ABSTRACT

The southernmost record of Maestrichtian pelagic carbonate sedimentation was recovered from ODP Leg 113 Holes 689B and 690C, drilled on the Maud Rise in the eastern Weddell Sea sector of the Southern Ocean (65°S). Well preserved and abundant planktonic foraminifers occur throughout Maestrichtian cores from both holes, providing a nearly complete biogeographic and biostratigraphic history of this region. Diversity is low compared to tropical and subtropical assemblages, with a maximum within sample diversity of 16 planktonic foraminifer species and a diversity total for the Maestrichtian of 24 species. The assemblages are dominated throughout by Heterohelix, Globigerinelloides, and a new species of Archaeoglobigerina, whereas keeled taxa are completely absent from the lower Maestrichtian and rare in the middle through upper Maestrichtian sediments.

Three planktonic foraminifer species are described as new and are recognized as being endemic to the Austral Province. These include Archaeoglobigerina australis n. sp., Hedbergella silieri n. sp., and Archaeoglobigerina mateola n. sp. The former two species were previously illustrated in reports on Late Cretaceous foraminifers from the Falkland Plateau and the northern Antarctic Peninsula. Two keeled and five non-keeled planktonic foraminifers, previously not found in high latitude Maestrichtian sediments, first appeared at the Maud Rise during the late early and late Maestrichtian. Correlation with the foraminifer ranges in low latitude sequences shows that their first appearance datums are considerably younger at the Maud Rise than in the lower latitudes. The most likely explanation for this observation is that there was a warming in the south polar region during the late early and late Maestrichtian and a concomitant poleward migration of stenothermal taxa. However, oxygen isotopic paleotemperature results from Sites 689 and 690 (Barrera and Huber, this volume) show a long-term cooling trend throughout the Maestrichtian, indicating that other factors may have played a more important role than temperature in the distribution of Maestrichtian planktonic foraminifers.

A new biostratigraphic scheme is proposed for the Antarctic because of the absence of thermophilic planktonic foraminifers used to identify existing low to middle latitude zones. The Globigerinelloides impensus Partial Range Zone is defined for the late Campanian-Maestrichtian, the Globotruncanella havanensis Partial Range Zone is redefined for the early to late early Maestrichtian, and the Abathomphalus mayaroensis Total Range Zone is recognized. Good quality magnetic polarity data obtained from both Maud Rise sites (Hamilton, this volume) enables magnetobiostratigraphic correlation of twelve foraminifer datums with the geomagnetic polarity time scale of Haq et al. (1987). The geochronology thus obtained is crucial for accurate cross-latitudinal correlation and interpretation of the paleoceanographic history of the Antarctic region during the Maestrichtian time period.

INTRODUCTION

Maestrichtian foraminifers were recovered from Holes 689B (64°31'S, 03°06'E) and 690C (65°10'S, 1°12'E) on the Maud Rise (southern South Atlantic Ocean) during Ocean Drilling Program Leg 113 (Fig. 1). These are the southernmost Maestrichtian assemblages yet recovered from deep sea sediments, providing valuable information for high southern latitude paleobiogeographic and paleoceanographic reconstructions. In addition, the Maud Rise sequence fills an important stratigraphic gap in the southern South Atlantic region because upper Maestrichtian sediments were not recovered at DSDP Sites 327 and 511 on the Falkland Plateau (51°S), which were the southernmost Cretaceous deep sea sites prior to Leg 113. The nearest other occurrence of Late Cretaceous foraminifers in the high southern latitudes is in ODP Leg 114 Holes 698A and 700B on the northeast Georgia Rise (52°S) and the James Ross Island region (64°S) in the northern Antarctic Peninsula (Fig. 1). The faunal distributions at the Leg 114 sites closely correlate with those reported in this study, and are discussed by Huber (in


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Figure 1. Paleogeographic reconstruction for the early Maestrichtian (after Barron, 1987) showing the regional setting of ODP Sites 689 and 690 (Maud Rise), ODP Sites 698 and 700 (northeast Georgia Rise) and DSDP Sites 327, 511 (Falkland Plateau). JRI refers to the James Ross Island region of Antarctic Peninsula. Small dots represent other South Atlantic deep sea sites yielding Cretaceous sediments. Shaded pattern represents land areas above sea level. The inferred land-sea reconstruction for Antarctica is from Huber (1988b).
press). The James Ross Island region assemblages, however, were probably influenced by nearshore depositional processes and, thus, they are not considered useful for extra-basin correlation (Huber, 1988a).

Uncertainties in cross-latitudinal correlation have inhibited previous efforts to accurately portray high southern latitude paleoceanic and paleoclimatic evolution during the Late Cretaceous. Factors that have caused poor biostratigraphic accuracy in this region include: (1) absence of thermophilic planktonic foraminifers used in low latitude zonations, (2) low species diversity and equitability, with dominance by long-ranging, eurytopic taxa, (3) paleoenvironmental influence on faunal distributions, causing diachronous first and last occurrences of some species, (4) provincialism and morphologic variability of several planktonic species, causing uncertainties in phylectic relationships and taxonomic concepts, and (5) limited stratigraphic and areal distribution of circumpolar sites yielding Cretaceous sediments. In spite of these difficulties, several key marker species, previously not found in the south polar regions, occur at the Maud Rise. By correlating the Maud Rise foraminifers with calcareous nannoplankton distributions (Pospichal and Wise, this volume), a more precise chronostratigraphic framework can be developed for high southern latitude sequences deposited during the Maestrichtian time period. Thus, the paleoceanographic and paleoclimatic history of this region can be reconstructed more accurately than has hitherto been possible.

**METHOD OF STUDY**

Core-catcher samples and one sample per core section were obtained from the Cretaceous sequences recovered at Holes 689B and 690C. These were disaggregated in warm water, ultrasonically cleaned, and sieved through a 63 μm screen. The dried residue was sieved through a 150 μm screen and relative species abundances for 300 specimens were counted in both the > 150 μm and < 150 μm fractions of each sample (Tables 1-4). Foraminifers occurred in sufficient abundance for complete counts of all samples studied. Benthic foraminifer percentages and species relative abundances were calculated from the count totals.

Relative abundance rankings are as follows: abundant, 26%-100%; common, 16%-25%; few, 6%-15%; rare, 2%-5%; and very rare, < 1%. Species that were questionable present in samples were not included in counts of species diversity. Preservation of the Cretaceous foraminifers ranges from moderate to excellent. Specimens distinguished as having moderate preservation are fragmented and strongly etched or overgrown with secondary calcite. Samples showing good preservation yield mostly whole foraminifer tests showing minor evidence of dissolution or secondary calcite overgrowth. Foraminifers whose preservation was judged as excellent show no evidence of diagenetic alteration in transmitted light and their tests are optically translucent.

Core sample notation follows the standard ODP format, listing the leg number, hole designation, core number and coring method, section number, and the centimeter interval within the section.

**FORAMINIFER BIOSTRATIGRAPHY**

**Hole 689B**

A 63.9 m thick sequence of Maestrichtian chalk was recovered from Hole 689B, situated at the crest of the Maud Rise, 2,080 m below sea level in the southeastern South Atlantic Ocean (Fig. 1). The uppermost 2.9 m of the sequence, from 233.4 meters below sea floor (mbsf) to 236.3 mbsf, are included in lithologic Subunit IIIA (Fig. 2), which is composed of moderately bioturbated, white nannofossil and foraminifer ooze with some finely dispersed ash interbeds. The remainder of the Maestrichtian sequence comprises lithologic Subunit IIIB. This portion is more indurated than Subunit IIIA and is composed of moderately to strongly bioturbated, white to grey nannofossil chalk and foraminifer nannofossil chalk. Thin chert beds dispersed throughout Subunit IIIB caused poor drilling recovery (33%) and eventual abandonment of this hole. The Cretaceous-Tertiary boundary interval was recovered between 84 and 85 cm in Section 113-689B-25X-5. Details of the foraminiferal turnover through this interval are discussed elsewhere in this volume (see Stott and Kennett, this volume, chapter 47; Thomas, this volume).

