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13. PLANKTONIC FORAMINIFER BIOSTRATIGRAPHY OF CAMPANIAN-MAESTRICHTIAN SEDIMENTS FROM SITES 698 AND 700, SOUTHERN SOUTH ATLANTIC[1]

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ABSTRACT

Campanian-Maestrichtian planktonic foraminifers were examined from Sites 698 (2128 m water depth) and 700 (3611 m water depth) on the Northeast Georgia Rise (southern South Atlantic, 51°S). Site 698 penetrated 72.5 m of Campanian-Maestrichtian chalk and limestone with only 18.2% recovery, whereas Site 700 recovered 66.8% of a 152.7-m section of Coniacian-Maestrichtian limestone. Preservation of planktonic foraminifers from both sites is moderate in Maestrichtian samples, but worsens with increasing depth in the Campanian.

The Northeast Georgia Rise planktonic foraminifers are typical of Late Cretaceous Austral Province faunas described from other southern high-latitude sites; species diversity is low and the assemblages are dominated by species of *Heterohelix*, *Globigerinelloides*, *Hedbergella*, and *Archaeoglobigerina*. Five species, including *Globigerinelloides impensus* Sliter, *Archaeoglobigerina australis* Huber, *Archaeoglobigerina mateola* Huber, *Hedbergella sliteri* Huber, and *Rugotruncana circumnodifer* (Finlay), are considered to be endemic to the Austral Province. Formation of a cool temperate water mass in the circum-Antarctic region, resulting from the final breakup of the Gondwana continents, may have led to increased provincialism of the Austral Province planktonic foraminifers during Campanian-Maestrichtian time.

Magnetobiostratigraphic correlation of eight planktonic foraminifer datum events at Hole 700B with ages determined for datums at ODP Leg 113 Holes 689B and 690C (Maud Rise, 65°S) demonstrates regional synchroneity of first and last occurrences within the Austral Province. As was observed at the Maud Rise, several keeled and nonkeeled species previously thought to have been restricted to warmer low-latitude regions first occur later at the Northeast Georgia Rise than at the low-latitude sites. The causes for high-latitude diachroneity among these immigrant species are not clear; neither oxygen and carbon isotope data from the Maud Rise sites nor calcareous nannoplankton distributions for the southern South Atlantic region show conspicuous changes that correlate to the delayed first occurrences.

INTRODUCTION

Two of the seven sites drilled during Ocean Drilling Program (ODP) Leg 114 penetrated chalk and limestone sediments yielding Late Cretaceous foraminifers. Moderately well-preserved Maestrichtian assemblages were obtained from a chalk sequence drilled at Hole 698A, which is near the eastern edge of the Northeast Georgia Rise (51°28'S, 33°6'W) in a water depth of 2128 m (Fig. 1). Hole 700B is about 85 km to the east of Hole 698A on the northeastern slope of the Northeast Georgia Rise (51°32'S, 30°17'W) in a 3611-m water depth. Moderately to poorly preserved foraminifer assemblages, ranging from Coniacian to late Maestrichtian in age, were recovered from a thick limestone section at this deeper water site. Planktonic foraminifers from the Campanian-Maestrichtian sections of both holes were analyzed for comparison of their biostratigraphic and biogeographic distributions with those of other assemblages reported from the high-latitude South Atlantic region.

Campanian-Maestrichtian foraminifers were recovered previously from several sites in the southern South Atlantic and Weddell Sea region (Fig. 1). These include Deep Sea Drilling Program (DSDP) Sites 327 and 511 on the Falkland Plateau (Sliter, 1977; Krasheninnikov and Basov, 1983), the James Ross Island region of the northeastern Antarctic Peninsula (Huber, 1988), and ODP Sites 689 and 690 on the Maud Rise (Huber, 1990). Planktonic foraminifer assemblages from all of these sites are characterized by (1) low taxonomic diversity, (2) dominance by long-ranging globulose species, and (3) the rare occurrence of zonal markers used in low-latitude zonal schemes, particularly those forms bearing peripheral keels. The distinctive extratropical character of these high-latitude assemblages has been the basis for their inclusion in the Austral Province (Sliter, 1977; Krasheninnikov and Basov, 1983; Huber, 1988, 1990).

No planktonic foraminifers were recognized as endemic to the Austral Province prior to the recovery of Cretaceous samples from the Maud Rise. Taxonomic analysis of that assemblage and comparison with coeval assemblages from the James Ross Island region, Falkland Plateau DSDP Sites 327 and 511, and DSDP Site 208 (Tasman Sea) revealed that five species occur only within the southern high-latitude regions of the Austral Province. The total stratigraphic ranges of these species were not established previously, however, because of hiatuses and incomplete core recovery in Upper Cretaceous sediments at the Falkland Plateau and nonrecovery of pre-latest Campanian sediments at the Maud Rise (Fig. 2).

Site 700 provides a more continuous Campanian to Maestrichtian transition than was recovered at the other southern South Atlantic sites. Documentation of foraminifer distributions within this time frame at Sites 698 and 700 enables refinement of a new zonal scheme proposed for the southern high-latitudes and demonstrates regional synchroneity of changes in species diversity and composition. These results will provide a better understanding of the paleoenvironmental evolution of the southern South Atlantic region.

METHOD OF STUDY

Samples used in this study are from Cores 114-698A-14R through 114-698A-21R (118.3–182.8 m below seafloor [mbsf])

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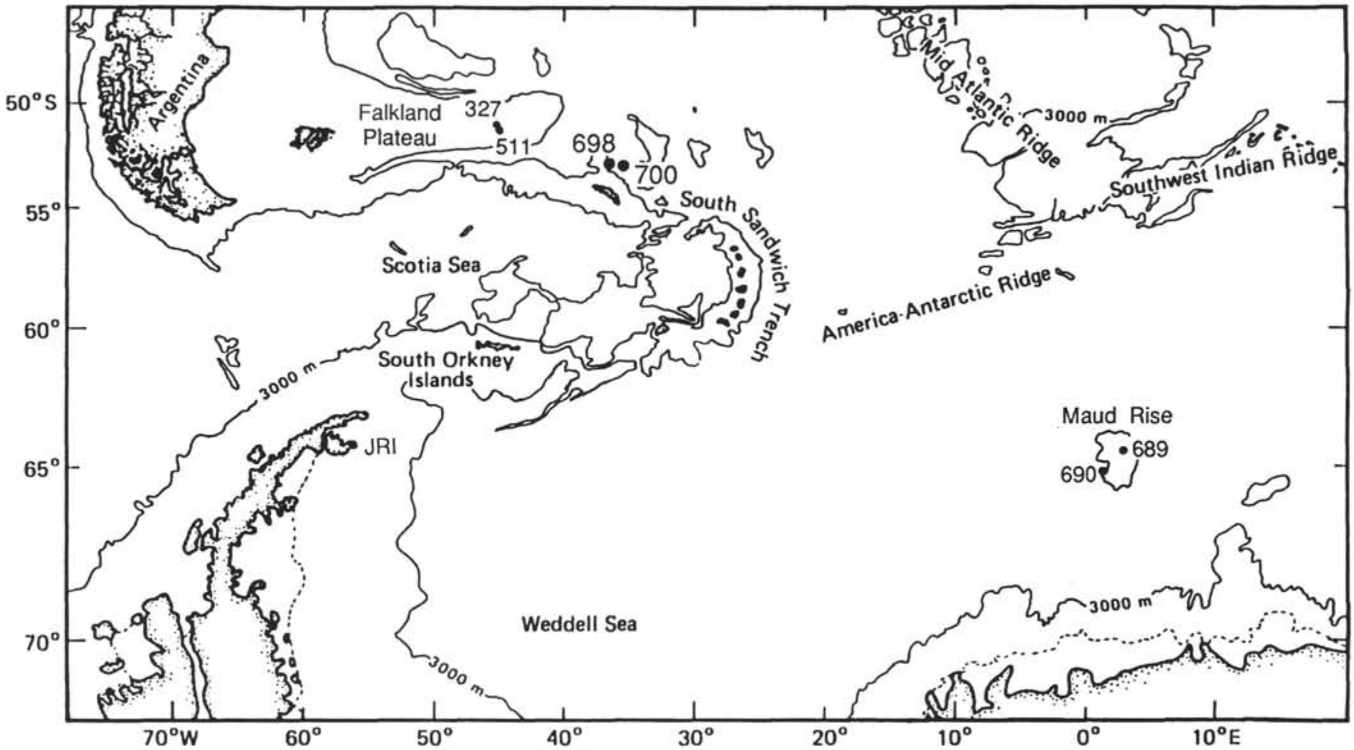

Figure 1. Map of the southern South Atlantic Ocean and Weddell Sea, showing the location of ODP Sites 698 and 700 on the Northeast Georgia Rise and 689 and 690 on the Maud Rise and DSDP Sites 327 and 511 on the Falkland Plateau. The 3000-m bathymetric contour is also portrayed.

and Cores 114-700B-37R through 114-700B-49R (330.7–440 mbsf). One sample per section was obtained from each available core. The samples were disaggregated in water, stirred over a warm hot plate, ultrasonically cleaned, and then sieved over a 63-μm screen. Numerical abundance counts of 300 specimens were performed separately for the >150-μm and <150-μm size fractions of most samples. Counts of 300 specimens from only the >63-μm size fraction were done on some moderately and some poorly preserved samples. Specimens found after the initial 300 specimen count are denoted by an *X* and species questionably present are denoted by a *?* on Tables 1 and 2.

Relative abundances of foraminifers and other biogenic constituents were determined for poorly preserved samples based on grain counts of the >63-μm size fraction from one field of view at low magnification. Relative abundance values for each species or microfossil constituent are as follows: abundant = 26%, common = 16%–25%, few = 6%–24%, rare = <5%. Total foraminifer abundances ranked as rare reflect the predominance of indurated grain aggregates rather than dominance by other biogenic constituents.

Preservation of the Leg 114 Cretaceous foraminifers ranges from moderate to very poor (Tables 1 and 2). A moderate (M) preservation rating was assigned to foraminifers with fragmented, strongly etched tests that are infilled with sediment and/or overgrown with secondary calcite. Poor (P) preservation ratings were assigned to foraminifer tests that are more severely fragmented, etched, and/or overgrown and difficult to identify to the species level. Very poor (VP) preservation was noted for samples yielding very few or no identifiable specimens.

The zonal scheme applied in this study was proposed previously for the southern high latitudes based on Maestrichtian foraminifer distributions at Maud Rise Sites 689 and 690 and their correlation with sections recovered from Sites 327 and 511 (Huber, 1990). The three planktonic foraminifer zones recognized are (1) the *Abathomphalus mayaroensis* Total Range Zone (upper Maestrichtian), (2) the *Globotruncanella havanensis* Interval Zone (lower Maestrichtian), and (3) the *Globigerinelloides impensus* Total Range Zone (middle through upper Campanian).

Sample notation follows the standard ODP format, listing the leg, hole, core number and coring method, section, and the downcore interval (cm).

BIOSTRATIGRAPHY

Hole 698A

Continuous rotary drilling at Hole 698A penetrated 72.5 m of Cretaceous sediment, but only 13.2 m of the section (18.2%) was recovered (Fig. 3). The Cretaceous/Tertiary boundary occurs in an unrecovered interval between the core catcher of Core 114-698A-13R and the top of Core 114-698A-14R, at about 118 mbsf (Ciesielski, Kristoffersen, et al., 1988). Chert stringers within the Cretaceous sequence hampered drilling efforts and probably caused the zero recovery in Cores 114-698A-18R and 114-698A-19R. Drilling terminated at 237 mbsf after 27 m of basalt was recovered.

