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18. NEOGENE AND QUATERNARY PLANKTONIC FORAMINIFER BIOSTRATIGRAPHY AND BIOCHRONOLOGY IN BAFFIN BAY AND THE LABRADOR SEA[1]

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ABSTRACT

During Ocean Drilling Program Leg 105, 11 holes were drilled in the Labrador Sea and Baffin Bay. Site 645 in Baffin Bay was drilled to a depth of 1147 meters below seafloor (mbsf); planktonic foraminifers were recovered in the upper 110.3 m and in a short interval between 283.8 and 293.5 mbsf. Low species diversity and the lack of species with short stratigraphic ranges inhibited establishment of a planktonic foraminifer biostratigraphic framework at Site 645. Holes 646B and 647A in the Labrador Sea were drilled to depths of 766.7 and 716.6 mbsf, respectively. Although the observed assemblages in the Labrador Sea holes were of low diversity, the first and last occurrences of several age-diagnostic species, when integrated with paleomagnetic stratigraphy, allowed the establishment of a high-latitude Miocene to Holocene planktonic foraminifer biochronology. To determine the relative timing of planktonic foraminifer datum events in the eastern North Atlantic and the Labrador Sea, this biochronology is compared with the temperate-subpolar biozonation of Weaver and Clement (1986).

The late Miocene dextral-to-sinistral coiling change in *Neogloboquadrina atlantica* was observed ~1.6 m.y. earlier at Site 646 than at any other site in the Atlantic. The first appearance datums (FAD) of *Globorotalia margaritae, Globorotalia puncticulata, Globorotalia inflata*, and the last appearance datum (LAD) of *N. atlantica* are isochronous with their reported ages in the eastern North Atlantic, but the FADs of *Globorotalia truncatulinoides* and the modern, encrusted form of *Neogloboquadrina pachyderma* are diachronous.

INTRODUCTION

Standard planktonic foraminifer zonations use tropical to subtropical species whose stratigraphic ranges have been correlated with the geomagnetic polarity-reversal record at low-latitude Deep Sea Drilling Project (DSDP) sites (Berggren et al., 1985). The Labrador Sea is situated near or beyond the geographic range limit of most low-latitude species; thus, the warm-water species present were expected to have local stratigraphic ranges that are shorter than their recognized global ranges. Foraminifer studies conducted during DSDP Leg 94 in the eastern North Atlantic demonstrated the diachrony of many stratigraphically important planktonic foraminifer datums between high and low latitudes (Weaver and Clement, 1986). This diachrony renders the standard biochronology inaccurate in the Labrador Sea and necessitates the establishment of a local biochronology.

Until now, knowledge of Neogene planktonic foraminifer biostratigraphy in Labrador Sea sediments was limited to relatively short piston cores (Fillon and Duplessy, 1980; Aksu and Mudie, 1985), exploration wells along the Labrador margin (Gradstein and Srivastava, 1980; Gradstein and Agterberg, 1982), and spot-cored holes drilled during DSDP Leg 12 (Berggren, 1972). ODP Leg 105 offered a unique opportunity to study Miocene to Holocene planktonic foraminifer biostratigraphy in continuously cored sections. The primary objective of this study was to examine the stratigraphic distribution of planktonic foraminifers and to correlate the first and last occurrences of taxa to paleomagnetic stratigraphy to establish a biochronological framework for the Labrador Sea.

During Leg 105, 11 holes were drilled at three sites in the Labrador Sea and Baffin Bay (Fig. 1; Table 1). Holes 645A through 645G were drilled on the slope apron in southwestern Baffin Bay. With the exception of the upper 110 m and sporadic and rare occurrences of poorly preserved specimens in isolated

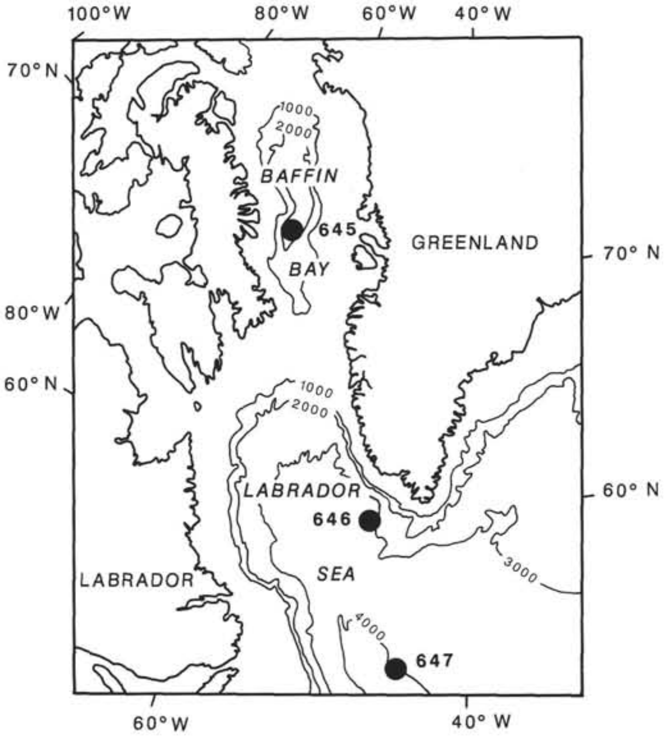

Figure 1. Bathymetric map of the Labrador Sea and Baffin Bay showing the locations of the Leg 105 Sites. Depth contours are in meters.

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Table 1. Locations and water depths of sites drilled during ODP Leg 105.

Hole	Latitude (N)	Longitude (W)	Water depth (m)	Penetration (mbsf)
645A	70°27.43′	64°39.26′	2006	4.9
645B	15.2 m offset to E		2001	298.9
645C	15.2 m offset to N		2001	23.3
645D	70°27.43′	64°39.37′	2006	465.8
645E	70°27.48′	64°39.30′	2006	1147.1
645F	70°27.43′	64°39.29′	2006	23.0
645G	15.2 m offset to E		2006	17.0
646A	58°12.56′	48°22.15′	3451	103.5
646B	30.5 m offset to NW		3451	766.7
647A	53°19.88′	45°15.72′	3861	736.0
647B	53°19.88′	45°15.72′	3851	103.3

samples between 283 and 293 mbsf, all samples examined from Site 645 were barren of planktonic foraminifers. Site 646 is located on the Eirik Ridge off the southern tip of Greenland; an upper Miocene to Holocene sedimentary section containing generally abundant and well-preserved planktonic foraminifers was recovered in Holes 646A and 646B. The modern hydrography of the area is influenced by the East Greenland Current, which transports low-salinity subpolar water around Greenland and into the Labrador Sea (Robinson et al., 1979). A major goal of drilling at Site 646 was to provide a record of late Cenozoic surface environments and to assess the nature of east-west climatic gradients across the North Atlantic in response to Miocene climatic cooling (Shipboard Scientific Party, 1987a). Site 647 (Holes 647A and 647B) is located about 100 km south of the Gloria Drift in the southern Labrador Sea. Above a late Miocene to late Pliocene hiatus located at approximately 116 mbsf, upper Pliocene to Holocene sediments contain relatively diverse and well-preserved planktonic foraminifers and an excellent magnetostratigraphic record, which allows us to determine precisely the planktonic foraminifer biochronology in the southern Labrador Sea. Sites 646 and 647 may be viewed as a northern extension of the transect of sites drilled during DSDP Leg 94, and provide us with an opportunity to integrate important biochronological findings from those sites to determine the relative timing of microfossil events across the North Atlantic.

MATERIAL AND TECHNIQUES

Core-catcher samples and an additional one or two samples per section were examined for planktonic foraminifers. Samples were disaggregated in a 1% Calgon solution and wet sieved through a 63-μm screen. The >63-μm fractions were oven-dried, and the dry weights recorded; then these <63-μm fractions were saved for further studies. Planktonic foraminifers from the coarse fraction were sprinkled on a 45-square micropaleontological tray, and the total abundance of planktonic foraminifers in the whole sample was estimated as rare (0–10 specimens), few (10–50 specimens), common (50–500 specimens), or abundant (>500 specimens). All planktonic foraminifers on at least one transect (nine squares on the tray) were identified and counted, with total counts not exceeding 150 specimens. Individual species abundances were converted to percentages of the total planktonic foraminifers and displayed as rare (<3%), few (3–15%), common (15–30%), or abundant (>30%). The amount of fragmentation of planktonic foraminifers and the ratio between planktonic and benthic foraminifers also were estimated from samples strewn on a picking tray. In several samples where the total abundance of planktonic foraminifers was rare to few and species diversity was low, the abundances of individual species were described as common or abundant, even though only a few specimens of that particular species were observed in the sample. Abundance estimates of the planktonic foraminifer taxa from Holes 646B and 647A are provided in Tables 2 and 3.

Low species diversity and relatively long stratigraphic ranges of polar and subpolar species preclude the interpretation of the foraminifer assemblage in terms of standard low-latitude zonations at Sites 645, 646, and to a lesser extent, 647. This is particularly true for the tropical zonations of Blow (1969, 1979), and Bolli and Saunders (1985). Subtropical zonations, the "M" zones proposed by Berggren et al. (1983) and "PL" zones of Berggren (1973, 1977), are likewise inadequate because of the sparse occurrence and the diachronous stratigraphic ranges of tropical and subtropical species in high latitudes (Weaver and Clement, 1986). Previous studies in the North Atlantic and Greenland and Norwegian seas used second-order foraminifer datums in an attempt to correlate high-latitude sites with the standard zonations (Berggren, 1972; Poore, 1979; Huddlestun, 1984; Weaver and Clement, 1986; Weaver, 1987). In the temperate eastern North Atlantic, many of the "PL" primary zonal marker species of foraminifers show marked diachrony, as indicated by direct correlation with magnetostratigraphy (Weaver and Clement, 1986). Here, the primary datums of Berggren et al. (1985) and Weaver and Clement (1986) were used because these datums can be directly correlated with calcareous nannofossil zonations and the geomagnetic polarity time scale. The ages of magnetostratigraphic units and epoch boundaries used throughout this study are after Berggren et al. (1985), with one exception: the age of the Miocene/Pliocene boundary (4.83 Ma) follows new estimates by Zijderveld et al. (1986). The chronostratigraphic framework for high-latitude planktonic foraminifer biostratigraphy used here is illustrated in Figure 2.

RESULTS

Site 645

Biostratigraphy

Except for a short interval between 283.8 and 293.5 mbsf (Sections 105-645B-30X, CC and 105-645B-31X, CC), planktonic foraminifers are present only in the upper 110.3 m of Hole 645B (from the surface to Section 105-645B-12X, CC). Faunal abundance in the upper 110.3 m is extremely variable and ranges from abundant to barren. When present, foraminifer assemblages are dominated numerically by *N. pachyderma* (sinistral), with low percentages of *N. pachyderma* (dextral), *Globigerina quinqueloba, Globigerina bulloides* and *Globigerinita uvula*. Low benthic to planktonic (B/P) foraminifer ratios and the occurrence of dissolution-susceptible species such as *G. quinqueloba* and *G. bulloides* correlate with higher total abundance of foraminifers. Conversely, monospecific samples composed of *N. pachyderma* (s) correlate with high B/P ratios and low total planktonic abundances. These trends suggest variations in the preservation state of carbonate debris in Baffin Bay. Samples between 283.8 and 293.5 mbsf contain *N. pachyderma* (s) and *G. bulloides*. In this interval, B/P ratios of >10 suggest poor preservation of biogenic carbonate.

