26. CENOZOIC PLANKTONIC FORAMINIFERA[1]—DSDP LEG 39 (SOUTH ATLANTIC)

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ABSTRACT

Tertiary planktonic foraminiferal faunas were recovered at Sites 354, 355, 356, 357, 358, and 359 during DSDP Leg 39 in the western South Atlantic; faunas at Site 355 are considered redeposited.

At Site 354 the Tertiary section is characterized throughout by strong dissolution; the low-latitude planktonic foraminiferal faunas indicate deposition above the CCD. Dissolution across the Miocene/Pliocene boundary has resulted in the unique "*Sphaeroidinellopsis* fauna," typical of the circum-Mediterranean and equatorial Atlantic for this interval. An extensive middle Miocene hiatus occurs at this site.

Site 356 contains the oldest Tertiary, basal "*Globigerina*" *eugubina* Zone, which includes the ancestor to *Globoconusa daubjergensis*. An extensive middle Miocene hiatus also occurs at this site. Some unusual planktonic foraminiferal morphotypes with abundant spines characterize a temperature maximum in the early Miocene.

The faunas at Site 357 contain a greater number of high latitude species than the adjacent Site 356, particularly in the early Tertiary. There is a significant hiatus across the Eocene/Oligocene boundary, preceded by a marked drop in planktonic foraminiferal diversity; this is also the time of cooling bottom and surface temperatures in the South Atlantic. The very long lower Miocene section, so typical of the South Atlantic, is followed by a relatively short middle Miocene hiatus. Several unusual planktonic foraminifera occur at this site. The first appearance of *Streptochilus*, known previously only from the middle Miocene to Recent, was recorded here in the latest Oligocene. Unusual spiny morphotypes of *Globoquadrina* and *Catapsydrax* appear during a temperature rise in the early Miocene. *Globorotalia miozea* morphotypes have a long stratigraphic range, occurring from the early Miocene into the Pliocene. Because of the high latitude component it was difficult to zone the late Miocene; it was, however, possible to use these higher latitude elements to interrelate the Neogene temperate and high latitude zonations with the low latitude zonation of Berggren (1972).

Site 358 contains an unusual sequence of moderately well preserved to poorly preserved Paleocene through middle Eocene planktonic foraminifera. This site, deep in the Argentine Basin, was apparently near the foraminiferal lysocline and CCD throughout the early Tertiary until it sank permanently below these levels in the middle Eocene. Using the paleodepth of the site during this time period, it is possible to estimate the depth of the paleo CCD in this part of the Southern Atlantic from the Maestrichtian through the Eocene.

Site 359 faunas are similar to those at Site 357. Only intermittent coring was done and only Pliocene, Miocene, and upper Eocene intervals were recovered. Eocene samples are full of volcanic debris and displaced foraminifera; *Hantkenina* is very abundant at this site, which must have lain at about 1000 meters in the Eocene.

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[1]The author has expressed strong preference for using "foraminifera" rather than the common form "foraminifer." Although the DSDP editors feel that the common form of the word is preferable in English, and have decided for consistency to use it in the Initial Reports, they accede here to the author's wishes.

INTRODUCTION

Cenozoic planktonic foraminifera were retrieved from all sites drilled on Leg 39 (Table 1). The planktonic foraminiferal faunas from Site 355 in the Brazil Basin are considered redeposited. The location of Sites 354-359 and their stratigraphy are shown in Figure 1. This chapter gives an introduction to the types of planktonic foraminiferal faunas recovered from these sites, and calls attention to some oceanographic problems that may be approached or are raised by a knowledge of these faunas. Detailed taxonomic analysis is beyond the capacities of the present writer; hence there is little taxonomic detail included here. For such an analysis of the Neogene of Site 357 see Berggren (this volume).

TAXONOMY

In the past few years there have been a number of taxonomic revisions of the planktonic foraminifera (Fleischer, 1974; Premoli Silva, in preparation). There still appears to be confusion regarding the phylogenetic relationships of species and particularly genera, specifically those of the Oligocene and lower Paleocene. A compromise position is adopted in this study. Where generic relationships are considered established, the new generic or subgeneric designations are included in quotation marks along with the older generic designation. Otherwise the older generic assignment is used. As the species name conveys the most information at this time, this position should allow understanding of what forms are being discussed.

ZONATION

The standard zonation of Berggren (1972) was applied to all sites in this study. In only a few instances was there trouble recognizing the standard zones, for example in the upper Miocene at Site 357. The location of Site 357 close to 30° south latitude results in the presence there of many higher latitude species. Thus it was also possible to locate several of the higher latitude zonal boundaries of Jenkins (1971) and Kennett (1973). If there is an ecological "delay" effect on the extinction of taxa between higher and lower latitudes, then zonal boundaries will not correspond in time with those recognized at higher latitudes. But we will know when high latitude zonal markers appear or disappear in terms of a low latitude zonation and time scale.

TABLE 1
Locations and Water Depths
of Leg 39 Drilling Sites

Site	Latitude	Longitude	Water Depth (m)
353	10°55'N	44°02.25'W	5165
354	05°53.95'N	44°11.78'W	4052
355	15°42.59'S	30°36.03'W	4896
356	28°17.22'S	41°05.28'W	3203
357	30°00.25'S	35°33.59'W	2109
358	37°39.31'S	35°57.82'W	5000
359	34°59.10'S	04°29.83'W	1658

SITE 354

Site 354 on the Ceará Rise was drilled at a depth of 4045 meters. The ranges of selected planktonic foraminiferal species in the Tertiary of Site 354 are shown in Figure 2. The planktonic foraminiferal zonation is that of Berggren (1972). However, the location of several zonal boundaries was obscured by episodes of dissolution, recrystallization, and inferred diagenetic alteration of the foraminiferal faunas.

Preservation

Preservation is particularly poor in Cores 11 to 16. The bottom cores contain dissolved, pitted, and barely recognizable planktonic foraminifera, some strongly stained red. In many instances the foraminifera have been squashed flat into calcareous pancakes. In Cores 11 and 12, foraminifera are often pitted, recrystallized, and fragmented. In these same samples radiolarians and/or diatoms are abundant and often pyritized. This suggests that the foraminifera were dissolved during episodes of increased productivity, increased organic flux to the bottom, and micro-reducing conditions.

In Core 10 preservation has improved markedly, although there are levels in almost every core where preservation again degenerates and forms become chalky, dissolved, and fragmented.

Cores 4 to 8 contain highly dissolved faunas with "peeled" *Sphaeroidinellopsis* and reduced faunal diversity. Above Core 4, preservation is moderate to good.

Sphaeroidinellopsis Fauna

Above Core 8 an unusual sequence of dissolved faunas occurs. These faunas are often rich in planktonic foraminifers, only a couple of which dominate the fauna. Such faunas typically contain the species *Sphaeroidinellopsis seminulina* and *Sphaeroidinellopsis subdehiscens* in abundance, with occasional *Globigerinoides* preserved along with the more resistant keeled globorotaliids and *Sphaeroidinellopsis* spp.

