# 50. OLIGOCENE AND OTHER TERTIARY BENTHIC FORAMINIFERS FROM A DEPTH TRAVERSE DOWN WALVIS RIDGE, DEEP SEA DRILLING PROJECT LEG 74, SOUTHEAST ATLANTIC<sup>1 2</sup>

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#### ABSTRACT

Analyses were made of benthic foraminifers in the >149  $\mu$ m fractions of sediments from five depth-graded sites, 525, 526, 527, 528, and 529, down the flanks of the Walvis Ridge into the southern Angola Basin. Faunal contamination, in part attributed to the coring process, is prevalent through the Miocene at Sites 525, 526, and 528, where extremely large and some modern specimens are emplaced in the faunas. Oligocene-age taxa from Sites 526 and 529 were studied in the greatest detail, in order to allow comparison of faunas from deep water and intermediate water depths through this time.

In the Paleocene, Site 525 (1400 m paleodepth) contained at least 11 species with "Midway" affinities; the adjacent deep-water Site 527 (3200 paleodepth) contained typical Paleocene deep-water taxa, at least 10 of which did not range up into the intermediate water depths at Site 525. The Paleocene/Eocene boundary is indicated by the extinction of *Gavelinella beccariformis* and the first abundant appearance of *Tappanina selmensis* at all paleodepths. Diachrony between these events increases at greater water depths.

Little Eocene-age sediment was well preserved, so faunas were not analyzed except across the Eocene/Oligocene boundary, which was represented by mixing and an erosional hiatus in Hole 526A (near 800 m paleodepth) and short dissolution intervals at Site 529 (near 2800 m paleodepth). Taxonomic overturn across the boundary at these sites is considered ecologically controlled, not evolutionary.

Characteristic Oligocene faunas distinguish Site 526, of intermediate water depth, from deep-water Site 529; taxa restricted to the shallower site include Uvigerina semivestita, Rectuvigerina postprandia, U. spinulosa, Bolivina tectiformis, Nodogenerina sp., Palmula sp., and Cibicides lobulatus. Species richness and the number of benthic specimens/ 0.5 g sediment are both much greater at the intermediate-depth site.

Miocene faunas at Sites 525 and 526 are depleted in benthic foraminifers; this depletion is particularly evident at Site 526, where the benthics were very abundant in the Oligocene. Faunas at the two sites (through 1000–2500 m paleodepth) are markedly similar, although first and last appearances are diachronous through depth. Several originations in Zones N11–N13 are, however, synchronous and may represent the effects of the mid-Miocene glaciation.

Comparison of Pliocene faunas at deep-water Site 525 and at Site 527 (near 4000 m paleodepth) demonstrates higher benthic abundance and diversity at the shallower site. The major change in faunas occurs in Pliocene zones Pl5-Pl6, where faunas again are homogeneous through depth and *Nuttallides umbonifera*, a bottom-water index, occurs in nearly equal abundances at all sites.

### INTRODUCTION

On Leg 74, five sites were drilled along a traverse from the Walvis Ridge crest into the southern Angola Basin to the north. Site locations are shown in Figure 1. The sections recovered at Sites 525, 527, 528, and 529 range from basal Paleocene through Pleistocene; at Site 526, sediments of the upper Paleocene through Pleistocene were recovered. (See Fig. 2.)

From the Oligocene of Sites 526 and 529, benthic foraminifers from the >149  $\mu$ m fraction of sediments in core catchers and one additional sample per core were analyzed. Through the Tertiary section at other sites, one sample per core was analyzed. Benthic foraminifers from 0.5 g of sediment were picked, identified, and counted for the Oligocene at Sites 526 and 529, for one core from Miocene sediments at Site 525, and for the Pliocene at Sites 525 and 527. Specific "diversity" is a simple estimate of species richness.

## BIOSTRATIGRAPHY OF BENTHIC FORAMINIFERAL FAUNAS

## Paleocene

Incomplete Paleocene sections were recovered from Sites 525, 527, 528, and 529. Hole 526C bottomed in shallow-water carbonate sands and limestone which, according to nannofossil data (Manivit, in press), may have been late Paleocene in age. These sediments contain only few abraded larger foraminifers which are not described in this study.

The Paleogene sections were subdivided according to the biostratigraphic zonation of Hardenbol and Berggren (1978). The most complete section was found at Site 527, which includes small thicknesses of all Paleogene zones. At the other sites, Zones P1d and P2 are missing; Zone P3a is only found mixed into Zone P1 levels at Site 528. Site 529 (and to a lesser degree, Site 528) contains several slumps in the mid and upper Paleocene.

Benthic foraminifers from the Paleocene of Holes 525A and 527 are listed in Figures 3 and 4. At both sites the preservation is moderate to good, but it is generally better at Site 527. Although the section at Site 525 is less

Hay, W. W., Sibuet, J.-C., et al., *Init. Repts. DSDP*, 75: Washington (U.S. Govt. Printing Office).
 <sup>2</sup> Moore, T. C., Jr., Rabinowitz, P. D., et al., *Init. Repts. DSDP*, 74: Washington (U.S.

<sup>&</sup>lt;sup>4</sup> Moore, T. C., Jr., Rabinowitz, P. D., et al., *Init. Repts. DSDP*, 74: Washington (U.S. Govt. Printing Office).



Figure 1. Location map of Leg 74 site.

complete, it contains longer sections of the zones represented. Site 527 was drilled at significantly greater depths than was Site 525. Paleodepth estimates derived from the backtrack curve in Figure 5 indicate that in the Paleocene Site 525 lay close to 1400 m depth, and Site 527 near 3200 m depth.

Taxa present in the shallower Hole 525A but not at Site 527 include Lagena sulcata, Bolivina crenulata, Dentalina naheolensis, Nodosaria latejugata, Frondicularia sp., Vulvulina spinosa, Robulus turbinatus, Gavelinella danica, Allomorphina paleocenica, Globulina gibba, and Coryphostoma midwayensis. Most of these species were identified originally by Cushman (1951) from shallow, onshore Midway sections of the Gulf Coast of the United States.

The species restricted to Site 527 in the Paleocene are Abyssamina poagi, Clinapertina inflata, Cibicidoides cf. tuxpamensis, Gavelinella hyphalus, Gaudryina spp., Spiroplectammina haeringensis, N. limbata, Ammobaculites sp., D. eocenica, and D. nasuta.

Most of the appearances or disappearances at these sites are considered to reflect varying ecologic conditions. Species which first appear synchronously at both sites may indicate first appearances: they are *Bolivinopsis cubensis* and *Bulimina quadrata* in Zone P3b, and *Tappanina selmensis* and *Globocassidulina subglobosa* in Zone P6.

### **Paleocene/Eocene Boundary**

Three apparently complete Paleocene/Eocene boundary sequences were recovered on Leg 74, at the shallower Site 525 and the two deeper Sites 527 and 528. The boundary was initially located by planktonic foraminifers (Fig. 6).

The major evolutionary change in Tertiary benthic foraminifers occurs at the Paleocene/Eocene boundary and is signalled worldwide by (*inter alia*) the extinction of *Gavelinella beccariformis*, the ecologic reappearance and entrance into deeper marine sections of *Tappanina selmensis*, the appearance of common Eocene buliminids, and a decrease in size of most benthic species across the boundary (R. C. Tjalsma, personal communication, 1982). These events were determined in detail at the three Leg 74 sites and compared with the placement of the boundary based on planktonic foraminifers. As shown in Figure 6, the exact timing and nature of these events may be depth-related, as follows:

1) At all sites, *T. selmensis* appears before *G. bec-cariformis* becomes extinct; however, the offset between the two events is significantly less at the shallower Hole 525A;

2) At all sites the decrease in size of the benthic individuals occurs just following an excursion in carbon isotopes (Shackleton and Hall, in press); there is a significant offset between the carbon isotope excursion and the evolutionary events among the benthic foraminifers at Sites 525 and 527, but changes in the foraminifers bracket both the boundary and the carbon isotope excursion at Site 528.

