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10. LATEST MIOCENE TO QUATERNARY BIOSTRATIGRAPHY AND PALEOCEANOGRAPHY, SITE 704, SUBANTARCTIC SOUTH ATLANTIC OCEAN[1]

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ABSTRACT

The planktonic foraminiferal zonation of Jenkins and Srinivasan (1986), which was defined for the southwestern sector of the temperate South Pacific Ocean, was successfully extended to the temperate sequences at Site 704. The zonation is based on first and last appearances of globorotalids, principally *Globoconella* species, which are indigenous to temperate surface-water masses. Most of the first and last appearances at ODP Site 704 are diachronous with those in the warmer temperate to subtropical South Atlantic, North Atlantic, and South Pacific oceans.

The upper Miocene, upper Pliocene, and Quaternary sequences are punctuated by frequent incursions of subantarctic and polar assemblages of planktonic foraminifers. I assume that the appearance of an assemblage dominated by sinistral *Neogloboquadrina pachyderma* means that the Polar Front has migrated northward, but I do not know its position north or south of the site based on this preliminary work. The upper Miocene sequence contains five incursions between 6.5 and 5 Ma and the upper Pliocene and Quaternary sequence contains 16 events since 2.47 Ma. These are minimum estimates because the number of observed events will probably increase with higher sample density and use of quantitative methods to reveal more subtle events.

INTRODUCTION

Late Cenozoic biostratigraphy of subantarctic regions is poorly defined because few sequences are available and few of these sequences are also calibrated to an absolute time scale. Correlation to an absolute time scale is essential in the subantarctic province because first and last appearances of planktonic foraminiferal species are likely to be migrational events that are diachronous with appearances in temperate and subtropical biogeographic provinces of the oceans.

The purpose of this paper is to (1) detail subantarctic planktonic foraminiferal biostratigraphy in the east Atlantic quadrant of the Southern Ocean during the Quaternary, Pliocene, and latest Miocene, (2) calibrate first and last appearances of planktonic foraminiferal species of the subantarctic to the geomagnetic polarity time scale, and 3) test the sequences for sensitivity to migrations of the Polar Front. This work paves the way for paleoceanographic, biogeographic, and evolutionary studies of the promising high-latitude, carbonate-rich Site 704 of the Ocean Drilling Program (ODP).

METHODS

Samples from Hole 704A were prepared by Allen and Warnke (this volume) and are identical to those used in their study. Samples from Hole 704B were selected from the data set of Müller et al. (this volume) and were prepared as described therein. Both sets of prepared samples consist of the >63-μm size fraction. To facilitate microscopic inspection of planktonic foraminifers, samples from Hole 704A were further subdivided into two size fractions, a 63- to 250-μm fraction and a >250-μm fraction. I recorded the species present in both fractions and combined the data on a range chart. I determined the dominant genus or codominant genera in the >250-μm fraction by visual inspection, and I counted the ratio of sinistral to dextral forms of *Neogloboquadrina pachyderma*. Because few specimens in samples from Hole 704B were larger than 250 μm, I viewed the >63-μm fraction to determine the species present and determined the most common genus or codominant genera in the >150-μm fraction.

Ages listed on all tables and in the manuscript are from a preliminary age model made in 1989 by interpolation between magnetostratigraphic and diatom datums. In January 1990, P.F. Ciesielski (pers. comm.) provided a revised age model for Site 704 in which the depths of datums are slightly different from those in the 1989 model. The differences in depth are shown on Table 1. The depths of five datums have changed by more than 1 m and less than 2.75 m. The slight differences in estimated ages of samples generated by the 1990 model are insignificant for the purposes of this manuscript.

LOCALITY

Site 704 lies at 46°52.76′S, 07°25.23′E, on the southern Meteor Rise in 2532 m of water. Seismic units in the region are gently folded, and the folds increase in amplitude downsection. The folds apparently formed as the result of differential compaction and tectonic movements rather than by large-scale sliding because the folds lie on flat basement. The site rests in the axis of a gentle syncline, where the thick upper seismic units promise a thick sequence of Neogene-age sediments.

Site 704 was located near the Polar Front on Meteor Rise in the hope that the front had migrated across the region during periods of climatic change and that the migrational events were recorded in the sedimentary sequence. Subantarctic Surface Water (SSW) overlies Site 704 at present. SSW is bounded by the Subtropical Convergence approximately 5° north of Site 704 and by the Antarctic Convergence Zone approximately 2.5° south of the site (Lutjeharms and Valentine, 1984). The position of the Antarctic Convergence is constrained bathymetrically south of Africa and moves little compared with positions in other sectors of the Southern Ocean (Gordon, 1967, 1971). For example, during the last glacial maximum the Polar Front advanced no more than 4° in the eastern Atlantic, compared with 7° in the western Atlantic

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Table 1. Comparison of age and depth of datums used to calculate sample ages in this study with the 1990 age model (Hailwood and Clement this volume).

	Age (Ma)	Reference[a]	Depth (mbsf) This study	Depth (mbsf) Revised (January 1990)
Hole 704A				
LAD *Hemidiscus karstenii*	0.195	1	1.14	1.14
LAD *Actinocyclus ingens*	0.62	2	15.15	13.25
Brunhes/Matuyama boundary	0.73	3	34.51	34.51
Top Jaramillo Subchron	0.91	3	40.97	[b]38.41
Base Jaramillo Subchron	0.98	3	44.66	[b]44.27
Top Olduvai Subchron	1.66	3	87.40	89.09
LAD *Coscinodiscus kolbei*	1.89	4	100.25	Not used
Matuyama/Gauss boundary	2.47	3	168.72	168.45
Top Kaena Subchron	2.92	3	176.70	176.10
Base Kaena Subchron	2.99	3	177.98	177.80
Top Mammoth Subchron	3.08	3	178.96	179.10
Base Mammoth Subchron	3.18	3	181.13	181.50
Gauss/Gilbert boundary	3.40	3	186.69	186.65
Top Cochiti Subchron	3.88	3	195.80	198.55
Base Cochiti Subchron	3.97	3	201.94	201.95
Top Nunivak Subchron	4.10	3	204.19	204.20
Base Nunivak Subchron	4.24	3	210.29	210.35
Top Sidufjall Subchron	4.40	3	211.99	212.00
Base Sidufjall Subchron	4.47	3	213.22	213.25
Top Thvera Subchron	4.57	3	217.29	215.40
Base Thvera Subchron	4.77	3	219.44	219.45
Gilbert/C3AN boundary	5.35	3	224.89	Not recognized
Hole 704B				
Top Sidufjall Subchron	4.40	3	212.00	Not recognized
Base Sidufjall Subchron	4.47	3	214.00	Not recognized
Top Thvera Subchron	4.57	3	215.30	Not recognized
Base Thvera Subchron	4.77	3	219.45	Not recognized
C3AN/Gilbert boundary	5.35	3	224.60	224.76
C3AN.3	5.53	3	231.00	231.04
C3AN.6	5.68	3	234.00	233.84
C3AR/C3AN boundary	5.89	3	241.50	241.62
C3AR.6	6.37	3	252.20	251.25
C3AR.75	6.50	3	257.50	256.75
C4N/C3AR boundary	6.70	3	259.50	259.50
C4N.1	6.78	3	264.50	264.29
C4N.2	6.85	3	265.50	265.79
C4N.8	7.28	3	267.50	267.29
C4N.9	7.35	3	270.20	270.82

[a] 1 = Burckle (1982); 2 = isotopic correlation based on Site 594: Ciesielski (1983); 3 = Berggren et al. (1985); 4 = Ciesielski (1983).
[b] In Hole 704B.

Ocean (Hays et al., 1976). Despite the limited movement of the front in this sector of the South Atlantic Ocean, the sequence at Site 704 is likely to record frontal migrations because of its ideal location. In support of this hypothesis, radiolarian assem blages from piston cores indicate that the site was beneath the Antarctic Convergence Zone during the last glacial maximum (18,000 yr B.P.; Hays et al., 1976).

At present, Site 704 lies beneath the subantarctic biogeographic province of planktonic foraminifers that is characterized by abundant *Neogloboquadrina pachyderma* (Ehrenberg) and *Globigerina bulloides* d'Orbigny. North of the site, *Neogloboquadrina dutertrei* (d'Orbigny) is abundant in waters warmer than 15°C, and *Globorotalia inflata* occurs commonly in assemblages in waters near 15°C. Near the site, *G. bulloides* reaches peak abundances in waters near 5° to 10°C, and south of the site, *N. pachyderma* dominates the fauna in waters cooler than 5°C (Bé and Tolderlund, 1971). In general, the geographic ranges of species in the South Atlantic Ocean are similar to those in the South Pacific Ocean (Parker and Berger, 1971). The temperate assemblage characterized by *G. inflata* is distinctly different from the polar assemblage, which is dominated by sinistral *N. pachyderma*, a relationship that facilitates paleoceanographic interpretation.

LITHOSTRATIGRAPHY

The upper Miocene to Quaternary sequences considered in this study (Table 2) comprise four lithostratigraphic subunits within Unit I. Subunit IA is highly variable in color and lithology at intervals of about 20 to 100 cm. The pelagic sediment consists of sharply bounded layers of diatom ooze alternating with carbonate-enriched diatom ooze and calcareous ooze. Subunit IB also consists of mixed carbonate and siliceous ooze, but the sequence is slightly more enriched in carbonate than Subunit IA. Subunit IC has two divisions. Subunit IC_1 is enriched in carbonate and fairly homogeneous in color, whereas the variable color and lithology and enrichment by diatom ooze of Subunit IC_2 are similar to Subunits IA and IB. Subunit ID consists of nannofossil ooze.