Similar small faunas dominated by *Sphaeroidinellopsis* spp. have been reported from the circum-Mediterranean region (Cita et al., 1973) as well as Leg 4, Site 29 (Bolli, 1970) Leg 13, Site 132 (Cita et al., 1973), and Leg 14, Sites 141 and 142 (Beckman, 1972). *Sphaeroidinellopsis* spp. are accompanied by the following species:
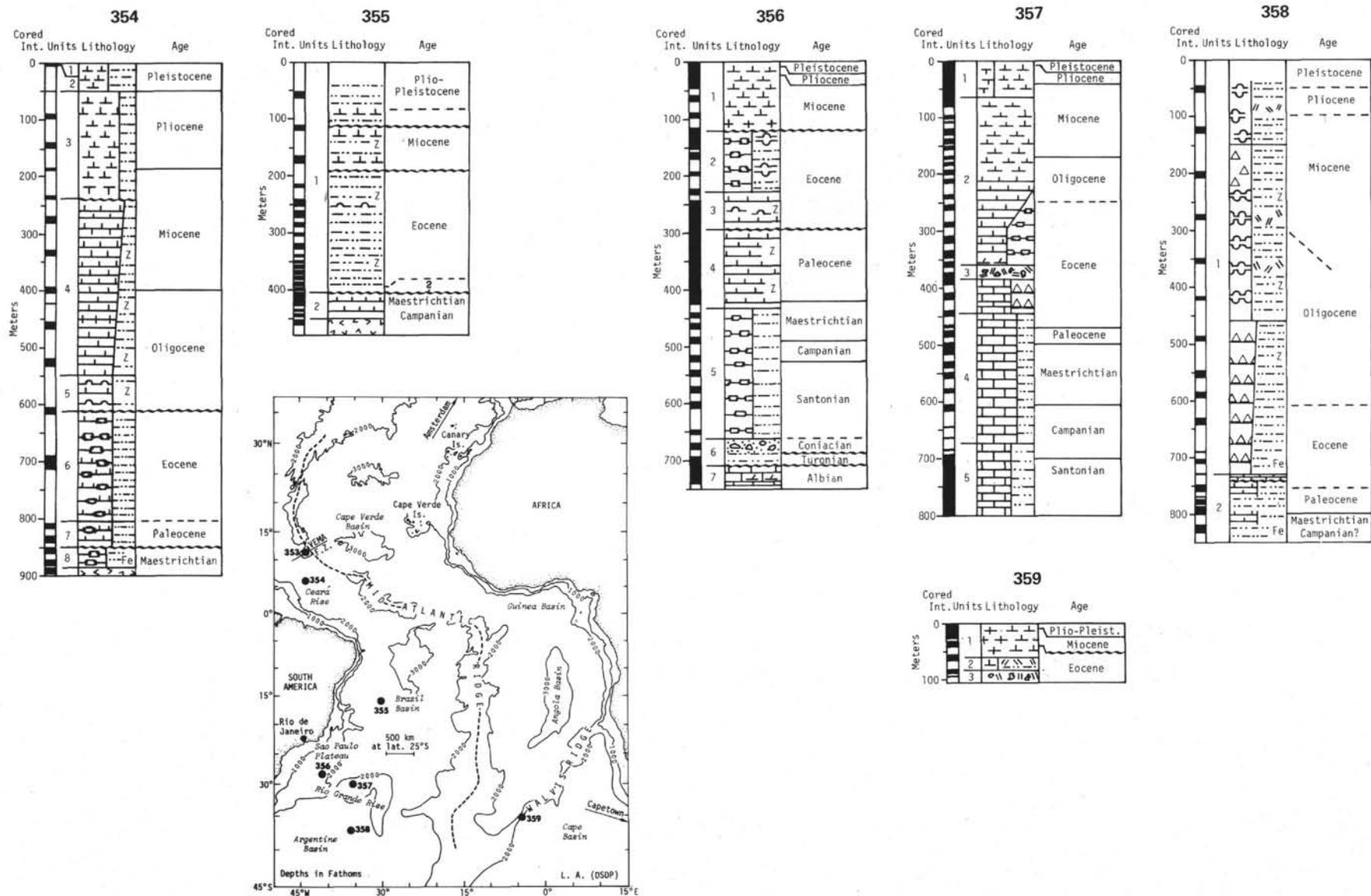
Site 29: *Neogloboquadrina acostaensis, Globoquadrina altispira, G. dutertrei, Globigerinoides sacculifer,*

Site 132: *Globoquadrina acostaensis, Globoquadrina humerosa, Globorotalia scitula.*

Site 141: *Globigerina nepenthes, Globoquadrina dehiscens, G. venezuelana, Globorotalia cultrata.*

Site 142: *N. acostaensis, Globorotalia tumida, Globigerinoides obliquus.*

In the Mediterranean the fauna characterized by high abundances of *Sphaeroidinellopsis* spp. has been related to the catastrophic transgression of Atlantic waters into the Mediterranean after the Messinian salinity crisis (Cita et al., 1973).
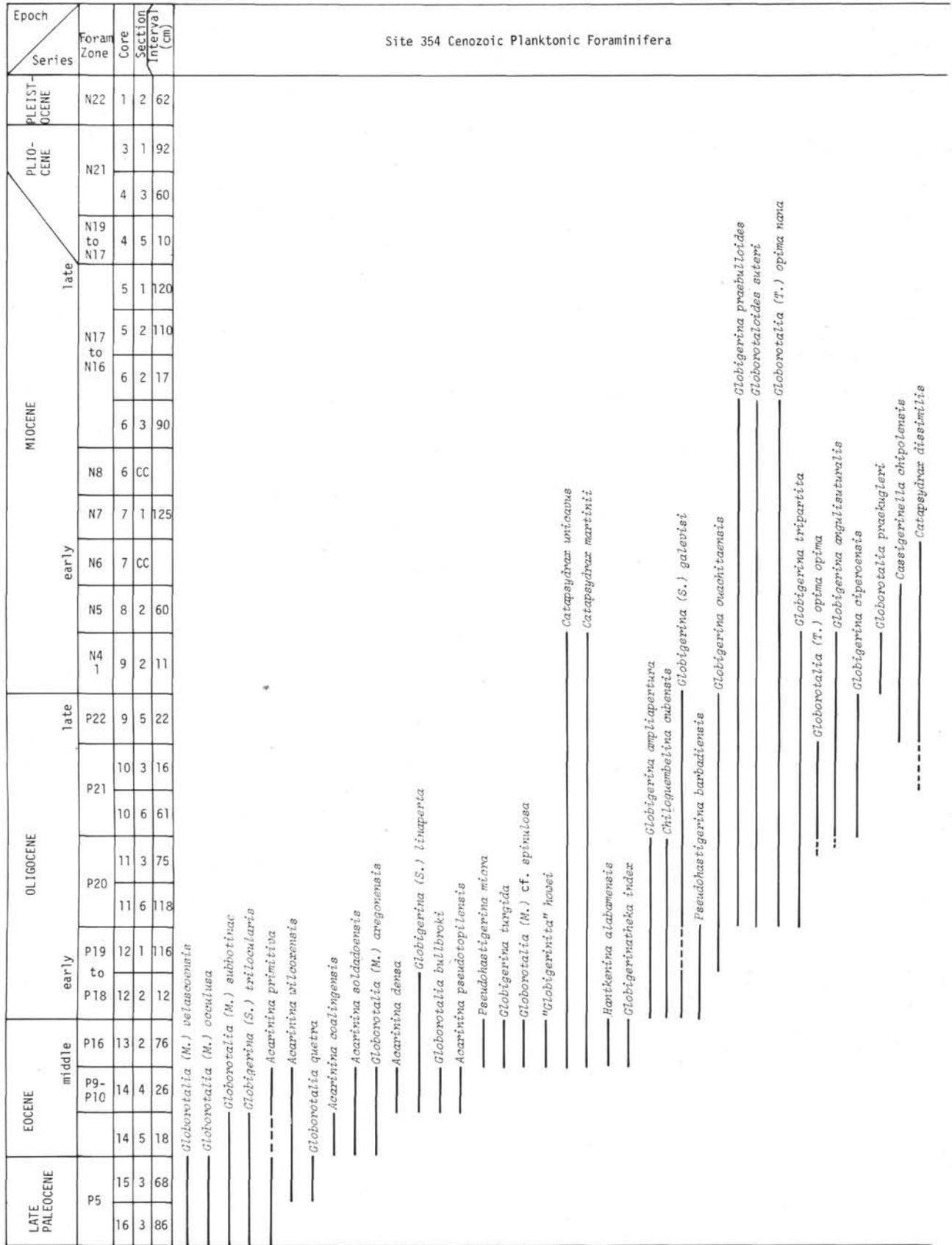
Figure 1. *Locations of DSDP Leg 39 sites in the South Atlantic containing Tertiary sediments. Stratigraphic column for each site: biostratigraphic subdivisions are based on the zonation and time scale of Berggren, 1972.*

Figure 2. *Stratigraphic ranges of selected planktonic foraminifera during the Cenozoic at Site 354 on the Ceará Rise.*

Figure 2. *(Continued)*.

