33. EOCENE TO MIOCENE BENTHIC FORAMINIFERS FROM DEEP SEA DRILLING PROJECT SITE 516, RIO GRANDE RISE, SOUTH ATLANTIC¹

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ABSTRACT

DSDP Site 516 contains a complete middle Eocene to lower Miocene interval with a well-developed Oligocene sequence that is more than 300 m thick. In this paper, the most important and characteristic benthic foraminiferal species from this interval are described and illustrated, and their quantitative and biostratigraphic distribution is given. Middle Eocene benthic assemblages, derived from pelagic intercalations in a partly turbiditic sequence, are low in diversity. Benthic assemblages of fairly high diversity occur in limestones, chalks, and oozes of the upper Eocene to lower Miocene. The consistently high rate of new species appearances at Site 516 during late Eocene and Oligocene contrasted greatly with the very slow rate of change in abyssal faunas at that time; there were no significant faunal changes at the Eocene/Oligocene boundary. The assemblages are dominated by *Cibicidoides* (mostly *C. ungerianus* or *C. kullenbergi*) and *Lenticulina*. Buliminids were also important during the Eocene and early Oligocene. Faunal comparison with other Atlantic DSDP sites and drill holes in the Gulf of Mexico suggest an approximately mid-bathyal (500–1500 m) depth of deposition during late Eocene and Oligocene.

INTRODUCTION

Leg 72 began on February 26, 1980, in Santos, Brazil, and ended in the same port on April 8, 1980. Major objectives were to investigate the paleocirculation of the western South Atlantic and the tectonic history of the Rio Grande Rise. Of the four sites drilled (Sites 515-518), the latter three were selected to compare the geologic and paleoenvironmental record of a transect (1300-3900 m water depth) east of the Vema Channel (Fig. 1). Adverse weather and time constraints unfortunately limited the recovery of comparable sediments from Quaternary to middle Pliocene.

The subject of this study, Site 516, is located on the upper flank of the Rio Grande Rise in a water depth of 1313 m. The hydraulic piston corer (HPC) was used in Hole 516 to core to 183.3 m sub-bottom depth (lower Miocene). Hole 516F was then washed to 169.1 m subbottom depth and cored continuously to 1250 m, terminating in basement basalts. An almost continuous sedimentary record spanning Coniacian-Santonian through Pliocene was recovered. Site 516 with its almost continuous record, its high sedimentation rate, and the generally good preservation of its faunas, offered a rare opportunity to study the distribution of mid-bathyal benthic foraminiferal faunas in a purely oceanic environment.

The Upper Cretaceous through Paleocene benthic faunas were studied by Dailey (this volume). The interval chosen for this study was limited by intensely lithified basal Eocene sediments with poorly preserved faunas and a condensed middle Miocene section (Fig. 2). Hence, it is not possible to document in detail the faunal evolution through two periods of accelerated faunal turnover, the latest Paleocene (Tjalsma and Lohmann, 1983) and

¹Barker, P. F., Carlson, R. L., Johnson, D. A., et al., *Init. Repts. DSDP*, 72: Washington (U.S. Govt. Printing Office).

early middle Miocene (Woodruff and Douglas, 1981). A basic problem in studying deep-sea benthic foraminiferal distribution is that most of the taxonomic concepts used in recent literature are derived from classic studies of uplifted deep-water sections, particularly in Mexico and Trinidad. Much of this work is in need of taxonomic revision. A taxonomic review of Paleocene and Eocene species is given by Tjalsma and Lohmann (1983) and serves as the framework for their distributional study of Atlantic benthic foraminifers. Their Eocene species concepts have been useful in studies of Oligocene abyssal faunas (Miller, 1983; Miller et al., in press). However, a taxonomic review was necessary for bathyal faunas of the late Eocene and Oligocene, as numerous new species migrated into, or evolved in, this realm at that time.

This report is an initial attempt to describe and illustrate many of the benthic species, which were compared with type material where possible. It documents in some detail their quantitative and stratigraphic distribution, and compares the fauna with benthic faunas from other areas.

METHODS

Benthic species recovered from 34 samples at Site 516, and ranging in age from middle Eocene to early Miocene, are documented in this study (Table 1). In addition, three samples from the middle part of the upper Miocene section were counted, and the results incorporated in the generic frequency chart (Figure 3) and the stratigraphic range chart (Figure 4). Samples of the uppermost Paleocene to lower Eocene were examined but not counted because of the poor state of preservation of the faunas in this interval.

All samples were treated with hydrogen peroxide and washed through a $63-\mu$ sieve. The dried residues were fractionated, aliquots of the >149 micron fraction were picked, and the benthics were mounted on reference slides. Approximately 300 specimens were picked whenever possible.

MATERIAL

In general, upper middle Eocene through Recent benthic foraminifers occur frequently and are well preserved. Below the upper middle Eocene, all foraminifers become diluted in the clastic sediments, and their preservation deteriorates with increased lithification. Evidence



Figure 1. Rio Grande Rise with locations of Sites 515–518 drilled on Leg 72, Sites 21–22 of Leg 3, and Site 357 of Leg 39. Depth contours are shown in meters.

of contamination (downhole caving) was found at certain levels in Hole 516. The problem is related to washing procedures during the HPC process. Such levels of sand-sized foraminifers and mollusc debris of Quaternary age were found typically in the upper 10–50 cm of the cores. In Cores 516-16 and 516-18 their extent is much wider; they also occur in the core-catcher samples of Cores 516-14 and 516-37.

In the Oligocene of Hole 516F, levels of sand-sized foraminifers (often with mollusc debris) are not related to downhole caving, for the planktonic assemblages are uncontaminated. Large benthic species of *Lenticulina, Nodosaria, Planulina, Cibicidoides*, and agglutinants, as well as small, thin-shelled molluscs, occur scattered throughout the section, but are particularly concentrated at certain levels in Cores 5, 19, 30, and 31 of Hole 516F. The abundance of large, flat specimens of *Cibicidoides* and *Planulina*, often severely corroded, suggests winnowing. By such a process, untransportable benthic specimens are left exposed to corrosion. Further evidence for winnowing comes from the abnormal grain-size distribution at these levels (as estimated from the fractionated washed residues), reflecting a lack of fine material.

Evidence for downslope sediment transport exists in the middle Eocene, where two levels of reefal debris consisting of calcareous algae, bryozoa, and larger foraminifers were found. In Core 516F-50, *Discocyclina, Linderina* (?), and *Nummulites* occur in a thin limestone bed, whereas in Core 516F-63, specimens of *Discocyclina, Asterocyclina*, and *Nummulites* were isolated from a soft nodule of reefal debris. These two levels occur in an interval of turbidites. The base of this interval is formed by a displaced block of Maestrichtian limestone, including most of Cores 516F-78 through 516F-80. Sample 516F-79-2, 8587 cm, contains an upper Maestrichtian fauna with *Gavelinella beccariiformis, Praebulimina reussi,* and, to a much lesser extent, *Nuttallides truempyi* dominating the assemblage. According to Dailey (personal communication), the assemblage suggests a depositional environment not deeper than 1000–1500 m.

BENTHIC FORAMINIFERAL ASSEMBLAGES

Upper Paleocene-Eocene

The latest Paleocene (Zone P6a) benthic faunal turnover, which formed perhaps the most dramatic event in the evolution of Mesozoic and Cenozoic deep-water benthic foraminifers (Tjalsma and Lohmann, 1983), can be recognized at Site 516. Basically, it involved the abrupt extinction of relic Cretaceous taxa. The majority of these taxa were contained in the shallower *Gavelinella beccariiformis* assemblage, which became restricted to shallower and shallower water before its extinction during the latest Paleocene. Impoverished assemblages, consisting mainly of long-ranging taxa, characterize the strata just above the extinctions. The faunal turnover closed off a long period of *Gavelinella*-dominated faunas. *Gavelinella* was not replaced by any genus in particular,



Figure 2. Generalized lithology in Holes 516 and 516F.

but *Cibicidoides* became as important during the Eocene and Oligocene as *Gavelinella* was during the Paleocene.

The complete recovery of Paleocene-Eocene transitional strata would offer a good opportunity to study this event in detail, but the faunal change coincides with a drastic deterioration in preservation. At Site 516, it starts with the abrupt extinction of Cretaceous-Paleocene taxa, such as Gavelinella beccariiformis, G. hyphalus, G. velascoensis, Pullenia coryelli, Bolivinoides delicatulus and Neoflabellina semireticulata above Sample 516F-83-4, 15-17 cm. The overlying sample (Sample 516F-83-3, 15-17 cm) contains an extremely low-diversity assemblage consisting mainly of taxa with long-stratigraphic ranges, such as Nuttallides truempyi, Oridorsalis umbonatus, Lenticulina whitei, and Cibicidoides pseudoperlucidus. A somewhat more diverse fauna was reported by Dailey (this volume) from Sample 516F-83-2, 28-30 cm, with Aragonia semireticulata as a new faunal element. Finally, there are more new taxa in the core catcher of Core 516F-82 (top of Zone P6a), including Vulvulina mexicana, V. spinosa, Abyssamina poagi, Clinapertina inflata, and Alabamina dissonata. The overlying Zone P6b interval is truncated by slumped Cretaceous strata.

