# 25. MAESTRICHTIAN PLANKTONIC FORAMINIFER BIOSTRATIGRAPHY AND THE CRETACEOUS/TERTIARY BOUNDARY AT HOLE 738C (KERGUELEN PLATEAU, SOUTHERN INDIAN OCEAN)<sup>1</sup>

Brian T. Huber<sup>2</sup>

#### ABSTRACT

A biostratigraphically complete upper Maestrichtian-Danian sequence was recovered at ODP Leg 119 Site 738 on the southern Kerguelen Plateau (62°S). Planktonic foraminifers are abundant and well to moderately preserved in all upper Maestrichtian samples to within 6 cm of the Cretaceous/Tertiary boundary, where foraminifers are rare and poorly preserved due to increased sediment lithification. Lowermost Danian samples are also poorly preserved, but specimen abundance is sufficient for preliminary quantitative biostratigraphic analysis. Despite the poor foraminifer preservation, evidence is presented for paleoenvironmental change immediately below a thin, iridium-rich calcareous clay horizon that is recognized as the Cretaceous/Tertiary boundary. The most significant indicators for preboundary change include; (1) loss of sediment bioturbation; (2) loss of keeled planktonic foraminifers; and (3) diminished size and diversity of benthic foraminifers. Planktonic foraminifers showing transitional morphologies between Cretaceous and Tertiary planktonic biserial heterohelicids first appear 4 cm below the boundary clay. Although some Cretaceous planktonic foraminifers consistently occur with early Danian marker species in initially high abundance above the boundary clay, they are not considered as survival species, but are considered as reworked because of their co-occurrence with Campanian and Maestrichtian species whose extinctions took place well before the end of the Maestrichtian.

The recovered Maestrichtian planktonic foraminifers are identical to Austral Realm assemblages found in the southern South Atlantic region. All five species previously recognized as being endemic to this realm were recovered from Hole 738C. Lower Danian assemblages strongly resemble coeval low-latitude foraminifer faunas, whereas upper Danian assemblages differ only in the absence of indicator species, particularly the morozovellids. The stratigraphy of this sequence is correlated using existing zonal schemes for the southern high-latitudes, with modification of one Antarctic Paleogene zone and subzone. Only broad subdivisions of tropical zonal schemes were recognized, as most of the nominate taxa are absent from the southern high-latitudes.

#### INTRODUCTION

Ocean Drilling Program Site 738 lies on the southern end of the Kerguelen Plateau ( $62^{\circ}42'$ S,  $82^{\circ}47'$ E) at 2253 m water depth (Fig. 1). It is one of the southernmost Indian Ocean deep-sea drilling sites, and thus provides an important biostratigraphic reference section for high-latitude Cretaceous and Paleogene correlation. Over 100 m of Upper Cretaceous sediments were recovered from Hole 738C (from 377.2 m below seafloor (mbsf) to 485.9 mbsf), but only the upper portion of the Cretaceous section yields foraminifers of sufficient preservation for accurate species identification. Details of the Hole 738C lithostratigraphy are outlined in Barron, Larsen, et al. (1989).

An apparently complete Cretaceous/Tertiary boundary interval was recovered in Core 119-738C-20R, within an undisturbed, 15-cm-thick, finely laminated (nonbioturbated), clayrich calcareous chalk. The boundary is placed within Sample 119-738C-20R-5 96.0–96.2 cm (377.16 mbsf), at the level of a clay-rich layer that has yielded an extraordinarily high concentration of iridium (18 ppb; see Schmitz et al., this volume). Virtually all other previously recovered deep-sea cores that span the Cretaceous/Tertiary boundary have been unsatisfactory for detailed biostratigraphic distribution analysis because of the occurrence of intense bioturbation (Stott and Kennett, 1990a), sediment reworking (Smith and Poore, 1984; Gerstel et al., 1986), or hiatuses (Thierstein, 1982; Perch-Nielsen et al., 1982) span-

<sup>&</sup>lt;sup>2</sup> Department of Paleobiology, NHB-121, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560, U.S.A.



Figure 1. Location of ODP Site 738 on the southern flank of the Kerguelen Plateau. Other sites drilled during Leg 119 are also shown. Contours in meters.

<sup>&</sup>lt;sup>1</sup> Barron, J., Larsen, B., et al., 1991. Proc. ODP, Sci. Results, 119: College Station, TX (Ocean Drilling Program).

ning through the Cretaceous/Tertiary intervals. As a result, the highest resolution studies have been concentrated in land-based sections where sedimentation rates are high and the stratigraphic sections are expanded relative to those from the deep sea (Perch-Nielsen et al., 1982; Smit, 1982; Margaritz et al., 1985; Keller, 1988a, 1988b, 1989). Stratigraphic continuity across the Hole 738C Cretaceous/Tertiary boundary provides a unique opportunity for investigation of the rate and order of species extinction in deep-sea environments.

The main objectives of this work are to use planktonic foraminifers to provide a biostratigraphic framework for Maestrichtian-Danian sediments recovered from Hole 738C and to interpret the pattern of extinction, survivorship, and recovery across the Cretaceous/Tertiary boundary sequence. Only general comments will be made on the distribution of benthic foraminifer taxa through this interval. Biostratigraphic data for younger Paleogene planktonic foraminifers from Site 738 are outlined in a separate chapter (Huber, this volume).

#### METHOD OF STUDY

The sampling strategy for foraminifer analysis of the Upper Cretaceous and lower Tertiary sequence at Hole 738C differed depending on proximity to the Cretaceous/Tertiary boundary. One sample between 10 and 20 cm<sup>3</sup> was taken from each core section below Core 119-738C-20R. One cubic centimeter samples were taken every 1 cm from Sample 119-738C-20R-5, 102 cm (377.22 mbsf), to Sample 119-738C-20R-5, 82 cm (377.02 mbsf), and every 10 cm up to Sample 119-738C-20R-5, 4–5 cm (376.24 mbsf). Two 1 cm<sup>3</sup> samples per core section were obtained from the overlying Danian sediments in Core 119-738C-20R and one 20 cm<sup>3</sup> sample was taken from each core section to the top of the recovered Paleogene sequence.

All samples were disaggregated in warm water, ultrasonically cleaned, wet-sieved through a 63  $\mu$ m screen, and then dried over a warm hot plate. This procedure was repeated several times for some samples because of their indurated nature. Counts of 100 specimens that were split in a microsplitter and randomly strewn on a picking tray were done on the >63  $\mu$ m fraction for all sufficiently preserved Cretaceous and early Danian samples. Larger, statistically accurate population counts were not possible within the time framework of this study, as many samples were predominantly composed of carbonate grain aggregates.

Core sample notation follows the standard ODP format, with reference to the drilling leg followed by the site number, the hole drilled, the core number, the core-type letter (R = rotary), the core section, and the depth below the top of the core section. The abbreviation "CC" refers to a core catcher sample from the bottom of the cored interval.

The range chart for planktonic foraminifers found below 375 mbsf and above 414 mbsf is shown in Table 1. Paleogene planktonic foraminifer distributions within and above this core section are presented in a separate chapter (Huber, this volume). Species occurrences denoted by an "X" in Table 1 represent specimens found after the first 100 counts, except in samples which were poorly disaggregated; the "X" in the poorly preserved samples only denotes the presence of a species. Species that are questionably present are denoted by a "?". Foraminifers judged as having good (G) preservation show little diagenetic alteration and minimal test fragmentation. A moderate (M) preservation rating is given for foraminifers that have minor to moderate test fragmentation and are moderately etched or overgrown with secondary calcite. Poor (P) preservation is denoted for specimens that are severely fragmented, etched, and/ or overgrown and difficult to identify at the species level. Relative abundances recorded for benthic and total foraminifers include abundant (A, >25%), common (C, 16%-25%), few (F, 6%-15%), and rare (R, <1%).