RESULTS: DESCRIPTION OF PLANKTONIC FORAMINIFERAL FAUNA

The assemblage at the top of Hole 704A, from 0.0 to 16.86 m below seafloor (mbsf) (Table 3), is typical of modern assemblages of the subantarctic and polar South Atlantic Ocean (Bé and Tolderlund, 1971) and consists of abundant *Globigerina bulloides* and its phenotypes or *Neogloboquad-*

Table 2. Comparison of lithostratigraphic units and informal assemblage zones, Site 704.

Lithostratigraphic unit			Assemblage zone	
Unit	Depth (mbsf)	Cores studied	Zone	Depth (mbsf)
Hole 704A				
IA	0.0–102.2	1H to 11H	$A_1 + A_2$	0–101.82
IB	102.2–178.2	12H to 19X	B	102.92–165.92
IC	178.2–254.2	20X to 27X	C	167.42–234.22
IC_1	178.2–222.2	20X to 24X-5	C_1	167.42–217.50
IC_2	222.2–254.2	24X-5 to 25X-6	C_2	219.00–261.20
Hole 704B				
IC	175.7–251.7	24X to 27X	C	214.50–251.70
IC_1	175.7–219.0	24X to 24X-4	C_1	214.50–219.90
IC_2	219.0–251.7	24X-4 to 27X-CC	C_2	221.90–251.70
ID	251.7–451.2	28X	D	253.10–261.20

rina pachyderma, with common *Globigerina quinqueloba*, *Globorotalia inflata*, and *Globigerinita glutinata* and rare occurrences of *Globorotalia scitula*, *Globorotalia crassaformis*, and *Globorotalia truncatulinoides*, the marker species of the Pleistocene in low latitudes of the Atlantic Ocean. *G. truncatulinoides* first occurs in Sample 114-704A-2H-1, 64–68 cm, and *Globorotalia crassula* last occurs in Sample 114-704A-1H-5, 70–74 cm.

The assemblage in the middle interval at Hole 704A is mostly dominated by *Globorotalia puncticulata* and its subspecies, which last occur in Sample 114-704A-2H-7, 30–34 cm, and first occur in Sample 114-704A-23X-3, 128–132 cm. The assemblage bears *N. pachyderma*, *G. quinqueloba*, *G. glutinata*, and *Globigerinella calida* with rare and sporadic occurrences of *G. crassaformis* and *Globorotalia theyeri*. *G. crassula* first occurs in Sample 114-704A-8H-2, 69–73 cm, and ranges to near the top of the section at the site; *G. inflata* first occurs in Sample 114-704A-17X-1, 70–74 cm, and recurs sporadically upsection to the top of the core. *Globorotalia* cf. *pliozea* first occurs in Sample 114-704A-24X-2, 128–132 cm, and occurs commonly up to Sample 114-704A-6H-5, 68–72 cm. The distinctive species *Globigerina cariacoensis* ranges from Samples 114-704A-21X-3, 8–12 cm, to 114-704A-3H-5, 96–100 cm. *Globorotalia* cf. *margaritae*, which grades morphologically into *G. theyeri*, occurs in Samples 114-704A-21X-2, 8–12 cm, to 114-704A-22X-1, 39–43 cm.

The ranges of species characteristic of the underlying assemblage overlap with the ranges of species of the association described in the preceding text. Specifically, *Globorotalia cibaoensis*, *Globorotalia juanai*, and *Globigerina woodi* last occur above the base of the overlying association, in Sample 114-704A-23X-3, 128–132 cm, where *Globorotalia puncticulata* first appears. These species extend below the overlying association to the lowermost sample examined from this hole. *Globorotalia sphericomiozea* occurs in the lower portion of the hole, from Sample 114-704A-23X-3, 128–132 cm, to the bottom. Other important but long-ranging species of this deepest association include *N. pachyderma*, *G. quinqueloba*, *G. glutinata*, and *Globigerina bulloides*. Assemblages beneath 218 mbsf in the hole suffer dissolution and bear only a few robust specimens.

Samples examined in Hole 704B (Table 4) appear to underlie closely the sequence described from Hole 704A. Samples 114-704B-24X-1, 80–82 cm, to 114-704B-24X-4, 80–82 cm, bear the same species and are dominated by *Globorotalia*, as is the bottommost association of Hole 704A. Beneath this association are two others. The upper one is characterized by *Globorotalia miozea*, which ranges from Samples 114-704B-24X-4, 80–82 cm, to 114-704B-27X-3, 86–90 cm. *Globorotalia conoidea* occurs near the base of the range of *G. miozea* in Samples 114-704B-26X-5, 50–54 cm, 114-704B-27X-2, 110–112 cm, and 114-704B-27X-4, 50–52 cm. The hirsutellid species *G. cibaoensis*, *G. juanai*, *G. theyeri*, and *G. scitula*, along with the globoconellid *Globorotalia panda*, occur sporadically throughout this interval and comprise their own association beneath the first occurrence of *G. miozea*.

Intermixed with samples bearing globorotalids are samples of low diversity, poor preservation, and small foraminiferal numbers. The depauperate samples are dominated by *Globigerina* or *Neogloboquadrina* and may record Miocene advances of polar waters to the Meteor Rise. Tentative age assignments of these events based on the 1989 age model (see Table 1) are in Table 4.

ZONATION

The zonations of Jenkins (1967, 1971) and Jenkins and Srinivasan (1986) best subdivide the subantarctic sequences. Most zonal boundaries are likely diachronous with those of temperate waters. In the zonation cited in the following, LA = last appearance and FA = first appearance.

Globorotalia miotumida Zone (Jenkins, 1967)

Base. LA *Globorotalia mayeri mayeri*.
Top. FA *Globorotalia sphericomiozea* or *Globorotalia conomiozea*.
Remarks. The *G. miotumida* Zone ranges from Samples 114-704B-28X-7, 49–51 cm, which was the lowest sample examined, to 114-704B-25X-2, 80–82 cm.

Globorotalia sphericomiozea Zone (Jenkins, 1967)

Base. FA of nominate taxon.
Top. LA of nominate taxon.
Remarks. The definition of the top of this zone is modified from that in Jenkins (1967) and is consistent with that in Jenkins and Srinivasan (1986). The zone occurs in both holes at the site, extending from Sample 114-704B-25X-1, 20–22 cm, to the top of the studied interval, and from the base of the studied sequence to Sample 114-704A-23X-3, 128–132 cm.

Globorotalia puncticulata Zone (Jenkins and Srinivasan, 1986)

Base. LA of *Globorotalia sphericomiozea*.
Top. FA of *Globorotalia inflata*.
Remarks. The *G. puncticulata* Zone extends from Samples 114-704A-23X-2, 128–132 cm, to 114-704A-17X-2, 70–74 cm.

Globorotalia inflata Zone (Jenkins and Srinivasan, 1986)

Base. FA of nominate taxon.
Top. FA of *Globorotalia truncatulinoides*.
Remarks. The *G. inflata* zone extends from Samples 114-704A-17-1, 70–74 cm, to 114-704A-2H-2, 64–68 cm.

Globorotalia truncatulinoides Zone (Jenkins, 1975; Jenkins and Srinivasan, 1986)

Base. FA of nominate taxon.
Top. Not defined.
Remarks. The *G. truncatulinoides* Zone extends from Sample 114-704A-2H-1, 64–68 cm, to the top of the hole.

FIRST AND LAST APPEARANCES OF SPECIES

First and last appearances of planktonic foraminiferal species in the Atlantic sector of the subantarctic are in several instances diachronous with appearances in other water masses and in other oceans. Discussed in the following are appearances of selected species used to zone Site 704 (Table 5).

Globorotalia truncatulinoides appeared at Meteor Rise about 400,000 yr ago, later than in the North Atlantic Ocean (Weaver and Clement, 1986, 1987), the subtropical South Pacific Ocean (Dowsett, 1988), and the South Atlantic Ocean (Berggren et al., 1983). Its appearance in the northern subant-

Table 3. Planktonic foraminifers from Hole 704A, Meteor Rise.