#### **Eocene-Oligocene**

Incomplete Eocene sections were recovered at all sites. Because of the small, discontinuous segments of material recovered from this time period, the benthic foraminifers were not studied in detail.

A somewhat mixed, but relatively complete Eocene/ Oligocene boundary sequence was found at Site 529. Marking the boundary were the disappearance of *Nuttallides truempyi*, the appearance of *N. umbonifera*, a dissolution horizon and a reduction in benthic abundance, and a short-lived influx of miliolids just above the boundary and above the dissolution horizon.

A nearly complete Oligocene sequence was recovered at Site 529; benthic species through this interval are listed in Figure 7. Sediments throughout the sequence are well preserved, with the exception of the dissolution horizon across the boundary. Some mixing of Eocene into Oligocene was observed at discrete intervals in the lower Oligocene. A long, but less complete section ranging from Zones P19/20 through Zone P22 was drilled in Hole 526A. As shown in Figure 5, this site lay near 800 m through the course of the Oligocene and thus was in a markedly different watermass from Site 529. Species at Site 526 are listed in Figure 8.

Most appearances or disappearances of species are diachronous between the two sites and are considered ecologically controlled, except for (1) the appearance of *Uvigerina pygmaea* at the base of Zone P22; and (2) the appearance of *Rectuvigerina postprandia* at the base of Zone P20.

## **Miocene-Pliocene**

Long, but incomplete Miocene sections were recovered at all but the deepest Site 527, which apparently lay below the foraminiferal CCD during this epoch. The sediments are uniformly well preserved; short hiatuses and poorer preservation occur in the middle/lower Miocene boundary interval. Unfortunately, in the top sections of many cores, particularly at the HPC sites, coarse, sizesorted Miocene-Pliocene sediments were emplaced by the coring process. This downhole contamination has rendered biostratigraphy more difficult and has confused interpretation of the benthic faunas.

Miocene benthic species are listed in Table 1 and Figure 9 for the two shallowest sites, 525 and 526. As shown in Figure 5, at this time Site 525 had a depth near its present depth of 2450 m; Site 526 was located at 900-1000 m paleodepth.

Faunas at Site 526 contain many species deriving from the Oligocene, such as *Cibicides lobatulus, Textularia mexicana*, and *Rectuvigerina postprandia*, which recur episodically through the Miocene. The major time of faunal turnover is Zones N12-13, when several species, including *Sphaeroidina bulloides*, disappear and eight new species first appear in the faunas. These include the characteristic Pliocene species Pleurostomella alternans, Bulimina mexicana striata, and Stilostomella lepidula.

At Site 525 Miocene benthic foraminifers are not common in any sample, and only abbreviated lists were compiled of the several taxa which did occur in a  $10 \text{ cm}^3$ sample. Most species which appear by Zone N14 range into and through the Pliocene (see Table 1).

# PALEOECOLOGY

Several more detailed paleoecologic studies were undertaken in order to examine

1) the relation of benthic faunas to the depths along the depth traverse and hence to water masses at the several different bottom depths;

2) the utility of benthic faunas for predicting the depth of a site in the past;

3) the relation between benthic faunas and burrowing cycles and sediment disturbance; and

4) the effect of dissolution on benthic faunas.

### Faunal Change with Depth

Variation in benthic faunas with depth through the early Paleocene was examined qualitatively by making a census of the most common three or four species or genera at Sites 525, 528, and 527, which range in paleodepths (Fig. 5) from approximately 1400–3500 m in the early Paleocene to 2200–4200 m by the late Eocene. These faunas and their variability through time are shown in Table 2. Throughout this time the shallower Site 525 was dominated by *Nuttalides truempyi*, *Gavelinella beccariformis*, and/or *Osangularia mexicana*. *Nuttallides* and pleurostomellids were typical of the intermediate Site 528, whereas at the deepest site *Nuttallides*, *Aragonia* spp., and the stilostomellids are the most common components of the faunas.

Detailed analyses of the Oligocene faunas at Site 526, at a paleodepth near 600 m, and at Site 529, lying closer to 2800 m, included counts of all species in 0.5 g of sediment of the >64  $\mu$ m fraction. Comparative samples from Sites 525 and 363 (Leg 40) were also counted and the results are shown in Figures 10–12.

Over 41 species were identified from the Oligocene of Site 526 in sediments of Zones P20–P22 age. Species diversity is lower at the base of Zone P20, increases through Zones P20 and P21, then decreases again slightly near the top of Zone P22. The Benthic Number (the number of benthic specimens in 0.5 g of sediment) is very high at this site, averaging near 400 specimens (Fig. 10). The percentage of rectilinear benthic specimens is higher in Zone P20 and decreases gradually through the course of the upper Oligocene.

In Zone P20 at Site 526 (Fig. 11) faunas contain large proportions of uvigerinids and stilostomellids, and slightly fewer buliminids. By Zone P21b the faunal content changes: *Cibicides, Robulus*, and the agglutinated foraminifers increase in import so that they occur in nearly equal amounts with *Stilostomella* spp. Uvigerinids remain the most abundant forms. By the end of the Oligocene stilostomellids and cibicidids dominate the faunas along with significant numbers of agglutinants.

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Figure 2. Biostratigraphic sections, Leg 74 sites.

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Figure 2. (Continued).

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Epoch	P Zone	Core-Section (level in cm)	Gavelinella beccariformis (White)	Nuttallides truempyi (Nuttall)	Nuttaniaes ianaia (Dioizen) Triavia naleocenica Tialema and I ohmann	Lapena sulcata (Walker and Jacob)	Pullenia auinaueloba (Rcuss)	Pullenia coryelli White	Dorothia trochoides (Marsson)	Tritaxia trilatera (Cushman)	Bolivina crenulata Cushman	Aragonia ouezzanensis (Rey)	Anomalinoides acuta (Plummer)	Bulimina trinitatensis Cushman and Jarvis	Stilostomella paleocenica (Cushman and Todd)	Dentalina naheolensis Cushman and Todd	Dentalina wilcoxensis Cushman	Gyroidinoides globulosa (Hagenow)	Spiroplectammina laevis (Roermer)	Gavelinella velascoensis (Cushman)	Alabamina creta (Finlay)	Gyroidinoides girardana (Reuss)	Pleurostomella paleocenica (Cushman and Todd)	Nodosaria latejugata Guembel	Bulimina midwayensis Cushman and Parker	Gyroidinoides aequilateralis (Plummer)	Spiroplectammina mexiaensis Lalicker	Osangularia velascoensis (Cushman)	Coryphostoma midwayensis Plummer	Gavelinella semicribrata (Bermudez)	Guttulina problema d'Orbigny	Robulus cf. rosettus (Guembel)	Paimula sp.	Fronaicularia sp.	Nonion navanense Cusimian and Definitudez Nacenonides hilloheandti (Fischer)	iveoepontaes nuteoranati (riscuci) Vuluulina enimoca Cuehman	Amonio udeconarie (Cuchman)		Builminella grata (Farker and Bermudez)		BORMROPSIS CHOERSIS (CUSINNAIN AND BERMUGEZ)	Cibicidalities spp.	Ortaorsaits umbonatus (Keuss)	Kobulus furbinatus (Plummer)	Robulus whilei (Tjalsma and Lohmann)	Gavelinella danica (Brotzen)	Stilostomella midwayensis Cushman and Todd	Schenckiella sp.	Marginulina scitula Bornemann	Allomorphina paleocenica Cushman	Siphogenerinoides eleganta (Plummer)	Globulina gibba d'Orbigny	Clavulinoides midwayensis Cushman	Quadrimorphing profunda Schnitker and Tjalsma	Cibicidoides pseudoperlucidus (Cole)	Giobocassidulina subgiobosa (Brady)	tuppannina seimensis (Cusuman) Rulimina valoscoancis (Cushman)	Duiming velascoensis (Cusuman) Dullenia mudriloha Reuce	Futurnia quadritora reass	
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Figure 3. Stratigraphic ranges of most common benthic foraminifers through the Paleocene of Hole 525A. Samples are zoned according to the timescale and zonation of Hardenbol and Berggren (1978).