The Austral Realm zonal scheme of Huber (1990) is used for the Maestrichtian part of the Hole 738C sequence, and the Antarctic Paleogene zonation of Stott and Kennett (1990a) is applied to the Danian section with some modification.

# CRETACEOUS PLANKTONIC FORAMINIFERS

### Biostratigraphy

Cretaceous foraminifers included in this study occur in a Maestrichtian calcareous chalk that extends from 418.2 to 377.2 mbsf (Cores 119-738C-24R through 119-738C-21R), as shown in Figure 2. Turonian-Campanian foraminifers recovered from a limestone sequence below this interval are very poorly preserved and, hence, are not discussed. Core recovery averaged less than 50% in the Maestrichtian sequence because of the presence of interstratified chert nodules.

Maestrichtian planktonic foraminifer distributions are shown in Table 1, and important biostratigraphic datums are listed in Table 2 and shown in Figure 2. Test preservation is moderate in most of the Maestrichtian samples, but poor for specimens recovered from an indurated interval within the uppermost Maestrichtian of Core 119-738C-20R and below Section 119-738C-23R-CC. Samples from below 409.66 mbsf in Core 119-738C-24R lack age-diagnostic species and are included in an unzoned interval within the Campanian-lower Maestrichtian.

The nominate taxon of the late Maestrichtian Abathomphalus mayaroensis Total Range Zone first occurs within the latter core at 409.66 mbsf. This first-appearance datum (FAD) closely corresponds with the FAD of the late Maestrichtian calcareous nannoplankton Nephrolithus frequens (Wei and Thierstein, this volume). At ODP Sites 689, 690, and 700 in the southern South Atlantic, both datums occur within magnetic polarity Chron 31R and have been dated as 70.5 Ma, based on magnetobiostratigraphic correlation with the Kent and Gradstein (1985) geochronology (Huber, 1991). First occurrence within Chron 31N at Hole 738C (Sakai, this volume) suggests either diachronous FAD's of both species within the southern high-latitudes or the presence of a hiatus truncating the lower part of their ranges. The latter is more probable as the lithology changes from a calcareous chalk to limestone just below 409.66 mbsf.

Important species first occurring in the A. mayaroensis Zone include Globotruncanella petaloidea, Abathomphalus intermedius, Globotruncanella citae, Globigerinelloides subcarinatus, and Pseudotextularia elegans. The brief appearances of the latter three species in the upper part of the A. mayaroensis Zone is consistent with their diachronous (late) first occurrences in the southern South Atlantic region (Huber, 1990). Dominant species recovered from the Maestrichtian sediments include Heterohelix globulosa Heterohelix planata, Globigerinelloides multispinus, and Archaeoglobigerina australis.

The presence of several well-preserved specimens of Zeauvigerina teuria in Sample 119-738C-21R-CC marks the first time this species has been found in Cretaceous sediments; it was previously known only from the New Zealand Teurian stage of the lower Tertiary and has never been reported from outside New Zealand. Although Z. teuria occurs more regularly above the Cretaceous/Tertiary boundary at Hole 738C, no Danian specimens are as well preserved as the Cretaceous specimens and, therefore, the Cretaceous occurrence is not attributed to downhole contamination. The biostratigraphic significance of the Cretaceous Z. teuria specimens from Hole 738C cannot be judged because of its restricted biogeographic distribution.

Occurrence of single specimens of *Globigerinelloides impen*sus in two Maestrichtian and one Danian sample at Hole 738C (Table 1) suggests reworking of upper Campanian sediments during late Maestrichtian and Danian time (see the following). This species has been found to be a good marker for the Cam-

									Cr	eta	ceo	us s	spe	cies	3											Те	rtia	y s	pec	ies										
DEPTH (mbsf)	Archaeoglobigerina australis	Globigennelloides multispinus	Hedbergella monmouthensis	Heterohelix globulosa	Heterohelix planata	Hedbergella sliteri	Abathomphalus mayaroensis	Archaeoglobigerina mateola	Globotruncanella? sp.	Heterohelix dentata	Rugotruncana circumnodifer	Rugoglobigerina rugosa	Globigerinelloides subcarinatus	Globigerinelloides impensus	Abathomphalus intermedius	Globotruncanella citae	Glohotruncanella petaloidea	Guhlerina rohusta	Guembelitria cretacea	Hedbergella sp.	Pseudotextularia elegans	Shackoina multispinata	Zeauvigerina teuria	Chiloguembelina sp.	Chiloguembelina crinita	Eoglobigerina fringa	Eoglobigerina eobulloides	Eoglobigerina? sp.	Bifarina alabamensis	Chiloguembelina waiparensis	Eoglohigerina simplicissima	Globoconusa daubjergensis	Subbotina pseudobulloides	Benthic foraminifers	Foraminifer abundance Foraminifer preservation Calcispheres			(cm)	TONE	FUNC
376.00 376.24 376.35 376.45 376.54 376.64 376.64 376.64 376.64 376.86 377.02 377.03 377.04 377.05 377.05 377.05 377.06 377.07 377.08 377.09 377.10 377.10 377.12 377.12	x 1 1 x ···· ?	6210 101358 207126117768 8X11454733	X	1 2 1 4 6 3 3 9 9 3 3 1 1 1 3 3 2 2 1 1 1 2 2 1 1 1 2 2 1 1 1 2 1 1 3 3 3 2 1 1 1 1	X 1 1 1 1 1 1 2 2 1 1 1 	X 2 1 1 X 	x  x  x			 2 3 x 1 1 x  x 1  x 1 			1 X 3 2 2 3 3 5 1 1 X 1 X . 1 1 X ? X 1 2 2	···· x			     		x		· · · · · · · · · · · · · · · · · · ·	x	x  1 2 1  1  x  2 1		28 31 18 27 9 22 21 11 31 27 24 21 9 24 8 10 21 13 27 24 21 9 24 8 10 21 132 21 9 22 10 10 10 10 10 22 10 10 10 10 10 10 10 10 10 10 10 10 10		14 9 16 12 18 9 2 3 11 9 18 6 1 3 4 2 1 1 3 1 2	····	x x x x x 1  x	13 10 19 9 9 10 23 20 6 4 8 7 7   	11 16 5 2 12  2 	2 4 x 1	1 5 X X X	23 20 21 28 29 46 28 34 5 38 45 38 45 38 45 38 45 38 45 70 81 58 485 779 61 72 74	A A A F A F C C R C C C C C C C C C C C C C C C C	20R 20R 20R 20R 20R 20R 20R 20R 20R 20R	-4, 4, 14 -5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5	30-13 5-16 4-35 5-26 4-45 6-57 6-57 6-78 2-83 4-85 5-86 6-87 7-88 9-90 0-91 1-92 3-94 4-95 4-95 4-95 4-95 5-94 4-95 4-95 5-94 4-95 5-95 5-95 5-95 5-95 5-95 5-95 5-95 5-95 5-95 5-86 5-87 5-88 5-88 5-95 5-88 5-95 5-88 5-95 5-88 5-95 5-88 5-95 5-88 5-95 5-88 5-95 5-88 5-95 5-95 5-88 5-95 5-95 5-88 5-95 5-88 5-95 5-95 5-88 5-95 5-88 5-95 5-95 5-95 5-95 5-95 5-88 5-95 5-95 5-95 5-95 5-88 5-95 5-9	1	Ara
377.16 377.17 377.18 377.20 377.20 377.21 379.90 379.92 380.24 380.24 380.24 380.24 380.56 392.83 392.66 392.83 395.66 397.63 397.63 393.66	···· ···· ··· ··· ··· ··· ··· ··· ···	13 X X X X X X X X X X X X X	···· ···· ··· ··· ··· ··· ··· ··· ···	133 XX XX XX XX XX XX XX XX XX XX XX XX X	        	  X 1 2 3 1 3 6 4 4	···· ··· ··· ··· ··· ··· ··· ··· ··· ·	····	×	 x 223 131 11 2 2 2 4 4 x 4 2 1	···· ··· ··· ··· ··· ··· ···	×	x x x 3 3 6 4 3 8 3 3 		x	1	x x x x x x x x x	× × ×	x	 1 	×		2  	x										43  7 21 3 10 18 13 21 34 21 34 21 34 21 34 21 38	RRPPRRPPRRPP	20R 20R 20R 20R 20R 20R 21R 21R 21R 21R 22R 22R 22R 22R 22R 22	-5,9 -5,9 -5,9 -5,9 -5,1 -5,1 ,CC -1,2 -1,3 -1,4 -2,1 -3,2 -3,1 ,CC -3,1 ,CC -3,1 ,CC -3,1	5-96 6-97 7-98 8-99 9-100 00-101 01-102 -4 4-36 8-50 6-98 06-102 30-102 30-132 6-78	1 2 8 8 2 3	And the test of te
411.11 413.23 413.43	52?	41 59 74	···· 7 3	22	4			::: :::	:			::: ::::	: :	:::: ::::	····	···· ····		:::: ::::		···· ····							···· ····		 					28 17 14	RP. RP. RP.	24R 24R 24R	-2,7 -3,1 ,cc	1-73 33-13	5	?

