Ruddiman, W., Sarnthein M., et al., 1989
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 108

28. BIOSTRATIGRAPHIC SYNTHESIS: LEG 108, EASTERN EQUATORIAL ATLANTIC[1]

P.P.E. Weaver,[2] J. Backman,[3] J. G. Baldauf,[4] J. Bloemendal,[5] H. Manivit,[6] K. G. Miller,[7,8] E. M. Pokras,[8] M. E. Raymo,[8] L. Tauxe,[9] J.-P. Valet,[10] A. Chepstow-Lusty,[11] and G. Olafsson[3]

ABSTRACT

Leg 108 cored 12 sites in the eastern equatorial Atlantic and along the northwest African continental margin to investigate the late Neogene and Quaternary oceanographic and climatic history of these regions. Sediments recovered during Leg 108 provide in part a high-resolution stratigraphic record for the upper Pliocene through Holocene interval. The bio- and magnetostratigraphy are intercalibrated where possible and provide a useful chronostratigraphy for paleoceanographic studies.

INTRODUCTION

The objective of Ocean Drilling Program (ODP) Leg 108 was to retrieve Neogene sediment using advanced hydraulic piston core/extended core barrel (APC/XCB) techniques for high-resolution paleoclimatic studies along a latitudinal transect in the eastern equatorial Atlantic. This data was required to complete the latitudinal transect of cores taken in the North Atlantic during Deep Sea Drilling Project (DSDP) Leg 94 and to investigate other questions associated with the response of surface productivity and eolian input to changing climatic and oceanographic conditions. In addition, this program was ideal for establishing biostratigraphic reference sections in undisturbed Neogene sediment cores from the low-latitude Atlantic Ocean.

Another major objective was to establish a high-resolution paleomagnetic stratigraphy, thus providing the first opportunity to investigate and evaluate the chronologic properties of biostratigraphic marker events in pre-upper Pliocene sediments from the low-latitude Atlantic Ocean. Considering the substantial number of DSDP/ODP sites that have been drilled in the Atlantic Ocean and the prominence of the low-latitude Atlantic regions in the history of paleoceanography, surprisingly little sediment has been cored with the APC/XCB tools. The sediments cored during Leg 108 represent the only APC material available from tropical or equatorial environments of the Atlantic Ocean.

Leg 108 sailed less than a year after Berggren et al. (1985a, 1985b) published their attempt to establish a Cenozoic geochronology and a thorough compilation of correlations between Cenozoic bio- and magnetostratigraphy, encompassing most important marine microfossil groups. When the authors published their correlations, they clearly suffered from a lack of adequate magnetostratigraphic sections representing equatorial environments even in the Neogene realm. Consequently, the bio- and magnetostratigraphers on Leg 108 anticipated being able to provide this missing low-latitude bio- and magnetostratigraphy.

With respect to calcareous nannofossil biostratigraphy, our interest was focused on the time interval preceding the top of the Thvera Subchron (prior to about 4.6 Ma). Pleistocene and Pliocene calcareous nannofossil marker events that have occurred since then have been directly correlated to oxygen isotope stratigraphy (e.g., Thierstein et al., 1977) or to magnetostratigraphy (e.g., Backman and Shackleton, 1983) in numerous piston cores from low-latitude regions. Therefore, we saw little reason to expect substantial revision, on the order of 5%–10% or more, in the age estimates of Pliocene-Pleistocene calcareous nannofossil markers, as viewed within the frame of the marine magnetic anomaly time scale of Berggren et al. (1985a, 1985b).

In many early DSDP legs, planktonic foraminifers were regarded as more important than calcareous nannofossils for biostratigraphy. Recent investigations, such as those of Weaver and Clement (1987) and Hodell and Kennett (1986), however, have shown that many late Neogene species have diachronous first and last occurrences, and it has become important to test the accuracy of these datums against the paleomagnetic record in as many areas as possible. Because many of the original data were collected in tropical regions, we hoped that Leg 108 would provide important additional data, particularly from sites lying in the tropics but under the influence of cool surface currents. The ages of datum levels below the Miocene/Pliocene boundary are less well defined; thus, all additional data from paleomagnetically dated cores in this interval are of importance.

Considerable problems were encountered in obtaining good paleomagnetic records during Leg 108. These included the combined effects of low magnetic intensities, the occurrence of slumps and turbidites, the recovery of condensed sequences, improperly functioning core-orienting devices,

[1] Ruddiman, W., Sarnthein, M., et al., 1989. *Proc. ODP, Sci. Results*, 108: College Station, TX (Ocean Drilling Program).
[2] Institute of Oceanographic Sciences, Brook Road, Wormley, Godalming, Surrey GU8 5UB, United Kingdom.
[3] Department of Geology, University of Stockholm, S-10691 Stockholm, Sweden.
[4] Ocean Drilling Program, Texas A&M University, 1000 Discovery Drive, College Station, TX 77843.
[5] Graduate School of Oceanography, University of Rhode Island, Narragansett Bay Campus, Narragansett, RI 02882.
[6] CNRS-UA 319, Laboratoire de Stratigraphie des Continents et Océans, Université Paris IV, 4 Place Jussieu, 75230 Paris Cedex, France.
[7] Department of Geological Sciences, Rutgers University, New Brunswick, NJ 08903.
[8] Lamont-Doherty Geological Observatory, Columbia University, Palisades, NY 10964.
[9] Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093.
[10] Centre des Faibles Radioactivités, Laboratoire Mixte CNRS-CEA, Parc du CNRS, B. P. 91198, Gif/Yvette Cedex, France.
[11] Godwin Laboratory, Subdepartment of Quaternary Research, University of Cambridge, Cambridge CB2 3RS, United Kingdom.

and magnetic overprinting. In fact, we were only able to define and identify magnetostratigraphic polarity zones in the Pliocene-Pleistocene interval. These paleomagnetically dated intervals strengthen our interpretation of Pliocene-Pleistocene stratigraphy by adding Atlantic tropical sites to the relatively small number of DSDP and ODP sites with independent age control. The lack of paleomagnetic signals in pre-Pliocene sediments, however, does little to improve the dating of biostratigraphic datum levels in these older sequences.

RESULTS

The biostratigraphic results, together with some previously unpublished Leg 108 data, have been compiled into tables showing first or last occurrences of biostratigraphic marker species, and the sub-bottom depth intervals assigned for these marker events (Tables 1–3). In the *Proceedings of the Ocean Drilling Program, Initial Results* volume (Ruddiman, Sarnthein, et al., 1988), we outline the stratigraphic scheme used to determine stratigraphic ages in these sites. For calcareous nannofossils, planktonic foraminifers, and paleomagnetics, this largely follows Berggren et al. (1985a, 1985b). Departures from the Berggren dates are discussed in the "Introduction" chapter of the *Initial Results* volume. Where paleomagnetic data were available, it has been possible to assess the accuracy of the microfossil datum levels. Where paleomagnetic data were not available, we were forced to rely on the biostratigraphy alone.