Middle Eocene sediments (Zone P10) occur above the Cretaceous slump block (Pujol, this volume). The heterogenous, displaced character of this series of pelagic limestones interbedded with volcanic ash layers, turbidites, breccias, and strata with reefal debris, is reflected by benthic assemblages low in species diversity even in the pelagic limestones. The assemblages are dominated by *Cibicidoides*, buliminids, *Lenticulina*, and agglutinants. The most frequently occurring species are *Cibicidoides ungerianus* and *Oridorsalis umbonatus*. More irregular in their distribution are *Hanzawaia cushmani*, *Plectina elongata*, *Bulimina impendens*, and several unidentified species of *Pyramidina*, *Reussella*, and *Trifarina*. *Nuttalides truempyi* and *Buliminella grata* are abundant only at the base of the section.

Although the upper Eocene was not biostratigraphically subdivided, there is no reason to suspect that the section is discontinuous. The Eocene/Oligocene boundary was drawn just above Core 516F-39, Section 2, based on the common occurrence of Globigerinatheca index and rare G. barri and Globorotalia cerroazulensis in Sample 516F-39-2, 5-6 cm. Upper Eocene assemblages are dominated by Cibicidoides, Lenticulina, and buliminids. Common species are Oridorsalis umbonatus and Bulimina tuxpamensis, with Osangularia mexicana and Cibicidoides dickersoni fluctuating in abundance. Some species show short peaks in their relative abundance, such as Globocassidulina subglobosa, Siphonina tenuicarinata, and Plectofrondicularia lirata. The last peak seems significant, because similar upper Eocene peaks of P. lirata are present at DSDP Sites 19 and 357 in the South Atlantic. Assemblages of the upper Eocene are characterized by higher species diversity than those of the middle Eocene. Many species appear for the first time, particularly during the upper part of the upper Eocene. The number of extinctions remains relatively low. Species that give this interval a distinct character are

Uvigerina havanensis, Cibicidoides sp. 3, C. sp. 4, Siphonina tenuicarinata, Discorbis subvilardeboanus, Planulina renzi, and Bolivina byramensis. Other species appearing in this interval, such as Bulimina alazanensis, Gavelinella micra, U. rippensis, G. subglobosa, and C. aff. laurisae, are reported from much lower stratigraphic levels at other DSDP sites. Their delayed appearance might be related to the unfavorable depositional environment that existed at the site during most of the middle Eocene.

Oligocene-Miocene

The Eocene/Oligocene boundary occurs in a short interval of strong dissolution and makes up the top of Core 516F-39 and the base of Core 516F-38. Neither the generic frequency distribution (Fig. 3) nor the stratigraphic distribution of species (Fig. 4) indicates any significant faunal change at the boundary. The generic dominance remains basically unchanged from the upper Eocene through the Oligocene, except for the increase in abundance of Cibicidoides and the gradual decline of the buliminids within the upper Oligocene. Uvigerinids become important, but their abundances fluctuate considerably. Sphaeroidina is the only new genus to appear, but its abundances are still low in the Oligocene. The most common species are C. ungerianus (gradually replaced by C. kullenbergi), Oridorsalis umbonatus, Globocassidulina subglobosa, and Pullenia bulloides, while the abundances of Siphonina tenuicarinata, Planulina renzi, and Bulimina tuxpamensis are more variable.

Lower Oligocene and upper Eocene assemblages share many characteristic species, such as Gavelinella micra, C. sp. 3, Hanzawaia cushmani, Uvigerina havanensis, B. byramensis, Anomalina corrugata, Discorbis subvilardeboanus, Siphonina tenuicarinata, and Planulina renzi. In the lower part of the upper Oligocene, many short-ranged taxa occur, such as C. cf. cookei, C. trinitatensis, C. tuxpamensis, C. perlucidus, U. spinulosa, Trifarina danvillensis, and Bolivina reticulata. At least two of them (C. tuxpamensis and C. perlucidus) are found at much lower stratigraphic levels elsewhere in the Atlantic. The upper Oligocene is characterized by the first appearance of some Neogene taxa, such as Sphaeroidina bulloides, Textularia milletti, Rectuvigerina vesca, C. kullenbergi, C. cicatricosus, and Osangularia culter.

Within the lower Miocene, the number of first appearances tapers off and the number of last appearances progressively increases. Important long-ranging Paleogene taxa (such as O. mexicana, Bulimina impendens, B. tuxpamensis, Anomalinoides spissiformis, D. subvilardeboanus, and P. renzi) have their last appearance within the lower Miocene. Among the species characterizing lower Miocene assemblages are P. karsteni, Martinottiella scabra, C. reussi, Trifarina bradyi, and U. auberiana. Nuttallides umbonifera appears in Zone N8 and continues into the middle and upper Miocene. The generic frequency distribution shows some changes, below the faunal change in upper lower Miocene and lower middle Miocene. Siphonina disappears; Planulina, Sphaeroidina, and Uvigerina increase in importance,



Figure 3. Frequency distribution of selected benthic foraminiferal genera from Eocene to Miocene. Section of cores is a composite, containing Eocene to lower Miocene of Hole 516F and lower Miocene to upper Miocene of Hole 516. Cutoff point is at 169.3 m (base of Hole 516, Core 39), based on the assumption of identical stratigraphic thickness between the two holes. The first 11 samples (Sections 516-13-1 through 516-39-1) are from Hole 516; the remaining samples (Sections 516F-2-2 through 516F-76-5) are from Hole 516F.



Figure 4. Stratigraphic ranges of selected benthic foraminiferal species at Site 516, based on census data as well as intermediate samples.

although the latter two fluctuate much in abundance. Furthermore, *Lenticulina* and *Bulimina* decrease in relative abundance.

The sedimentation between the lower and the middle Miocene seems to be continuous (Pujol, this volume), but the middle Miocene interval is much condensed and has not been biostratigraphically subdivided. The middle and upper Miocene assemblages differ from those of the lower Miocene by much lower frequencies of Lenticulina, Cibicidoides, Osangularia, and Sphaeroidina. Conversely, Stilostomella, Bolivina, and Planulina are more abundant, and at certain levels Uvigerina and Bulimina are also abundant. Among the new species appearing in the middle Miocene are P. wuellerstorfi, Epistominella exigua, Bolivina cf. thalmanni, B. globulosa, and Siphotextularia rolshauseni.

EOCENE/OLIGOCENE BOUNDARY

The change in deep-sea benthic faunas across the Eocene/Oligocene boundary has been the subject of considerable discussion. The original suggestion that deepsea benthic assemblages would show a major crisis coinciding with an observed oxygen isotope enrichment in the earliest Oligocene (Kennett and Shackleton, 1976) has not been substantiated. Corliss (1979) demonstrated the lack of any faunal response to the inferred temperature drop of at least 3°C at DSDP Site 277 (Campbell Plateau). Corliss (1981), in a compilation of published benthic foraminiferal distribution charts from 6 DSDP sites in the Atlantic and Pacific, concluded that only gradual changes occurred from the middle Eocene to the early Oligocene.

A sequence of faunal changes occurred from the late Eocene to the early Oligocene in the Atlantic, initiated by the replacement of the abyssal Nuttallides assemblage in the earliest late Eocene by the Globocassidulina subglobosa-Gyroidinoides-C. ungerianus-O. umbonatus assemblage (Tjalsma and Lohmann, 1983; Miller et al., in press). This latter assemblage continued its dominance in the Oligocene. In the deep abyssal South Atlantic, N. umbonifera became an important taxon in the early Oligocene. The late Eocene was a period of relative faunal stability with few new appearances and few extinctions. Similarly, few new species were introduced during the Oligocene, particularly in the deep abyssal (>3 km) sites. These gross distributional trends have been confirmed by Miller (1983) and Miller and others (in press), who noted similar changes in the northeastern Atlantic (Gulf of Biscay and Goban Spur).