Table 1. Range chart showing the distribution of Cretaceous and early Danian species recovered from 376.0 mbsf and below. See the "Methods" section of this report for explanation of preservation and abundance codes.



Figure 2. Lithostratigraphy and magnetobiostratigraphy of the Upper Cretaceous and lower Paleocene sequence recovered at ODP Site 738. The relative frequencies of Tertiary planktonic foraminifers and benthic foraminifers and important first and last appearance datums (FAD's and LAD's) of planktonic foraminifers are based on data presented in Table 1...Magnetic chron assignments shown for samples below 409.66 mbsf have been revised in this study (see text). Tick marks in the "core recovery" column denote the strati-graphic positions of samples analyzed. Magnetic polarity from Sakai and Keating (this volume); calcareous nannofossil biozones from Wei and Thierstein (this volume); Antarctic foraminifer zones from Stott and Kennett (1990) and Huber (1990; this report); tropical foraminifer biozones from Berggren and Miller (1988) and Caron (1985). See Figure 3 for sampling and stratigraphic details for Section 119-738C-20R-5, and see Figure 4 for key to lithostratigraphic and magnetostratigraphic symbols.

 
 Table 2. Planktonic foraminifer datums of species encountered in Maestrichtian through Danian samples from Hole 738C.

Datum	Chron	Species	Depth interval (mbsf)	Age (Ma)
FAD	?	Acarinina mckannai	337.00-338.50	
FAD	?	Acarinina esnaensis	338.50-340.00	
FAD	?	Igorina spiralis	346.70-348.20	
FAD	?	"Planorotalites" imitatus	350.45-350.90	
LAD	?	Globoconusa daubjergensis	350.90-351.59	a64.00
FAD	?	"Morozovella" inconstans	372.88-374.10	
FAD	?	Planorotalites compressus	372.88-374.10	a64.50
FAD	?	Subbotina triloculinoides	374.10-374.87	
FAD	<sup>b</sup> 29R	Subbotina pseudobulloides	376.54-376.64	a66.10
FAD	<sup>b</sup> 29R	Globoconusa daubjergensis	376.76-376.85	a66.35
FAD	<sup>b</sup> 29R	Eoglobigerina fringa	377.16-377.17	a66.35
LAD	?	Abathomphalus mayaroensis	377.41-379.92	<sup>a</sup> 66.40
FAD	<sup>c</sup> 31N	Abathomphalus mayaroensis	409.66-411.11	<sup>d</sup> 70.50

<sup>a</sup> Berggren et al., 1985.

<sup>b</sup> Sakai and Keating, this volume.

<sup>c</sup> This study.

<sup>d</sup> Huber, 1991.

panian/Maestrichtian boundary in the southern South Atlantic region, and its last-appearance datum (LAD) has been dated as 75.1 Ma (Huber, 1991).

#### **Planktonic Foraminifer Biogeography**

The Maestrichtian planktonic foraminifer assemblages recovered from Hole 738C are identical to Austral Realm assemblages described from the southern South Atlantic region (Sliter, 1976; Krasheninnikov and Basov, 1983, 1986; Huber, 1990, 1991, in press). These assemblages are characterized by their low taxonomic diversity, dominance by simple biserial and planispiral morphotypes, restricted occurrence of double-keeled species, and absence of single-keeled species. Five species, including *Globigerinelloides impensus, Hedbergella sliteri, Archaeoglobigerina australis, Archaeoglobigerina mateola*, and *Rugotruncana circumnodifer*, were probably endemic to the Austral Realm (Huber, 1990, 1991, in press). Occurrence of these taxa at Site 738 extends the limit of the Austral Realm to the southern Indian Ocean.

#### **CRETACEOUS/TERTIARY BOUNDARY**

#### Stratigraphy

The Cretaceous/Tertiary boundary is placed in Sample 119-738C-20R-5, 96.0–96.2 cm, at the level of a distinctive clay-rich layer that has yielded one of the highest iridium enrichments ever found in Cretaceous/Tertiary sections (Schmitz et al., this volume). Unfortunately, a sampling gap of as much as 2 m occurs in the uppermost Maestrichtian, between a chert nodule 8 cm below the boundary clay (Section 119-738C-20R-5, 104 cm) and the top of Core 119-738C-21R (Fig. 2). The stratigraphic position of the core catcher of Core 119-738C-20R is uncertain, but by convention is placed at the bottom of the recovered interval (Figs. 3, 4).

Significant lithologic changes that occur across the Section 119-738C-20R-5 Cretaceous/Tertiary boundary interval include (1) increased lithification of the white upper Maestrichtian calcareous chalk from the core catcher to the boundary clay, (2) the appearance at 100 cm of faint, irregularly-spaced dark laminae that become more continuous and distinct from 97.5 to 82 cm, (3) an increase in clay content from 3% at 100.3 cm to 9% at 96.4 cm, and peak clay concentration of 21% in the boundary clay at 96.1 cm (Thierstein et al., this volume), and (4) a color change of the calcareous chalk from predominantly white in the Maestrichtian sediments to grayish green in the Da-

nian sediments. The green color above the boundary clay is due to a relatively high clay concentration of between 16% and 23% (Thierstein et al., this volume). There is no significant change in clay mineralogy above and below the boundary clay (Thierstein et al., this volume).

Calcareous nannoplankton distributions in the Cretaceous/ Tertiary boundary interval of Hole 738C show a gradual turnover, with an increase in the proportion of Tertiary species from 0% to 2% between the boundary clay and 89.4 cm to between 7% and 85% from 86.5 cm to 43 cm (Thierstein et al., this volume). The high proportion of Cretaceous species continues through several cores above the Cretaceous/Tertiary boundary and is attributed to sediment reworking (Wei and Thierstein, this volume). Calcispheres occur throughout most of the Cretaceous/Tertiary sequence, often in greater abundance than foraminifers (Table 1). No taxonomic turnover of calcispheres is apparent, however.

#### **Benthic Foraminifer Distributions**

Lithification of the uppermost Maestrichtian chalk in Core 119-738C-20R prevents a quantitative assessment of foraminifer assemblage changes that occur immediately below the Cretaceous/Tertiary boundary clay. Nevertheless, observations of the recovered assemblages and SEM analysis of carbonate aggregates suggest that: (1) robust and ornate morphotypes, such as *Nodosaria multicostata, Neoflabellina praereticulata, Frondicularia* spp., and *Bolivinoides draco* last occur several meters below the Cretaceous/Tertiary boundary clay (Table 3); (2) test size of *Gavelinella beccariiformis* is reduced and taxonomic diversity is diminished within 0.5 m below the Cretaceous/Tertiary boundary; and (3) there is no recognizable taxonomic turnover among the benthic foraminifers at the Cretaceous/Tertiary boundary clay.

