

34. PALEOGENE BENTHIC FORAMINIFERS FROM THE SOUTHERN INDIAN OCEAN (KERGUELEN PLATEAU): BIOSTRATIGRAPHY AND PALEOECOLOGY¹

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ABSTRACT

Benthic foraminifers were studied from lower Paleocene through upper Oligocene sections from Sites 747 and 748. The composition of the benthic foraminifer species suggests a middle to lower bathyal (600–2000 m) paleodepth during the Neogene and a probable upper abyssal (2000–3000 m) paleodepth during the Paleocene at Site 747. Site 748 is thought to have remained at middle to lower bathyal paleodepths throughout the Cenozoic. Principal component analysis distinguished four major benthic foraminifer assemblages: (1) a Paleocene *Stensioina beccariiformis* assemblage at Sites 747 and 748, (2) an early Eocene *Nuttallides truempyi* assemblage at lower bathyal Site 747, (3) an early through middle Eocene *Siliostomella-Lenticulina* assemblage at middle bathyal Site 748, and (4) a latest Eocene through Oligocene *Cibicidoides-Astrononion pusillum* assemblage at both sites. Major benthic foraminifer changes, as indicated by the principal components and first and last appearances, occurred at or close to the Paleocene/Eocene boundary, and in the late Eocene close to the middle/late Eocene boundary.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 120 drilled three sites on the Kerguelen Plateau in the southern Indian Ocean: northern Site 747 (1696 m, present water depth; 54°48.68'S, 76°47.64'E) and southern Sites 748 (1288 m, present water depth; 58°26.45'S, 78°58.89'E) and 749 (1070 m, present water depth; 58°43.03'S, 76°24.45'E). Below Neogene sediments of varying thicknesses, these sites recovered Paleogene sections of foraminifer oozes and diatom nannofossil oozes between 60 and 320 m thick.

We quantitatively examined benthic foraminifers from the Paleogene sections of Sites 747 and 748. The Neogene benthic foraminifer fauna is treated in a companion paper (Mackensen, this volume).

METHODS

Sample Preparation and Statistical Data Treatment

Benthic foraminifers were studied from 49 samples (10-cm³, 20-cm³, and core-catcher samples) from lower Paleocene through upper Oligocene sections from Holes 747A and 747C (15 samples; Table 1) and from Holes 748B and 748C (34 samples; Table 2). The samples were washed through a 63-μm sieve and dried in an oven at 60°C. The residue was dry sieved over a 125-μm sieve and aliquots from this fraction were analyzed. Between 200 and 400 specimens were picked when possible. Because of limited sample size, however, only about half of the samples yielded more than 200 benthic foraminifers. The number of individuals is given according to the stratigraphic ranges of the species (Tables 1 and 2). A list of all species identified is given (Appendix A). In addition, range charts of important taxa are plotted (Figs. 1 and 2).

One simple measure of the faunal diversity is the number of species; however, up to a certain threshold, the number of

species depends on the number of counted specimens. Therefore, we plotted the number of species vs. the number of specimens counted per sample for the two sites and found only a weak correlation between these two for counts >100 (Fig. 3). This demonstrates that the benthic foraminifer species were well represented within most of the samples and, in combination with the good preservation of the calcareous fauna, that the number of species can be regarded as a rough approximation of the faunal diversity in samples yielding more than 100 specimens.

For paleoecological reconstructions and for assistance in evaluating the major changes in faunal compositions, Q-mode principal component analysis (with subsequent varimax rotation) was conducted on the census data of all sites (Table 3) to reduce the benthic foraminifer raw data matrix (107 taxa × 49 samples) to four principal components (PCs), which explain 59.2% of the total variance. Only species that occurred in at least two samples and with a relative abundance of ≥1% in at least one sample, and samples that contained more than 30 specimens were used for statistical analysis (Appendices B and C).

Stratigraphy and Paleodepth

The stratigraphy of the Paleogene used in this paper is preliminarily based on planktonic foraminifers, calcareous nannofossils and paleomagnetic data as outlined by the Shipboard Scientific Party (Schlich, Wise, et al., 1989), including the modifications of Berggren (this volume). The geochronology is according to Berggren et al. (1985) and Aubry et al. (1988). At Site 748, the Paleogene sedimentary record starts in the lower upper Paleocene above a hiatus spanning the Cretaceous/Paleocene boundary. The sedimentary sequence appears to be continuous to the Oligocene/Miocene boundary (Berggren, this volume), possibly interrupted by two short disconformities in the lower and upper Oligocene, respectively (Schlich, Wise, et al., 1989). Recovery was poor in the upper Paleocene through lower middle Eocene (Fig. 2). Paleogene sediments of Site 747 reflect a more complicated tectonic history of extremely rapid subsidence during the late Maestrichtian and early Danian. Consequently, after an approximately 2–3 m.y. hiatus from the late Maestrichtian through early Danian, sedimentation commenced abruptly with volcaniclastic deposits (Aubry and Berggren, 1989;

¹ Wise, S. W., Jr., Schlich, R., et al., 1992. Proc. ODP, Sci. Results, 120: College Station, TX (Ocean Drilling Program).

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Table 1. Benthic foraminifer raw data of Site 747 given as number of specimens arranged according to the range of species.

Paleocene			Eocene						Oligocene						Age Benthic assemblage zones	
early			early			late			early		late					
III	III	III	IV	IV	IV	IV	IV	IV	II	II	II	II	II	II		
747A 19X CC 176.72	747C 3R-2 2R-5 9-11	747C 2R-4 2R-4 90-92	747C 2R-4 2R-4 49-51	747C 2R-3 4-6	747C 2R-3 139-141	747C 2R-2 98-100	747C 2R-2 69-71	747C 2R-1 82-84	747A 18X CC 165.28	747A 17X CC 159.70	747A 16H CC 151.93	747A 15H CC 142.35	747A 14H CC 132.76	747A 14H CC 132.76	Hole Core, section Interval (cm) Depth (mbsf)	
4 2	7 5	2	6 1	6 173.90	1 173.49	18 173.04	21 172.89	12 172.48	5 169.32	5 17	5 23	3 16	8 14	17 6	Stilostomella spp. Cibicidoides mundulus Nuttallides umbonifer Uvigerina spp. Gyroidina spp. Laticarinina pauperata Fissurina spp. Eggerella bradyi Astronion pusillum Globocassidulina subglobosa Cassidulina cf. havanense Epistominella exigua Oridorsalis umbonatus Lagena spp. Reophax spp. Bulimina cf. alazanensis Buliminoides sp. Cibicidoides spp. Pullenia bulloides Cibicidoides bradyi Melonis affinis Pleurostomella spp. Fursenkoina spp. Quinqueloculina spp. Nonion sp. 6 Pullenia subcarinata Eponides tumidulus Rhabdammina/Hyperammina Glomospira charoides Lenticulina spp. Karreilla bradyi Cribrostomoides spp. Spiroplectammina spectabilis Turrilina alsatica Bolivina spp. Bulimina impendens Bulimina jarvisi Eponides sp. 31 Karreriella sp. Cibicidoides laurisae Plectofrondicularia sp. Uvigerina havenensis Gyroidinoides spp. Cibicidoides praemundulus Cibicidoides mexicanus Bulimina glomarchallengeri Cibicidoidea eocaenaeus Trifarina sp. Karreriella chapapotensis Anomalinoidea spissiformis Anomalinoidea semicibratus Pullenia eocenica Bulimina spp. Cibicidoides grimsdalei Heronallenina sp. Nodosaria spp. Sigmoilopsis sp. Valvularia laevigata Alabamina dissonata Nonion havanense Osangularia mexicana Nuttallides truempyi Turrilina robertsi/brevispira Anomalinoidea capitatus Hanzawaia cushmani Bulimina semicostata Buliminella grata Stensioina beccariiformis Bulimina bradburyi Cibicidoides micrus	
9 2	10 5	9 1	1 26	1 17	1 22	1 1	1 1	1 1	1 3	1 6	1 4	1 7	1 11	1 4	1 3	
2	13 1	5 1	30 4	34 8	41 8	22 5	10 1	2 2	5 3	2 1	5 3	2 1	2 1	1 1	1 1	
3	2 1	12 1	9 2	2 6	2 1	1 3	1 1	1 1	3 1	1 1	16 26	9 2	9 1	9 1	9 1	
1	7 1	1 1	2 1	2 6	2 1	4 1	1 1	1 1	1 1	1 1	1 2	1 1	1 1	1 1	1 1	
1	2 46	12 7	9 11	2 24	2 26	2 28	1 14	1 10	6 5	1 1	12 11	1 1	1 1	1 1	1 1	
2	5 14 8 4	29 6 5 3	9 1	40 7 1	40 7 2	35 6 4	65 6 3	6 2	1 1							
1	20 6 4 2	1 1 2 3	1 2 3	1 3 4	1 3 4	1 2	1 2	1 2	1 1							
24	44 11 2 19 7	93 34 59 41 2	211 11 2 19 7	34 1 2 4 2	59 2 3 4 2	41 2 3 1 2	15 2 3 1 2	4 3 2 2 4	16 16 3 2 4	16 16 3 2 4	56 8 2 2 4	56 8 2 2 4	56 8 2 2 4	56 8 2 2 4		
43	83 7	114 2	1 2	1 2	1 2	1 2	1 2	1 2	1 1							

Table 1 (continued).

Paleocene			Eocene						Oligocene						Age
early			early			late			early		late				Benthic assemblage zones
III	III	III	IV	IV	IV	IV	IV	IV	II	II	II	II	II	II	Hole Core, section Interval (cm) Depth (mbsf)
747A 19X CC 176.72	747C 3R-2 9-11 179.59	747C 2R-5 90-92 117-119 175.67	747C 2R-4 49-51 173.90	747C 2R-4 4-6 173.49	747C 2R-4 139-141 173.04	747C 2R-3 98-100 172.89	747C 2R-3 69-71 172.48	747C 2R-2 170.69	747C 2R-1 82-84 169.32	747A 18X CC 165.28	747A 17X CC 159.70	747A 16H CC 151.93	747A 15H CC 142.35	747A 14H CC 132.76	Vulvulina spinosa Cyclammina spp. Neoponides cf. lunata Cibicidoides subspiratus Bulimina trinitatensis Bulimina tuxpamensis Gaudryina cf. laevigata Gyroidinoides globosus Aragonina aragonensis Dentalina spp. Bulimina thanetensis Clinapertina complanata Bulimina macilenta Abyssamina poagi Pullenia coryelli Anomalina paeacuta Lenticulina whitei Bolivinoides sp. 4 Pyramidina rudita Bulimina velascoensis Bolivinoides delicatus Osangularia velascoensis Dorothia trochoidea Tritaxia spp. Aragonina velascoensis Alabamina creta Neoflabellina semireticulata Tappanina selmensis Neoponides hillebrandti Cibicidoides velascoensis Coryphostoma midwayensis Sp. indet.
12	19	22	1	4	2	2	2	1	1	1	1	1	1	1	
3	5														
1															
10	35	48													
2	16	25													
	4	13													
		11													
	9	10													
		5													
11	16	4													
4	4	2													
3		2													
2		1													
1		1													
2	12														
	5														
	2														
	4	3													
137	301	405	424	119	155	248	212	320	261	102	86	205	66	66	Count
21	21	27	27	27	24	28	31	31	26	23	24	27	19	18	No. of species

Note: Number of species and number of specimens counted in each sample are also given. Asterisk (*) denotes reworked specimens.

Schlüch, Wise, et al., 1989, "Site 747" chapter), followed by a pelagic Danian sequence. Then, after a hiatus from =64–58 Ma, of the remaining Paleocene and the Eocene only the early Eocene (=57–53 Ma) is recorded in the sediments. (Probably, the uppermost Paleocene including a complete Paleocene/Eocene boundary is also recorded, but a meaningful separation between distinct bioevents is not possible because of the extremely low sedimentation rate [Berggren, this volume]). After a long hiatus (=15 m.y.), sediments are recorded again at the Eocene/Oligocene boundary (=38–35 Ma). After a short hiatus of =4 m.y. in the early Oligocene, sedimentation continued uninterrupted throughout the Oligocene.

Paleodepths for the sites cannot be estimated by backtracking because the Kerguelen Plateau together with the Broken Ridge form a pair of aseismic ridges separated by the Southeast Indian Ridge (Schlüch, Wise, et al., 1989, "Introduction" chapter). Consequently, the basaltic basement drilled at Sites 747 and 748 is not a typical mid-oceanic-ridge basalt (MORB) but is transitional between normal Indian Ocean MORB and Kerguelen and Heard Islands oceanic-island basalt (OIB) (Storey et al., 1988).

In this paper we use the following bathymetric divisions (Berggren and Miller, 1989): (1) bathyal from 200 to 2000 mbsl and (2) abyssal >2000 mbsl, subdivided into upper bathyal (200–600 mbsl), middle bathyal (600–1000 mbsl), and lower bathyal (1000–2000 mbsl); and upper abyssal (2000–3000

mbsl) and lower abyssal (>3000 mbsl), respectively. Benthic foraminifer assemblages indicate middle to lower bathyal paleodepths for Site 747 for the Neogene and a probable upper abyssal paleodepth for the early Paleocene (Schlüch, Wise, et al., 1989, "Site 747" chapter; this chapter). The paleodepth of Site 748 is thought to have remained similar to that of the present day, that is, middle to lower bathyal, throughout the Cenozoic (Schlüch, Wise, et al., 1989, "Site 748" chapter; this chapter).

BIOSTRATIGRAPHIC RESULTS AND DISCUSSION

A large number of systematic studies on deep-sea benthic foraminifers have been conducted on DSDP material (Douglas, 1973; Schnitker, 1979; Tjalsma and Lohmann, 1983; Murray and Weston, 1984; Thomas, 1985; Woodruff, 1985; Boersma, 1986; van Morkhoven et al., 1986; Boltovskoy and Boltovskoy, 1989; among others). In spite of this, no widely applicable zonation of the Cenozoic by means of benthic foraminifers has been established, because benthic foraminifers are usually rare in comparison to planktonic organisms, and those species that are more common are long ranging. In addition, benthic foraminifers have changed their depth distribution patterns through time (Douglas and Woodruff, 1981; Tjalsma and Lohmann, 1983; van Morkhoven et al., 1986), and therefore, deep-sea benthic foraminifer stratigraphic ranges may partly reflect the migration of species across depth

Table 2. Benthic foraminifer raw data of Site 748 given as number of specimens arranged according to the range of species.

Table 2 (continued).