Hole-core-section-interval (in cm)	*Ba. digitata*	*Ba. praedigitata*	*Ga. bulloides*	*Ga. bulloides umbilicata*	*Ga. cariacoensis*	*Ga. clarkei*	*Ga. decoraperta*	*Ga. eamesi*	*Ga. falconensis*	*Ga. quinqueloba*	*Ga. rubescens*	*Ga. woodi*	*Ga.* cf. *bulloides*	*Ga.* cf. *woodi*	*Ga.* sp. A	*Gd. hexagona*	*Ge. calida*	*Ge. obesa*	*Ge. pseudobesa*	*Gr. blowi*	*Gr. cibaoensis*	*Gr. crassaformis*	*Gr. crassula*	*Gr. inflata*	*Gr. juanai*	*Gr. puncticulata puncticulata*	*Gr. puncticulata puncticuloides*	*Gr. puncticulata* var. A	*Gr. scitula*	*Gr. sphericomiozea*	*Gr. theyeri*	*Gr. tosaensis*	*Gr. truncatulinoides*	*Gr.* cf. *margaritae*	*Gr.* cf. *pliozea*
A-1H-1-70-74			X	X		X				X			X											X									X		
A-1H-2-70-74			X	X						X			X									X		X					X				X		
A-1H-3-70-74			X	X						X			X									X		X									X		
A-1H-5-70-74			X						X	X			X									X	X	X					X						
A-2H-1-64-68			X	X									X									X	X	X					X				X		
A-2H-2-64-68			X	X						X			X																						
A-2H-3-64-68			X							X			X									X	X	X											
A-2H-4-64-68			X							X			X									X	X	X					X						
A-2H-5-64-68			X							X			X									X	X	X											
A-2H-6-64-68			X							X	X		X						X			X	X						X						
A-2H-7-30-34	X		X							X						X	X										X	X	X						
A-3H-1-96-100			X							X							X						X	X			X	X	X						
A-3H-2-96-100			X										X				X					X	X	X			X	X							
A-3H-3-96-100			X							X			X				X							X			X	X			X				
A-3H-4-96-100			X						X	X							X			X		X	X				X	X							
A-3H-5-96-100			X		X				X	X							X						X	X			X								
A-3H-6-96-100			X		X	X			X	X							X					X	X	X			X	X			X				
A-4H-3-68-72			X							X			X				X					X	X	X			X	X							
A-4H-6-38-42			X	X						X													X	X		X									
A-5H-3-29-33			X							X			X										X	X			X	X							
A-5H-5-29-33			X	X						X			X				X					X	X	X			X	X				X			
A-5H-6-29-33										X																									
A-6H-1-68-72			X																			X	X	X		X					X				
A-6H-2-68-72								X	X	X							X					X	X	X			X	X							
A-6H-3-68-72			X	X					X	X							X					X		X			X								
A-6H-4-68-72										X							X							X			X								
A-6H-5-68-72										X							X						X				X								X
A-6H-6-68-72									X	X							X						X	X		X	X	X	X		X				X
A-6H-7-28-32										X							X					X	X	X			X	X			X				X
A-7H-2-70-74		X								X							X					X		X		X	X								X
A-7H-3-68-72			X						X	X							X					X	X	X			X	X	X						X
A-7H-4-71-75			X	X											X									X			X	X							X
A-7H-5-70-74										X					X									X			X								X
A-7H-6-73-77			X							X							X					X				X					X				X
A-8H-1-69-73									X	X												X					X	X							X
A-8H-2-69-73			X						X	X			X										X	X		X	X								X
A-8H-3-69-73			X																					X		X	X								X
A-8H-4-69-73			X							X					X									X		X	X								X
A-8H-5-69-73															X											X									X
A-8H-6-69-73			X							X							X					X		X		X					X				X
A-9H-1-68-72									X	X							X										X				X				X
A-9H-2-68-72			X							X					X		X					X		X		X		X							X
A-9H-3-68-72			X						X	X							X							X		X	X	X							X
A-9H-4-68-72			X							X							X					X		X		X		X	X			X			X
A-9H-5-68-72			X						X	X							X							X		X									X
A-9H-6-68-72										X																X		X							X
A-9H-7-8-12									X								X																		X
A-10H-1-68-72									X	X							X																		X
A-10H-2-68-72			X						X	X							X					X		X		X		X	X						X
A-10H-3-68-72									X								X							X		X									X
A-10H-4-68-72									X	X							X					X		X		X	X	X			X				X
A-10H-5-68-72																																			
A-10H-6-68-72										X							X					X		X				X							X
A-10H-7-68-72										X							X					X				X									X
A-11H-1-70-74																						X		X		X									X
A-11H-2-70-74										X							X					X		X		X									X
A-11H-3-70-74			X														X									X									X
A-11H-4-70-74		X			X	X				X							X							X		X									X
A-11H-5-63-65		X	X		X					X							X									X									X
A-11H-6-70-74			X		X					X							X							X		X	X	X							X
A-11H-7-10-14			X		X					X							X							X		X	X				X				X
A-12H-1-70-74			X		X			X		X							X							X		X	X	X			X				X

Note: X = present

Note: Species arranged alphabetically.

Table 3 (continued).

Gr. cf. *tosaensis*	*Gr.* sp. A	*Gt. glutinata*	*Gt. iota*	*Gt. uvula*	*Gt.* cf. *uvula*	*Nq. pachyderma*	*Nq.* cf. *continuosa*	*Nq.* sp. A	*Or. universa*	*Ss.* cf. *seminulina*	Depth	
		X		X	X	X		X			**0.72**	
		X		X		X					**2.22**	*Globorotalia truncatulinoides* Zone
		X		X	X	X					**3.72**	
		X		X	X	X					**6.72**	
		X		X	X	X					**7.86**	
						X					**9.36**	
					X						**10.86**	
X		X		X	X	X					**12.36**	
		X		X	X	X					**13.00**	
						X		X		X	**15.36**	
				X		X		X			**16.86**	
	X			X	X	X					**17.68**	
	X			X	X	X					**19.18**	
	X			X		X					**20.08**	
						X		X			**22.18**	
				X	X	X					**23.68**	
		X		X	X	X		X			**25.18**	
				X		X					**29.90**	
X				X		X					**34.10**	
						X					**39.01**	
		X		X	X	X					**42.01**	
						X					**43.51**	
	X	X		X	X	X					**45.90**	
X		X		X		X					**47.40**	
	X			X	X	X		X			**48.90**	
				X	X	X					**50.40**	
						X					**51.90**	
						X		X			**53.40**	
X					X	X					**54.50**	
	X					X					**56.92**	
		X			X	X					**58.40**	
	X			X	X	X					**59.93**	
				X		X					**61.42**	
				X		X					**62.95**	*Globorotalia inflata* Zone
		X		X	X	X					**64.91**	
		X				X					**66.41**	
						X					**67.91**	
		X				X					**69.41**	
						X		X			**70.91**	
						X		X			**72.41**	
				X		X		X			**74.41**	
		X				X		X			**75.91**	
				X		X		X			**77.41**	
		X		X		X		X			**78.91**	
						X		X			**80.41**	
						X		X			**81.91**	
						X	X	X			**82.81**	
						X		X			**83.90**	
		X				X		X			**85.40**	
						X		X			**86.90**	
		X				X		X			**88.40**	
											89.90	
						X		X			**91.40**	
						X		X			**92.90**	
						X					**93.40**	
		X				X					**94.92**	
						X		X			**96.42**	
		X				X		X			**97.92**	
						X		X			**99.35**	
		X				X		X			**100.92**	
				X		X		X			**101.82**	
						X		X			**102.92**	

arctic of the South Atlantic Ocean predates that in the northern subantarctic Pacific Ocean by about 100,000 yr (Kennett, 1970).

Globorotalia inflata appeared at Meteor Rise at about the same time it appeared in the subtropical and temperate North Atlantic Ocean (Weaver and Clement, 1986, 1987), at about 2.3 Ma, but the appearance is later by about 1 to 2 m.y. than that reported in the South Atlantic Ocean (Berggren et al., 1983; Hodell and Kennett, 1986). It is possible that reported disconformities, dissolution, and downhole contamination have confused the proper age assignment of its first appearance in the subtropical South Atlantic waters (Poore, 1984; Scott, 1983; Berggren et al., 1983). *G. inflata* appeared in the Pacific Ocean about 1 m.y. earlier than at Site 704 (Hodell and Kennett, 1986).

In contrast to the subtropical South Atlantic Ocean, *Globorotalia puncticulata* and its subspecies are the dominant globorotalids in the Pliocene to middle Pleistocene sections of the site. The taxon last appeared in the middle Pleistocene at Meteor Rise about 628,000 yr ago, which is similar to its last appearance in the South Pacific Ocean (Hornibrook, 1982). It first appeared about 4.3 m.y. ago at Meteor Rise, 1 m.y. later than at some subtropical and temperate sites of the South Pacific Ocean (Hodell and Kennett, 1986) and a few hundred thousand years to 1 m.y. later than in the subtropical South Atlantic Ocean (Hodell and Kennett, 1986).

Globorotalia crassaformis first appeared 3.9 m.y. ago, about 375,000 yr later than *G. puncticulata*, at Meteor Rise. The age of the first appearance of *G. crassaformis* was close to that of the warm subtropical South Pacific Ocean, but 1 m.y. younger than its age of appearance in the temperate South Pacific Ocean (Hodell and Kennett, 1986). The species appeared at midlatitudes in the South Atlantic Ocean a little more than 1 m.y. (Poore et al., 1983) before it appeared at Meteor Rise. However, *G. crassaformis* is very rare, although persistent, at Site 704, which makes accurate recognition of its first occurrence difficult.

Globorotalia sphericomiozea first appeared 5.2 m.y. ago at Meteor Rise, a date consistent with those from the subtropical and temperate South Pacific Ocean (Hodell and Kennett, 1986). It last appeared 4.3 m.y. ago, prior to the final appearance of *Globorotalia juanai* at 3.5 m.y. The extinction sequence is similar to that at Deep Sea Drilling Project (DSDP) Site 284 in the South Pacific Ocean. Scott (1982) reported primitive forms of *G. sphericomiozea* in the subtropical Atlantic Ocean, but commonly the taxon is not reported or it is lumped with *G. puncticulata* (Poore and Berggren, 1975).

SUCCESSION OF DOMINANT GENERA

Three genera dominate samples from Site 704: *Globigerina*, *Globorotalia*, and *Neogloboquadrina* (Fig. 1 and Table 6). The *Neogloboquadrina* assemblage consists of sinistral *Neogloboquadrina pachyderma* and very rare occurrences of other neogloboquadrinids. At Hole 704A, most samples contain assemblages dominated by *Globorotalia* (75 samples), followed by *Neogloboquadrina* (21 samples), and *Globigerina* (7 samples). Genera are codominant in some samples. The most common codominance pair is *Globigerina* and *Globorotalia* (12 samples), followed by *Globorotalia* and *Neogloboquadrina* (7 samples) and *Neogloboquadrina* and *Globigerina* (2 samples). Five samples bear near equal numbers of all three genera. At Hole 704B, either *Globigerina* or *Neogloboquadrina* dominates most samples (36), whereas *Globorotalia* dominates or codominates assemblages of only five of 41 samples examined.

Table 3 (continued).