Chronostratigraphy

All species identified in samples from 0 to 110.3 mbsf in Hole 645B range from Miocene to Holocene, which makes it impossible to assign a zone on the basis of ranges of taxa. The dextral-to-sinistral (d/s) coiling change of *N. pachyderma*, previously reported to occur in the Arctic Ocean, Labrador Sea, North Atlantic, and Norwegian-Greenland Sea, was not observed in Baffin Bay. Moreover, the age of this datum is not well-constrained geographically in Baffin Bay, and is clearly diachronous in other regions. In the Arctic Ocean, a downcore increase in the percentage (from ~0% to ~50%) of *N. pachyderma* (d) was reported immediately above the Brunhes-Matuyama magnetochron transition (Herman, 1974). The d/s coiling change in *N. pachyderma* was reported to occur at about 2.7 Ma in the Labrador Sea (Berggren, 1972), and near the top of the Pliocene in the Rockall Plateau region (Poore and Berggren, 1975; Huddlestun, 1984). However, at Site 642 in the Norwegian-Greenland Sea, the coiling change occurs within Chron 7, at about 7 Ma (Shipboard Scientific Party, 1987). Taking the youngest reported age for the d/s coiling change in *N. pachy-*

Table 2. Occurences of planktonic foraminifers in samples from Hole 646B.

Depth (mbsf)	Core/section interval (cm)	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	1	2
0.61	1H-1, 61-63		R				R				R															R	A		A
2.21	1H-2, 71-73						F																			F	A		C
3.61	1H-3, 61-63						R																			R	A		A
5.00	1H-4, 50-52		F				F																			R	A		A
6.60	1H-5, 60-62																									R	A		A
8.01	1H-6, 51-53																									R	A		C
9.00	1H, CC		R				R																			R	A		A
11.35	2H-3, 40-42																										R		R
12.32	2H-4, 39-40		F				F			R	R															A	A		A
13.51	2H-5, 61-63		R				F			R	F															R	F		F
14.39	2H-6, 51-53																									R	F		F
14.60	3H-1, 20-22																									R	A		A
15.99	3H-2, 9-11		R				R			R	R															R	C		C
17.53	3H-3, 13-15		R				R			R	R								R							F	C		C
19.79	3H-4, 89-91		R				C			R	R															F	A		A
20.07	3H-5, 30-32		R				R			R	R															F	C		C
22.65	3H-6, 75-77						R			R	R															R	F		F
23.50	3H-7, 10-12																									R	C		C
24.10	3H, CC																									R	A		A
24.57	4H-1, 47-49		F				F			R	R															F	C		C
25.99	4H-2, 39-41		F				F			R	R															C	F		C
27.49	4H-3, 39-41																										R		R
28.99	4H-4, 39-41																									R	A		A
30.26	4H-5, 16-18																									R	A		A
33.80	4H, CC						F																			F	A		A
34.20	5H-1, 40-44		R				F			R	R					R			R							R	F		F
35.70	5H-2, 40-44																									R	F		F
37.20	5H-3, 40-44																									R	A		A
43.40	5H, CC																									R	A		A
43.83	6H-1, 43-47		F				F			R	R															R	A		A
45.30	6H-2, 40-44		R				R																			R	A		A
46.80	6H-3, 40-44		R				F																			R	A		A
48.70	6H-4, 80-84		R				F			R	F				R	R										F	C		C
49.75	6H-5, 35-39						R																			R	A		A
51.71	6H-6, 81-85																									R	F		F
53.10	6H, CC																									F	A		A
62.70	7H, CC						R																			F	C		C
73.20	9H-1, 80-84		R				R			R	R				R	R										R	A		A
74.11	9H-2, 21-25		R				R																			R	F		F
75.40	9H-3, 0-4		R				R			R	R				R	R										F	A		A
77.50	9H-4, 60-64						R																			R	C		C
78.80	9H-5, 40-44		R				R			R	R															R	A		A
79.90	9H-6, 0-4		R				R			R	R															R	F		F
81.40	9H-7, 0-4																										F		F
91.70	10H, CC															R											R		R
101.40	11H, CC																										R		R
103.01	12H-2, 11-3																									R	A		A
103.65	12H-2, 75-80																										R		R
105.15	12H-3, 75-80		R				R				R															R	F		F
106.65	12H-4, 75-80																										R		R
108.15	12H-5, 75-80																									R	F		F
111.10	12H, CC																										R		R
111.30	13H-1, 20-25																									R	F		F
112.80	13H-2, 20-25						R																			R	F		F
113.21	13H-2, 61-63																										R		R
114.30	13H-3, 20-25																										R		R
115.80	13H-4, 20-25																										R		R
117.30	13H-5, 20-25						R				R															R	F		F
117.98	13H-5, 88-90		R				F								R	R			R							F	A		A
120.80	13H, CC																									R	R		R
121.15	14H-1, 35-40																		F			?				R	A		A
122.65	14H-2, 35-40		R				R				R				R	R			R							F	A		A
124.15	14H-3, 35-40		R				R				R					R			R							F	C		C
125.65	14H-4, 35-40		R				F				R															F	C		A
127.15	14H-5, 35-40						R																			R	C		C
127.61	14H-5, 81-83																										F		F
149.80	16X, CC		R				R	R			R					R			R			R					C		C
159.10	17X, CC		R				C									R										R	C		C
159.50	18X-1, 40-45																										R		R
160.88	18X-2, 28-33																										R		R
161.04	18X-2, 44-46																										R		R
162.38	18X-3, 28-33						R												R			R				C	F		C
168.80	18X, CC						R																			R	R		R
178.50	19X, CC						R																			R	F		F
178.77	20X-1, 27-32		F																F								F		F
180.27	20X-2, 27-32																										R		R
183.27	20X-4, 27-32		R				R															R				R	F		F
188.20	20X, CC		F				R	R			R											C					A		A

Table 2 (continued).

Depth (mbsf)	Core/section interval (cm)	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	1	2
190.88	21X-2, 118–120																									R	R		R
197.80	21X, CC																										R		R
206.14	22X-6, 84–86		R																										R
207.85	23X-1, 35–40																				R	C							C
212.34	23X-4, 34–39																				R	F							F
213.84	23X-5, 34–39																					R							R
214.72	23X-5, 122–124		R																			R					R		R
217.10	23X, CC										R											R					R		F
236.10	25X, CC		R				R	R													R	C				C	A	R	A
236.50	26X-1, 40–45		C					C		R	R								R		R	C				R	R		A
237.80	26X-2, 20–22		R																			R			F		F		
238.00	26X-2, 40–45		F					F		R	R										R	F				R	R		F
239.50	26X-3, 40–45		C					F			R										R	C					R		C
241.00	26X-4, 40–45		C					F													R	C					R		C
242.50	26X-5, 40–45		F					R													R	F					F		F
243.35	26X-5, 125–127		R													R					R	F							F
246.00	26X, CC		C				R	R											R			R				R	C		C
265.30	28X, CC				?																R	F					F		F
265.70	29X-1, 40–45																					R							R
267.20	29X-2, 40–45		F																R		R	F		R	C		R		C
268.70	29X-3, 40–45		R				R														F	C			C	R	F		C
270.20	29X-5, 40–45																					R							R
272.1	29X-5, 88–90																		R		R	C			R				C
273.20	29X-6, 40–45		F									R								?	R	C			F	R	R		C
275.00	29X, CC		R																		R	A			R	R	F		A
275.39	30X-1, 39–44		F				R				R										R	C			F	R	F		A
276.89	30X-2, 39–44		F						R				R							?	R	C			C	R	R		C
277.23	30X-2, 73–75		R																		R	F			R				F
278.39	30X-3, 39–44																					R			R				R
281.63	30X-5, 63–65																					R							R
282.89	30X-6, 39–44		R																R		R	F			F	R	R		F
284.97	31X-1, 27–32		R				R								R						R	F			F		F		F
286.30	31X-2, 10–12																					R							R
286.47	31X-2, 27–32		R																R		R	F					F		F
287.97	31X-3, 27–32		F				R														R	C			F	R	R		C
289.47	31X-4, 27–32		R				R														R	F			F	R	F		C
290.97	31X-5, 27–32		R																		R	F			R				F
294.40	31X, CC		R				R														R	C			R	R	F	R	C
294.58	32X-1, 18–23		R				R														R	F					R		F
296.08	32X-2, 18–23		R																		R	F							F
296.48	32X-2, 58–60																				R	F			R				F
302.88	32X-6, 98–100																					R							R
304.10	32X, CC																					R							R
305.64	33X-2, 4–6																		R		R	F							F
305.85	33X-2, 25–30		R				R														R	C			R	R	R		C
307.35	33X-3, 25–30				R		R								?				R		R	F				R	R		F
308.85	33X-4, 25–30			R																		R					R		R
310.35	33X-5, 25–30		R	R			R												R		R	C					R		C
311.39	33X-5, 129–131		R																		R	C				R	R		C
313.80	33X, CC		R								R										R	A				R	R		A
323.40	34X, CC		R				R														R	A				R	R	R	A
323.62	35X-1, 22–28																				R	C					R		C
324.99	35X-2, 9–11																					C							C
325.13	35X-2, 23–28																				R	F							F
326.48	35X-3, 8–10																					A							A
333.92	36X-1, 82–87		R																		R	C			R				C
334.65	36X-2, 5–7																		R		R	C							C
335.31	36X-2, 71–76		F				R											R	R		F	A			F			R	A
336.18	36X-3, 8–13		R																		R	C			R		R		C
338.13	36X-4, 53–55		F															F	R		F	C			R		R	F	C
338.22	36X-4, 62–66																	F	R		R	C			R			F	C
339.18	36X-5, 8–10		F				R											R	R		F	A						F	A
339.24	36X-5, 14–17		F				R											R	R		F	A			R			F	A
341.74	36X-6, 114–119																	R	R		R	C							C
341.98	36X-6, 138–140																				R	A							A
342.16	36X-7, 6–9		R																		R	A			R				A
342.80	36X, CC								R				R								F	A			R				A
343.10	37X-1, 30–35		R																		R	F			R				F
344.46	37X-2, 16–18																		R		R	R							R
344.60	37X-2, 30–35																		R		R	F							F
346.10	37X-3, 30–35						R														R	F				R	F		F
347.60	37X-4, 30–35		F				R												R		F	A			F				A
349.10	37X-5, 30–35		F								R				R			R	R		R	C			R				C
350.60	37X-6, 30–35		F								R								R		R	C							C
351.96	37X-7, 16–18		R															R	R			A							A
352.04	37X-7, 24–29		F															R	R		R	C			R				C
352.40	37X, CC		F																F			A			R				A
352.98	38X-1, 58–61																				R	F							F

Table 2 (continued).