Oligocene															Age		
early																	
II	II	II	II	II	II	II	II	II	II	II	II	II	II	II			
748B 14H CC 123.45	748B 14H-5 72-76 120.82	748B 14H-2 72-76 116.32	748B 13H CC 114.59	748B 13H-2 72-76 106.82	748B 12H CC 104.94	748B 12H-2 72-76 97.32	748B 11H CC 95.68	748B 11H-2 72-76 87.82	748B 10H CC 84.31	748B 10H-5 72-76 82.82	748B 9H CC 76.31	748B 9H-2 72-76 68.82	748B 8H CC 67.20	748B 8H CC 67.20	Benthic assemblage zones		
47	10	1	55	24	13	43	11	21	22	10	60	40			Hole Core, section Interval (cm) Depth (mbsf)		
						6	5	9	12	14	11	8	1	16		<i>Stilostomella</i> spp. <i>Uvigerina hispido-costata</i>	
	61	4		27		38	55	22		47	40	43	14		<i>Laticarinina paupera</i>		
1	1	1	8	139	2	52	14	93		27	20	27	10		<i>Cibicidoides mundulus</i>		
29	1		33		2		18		6		11		7		<i>Astrononion pusillum</i>		
															<i>Gyroidina</i> spp.		
															<i>Cibicides boueana?</i>		
6	12		5	8		1	1	8	2		5	5	4	4		<i>Pullenia subcarinata</i>	
18	3	1	5					17	3		5	1		3	<i>Pleurostomella</i> spp.		
															<i>Uvigerina graciliformis</i>		
37	50	5	15	11	4	14	5	23	2	13	5		2		<i>Oridorsalis umbonatus</i>		
						2			4	3	1				<i>Anomalinoidea</i> spp.		
										10					<i>Martinotiella nodulosa</i>		
															<i>Tritaxia?</i> sp.		
3	3	1	6	3	2	1	1	5		5	1	4	1		<i>Fissurina</i> spp.		
	1	1	1	2	1	2		2	1	3		1	1		<i>Lagena</i> spp.		
2					4		1				2		1		<i>Bulimina</i> spp.		
															<i>Cassidulina cressa?</i>		
													1		<i>Karreriella</i> sp.		
2	7			3	2	12	6	18	1	2	17	34			<i>Nuttallides umbonifer</i>		
2	1		1	3		12	1	4				11			<i>Globocassidulina subglobosa</i>		
71	12	12	25	18		8		27	3	8		9			<i>Cibicidoides</i> spp.		
	5			4		2		5		5		9			<i>Gyroidinoides soldanli</i>		
	64		4	27	5	5	2		4		2	8			<i>Uvigerina</i> spp.		
									1		6	6			<i>Hanzawaia cushmani</i>		
															<i>Bulimina striata</i>		
															<i>Cibicidoides bradyi</i>		
1					12		2		9	4		3			<i>Nonion</i> sp. 6		
							2		2	7		3			<i>Nonionella iridea</i> + spp.		
									2	1		3			<i>Siphonostularia</i> sp.		
									2			2			<i>Anomalinoidea semicibratus</i>		
						12	2					2			<i>Bulimina alazanensis</i>		
															<i>Furstenkoina</i> sp. 27		
			12	8			3					2			<i>Gyroidina lamarckiana</i>		
4			5				4			1		2			<i>Gyroidina</i> sp. klein		
10			17		4		34			14		2			<i>Gyroidinoides</i> spp.		
2						2	2		1			2			<i>Nonion havanense</i>		
22	26	2	22	26	2	11	4	7	27	1	9	6	1		<i>Rectuvigerina multicostata</i>		
5	1	1	6	5	1	1		3	2	2	1	1			<i>Pullenia bulloides</i>		
	1			4		1		3	2	2		1			<i>Lenticulina</i> spp.		
	4	2		2			1	1	3			1			<i>Eggerella bradyi</i>		
	2				1	1						1			<i>Karreriella subglabra</i>		
															<i>Osangularia culter</i>		
															<i>Sphaeroidina bulloides</i>		
7						1	3				4				<i>Furstenkoina earlandi</i>		
											3				<i>Melonis</i> sp.		
											1				<i>Bolivina silvestri</i>		
8	1										8				<i>Bolivina</i> cf. <i>B. thalmanni</i>		
1	1		1					1			1				<i>Orthomorphina</i> sp.		
															<i>Cibicidoides cicatricosus</i>		
															<i>Vulvulina spinosa</i>		
															<i>Cassidulina havenensis</i>		
															<i>Cibicidoides praemundulus</i>		
															<i>Cribrostomoides subglobosus</i>		
															<i>Rhabdammina/Hyperammina</i>		
															<i>Anomalinoidea capitatus</i>		
															<i>Cyclammina</i> spp.		
6			12				1			1		1			<i>Karreriella bradyi</i>		
3	2		18	44		2		4							<i>Reophax</i> sp.		
				6		11	1	2							<i>Turritina alsatica</i>		
1	1			1		1		2							<i>Astrononion stelligaram</i>		
															<i>Cibicidoides pachyderma</i>		
															<i>Nodosaria</i> sp.		
															<i>Bulimina trinitatis</i>		
															<i>Epistominella rugosa</i>		
															<i>Eggerella</i> sp.		
															<i>Orthomorphina glandigena</i>		
															<i>Pullenia</i> sp. 52		
															<i>Bulimina elongata</i>		
															<i>Epistominella exigua</i>		

Table 2 (continued).

Note: Number of species and number of specimens counted in each sample are also given.

Table 2 (continued).

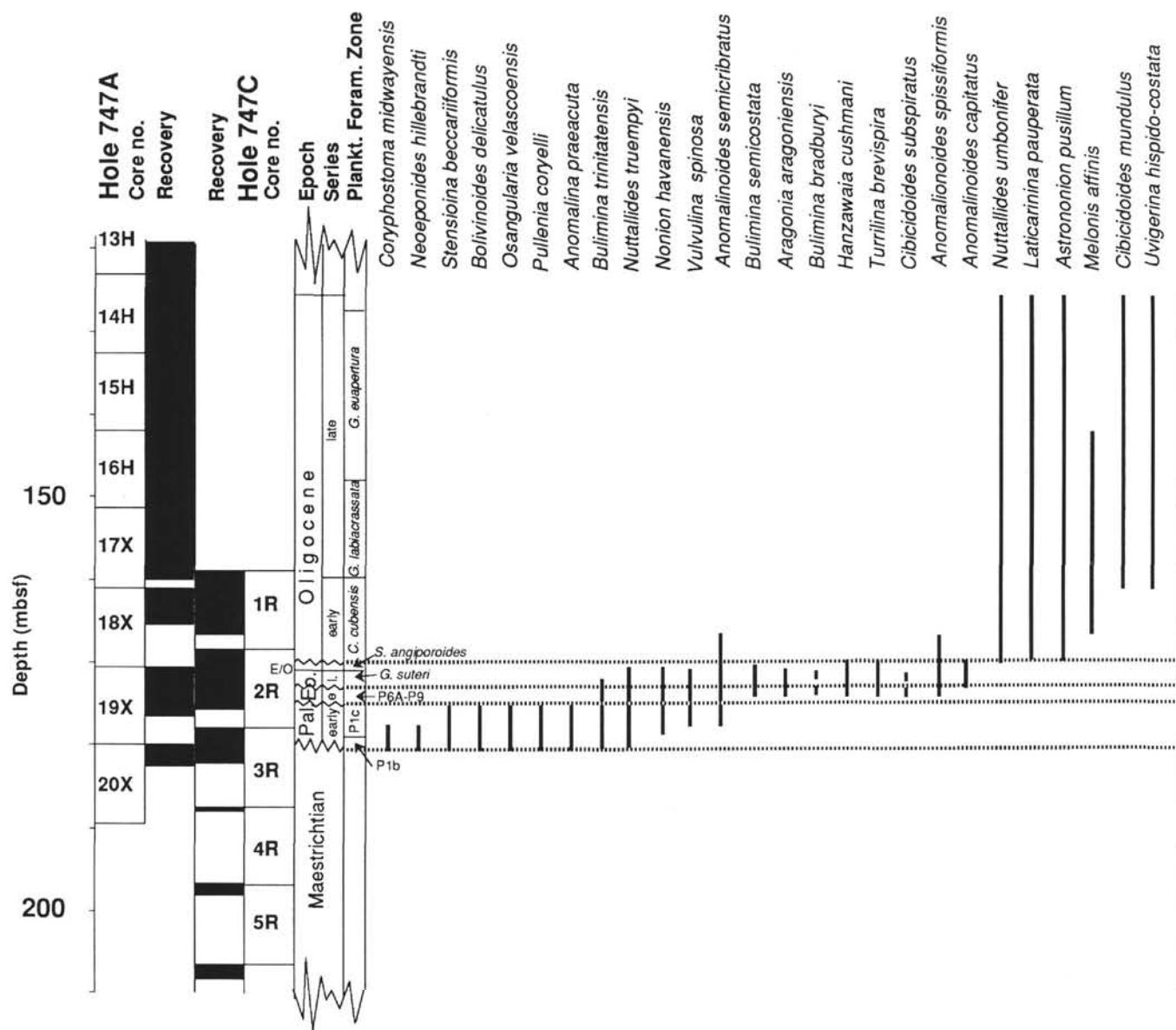


Figure 1. Range of selected species in the Paleogene at Site 747. Planktonic foraminifer zones after Berggren (this volume). (Note: Not shown in this overview figure because of scale limitations, the lowermost Eocene was recovered and there are indications that the uppermost part of the Paleocene was recovered as well. Thus, the hiatus between the Paleocene and the Eocene would be within the uppermost Paleocene, and consequently the Paleocene/Eocene boundary would be recovered at this site.)

zones. Two principal patterns of depth migration were observed: (1) species change their total depth range by extending their upper and/or lower depth limits, and (2) the depth of the species maximum abundance changes without changing the total depth range (Douglas 1979; Tjalsma and Lohmann, 1983). The depth migration in time and the long ranges of common species severely limits the stratigraphic use of benthic deep-water foraminifers. To avoid the most serious problems with diachronous first and last occurrences of species caused by vertical migration, Berggren and Miller (1989) suggested two independent benthic zonations for the bathyal realm (200–2000 mbsl) and the abyssal realm (>2000 mbsl).

In spite of the low biostratigraphic resolution available for Sites 747 and 748, in this paper we compare the Kerguelen Plateau ranges of the biostratigraphic useful species with the Atlantic ranges from Tjalsma and Lohmann (1983) and Thom-

as (1990), and with the proposed global ranges given in van Morkhoven et al. (1986) and Berggren and Miller (1989). On the Kerguelen Plateau at Site 748, highly diagnostic species such as *Coryphostoma midwayensis* and *Bolivinoides delicatus*, which range worldwide from the Late Cretaceous through the late Paleocene (Zone P5), have their last occurrence (LO) within Core 120-748C-24R, which is dated by calcareous nannofossils as Zones NP8 or base NP9 (Schlich, Wise, et al., "Site 748" chapter), equivalent to planktonic foraminifer Zone P4 (Berggren, 1969; Berggren and Miller, 1988). At Site 747, the LO of these species is found in Sample 120-747C-2R-5, 117–119 cm (Zones P2-P3), but this is the youngest sample investigated before the hiatus ranging through Subzone P6a (Aubry and Berggren, 1989). Also, the LO of *S. beccariiformis* in the late Paleocene (Subzone P6a) coincides with the previously observed worldwide ranges,

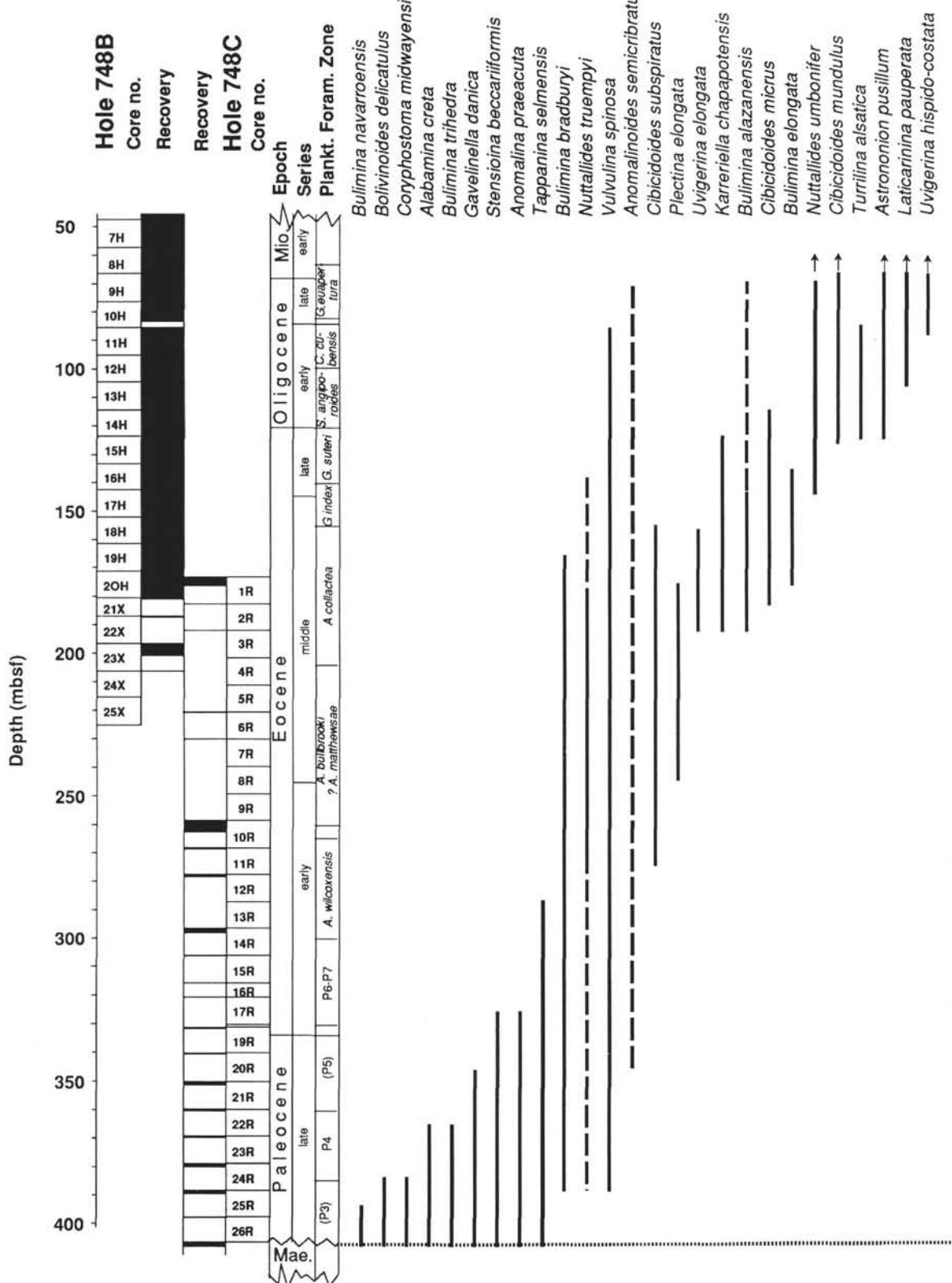


Figure 2. Range of selected species in the Paleogene at Site 748. Planktonic foraminifer zones after Berggren (this volume).

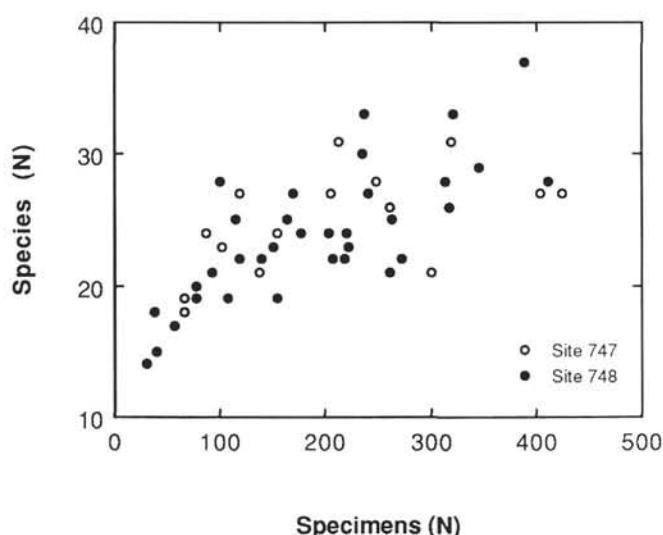


Figure 3. Number of species vs. number of specimens counted for all samples from Sites 747 and 748.

although this species is known to have significantly changed its depth range during the Paleocene (see below).

We found *Tappanina selmensis* at Site 748 from the unconformity in the late Paleocene up to the middle early Eocene. This roughly coincides with the findings on Maud Rise, where *T. selmensis* is common up to the middle early Eocene, but it is very rarely found also in the middle middle Eocene (Thomas, 1990). Tjalsma and Lohmann (1983) give a very short range for this species in the Atlantic from the middle late Paleocene (Zone P4) through the early Eocene (Subzone P6b), and van Morkhoven et al. (1986) report the first occurrence (FO) of *T. selmensis* in the Maestrichtian and the LO also in Subzone P6b.

