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39. HIGH-RESOLUTION PLIOCENE–PLEISTOCENE BIOSTRATIGRAPHY OF SITE 959, EASTERN EQUATORIAL ATLANTIC OCEAN[1]

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ABSTRACT

High-resolution calcareous nannofossil biostratigraphy was examined from Cores 159-959C-1H through 8H in 20-cm intervals for the Ocean Drilling Program in the eastern equatorial Atlantic Ocean. Well-preserved marker species occur continuously and are relatively abundant in Hole 959C. Six zones (CN10 through CN15) are identified. All calcareous nannofossils are well preserved. Late Neogene (Pliocene–Pleistocene) sediment is dominated by *Florisphaera profunda, Gephyrocapsa caribbeanica, G. oceanica, Gephyrocapsa* spp., *Reticulofenestra pseudoumbilica, R. minutula,* and small *Reticulofenestra.* The sedimentation rate varies from 0.4 cm/k.y. to 13.5 cm/k.y. This strong variations are related to disconformities. The lowest sedimentation rate occurs in the early late Pliocene (Subzone CN12a; 0.4 cm/k.y.), and the highest sedimentation rate in the early early Pleistocene (Subzone CN13b; 13.5 cm/k.y.). The average sedimentation rate from Cores 159-959C-1H through 8H is 1.5 cm/k.y.

INTRODUCTION

The objective of this paper is to describe more accurately the age of Pliocene to Pleistocene sediment based on the calcareous nannofossils in the equatorial Atlantic Ocean. Leg 159 drilled four sites (Sites 959–962) on the Marginal Ridge of the Cote d'Ivoire Transform Margin (CIG Transform Margin) in the eastern equatorial Atlantic. Four holes were drilled at Site 959: Holes 959A, 959B, 959C, and 959D. Pliocene to Pleistocene sediment from Hole 959C was chosen for the purposes of this study. Hole 959C was drilled at 3°37.669′N, 2°44.116′W, in a water depth of 2090 m (Fig. 1), using advanced hydraulic piston coring (APC) until refusal at 179.6 meters below seafloor (mbsf).

Core recovery from Hole 959C was complete, with a relatively high sediment accumulation rate. Hole 959C also contains abundant well-preserved calcareous nannofossils; therefore, it is an ideal site for the study of high-resolution calcareous nannofossil biostratigraphy.

MATERIALS AND METHODS

Conventionally, the smear-slide method is used by paleontologists for the biostratigraphy and quantitative study of calcareous nannofossils. However, size fractionation on smear slides has been observed as a result of tooth-pick action on a slide (Wei, 1988). Beaufort (1991; p. 415) stressed that "a count of relative abundance using smear slides is accurate only for species of similar size unless a large number of view fields are examined." To avoid the size fractionation of calcareous nannofossils during the preparation of smear slides, the settling method developed by Beaufort (1991) and Ehrendorfer (1993) is used.

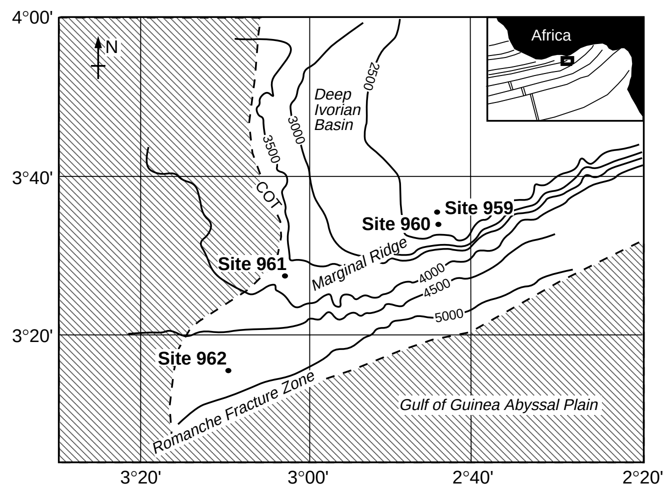

Figure 1. Site 959 location map.

Neogene zonation of Okada and Bukry (1980) was used for the biostratigraphy (Table 1). Biostratigraphy was based on analysis of 371 Neogene (Pliocene to Pleistocene) samples from Cores 1H through 8H. Samples were selected at 20-cm sampling intervals. Cores 1H through 8H are composed of nannofossil ooze with foraminifers (Shipboard Scientific Party, 1996). Only the presence or absence of the biostratigraphic marker species are checked in the 371 samples. Relative abundances of calcareous nannoplankton species per section (1.5-m intervals) among the above mentioned 371 samples are reported based on 500 countings from the settled slide (Table 2). The light microscope with a magnification 1000× was used for this study. Species that do not occur within 500 countings are designed with a "R" in the species percentage chart (Table 2).

The sedimentation rate curve is drawn based on the known age of calcareous nannofossil marker species.