Hole-core-section-interval (in cm)	*Ba. digitata*	*Ba. praedigitata*	*Ga. bulloides*	*Ga. bulloides umbilicata*	*Ga. cariacoensis*	*Ga. clarkei*	*Ga. decoraperta*	*Ga. eamesi*	*Ga. falconensis*	*Ga quinqueloba*	*Ga. rubescens*	*Ga. woodi*	*Ga.* cf. *bulloides*	*Ga.* cf. *woodi*	*Ga.* sp. A	*Gd. hexagona*	*Ge. calida*	*Ge. obesa*	*Ge. pseudobesa*	*Gr. blowi*	*Gr. cibaoensis*	*Gr. crassaformis*	*Gr. crassula*	*Gr. inflata*	*Gr. juanai*	*Gr. puncticulata puncticulata*	*Gr. puncticulata puncticuloides*	*Gr. puncticulata* var. A	*Gr. scitula*	*Gr. sphericomiozea*	*Gr. theyeri*	*Gr. tosaensis*	*Gr. truncatulinoides*	*Gr.* cf. *margaritae*	*Gr.* cf. *pliozea*
A-12H-2-70-74															X											X	X								X
A-12H-3-70-74			X		X			X									X							X		X		X							X
A-12H-4-70-74			X		X			X	X	X							X							X		X			X						X
A-12H-5-70-74			X		X			X		X							X					X		X		X	X	X	X						X
A-12H-6-70-74			X		X					X							X							X			X				X				X
A-13H-1-70-74																								X		X									X
A-13H-2-70-74																	X							X		X									X
A-13H-3-72-76			X		X					X																X	X								X
A-13H-4-70-74			X		X			X									X							X		X					X	X			X
A-13H-5-70-74			X		X			X		X														X		X	X								X
A-13H-6-70-74			X		X			X		X														X		X	X	X							X
A-13H-7-10-14			X		X					X							X							X		X	X								X
A-14H-1-70-74			X		X												X							X		X	X								X
A-14H-2-70-74			X		X				X	X							X							X		X	X	X			X				X
A-14H-3-70-74			X		X				X	X							X							X		X	X				X				X
A-14H-4-70-74			X		X			X		X							X							X			X				X				X
A-14H-5-70-74			X		X			X		X														X		X		X			X				X
A-14H-6-70-74			X		X																			X		X	X								X
A-15H-1-70-74					X				X	X														X			X				X				X
A-15H-2-70-74			X		X																			X		X	X		X		X				X
A-15H-3-70-74					X																			X		X		X			X				X
A-15H-4-70-74			X		X					X	X													X		X	X	X			X				X
A-15H-5-70-74					X	X				X														X		X	X		X						X
A-15H-6-70-74					X					X												X					X	X							X
A-15H-7-10-14			X		X					X												X		X			X	X							X
A-16H-1-70-74			X		X					X																X	X	X							X
A-16H-2-70-74			X		X					X	X											X				X	X								X
A-16H-3-70-74			X		X					X												X				X	X								X
A-16H-4-70-74			X		X												X					X				X									X
A-16H-5-70-74					X												X					X				X	X	X							X
A-16H-6-70-74			X						X	X							X					X				X	X	X							X
A-17X-1-70-74			X																			X		X			X								X
A-17X-2-70-74			X		X					X												X					X		X						X
A-17X-3-70-74					X																					X	X								X
A-17X-4-70-74					X																					X					X				X
A-17X-5-70-74					X																	X				X	X	X	X						X
A-17X-6-70-74					X																	X				X	X								X
A-18X-1-70-74					X			X		X												X				X									X
A-18X-2-70-74					X																					X	X				X				X
A-18X-3-70-74			X		X					X												X				X	X		X						X
A-18X-4-70-74			X		X					X			X									X				X		X			X				X
A-18X-5-70-74			X		X								X									X				X	X	X							X
A-18X-6-70-74			X																			X					X								X
A-19X-1-70-74			X							X												X				X									X
A-19X-2-70-74			X		X																	X				X									X
A-19X-3-70-74			X							X												X				X	X								X
A-19X-4-70-74			X							X											X	X				X	X	X							X
A-19X-5-70-74			X						X			X										X													X
A-19X-6-70-74			X									X	X									X				X	X	X							X
A-20X-1-90-94			X							X												X				X		X							X
A-20X-2-90-94			X																								X	X							X
A-20X-3-90-94			X																		X					X									X
A-20X-4-90-94			X																		X						X				X				X
A-20X-5-90-94			X																		X					X									
A-20X-6-90-94										X			X								X					X		X			X				X
A-21X-1-8-12			X																		X	X				X		X	X		X				
A-21X-2-8-12			X														X				X				X	X	X	X			X			X	
A-21X-3-8-12			X		X				X												X					X	X	X	X					X	
A-21X-4-8-12			X																		X	X				X	X	X	X		X			X	X
A-22X-1-39-43			X																							X					X			X	
A-22X-2-39-43			X														X					X				X			X		X				
A-22X-3-39-43												X																							

Note: X = present

Table 3 (continued).

Gr. cf. *tosaensis*	*Gr.* sp. A	*Gt. glutinata*	*Gt. iota*	*Gt. uvula*	*Gt.* cf. *uvula*	*Nq. pachyderma*	*Nq.* cf. *continuosa*	*Nq.* sp. A	*Or. universa*	*Ss.* cf. *seminulina*	Depth	
						X		X			104.42	
		X				X		X			105.92	
		X				X		X			107.42	
		X		X		X		X			108.92	
						X		X			110.42	
						X		X			112.42	
						X		X			113.92	
						X		X			115.44	
		X				X		X			116.92	
		X				X		X			118.42	
		X				X		X			119.92	
		X				X		X			120.82	
						X		X			121.92	
						X		X			123.42	
		X				X		X			124.92	*Globorotalia inflata* Zone
				X		X		X			126.42	
				X		X		X			127.92	
					X	X					129.42	
		X		X	X	X		X			131.42	
				X		X		X			132.92	
		X		X		X		X			134.42	
		X		X	X	X		X			135.92	
		X			X	X		X			137.42	
		X		X	X	X		X			138.92	
		X		X	X	X		X			139.82	
		X		X	X						140.92	
				X	X	X		X			142.42	
		X		X		X		X			143.92	
						X					145.42	
		X		X		X					146.92	
				X		X		X			148.42	
						X		X			150.42	
						X					151.92	
				X	X	X		X			153.42	
				X		X					154.92	
		X		X	X	X		X			156.42	
						X					157.92	
		X	X			X		X			159.92	
						X					161.42	
		X		X	X	X	X	X			162.92	
				X	X	X		X			164.42	
				X	X	X		X			165.92	
						X		X			167.42	
		X				X		X			169.42	
		X				X					179.92	
		X		X	X	X		X			172.42	
		X				X		X			173.92	*Globorotalia puncticulata* Zone
						X		X			175.42	
		X		X				X			176.92	
		X				X		X			179.12	
		X			X	X		X			180.62	
		X				X		X			182.12	
		X				X					183.62	
		X				X		X			185.12	
		X				X		X			186.62	
		X									187.80	
		X						X			189.30	
		X		X		X		X			198.80	
		X		X				X			192.30	
						X					197.61	
						X		X			199.11	
						X					200.61	

The pattern of assemblage succession can be divided into informal assemblage zones: five zones and subzones in Hole 704A and three in Hole 704B (Fig. 1 and Table 2). At Hole 704A, the top zone, A, is divided into two parts, subzones A_1 and A_2. Subzone A_1, which ranges from 0 to 17 mbsf, is dominated by *Globigerina* interspersed with some *Neogloboquadrina*. The underlying subzone, A_2, is dominated by *Globorotalia* and *Neogloboquadrina* and extends from 17 to 102 mbsf. Beneath zone A lies zone B, in which most samples are dominated by *Globorotalia* interspersed with *Globigerina* and *Neogloboquadrina*. Zone B bottoms at 166 mbsf. The next deepest zone, C, is divided into two parts. Subzone C_1 at Hole 704A consists of *Globorotalia* and ranges in depth from 166 to 218 mbsf. Samples below 218 mbsf contain too few fossils to determine dominance, and I refer this interval of poor carbonate preservation to subzone C_2.

At Hole 704B (Fig. 1 and Table 2), the top zone is dominated by *Globorotalia* and is referable to subzone C_1. The middle zone is characterized by barren intervals and poorly preserved samples with either *Neogloboquadrina* or *Globigerina* and is referable to subzone C_2. The bottom interval is characterized by well-preserved samples dominated by *Neogloboquadrina* or *Globigerina* and is assigned to zone D.

The boundaries of the assemblage zones described here correspond closely to the boundaries of the lithostratigraphic units (Table 2). The correspondence is natural because the sediment is primarily biogenic and lithology and fossil assemblages are both controlled by pelagic environment. The boundary between informal assemblage zones B and C does not correspond to a lithologic boundary but is distinguished by the first large input of ice-rafted, sand-size mineral grains (Allen and Warnke, this volume) and a marked increase in oxygen isotope anomaly (Müller et al., this volume).

Assemblages dominated by *Neogloboquadrina pachyderma* occur in alternation with other assemblages in the upper Miocene and above the first abundant ice-rafted debris at 167.42 mbsf (2.46 Ma), whereas the *Globorotalia* assemblage persists throughout the lower Pliocene. I assume that the appearance of the *Neogloboquadrina* assemblage marks the incursion of polar waters and the northward migration of the Polar Front. Five incursions are recorded within the upper Miocene samples, and 16 migrations are revealed in the upper Pliocene and Quaternary samples (Fig. 1 and Table 6). More migrational events are likely to be revealed by finer sampling and a quantitative census of specimens which will reveal subtle variations.

The ratio between sinistral and dextral forms of *Neogloboquadrina pachyderma* is typically proportional to temperature and should serve as second line of evidence to support migration of warm and cool water masses. Sinistral forms of *N. pachyderma*, however, dominate all samples that bear the species. In samples from the tops of cores from the temperate South Pacific Ocean, sinistral forms comprise greater than 90% of the population of *N. pachyderma* in the southern half of the waters bounded by the Antarctic and Subtropical convergences (Kennett, 1968). Throughout the late Miocene and Quaternary, Site 704 apparently lay south of the water mass in which coiling forms are sensitive to temperature.