The Cretaceous sequence was subdivided into two lithostratigraphic units and five subunits. The upper 28 m, from Cores 114-698A-14R though 114-698A-16R, is included in Subunit IIB, which consists of a moderately bioturbated nannofossil chalk with sporadic intercalations of foraminifer-bearing nannofossil ooze and chert. Subunit IIC, in Cores 114-698A-17R through 114-698A-21R (146.5 to 190.5 mbsf), is a faintly to moderately bioturbated, fine-grained limestone with chert intercalations increasing in number toward the bottom of the subunit. Minor constituents in Subunit IIC include volcanic ash, radiolarians, diatom fragments, zeolites, and clay. The three subunits comprising Unit III include

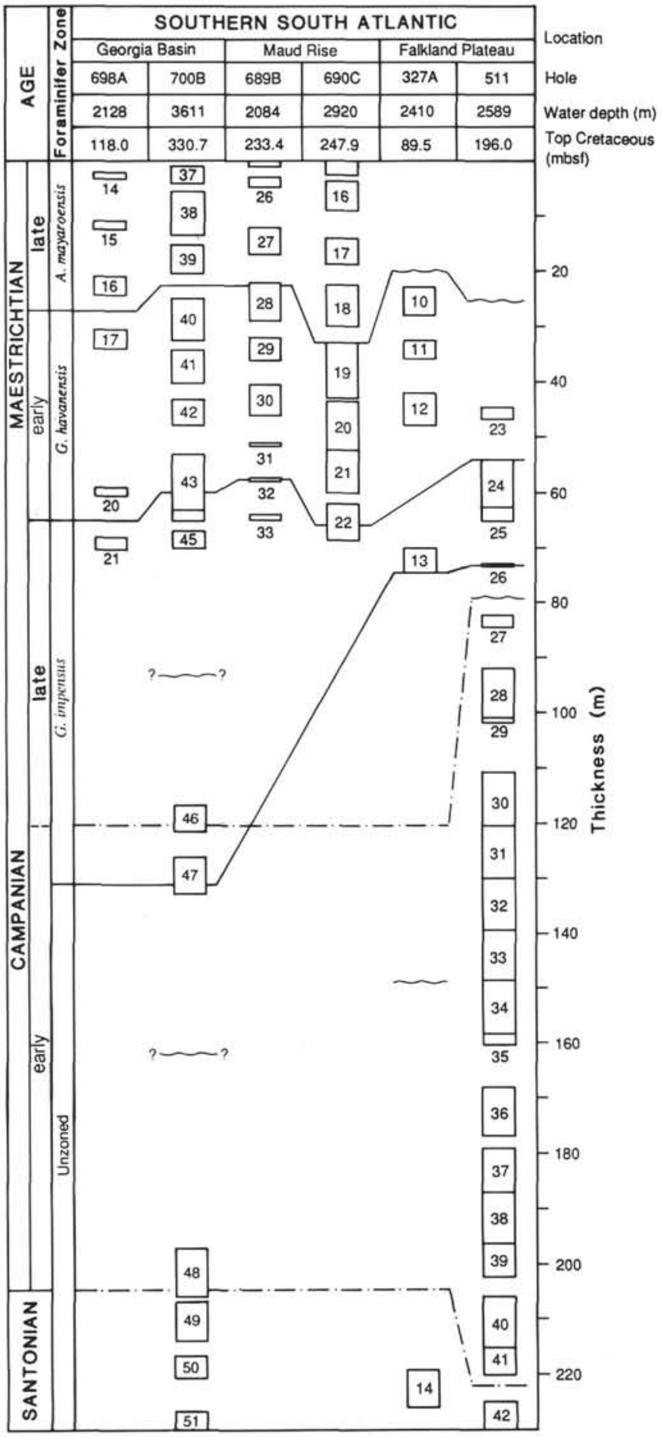

Figure 2. Correlation of Santonian through Maestrichtian deep-sea sites in the southern South Atlantic based on recognition of the *Globigerinelloides impensus* Zone, *Globotruncanella havanensis* Zone, and *Abathomphalus mayaroensis* Zone (solid lines). The early/late Campanian and Santonian/Campanian boundaries are defined at Site 700 based on the age-depth model for that site (see text) and are shown correlated with DSDP Site 511 (broken lines). All cores are scaled to their stratigraphic thickness.

sandy mud (Subunit IIIA), aphanitic basalt (Subunit IIIB), and hematitic claystone (Subunit IIIC). Calcareous nannofossils found in Subunit IIIA are the only biogenic constituents reported for Unit III, and these are considered to be reworked (Ciesielski, Kristoffersen, et al., 1988).

Numerical and relative abundance counts of the Hole 698A foraminifers are presented in Table 1, together with foraminifer preservation ratings and relative abundance rankings for other biogenic constituents. The stratigraphic distribution of several important planktonic foraminifers is shown in Figure 3, together with plots of total and keeled species diversity and planktonic/benthic ratios. Calcareous nannoplankton distributions of two marker species also shown in Figure 3 are based on data from Crux (this volume).

Preservation

Foraminifers from Cores 114-698A-14R through 114-698A-17R show evidence of minor to moderate test recrystallization and slight effects of dissolution. Numerical abundance counts were performed for both the >150-μm and <150-μm size fractions (300 specimens each) of samples from within this interval. Samples from Cores 114-698A-20R through 114-698A-21R are too poorly preserved to allow specimen counts of the >150-μm size fraction, and, therefore, counts were only performed for the >63-μm size fraction (Table 1).

Foraminifer Distributions

The planktonic foraminifer *Abathomphalus mayaroensis* (Bolli) ranges from the top of Core 114-698A-14R to Sample 114-698A-16R-2, 67–71 cm, enabling correlation with the upper Maestrichtian *Abathomphalus mayaroensis* Zone used in low-latitude zonal schemes (e.g., Caron, 1985). This zone was also recognized at Maud Rise Sites 689 and 690 (Fig. 2). Other important marker species identified in the upper Maestrichtian samples include *Globigerinelloides subcarinatus* (Brönnimann), *Globotruncanella petaloidea* (Gandolfi), *Rugotruncana circumnodifer* (Finlay), and *Globotruncana bulloides* Vogler. The distribution of *G. petaloidea* and *G. subcarinatus* at Site 698 and Maud Rise Sites 689 and 690 (Huber, 1990) is limited to the *A. mayaroensis* Zone, but both species have been reported from lower through upper Maestrichtian sediments in tropical to subtropical regions (e.g., Pessagno, 1967; Caron, 1985).

Large specimens of *R. circumnodifer* occur in all upper Maestrichtian samples examined, whereas smaller forms of this species first appear in Sample 114-698A-17R-2, 12–16 cm (Pl. 1, Figs. 4–10). *R. circumnodifer* shows a similar stratigraphic distribution at the Maud Rise, ranging from the upper *Globotruncanella havanensis* Zone through the *A. mayaroensis* Zone (late early through late Maestrichtian). Occurrence of *Hedbergella sliteri* in Cores 114-698A-16R and 114-698A-17R correlates with the partial range of this species at the Falkland Plateau and its total range at the Maud Rise. *Globotruncana bulloides* is reported to range from the latest Santonian through late Maestrichtian (Caron, 1985), but this species was not found below the *A. mayaroensis* Zone at Site 698. The occurrence of *Guembelitria cretacea* Cushman in Sample 114-698A-17R-1, 28–32 cm, is consistent with its upper lower to upper Maestrichtian distribution reported from the Maud Rise (Huber, 1990) and other Cretaceous localities (Caron, 1985).

Numerical abundance counts of the >150-μm size fractions of samples from Cores 114-698A-14R through 114-698A-17R (Table 1) show that *Archaeoglobigerina australis* is the dominant species in the coarser sediment residues. This is also the most common taxon in Maestrichtian sediments from the Maud Rise and the Falkland Plateau (Huber, 1990). The

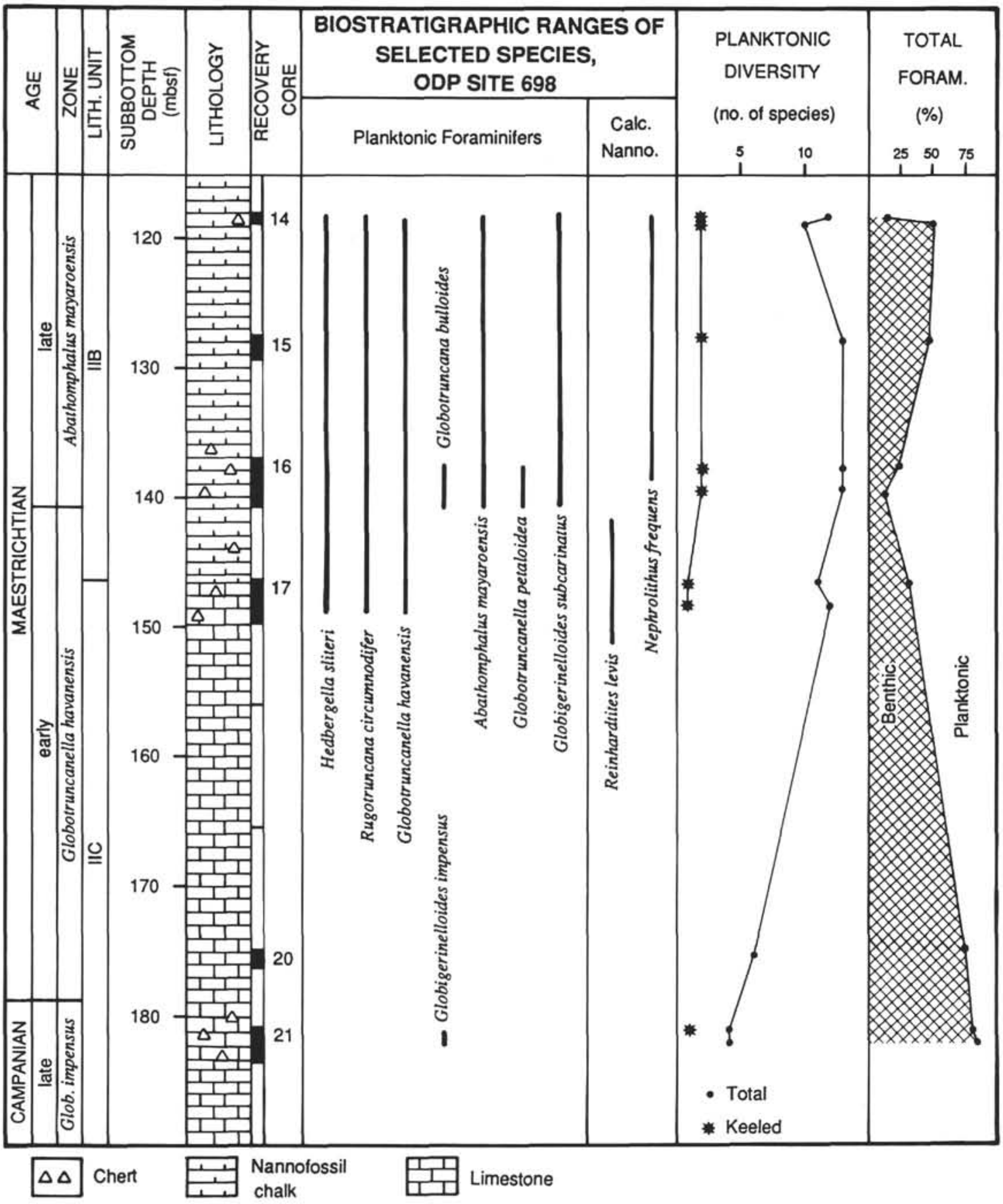

Figure 3. Hole 698A lithostratigraphy and stratigraphic ranges of selected planktonic foraminifer and calcareous nannoplankton species, total and keeled planktonic foraminifer diversity plots, and planktonic/benthic foraminifer ratio plots. The calcareous nannoplankton ranges are based on data from Crux (this volume).

occurrence of *A. australis* together with *Archaeoglobigerina mateola* and *H. sliteri* at Site 698 demonstrates that these species are broadly distributed within the southern high latitudes.