Depth (mbsf)	Core/section interval (cm)	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	1	2
354.04	38X-2, 14–16		R															F	R		R	A			R				A
354.48	38X-2, 58–61		R																R		R	F			R				F
355.93	38X-3, 53–56		R																R		R	F			R				F
357.48	38X-4, 58–61		R															F	R			F							F
358.97	38X-5, 57–60																				R	F			R				F
360.45	38X-6, 55–58		F															R	F		R	C			R				C
361.68	38X-7, 28–30																					F							F
362.00	38X, CC		R										R					R			R	C							C
362.19	39X-1, 19–24		F																R		R	A			R			R	A
363.65	39X-2, 15–17		R															R	R			A							A
363.69	39X-2, 19–24		F												R			R	F		F	A			F				A
365.19	39X-3, 19–24		R																R		R	F							F
366.69	39X-4, 19–24		R															R	R		F	A			R				A
368.11	39X-5, 11–13		F																F		R	A							A
368.19	39X-5, 19–24		R														R	R	F		R	C			R				C
369.69	39X-6, 19–24																R		F		R	C			R				C
371.70	39X, CC		R															R	R			C							C
371.91	40X-1, 21–26		R				R				R						R	R	R		R	F							F
373.34	40X-2, 14–16																		R			R							R
373.41	40X-2, 21–26																					R			R				R
374.91	40X-3, 21–26																		R			F			R				F
376.41	40X-4, 21–26		R											R			R	R	F		R	F			R				F
377.91	40X-5, 21–26		F				R				R							R	F		R	A			R				A
378.97	40X-5, 127–129		R																R			A			R				A
379.41	40X-6, 21–26		F				R											R	R		F	A			R				A
380.87	40X-7, 17–22		C															R	F		F	A			R				A
381.30	40X, CC		F														R	R			R	C							C
383.06	41X-2, 26–30		C				R				R			R				R	R		F	A			F				A
384.57	41X-3, 27–31		C				R		R		R								R		R	A				R			A
385.99	41X-4, 19–23		R								R						R		F		F	C			R				C
387.40	41X-5, 10–12		F																		R	A							A
387.57	41X-5, 27–31					R	R												R		F	C					R		C
389.07	41X-6, 27–31		R			R													R		R	A			R		R		A
391.00	41X, CC		R																R			C							C
391.16	42X-1, 16–21																		R		R	F							F
391.64	42X-1, 64–66		R																			A							A
392.59	42X-2, 9–14					F	F												R		R	C							C
394.09	42X-3, 9–14		R			R													R		F	C			R				C
395.59	42X-4, 9–14		F				F												F		F	A			F				A
397.08	42X-5, 8–14		F			R	R												R		F	A			F				A
397.89	42X-5, 89–91																					A							A
398.67	42X-6, 17–22																					F			R				F
400.70	42X, CC		F				F						R								R	C					F		C
404.23	43X-3, 53–55		R																			A							A
404.81	43X-3, 111–116		F				R															C			R				C
410.40	43X, CC		R																		R	A					R		A
420.10	44X, CC		R				R														R	A				R	R	R	A
429.80	45X, CC												?						R		R	A			R		R		A
431.72	46X-2, 42–44		R																			A							A
431.94	46X-2, 64–67		R																			A							A
439.50	46X, CC									R			R				?				F	A			R		R		A
449.10	47X, CC																					C							C
458.80	48X, CC																					C							C
460.53	49X-2, 23–28																R				F	A							A
460.84	49X-2, 54–56																				R	F							F
468.50	49X, CC		C																		R	A							A
469.22	50X-1, 72–77																R				F	A			F			R	A
470.10	50X-2, 10–12		R																			A							A
471.50	50X-3, 0–5		R																		R	A			R				A
478.10	50X, CC																R		R		R	C			F		R		C
479.17	51X-1, 107–112						R							R			R		R	R	F	A			R				A
480.20	51X-2, 60–62																		R		R	F							F
487.40	51X, CC																R				R	A			F	R	F		A
497.10	52X, CC																?		R		R	C			F		R	R	C
506.90	53X, CC																R		R		R	C					R		C
516.50	54X, CC		R																		R	F				R	F		F
519.83	55X-3, 33–35		R																			R	A						A
526.20	55X, CC		R																		R	R	F			R	F		F
526.77	56X-1, 7–10		R																R		R	F						R	F
527.10	56X-1, 40–42																					F							F
528.24	56X-2, 4–6																		R			F							F
528.37	56X-2, 17–20		R				R												R			F			R				F
529.90	56X-3, 20–23		F				R												R		R	C			R			R	C
535.80	56X, CC				R		R														R	F					R		F
545.50	57X, CC																				R	F							F
555.20	58X, CC																					C							C
564.40	59X, CC		F	R	R					R	R									R	R	C					F		C
565.17	60X-1, 77–79		R																			F							F

Table 2 (continued).

Depth (mbsf)	Core/section interval (cm)	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	1	2
565.75	60X-1, 135–139		R																			F				R			F
566.35	60X-2, 45–49																					R							R
566.49	60X-2, 59–61																					F							F
574.00	60X, CC												R								R	C					F		C
575.00	61X-1, 100–103																					R							R
583.60	61X, CC		C	R	R							R	R								R	A					C	R	A
584.26	62X-1, 66–70		R				R														R	F							F
585.12	62X-2, 2–4																					C							C
585.29	62X-2, 19–23		R																			F							F
586.78	62X-3, 18–21		R																		R	F			R				F
588.16	62X-4, 6–10		F																		R	A						R	A
589.78	62X-5, 18–20		F																		F	A						R	A
590.14	62X-5, 54–56																				R	A							A
593.20	62X, CC				R																R	C					F		C
593.66	63X-1, 46–50		F																	F	F	A	R		R			R	A
594.84	63X-2, 14–16																					A							A
596.34	63X-3, 14–16		R																			F			R				F
602.90	63X, CC		R										R									F					R		F
612.50	64X, CC		C		R							F	R								R	A			F		R	C	A
612.90	65X-1, 40–44		F																		F	C			R				C
614.03	65X-2, 3–5		R																		R	A							A
614.54	65X-2, 54–59		F																	R	F	A			F			R	A
615.55	65X-3, 5–8		R																	R	R	F			R				F
617.07	65X-4, 7–11		F																	R	F	C	R					R	C
618.03	65X-4, 103–105																				R	A							A
619.38	65X-5, 88–93		F																	R	F	A	R		R				A
622.20	65X, CC																				R	C							C
622.31	66X-1, 11–15		R																		R	A			R				A
624.04	66X-2, 34–36																					C							C
631.80	66X, CC		R																	R	R	C			R		R		C
631.93	67X-1, 13–16		R																	F	R	A	R		F				A
633.33	67X-2, 3–7																				R	F							F
634.41	67X-2, 111–113																				R	F							F
634.91	67X-3, 11–15																					R							R
636.30	67X-4, 0–4		F																		R	C	R					R	C
637.93	67X-5, 13–17		R				R															R							R
638.86	67X-5, 106–108																					F							F
639.59	67X-6, 29–32																					F					R		F
641.30	67X, CC																				R	R					R		R
641.60	68X-1, 30–35					R																C							C
642.81	68X-2, 1–6		R																		R	C							C
642.91	68X-2, 11–13																					R							R
644.38	68X-3, 8–13		R				F														R	C							C
644.77	68X-3, 47–49																		R			R							R
645.91	68X-4, 11–16																					R							R
650.90	68X, CC																					C					F		C
651.23	69X-1, 33–35		R																		F	C							C
651.57	69X-1, 47–52		R																	R	F	C							C
660.50	69X, CC												R								F	C			F		F		C
661.08	70X-1, 58–62		R			R														R	F	A							A
670.20	70X, CC		R																			R					R		R
671.79	71X-2, 9–11																					R							R
672.13	71X-2, 43–47																					R							R
675.21	71X-4, 51–56						R														R	R							R
676.50	71X-5, 30–35	R					R		R										R		R	F						R	F
677.81	71X-6, 11–16		R																R										R
679.70	71X, CC		R	R			R														R	R							R
680.10	72X-1, 40–43		R			R															R	R							R
680.30	72X-1, 60–62																		R		F	C							C
681.57	72X-2, 37–40	R	R			R			R													R							R
682.47	72X-2, 127–129																				F	F							F
689.30	72X, CC		C																			R							C
690.13	73X-1, 83–87	R	A			R			R											R	F	F	R						A
691.38	73X-2, 58–60																				C	A							A
699.00	73X, CC		C				R														R	C					R		C
699.45	74X-1, 45–49		F			F			R	R									R	R	F	C			R			R	C
700.50	74X-2, 0–2		F																R		R	C							C
700.70	74X-2, 20–24	F	F			R	R		R		R									F	F	C	F		F				A
703.51	74X-4, 1–4	R	F			R	R		R											R	R	C	R						C
703.60	74X-4, 10–12																					F							F
708.60	74X, CC		R																		R	F					R		F
709.13	75X-1, 53–56	R																				F							F
710.98	75X-2, 88–90																					R							R
711.76	75X-3, 16–21																				R	R							R
713.76	75X-4, 66–70	R					R		R												R	R							R
713.97	75X-4, 87–89																					R							R
718.30	75X, CC		R																			F					R		F
719.97	76X-2, 17–19		R																			F							F

Table 2 (continued).

Depth (mbsf)	Core/section interval (cm)	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	1	2
727.90	76X, CC		R																		R	F							F
732.77	77X-4, 37–39																				R	R							R
734.15	77X-5, 25–27		R				R														R	R							R
737.70	77X, CC																					R							R
739.28	78X-2, 8–10						R														F	R							F
739.60	78X-2, 40–42		R								R										C	F							C
747.40	78X, CC	F	F			R			F		F										C	R	R						C
747.54	79X-1, 14–18	R	R			R	R		R		R									R	A	R	R		R				A
749.09	79X-2, 19–25		F																		F	R							F
750.30	79X-2, 140–142										R										C	F							C
757.00	79X, CC																				C	A							A
758.65	80X-2, 15–18		R								R										C	R							C
766.70	80X, CC								R		R										C	F				F			C

Relative abundance scale, R = rare, F= few, C= common, A = abundant, ? = questionable. a = *G. apertura*, b = *G. bulloides*, c = *G. falconensis*, d = *G. nepenthes*, e = *G. praebulloides*, f = *G. quinqueloba*, g = *G. umbilicata*, h = *G. woodi* sp., i = *G. uvula*, j = *G. glutinata*, k = *G. obessa*, l = *G. venezuelana*, m = *G. crassula*, n = *G. crassaformis*, o = *G. inflata*, p = *G. margaritae*, q = *G. puncticulata*, r = *G. scitula*, s = *N. scotaensis*, t = *N. atlantica* (d), u = *N. atlantica* (s), v = *N. continuosa*, w = *N. dutertrei*, x = *N. humerosa*, y = *N. pachyderma* (d), z = *N. pachyderma* (s), 1 = *O. universa*, 2 = Total planktonic foraminifer abundance. The following samples were barren of plantonic foraminifers: 105-646B-8X, CC; -9X, CC; -12X-1, 75–80; -12X-5, 22–24; -13X-6, 20–25; -14X-6, 35–40; -14X, CC; -18X-1, 144–146; -20X-2, 7–9; -20X-3, 27–32; -20X-5, 27–32; -20X-5, 108–110; -21X-1, 17–22; -21X-2, 17–22; -21X-3, 17–22; -21X-4, 17–22; -21X-4, 118–120; -21X-5, 17–22; -22X-1, 65–70; -22X-2, 7–9; -22X-2, 64–69; -22X-3, 65–70; -22X-4, 64–69; -22X-6, 64–69; -22X-7, 5–10; -22X, CC; -23X-2, 8–10; -23X-2, 8–10; -23X-2, 35–40; -23X-3, 35–40; -27X, CC; -29X-2, 14–16; -29X-4, 40–45; -30X-4, 39–44; -30X-5, 39–44; -30X, CC; -31X-6, 27–32; -31X-6, 76–78; -32X-3, 18–23; -32X-4, 18–23; -32X-5, 18–23; -32X-6, 18–23; -33X-1, 25–30; -58X-1, 59–61; -61X-2, 16–18; -63X-2, 54–56; -71X-1, 43–47; -71X-3, 43–47; -75X-2, 17–21; -76X-3, 1–3; -76X-3, 4–6; and -77X-4, 68–73.

derma, its absence in Hole 645B suggests that the section above 110 mbsf is as young as 0.73 Ma.