Epoch	P Zone	Core-Section (level in cm)	 Ciocidotaes ci. dayi (winte) Minimilidas truemnui (Nintrall)	Alabamines tracingue (Funda)	Gavelinella velascoensis (Cushman)	Anomalinoides acuta (Plummer)	Neoeponides hillebrandti Fischer	Spiroplectammina mehiaensis Lalicker	Gyroidinoides globulosa (Hagenow)	Dentalina wilcoxensis Cushman	Stilostomella midwayensis Cushman and lodd	Nonion havanense Cushman and Bermudez	Gyroidinoides girardana (Reuss)	Builming trinitalensis Cushman and Jarvis	Kobutus all. rosettus (Jucmoci)	Aragonia velascoensis (Cushman)	Osanguaria velascoensis (Cusuman)	Tritovia naleocenica Tialsma and I ohmann	Snironlectammina haerineensis (Guembel)	Chrvsalosonium sn.	Gavelinella heccariiformis (White)	Rohuhus miduavonsis (Plummer)	Oridorealis umbonatus (Reuss)	Oridorsatis uniformatus (Actuss) Pleurostomella paleocenica Cushman	Pullenin corvelli White	Aragonia Quezzanensis (Rev)	Dorothia trochoides (Marsson)	Cibicidoides spp.	Guttulina problema d'Orbigny	Nodosaria limbata d'Orbigny	Bulimina midwayensis Cushman and Parker	Bolivinopsis cubensis (Cushman and Bermudez)	Siphogenerinoides eleganta (Plummer)	Quadrimorphina profunda Tjalsma and Lohmann	Buliminella beaumonti Cushman and Renz	Nuttallides lunata (Brotzen)	Ammobacuities sp.	Condensing automidate Cushman	Palmula cf. rueosa d'Orbiany	Bulimina auadrata Plummer	Pullenia auadriloba Reuss	Nuttallinella sp.	Tritaxia tritatera (Cushman)	Dentalina inepta Cushman	Gavelinella hyphalus (Fischer)	Marginulina scitula Bornemann	Cibicidoides pseudoperlucidus (Cole)	Gavelinella semicribrata (Bermudez)	Dentalina eocenica Cushman	Cibicidoides cf. tuxpamensis (Cole)	Pullenia quinqueloba (Reuss)	Clinaperting inflata 1 jalsma and Lohmann	Boirvinoiaes deucatuta Cushinan Tonnonina colmonsis (Cushman)	Tuppuntus serrerata (Custinum)	Globocassidulina subglobosa (Brady)	Abyssamina poagi Schnitker and Tjalsma
	P6	23-1, 30 24-3, 30	1			-		ĩ	I		i.	1				I		1			ĩ	1			1	1				1		ĩ	1	1		ļ			I		ï		ĩ		ĩ		Ĩ	ì		ĩ		1		1	1	I
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cene	P3	28-4, 89 29-2, 100 30-4, 41										-													İ				1	i	1			Ì	I.	1	Ľ		1	1	1	1	ļ													
	P1	31-3, 95 31-5, 92	L							Î				1					1	İ						i	i	İ	1																											

Figure 4. Stratigraphic ranges of most common benthic foraminifers through the Paleocene at Site 527. Samples are zoned according to the zonation of Hardenbol and Berggren (1978).





Figure 5. Depth versus age, crustal cooling and subsidence curves for the Leg 74 sites compiled by T. Moore. Ages (in m.y.) are derived from the timescale of Hardenbol and Berggren (1978) and Berggren (1972).

Core	Section		Ho	le 52	7	Core	Section		н	ole	528		Core	Section		Ho	ole 5	25 <i>A</i>	\$
23	cc-	Eocene	thics		Т	21	cc-	Eocene	Smaller-sized	benthics		-	30	cc-	Eocene			T	
	1-	-	Smaller-sized ben		riformis		1.	ninate age	c 13~ 1	2.0		formis		1 -			selmensis		
24	2 -	eocene	13C	selmensis	linella beccai	22	2 -	Indetern				inella beccari		2 -			Tappanina		ormis
	3 -	Pa	181	Tappanina	Gave		3	Paleocene			T. selmensis	Gavel	31	3 -	Paleocene		Γ		linella beccariif
														4 -		iized benthics			Gave
														5 -		Smaller-			
														6	t		δ <sup>13</sup> C	1	

Figure 6. Stratigraphy of events across the Paleocene/Eocene boundary in Holes 527, 528, and 525A. The Paleocene/Eocene boundary indicated on the figure is estimated on the basis of planktonic foraminifers according to the zonation of Hardenbol and Berggren (1978). Also plotted are the levels of the extinction of *Gavelinella beccariformis* and origination of *Tappanina selmensis*, the level of the carbon isotope excursion (Shackleton and Hall, in press), and the point above which benthic foraminifers become smaller in size.

Table 1. Commonly occurring	Miocene-Pliocene benthic fora-
minifers in Hole 525B.	