Calcareous nannofossil ages are well established throughout the Pliocene and Quaternary, but there are several problems in pre-Pliocene sediments. Unfortunately, we did not identify any paleomagnetic boundaries below the Pliocene and so these biostratigraphic problems could not be resolved. The planktonic foraminiferal datum levels are also unreliable in pre-Pliocene sediments, and our accumulation rate curves are therefore based on best-fit criteria.

Since the pre-Pliocene accumulation rates may be subject to error, it is difficult to use them to assess the accuracy of biostratigraphic datum levels. It is generally accepted, however, that calcareous nannofossils give more reliable age information than planktonic foraminifers, and the accumulation rate curves do fit more calcareous nannofossil datum points than planktonic foraminiferal ones. Therefore, we have given age estimates throughout of the planktonic foraminifers derived from the accumulation rate curves (Table 3). A comparison between Tables 1 and 3 will indicate where paleomagnetic control of this data existed.

OCCURRENCE OF MAJOR GROUPS

Of the 12 sites cored during Leg 108 (Fig. 1), 8 did not penetrate below the upper Miocene; the deepest site, however, penetrated into the Upper Cretaceous. Figures 2 and 3

Table 1. Stratigraphic placement in meters (to the nearest decimeter) of the Leg 108 chron and subchron boundaries.

Site and time zone	Age (Ma)	Depth (mbsf)
108-657B-		
Brunhes/Matuyama	0.73	29.0
Jaramillo (upper)	0.91	30.7–34.7
Jaramillo (lower)	0.98	36.2
Matuyama/Gauss	2.47	72.1–73.7
108-658A-		
Olduvai (upper)	1.66	109.2–109.8
Olduvai (lower)	1.88	124.1–129.7
108-658B-		
Olduvai (upper)	1.66	108.2
Olduvai (lower)	1.88	126.2
108-659A-		
Brunhes/Matuyama	0.73	22.8
Jaramillo (upper)	0.91	28.6
Jaramillo (lower)	0.98	31.0
108-659B-		
Jaramillo (upper)	0.91	26.4
Jaramillo (lower)	0.98	29.3
Olduvai (upper)	1.66	47.8
Olduvai (lower)	1.88	52.4
Matuyama/Gauss	2.47	74.7
108-660A-		
Brunhes/Matuyama	0.73	18.5
Jaramillo (upper)	0.91	22.9
Jaramillo (lower)	0.98	24.6
Olduvai (upper)	1.66	36.4
Olduvai (lower)	1.88	28.4
108-661A-		
Brunhes/Matuyama	0.73	10.5–12.7
Jaramillo (upper)	0.91	14.8
Jaramillo (lower)	0.98	16.0
Olduvai (upper)	1.66	26.1–26.7
Matuyama/Gauss	2.47	36.8
108-661B-		
Brunhes/Matuyama	0.73	13.1–15.7
Jaramillo (upper)	0.91	—
Jaramillo (lower)	0.98	—
Olduvai (upper)	1.66	25.4
Olduvai (lower)	1.88	30.2
Matuyama/Gauss	2.47	36.2
Gauss/Gilbert	3.40	52.5
108-664B-		
Brunhes/Matuyama	0.73	27.0
Jaramillo (upper)	0.91	35.5
108-664C-		
Brunhes/Matuyama	0.73	25.9
Jaramillo (upper)	0.91	34.5
Jaramillo (lower)	0.98	37.6
108-664D-		
Brunhes/Matuyama	0.73	27.9
Jaramillo (upper)	0.91	35.8
Jaramillo (lower)	0.98	38.2
108-665A-		
Brunhes/Matuyama	0.73	14.8
Jaramillo (upper)	0.91	19.3
Jaramillo (lower)	0.98	21.0
Olduvai (upper)	1.66	33.2
Olduvai (lower)	1.88	36.4
Matuyama/Gauss	2.47	49.1
108-665B-		
Brunhes/Matuyama	0.73	13.8
Jaramillo (upper)	0.91	16.9
Jaramillo (lower)	0.98	18.7
Olduvai (upper)	1.66	32.6
Olduvai (lower)	1.88	34.3–35.0
Matuyama/Gauss	2.47	49.1
108-666A-		
Brunhes/Matuyama	0.73	18.4
Olduvai (upper)	0.91	34.4–37.1
Olduvai (lower)	0.98	45.0
Matuyama/Gauss	2.47	77.6
108-668B-		
Brunhes/Matuyama	0.73	12.1–15.3
Olduvai (upper)	0.91	27.6
Olduvai (lower)	0.98	29.8

Table 2. Stratigraphic placement in meters of calcareous nannofossil events from Leg 108 sites and their assigned ages.

Species	Age (Ma)	Depth (mbsf)
108-657A-		
FO *Emiliania huxleyi*	0.27	0.9–3.3
LO *Pseudoemiliania lacunosa*	0.46	0.9–3.3
LO *Calcidiscus macintyrei*	1.45	50.2–51.0
LO *Discoaster brouweri*	1.89	55.2–61.2
FO acme *Discoaster triradiatus*	2.07	61.9–62.8
LO *Discoaster pentaradiatus*	2.35	59.7–68.5
LO *Discoaster surculus*	2.45	—
LO *Discoaster tamalis*	2.65	69.2–78.8
LO *Sphenolithus* spp.	3.45	88.2–97.7
LO *Reticulofenestra pseudoumbilica*	3.56	98.1–98.9
LO *Amaurolithus* spp.	3.7	97.9–103.6
FO *Ceratolithus rugosus*	4.6	135.7–146.0
FO *Ceratolithus acutus*	5.0	135.7–146.0
LO *Discoaster quinqueramus*	5.6	135.7–146.0
LO *Amaurolithus amplificus*	5.6	145.2–146.0
FO *Amaurolithus amplificus*	5.9	148.1–150.0
FO *Amaurolithus primus*	6.5	150.0–154.8
FO *Discoaster quinqueramus*	8.2	150.0–154.8
108-658A-		
FO *Emiliania huxleyi*	0.27	34.2–43.7
LO *Pseudoemiliania lacunosa*	0.46	68.7–70.2
LO *Calcidiscus macintyrei*	1.45	99.1–99.4
LO *Discoaster brouweri*	1.89	124.7–126.9
FO acme *Discoaster triradiatus*	2.07	135.0–145.0
LO *Discoaster pentaradiatus*	2.35	165.3–165.7
LO *Discoaster surculus*	2.45	165.8–166.2
LO *Discoaster tamalis*	2.65	197.7–201.3
LO *Sphenolithus* spp.	3.45	281.4–290.9
108-659B-		
LO *Pseudoemiliania lacunosa*	0.46	7.8–8.1
LO *Calcidiscus macintyrei*	1.45	45.8–55.3
LO *Discoaster brouweri*	1.89	54.7–55.9
FO acme *Discoaster triradiatus*	2.07	59.8–61.3
LO *Discoaster pentaradiatus*	2.35	70.6–70.8
LO *Discoaster surculus*	2.45	70.9–71.1
LO *Discoaster tamalis*	2.65	78.5–80.0
LO *Sphenolithus* spp.	3.45	104.1–112.4
LO *Reticulofenestra pseudoumbilica*	3.56	104.1–112.4
LO *Amaurolithus* spp.	3.7	123.3–124.8
FO *Ceratolithus rugosus*	4.6	136.4–143.1
FO *Ceratolithus acutus*	5.0	148.8–151.1
LO *Discoaster quinqueramus*	5.6	148.8–151.1
FO *Amaurolithus primus*	6.5	159.8–178.8
FO *Discoaster quinqueramus*	8.2	182.6–184.8
LO *Discoaster hamatus*	8.9	188.3–191.7
FO *Catinaster calyculus*	10.0	191.7–199.1
FO *Discoaster hamatus*	10.0	191.7–199.1
FO *Catinaster coalitus*	10.8	199.1–200.7
LO *Cyclicargolithus floridanus*	11.6	211.7–212.9
FO *Triquetrorhabdulus rugosus*	14.0	211.7–212.9
LO *Sphenolithus heteromorphus*	14.4	212.9–214.4
LO *Helicosphaera ampliaperta*	16.0	229.1–232.3
FO *Sphenolithus heteromorphus*	17.1	235.8–245.3
LO *Sphenolithus belemnos*	17.4	235.8–245.3
FO *Sphenolithus belemnos*	21.5	245.3–246.7
LO *Triquetrorhabdulus carinatus*	?	245.3–246.7
FO *Discoaster druggii*	23.2	246.7–248.6
LO *Sphenolithus ciperoensis*	25.2	252.1–254.8
108-660A-		
LO *Pseudoemiliania lacunosa*	0.46	11.3–16.5
LO *Calcidiscus macintyrei*	1.45	32.3–33.1
LO *Discoaster brouweri*	1.89	39.8–40.9
FO acme *Discoaster triradiatus*	2.07	41.6–42.7
LO *Discoaster pentaradiatus*	2.35	45.7–47.2
LO *Discoaster surculus*	2.45	47.2–48.7
LO *Discoaster tamalis*	2.65	53.0–54.5
LO *Sphenolithus* spp.	3.45	61.9–63.4
LO *Reticulofenestra pseudoumbilica*	3.56	63.4–64.9
FO *Ceratolithus rugosus*	4.6	71.9–74.5
LO *Discoaster quinqueramus*	5.6	74.5–76.5
108-661A-		
LO *Pseudoemiliania lacunosa*	0.46	5.3–8.5
LO *Calcidiscus macintyrei*	1.45	21.4–22.9