Hole 646B

Biostratigraphy

Samples between 0 and 207.5 mbsf in Hole 646B contain a low-diversity planktonic foraminifer assemblage. In samples between 0 and 78.8 mbsf (Sample 105-646B-9H-5, 40–44 cm), the abundance of planktonic foraminifers is generally high, and the assemblage is dominated numerically by the modern, encrusted variety of *N. pachyderma* (s), with minor but persistent occurrences of *N. pachyderma* (d) and *G. quinqueloba*. Small numbers of *G. bulloides, G. uvula, G. glutinata, Globorotalia scitula*, and *G. inflata* occur sporadically in this interval (Plates 1 and 2). The quadrate form of *N. pachyderma*, with four to four and one-half chambers in the final whorl, is the dominant morphotype in the samples from this interval, but smaller proportions of the five-chambered variety also occur. Low B/P ratios of <0.01 and generally $<30\%$ test fragmentation suggest relatively good preservation of biogenic carbonate on the seafloor, which indicates an assemblage representative of water-mass characteristics existing at the time of deposition. Between 78.8 mbsf (Sample 105-646B-9H-5, 40–44 cm) and 207.5 mbsf (Section 105-646B-22X, CC), foraminifer abundance and species diversity are generally low. Except for a few samples, the assemblages consist predominantly of *N. pachyderma*, with minor occurrences of the above-mentioned species and sporadic and rare occurrences of *N. atlantica* sinistral, which may be redeposited (Table 2). The modern encrusted variety of *N. pachyderma* (s) was not observed below 161.0 mbsf (Sample 105-646B-18X-2, 44–46 cm). Samples studied from this lower interval exhibit up to 80% fragmentation of tests and considerably higher B/P ratios (>5), which suggests poorer preservation of biogenic carbonate debris on the seafloor. This interpretation is consistent with the pore-water chemistry, which displays undersaturation with respect to calcium carbonate (Zachos and Cederberg, this volume). All samples examined between 188.2 mbsf (Section 105-646B-20X, CC) and 207.5 mbsf (Section 105-646B-22X, CC) are barren of foraminifers, and this interval is characterized by abundant coarse detrital debris.

Samples between 207.5 mbsf (Section 105-646B-22X, CC) and 526.2 mbsf (Section 105-646B- 55X, CC) are characterized by a higher-diversity planktonic foraminifer assemblage dominated by *N. atlantica* (s), with minor (rare to few) occurrences of *N. atlantica* (dextral), *N. humerosa, G. bulloides, G. quinqueloba* and *N. pachyderma* (Pls. 3 and 4). The occurrence of *N. pachyderma* is more variable than in the overlying interval, where the quadrate form is the dominant morphotype in samples between 207.5 mbsf (Section 105-646B-22X, CC) and 339.2 mbsf (Sample 105-646B-36X-5, 8–10 cm) and the more reticulate and open form dominates below 339.2 mbsf (Sample 105-646B-36X-5, 14–17 cm). We believe that the more open form of *N. pachyderma* displays greater affinity to *N. atlantica* because it was often difficult to differentiate the two species consistenty below the last common occurrence of *N. atlantica*. In most samples between 207.5 and 564.4 mbsf, the dextral form of *N. pachyderma* is generally less than 10% of the fauna. Between 282.9 mbsf (Sample 105-646B-36X-6, 39–44 cm) and 506.9 mbsf (Section 105-646B-53X, CC), most samples contain rare, but consistent occurrences of *G. scitula, G. puncticulata, G. crassula*, and *G. margaritae* (Pls. 1 and 2). A number of samples from this interval also contain rare and sometimes poorly preserved specimens of *G. nepenthes, G. umbilicata, G. woodi, G. falconensis, Globoquadrina venezuelana*, and *Orbulina universa*.

Assemblages in samples between 526.8 mbsf (Sample 105-646B-56X-1, 7–10 cm) and 766.7 mbsf (Section 105-646B-80X, CC) display lower species diversity and abundance and are dominated numerically by *N. atlantica* (s), followed by *N. atlantica* (d), *G. bulloides, G. praebulloides, G. apertura, G. quinqueloba*, and the reticulate and open form of *N. pachyderma*. The species *N. humerosa, N. continuosa, G. woodi*, and *G. venezuelana* occur rarely and sporadically in several samples. Most of the samples from this interval also contain flattened and mostly broken planktonic foraminifer specimens that constitute up to 40% of the total assemblage. We interpreted these specimens as reworked. A coiling change of *N. atlantica* was ob-

Table 3. Occurrences of planktonic foraminifers in samples from Hole 647A.

Depth (mbsf)	Core/section interval (cm)	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	1	2	3
0.58	105-647A-1R-1, 58–64				R		R	R	R					R				R								F	A			A
2.13	1R-2, 63–69				R		R							R												F	A			A
8.32	1R-6, 82–88				C		F	F	F					F											R	C	A			A
9.20	1R, CC				A		A	F	F		R		R	A		R		R							R	C	C	R		A
9.27	2R-1, 7–12				F		F	R	R		R			R											R	F	A	R		A
17.03	2R-6, 33–39				C		C	F	F					F		R										C	A			A
18.90	2R, CC				A		A	F	F					C		C		F							F	C	A	R		A
29.52	4R-1, 92–96				C		F	R	R	R	R			C	R			F							R	A	C			A
30.79	4R-2, 69–74				F		F	R	R		R			F												F	A			A
31.96	4R-3, 36–41				F		F	R	R	R	R			C	R	R		R							R	F	F	R		C
33.53	4R-4, 43–48				F		F	R	F		R			C		R		R		R						C	C	R		C
35.46	4R-5, 86–91				F		C				R			F	R	R										F	A			A
36.94	4R-6, 84–89				C		C	F	F					F				R								C	A			A
38.10	4R, CC				A		A	R	R	R	F			C				C			R	R			R	F	F	C	R	A
48.60	5R, CC				C		C	R	R	R	F		R	C	R	F		F							R	R	C	R		A
49.03	6R-1, 43–48				F		C	F	F					C		R										F	C	R		C
50.53	6R-2, 43–48				F		C		R					C													F	C		C
52.03	6R-3, 43–48				F		F	R	F		R			C	R			R			R				R	C	C			A
53.53	6R-4, 43–48				F		F	R	R	R	R			F				R		R					R	A	C	R	R	A
55.03	6R-5, 43–48				F		C	R	R	R	F			F	R			R	R						R	A	C	R	R	A
56.53	6R-6, 43–48				F		F	R	R		F			F		R		R			R	R			R	A	C	R		A
58.30	6R, CC				C		C				F			C				F			R				R	C	F			A
58.33	7R-1, 3–8				R		R				F			C												C	F			C
59.83	7R-2, 3–8				F		F		R	R	F			C		R		R		R					R	C	C	R	R	A
61.33	7R-3, 3–8				F		F	R	F	R	R		R	F				F							R	C	C	R		A
62.83	7R-4, 3–8				F		F	R	R		F		R	C				F		R					R	A	F	R	R	A
64.33	7R-5, 3–8				C		F		R		R		R	C				R			R				R	A	C			A
65.83	7R-6, 3–8				C		F		F		R			C				R							R	C	F		R	C
68.00	7R, CC				C		C							C		R		R			R				R	C	C	R		A
68.21	8R-1, 21–26				C		F	R	R		R			C	R	R									R	C	F	R		C
69.71	8R-2, 21–26				A		C	F	F		R	R		C	R	R					R	R			R	C	F	R	R	A
71.21	8R-3, 21–26				F		F		R	R	R	R		C	R	R			R	R	R	R			R	C	F	R	R	A
77.60	8R, CC				C		C	F	F		R		R	A					R	R		R			F	C	F	R	R	A
77.75	9R-1, 15–20				F		F		R		R			F						R	R					A	A	R		A
79.25	9R-2, 15–20				F		F		R					R											R	F	A			A
80.75	9R-3, 15–2				F		R		R												R					C	C			C
87.30	9R, CC				A		C	F	F		F		R	A		R					R				F	C	F			A
87.39	10R-1, 9–14				R									R												F	F			F
88.89	10R-2, 9–14				A		R				R	R	R	F	R	R					R				R	C	F			A
90.39	10R-3, 9–14				R		F							F												C	F			C
91.89	10R-4, 9–14						R							F												F	F			F
97.00	10R, CC				F		F							F												F	F			F
97.29	11R-1, 29–34				R																					F	R			F
98.79	11R-2, 29–34				R																					F	R			F
100.29	11R-3, 29–34				F		R		R			R														F	R			F
101.79	11R-4, 29–34				A		R		R		R	R		F		R	R			R	R	R			R	A	R	R		A
106.70	11R, CC				F						R			R												F	R			F
107.03	12R-1, 33–38																									R				R
116.00	12R, CC				F									R	R					C			R	C			R	R		C
117.66	13R-2, 16–2						R																	R		F				F
119.16	13R-3, 16–21																										R			R
120.66	13R-4, 16–21																										R			R
137.09	15R-2, 19–25			R																										R
138.50	15R-3, 18–24	R		R																										R
145.10	15R, CC			R																										R
145.44	16R-1, 34–40			R																										R
146.92	16R-2, 32–38			R																										R
154.80	16R, CC	R	R	F		R																								F
155.13	17R-1, 33–35	R	R	F																										F
158.10	17R-3, 30–32	R	R	F																										F
159.62	17R-4, 32–34	R		F		F																								F
161.14	17R-5, 34–36	R		R		R																								R
164.10	17R, CC	R		R																										R
164.25	18R-1, 15–20	R		R																										R
165.75	18R-2, 15–20	R		R																										R
173.80	18R, CC	R		F		R																								F

Relative abundance scale is R = rare, F = few, C = common, A = abundant, ? = questionable. a = *C. dissimilis*, b = *C. parvulus*, c = *C. unicavus*, d = *G. bulloides*, e = *G. praebulloides*, f = *G. quinqueloba*, g = *G. glutinata*, h = *G. uvula*, i = *G. aequilateralis*, j = *G. crassformis*, k = *G. crassula*, l = *G. hirsuta*, m = *G. inflata*, n = *G. menardii*, o = *G. scitula*, p = *G. tosaensis*, q = *G. truncatulinoides*, r = *G. tumida*, s = *G. conglobatus*, t = *G. ruber*, u = *G. sacculifer*, v = *N. atlantica* (d), w = *N. atlantica* (s), x = *N. dutertrei*, y = *N. pachyderma* (d), z = *N. pachyderma* (s), 1 = *O. universa*, 2 = *P. obliquiloculata*, 3 = Total planktonic foraminfer abundance. The following samples were barren of planktonic foraminifers: 105-647-12R-2, 33–38; -12R-3, 33–38; -12R-4, 33–38; -13R-1, 16–21; -13R-5, 16–21; -13R, CC; -14R-1, 26–32; -14R-2, 32–38; -14R-3, 26–31; 14R, CC; and -15R-1, 20–26.