The Cretaceous samples at Hole 689B all yield abundant foraminifers whose preservation ranges from excellent, predominantly in the middle of the section, to good in all but the lowermost sample, which was rated as moderately preserved (Fig. 2). Benthic foraminifer percentages are lowest at the base of the sequence (33% in Sample 113-689B-33X, CC), and range between 3% and 25% above that level. Total planktonic species diversity is low throughout the studied interval compared with coeval assemblages from lower latitudes, with fewer than 11 species in the lower Maestrichtian sediments, and up to 16 species in the upper Maestrichtian (Fig. 2).

Assemblages throughout the sequence are dominated by *Globigerinelloides multispinatus*, *Heterohelix* spp., and a new species designated as *Archaeoglobigerina australis* (Fig. 3; Tables 1, 2). *Globigerinelloides impensus*, which was previously known only from upper Campanian sediments at the Falkland Plateau (Silter, 1977; Krasheninnikov and Basov, 1983), comprises a significant proportion of the assemblages in the lowermost part of the sequence. This species was not present above Section 113-689B-32X-1. *Hedbergella holomeldeensis* occurs only in Sample 113-689C-33X, CC, whereas *Hedbergella monmouthensis* is present in nearly all Maestrichtian samples in Hole 689B. A distinctive new species, *Archaeoglobigerina mateola*, also ranges throughout the sequence, occurring in very rare to common abundance. Specimens of *Globotruncanella havanensis* and the new species *Hedbergella sliteri* both appear in Samples 113-689B-30X-1 and range through Section 113-689B-27X. The Maestrichtian species *Globotruncanella petaloidea* and *Globigerinelloides subcarinatus* first occur in upper Maestrichtian Samples 113-689B-28X-3, 83-87 cm and -28X-1, 76-80 cm, respectively, and *Globotruncanella citae* and *Pseudotextularia elegans* first occur in Sample 113-689B-25X-5, 105-107 cm, just below the Cretaceous/Tertiary boundary.

The most pronounced assemblage change in this section occurs in the late early Maestrichtian with the appearance of the double keeled planktonic species *Rugotruncana circummodifer* in Samples 113-689B-29X-2, 83-87 cm (267.5 mbsf) and first occurrences of *Globotruncanella bulloides* and *G. subcircumnodifer* in Sample 113-689B-28X, CC (265 mbsf). The diversity of double keeled taxa increases with the appearance of the late Maestrichtian marker species *Abathomphalus intermedius* and *A. mayaroensis* (Fig. 2; Table 1).

**Hole 690C**

Hole 690C is located on the southwestern flank of the Maud Rise, 116 km southwest of Site 689 (Fig. 1) in 2,914 m water depth. Cores 113-690C-16X through -22X penetrated 69.2 m of Maestrichtian chalk that differs from sediments recovered at Hole 689B by its higher terrigenous component of fine-grained quartz, clay, and mica. Drilling recovery averaged 66% for this sequence. The Cretaceous/Tertiary boundary was determined to occur between 48 and 50 cm in Section 113-690C-15X-4 and is discussed elsewhere (Pospichal and Wise, this volume, chapter 32; Stott and Kennett, this volume, chapter 47; Thomas, this volume).
Figure 2. Summary of the drilling recovery, lithology, planktonic/benthic ratios, and planktonic foraminifer species diversity graphs for samples analyzed from the Cretaceous sequence of Hole 689B. These were taxonomically differentiated by family using the classification of Loeblich and Tappan (1988).
The lithologic units are shown differentiated in the Cretaceous sequence based on the relative amounts of nannofossil and terrigenous components (Fig. 4). Unit V (281.1-317 mbsf) includes light gray to pale brown mudstone, with minor to moderate bioturbation, and nannofossil-bearing mudstone. Chert beds and an ash horizon occur in Core 113-690C-22X. A sharp contact between Unit V and the underlying sequence at 317 mbsf in Section 113-690C-22X occurs at 317 mbsf in Section 113-690C-22X, CC.

As expected from the close proximity of Sites 689 and 690, the foraminifer distribution patterns at Hole 690C are very similar to those of Hole 689B. Foraminifer preservation is excellent in Unit V between Samples 113-690C-19X-2, 141-192, and 141-21X, CC (284-310 mbsf), where clay content is high. Preservation is excellent in Unit V between Samples 113-690C-19X-2, 141-192, and 141-21X, CC (284-310 mbsf), where clay content is high.

**Figure 3.** Distribution and relative abundance of Maestrichtian planktonic foraminifers from Hole 689B. The plots are based on combined totals of 300 specimen counts of the > 150 µm and < 150 µm size fractions (Tables 1, 2). Relative abundance rankings and planktonic foraminifer zones are shown at the bottom of the figure. Magnetostratigraphic information from Hamilton (this volume).

**Table 3.** Distribution and relative abundance of Maestrichtian planktonic foraminifers from Hole 689B. The plots are based on combined totals of 300 specimen counts of the > 150 µm and < 150 µm size fractions (Tables 1, 2). Relative abundance rankings and planktonic foraminifer zones are shown at the bottom of the figure. Magnetostratigraphic information from Hamilton (this volume).
Table 1. Counts of planktonic foraminifers from the >150 μm size fraction for all samples studied at Hole 689B. Crosses denote specimens found after the first 300 specimen count.

Table 2. Counts of planktonic foraminifers from the <150 μm size fraction for all samples studied at Hole 689B. Crosses denote specimens found after the first 300 specimen count.

tion is good in all other samples examined (Fig. 4). Benthic foraminifer percentages are lower than for Hole 689B, with highest values (22%) just above basaltic basement. Benthic foraminifers are less common in the overlying Cretaceous sequence, comprising less than 3% of the total assemblage. Total planktonic diversity is less than 12 species for most of the sequence and reaches a maximum of 16 species in Sample 113-690C-19X-1, 119-123 cm (Fig. 4). Diversity remains relatively high throughout the upper Maestrichtian sequence. The dominant planktonic foraminifers at Hole 690C are the same species that occur most frequently in the Cretaceous sequence of Hole 689B (Fig. 5; Tables 3, 4). Archaeoglobigerina australis is common to abundant in nearly all samples up to the upper Abathomphalus mayaroensis Zone. Archaeoglobigerina
Figure 4. Summary of the drilling recovery, lithology, planktonic/benthic ratios, and planktonic foraminifer species diversity graphs for samples analyzed from the Cretaceous sequence of Hole 690C. These were taxonomically differentiated by family using the classification of Loeblich and Tappan (1988).
mateola also ranges throughout most of the Maestrichtian sequence at Hole 690C, occurring as a minor component of the planktonic assemblages. Specimens of Globigerinelloides imperatus occur only at the bottom of Hole 690C (314 mbsf to 316 mbsf), as at Hole 689B. Both Globotruncanella havanensis and Hedbergella siltii first occur in lower Maestrichtian Sample 113-690C-21X-5, 118-122 cm and have a sporadic distribution above. The latter species is consistently present at higher abundances within the upper Maestrichtian sediments. Globotruncanella petaloidea and Globigerinelloides subcarinatus first appear in Samples 113-690C-19X-4, 119-123 cm and -17X, CC, respectively, and Globotruncanella citae first occurs in Sample 113-690C-16X-2, 114-116 cm and ranges to just below the Cretaceous/Tertiary boundary (Fig. 5; Tables 3, 4; Stott and Kennett, this volume, chapter 47).