These unique faunas, existing in the circum-Mediterranean area as well as spanning the equatorial Atlantic consistently characterize the uppermost Miocene and lower Pliocene interval.

Stratigraphic Boundaries

Because of the large number of hiatuses and coring gaps, there were few epoch boundaries to be identified at this site. Only the Miocene/Oligocene and the Miocene/Pliocene boundaries were cored. The Oligocene/Miocene boundary was placed within Core 9 on the basis of the overlap between *Globigerina angulistuturalis* and *Globorotalia kugleri*, immediately below the abundant occurrence of *Globigerinoides primordius*.

The Miocene/Pliocene boundary was placed in the interval between Section 4 and the core-catcher sample of Core 4. *Globoquadrina dehiscens* last occurs in Section 5-1; however, faunal dissolution above this level has removed most diagnostic species so that the "real" top of *G. dehiscens* is not known. Cita et al. (1973) places her dissolution interval in the top of the Miocene; this may also be the case at Site 354.

Zonal Boundaries and Hiatuses

Zonal boundaries have been determined on the basis of diagnostic zonal fossils where possible. However, poor preservation and dissolution sometimes necessitated using other criteria. This was true for the Eocene zones which were determined primarily on the co-occurrence of species, not necessarily on the presence or absence of the zonal markers. As the Oligocene through lower Miocene was more complete, most of the zonal markers were present and allowed more precise zonal assignments.

There are three Paleogene hiatuses: between the Eocene/Oligocene, the upper and middle Eocene, and the lower and upper Paleocene (see Figure 1). Several hiatuses above the lower Miocene made the recognition of Neogene zonal boundaries difficult. A middle Miocene hiatus between Zones N.8 and N.16 is typical of the South Atlantic, although the duration of the hiatus differs from site to site. Parts of the middle Miocene are absent also from DSDP Sites 14, 17, 19, 20, 25, possibly 142, 356, and 357 all in the southern and western Atlantic. This middle Miocene hiatus is considered the result of dissolution intensity and current scour related to a shallower CCD with a peak dissolution time in the late middle Miocene.

A second hiatus spans most of the lower Pliocene. The sediments above the hiatus appear to belong to the lower part of Zone N.21, as *Globorotalia multicamerata* is already present in the first sample above the hiatus, and *Globigerina nepenthes* and *Sphaeroidinellopsis seminulina* are absent; but there is an overlap between *Sphaeroidinellopsis subdehiscens* and *G. multicamerata*. Higher in this sequence *Globorotalia miocenica* and *Globigerinoides fistulosus* make their first appearance. However, the top part of Zone N.21 may be missing, as *Globorotalia tosaensis* was not found. Thus there may be another hiatus between the lower part of N.21 and the Pleistocene *Globorotalia truncatulinoides* Zone (N.22).

Adjacent Sites

Site 142 from Leg 14 lies in the Ceará Abyssal Plain below the Ceará Rise (see Figure 4). The following zones were recognized in the sediments cored at Site 142: *G. margaritae*, *G. dutertrei*, *G. acostaensis*, mixed mid-late Miocene, and the *G. insueta* Zone. Within the upper Miocene/Pliocene interval, there are levels with few species which may correlate with the *Sphaeroidinellopsis* layers at Site 354. Although a bit of middle Miocene found at this site was mixed in with upper Miocene sediments, there may be a middle Miocene hiatus at this site also. Unlike Site 354, there is a gap in the lower Miocene down to the *G. insueta* Zone. This may be a stratigraphic gap, except that the unrecovered interval may have been contained in the near-40-meter coring gap immediately above the *G. insueta* Zone and below the section generally called lower Miocene, but given no zonal designation. Thus the Miocene at Site 142 bears close resemblance to that of Site 354 on the rise. However, the *G. margaritae* Zone of Site 141 was not found at Site 354. The upper Pliocene may be present at Site 142; however, there is a 60-meter coring gap between the lower Pliocene and the Pleistocene, so that Zone N.19 may occur in the uncored sediment column.

Site 144 on the Demerara Rise was drilled into Paleogene sediments at a depth of 2957 meters. There is a hiatus between the lower Oligocene Zone P.18 and the middle Eocene within Core 2 in Hole 144A. However, the remainder of the Eocene may be present but uncored in the near-100-meter coring gap between the middle Eocene and the upper Paleocene (Zone P.4) that was recovered.

As fossils from Zone P.16 were recovered from Site 354, the Eocene/Oligocene hiatus on the Ceará Rise is not as extensive as that on the Demerara Rise. The upper/middle Eocene hiatus at Site 354 is contained in Core 13 and covers Zones P.16 to P.10. Hence, parts of the middle Eocene missing here are in fact preserved on the Demerara Rise nearby. The lower Eocene/upper Paleocene hiatus is also contained within one core at Site 354, but comparison with the Demerara Rise is not possible because of the extensive coring gap at that site.

SITE 355

Planktonic foraminifera were recovered in several layers of presumed turbidite origin. Coarse-grained shallow water deposits containing larger benthic foraminifera such as *Miogypsina* are occasionally intercalated into the foraminiferal ooze layers.

Foraminifera recovered from Core 2 included *Globigerina nepenthes*, *Globorotalia mayeri*, *S. seminulina*, and *S. subdehiscens* at the top, locating this level somewhere between Zones N.13 and N.19. A second fauna (Cores 2 and 3), including *Praeorbulina glomerosa*, *P. transitoria*, *Globorotalia peripheroronda*, and *Globigerinoides diminutus*, represented the interval from Zones N.7 to N.9. The foraminifera from Section 3-1 and Sample 3, CC, representing the interval from N.5 to P.22 include *Globoquadrina dehiscens*, *Globigerinoides primordius*, *Globorotalia "T." opima nana*, *G. cuachitaensis*, and *Globoquadrina altispira*.

SITE 356

Site 356 was drilled at a depth of 3175 meters on the São Paulo Plateau. At this depth, the plateau presently lies in the path of the middle North Atlantic Deep Water. Site 356 lies in the southward path of the surface Brazil Current in the more steady continentward zone of this surface current system.

The Tertiary section drilled at this site extends from the very oldest Paleocene yet recovered to upper Pliocene (see Figure 1). The faunas are subtropical in character, but do not include the higher latitude components so abundant in parts of the section at Site 357. Otherwise, foraminiferal events at the two sites are similar.

Hiatuses

There are five significant hiatuses in the Tertiary section at Site 356. Briefly, the Danian is relatively complete, except for a gap covering the interval of Zone P.1b. The Paleocene sequence above this continues into Zone P.4 above which there is a hiatus (within Core 16) extending into the lower Eocene.

There is a fairly continuous lower to middle Eocene section; however, poor preservation makes zonation speculative. There is then a hiatus in Core 6 between the upper middle Eocene and the Oligocene/Miocene transition. A thick lower Miocene is then followed by a hiatus, within an unrecovered interval between Cores 3 and 2. This uncored interval of 19 meters was not long enough to have included the remainder of the Miocene and lower Pliocene. Further, this is a time of extensive and geographically widely distributed hiatuses in the South Atlantic.