No significant faunal changes were observed at the Eocene/Oligocene boundary of Site 516. *Lenticulina* is as important in the Oligocene as in the Eocene. Many new species appear in the upper Eocene and this influx continues throughout the Oligocene. The first appearance of many of these taxa seems to be a faunal response to the return of a fully pelagic depositional environment at Site 516, for they are reported at much lower stratigraphic levels at other DSDP sites. But the first appearances of many other taxa, among them representatives of *Bolivina, Uvigerina, Planulina, Cibicidoides, Discorbis*, and *Siphonina*, are more or less coeval with those

noted at other bathyal DSDP sites. These taxa became more abundant and widespread during the Oligocene. Based on the combined data from DSDP sites in the South Atlantic and the Gulf of Mexico, it appears that the faunal differences between the middle and upper Eocene are in fact greater than those between the upper Eocene and the Oligocene. This pattern of faunal change seems in agreement with the benthic faunal patterns at shallow DSDP Site 548 (estimated paleodepth 1000 m) in the northeastern Atlantic. A major faunal change, from a Nuttallides-Lenticulina assemblage to a Gyroidinoides-Bulimina alazanensis-Globocassidulina subglobosa assemblage, begins just above the middle/upper Eocene boundary at Site 548 (Miller et al., in press).

COMPARISON WITH DSDP SITE 357

Previous cruises in the southwest Atlantic (DSDP Legs 3 and 39) have cored three sites on the Rio Grande Rise, all of them located in greater water depths than Site 516 (Fig. 1). Although they contain well-preserved benthic faunas, the sections are incomplete, because all three sites were spot-cored. Site 357, drilled in close proximity to Site 516 in a water depth of 2086 m, had more complete recovery than the other two sites (21 and 22) in Eocene and upper Oligocene sediments. Its lithologies are similar to those at Site 516 with a thin middle Eocene interval in which a volcanic breccia was recovered. The dominant components of this breccia are basaltic glass, sediment clasts, and separate fossils. Larger benthic foraminifers occur in this interval together with red algae, bivalves and gastropods, indicating a shallow water origin.

Boersma (1977) recorded the stratigraphic ranges of a large number of benthic species from the Eocene to the Miocene. The taxonomy that she used is derived from the older literature without revision. Boersma (1977) considered the restrictions of stratigraphic ranges of these species to be ecological rather than caused by evolutionary change. The stratigraphic ranges of many species at Site 516 indicate this also. The close correlation between the paleobathymetric and stratigraphic distribution of many species was demonstrated by Tjalsma and Lohmann (1983), who documented the change in paleobathymetric range of many species (and genera) during the Eocene. This correlation seems also to be characteristic of the distributions of many Oligocene taxa, although it has yet to be documented in detail.

The benthic assemblages at Site 357 differ from those at Site 516 mainly by the lower frequencies of *Lenticulina* throughout the Eocene and Oligocene. *Bulimina* is the dominant genus in the middle Eocene, but in the upper Eocene *Cibicidoides* and *Oridorsalis* become more important. In the Oligocene, *Bulimina* declines further as it does at Site 516. *Cibicidoides* remains the most important genus in the upper Oligocene. Some of the characteristic species at Site 357 are absent at Site 516, including *Bulimina semicostata*, *B. jarvisi*, and *B. glomarchallengeri* in the middle and upper Eocene, species which have their optimal abundance at sites of shallow abyssal depths (2–3 km). During the late Oligocene, *Nuttallides umbonifera* was present at Site 357, but not Site 516; at that time, N. umbonifera had expanded its bathymetric range from deep abyssal to shallow abyssal.

PALEOBATHYMETRY

The construction of a subsidence curve for Site 516 is hampered by geophysical and geologic uncertainties about the history of the Rio Grande Rise. A simple oceanic cooling curve from sea level from 84 Ma to present would give 520 m too much subsidence (Barker, personal communication). Hence, an uplift during the early part of the middle Eocene has been assumed (supported by ample geologic evidence), but the amount of uplift remains uncertain. In this model, the greatest paleodepth during the early Cenozoic would have been reached in the Paleocene, although there is a discrepancy between the geophysically "calculated" depth of 600–900 m and Dailey's (this volume) estimate of 1500–2000 m based on Paleocene benthic assemblages.

These age-versus-paleodepth curves (Sclater et al., 1971) have given a new dimension to our understanding of benthic foraminiferal distribution in the deep sea. By "backtracking" DSDP sites, faunal data can be plotted against a paleodepth derived from geophysical rather than faunal evidence. Based on such "backtrack" data Tjalsma and Lohmann (1983) attempted to reconstruct the distribution of Paleocene and Eocene benthic foraminifers in the Atlantic in terms of age, paleodepth, and paleolatitude.

Preliminary data from Oligocene DSDP sites in the South Atlantic and the Gulf of Mexico indicate that the shallow Eocene assemblage characterized by Lenticulina-B. impendens-O. mexicana continues in the Oligocene, although some of its constituents may have changed because of accelerated faunal evolution during the late Eocene and Oligocene. The data further suggest that Oligocene benthic taxa tend to be as restricted bathymetrically as those of the Eocene. Taxa that are largely restricted to a bathyal depth (< 2000 m) include Lenticulina spp., Hanzawaia cushmani, Osangularia mexicana, Planulina renzi, Pullenia bulloides, Bulimina macilenta, B. alazanensis, Sphaeroidina bulloides, Bolivina tectiformis, and Uvigerina spp. All these taxa occur more commonly at Site 516 than at any other South Atlantic DSDP site studied. This abundance suggests a shallower paleodepth at Site 516 than at Sites 22 and 357 (Rio Grande Rise), 329 (Falkland Plateau), and 363 (Walvis Ridge), which have estimated paleodepths of between 1700 and 2200 m.

Apart from these common bathyal taxa, the upper Eocene to lower Miocene assemblages of Site 516 are unique in the South Atlantic in that they contain taxa that have so far not been observed at any of the other bathyal DSDP sites. These include Siphonina tenuicarinata, Discorbis subvilardeboanus, B. byramensis, B. reticulata, Cibicidoides dickersoni, Anomalinoides cf. alazanensis, Bulimina tuxpamensis, U. havanensis, U. mexicana, and Rectuvigerina vesca. The majority of these taxa were originally described from uplifted deepwater sections in Mexico, Cuba, Europe, and New Zealand; a few were described from deeper shelf sediments of the U.S. Gulf Coast. Many also occur in the Eureka and Conslope drill holes in the northern part of the Gulf of Mexico, and some have also been found at DSDP Sites 94 and 95 in the western part of the Gulf of Mexico (Campeche Bank).

A Siphonina fauna has been reported by Berggren (1972) from Rockall Bank (DSDP Sites 116 and 117). In the Oligocene and lower Miocene assemblages from these sites, Siphonina tenuicarinata is the most dominant species. It is accompanied by Cibicidoides mexicanus, C. perlucidus, A. alazanensis, and Vulvulina jarvisi in the Oligocene and by P. renzi in the lower Miocene. According to Berggren (1974), lower Eocene benthic assemblages indicate a depth in excess of 500 m. With its present water depth of approximately 1000 m, it is assumed that Oligocene-lower Miocene water depths must have been between these two values.

DSDP Site 548 (Goban Spur) in the northeastern Atlantic has been studied by Miller and others (in press), who reported a *Gyroidinoides-Bulimina alazanensis-Globocassidulina subglobosa* assemblage in the upper Eocene and Oligocene. Based on the assumption that the elevation difference of basement between Site 548 (on continental crust) and Site 550 (on oceanic crust) remained constant since the late Eocene, Miller and others (in press) estimated its paleodepth at 1000-1100 m. Picked samples from upper Eocene to lowest Miocene (provided by K. G. Miller) contain Siphonina tenuicarinata, Bolivina byramensis, rare B. reticulata, Cibicidoides sp. 4, Bulimina tuxpamensis, and Rectuvigerina vesca.

The benthic foraminiferal distribution data collected from the Eocene and Oligocene of the Atlantic is of limited value in estimating the postuplift paleodepth at Site 516. This is because other South Atlantic Eocene and Oligocene DSDP sites have "backtrack" depths in the range of 1700-4500 m. Our knowledge of the faunas from upper and middle bathyal depths comes entirely from continental slope areas where no faunal-independent paleodepth estimates are available. Based on faunal trends in the Oligocene, it is suggested that Site 516 was considerably shallower than the approximately lower bathyal DSDP sites in the South Atlantic. If Site 516 had sediments deposited at an upper bathyal paleodepth, one would expect a far greater abundance of benthic species with an outer shelf-upper slope bathymetric range. Thus, the most probable depth of deposition for the observed assemblages would be from 500 to 1500 m (approximately middle bathyal).

TAXONOMIC NOTES

The species below are listed alphabetically. Included are the most relevant Paleogene species. For the census, the species concept of Tjalsma and Lohmann (1983) was followed for the Paleogene species and that of Boltovskoy (1978) for the Neogene species. Most of the Paleogene species have been compared with type material in the Cushman collection (U.S. National Museum). Study of original specimens proved to be very useful as some of the types have been illustrated quite unsatisfactorily. The quantitative distribution of many of the species is presented in Table 1, and their stratigraphic distribution is shown in Figure 4.

> Anomalina cf. capitata (Guembel) (Plate 3, Figs 2a-b; Plate 7, Figs. 2a-c)

cf. Rotalia capitata Guembel, 1868, p. 653, pl. 2, figs. 92a-c.