A conspicuous influx of double keeled planktonic foraminifers and increase in species diversity also occurs in the late early Maestrichtian sequence at Hole 690C, beginning in Sample 113-690C-19X, CC (Fig. 5; Table 3). Specimens of Rugotruncana circumnodifer and Globotruncanella subcircumnodifer are both

![Figure 5. Distribution and relative abundance of Maestrichtian planktonic foraminifers at Hole 690C. The plots are based on combined totals for 300 specimen counts of the >150 μm and <150 μm size fractions (Tables 3, 4). Magnetostratigraphic information from Hamilton (this volume). See Figure 3 for the key to relative abundance rankings and planktonic foraminifer zonal subdivisions.](image-url)
present in this sample. This is followed by first appearances of Globotruncana bulloides in Section 113-690C-19X-4, Abathomphalus intermedius in Section 113-690C-19X-1, and A. mayaroensis in Section 113-690C-18X-5.

**BIOSTRATIGRAPHIC ZONATION**

Previous studies of Late Cretaceous planktonic foraminifer assemblages from the southern South Atlantic region were unable to apply low latitude biostratigraphic schemes because of the absence of zonal marker species (Sliter, 1977; Krasheninnikov and Basov, 1983, 1986; Huber, 1988a). Uncertainty in cross-latitudinal biostratigraphic correlation is especially prevalent in the lower Maestrichtian sediments at the Maud Rise; the zonal marker species Globotruncana falsostuarti, G. ventricosa, G. gansseri are completely absent and the assemblages are dominated by long-ranging, eurythermal taxa. Previous zonal schemes proposed for Upper Cretaceous high latitude sequences in New Zealand (Webb, 1971) and the Antarctic Peninsula (Huber, 1988a), shown in Figure 6, are of limited regional utility because of incomplete stratigraphic reference sections or local facies control on faunal distributions. Incomplete recovery of Maestrichtian sediments at DSDP Sites 327 and 511 on the Falkland Plateau (Figs. 1, 7) limited the biostratigraphic utility of the planktonic foraminifers described by Sliter (1977) and Krasheninnikov and Basov (1983). Thus, Maud Rise Sites 689 and 690 provide the most complete biostratigraphic range data for Maestrichtian planktonic foraminifers yet recovered from the high southern latitudes. Description of a new Antarctic zonal scheme is presented below.

**Globigerinelloides impensus Partial Range Zone**

**Definition.** Interval from the first to last occurrence of G. impensus Sliter.

**Associated species.** Globigerinelloides multispinatus, Hedbergella holmdelensis, and Archaeoglobigerina australis.

**Age.** Late Campanian to early Maestrichtian. The LAD of G. impensus is in upper Chron 33N (early Maestrichtian) at Sites 689 and 690, and is estimated at 73.71 Ma (Table 5).

**Distribution.** From Samples 113-689B-33X, CC through -32X-1, 41-31 cm (294.3-291.2 mbsf) and 113-690C-22X-4, 118-122 cm through -22X-3, 107-111 cm (315.6-314.5 mbsf). The earliest occurrence of Globigerinelloides impensus at Holes 689B and 690C are in the lowermost samples analyzed and, therefore, the total stratigraphic range of this species probably not recovered. Sliter (1977) reported that this species was restricted to upper Campanian sediments at Falkland Plateau DSDP Site 327, occurring only in Core 36-327A-13R. This latter core is separated from overlying Maestrichtian sediments by a 23 cm coring gap (Fig. 7). Although Krasheninnikov and Basov (1983) reported G. impensus to range from Cores 71-511-26R to -23R at Falkland Plateau DSDP Site 511 (Fig. 7), re-examination of samples from that sequence suggests that this species is absent from the Maestrichtian core. This species was probably mistaken for a similar form, presently referred to as Globigerinelloides sp., which occurs in low abundance in Core 71-511-23R. Therefore, the last appearance datum (LAD) of G. impensus at Site 511 is shown in Figure 7 at the top of Core 71-511-24R, which was assigned to the late Campanian by Wind and Wise (1983). The G. impensus Zone was not recovered at DSDP Site 208 (Tasman Sea), as coring terminated in middle Maestrichtian sediments only 10 m below the Abathomphalus mayaroensis Zone. Absence of G. impensus from the Lopez de Bertodano Formation in the James Ross Island region (Antarctic Peninsula) (Huber, 1988a) may be due to paleobathymetric exclusion of this species or because that sequence is younger than was previously reported.
Table 4. Counts of planktonic foraminifera from the <150 μm size fraction for all samples studied at Hole 690C. Crosses denote specimens found after the first 300 specimen count.

Globotruncanella havanensis Interval Zone

Definition. Interval from the last occurrence of Globigerinelloides impensus to the first appearance of Abathomphalus mayorensis.

Age. Early Maestrichtian. This zone extends from upper Chron 33N to the middle of Chron 31R at Sites 689 and 690.


Distribution. The range of the nominate species at the Maud Rise [Samples 113-689B-30X, CC through 28X-2, 80-84 cm (246.4-267.5 mbsf); 690C-32X-2, 118-122 cm through 14X, CC (313.1-321.1 mbsf)] begins in the middle of Chron 31R and continues in the middle of Chron 32R. This zone extends from upper Chron 33N to the middle of Chron 31R at Sites 689 and 690.

Abathomphalus mayorensis Total Range Zone

Definition. Brommann (1952) originally defined this zone on the total range of A. mayorensis.

Associated species. Gubertina robusta, Globigerinelloides subcircularis, Hedbergella sitleri, Globotruncanella petaloidea, Rugotruncanella circummoderior, and Abathomphalus intermedius.

Age. Late Maestrichtian. The first appearance datums (FAD's) of Abathomphalus mayorensis and the calcareous nanoplankton species Nephroleptus frequens occur within 0.5 m of each other at Sites 689 and 690 and are used as the basis for delimiting the early/late Maestrichtian boundary at both sites. First occurrences of both species in Chron 31R at Sites 689 and 690, about 69.9 Ma (Table 5), are earlier than their FAD's in Chron 30N reported from lower latitude sequences (Premoli Silva, 1977; Kent and Gradstein, 1985; Monéchi and Thierstein, 1985) and, thus, their distributions are considered to be transgressive from the high to low latitudes (see below).

Distribution. From Samples 113-689B-2B-1, 76-80 cm through 85-90 cm (246.3-233.7 mbsf) and 690C-18X-5, 46-49 cm through 690C-18X-5, 46-49 cm (233.7-247.8 mbsf). The late Maestrichtian A. mayorensis Zone was not recovered at either DSDP Site 327 or 511 at the Falkland Plateau (Fig. 7). At DSDP Site 208, Webb (1973b) reported the FAD of A. mayorensis in Section 21-208-33-2.5 m below the top of the Cretaceous sediments. This species was probably absent from Maestrichtian sediments on Seymour Island because of the shallow paleodepth (Huber, 1988a).

BIOCHRONOLOGY

Sedimentation rate curves for Holes 689B and 690C, shown plotted on Figure 8, are based on the stratigraphic positions of magnetostratigraphic chron boundaries (Hamilton, this volume) and their correlation with the Haaq et al. (1987) time scale for the Maestrichtian. This time scale was chosen because of the absence of definite Campanian age calcareous nanoplankton that have not been reworked (Pospichal and Wise, this volume, chapter 30), but presence of a relatively long interval of normal polarity assigned to Chron 33N at the bottom of Holes 689B and 690C. Figure 8 shows that the Maestrichtian rate of sedimentation at Hole 689B was slower (about 5.18 m/My) and
more constant than at Hole 690C, which has an average sedimentation rate of 9.53 m/my. Extrapolation of these sedimentation rate curves to the bottom of both holes indicates that the oldest sediments recovered from Hole 689B were deposited during the latest Campanian, at about 75.05 Ma, and the oldest at Hole 690C were deposited during the earliest Maestrichtian at about 73.96 Ma.