Core- Section (level in cm)	Zone	Species and genera
Through the upp	per Mioc	ene
16-2, 100	N17	Osangularia culter, Uvigerina hispido-costata, Pyrgo spp., Globocassidulina subglobosa, Chrysalogo- nium spp.
18-1, 53	N16	Eggerella bradyi, Planulina rugosa, G. subglobosa, Oridorsalis umbonatus, Pyrgo spp.
19-2, 66	N16	<ol> <li>culter, Oridorsalis umbonatus, Textularia mexi- cana, Gyroidinoides altiformis, Laticarinina halophora, Globocassidulina subglobosa, Cibici- doides granulosus.</li> </ol>
24-2, 64	N16	O. umbonatus, Gyroidinoides altiformis, Angulo- gerina angulosa, Triloculina spp., C. granulosus, Nuttallides umbonifera, Stilostomella lepidula.
25-2, 55	N16	Globocassidulina subglobosa, Osangularia culter, C. granulosus, Planulina rugosa, N. umbonifera, Epistominella exiguua, Karreriella sp.
26-2, 120	N16	U. hispido-costata, Bulimina alazanensis, G. subglo- bosa, B. striata mexicana, S. lenidula.
27-2, 60	N15	Planulina renzi, Cibicides wuellerstorfi, O. culter, G. subglobosa, C. granulosus, Chrysalogonium
29-2, 73	N15	Oridorsalis umbonatus, G. subglobosa, S. lepidula, N. umbonifera, Pullenia quinqueloba, Uvigerina guberiena, B. alagameric, L. kalanhora
31-2, 50	N14	Heterolepa kullenbergi, G. subglobosa, Chrysalogo- nium sp., Vulvulina spinosa, Ehrenbergina spinossissima, L. bullbrooki, Osangularia culter, Gavelinella semicribrata, N. umbonifera, B. alazanensis.
32-3, 55	N14	S. lepidula, B. alazanensis, Globocassidulina sub- globosa, O. culter, Planulina renzi, C. wueller- storfi, Bolivina subaenariensis, Oridorsalis umborature
34-2, 55	N14	Bulimina alazanensis, B. striata mexicana, G. subglobosa, O. umbonatus, N. umbonifera, B.
35-2, 55	N14	suoaenariensis. C. wuellerstorfi, N. umbonifera, P. renzi, U. pyg- maea, E. bradyi, Siphonodosaria modesta, O. umbonatus, Cibicidoides cf. spirolimbatus, pullenia bulloidee Cassidulina crassa
36-2, 55	N14	G. subglobosa, E. bradyi, U. hispido-costata, N. umbonifera, Karreriella bradyi, C. wuellerstorfi, Cibicidoides cf. spirolimbatus, O. umbonatus, B. alazanensis.
Through the Plic	ocene	
1,CC	N23	G. subglobosa, Sigmoilopsis schlumbergeri, O. umbonatus, H. kullenbergi, C. wuellerstorfi, B. alazanensis, L. halophora, N. umbonifera, E. bendri, U. bingido contest. U. paraming.
2,CC	N22	Pyrgo spp., G. subglocossala, C. pergrina. Pyrgo spp., G. subglocossa, H. rugosa, H. kullen- bergi, U. hispido-costata, O. umbonatus, No- torotoli sp. Pullenia bullaides. Tilocyling spp.
3,CC	N22	U. peregrina, U. pygmaea, L. halophora, C. wuel- lerstorfi, H. kullenbergi, B. alazanensis, S. schlumbergeri
4,CC	P15-6	U. pygmaea, Planulina spp., G. subglobosa, Nuttal- lides umbonifera, Pyrgo spp., S. schlumbergeri.
5,CC	P14	O. umbonatus, Stilostomella lepidula, L. ha- lophora, H. kullenbergi, Pleurostomella al- ternans, Osangularia culter, Pullenia bulloides, C. wuellerstorfi, U. hispido-costata, S. schlum- bergeri, N. umbonifera, Gavelinella semicribra- ta
6,CC	P13	C. wuellerstorfi, Bulimina consanguinea, N. umbo- nifera, O. culter, Textularia mexicana, U. pyg- maea, Globocassidulina subglobosa, B. alaza- nensis, Gavelinella semicribrata, Oridorsalis umbonatus.
7,CC	P13	Stilossomella lepidula, C. wuellerstorfi, miliolid fragments, U. auberiana, U. pygmaea, T. mexi- cana, H. kullenbergi, O. umbonatus, Osangula- ria culter, Pullenia quinqueloba, U. hispido- costata, L. halohora.
9,CC	P12	N. umbonifera, Globocassidulina subglobosa, P. bulloides, O. umbonatus, U. hispido-costata, E. bradyi, S. lepidula, C. wuellerstorfi, H. kullen- brady.
11,CC	Pl 1	oergi. Miliolid fragments, U. hispido-costata, E. bradyi, G. subglobosa, P. bulloides, C. wuellerstorfi,
12,CC	Pl 1	various iagenias. G. subglobosa, miliolid fragments, H. kullenbergi, Oridorsalis umbonatus, Triloculina spp., Pyrgo
15,CC	Pl 1a	spp. Uvigerina hispida, H. rugosa, G. subglobosa, Pyrgo spp., S. schlumbergeri, O. umbonatus.

Note: For aminifers were picked from the >149  $\mu$ m fractions. Samples are zoned according to Berggren (1972).

Diversity	P Zone	Epoch	Core	Bulimina semicostata Nuttall	Globocassidulina subglobosa (Brady) Demontorio movienna (Cola)	Pullenia quinqueloba (Reuss)	Cibicidoides havanensis (Cushman and Bermudez)	Anomainolaes aragonensis (nuttatt) Sinhonodosaria modesta (Bermudez)	Bolivinopsis cubensis (Cushman and Bermudez)	Stilostomella subspinosa (Cushman)	Heterolepa ungeriana (d'Orbigny)	Buliminella grata (Parker and Bermudez)	Miliolids	Nuttallides umbonifera (Cushman)	Bulimina alazanensis Cushman	Heterolepa mexicana (Nuttall)	Gyroidinoides planulata (Cushman and Renz)	Heterolepa grimsdalei (Nuttall)	Cibicidoides haitiensis (Coryell and Rivero)	Uvigering spinicostata Cushman and Jarvis	Vulvulina spinosa Cushman	Bulimina consanguinea Parker and Bermudez	Bulimina jarvisi Cushman and Parker	Bulimina macilenta Cushman and Parker	Karreriella chilostoma (Reuss)	Robulus occidentalis (Cushman) group	Oridorsalis umbonatus (Reuss)	Cibicidoides tuxpamensis (Cole)	Stilostomella abyssorum (Brady)	Pullenia bulloides (d'Orbigny)	Planulina renzi Cushman and Stainforth	Heterolepa trincherasensis (Bermudez)	Cassidulinoides bradyi (Norman)	Bolivina tortuosa Brady	Karreriella chapapotensis (Cole)	Uvigerina pygmaea d'Orbigny
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12 12 6 7 7	P19- P18	cene	18 19																Ĩ																	
12 12 19 19	P17		20 21 22																			I		İ		İ										

Figure 7. Stratigraphic ranges of most common benthic foraminifers through the Oligocene at Site 529. Samples are zoned according to the zonation of Hardenbol and Berggren (1978).

Table 2. Most common Maestrichtian-Paleogene benthic foraminifers at the shallower Site 525, intermediate Site 528, and deep Site 527 on the Walvis Ridge.

Site	Maestrichtian	Lower Paleocene	Upper Paleocene	Lower Eocene	Mid-upper Eocene
527	Gyroidinoides	Nuttallides	Aragonia	N. truempyi	Anomalina
	Lenticulina	Stilostomella	N. truempyi	G. subglobosa	N. truempyi
	Gavelinella	G. beccariiformis	S, abyssorum	S. gracillima	A. aragonensis
			G. beccariformis	A. velascoensis	S. gracillima
528	Gyroidinoides	Gavelinella beccariformis	Pleurostomella	Pleurostomella	A. aragonensis
	Cibicidoides	Nuttalides truempyi	N. truempyi	N. truempvi	N. truempyi
		Lenticulina	Nodosariids	Nodosariids	Anomalina
525	Gavelinella	N. truempyi	G. beccariformis	N. truempvi	N. truempvi
	Praebulimina	G. beccariformis	N. truempyi	Osangularia	O. mexicana
	Gyroidinoides	Anomalina	Vulvulina	Stilostomella	S. abyssorum
	Lenticulina .	Cibicidoides		Vulvulina	Nodosariids

Note: Genera and/or species are listed in order of abundance.

At Site 529 over 35 species were identified through the nearly complete Oligocene section (Fig. 7). Diversities and the Benthic Number are relatively low (Fig. 10); diversity decreases slightly above Zone P17, increases again from Zone P19–P20, then drops in Zones P21– P22.