TAXONOMIC NOTES

Beella digitata (Brady), 1884
Beella praedigitata (Parker), 1967
Globigerina bulloides d'Orbigny, 1826
Globigerina bulloides umbilicata Orr and Zaitzeff, 1971

Table 3 (continued).

Hole-core-section-interval (in cm)	*Ba. digitata*	*Ba. praedigitata*	*Ga. bulloides*	*Ga. bulloides umbilicata*	*Ga. cariacoensis*	*Ga. clarkei*	*Ga. decoraperta*	*Ga. eamesi*	*Ga. falconensis*	*Ga. quinqueloba*	*Ga. rubescens*	*Ga. woodi*	*Ga.* cf. *bulloides*	*Ga.* cf. *woodi*	*Ga.* sp. A	*Gd. hexagona*	*Ge. calida*	*Ge. obesa*	*Ge. pseudobesa*	*Gr. blowi*	*Gr. cibaoensis*	*Gr. crassaformis*	*Gr. crassula*	*Gr. inflata*	*Gr. juanai*	*Gr. puncticulata puncticulata*	*Gr. puncticulata puncticuloides*	*Gr. puncticulata* var. A	*Gr. scitula*	*Gr. sphericomiozea*	*Gr. theyeri*	*Gr. tosaensis*	*Gr. truncatulinoides*	*Gr.* cf. *margaritae*	*Gr.* cf. *pliozea*
A-22X-4-39-43																																			
A-22X-5-39-43			X									X																							
A-23X-1-128-132			X																		X				X	X					X				
A-23X-2-128-132			X																						X	X									
A-23X-3-128-132			X																						X	X				X					
A-23X-4-128-132			X							X											X				X					X					
A-23X-5-128-132			X																											X					
A-24X-1-128-132			X							X											X				X					X					
A-24X-2-128-132																									X					X					X
A-24X-3-128-132																									X										
A-24X-4-128-132			X																											X					
A-24X-5-128-132																																			
A-25X-1-100-104							X			X																			X						
A-25X-2-100-104												X																							
A-25X-3-100-104						X						X																							
A-25X-4-100-104												X						X																	
A-25X-5-100-104										X		X	X																						
A-25X-6-100-104			X				X			X		X		X							X														

Note: X = present

Globigerina cf. *bulloides*. *G. bulloides* is highly variable in the studied section. These forms have an unusually compressed aperture. Some specimens have only three chambers in the final whorl.

Globigerina cariacoensis Rogl and Bolli, 1973. This form differs from *G. bulloides* in its high spire and, in this section, by its rugged, spiny texture and radially elongate chambers. The forms are similar to those in Poore and Berggren (1975; pl. 5, figs. 9–12) from DSDP Site 116, at 57°30′N latitude in the North Atlantic Ocean. The taxon may be a form of *Globigerina megastoma* Earland, 1934, which was described from high latitude. Kennett and Srinivasan (1983) call *G. megastoma* a phenotype of *G. bulloides*.

Globigerina clarkei Rogl and Bolli, 1973

Globigerina decoraperta Takayanagi and Saito, 1962

Globigerina eamesi Blow, 1959

Globigerina falconesis Blow, 1959

Globigerina quinqueloba Natland, 1938

Globigerina rubescens Hofker, 1956

Globigerina woodi Jenkins, 1960

Globigerina cf. *woodi*

Globigerina sp. A. This taxon is identical to *Globigerina* sp. A illustrated in Poore (1979).

Globigerinella calida (Parker), 1962

Globigerinella obesa (Bolli), 1957

Globigerinella pseudobesa (Salvatorini), 1966

Globigerinita glutinata (Egger), 1893

Globigerinita iota Parker, 1962

Globigerinita uvula (Ehrenberg), 1861

Globigerinita cf. *uvula*. This taxon is similar to the high-latitude form of *G. uvula* illustrated in Parker (1962, pl. 8, specimens 24, 25, and 26).

Globorotalia anfracta Parker, 1967

Globorotalia cibaoensis Bermudez, 1949. Scott (1983) does not distinguish this taxon from *Globorotalia juanai* at DSDP Site 284. I find that it is somewhat gradational with all the hirsutellids at Site 704.

Globorotalia blowi (Thompson), 1973

Globorotalia conoidea Walters, 1965

Globorotalia crassaformis (Galloway and Wissler), 1927

Globorotalia crassula Cushman and Stewart, 1930

Globorotalia inflata d'Orbigny, 1839

Globorotalia juanai Bermudez and Bolli, 1969

Globorotalia margaritae Bolli and Bermudez, 1965 cf. *margaritae*. The specimens are gradational with *Globorotalia theyeri*.

Globorotalia miozea Finlay, 1939

Globorotalia panda Jenkins, 1960

Globorotalia cf. *pliozea*. The form in Hole 704A differs from that described by Hornibrook (1982) in that this form has no keel. Its test shape, surface texture, aperture, and chamber shape are identical to the taxon described by Hornibrook (1982). The specimens at Hole 704A typically bear a thick secondary crust of calcite.

Globorotalia puncticulata puncticulata (Deshayes), 1832. Forms like those of figures 5k–5q of Hornibrook (1982) were noted.

Globorotalia puncticulata var. A. This form is like those of figures 5e and 5f of Hornibrook (1982) and is believed to

Table 3 (continued).

Gr. cf. *tosaensis*	*Gr.* sp. A	*Gt. glutinata*	*Gt. iota*	*Gt. uvula*	*Gt.* cf. *uvula*	*Nq. pachyderma*	*Nq.* cf. *continuosa*	*Nq.* sp. A	*Or. universa*	*Ss.* cf. *seminulina*	Depth	
											202.11	*Globorotalia puncticulata* Zone
						X			X		203.61	
		X				X	X				208.00	
						X					209.50	
		X				X					211.00	*Globorotalia sphericomiozea* Zone
						X		X			212.50	
						X					214.00	
		X		X		X	X				217.50	
						X					219.00	
											220.50	
		X				X	X				222.00	
							X				223.50	
		X				X					226.72	
						X	X				228.22	
						X					229.72	
						X					231.22	
						X					232.72	
		X				X	X		X		234.22	

be a pregametogenic form of *G. puncticulata puncticulata*.

Globorotalia puncticulata puncticuloides Hornibrook, 1981. Of the two forms observed, one is like figure 5a of Hornibrook (1982) and the other is like figure 5c of Hornibrook (1982) and figures 7a and 7c of Hornibrook (1981). The form commonly appears to bear a rim when viewed with a light microscope, but no rim is evident under the scanning electron microscope.

Globorotalia scitula (Brady), 1882

Globorotalia sphericomiozea Walters, 1965

Globorotalia theyeri Fleisher, 1974

Globorotalia tosaensis Takayanagi and Saito, 1962

Globorotalia truncatulinoides (d'Orbigny), 1839

Globorotaloides hexagona (Natland), 1938

Neogloboquadrina cf. *continuosa* (Blow), 1959

Neogloboquadrina pachyderma (Ehrenberg), 1861

Orbulina universa d'Orbigny, 1839

Sphaeroidinellopsis cf. *seminulina* (Schwager), 1866

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Table 4. Planktonic foraminifers from Hole 704B, Meteor Rise.

Hole-core-section-interval (in cm)	*Ga. bulloides*	*Ga.* cf. *bulloides*	*Ga.* cf. *woodi*	*Ga. clarkei*	*Ga. decoraperta*	*Ga. eamesi*	*Ga. falconensis*	*Ga. quinqueloba*	*Ga. woodi*	*Ge. obesa*	*Gr. anfracta*	*Gr.* cf. *pliozea*	*Gr. cibaoensis*	*Gr. conoidea*	*Gr. crassula*	*Gr. juanai*	*Gr. miozea*	*Gr. panda*	*Gr. puncticulata puncticulata*	*Gr. scitula*	*Gr.* sp. (=*Menardella*)	*Gr. sphericomiozea*	*Gr. theyeri*	*Gt.* cf. *uvula*	*Gt. glutinata*	*Gt. uvula*	*Nq.* cf. *continuosa*	*Nq. pachyderma*	*Or. universa*	Depth	
B-24X-1-80-82								X	X		X	X			X				X				X		X	X		X		**214.50**	
B-24X-2-80-82	X	X										X	X		X	X			X			X	X		X			X		**216.00**	
B-24X-3-80-82	X												X			X						X	X		X					**217.50**	
B-24X-4-80-82	X												X			X	X					X	X		X					**219.00**	
B-24X-5-20-22		X														X	X	X				X	X					X		**219.90**	*Globorotalia sphericomiozea* Zone
B-24X-6-70-72																														**221.90**	
B-24X-7-50-52	X	X																										X		**223.20**	
B-25X-1-20-22								X					X			X	X					X	X		X			X		**223.40**	
B-25X-2-20-22																	X						X		X			X		**224.90**	
B-25X-2-38-42																														**225.08**	
B-25X-2-80-82																														**225.50**	
B-25X-3-80-82			X	X					X								X								X			X		**227.00**	
B-25X-4-80-82			X										X					X					X							**228.50**	
B-25X-5-50-52	X	X	X														X											X		**229.70**	
B-25X-6-20-22									X	X							X						X		X			X		**230.90**	
B-25X-6-38-42					X				X	X														X	X			X		**231.08**	
B-25X-6-80-82		X	X						X																X			X		**231.50**	
B-25X-7-50-52									X																			X		**232.70**	
B-26X-1-50-52		X				X			X																			X		**233.20**	
B-26X-2-50-52	X					X			X																			X		**234.70**	
B-26X-3-20-22									X																			X		**235.90**	
B-26X-4-80-82			X																									X		**238.00**	
B-26X-5-50-52	X						X		X	X				X			X	X										X		**239.20**	
B-26X-6-20-22	X	X	X						X								X			X	X		X					X		**240.40**	
B-27X-1-140-142	X	X																												**243.60**	*Globorotalia miotumida* Zone
B-27X-2-110-112	X		X						X					X			X				X									**244.80**	
B-27X-3-86-90	X								X								X											X		**246.06**	
B-27X-3-110-112	X		X						X	X																X	X			**246.30**	
B-27X-4-50-52			X						X					X														X		**247.20**	
B-27X-4-110-112			X						X	X																		X		**247.80**	
B-27X-4-140-142								X	X																			X	X	**248.10**	
B-27X-5-110-112						X			X																X			X		**249.30**	
B-27X-6-110-112			X						X																					**250.80**	
B-27X-7-50-52									X																X			X		**251.70**	
B-28X-1-140-142	X												X			X									X					**253.10**	
B-28X-2-79-81	X								X				X			X									X					**253.99**	
B-28X-3-49-51	X	X							X							X				X					X					**255.19**	
B-28X-4-79-81	X	X							X	X																X				**256.99**	
B-28X-5-49-51	X								X									X												**258.19**	
B-28X-6-49-51	X	X							X									X							X					**259.69**	
B-28X-7-49-51	X								X							X		X							X					**261.20**	

Note: X = present

Note: Presence/absence by highest appearance.