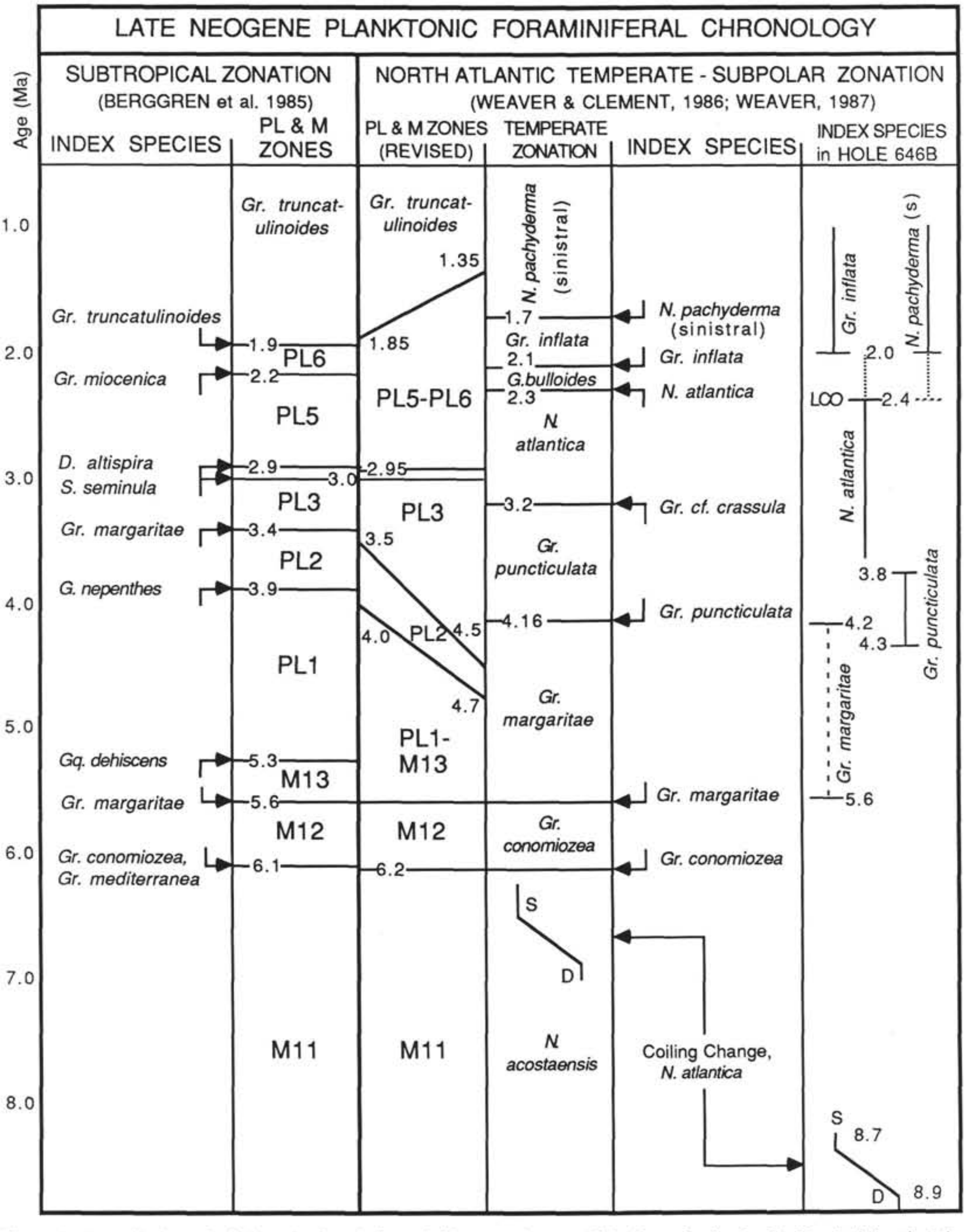

Figure 2. Compilation of existing planktonic foraminifer zonations and biochronologies for the North Atlantic. The subtropical zonation is that of Berggren et al. (1983) calibrated to the time scale of Berggren et al. (1985). The temperate-subpolar zonation shows the chronology of the PL zonal markers in the North Atlantic (after Weaver and Clement, 1986) and the temperate zonation of Weaver and Clement (1986). The chronology of the M zonal markers was compiled by Weaver (1987) and respective Leg 94 site reports (Srivastava, Arthur, et al., 1987). Also shown are the chronostratigraphy of the temperate zonal markers in Hole 646B.

served between 737.7 mbsf (Section 105-646B-77X, CC) and 739.3 mbsf (Sample 105-646B-78X-2, 8–10 cm). From 739.3 to 766.7 mbsf, *N. atlantica* (d) is numerically dominant.

Chronostratigraphy

Although the observed assemblages in Hole 646B generally display low diversity, the occurrence of several age-diagnostic species present in our samples allowed us to establish a biochronology for this site. The numeric ages of first and last occurrences of the age-diagnostic species were interpolated from the age-depth model for Hole 646B Baldauf et al. (this volume), which is reproduced in Table 4. The first appearance datums (FADs) and last appearance datums (LADs) of planktonic foraminifers in Hole 646B, their corresponding depths, and their numeric ages are listed in Table 5. The range chart for selected planktonic foraminifers from Hole 646B and the summary biostratigraphic zonal assignments based on planktonic foraminifers are illustrated in Figure 3.

Table 4. Depths below seafloor of biostratigraphic and magnetostratigraphic ages selected to construct the age-depth model for Hole 646B, modified from Baldauf et al. (this volume).

Name of datum	Age (Ma)	Depth (mbsf)
Paleomagnetic:		
Brunhes/Matuyama	0.73	52.10–73.86
Jaramillo (top)	0.91	76.60–76.80
Jaramillo (bottom)	0.93	81.70–83.60
Matuyama/Gauss	2.47	190.40–192.60
Gauss/Gilbert	3.40	292.85–292.95
Chron C4 (top N2)	6.85	625.24–632.18
Chron C4 (bottom N2)	7.28	661.60–671.34
Chron C4A (top N1)	7.90	680.06–682.01
Chron C4A (bottom)	8.21	702.85–708.39
Calcareous nannofossils:		
FAD *Emiliania huxleyi*	0.275	12.03–13.55
LAD *Pseudoemiliania lacunosa*	0.474	32.99–34.47
LAD *Calcidiscus macintyrei*	1.45	130.00–149.80
Occ. *Discoaster brouweri*	>1.9	161.70–162.51
LAD *Discoaster surculus*	2.4	207.50–208.13
LCO *Reticulofenestra pseudoumbilica*	3.5	343.84–345.34
FAD *P. lacunosa*	3.4	384.44–385.94
FAD *Ceratolithus rugosus*	4.5	431.56–439.50
LAD *Discoaster quinqueramus*	5.6	497.10–506.90
Occ. *Amaurolithus primus*	6.5–4.4	574.00–574.50
FAD *D. quinqueramus*	8.2	709.69–710.50
Foraminifers:		
LAD *Globorotalia inflata*	[a]2.1	159.10–159.51
LCO *Neogloboquadrina atlantica*	[a]2.3	183.30–188.20
FAD encrusted *N. pachyderma* (s)	[a]1.7	161.05–162.40
FAD *Globorotalia puncticulata*	[a]4.16	383.08–384.59
FAD *Globorotalia margaritae*	5.6	506.90–516.50
Diatoms:		
LAD *Rhizosolenia curvirostris*	0.26	9.0–15.69

[a] The ages of planktonic foraminiferal datums are from Weaver and Clement (1986). LAD = last appearance datum; FAD = first appearance datum; LCO = last common occurrence; Occ = single occurence.

Table 5. The first and last occurrences of age-diagnostic species in Hole 646B.

Occurrence	Species	Core	Depth (mbsf)	Age (Ma)
Last	*N. atlantica*	105-646B-16X, CC	149.80	1.90
First	*Gr. inflata*	-17X, CC	159.10	2.00
First encrusted	*N. pachyderma*	-18X-2, 44–46	162.54	2.06
Last common	*N. atlantica*	-20X, CC	188.20	2.40
First	*G. umbilicata*	-26X, CC	246.00	2.95
Last common	*N. humerosa*	-29X-2, 40–45	267.20	3.15
Last	*G. woodi*	-30X-2, 39–44	276.89	3.20
Last	*Gq. venezuelana*	-30X-2, 39–44	276.89	3.20
Last	*Gr. puncticulata*	-36X-2, 71–76	335.31	3.85
Last	*Gr. margaritae*	-39X-5, 19–24	369.69	4.15
First	*Gr. puncticulata*	-41X-2, 26–30	383.06	4.30
Last common	*N. acostaensis*	-51X-1, 107–112	479.11	5.30
First	*Gr. margaritae*	-53X, CC	506.90	5.60
Last	*N. continuosa*	-63X-1, 46–50	593.66	6.50
Coiling D-S	*N. atlantica*	-78X-2, 8–10	739.28	8.75

The ages of datums are interpolated using the age-depth relationship (Baldauf et al., this volume).

In the Goban Spur area of the eastern North Atlantic, Snyder and Waters (1985) used the last occurrence of *N. atlantica* to determine the base of the Pleistocene in DSDP Hole 548. More recent studies in the North Atlantic (Leg 94) placed the LAD of this taxon between 2.26 and 2.36 Ma (Weaver and Clement, 1986). At the northernmost DSDP Sites 610 and 611, the LAD of *N. atlantica* was determined at ~2.28 Ma. Linear interpolation using the last common occurrence of this taxon at 188.2 m (Section 105-646B-20X, CC) and a sedimentation rate of 73 m/m.y. (calculated from the age-depth model) would place the Pliocene/Pleistocene boundary at approximately 140 mbsf in Hole 646B. This is within 13 m of the depth of 127 mbsf for the Pliocene/Pleistocene boundary predicted by the age-depth relationship of Baldauf et al. (this volume), which is based on magnetostratigraphic data. The FAD of *G. inflata* was reported to occur at 3.0 Ma at low latitudes (Berggren et al., 1985), but Weaver and Clement (1986) showed that it occurs between 2.0 and 2.2 Ma in the high-latitude North Atlantic. The first occurrence of *G. inflata* at 159.1 mbsf is much higher in the section than expected from the chronology of Berggren et al. (1985), but corresponds to its expected position according to the zonation of Weaver and Clement (1986). Although sporadic, the occurrence of *G. inflata* in several samples down to 159.1 mbsf agrees well with placement of the Pliocene/Pleistocene boundary at 127 mbsf. Considering the high-latitude location of Site 646 and today's dominance of the region by subpolar water masses, it is likely that the occurrence of *G. inflata* in Hole 646B was influenced by the paleoceanographic regime of the Labrador Sea.

The early/late Pliocene boundary (PL2/PL3 boundary) is usually determined on the basis of the last occurrence (LO) of *G. margaritae*. In Hole 646B, the LO of *G. margaritae* occurs at approximately 369.7 mbsf (Sample 105-646B-39X-5, 19–24 cm). However, this species was rare at Site 646, and its LAD has been shown to be highly diachronous in the North Atlantic, where it occurs between 3.8 and 4.5 Ma (Weaver and Clement, 1986). Interpolation using the age-depth model placed the LAD of *G. margaritae* at about 4.15 Ma, well within the range determined in the North Atlantic. The LO of *G. venezuelana* at 276.9 mbsf (Sample 105-646B-30X-2, 39–44 cm) provides a better approximation of the early/late Pliocene boundary. In Hole 548, the LO of *G. venezuelana* was found within 1.5 m of the FAD of *Reticulofenestra pseudoumbilica* (Snyder and Waters, 1985; Müller, 1985), which corresponds to an age of 3.5 Ma (Berggren et al., 1985).

The PL1/PL2 boundary in low latitudes is defined by the LO of *G. nepenthes* at ~3.9 Ma (Berggren et al., 1985). Since this species is absent in Hole 646B, this boundary can be approximated using the LO of *G. puncticulata* at 335.3 mbsf (Sample 105-646B-36X-2, 71–76 cm). Interpolation using the age-depth model yields an age of 3.8 to 3.9 Ma for its LO in Hole 646B. The FAD of *G. puncticulata* was dated at 4.16 Ma and shown to be isochronous in Leg 94 sites (Weaver and Clement, 1986). In Hole 646, its FO occurs at 384.6 mbsf (Sample 106-646-41X-2, 26–30 cm), which corresponds to an age of ~4.3 Ma, according to the age-depth model.