The FO of *Bulimina bradburyi* is used as the boundary criterion between the abyssal benthic foraminifer Zones AB1 and AB2 of Berggren and Miller (1989), which is placed between planktonic Subzones P3a and P3b (Berggren, 1969). Tjalsma and Lohmann (1983) noted the FO of this taxon in Zone P4. At Site 748, *B. bradburyi* first occurs in Sample 120-748C-24R-CC (388 mbsf), which was dated as Zone P4 (Schlich, Wise, et al., "Site 748" chapter). At Site 747, only a few specimens were found in the lower Eocene.

Although *Nuttallides truempyi* ranges to the end of the Eocene, it is often rare in the upper Eocene (Tjalsma and Lohmann, 1983; van Morkhoven, et al., 1986; Miller and Berggren, 1989; Thomas, 1990). At Site 748, few specimens of this species are found from the lower Paleocene (Zone P4) Sample 120-748C-24R-CC through the upper Eocene (calcareous nannoplankton Zone NP18) Sample 120-748B-16H-CC, although several samples from this section did not contain any *N. truempyi*. On Maud Rise (Sites 689 and 690), *N. truempyi* ranged through the early late Eocene and the latest Eocene, respectively (Thomas, 1990). At Site 747, *N. truempyi* was dominant in the basal early Eocene (see discussion below).

In Sample 120-748B-16H-CC (upper Eocene), transitional forms between *N. truempyi* and *N. umbonifer* as well as specimens of *N. umbonifer* (s.s.) are present. *Nuttallides umbonifer* was a common constituent of the Oligocene fauna of both Sites 747 and 748, and it was a dominant component until the late Miocene at Sites 747 and 751 (Mackensen, this volume; Mackensen et al., this volume). In the Weddell Sea, the distribution of live *N. umbonifer* was found associated

with carbonate corrosive bottom water (Mackensen et al., 1990). Our data suggest that in the southern oceans the transition from *N. truempyi* to *N. umbonifer* occurred during the late Eocene, possibly coeval with the buildup of an East Antarctic ice sheet (Prentice and Matthews, 1988; Hambrey et al., 1989; Barron, Larsen, et al., 1989). This does not agree with data from Maud Rise, where *N. umbonifer* was found in lower Eocene sediments (Thomas, 1990). Berggren and Miller (1989) put the LCO (last common occurrence) of *N. truempyi* at the middle/late Eocene boundary, the LO of *N. truempyi* at the Eocene/Oligocene boundary, but the FO of *N. umbonifer* at the middle/late Eocene boundary. This view is corroborated by our data from Site 748.

Tjalsma and Lohmann (1983) place the FO of *Vulvulina spinosa* and *V. mexicana* within the earliest Eocene (Subzone P6b) in the Atlantic Ocean. At Site 748, *V. spinosa* ranges from late Paleocene (Zone P4) Sample 120-748C-24R-CC through the early Oligocene, and at Site 747 from Paleocene Samples 120-748C-2R-5, 117–119 cm (Zones P2–P3), through 120-747C-2R-3, 98–100 cm (Zone P9). Consequently, our data suggest a FO of *Vulvulina* at or near the early/late Paleocene boundary in the southern Indian Ocean. This corroborates previous reports of *V. spinosa* from the late Paleocene of the eastern Atlantic Ocean (DSDP Site 525) by Boltovskoy and Boltovskoy (1989) and is in contrast to the findings of Tjalsma and Lohmann (1983).

The FO of *Anomalinoides semicribratus* is used to define the base of abyssal benthic foraminifer Zone AB6 (Berggren and Miller, 1989). The age is given as middle Eocene (planktonic foraminifer zone correlative boundary P11/P12). At Sites 748 and 747, one specimen in Sample 120-748C-19R-CC and two specimens in Sample 120-747C-2R-5, 117–119 cm, respectively, are found in the latest Paleocene. This species is also present in the early Eocene of Site 747. In this study we applied a rather wide taxonomic view because of difficulties in the differentiation of this rare species and lumped forms that may be transitional between *A. capitatus* and *A. semicribratus* and atypical forms as discussed in van Morkhoven et al. (1986) together with *A. semicribratus* (s.s.). (see also discussion in Berggren and Miller, 1989). From the Maud Rise only the occurrence of *A. pseudogrosserugosus* is reported (Thomas, 1990).

Cibicidoides subspiratus and *Cibicidoides micrus* (mostly reported as *Gavelinella micra*) belong to those *Cibicidoides* species that are easily identifiable and have some age diagnostic value. *Cibicidoides micrus* has a long range from the early Eocene (Subzone P6b; van Morkhoven et al., 1986) or middle Eocene (Zone P10; Berggren and Miller, 1989) through the late Oligocene (Subzone P21b; van Morkhoven et al., 1986; Berggren and Miller, 1989). *Cibicidoides subspiratus* is reported to occur from the late early Eocene (Zone P9) through the middle middle Eocene (Zone P12; Tjalsma and Lohmann, 1983) or through the late middle Eocene (Zone P13; van Morkhoven et al., 1986). Both of the species were used as index species in the recently proposed benthic foraminifer zonation of Berggren and Miller (1989). At Site 748 the FO of *C. subspiratus* is found in Sample 120-748C-10R-CC (Zones P8–P9, NP13) and the LO in Sample 120-748B-18H-CC (Zones P12–P13, NP16). *Cibicidoides micrus* is found from Samples 120-748B-20H-CC (Zones P11–P12, NP15–NP16) through 120-748B-14H-CC (lower Oligocene).

At Sites 689 and 690 from the Maud Rise, Thomas (1990) describes a middle Eocene through upper Eocene benthic fauna (Assemblage 3), with *Bulimina elongata* as one of its characteristic to dominant constituents. The upper boundary of this assemblage is proposed at the LCO of *B. elongata* and the FCO of *Turrilina alsatica* at about 38.4 Ma (Thomas, pers.

comm., 1990). On the Kerguelen Plateau at Site 748, *B. elongata* first occurs in Sample 120-748B-19H-CC (Zone P11/12) and dominates the benthic foraminifer fauna from Samples 120-748B-17H-CC (Zone P14) through 120-748B-16H-CC (Zone P15) with its abrupt LO in the same sample. *Turrilina alsatica* has its FO not before Sample 120-748B-14H-CC (lower Oligocene). Our data suggest a middle middle Eocene FO of *B. elongata* with a LO in the late Eocene. This agrees with the Maud Rise sites in which *B. elongata* ranged from about 46.5 through 38.4 Ma (Thomas, pers. comm., 1990). Preliminary studies of Site 749 with an extended Eocene sequence are promising for a benthic foraminifer zonation of the lower bathyal realm by means of *Bulimina* chronoclines (Schlich, Wise, et al., 1989, "Site 749" chapter).

Turrilina alsatica is found from Samples 120-748B-14H-CC up to 120-748B-11H-2, 72–76 cm, which essentially constitutes the lower Oligocene. At Site 748, together with *T. alsatica*, *Astrononion pusillum* first occurs in the early Oligocene; its FO is found in Sample 120-748B-14H-CC, but its FCO in Sample 120-748B-13H-2, 72–76 cm. At Site 747, the FO of *A. pusillum* is found in Sample 120-747C-2R-1, 82–84 cm (Zone NP22) just above the unconformity within the lower Oligocene (Schlich, Wise, et al., 1989, "Site 747" chapter). This species is a common constituent throughout the Oligocene and Miocene sections of the Kerguelen Plateau sites. At Sites 747 and 751, it becomes the dominant benthic foraminifer component in the late Miocene (Mackensen, this volume).

Laticarinina pauperata is reported to occur from the early Oligocene (Zone P18 or P19; van Morkhoven et al., 1986) to the Holocene. At Site 748, its FO is in Sample 120-748B-12H-CC, dated as upper lower Oligocene (Zone P19/20; Schlich, Wise, et al., 1989, "Site 748" chapter).

PALEOECOLOGIC RESULTS AND DISCUSSION

Preservation and Diversity

Benthic foraminifers are generally well preserved and abundant in all of the Paleogene samples from Sites 747 and 748, although they are rare in comparison to planktonic foraminifers. Benthic foraminifer faunas in Danian samples from Site 747 are extremely well preserved. Consequently, differences in the diversity between Paleogene samples are unlikely to be a result of diagenetic processes that are triggered by compaction, such as selective dissolution of small and thin-walled species.

At Site 747, the number of species varies between 18 and 31 per sample, and at Site 748 between 14 and 37 per sample (Figs. 4, 5). At Site 747 high diversities were found in Eocene samples and low diversities occurred in the upper Oligocene and above the hiatus associated with the Cretaceous/Paleogene boundary. At Site 748, the diversity decreased from a peak value in the lower upper Paleocene to a minimum in the upper Paleocene. Subsequently, diversities gradually increased during the Eocene to a maximum in the uppermost middle Eocene; they then decreased again toward a minimum in the uppermost Eocene, just below the Eocene/Oligocene boundary (Fig. 5). The Oligocene is characterized by varying numbers of species, which were on average higher in the late Oligocene.

Benthic Foraminifer Assemblages

Stensioina beccariiformis Assemblage (PC III): Paleocene, Sites 747 and 748

Beside the dominant species *S. beccariiformis*, complementary species of minor importance include *Cibicidoides* spp., *C. praemundulus*, *Stilostomella* spp., and *Pullenia*

coryelli; *Anomalina praecutata* and *Nuttallides truempyi* are accessory components. At the deep Site 747, this assemblage dominates the fauna in the lower Paleocene from Samples 120-747C-3R-2, 9–11 cm (180.0 mbsf), through 120-747C-2R-5, 117–119 cm (175.67 mbsf) (Fig. 6). At Site 748 the *Stensioina beccariiformis* assemblage characterizes the upper Paleocene benthic foraminifer fauna from Samples 120-748C-24R-CC (388.0 mbsf) through -19R-CC (340.5 mbsf) (Fig. 7).

Nuttallides truempyi Assemblage (PC IV): Early Eocene, Site 747

This benthic foraminifer assemblage is dominated by *N. truempyi*. Other important constituents include *Cibicidoides eocaenus*, *C. praemundulus*, and *Oridorsalis umbonatus*. Accessory components are *Pullenia eocenica*, *Gyroidinoides* spp., and *Alabamina dissonata*. The *N. truempyi* fauna is found only at Site 747 (Fig. 6), where this assemblage dominates the benthic foraminifer fauna in the lowermost Eocene from Samples 120-747C-2R-4, 90–92 cm (173.9 mbsf), through -2R-1, 82–84 cm (169.32 mbsf).

Stilostomella-Lenticulina Assemblage (PC I): Early and Middle Eocene, Site 748

This assemblage is dominated by *Stilostomella* spp., with *Lenticulina* spp. as an important component. *Cibicidoides praemundulus* is an accessory species. The *Stilostomella-Lenticulina* assemblage is dominant only at Site 748 from Samples 120-748C-14R-CC (306 mbsf), through 120-748B-17H-CC (152.1 mbsf) (Fig. 7). This may be partly caused by the incomplete stratigraphic sequence at Site 747; it is probably not the result of different paleoenvironmental conditions at the two sites. At Site 748, the *Stilostomella-Lenticulina* assemblage dominates the benthic fauna in middle lower through middle Eocene samples. At Site 747, only a lowermost Eocene sedimentary sequence dominated by *N. truempyi* was recovered.

Cibicidoides-Astrononion pusillum Assemblage (PC II): Latest Eocene and Oligocene

This assemblage is dominated by *Cibicidoides mundulus* and *Astrononion pusillum*. Common accessory components include other *Cibicidoides* species, different *Uvigerina* species (predominantly *U. hispido-costata*), *Nuttallides umbonifer*, *Stilostomella* spp., *Lenticulina* spp., and *Laticarinina pauperata*.

At Site 747, this assemblage characterizes the benthic fauna in the lowermost Oligocene and becomes dominant in the upper lower Oligocene throughout the rest of the Paleogene from Samples 120-747A-18X-CC (170.5 mbsf) through 120-747A-14H-CC (132.5 mbsf) (Fig. 6). At Site 748, the *Cibicidoides-Astrononion* assemblage becomes the characteristic species association in the uppermost Eocene and dominates the benthic foraminifer fauna from the upper lower Oligocene through the rest of the Paleogene from Samples 120-748B-15H-CC (133.1 mbsf), through 120-748B-9H-2, 72–76 cm (68.82 mbsf) (Fig. 7).

Differences Between Sites

Faunas at Sites 747 and 748 differ in relative abundances of some species but are similar in species composition. One of the most striking differences between the quantitative faunal composition occurred in the Paleocene and the earliest Eocene, when the relative abundances of *Nuttallides truempyi* and *Stensioina beccariiformis* were different at the two sites. At Site 747, the early Danian was characterized by PC III, dominated by *S. beccariiformis*, and the early Eocene was characterized by PC IV, dominated by *N. truempyi*. At Site 748, PC III dominated the benthic foraminifer fauna in the late Paleocene and only a few *N.*

Table 3. Benthic foraminifer census data of all samples and species used for statistical data treatment.

Hole Core, section Interval (cm) Depth (mbsf)	748B 8H	748B 9H-2	748B 9H	748B 10H-5	748B 10H	748B 11H-2	748B 11H	748B 12H-2	748B 12H	748B 13H-2	748B 13H	748B 14H-2	748B 14H-5	748B 14H	748B 15H-2	748B 15H	748B CC
	67.20	68.82	76.31	82.82	84.31	87.82	95.68	97.32	104.94	106.82	114.59	116.32	120.82	123.45	125.82	133.41	
<i>Abyssammina poagi</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Alabamina creta</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Alabamina dissonata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0
<i>Anomalina praecuta</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Anomalinooides</i> spp.	1.3	0.0	0.5	1.1	2.7	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Anomalinooides capitatus</i>	0.0	0.0	0.0	0.0	0.7	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Anomalinooides semicribratus</i>	0.0	0.8	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Anomalinooides spissiformis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	2.6	5.9	3.8	2.6	5.7	
<i>Aragonina aragonensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Aragonina velascoensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Astronion pusillum</i>	6.5	11.4	9.9	10.3	0.0	23.8	7.9	22.1	2.6	33.7	3.1	2.6	0.3	0.3	0.0	0.0	0.0
<i>Bolivina</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bolivinoides delicatulus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina alazanensis</i>	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.9	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina bradburyi</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina elongata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina jarvisi</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina macilenta</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	
<i>Bulimina semicostata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina striata</i>	0.0	2.1	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina navarroensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina thanetensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina trihedra</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina trinitatensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina</i> spp.	0.6	0.0	1.0	0.0	0.0	0.3	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
<i>Buliminella grata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cassidulina</i> cf. <i>havanense</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides bradyi</i>	0.0	1.3	0.0	1.5	0.0	2.3	0.0	1.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
<i>Cibicidoides eocaenus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides laurisae</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
<i>Cibicidoides micrus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	2.6	6.4	
<i>Cibicidoides mundulus</i>	9.0	18.1	19.7	17.9	0.0	5.6	31.1	16.2	0.0	6.6	0.0	10.5	19.0	0.0	20.5	0.0	
<i>Cibicidoides pachyderma</i>	0.0	0.0	0.0	0.0	0.0	0.5	6.2	0.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides praemundulus</i>	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	28.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides subspiratus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides velascoensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides</i> spp.	0.0	3.8	0.0	3.0	2.0	6.9	0.0	3.4	0.0	4.4	9.6	31.6	3.7	22.4	7.7	25.7	
<i>Coryphostoma midwayensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Dentalina</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.5	0.4	0.0	0.6	0.9	0.0	2.9	
<i>Eggerella bradyi</i>	0.0	0.4	0.0	0.0	2.0	0.3	0.0	0.4	0.0	1.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
<i>Eggerella</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0
<i>Epistominella exigua</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Eponides</i> sp. 31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Fissurina</i> spp.	0.6	1.7	0.5	1.9	0.0	1.3	0.6	0.4	2.6	0.7	2.3	2.6	0.9	0.9	0.0	1.4	
<i>Furstenkoina</i> spp.	0.0	0.8	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
<i>Gaudryina</i> cf. <i>laevigata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gavelinella danica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Globocassidulina subglobosa</i>	0.0	4.6	0.0	0.0	0.0	1.0	0.6	5.1	0.0	0.7	0.4	0.0	0.3	0.6	0.0	0.0	0.0
<i>Glomospira charoides</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gyroidina lamarciana</i>	0.0	0.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	1.9	4.6	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gyroidina</i> sp. "small"	0.0	0.8	0.0	0.4	0.0	1.0	0.0	0.0	0.0	1.2	0.0	0.0	1.2	0.0	0.0	0.0	0.0
<i>Gyroidina</i> spp.	4.5	0.0	5.4	0.0	4.0	0.0	10.2	0.0	2.6	0.0	12.6	0.0	0.3	9.1	0.0	0.0	0.0
<i>Gyroidinoides soldanii</i>	0.0	3.8	0.0	1.9	0.0	1.3	0.0	0.9	0.0	1.0	0.0	0.0	1.6	0.0	7.7	0.0	0.0
<i>Gyroidinoides</i> spp.	0.0	0.8	0.0	5.3	0.0	8.7	0.0	1.7	0.0	4.1	0.0	0.0	3.1	0.0	5.1	3.6	
<i>Hanzawaia cushmani</i>	0.0	2.5	3.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6
<i>Hanzawaia</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Karreriella bradyi</i>	0.0	0.0	0.0	0.0	0.7	0.0	0.6	0.0	0.0	0.0	4.6	0.0	0.0	1.9	0.0	0.0	0.0
<i>Karreriella chapapotensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	3.6
<i>Karreriella subglabra</i>	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	5.3	1.2	0.0	2.6	0.0	0.0
<i>Karreriella</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Lagena</i> spp.	0.6	0.4	0.0	1.1	0.7	0.5	0.0	0.9	1.3	0.5	0.4	2.6	0.3	0.0	0.0	0.0	1.4
<i>Laticarinina pauperata</i>	10.3	0.4	3.9	4.2	9.3	3.1	5.1	2.1	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Lenticulina whitei</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Lenticulina</i> spp.	0.0	0.4	0.5	0.8	1.3	0.8	0.0	0.4	1.3	1.2	2.3	2.6	0.3	1.6	0.0	3.6	
<i>Marginulina</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Martinotiella nodulosa</i>	1.3	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0
<i>Melonis affinis</i>	0.0	0.0	1.5	0.0</													