Table 2 (continued).

Species	Age (Ma)	Depth (mbsf)
LO *Discoaster brouweri*	1.89	27.7–28.9
FO acme *Discoaster triradiatus*	2.07	30.0–30.9
LO *Discoaster pentaradiatus*	2.35	33.9–35.4
LO *Discoaster surculus*	2.45	35.4–36.9
LO *Discoaster tamalis*	2.65	40.5–41.6
LO *Sphenolithus* spp.	3.45	51.5–52.4
LO *Reticulofenestra pseudoumbilica*	3.56	53.0–54.5
LO *Amaurolithus* spp.	3.7	54.6–56.0
FO *Ceratolithus rugosus*	4.6	65.1–67.0
FO *Ceratolithus acutus*	5.0	67.0–69.0
LO *Discoaster quinqueramus*	5.6	68.2–69.0
LO *Amaurolithus amplificus*	5.6	69.0–71.6
FO *Amaurolithus amplificus*	5.9	71.6–73.1
FO *Amaurolithus primus*	6.5	73.1–77.6
FO *Discoaster quinqueramus*	8.2	78.3–78.7
LO *Discoaster hamatus*	8.9	81.9–82.1
FO *Catinaster calyculus*	10.0	82.6–?
FO *Micula prinsii*	66.6	107.1–107.5
FO *Micula murus*	68.7	114.5–115.6
LO *Quadrum trifidum*	72.3	124.0–124.9
108-662A-		
FO *Emiliania huxleyi*	0.27	4.1–4.8
LO *Pseudoemiliania lacunosa*	0.46	21.7–22.2
LO *Calcidiscus macintyrei*	1.45	106.8–108.5
LO *Discoaster brouweri*	1.89	122.2–123.2
FO acme *Discoaster triradiatus*	2.07	130.4–133.5
LO *Discoaster pentaradiatus*	2.35	148.3–152.1
LO *Discoaster surculus*	2.45	151.3–151.5
LO *Discoaster tamalis*	2.65	159.5–160.5
LO *Sphenolithus* spp.	3.45	189.7–193.9
LO *Reticulofenestra pseudoumbilica*	3.56	193.9–196.7
108-663A-		
FO *Emiliania huxleyi*	0.27	4.3–5.8
LO *Pseudoemiliania lacunosa*	0.46	14.5–15.8
LO *Calcidiscus macintyrei*	1.45	48.2–61.9
LO *Discoaster brouweri*	1.89	103.1–103.7
FO acme *Discoaster triradiatus*	2.07	109.8–111.7
LO *Discoaster pentaradiatus*	2.35	133.0–135.0
LO *Discoaster surculus*	2.45	135.0–138.6
LO *Discoaster tamalis*	2.65	141.6–143.2
108-664D-		
LO *Pseudoemiliania lacunosa*	0.46	14.9–16.4
LO *Calcidiscus macintyrei*	1.45	59.3–68.8
LO *Discoaster brouweri*	1.89	68.8–78.3
FO acme *Discoaster triradiatus*	2.07	89.6–92.6
LO *Discoaster pentaradiatus*	2.35	99.4–102.4
LO *Discoaster surculus*	2.45	97.3–106.8
LO *Discoaster tamalis*	2.65	116.3–125.8
LO *Sphenolithus* spp.	3.45	157.0–160.0
LO *Reticulofenestra pseudoumbilica*	3.56	163.0–163.8
LO *Amaurolithus* spp.	3.7	?–192.3
FO *Ceratolithus rugosus*	4.6	203.4–207.9
FO *Ceratolithus acutus*	5.0	222.6–227.1
LO *Discoaster quinqueramus*	5.6	227.1–231.9
LO *Amaurolithus amplificus*	5.6	231.9–236.2
FO *Amaurolithus amplificus*	5.9	250.9–255.6
FO *Amaurolithus primus*	6.5	260.4–263.4
FO *Discoaster quinqueramus*	8.2	282.5–285.5
LO *Discoaster hamatus*	8.9	294.4–295.9
FO *Catinaster calyculus*	10.0	296.8–?
FO *Discoaster hamatus*	10.0	294.4–295.9
108-665A-		
LO *Pseudoemiliania lacunosa*	0.46	8.9–9.5
LO *Calcidiscus macintyrei*	1.45	29.9–30.7
LO *Discoaster brouweri*	1.89	35.6–36.8
FO acme *Discoaster triradiatus*	2.07	39.6–39.8
LO *Discoaster pentaradiatus*	2.35	45.5–47.0
LO *Discoaster surculus*	2.45	47.0–48.5
LO *Discoaster tamalis*	2.65	50.7–51.2
LO *Sphenolithus* spp.	3.45	63.8–64.4
LO *Reticulofenestra pseudoumbilica*	3.56	65.0–65.4
LO *Amaurolithus* spp.	3.7	67.1–69.9
FO *Ceratolithus rugosus*	4.6	72.7–73.8

Table 2 (continued).