The Miocene/Pliocene boundary in the open marine record is usually placed at the LAD of *G. dehiscens* at 5.3 Ma (Berggren et al., 1985). However, detailed magnetostratigraphic studies of the stratotype basal Pliocene in Italy resulted in a refined age estimate of 4.83 Ma for the initial marine transgression overlying Messinian evaporites (Zijderveld et al., 1986). Therefore, the Miocene/Pliocene boundary stratotype actually correlates to a level within Zone PL1. The absence of planktonic foraminifer datums between 5.1 and 4.4 Ma in the biochronology of Berggren et al., (1985) indicates that the true Miocene/Pliocene boundary cannot be determined accurately using planktonic foraminifers. In Hole 646B, our placement of the Miocene/Pliocene boundary is derived from the age-depth curve. A straight-line interpretation between the Gauss/Gilbert boundary at 292.85–292.95 mbsf and the top of Chron C4, N2 event at 625.24–632.18 mbsf places the Miocene/Pliocene boundary at ~433 ± 5 mbsf. Because the tropical species *G. dehiscens* is absent in Hole 646B, the M13/PL1 Zonal boundary cannot be determined in Hole 646B. The first occurrence (FO) of *G. marga-*

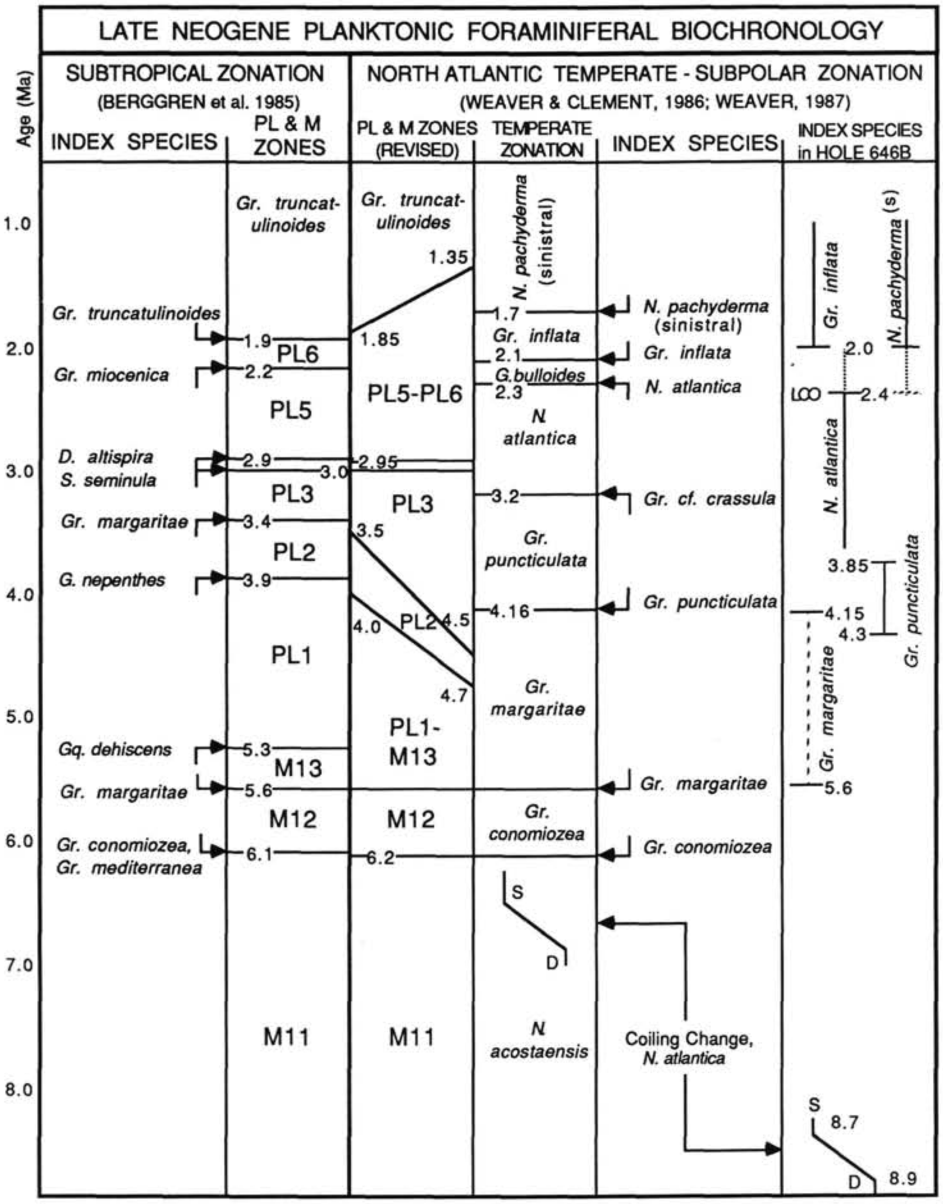

Figure 3. Range chart for selected planktonic foraminifers from Hole 646B. Magnetostratigraphy from Clement et al. (this volume).

ritae in Section 105-646-53X, CC places the M12/M13 zonal boundary at ~506.9 mbsf. This is in excellent agreement with the LAD of *Discoaster quinqueramus* that was determined in the same sample (Srivastava, Arthur, et al. 1987). Because neither *G. conomiozea* nor *G. mediterranea* were present in our samples, the underlying late Miocene section of Hole 646B cannot be subdivided further into "M Zones" using planktonic foraminifers.

The dextral-to-sinistral coiling change in *N. atlantica* was determined to occur within Chron C4 (~7.0 Ma) at DSDP Sites 552 and 611 in the northeastern Atlantic (Keigwin et al., 1987; Weaver and Clement, 1986) . In Hole 646B the dextral-to-sinistral change in *N. atlantica* occurs at ~739.3 mbsf in Chron C4A, and linear extrapolation using the age-depth model yields an age range of 8.75 Ma for this datum. If this age estimate is correct, the coiling change in *N. atlantica* is highly diachronous from north to south and occurs at least 1.6 m.y. earlier in Hole 646B than at DSDP Sites 552 and 611 in the northeastern Atlantic. The coiling change in this taxon is probably climatically controlled as it occurs at approximately the same level as a significant increase (~1.5‰) in planktonic $\delta^{18}O$ values in Hole 646B (Aksu and Hillaire-Marcel, this volume), which can be interpreted as indicating cooling of the surface waters in the East Greenland Current. This interpretation is supported by the paleobiogeographic pattern of the coiling change, which was found at youngest levels (6.15–6.75 Ma) at Site 609, the southernmost site of the Leg 94 transect containing this event (Weaver and Clement, 1986).

Hole 647A

Biostratigraphy

The relative abundances of planktonic foraminifers in the upper 173.4 m of Hole 647A are presented in Table 3. The interval between 0 and 90.4 mbsf (Sample 105-647A-10R-3, 9–14 cm) is characterized by generally high abundances of planktonic foraminifers and species diversity. Between 90.4 mbsf and 120.7 mbsf (Sample 105-647A-13R-4, 16–21), abundance of foraminifers is considerably lower and the assemblages less diverse. The assemblage of lithologic Unit I, between 0 and 116 mbsf (Section 106-647A-12, CC), is dominated by *N. pachyderma* (s) and (d), *G. bulloides, G. quinqueloba*, and *G. inflata* (Table 3). Rare-to-common occurrences of *G. uvula, G. glutinata, N. dutertrei, O. universa, G. truncatulinoides*, and *G. crassaformis* also are found in this interval and are associated with sporadic occurrences of auxiliary species such as *Gr. scitula, G. menardii, G. tumida, G. hirsuta, G. crassula, Globigerinella aequilateralis, Globigerinoides conglobatus, G. ruber, G. sacculifer, O. universa*, and *Pulleniatina obliquiloculata* (Table 3; Plates 1, 2, and 4). Two samples (105-647A-4R-5, 86–91 cm and 105-647A-12R, CC) contain rare *G. umbilicata*. One sample (105-647A-11R-4, 29–34 cm) includes a few specimens of *Gr. tosaensis*, and two samples (105-647A-12R, CC and 105-647A-13R-2, 16–21 cm) contain *N. atlantica*. Samples between 120.7 mbsf (105-647A-13R-4, 16–21 cm) and 135.6 mbsf (105-647A-15R-1, 20–26 cm) are barren of foraminifers.

Samples between 135.6 mbsf (105-647A-15R-1, 2026 cm) and 173.8 mbsf (105-647A-18R, CC) are characterized by a major turnover in the planktonic foraminifer assemblage. The fauna is much less diverse than that observed in the upper interval, and it is dominated by *Catapsydrax unicavus, C. dissimilis*, and *G. praebulloides* (Table 3; Plate 2).

Chronostratigraphy

The range chart for selected planktonic foraminifers from Hole 647A and the summary biostratigraphy based on planktonic foraminifers are illustrated in Figure 4. At lower latitudes, the FAD of *G. truncatulinoides* is generally accepted to occur at 1.9 Ma, immediately below the Olduvai magnetic subchron (Berggren et al., 1985). The FO of this taxon was found in Section 105-647A-7R, CC, which suggests that the upper 68.0 m of Hole 647A can be correlated with foraminifer Zones N22 and N23 of Berggren et al. (1985). However, note that this taxon was reported to have a diachronous FAD in the North Atlantic (Weaver and Clement, 1986; Baldauf et al., 1987). The upper interval of Hole 647A is well dated magnetostratigraphically, and interpolation using the age-depth relationship yielded an age of 1.25 Ma for the FAD of *G. truncatulinoides* in the Labrador Sea. This age is 0.1 m.y. younger than the FAD observed at DSDP Site 611, which is the youngest FO of this species in the transect of sites drilled during Leg 94.

The occurrence of *G. inflata* and *G. crassaformis* in most samples down to 106.7 and 116.0 mbsf (Sections 105-647A-11R, CC and 105-647A-12R, CC), respectively; sporadic occurrence of *G. crassula* between 69.7 and 101.8 mbsf (Samples 105-647A-8R-2, 21–26 cm, and 105-647A-11R-4, 29–34 cm); and the single occurrence of *G. tosaensis* at 101.8 mbsf all suggest that the lower part of lithologic Unit I in Hole 647A can be correlated with the *G. inflata* Zone of Weaver and Clement (1986).

A low-diversity assemblage containing late Miocene species was found between 116.0 and 120.7 mbsf, but this assemblage did not allow us to estimate age for this interval with precision. Samples between 120.7 and 137.1 mbsf are barren of foraminifers; however, an early Miocene age is suggested by radiolarians (Lazarus and Pallant, this volume).

Both *C. dissimilis* and *C. unicavus* range from the Eocene to early Miocene (Kennett and Srinivasan, 1983). An Oligocene age was tentatively assigned to the section between 137.1 and 173.8 mbsf (Sample 105-647A-15R-2, 19–25 cm, and Section 105-647A-18R, CC) based on the absence of diagnostic Miocene fauna and the similarity of the observed *C. dissimilis—C. unicavus* assemblage with those described from Oligocene sections recovered during DSDP Legs 12, 49, 80, and 81 (Berggren, 1972; Poore, 1979; Snyder and Waters, 1985).

CONCLUSIONS

The low diversity of the planktonic foraminifer assemblages at Site 645 and, to a lesser extent, in Holes 646B and 647A precluded the use of standard planktonic foraminifer zonations in the Labrador Sea and Baffin Bay. A detailed chronology based on planktonic foraminifers could not be established at Site 645. Subtropical-to-temperate planktonic foraminifer zonation schemes used during previous North Atlantic DSDP legs were of limited use in Holes 646B and 647A because some of the species used in these zonations are rare or diachronous. The zonation of Weaver and Clement (1986) was most applicable in the Labrador Sea; however, some of the marker species in their zonation are also diachronous. The most usable FADs were *G. inflata* and *G.*

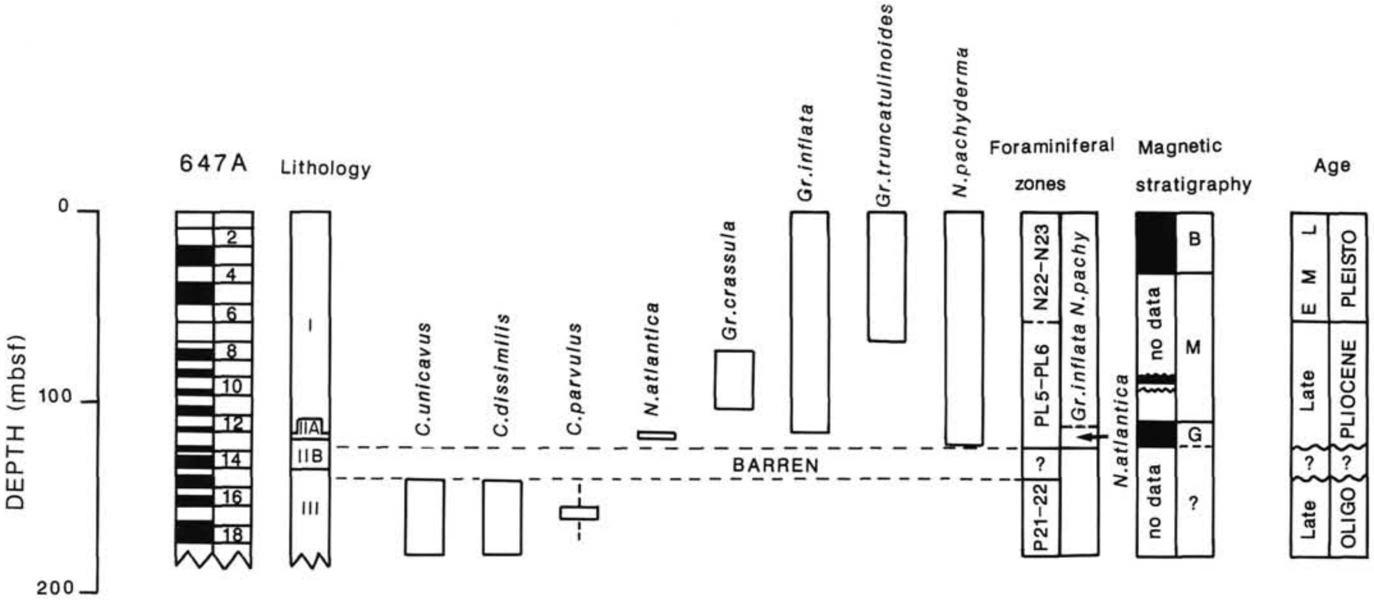

Figure 4. Range chart for selected planktonic foraminifers from Hole 647A. Magnetostratigraphy from Clement et al. (this volume).

puncticulata, which are probably isochronous between the Labrador Sea and the eastern North Atlantic.