The high relative frequency (>50%) of benthic foraminifers in the lower Danian sediments (Fig. 3) attests to poor foraminifer preservation within this interval. Specimens from most of Section 119-738C-20R-5 are strongly recrystallized and overgrown with calcite.

The dominant benthic species occurring in the uppermost Maestrichtian and lowermost Danian samples in Section 119-738C-20R-5 include *Gavelinella beccariiformis*, *Gyroidinoides globulosus*, and *Nuttallides truempyi* (Table 3). The presence of the latter species throughout the Maestrichtian sequence indicates deposition beyond the shelf/slope break at water depths greater than 500-600 m (Berggren and Aubert, 1983).

#### Planktonic Foraminifer Distributions

The late Maestrichtian planktonic foraminifer Abathomphalus mayaroensis occurs in the core catcher of Core 119-738C-20R, but it has not been found in samples examined between the core catcher and the Cretaceous/Tertiary boundary clay. The latter interval is not assigned to a biostratigraphic zone because of the absence of A. mayaroensis and other diagnostic species (Fig. 3). Planktonic foraminifer assemblages recovered from the uppermost Maestrichtian section include small specimens of Heterohelix globulosa and Globigerinelloides multispinus, with rare occurrences of Globotruncanella petaloidea and Globigerinelloides subcarinatus (Table 1).

The first Tertiary planktonic foraminifer morphotype to appear in Hole 738C, *Chiloguembelina* sp., occurs below the Cretaceous/Tertiary boundary clay at 100-101 cm in Section 119-738C-20R-5 (Fig. 3). This taxon differs from Cretaceous biserial heterohelicids by the absence of longitudinal costellae, presence of a pustulose surface texture, and asymmetry of the aperture (Fig. 5). Biserial heterohelicids occurring immediately above the Cretaceous/Tertiary boundary clay are identified as *Chiloguembelina crinita*, which has a more off-centered aperture than *Chi*-



Figure 3. Detail of the Cretaceous/Tertiary boundary sequence preserved in Section 119-738C-20R-5 showing the Cretaceous/Tertiary boundary clay at 96.0–96.2 cm and the laminated interval extending 14 cm above and 4 cm below the boundary clay. See caption of Figure 2 for paleomagnetic and zonal scheme references. Tick marks in the "age" column denote the stratigraphic positions of samples analyzed in this study. See Figure 4 for key to lithostratigraphic symbols.



Figure 4. Key to lithostratigraphic and magnetostratigraphic symbols and patterns used in Figures 2 and 3.

Table 3. Selected	late Maestrichtian	and early Danian
benthic foraminife	er species occurring	at Hole 738C.

Core 119-738C-21R and below	Taxa from laminated interval
Angulogerina szajnoche	Alabamina creta
Bolivinoides draco	Bolivinoides laevigata
Frondicularia sp. 1	Buliminella sp.
Frondicularia sp. 2	Cibicides sp.
Gavelinella eriksdalensis	Conorbina sp.
Neoflabellina praereticulata	Coryphostoma incrassata
Nodosaria multicostata	Dentalina sp.
	Epistominella sp.
	<sup>a</sup> Gavelinella beccariformis
	Gavelinella sp.
	<sup>a</sup> Gyroidinoides globulosus
	Lenticulina sp.
	<sup>a</sup> Nuttalides truempyi
	Praebulimina reussi
	Pullenia coryelli
	Spiroplectammina sp.
	Stilostomella subspinosa

<sup>a</sup> Common occurrence.

*loguembelina* sp. from below. Although the small size (<100  $\mu$ m) and rare abundance of *Chiloguembelina* sp. would suggest the possibility of downhole contamination, the transitional nature of its morphology indicates that it may represent an evolutionary link between Maestrichtian and Danian biserial heterohelicids.

The interval from immediately above the Cretaceous/Tertiary boundary clay to between 56 and 34 cm in Section 119-738C-20R-5 is assigned to the lower Danian *Eoglobigerina fringa* Partial Range Zone (AP $\alpha$  Zone) of Stott and Kennett (1990a) based on the co-occurrence of *E. fringa* (sensu Smit, 1982) with other species of *Eoglobigerina*, and the absence within this interval of *Globoconusa daubjergensis* and *Subbotina pseudobulloides*. Absence from Hole 738C of *Parvularugoglobigerina eugubina*, the nominal species of the lower Danian P $\alpha$  Zone of Berggren and Miller (1988), is probably due to its biogeographic restriction to lower latitude regions (Stott and Kennett, 1990a). The lower range of *E. fringa* is within magnetic polarity Chron 29R at Site 738 (Sakai, this volume), as has been observed elsewhere (Keller, 1989; Stott and Kennett, 1990a).

Chiloguembelinids are the most common early Danian planktonic foraminifers, comprising 40%-84% of the assemblages within Section 119-738C-20R-5 (Table 1 and Fig. 6). *Eoglobigerina fringa*, which first occurs immediately above the Cretaceous/Tertiary boundary clay, comprises a very small proportion of the Danian assemblages. *Eoglobigerina eobulloides* and *Eoglobigerina simplicissima* first appear successively higher in Section 119-738C-20R-5, forming less than 20% of the total assemblage.

The disjunct first appearances in Hole 738C of Globoconusa daubjergensis and Subbotina pseudobulloides is the reason for modification of the Stott and Kennett (1990a) API and APIa zonal definitions (see the following). Some authors (e.g., Berggren and Miller, 1988) have suggested that the FAD's of these two species are nearly coeval, while others, (e.g., Blow, 1979) indicate that G. daubjergensis appears before S. pseudobulloides. Stott and Kennett (1990a) found G. daubjergensis below the "first common occurrence" of S. pseudobulloides at the Maud Rise (southern South Atlantic), but they could not precisely determine the relative positions of the FAD's of these species because of sediment bioturbation. Although the base of the API Zone was defined by Stott and Kennett on the "first common occurrence" of S. pseudobulloides, this species is rare at Hole 738C until 30 cm above its initial appearance.

The FAD's of Subbotina triloculinoides and Planorotalites compressus at Hole 738C occur in the lower part of the APla Zone (Fig. 2). This is contrary to the succession of these species reported by Berggren and Miller (1988), but is consistent with their distribution at the Maud Rise (Stott and Kennett, 1990a). The threefold subdivision of the lower Danian used in tropical zonal schemes (e.g., Berggren 1969; Berggren and Miller, 1988) cannot be recognized in the Kerguelen Plateau sequence.

The FAD of "Morozovella" inconstans at 365.22 mbsf marks the base of the "M." inconstans Interval Subzone (APlb Subzone), which was defined as the interval from the first occurrence of the nominal taxon to the first occurrence of "Planorotalites" imitatus (Stott and Kennett, 1990a). The latter species first occurs at 350.45 mbsf in the upper Danian and is the nominal taxon of the AP2 Interval Zone. Globoconusa daubjergensis consistently occurs in samples up to its LAD at 350.90 mbsf, just below the base of the AP2 Zone. Berggren et al. (1985) reported the LAD of this species within the middle of magnetic polarity Chron 27N, and they determined the age of this datum as 64.0 Ma (Table 2). The Danian/Selandian (early/late Paleocene) boundary is inferred to occur at about 346 mbsf, below the first appearance of Acarinina esnaensis (Fig. 2). This boundary is placed about 6 m higher than the level determined from analysis of calcareous nannoplankton (Wei and Thierstein, this volume: Wei and Pospichal, this volume). A more detailed discussion of the upper Paleocene and younger Paleogene biostratigraphy is presented in a separate chapter (Huber, this volume).