Species	Age (Ma)	Depth (mbsf)
108-666A-		
LO *Pseudoemiliania lacunosa*	0.46	9.1–10.6
LO *Calcidiscus macintyrei*	1.45	32.9–33.3
LO *Discoaster brouweri*	1.89	46.0–48.6
FO acme *Discoaster triradiatus*	2.07	51.6–54.5
LO *Discoaster pentaradiatus*	2.35	67.0–68.3
LO *Discoaster surculus*	2.45	70.0–75.7
LO *Discoaster tamalis*	2.65	75.7–86.9
LO *Sphenolithus* spp.	3.45	123.1–126.3
LO *Reticulofenestra pseudoumbilica*	3.56	123.1–126.3
LO *Amaurolithus* spp.	3.7	126.3–131.5
FO *Ceratolithus rugosus*	4.6	144.9–150.5
FO *Ceratolithus acutus*	5.0	150.5–?
108-667A-		
LO *Pseudoemiliania lacunosa*	0.46	6.6–6.9
LO *Calcidiscus macintyrei*	1.45	16.5–29.8
LO *Discoaster brouweri*	1.89	16.5–29.8
FO acme *Discoaster triradiatus*	2.07	16.5–29.9
LO *Discoaster pentaradiatus*	2.35	32.2–33.8
LO *Discoaster surculus*	2.45	35.1–37.0
LO *Discoaster tamalis*	2.65	40.5–41.7
LO *Sphenolithus* spp.	3.45	48.8–49.6
LO *Reticulofenestra pseudoumbilica*	3.56	49.6–54.2
LO *Amaurolithus* spp.	3.7	58.3–67.8
FO *Ceratolithus rugosus*	4.6	75.8–78.3
FO *Ceratolithus acutus*	5.0	79.7–85.1
LO *Discoaster quinqueramus*	5.6	84.2–85.1
FO *Amaurolithus primus*	6.5	106.8–108.3
FO *Discoaster quinqueramus*	8.2	118.3–120.0
LO *Cyclicargolithus floridanus*	11.6	157.9–158.3
FO *Triquetrorhabdulus rugosus*	14.0	157.6–158.0
LO *Sphenolithus heteromorphus*	14.4	160.3–160.9
LO *Helicosphaera ampliaperta*	16.0	166.2–166.6
FO *Sphenolithus heteromorphus*	17.1	207.7–208.0
LO *Sphenolithus belemnos*	17.4	211.3–211.7
FO *Sphenolithus belemnos*	21.5	244.7–229.8
LO *Triquetrorhabdulus carinatus*	?	251.4–251.8
FO *Discoaster druggii*	23.2	250.4–257.8
LO *Sphenolithus ciperoensis*	25.2	293.0–293.4
LO *Sphenolithus distentus*	28.2	343.3–352.2
FO *Sphenolithus ciperoensis*	30.2	364.8–376.0
108-668B-		
LO *Pseudoemiliania lacunosa*	0.46	8.5–10.0
LO *Calcidiscus macintyrei*	1.45	22.8–24.6
LO *Discoaster brouweri*	1.89	29.6–30.1
FO acme *Discoaster triradiatus*	2.07	31.2–?

Note: Ages are as presented in Ruddiman, Sarnthein, et al., 1988. FO = first occurrence and LO = last occurrence.

show the intervals that were cored at each site and indicate the stratigraphic occurrence of the major microfossil groups (calcareous nannofossils, planktonic and benthic foraminifers, and diatoms), together with the intervals in which paleomagnetic results can be regarded as reliable. One can see from the distributions that the paleomagnetic signals were only detected between 0 and 2.5 or 3 Ma in most cases and only reach the Gauss/Gilbert boundary in Hole 661B.

The most complete biostratigraphic records are also limited to the Pliocene to Holocene interval, although there is some information from the Miocene and Oligocene, particularly from Sites 659 and 667. The Eocene was cored at Site 660. Although no calcareous microfossils were found in these cores, middle Eocene diatoms and radiolarians do occur. Site 661 drilled through to the Upper Cretaceous, which was recognized on the basis of its calcareous nannofossil flora.

Calcareous nannofossils are the most widely distributed group in Leg 108 sites. Although this group suffers dissolution and the placoliths disappear along with the foraminifers, the discoasters survive longer and frequently provide stratigraphic information in strongly dissolved intervals. Calcareous nannofossils were completely absent below the uppermost part of the upper Miocene at Site 660, from the middle Miocene to the lowermost Pliocene at Site 661, and below the lower Pliocene at Site 665.

Manivit (this vol.) has provided a site-by-site description of the calcareous nannofossil biostratigraphy, including range charts that show the stratigraphic distribution of the total assemblages and the critical marker species. She also discussed the general character of preservation, abundance, and diversity of the nannofossil assemblages, with respect to the environmental setting of the individual sites.

Chepstow-Lusty et al. (this vol.) and Olafsson (this vol.) provided quantitative studies of calcareous nannofossils from the late Pliocene of Sites 658, 659, and 662 and the Oligocene to middle Miocene of Site 667, respectively. These studies have in common (1) the adoption of an identical counting technique, (2) the use of closely spaced sample intervals, and (3) resolved biostratigraphic information—in the case of Olafsson, as a main focus in the Oligocene through middle Miocene interval from Site 667, and in the case of Chepstow-Lusty and others, as a by-product of their interest in the significance of late Pliocene discoaster abundance fluctuations from Sites 658, 659, and 662.

Planktonic and benthic foraminifers have similar stratigraphic distributions at Leg 108 sites and are absent when there is strong dissolution. They are present in all sites throughout the Quaternary and upper Pliocene, but they become poorly represented in the deeper water sites through the early Pliocene and Miocene. Sites 659 and 667 contain foraminifers from the middle Oligocene to Holocene. The planktonic foraminiferal fauna from the upper Miocene to Holocene has been discussed by Weaver and Raymo (this vol.), and the Oligocene to middle Miocene fauna has been described by Miller et al. (this vol.). The former study was limited to core-catcher samples augmented by extra samples from around zonal boundaries. The study by Miller et al. (this vol.) was based on a more detailed examination of 1–6 samples per core and included a comparison of Site 667 with Site 366, which was also drilled on the Sierra Leone Rise during DSDP Leg 41.

The quality of the diatom assemblage in the upper Pliocene to Holocene varied greatly among the Leg 108 sites. Preservation and abundances were relatively good at sites underlying the waters with the highest primary productivity, specifically Sites 658, 662, and 663. Abundances and preservation were moderate at Site 664. Sites underlying unproductive waters, such as Sites 657, 659–661, and 665–668, were generally very poor in diatoms. Diatoms only occur sporadically in sediments older than Pliocene in age. The marine diatom flora is described by Baldauf and Pokras (this vol.).

CONCLUSION

The stratigraphic resolution obtained in the Pliocene-Pleistocene interval of all the Leg 108 sites was excellent and usually backed up by paleomagnetic data. Therefore, these sites will provide considerable insight into previous oceanographic and climatic conditions that prevailed in the eastern equatorial Atlantic Ocean during the latest Neogene. Below the Pliocene, numerous biostratigraphic problems still remain; and, although we cored significant thicknesses of these sediments, we did not obtain the vital paleomagnetic results that could have improved the stratigraphic resolution.