RESULTS AND DISCUSSION

Biostratigraphy

The results of biostratigraphy analysis of each sample are shown in Figure 2 and Tables 2 and 3. Six zones (Zone CN15–CN10) from

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Pliocene to Pleistocene are identified in Hole 959C (Fig. 2, Table 3). The boundary between Zone CN15 and Subzone CN14b is identified by the interval from the first occurrence (FO) of *E. huxleyi*. In this study, Zone CN15 and Subzone 14b are combined because of the difficulties of identifying *E. huxleyi* under the light microscope. Subzone CN14b (*C. cristatus* Zone) is defined as the interval from the last occurrence (LO) of *P. lacunosa* to the FO of *E. huxleyi*. Samples 159-959C-1H-1, 0.0–2.5 cm, to 2H-2, 80.0–82.5 cm (0.01–4.61 mbsf), belong to Zone CN15 and Subzone CN14b. These zones are dominated by *E. huxleyi, Florisphaera profunda, G. oceanica, G. caribbeanica,* and small *Gephyrocapsa spp.* (Table 2). Samples from this zone contain no broken nannoplanktons, well-preserved bridges of *Gephyrocapsa* species (including *G. aperta),* and *Scapholithus fossilis,* indicating good preservation. Sample 159-959C-1H-1, 120.0–122.5 cm (1.21 mbsf), contains a trace amount of reworked *Discoasters*, which became extinct at the Pliocene/Pleistocene boundary. A trace amount of reworked *Calcidiscus macintyrei* also is observed in Samples 159-959C-2H-1, 0.0–2.5 cm (2.31 mbsf), 2H-1, 120.0–122.5 cm (3.51 mbsf), 2H-2, 0.0–2.5 cm (3.81 mbsf), and 2H-2, 40.0–42.5 cm (4.21 mbsf).

The *Emiliania ovata* Subzone (CN14a) is defined by the interval from the FO of *G. oceanica* to the LO of *P. lacunosa*. The *E. ovata* Subzone includes the interval from Sample 159-959C-2H-2, 100.0–102.5 cm, to 3H-1, 80.0–82.5 cm (4.81–12.61 mbsf). *Gephyrocapsa caribbeanica, G. oceanica, Gephyrocapsa* spp. (mostly *G. aperta*), and *F. profunda* are abundant in this zone (Table 2). The following five samples contain a trace amount of reworked nannofossils from this zone: Samples 159-959C-2H-2, 100.0–102.5 cm, contains reworked *C. macintyrei* (middle Miocene–lower Pleistocene) and *S. belemnos* (lower Miocene); Sample 159-959C-2H-2, 140.0–142.5 cm, contains *Coronocyclus nitescens* (upper Eocene–Miocene); Sample 159-959C-2H-4, 40.0–42.5 cm, contains *D. berggrenii* (late Miocene); Sample 159-959C-2H-6, 80.0–82.5 cm, contains reworked *C. luminus* (Eocene–Oligocene). Sample 159-959C-3H-1, 60.0–62.5 cm, contains reworked *D. quinqueramus* (late Miocene). Many samples contain *S. fossilis*, suggesting good preservation. The LO of *P. lacunosa* shows very scarce distribution in the eastern equatorial Atlantic Ocean (Leg 108), and that makes the boundary between Subzones CN14a and CN14b imprecise (Manivit, 1989). However, this hole contains relatively abundant and well-preserved *P. lacunosa,* and the LO datum of *P. lacunosa* is clearly distinguished.

The interval from Sample 159-959C-3H-1, 100.0–102.5 cm, to 3H-3, 0.0–2.5 cm (12.81–14.81 mbsf; 13 samples), is assigned to Subzones CN13a and CN13b. These 13 samples do not contain any *G. caribbeanica* or *G. oceanica*. *G. aperta* is abundant in the above 13 samples. These 13 samples also do not contain *D. brouweri*. Therefore, these samples are assigned to Subzone CN13a. However, the samples below Sample 159-959C-3H-3, 0.0–2.5 cm (14.81 mbsf), contain *G. caribbeanica,* suggesting Subzone CN13b. Therefore, we assigned these 13 samples to Subzones CN13a–b. Young et al. (1994) mentioned that some ambiguity exists for the CN14a/CN13b boundary. Several samples from this interval contain *Scapolithus fossilis,* suggesting good preservation. Sample 159-959C-3H-2, 80.0–82.5 cm (14.11 mbsf), contains a trace amount of reworked *Fasciculithus tympaniformis* (late Paleocene).

The *G. caribbeanica* Subzone (CN13b) is identified by the FO of *G. caribbeanica* to the FO of *G. oceanica.* Samples between 159-959C-3H-3, 20.0–22.5 cm, and 3H-6, 140.0–142.5 cm (15.01–20.71 mbsf), are assigned to this zone. Well-preserved bridges of *G. caribbeanica* and *S. fossilis* indicate good preservation of calcareous nannofossils from this zone. *Florisphaera profunda* and *Gephyrocapsa* spp. are the most abundant species (Table 2).