Preservation

Probably the most spectacular preservation at this site can be seen in the Danian (Cores 29-22), particularly in the lower Danian. The basal Tertiary "G." eugubina Zone, as well as other sections of Zone P.1 show excellent preservation. However, significant episodes of dissolution begin in Core 21 and become so intense in the upper Paleocene and Eocene as to make recognition of fossils often impossible. Recrystallization of forms as well as squashing of individuals become common. Increase in siliceous cement in Core 16, hence increased induration, leaves residues altered to the point that the entire sample will contain no recognizable fossils. Beginning in Core 10 there is an influx of radiolarians and diatoms which precedes a marked improvement in preservation from Cores 10 to 6. Dissolution is less obvious except in the top of this section; nevertheless, faunas appear reduced in diversity by dissolution. A notable exception is Core 6 which contains a rich assemblage of the Globorotalia "M." lehneri Zone.

In Cores 15 through 6 the presence of redeposited fossils of various ages is common. For example, G. "M." palmerae is present as a contaminant in older sediments (see Figure 3).

Preservation of the Neogene is not much better, although there are several well-preserved levels scattered throughout the five cores. In lower Miocene sediments, radiolarians, particularly the giant forms, are abundant. Several levels contain pyrite, suggesting micro-reducing intervals. Preservation improves toward the top of the lower Miocene and the Pliocene is well preserved.

Paleogene Zonation

The ranges of the most abundant planktonic foraminifera at Site 356 are shown in Figure 4. Because of unusually bad preservation the zonation of the Paleogene was based on whatever evidence could be used. Paleobiogeographic information supplied by I. Premoli-Silva (personal communication, 1976) helped immensely, as faunal events occurring at other sites could be used to identify the time intervals represented at this site.

The Paleocene at this site is thick. According to Dr. Premoli-Silva, the very base of the "Globigerina" eugubina Zone is represented in Core 29, Section 3 at this site; it contains the ancestor of Globoconusa daubjergensis and is dominated by "G." fringa (Plate 1). The top of the "G." eugubina Zone is in Core 29, Section 2. The upper Danian lacks only the Globigerina (S.) triloculinoides interval. Otherwise the G. pseudobulloides and G. trinidadensis intervals of Zone P.1 are well represented and the faunas are typical of subtropical latitudes. The Paleocene sequence is continuous to the base of the Globorotalia "P." pseudomenardii Zone (P.4). This interval contains very rare G. "M." velascoensis, which may not be in place.

Preservation in the overlying Eocene sediments is very poor and faunas are greatly reduced in diversity. The top of Core 16 is assigned to the base of the Globorotalia "M." formosa Zone (P.7) primarily on the basis of right-coiled Globorotalia "M." aragonensis. The base of the G. "M." aragonensis Zone (P.8) was located in Core 13, as most of the sediments in Core 14 yielded no recognizable fossils. Throughout this zone the faunas are small and the acarininids predominate. Premoli-Silva (in preparation) found in studies on the paleobiogeography of Paleogene planktonics that keeled globorotalids become scarce at mid-latitudes after the G. "M." formosa Zone (P.7). This may explain the lack of those forms at Sites 356 and 357, rather than simply dissolution. In Core 13, Section 2 the fauna consists entirely of two acarininid species: Acarinina densa and A. wilcoxensis.

The first bullate forms appeared in Core 10 along with increased numbers of globigerinids. However, there are many contaminants in this core. Cores 9 and 8 are placed in the Hantkenina aragonensis Zone (P.10) on the basis of primitive Globigerinatheka sp. as well as the continuing presence of G. "M." aragonensis. No Hantkenina sp. was present. The sequence of appearances, if they are real and not just a function of poor preservation, in Cores 9 through 6 parallel that during the same time interval at Site 357. The primitive Globigerinatheka in Core 9 is accompanied by the first specimens of "Globigerina" higginsi, and Acarinina pseudotopilensis which significantly change the overall aspect of the fauna. Chiloguembelina sp. is first
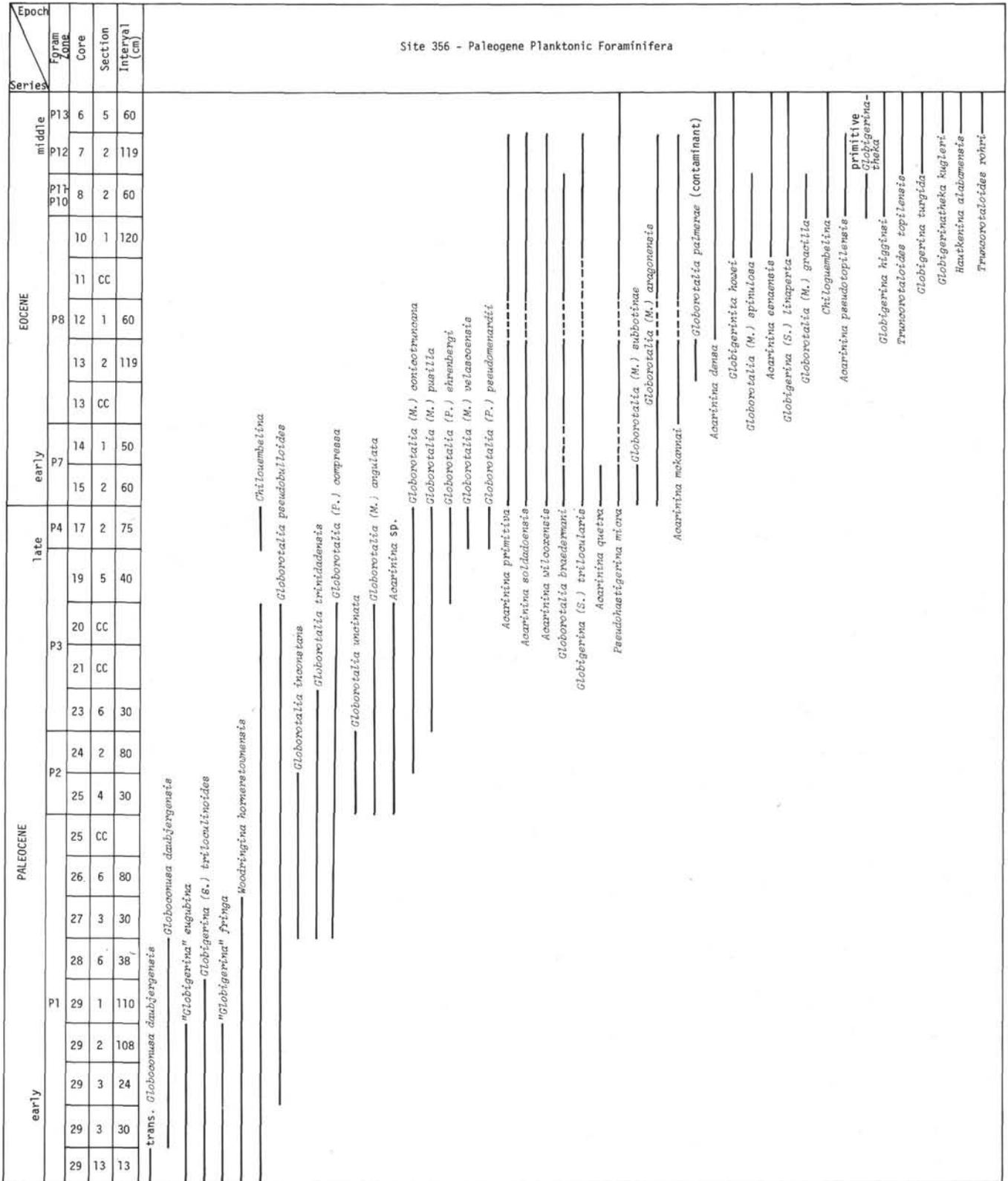
Figure 3. *Stratigraphic ranges of selected planktonic foraminifera during the Paleogene at Site 356 on the São Paulo Plateau.*

encountered also at this level, but this appearance is considered a function of the poor preservation of underlying samples. *Truncorotaloides topilenses* and *Globigerina turgida* first appear in Core 7, followed in Core 6 by recognizable *Globigerinatheka kugleri* and *Truncorotaloides rohri. Hantkenina alabamensis* is also

present; the absence of *Hantkenina* in older sediments is due to poor preservation of faunas.