Table 3 (continued).

Table 3 (continued).

Hole Core, section Interval (cm) Depth (mbsf)	748B 8H CC 67.20	748B 9H-2 CC 68.82	748B 9H CC 76.31	748B 10H-5 CC 82.82	748B 10H CC 84.31	748B 11H-2 CC 87.82	748B 11H CC 95.68	748B 12H-2 CC 97.32	748B 12H CC 104.94	748B 13H-2 CC 106.82	748B 13H CC 114.59	748B 14H-2 CC 116.32	748B 14H-5 CC 120.82	748B 14H CC 123.45	748B 15H-2 CC 125.82	748B 15H CC 133.41
<i>Orthomorphina</i> sp.	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	2.5	0.0	2.6	0.0	0.0
<i>Osangularia culter</i>	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.4	1.3	0.0	0.0	0.0	0.6	0.0	0.0	0.0
<i>Osangularia mexicana</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Osangularia velascoensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Plectina elongata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Plectofrondicularia</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pleurostomella</i> spp.	1.9	0.4	2.5	0.0	0.0	0.5	4.5	0.4	1.3	0.0	1.9	2.6	0.9	5.7	2.6	1.4
<i>Pullenia bulldoidea</i>	0.0	0.4	3.0	3.4	0.7	1.8	2.3	4.7	2.6	6.3	8.4	5.3	8.1	6.9	10.3	0.0
<i>Pullenia coryelli</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pullenia eocenica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3
<i>Pullenia subcarinata</i>	2.6	1.7	2.5	1.9	0.0	0.8	0.0	0.4	3.9	1.9	1.9	0.0	3.7	3.8	0.0	2.9
<i>Pyramidina ruditia</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Quinqueloculina</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Rectuvigerina multicostata</i>	0.0	0.8	0.0	0.0	18.0	0.5	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Rhabdammina/Hyperammina</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Siphonotextularia</i> sp.	0.0	1.3	0.0	0.4	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Spiroplectammina spectabilis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Stensioina beccariiformis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Stilostomella</i> spp.	33.5	16.9	29.6	3.8	14.7	5.4	6.2	18.3	16.9	5.8	21.1	2.6	3.1	14.8	20.5	9.3
<i>Tappanina selmensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Trifarina</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9
<i>Tritaxia</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Turritina alsatica</i>	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.9	0.0	10.7	6.9	0.0	0.6	0.9	0.0	0.0
<i>Turritina robertsi/brevispira</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4
<i>Uvigerina elongata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Uvigerina graciliformis</i>	1.9	0.0	0.5	0.0	0.0	0.8	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Uvigerina havanensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Uvigerina hispido-costata</i>	18.1	0.0	0.0	24.7	28.0	15.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Uvigerina</i> spp.	0.0	3.4	1.0	0.0	2.7	0.0	1.1	2.1	6.5	6.6	1.5	0.0	19.9	0.0	0.0	0.0
<i>Vulvulina spinosa</i>	0.0	0.0	0.0	0.4	0.0	0.3	0.0	0.0	0.0	0.2	0.0	2.6	0.3	0.0	0.0	0.0
Sp. indet.	0.0	0.0	0.5	0.0	0.0	0.3	1.7	0.4	0.0	0.2	1.1	0.0	0.3	1.6	7.7	2.9
All others	5.8	1.7	1.5	3.4	4.0	0.8	2.3	1.3	2.6	0.0	1.9	0.0	0.9	8.2	0.0	0.7

truempyi are found in both the upper Paleocene and the lower Eocene. Consequently, no PC IV was calculated at this site, and the Eocene is characterized by the *Stilostomella-Lenticulina* assemblage. From the Atlantic Ocean, an early Paleocene abyssal *Gavelinella beccariiformis* association was described, which gradually became restricted to shallower water during the late Paleocene (Tjalsma and Lohmann, 1983). On the other hand, the main distribution of *N. truempyi* was restricted to abyssal waters during most of the Paleocene; only in the latest Paleocene did its bathymetric range extend to lower and middle bathyal water depths. Applying this to Site 747 Paleocene faunas we conclude that if the site was at the present day water depth (lower bathyal), the observed faunal change from the *S. beccariiformis* assemblage (PC III) to the *N. truempyi* assemblage (PC IV) reflects the depth migration of these faunas during the Paleocene. Application of this scheme to the Paleocene Site 748 fauna indicates a middle or lower bathyal water depth during the late Paleocene; however, at least since the latest Paleocene, this site has remained at middle bathyal paleodepth, above the upper depth limit of the *N. truempyi* fauna.

Boundary Events

Paleocene/Eocene Boundary

At Site 748, during the late Paleocene, a gradual or sequential disappearance of benthic foraminifer species is indicated (Fig. 2); also the diversity rapidly dropped (Fig. 5) and an overall change in species composition, as indicated by the principal component analysis, occurred (Fig. 7). The duration of the extinction event could not be ascertained because of the poor recovery in Hole 748C. The *Stensioina beccariiformis* assemblage (PC III) was replaced by the *Stilostomella-Lenticulina* assemblage (PC I). Benthic foraminifers underwent

severe extinction globally at this time (Schnitker, 1980; Tjalsma and Lohmann, 1983; Miller et al., 1987; Berggren and Miller, 1989; Thomas, 1990). Planktonic foraminifers underwent faunal change at the Paleocene/Eocene boundary as well, but there were fewer LOs than at the end of the Cretaceous (Corfield and Shackleton, 1988).

At Site 747, the Paleocene/Eocene boundary, if present at all, probably is somewhat disturbed because only a very condensed uppermost part of the upper Paleocene was recovered above a disconformity and below the lowermost Eocene (see Aubry and Berggren, 1989; Berggren, this volume; "Stratigraphy and Paleodepth" section, this chapter). However, both the individual ranges of many of the "old" species and the change in overall faunal composition, as indicated by the principal component analysis, suggest a strong event at or close to the Paleocene/Eocene boundary (Figs. 1 and 6), when the *Stensioina beccariiformis* assemblage (PC III) was replaced by the *Nuttallides truempyi* assemblage (PC IV).

Thomas (1990) stated that the faunal turnover at the Paleocene/Eocene boundary mostly affected trochospiral (possibly epifaunal) benthic species and biserial and triserial (possibly infaunal) species proliferated for a short period (<300,000 yr). According to the classification given by Thomas (1990), at Site 747 both assemblages, dominated by *S. beccariiformis* or *N. truempyi*, would have been epifaunal. The lack of recovery, however, prevented a detailed study of events across the boundary.

Eocene/Oligocene Boundary

At Site 748, an increase in the number of LOs and FOs occurred in the late Eocene and especially in the latest Eocene (Fig. 2). Principal component analysis indicates a major faunal shift at the middle to late Eocene boundary,

Table 3 (continued).

when the *Stilostomella-Lenticulina* assemblage (PC I) disappears. After a short interval of stability characterized by reduced diversity, a new fauna dominated by *Cibicidoides* spp. and *Astrononion pusillum* (PC II) evolved in the late Eocene and became subsequently characterized by Oligocene species such as *Nuttallides umbonifer* and *Turrilina alsatica* (Fig. 7).

In the oceans of both hemispheres, major benthic foraminifer faunal changes were described in the late Eocene, but no major benthic faunal changes were associated with the Eocene/Oligocene boundary (Tjalsma and Lohmann, 1983; Miller et al., 1984; Murray and Weston, 1984; Corliss et al., 1984). In the early Oligocene an increase in $\delta^{18}\text{O}$ values of $=1\text{\textperthousand}$ occurred worldwide (e.g., Savin et al., 1975; Kennett and Shackleton, 1976; Oberhänsli et al., 1984; Keigwin and Corliss, 1986; Miller et al., 1987). At the Maud Rise sites, the greater part of benthic faunal change is definitely within the Eocene and below the lower Oligocene increase in $\delta^{18}\text{O}$ values in benthic foraminifers (Thomas, 1990). Even if the resolution of our study at this stage is much less, our data also indicate a major benthic faunal turnover within the late Eocene. The $\delta^{18}\text{O}$ values of *Cibicidoides* spp. from Site 748 increase by $=2.5\text{\textperthousand}$ over the early to late middle Eocene and then reverse close to the middle/late Eocene boundary, decreasing by $=0.5\text{\textperthousand}$ during the late Eocene, until in the early Oligocene a rapid $1.2\text{\textperthousand}$ enrichment occurred (Zachos et al., this volume). The onset of the slight decrease in $\delta^{18}\text{O}$ values in the late Eocene coincides with the benthic foraminifer change from the *Stilostomella-Lenticulina* fauna (PC I) to the *Cibicidoides-Astrononion pusillum* fauna (PC II). If this decrease in $\delta^{18}\text{O}$ values is considered to be significant, it corroborates evidence from benthic foraminifers that a change in bottom-water circulation occurred well before the early Oligocene $\delta^{18}\text{O}$

shift. The planktonic $\delta^{18}\text{O}$ values (*Chiloguembelina cubensis*) at Site 748 slightly increase in the uppermost Eocene close to the Eocene/Oligocene boundary and become similar to the benthic foraminifer values. This is interpreted as a precursor-cooling of surface waters over the Kerguelen Plateau, before the major $\delta^{18}\text{O}$ shift of benthic and planktonic foraminifer stable isotopes in the early Oligocene (Zachos et al., this volume). The $>1\text{\%}$ $\delta^{18}\text{O}$ shift in planktonic and benthic foraminifers and the coeval occurrence of ice-rafted debris (Breza et al., this volume) indicate that much of the $\delta^{18}\text{O}$ increase was the result of an increase in ice volume and not a drop in global temperatures (Zachos et al., this volume).

SUMMARY AND CONCLUSIONS

Four different benthic foraminifer assemblages populated the central Kerguelen Plateau during Paleogene times at Sites 747 and 748:

1. A *Stensioina beccariiformis*-dominated assemblage characterizes the Paleocene at both sites.
 2. At Site 747, the early Eocene is characterized by a *Nuttallides truempyi*-dominated assemblage. This site is believed to have been at a lower bathyal paleodepth at that time.
 3. At Site 748, an assemblage characterized by *Stilostomella* and *Lenticulina* spp. dominated the early and middle Eocene. In the latest Paleocene and early Eocene, this site was situated above the upper paleodepth limit of *Nuttallides truempyi*, which changed its depth distribution pattern from abyssal during the Paleocene to middle bathyal in the early Eocene.
 4. At both sites, the latest Eocene and the Oligocene were characterized by a benthic foraminifer assemblage dominated by *Cibicidoides* spp. and *Astromonion pusillum*.

Table 3 (continued).