The *E. annula* Subzone (CN13a) is identified by the LO of *D. brouweri* to the FO of *G. caribbeanica.* Samples 159-959C-3H-7, 0.0–2.5 cm, to 4H-3, 60.0–62.5 cm (20.81–24.91 mbsf), belong to this zone. Sample 959C-3H-7, 20.0–22.5 cm (21.01 mbsf), contains a trace amount of reworked *Discoaster*. Samples 159-959C-4H-2, 80.0–82.5 cm (23.61 mbsf), and 4H-2, 140.0–142.4 cm (24.21 mbsf), also contain reworked *D. brouweri*. *Florisphaera profunda, P. lacunosa,* and *R. minutula* are the most abundant species (Table 2). The relative abundance of *Gephyrocapsa* spp. starts to decrease from this zone (Table 2). Most samples contain dissolution-susceptible species of *S. fossilis.* On the other hand, three samples (Samples 159-959C-4H-2, 100.0–102.5 cm, 4H-2, 120.0–122.5 cm, and 4H-3, 60.0–62.5 cm) contain several nannofossil fragments.

Table 1. Standard Neogene zonation of Okada and Bukry (1980).

Age	Epoch	NN	NN zone	CN		CN subzone	Datum at base
0	Pleistocene	21	*E. huxleyi*	15			*∗E. huxleyi*
		20	*G. oceanica*	14	b	*C. cristatus*	*+P. lacunosa*
		19			a	*E. ovata*	*∗G. oceanica*
			C. doronicoides	13	b	*G. caribbeanica*	*∗G. caribbeanica*
					a	*E. annula*	*+D. brouweri*
1.6	Pliocene	18	*D. brouweri*	12	d	*C. macintyrei*	*+D. pentaradiatus*
		17			c	*D. pentaradiat.*	*+D. surculus*
		16			b	*D. surculus*	*+D. tamalis*
					a	*D. tamalis*	*(+D. challengeri, D. variabilis) +R. pseudo., Sphenolithus spp. (∗ P. lacunosa)*
		15	*R. pseudoumbili.*	11	b	*D. asymmetri.*	*∗D. asymmetricus Acme*
3.4					a	*S. neoabies*	*+A. primus, A. tricor.*
		14	*A. tricorniculatus*	10	d	*A. delicatus*	*∗D. asymmetricus*
		13			c	*C. rugosus*	*∗C. rugosus, +C. actus*
		12			b	*C. acutus*	*∗C. actus, + T. rugosus*
5.3					a	*T. rugosus*	*+D. quinqueramus*
	Miocene	11	*D. quinqueramus*	9	b	*A. primus*	*∗A. primus*
					a	*D. berggrenii*	*∗D. quinque., + D. neorectus*
		10	*D. neohamatus*	8	b	*D. neorectus*	*∗D. neorectus, D. loeblichii*
					a	*D. bellus*	

Note: * = first occurrence; + = last occurrence.

The *C. macintyrei* Subzone (CN12d) is defined by the LO of *D. pentaradiatus* to the LO of *D. brouweri*. Samples 159-959C-4H-3, 80.0–82.5 cm, to 4H-5, 140.0–142.5 cm (25.11–28.71 mbsf), are assigned to this zone. *Florisphaera profunda* and *R. minutula* are the most abundant species (Table 2). Samples 159-959C-4H-3, 80.0–82.5 cm (25.11 mbsf), and 4H-3, 100.0–102.5 cm (25.31 mbsf), contain several nannofossil fragments.

The *D. pentaradiatus* Subzone (CN12c) is defined by the LO of *D. surculus* to the LO of *D. pentaradiatus.* Sample 159-959C-4H-6, 0.0–2.5 cm, to 5H-7, 40.0–42.5 cm (28.81–40.21 mbsf), are assigned to this zone. This zone is dominated by *F. profunda, R. minutula, R. minuta,* and small specimens of *Reticulofenestra*. Nannofossils from this zone are well preserved.

The *D. surculus* Subzone (CN12b) is defined by the LO of *D. tamalis* to the LO of *D. surculus.* Samples 159-959C-5H-7, 60.0–62.5 cm, to 6H-1, 80.0–82.5 cm (41.31–46.21 mbsf), are assigned to this zone. The central arm of *D. surculus* is well preserved in all samples from this interval. This zone, which has a duration of 0.4 m.y. (Okada and Bukry, 1980) is only 1.8 m thick. *F. profunda, R. minuta,* and *R. minutula* are the most abundant species.

The *D. tamalis* Subzone (CN12a) is divided into upper and lower by the LO of *D. challengeri* and *D. variabilis.* Samples 159-959C-6H-1, 100.0–102.5 cm, through 6H-4, 140.0–142.5 cm (41.31–46.21 mbsf), belong to the upper part of Subzone CN12a, based on the absence of *D. challengeri* and *D. variabilis.* However, Samples 159-959C-6H-5, 0.0–2.5 cm, through 6H-6, 100.0–102.5 cm (46.31–48.81 mbsf), belong to the lower part of CN12a, based on the presence of *D. challengeri, D. variabilis,* and *R. pseudoumbilica.* This zone (both upper and lower CN12a) is dominated by *F. profunda, R. minutula,* and *R. minuta.* A trace amount of reworked *S. abies* occurs in Sample 159-959C-6H-6, 80.0–82.5 cm (48.61 mbsf).