Neogene Zonation

Ranges of selected Neogene planktonic foraminiferal species are shown in Figure 5. The primary problem in

the zonation of the Neogene at this site was the determination of the Oligocene/Miocene boundary. The lowest Neogene levels at this site could be considered either Oligocene or Miocene since the first appearance of *Globigerinoides* is no longer a criterion applicable to the location of this boundary. At this time Core 5 is placed in the Miocene, Zone N.4, not the Oligocene (P.22). In the lowest samples there are still a few individuals of *Globorotalia praekugleri*; however, it is assigned to the *Globigerinoides primordius-G. kugleri* Zone and hence according to Berggren (1972) belongs to the Miocene (Zone N.4). The sequence of foraminiferal appearances in Cores 5 through 3 parallel those at Site 357, particularly the appearance (ecological?) of a spiny *Catapsydrax* sp. and *Globoquadrina dehiscens*, along with *Globoquadrina altispira*, just following the appearance of *Globigerinoides* spp. in abundance between Zones N.4 and N.5. Then in Zone N.6 *G. altiaperturus* and the spiny species appear. At Site 357 this sequence of events is associated with a warming in the lower Miocene, culminating with the first abundance of *G. altiaperturus* and the spinose forms. Such a temperature event was apparently recorded also at Site 356.

Core 2, down to Section 2, belongs to the Pliocene Zone N.21, specifically the interval above the extinction of *Sphaeroidinellopsis subdehiscens*, but below the top of *Globorotalia margaritae*. The higher sections, as well as Core 1, contain *Globorotalia multicamerata, Globorotalia miocenica*, and *Globigerinoides fistulosus*, placing them higher in Zone N.21.

SITE 357

Site 357 was drilled at a depth of 2086 meters on the eastern extension of the Rio Grande Rise. The site lies within the path of the NADW and the southward flowing surface Brazil Current. Paleogeographical reconstructions (Ladd, 1974) indicate that from the Santonian to the present this site has moved from approximately 40° to 30° south latitude.

An extensive Tertiary section was drilled at this site, allowing precise biostratigraphic determination as well as analysis of the oxygen isotopic record at this site (Boersma and Shackleton, this volume). The biostratigraphic framework and [18]O measurements allow us to draw some paleoecological conclusions as to the oceanographic phenomena affecting this site and its faunas.

Hiatuses

There are nine recognizable hiatuses in the Tertiary record at this site. As at Site 356, two hiatuses occur in the Paleocene. The first includes the short Danian interval P.1b. The second spans the entire upper Paleocene and lower Eocene. There is a 20-meter coring gap between the Paleocene Zone P.4 and the early Eocene Zone P.7, so it is possible that more of the Paleocene may be present, but was not recovered. The presence of well-preserved faunas of Zone P.4 corroborates this suggestion.

In addition to the Paleocene/Eocene hiatus, there are three other gaps in the Eocene. Zones P.9, P.10, P.14,

P.15, and most of P.16 and P.17 are all missing at this site. In the case of zones P.9 and P.10, part of this interval may be present in the 27-meter coring gap between Cores 26 and 27. The hiatus between Zones P.13 and P.16 occurs within Core 20. The Oligocene/Eocene boundary hiatus is typical of several adjacent sites (Legs 3, Sites 19 and 20C, Figure 4) and thus represents a widespread and significant oceanographic event at this time in the South Atlantic. At these sites, the part of Zone P.16 corresponding to the nannofossil *Isthmolithus recurvus* Zone is all that has been recovered. Zone P.17 is missing.

The Oligocene lacks the basal Zone P.18, as well as the topmost section of Zone P.21. While the lower Miocene appears complete here, a hiatus spans the lower/middle Miocene interval between zones N.8 and N.11 in Core 6. A second hiatus includes parts of Zones N.14 and N.15. As the Neogene was continuously cored, all of these hiatuses are considered real and are not inferred.

The upper Pliocene is missing, along with sections of the lower Pleistocene; thus, Zone N.21 and a part of Zone N.22 are not present at this site.

Preservation

Preservation varies from sample to sample, but is not particularly good until the Miocene and parts of the Oligocene. The Paleocene and lower Eocene are moderately preserved, although some levels contain badly recrystallized faunas. Beginning in the lower Eocene samples contain also volcanic glass and a siliceous component, sometimes radiolarians, sometimes diatoms. The amount of siliceous material and volcanic glass increases by Core 25 in which a volcanic breccia was found embedded in the foraminiferal ooze. Radiolarians are very abundant and the foraminifera are only moderately well preserved. Preservation improves slightly above Core 25 and the siliceous and volcanic components are gone from the residues; however there is abundant fragmentation of the foraminifera. Beginning in Core 22 and continuing through Core 20 preservation deteriorates; more foraminifera are dissolved out of the sediment, and the residues are chalky. Within this interval there are occasional levels where preservation is markedly improved, for example, Sample 21, CC. Also throughout this interval mixing of faunas is common and confusing.

The lower Oligocene shows evidence of dissolution. Occasionally the larger size fraction of the sediments is gone, leaving only small fossils and the broken remnants of the larger fossils. Preservation improves later in the Oligocene, although there are still many broken or corroded specimens. A reincursion of radiolarians occurs in Cores 17 and 18 and continues into the lower Miocene.