Site 646 is situated beneath the subpolar West Greenland Current. The absence of subtropical and temperate species at Site 646 indicates that the site has been influenced by subpolar water masses since the late Miocene. The planktonic foraminifer biochronology indicates that stratigraphic events marking cold conditions (such as the coiling change in *N. atlantica* and the FO of heavily encrusted *N. pachyderma* [s]) occurred earlier at Site 646 than at DSDP sites in the eastern North Atlantic.

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APPENDIX

Taxonomic Notes

The taxonomy used here is based largely on the atlas of Kennett and Srinivasan (1983).

Catapsydrax dissimilis (Cushman and Bermudez, 1937)
Catapsydrax unicavus Bolli, Loeblich and Tappan, 1957
Catapsydrax parvulus Bolli, Loeblich and Tappan, 1957
Globigerina (Globigerina) bulbosa LeRoy, 1944
Globigerina (Globigerina) bulloides d'Orbigny, 1826
Globigerina (Globigerina) falconensis Blow, 1959
Globigerina (Globigerina) praebulloides Blow, 1959
Globigerina (Globigerina) quinqueloba Natland, 1938
Globigerina (Globigerina) umbilicata Orr and Zaitsdeff, 1971
Globigerina (Zeaglobigerina) apertura Cushman, 1918
Globigerina (Zeaglobigerina) nepenthes Todd, 1957
Globigerina (Zeaglobigerina) rubescens Hofker, 1965
Globigerina (Zeaglobigerina) woodi Jenkins, 1960
Globigerinella aequilateralis (Brady, 1870)

Globigerinitida uvula (Ehrenberg, 1861)
Globigerinitida glutinata (Egger, 1893)
Globigerinoides conglobatus (Brady, 1879)
Globigerinoides ruber (d'Orbigny, 1839)
Globigerinoides sacculifer (Brady, 1877)
Globorotalia (*Globoconella*) *inflata* (d'Orbigny, 1839)
Globorotalia (*Globoconella*) *puncticulata* (Deshayes, 1832)
Globorotalia (*Globorotalia*) *tumida* (Brady, 1877)
Globorotalia (*Hirsutella*) *hirsuta* (d'Orbigny, 1839)
Globorotalia (*Hirsutella*) *margaritae* Bolli and Bermudez, 1965
Globorotalia (*Hirsutella*) *scitula* (Brady, 1882)
Globorotalia (*Menardella*) *menardii* (Parker, Jones and Brady, 1865)
Globorotalia (*Truncorotalia*) *crassaformis* Galloway and Wissler, 1927
Globorotalia (*Truncorotalia*) *crassula* Cushman and Steward, 1930
Globorotalia (*Truncorotalia*) *tosaensis* Takayanagi and Saito, 1962
Globorotalia (*Truncorotalia*) *truncatulinoides* (d'Orbigny, 1839)
Neogloboquadrina acostaensis (Blow, 1959)
Neogloboquadrina atlantica (Berggren, 1972)
Neogloboquadrina continuosa (Blow, 1959)
Neogloboquadrina dutertrei (d'Orbigny, 1839)
Neogloboquadrina humerosa (Takayanagi and Saito, 1962)
Neogloboquadrina pachyderma (Ehrenberg, 1861)
Orbulina universa d'Orbigny, 1839 *Pulleniatina obliquiloculata* (Parker and Jones, 1865)

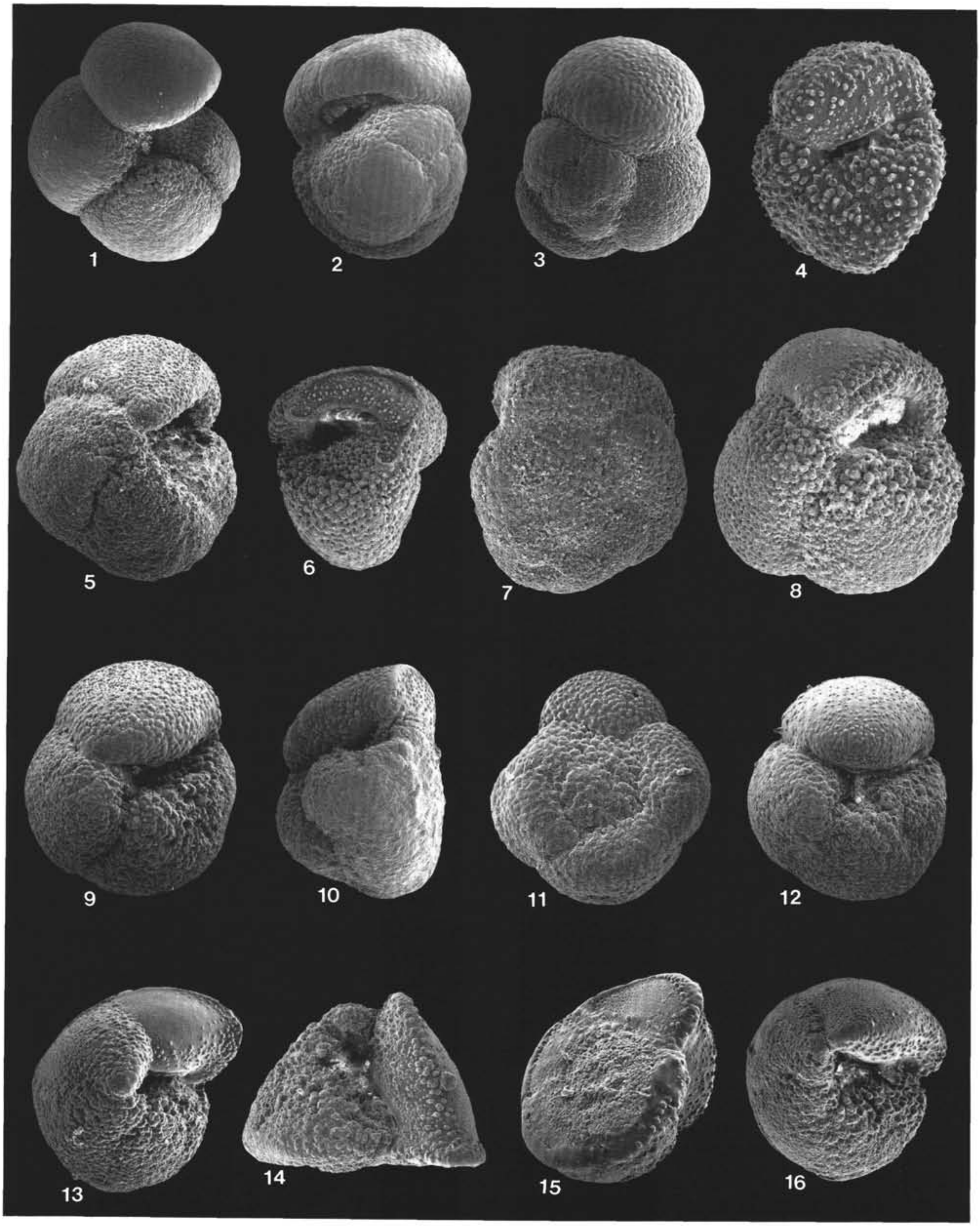

Plate 1. **1–3.** *Globorotalia (Globoconella) inflata* (d'Orbigny), from Sample 105-647A-7R-3, 3–8 cm, (1,2 = X65; 3 = X60). **4–8.** *Globorotalia (Globoconella) puncticulata* (Deshayes), from Sample 105-646B-40X-1, 21–26 cm, (4 = X131; 5 = X65; 6,7 = X77; 8 = X118). **9–12.** *Globorotalia (Truncorotalia) crassaformis* Galloway and Wissler, from Sample 105-647A-6R-6, 43–48 cm, (9,10 = X65; 11 = X71; 12 = X60). **13–16.** *Globorotalia (Truncorotalia) truncatulinoides* (d'Orbigny), from Sample 105-647A-4R-1, 92–96 cm (13,14 = X65; 15 = X71; 16 = X77).