Table 3. Stratigraphic placement in meters of planktonic foraminifer events from Leg 108 sites and their assigned ages.

Species	Age[a]	Depth	Age[b]
108-657A-			
FO *Globorotalia truncatulinoides*	1.9	54.7–60.6	1.7–1.95
LO *Globigerinoides obliquus*	1.8	54.7–60.6	1.7–1.95
FO *Globorotalia inflata*	2.1	64.2–65.9	2.15–2.25
LO *Globorotalia miocenica*	2.2	64.2–65.9	2.15–2.25
Reapp. *Pulleniatina* spp.	2.2	64.2–65.9	2.15–2.25
LO *Globorotalia puncticulata*	2.3	65.9–68.2	2.25–2.35
LO *Dentogloboquadrina altispira*	2.9	83.2–84.5	2.97–3.05
LO *Sphaeroidinellopsis seminulina*	3.0	83.2–84.5	2.97–3.05
Disapp. *Pulleniatina* spp.	3.3	130.7–131.6	4.18–4.28
LO *Globorotalia margaritae*	3.4	92.7–130.7	3.35–4.18
FO *Globoratalia crassaformis*	4.15	131.6–134.6	4.28–4.55
LO *Globigerina nepenthes*	3.9	130.7–131.6	4.18–4.28
FO *Globorotalia puncticulata*	4.15	[c]131.6–134.6	4.28–4.55
FO *Globorotalia miocenica*	3.4	92.7–130.7	3.35–4.18
FO *Globorotalia margaritae*	5.6	144.3–146.1	5.40–5.55
108-658A-			
FO *Globorotalia truncatulinoides*	1.9	119.7–129.2	1.75–1.90
LO *Globigerinoides obliquus*	1.8	91.2–100.7	0.62–1.46
LO *Globorotalia miocenica*	2.2	155.3–157.7	2.30–2.36
FO *Globorotalia inflata*	2.1	138.7–148.2	2.04–2.19
LO *Globorotalia puncticulata*	2.3	157.7–167.4	2.36–2.48
LO *Dentogloboquadrina altispira*	2.9	214.9–224.9	2.90–3.00
LO *Sphaeroidinellopsis seminulina*	3.0	224.4–233.9	3.00–3.08
LO *Globorotalia margaritae*	3.4	290.9–300.4	3.60–3.69
108-659A-			
FO *Globorotalia truncatulinoides*	1.9	36.3–45.8	1.25–1.60
LO *Globigerinoides obliquus*	1.8	45.8–64.8	1.60–2.20
FO *Globorotalia inflata*	2.1	45.8–64.8	1.60–2.20
LO *Globorotalia exilis*	2.1	64.8–65.7	2.20–2.25
LO *Globorotalia miocenica*	2.2	64.8–65.7	2.20–2.25
Reapp. *Pulleniatina* spp.	2.2	64.8–65.7	2.20–2.25
LO *Globorotalia puncticulata*	2.3	65.7–74.3	2.25–2.50
LO *Dentogloboquadrina altispira*	2.9	83.8–84.8	2.85–2.90
LO *Sphaeroidinellopsis seminulina*	3.0	87.5–90.5	2.95–3.05
Disapp. *Pulleniatina* spp.	3.3	93.3–102.8	3.15–3.45
LO *Globorotalia margaritae*	3.4	102.8–112.3	3.45–3.72
FO *Globorotalia crassaformis*	4.15	125.5–131.3	4.20–4.40
LO *Globigerina nepenthes*	3.9	125.5–131.3	4.20–4.40
FO *Globorotalia puncticulata*	4.15	125.5–131.3	4.20–4.40
FO *Globoratalia miocenica*	3.4	112.3–116.0	3.72–3.85
FO *Globoratalia margaritae*	5.6	159.8–182.8	6.20–8.10
LO *Globoquadrina dehiscens*	5.3	188.3–197.8	8.20–10.50
FO *Neogloboquadrina humerosa*	7.5	159.8–182.8	8.20–10.50
FO *Neogloboquadrina acostaensis*	10.2	159.8–182.8	8.20–10.50
108-660A-			
FO *Globorotalia truncatulinoides*	1.9	39.8–44.0	1.95–2.25
LO *Globigerinoides obliquus*	1.8	20.8–30.3	[d]0.80–1.30
FO *Globorotalia inflata*	2.1	39.8–44.0	1.95–2.25
LO *Globorotalia exilis*	2.1	44.0–46.7	2.25–2.42
LO *Globorotalia miocenica*	2.2	44.0–46.7	2.25–2.42
Reapp. *Pulleniatina* spp.	2.2	39.8–41.6	1.90–2.07
LO *Globorotalia puncticulata*	2.3	44.0–46.7	2.25–2.42
LO *Dentogloboquadrina altispira*	2.9	53.8–56.6	2.87–3.08
LO *Sphaeroidinellopsis seminulina*	3.0	56.6–58.8	3.08–3.24
FO *Globorotalia crassula*		56.6–58.8	3.08–3.24
Disapp. *Pulleniatina* spp.	3.3	58.8–68.3	3.24–3.84
FO *Globorotalia miocenica*	3.4	56.6–58.8	3.08–3.24
LO *Globorotalia margaritae*	3.4	68.3–69.4	3.84–3.90
FO *Globorotalia crassaformis*	4.15	69.4–72.1	3.90–4.55
LO *Globigerina nepenthes*	3.9	69.4–72.1	3.90–4.55
LO *Neogloboquadrina pachyderma* (s)		69.4–72.1	3.90–4.55
FO *Globorotalia puncticulata*	4.15	58.8–68.3	3.24–3.84
108-661A-			
FO *Globorotalia truncatulinoides*	1.9	1.6–11.1	0.1–0.67
LO *Globigerinoides obliquus*	1.8	11.1–20.6	0.67–1.30
LO *Globorotalia exilis*	2.1	31.5–34.5	1.96–2.24
FO *Globorotalia inflata*	2.1	30.1–31.5	1.85–1.96
LO *Globorotalia miocenica*	2.2	31.5–34.5	1.96–2.24
Reapp. *Pulleniatina* spp.	2.2	31.5–34.5	1.96–2.24
LO *Globorotalia puncticulata*	2.3	31.5–34.5	1.96–2.24