The boundary between *D. asymmetricus* Subzone (CN11b) and *S. neoabies* Subzone (CN11a) is defined by the LO of *D. asymmetricus*

Table 2. Relative abundances of calcareous nannofossils with one sample per section, Hole 959C.

Age	Nannofossil zone	Core, section, interval (cm)	Depth (mbsf)	*Angulolithina arca*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Ceratolithus cristatus*	*Ceratolithus rugosus*	*Coccolithus pelagicus*	*Dictyococcites productus*	*Discoaster asymmetricus*	*Discoaster brouweri*	*Discoaster challengeri*	*Discoaster pentaradiatus*	*Discoaster quadramus*	*Discoaster surculus*	*Discoaster tamalis*	*Discoaster triradiatus*	*Discoaster variabilis*	*Emiliania huxleyi*	*Florisphaera profunda*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Gephyrocapsa* spp.
late/middle Pleistocene	*E. huxleyi*/ *C. cristatus* (CN15/CN14b)	1H-1, 0-2.5	0.01		1.63															20.56	26.04	8.88	14.50	21.50
		1H-1, 80-82.5	0.81		1.22															15.41	32.57	15.14	10.00	20.95
		2H-1, 80-82.5	3.11		0.35															4.79	6.55	24.25	1.42	61.59
		2H-2, 80-82.5	4.61		0.34															4.11	6.44	31.84	0.18	55.64
early Pleistocene	*E. ovata* (*CN14a*)	2H-3, 80-82.5	6.11		1.11																20.38	16.72	0.96	59.71
		2H-4, 80-82.5	7.61		1.06																33.29	8.09	9.28	45.23
		2H-5, 80-82.5	9.11		0.31																49.14	3.46	9.05	35.40
		2H-6, 80-82.5	10.61		1.31					0.87											27.95	4.80	5.24	55.31
		3H-1, 80-82.5	12.61		2.45					3.73											35.78		0.13	43.50
	G. caribbeanica (CN13b)	3H-2, 80-82.5	14.11		1.51	0.17				0.17											16.08			74.54
		3H-3, 80-82.5	15.61		1.50					0.33											16.53	0.17		79.80
		3H-4, 80-82.5	17.11		1.52				1.07	7.62											23.78	3.20		58.08
		3H-5, 80-82.5	18.61		0.85	R	0.14		0.28	6.68											29.12	11.36		47.02
		3H-6, 80-82.5	20.11		1.33	0.48				1.21											39.35	5.81		45.04
	E. annula (CN13a)	4H-1, 80-82.5	22.11		2.00	1.00			1.00												55.40			10.80
		4H-2, 80-82.5	23.61		2.62	0.20	0.20		1.01												56.25			4.84
late Pliocene	*C. macintyrei* (CN12d)	4H-3, 80-82.5	25.11		0.80	0.20			0.40			0.60									44.40			8.40
		4H-4, 80-82.5	26.61		0.80	0.20	0.20		0.20		1.20	1.20									66.00			3.20
		4H-5, 80-82.5	28.11		1.80	0.20															42.00			2.00
	D. pentaradiatus (CN12c)	4H-6, 80-82.5	29.61		0.80	0.20	0.20		0.40					0.20							47.60			1.60
		5H-1, 80-82.5	31.61		0.80							0.60		R							58.50			2.60
		5H-2, 80-82.5	33.11		1.00	0.80								0.20							55.40			3.60
		5H-3, 80-82.5	34.61		0.20	0.40						R		0.20							58.40			1.00
		5H-4, 80-82.5	36.11		0.60					0.60		R		0.20							70.34			0.20
		5H-5, 80-82.5	37.61		0.40	0.20				0.60				1.20							55.60			0.20
		5H-6, 80-82.5	39.11		0.80	0.40	R			0.20		0.60		0.60							62.40			0.20
	D. surculus (CN12b)	6H-1, 80-82.5	41.11		1.17	1.17			0.20		0.20	0.20		2.35		R					58.71			1.17
	D. tamalis (upper CN12a)	6H-2, 80-82.5	42.61		0.60	0.20					0.20	R		0.60		R	R				75.90			1.99
		6H-3, 80-82.5	44.11		0.99	0.60			0.20			0.40		2.39		R	R				40.76			14.71
		6H-4, 80-82.5	45.61		0.80							0.60				0.2					27.15			0.60
	D. tamalis (lower CN12a)	6H-5, 80-82.5	47.11		0.40	0.20				0.79			R			0.2		R	R		38.98			1.57
		6H-6, 80-82.5	48.61		1.80	0.40							R	0.60		R	R		R		42.40			0.80
early Pliocene	*D. asymmetricus* (upper CN11b)	7H-1, 80-82.5	50.61		1.00	0.20						0.20		0.80			R				35.00			4.00
		7H-2, 80-82.5	52.11		1.40	0.20					R	1.00		2.99		R					57.49			7.58
		7H-3, 80-82.5	53.61		1.20	R					0.20	0.80	R	0.80			R	R			45.40			6.20
		7H-4, 80-82.5	55.11		R	0.20					R	R		0.40							55.22			12.65
		7H-5, 80-82.5	56.61		1.00	1.00						R		1.20							52.40			2.00
		7H-6, 80-82.5	58.11		1.20	0.80		0.20			0.20	0.60		1.00							49.60			1.40
		8H-1, 80-82.5	60.11		1.40	0.40						R		0.80				R			50.10			0.60
	D. asymmetricus (lower CN11)	8H-2, 80-82.5	61.61		1.40	0.20		0.20				0.20		1.40		R					39.00			0.60
		8H-3, 80-82.5	63.11		1.01	0.61						0.61	R	2.42		0.4			R		40.40			0.40
		8H-4, 80-82.5	64.61	0.20	1.43	1.22	R		0.20			0.81		2.44		R					32.79			0.41
		8H-5, 80-82.5	66.11		1.20	0.40	R		R	0.80		0.40		2.20	R	R					33.00			1.40
		8H-6, 80-82.5	67.61		1.19	0.99				0.20		0.40		3.58		R			R		23.46			0.80