Age estimates for 12 planktonic foraminifer datums, listed in Table 5 and shown on Figure 8, were determined by plotting the stratigraphic level of their first or last appearance on (or extrapolated beyond) the sedimentation rate curves for both Maud Rise sites. Between the two sites, agreement of these age estimates is dependent on completeness of recovery and sample spacing. For example, the FAD of *Globigerinelloides impensus* is older at Hole 689B (74.72 Ma) than at Hole 690C (73.71 Ma) because of a 20 m recovery gap between Cores 113-689B-30X and -32X (Fig. 2). Although age assignments for datums that occur within intervals of good recovery compare to within 0.6 m.y. of each other at the two Maud Rise sites, it is difficult to further evaluate their accuracy because of the paucity of paleomagnetically constrained datums elsewhere. The best and closest site for comparison is ODP Hole 700B, drilled on the northeast Georgia Rise in the southern South Atlantic (Fig. 1). The Maestrichtian foraminifers from that site are nearly identical to the Maud Rise assemblage in species composition and the biostratigraphic datums occur within the same magnetic polarity sequences (Huber, in press).

Several species listed in Table 5 have diachronous first occurrences compared to their lower latitude distribution. The FAD at the Maud Rise of *Abathomphalus mayaroensis* in Chron 31R at the Maud Rise, and at Hole 700B, 13° of latitude to the north (Huber, in press), is considerably older than its first occurrence within Chron 30N in the Umbrian Appenines (Premoli Silva, 1977; Monechi and Thierstein, 1985). Berggren et al. (1983) recorded an FAD of *A. mayaroensis* that is slightly younger than the Leg 113 and 114 sites to the south, occurring just below the C31N/C31R boundary at the Rio Grande Rise in the South Atlantic (35°S paleolatitude). These authors also report that the FAD of *Globorotruncaella havanensis* is just below the
C32N/C32R boundary, whereas this species first occurs at the base of Chron 32R at the Maud Rise. Although Boersma (1984) reported the FAD of A. mayaroensis at the base of C31N at Hole 525A on the Walvis Ridge, she considered that occurrence to be an artifact of sediment reworking. In the circum-Pacific region, the FAD of A. mayaroensis is reported by Sliter (1989) to occur within the middle of Chron 31N.

Species with older FAD’s in the south polar region than in the low latitudes include Pseudotextularia elegans, Globigerinelloides subcarinatus, Globotruncanella bulloides, and Globotruncanella subcircumnodifer. All of these taxa range from the Campanian through Maestrichtian in tropical and subtropical regions (Caron, 1985; Sliter, 1989), but first occur in upper lower to upper Maestrichtian sediments at the Maud Rise.
PALEOBIOGEOGRAPHY

The Austral Biogeographic Province

Late Cretaceous planktonic foraminifers from the Maud Rise and other sites that occupied paleolatitudes poleward of about 50°S are included in the Austral Province. Scheibnerova (1971, 1973), Sliter (1977), and Krasheninnikov and Basov (1983, 1986) distinguished this cool-temperate biogeographic province from the Transitional (subtropical) and Tethyan (tropical) Provinces based on the absence of Late Cretaceous thermophilic planktonic foraminifers. Species of Racemigumbelina, Ventilabrella, Planoglobulina, Heterigerinoides, Sigalina, Pseudogumbelina, Plummerina, Trinitella, and single keeled Globotruncanita are very rare to absent. Prior to this study, no planktonic foraminifers were recognized as having distributions restricted to any of the extra-tropical provinces. Instead, Austral Province assemblages were identified by having low species diversity and dominance of simple globular species of the Heterohelicidae, Planomaliniidae, Hedbergellidae, and rare Rugoglobigerinidae (Scheibnerova, 1971; Webb, 1973a; Sliter, 1977; Krasheninnikov and Basov 1983).

Analysis of Cretaceous foraminifer assemblages from the Maud Rise and Falkland Plateau reveals that several planktonic foraminifer species were restricted in their paleobiogeographic distribution to the high southern latitudes. Globigerinelloides impensus was previously known only from the Falkland Plateau (Sliter, 1977; Krasheninnikov and Basov, 1983), but its occurrence at the Maud Rise extends its paleobiogeographic range to the eastern side of the southern South Atlantic. The new species Archaeoglobigerina australis is not only a dominant component of the Maud Rise assemblages, but it also dominates the late Campanian-early Maestrichtian assemblages at Sites 327 and 328. Considerable morphologic variability of this species (see systematic discussion) has led to substantial confusion in taxonomic concepts of the high latitude morphotypes and incorrect age assignments for the species that were misidentified. Detailed comparison and morphometric study of large populations of A. australis from the Falkland Plateau and the Maud Rise (Huber, 1987; 1988b) has shown that specimens previously referred to as Rugoglobigerina pilula Belford, Rugoglobigerina rotundata Brönnimann, and Hedbergella monmouthensis Olsson (by several authors (Sliter, 1977; Krasheninnikov and Basov 1983; Huber, 1988a) are in fact morphovariants of Archaeoglobigerina australis. Topotypes of the incorrectly identified taxa were morphometrically compared with A. australis and their taxonomic distinction has been documented (Huber, 1988b).

A third species determined to be restricted to the Austral Province is Hedbergella sliteri (previously designated as H. holmdelensis by Sliter, 1977 and H. monmouthensis by Webb, 1973b and Huber, 1988a). Morphometric comparison of populations of this species from the Maud Rise and the Falkland Plateau with toptotypes of H. holmdelensis and H. monmouthensis (Huber, 1988b) has also clarified their taxonomic differences (see also systematic discussion below). The paleobiogeographic range of H. sliteri extends from the southern South Atlantic to the southwest Pacific Ocean.

Planktonic specimens similar in morphology to the distinctive new species Archaeoglobigerina mateola were found in one sample from lower Maestrichtian sediments on Seymour Island (northern Antarctic Peninsula) (distinguished as Rugoglobigerina sp. 2 by Huber, 1988a). The absence of A. mateola from other austral localities is puzzling. The range of this species at the Maud Rise does overlap with the age of sediments recovered in Cores 10 through 12 of Falkland Plateau Hole 327A (Fig. 7), but examination of samples from these cores has failed to reveal...
its presence. Archaeoglobigerina mateola is quite rare and somewhat sporadic in its occurrence within its Maestrichtian range at the Maud Rise. Thus, its absence from the Falkland Plateau cannot be entirely substantiated until the existing material is studied further or until younger Maestrichtian sediments are recovered.

The northern limit of the Austra Province in the southern South Atlantic probably occurred poleward of about 40°S paleolatitude (the Walvis Ridge), but north of 55°S paleolatitude (the Falkland Plateau and Leg 114 sites shown on Fig. 1). Assemblages reported from DSDP Sites 524, 525, and 527, drilled on the Walvis Ridge (Boersma, 1984; Smith and Poore, 1984), are considerably more diverse in keeled and total planktonic foraminifer species than sites drilled further south on the Falkland Plateau (Sliter, 1977; Krasheninnikov and Basov, 1983), the northeast Georgia Rise (Huber, in press) and the Maud Rise. This biogeographic boundary most likely paralleled the border between two oceanic surface gyres which differed primarily in temperature. These water masses probably converged at about the latitude of the northern Falkland Plateau, as was postulated by Ciesielski et al. (1977).

**PALEOENVIRONMENTAL INFERENCES**

The most important factor controlling Cretaceous planktonic foraminifer biogeography has been interpreted to be the arrangement of paleoclimatic belts (Douglas, 1972; Smier, 1972, 1977; Krasheninnikov and Basov, 1986). On the basis of changes in foraminiferal assemblages at Falkland Plateau DSDP Sites 327 and 511, Krasheninnikov and Basov (1986) constructed a paleoclimatic curve for the Barremian-Maestrichtian time period, which is partly reproduced in Figure 9. Absence of keeled taxa and dominance of simple globigerine species of Heterohelix, Globigerinelloides, and Globigerina were used by these authors as indicators of cold conditions, while warm periods were recognized by the presence of higher diversity assemblages yielding keeled “stenothermal” species. Although Krasheninnikov and Basov (1986) show a cooling trend throughout the Maestrichtian period, data for the late early through late Maestrichtian interval of their plot are lacking due to an erosional disconformity on the Falkland Plateau (Wind and Wise, 1983; this study).