LO *Dentogloboquadrina altispira*	2.9	41.0–44.0	2.70–2.87
LO *Sphaeroidinellopsis seminulina*	3.0	44.0–47.0	2.87–3.05
Disapp. *Pulleniatina* spp.	3.3	49.1–58.6	3.20–3.75
LO *Globorotalia margaritae*	3.4	58.6–59.9	3.74–3.80
FO *Globorotalia crassaformis*	4.15	59.9–62.5	3.80–4.00
LO *Globigerina nepenthes*	3.9	59.9–62.5	3.80–4.00
FO *Globorotalia puncticulata*	4.15	59.9–62.5	3.80–4.00
FO *Globorotalia miocenica*	3.4	49.1–58.6	3.18–3.74
FO *Globorotalia margaritae*	5.6	65.1–68.1	4.60–5.38
LO *Globoquadrina dehiscens*	5.3	65.1–68.1	4.60–5.38
108-662A-			
LO *Globigerinoides obliquus extremus*	1.8	117.2–126.7	1.73–1.94
FO *Globorotalia truncatulinoides*	1.9	82.4–107.7	1.52
FO *Globorotalia inflata*	2.1	126.7–136	1.94–2.14
LO *Globorotalia exilis*	2.1	140.5–145.7	2.24–2.36
LO *Globorotalia miocenica*	2.2	137.5–140.5	2.18–2.24
Reapp. *Pulleniatina* spp.	2.2	137.5–140.5	2.18–2.24
LO *Globorotalia puncticulata*	2.3	137.5–140.5	2.18–2.24
LO *Dentogloboquadrina altispira*	2.9	166.8–168.4	2.86–2.90
LO *Sphaeroidinellopsis seminulina*	3.0	168.4–174.2	2.90–3.04
Disapp. *Pulleniatina* spp.	3.3	183.7–193.2	3.26–3.49
LO *Globorotalia margaritae*	3.4	197.5–200.5	3.59–3.66
FO *Globorotalia miocenica*	3.4	183.7–193.2	3.26–3.49
108-664D-			
LO *Globigerinoides obliquus extremus*	1.8	49.8–59.3	1.20–1.40
FO *Globorotalia truncatulinoides*	1.9	78.3–87.8	1.80–1.95
FO *Globorotalia inflata*	2.1	78.3–87.8	1.80–1.95
LO *Globorotalia exilis*	2.1	87.8–97.3	1.95–2.2
LO *Globorotalia miocenica*	2.2	97.3–106.8	2.20–2.4
Reapp. *Pulleniatina* spp.	2.2	97.3–106.8	2.20–2.4
LO *Globorotalia puncticulata*	2.3	106.8–125.8	2.40–2.8
LO *Dentogloboquadrina altispira*	2.9	125.8–135.3	2.80–3.0
LO *Sphaeroidinellopsis seminulina*	3.0	125.8–135.3	2.80–3.0
Disapp. *Pulleniatina* spp.	3.3	154.3–163.8	3.38–3.57
LO *Globorotalia margaritae*	3.4	173.3–182.8	3.78–3.97
FO *Globorotalia miocenica*	3.4	211.3–220.8	4.60–4.80
LO *Globigerina nepenthes*	3.9	182.8–192.3	3.97–4.18
FO *Globorotalia crassaformis*	4.15	182.8–192.3	3.97–4.18
FO *Globorotalia puncticulata*	4.15	192.3–201.8	4.18–4.38
FO *Globorotalia margaritae*	5.6	230.3–239.8	5.72–6.22
LO *Globoquadrina dehiscens*	5.3	230.3–239.8	5.72–6.22
FO *Neogloboquadrina humerosa*	7.5	230.3–239.8	5.72–6.22
108-665A-			
LO *Globigerinoides obliquus extremus*	1.8	46.1–50.4	2.28–2.57
FO *Globorotalia truncatulinoides*	1.9	21.9–31.4	1.03–1.52
FO *Globorotalia inflata*	2.1	40.9–46.1	2.09–2.28
LO *Globorotalia exilis*	2.1	40.9–46.1	2.09–2.28
LO *Globorotalia miocenica*	2.2	40.9–46.1	2.09–2.28
Reapp. *Pulleniatina* spp.	2.2	40.9–46.1	2.09–2.28
LO *Globorotalia puncticulata*	2.3	40.9–46.1	2.09–2.28
LO *Dentogloboquadrina altispira*	2.9	52.6–55.7	2.67–2.92
LO *Sphaeroidinellopsis seminulina*	3.0	55.7–58.9	2.92–3.13
Disapp. *Pulleniatina* spp.	3.3	69.4–69.9	3.82–3.86
108-667A-			
LO *Globigerinoides obliquus extremus*	1.8	18.1–27.4	1.1–2.00
FO *Globorotalia truncatulinoides*	1.9	18.1–27.4	1.48–2.00
FO *Globorotalia inflata*	2.1	10.8–14.9	0.76–1.05
LO *Globorotalia exilis*	2.1	27.4–29.8	2.00–2.18
LO *Globorotalia miocenica*	2.2	27.4–29.8	2.00–2.18
Reapp. *Pulleniatina* spp.	2.2	29.8–39.3	2.18–2.68
LO *Globorotalia puncticulata*	2.3	27.4–29.8	2.00–2.18
LO *Dentogloboquadrina altispira*	2.9	40.6–43.6	2.72–2.85
LO *Sphaeroidinellopsis seminulina*	3.0	40.6–43.6	2.72–2.85
Disapp. *Pulleniatina* spp.	3.3	52.9–55.9	3.32–3.50
LO *Globorotalia margaritae*	3.4	52.9–55.9	3.32–3.50
FO *Globorotalia miocenica*	3.4	77.3–86.8	4.56–5.70
LO *Globigerina nepenthes*	3.9	62.3–65.3	3.80–3.98
FO *Globorotalia crassaformis*	4.15	68.8–77.3	4.12–4.56
FO *Globorotalia puncticulata*	4.15	68.8–77.3	4.12–4.56
FO *Globorotalia margaritae*	5.6	96.3–105.8	5.50–6.34
LO *Globoquadrina dehiscens*	5.3	77.3–86.8	4.56–5.70
LO *Neogloboquadrina humerosa*	7.5	105.8–115.3	6.34–7.80
LO *Neogloboquadrina acostaensis*	10.2	124.8–134.3	8.60–10.30