This relatively small Oligocene form shares its coiling pattern with the Eocene A. capitata. There are differences, however, including its less-inflated chambers and its sutures, which tend to become limbate and quite curved, particularly on the dorsal side. Also, the pores are less densely distributed and generally arranged around or parallel to the sutures; there are two whorls with eight to nine chambers in the final whorl.

Anomalina corrugata Cushman and Bermudez (Plate 3, Figs. 1a-c; Plate 7, Figs. 1a-c)

Anomalina corrugata Cushman and Bermudez, 1937, p. 27, pl. 2, figs. 57-59.

The concavo-convex axial outline and the coarse pore pattern sets apart this species from other anomalinids. The holotype has been figured quite schematically, but our specimens are nearly identical to the primary types. The smooth peripheral band present in some of our specimens (Plate 3, Fig. 1b; Plate 7, Fig. 1b) has not been observed in the types.

Anomalina pseudogrosserugosa Colom (Plate 7, Figs. 3a-4c)

Anomalina pseudogrosserugosa Colom, 1945, p. 290. pl. 31, figs. 19-30.

Anomalinoides sp. 1, Douglas, 1973, pl. 19, figs. 4-5; pl. 24, figs. 15-16.

Anomalinoides sp. 1, Douglas, Resig, 1976, pl. 4, figs. 10-11.

This small *Anomalina* is distinguished by its tangential ventral sutures, flat ventral side, and convex dorsal side. In large specimens (with up to nine chambers in the last whorl), the ventral side tends to become concave. Perforation is usually fine but may become more coarse on the ventral side.

Anomalinoides cf. alazanensis (Nuttall) (Plate 4, Fig. 4; Plate 5, Figs. 3a-c)

cf. Anomalina alazanensis Nuttall, 1932, p. 31, pl. 8, figs. 5-7.

Our form, unlike Nuttall's types of *A. alazanensis*, is involute and flattened to slightly concave on the ventral side, and it develops a smooth and convex dorsal side. Infilling of shell material obscures the early part of the test on the ventral side. On the dorsal side, chambers of earlier whorls are generally visible, although there is a tendency for depositing secondary shell material here also. The sutures are limbate, slightly depressed, and curved more strongly towards the periphery. Some of the paratypes from the state of Vera Cruz (Mexico) tend to have a smooth dorsal side. In those specimens, however, the coiling is reversed, resulting in a flattened (and smooth) dorsal side and a convex (coarsely perforated) ventral side.

Astrononion pusillum Hornibrook (Plate 4, Figs. 2a-b)

Astrononion pusillum Hornibrook, 1961, p. 96, pl. 12, figs. 229, 236. Astrononion pusillum Hornibrook. Miller et al., in press, pl. 5, figs. 5-6.

The chambers in our specimens are more loosely appressed than those described by Hornibrook, and supplementary chambers are not always well developed. Although present in the upper Eocene of DSDP Sites 277 (Corliss, 1979) and 363, it does not appear in Site 516 below the upper Oligocene.

Bolivina byramensis Cushman

(Plate 1, Figs. 1a-b)

Bolivina caelata Cushman var. byramensis Cushman, 1923, p. 19, pl. 1, fig. 9.

Bolivina caelata Cushman. Nuttall, 1932, p. 20, pl. 5, fig. 3.

Bolivina byramensis Cushman. Bermudez, 1949, p. 187, pl. 12, fig. 29.

Aragonia janoscheki Gohrbrandt, 1962, p. 81, pl. 3, figs. 5a-b.

Bolivina byramensis differs from B. caelata Cushman in its greater compression, distinct keel, and less well-developed reticulate ornamentation. Although the holotype shows a reticulate pattern on the early part of the test only, at least one paratype slide (from the Byram Marl, Mississippi) includes specimens that feature all gradations between smooth and completely reticulate. Examination of Nuttall's material of B. caelata from Vera Cruz (Mexico) shows they should be included in B. byramensis. Most of these specimens are completely reticulate, and they are identical to the material from Site 516. Gohrbrandt (1962) included Nuttall's *B. caelata* in his *Aragonia janoscheki*. However, his figure shows a perforate species, which is at variance with the generic definition of *Aragonia*.

Bolivina reticulata Hantken (Plate 1, Figs. 2a-b)

Bolivina reticulata Hantken, 1875, p. 65, pl. 15, figs. 6a-b. Bolivina reticulata Hantken. AGIP Mineraria, 1957, pl. 30, fig. 10.

Although identification from the original publication was not possible (due to poor illustrations), topotypes identified by Hantken from the Kleinzeller Tegel near Budapest match very closely the material from Site 516. *B. reticulata* is distinguished from *B. byramensis* Cushman in that it is less compressed, lacks a keel, and develops more numerous and broadly rounded reticulating costae (Plate 1, Fig. 2b).

Bolivina tectiformis Cushman (Plate 1, Figs. 3a-b)

Bolivina tectiformis Cushman, 1926, p. 83, pl. 12, fig. 6a.

Bolivina tectiformis Cushman. Galloway and Heminway, 1941, p. 491, pl. 31, fig. 2.

Bolivina tectiformis Cushman. Bermudez, 1949, p. 195, pl. 12, fig. 47.

Our material compares well with the types (which are poorly preserved), except for the median ridge, which usually is developed only on the early part of the test, as is the pattern of subparallel ridges and channels. *B. antegressa* Subbotina described from the Crimea (USSR) may be a junior synonym.

Bulimina alazanensis Cushman (Plate 1, Figs. 4-5)

Bulimina alazanensis Cushman, 1927, p. 161, pl. 25, fig. 4.

Bulimina alazanensis Cushman. Tjalsma and Lohmann, 1983, p. 24, pl. 14, fig. 4.

Bulimina macilenta Cushman and Parker (Plate 1, Fig. 6)

Bulimina denticulata Cushman and Parker, 1936, p. 42, pl. 7, figs. 7a-8c.

Bulimina macilenta Cushman and Parker, 1939 (new name), p. 93. Bulimina macilenta Cushman and Parker. Tjalsma and Lohmann, 1983, p. 25, pl. 14., fig. 3.

Bulimina tuxpamensis Cole (Plate 6, Figs. 1-2)

Bulimina tuxpamensis Cole, 1928, p. 212, pl. 32, fig. 23.

Bulimina tuxpamensis Cole. Tjalsma and Lohmann, 1983, p. 26, pl. 12, figs. 3a-4.

Cibicidoides cf. cookei (Cushman and Garrett) (Plate 10, Figs. 4a-c)

cf. Cibicides cookei Cushman and Garrett, 1938, p. 65, pl. 11, figs. 3a-c.

Our specimens resemble the primary types (which have been poorly figured) from the lower Oligocene of Alabama; however, they differ in the larger number of chambers in the last whorl (usually 8-10), the shorter spire, and the absence of a weak umbilical depression.

Cibicidoides dickersoni (Bermudez) (Plate 10, Figs. 1a-2c)

Cibicides dickersoni Bermudez, 1937, p. 244, pl. 21, figs. 8-9.

Our material seems very similar to the primary types, which have been poorly figured. In general, our specimens are smaller, somewhat less flattened on the dorsal side, and less convex on the ventral side. This conspicuous and sometimes common species is generally characterized by 12 chambers in the last whorl, wide umbilical sutures, a prominent umbilical plug of clear shell material, coarse perforation on the ventral side, and the granular surface developed at the center of the dorsal side.

Table 1. Benthic foraminiferal census data (in %), DSDP Site 516.

