, 1984) and may therefore be related to the onset of widespread Northern Hemisphere glaciation (Shackleton and Kennett, 1975). The fluctuation of ratio values in the late Pliocene may be due to multiple glacial-interglacial cycles.

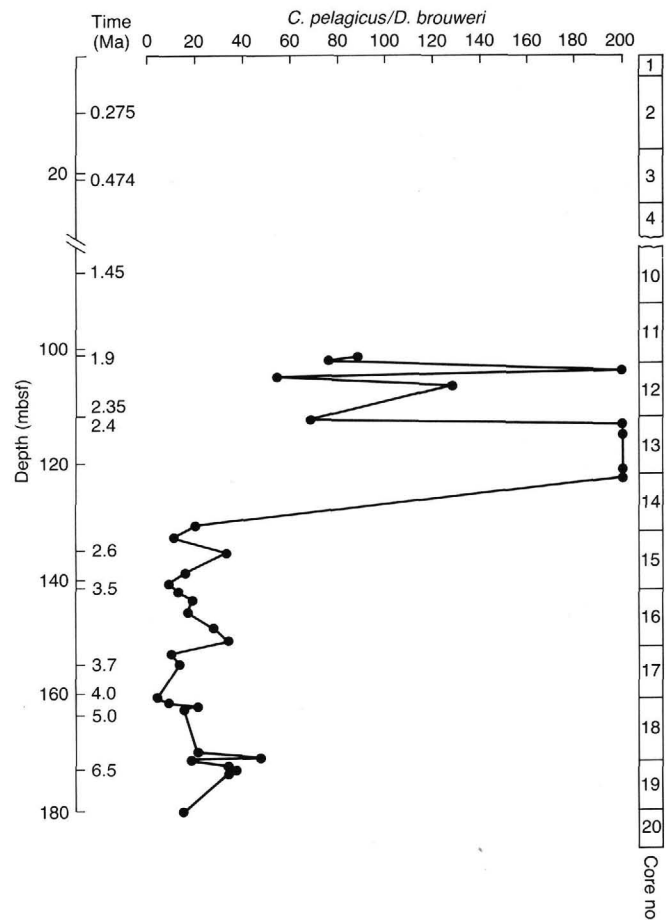


Figure 6. *Coccolithus pelagicus/Discoaster brouweri* ratio diagram for Hole 637A. Ratios plotted at a value of 200 indicate samples in which 200 specimens of *C. pelagicus* were counted without encountering *D. brouweri* during random track counting. Ages are from Berggren et al. (1985).

C. pelagicus/D. brouweri ratios for Hole 638B presented in Figure 7 show many fluctuations, though the general trend is that the ratios increase with time in the late Miocene and early Pliocene. With the data presently available, it is very difficult to interpret these fluctuations. The ratio record of Hole 638B differs from that of Hole 637A, as do the sediment-accumulation rates and nannofossil species abundances. Meaningful interpretation of these differences can not be made until more data are available.

SUMMARY

Two holes (637A and 638B) from the ODP Leg 103 yielded significant Cenozoic sedimentary sections ranging from late Miocene to late Pleistocene in age. Calcareous nannofossils are abundant or common and moderately well preserved in most of the samples examined. Nannofossil zones were determined for the midlatitude area drilled using a modification of the schemes proposed by Bukry (1973, 1985), Okada and Bukry (1980), and Gartner (1977). Two emendations of their schemes are made: the datum level marked by the beginning of the acme of *Discoaster asymmetricus* is replaced by the FOD of *Pseudoemiliania lacunosa* and the FOD of *Amaurolithus delicatus* is substituted for that of *A. primus*. In Hole 637A, all of the nannofossil zones or subzones from *Discoaster quinqueramus* Zone (CN9)