Lower Oligocene faunas (Fig. 10) at Site 529 are dominated by stilostomellids and *Oridorsalis umbonatus* with lesser percentages of cibicidids and the agglutinants. By the upper Oligocene the percentages of stilostomellids increases, with nearly equal but subsidiary amounts of *Oridorsalis*, cibicidids, and buliminids. Agglutinants drop markedly in importance by the Oligocene. For comparative purposes the generic contents of faunas from two intermediate-depth sites, 525 and 363, farther to the east on the Walvis Ridge, are shown in Figure 11. Faunas at these two sites are markedly different from those at either Site 526 or Site 529.

Comparison of species between Sites 526 and 529 indicates that many species are unique to one or the other site. Species found only at Site 526 are Uvigerina semivestita, U. spinulosa, Rectuvigerina postprandia, Bolivina tectiformis, Discocibicides sp., U. camagueyana, Oridorsalis ecuadorensis, Gavelinella semicribrata, Robulus peregrinus, Cibicides lobatulus, Sphaeroidina bulloides, Cassidulina crassa, Cibicidoides whitei, C. io, and Nodogenerina sp.

Species found at Site 529, but not at Site 526, include Bulimina consanguinea, B. semicostata, Uvigerina spinicostata, Buliminella grata, Cassidulinoides bradyi, Nuttalides umbonifera, Bulimina jarvisi, Cibicidoides haitiensis, and Bolivinopsis delicatulus.

Abundances of several species among the Oligocene sites appear to vary with depth, as shown in Figure 12. Although *Buliminella grata, O. umbonatus*, and *Globocassidulina subglobosa* occur at all four sites, they are significantly more abundant at the deeper Site 529 and least abundant at the shallowest Site 526. The opposite pattern is demonstrated by *Bulimina alazanensis*, which is more abundant at Site 526 than at the the other three sites. *Uvigerina spinicostata* is not present at Site 526

Diversity	P Zone	Epoch	Core	Gyroidinoides girardana (Reuss) Gavelinella semirribrata (Bermudez)	Bulimina tuxpamensis Cole	Spiroplectammina haeringensis (Guembel) Pullenia auinaueloba (Reuss)	Uvigerina semivestita Bermudez	Oridorsalis umbonatus (Reuss) Stilioetomella curvatura (Cushman)	Robulus occidentalis (Cushman) group	Globocassidulina subglobosa (Brady)	Bulimina alazanensis Cushman	Planulina renzi Cushman and Stainforth	Heterolepa ungeriana (d'Orbigny)	Bultiming maculenta Cushman and Parker	Citizidation of harmonic (Cuchana and Barmuday)	Cioletaolaes ei, navanensis (Cusimian anu bermuuez) Karreriella chilostoma (Reuss)	Uvigerina cf. auberiana d'Orbigny	Pullenia bulloides (d'Orbigny)	Uvigerina spinulosa Hadley	Anomalinoides alazanensis Nuttall	Oridorsalis ecuadorensis (Galloway and Morrey)	Vulvulina spinosa Cushman	Cassidulina crassa d'Orbigny	Bolivina tectiformis Cushman	Heterolepa trincherasensis (Bermudez)	Cibicidoides io (Cushman)	Heterolepa mexicana (Nuttall)	Nodogenerina sp.	Osangularia mexicana (Cole)	Stilostomella abyssorum (Brady)	Stilostomella subspinosa (Cushman)	Rectuvigerina postprandia Finlay	Dyocibicides sp.	Cibicidoides whitei (Cushman)	Cibicidoides havanensis (Cushman and Bermudez)	Sphaeroidina bulloides d'Orbigny	Cibicides lobatulus d'Orbigny	Anomalinoides aragonensis Nuttall	Uvigerina pygmaea d'Orbigny
19 20	P22		31 32							Ĩ		!													ī		T								1			1	
22 25 25 30	P21	Oligo- cene	33 34 35 36																									İ					1					1	
21 20 13 16 14	P20- P19		37 38 39 40 41																								İ		İ			'	'	1		1			

Figure 8. Stratigraphic ranges of most common benthic foraminifers through the Oligocene at Site 526. Samples are zoned according to the zonation of Hardenbol and Berggren (1978).

but grades from more to less abundant through depth. *Bulimina consanguinea*, a form of *B. alazanensis* with confluent costae, is present at the deepest Site 529 and is most common at the two intermediate depth sites, but is absent at the shallowest Site 526.

Comparison of the Benthic Numbers of the four Walvis sites also demonstrates a gradation: larger numbers of benthics are characteristic of the shallowest site; the smallest numbers are characteristic of the deepest site (Fig. 10).

#### Pliocene

Similar but less detailed analyses were made of Sites 525 and Site 527 through the Pliocene (Figs. 13–14). Benthic foraminifers in 0.5 g of sediment from two fractions (>355  $\mu$ m and <355  $\mu$ m, >149  $\mu$ m) were picked and counted from Hole 525B. These can be compared with counts from the <355  $\mu$ m, >149  $\mu$ m fractions from Site 527 (Fig. 13).

As in the Oligocene the Benthic Number is greater at the shallower site during the Pliocene. The one sample in Zone N17 where that number is higher at the deeper Site 527 reflects the extreme dissolution of planktonic foraminifers in that interval. Above Section 527-14-2, the Benthic Number at Site 527 is less than 100 until the uppermost Pliocene, when it increases both here and at Site 525. The greatest difference between the two sites occurs during the mid Pliocene, when values at Site 525 reach over 600 specimens/0.5 g sediment.

The major change in benthic faunas at Site 525 occurs in the interval from Zones Pl4 through Pl6, when several species including *Nuttallides umbonifera* and *Cibicides wuellerstorfi* increase markedly in abundance. There is little discernible change in the faunas accompanying the large increase in numbers of benthics in Zone Pl3.

Comparison of abundances of C. wuellerstorfi in the fractions >355  $\mu$ m and <355  $\mu$ m, >149  $\mu$ m is representative of other species as well. That is, there is little similarity between the abundance of this species in the two fractions, and little parallelism in the curves of their abundance through the Pliocene. Since there is a much larger population in the <355  $\mu$ m, >149  $\mu$ m fraction, the abundance figures for species in this fraction are probably more accurate.

At Site 527 the Benthic Number is highest in the uppermost Miocene, when the site first rises above the CCD, and again in the uppermost Pliocene, where fragment counts indicate a decrease in dissolution of carbonates (Fig. 13). The Benthic Number reaches its minimum in the mid Pliocene in Zone Pl3. There is significant specific variation through the Pliocene. Uvigerina spp. and C. wuellerstorfi reach peak abundances in Zone Pl1. C. wuellerstorfi and Globocassidulina subglobosa then reach