| Core-section (interval in cm) | Planktonic zone | Total number counted | Percent listed | Vulvulina spp. | Textularia milletti | Textularia flintii | Plectina elongata | Karreriella subglabra/ bradyi | Martinottiella scabra | Eggerella bradyi | Lenticulina spp. | Stilostomella aculeata | Stilostomella curvatura | Bolivina tectiformis | Uvigerina rippensis | Uvigerina elongata | Uvigerina havanensis | Uvigerina spinulosa | Uvigerina mexicana | Uvigerina auberiana | Rectuvigerina vesca | Trifarina danvillensis | Trifarina bradyi | Buliminella grata | Bulimina macilenta group | Bulimina impendens | Bulimina tuxpamensis | Bulimina alazanensis | Reussella oligocenica | Turrilina robertsi | Pleurostomellids | Pullenia eocaenica | Pullenia bulloides | Pullenia quinqueloba |
|---|---|--|--|---|---------------------|--------------------|-------------------|--|--------------------------|--|---|---------------------------------|---|--------------------------|---------------------|--------------------|----------------------|--------------------------|--------------------|---------------------|---------------------|------------------------|---------------------------------|-------------------|---|--|--|--|-----------------------|--------------------|--|--------------------------|--|--|
| Hole 516 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 20-3, 86-88 22-1, 100-102 24-3, 83-85 26-1, 50-52 28-1, 60-62 30-2, 50-52 35-3, 80-82 39-1, 70-72 | N8 N8 N7 N5-6 N5-6 N5-6 N5-6 | 285 348 321 248 273 253 212 249 | 67.4 55.0 70.8 74.4 63.0 75.3 80.6 75.0 | 0.4 0.6 1.2 0.7 0.4 2.8 1.6 | 11.6 4.6 3.8 | 2.0 1.2 0.4 | | 2.1 1.6 0.9 1.2 | 1.8 0.3 2.6 2.0 | 1.1 0.4 1.8 0.4 0.5 2.4 | 4.2 4.6 4.0 5.2 6.2 12.3 14.2 3.2 | | 0.4 1.8 1.9 4.8 | | | | | | | 6.3 0.6 5.9 | 10.3 4.0 0.5 | | 0.7 5.5 0.9 1.2 1.8 | | 0.4 2.4 1.4 | 0.4 2.0 1.4 0.8 | 2.8 4.8 | 0.9 2.2 0.4 | | | 1.1 0.9 1.9 0.4 0.7 0.4 0.4 | | 3.2 0.6 0.6 0.4 5.1 0.4 0.9 9.6 | 0.7 0.9 2.2 1.2 1.1 4.3 1.9 |
| Hole 516F | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| $\begin{array}{c} 2\text{-2, } 60\text{-}62 \\ 4\text{-5, } 60\text{-}62 \\ 8\text{-1, } 73\text{-}75 \\ 11\text{-3, } 102\text{-}103 \\ 15\text{-1, } 60\text{-}62 \\ 18\text{-1, } 60\text{-}62 \\ 20\text{-4, } 5\text{-}57 \\ 23\text{-3, } 33\text{-}35 \\ 26\text{-2, } 56\text{-}58 \\ 29\text{-2, } 91\text{-}92 \\ 32\text{-}6, \ 72\text{-}74 \\ 35\text{-}2, \ 2\text{-}4 \\ 37\text{-}1, \ 2\text{-}3 \\ 38\text{-}1, \ 66\text{-}67 \\ 39\text{-}2, \ 5\text{-}6 \\ 40\text{-}2, \ 102\text{-}104 \\ 43\text{-}2, \ 25\text{-}27 \\ 44\text{,}CC \\ 48\text{-}1, \ 54\text{-}56 \\ 51\text{-}1, \ 27\text{-}29 \\ 53\text{-}3, \ 31\text{-}33 \\ 56\text{-}4, \ 59\text{-}60 \\ 60\text{-}2, \ 136\text{-}138 \end{array}$ | N4 N4 P22 P22 P21b P21a P21a P21a P20 P18-19 P18-19 P18-19 P18-19 P15-16 P15-16 P15-16 P15-16 P15-16 P15-16 P15-16 P15-16 P15-16 P15-16 P11-13 P11-13 P11-13 | 237 306 224 296 202 294 304 318 306 381 257 362 272 249 335 243 299 442 295 227 281 227 281 227 | 78.5 70.5 87.0 80.3 78.0 78.3 79.0 74.3 81.7 88.3 86.9 80.2 84.8 88.0 78.0 81.4 88.3 71.2 87.1 65.2 70.9 72.0 65.0 | 0.8 0.3 0.7 4.1 2.0 0.6 2.3 2.6 6 2.7 2.7 4.0 1.6 2.7 0.7 2.0 1.3 0.4 4.5 | 0.8 0.9 0.6 | | 8.1 4.1 | 1.3 1.3 3.1 2.4 1.0 1.3 1.2 2.2 2.9 1.2 1.2 0.5 | 1.3 | 0.3 | 12.2 8.8 17.3 12.5 5.9 7.5 14.1 3.5 13.7 7.6 8.2 3.6 9.9 9.17 8.4 19.8 13.7 9.3 13.6 11.6 13.2 19.9 9.0 | 0.3 2.4 0.3 1.1 2.3 | 5.6 3.1 0.7 8.1 0.8 1.5 9.3 1.2 1.0 | 1.0 1.6 1.3 0.7 | 0.6 1.0 3.2 | 7.2 | 2.2 14.9 4.7 | 3.6 5.8 0.8 5.8 | 8.9 | | 1.4 0.7 | 3.4 0.4 | 0.4 | | 0.4 2.0 1.0 2.8 0.3 4.1 3.3 0.8 11.3 2.9 0.7 1.0 1.1 0.4 | 7.0 1.6 0.9 2.0 0.3 2.6 7.7 3.3 1.2 2.9 0.7 2.3 5.8 0.4 14.9 8.6 0.4 | 10.1 1.0 0.3 6.6 4.4 7.4 3.2 3.3 4.5 10.0 3.6 4.7 1.1 2.7 | 0.4 0.7 5.8 0.7 1.0 3.9 7.1 9.4 0.7 4.8 | 0.3 2.1 0.9 | 3.2 | 0.4 0.3 0.3 0.3 0.3 0.3 0.3 0.4 0.6 0.7 0.5 0.3 0.9 0.4 | 3.0 1.2 1.1 0.7 | 2.5 1.3 1.3 6.8 1.0 4.8 0.7 2.5 4.9 5.0 1.2 3.6 4.0 2.0 | 3.0 2.0 0.9 0.7 1.0 1.4 1.0 0.6 1.6 0.8 2.3 0.5 2.2 3.6 2.5 0.3 0.4 1.1 |
| 63-1, 51-53 69-2, 34-36 76-5, 52-54 | P11-13 P10 P10 | 340 158 158 | 82.4 51.2 55.6 | 0.6 0.6 0.6 | | | 11.2 | 1.3 1.3 | | | 7.4 12.0 8.9 | 3.2 | | | | 0.6 | | | | | | | | 17.9 | 2.6 | 0.6 0.6 | 2.9 2.5 | | | 2.1 5.7 | 0.6 1.9 0.6 | 1.2 5.7 4.4 | | 2.5 3.8 |