If the Krasheninnikov and Basov (1986) method for determining relative paleotemperatures is used to reconstruct the Maestrichtian climate at the Maud Rise, a significantly different paleotemperature curve would result. The increase in planktonic foraminifer species diversity and occurrence of several keeled planktonic species during the late early through late Maestrichtian (Figs. 2, 4, 9) would suggest a warming of high latitudinal surface waters and a poleward expansion of the Transitional Province. Although this interpretation is consistent with results from middle latitude palynological and plant physiognomy studies in the Northern Hemisphere by Wolfe (1987), which indicate a late Maestrichtian warming event, oxygen isotope values from the Maud Rise (Barrera and Huber, this volume; Fig. 9), the Antarctic Peninsula (Barrera et al., 1978), and the equatorial Pacific Ocean (Douglas and Savin, 1975, Shackleton and Boersma, 1981) show a cooling trend throughout the Maestrichtian. Furthermore, a global cooling was proposed by Pospichal and Wise (this volume, chapter 30) and Worsley and Martini (1970) for the late Maestrichtian to explain the equatorward migration of the calcareous nanoplankton species Nephroleithus frequens. The earlier appearance of Abathomphalus mayorensis at the Maud Rise relative to lower latitude sites indicates that this species also migrated from the high to low latitudes, perhaps following cooler surface waters as they expanded toward the tropics.

It is apparent from the above discrepancies among paleoclimatic indicators that latitudinal climatic gradients or relative paleotemperature curves cannot be reconstructed by using keeled/non-keeled ratios of planktonic foraminifers alone. As Cifelli and Scott (1986, p. 66) noted, “…the parallel of latitude are man-made constructs and not, in themselves, natural phenomena.” It is well known that many biotic and abiotic parameters affecting modern foraminifer distributions cannot be directly measured from the fossil record. In addition to the arrangement of paleoclimatic belts, the salinity and density stratification of surface waters, surface water turbidity, nutrient supply, and seasonal variation in environmental factors all played important roles in controlling the distribution of planktonic foraminifers. The poleward pulses of planktonic foraminifer migration observed in the upper lower through upper Maestrichtian sediments at the Maud Rise and other southern high latitude sites would be best explained by a concomitant shift in water mass boundaries. However, this is not a satisfactory explanation because of the lack of corroborating evidence from the calcareous nanoplankton distributions (Pospichal and Wise, this volume, chapter 30) and oxygen and carbon isotope results (Barrera and Huber, this volume) from both Maud Rise sites. Unfortunately, the present stratigraphic and geographic record from the high southern latitudes is too limited to decipher the paleoceanographic changes that most influenced the anomalous Antarctic foraminifer distributions.

**CONCLUSIONS**

1. Sedimentation rates determined for the Maestrichtian sequence at Holes 689B and 690C average 5.18 m/My and 9.53 m/My, respectively. No depositional hiatuses are apparent at either Maud Rise site.

2. The oldest sediments recovered from Hole 689B were deposited in the latest Campanian, at about 75.05 Ma, whereas those from Hole 690C were deposited in the earliest Maestrichtian at about 73.96 Ma.

3. Recognition of three new planktonic foraminifer species that were endemic to the circum-Antarctic region during the Maestrichtian time period confirms the existence of the Austra Province as a biogeographically segregated entity. Planktonic foraminifer assemblages within this province are characterized by their low species diversity, paucity or absence of many thermophilic index species found in the Tethyan and Transitional Provinces, and dominance by simple globular planktonic morphotypes. The Maud Rise assemblages are nearly identical to upper Campanian-Maestrichtian planktonic foraminifers described from the Falkland Plateau and other high southern latitude assemblages, but distinctly differ from coeval assemblages from the Walvis Ridge (about 40°S paleolatitude) and foraminifer faunas to the north. This biogeographic isolation was probably caused by convergence of subtropical and temperate oceanic gyres at about 50°S paleolatitude in the South Atlantic.

4. Several keeled and non-keeled species have considerably younger first occurrences at the Maud Rise than in lower latitude sequences. These poleward migration events are estimated to have occurred at about 71, 70.5, 69.5, and 66.5 Ma. Although this may be attributed to latitudinal shifts in warm versus cool water mass boundaries, no corroborating evidence has been obtained from analysis of calcareous nanoplankton distributions (Pospichal and Wise, this volume, chapter 30) and oxygen isotope paleotemperatures (Barrera and Huber, this volume). Paleoceanographic factors other than temperature, such as surface water turbidity, nutrient supply, salinity, and/or vertical stratification, must be invoked as causes for the diachronous planktonic foraminifer distributions.

**SYSTEMATIC DESCRIPTIONS**

Planktonic foraminifer species encountered in this study are briefly discussed below and are illustrated on Plates 1–6.
Figure 9. Relative paleotemperature curve for the Campanian-Maestrichtian periods from Krasheninnikov and Basov (1987) compared with results from the Maestrichtian of Hole 690C showing a relative abundance plot for keeled planktonic foraminifers from Hole 690C (this study) and the oxygen isotope paleotemperature curve from Barrera and Huber (this volume) for Gavelinella beccariformis (a benthic species) and Globigerinelloides multispinatus (a planktonic species).

Ymy lists are limited to the original reference, with additional synonymies added for clarification of taxonomic uncertainties among some species. Three species are formally described as new. Details of their morphologic variability, distinction from other taxa, size range, and stratigraphic distribution are also provided. Holotypes and paratypes of each new species are deposited at the U.S. National Museum of Natural History in Washington, D.C. Discussion of some previously described taxa is included to elucidate differences in morphologically similar or phylogenetically related forms.

Guembelitria cretacea Cushman (Pl. l.Fig. 1)

Guembelitria cretacea Cushman, 1933, p. 37, pl. 4, figs. 12a–b.

Occurrence. First appears in Samples 113-689B-29X, CC and -690C-21X-5, 118–122 cm and sporadically occurs in low abundance through
the younger Maestrichtian sequence. Caron (1985) and other authors have noted that the range of this species is restricted to the Maestrichtian stage.

**Heterohelix dentata Stenestad**

(Pl. 1, Fig. 2)

**Heterohelix dentata** Stenestad, 1968, p. 67–68, pl. 1, figs. 6–8, 9, 10, 12; pl. 2, figs. 1–3.

**Heterohelix globulosa** Ehrenberg, 1840 (1838), p. 135, pl. 4, figs. 2B, 4B, 5B, 7B, 8B.

Remarks. Most forms included in this species resemble the specimen shown on Pl. 1, Fig. 3, which has fine costate ornamentation on all chambers. However, some (e.g., Pl. 1, Fig. 4) have an elongate test with pustule surface ornament on the earlier chambers, resembling *Heterohelix papula* Belford, which was described from the Santonian Toolonga Calcilutite in Western Australia (Belford, 1960, 1983), but has not since been reported elsewhere.

Occurrence. Present in all Cretaceous samples at Sites 689 and 690 in very rare to high abundance. Ranges from the upper Campanian through Maestrichtian elsewhere.

**Heterohelix globulosa** Ehrenberg

(Pl. 1, Figs. 3–4)

**Textularia globulosa** Ehrenberg, 1840 (1838), p. 135, pl. 4, figs. 2B, 4B, 5B, 7B, 8B.

Remarks. Most forms included in this species resemble the specimen shown on Pl. 1, Fig. 3, which has fine costate ornamentation on all chambers. However, some (e.g., Pl. 1, Fig. 4) have an elongate test with pustule surface ornament on the earlier chambers, resembling *Heterohelix papula* Belford, which was described from the Santonian Toolonga Calcilutite in Western Australia (Belford, 1960, 1983), but has not since been reported elsewhere.

Occurrence. Present in all Cretaceous samples at Sites 689 and 690 in rare to high abundance. A common component of Late Cretaceous assemblages worldwide.

