50. OLIGOCENE AND OTHER TERTIARY BENTHIC FORAMINIFERS FROM A DEPTH TRAVERSE DOWN WALVIS RIDGE, DEEP SEA DRILLING PROJECT LEG 74, SOUTHEAST ATLANTIC

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ABSTRACT

Analyses were made of benthic foraminifers in the >149 µm 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 attributable 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 overlap 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 seminvesita, Rectuigerina postprandia, U. spinulosa, Bolivina testiformis, Nodogenerina sp., Paimula 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 P15-P16, where faunas again are homogeneous through depth and Nuttalidites umboniferus, 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 µm 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
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 Lagenula sulcata, Bolivina crenulata, Den
tatina naheolensis, Nodosaria latejugata, Prondicularia sp., Viviulina 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 Abyssinina poagi, Cibicidina inflata, Cibicidoides cf. tuxpanensis, Gavelinella hypahus, Gaudryina spp., Spi
tropectammina haeringensis, N. limbata, Ammobac
tulites 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. beccariformis 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 indi
dividuals occurs just following an excursion in carbon iso
topes (Shackleton and Hall, in press); there is a signifi-
cant 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 *Nuttalides truempyi*, the appearance of *N. umbonifera*, a dissolution horizon and a reduction in benthic abundance, and a short-lived influx of miolids 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 9, this site lay near 1250 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 *Rectuviornina postrandia* 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, size-sorted 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 postrandia*, 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 cm³ 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 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 beccariiformis*, and/or *Oasangularia mexicana*. *Nuttalides* and *pleurostomellids* were typical of the intermediate Site 528, whereas at the deepest site *Nuttalides*, *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 µm 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.
Figure 2. Biostratigraphic sections, Leg 74 sites.
### Paleocene
- G. oceanica
- P. lacunosa

### Eocene
- D. brouweri
- ~R. bSèUdàürnbilit

### Foraminiferal Zones
- NN20.
- NN19
- NN15
- NN12
- NN11
- NN10
- NN9
- NN7
- NN6

### Calcareous Nannoplankton Zones
- NP25
- IMP24
- NP23
- NP20
- NP18

### Late Eocene
- D. multiradiatus
- D. gemmeus
- H. riedeli

### Early Eocene
- D. multiradiatus
- H. riedeli

### Sub-bottom Depth (m)

<table>
<thead>
<tr>
<th>Paleocene</th>
<th>Eocene</th>
<th>Oligocene</th>
<th>Miocene</th>
<th>Pliocene</th>
<th>Cont.</th>
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<tbody>
<tr>
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<td>Late</td>
<td>Early</td>
<td>Middle</td>
<td>Late</td>
<td>Early</td>
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</table>

### Lithology
- Core
- Recovery

### Carbonate Chemistry
- CaCO₃ (%)

### Figure 2.
(Continued)
Figure 2. (Continued).
Figure 2. (Continued).
Figure 2. (Continued).
<table>
<thead>
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<td>P4</td>
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<td>P3</td>
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<tr>
<td></td>
<td>P1</td>
<td>37-1, 140</td>
</tr>
<tr>
<td></td>
<td>eugubinus</td>
<td>38-3, 15</td>
</tr>
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<td></td>
<td>39-2, 8</td>
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<td>39-4, 116</td>
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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).

<table>
<thead>
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<th>Epoch</th>
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<td>P3</td>
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<tr>
<td></td>
<td>P1</td>
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<td>eugubinus</td>
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<td>31-5, 92</td>
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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).

Table 1. Commonly occurring Miocene–Pliocene benthic foraminifers in Hole 525B.

<table>
<thead>
<tr>
<th>Core-Section (level in cm)</th>
<th>Zone</th>
<th>Species and genera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Through the upper Miocene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-2, 100</td>
<td>N17</td>
<td>Osangularia culter, Uvigerina hispida-costata, Pyrgo spp., Globocassidulina subglobosa, Chrysalogondium spatula, Gavelinella semicribra, N. umbonifera.</td>
</tr>
<tr>
<td>18-1, 53</td>
<td>N16</td>
<td>Eggerella bradyi, Planulina rugosa, G. subglobosa, Osangularia umbonifer, Pyrgo spp.</td>
</tr>
<tr>
<td>19-2, 66</td>
<td>N16</td>
<td>O. culter, Osangularia umbonifer, Textularia mexicana, Gyroidinoides altiformis, Lutocassidulinula halophora, Globocassidulina subglobosa, Cibicidoides granulosus.</td>
</tr>
<tr>
<td>24-2, 64</td>
<td>N16</td>
<td>O. umbonifer, Gyroidinoides altiformis, Angulogerina angulosa, Triloculina spp., C. granulosus, Nautilusites umbonifer, Stilostomella alata, Stilostomella halophora.</td>
</tr>
<tr>
<td>25-2, 56</td>
<td>N16</td>
<td>Globocassidulina subglobosa, Osangularia culter, C. granulosus, Planulina rugosa, N. umbonifer.</td>
</tr>
<tr>
<td>27-2, 60</td>
<td>N15</td>
<td>Planulina renzi, Cibicidus wuellerstorfi, O. culter, G. subglobosa, C. granulosus, Chrysalogondium spatula.</td>
</tr>
<tr>
<td>31-2, 50</td>
<td>N14</td>
<td>Heterolepa kullenbergi, G. subglobosa, Chrysalogondium spatula, Valvulina spinosa, Ehrbergina spinissima, L. bullbrooki, Osangularia culter, Gavelinella semicribra, N. umbonifer, B. alazanensis.</td>
</tr>
<tr>
<td>32-3, 54</td>
<td>N14</td>
<td>S. lepidula, B. alazanensis, Globocassidulina subglobosa, O. culter, Planulina renzi, C. wuellerstorfi, Bolivina subaenariensis, Osangularia umbonifer.</td>
</tr>
<tr>
<td>34-2, 54</td>
<td>N14</td>
<td>Bulimina alata, B. straita mexicana, G. subglobosa, O. umboniferum, B. subaenariensis.</td>
</tr>
</tbody>
</table>

Through the Pliocene


11,CC P1 G. subglobosa, miliolid fragmen, H. kullenbergi, Osangularia umboniferum, Triloculina spp., Pyrgo spp.