Hole Core, section Interval (cm) Depth (mbsf)	747A 15H CC 142.35	747A 16H CC 151.93	747A 17X CC 159.70	747A 18X CC 165.28	747C 31413 82-84 169.32	747C 2R-2 69-71	747C 2R-3 98-100	747C 2R-3 139-141	747C 2R-4 4-6	747C 2R-4 49-51	747C 2R-4 90-92	747C 2R-4 117-119	747C 2R-5 117-119	747A 19X CC 175.67	747C 3R-2 9-11 180.00
<i>Abyssammina poagi</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
<i>Alabamina creta</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Alabamina dissonata</i>	0.0	0.0	0.0	0.0	0.0	17.5	1.4	1.2	12.9	0.8	1.4	0.0	0.0	0.0	0.0
<i>Anomalina praecuta</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Anomalinoidea</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Anomalinoidea capitatus</i>	0.0	0.0	0.0	0.0	0.0	0.6	0.0	1.6	1.9	1.7	0.0	0.0	0.0	0.0	0.0
<i>Anomalinoidea semicribratus</i>	0.0	0.0	0.0	0.0	1.5	0.0	0.5	0.0	3.2	0.8	1.9	0.5	0.0	0.0	0.0
<i>Anomalinoidea spissiformis</i>	0.0	0.0	0.0	0.0	1.9	2.2	0.5	2.4	4.5	4.2	3.3	0.0	0.0	0.0	0.0
<i>Aragonina aragonensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	5.0	2.8	0.0	0.0	0.0	0.0
<i>Aragonina velascoensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.5	0.0	0.0
<i>Astromonion pusillum</i>	3.0	17.6	5.8	2.0	7.7	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bolivina</i> spp.	0.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bolivinoides delicatulus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	8.0	5.3	0.0
<i>Bulimina alazanensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina bradburyi</i>	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0
<i>Bulimina elongata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina jarvisi</i>	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0
<i>Bulimina macilenta</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina semicostata</i>	0.0	0.0	0.0	0.0	0.0	0.0	1.9	1.2	0.0	3.4	4.5	0.0	0.0	0.0	0.0
<i>Bulimina striata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina navarroensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina thanetensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0
<i>Bulimina trihedra</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bulimina trinitatensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.9	0.0	2.8	5.4	8.8	6.3	0.0
<i>Bulimina</i> spp.	0.0	0.0	0.0	0.0	1.1	0.0	0.9	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cassidulina</i> cf. <i>havanense</i>	1.5	1.5	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides bradyi</i>	4.5	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides eocaenus</i>	0.0	0.0	0.0	0.0	5.4	8.8	12.0	9.6	7.1	5.9	10.8	0.0	0.0	0.0	0.0
<i>Cibicidoides laurisae</i>	0.0	0.0	1.2	0.0	0.8	0.3	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides micrus</i>	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides mundulus</i>	13.6	7.3	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides pachyderma</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicidoides praemundulus</i>	0.0	0.0	0.0	5.9	24.9	12.5	4.2	11.6	0.0	0.0	1.2	0.0	0.0	0.0	0.0
<i>Cibicidoides subspiratus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	3.4	1.2	0.0	0.0	0.0	0.0
<i>Cibicidoides velascoensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
<i>Cibicidoides</i> spp.	13.6	7.8	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.2	1.5	4.3
<i>Coryphostoma midwayensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
<i>Dentalina</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Eggerella bradyi</i>	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Eggerella</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Epistominella exigua</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Eponides</i> sp. 31	0.0	0.0	1.2	1.0	0.0	0.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Fissurina</i> spp.	0.0	1.0	1.2	2.0	1.1	0.3	0.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Fursenkoina</i> spp.	1.5	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gaudryina</i> cf. <i>laevigata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	5.0	0.0	0.0	0.0	0.0	0.0
<i>Gavelinella danica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Globocassidulina subglobosa</i>	3.0	6.8	4.7	3.9	9.6	1.3	9.3	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
<i>Glomospira charoides</i>	0.0	1.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gyroidina lamarckiana</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gyroidina</i> sp. "small"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gyroidina</i> spp.	6.1	7.8	4.7	0.0	0.0	6.9	7.9	10.4	0.0	0.0	2.1	2.5	0.0	3.0	0.0
<i>Gyroidinoides soldanii</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	1.7	0.0	0.0	2.2	1.7	0.0
<i>Gyroidinoides</i> spp.	0.0	0.0	0.0	10.8	13.4	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
<i>Hanzawaia cushmani</i>	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.4	2.6	2.5	0.5	0.0	0.0	0.0	0.0
<i>Hanzawaia</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Karreriella bradyi</i>	0.0	0.5	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Karreriella chapapotensis</i>	0.0	0.0	0.0	0.0	2.3	0.6	0.0	0.8	0.0	0.0	0.0	0.0	0.7	0.0	0.0
<i>Karreriella subglabra</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Karreriella</i> spp.	0.0	0.0	1.2	1.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
<i>Lagena</i> spp.	0.0	1.5	2.3	1.0	1.9	2.5	1.9	0.0	0.6	1.7	0.2	0.0	1.5	1.7	0.0
<i>Laticarinina pauperata</i>	6.1	5.4	8.1	4.9	2.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Lenticulina whitei</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	1.3
<i>Lenticulina</i> spp.	0.0	0.5	0.0	1.0	0.4	0.6	0.9	0.8	5.8	10.1	0.5	0.0	2.2	0.0	0.0
<i>Marginulina</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Martinotiella nodulosa</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Melonis affinis</i>	3.0	12.7	1.2	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Neoeponides hillebrandti</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	4.0	0.0
<i>Neoeponides</i> cf. <i>lunata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Nodosaria</i> sp.	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.8	0.0	4.9	1.5	0.0
<i>Nonion</i> sp.	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
<i>Nonion</i> <i>havanense</i>	0.0	0.0	0.0	0.0	0.0	5.0	1.4	2.8	1.3	2.5	0.0	0.5	0.0	0.3	0.0
<i>Nuttallides truempyi</i>	0.0	0.0	0.0	0.0	0.0	1.3	6.9	16.4	38.1	28.6	49.8	23.0	17.5	14.6	0.0
<i>Nuttallides umbonifer</i>	7.6	7.8	3.5	22.5	6.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Oridorsalis unbonatus</i>	3.0	2.4	2.3	9.8	8.4	12.8	15.7	12.0	0.0	1.7	3.1	1.0	2.9	2.3	0.0
<i>Orthomorphina</i> sp.	0.0	0.0	0.0</												

Table 3 (continued).

Hole Core, section	747A 15H CC	747A 16H CC	747A 17X CC	747A 18X CC	747C 31413 82-84	747C 2R-2 69-71	747C 2R-3 98-100	747C 2R-3 139-141	747C 2R-4 4-6	747C 2R-4 49-51	747C 2R-4 90-92	747C 2R-5 117-119	747A 19X CC	747C 3R-2 9-11
Interval (cm)	142.35	151.93	159.70	165.28	169.32	170.69	172.48	172.89	173.04	173.49	173.90	175.67	176.72	180.00
<i>Osangularia mexicana</i>	0.0	0.0	0.0	0.0	0.0	2.5	0.0	1.2	1.3	0.0	0.9	0.0	0.0	0.0
<i>Osangularia velascoensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.9	1.3
<i>Plectina elongata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Plectofrondicularia</i> sp.	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
<i>Pleurostomella</i> spp.	1.5	1.0	0.0	0.0	0.0	1.9	0.0	0.8	0.6	1.7	0.0	0.0	0.0	0.0
<i>Pullenia bulloides</i>	4.5	2.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pullenia coryelli</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.9	7.3	11.6
<i>Pullenia eocenica</i>	0.0	0.0	0.0	0.0	1.5	6.9	7.9	10.0	1.9	3.4	0.9	0.0	0.0	0.0
<i>Pullenia subcarinata</i>	0.0	2.0	2.3	1.0	1.5	2.5	0.9	0.8	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pyramidina rudita</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	3.0
<i>Quinqueoculina</i> spp.	1.5	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Rectuvigerina multicostata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Rhabdammina/Hyperammina</i>	0.0	1.0	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Siphonotularia</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Spiropectammina spectabilis</i>	0.0	0.5	0.0	0.0	1.1	0.3	2.8	0.8	0.0	0.0	0.2	0.0	0.0	0.0
<i>Stensiola beccariiformis</i>	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.8	0.0	0.0	0.0	28.1	31.4	27.6
<i>Stilostomella</i> spp.	12.1	1.5	5.8	4.9	0.0	3.8	9.7	7.2	0.6	5.0	1.4	0.5	2.9	2.3
<i>Tappanina selmensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
<i>Trifarina</i> sp.	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Tritaxia</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.2	0.0
<i>Turrilina alsatica</i>	0.0	0.5	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Turrilina robertsibrevispira</i>	0.0	0.0	0.0	0.0	0.0	0.9	0.9	0.8	1.3	0.8	2.6	0.0	0.0	0.0
<i>Uvigerina elongata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Uvigerina graciliformis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Uvigerina havanensis</i>	0.0	0.0	0.0	11.8	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Uvigerina hispido-costata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Uvigerina</i> spp.	9.1	6.8	18.6	0.0	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
<i>Vulvulina spinosa</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.8	1.3	1.7	0.9	0.2	0.0	0.0
Sp. indet.	3.0	1.5	0.0	0.0	0.0	0.9	0.0	0.0	1.3	0.0	0.0	0.7	0.0	1.3
All others	0.0	1.5	3.5	2.9	1.9	0.3	1.4	0.0	4.5	2.5	0.7	2.2	0.7	0.3

Major benthic foraminifer changes occurred at or close to the Paleocene/Eocene boundary and in the late Eocene close to the middle/late Eocene boundary, respectively. These changes are indicated by relative abundance changes, as calculated by principal component analysis, and by a series of LOs and FOs of species in the latest Paleocene and the late Eocene.

Although benthic foraminifer assemblages as used in this paper are not biostratigraphic zones, the upper boundary of the *Stensiola beccariiformis* assemblage close to the Paleocene/Eocene boundary seems to coincide with the upper boundaries of Berggren and Miller's (1989) bathyal and abyssal benthic foraminifer Zones BB1 and AB2, respectively. The upper boundary of the *Stilostomella-Lenticulina* assemblage at bathyal Site 748 close to the middle/late Eocene boundary possibly roughly coincides with the bathyal benthic foraminifer zonal boundary between BB3 and BB4 (Berggren and Miller, 1989), but more precisely it fits the abyssal zonal boundary of AB6/AB7.

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APPENDIX A

Species List

- Abyssamina poagi* Schnitker and Tjalsma 1980
Alabamina creta (Finlay) = *Pulvinulinella creta* Finlay 1940
Alabamina dissonata (Cushman and Renz) = *Pulvinulinella atlanticae* Cushman var. *dissonata* Cushman and Renz 1948
Anomalina spp.
Anomalinoides spissiformis (Cushman and Stainforth) = *Anomalina alazanensis* Nuttall var. *spissiformis* Cushman and Stainforth 1945
Anomalinoides capitatus (Gümbel) = *Rotalia capitata* Gümbel 1868
Anomalinoides semicribritatus (Beckmann) = *Anomalina pompilioides* Galloway and Heminway var. *semicribritata* Beckmann 1954
Aragonia aragonensis (Nuttall) = *Textularia aragonensis* Nuttall 1930
Aragonia velascoensis (Cushman) = *Textularia velascoensis* Cushman 1925
Astrononion pusillum Hornbrook 1961
Bolivina spp.
Bolivinoides delicatulus Cushman = *Bolivinoides decorata* (Jones) var. *delicatula* Cushman 1927
Bulimina alazanensis Cushman 1927
Bulimina bradburyi Martin 1943
Bulimina elongata d'Orbigny 1826
Bulimina jarvisi Cushman and Parker 1936
Bulimina macilenta Cushman and Parker 1939
Bulimina semicostata Nuttall 1930
Bulimina striata d'Orbigny 1826
Bulimina navarroensis Cushman and Parker = *Bulimina reussi* Morrow var. *navarroensis* Cushman and Parker 1935
Bulimina thanetensis Cushman and Parker 1947
Bulimina trihedra Cushman 1926
Bulimina trinitatis Cushman and Jarvis 1928
Bulimina spp.
Buliminella grata Parker and Bermúdez 1937
Cassidulina havanensis Cushman and Bermúdez 1936
Cibicidoides bradyi (Trauth) = *Truncatulina bradyi* Trauth 1918
Cibicidoides eocaenus (Gümbel) = *Rotalia eocaena* Gümbel 1868
Cibicidoides laurisae (Mallory) = *Cibicides laurisae* Mallory 1959
Cibicidoides micrus (Bermúdez) = *Cibicides micrus* Bermúdez 1949
Cibicidoides mundulus (Brady, Parker and Jones) = *Truncatulina mundula* Brady, Parker and Jones 1888
Cibicidoides pachyderma (Rzehak) = *Truncatulina pachyderma* Rzehak 1886
Cibicidoides praemundulus Berggren and Miller 1986
Cibicidoides subspiratus (Nuttall) = *Cibicides subspirata* Nuttall 1930
Cibicidoides velascoensis (Cushman) = *Anomalina velascoensis* Cushman 1925
Cibicidoides spp.
Coryphostoma midwayensis (Cushman) = *Bolivina midwayensis* Cushman 1936
Dentalina spp.
Eggerella bradyi (Cushman) = *Verneuilina bradyi* Cushman 1911
Eponides sp.
Epistominella exigua (Brady) = *Pulvinulina exigua* Brady 1884
Fissurina spp.
Furkenkoina spp.
Gaudryina cf. laevigata Franke cf. *Gaudryina laevigata* Franke 1914
Gavelinella danica (Brotzen) = *Cibicides danica* Brotzen 1940 (including *Anomalinoides rubigonosus* (Cushman) 1926)
Globocassidulina subglobosa (Brady) = *Cassidulina subglobosa* Brady 1884
Glomospira charoides (Jones and Parker) = *Trochammina squamata* Jones and Parker var. *charoides* Jones and Parker 1860
Gyroidina lamarckiana (d'Orbigny) = *Rotalina lamarckiana* d'Orbigny 1839
Gyroidinoides soldanii (d'Orbigny) = *Gyroidina soldanii* d'Orbigny 1826
Gyroidina sp. "small"
Gyroidina spp.
Gyroidinoides spp.
Hanzawaia cushmani (Nuttall) = *Cibicides cushmani* Nuttall 1930
Hanzawaia spp.
Karreriella bradyi (Cushman) = *Gaudryina bradyi* Cushman 1911
Karreriella chapapensis (Cole) = *Textularia chapapensis* Cole 1928
Karreriella subglabra (Gümbel) = *Gaudryina subglabra* Gümbel 1868

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Karreriella spp.
Lagena spp.
Laticarinina pauperata (Parker and Jones) = *Pulvinulina repanda* Fichtel and Moll var. *menardii* d'Orbigny subvar. *pauperata* Parker and Jones 1865
Lenticulina whitei Tjalsma and Lohmann 1983
Lenticulina spp.
Marginulina spp.
Martinottiella nodulosa (Cushman) = *Clavulina nodulosa* Cushman 1922
Melonis affinis (Reuss) = *Nonionina affinis* Reuss 1851
Neoeponides hillebrandti Fisher 1969
Neoeponides cf. lunata (Brotzen) cf. *Eponides lunata* Brotzen 1948
Nodosaria spp.
Nonion sp. 6
Nonion havanense Cushman and Bermúdez 1937
Nuttallides truempyi (Nuttall) = *Eponides truempyi* Nuttall 1930
Nuttallides umbonifer (Cushman) = *Pulvinulinella umbonifera* Cushman 1933
Oridorsalis umbonatus (Reuss) = *Rotalina umbonata* Reuss 1851
Orthomorphina spp.
Osangularia culter (Parker and Jones) = *Planorbulina culter* Parker and Jones 1865
Osangularia mexicana (Cole) = *Pulvinulinella culter* (Parker and Jones) var. *mexicana* Cole 1927
Osangularia velascoensis (Cushman) = *Truncatulina velascoensis* Cushman 1925
Plectina elongata Cushman and Bermúdez 1936
Plectofrondicularia sp.
Pleurostomella spp.
Pullenia bulloides (d'Orbigny) = *Nonionina bulloides* d'Orbigny 1826
Pullenia coryelli White 1929
Pullenia eocenica Cushman and Siegfus 1939
Pullenia subcarinata (d'Orbigny) = *Pullenia subcarinata* d'Orbigny 1839
Pyramidina rudita (Cushman and Parker) = *Bulimina rudita* Cushman and Parker 1936
Quinqueloculina spp.
Rectuvigerina multicostata (Cushman and Jarvis) = *Siphogenerina multicostata* Cushman and Jarvis 1929
Rhabdammina/*Hyperammina*
Siphonotularia spp.
Spiroplectammina spectabilis (Grzybowski) = *Spiroplecta spectabilis* Grzybowski 1898
Stensioina beccariiformis (White) = *Rotalia beccariiformis* White 1928
Stilostomella spp.
Tappanina selmensis (Cushman) = *Bolivinita selmensis* Cushman 1933, emend. Brotzen 1948
Trifarina sp.
Tritaxia spp.
Turrilina alsatica Andreae 1848
Turrilina brevispira ten Dam 1944
Uvigerina elongata Cole 1927
Uvigerina graciliformis Papp and Turnovsky 1953
Uvigerina havanensis Cushman and Bermúdez 1936
Uvigerina hispidocostata Cushman and Todd 1945
Uvigerina proboscidea Schwager 1866
Uvigerina spp.
Vulvulina spinosa Cushman 1927 (including *V. jarvisi* Cushman 1932, and *V. mexicana* Nuttall 1930)

APPENDIX B. Varimax-rotated principal component loadings.