**Heterohelix planata** (Cushman)

(Pl. 1, Figs. 3–6)

**Guembelina planata** Cushman, 1938, p. 12–13, pl. 2, figs. 13–14.

**Heterohelix pulchra** (Brotzen), Sliter, 1977, p. 547, pl. 7, fig. 1. Huber, 1988a, p. 206, figs. 27.2–27.3.

Remarks. This species is distinguished from *Heterohelix globulosa* (Cushman) by having chambers that are more reniform in morphology. It differs from *Globorotalia multispinata* Sliter by having narrower chambers in the final whorl, slightly smaller size, and having a more broadly rounded equatorial periphery.

Occurrence. Sporadically occurs in very rare abundance throughout the Cretaceous at Sites 689 and 690. This form also occurs in Cores 23 and 24 of DSDP Site 511 on the Falkland Plateau (pers. observ.).

**Schackoia multisponata** (Cushman and Wickenden)

(Pl. 2, Fig. 1)

**Hantkenina multisponata** Cushman and Wickenden, 1930, p. 40, pl. 6, figs. 4–6.

Remarks. This species differs from *Globigerinellina multispinata* (Lalicker) by its greater number of chambers in the final whorl (commonly 6–7), finer surface ornament, thinner test and broader umbilicus. It is distinguished from *G. impensus* Sliter by having fewer chambers in the final whorl, slightly smaller size, and having a more broadly rounded equatorial periphery.

Occurrence. Very rare at the Maud Rise, occurring in the Globigerinellina impensus Zone and the lower Globorotaliina havanaensis Zone. Re-examination of material from the Falkland Plateau indicates its range extends from Section 36–327A-13R–2 through 12R–2 and Section 71–511–4R–3 through 28R–7, which have been dated as Campanian through early to early middle Maestrichtian (Wind and Wise, 1983). Caron (1985) reported that *H. holmdelensis* ranges from the Coniacian through Maestrichtian, but this extensive range is probably an artifact of confused taxonomic concepts.

**Hedbergella holmdelensis** Olsson

(Pl. 2, Figs. 2–4; Pl. 6, Fig. 1)


Remarks. *Hedbergella holmdelensis* is distinguished from *H. monmouthensis* (Olsson) by its larger size (up to 300 μm in diameter), by having a more compressed test and by the asymmetry of the final chamber face. Topotypes of this species were compared with the Maud Rise specimens and found to be identical in external and internal morphology (Huber, 1988b). It differs from *H. sliteri* by its smaller size and narrower, deeper umbilicus.

Occurrence. Very rare at the Maud Rise, occurring in the Globigerinellina impensus Zone and the lower Globorotaliina havanaensis Zone. Examinations of material from the Falkland Plateau indicates its range extends from Section 36–327A-13R–2 through 12R–2 and Section 71–511–4R–3 through 28R–7, which have been dated as Campanian through early to early middle Maestrichtian (Wind and Wise, 1983). Caron (1985) reported that *H. holmdelensis* ranges from the Coniacian through Maestrichtian, but this extensive range is probably an artifact of confused taxonomic concepts.
Remarks. This species has frequently been confused with similar juvenile forms of other species. It is distinguished by its small size (less than 200 µm diameter), chambers that increase moderately in size, and symmetrically globose final chamber face. The ontogenetic morphology of the Maud Rise forms were compared with topotypes (Pl. 6, Fig. 2) of this species and found to be identical.

Occurrence. Incorrect identifications of *H. monmouthensis* have led to uncertainty in its stratigraphic distribution. Robaszynski et al. (1984) suggest that it ranges from the lowermost Campanian through the Maastrichtian, whereas Olsson (1987) maintains that this species evolved from *H. holmdelensis* during the early Maastrichtian. At the Maud Rise, *H. monmouthensis* ranges from the Globigerinelloides impensus Zone to the Globorotalia inflata Zone. Re-examination of the stratigraphic distribution of *H. monmouthensis* at the Falkland Plateau indicates its first appearance is in upper Campanian Sections 36-327A-13R-2 and 71-511-24R-7.

**Hedbergella sliteri** n. sp.

(Pl. 2, Figs. 5, 9-10; Pl. 6, Figs. 4-5)


**Hedbergella monmouthensis** (Olsson). Huber, 1988a, p. 206, figs. 27.14-17.

**Etyology.** Named for W. V. Sliter (USGS, Menlo Park), a pioneer in the study of Late Cretaceous planktonic foraminifera biogeography of the southern South Atlantic.

**Diagnosis.** Test nearly planispiral to low trochospiral, chambers gradually increasing in size, five to six in final whorl, umbilicus broad and shallow, aperture a low extra-umbilical arch bordered by a narrow portico near the equatorial periphery.

**Description.** Test coiled in a low trochospire, occasionally nearly planispiral, often flattened on the spiral side, convex on the umbilical side, average diameter 273 µm, average breadth 123 µm. Chambers inflated, slightly reniform to globular, increasing gradually in size, usually five to six in the final whorl, four and one-half to six in the penultimate whorl. 12 to 15 comprising the entire test of adult specimens, final chamber normalform or sometimes kummerform. Proloculus diameter averaging 17 µm, initial whorl diameter averaging 74 µm, with a mean of 5.0 chambers in the initial whorl. Sutures strongly depressed, radial and straight on the spiral and umbilical sides. Umbilicus shallow, broad, averaging 28% of the maximum test diameter. Aperture a low, interomarginally produced, extra-umbilical, sometimes positioned very near the equatorial periphery, bordered by a narrow portico. Relict apertural and apertural flaps well-developed. Test surface nearly smooth to finely pustulose, outer wall radial hyaline, finely perforate.

**Remarks.** Populations of this species were compared with topotypes of *H. monmouthensis* (Olsson) from the Red Bank Formation (New Jersey) and SEM illustrations of *H. holmdelensis* Olsson and *H. monmouthensis* provided by R. K. Olsson (pers. comm., 1987). *Hedbergella sliteri* differs by its larger size, chambers that increase more gradually in size, fewer number of chambers in the penultimate whorl and broader umbilical region. The frequency of specimens with kummerform final chambers is higher among the Maud Rise assemblages than those of the Falkland Plateau.

**Occurrence.** At the Maud Rise, the FAD of *H. sliteri* is within lower Campanian, and it ranges from the Globorotalia tenera nannofossil Zone through the Abathomphalus mayorensis Zone, occurring in very rare to common abundance. It is a common component of samples correlated with the *G. tenera* Zone at the Falkland Plateau, occurring within Cores 36-327A-12 through 36-327A-10, but it is absent from DSDP Site 511 and all samples examined from the Globigerinelloides impensus Zone. Forms described by Webb (1973b) from Lord Howe Rise DSDP Site 208 occur in sediments of middle to late Maastrichtian age. This species is considered to be endemic to the Antarctic Province.

**Holotype.** USNM 41770 (Pl. 2, Figs. 5, 9-10). Maximum diameter: 370 µm, maximum breadth: 155 µm.

**Paratypes.** USNM 41771.

**Type locality.** Maud Rise, southern South Atlantic, Sample 113-690C-18X-5, 46.49 cm.

**Archaoglobigerina australis** n. sp.

(Pl. 2, Figs. 11-13; Pl. 3, Figs. 1-7; Pl. 6, Figs. 7-9)


**Etyology.** From *australis* (Latin), referring to the southern latitude region where it is found.

**Diagnosis.** Test biconvex, moderate to high spired, chambers strongly inflated, globular, final whorl chambers on adult specimens four to six, increasing moderately in size, adult apertures umbilical to slightly extra-umbilical with a broad flap, surface composed of randomly situated pustules.