The Miocene is generally moderately to well preserved, although some levels are particularly chalky and contain many fragmented foraminifera. Although preservation is generally good in the upper Miocene, episodes of solution of the sediments are attested to by peeled *Sphaeroidinellopsis* spp. which have lost their
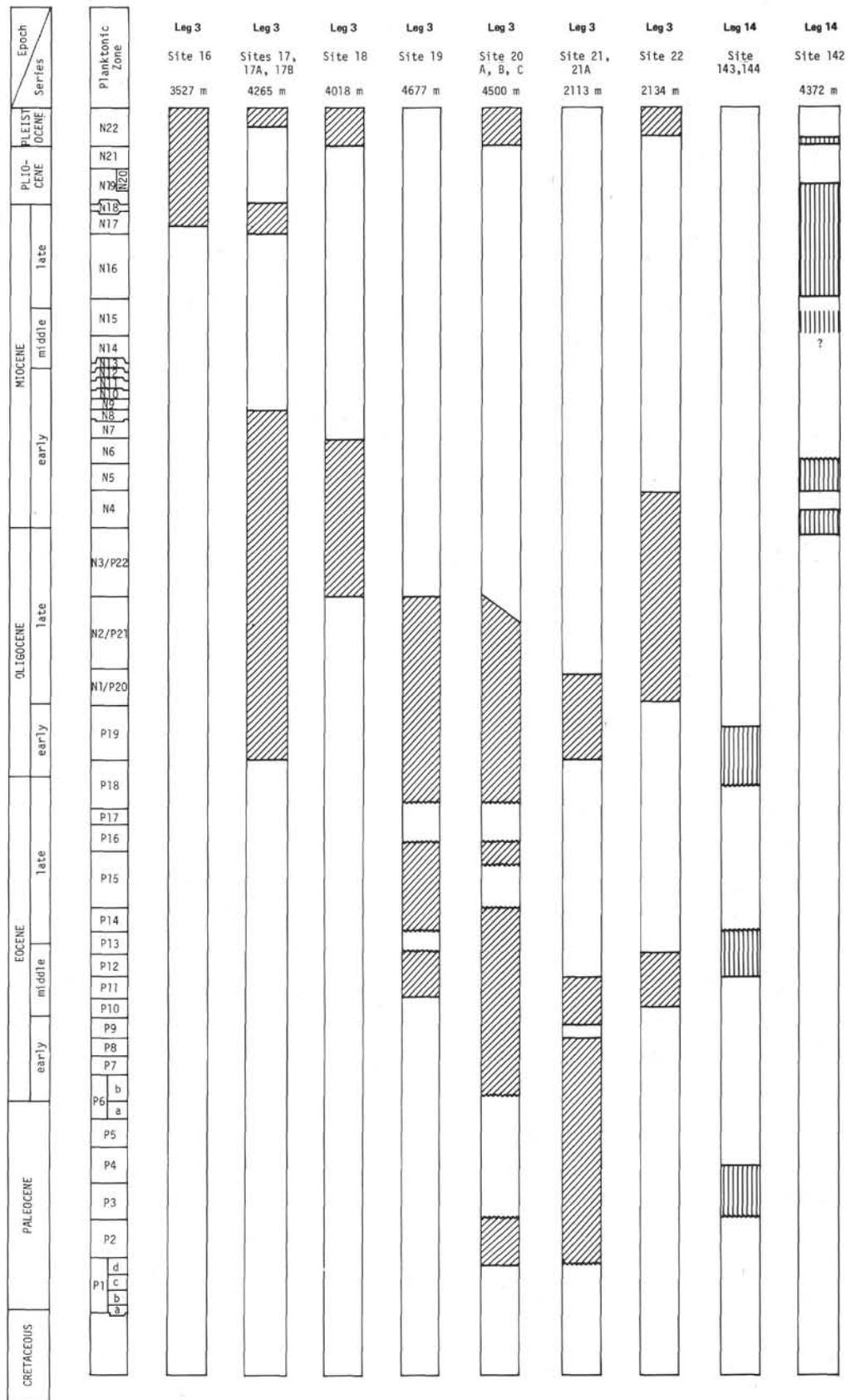
Figure 4. *Stratigraphic columns of Tertiary age recovered during Legs 39, 3, and 14 in the central and south Atlantic. Black areas represent cored interval. Where any part of a plank-tonic foraminiferal zone was recovered, the black area was extended to the upper and*
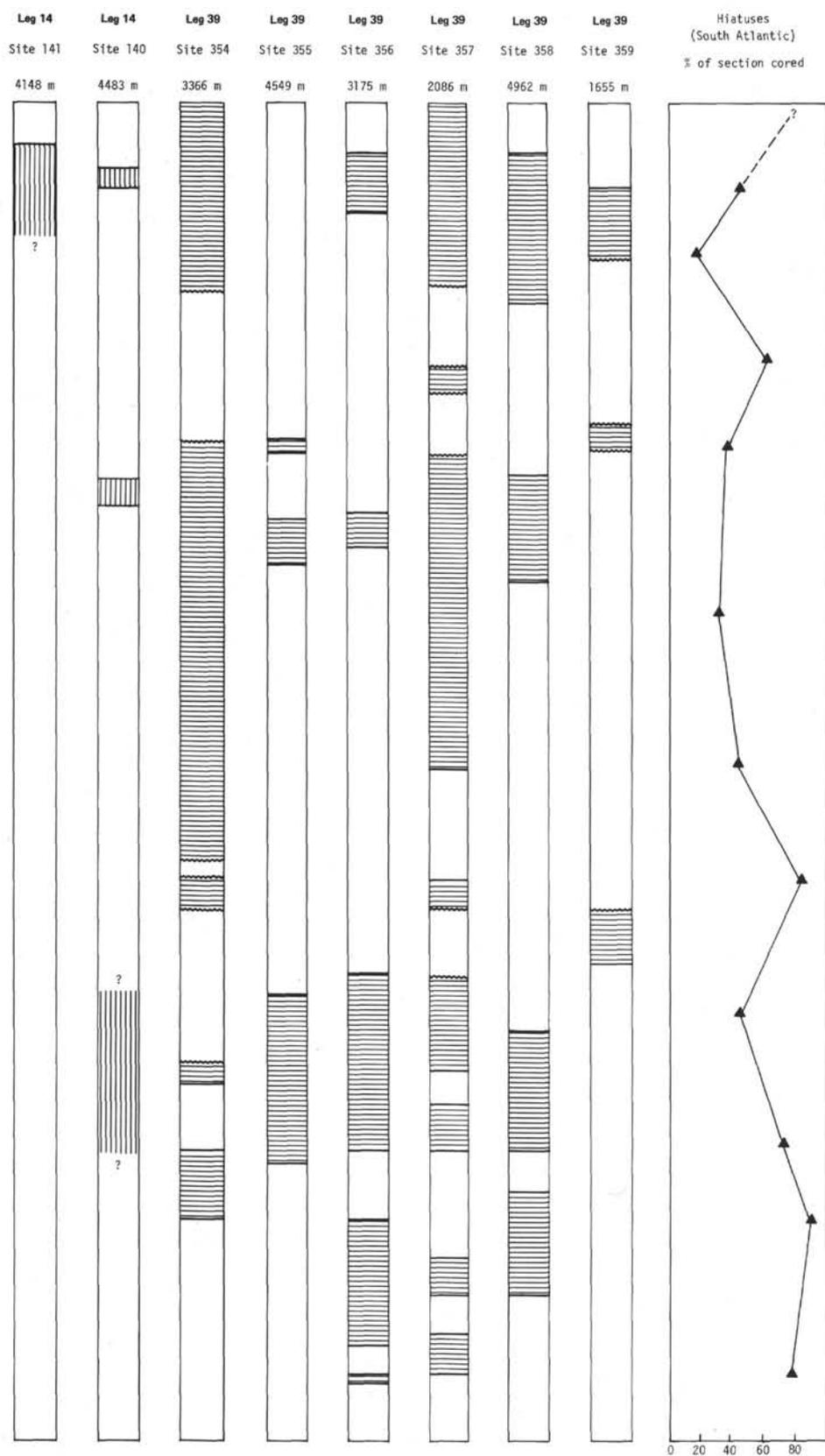
Figure 4. *(Continued). lower limits of that zone. Within-core hiatuses are signified by jagged lines above and below the hiatus. The hiatus curve is based on the percentage of sites where sediment was retrieved and in which some part of the stratigraphic succession was missing.*
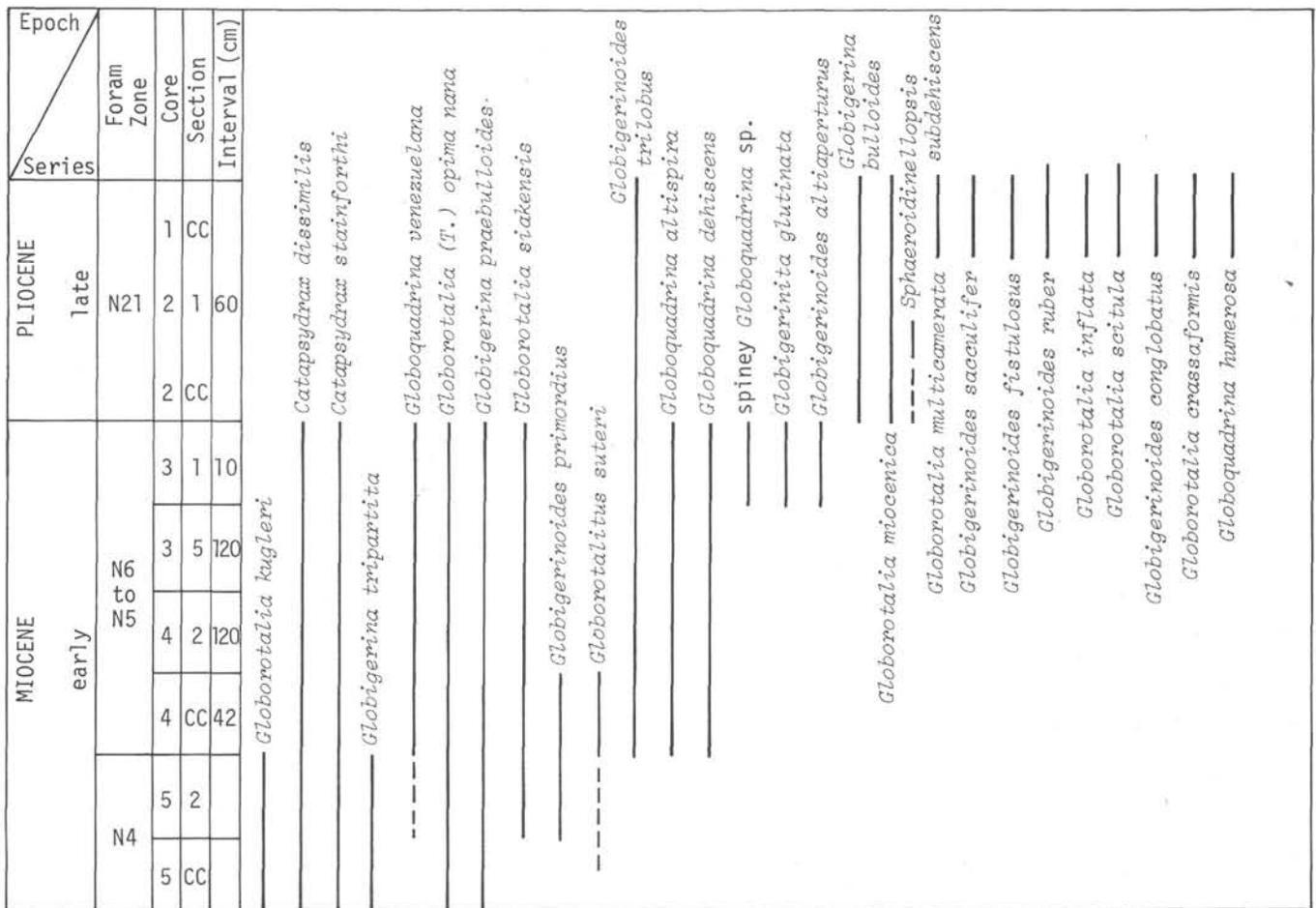
Figure 5. *Ranges of selected planktonic foraminifera during the Neogene at Site 356 on the São Paulo Plateau.*