The first occurrence of *Igorina spiralis* is in the "*Planorotali*tes" imitatus Interval Zone (AP2 Zone) in Sample 119-738C-17R-4, 90-95 cm (348.20 mbsf). This correlates with the upper Danian Morozovella uncinata-Igorina spiralis Partial Range Zone (P2 Zone) of Berggren and Miller (1988).

#### **Recycled Cretaceous Species**

Late Cretaceous planktonic foraminifers comprise up to 45% of the total planktonic foraminifer assemblages in the Tertiary sediments of Section 119-738C-20R-5 (Fig. 3). The most common Cretaceous species occurring in that core section is *Globigerinelloides multispinus*, which constitutes up to 38% of the early Danian assemblages (Fig. 7). *Heterohelix globulosa* is next in abundance, comprising up to 25% of the assemblages, and



# Sample 119-738C-20R-5, 93-94 cm (377.13 mbsf)

Chiloguembelina crinita



Sample 119-738C-20R-5, 100-101 cm (377.20 mbsf)

Figure 5. Comparison of biserial planktonic foraminifers that occur 3 cm above and 4 cm below the Cretaceous/Tertiary boundary clay. Note that Cretaceous morphotypes included in *Heterohelix* have a centered and symmetrically arched aperture and a striate or smooth test surface. Typical earliest Danian chiloguembelinids have off-centered apertures with a pustulose or spinose surface ornament (see also Pl. 1, Fig. 2, Pl. 2, Figs. 3, 4). Latest Maestrichtian specimens referred to as *Chiloguembelina* sp. have a low asymmetrically arched aperture that is centered in edge view and a pustulose surface ornament. These characters suggest that the latter species represents an intermediate link between the Cretaceous and Tertiary biserial planktonic foraminifers.

Heterohelix dentata, Heterohelix planata, and Globigerinelloides subcarinatus occur in frequencies of 2% to 8%. Other Cretaceous species found in Tertiary sediments include Rugoglobigerina rugosa, Rugotruncana circumnodifer, and Archaeoglobigerina australis. Because of the presence of laminae (i.e., absence of bioturbation) and lack of other textural evidence of sediment reworking, the consistent occurrences of Cretaceous species in Section 119-738C-20R-5 were initially considered to be evidence for species survivorship (Huber, 1989). However, subsequent detailed analysis of the Cretaceous/Tertiary sequence revealed a definite reworking signal based on the sporadic distribution of *Globigerinelloides impensus*, *Shackoina multispinata*, and *Abathomphalus mayaroensis* in Paleogene samples up to Core 119-738C-10R (Huber, this volume). The LAD of *G. impensus* was recorded at about 75.1 Ma and that of *S. multispinata* was estimated as 70.5 Ma at other southern high-latitude



Figure 6. Relative frequencies of Tertiary planktonic foraminifer species recovered from Section 119-738C-20R-5. The values were calculated from the total number of planktonic foraminifer species encountered after the 100 specimen counts. No quantitative data could be obtained from within 6 cm below the Cretaceous/Tertiary boundary clay (96.2–102 cm).

sites (Huber, 1991), while the LAD of *A. mayaroensis* has been estimated at about 66.4 Ma in tropical latitudes (Berggren et al., 1985). None of these species has been shown to range into Tertiary sediments at any localities. On the other hand, the high relative abundance of *G. multispinus* and *H. globulosa* within the lower Danian section may yet indicate that these did survive the terminal Cretaceous extinction event, as suggested by Keller (1988b, 1989) and Barrera and Keller (in press). Additional evidence from carbon isotope analyses of the Hole 738C Cretaceous and Tertiary species is needed before this can be verified.

#### **Biostratigraphic Zonation**

Abathomphalus mayaroensis Total Range Zone

**Definition.** Total stratigraphic range of *A. mayaroensis.* **Reference.** Brönnimann (1952).

Stratigraphic range. 410.39-378.56 mbsf (upper Maestrichtian).

#### Subbotina pseudobulloides Interval Range Zone (API)

**Definition.** Interval between the first occurrence of *G. daubjergensis* (base) and the first occurrence of *"Planorotalites" imitatus* (top).

Reference. Modified after Stott and Kennett (1990).

Stratigraphic range. 376.80-350.07 mbsf (lower Paleocene). Remarks. Previous recognition of the base of this zone depended on identification of the first common occurrence of Subbotina pseudobulloides. As the latter definition is somewhat ambiguous, use of the more obvious first appearance of G. daubjergensis is herein preferred. Revision of this zone will also enable correlation of nearshore, high-latitude sequences of Danian age, where G. daubjergensis occurs as the only marker species (e.g., Hansen, 1970; Huber, 1988). "Morozovella" pseudobulloides, Planorotalites compressus, "Morozovella" inconstans, and Subbotina triloculinoides all make their first appearances within the APl Zone.

#### Globoconusa daubjergensis Partial Range Subzone (APla)

**Definition.** Partial range of the nominal taxon between the first occurrence of *G. daubjergensis* (base) and the first appearance of "*M.*" inconstans (top).

Reference. Modified after Stott and Kennett (1990).

Stratigraphic range. 376.80–372.05 mbsf (lower Paleocene). Remarks. This zone is characterized by the co-occurrence of

G. daubjergensis and S. pseudobulloides and includes the last occurrences of Eoglobigerina fringa and Eoglobigerina eobulloides.

## CONCLUSIONS

1. Late Maestrichtian and older Campanian-early Maestrichtian planktonic foraminifers characteristic of the Austral Realm were recovered from the southern Kerguelen Plateau Hole 738C. All five planktonic foraminifers previously recognized as having been endemic to the Austral Realm were found in this sequence, thus verifying unimpeded surface marine communication between the southern Indian Ocean and the southern South Atlantic during Late Cretaceous time.

2. A biostratigraphically complete record of Cretaceous/Tertiary boundary sedimentation was recovered in Core 119-738C-



Figure 7. Relative frequencies of "reworked" Cretaceous planktonic foraminifer species recovered from Section 119-738C-20R-5. See caption of Figure 6 for additional explanation.

20R. Evidence that paleoenvironmental changes occurred prior to the iridium enrichment event include: (1) appearance of clay laminae beginning at 2 cm below the Cretaceous/Tertiary boundary clay; (2) elevated concentrations of iridium and clay beginning 6 cm below the boundary clay (Schmitz et al., this volume; Thierstein et al., this volume); (3) loss of keeled planktonic foraminifers between 8 cm and 2.29 m below the boundary clay; and (4) loss of several benthic foraminifer species and reduction in the overall test size in at least one species.

3. Occurrence at 4 cm below the boundary clay of biserial heterohelicids that have centered, asymmetric apertures and non-striate, pustulose surface ornamentation typical of Tertiary species of *Chiloguembelina* either indicates a Cretaceous origin for the chiloguembelinid stock, or the turnover of biserial heterohelicids was more transitional than previously thought.

4. The controversy of species survivorship and determination of mode of extinction (i.e., graded, stepwise, or mass extinction) at the Cretaceous/Tertiary boundary cannot be resolved using the present data. Chemical, mineralogic, and biogenic distribution patterns across the Hole 738C Cretaceous/Tertiary boundary were undoubtedly influenced by reworking of older Maestrichtian and Campanian sediments. The relatively abundant Cretaceous planktonic foraminifer species occurring in lower Danian sediments at Site 738 may have been eroded from shelfal outcrops and redeposited further offshore during pulses of tectonic subsidence that are known to have occurred at the Kerguelen Plateau during this time period (Barron, Larsen, et al., 1989). Monospecific carbon isotope analyses of Cretaceous taxa that occur above and below the Cretaceous/Tertiary boundary may further elucidate the species survivorship question.