**Description.** Test coiled in a moderate to high spire, uniquely biconvex, spiral side usually more convex than umbilical side, average diameter of adult specimens 280 µm, average breadth 150 µm. Chambers strongly inflated, globular, increasing moderately in size with four to five and one-half in the penultimate whorl, increasing gradually in size with three and three-quarters to five and three-quarters in the ultimate whorl. 12 to 15 comprising the tests of adult specimens of chambers usually kummerform. Proloculus diameter of adult specimens averaging 16 µm, initial whorl diameter averaging 71 µm, with a mean of 4.4 chambers in the initial whorl. Sutures moderately to strongly depressed, radial and straight on both the spiral and umbilical sides. Apertures of juvenile specimens extra-umbilical in position, having greater width than height, bordered by a narrow, thickened lip. Apertures of adult specimens umbilical to slightly extra-umbilical in position, often bordered by a broad flap that may completely extend across the umbilicus, with relict apertural flaps sometimes coalescing to form a pseudo-tegillum. Umbilicus deep, narrow to broad, comprising an average of 28% of the maximum test diameter. Test surface covered with fine to coarse, randomly situated pustules, surface of final chamber usually with finer pustulose ornament than previous chambers. Outer wall radial hyaline and finely perforate.

**Remarks.** Although end member morphotypes included in this species show considerable differences in chamber development and apertural characteristics (e.g., compare Pl. 2, Figs. 11-12 with Pl. 3, Figs. 2-4), no distinct populations could be recognized as a separate species in the Maud Rise and Falkland Plateau assemblages. Serial dissection of large, adult specimens and X-ray micrographs (Huber, 1987, 1988b) have revealed penultimate whorl morphologies identical to small forms (see Pl. 2, Figs. 11-13; Pl. 6, Figs. 7-9), here considered as juvenile specimens of *A. australis*.

**Generic forms of** *A. australis* **resemble** specimens of *A. bosquensis* Pessagno that were described from Santonian sediments in the western Gulf Coastal Plain (Pessagno, 1967) and the Falkland Plateau (Sliter, 1977; Krasheninnikov and Basov, 1983). The Gulf Coast holotype and paratype of *A. bosquensis* differ from *A. australis* by having a smoother test surface and lacking kummerform chambers and apertural flaps. However, poor preservation of the type material and uncertainty of the morphologic variability among Gulf Coast populations of *A. bosquensis* preclude an adequate comparison of these taxa. Falkland Plateau specimens described as *A. bosquensis*, which are very well preserved and occur in high abundance, do not bear apertural flaps, are generally higher spired and have a narrower, deeper umbilicus than most forms of *A. australis*, although some forms of the latter species (e.g., Pl. 3, Fig. 7) are very similar. The stratigraphic distribution of these two species and their morphologic similarity suggest that *A. australis* is a descendant of *A. bosquensis*.

No specimens with tegilla, imperforate peripheral margins, peripheral keels, or meridionally arranged costellae have been found. Therefore, this species is not placed in *Rugoglobigerina* or *Rugotruncana*. Inclusion in *Archaoglobigerina* differs from the original description of that genus, which suggests that tegilla should be observed in "perfectly preserved specimens" (Pessagno, 1967, p. 315). Because this structure is
absent from the Gulf Coast type species of Archaeoglobigerina (A. blowi Pessago) and the holotype of Archaeoglobigerina bosquensis, it is not considered as a primary generic character. Either the definition of this genus needs to be modified, or a new genus should be created to accommodate the non-keeled, non-telgteille forms.

**Occurrence.** Archaeoglobigerina australis dominates the Maud Rise planktonic foraminifer assemblages from the Globigerinelloides impensus Zone through to the third W. Abathomphalus mayaroensis Zone. It is also a dominant component of late Campanian through early Maestrichtian assemblages at Falkland Plateau DSDP Sites 327 and 511 and is very rare on Seymour Island (see synonymy above). Its first appearance at the Falkland Plateau is in lower Campanian Sample 71-30-3, 6136 cm (pers. observ.).

**Holotype.** USNM 415772 (Pl. 3, Figs. 2-4). Maximum diameter: 334 μm, maximum breadth: 190 μm.

**Paratypes.** USNM 415773.

**Type locality.** Maud Rise, southern South Atlantic, Sample 113-690C-19X-3, 119-123 cm.

**Archaeoglobigerina mateola n. sp.**

(Pl. 3, Figs. 8-10; Pl. 4, Figs. 1-3; Pl. 6, Fig. 6)

**Rugoglobigerina? sp. 2, Huber, 1988a, p. 207, figs. 31.12, 15-16.**

**Eymology.** From mateus (Latin), a medieval war club with a blunt, spiny terminus.

**Diagnosis.** Test moderate to high spired, often unequally biconvex, chambers increasing moderately in size, three and three-quarters to four and one-half in final adult whorl, adult aperture umbilical, often covered by a flap or thickened bulla, final chambers usually kummerform, surface distinctly ornamented by coarse pustules or long, narrow spines.

**Description.** Test coiled in a moderate to high spire, equally to unequally biconvex, spiral side often more convex than umbilical side, average diameter of adult specimens 280 μm, average breadth 190 μm. Chambers globular, inflated, increasing moderately in size, three and three-quarters to four and one-half in the final adult whorl, four to four and one-half in the penultimate whorl, 10-12 comprising the tests of adult specimens, final chambers usually kummerform. Proloculus diameter averaging 17 μm, initial whorl diameter averaging 74 μm with a mean of 4.5 chambers in the initial whorl. Sutures radial and straight, strongly depressed on umbilical side, moderately depressed on spiral side. Aperture umbilical in position on adult specimens, usually obscured by a broad flap or thickened umbilical bulla. Apertures of juvenile specimens umbilical to extra-umbilical, having greater width than height. Surface distinctly ornamented with randomly situated, large pustules or very finely pustulose to smooth on juvenile. Outer wall radial hyaline and finely perforate.

**Remarks.** This species has a very unusual external morphology compared with other known Late Cretaceous planktonic foraminifer taxa. Similarity in the ontogenetic development of this species suggests a close ancestral relationship with A. australis (Huber, 1988b). Inclusion in Archaeoglobigerina is primarily because of the globigerine chamber arrangement and absence of meridional costellae. Neither tegilla nor peripheral keel bands were observed in the Maud Rise populations, however, so similarity to the original definition of Archaeoglobigerina (see Pessago, 1967, p. 315) is limited.

**Occurrence.** At the Maud Rise, this species occurs in very rare abundance in the Globigerinelloides impensus Zone and lower Globotruncanella havanensis Zone, and rare to common abundance through the Abathomphalus mayaroensis Zone. Very rare occurrences of this species were reported by Huber (1988a); see synonymy above) from one sample in the lower Maestrichtian of Seymour Island (Antarctic Peninsula).

**Holotype.** USNM 415774 (Pl. 3, Figs. 8-10). Maximum diameter: 301 μm, maximum breadth: 215 μm.

**Paratypes.** USNM 415775.

**Type locality.** Maud Rise, southern South Atlantic, Sample 113-690C-20X-3, 116-118 cm.

**Rugotruncana circummodifier (Finlay)**

(Pl. 4, Figs. 4-10; Pl. 6, Fig. 3)

**Globigerina circummodifier** Finlay, 1940, p. 469, pl. 65, figs. 150-157.

**Globotruncanella (Rugotruncana) circummodifier** (Finlay). Webb, 1973b, p. 552, pl. 4, figs. 1-4.

**Remarks.** This species is distinguished by having strongly inflated chambers numbering four to five and one-half in the final whorl and paired keells on the equatorial periphery. The keels are usually not visible on the ultimate chambers and are sometimes only expressed by an imperforate peripheral band (e.g., Pl. 4, Figs 8-9). Surface ornament varies from randomly situated, small pustules to well-developed costellae aligned in a meridional pattern. Tegilla are usually preserved on the Maud Rise specimens.