smoother shiny outer coating and exhibit, rather, rough, porous surfaces. There is also a great deal of mixing in these faunas, due in part to the "soupy" character of the sediment in the core barrels. Pliocene fossils are well preserved, although some corrosion is evident in nearly every sample.

Paleogene Zonation

Zonation of the Paleocene was based on the standard zonation (Berggren, 1972); ranges of the most important planktonic foraminifera are shown in Figure 6.

Briefly, the Paleocene zonal fossils are all easily recognizable. In the Eocene the keeled globorotaliids are relatively rare. Zone P.7 was recognized by the overlap between *G. "M." subbotinae* and very small specimens of *G. "M." aragonensis. G. "M." formosa* was not found. The fauna of this zone is dominated by the acarininids. The overlying Zone P.8 contains true *G. "M." aragonensis*, the first bullate species, but no *G. "M." subbotinae*. Above the hiatus spanning Zones P.9 and P10, Core 26 contains primitive *Globigerinatheka, Truncorotaloides pseudotopilensis, "Globigerina" higginsi*, and *Hankkenina alabamensis*. The evolutionary appearance of *G. "M." lehneri* occurs in this core. Also present is the first *G. kugleri*. An influx of new species occurs in Core 23 and includes *Globiginatheka index, Globigerina "S." linaperta*, and members of the

Catapsydrax martini group. A few specimens of *G. "M." lehneri* persist, but keeled forms are very rare. On the basis of its fauna, the core could be placed in either Zone P.11 or P.12, but is considered as belonging in the latter.

The appearance of *Globorotalia "T." cerroazulensis* and *Truncorotaloides rohri* in these faunas is slightly higher than recorded in other areas (Cita and Premoli Silva, unpublished range charts) as they do not appear until Core 21, which is here considered to belong to Zone P.13, whereas Cita and Premoli Silva record these forms as appearing in the *G. kugleri* Zone (P.11). *Orbulinoides beckmanni* was not found at this site, but deteriorating preservation has apparently resulted in the loss of many fossils and perhaps species. However, an assignment of Core 22 through Core 20, Section 3 to Zone P.13 agrees well with the nannofossil evidence for Zone NP.16 (*D. tanii nodifer*).

During this time there is a gradual reduction in faunal diversity. Despite mixing, the faunas from Core 21, Section 1, contain about 18 typical upper middle Eocene as well as several upper Eocene species. In Core 20, Section 3, the fauna is reduced to closer to eight species, dominated by large *Globigerinatheka* spp. In Core 20, Section 1, only six, sometimes fewer species are found, so the fauna has the overall appearance of an ooze of small balls. The same sequence of faunal

reduction can be found in adjacent holes from Leg 3, Holes 19 and 20C, both of which recovered the interval described here (see Figure 4). Only two species, *G. index* and "*Globigerina*" *senni* were consistently reported in the anomalous faunas from those sites. Such faunas strongly resemble some from the upper Eocene of Site 277 (Leg 29), in the South Pacific at 52° south. By the top of the upper Eocene sequence *H. alabamensis*, *Globigerina* "*S.*" *angiporoides*, *Chiloguembelina*, *Globigerina praebulloides*, and *G.* "*T.*" *cerroazulensis* are occasionally present, along with abundant *Globigerinatheka* spp. These faunas were placed in Zone P.16 on the basis of the occasional presence of *Globigerinatheka mexicana*. The nannofossil *Isthmolithus recurvus* Zone was the only one recognized in the upper Eocene of the adjacent Holes 19 and 20C, and is the only one recovered at Site 357, all of which corroborates the placement of these sediments in foraminiferal Zone P.16.

Above the Eocene/Oligocene boundary hiatus, the Oligocene sequence contained the zonal index fossils for the recognition of Zones P.19 through P.22. *Globigerina angulisuturalis* occurs rather low in this Oligocene succession and resembles the higher latitude forms of Jenkins (1971). Two forms of *Globorotalia* "*T.*" *nana* were found at this site; *G.* "*T.*" *nana pseudocontinuosa* was found in Cores 16 through 10. *Globigerina euapertura* occurs from Core 19 into Core 13 in the lower Miocene. *Globigerina* "*S.*" *angiporoides*, first encountered in the middle Eocene, continues into the bottom of Zone P.21 in Core 18. Also in Core 18 *Globorotalia* "*T.*" *opima opima* and *Chiloguembelina cubensis* become extinct at the same level. According to Berggren (1972) *Chiloguembelina* should become extinct during Zone P.21, the top of which is characterized by the presence of *G.* "*T.*" *opima opima* after the extinction of *Chiloguembelina*; Zone P.21 is therefore considered incomplete. However this sequence of extinctions may be a function of latitude.