Table 5. First and last appearances in the subantarctic Atlantic.

Species	Appearance[a]	Age[b] (Ma)	Depth (mbsf)
Hole 704A			
Globorotalia truncatulinoides	FA	0.393	7.86
Globorotalia puncticulata puncticuloides	LA	0.628	16.86
Globigerina cariacoensis	LA	0.667	23.68
Globorotalia puncticulata puncticulata	LA	0.728	34.10
Globorotalia cf. *pliozea*	LA	1.098	51.90
Globorotalia inflata	FA	2.308	150.42
Globorotalia cibaoensis	LA	2.763	173.92
Globigerina woodi	LA	2.848	175.42
Globorotalia juanai	LA	3.538	189.30
Globorotalia cf. *margaritae*	LA	3.538	189.30
Globigerina cariacoensis	FA	3.617	190.80
Globorotalia puncticulata puncticuloides	FA	3.696	192.30
Globorotalia cf. *margaritae*	FA	3.907	197.61
Globorotalia crassaformis	FA	3.929	199.11
Globigerinella calida	FA	3.929	199.11
Globorotalia sphericomiozea	LA	4.307	211.00
Globorotalia puncticulata puncticulata	FA	4.307	211.00
Globorotalia cf. *pliozea*	FA	4.729	219.00
Hole 704B			
Globorotalia miozea	LA	4.748	219.00
Globorotalia sphericomiozea	FA	5.215	223.40
Globorotalia conoidea	LA	5.826	239.20

Note: Reassignment of datums to the more precise depths of the 1990 age model (P. F. Ciesielski, pers. comm.) results in only slight differences in the ages of the first and last appearances at Site 704.
[a] FA = first appearance; LA = last appearance.
[b] Ages calculated using the 1989 age model.

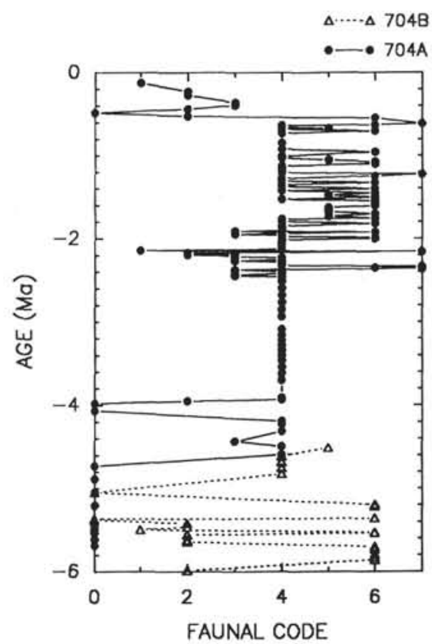

Figure 1. Composite plot of estimate age vs. faunal code for Holes 704A (line with solid circles) and 704B (dashed line with open triangles). Faunal codes are for the dominant genus in each sample: 0 = barren; 1 = *Globigerina* and *Neogloboquadrina*; 2 = *Globigerina*; 3 = *Globigerina* and *Globorotalia*; 4 = *Globorotalia*; 5 = *Globorotalia* and *Neogloboquadrina*; 6 = *Neogloboquadrina*; 7 = *Globigerina*, *Globorotalia*, and *Neogloboquadrina*.

Table 6. Dominant genera in each sample, Holes 704A and 704B.

Core, section, interval (cm)	Depth (mbsf)	Dominant genera	Age[a] (Ma)
114-704A-			
1H-1, 70	0.72	*Nq. + Ga.*	0.12
1H-2, 70	2.22	*Ga.*	0.23
1H-3, 70	3.72	*Ga.*	0.27
1H-5, 70	6.72	*Ga. + Gr.*	0.36
2H-1, 64	7.86	*Ga. + Gr.*	0.39
2H-2, 64	9.36	*Ga.*	0.44
2H-3, 64	10.86	Near barren	0.48
2H-4, 64	12.36	*Ga.*	0.53
2H-5, 64	13.00	*Nq.*	0.55
2H-6, 64	15.36	*Nq. + Ga. + Gr.*	0.61
2H-7, 30	16.86	*Nq.*	0.63
3H-1, 96	17.68	*Gr.*	0.63
3H-2, 96	19.18	*Gr.*	0.64
3H-3, 96	20.68	*Gr.*	0.65
3H-4, 96	22.18	*Gr.*	0.66
3H-5, 96	23.68	*Nq. + Ga. + Gr.*	0.67
3H-6, 96	25.18	*Gr.*	0.68
4H-3, 68	29.90	*Nq.*	0.70
4H-6, 38	34.10	*Gr.*	0.73
5H-3, 29	39.01	*Gr.*	0.84
5H-5, 29	42.01	*Gr.*	0.92
5H-6, 29	43.51	*Nq.*	0.96
6H-1, 68	45.90	*Gr.*	1.00
6H-2, 68	47.40	*Gr.*	1.03
6H-3, 68	48.90	*Nq. + Gr.*	1.05
6H-4, 68	50.40	*Nq.*	1.07
6H-5, 68	51.90	*Nq.*	1.10
6H-6, 68	53.40	*Gr.*	1.12
6H-7, 28	54.50	*Gr.*	1.14
7H-2, 70	56.92	*Gr.*	1.18
7H-3, 68	58.40	*Gr.*	1.20
7H-4, 71	59.93	*Nq. + Ga. + Gr.*	1.23
7H-5, 70	61.42	*Nq.*	1.25
7H-6, 73	62.95	*Gr.*	1.27
8H-1, 69	64.91	*Gr.*	1.30
8H-2, 69	66.41	*Nq.*	1.33
8H-3, 69	67.91	*Gr.*	1.35
8H-4, 69	69.41	*Gr.*	1.38
8H-5, 69	70.91	*Nq.*	1.40
8H-6, 69	72.41	*Gr.*	1.42
9H-1, 68	74.41	*Nq.*	1.45
9H-2, 68	75.91	*Nq. + Gr.*	1.48
9H-3, 68	77.41	*Nq.*	1.50
9H-4, 68	78.91	*Gr.*	1.53
9H-5, 68	80.41	*Ng.*	1.55
9H-6, 68	81.91	*Ng.*	1.57
9H-7, 8	82.81	*Nq.*	1.59
10H-1, 68	83.90	*Nq.*	1.61
10H-2, 68	85.40	*Nq. + Gr.*	1.63
10H-3, 68	86.90	*Nq. + Gr.*	1.65
10H-4, 68	88.40	*Nq. + Gr.*	1.68
10H-5, 68	89.90	*Gr.*	1.71
10H-6, 68	91.40	*Nq. + Gr.*	1.73
10H-7, 68	92.90	*Nq.*	1.76
11H-1, 70	93.42	*Gr.*	1.77
11H-2, 70	94.92	*Gr.*	1.80
11H-3, 70	96.42	*Nq.*	1.82
11H-4, 70	97.92	*Gr.*	1.85
11H-5, 63	99.35	*Gr.*	1.87
11H-6, 70	100.92	*Gr.*	1.90
11H-7, 10	101.82	*Gr.*	1.90
12H-1, 70	102.92	*Ga. + Gr.*	1.91
12H-2, 70	104.42	*Nq.*	1.92
12H-3, 70	105.92	*Gr.*	1.94
12H-4, 70	107.42	*Ga. + Gr.*	1.95
12H-5, 70	108.92	*Gr.*	1.96
12H-6, 70	110.42	*Gr.*	1.97
13H-1, 70	112.42	*Nq.*	1.99
13H-2, 70	113.92	*Nq.*	2.00
13H-3, 72	115.44	*Gr.*	2.01
13H-4, 70	116.92	*Gr.*	2.02
13H-5, 70	118.42	*Gr.*	2.04
13H-6, 70	119.92	*Gr.*	2.05
13H-7, 10	120.82	*Gr.*	2.06
14H-1, 70	121.92	*Gr.*	2.06
14H-2, 70	123.42	*Gr.*	2.08
14H-3, 70	124.92	*Gr.*	2.09
14H-4, 70	126.42	*Gr.*	2.10
14H-5, 70	127.92	*Gr.*	2.11
14H-6, 70	129.42	*Gr.*	2.12
15H-1, 70	131.42	*Nq. + Ga.*	2.14
15H-2, 70	132.92	*Nq. + Ga. + Gr.*	2.15
15H-3, 70	134.42	*Ga.*	2.17
15H-4, 70	135.92	*Ga. + Gr.*	2.18
15H-5, 70	137.42	*Ga.*	2.19
15H-6, 70	138.92	*Ga. + Gr.*	2.21
15H-7, 70	139.82	*Ga. + Gr.*	2.21
16H-1, 70	140.92	*Gr.*	2.22
16H-2, 70	142.42	*Gr.*	2.24
16H-3, 70	143.92	*Gr.*	2.25
16H-4, 70	145.42	*Ga. + Gr.*	2.26
16H-5, 70	146.92	*Gr.*	2.28
16H-6, 70	148.42	*Gr.*	2.29
17X-1, 70	150.42	*Gr.*	2.31
17X-2, 70	151.92	*Gr.*	2.32
17X-3, 70	153.42	*Nq. + Ga. + Gr.*	2.33
17X-4, 70	154.92	*Nq.*	2.35
17X-5, 70	156.42	*Nq. + Ga. + Gr.*	2.36
17X-6, 70	157.92	*Ga. + Gr.*	2.37
18X-1, 70	159.92	*Gr.*	2.39
18X-2, 70	161.42	*Gr.*	2.41
18X-3, 70	162.92	*Gr.*	2.42
18X-4, 70	164.42	*Ga. + Gr.*	2.43
18X-5, 70	165.92	*Ga. + Gr.*	2.45
18X-6, 70	167.42	*Gr.*	2.46
19X-1, 70	169.42	*Gr.*	2.51
19X-2, 70	170.92	*Gr.*	2.59
19X-3, 70	172.42	*Gr.*	2.68
19X-4, 70	173.92	*Gr.*	2.76
19X-5, 70	175.42	*Gr.*	2.85
19X-6, 70	176.92	*Gr.*	2.93
20X-1, 90	179.12	*Gr.*	3.09
20X-2, 90	180.62	*Gr.*	3.16
20X-3, 90	182.12	*Gr.*	3.22
20X-4, 90	183.62	*Gr.*	3.28
20X-5, 90	185.12	*Gr.*	3.34
20X-6, 90	186.62	*Gr.*	3.40
21X-1, 8	187.80	*Gr.*	3.46
21X-2, 8	189.30	*Gr.*	3.54
21X-3, 8	190.80	*Gr.*	3.62
21X-4, 8	192.30	*Gr.*	3.70
22X-1, 39	197.61	*Gr.*	3.91
22X-2, 39	199.11	*Gr.*	3.93
22X-3, 39	200.61	*Ga.*	3.95
22X-4, 39	202.11	Near barren	3.98
22X-5, 39	203.61	Near barren	4.07
23X-1, 128	208.00	*Gr.*	4.19
23X-2, 128	209.50	*Gr.*	4.22
23X-3, 128	211.00	*Gr.*	4.31
23X-4, 128	212.50	*Ga. + Gr.*	4.43
23X-5, 128	214.00	*Gr.*	4.49
24X-1, 128	217.50	*Gr.*	4.59
24X-2, 128	219.00	Near barren	4.73
24X-3, 128	220.50	Near barren	4.88
24X-4, 128	222.00	Near barren	5.04
24X-5, 128	223.50	Near barren	5.20
25X-1, 100	226.72	Near barren	5.40
25X-2, 100	228.22	Near barren	5.45
25X-3, 100	229.72	Near barren	5.49
25X-4, 100	231.22	Near barren	5.54
25X-5, 100	232.72	Near barren	5.62
25X-6, 100	234.22	Near barren	5.69
114-704B-			
24X-1, 80	214.50	*Gr. + Nq.*	4.51
24X-2, 80	216.00	*Gr.*	4.60
24X-3, 80	217.50	*Gr.*	4.68
24X-4, 80	219.00	*Gr.*	4.75
24X-5, 20	219.90	*Gr.*	4.82
24X-6, 70	221.90	Barren	5.05
24X-7, 50	223.20	*Nq.*	5.19
25X-1, 20	223.40	*Nq.*	5.22
25X-2, 20	224.90	*Nq.*	5.36