Table 2 (continued).

Age	Nannofossil zone	Core, section, interval (cm)	Depth (mbsf)	*Helicosphaera inversa*	*Helicosphaera kamptneri*	*Helicosphaera sellii*	*Helicosphaera wallichii*	*Pontosphaera japonica*	*Pseudoemiliania lacunosa*	*Pyrocyclus ranginess*	*Reticulofenestra pseudoumbilica*	*Reticulofenestra minutula*	*Reticulofenestra minuta*	*Reticulofenestra* small	*Rhabdosphaera clavigera*	*Rhabdosphaera procera*	*Scapholithus fossilis*	*Sphenolithus abies*	*Sphenolithus neoabies*	*Syracosphaera histrica*	*Syracosphaera pulchra*	*Umbellosphaera irregularis*	*Umbellosphaera sibogae*
late/middle Pleistocene	*E. huxleyi*/ *C. cristatus* (CN15/CN14b)	1H-1, 0-2.5	0.01		0.89		5.18										R						0.89
		1H-1, 80-82.5	0.81		0.41		2.84								0.54		0.14			0.41	0.14	0.14	0.14
		2H-1, 80-82.5	3.11		0.18		0.88													R			R
		2H-2, 80-82.5	4.61		0.18		0.72											R		0.18			0.54
early Pleistocene	*E. ovata* (CN14a)	2H-3, 80-82.5	6.11		R		0.32		0.80								R			R			R
		2H-4, 80-82.5	7.61		0.53		1.59	R	0.66						0.13		R						0.13
		2H-5, 80-82.5	9.11				1.42	0.10	0.31								0.10			0.61			0.10
		2H-6, 80-82.5	10.61		0.87		0.44	R	2.18						0.15					R			0.87
		3H-1, 80-82.5	12.61		1.16		1.42	0.26	10.30	0.13	0.13												1.03
	G. caribbeanica (CN13b)	3H-2, 80-82.5	14.11		0.43		0.43	R	4.69	0.17					R								1.68
		3H-3, 80-82.5	15.61		0.17		1.00	R	R	R												0.50	
		3H-4, 80-82.5	17.11		0.61		1.83	0.15	0.76			0.30				0.15					0.30		0.61
		3H-5, 80-82.5	18.61	R	0.28		0.43		1.99			0.57											1.28
		3H-6, 80-82.5	20.11	0.48	0.61		0.73	0.12	2.54	0.24		1.21				R							0.85
	E. annula (CN13a)	4H-1, 80-82.5	22.11	2.80		0.40	0.40		11.40			8.60		3.60			0.20			0.60			1.80
		4H-2, 80-82.5	23.61	2.82	0.60	0.20	3.02		6.05			14.31		3.43			0.20			0.81			3.43
late Pliocene	*C. macintyrei* (CN12d)	4H-3, 80-82.5	25.11	0.60	2.00	1.40	0.80		10.20			33.00		1.60	0.40		0.20			0.20			1.40
		4H-4, 80-82.5	26.61		3.00	0.20	0.60	0.20	1.80			16.80		0.40		0.20				0.60	0.20		4.20
		4H-5, 80-82.5	28.11	1.40	1.40	0.20	1.00	0.40	1.80			45.40								0.40			2.00
	D. pentaradiatus (CN12c)	4H-6, 80-82.5	29.61	0.20	0.40	0.40	0.40		4.60			26.00		17.00						0.20			0.20
		5H-1, 80-82.5	31.61	0.40	2.60	0.40		0.60	0.80			6.94		24.80						0.20			0.40
		5H-2, 80-82.5	33.11	0.20	2.40	0.20			1.60			17.20		16.40	0.20	0.20				0.40			0.20
		5H-3, 80-82.5	34.61	0.60	1.60				1.40			15.60		20.00			0.20				0.20		0.20
		5H-4, 80-82.5	36.11	0.40	1.60			0.20	R			16.63	8.62							0.20	0.20		0.20
		5H-5, 80-82.5	37.61	0.40	0.80	0.20		0.20	1.80			11.80	25.00	4.00	0.20					0.20			0.40
		5H-6, 80-82.5	39.11	0.60	2.00	0.60		0.40	2.20			6.60	21.40	0.20									0.80
	D. surculus (CN12b)	6H-1, 80-82.5	41.11	1.37	0.20			R	1.96			9.78	20.90	0.20						R			0.39
	D. tamalis (upper CN12a)	6H-2, 80-82.5	42.61		2.19	0.20		0.20	4.58			3.98	7.77	0.20		0.20		Rework		0.20	0.20		0.60
		6H-3, 80-82.5	44.11	0.40	1.19	0.20		0.40	6.16			4.37	26.44			0.20	0.20				R		0.80
		6H-4, 80-82.5	45.61		0.80				5.59			17.37	4.39	1.00									0.20
	D. tamalis (lower CN12a)	6H-5, 80-82.5	47.11		1.18			0.40	2.36			2.95	43.70	3.94			0.20						1.38
		6H-6, 80-82.5	48.61		3.20	0.20			8.00			13.00	29.00	0.00				?			0.20		0.20
early Pliocene	*D. asymmetricus* (upper CN11b)	7H-1, 80-82.5	50.61		1.40			0.80	12.20			13.20	23.00	1.00	0.20	0.20	R	3.60	1.80		0.20		1.20
		7H-2, 80-82.5	52.11		1.60			0.40	4.99			2.99	7.19	3.79		0.20	R	3.59	2.79	0.20			1.60
		7H-3, 80-82.5	53.61	2.80					7.00			10.60	7.00	6.00			0.20	6.80	3.00	0.40			1.60
		7H-4, 80-82.5	55.11		2.00			0.20	3.21		0.60	7.23	9.64	1.20				4.22	2.21				1.00
		7H-5, 80-82.5	56.61		1.60			0.40	7.40		0.60	13.80	7.60	3.20			R	4.40	1.60	0.40			1.20
		7H-6, 80-82.5	58.11		3.40	R		0.20	5.20		R	4.00	15.40	6.20			R	3.20	6.40				0.80
		8H-1, 80-82.5	60.11		4.21			R	R		R	7.21	14.83	11.22				4.81	3.61		0.20		0.60
	D. asymmetricus (lower CN11)	8H-2, 80-82.5	61.61		3.00						0.20	8.00	5.40	31.00				3.60	5.20				0.60
		8H-3, 80-82.5	63.11	2.02							0.81	6.46	14.55	25.25		0.20		2.22	1.82				0.81
		8H-4, 80-82.5	64.61		5.30			1.22			1.63	16.30	6.52	21.79		0.20		1.22	5.91		0.20		0.81
		8H-5, 80-82.5	66.11		3.00			0.20			0.40	20.40	10.00	1.92			0.20	2.00	5.20		R		R
		8H-6, 80-82.5	67.61		5.96			R			1.59	22.27	8.55	25.65				1.39	3.78		R		0.20