**Occurrence.** This species was first described by Finlay (1940) from New Zealand where it occurs with Abathomphalus mayaroensis (Webb, 1971). Rugotruncana circummodifier was also reported from DSDP Site 208 in the Tasman Sea (Webb, 1973b). A single specimen resembling this species, referred to as Rugotruncana cf. R. circummodifier, was found on Seymour Island (Antarctic Peninsula) in the lower Hederigella monmouthensis Zone (Huber, 1988a). At the Maud Rise, R. circummodifier first appears in Chron 32N, within the upper Globotruncanella havanensis Zone and ranges through the Abathomphalus mayaroensis Zone. It is uncertain whether R. circummodifier was restricted to the Austral Province, as it may have been confused with other globular, double keeled species, such as Rugotruncana subpennyi (Gandolfi) and Globotruncanella subcircummodifier Gandolfi, Olson (1964, pl. 6, figs. 5a-c).

**Globotruncanella citae (Bolli)**

**Globotruncanella citae** Bolli, 1951, p. 197, pl. 35, figs. 4-6.

**Occurrence.** Restricted to the upper Abathomphalus mayaroensis Zone at the Maud Rise. Its earlier (middle Maestrichtian) first appearance at lower latitude sites suggests a time-transgressive migration from the tropics toward the south polar region during the late Maestrichtian.

**Globotruncanella havanensis** (Voorwijk)

(Pl. 5, Figs. 1-2)


**Occurrence.** This is the nominal taxon of the G. havanensis Zone at the Maud Rise. It appears in lower Chron 32R, above the LAD of Globigerinelloides impensus in Samples 113-689B-30X-1, 83-85 cm and 113-690C-21X-5, 118-122 cm and ranges into the Abathomphalus mayaroensis Zone, occurring in very rare to rare abundance. Caron (1985) and others report that G. havanensis ranges from the uppermost Campanian through the Maestrichtian.

**Globotruncanella petaloidea** (Gandolfi)

(Pl. 4, Fig. 11)

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

**Globotruncanella? sp., Huber, 1988a, p. 208, figs. 31.4, 31.7-31.8.**

**Occurrence.** At the Maud Rise, this species ranges from upper Chron 32N in the upper Globotruncanella havanensis Zone through the Abathomphalus mayaroensis Zone. A single specimen of G. petaloidea, previously identified as Globotruncanella? sp., occurs only in the uppermost Maestrichtian beds on Seymour Island in the northern Antarctic Peninsula (Huber, 1988a).

**Abathomphalus intermedius** (Bolli)

(Pl. 5, Figs. 5-6)

**Globotruncanella intermedius** Bolli, 1951, p. 197-198, pl. 35, figs. 7-9.

**Occurrence.** This species appears just below the FAD of A. mayaroensis in Chron 30R at Maud Rise Sites 689 and 690, and occurs in very rare abundance. Caron (1985) reports that the stratigraphic distribution of A. intermedius is limited to the late Maestrichtian, ranging from the middle of the tropical Gansserina gansseri Zone through the A. mayaroensis Zone.

**Abathomphalus mayaroensis** (Bolli)

(Pl. 5, Figs. 3-4)

**Globotruncanella mayaroensis** Bolli, 1951, p. 190, 198, pl. 35, figs. 10-12.

**Occurrence.** This is the nominal taxon for the A. mayaroensis Zone, which is recognized worldwide as being late Maestrichtian in age. The FAD of this species at the Maud Rise is in the middle of Chron 31R and it ranges up to the Cretaceous-Tertiary boundary at both sites.
Globotruncana bulloides Vogler 
(Pl. 5. Figs. 9-11)

Globotruncana bulloides Vogler, 1941, p. 287, pl. 23, fgs. 32-39.

Occurrence. This species first appears in the middle of Chron 32N in the Globotruncana havanensis Zone and occurs sporadically and in very rare abundance in the Abathomphalus mayaroensis Zone at the Maud Rise. Globotruncana bulloides is reported as ranging from the G. elevata Zone to within the A. mayaroensis Zone at lower latitude sites (Caron, 1985). Thus, its first occurrence in the middle Maastrichtian at the Maud Rise considerably post-dates its first evolutionary appearance in tropical to subtropical regions.

Globotruncana subcircumnodifer (Gandolfi) 
(Pl. 5. Figs. 7-8, 12)

Globotruncana (Rugoglobigerina) subcircumnodifer Gandolfi, 1955, p. 44, pl. 2, fgs. 7a-c.

Occurrence. This species ranges from the middle of Chron 32N in the upper part of the Globotruncana havanensis Zone through the Abathomphalus mayaroensis Zone at the Maud Rise, occurring in very rare to rare abundance. As it is reported to first appear in the upper Globotruncana calcarea Zone (upper Campanian) at lower latitude sites (Caron, 1985), the FAD of G. subcircumnodifer in the southern South Atlantic is regarded as diachronous.

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Plate 3. 1. Archaeoglobigerina australis n. sp., s.s., Sample 113-690C-19X-3, 119-123 cm. Note the considerable variability of chamber development, umbilical size, and apertural flaps. 2-4. Archaeoglobigerina australis n. sp., holotype, Sample 113-690C-19X-3, 119-123 cm. 5. Archaeoglobigerina australis n. sp., s.l., Sample 113-690C-19X-3, 119-123 cm. 6. Archaeoglobigerina australis n. sp., s.l., Sample 113-689B-30X-3, 83-87 cm. 7. Archaeoglobigerina australis n. sp., s.l., Sample 113-689B-28X-3, 83-87 cm. 8-10. Archaeoglobigerina mateola n. sp., holotype, Sample 113-690C-20X-3, 119-123 cm. Scale bar for Figures 1-10 is 50 μm.
Plate 4. 1. Archaeoglobigerina mateola n. sp., Sample 113-690C-20X-3, 119-123 cm. 2. Archaeoglobigerina mateola n. sp., Sample 113-689B-28X-1, 76-80 cm. 3. Archaeoglobigerina mateola n. sp., Sample 113-690C-18X-2, 99-103 cm. Enlarged cross-sectional view of the outer wall showing microstructure of distinctive large spines that characterize this species. 4. Rugotruncana circumnodifer (Finlay), Sample 113-690C-17X-3, 119-123 cm. 5-7. Rugotruncana circumnodifer (Finlay), Sample 113-690C-19X-3, 119-123 cm. 8-9. Rugotruncana circumnodifer (Finlay), Sample 113-690C-18X-5, 46-49 cm. Note the absence of a visible keel, but presence of an imperforate peripheral band. 10. Rugotruncana circumnodifer (Finlay), Sample 113-690C-17X-3, 119-123 cm. 11. Globotruncanella petaloidea (Gandolfi), Sample 113-690C-18X-1, 119-123 cm. Scale bar for Figures 1-2, 4-11 is 50 μm and for Figure 3 is 10 μm.
Plate 6. Microradiographs of holotypes and several other species described in this study. 1. *Hedbergella holmdelensis* Olsson, Sample 113-690C-21X-4, 118-122 cm. 2. *Hedbergella monmouthensis* (Olsson), Sample 113-690C-20X-5, 108-110 cm. 3. *Rugotruncana circumnodifer* (Finlay), Sample 113-690C-18X-5, 46-49 cm. 4. *Hedbergella sliteri* n. sp., holotype, Sample 113-690C-18X-5, 46-49 cm. 5. *Hedbergella sliteri* n. sp., from Falkland Plateau DSDP Site 327, Sample 71-327-10-3, 22-24 cm. Note the differences in ontogenetic morphology between the microradiographs of *H. sliteri* and those of *H. holmdelensis* and *H. monmouthensis*. 6. *Archaeoglobigerina mateola* n. sp., holotype, Sample 113-690C-20X-3, 119-123 cm. 7. *Archaeoglobigerina australis* n. sp., holotype, Sample 113-690C-19X-3, 119-123 cm. 8. *Archaeoglobigerina australis* n. sp. Juvenile form from DSDP Site 511, Sample 71-511-23-4, 67-69 cm. 9. *Archaeoglobigerina australis* n. sp., Sample 113-690C-19X-6, 119-121 cm. Edge view showing ontogenetic changes in morphology. Scale bar for Figures 1-9 is 50 μm.