Poor foraminifer preservation and the absence of age-diagnostic species preclude an accurate age determination for Sample 114-698A-20R, 16–18 cm. *Globigerinelloides multispinatus* (Lalicker), *Heterohelix globulosa* (Ehrenberg), and *Heterohelix planata* Cushman are the dominant planktonic foraminifer species in this sample. All have long stratigraphic ranges in the Upper Cretaceous. An early Maestrichtian age is inferred based on the presence of *Archaeoglobigerina australis* Huber, *Hedbergella monmouthensis* (Olsson), and *Heterohelix dentata* Stenestad and the absence of *Globigerinelloides impensus* Sliter. The Campanian/Maestrichtian boundary is placed between Samples 114-698A-21R-1, 12–16 cm, and 114-698A-21R-1, 30–32 cm, based on the last occurrence of *G. impensus* in the latter sample. Several poorly preserved globotruncanid specimens, tentatively identified as *Globotruncana bulloides*, were found within upper Campanian Sample 114-698A-21R-1, 30–32 cm.

The high relative abundance of benthic foraminifers (Fig. 3 and Table 1) and strong etching of foraminifer tests in samples from below Core 114-698A-17R indicate strongly corrosive

Table 1. Numerical abundance counts of planktonic foraminifers (totaling 300 specimens) and other biogenic constituents for Hole 698A.

Core, section, interval (cm)	*Globigerinelloides impensus*	*Globigerinelloides multispinatus*	*Heterohelix globulosa*	*Heterohelix planata*	*Archaeoglobigerina australis*	*Globotruncana bulloides*	*Hedbergella monmouthensis*	*Heterohelix dentata*	*Archaeoglobigerina mateola*	*Globotruncanella havanensis*	*Hedbergella holmdelensis*	*Rugotruncana circumnodifer*	*Schackoina multispina*	*Hedbergella sliteri*	*Guembelitria cretacea*	*Abathomphalus mayaroensis*	*Globigerinelloides subcarinatus*	*Globotruncanella petaloidea*	*Gublerina robusta*	Benthic foraminifers	Foraminifer abundance	Foraminifer preservation	Calcispheres	Echinoid spines	*Inoceramus* prisms	Ostracodes	Radiolarians	Size fraction (µm)	Depth (mbsf)	Zone	Age	
14R-1, 3–6	·	123	33	22	26	·	·	14	1	·	·	5	·	18	·	3	9	·	X	46	A	M	·	·	·	R	R	>150	118.30	*A. mayaroensis*	late	Maestrichtian
	·	133	80	28	4	·	1	20	·	·	·	·	·	X	·	·	19	·	·	15	A	·	F	R	·	·	·	<150				
14R-1, 63–64	·	13	23	29	11	·	·	3	·	1	·	12	·	6	·	34	·	·	X	168	A	M	·	·	·	F	R	>150	118.63			
	·	27	102	14	3	·	·	29	·	·	·	·	·	X	·	2	4	·	·	119	F	·	A	·	·	·	·	<150				
15R-1, 49–51	·	41	7	24	25	·	·	·	2	·	·	39	·	3	·	10	2	·	·	147	A	M	·	·	·	R	·	>150	128.00			
	·	105	92	34	4	·	·	14	·	·	·	·	·	X	·	·	10	·	·	41	F	·	A	·	·	·	·	<150				
16R-1, 67–71	·	49	30	27	75	X	·	·	9	·	·	24	·	6	·	11	X	X	·	69	C	M	·	R	·	R	·	>150	137.67			
	·	61	81	58	26	·	4	5	2	·	·	1	·	2	·	2	X	X	·	58	A	·	R	·	·	·	·	<150				
16R-2, 67–71	·	27	28	34	74	X	·	8	42	·	·	13	·	27	·	9	·	X	·	38	A	M	·	R	·	R	·	>150	139.17	*G. havanensis*	early	
	·	75	69	57	30	X	9	5	4	·	·	2	·	6	·	2	1	X	·	40	A	·	F	R	·	·	R	<150				
17R-1, 28–32	·	28	1	29	130	·	·	·	9	·	·	1	·	5	·	·	·	·	·	97	A	M	·	R	·	R	·	>150	146.78			
	·	73	60	33	41	·	12	1	X	·	X	X	·	X	3	·	·	·	·	77	A	·	R	R	·	·	R	<150				
17R-2, 12–16	·	60	8	54	123	·	·	·	6	X	2	3	·	2	·	·	·	·	·	42	A	M	·	R	R	R	R	>150	148.12			
	·	59	99	37	14	·	28	X	1	X	2	2	6	·	·	·	·	·	·	53	A	·	R	R	R	·	R	<150				
20R-1, 16–18	·	X	X	X	X	·	X	X	·	·	·	·	·	·	·	·	·	·	·	A	R	P	F	R	R	·	F	>63	175.16	*G. imp.*	Camp.	
21R-1, 30–32	X	·	X	·	X	?	·	·	·	·	·	·	·	·	·	·	·	·	·	A	F	P	C	·	F	·	·	>63	181.30			
21R-2, 30–32	X	X	X	X	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	R	P	R	·	A	·	R	>63	182.80			

Note: A = abundant, C = common, F = few, and R = rare occurrence in the sieved residues; X = species found after first 300 specimen counts; ? = questionable occurrence; M = moderate preservation and P = poor preservation.

conditions during late Campanian–early Maestrichtian time at Hole 698A, perhaps due to deposition below the foraminifer lysocline.

Hole 700B

A thick (158.3 m) sequence of Coniacian through upper Maestrichtian limestone was continuously rotary cored from 330.7 to 489 mbsf at Hole 700B (Fig. 4). Recovery of the Cretaceous sediments, which averaged 66.8% (105.7 m), was much better at this hole than at Hole 698A, probably as a result of the near absence of chert interbeds. The Cretaceous/Tertiary boundary was not recovered at Hole 700B, as Cretaceous calcareous nannoplankton were reported no higher than the top of Core 114-700B-37R and Tertiary species were found no lower than the core catcher of Core 114-700B-36R (Crux, this volume). Drilling was terminated at Hole 700B as a result of premature bit release after Core 114-700B-54R was retrieved.

The Cretaceous limestone sequence cored at Hole 700B was included in lithostratigraphic Unit V and extends from 319 mbsf to the bottom of the hole. This unit was subdivided into three subunits based on the degree of lithologic homogeneity and differences in the amount and type of nonbiogenic constituents. Subunit VA (319–359 mbsf) consists predominantly of a strongly bioturbated, homogeneous, nannofossil-bearing micritic limestone with sporadic horizons of clay-bearing limestone. This is underlain by the faintly to moderately bioturbated clay-bearing limestone of Subunit VB (359–441.5 mbsf). Subunit VC (441.5–489 mbsf) is differentiated from the overlying sequence only by the presence of ash-bearing zeolitic clay horizons and a volcanic ash component that increases gradually downhole.

Preservation

Preservation of Cretaceous foraminifers at Site 700 ranges from moderate to very poor (Table 2). All specimens show evidence of test recrystallization and many samples yield foraminifer tests completely infilled with calcite. Several samples from Cores 114-700B-39R and 114-700B-40R show evidence of their deposition below the foraminifer lysocline. Samples 114-700B-39R-2, 72–76 cm, 114-700B-39R-4, 72–76 cm, and 114-700B-40R-1, 68–72 cm, have much lower planktonic/benthic ratios than the other Cretaceous samples (Fig. 4) and yield foraminifers with moderately to strongly etched tests. Foraminifer test dissolution was also apparent in the other samples examined from Cores 114-700B-39R and 114-700B-40R, as well as in Sample 114-700B-42R-2, 35–39 cm. Numerical abundance counts were not performed separately for sample splits from the >150- and <150-μm size fractions because of the insufficient preservation. Counts of 300 specimens were made on the >63-μm fraction of all moderately preserved and some poorly preserved foraminifer samples (Table 2).

Foraminifer Distributions

Planktonic foraminifer distributions in the Maestrichtian sequence at Site 700 (Table 2) are similar to those from Site 698 and to distributions reported from Maud Rise Sites 689 and 690 (Huber, 1990). The only apparent difference is the relatively low numerical abundance of *Archaeoglobigerina australis*. Much higher abundance was observed at the other southern South Atlantic sites because (1) the size fraction in which *A. australis* is most abundant (>150 μm) was not separated and counted at Site 700 and (2) preservation is much better at the other sites so that test breakage by harsh sample preparation was avoided. Other species considered as endemic to the Austral Province, including *Archaeoglobigerina mateola*, *Hedbergella sliteri*, *Rugotruncana circumnodifer*, and *Globigerinelloides impensus*, also occur in low abundances at Site 700. Dominant species throughout the upper Campanian–Maestrichtian sequence at Site 700 include *Heterohelix globulosa*, *Heterohelix planata*, and *Globigerinelloides multispinatus*.

The interval from Samples 114-700B-40R-1, 25–27 cm, to 114-700B-37R-1, 90–94 cm (354.97–331.6 mbsf), is assigned to the *Abathomphalus mayaroensis* Zone of the upper Maestrichtian and is defined by the total range of the nominal taxon. The late/early Maestrichtian boundary is placed at 354.97 mbsf, based on the presence of *A. mayaroensis* in Sample 114-700B-40R-1, 27 cm, (Ciesielski, Kristoffersen, et al., 1988) and its absence from Sample 114-700B-40R-1, 68–72 cm. Other important taxa occurring in the *A. mayaroensis* Zone include *Globigerinelloides subcarinatus*, *Globotruncanella petaloidea*, *R. circumnodifer*, and *Globotruncana bulloides*.

The older range at Site 700 of the late Maestrichtian calcareous nannoplankton *Nephrolithus frequens*, which is reported by Crux (this volume) to occur down to 367 mbsf (Fig. 4), is inconsistent with the nearly synchronous first occurrences of *A. mayaroensis* and *N. frequens* at Maud Rise Holes 689B and 690C (Pospichal and Wise, 1990; Huber, 1990). This discrepancy is probably an artifact of differing taxonomic concepts of the *Nephrolithus* genus; Pospichal and Wise (1990) distinguish *Nephrolithus corystus* as an ancestral form of *N. frequens*, first occurring in the late early Maestrichtian, whereas Crux (this volume) does not distinguish these two species.

The *Globotruncanella havanensis* Zone of the lower Maestrichtian is recognized from Samples 114-700B-40R-1, 68–72 cm, through 114-700B-43R-2, 137–141 cm (355.2 to 385.9 mbsf), based on the sporadic occurrence of *G. havanensis* and the absence of *G. impensus* (Table 2). First occurrences of *R. circumnodifer* in Sample 114-700B-40R-4, 68–72 cm, and *H. sliteri* in Sample 114-700B-40R-5, 68–72 cm, indicate a late early Maestrichtian age based on correlation with their distributions at Maud Rise Sites 689 and 690 (Huber, 1990). This age assignment is supported by the last-occurrence datum of the calcareous nannoplankton species *Reinhardtites levis* at 350.5 mbsf (Fig. 4), which has been dated paleomagnetically at 71.50 Ma (late early Maestrichtian) (Kent and Gradstein, 1985). Absence of *G. bulloides* and all other keeled species from the lower part of the *G. havanensis* Zone is consistent with the Maud Rise foraminifer distributions.