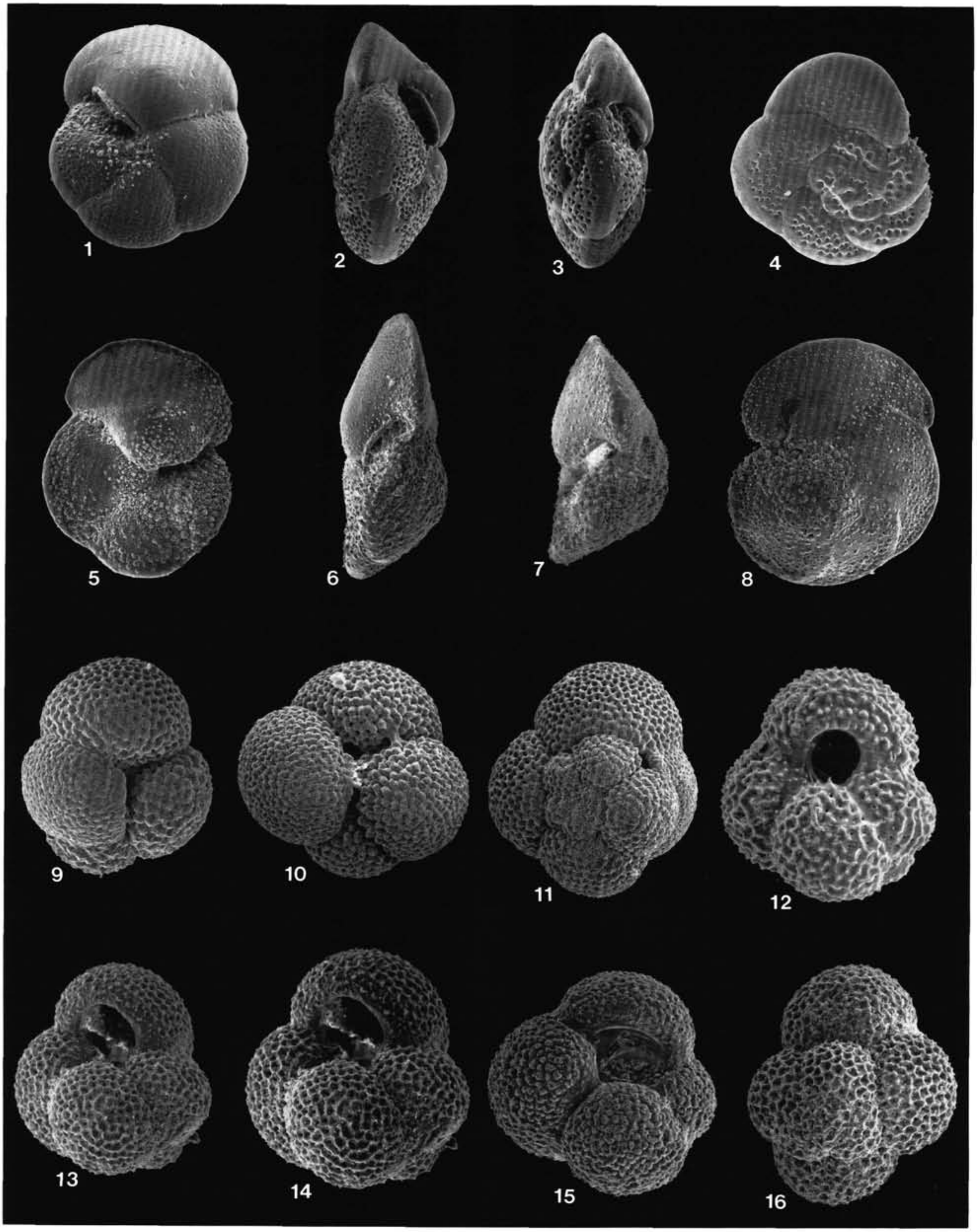

Plate 2. **1–4.** *Globorotalia* (*Hirsutella*) *scitula* (Brady), from Sample 106-646B-39X-2, 19–24 cm, (1 = X77; 2 = X89; 3 = X71; 4 = X119). **5–8.** *Globorotalia* (*Hirsutella*) *margaritae* Bolli and Bermudez, from Sample 105-646B-39X-5, 19–24 cm, (5,6 = X77; 7,8 = X89). **9–11.** *Catapsydrax unicavus* Bolli, Loeblich and Tappan, from Sample 105-647A-17R-3, 30–32 cm (9 = X101; 10,11 = X89). **12.** *Globigerina* (*Zeaglobigerina*) *rubescens* Hofker, from Sample 105-646B-30X-1, 39–44, X179. **13–16.** *Globigerina* (*Zeaglobigerina*) *woodi* Jenkins, from Sample 105-646B-72X-2, 37–40 cm, (13,15,16 = X131; 14 = X149).

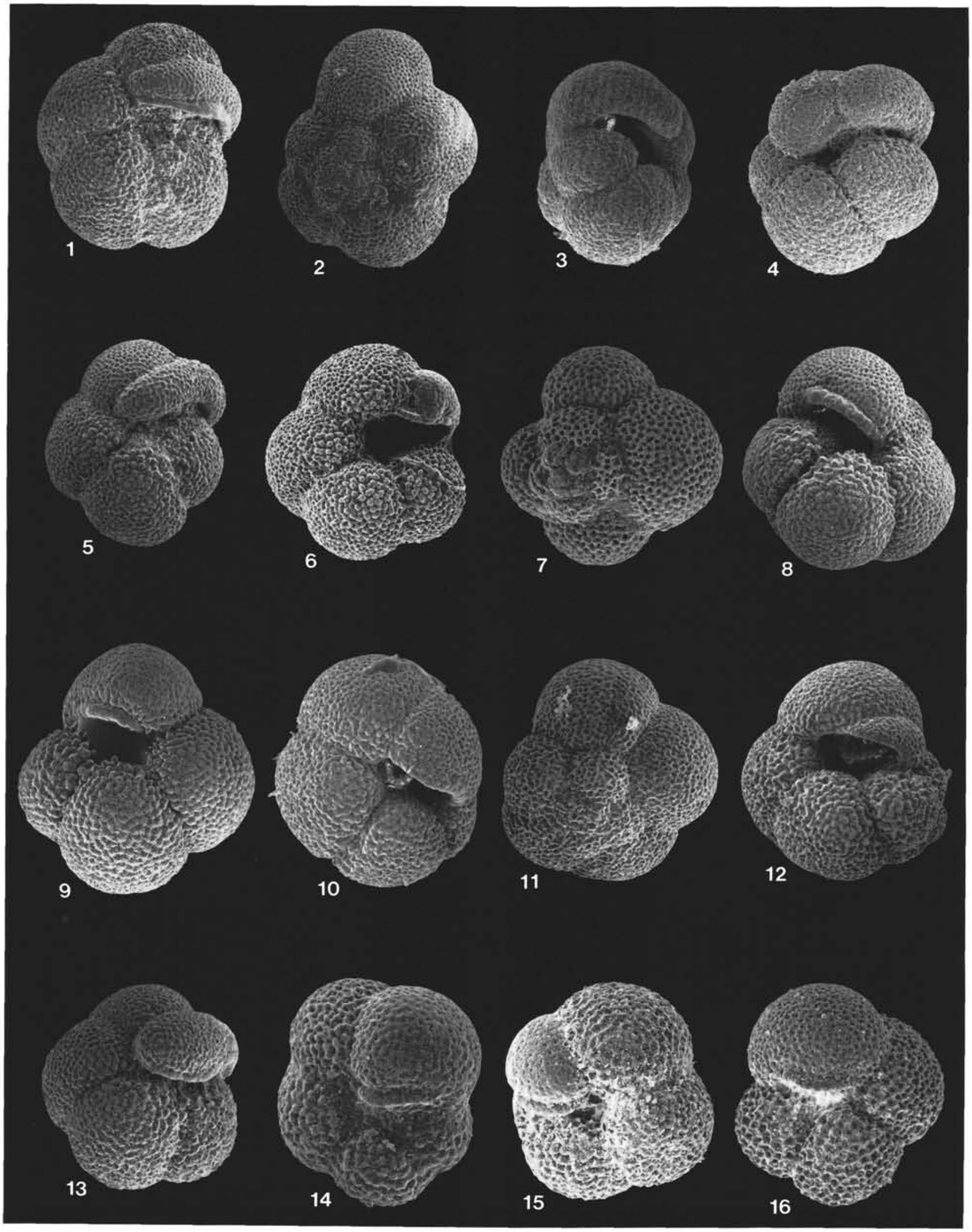

Plate 3. **1–5.** *Neogloboquadrina humerosa* (Takayanagi and Saito), from Sample 105-646B-50X-1, 72–74 cm, (1,2,5 = X65; 3 = X60; 4 = X71). **6–9.** *Neogloboquadrina atlantica* (Berggren), from Sample 105-646B-62X-5, 18–20 cm, (6,8 = X65; = X119; 9 = X77). **10–12.** *Neogloboquadrina pachyderma* (Ehrenberg), from Smple 105-645B-9X-1, 27–30 cm (10 = X101; 11,12 = X89). **13–16.** *Neogloboquadrina acostaensis* (Blow), from Sample 105-646B 51X-1, 107–112 cm (13 = X71; 14,15,16 = X119).

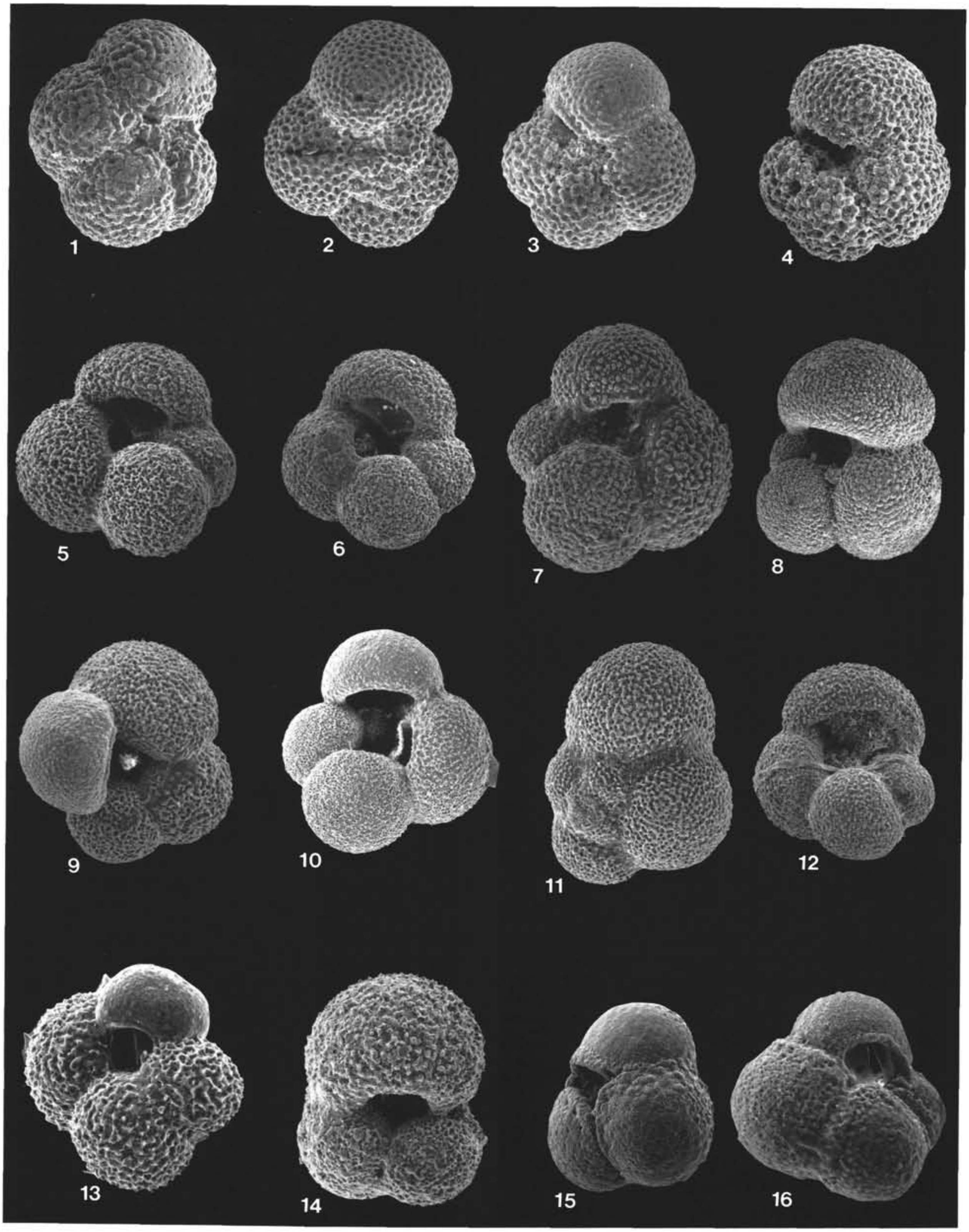

Plate 4. **1–4.** *Neogloboquadrina continuosa* (Blow), from Sample 105-646B 63X-1, 46–50 cm, (1 = X101; 2 = X119; 3,4 = X149). **5–7.** *Globigerina (Globigerina) praebulloides* Blow, from Sample 105-647A 17R-4, 32–34 cm (5 = X89; 6 = X89; 7 = X77). **9.** *Globigerina (Globigerina) falconensis* Blow, from Sample 105-646B-33X-5, 25–30 cm (X89). **8, 10–12.** *Globigerina (Globigerina) bulloides* d'Orbigny, from Sample 105-647A-10R-2, 9–14 cm (8 = X65; 10= X77; 11 = X101 12 = X71). **13.** *Globigerina* sp., from Sample 105-646B-36X-2, 71–76 cm (X149). **14.** *Globigerina bulbosa* LeRoy, from Sample 105-646B-74X-2, 20–24 cm (X101). **15 and 16.** ?*Sphaeroidinellopsis* sp., from Sample 105-646B-36X-2, 71–76 cm (15 = X130; 16 = X149).