Note: R = rare species that occur in the sample but were not seen in a count of 500 specimens.

Acme. A quantitative count of *D. asymmetricus* was not performed in this study. Therefore, the boundary between Subzones CN11a and CN11b is not determined in this report. However, in this study, Zone CN11 is divided into upper CN11b by the FO of *P. lacunosa* and the absence of *R. pseudoumbilicata* and lower CN11 (meaning, the lower part of CN11b + CN11a), based on the absence of *P. lacunosa*, *A. primus*, and *A. tricorniculatus* (Table 1). Samples 159-959C-6H-6, 120.0–122.5 cm, through 8H-1, 100.0–102.5 cm (49.01–60.31 mbsf), are assigned to the upper part of Subzone CN11b. Most samples from this interval contain typical rounded *P. lacunosa.* However, Samples 159-959C-8H-1, 40.0–42.5 cm, to 8H-1, 100.0–102.5 cm (59.71–60.31 mbsf), contain typically rounded and elliptical *P. lacunosa* occurring together. This zone is dominated by *F. profunda, R. minutula,* and *R. minuta.* Sample 159-959C-7H-1, 20.0–22.5 cm (50.01 mbsf), contains seven-armed *D. brouweri.* All samples show good preservation of calcareous nannofossils.

Samples 159-959C-8H-1, 120.0–122.5 cm, to 8H-7, 20.0–22.5 cm (60.51–68.51 mbsf), are assigned to the lower part of Zone CN11. *Florisphaera profunda, R. minutula, R. minuta,* and small *Reticulofenestra* are the most abundant species. All samples show good preservation.