Core, section, interval (cm)	Depth (mbsf)	PC I	PC II	PC III	PC IV
120-747A-					
14H-CC	132.76	0.477	0.702	0.118	-0.048
15H-CC	142.35	0.237	0.820	0.152	-0.046
16H-CC	151.93	-0.105	0.755	-0.066	0.053
17X-CC	159.70	0.022	0.687	-0.091	0.018
18X-CC	165.28	0.128	0.367	-0.132	0.155
19X-CC	176.72	-0.124	-0.059	0.790	0.428
120-747C-					
2R-1, 82-84	169.32	0.160	0.210	-0.333	0.380
2R-2, 69-71	170.69	0.360	0.058	-0.217	0.508
2R-3, 98-100	172.48	0.434	0.166	0.019	0.600
2R-3, 139-141	172.89	0.347	0.071	-0.010	0.838
2R-4, 4-6	173.04	-0.019	-0.090	0.135	0.826
2R-4, 49-51	173.49	0.164	-0.084	0.173	0.776
2R-4, 90-92	173.90	-0.074	-0.039	0.155	0.862
2R-5, 117-119	175.67	-0.197	-0.073	0.765	0.515
3R-2, 9-11	180.00	-0.153	-0.031	0.836	0.386
120-748B-					
8H-CC	67.20	0.579	0.528	0.143	-0.065
9H-2, 72-76	68.82	0.269	0.823	0.060	-0.044
9H-CC	76.31	0.517	0.731	0.125	-0.035
10H-5, 72-76	82.82	-0.032	0.666	-0.044	-0.026
10H-CC	84.31	0.315	0.258	0.002	-0.025
11H-2, 72-76	87.82	-0.001	0.699	-0.037	0.020
11H-CC	95.68	0.014	0.747	-0.029	-0.002
12H-2, 72-76	97.32	0.278	0.853	0.053	0.010
12H-CC	104.94	0.543	0.249	-0.152	0.233
13H-2, 72-76	106.82	-0.030	0.650	-0.049	0.009
13H-CC	114.59	0.593	0.414	0.213	0.007
14H-2, 72-76	116.32	0.058	0.486	0.221	-0.007
14H-5, 72-76	120.82	0.013	0.649	-0.024	0.090
14H-CC	123.45	0.423	0.423	0.279	0.019
15H-2, 72-76	125.82	0.381	0.661	0.215	-0.097
15H-CC	133.41	0.295	0.312	0.250	-0.043
16H-CC	142.27	0.258	0.005	-0.173	0.206
17H-CC	152.49	0.652	0.116	0.009	0.080
18H-CC	162.10	0.797	0.015	0.070	0.057
19H-CC	171.24	0.800	0.043	0.063	0.172
20H-CC	181.28	0.771	0.046	0.068	0.100
21X-CC	181.30	0.724	0.054	0.102	-0.011
23X-CC	200.92	0.857	0.079	0.023	0.152
120-748C-					
6R-CC	220.67	0.848	0.007	0.055	0.116
10R-CC	262.36	0.866	0.163	0.209	0.103
11R-CC	268.20	0.858	0.145	0.064	0.270
12R-CC	278.39	0.928	0.145	0.122	0.074
14R-CC	298.14	0.813	0.080	0.186	-0.016
19R-CC	331.51	0.249	0.181	0.720	-0.023
21R-CC	351.04	0.335	0.025	0.658	-0.072
22R-CC	359.92	0.148	-0.014	0.637	-0.078
23R-CC	369.27	0.181	0.080	0.822	-0.016
24R-CC	379.82	0.723	0.148	0.541	-0.067
26R-CC	397.74	0.221	0.013	0.386	-0.048

APPENDIX C. Varimax-rotated principal component scores.

Species	PC I	PC II	PC III	PC IV
<i>Abyssammina poagi</i>	-0.213	-0.379	-0.098	-0.326
<i>Alabamina creta</i>	-0.221	-0.397	0.124	-0.450
<i>Alabamina dissonata</i>	0.493	-0.493	-0.790	1.376
<i>Anomalinooides spissiformis</i>	0.417	-0.061	-0.228	0.531
<i>Anomalina paeacuta</i>	-0.306	-0.495	1.903	-0.555
<i>Anomalinooides spp.</i>	-0.241	-0.250	-0.252	-0.334
<i>Anomalinooides capitatus</i>	0.548	-0.599	-0.239	-0.145
<i>Gavelinella danica</i>	-0.149	-0.404	0.159	-0.482
<i>Anomalinooides semicribratus</i>	-0.197	-0.321	-0.194	0.032
<i>Aragonina aragonensis</i>	-0.298	-0.362	0.232	0.112
<i>Aragonina velascoensis</i>	-0.270	-0.380	0.436	-0.446
<i>Astronion pusillum</i>	-1.305	4.555	-0.895	0.400
<i>Bolivina spp.</i>	-0.312	-0.177	-0.295	-0.257
<i>Bolivinoides delicatulus</i>	-0.517	-0.347	0.512	0.070
<i>Bulimina alazanensis</i>	0.238	-0.384	-0.334	-0.348
<i>Bulimina bradburyi</i>	0.447	-0.604	0.637	-0.516
<i>Bulimina elongata</i>	0.683	-0.568	-0.917	0.110
<i>Bulimina jarvisi</i>	-0.314	-0.219	-0.276	-0.222
<i>Bulimina macilenta</i>	0.099	-0.473	-0.255	-0.413
<i>Bulimina semicostata</i>	-0.282	-0.343	-0.274	0.244
<i>Bulimina striata</i>	-0.278	-0.252	-0.248	-0.317
<i>Bulimina navarroensis</i>	-0.130	-0.460	0.436	-0.597
<i>Bulimina thanetensis</i>	-0.237	-0.471	0.992	-0.575
<i>Bulimina trihedra</i>	-0.141	-0.435	0.678	-0.632
<i>Bulimina trinitatensis</i>	-0.560	-0.338	0.686	0.438
<i>Bulimina spp.</i>	-0.213	-0.248	-0.193	-0.240
<i>Buliminella grata</i>	-0.199	-0.379	-0.101	-0.135
<i>Cassidulina cf. havanense</i>	-0.275	-0.163	-0.241	-0.298
<i>Cibicidoidea bradyi</i>	0.289	-0.188	-0.279	-0.436
<i>Cibicidoidea eocaenesis</i>	1.193	-0.702	-1.195	2.778
<i>Cibicidoidea laurisae</i>	0.393	-0.468	-0.326	-0.160
<i>Cibicidoidea micrus</i>	0.127	-0.346	-0.197	-0.287
<i>Cibicidoidea mundulus</i>	-1.212	6.053	-0.169	-0.387
<i>Cibicidoidea pachyderma</i>	-0.216	-0.121	-0.399	-0.184
<i>Cibicidoidea praemundulus</i>	2.248	-0.373	-2.704	2.889
<i>Cibicidoidea subspiratus</i>	0.128	-0.488	-0.269	-0.004
<i>Cibicidoidea velascoensis</i>	-0.276	-0.370	0.006	-0.341
<i>Cibicidoidea spp.</i>	-0.294	2.616	2.732	-0.922
<i>Coryphostoma midwayensis</i>	-0.273	-0.352	-0.209	-0.301
<i>Dentalina spp.</i>	0.436	-0.509	-0.246	-0.384
<i>Eggerella bradyi</i>	-0.278	-0.041	-0.280	-0.319
<i>Eggerella sp.</i>	-0.285	-0.287	-0.215	-0.316
<i>Epistominella exigua</i>	-0.253	-0.265	-0.241	-0.328
<i>Eponides sp. 31/E. weddellensis</i>	-0.261	-0.289	-0.300	-0.227
<i>Fissurina spp.</i>	-0.128	0.195	-0.269	-0.208
<i>Fursenkoina spp.</i>	-0.128	-0.247	-0.211	-0.378
<i>Gaudryina cf. laevigata</i>	-0.175	-0.408	-0.152	0.051
<i>Globocassidulina subglobosa</i>	-0.365	0.891	-0.752	0.680
<i>Glomospira charoides</i>	-0.293	-0.266	-0.262	-0.296
<i>Gyroidina lamarckiana</i>	-0.211	-0.209	-0.228	-0.327
<i>Gyroidina sp. "small"</i>	-0.302	-0.215	-0.259	-0.295
<i>Gyroidina spp.</i>	0.812	0.981	-0.231	1.148
<i>Gyroidinoidea soldanii</i>	-0.369	0.088	0.590	-0.264
<i>Gyroidinoidea spp.</i>	-0.452	0.812	-0.733	0.312

APPENDIX C (continued).

Species	PC I	PC II	PC III	PC IV
<i>Hanzawaia cushmani</i>	0.180	-0.305	0.148	-0.142
<i>Hanzawaia spp.</i>	-0.224	-0.365	-0.131	-0.362
<i>Karreriella bradyi</i>	-0.206	-0.198	-0.200	-0.338
<i>Karreriella chapapotensis</i>	-0.067	-0.295	-0.263	-0.212
<i>Karreriella subglabra</i>	-0.253	-0.153	-0.171	-0.332
<i>Karreriella spp.</i>	-0.282	-0.291	-0.247	-0.264
<i>Lagena spp.</i>	0.197	-0.113	-0.106	0.087
<i>Laticarinina pauperata</i>	-0.287	1.351	-0.608	-0.081
<i>Lenticulina whitei</i>	-0.326	-0.380	0.531	-0.356
<i>Lenticulina spp.</i>	4.330	-1.640	0.245	0.102
<i>Marginulina spp.</i>	0.229	-0.513	-0.246	-0.332
<i>Martinotiella nodulosa</i>	-0.306	-0.178	-0.223	-0.321
<i>Melonis affinis</i>	-0.505	0.552	-0.387	-0.088
<i>Neoponides hillebrandti</i>	-0.348	-0.348	0.022	-0.200
<i>Neoponides cf. lunata</i>	-0.200	-0.400	0.053	-0.428
<i>Nodosaria sp.</i>	0.205	-0.490	0.257	-0.224
<i>Nonion sp. 6</i>	-0.102	-0.130	-0.305	-0.258
<i>Nonion havanense</i>	0.221	-0.411	-0.374	0.378
<i>Nuttallides truempyi</i>	-1.427	-0.331	1.902	8.110
<i>Nuttallides umbonifer</i>	-0.425	2.290	-0.875	0.397
<i>Oridorsalis umbonatus</i>	1.215	1.619	-0.112	2.630
<i>Orthomorphina sp.</i>	-0.262	-0.176	-0.199	-0.327
<i>Osangularia culter</i>	-0.251	-0.303	-0.269	-0.292
<i>Osangularia mexicana</i>	-0.179	-0.368	-0.359	0.000
<i>Osangularia velascoensis</i>	-0.330	-0.351	-0.035	-0.212
<i>Pectina elongata</i>	0.109	-0.485	-0.304	-0.335
<i>Plectofrondicularia sp.</i>	-0.284	-0.308	-0.226	-0.292
<i>Pleurostomella spp.</i>	0.507	-0.030	0.036	-0.283
<i>Pullenia bulloides</i>	-0.341	1.277	-0.035	-0.338
<i>Pullenia coryelli</i>	-0.561	-0.422	2.392	-0.031
<i>Pullenia ecenica</i>	0.472	-0.425	-0.723	1.428
<i>Pullenia subcarinata</i>	0.218	0.194	-0.493	-0.006
<i>Pyramidina rudita</i>	-0.351	-0.348	0.008	-0.184
<i>Quinquelculina spp.</i>	-0.273	-0.261	-0.259	-0.293
<i>Rectuvigerina multicostata</i>	-0.126	-0.202	-0.319	-0.357
<i>Rhabdammina/Hyperammina</i>	-0.332	-0.135	-0.296	-0.274
<i>Siphonularia sp.</i>	-0.275	-0.280	-0.247	-0.316
<i>Spiroplectammina spectabilis</i>	-0.139	-0.348	-0.348	-0.064
<i>Stensioina beccariiformis</i>	-1.349	-0.529	7.415	0.689
<i>Stilosomella spp.</i>	7.916	2.747	2.512	-0.740
<i>Tappanina selmensis</i>	-0.114	-0.420	0.320	-0.534
<i>Trifarina sp.</i>	0.092	-0.344	-0.293	-0.225
<i>Tritaxia spp.</i>	-0.295	-0.353	-0.142	-0.262
<i>Turrilina alsatica</i>	-0.286	0.117	-0.241	-0.287
<i>Turrilina robertsi/brevispira</i>	-0.109	-0.385	-0.133	-0.025
<i>Uvigerina elongata</i>	0.081	-0.478	-0.291	-0.332
<i>Uvigerina graciliformis</i>	-0.341	-0.007	-0.272	-0.298
<i>Uvigerina havanensis</i>	-0.255	-0.159	-0.454	-0.059
<i>Uvigerina hispido-costata</i>	-0.320	1.254	-0.430	-0.422
<i>Uvigerina spp.</i>	-0.659	2.135	-0.611	0.138
<i>Vulvulina spinosa</i>	0.100	-0.413	0.242	-0.232
Sp. indet.	0.106	0.097	1.241	-0.623
All others	0.089	0.398	0.197	0.106

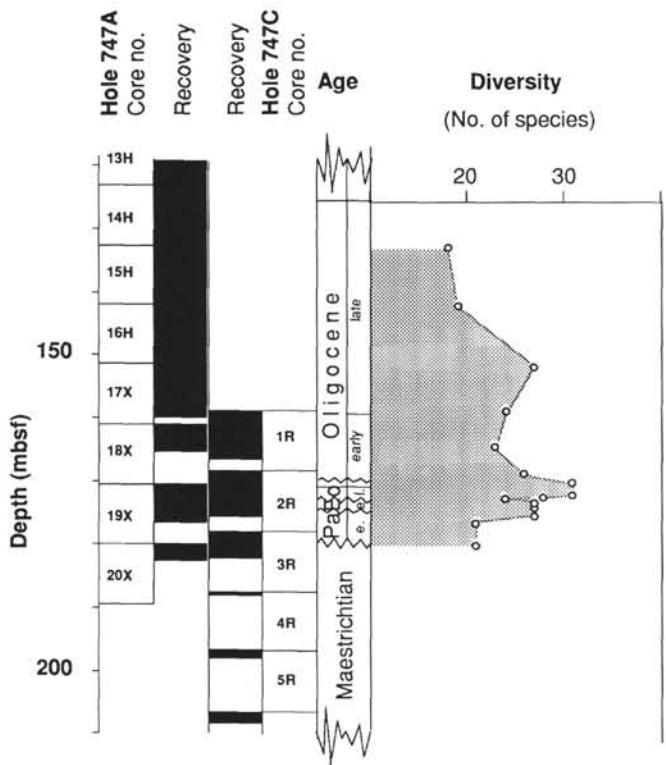


Figure 4. Number of benthic foraminifer species at Site 747 vs. sub-bottom depth. (Note: Not shown in this overview figure because of scale limitations, the lowermost Eocene was recovered, and there are indications that the uppermost part of the Paleocene was recovered as well. Thus, the hiatus between the Paleocene and the Eocene would be within the uppermost Paleocene, and consequently the Paleocene/Eocene boundary would be recovered at this site.)

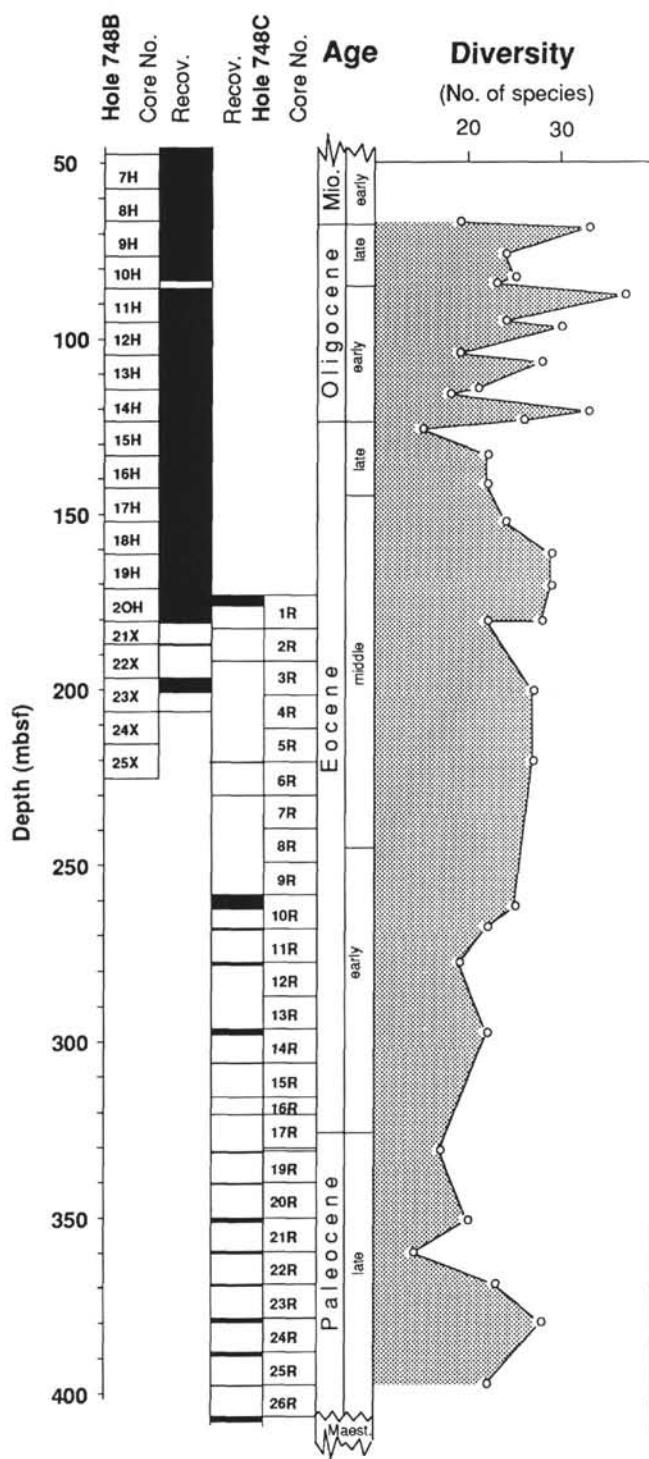


Figure 5. Number of benthic foraminifer species at Site 748 vs. sub-bottom depth.