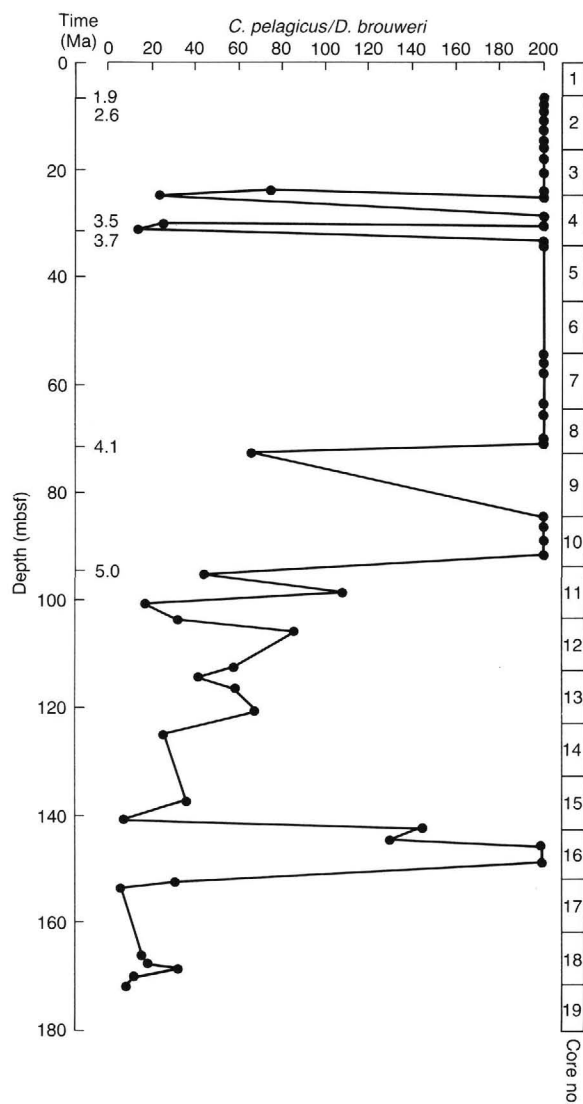


Figure 7. *Coccolithus pelagicus/Discoaster brouweri* ratio diagram for Hole 638B. Ratios plotted at a value of 200 indicate samples in which 200 specimens of *C. pelagicus* were counted without encountering *D. brouweri* during random track counting. Ages are from Berggren et al. (1985).

to *Emiliania huxleyi* Zone are present, except for the *Discoaster pentaradiatus* Subzone (CN12c). Cenozoic nannofossil zones from *D. quinqueramus* Zone to the *Calcidiscus macintyreii* Zone are identified in Hole 638B. Two major hiatuses, one at 1.9–2.6 Ma and another at 3.5–3.7 Ma, are present in Hole 638B. Sediment-accumulation rates for Holes 637A and 638B have been calculated based on the ages of nannofossil datums taken from Berggren et al. (1985) and Backman and Shackleton (1983). The variation in abundance of the cool-water species *Coccolithus pelagicus* and that of warm-water species *Discoaster brouweri* have been observed for Holes 637A and 638B. The *C. pelagicus/D. brouweri* ratios from Hole 637A show relatively lower, stable values between 6.5 to 2.5 Ma, indicating relatively higher and stable surface-water temperature at that time. Beginning at about 2.5 Ma, the *C. pelagicus/D. brouweri* ratio values sharply increase and fluctuate widely, suggesting relatively lower and unstable surface-water temperatures. This change coincides in time with the onset of widespread Northern Hemisphere glaciation. The fluctuation of the *C. pelagicus/D. brouweri* ratios during the

late Pliocene may be related to the multiglacial-interglacial cycles. The *C. pelagicus/D. brouweri* ratios from Hole 638B also show increasing values with time from the late Miocene to the late Pliocene but show much more fluctuation and a different pattern than the record of Hole 637A.

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APPENDIX A

Nannofossil Species Considered in this Paper

Most of the bibliographic references for the taxa are presented by Loeblich and Tappan (1968, 1969, 1970a, 1970b, 1971, 1973), van Heck (1979a, 1979b, 1980a, 1980b, 1981a, 1981b, 1982a, 1982b, 1983), and Steinmetz (1984a, 1984b, 1985a, 1985b). Any references not included in these are included in the references of this paper.

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- Amaurolithus delicatus* Gartner and Bukry, 1975
- Amaurolithus primus* (Bukry and Percival) Gartner and Bukry, 1975
- Amaurolithus ninae* Perch-Nielsen, 1977
- Amaurolithus tricorniculatus* (Gartner) Gartner and Bukry, 1975
- Calcidiscus leptoporus* (Murray and Blackman) Loeblich and Tappan, 1978
- Calcidiscus macintyre* (Bukry and Bramlette) Loeblich and Tappan, 1978
- Ceratolithus acutus* Gartner and Bukry, 1974
- Ceratolithus cristatus* Kamptner, 1950
- Coccolithus pelagicus* (Wallich) Schiller, 1930
- Discoaster asymmetricus* Gartner, 1969
- Discoaster berggrenii* Bukry, 1971
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