A. delicatus Subzone (CN10d) is defined by the FO of *D. asymmetricus* to the LO of *A. primus* and *A. tricorniculatus.* Two samples (159-959C-8H-7, 40.0–42.5 cm, and 8H-7, 60.0–62.5 cm; 68.71–68.8 mbsf) contain extremely rare specimens of *A. primus* and *A. tricorniculatus* and are assigned to Subzone CN10d.

Sedimentation Rate

A sedimentation rate curve is drawn based on the first appearance datum (FAD) and the last appearance datum (LAD) of marker species (Table 4). The age assignment of the marker species is based on Berggren et al. (1985, 1995). The sedimentation rate varies in each nannofossil datum (0.4–13.5 cm/k.y.; see Fig. 3). Subzone CN13b (lower lower Pleistocene; 15.01–20.71 mbsf), which has a duration of 0.7 m.y. (Okada and Bukry, 1980), shows the highest sedimentation rate (13.5 cm/k.y.). The lower part of Subzone CN12a; (lower upper Pliocene; 46.31–48.81 mbsf) exhibits the lowest sedimentation rate (0.4 cm/k.y.). Overall, the Neogene sediments (interval from Core 159-959C-1H through 8H) show a very low sedimentation rate (1.5 cm/k.y.).

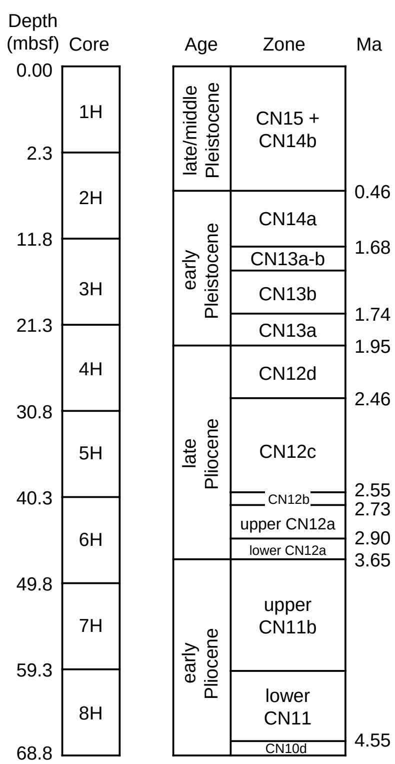

Figure 2. Biostratigraphic zonation of Hole 959C Cores 159-959C-1H through 8H. The age assignments are based on Berggren et al. (1985, 1995).

SUMMARY AND CONCLUSIONS

Six calcareous nannofossil zones (Zones CN10–CN15) were identified in Cores 159-959C-1H through 8H. Each zone contains well-preserved calcareous nannofossils, and marker species are relatively abundant. *Florisphaera profunda* is the most abundant species throughout all the samples investigated. The sedimentation rate varies from 0.4 cm/k.y. to 13.5 cm/k.y. This strong variation may indicate the existence of a disconformity. The average sedimentation rate for the late Neogene (Pliocene to Pleistocene) is 1.5 cm/k.y.

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APPENDIX

Calcareous Nannofossil Species Considered in this Report (Listed Alphabetically by Genus Epithets)

Angulolithina arca Bukry, 1973
Calcidiscus leptoporus (Murray and Blackman, 1898) Loeblich and Tappan, 1978
Calcidiscus macintyrei (Bukry and Bramlette, 1969) Loeblich and Tappan, 1978
Ceratolithus cristatus Kamptner, 1950
Ceratolithus rugosus Bukry and Bramlette, 1968
Coccolithus pelagicus (Wallich) Schiller, 1930
Dictyococcites productus (Kamptner, 1963) Backman, 1980
Discoaster asymmetricus Gartner, 1969
Discoaster brouweri (Tan) emend. Bramlette and Riedel, 1963
Discoaster challengeri Bramlette and Riedel, 1954
Discoaster pentaradiatus (Tan) emend. Bramlette and Riedel, 1954
Discoaster quadramus Bukry, 1973
Discoaster surculus Martini and Bramlette, 1963
Discoaster tamalis Kamptner, 1967
Discoaster triradiatus Tan, 1927
Discoaster variabilis Martini and Bramlette, 1963
Emiliania huxleyi (Lohmann, 1902) Hay and Mohler, 1967
Florisphaera profunda Okada and Honjo, 1973
Gephyrocapsa caribbeanica Boudreaux and Hay, 1969
Gephyrocapsa oceanica Kamptner, 1943
Helicosphaera inversa Gartner, 1980
Helicosphaera kamptneri Bramlette and Martini, 1964
Helicosphaera sellii Bukry and Bramlette, 1969
Helicosphaera wallichii (Lohmann, 1902) Boudreaux and Hay, 1969
Pontosphaera japonica (Takayama) Nishida, 1971
Pseudoemiliania lacunosa (Kamptner, 1963) Gartner, 1969
Pyrocyclus orgensis (Bukry, 1971) Backman, 1980
Reticulofenestra pseudoumbilica (Gartner, 1967) Gartner, 1969
Reticulofenestra minutula (Gartner, 1967) Haq and Berggren, 1978
Reticulofenestra minuta Roth, 1970
Rhabdosphaera clavigera Murray and Blackman, 1898
Rhabdosphaera procera Martini, 1969
Scapholithus fossilis Deflandre in Deflandre and Fert, 1954
Sphenolithus abies Deflandre in Deflandre and Fert, 1954
Sphenolithus neoabies Bukry and Bramlette, 1969
Syracosphaera histrica Kamptner, 1941
Syracosphaera pulchra Lohmann, 1902
Umbellosphaera irregularis Paasche in Markali & Paasche, 1955
Umbellosphaera sibogae (Weber-van Bosse, 1901) Gaarder, 1970