Note: FO = first occurrence, LO = last occurrence, and Disapp. = disappearance.

[a] Ages as presented in Ruddiman, Sarnthein, et al., 1988.

[b] Revised ages interpolated from the sedimentation curves presented in Ruddiman, Sarnthein, et al., 1988.

[c] Interval occurs in a slump.

[d] Probably reworked.

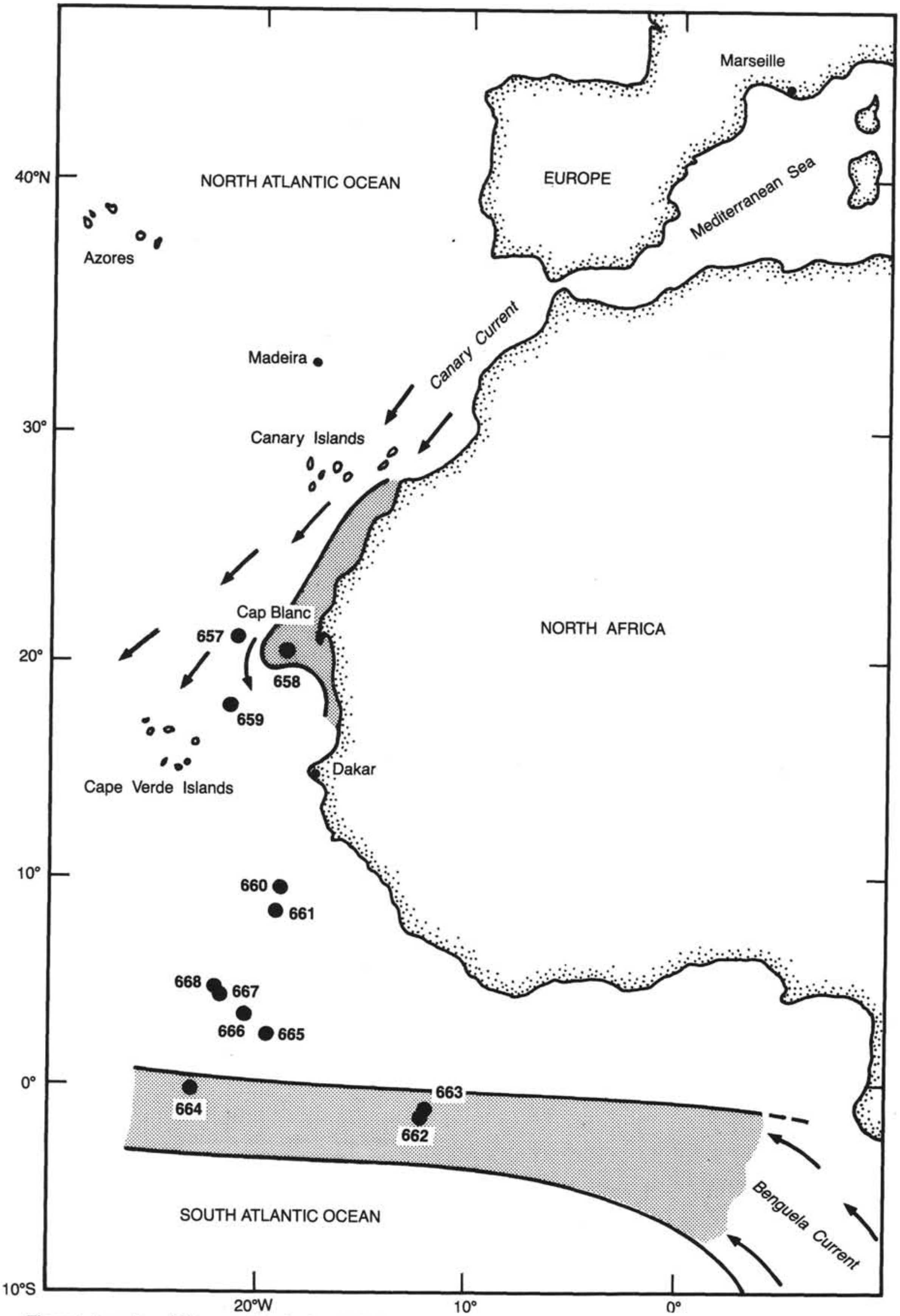

Figure 1. Location of sites cored during Leg 108. Arrows mark current systems; stippled areas indicate regions of strong Pliocene-Pleistocene upwelling and divergence.

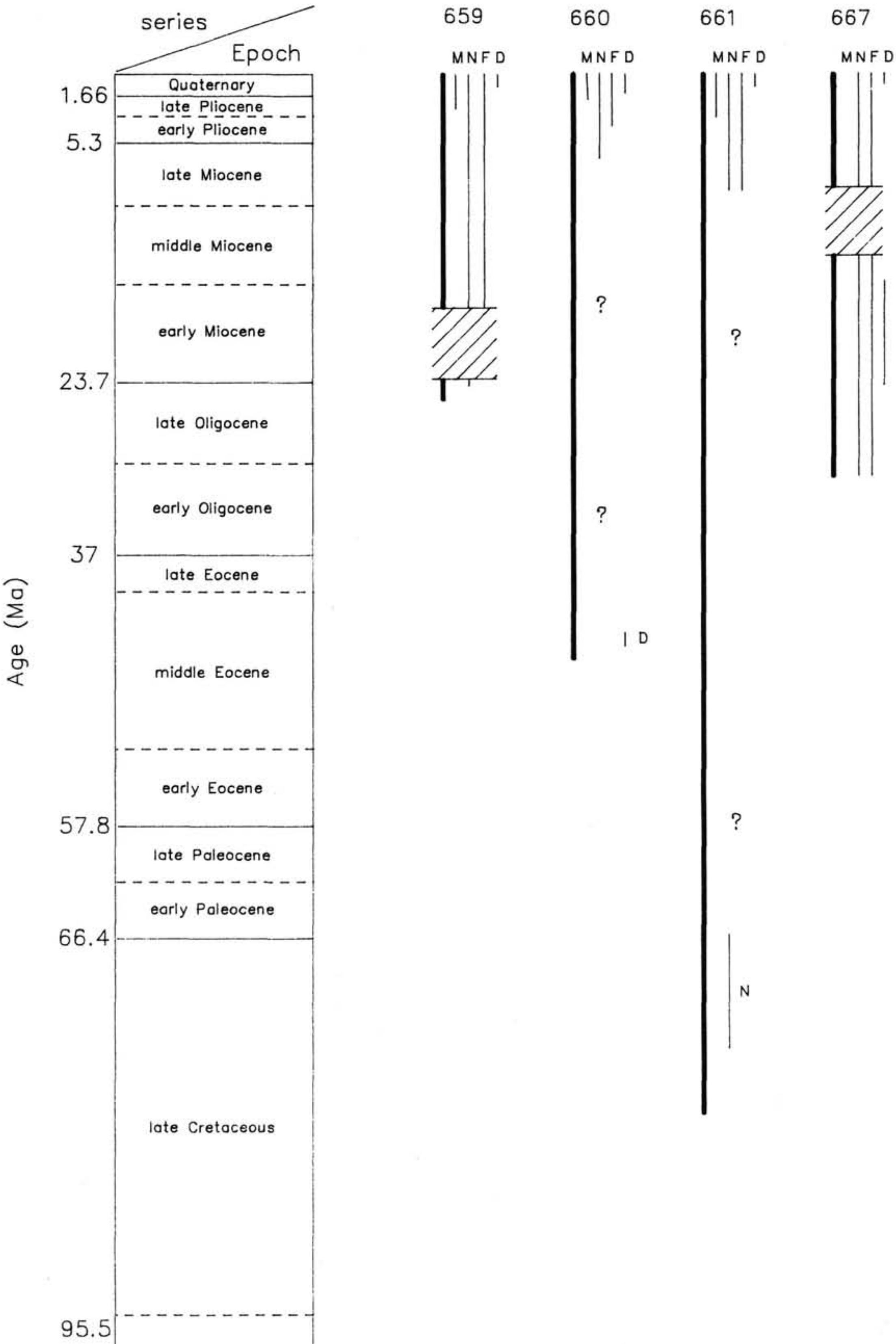

Figure 2. Representation of cored intervals (thick lines) and distribution of major fossil groups in the deeper Leg 108 sites. Diagonal shading = hiatuses, M = paleomagnetic record, N = calcareous nannofossil distribution, F = planktonic and benthic foraminifer distribution, and D = diatom distribution.