Epoch	P Zone	Core-Section (level in cm)	Heterolepa kullenbergi (Parker)	Osangutaria mexicana (Cole) Globocassidulina subglobosa (Brady)	Bulimina macilenta Cushman and Parker	Eggerella bradyi (Cushman)	Pullenia quadriloba Reuss	Siphonodosaria modesta (Bermudez) Subaamidina hulloidas d'Orbiano	Spinecontana amonas a crogar Stilostomella abysorum (Brady)	Robulus calcar (Linne)	Purpura spinosa Custinan Pullenia bulloides (d'Orbigny)	Uvigerina cf. auberiana d'Orbigny	Koouius yaquensis Bermuaez Stilostomella subspinosa (Cushman)	Textularia mexicana Cushman	Cassidulina crassa d'Orbigny	Robulus peregrinus (Schwager)	Urinomorphina perversa (sciiwager) Trifarina bradyi Cushman	Gavelinela semicribrata (Bermudez)	Pullenia quinqueloba (Reuss)	Criticizaris ecuatorensis (Janoway and Montey) Cibicidoides in (Cushman)	Uvigerina mexicana Nuttall	Planulina renzi Cushman and Stainforth	Cibicides lobatulus (d'Orbigny) Rolivina tornosa Brady	Bulimina consanguinea Parker and Bermudez	Robulus alazanensis (Cushman)	Rectuvigerina postprandia Finlay	Bolivina tectiformis Cushman	Vulvulina miocenica Cushman	Cibicides wuellerstorfi (Schwager)	Bouving muticostata Cushman Dentaling comilgevits Hantken	Pleurostomella alternans Schwager	Bulimina mexicana striata Cushman	Nodosaria soluta (Reuss)	Stilostomella lepidula Schwager	Pseudoglandulina spinosa Bermudez	Orthomorphina challengeriana Thalmann	Uvgerina spinuosa riaurey Uviserina nrohoscidea Schwager	Bolivina subaenariensis Cushman	Ehrenbergina spinosissima Cushman and Jarvis	Planulina cf. ariminensis d'Orbigny	Planulina Joveolata Brady Textularia of Bintii Cushman	Heterolepa rugosa (Phieger and Parker)	Siphotextularia mincenica Cushman and Todd
	N17	8-2, 60 9-2, 65	1											Ĩ									1													2							I
	N16	11-2, 14					1				ĩ	1					ĩ		1										1					1			Ι.	1	1	0.20			
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Miocene	N9	20-3, 50		1			÷.										- 1						i –				1	T.	i i														
	N6	22-2, 105 23-2, 60		İ									- 12	l		2	1	2	i				1				ł.	1	0														
	N5	24-2, 70 25-2, 80 26-2, 70		.					T								i							1	١		۱																
	N4	27-2, 65 28-3, 75 29-3, 70 30-3, 63						Ì		L			,		l	İ	1	1			1	Ì	1																				

Figure 9. Stratigraphic ranges of most common benthic foraminifers through the Miocene of Hole 526A. Samples are zoned according to the zonation of Berggren (1972).



Figure 10. Counts of benthic foraminiferal faunas plotted against the oxygen and carbon isotope curves for the Oligocene (Shackleton et al., in press). Benthic numbers for four sites are plotted against time through the Oligocene according to the zonation and timescale of Hardenbol and Berggren (1978). The percentage of rectilinear species includes all specimens of *Nodosaria, Bulimina, Uvigerina, Stilostomella, Pleurostomella, Dentalina, Siphonodosaria, Rectuvigerina*, and *Bolivina*.



Figure 11. Percentages of the most common genera found at Sites 525, 526, 363, and 529 in Oligocene Zones P20 and P21b. Generic percentages are expressed as degrees of arc and plotted using the following symbols: U, Uvigerina; B, Bulimina, A, agglutinants, C, Cibicidoides, R, Robulus, S, Stilostomella, and O, Oridorsalis. Samples were zoned according to the zonation of Hardenbol and Berggren (1978).



Figure 12. Gradational abundances of various benthic species through depth at Sites 525, 526, 363, and 529 during the Oligocene. Abundance on this diagram is represented by the direction and amount of opening of the elongate V bracketing each specific name. That is, *Bulimina alazanensis* grades from less abundant at the deepest Site 529 to most abundant at the shallowest Site 526. Paleodepths were taken from the age-depth curve shown in Figure 5.

an abundance peak in Zone PI3. The porcellaneous foraminifers demonstrate a large increase in their numbers near the top of the Pliocene in Zones PI5 to PI6.

Comparison of the faunas between the two sites demonstrates that:

1) Nuttallides umbonifera is more common at the deeper Site 527 through most of the Pliocene, until Zones Pl5 to Pl6, where it increases markedly at the shallower Site 525, but decreases at Site 527.

2) Uvigerina spp. are more common at the shallower Site 525 except near the top of Zone Pl1, where a Uvigerina maximum is reached at Site 527. This maximum is diachronous with the uvigerinid maximum at Site 525.

3) Porcellaneous foraminifers are more abundant and common at the deeper Site 527.

4) There appears to be greater amplitude of specific variability at the deeper Site 527.

#### **Benthic Foraminifers as Paleodepth Estimators**

The presence at Site 526 of large and distinct populations of species of the genus Uvigerina through the Oligocene provided a unique opportunity to test the utility of these forms to predict paleodepths, in comparison with the backtrack estimates of the paleodepths of the site during the Oligocene. Paleodepths for the Site 526 sediments were estimated from the upper Eocene through the Oligocene (Cores 45-30) on the basis of uvigerinid depth indices determined by Boersma (1974) as shown in Table 3. Plots of these depth estimates (Fig. 15) comTable 3. Species of the genus Uvigerina present through the upper Eocene and Oligocene of Hole 526A.

Core	Zone	Estimated paleodepth (m)	Species present
43-41	P15	200-500	Uvigerina semivestita, U. camaguey- ana, U. cocoaensis
42	P16-17	300-600	U. semivestita, U. mexicana
41-40	P19-20	200-500	U. semivestita, U. camagueyana
39	P20	600-800	U. semivestita trans. spinulosa
38	P20	600-1000	U. spinulosa
37-33	P21	600-1000	U. spinulosa with striae restricted to individual chambers
33-30	P22	?600-1000	Rectuvigerina postprandia and U. auberiana, not depth-diagnostic

Note: Samples are zoned according to the zonation of Hardenbol and Berggren (1978). Estimated paleodepths are assigned according to the criteria of Boersma (1974).

pared with the backtrack estimate derived from Figure 5 demonstrate the close correlation of the two estimators. In the upper Eocene and lower Oligocene the uvigerinids give slightly shallower depth estimates than the backtrack curve, but by the upper Oligocene the two curves overlap.

Since Eocene sediments of Zone P14 contain calcareous algae and other carbonate bank material but no planktonic foraminifers, it is possible that the backtrack estimates are too deep. Otherwise agreement between the two curves is excellent and corroborates the potential of uvigerinids to estimate paleodepths, at least through the depth range from  $\sim 200-800$  m in the Eocene to upper Oligocene.

#### **Benthic Faunas and Burrowing**

Properties other than those of bottom watermasses may be determining the content of benthic foraminiferal faunas. Postdepositional processes within the sediment, for example, may significantly alter the benthic thanatocoenoses. Since cores from the Miocene of Hole 525A contain distinct bioturbation cycles, benthic foraminifers and other microfossils through these cycles were picked every 10 cm from 0.5 g of sediment of the fraction <355  $\mu$ m, >149  $\mu$ m. The foraminifers were counted and are compared with sedimentary evidence of burrowing in Figure 16. Carbonate dissolution is estimated by counting the numbers of fragments in 350 particles from the same fraction.

Two types of burrowing cycles are indicated in Figure 16; the first, from 75–90 cm, is associated with an intense dissolution episode at 80 cm; and the second, at 35–47 cm and 95–100 cm, is not associated with evidence of intensified dissolution.

Characteristic of the burrowing and dissolution cycle at 80 cm are

1) a major increase in fragmentation;

2) a minimum Benthic Number (the number of benthic individuals in 0.5 g of sediment);

3) a decrease in the number of echinoid remains;

4) a maximum of agglutinants and a maximum abundance of the agglutinated species, *Vulvulina spinosa;* 

5) a decrease in the numbers of stilostomellids; and

### BENTHIC FORAMINIFERS FROM WALVIS RIDGE



Figure 13. Percentages of benthic foraminiferal species, fragments, porcellaneous genera, and the Benthic Number through the Pliocene at Site 527. Foraminifera were picked and counted from 0.5 gm of sediment of the  $<355 > 149 \ \mu m$  fraction. Samples were zoned according to the zonation of Berggren (1973).