The *Globigerinelloides impensus* Zone extends from Sample 114-700B-47R-5, 12–16 cm (417.62 mbsf), in the lower Campanian, to Sample 114-700B-43R-3, 140–144 cm (387.40 mbsf), which is considered as latest Campanian in age. Foraminifer preservation is quite poor especially in the lower part of this zone, and, thus, faunal distribution data are incomplete. Foraminifer assemblages in the *G. impensus* Zone are dominated by heterohelicids, *Globigerinelloides*, and *Hedbergella planispira*, with rare double-keeled specimens of *Globotruncana linneiana* in the lower Campanian samples. No diagnostic zonal taxa were recognized in samples from below the *G. impensus* Zone.

Biochronology

Recovery of good-quality magnetic polarity data from Cretaceous sediments at Site 700 (Ciesielski, Kristoffersen, et al., 1988) enables magnetobiostratigraphic correlation of planktonic foraminifer first-appearance datums (FADs) and last-appearance datums (LADs) with the geomagnetic time scale of Kent and Gradstein (1985). Because the shipboard correlation of magnetic polarity zones did not follow the

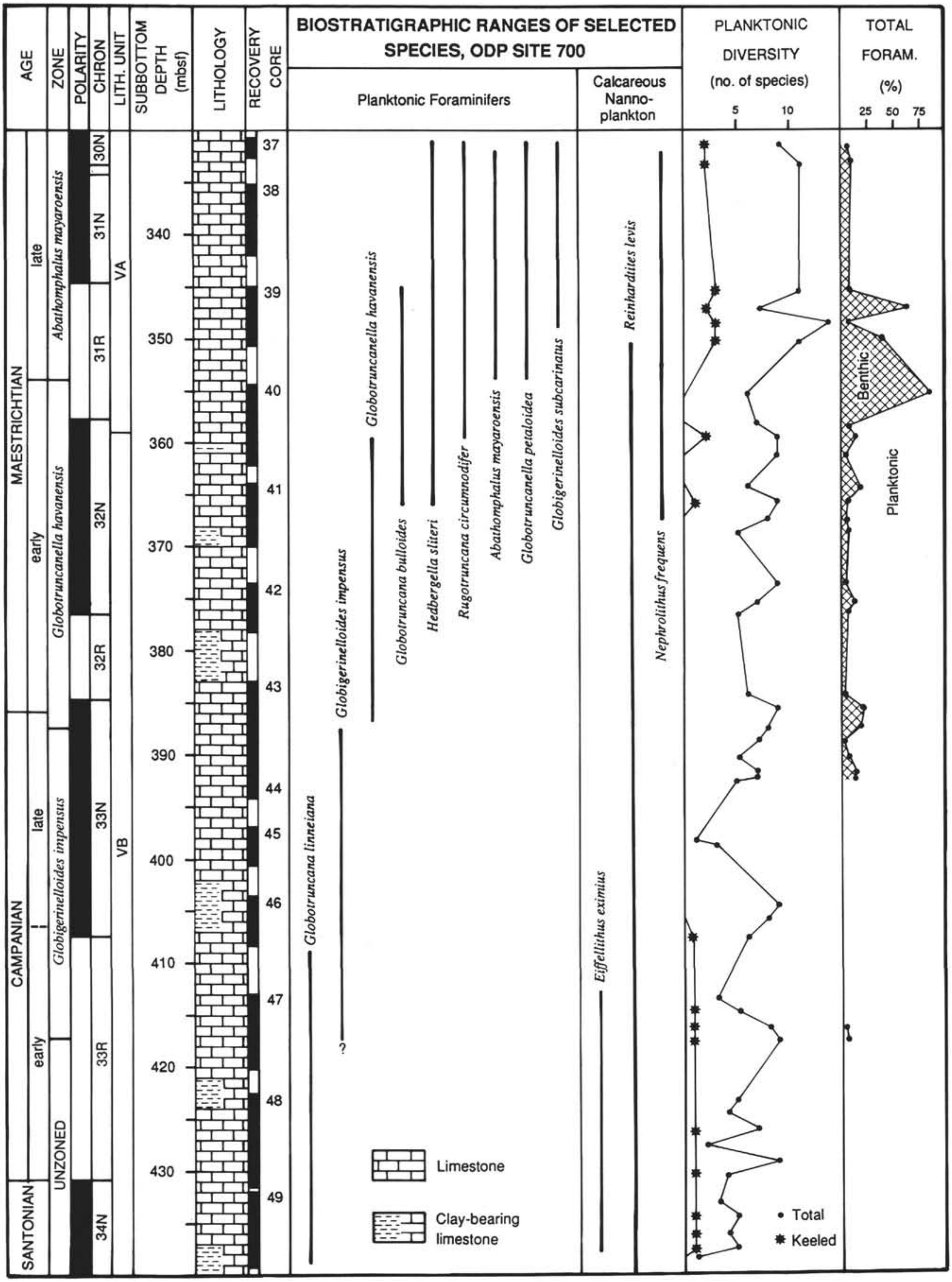

Figure 4. Hole 700B lithostratigraphy, magnetostratigraphy, and stratigraphic ranges of selected planktonic foraminifer and calcareous nannoplankton species, total and keeled planktonic foraminifer diversity plots and planktonic/benthic foraminifer ratio plots. The calcareous nannoplankton distributions are based on data from Crux (this volume).

Table 2. Numerical and relative abundance counts of planktonic foraminifers and other biogenic constituents for Hole 700B.

Core, section, interval (cm)	*Globigerinelloides* sp.	*Archaeoglobigerina australis*	*Globotruncana linneiana*	*Hedbergella planispira*	*Heterohelix* sp.	*Heterohelix globulosus*	*Schackoina multispina*	*Globigerinelloides multispinatus*	*Globigerinelloides impensus*	*Heterohelix planata*	*Heterohelix dentata*	*Archaeoglobigerina mateola*	*Hedbergella monmouthensis*	*Globotruncanella havanensis*	*Globotruncana bulloides*	*Hedbergella sliteri*	*Guembelitria cretacea*	*Rugotruncana circumnodifer*	*Abathomphalus mayaroensis*	*Globotruncanella petaloidea*	*Globigerinelloides subcarinatus*	*Gublerina robusta*	Benthic foraminifers	Foraminifer abundance	Foraminifer preservation	Calcispheres	Echinoid spines	*Inoceramus* spines	Ostracodes	Radiolarians
37R-1, 90–94	·	·	·	·	·	157	·	61	·	30	8	·	5	·	·	1	·	X	·	X	15	·	23	C	M	R	·	·	·	R
37R-2, 90–94	·	X	·	·	·	82	·	94	·	49	10	·	1	·	·	5	·	1	X	X	25	·	31	A	M	R	R	·	R	·
39R-1, 66–70	·	6	·	·	·	121	·	45	·	92	5	·	2	·	X	1	·	4	2	2	·	·	20	A	M	F	R	·	·	R
39R-2, 72–76	·	·	·	·	·	28	·	31	·	19	14	·	12	·	·	·	·	X	1	·	·	·	195	A	M	F	R	·	·	R
39R-3, 72–76	·	21	·	·	·	115	·	63	·	31	21	·X	21	·	X	1	·	4	2	·	6	X	17	A	M	R	R	·	R	R
39R-4, 72–76	·	4	·	·	·	42	·	70	·	13	13	·	37	·	X	X	·	X	X	X	·	·	121	C	M	A	R	·	·	R
40R-1, 68–72	·	X	·	·	·	2	·	17	·	3	6	·	7	·	·	·	·	·	·	·	·	·	265	C	P	C	R	·	·	R
40R-3, 95–99	·	7	·	·	·	70	·	86	·	60	8	·	43	·	·	·	5	·	·	·	·	·	21	A	M	R	R	·	·	R
40R-4, 68–72	·	9	·	·	·	57	·	98	·	41	1	·	53	·	X	X	·	X	·	·	·	·	41	A	M	R	R	·	R	R
40R-5, 68–72	·	8	·	·	·	79	·	80	·	78	3	·	38	X	·	5	X	·	·	·	·	·	9	A	M	R	R	·	·	R
41R-1, 40–44	·	20	·	·	·	38	·	60	·	91	·	·	33	4	·	·	·	·	·	·	·	·	54	R	M	R	R	·	·	R
41R-2, 40–44	·	14	·	·	·	98	·	29	·	105	6	·	21	6	X	X	·	·	·	·	·	·	21	A	M	F	R	·	·	R
41R-3, 40–44	·	21	·	·	·	81	X	48	·	78	3	·	54	·	·	·	·	·	·	·	·	·	15	C	M	C	·	·	·	R
41R-4, 40–44	·	18	·	·	·	29	·	79	·	138	·	·	15	·	·	·	·	·	·	·	·	·	21	R	M	R	R	·	·	R
42R-1, 40–44	·	3	·	·	·	57	·	63	·	102	6	X	54	·	·	·	·	·	·	·	·	·	15	A	M	F	R	R	·	R
42R-2, 35–39	·	15	·	·	·	53	3	45	·	81	6	·	61	·	·	·	·	·	·	·	·	·	36	R	M	R	R	·	·	R
42R-3, 35–39	·	9	·	·	·	49	·	88	·	65	·	·	64	·	·	·	·	·	·	·	·	·	25	C	M	F	R	·	·	R
43R-1, 137–141	·	6	·	·	·	37	4	44	·	157	·	·	39	·	·	·	·	·	·	·	·	·	13	C	M	F	R	·	·	R
43R-2, 137–141	·	X	·	·	·	36	X	78	·	91	9	·	20	?	·	·	·	·	·	·	·	·	66	R	M	F	R	C	·	R
43R-3, 140–144	·	X	·	·	·	42	1	44	2	92	·	·	62	·	·	·	·	·	·	·	·	·	57	F	M	F	R	F	·	R
43R-4, 140–144	·	X	·	·	·	28	·	78	6	89	9	·	82	·	·	·	·	·	·	·	·	·	8	F	P	F	R	A	·	R
43R-5, 140–144	·	·	·	·	·	24	·	92	1	135	·	·	21	·	·	·	·	·	·	·	·	·	27	R	P	R	R	R	·	·
43R-6, 140–144	·	X	·	·	·	25	·	53	4	137	4	·	35	·	·	·	·	·	·	·	·	·	42	C	M	F	R	R	·	R
43R-7, 49–53	·	·	·	·	·	34	X	45	8	156	6	·	13	·	·	·	·	·	·	·	·	·	38	A	P	F	R	R	·	R
44R-1, 37–41	·	R	·	·	·	R	·	R	R	R	·	·	·	·	·	·	·	·	·	·	·	·	R	R	P	R	R	·	·	R
45R-1, 133–137	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	·	·	·	·	R
45R-2, 134–138	·	·	·	·	·	·	·	R	R	R	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	·	·	R	·	R
46R-1, 124–128	·	6	·	27	·	40	·	92	76	53	X	·	18	·	·	·	·	·	·	·	·	·	6	C	P	R	R	R	·	R
46R-2, 99–103	·	·	·	7	·	32	·	69	104	78	·	4	·	·	·	·	·	·	·	·	·	·	6	C	P	R	R	R	·	R
46R-3, 124–128	·	·	X	X	·	25	·	131	91	46	·	·	·	·	·	·	·	·	·	·	·	·	7	C	P	R	·	F	·	R
47R-1, 87–91	·	·	·	?	·	·	·	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	R	R	R	·	R
47R-2, 28–32	·	·	R	R	·	·	·	R	R	R	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	F	·	R	·	R
47R-4, 25–29	13	·	6	39	·	24	·	130	3	69	10	·	·	·	·	·	·	·	·	·	·	·	6	C	P	R	·	R	·	R
47R-5, 12–16	21	24	X	33	·	12	·	126	4	67	·	·	·	·	·	·	·	·	·	·	·	·	13	C	P	R	·	R	·	R
48R-1, 60–64	R	?	·	R	·	R	·	?	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	R	·	·	·	R
48R-2, 60–64	R	·	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	R	·	·	·	R
48R-3, 56–60	R	?	R	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	R	R	·	·	R
48R-4, 58–62	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	·	·	·	·	R
48R-5, 57–61	F	?	R	R	F	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	C	P	R	R	·	·	R
48R-6, 57–61	R	?	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	P	R	·	·	·	R
49R-1, 107–111	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	R	·	·	·	R
49R-2, 107–111	R	·	?	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	F	VP	R	R	·	·	R
49R-3, 107–111	R	·	R	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	R	·	·	·	R
49R-4, 107–111	R	?	?	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	F	VP	·	·	·	·	R
49R-5, 56–60	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	VP	·	·	·	·	·