Table 6 (continued).

Core, section, interval (cm)	Depth (mbsf)	Dominant genera	Age[a] (Ma)
25X-2, 38	225.08	Barren	5.36
25X-2, 80	225.50	Barren	5.38
25X-3, 80	227.00	*Ga.*	5.42
25X-4, 80	228.50	*Ga.*	5.46
25X-5, 50	229.70	*Ga.* + *Nq.*	5.49
25X-6, 20	230.90	*Nq.*	5.53
25X-6, 38	231.08	*Nq.*	5.53
25X-6, 80	231.50	*Ga.*	5.56
25X-7, 50	232.70	*Ga.*	5.62
26X-1, 50	233.20	*Ga.*	5.64
26X-2, 50	234.70	*Nq.*	5.70
26X-3, 20	235.90	*Nq.*	5.73
26X-4, 80	238.00	*Nq.*	5.79
26X-5, 50	239.20	*Nq.*	5.83
26X-6, 20	240.40	*Nq.*	5.86
27X-1, 140	243.60	*Ga.*	5.98
27X-2, 110	244.80	*Ga.*	6.04
27X-3, 86	246.06	*Ga.*	6.10
27X-3, 110	246.30	*Ga.*	6.11
27X-4, 50	247.20	*Ga.*	6.15
27X-4, 110	247.80	*Ga.*	6.17
27X-4, 140	248.10	*Ga.*	6.19
27X-5, 110	249.30	*Ga.*	6.24
27X-6, 110	250.80	*Ga.*	6.31
27X-7, 50	251.70	*Ga.*	6.35
28X-1, 140	253.10	*Nq.*	6.39
28X-2, 79	253.99	*Nq.*	6.41
28X-3, 49	255.19	*Ga.*	6.44
28X-4, 79	256.99	*Ga.*	6.49
28X-5, 49	258.19	*Nq.* + *Ga.*	6.57
28X-6, 49	259.69	*Ga.*	6.70
28X-7, 49	261.20	*Ga.*	6.73

[a] The revised 1990 age model (P. F. Ciesielski, pers. comm.) results in only slight age differences (see Table 1).