5. Changes in biogenic and nonbiogenic sedimentation rates across the Cretaceous/Tertiary boundary at Hole 738C may account for variations observed in sediment lithification, concentration of clay minerals and rare metal elements, and presence or absence of clay laminae. However, magnetobiochronologic resolution is insufficient to detect any changes that occurred within 500,000 yr before or after the Cretaceous/Tertiary event.

6. A relatively complete and expanded Danian section enables correlation with some of the lower Paleocene Antarctic zones defined by Stott and Kennett (1990a). Definition of the base of the API Zone is herein modified using first occurrence of *Globoconusa daubjergensis* rather that the first common occurrence of *Subbotina pseudobulloides* to avoid ambiguity in its recognition.

#### SPECIES LIST AND TAXONOMIC NOTES

All planktonic foraminifer species included in the range chart of Table 1 and/or illustrated in Plates 1–3 are enumerated. Stratigraphically important species that were discussed in the text but do not appear in the list below are presented in a separate report (Huber, this volume). Comments are included for several species to clarify my taxonomic concepts and to note significant morphological features. Abathomphalus intermedius (Bolli) 1951 (Pl. 1, Fig. 19). Abathomphalus mayaroensis (Bolli) 1951 (Pl. 1, Fig. 20) Archaeoglobigerina australis Huber 1990 (Pl. 1, Figs. 10, 11)

Considerable morphologic variability has been used in the concept

of A. australis (see Huber, 1990, in press). Gerontic forms included in this species are moderately to strongly pustulose, have umbilical portici but no umbilical tegilla, and have umbilical to slightly extra-umbilical apertures. Morphotypes that are smaller, show a less gradual chamber size increase, and have apertures that are more extra-umbilical in position are considered as juveniles of A. australis, although they may represent a paedomorphic descendant species (Huber, unpubl. data). Archaeoglobigerina australis is a dominant component of Maestrichtian planktonic foraminifer assemblages from the Austral Realm.

Archaeoglobigerina mateola Huber 1990 (Pl. 1, Figs. 12, 13)

This distinctive species is coarsely pustulose to spinose and has portical flaps or bullae covering the umbilical region. No specimens with umbilical tegilla occur in this species. Archaeoglobigerina mateola was described previously from the southern South Atlantic region and is a characteristic species of the Austral Realm.

Bifarina alabamensis (Cushman) 1940 (Pl. 2, Fig. 1)

Chiloguembelina crinita (Glaessner) 1937 (Pl. 2, Figs. 3, 4) Chiloguembelina sp. (Text-Fig. 5)

These morphotypes are distinguished from Danian chiloguembelinids by having a centered, but asymmetric, aperture. They are unlike Cretaceous biserial heterohelicids in that they have an asymmetric aperture and a pustulose rather than striate or smooth surface texture. Rare specimens of Chiloguembelina sp. were found with more common specimens of Heterohelix globulosa in an uppermost Maestrichtian sample 4 cm below the Cretaceous/Tertiary boundary and may represent an evolutionary link between Cretaceous and Tertiary biserial planktonic foraminifers.

Chiloguembelina waiparensis Jenkins 1966 (Pl. 2, Figs. 5, 6) Eoglobigerina eobulloides (Morozova) 1959 (Pl. 2, Figs. 9-11)

This species is distinguished from E. simplicissima by its more extraumbilical position of the aperture and more flattened dorsal side. Eoglobigerina fringa (Subbotina) 1950 (Pl. 2, Fig. 8)

This species is distinguished by having a laterally compressed test with four chambers in the final whorl. It strongly resembles E. fringa of Smit (1982, pl. 2, fig. 11B), which also has a portical extension partly obscuring the umbilicus. The final whorl chambers are more equidimensional than Subbotina's (1950) figured type specimens. Eoglobigerina polycamera (Khalilov) 1956 (Pl. 3, Figs. 6-8)

Eoglobigerina quadrilocula (Blow) 1979 (Pl. 3, Figs. 5, 9, 10)

Eoglobigerina simplicissima Blow 1979 (Pl. 2, Figs. 13-15)

This species has a higher spire than E. eobulloides and its aperture

opens into the umbilical region.

Eoglobigerina? sp.

Single poorly preserved specimens of this morphotype resemble Smit's (1982, pl. 3, figs. 3-5) figured specimen of Globigerina minutula, but the Kerguelen Plateau forms are not as high-spired.

Globigerinelloides impensus Sliter 1976 (Pl. 1, Fig. 4)

Rare specimens of G. impensus found in upper Maastrichtian and Danian samples at Hole 738C are considered as reworked. The LAD of this species occurs in magnetic polarity Chron 33N at ODP Sites 689, 690, and 700 in the South Atlantic, and has been used to define the Campanian/Maestrichtian boundary at those sites (Huber, 1990, 1991). Globigerinelloides multispinus (Lalicker) 1948 (Pl. 1, Fig. 4)

Specimens with single apertures and rare double apertures are included in this species.

Globigerinelloides subcarinatus (Brönnimann) 1952 (Pl. 1, Fig. 6)

Globoconusa daubjergensis (Brönnimann) 1953 (Pl. 2, Figs. 18) Globotruncanella citae (Bolli) 1951 (Pl. 1, Fig. 14)

This species is distinguished from G. petaloidea by having 4.5-5 rather than 3.5-4 chambers in the final whorl, a more subangular equatorial periphery, and a more convex dorsal side.

Globotruncanella petaloidea (Gandolfi) 1955 (Pl. 1, Fig. 15)

Globotruncanella? sp. (Pl. 1, Fig. 16)

This small, laterally compressed taxon has an umbilical-extra-umbilical aperture and a moderately pustulose surface ornament. Absence of an imperforate keel band on the equatorial periphery of the Hole 738C specimens precludes definite assignment to Globotruncanella. Gublerina robusta de Klasz 1953

Guembelitria cretacea Cushman 1933 (Pl. 1, Fig. 1)

Guembelitrioides sp. (Pl. 3, Fig. 20)

See Huber (this volume) for discussion of this distinctive taxon. Hedbergella monmouthensis (Olsson) 1960 (Pl. 2, Figs. 7, 12) Hedbergella sp. (Pl. 1, Figs. 7, 8)

This taxon differs from H. monmouthensis (Olsson) by having seven rather than five or six chambers in the final whorl. Specimens are very rare, occurring in only two upper Maestrichtian samples. Hedbergella sliteri Huber 1990 (Pl. 1, Fig. 9)

This species, previously described from the southern South Atlantic region, differs from H. monmouthensis in its larger size, more pustulose surface ornament, and more evolute umbilical region. Heterohelix dentata Stenestad 1968

Heterohelix globulosa (Ehrenberg) 1840 (Pl. 1, Fig. 2)

Heterohelix planata (Cushman) 1938

Igorina spiralis (Bolli) 1957 (Pl. 3, Figs. 13-15)

"Morozovella" inconstans (Subbotina) 1953 (Pl. 3, Figs. 11, 12) Planorotalites cf. P. appressus (Blow) 1979 (Pl. 3, Figs. 3, 4)

This species is very similar to one of Blow's (1979, pl. 72, fig. 9) figured paratypes, but it is more axially compressed than his other figured P. appressus specimens. It differs from Planorotalites compressus by having fewer (4-4.5) chambers in the final whorl and a coarsely pitted surface on the spiral side.