EOCENE-MIOCENE BENTHIC FORAMINIFERS

| Astrononion pusillum | Nonion havanense | Gyroidinoides spp. | Rotaliatina mexicana | Anomalina capitata group | Anomalina semicribrata group | Anomalina corrugata | Anomalina pseudogrosserugosa | Anomalinoides spissiformis | Anomalinoides cf. alazanensis | Nuttallides truempyi | Nuttallides umbonifera | Osangularia mexicana | Osangularia culter | Oridorsalis umbonatus | Alabamina wilcoxensis | Hanzawaia cushmani | Discorbis subvilardeboanus | Sphaeroidina bulloides | Siphonina tenuicarinata | Globocassidulina subglobosa | Cassidulina havanensis | Planulina renzi | Ptanulina karsteni | Gavelinella micra | Cibicidoides tuxpamensis | Cibicidoides perlucidus | Cibicidoides dickersoni | Cibicidoides mexicanus | Cibicidoides sp. 4 | Cibicidoides ungerianus/ kullenbergi | Cibicidoides haitiensis | Cibicidoides laurisae group | Cibicidoides cicatricosus | Cibicidoides reussii | Cibicidoides sp. 3 |
|--------------------------|--|--|----------------------|---|--|---------------------|---------------------------------|--|--|---------------------------|------------------------|--|-----------------------------------|--|-----------------------|---|-------------------------------|---|--|--|------------------------|---|---------------------------------|--------------------------|--|-------------------------|--|--|---------------------------------|--|-----------------------------------|--|---------------------------|----------------------|--------------------|
| 0.4 | 0.4 | 5.3 0.3 5.9 5.2 4.4 7.5 2.8 5.6 | | 0.9 | 0.3 | | 2.1 0.3 1.5 3.6 0.5 | 0.9 | | | 0.7 8.6 0.4 | 1.4 | 0.6 24.9 16.5 3.7 1.2 | 0.6 0.3 3.6 1.1 6.3 0.5 4.4 | 2.2 | | 0.6 0.5 | 11.2 3.4 0.6 15.7 2.9 2.0 16.5 4.0 | 1.2 | 2.8 1.4 2.5 7.3 2.2 1.2 0.9 0.8 | 0.3 | 2.5 1.8 5.9 1.9 1.2 | 3.2 0.6 0.4 1.1 0.5 | | | | | | | 6.7 0.3 8.1 11.7 2.6 7.1 19.3 0.8 | 13.4 5.5 0.4 3.8 14.5 | 0.6 0.4 | 1.1 11.1 13.3 | 6.0 1.5 0.4 | |
| 1.0 3.3 6.3 4.9 | 2.0 1.0 4.1 0.3 1.0 0.5 3.1 1.1 1.2 0.9 0.9 0.9 2.8 0.6 | 3.0 3.3 2.2 4.7 3.0 3.4 5.3 1.3 3.6 3.1 7.0 5.2 4.4 5.2 4.4 5.2 4.4 5.7 3.8 13.6 5.7 3.6 1.4 2.5 2.6 1.3 5.7 3.6 1.4 2.5 2.6 1.3 5.7 | 2.6 | 2.1 1.5 1.7 0.3 2.2 2.0 2.3 7.0 1.2 2.5 0.3 1.8 3.4 0.9 3.2 2.5 2.5 | 0.3 1.3 0.4 2.2 0.8 2.3 1.6 2.7 0.5 1.3 | 1.8 1.8 0.4 | 0.3 0.4 2.0 2.9 5.1 | 2.5 1.0 0.3 0.7 2.6 0.4 4.4 1.8 | 0.4 0.5 1.4 0.3 0.5 0.8 0.3 0.4 0.4 1.3 1.1 3.9 | 1.1 6.2 16.5 1.9 | | 15.2 3.4 1.0 4.7 0.5 17.0 11.0 7.5 1.3 5.4 9.5 | 5.8 0.7 1.0 | $\begin{array}{c} 1.8\\ 1.7\\ 11.4\\ 3.4\\ 6.6\\ 4.1\\ 7.8\\ 2.1\\ 1.9\\ 5.1\\ 2.0\\ 0.7\\ 3.3\\ 9.0\\ 2.7\\ 3.3\\ 1.4\\ 13.7\\ 8.5\\ 3.2\\ 1.2\\ 3.8\\ 6.3\\ \end{array}$ | 2.4 0.7 11.0 | 2.5 7.0 1.2 6.3 3.3 0.7 1.0 4.8 14.0 11.8 0.6 | 0.5 | 3.4 24.5 5.8 3.4 3.1 0.7 5.3 0.3 0.5 0.4 | 10.5 4.2 5.2 4.8 6.9 3.5 5 0.3 4.7 6.6 3.9 0.4 0.6 16.5 0.3 0.7 | 6.3 1.3 2.0 3.5 4.6 16.0 2.9 4.5 1.6 6.5 5.6 6.6 0.4 2.1 1.0 21.7 | 3.6 7.4 0.4 | 7.6 3.3 1.8 0.3 4.0 2.0 1.9 1.6 0.4 1.1 10.5 4.5 | | 0.3 1.2 4.3 0.2 | 1.4 1.9 1.3 0.8 7.8 1.4 | 0.7 0.3 | 3.4 2.3 0.9 1.3 2.3 4.4 3.2 0.6 5.0 0.2 15.6 | 2.0 1.7 8.2 0.3 2.0 3.4 | 3.7 5.0 1.1 3.3 1.0 | 6.3 8.8 18.3 15.5 28.7 19.0 7.9 15.1 9.5 14.7 7.4 0.8 3.3 12.8 4.9 8.4 22.0 16.0 8.6 15.9 13.2 | 0.3 0.3 3.9 1.3 0.7 | 0.3 4.0 2.0 1.3 1.3 0.8 1.1 1.1 1.2 0.9 0.4 0.3 1.1 1.1 0.7 4.5 | 3.1 1.4 0.7 6.3 | | 0.7 3.0 2.3 |

Table 1. (Continued).

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Cibicidoides aff. laurisae (Mallory) (Plate 8, Figs. 2a-c)

aff. Cibicides laurisae Mallory, 1959, p. 267, pl. 24, figs. 8a-c. Cibicidoides aff. laurisae (Mallory). Tjalsma and Lohmann, 1983, p. 27, pl. 17, figs. 2a-c.

In Site 516, this species exhibits a generally rounded axial periphery. In this respect, it differs from the Eocene C. aff. *laurisae* described from other DSDP sites in the Atlantic (Tjalsma and Lohmann, 1983).

Cibicidoides mexicanus (Nuttall) (Plate 3, Fig. 5; Plate 9, Figs. 1a-2c)

Cibicides mexicana Nuttall, 1932, p. 33, pl. 9, figs. 7-9.

Morphologic characters developed in this distinctive species are constant except for preadult individuals, which often have a raised proloculus in the umbilical region rather than a depressed area characteristic of the adult stage.

Cibicidoides perlucidus (Nuttall) (Plate 9, Figs. 3a-c)

Cibicides perlucidus Nuttall, 1932, p. 33, pl. 8, figs. 10-12.

These small specimens do not exhibit the morphologic variation seen in the type material. They match well some of the paratypes, however. *Cibicidoides perlucidus* differs from *C. tuxpamensis* in its acute periphery and the longer spire that increases in height more gradually.

Cibicidoides popeliensis Myatlyuk (Plate 8, Figs. 1a-c)

Cibicidoides popeliensis Myatlyuk, 1970, p. 155, pl. 39, figs. 5-6,10; pl. 41, fig. 7; pl. 62, figs. 4a-c.

This species seems to be related to *C. laurisae;* the differences are that *C. popeliensis* has more chambers in the final whorl and a longer spire that increases in height more gradually.

Cibicidoides trinitatensis (Nuttall) (Plate 10, Figs. 3a-c)

Truncatulina trinitatensis Nuttall, 1928, p 97, pl. 7, figs. 3,5-6. Cibicides trinitatensis (Nuttall) Nuttall, 1932, p. 33, pl. 7, fig. 9. Anomalinoides trinitatensis (Nuttall) Renz, 1948, p. 115, pl. 10, figs.

11a-c.

Our specimens could only be compared with plesiotypes from the Oligocene of Mexico (Nuttall, 1932), which they resemble closely. Both the Mexican and Site 516 specimens are characterized by a fairly smooth test surface and a large, often raised boss of shell material, usually encircled by a narrow groove. The ventral side is fairly smooth with a central glassy mass.

Cibicidoides tuxpamensis (Cole) (Plate 9, Figs. 4a-5)

Cibicides tuxpamensis Cole, 1928, p. 219, pl. 1, figs. 2-3; pl. 3, figs 5-6.

Cibicidoides tuxpamensis (Cole). Tjalsma and Lohmann, 1983, p. 28, pl. 18, figs. 3a-4c; pl. 22, figs. 1a-3c.

Specimens of this species recovered from Oligocene strata at Site 516 show greater variation than those from the Eocene described by Tjalsma and Lohmann (1983). Large specimens, which are relatively less dome-shaped than the smaller specimens, often show a strongly curved sutural pattern on the ventral side (Plate 9, Figs. 4a-c).

Cibicidoides ungerianus (d'Orbigny) (Plate 8, Figs. 4a-c)

Rotalina ungeriana d'Orbigny, 1846, p. 157, pl. 8, figs. 16-18. Cibicides ungeriana (d'Orbigny) Nuttall, 1932, p. 34, pl. 9, figs. 4-8.

Cibicidoides ungerianus (d'Orbigny) Tjalsma and Lohmann, 1983, p. 28, pl. 18, figs. 1a-c; pl. 21, figs. 5-6.

This common species is characterized by its circular outline, lenticular cross-section, acute periphery with imperforate band, distinct umbilical mass of glassy shell material, curved ventral sutures, and the fairly long spire that gradually increases in height. In many respects, it resembles the younger *C. kullenbergi*, but is much smaller and more compressed. Tjalsma and Lohmann (1983) identified this species as *C. ungerianus* based on resemblance of Nuttall's figured plesiotype from the Oligocene of Mexico. Nuttal compared his specimens with topotypes of the original species. Side by side comparison of our material with Nuttall's plesiotypes show relatively little resemblance, particularly on the dorsal side. Further comparison with type material is necessary to determine if this form is indeed a separate species.

Cibicidoides sp. 3

(Plate 4, Figs. 1a-d; Plate 8, Figs. 5a-6)

A lenticular *Cibicidoides* characterized by abundant large pores, many of which are bordered by a rim (see Plate 4, Figs. 1c-d). Except for their absence on sutures and the narrow peripheral band, the pores are distributed evenly over the test. The sutures are radial, straight to strongly curved on the ventral side but are tangential and only moderately curved on the dorsal side. About two and one-half whorls are present, increasing gradually in height. Approximately nine chambers are developed in the final whorl. *Cibicidoides* sp. 3 has a stratigraphic range confined to the upper Eocene and lower Oligocene. It is also present in the Gulf of Mexico, at DSDP Site 94, and Conslope. Its stratigraphic range in those regions is similar to that at Site 516.

Cibicidoides sp. 4

(Plate 7, Figs. 5-6c)

A low trochospiral *Cibicidoides* with relatively few chambers in the final whorl (usually 6 to 8). The periphery is acute with a narrow imperforate band. The ventral side is low convex, the sutures are gently curved with those of the last two chambers often somewhat depressed. The dorsal side is flat to very low convex; two whorls are visible on this side. The sutures are fairly curved and slightly tangential. Perforation is moderately coarse, very regular in distribution, and often present on both sides. This species is rare to common from upper Eocene to upper Oligocene. It is also present in the lower Oligocene of Conslope and DSDP Site 548 (Goban Spur).