Note: A = abundant, C = common, F = few, and R = rare occurrence in the sieved residues; X = species found after first 300 specimen counts; ? = questionable occurrence; M = moderate preservation, P = poor preservation, and VP = very poor preservation.

conventional magnetic anomaly number assignments of LaBrecque et al. (1977) for Chrons 30 through 32, a revised interpretation using the LaBrecque et al. (1977) numbering scheme is shown in Figure 4. A sedimentation-rate curve, derived from plots of the stratigraphic positions of magnetostratigraphic chron boundaries and their correlation with the Kent and Gradstein (1985) Cretaceous time scale, is shown in Figure 5. From this plot, average sedimentation rates are calculated as 8.8 m/m.y. between 333 and 385 mbsf, 3.85 m/m.y. between 385 and 408 mbsf, and 6.14 m/m.y. between 407.45 and 430.95 mbsf. The diminished sedimentation rate between 385 and 431 mbsf may be the result of at least one hiatus occurring within Chron 33N and perhaps another occurring within Chron 33R (Figs. 2 and 4). However, biostratigraphic resolution is insufficient to verify the presence of stratigraphic gaps within the upper Campanian sequence.

The stratigraphic positions of the early/late Campanian boundary (402 mbsf) and the Santonian/Campanian boundary (431 mbsf) (Fig. 4) are interpolated from correlation of the sedimentation-rate curve for Site 700 (Fig. 5) with the Kent and Gradstein (1985) magnetogeochronology. An age of 79 Ma is informally used for the early/late Campanian boundary, and an age of 84 Ma is used for the Santonian/Campanian boundary. The late Santonian–early Maestrichtian age range of *Globotruncana linneiana* (Caron, 1985) does not conflict with the distribution of this species at Site 700, but poor planktonic foraminifer preservation and absence of other diagnostic species prevent further biostratigraphic refinement of the Santonian-Campanian sequence.

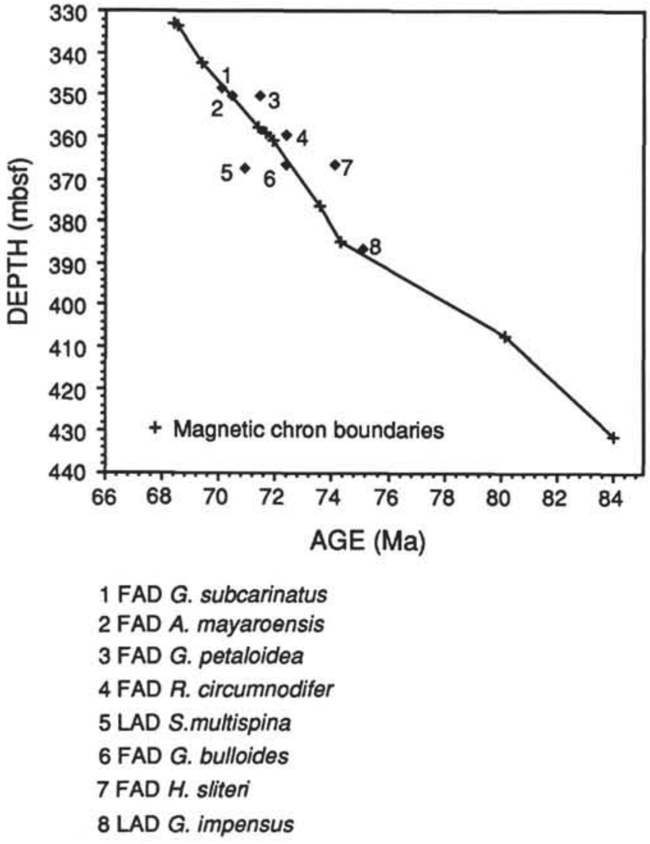

Figure 5. Age-depth plot for the Santonian-Maestrichtian time interval represented at Hole 700B. The magnetic reversal stratigraphy for Hole 700B was reinterpreted from data presented in Ciesielski, Kristoffersen, et al. (1988) and correlated with the Kent and Gradstein (1985) time scale. Ages for planktonic foraminifer datums are based on the magnetobiostratigraphy of Maud Rise Holes 689B and 690C (Thomas et al., 1990) and are listed in Table 3.

Eight late Campanian–Maestrichtian planktonic foraminifer datums are listed according to their stratigraphic position at Hole 700B and their interpolated ages at Maud Rise Holes 689B and 690C (Table 3). Age estimates for the Maud Rise datums are based on cross-correlation with the age-depth model of Thomas et al. (1990) and the Cretaceous time scale of Kent and Gradstein (1985). These were previously cross-correlated with the Haq et al. (1987) time scale by Huber (1990).

Figure 5 shows the averaged Maud Rise datum ages plotted against the Hole 700B sub-bottom depths to compare the relative timing of first and last occurrences within the southern South Atlantic region. Five species, including *Globigerinelloides subcarinatus*, *Abathomphalus mayaroensis*, *Rugotruncana circumnodifer*, *Globotruncana bulloides*, and *Globigerinelloides impensus*, plot near or on the sedimentation-rate curve for Hole 700B, demonstrating regional synchroneity in their first or last southern high-latitude occurrences. However, correlation between the high and low latitudes of several of these FADs reveals significant latitudinal diachroneity. The FAD of *G. subcarinatus* in the southern South Atlantic is in Chron 31N (~70.1 Ma) of the late Maestrichtian, whereas this species has been reported in upper Campanian (e.g., Sliter, 1989) and lowermost Maestrichtian (e.g., Caron, 1985) sediments at low-latitude sites. *G. bulloides* also has an older low-latitude range, occurring in Santonian to lower Maestrichtian sediments in the low latitudes, but only in Maestrichtian sediments (FAD ~72.4 Ma) in the southern South Atlantic.

On the other hand, *A. mayaroensis* occurs earlier in the southern high latitudes than in the tropical latitudes. The FAD of this species at all southern South Atlantic sites is in the middle of Chron 31R (~70.5 Ma), whereas this species first occurs in Chron 30N in the Umbrian Appenines (Premoli Silva, 1977; Monechi and Thierstein, 1985), the equatorial Pacific (Sliter, 1989), and Site 208 in the Tasman Sea (Keating et al., 1975). Berggren et al. (1983) reported that the FAD of *A. mayaroensis* occurs just below the Chron 31N/Chron 31R boundary at Site 516 in the South Atlantic (35°S paleolatitude) providing further evidence that this species migrated equatorward during late Maestrichtian time.

Datums interpolated for *Globotruncanella petaloidea*, *Schackoina multispina*, and *Hedbergella sliteri* plot away from the Hole 700B sedimentation-rate curve (Fig. 5), indicating poor agreement between the southern South Atlantic sites. Because of the small size or indistinctive character of these

Table 3. Sub-bottom depths of first- and last-appearance datums of selected planktonic foraminifer species at Hole 700B and ages of those datums determined for Maud Rise Holes 689B and 690C based on the magnetobiostratigraphy of Thomas et al. (1990).

Species	Datum	Hole 700B depth (mbsf)	Hole 698B age (Ma)	Hole 690C age (Ma)
1. *G. subcarinatus*	FAD	348.76	70.5	69.6
2. *A. mayaroensis*	FAD	350.26	70.5	70.4
3. *G. petaloidea*	FAD	350.26	71.1	71.6
4. *R. circumnodifer*	FAD	359.72	72.6	72.2
5. *S. multispina*	LAD	367.40	70.5	71.3
6. *G. bulloides*	FAD	366.67	72.6	72.2
7. *H. sliteri*	FAD	366.67	74.0	74.2
6. *G. impensus*	LAD	386.67	[a]76.4	75.1

[a] Unreliable estimate because of upper range truncation caused by incomplete core recovery.

species, the discrepancies are considered to be an artifact of poor preservation at Site 700 rather than evidence of diachroneity in species distributions within the southern South Atlantic region.

The LAD of *G. impensus* occurs within upper Chron 33N at Sites 689 and 690 on the Maud Rise as well as at Site 700 (Figs. 4 and 5). In the absence of low-latitude indicator species, this datum has proven to be very useful for delineating the position of the Campanian/Maestrichtian boundary. Previous suggestion that *G. impensus* ranged into the earliest Maestrichtian (~73.7 Ma) was based on magnetobiostratigraphic correlation of the Cretaceous sequence at the Maud Rise with the Haq et al. (1987) time scale (Huber, 1990) and a Campanian/Maestrichtian boundary age of 74 Ma. However, correlation with the Kent and Gradstein (1985) time scale provides an age of about 75.1 Ma for the LAD of *G. impensus* (Table 3) and the Campanian/Maestrichtian boundary is given an age of 74.5 Ma. Prior to this study, the FAD of *G. impensus* has only been recorded in incomplete Campanian sections in the southern South Atlantic region (Sliter, 1977; Krasheninnikov and Basov, 1983; Huber, 1990), and, thus, its reliability as a correlatable datum event had not been determined. Specimens of this species occur in upper lower Campanian sediments at Hole 700B, but older occurrences cannot be verified because of poor preservation.

Diversity Trends

Taxonomic diversity values are highest within the *Abathomphalus mayaroensis* Zone, which yields a maximum of 14 planktonic foraminifer species (Fig. 4). Total diversity diminishes below this zone, ranging from between five and nine species in the *Globotruncanella havanensis* Zone and between one and nine species in the *Globigerinelloides impensus* Zone. Diversity values in the lower part of the sequence are biased by poor preservation quality and thus do not reflect a regionally significant trend. Nevertheless, preservation is not considered a factor controlling diversity for samples above Section 114-700B-43R-4, all of which have moderate preservation quality. Diminishing diversity values with increasing depth in the *G. havanensis* Zone were also observed at Maud Rise Sites 689 and 690 (Huber, 1990).