Planorotalites compressus (Plummer) 1926 (Pl. 3, Figs. 1, 2)

Planorotalites sp. 1 (Pl. 2, Figs. 20-22)

This taxon is characterized by having 6-7 chambers that increase very gradually in size in the final whorl. Specimens are very rare and generally poorly preserved in the Danian section of Hole 738C. Pseudotextularia elegans (Rzehak) 1891 (Pl. 1, Fig. 3)

This range of this species is restricted to the latest Maestrichtian in the southern high-latitudes (Huber, 1990, in press), although it has been recorded from Campanian age sediments in lower latitude sites (Caron, 1985; Sliter, 1989). The poleward migration of P. elegans may have coincided with a latest Maestrichtian oxygen isotopic warming event that was observed at Maud Rise ODP Site 690 (Stott and Kennett, 1990b). Rugoglobigerina rugosa (Plummer) 1927 (Pl. 1, Fig. 17)

The figured specimen shows faint meridional costellate surface ornamentation and a tegillum covering the umbilicus, unlike specimens included with Archaeoglobigerina australis. Occurrence of this species in the southern high-latitudes is erratic, as it has not been found at any southern South Atlantic deep sea sites (Sliter, 1976; Krasheninnikov and Basov, 1983; Huber, 1990, 1991), but has been recorded from Maestrichtian sediments at DSDP Site 208 in the Tasman Sea (Webb, 1973) and on Seymour Island in the northeast Antarctic Peninsula (Huber, 1988).

Rugotruncana circumnodifer (Finlay) 1940 (Pl. 1, Fig. 18)

Specimens included in this species exhibit faint double keels on the equatorial periphery and faint meridional costellate ornamentation on one or several chambers in the final whorl. Large forms of this species strongly resemble previously published specimens of Rugoglobigerina hexacamerata Brönnimann and Rugotruncana subpennyi Gandolfi. Further comparison is needed to clarify the taxonomic differences between these taxa.

Shackoina multispinata (Cushman and Wickenden) 1930 Subbotina pseudobulloides (Plummer) 1926 (Pl. 2, Figs. 16, 17) Subbotina triangularis (White) 1928 (Pl. 3, Fig. 19) Subboting triloculinoides (Plummer) 1926 (Pl. 3, Fig. 13) Subbotina trivialis (Subbotina) 1955 (Pl. 3, Figs. 16, 17)

Zeauvigerina teuria Finlay 1947 (Pl. 2, Fig. 2)

This is the first record of Z. teuria in Cretaceous sediments, as it was previously known only from Paleocene sediments in New Zealand and a few other localities (see Jenkins, 1971). Preservation of the illustrated specimen is much better than any specimens recovered from Danian sediments at Site 738, indicating that the Cretaceous occurrence is not due to downhole contamination.

#### ACKNOWLEDGMENTS

I am very grateful to John Barron, Birger Larsen, the ODP Leg 119 shipboard staff and the captain and crew of the JOIDES Resolution for such a successful and enjoyable cruise. Thanks are extended to John Barron and two anonymous reviewers for their helpful comments and suggestions on this manuscript. Discussions with Hans Thierstein, Birger Schmitz, and Jan Smit are also gratefully acknowledged. I especially owe thanks to Elisabeth Valiulis for her help with computer drafting of the figures.

#### REFERENCES

- Barrera, E., and Keller, G., in press. Foraminiferal stable isotope evidence for a gradual decrease of marine productivity and Cretaceous species survivorship in the earliest Danian. *Paleoceanography*.
- Barron, J., Larsen B., et al., 1989. Proc. ODP, Init. Repts. 119: College Station, TX (Ocean Drilling Program).
- Berggren, W. A., 1969. Rates of evolution in some Cenozoic planktonic foraminifera. *Micropaleontology*, 15:351–365.
- Berggren, W. A., and Aubert J., 1983. Paleogene benthonic foraminiferal biostratigraphy and bathymetry of the Central Coast Ranges of California. In Brabb, E. E. (Ed.), Studies in Tertiary Stratigraphy of the California Coast Ranges. Geol. Surv. Prof. Paper U.S., 1213: 4-21.
- Berggren, W. A., Kent, D. V., and Flynn, J. J., 1985. Jurassic to Paleogene: Part 2. Paleogene geochronology and chronostratigraphy. In Snelling, N. J. (Ed.), The Chronology of the Geologic Record. Geol. Soc. London Mem., 10:141-195.
- Berggren, W. A., and Miller, K. G., 1988. Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiochronology. *Micropaleontology*, 34:362–380.
- Blow, W. H., 1979. *The Cainozoic Globigerinida* (vol. 1-3): Leiden (E. J. Brill).
- Brönnimann, P., 1952. Globigerinidae from the Upper Cretaceous (Cenomanian-Maestrichtian) of Trinidad, B.W.I. Bull. Am. Paleontol., 34:1–70.
- Caron, M., 1985. Cretaceous planktic foraminifera. In Bolli, H. M., Saunders, J. B., and Perch-Nielsen, K. (Eds.), Plankton Stratigraphy: Cambridge (Cambridge Univ. Press), 17-86.
- Gerstel, J., Thunnell, R. C., Zachos, J. C., and Arthur, M. A., 1986. The Cretaceous/Tertiary boundary event in the North Pacific: planktonic foraminiferal results from Deep Sea Drilling Project Site 577, Shatsky Rise. *Paleoceanography*, 1:97-117.
- Hansen, H. J., 1970. Danian foraminifera from Nugssuaq, west Greenland. Medd. Gr
  énland, 3:1-131.
- Huber, B. T., 1988. Upper Campanian-Paleocene foraminifera from the James Ross Island region (Antarctic Peninsule). In Feldmann, R. M., and Woodburne, M. O. (Eds.), Geology and Paleontology of Seymour Island, Antarctica. Mem. Geol. Soc. Am., 169:163-251.
  - \_\_\_\_\_, 1989. Planktonic foraminiferal evolution, extinction, and survivorship in a high-latitude laminated K/T boundary sequence from ODP Site 738, Kerguelen Plateau. *Geol. Soc. Am. Abstr. Programs*, 20:229.
  - \_\_\_\_\_, 1990. Maestrichtian planktonic foraminifer biostratigraphy of the Maud Rise (Weddell Sea, Antarctica): ODP Leg 113 Holes 689B and 690C. *In* Barker, P. F., Kennett, J. P., et al., *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program), 489-531.
  - \_\_\_\_\_, 1991. Planktonic foraminifer biostratigraphy of Campanian-Maestrichtian sediments from ODP Leg 114, Sites 698 and 700, southern South Atlantic. *In* Ciesielski, P. F., Kristofferson, Y., et al., *Proc. ODP, Sci. Results*, 114: College Station, TX (Ocean Drilling Program).

\_\_\_\_\_, in press. Paleobiogeography of Campanian-Maastrichtian foraminifers in the southern high latitudes. *Palaeogeogr., Palaeoclima*tol., *Palaeoecol.* 

- Jenkins, D. G., 1971. Cenozoic planktonic foraminifera of New Zealand. N. Z. Geol. Surv. Paleontol. Bull., 42:1-278.
- Keller, G., 1988a. Biotic turnover in benthic foraminifera across the Cretaceous/Tertiary boundary at El Kef, Tunisia. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 66:153–171.

\_\_\_\_\_, 1988b. Extinction, survivorship and evolution of planktic foraminifers across the Cretaceous/Tertiary Boundary at El Kef, Tunisia. *Mar. Micropaleontol.*, 13:239–263.