Discorbis subvilardeboanus (Rzehak) (Plate 3, Fig. 3; Plate 5, Figs. 1a-c)

Discorbina subvilardeboana Rzehak, 1888, p. 263, pl. 11, figs. 6a-c. Discorbis(?) sp., Hagn, 1956, p. 158, pl. 14, figs. 15a-b.

Discorbis subvilardeboanus (Rzehak) Boltovskoy, 1978, p. 157, pl. 3, figs. 26-30.

This distinctive species has a very low convex dorsal side and a flat or concave ventral side. In axial view, it has a subacute periphery. It is coarsely perforate except for a broad band along the periphery. On the dorsal side two to two and one-half whorls are visible, which increase rapidly in height. There are five to six chambers in the final whorl. The dorsal sutures are limbate, slightly curved and often a little depressed. The ventral sutures are moderately to strongly curved, limbate and depressed. The wide umbilical area is often filled with irregular deposits of shell material. The aperture is umbilical to extraumbilical and is covered by an umbilical flap. The species was originally described from the upper Oligocene of Austria. Hagn reported it from the upper Eocene of Northern Italy, Boltovskoy from the Oligocene to lower Miocene of the Indian Ocean. In Site 516, it ranges from upper Eocene to lower Miocene. It has also been observed in DSDP Site 94 and Eureka wells in the Gulf of Mexico and in wells in the Java Sea.

> Gavelinella micra (Bermudez) (Plate 5, Figs. 2a-c)

Cibicides micrus Bermudez, 1949, p. 302, pl. 24, figs. 34-36.

Gavelinella micra (Bermudez) Tjalsma and Lohmann, 1983, p. 31, pl. 16, figs. 7a-b; pl. 20, fig. 7.

The form present at Site 516 is the shallow-water morphotype (Tjalsma and Lohmann, 1983) and is distinguished from the deep-water type by its greater compression and completely involute dorsal side. It is closer in morphology to the primary types than the deep-water morphotype.

Gyroidinoides sp. of Schnitker (1979) (Plate 8, Figs. 3a-c)

Gyroidinoides sp., Schnitker, 1979, pl. 9, figs. 16-18.

A small but distinct *Gyroidinoides* with a conical shape and reniform chambers on the dorsal side that are slightly imbricated. The

Heronallenia sp. (Plate 6, Figs. 4a-c)

This distinctive form is characterized by small dome-shaped "blisters" on the low-spired dorsal side. On the strongly concave ventral side, each chamber has a clavate-shaped lateral extension that overlays the previous chamber and forms a connection between the chambers. The aperture is small and hidden behind the clavate-shaped extension of the last chamber. Fine striae radiate out from the aperture over the surface of the last chamber. Figured specimen from the middle Oligocene, very rare in our material.

Osangularia mexicana (Cole) (Plate 6, Figs. 5a-c)

Pulvinulinella culter (Parker and Jones) var. mexicana Cole, 1927, p. 31, pl. 1, figs. 15-16.

Osangularia mexicana (Cole) Tjalsma and Lohmann, 1983, p. 35, pl. 20, fig. 6.

Both generations of this familiar species can be recognized at Site 516. Particularly conspicuous from upper middle Eocene to lower Miocene is a megalospheric morphotype (Plate 6, Figs. 5a-c) characterized by its small size, its short coil, and seven to eight chambers in the final whorl. In addition, tangential sutures and a large proloculus are visible on the ventral side. It is also present in the middle and upper Eocene of DSDP Site 357, as well as the upper Eocene and Oligocene of Site 363.

Planulina karsteni Petters and Sarmiento (Plate 6, Figs. 8a-c)

Planulina cf. wuellerstorfi (Schwager) Cushman and Stainforth, 1945, p. 71, pl. 14, figs. 6a-c.

Planulina karsteni Petters and Sarmiento, 1956, p. 31, pl. 1, figs. 9a-c.

This species first occurs at Site 516 in the upper Oligocene (Zone P22) and ranges into the Pliocene. In the course of its stratigraphic range, its relative size increases and its specific characteristics become more distinct. Lower Miocene representatives are generally small and often have a flattened or slightly concave dorsal side. Immature specimens (Plate 6, Figs. 8a-c) often have a fairly convex ventral side.

Planulina renzi Cushman and Stainforth (Plate 3, Fig. 4; Plate 6, Figs. 6a-7c)

Planulina renzi Cushman and Stainforth, 1945, p. 72, pl. 15, figs. 1a-c.

Planulina renzi Cushman and Stainforth. Douglas, 1973, pl. 13, figs. 7-9.

The fact that the primary types and all the other identified specimens in the Cushman collection are exceptionally large and multichambered (up to 18 in the final whorl) raises the suspicion that the species is based on a few extreme variants. Although large specimens occur at some levels at Site 516, at most other levels the whole size range is present in each population. Small individuals are relatively compact and less compressed when seen in side view (Plate 6, Figs. 7a-c). Adult specimens (Plate 6, Figs. 6a-b) are about half as large as the primary types, have about 10–11 chambers in the final whorl, lack the raised sutures, and have a smoother wall texture. In all other respects, they are close to the types. A few specimens from Trinidad, stored in the collection, are smooth and lack the raised sutures.

Rectuvigerina vesca (Finlay) (Plate 2, Fig. 3)

Siphogenerina vesca Finlay, 1939, p. 109, pl. 13, figs. 46-47.

Siphogenerina vesca Finlay. Boltovskoy, 1978, p. 169, pl. 7, figs. 7-8.

Rectuvigerina vesca (Finlay) Hayward and Buzas, 1979, p. 73, pl. 26, fig. 323.

At Site 516, this species is characterized by a uniserial section of two to four globular chambers; fine longitudinal, although discontinuous, costae; and a long apertural neck.

Reussella oligocenica Cushman and Todd

Reussella oligocenica Cushman and Todd, 1946, p. 94, pl. 16, figs. 6-7.

Siphonina tenuicarinata Cushman (Plate 5, Fig. 4)

Siphonina tenuicarinata Cushman, 1927, p. 166, pl. 26, figs. 11-12. Siphonina tenuicarinata Cushman. Berggren, 1972, pl. 10, figs. 12-13.

> Sphaeroidina bulloides d'Orbigny (Plate 6, Fig. 3)

Sphaeroidina bulloides d'Orbigny, 1826, p. 267. Modèle No. 65.

Stilostomella curvatura (Cushman) (Plate 1, Figs. 7, 11)

Ellipsonodosaria curvatura Cushman, 1939, p. 71, pl. 12, fig. 6.

Stilostomella curvatura (Cushman) Beckmann, 1953, p. 370, pl. 21, figs. 26-27.

Stilostomella curvatura (Cushman) Proto Decima and Bolli, 1978, p. 796, pl. 2, figs 8-9.

Stilostomella modesta (Bermudez)

(Plate 1, Fig. 10)

Ellipsonodosaria modesta Bermudez, 1937, p. 238, pl. 20, fig. 3. Stilostomella modesta (Bermudez) Beckmann, 1953, p. 371, pl. 21, fig. 32.

Siphonodosaria modesta (Bermudez) Douglas, 1973, pl. 5, fig. 4.

Orthomorphina modesta (Bermudez) Boltovskoy, 1978, p. 163, pl. 5, fig. 25.

This species has a long stratigraphic range. Although originally described from the upper Eocene of Cuba, *Stilostomella modesta* first appears in the upper Oligocene (Zone P21b) at Site 516, extending upward into the Pliocene. Its occurrence is sporadic in the upper Oligocene, becoming more common in the Miocene.

Stilostomella paucistriata (Galloway and Morrey) (Plate 1, Fig. 8)

Nodosarella paucistriata Galloway and Morrey, 1929, p. 42, pl. 6, fig. 12.

Ellipsonodosaria verneuili var. paucistriata (Galloway and Morrey) Cushman and Stainforth, 1945, p. 55, pl. 9, fig. 12.

Uvigerina mexicana Nuttall (Plate 2, Figs. 4-5)

Uvigerina mexicana Nuttall, 1932, p. 22, pl. 5, figs. 12-13. Uvigerina eocaena Guembel. Hagn, 1956, p. 149, pl. 13, figs. 9-10.

Our populations contain tapering forms as well as those with a blunt initial part (of this latter form only a juvenile is shown in Plate 2, Fig. 4). Both morphotypes are represented in Nuttall's paratype material from Vera Cruz, Mexico. Hagn (1956), who studied populations of U. eocaena from near Guembel's type locality at Lake Garda (Italy), found only tapering forms. Because it is not clear whether blunt-shaped forms should be included in U. eocaena, the name U. mexicana has been retained here.

Uvigerina spinulosa Hadley (Plate 2, Figs. 1-2)

Uvigerina canariensis d'Orbigny var. spinulosa Hadley, 1934, p. 22, pl. 5, fig. 9.