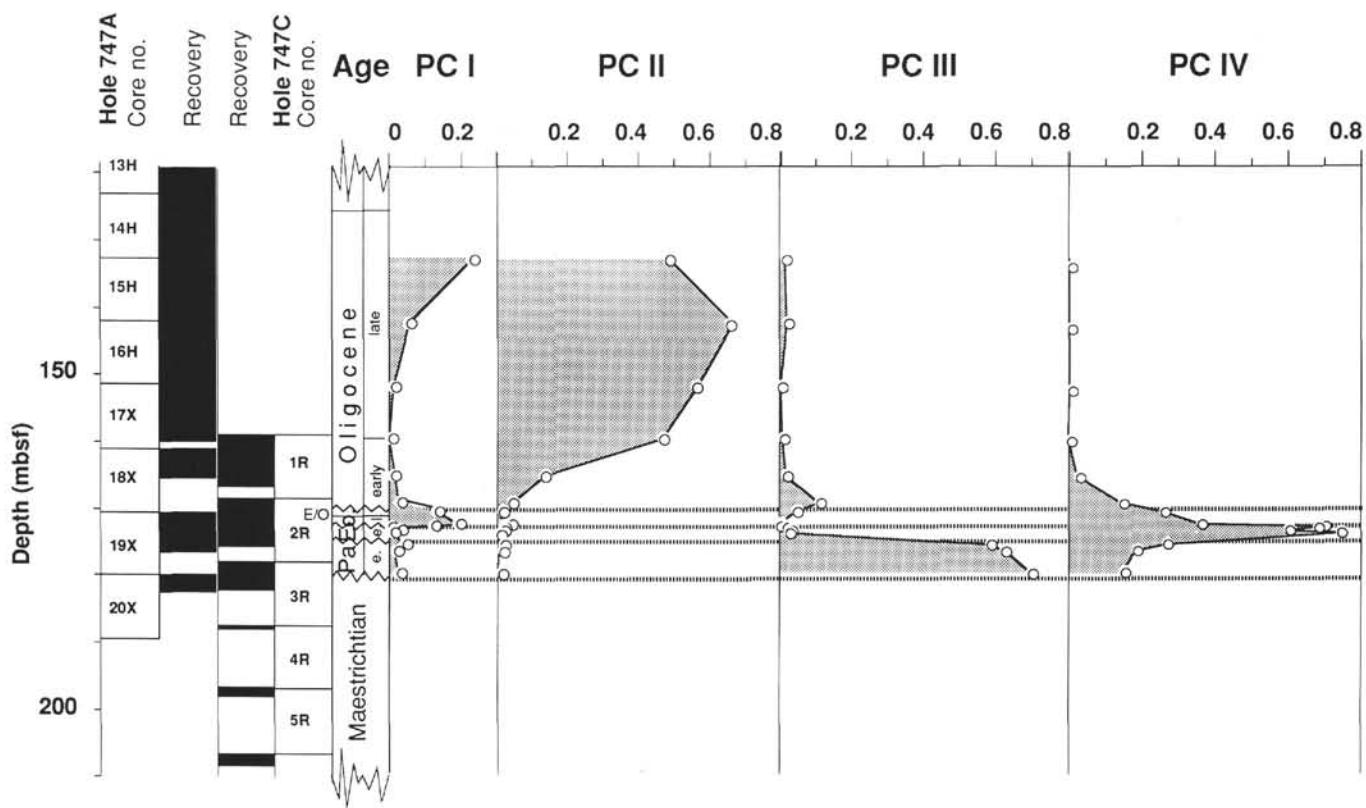


Figure 6. Squared varimax rotated principal component loadings vs. sub-bottom depth at Site 747. Cumulative squared loadings of all principal components give the communality. (Note: Not shown in this overview figure because of scale limitations, the lowermost Eocene was recovered, and there are indications that the uppermost part of the Paleocene was recovered as well. Thus, the hiatus between the Paleocene and the Eocene would be within the uppermost Paleocene, and consequently the Paleocene/Eocene boundary would be recovered at this site.)

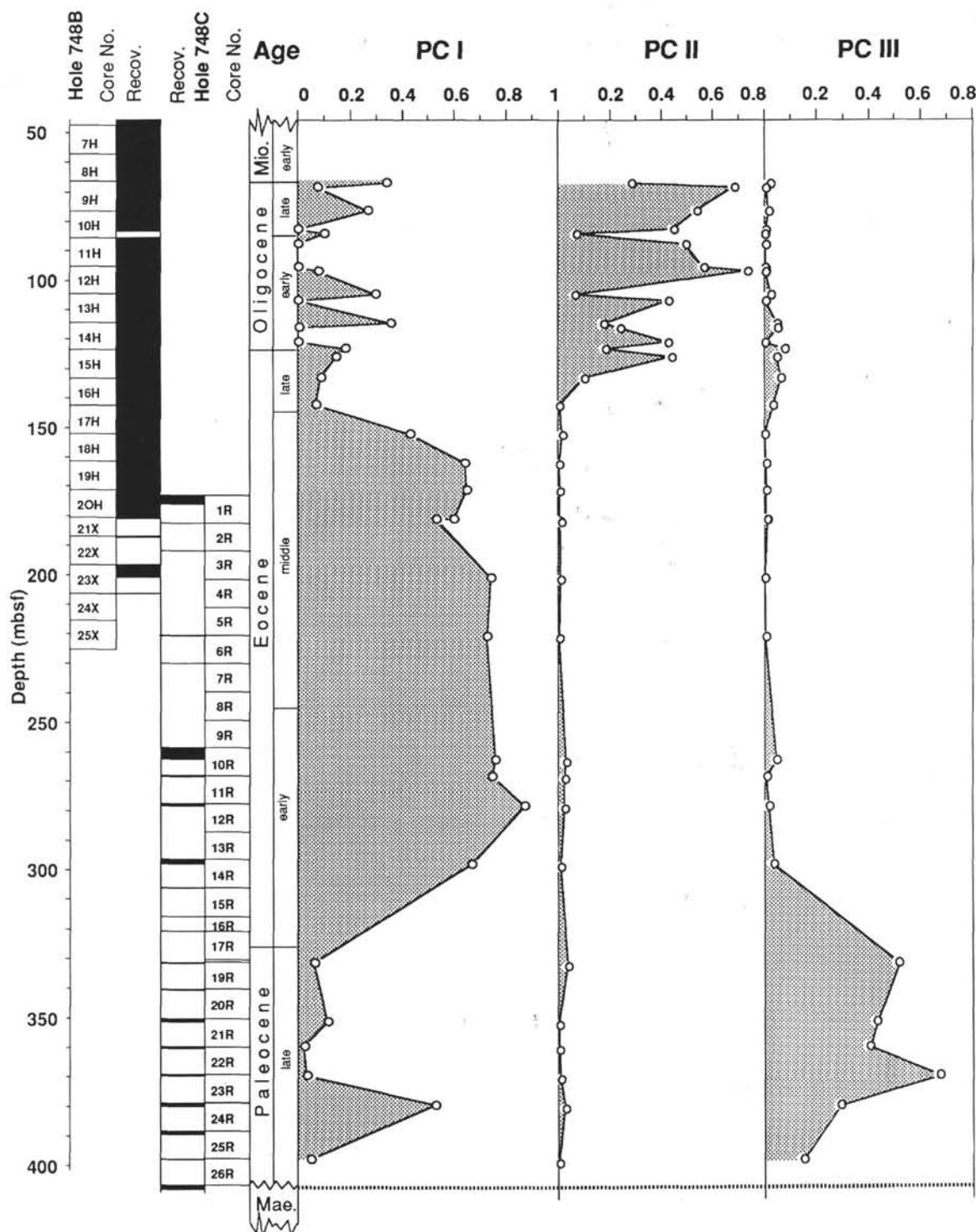


Figure 7. Squared varimax rotated principal component loadings vs. sub-bottom depth at Site 748. Cumulative squared loadings of all principal components give the communality.

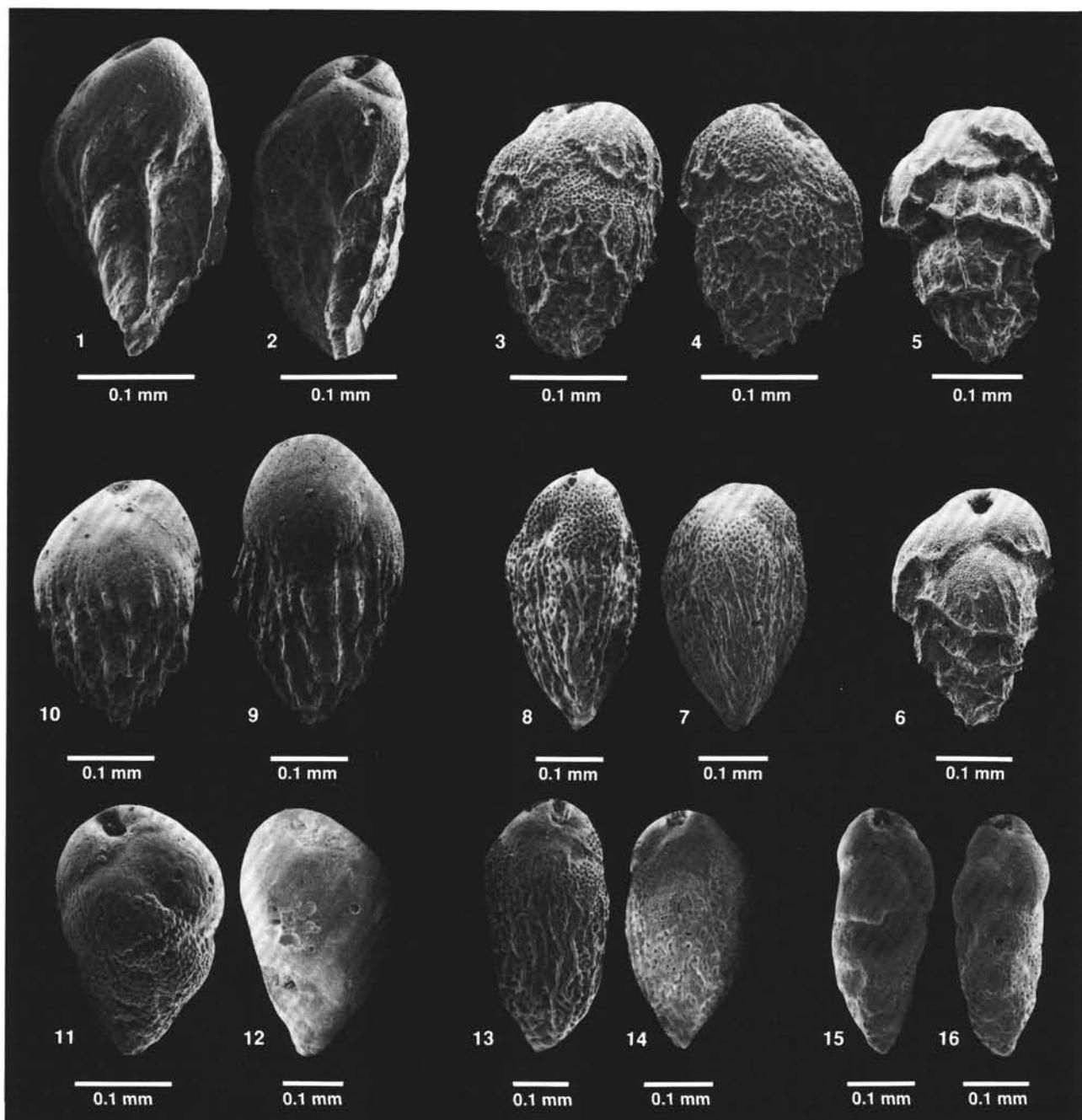


Plate 1. 1, 2. *Bulimina alazanensis* Cushman, Sample 120-748B-20H-CC. 3–6. *Bulimina trinitatensis* Cushman and Jarvis; (3, 4) Sample 120-747C-2R-4, 90–92 cm; (5, 6) Sample 120-747A-19X-CC. 7, 8. *Bulimina semicostata* Nuttall, Sample 120-747C-2R-4, 90–92 cm. 9, 10. *Bulimina macilenta* Cushman and Parker, Sample 748B-21X-CC. 11, 12. *Bulimina bradburyi* Martin; (11) Sample 120-747C-2R-4, 90–92 cm; (12) Sample 120-748C-23R-CC. 13, 14. *Bulimina cf. semicostata* Nuttall, Sample 120-747C-2R-4, 49–51 cm. 15, 16. *Bulimina elongata* d'Orbigny, Sample 120-748B-16H-5, 72–76 cm.