- \_\_\_\_\_\_, 1989. Extended period of extinctions across the Cretaceous/ Tertiary boundary in planktonic foraminifera of continental-shelf sections: implications for impact and volcanism theories. *Geol. Soc. Am. Bull.*, 101:1408-1419.
- Kent, D. V., and Gradstein, F. M., 1985. A Cretaceous and Jurassic geochronology. Geol. Soc. Am. Bull., 96:1419-1427.
- Krasheninnikov, V. A., and Basov, I. A., 1983. Stratigraphy of Cretaceous sediments of the Falkland Plateau based on planktonic foraminifers, Deep Sea Drilling Project, Leg 71. In Ludwig, W. J., Krasheninnikov, V. A., et al., Init. Repts. DSDP, 71: Washington (U.S. Govt. Printing Office), 789-820.
- \_\_\_\_\_, 1986. Late Mesozoic and Cenozoic stratigraphy and geological history of the South Atlantic high latitudes. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 55:145–188.
- Magaritz, M. S., Moshkovitz, C. B., Hansen, H. J., Kakansson, E., and Rasmussen, S., 1985. Carbon isotope, bio- and magnetostratigraphy across the Cretaceous-Tertiary boundary in the Zin Valley, Negev, Israel. *Newsl. Stratigr.*, 15:100–102.
- Perch-Nielsen, K., McKenzie, J. A., and He, Q., 1982. Biostratigraphy and isotope stratigraphy and the "catastrophic" extinction of calcareous nannoplankton at the Cretaceous/Tertiary boundary. Spec. Pap.—Geol. Soc. Am., 190:353-371.
- Sliter, W. V., 1976. Cretaceous foraminifera from the southwest Atlantic Ocean, Leg 36, Deep Sea Drilling Project. *In Barker*, P. F., Dalziel, I.W.D., et al., *Init. Repts. DSDP*, 36: Washington (U.S. Govt. Printing Office), 519–573.
- \_\_\_\_\_, 1989. Biostratigraphic zonation for Cretaceous planktonic foraminifers examined in thin section. J. Foraminiferal Res., 19:1-19.
- Smit, J., 1982. Extinction and evolution of planktonic foraminifera after a major impact at the Cretaceous/Tertiary boundary. In Silver, L. T., and Schultz, P. H. (Eds.), Geological implications of impacts of large asteroids and comets on the earth. Spec. Pap.—Geol. Soc. Am., 190:329-352.
- Smith, C. C., and Poore, R. Z., 1984. Upper Maastrichtian and Paleocene planktonic foraminiferal biostratigraphy of the northern Cape Basin, Deep Sea Drilling Project Hole 524. *In* Hsü, K. J., LaBrecque, J. L., et al., *Init. Repts. DSDP*, 73: Washington (U.S. Govt. Printing Office), 449-457.
- Stott, L. D., and Kennett, J. P., 1990a. Antarctic Paleogene planktonic foraminifer biostratigraphy: ODP Leg 113 Sites 689 and 690. In Barker, P. F., Kennett, J. P., et al., Proc. ODP, Sci. Results, 113: College Station, TX (Ocean Drilling Program), 549–569.
- Stott, L. D., and Kennett, J. P., 1990b. The paleoceanographic and paleoclimatic signature of the Cretaceous/Paleogene boundary in the Antarctic: stable isotopic results from ODP Leg 113. In Barker, P. F., Kennett, J. P., et al., Proc. ODP, Sci. Results, 113: College Station, TX (Ocean Drilling Program), 829-848.
- Thierstein, H. R., 1982. Terminal Cretaceous plankton extinctions: a critical assessment. In Silver, L. T., and Schultz, P. H., (Eds.), Geological implications of impacts of large asteroids and comets on the earth. Spec. Pap.—Geol. Soc. Am., 190:385-399.
- Webb, P.-N., 1973. Upper Cretaceous-Paleocene foraminifera from Site 208 (Lord Howe Rise, Tasman Sea), DSDP, Leg 21. In Burns, R. E., Andrews, J. E., et al., Init. Repts. DSDP, 21: Washington (U.S. Govt. Printing Office), 541–573.

Date of initial receipt: 19 December 1989 Date of acceptance: 18 June 1990 Ms 119B-143



Plate 1. Late Cretaceous planktonic foraminifers recovered from Hole 738C. Scale bars for Figure 1 = 50 µm and Figures 2-20 = 100 µm.
 1. Guembelitria cretacea Cushman (376.54 mbsf).
 2. Heterohelix globulosa (Ehrenberg) (380.72 mbsf).
 3. Pseudotextularia elegans (Rzehak) (380.72 mbsf).
 4. Globigerinelloides impensus Sliter. Specimen probably reworked from upper Campanian sediments (380.72 mbsf).
 5. Globigerinelloides subcarinatus (Brönnimann) (380.72 mbsf).
 7. 8. Hedbergella sp. (380.72 mbsf), (7) ventral view, (8), dorsal view.
 9. Hedbergella sliteri Huber (403.50 mbsf).
 10. Archaeoglobigerina australis Huber (403.50 mbsf).
 11. Archaeoglobigerina australis Huber (403.50 mbsf).
 12. Archaeoglobigerina mateola Huber (380.72 mbsf).
 13. Archaeoglobigerina mateola Huber (403.50 mbsf).
 14. Globotruncanella citae (Bolli) (380.72 mbsf).
 15. Globotruncanella getaloidea (Gandolfi) (380.72 mbsf).
 16. Globotruncanella view (403.50 mbsf).
 17. Rugoglobigerina rugosa (Plummer) (403.50 mbsf).
 18. Rugotruncana circumnodifer (Finlay) (403.50 mbsf).
 19. Abathomphalus intermedius (Bolli) (380.72 mbsf).
 20. Abathomphalus mayaroensis (Bolli) (380.72 mbsf).



Plate 2. Maestrichtian and Danian planktonic foraminifers recovered from Hole 738C. Scale bars =  $100 \ \mu\text{m}$ . **1.** Bifarina alabamensis (Cushman) (360.50 mbsf). **2.** Zeauvigerina teuria Finlay (380.72 mbsf). **3.** Chiloguembelina crinita (Glaessner) (377.14 mbsf). **4.** Chiloguembelina crinita (360.50 mbsf). **5.** 6. Chiloguembelina waiparensis Jenkins (376.00 mbsf), (5) lateral view, (6) edge view. **7.** 12 Hedbergella monmouthensis (Olsson) (376.24 mbsf), (7) edge view, (12) ventral view. Specimen was probably reworked from Maestrichtian sediments. **8.** Eoglobigerina fringa (Subbotina) (377.11 mbsf). **9-11.** Eoglobigerina eobulloides (Morozova) (376.54 mbsf), (9) ventral view, (10) edge view, (11) dorsal view. **13-15.** Eoglobigerina simplicissima (Blow) (376.00 mbsf), (13) ventral view, (14) edge view, (15) dorsal view. **16.** 17. Subbotina pseudobulloides (Plummer) (340.93 mbsf), (16) ventral view, (17) dorsal view. **18.** Globoconusa daubjergensis (Brönnimann) (365.22 mbsf). **19.** Subbotina triloculinoides (Plummer) (365.22 mbsf). **20-22.** Planorotalites ps. 1 (374.10 mbsf), (20) ventral view, (21) edge view, (22) dorsal view.



Plate 3. Danian planktonic foraminifers recovered from Hole 738C. Scale bars =  $100 \mu m$ . 1–2. *Planorotalites compressus* (Plummer) (340.93 mbsf), (1) ventral view, (2) edge view. **3**, **4**. *Planorotalites* cf. *P. appressus* (Blow) (345.20 mbsf), (3) ventral view, (4) dorsal view. **5**, **9**, **10**. *Eoglobigerina quadrilocula* (Blow) (348.20 mbsf), (5) edge view, (9) ventral view, (10) dorsal view. **6–8**. *Eoglobigerina polycamera* (Khalilov) (360.50 mbsf), (6) ventral view, (7) edge view, (8) dorsal view. **11**, **12**. "*Morozovella*" inconstans (Subbotina) (365.22 mbsf), (11) ventral view, (12) edge view. **13–15**. *Igorina spiralis* (Bolli) (338.50), (13) ventral view, (14) edge view, (15) dorsal view. **16**, **17**. *Subbotina trivialis* (Subbotina) (350.45 mbsf), (16) ventral view, (17) edge view. **18**. *Subbotina triangularis* (White) (360.50 mbsf). **19**. *Guembelitrioides* sp. (338.50 mbsf).