There is quite some variation in our material, concerning the overall shape (from short with blunt initial part to quite stretched and tapering), the degree of inflation of the chambers, and the ornamentation (from nearly absent to fairly continuously and moderately raised costae).

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Plate 1. 1. Bolivina byramensis Cushman, Sample 516F-20-4, 55-57 cm, (a) ×120, (b) detail of costae pattern, ×300. 2. Bolivina reticulata Hantken, Sample 516F-7, CC, (a) ×150, (b) detail of costae, ×750. 3. Bolivina tectiformis Cushman, Sample 516F-31-2, 87-91 cm, (a) ×100, (b) side view, ×60. 4-5. Bulimina alazanensis Cushman, Sample 516F-26, CC, ×150. 6. Bulimina macilenta Cushman and Parker, Sample 516F-26-3, 56-58 cm, ×180. 7. Stilostomella curvatura (Cushman), Sample 516F-17-1, 50-54 cm, ×30. 8. Stilostomella paucistriata (Galloway and Morrey), Sample 516F-15-7, 22-23 cm, ×30. 9. Marginulina hirsuta d'Orbigny, Sample 516F-17-1, 50-52 cm, ×40. 10. Stilostomella modesta (Bermudez), Sample 516-13-1, 100-102 cm, ×60. 11. Stilostomella curvatura (Cushman), Sample 516F-37-2, 83-86 cm, ×65.



Plate 2. 1-2. Uvigerina spinulosa Hadley, Sample 516F-26-3, 56-58 cm, (1) ×120, (2) ×90. 3. Rectuvigerina vesca (Finlay), Sample 516F-20-5, 55-57 cm, ×100. 4-5. Uvigerina mexicana Nuttall, Sample 516F-19-2, 60-62 cm, (4) juvenile specimen, ×90, (5) ×75. 6-7. Trifarina danvillensis (Howe and Wallace), Sample 516F-32-2, 34-36 cm, (6) ×145, (7) ×80. 8-10. Uvigerina havanensis Cushman and Bermudez, (8-9) Sample 516F-29, CC, (8, juvenile specimen, ×110; 9, ×65), (10) Sample 516F-37-2, 83-86 cm, ×65. 11. Uvigerina chirana Cushman and Stone, Sample 516F-26-3, 56-58 cm, ×165.



Plate 3. 1. Anomalina corrugata Cushman and Bermudez, Sample 516F-29-1, 91-92 cm, (a) ventral view, ×65, (b) oblique side view, ×75, (c) dorsal view, ×110.
2. A. cf. capitata (Guembel), Sample 516F-20-3, 55-57 cm, (a) oblique dorsal view, ×180, (b) oblique ventral view, ×100.
3. Discorbis subvilardeboanus (Rzehak), Sample 516F-19-2, 60-62 cm, ventral view, ×75.
4. Planulina renzi Cushman and Stainforth, Sample 516F-22-1, 45-46 cm, ventral view, ×30.
5. Cibicidoides mexicanus (Nuttall), Sample 516F-19-3, 60-62 cm, oblique side view, ×50.



Plate 4. 1. Cibicidoides sp. 3, Sample 516F-36-3, 95-96 cm, (a) ventral view, ×60, (b) dorsal view, ×100, (c) detail of pore pattern, ×600, (d) detail of pore ×1200.
2. Astrononion pusillum Hornibrook, Sample 516F-26-3, 56-58 cm, (a) ×195, (b) detail of supplementary chamber, ×375.
3. Textularia milletti Cushman, Sample 516F-26-3, 56-58 cm, ×120.
4. Anomalinoides cf. alazanensis (Nuttall), Sample 516F-18-1, 60-62 cm, ventral view, ×65.



Plate 5. 1. Discorbis subvilardeboanus (Rzehak), Sample 516F-31-3, 32-34 cm, ×70, (a) dorsal view, (b) side view, (c) ventral view. 2. Gavelinella micra (Bermudez), Sample 516F-41-1, 80-82 cm, ×70, (a) dorsal view, (b) side view, (c) ventral view. 3. Anomalinoides cf. alazanensis (Nuttall), Sample 516F-17-2, 50-54 cm, ×70, (a) ventral view, (b) side view, (c) dorsal view. 4. Siphonina tenuicarinata Cushman, Sample 516F-36-3, 95-96 cm, ×70. 5. Hanzawaia cushmani (Nuttall), Sample 516F-32-3, 11-13 cm, ×55, (a) ventral view, (b) side view.



Plate 6. (Magnification ×70 unless otherwise indicated.) 1-2. Bulimina tuxpamensis Cole, (1) Sample 516F-32-3, 11-13 cm, (2) Sample 516F-32-2, 34-36 cm.
3. Sphaeroidina bulloides d'Orbigny, Sample 516F-4-5, 60-62 cm, ×55.
4. Heronallenia sp., Sample 516F-20-3, 55-57 cm, (a) ventral view.
5. Osangularia mexicana (Cole), Sample 516F-31-4, 35-37 cm, megalospheric specimen, (a) dorsal view, (b) side view, (c) ventral view.
6. Planulina renzi Cushman and Stainforth, Sample 516F-20-1, 56-58 cm, ×35, (a) ventral view, (b) side view.
7. Planulina renzi Cushman and Stainforth, Sample 516F-18-1, 60-62 cm, juvenile specimen, ×55, (a) dorsal view, (b) side view, (c) ventral view.
8. Planulina karsteni Petters and Sarmiento, Sample 516F-2, CC, (a) dorsal view, (b) side view, (c) ventral view.
9. Cibicidoides robert-sonianus (Brady), Sample 516F-19-3, 60-62 cm, ventral view.



.Plate 7. (Magnification ×70 unless otherwise indicated.) 1. Anomalina corrugata Cushman and Bermudez, Sample 516F-31,CC, ×35, (a) ventral view, (b) oblique side view, (c) dorsal view. 2. A. cf. capitata (Guembel), Sample 516F-20-3, 25-27 cm, (a) dorsal view, (b) oblique side view, (c) ventral view. 3. A. pseudogrosserugosa Colom, Sample 516F-29-1, 91-92 cm, (a) ventral view, (b) side view, (c) dorsal view. 4. A. pseudogrosserugosa Colom, Sample 516F-2, CC, ×55, (a) dorsal view, (b) side view, (c) ventral view. 5-6. Cibicidoides sp. 4, (5) Sample 516F-11-1, 22-23 cm, ventral view, (6) Sample 516F-13-1, 20-21 cm, (a) ventral view, (b) side view, (c) dorsal view.



Plate 8. (Magnification ×70 unless otherwise indicated.) 1. Cibicidoides popeliensis Myatlyuk, Sample 516F-19-3, 60-62 cm, (a) ventral view, (b) side view, (c) dorsal view. 2. Cibicidoides aff. laurisae (Mallory), Sample 516F-19-3, 60-62 cm, (a) ventral view, (b) side view, (c) dorsal view. 3. Gyroidinoides sp. of Schnitker (1979), Sample 516F-20-3, 55-57 cm, (a) ventral view, (b) side view, (c) dorsal view. 4. Cibicidoides ungerianus (d'Orbigny), (a,c) Sample 516F-31,CC (a, ventral view; c, dorsal view), (b) side view, Sample 516F-26-3, 56-58 cm. 5-6. Cibicido-ides sp. 3, (5) Sample 516F-35-4, 19-21 cm, ×55, (a) dorsal view, (b) side view, (c) ventral view, (6) Sample 516F-36-3, 95-96 cm, ×55, ventral view.



Plate 9. (Magnification ×70 unless otherwise indicated.) 1. Cibicidoides mexicanus (Nuttall), Sample 516F-20-3, 55-57 cm, ×55, (a) ventral view, (b) side view, (c) dorsal view. 2. Cibicidoides mexicanus (Nuttall), Sample 516F-27-1, 56-58 cm, juvenile specimen, (a) ventral view, (b) side view, (c) dorsal view. 3. Cibicidoides perlucidus (Nuttall), Sample 516F-31, CC, (a) dorsal view, (b) side view, (c) ventral view. 4-5. Cibicidoides tuxpamensis (Cole), Sample 516F-33-3, 18-20 cm, (4) (a) dorsal view, (b) side view, (c) ventral view, (5) ventral view of juvenile specimen.



Plate 10. 1-2. Cibicidoides dickersoni (Bermudez), (1) Sample 516F-31,CC, ×40, (a) ventral view, (b) side view, (c) dorsal view. (2) Sample 516F-32-1, 53-54 cm, juvenile specimen, ×40, (a) ventral view, (b) side view, (c) dorsal view. 3. Cibicidoides trinitatensis (Nuttall), Sample 516F-31-4, 35-37 cm, ×55, (a) dorsal view, (b) side view, (c) ventral view. 4. Cibicidoides cf. cookei Cushman and Garrett, Sample 516F-33-4, 20-22 cm, ×70, (a) dorsal view, (b) side view, (c) ventral view.