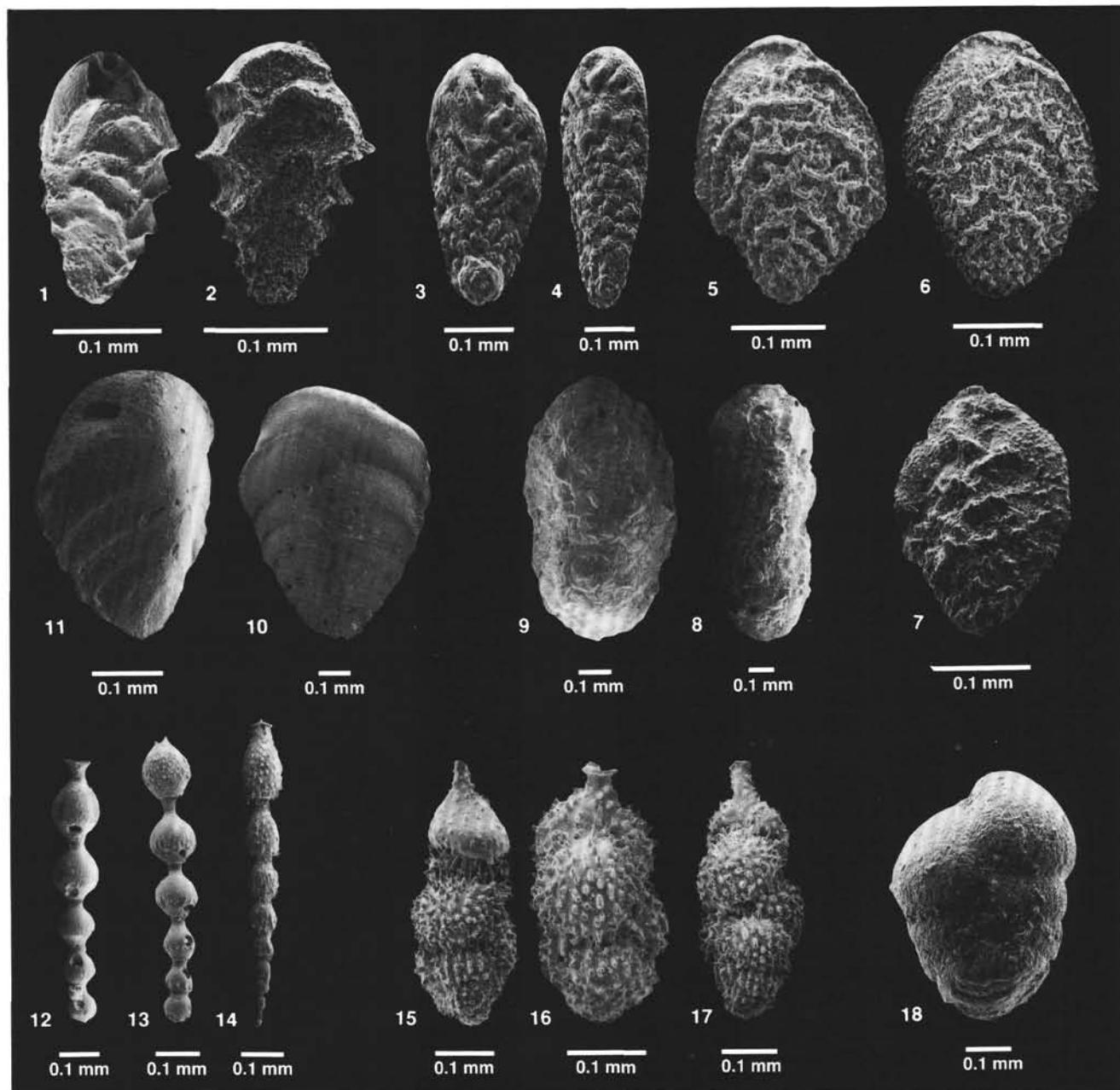


Plate 2. 1, 2. *Tappanina selmensis* (Cushman), Sample 120-748C-23R-CC. 3, 4. *Bolivinoides delicatulus* Cushman, Sample 120-747A-19X-CC. 5, 6. *Aragonia aragonensis* (Nuttall); (5) Sample 120-747C-2R-4, 90–92 cm. 7. *Aragonia velascoensis* (Cushman), Sample 120-748C-23R-CC. 8, 9. *Plectina elongata* Cushman and Bermudez, Sample 120-748B-20H-CC. 10, 11. *Vulvulina spinosa* Cushman, Sample 120-748B-21X-CC. 12, 13. *Stilostomella gracillima* (Cushman and Jarvis), Sample 120-748B-21X-CC. 14. *Stilostomella midwayensis* (Cushman and Todd), Sample 120-748B-21X-CC. 15–17. *Uvigerina elongata* Cole, Sample 120-748C-1R-2, 72–76 cm. 18. *Karreriella chapapotensis* (Cole), Sample 120-747A-19X-CC.

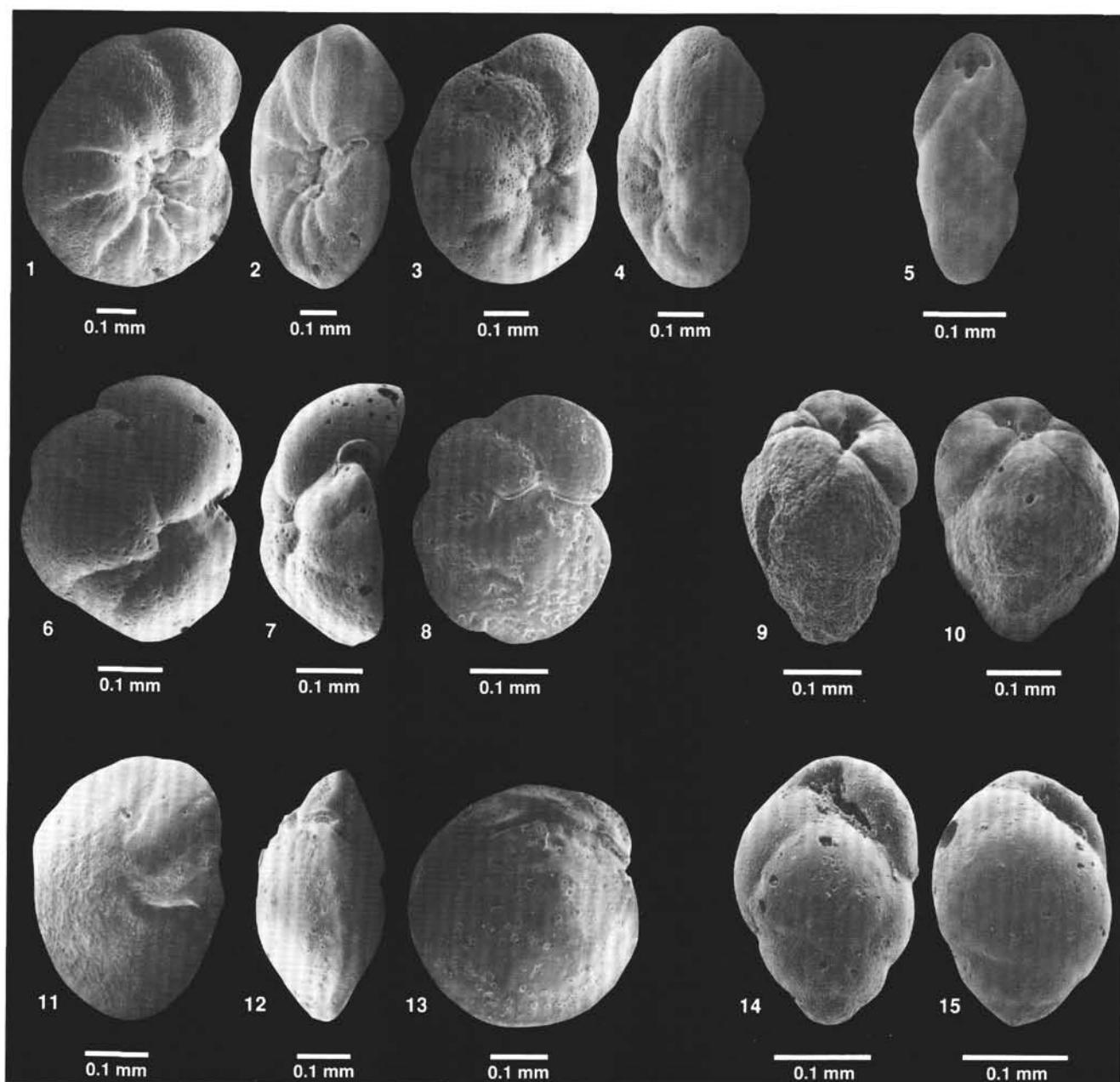


Plate 3. 1–4. *Hanzawaia cushmani* (Nuttall), Sample 120-748B-20H-CC. 5. *Pleurostomella* sp., Sample 120-747C-2R-4, 49–51 cm. 6–8. *Cibicidoides laurisae* (Mallory), Sample 120-748B-20H-CC. 9, 10. *Buliminella grata* Parker and Bermudez, Sample 120-747C-2R-4, 49–51 cm. 11–13. *Cibicidoides* sp., Sample 120-748C-23R-CC. 14, 15. *Turrilina brevispira* ten Dam, Sample 120-747C-2R-4, 90–92 cm.

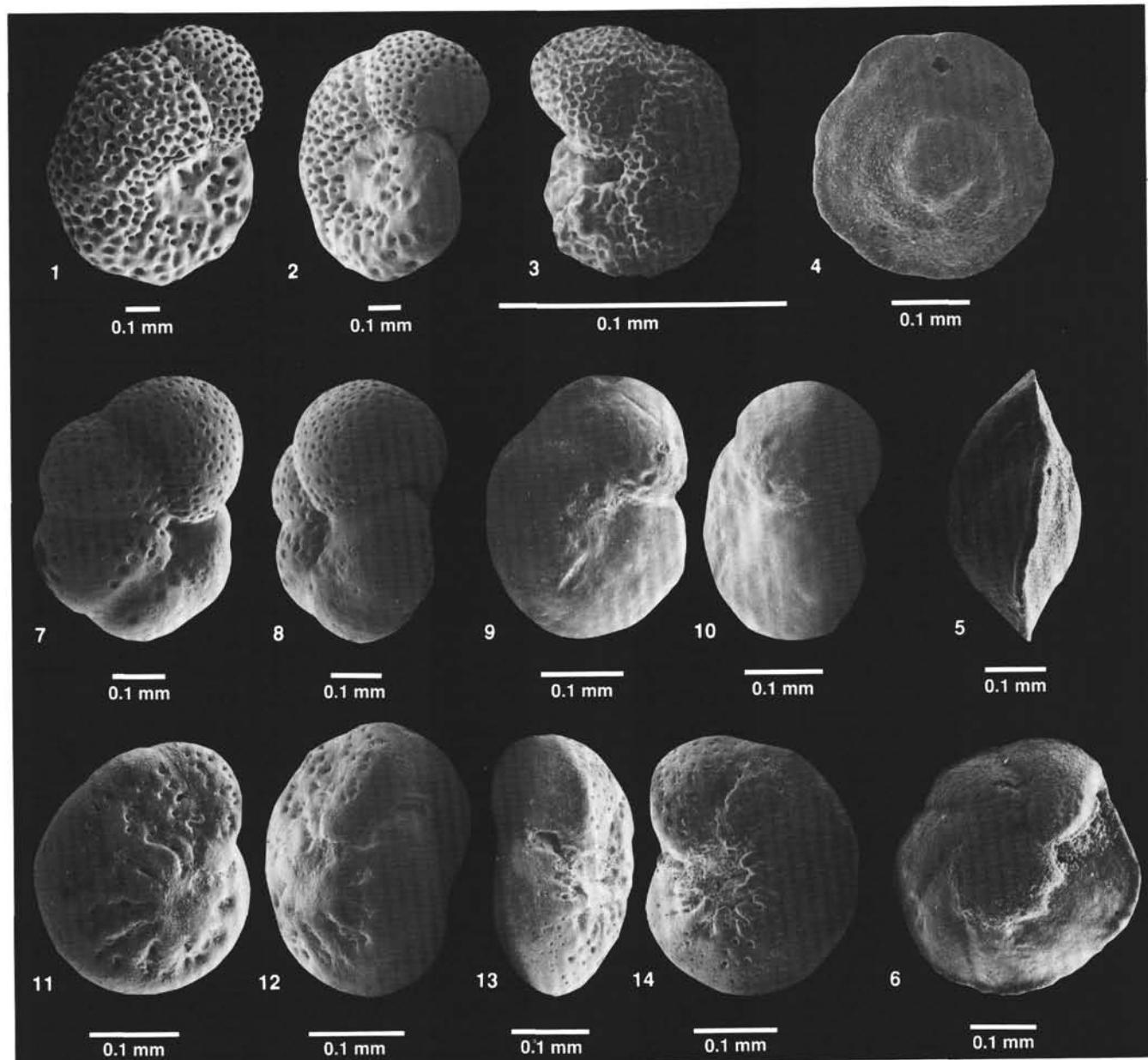


Plate 4. 1–3. *Anomalinoides capitatus* (Gümbel), Sample 120-748B-20H-CC. 4–6. *Nuttallides truempyi* (Nuttall); (5) Sample 120-747C-2R-4, 90–92 cm; (6, 7) Sample 120-747A-19X-CC. 7, 8. *Anomalinoides semicribratus* (Beckmann), Sample 120-748B-20H-CC. 9, 10. *Anomalinoides* sp., Sample 120-748C-23R-CC. 11–14. *Stensioina beccariiformis* (White), Sample 120-748C-23R-CC.

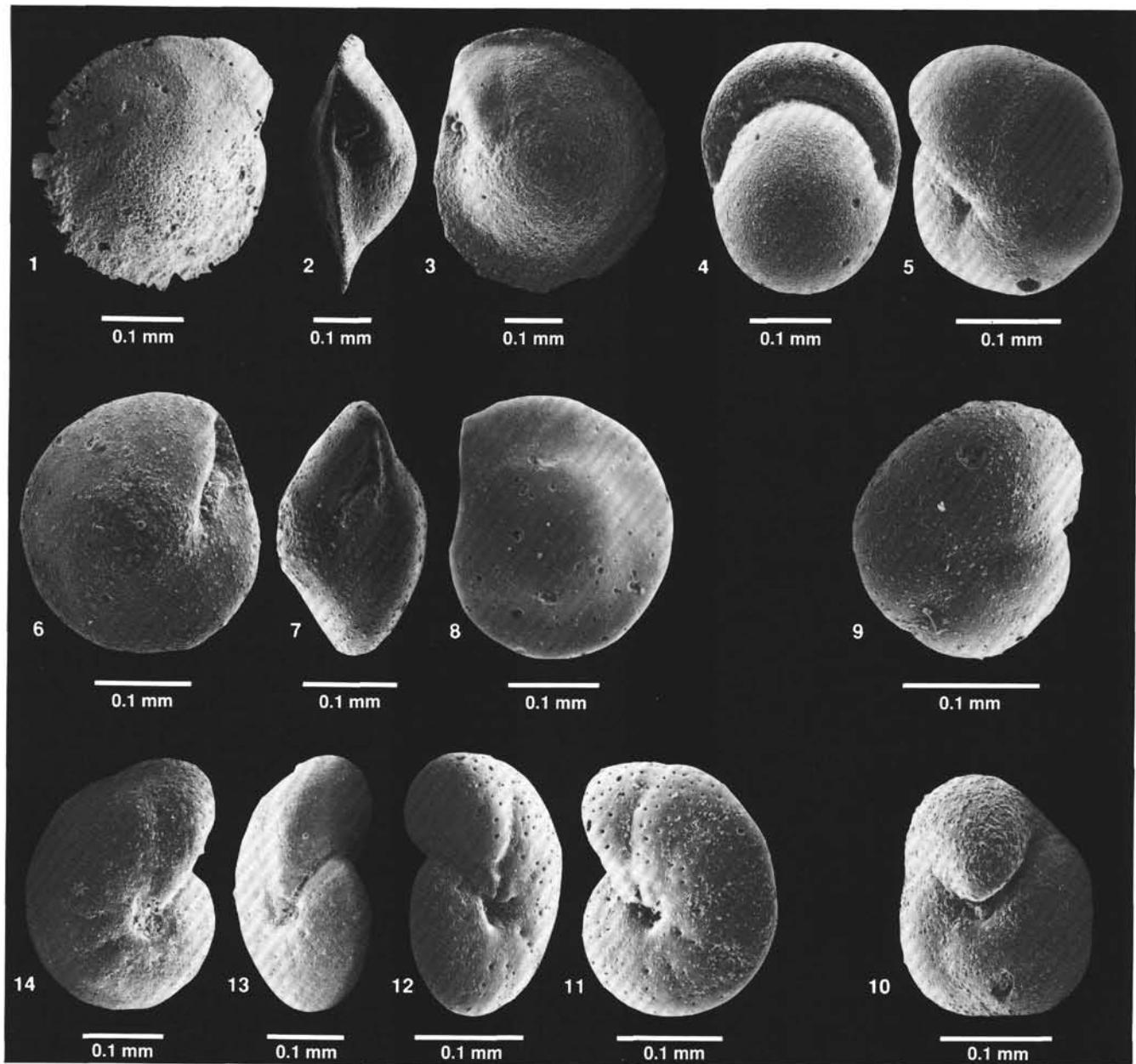


Plate 5. 1–3. *Osangularia velascoensis* (Cushman), Sample 120-747A-19X-CC. 4, 5. *Pullenia coryelli* White, Sample 120-747A-19X-CC. 6–8. *Alabamina dissonata* (Cushman and Renz), Sample 120-747C-2R-4, 49–51 cm. 9, 10. *Abyssamina poagi* Schnitker and Tjalsma, Sample 120-747C-2R-4, 90–92 cm. 11–14. *Anomalinoides spissiformis* (Cushman and Stainforth), Sample 120-747C-2R-4, 90–92 cm.