Keeled planktonic diversity is highest within the *A. mayaroensis* Zone, with a maximum of three double-keeled species (*A. mayaroensis*, *Globotruncana bulloides*, and *Rugotruncana circumnodifer*) occurring in several samples from Core 114-700B-39R. Keeled mophotypes are nearly absent from the *G. havanensis* Zone, and only one keeled species, *Globotruncana linneiana* (d'Orbigny), occurs in rare abundance within the Campanian section of the *G. impensus* Zone.

DISCUSSION

The Campanian-Maestrichtian planktonic foraminifer assemblages from Holes 698A and 700B are identical in species composition to Austral Province assemblages described from the Falkland Plateau (Sliter, 1977; Krasheninnikov and Basov, 1983) and the Maud Rise (Huber, 1990). These are characterized by low taxonomic diversity and dominance by species of *Heterohelix* and by *Globigerinelloides*, *Hedbergella*, and *Archaeoglobigerina*. Numerous species that are common components of Tethyan assemblages, particularly those of the Globotruncanacea, are absent from the southern South Atlantic assemblages.

Five planktonic foraminifer species, including *Globigerinelloides impensus*, *Hedbergella sliteri*, *Archaeoglobigerina australis*, *Archaeoglobigerina mateola*, and *Rugotruncana circumnodifer*, were restricted to the Austral Province during Campanian-Maestrichtian time (Table 4 and Fig. 6). Absence of these species from coeval assemblages reported from the Walvis Ridge (Boersma, 1984) and the Rio Grande Rise (Premoli Silva and Boersma, 1977) and latitudinal differences in taxonomic composition of South Atlantic planktonic foraminifer assemblages indicate that the northern limit of the Austral Province was probably just north of the Northeast Georgia Rise and Falkland Plateau, between about 45° and 55°S paleolatitude. This paleobiogeographic boundary was probably at about the same paleolatitude in all ocean basins, as three Austral Province species (*G. impensus*, *H. sliteri*, and *A. australis*) were found in the southern Indian Ocean (ODP Site 738, pers. observ.; ODP Site 750, P. Quilty, pers. comm., 1988), two (*R. circumnodifer* and *H. sliteri* = *Hedbergella monmouthensis* of Webb, 1973) were reported from the Tasman Sea (Site 208; Webb, 1973) and New Zealand (Webb,

Table 4. Sites of occurrence and age ranges of Campanian-Maestrichtian planktonic foraminifer species that are endemic to the Austral Province.

Endemic species	Site of occurrence[a]	Age range
Globerinelloides impensus	DSDP 327, 511 (FP)	late Campanian
	ODP 689, 690 (MR)	early Campanian to early Maestrichtian
	ODP 698, 700 (NGR)	early to late Campanian
	ODP 738, 750 (KP)	late Campanian
Hedbergella sliteri	DSDP 327, 511 (FP)	early Maestrichtian
	ODP 689, 690 (MR)	early to late Maestrichtian
	ODP 698, 700 (NGR)	early to late Maestrichtian
	DSDP 208 (LHR)	middle to late Maestrichtian
	ODP 738 (KP)	late Maestrichtian
	James Ross Island region	early to late Maestrichtian
Archaeoglobigerina australis	DSDP 327, 511 (FP)	late Campanian to early Maestrichtian
	ODP 689, 690 (MR)	late Campanian to late Maestrichtian
	ODP 698, 700 (NGR)	late Campanian to late Maestrichtian
	ODP 738 (KP)	late Maestrichtian
	James Ross Island region	early to middle Maestrichtian
Archaeoglobigerina mateola	DSDP 327, 511 (FP)	early to late Maestrichtian
	ODP 698, 700 (NGR)	early to late Maestrichtian
	James Ross Island region	early Maestrichtian
Rugotruncana circumnodifer	ODP 689, 690 (MR)	middle to late Maestrichtian
	ODP 698, 700 (NGR)	middle to late Maestrichtian
	James Ross Island region	early Maestrichtian

[a] FP = Falkland Plateau; MR = Maud Rise; NGR = Northeast Georgia Rise; KP = Kerguelen Plateau; LHR = Lord Howe Rise.

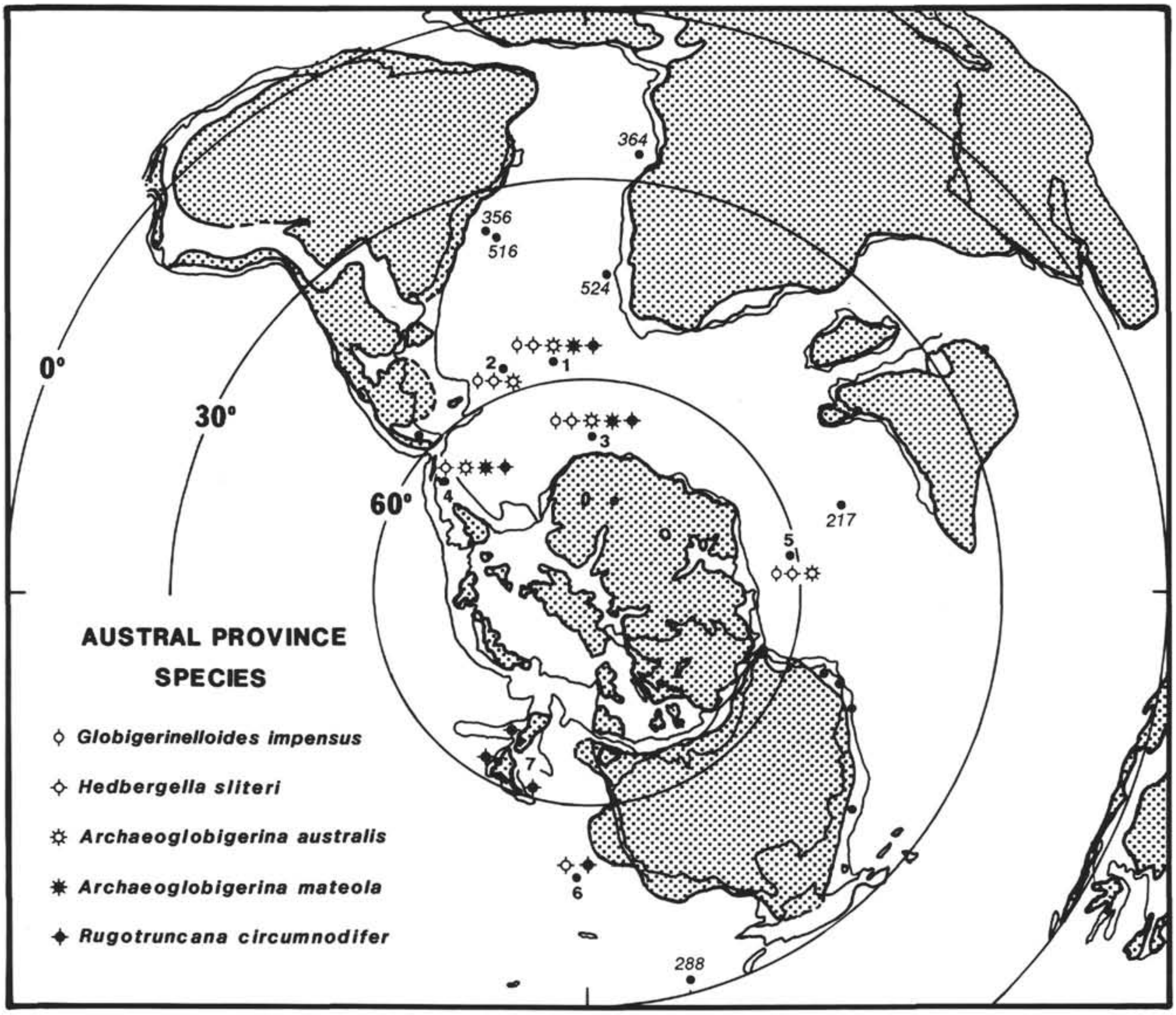

Figure 6. Paleogeographic reconstruction map showing the circum-Antarctic distribution of Campanian-Maestrichtian planktonic foraminifer species that are endemic to the Austral Province. Austral Province sites are as follows: 1 = ODP Sites 698 and 700, Northeast Georgia Rise; 2 = DSDP Sites 327 and 511, Falkland Plateau; 3 = ODP Sites 689 and 690, Maud Rise; 4 = James Ross Island region; 5 = ODP Sites 738 and 750, Kerguelen Plateau; 6 = DSDP Site 208, Lord Howe Rise; 7 = New Zealand. Other DSDP sites yielding Late Cretaceous foraminifers are labeled. Continental distributions are based on a reconstruction for 80 Ma by Smith et al. (1981), and the paleogeography of South America and Africa is based on the reconstruction of Barron (1987) for the early Maestrichtian. The basis for reconstruction of intra-Antarctic seaways was discussed by Huber (in press).

1971), and all five occur at the Falkland Plateau (DSDP Holes 327A and 511) and the Maud Rise (Sites 689 and 690) as well as on the Northeast Georgia Rise (Sites 698 and 700). The similarity of Campanian-Maestrichtian planktonic and shelf benthic foraminifer assemblages from the southern circum-Pacific and southern South Atlantic regions has been used as evidence for the former presence of marine passages within and around the remnant Gondwana continents of the Late Cretaceous (Huber and Webb, 1986; Huber, 1988). The final breakup of Gondwana may have been responsible for development of the Austral Province as a paleobiogeographic entity (Huber, in press).

Stratigraphic changes in planktonic foraminifer species diversity at Holes 698A and 700B (Figs. 3 and 4) are similar to those observed at Maud Rise Sites 689 and 690. Maximum values of keeled species diversity and total species diversity occur within the lower *Abathomphalus mayaroensis* Zone at all southern South Atlantic sites. The largest diameters (up to 600 μm) of keeled specimens of *R. circumnodifer* and *Globotruncana bulloides* are also attained within the lower *A. mayaroensis* Zone at all southern South Atlantic sites. Double-keeled planktonic foraminifer morphotypes are completely absent from the upper *Globigerinelloides impensus* Zone at Site 700 (between Cores 114-700C-41R and 114-700B-46R) and do not occur in any samples within that zone at the Falkland Plateau and at Maud Rise (Sliter, 1977; Krasheninnikov and Basov, 1983; Huber, 1990). The only bicarinate species found in Campanian sediments at the Northeast Georgia Rise is *Globotruncana linneiana*, which rarely occurs in the lower *G. impensus* Zone at Site 700 (Table 2).

Conventional paleobiogeographic models for Late Cretaceous planktonic foraminifers (e.g., Douglas, 1969; Scheibnerova, 1973; Sliter, 1977; Krasheninnikov and Basov, 1983,

1986) would suggest that the occurrence of immigrant low-latitude species and diversification of keeled morphotypes during the late early and late Maestrichtian at the southern high-latitude sites resulted from expansion of a warm, subtropical water mass into the Antarctic region. However, such a Maestrichtian warming has not been recognized in oxygen isotope paleotemperature studies of belemnites (e.g., Stevens and Clayton, 1971) or foraminifers (Douglas and Savin, 1975; Barrera et al., 1987; Barrera and Huber, 1990). In fact, these stable isotope studies, which together cover a very broad latitudinal range, portray a gradual cooling from the early through late Maestrichtian and culminate with an abrupt cooling at the end of the Maestrichtian.