Note: Foraminifers were picked from the >149 μm fractions. Samples are zoned according to Berggren (1972).
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, further 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 semives-tita, U. spinicostata, Rectuvigerina postprandia, Bolivina tectiformis, Discocibicides sp., U. camagueyana, Oridorsalis ecuadorensis, Gavelinella semicribrata, Robulus peregrinus, Cibicides lobatus, 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, Buliminella jarvisi, Cibicoides hattienisis, 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 other three sites. Uvigerina spinicostata is not present at Site 526.
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 shallowest 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 P14 through P16, 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 P13.

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 P13. There is significant specific variation through the Pliocene. *Uvigerina* spp. and *C. wuellerstorfi* reach peak abundances in Zone P11. *C. wuellerstorfi* and *Globocassidulina subglobosa* then reach

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**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).
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<td>N6-5</td>
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</table>

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).
Benthic foraminifers from Walvis Ridge

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, Siphonodaria, 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).
an abundance peak in Zone P13. The porcellaneous foraminifers demonstrate a large increase in their numbers near the top of the Pliocene in Zones P15 to P16.

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 P15 to P16, 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 P11, 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) compared 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 ~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 μm, >149 μm. 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 stiistrostomellids; and

### Table 3. Species of the genus *Uvigerina* present through the upper Eocene and Oligocene of Hole 526A.

<table>
<thead>
<tr>
<th>Core</th>
<th>Zone</th>
<th>Estimated paleodepth (m)</th>
<th>Species present</th>
</tr>
</thead>
<tbody>
<tr>
<td>43-41</td>
<td>P15</td>
<td>200-500</td>
<td><em>Uvigerina semivestita</em>, <em>U. camagueyana</em>, <em>U. cocoaensis</em></td>
</tr>
<tr>
<td>42</td>
<td>P16-17</td>
<td>300-600</td>
<td><em>U. semivestita</em>, <em>U. mexicana</em></td>
</tr>
<tr>
<td>41-40</td>
<td>P19-20</td>
<td>200-500</td>
<td><em>U. semivestita</em>, <em>U. camagueyana</em></td>
</tr>
<tr>
<td>39</td>
<td>P20</td>
<td>600-800</td>
<td><em>U. spinulosa</em></td>
</tr>
<tr>
<td>38</td>
<td>P20</td>
<td>600-1000</td>
<td><em>U. spinulosa</em> with striae restricted to individual chambers</td>
</tr>
<tr>
<td>37-33</td>
<td>P21</td>
<td>7600-1000</td>
<td><em>Rectuvigerina postprandica</em> and <em>U. auberiana</em>, not depth-diagnostic</td>
</tr>
</tbody>
</table>

Note: Samples are zoned according to the zonation of Hardenbol and Berggren (1978). Estimated paleodepths are assigned according to the criteria of Boersma (1974).
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 µm 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 µm and the <355 µm, >149 µm fractions are plotted for comparison. Samples were zoned according to the zonation of Berggren (1973).
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...
taxa such as *Oridorsalis umbonatus*, *Globocassidulina* the deeper Site 529, including also the isotopes at the shallower site. and a de-

Gavelinella beccariformis, the extinction of *Gavelinella beccariformis*, and the first appearance of *B. jarvisi* are more common at the late forms such as elongate cassidulinids, and spinocostata uvigerinids. *Nas was picked and counted through the Oligocene section and for the Oligocene through the Pliocene. Faunas deriving from *Tappanina selmensis* 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) Several episodes of faunal change occur near the top of 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 planulinds. The first appearance of the rugose cibicid is diachronous through depth; these forms first appear at the deeper Site S25 in Zone N15. 4) Comparison of changes in microfossil populations with burrowing episodes during the Miocene at Site S25 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 S25, with a paleodepth near 2450 m, and at Site S27, 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 S25. The abundance of both *Nuttallides umbonifera* and procellaneous benthics is generally higher at the deep Site S27.
2) There is a major change in benthic faunas in the upper Pliocene Zones P15–P16 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 P13 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 µm and <355 µm of all samples demonstrates that there is little agreement between these two fractions.

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REFERENCES


BENTHIC FORAMINIFERS FROM WALVIS RIDGE

Plate 1. (All specimens \( \times 110 \) unless otherwise indicated. Plate photographically reduced by 25%).

1. *Dorothia trochoides*, Sample 528-23, CC.
2. *Aragonia velascoensis*, \( \times 220 \), Sample 528-21-5, 70 cm.
3. *Tappanina selmensis*, Sample 528-21-5, 70 cm.
5. *Bulimina midwayensis*, Sample 528, 22-3, 32 cm.
6-7. *Bulimina bradburyi*, Sample 528-21-5, 70 cm.
8. *Clinaperitina inflata*, Sample 528-21-5, 70 cm.
9. *Nonion havanense*, Sample 528-22, CC.
10. *Alabamina creta*, Sample 528-22, CC.
11. *Oridorsalis unbonatus*, \( \times 220 \), Sample 528-21-5, 70 cm.
12. *Abyssaminapoagi*, \( \times 220 \), Sample 528-21-1, 50 cm.

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BENTHIC FORAMINIFERS FROM WALVIS RIDGE

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.