Figure 14. Percentages of benthic foraminiferal species and genera in Section 525A-12-3 and the Benthic Number through the Pliocene of Holes 525B and Hole 527. Abundances of *Cibicides wuellerstorfi* in the >355  $\mu$ m and the <355  $\mu$ m, >149  $\mu$ m fractions are plotted for comparison. Samples were zoned according to the zonation of Berggren (1973).



Figure 15. Comparison of paleodepth estimates of Site 526 during the Eocene-Oligocene based on benthic faunas and the age-depth curve in Figure 5. Faunal estimators, species of the genus *Uvigerina*, are listed in Table 3. Samples were assigned ages according to the time-scale and zonation of Hardenbol and Berggren (1978).

6) a small increase in the numbers of gyroidinids and cibicidids.

Typical of the second type of burrowing level around 40 cm are

1) a large drop in the Benthic Number;

2) a slight decrease in the abundance of echinoid remains;

3) a slight decrease in the numbers of stilostomellids and gyroidinids;

4) no appreciable change in the agglutinants; and

5) slight increases in the numbers of Heterolepa kullenbergi and Globocassidulina subglobosa.

Although faunal variation is more common during the burrowing episodes, its magnitude in these intervals is no greater than in nonburrowed intervals. However, the fact that two indices, Benthic Number and echinoid remains, both peak before the two burrowing episodes, then drop off to minima during the burrowing, may indicate that the sediment could support a larger epifaunal population, but later became useful to the infauna represented by the burrowers and the agglutinated foraminifers, many of which are thought to live submerged in the sediment. The fact that cibicidids behave inversely, and decrease in the levels supporting the larger populations, suggests that this genus is inhibited by some characteristic of the sediment/water interface at these times.

#### CONCLUSIONS

Benthic foraminifers have been analyzed from the five sites drilled on DSDP Leg 74. Census data were derived



Figure 16. Variations in benthic foraminiferal abundances, numbers of fragments and echnoid remains through Core 525A-12-3 during a burrowing cycle in the lower Miocene. Species of the genera *Stilostomella, Uvigerina, Gyroidina, Bulimina*, and *Cibicidoides* were combined for these plots. All agglutinated species were combined and plotted. The number of fragments in counts of 350 grains in the > 149  $\mu$ m fraction were plotted. Burrowing was indicated by characteristic sediment color changes, disturbance of lineations, and wavy features. Samples were zoned according to the zonation of Berggren (1972).

from the  $<355 \ \mu m$ ,  $>149 \ \mu m$  fraction for the Paleocene and for the Oligocene through the Pliocene. Faunas were picked and counted through the Oligocene sections at Sites 526 and 529 and the Pliocene sections at Sites 525 and 527. In one Miocene-age core from Hole 525A, benthics and other invertebrates were picked and counted at 10 cm intervals through several episodes of burrowing.

Analysis of Paleocene benthic foraminifers from Site 525, with a paleodepth near 1400 m, and Site 527, with a paleodepth near 3200 m, provided the following results:

1) Eleven species of benthic foraminifers with Midway affinities were present only at the shallower site 525; 10 species, including the new genus *Abyssamina*, were restricted to the deeper Site 527.

2) Most appearances or disappearances at these sites are considered to be ecologically controlled, except those which occur at the Paleocene/Eocene boundary (i.e., the extinction of *Gavelinella beccariformis*, and the first appearances of *Tappanina selmensis* and *Globocassidulina subglobosa*).

3) Zone P4 is a time of large faunal overturn at Site 525, involving the disappearance of 18 species, and the appearance of 11 new forms.

4) At all sites the Paleocene/Eocene boundary is characterized by the disappearance of benthic species (21 at Site 527 alone); by the origination of T. selmensis, the extinction of Gavelinella beccariformis, and a decrease in the size of benthic individuals. There is a greater offset between the appearance of T. selmensis and the disappearance of G. beccariformis at the deeper site; faunal changes are also diachronous relative to a carbon isotope excursion, the fauna changing later than the isotopes at the shallower site.

Although the Eocene was not studied, the Eocene/ Oligocene boundary and the Oligocene were analyzed in detail at Site 526, with a paleodepth near 600 m; at Site 529 with paleodepth near 2800 m; at Site 525, with a paleodepth near 2200 m and at Site 363, from Leg 40, with a paleodepth near 1800 m. The following results were drawn:

1) The Eocene/Oligocene boundary is nearly complete at Site 529; it is marked by several short dissolution pulses in Zone P17 and a number of appearances of new species including *Nuttallides umbonifera*, several cibicidids and buliminds, *Uvigerina spinicostata*, *Vulvulina spinosa*, and *Robulus* ex gr. occidentalis.

2) Twelve species are restricted to the shallowest Site 526, including uvigerinids typical of the upper Eocene of Cuba and, in the upper Oligocene, flat and attached cibicidids. The buliminids dominate the 9 species restricted to the deeper Site 529, including also *Nuttallides umbonifera*, elongate cassidulinids, and spinocostata uvigerinids.

3) Oligocene diversity and the Benthic Number are consistently higher at the shallower Site 526, lower at Sites 525 and 363, and lowest at the deepest Site 529. Species abundances also grade with depth: costate buliminids tend to be more abundant at the shallower sites, whereas reticulate forms such as *B. jarvisi* are more common at the deeper site, as are the long-ranging, cosmopolitan deep sea taxa such as *Oridorsalis umbonatus, Globocassidulina* 

subglobosa, and Buliminella grata. Hispidocostate uvigerinids of the U. havanensis-U. spinicostata group predominate at the intermediate sites and decrease in import with depth, but do not occur in the 600-800 m paleodepth range.

4) Major faunal overturn occurs in Zone P21, particularly at the deepest Site 529, and involves the elimination of 11 species and a large drop in benthic diversity and in the abundances of benthics in general. Attached cibicidids first appear at the shallowest Site 526 at this time, and *U. pygmaea* first evolves at both sites at the top of this zone.

5) Comparison of Oligocene paleodepth estimates of Site 526 based on uvigerinid faunas with the backtrack curve for the site corroborate the utility of the uvigerinids for estimating the paleodepths in the open ocean, at least in the 200–800 m depth ranges.

Miocene benthic foraminifers were studied at Sites 526, with a paleodepth near 1000 m, and at Site 525, with a paleodepth near 2450 m. In Core 525A-12, benthic foraminifers and other invertebrates were counted at 10 cm intervals. These analyses demonstrated that:

1) At the shallower Site 526 there is a major decrease in benthic foraminiferal abundance (the Benthic Number) in the lower Miocene; at this time diversity decreases and strongly keeled robulinids and the heavily ridged agglutinant *Textularia mexicana* appear. Faunas deriving from and typical of the Oligocene at this site recur episodically through the Miocene and at its top in Zone N17.

2) Cibicides wuellerstorfi first appears in Zone N9 at Site 526; however, during the time of major faunal overturn in Zones N12-N13, typical long-ranging Neogene species such as *Pleurostomella alternans and Bulimina striata mexicana* originated and *Sphaeroidina bulloides* disappeared. Along with the faunal overturn in N12-N13, there is a strong trend to rectilinear species typical of the Miocene of the Dominican Republic.