Table 3. Result of calcareous nannofossil zonation of Cores 159-959C-1H through 8H at 20-cm intervals.

Age	Nannofossil	Subzone	Core, section, interval (cm)	Depth (mbsf)
late/middle Pleistocene	*E. huxleyi/C. cristatus*	CN15/CN14b	1H-1, 0-2.5, to 2H-2, 80.0-82.5	0.01-4.61
	E. ovata	CN14a	2H-2,100.0-102.5, to 3H-1, 80.0-82.5	4.81-12.61
early Pleistocene	*G. caribbeanica/E.annula*	CN13a-b	3H-1, 100.0-102.5, to 3H-3, 0.0-2.5	12.81-14.81
	G. caribbeanica	CN13b	3H-3, 20.0-22.5, to 3H-6, 140.0-142.5	15.01-20.71
	E. annula	CN13a	3H-7, 0.0-2.5 to 4H-3, 60.0-62.5	20.81-24.91
late Pliocene	*C. macintyrei*	CN12d	4H-3, 80.0-82.5 to 4H-5, 140.0-142.5	25.11-28.71
	D. pentaradiatus	CN12c	4H-6, 0.0-2.5, to 5H-7, 40.0-42.5	28.81-40.21
	D. surclus	CN12b	5H-7, 60.0-62.5, to 6H-1, 80.0-82.5	40.3-41.11
	D. tamalis	upper CN12a	6H-1, 100.0-102.5, to 6H-4, 140.0-142.5	41.31-46.21
		lower CN12a	6H-5, 0.0-2.5, to 6H-6, 100.0-102.5	46.31-48.81
early Pliocene	*D. asymmetricus*	upper CN11b	6H-6, 120.0-122.5, to 8H-1, 100.0-102.5	49.01-60.31
		lower CN11	8H-1, 120.0-122.5, to 8H-7, 20.0-22.5	60.51-68.51
	A. delicatus	CN10d	8H-7, 40.0-42.5, to 8H-7, 60.0-62.5	68.71-68.8

Table 4. Calcareous nannofossil biostratigraphic datums used to calculate sediment accumulation rates for Hole 959C.

Datum	Depth (mbsf)	Age (Ma)
LAD *P. lacunosa*	4.61	0.46
FAD *G. oceanica*	12.62	1.68
FAD *G. caribbeanica*	20.71	1.74
LAD *D. brouweri*	24.91	1.95
LAD *D. pentaradiatus*	28.71	2.46
LAD *D. surculus*	40.21	2.55
LAD *D. tamalis*	41.11	2.73
LAD *D. variabilis*	46.31	2.9
LAD *R. pseudoumbilicata*	49.01	3.65
LAD *A. primus*	68.71	4.55

Notes: The age assignments of marker species are based on Berggren et al. (1985, 1995). FAD = first appearance datum; LAD = last appearance datum.

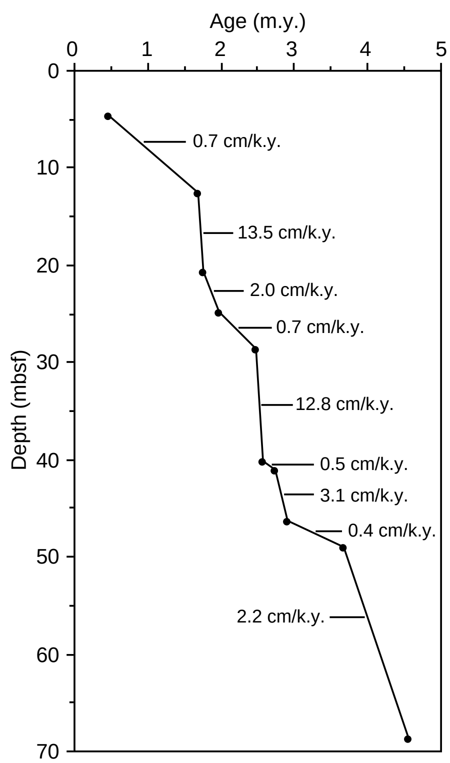

Figure 3. Late Neogene (Pliocene–Pleistocene) sedimentation rate curve for Hole 959C.