Calcareous nannoplankton distributions in the southern South Atlantic region do not show changes in diversity and incursion of Tethyan species correlative with those observed for the planktonic foraminifers. Pospichal and Wise (1990) report that the Maestrichtian calcareous nannofossil assemblages from Maud Rise Sites 689 and 690 are dominated by provincial species, with only rare and sporadic occurrences of Tethyan indicator taxa. Crux (this volume) also notes the general absence of Tethyan species throughout the Cretaceous sections of Sites 698 and 700. Several time-series studies of calcareous nannoplankton and planktonic foraminifer paleobiogeography have proven that these microfossil groups responded similarly to water-mass changes during the Holocene and Cenozoic (e.g., Cline and Hays, 1976; Haq et al., 1977). Thus, the absence of correlative changes in taxonomic diversity and provinciality between these two pelagic groups in the southern high latitudes during the Cretaceous is puzzling. With so little paleoceanographic data available for the Late Cretaceous southern high latitudes, speculation on factors controlling the observed changes in the diversity and taxonomic composition of the southern South Atlantic planktonic foraminifers is premature. Greater insight will only be achieved when more stratigraphically complete materials are recovered from more closely spaced sites in the circum-Antarctic region.

TAXONOMIC NOTES

The species composition of Cretaceous planktonic foraminifers from Leg 114 is nearly identical to the assemblages described from Leg 113 (Huber, 1990). Therefore, only original references and brief remarks are presented for selected taxa that are illustrated on Plates 1 through 3.

Globigerinelloides impensus Sliter
(Pl. 1, Fig. 1)

Globigerinelloides impensus Sliter, 1977, p. 541, pl. 6, figs. 1–3.

Remarks. The Northeast Georgia Rise specimens of this species are identical to specimens described from the Maud Rise (ODP Sites 689 and 690) and the Falkland Plateau (DSDP Sites 327 and 511). They are characterized by having nearly evolute tests with eight to 10 chambers in the final whorl and a subangular equatorial periphery. *Globigerinelloides impensus* appears to be a good marker for the Campanian/Maestrichtian boundary in the southern South Atlantic region, as its LAD occurs within uppermost Chron 33N (~75 Ma) at Maud Rise and Northeast Georgia Rise.

Hedbergella monmouthensis (Olsson)
(Pl. 1, Figs. 2 and 3)

Globorotalia monmouthensis Olsson, 1960, p. 74, pl. 9, figs. 22–24.

Remarks. This species persistently occurs in low to moderate abundance throughout the *Globotruncanella havanensis* Zone and *Abathomphalus mayaroensis* Zone of Sites 698 and 700. It is distinguished from *Hedbergella sliteri* Huber by its smaller size and narrower umbilical region.

Hedbergella sliteri Huber
(Pl. 1, Figs. 4 and 8)

Hedbergella sliteri Huber, 1990, pl. 2, figs. 5, 9, 10; pl. 6, figs. 4, 5.

Remarks. This species is distinguished by its large size, nearly evolute chamber arrangement, and a broad, shallow umbilical region. Its range at the Northeast Georgia Rise is restricted to the upper *Globotruncanella havanensis* Zone through the *Abathomphalus mayaroensis* Zone, which is comparable to its distribution at the Maud Rise and the Falkland Plateau (Huber, 1990). The FAD of this species is within Chron 32N at Maud Rise and Northeast Georgia Rise.

Hedbergella planispira (Tappan)
(Pl. 1, Figs. 5–7)

Globigerina planispira Tappan, 1940, p. 122, pl. 19, fig. 12.

Remarks. Poorly preserved specimens of this species occur in the *Globigerinelloides impensus* Zone below Core 114-700B-45R. It differs from *Hedbergella sliteri* by having six to seven, rather than five to six, chambers in the final whorl and a more axially compressed test.

Archaeoglobigerina australis Huber
(Pl. 1, Figs. 9–12; Pl. 2, Fig. 1)

Archaeoglobigerina australis Huber, 1990, pl. 2, figs. 11–13; pl. 3, figs. 1–7; pl. 6, figs. 7–9.

Remarks. The range of variability in ultimate chamber size, height of the coiling axis, and number of chambers in the ultimate whorl among the Northeast Georgia Rise specimens is similar to the range observed at the Maud Rise and the Falkland Plateau (see Huber, 1990). The occurrence of this species in Campanian through upper Maestrichtian sediments at the Leg 114 sites is consistent with its range elsewhere in the southern South Atlantic. Because of poor preservation, older occurrences of *A. australis* at Northeast Georgia Rise (Table 2) are questionable. The older forms cannot be distinguished from *Archaeoglobigerina bosquensis* Pessagno.

Archaeoglobigerina mateola Huber
(Pl. 2, Figs. 2 and 3)

Archaeoglobigerina mateola Huber, 1990, pl. 3, figs. 8–10; pl. 4, figs. 1–3; pl. 6, fig. 6.

Remarks. Forms of this species are identical to specimens described from the Maud Rise. It is distinguished by its tightly coiled, moderately high-spired test, having strong overlap of the final chamber in the umbilical region and a coarsely pustulose to strongly spinose surface. It occurs in middle and upper Maestrichtian sediments at Site 698 and from the lower to upper Maestrichtian at Site 700.

Rugotruncana circumnodifer (Finlay)
(Pl. 2, Figs. 4–10)

Globigerina circumnodifer Finlay, 1940, p. 469, pl. 65, figs. 150, 151.

Remarks. This species displays a wide range of test size, chamber arrangement, and test surface ornamentation. Specimens occurring in the earlier part of its stratigraphic range are generally smaller and more tightly coiled than specimens from younger sediments (e.g., compare Pl. 2, Figs. 4 and 5, with Pl. 2, Figs. 6–9). All specimens display an imperforate peripheral band (Pl. 2, Fig. 10) and a variable degree of pustule alignment parallel to the equatorial periphery. Meridionally aligned costellae on the umbilical and spiral chamber surfaces are either absent or faintly present. *Rugotruncana circumnodifer* differs from *Globotruncana subcircumnodifer* (Gandolfi) by having more globular chambers, greater convexity of the spiral side, and less well-developed peripheral keels. The first occurrence of *R. circumnodifer* in the southern high latitudes is in the middle of Chron 32N (~72.5 Ma), and its range extends through the *Abathomphalus mayaroensis* Zone.

Globotruncana bulloides Vogler
(Pl. 3, Figs. 1 and 2)

Globotruncana bulloides Vogler, 1941, p. 287, pl. 23, figs. 32–39.

Remarks. This species is very rare at Sites 698 and 700, occurring sporadically in the upper lower Maestrichtian and lower upper Maestrichtian. The Santonian-Maestrichtian age range of *Globotruncana* *bulloides* at lower latitude sites (Sliter, 1989) is much older than its range in the southern high latitudes.

Globotruncana linneiana (D'Orbigny)
(Pl. 3, Figs. 3–7)

Rosalina linneiana d'Orbigny, 1839, p. 101, pl. 5, figs. 10–12.

Remarks. This species is distinguished from *Globotruncana bulloides* by having a more symmetrical biconvex profile in edge view and a keel band that is parallel to the coiling axis. Although some specimens appear similar to *G. bulloides* (e.g., Pl. 3, Figs. 4 and 5), they are too rare and too poorly preserved to warrant their distinction as a different species. *Globotruncana linneiana* sporadically occurs in rare abundance within the Campanian section of Site 700. Its range elsewhere is reported as Campanian through lower Maestrichtian (Caron, 1985; Sliter, 1989).

Globotruncanella havanensis (Voorwijk)
(Pl. 3, Fig. 8)

Globotruncana havanensis Voorwijk, 1937, p. 195, pl. 1, figs. 25, 26.

Remarks. This species occurs rarely below the *Abathomphalus mayaroensis* Zone at Sites 698 and 700, first occurring in lower Maestrichtian sediments at both sites. It has a similar distribution at the Maud Rise and the Falkland Plateau, and is the nominal taxon of the *Globotruncanella havanensis* Zone. The reported range in the lower latitudes is from the uppermost Campanian through the Maestrichtian (Caron, 1985).

Globotruncanella petaloidea (Gandolfi)
(Pl. 3, Fig. 9)

Globotruncana (*Rugoglobigerina*) *petaloidea* Gandolfi, 1955, p. 52, pl. 3, fig. 13.

Remarks. This distinctive species occurs rarely within the upper Maestrichtian *Abathomphalus mayaroensis* Zone at Sites 698 and 700. Its stratigraphic range is from the lower through upper Maestrichtian at lower latitude localities (Caron, 1985; Sliter, 1989).

Abathomphalus mayaroensis (Bolli)
(Pl. 3, Fig. 10)

Globotruncana mayaroensis Bolli, 1951, p. 190, pl. 35, figs. 10–12.

Remarks. The FAD of *Abathomphalus mayaroensis* is time-transgressive from the southern high latitudes toward the equator. It first occurs in the middle of Chron 31R (~70.5 Ma) at the Northeast Georgia Rise and the Maud Rise, whereas it first occurs in Chron 31N at tropical and subtropical Pacific sites (Sliter, 1989), in the Mediterranean region (Premoli Silva, 1977; Monechi and Thierstein, 1985), and DSDP Site 208 in the Tasman Sea (Keating et al., 1975).

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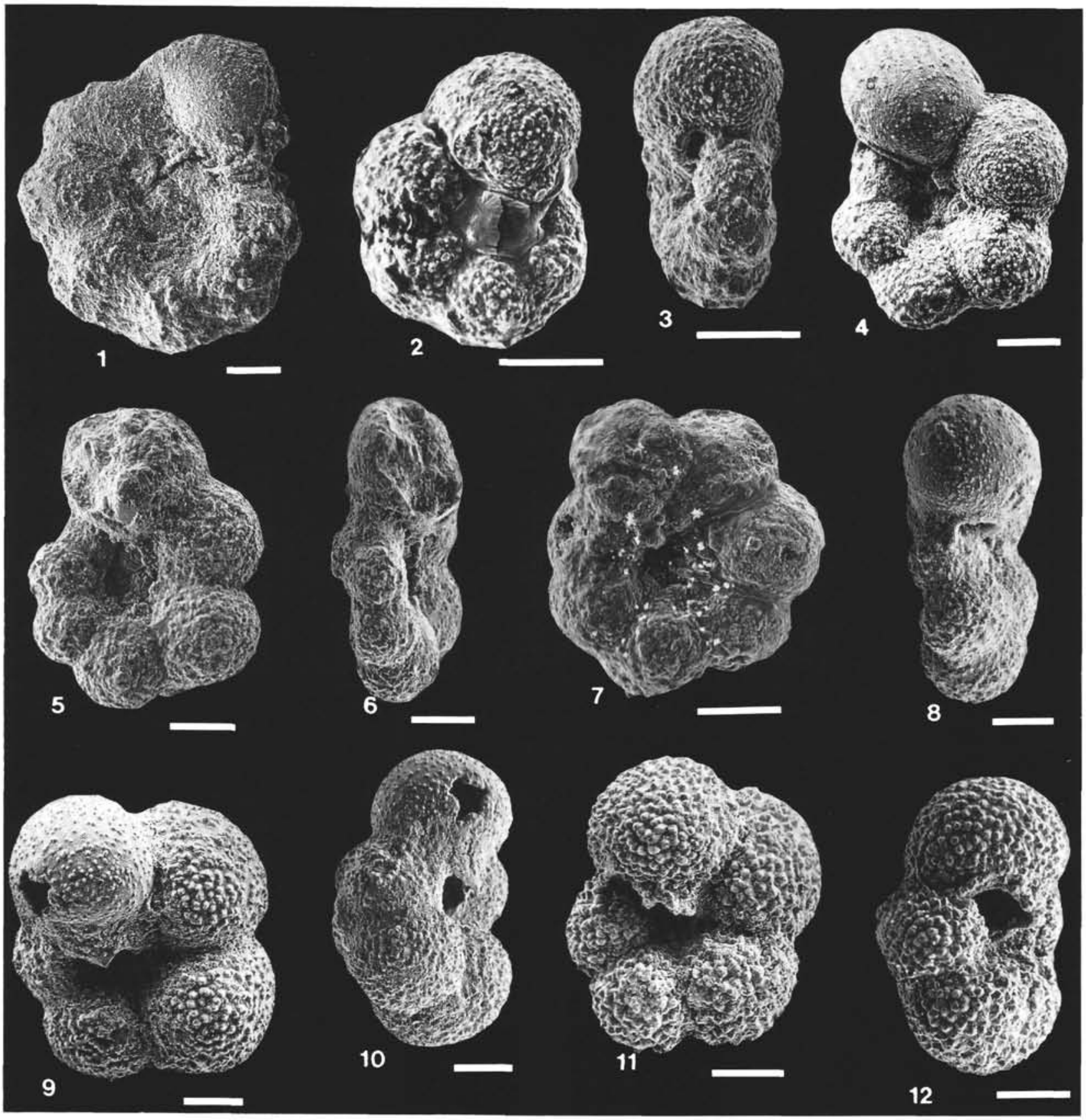