3) A second episode of faunal change near the top of Zone N17 involves the reappearance of the Oligocene-type fauna, including *Uvigerina spinulosa*, and the abundant appearance of rugose cibicidids and heavily limbate planulinids. The first appearance of the rugose cibicids is diachronous through depth; these forms first appear at the deeper Site 525 in Zone N15.

4) Comparison of changes in microfossil populations with burrowing episodes during the Miocene at Site 525 demonstrates that prior to the burrowing episode a large number of invertebrate epifauna inhabit the sediment; this environment is not preferred by cibicidids. During the burrowing episodes involving dissolution and increased fragmentation of carbonates, there is a large increase in the numbers of agglutinated species, suggesting that they are infaunal organisms and flourish in the sediments preferred or produced by the burrower.

Pliocene benthic foraminifers were counted at Site 525, with a paleodepth near 2450 m, and at Site 527, with a paleodepth near 4000 m. This is the first really deep site included in this study; conclusions are:

1) Diversity and the Benthic Number are higher at the shallower Site 525. The abundance of both *Nuttalli*des umbonifera and procellaneous benthics is generally higher at the deep Site 527. 2) There is a major change in benthic faunas in the upper Pliocene Zones Pl5-Pl6 where the Benthic Number becomes equivalent between the two sites; the percentages of N. *umbonifera* are nearly equal at the two sites because of a large increase in their numbers at Site 525 and a decrease at Site 527 that accompanies a decrease in dissolution; at the latter deeper site, the porcellaneous species increase markedly in import.

3) During the mid Pliocene Zone Pl3 there is a major decrease in the Benthic Number at the deep Site 527 and an increase at the shallower Site 525. Little faunal change accompanies these variations in benthic abundance.

4) Comparison of benthic specific abundances in the fractions >355  $\mu$ m and <355  $\mu$ m of all samples demonstrates that there is little agreement between these two fractions.

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Plate 1. (All specimens ×110 unless otherwise indicated. Plate photographically reduced by 25%.) 1. Dorothia trochoides, Sample 528-23, CC.
2. Aragonia velascoensis, ×220, Sample 528-21-5, 70 cm. 3. Tappanina selmensis, Sample 528-21-5, 70 cm. 4. Tappanina excavata, Sample 329-33-4, 54 cm. 5. Bulimina midwayensis, Sample 528, 22-3, 32 cm. 6-7. Bulimina bradburyi, Sample 528-21-5, 70 cm. 8. Clinapertina inflata, Sample 528-21-5, 70 cm. 9. Nonion havanense, Sample 528-22, CC. 10. Alabamina creta, Sample 528-22, CC. 11. Oridorsalis umbonatus, ×220, Sample 528-21-5, 70 cm. 12. Abyssamina poagi, ×220, Sample 528-21-1, 50 cm.



Plate 2. (All specimens ×110. Plate photographically reduced by 30%. Figs. 1, 3, 4, 5, 6, 11, 12, 13, Sample 525A-32, CC; figs. 2, 8, 9, Sample 525A-30, CC.) 1. Tritaxia havanensis. 2. Gaudryina laevigata. 3. Tritaxia trilatera. 4. Vulvulina spinosa. 5. Buliminella beaumonti. 6-7. Abyssamina poagi. 8, 9. Anomalinoides praeacuta. 10, 11. Gavelinella beccariformis. 12. Pullenia eocenica. 13. Cibicidoides pseudoperlucidus.



Plate 3. (All specimens ×110. Plate photographically reduced by 32.5%. Figs. from Sample 526A-41-12, 44 cm unless otherwise noted.) 1. Karreriella subglabra. 2. Robulus ex. gr. occidentalis. 3. Bolivina tortuosa. 4. Bulimina alazanensis. 5. Bulimina macilenta. 6. Rectuvigerina prisca, Sample 526A-34, CC. 7. Rectuvigerina postprandia, Sample 526A-34, CC. 8. Uvigerina semivestita. 9. Uvigerina spinulosa. Sample 526A-37-3, 70 cm. 10, 11. Stilostomella subspinosa, Sample 526A-37-3, 70 cm. 12. Gavelinella semicribrata. 13. Sphaeroidina bulloides, Sample 526A-41, CC. 14. Planulina renzi.



Plate 4. (Plate photographically reduced by 27.5%.) 1-4. Heterolepa rugosa, ×55, Sample 525B-19-2, 66 cm. 5. Heterolepa kullenbergi, ×110, Sample 525B-19-2, 66 cm. 6. Planulina sp., ×110, Sample 528-22-2, 32 cm.



Plate 5. (Plate photographically reduced by 28%.) Figs. from Sample 528A-14-2, 40 cm unless otherwise noted. 1. Karreriella bradyi, ×110, Sample 528A-14-2, 40 cm. 2. Pyrgo murrhina, 55, Sample 528A-6-2, 97 cm. 3. Uvigerina hispida, ×110, Sample 528A-14-2, 40 cm. 4. Ehrenbergina spinosissima, ×110, Sample 528A-14-2, 40 cm. 5. Nonion barleanum, ×110, Sample 528A-14-2, 40 cm. 6-7. Pullenia bulloides, ×110, Sample 528A-6-2, 97 cm. 8. Laticarinina bullbrooki, ×55, Sample 528A-14-2, 40 cm. 9. Nuttallides umbonifera, ×110, Sample 528A-14-2, 40 cm. 10. Planulina cf. ariminensis, ×55, Sample 528A-6-2, 97 cm. 11-12. Heterolepa rugosa, Sample 525A-14-2, 40 cm., (11), ×55, (12) ×35.



Plate 6. (All specimens ×110. Plate photographically reduced by 29.5%.) 1. Textularia sp. A, Sample 527-3-4, 35 cm. 2. Quinqueloculina sp., Sample 527-3-4, 35 cm. 3-5. Nonion barleanum, Sample 527-8-3, 64 cm. 6. Nuttallides umbonifera, Sample 527-8-3, 64 cm. 7. Bulimina semicostata, Sample 529-20, CC. 8. Bulimina jarvisi, Sample 529-20, CC. 9. Uvigerina havanensis, Sample 529-20, CC. 10. Cassidulinoides bradyi, Sample 529-6-2, 44 cm.



Plate 7. (All specimens ×110 unless otherwise indicated. Plate photographically reduced by 30%. Figs. 1, 5, 8, 10, 11, 13, Sample 525B-11, CC; Figs 2, 3, 4, 6, 9, 12, Sample 525B-3-3, 33 cm
1. Karreriella subrotundata, ×55.
2. Pyrgo murrhina.
3. Robulus cf. cultratus, ×55.
4. Ehrenbergina spinossissima.
5. Bulimina striata mexicana, ×55.
6. Uvigerina peregrina, 7. Uvigerina hispido-costata, Sample 525B,12, CC.
8. Uvigerina auberiana.
9. Stilostomella lepidula, ×55.
10. Laticarinina halophora, ×22.
11. Cassidulina laevigata.
12. Nuttallides umbonifera.



Plate 8. (All specimens ×110. Plate photographically reduced by 30.5%. Figs. 1, 5, 7, 8, 9, Sample 526A-11,CC; Figs. 2, 3, 4, 6, Sample 526A-4,CC.)
1. Eggerella bradyi. 2. Sigmoilopsis schlumbergeri. 3. Uvigerina proboscidea. 4. Chrysalogonium lanceolum. 5. Globocassidulina subglobosa. 6. Planulina cf. ariminensis. 7, 9. Heterolepa kullenbergi. 8. Pullenia quinqueloba.