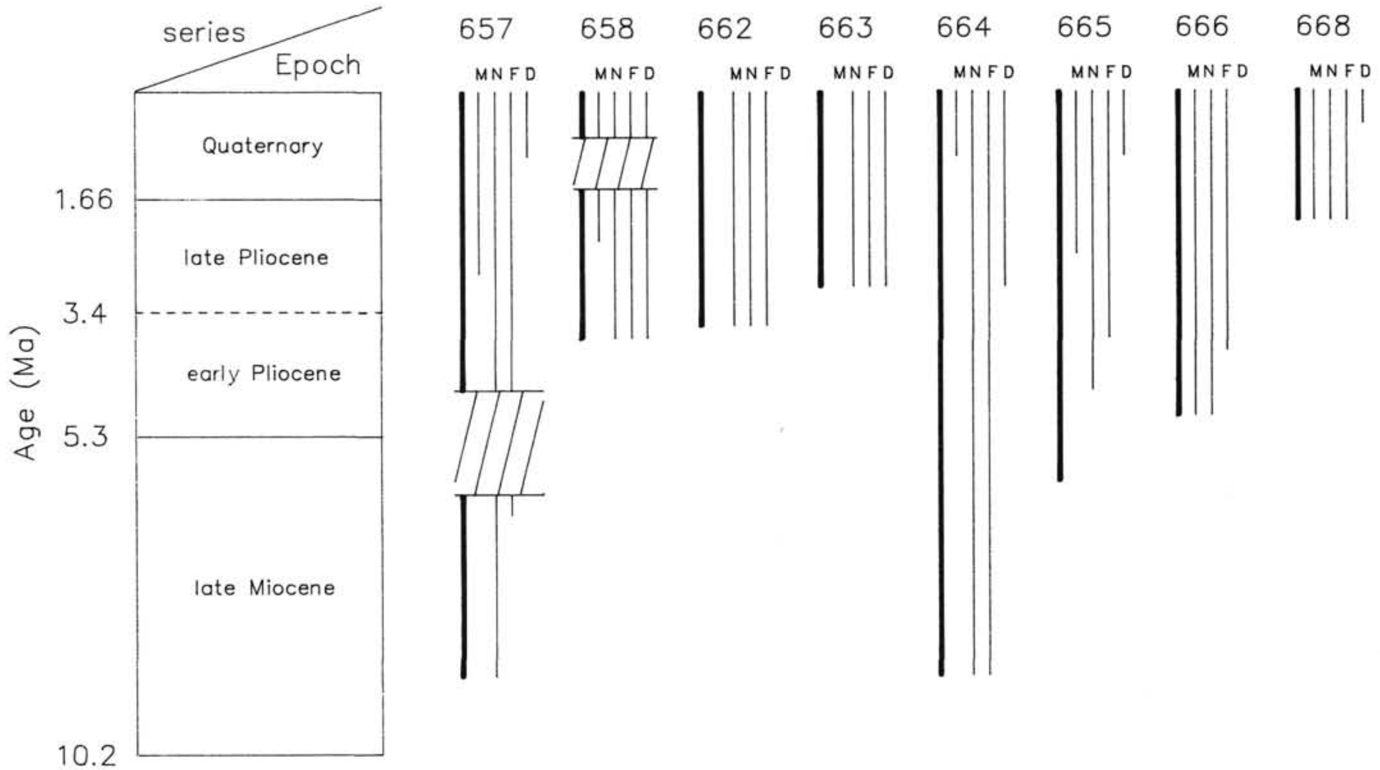

Figure 3. Representation of cored intervals (thick lines) and distribution of major fossil groups in the shallower Leg 108 sites. Diagonal lines = hiatuses, M = paleomagnetic record, N = calcareous nannofossil distribution, F = planktonic and benthic foraminifer distribution, and D = diatom distribution.

Table 4. Stratigraphic placement in meters of diatom events from Sites 658, 662, 663, and 664 and their assigned ages.

Species	Age (Ma)	Depth (mbsf)
108-658A/658B-		
LO *Nitzschia reinholdii*	[a]0.65(0.44)	60.2–64.7
FO *Pseudoeunotia doliolus*	1.8	126.4–132.9
Occ. *Thalassiosira convexa*	>2.2	163.1
108-662A-		
LO *Nitzschia reinholdii*	[a]0.65(0.44)	22.2–31.7
FO *Pseudoeunotia doliolus*	1.8	126.7–131.2
Occ. *Nitzschia jouseae*	>2.6	162.31
108-663A/663B-		
FO *Pseudoeunotia doliolus*	1.8	99.7–109.2
Occ. *Thalassiosira convexa*	>2.2	133.0
108-664D-		
FO *Pseudoeunotia doliolus*	1.8	78.3–87.8
LO *Nitzschia jouseae*	>2.6	125.8

Note: Ages are as presented in Ruddiman, Sarnthein, et al., 1988. FO = first occurrence, LO = last occurrence, and Occ. = occurrence.

[a] Age assigned to this event by Baldauf, 1987.

REFERENCES

Backman, J., and Shackleton, N. J., 1983. Quantitative biochronology of Pliocene and early Pleistocene calcareous nannofossils from the Atlantic, Indian and Pacific Oceans. *Mar. Micropaleontol.*, 8:141–170.

Baldauf, J., 1987. Diatom biostratigraphy of the middle- and high-latitude North Atlantic Ocean, Deep Sea Drilling Project Leg 94. *In* Ruddiman, W. F., Kidd, R. B., Thomas, E., et al., *Init. Repts. DSDP*, 94, Pt. 2: Washington (U.S. Govt. Printing Office), 729–763.

Berggren, W. A., Kent, D. V., and Flynn, J. J., 1985a. Jurassic to Paleogene: Part 2, Geochronology and chronostratigraphy. *In* Snelling, N. J. (Ed.), *The Chronology of the Geological Record.* Geol. Soc. Mem. (London), 10:141–195.

Berggren, W. A., Kent, D. V., and Van Couvering, J. A., 1985b. The Neogene: Part 2, Neogene geochronology and chronostratigraphy. *In* Snelling, N. J. (Ed.), *The Chronology of the Geological Record.* Geol. Soc. Mem. (London), 10:211–260.

Hodell, D. A., and Kennett, J. P., 1986. Late Miocene–early Pliocene stratigraphy and paleoceanography of the south Atlantic and southwest Pacific oceans: a synthesis. *Paleoceanography,* 1: 285–311.

Ruddiman, W., Sarnthein, M., et al., 1988. *Proc. ODP, Init. Repts.*, 108: College Station, TX (Ocean Drilling Program).

Thierstein, H. R., Geitzenauer, K. R., Molfino, B., and Shackleton, N. J., 1977. Global synchroneity of late Quaternary coccolith datum levels: validation by oxygen isotopes. *Geology,* 5:400–404.

Weaver, P.P.E., and Clement, B. M., 1987. Magnetobiostratigraphy of planktonic foraminiferal datums: Deep Sea Drilling Project Leg 94, North Atlantic. *In* Ruddiman, W. F., Kidd, R. B., Thomas, E., et al., *Init. Repts. DSDP,* 94, Pt. 2: Washington (U.S. Govt. Printing Office.), 815–829.

Date of initial receipt: 8 February 1989
Date of acceptance: 26 May 1989
Ms 108B-171