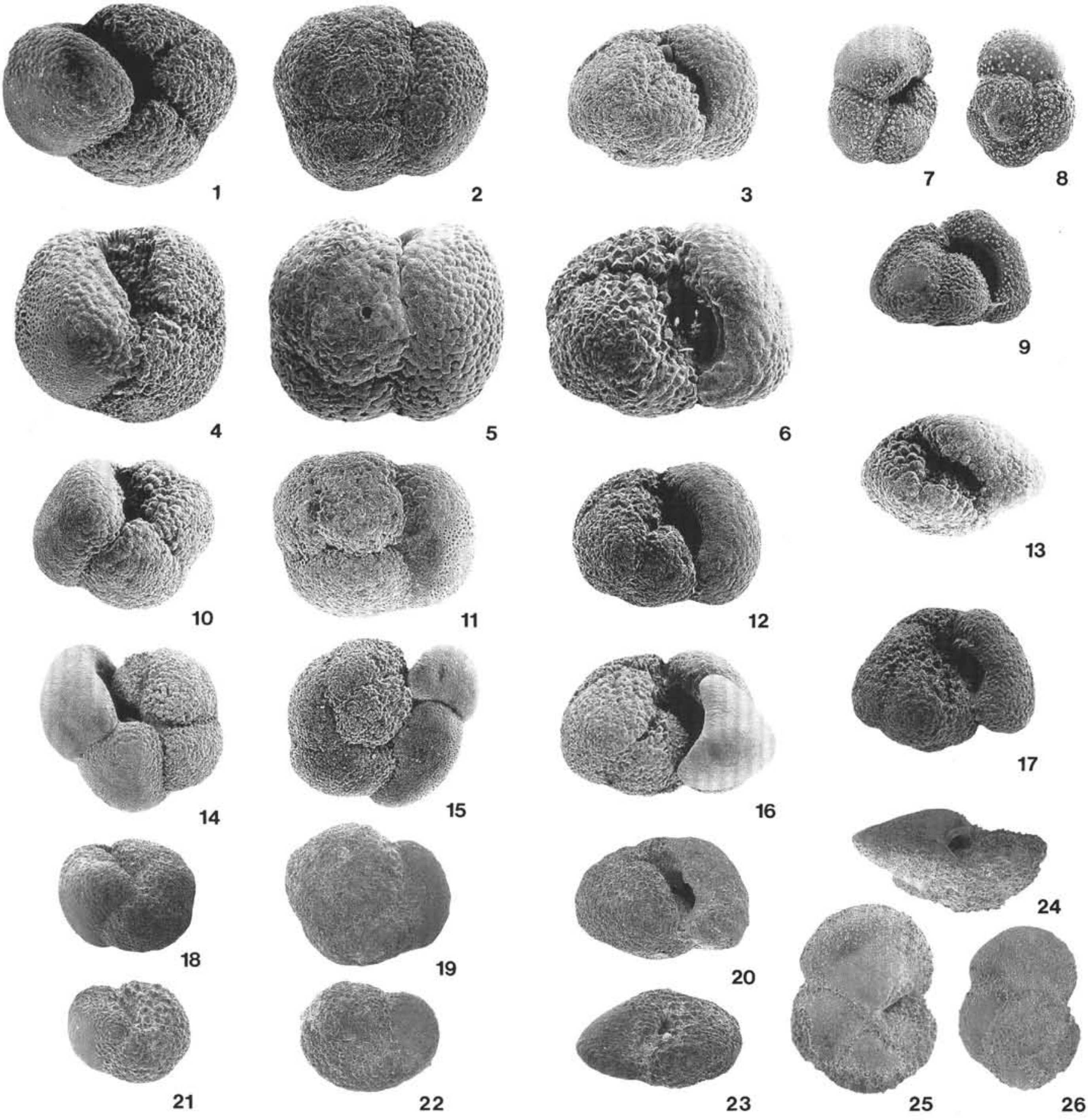

Plate 1. **1.** *Globorotalia crassaformis*, umbilical view, ×125, Sample 114-704A-19X-4, 70–74 cm. **2.** *Globorotalia crassaformis*, spiral view, ×125, Sample 114-704A-19X-3, 70–74 cm. **3.** *Globorotalia crassaformis*, side view, ×125, Sample 114-704A-19X-4, 70–74 cm. **4.** *Globorotalia inflata*, umbilical view, ×125, Sample 114-704A-15H-5, 70–74 cm. **5.** *Globorotalia inflata*, spiral view, ×150, Sample 114-704A-15H-5, 70–74 cm. **6.** *Globorotalia inflata*, side view, ×125, Sample 114-704A-15H-5, 70–74 cm. **7.** *Globorotalia puncticulata* var. A, umbilical view, ×100, Sample 114-704A-15H-3, 70–74 cm. **8.** *Globorotalia puncticulata* var. A, spiral view, ×100, Sample 114-704A-15H-4, 70–74 cm. **9.** *Globorotalia puncticulata* var. A, side view, ×100, Sample 114-704A-15H-4, 70-74 cm. **10.** *Globorotalia puncticulata puncticulata*, umbilical view, ×100, Sample 114-704A-15H-3, 70–74 cm. **11.** *Globorotalia puncticulata puncticulata*, spiral view, ×100, Sample 114-704A-14H-5, 70–74 cm. **12.** *Globorotalia puncticulata puncticulata*, side view, ×100, Sample 114-704A-15H-4, 70–74 cm. **13.** *Globorotalia* cf. *pliozea*, side view, ×125, Sample 114-704A-18X-5, 70-74 cm. **14.** *Globorotalia puncticulata puncticuloides*, umbilical view, ×85, Sample 114-704A-3H-1, 96–100 cm. **15.** *Globorotalia puncticulata puncticuloides*, spiral view, ×85, Sample 114-704A-3H-1, 96–100 cm. **16.** *Globorotalia puncticulata puncticuloides*, side view, ×85, Sample 114-704A-3H-1, 96–100 cm. **17.** *Globorotalia cf. sphericomiozea*, side view, ×125, Sample 114-704A-24X-1, 128–132 cm. **18.** *Globorotalia sphericomiozea*, umbilical view, ×150, Sample 114-704B-24X-2, 80–82 cm. **19.** *Globorotalia sphericomiozea*, spiral view, ×150, Sample 114-704B-24X-2, 80–82 cm. **20.** *Globorotalia sphericomiozea*, side view, ×150, Sample 114-704B-24X-1, 80–82 cm. **21.** *Globorotalia miozea*, umbilical view, ×200, Sample 114-704B-26X-6, 20–22 cm. **22.** *Globorotalia miozea*, spiral view, ×200, Sample 114-704B-26X-6, 20–22 cm. **23.** *Globorotalia miozea*, side view, ×200, Sample 114-704B-26X-5, 50–52 cm. **24.** *Globorotalia panda*, side view, ×200, Sample 114-704B-28X-5, 49–51 cm. **25.** *Globorotalia panda*, umbilical view, ×200, Sample 114-704B-28X-5, 49–51 cm. **26.** Globorotalia panda, spiral view, ×200, Sample 114-704B-28X-5, 49–51 cm.

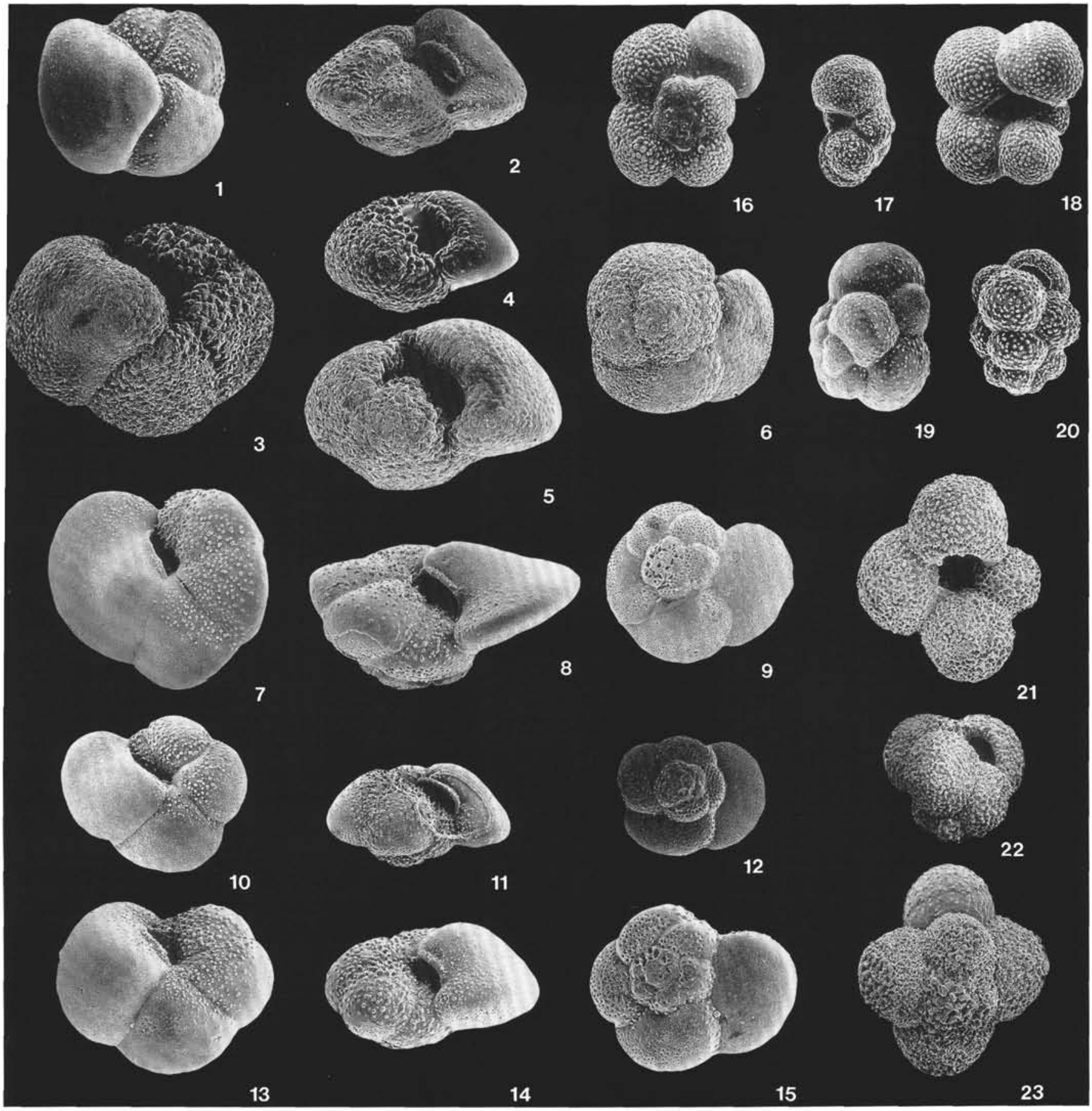

Plate 2. **1.** *Globorotalia crassula*, umbilical view, ×150, Sample 114-704A-2H-1, 64–68 cm. **2.** *Globorotalia crassula*, side view, ×150, Sample 114-704A-2H-1, 64–68 cm. **3.** *Globorotalia* cf. *pliozea*, umbilical view, ×100, Sample 114-704A-18X-5, 70–74 cm. **4.** *Globorotalia* cf. *pliozea*, side view, ×125, Sample 114-704A-8H-4, 69–73 cm. **5.** *Globorotalia* cf. *pliozea*, side view, ×100, Sample 114-704A-18X-5, 70–74 cm. **6.** *Globorotalia* cf. *pliozea*, spiral view, ×100, Sample 114-704A-18X-5, 70–74 cm. **7.** *Globorotalia* cf. *margaritae*, umbilical view, ×100, Sample 114-704A-21X-2, 8–12 cm. **8.** *Globorotalia* cf. *margaritae*, side view, ×175, Sample 114-704A-21X-2, 8–12 cm. **9.** *Globorotalia* cf. *margaritae*, spiral view, ×100, Sample 114-704A-21X-2, 8–12 cm. **10.** *Globorotalia cibaoensis*, umbilical view, ×125, Sample 114-704A-24X-1, 128–132 cm. **11.** *Globorotalia cibaoensis*, side view, ×125, Sample 114-704A-24X-1, 128–132 cm. **12.** *Globorotalia cibaoensis*, spiral view, ×125, Sample 114-704A-24X-1, 128–132 cm. **13.** *Globorotalia juanai*, umbilical view, ×175, Sample 114-704A-21X-2, 8–12 cm. **14.** *Globorotalia juanai*, side view, ×175, Sample 114-704A-21X-3, 8–12 cm. **15.** *Globorotalia juanai*, spiral view, ×175, Sample 114-704A-21X-2, 8–12 cm. **16.** *Globigerinella calida*, umbilical view, ×200, Sample 114-704A-9H-4, 68–72 cm. **17.** *Globigerinella calida*, side view, ×200, Sample 114-704A-9H-4, 68–72 cm. **18.** *Globigerinella calida*, spiral view, ×200, Sample 114-704A-9H-4, 68–72 cm. **19.** *Globigerinita* cf. *uvula*, side view, ×450, Sample 114-704A-8H-1, 69–73 cm. A bulla covers the aperture at the center, right margin of the specimen. **20.** *Globigerinita uvula*, side view, ×400, Sample 114-704A-7H-4, 71–75 cm. **21.** *Globigerina cariacoensis*, umbilical view, ×100, Sample 114-704A-12H-5, 70–74 cm. **22.** *Globigerina cariacoensis*, side view, ×100, Sample 114-704A-14H-4, 70–74 cm. **23.** *Globigerina cariacoensis*, spiral view, ×100, Sample 114-704A-12H-4, 70–74 cm.