Plate 1. Scale bars are 50 μm. **1.** *Globigerinelloides impensus* Sliter, Sample 114-700B-43R-3, 140–144 cm. **2** and **3.** *Hedbergella monmouthensis* (Olsson), Sample 114-698A-16R-2, 67–71 cm. **4, 8.** *Hedbergella sliteri* Huber, Sample 114-698A-16R-2, 67–71 cm. **5** and **6.** *Hedbergella planispira* (Tappan), Sample 114-700B-47R-4, 25–29 cm. **7.** *Hedbergella planispira* (Tappan), Sample 114-700B-46R-1, 124–128 cm. **9** and **10.** *Archaeoglobigerina australis* Huber, Sample 114-698A-17R-1, 28–32 cm. **11** and **12.** *Archaeoglobigerina australis* Huber, Sample 114-698A-17R-2, 12–16 cm.

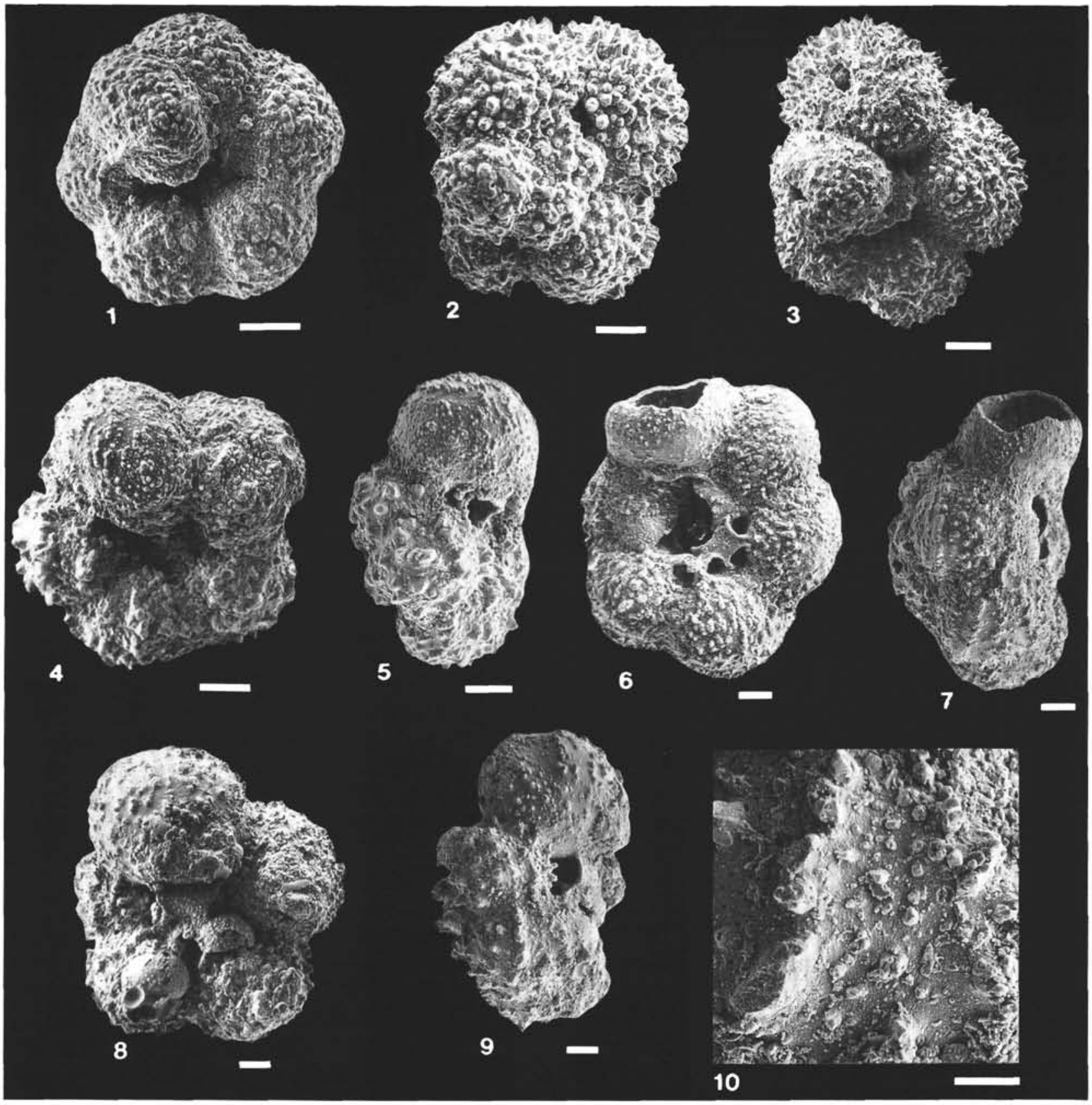

Plate 2. Scale bars for Figures 1–9 are 50 μm and for Figure 10 is 10 μm. **1.** *Archaeoglobigerina australis* Huber, Sample 114-698A-17R-1, 28–32 cm. **2.** *Archaeoglobigerina mateola* Huber, Sample 114-698A-16R-1, 67–71 cm. **3.** *Archaeoglobigerina mateola* Huber, Sample 114-698A-16R-1, 67–71 cm. **4** and **5.** *Rugotruncana circumnodifer* (Finlay), Sample 114-698A-17R-1, 12–16 cm. **6** and **7.** *Rugotruncana circumnodifer* (Finlay), Sample 114-698A-16R-1, 67–71 cm. **8** and **9.** *Rugotruncana circumnodifer* (Finlay), Sample 114-698A-16R-1, 67–71 cm. **10.** Closeup view of imperforate peripheral band and beaded keel of same specimen shown in Figures 8 and 9.

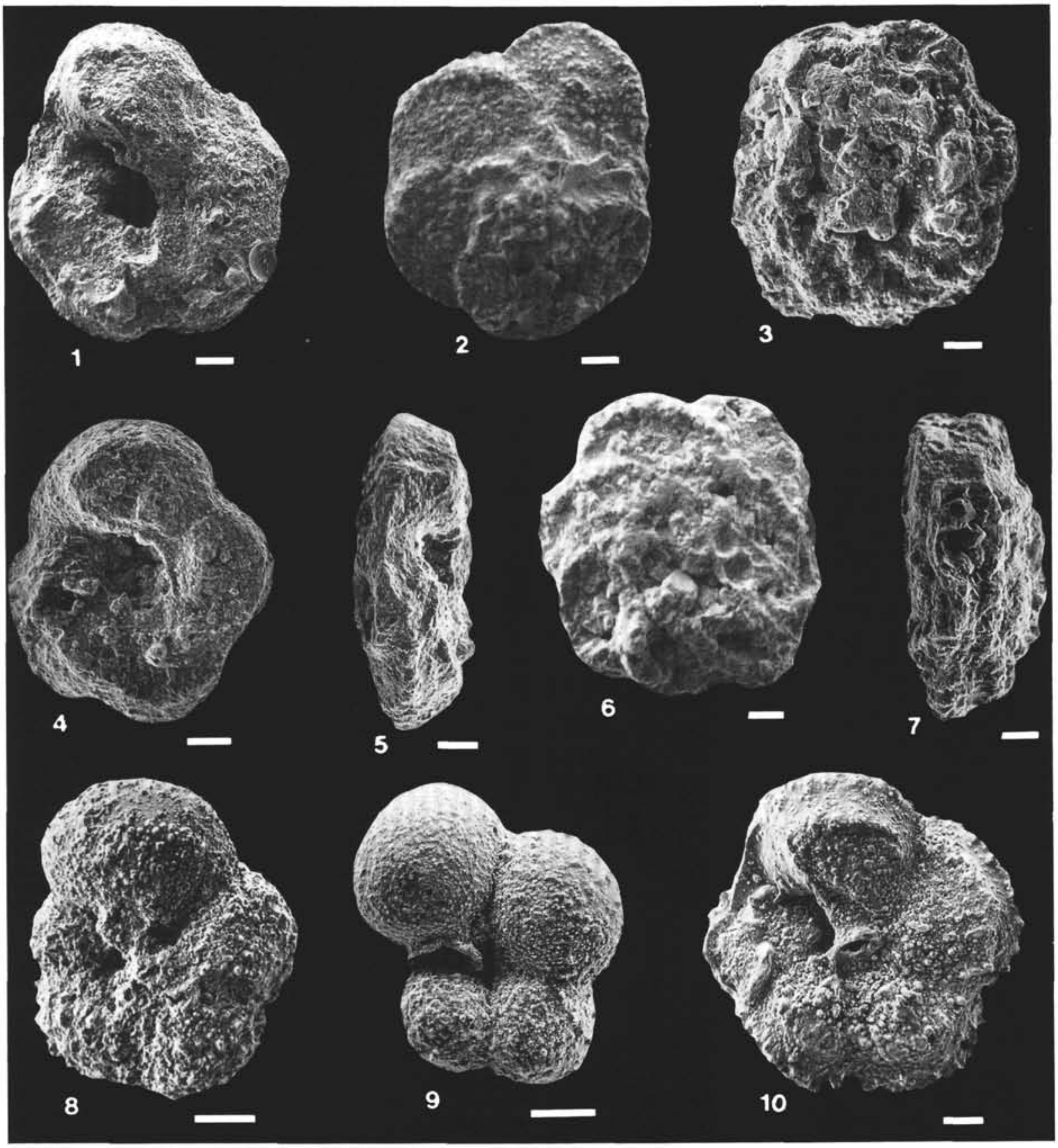

Plate 3. Scale bar is 50 μm. **1** and **2.** *Globotruncana bulloides* Vogler, Sample 114-698A-16R-1, 67–71 cm. **3, 6,** and **7.** *Globotruncana linneiana* (d'Orbigny), Sample 114-700B-47R-5, 12–16 cm. **4** and **5.** *Globotruncana linneiana* (d'Orbigny), Sample 114-700B-47R-4, 25–29 cm. **8.** *Globotruncanella havanensis* (Voorwijk), Sample 114-698A-17R-2, 12–16 cm. **9.** *Globotruncanella petaloidea* (Gandolfi), Sample 114-700B-39R-4, 72–76 cm. **10.** *Abathomphalus mayaroensis* (Bolli), Sample 114-698A-16R-1, 67–71 cm.