Neogene Zonation

The ranges of selected Neogene foraminifera are shown in Figure 7. For a more complete discussion of the late Neogene foraminifera, see Berggren (this volume). The foraminifera were zoned according to a standard low latitude zonation; however because of the presence of higher latitude forms, it was possible to recognize the limits of several of the higher latitude Neogene zones of Jenkins (1971) and Kennett (1973). Figure 8 depicts the limits of those recognizable zones against the nannofossil and foraminiferal zonation employed in this volume, as well as the upper Neogene zones defined in this volume by Berggren. This latter zonation agrees well with the general zonation adopted in this volume, only it is more precise and proposes the use of one upper Miocene zone to span parts of what are designated Zones N.16 and N.17 in his general zonation (Berggren, 1972).

The Oligocene/Miocene (P.22/N.4) boundary was arbitrarily placed in the top of Core 15 just prior to the co-occurrence of *Globorotalia kugleri* and *Globigerinoides primordius* in Core 14. According to the 1971 zonal scheme of Jenkins, the Oligocene/Miocene boundary occurs at the top of his *Globigerina euapertura* Zone, whose upper boundary is defined by the first appearance of *Globoquadrina dehiscens*. At Site 357, the first appearance of *G. dehiscens* occurs in Core 13, thus locating the Oligocene/Miocene boundary some 35 meters above the boundary used in this report. If the first appearance of *G. dehiscens* is ecologically controlled, as Jenkins asserts, then there is no reason to suspect that it will appear anywhere at the same time necessarily as Australia, and in fact Jenkins (1974) proposes that the *G. euapertura*, *G. dehiscens*, and the *G. woodi* zones all belong in the Oligocene in cores from DSDP Leg 29.

The three basal zones of Jenkins correlate with planktonic Zones N.4 and N.5 at this site. The *Globigerinoides trilobus* Zone of both Jenkins (1971) and Kennett (1973) coicides with Zones N.6 through N.8 at Site 357. Jenkins' *O. suturalis* Zone corresponds to the base of Zone N.11, whereas his *G. mayeri* Zone correlates with all of Zones N.12, N.13, and N.14 at this site. It then becomes difficult to locate the remainder of Jenkins' zones. The two upper Miocene zones, *G. miotumida* and *G. miozea sphaericomiozea*, are defined on the basis of forms not found at Site 357. The uppermost zone, *G. inflata*, however, can be located in Core 2 and falls within nannofossil Zone NN16 at this site. It also correlates with the base of Berggren's Pl.3.

The base of Kennett's *G. trilobus* Zone, the lowest in his 1973 subtropical zonation, occurs within Core 10. The zone spans Zones N.6, N.7, and N.8 as defined in this report. The *O. suturalis* Zone falls in the base of N.11.

The overlying *G. mayeri* Zone, defined on the total range of the nominate taxon correlates with parts of N.11 through N.14 and extends into an unzoned upper Miocene (called the *G. conomiozea-G. mediterranea* Zone by Berggren, this volume). Although it is possible to recognize the base of the overlying *G. nepenthes* Zone on the extinction level of *G. continuosa*, it is not even broadly equivalent to the *G. nepenthes* Zone (N.14) which terminates towards the bottom of Core 5 while Kennett's *G. mayeri* Zone begins in section 2 of Core 5. According to the criteria and ranges shown by Kennett, it is impossible to recognize his *G. continouosa* Zone, which should overlie the *G. mayeri* Zone, but underlie the *G. conomiozea* Zone. Similarly, the base of *G. conomoizea* at this site is equivalent to the base of the *G. nepenthes* Zone, and thus they are impossible to reconcile. The overlying *G. puncticulata* Zone can be recognized in Core 3 and corresponds to that part of Core 3 before the first appearance of *G. crassaformis*. The *G. puncticulata* Zone is thus equivalent to Berggren's Pl.1c and P.l2, as well with the middle portion of N.19 and nannofossil zones NN.13-NN.15 and part of NN.16. Throughout the rest of the zones there is little correspondence between the upper Neogene nannofossil foraminiferal zonal boundaries and the zones of Kennett. The exception is a correspondence between Kennett's *G. truncatulinoides-tosaensis* Zone and Zone N.22 as defined in this volume.

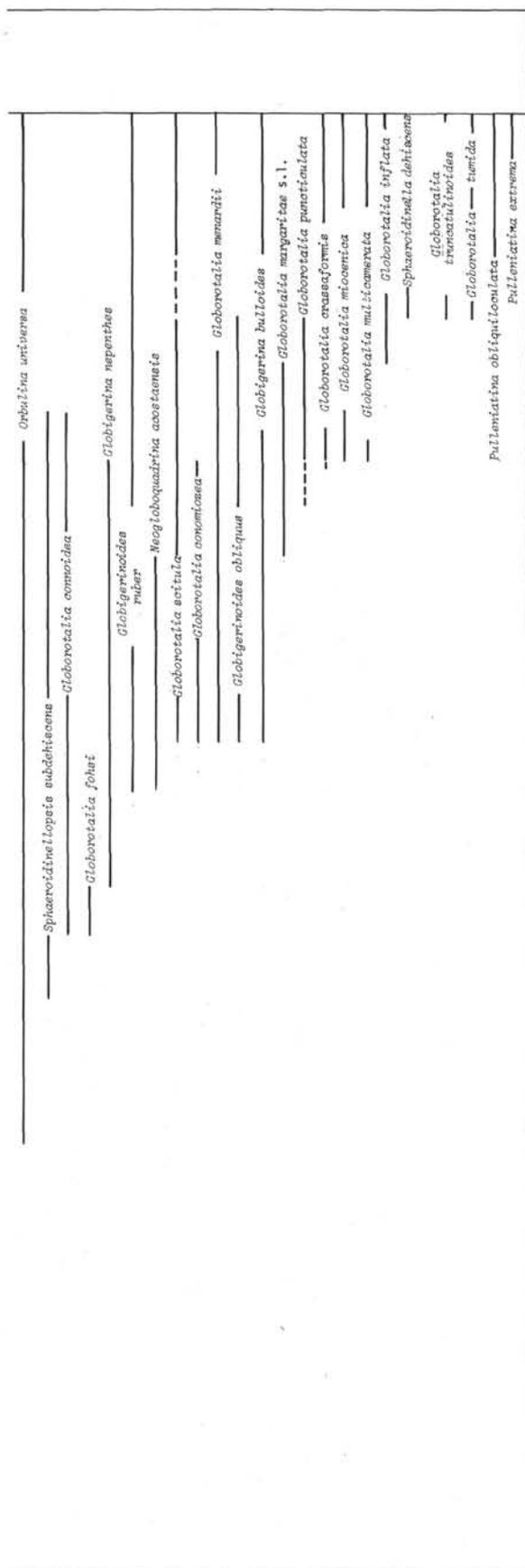Figure 6. *Stratigraphic ranges of selected Paleogene planktonic foraminifera at Site 357 on the Rio Grande Rise.*

Figure 6. *(Continued).*

Figure 7. *Stratigraphic ranges of selected Neogene planktonic foraminifera at Site 357 on the Rio Grande Rise.*

Kennett considers Jenkin's (1971) *G. inflata* Zone, based on the first appearance of *G. inflata*, to cover the entire Pliocene. However, the base of *G. inflata* both in Kennett's Leg 21 material and at Site 357 lies in the upper Pliocene.

Unusual Neogene Planktonic Foraminifera

Site 357 contains generally well-preserved Neogene subtropical planktonic foraminiferal faunas. In the lower Neogene there is a predominance of species of the genus *Globoquadrina*. At lower levels *G. venezuelana* and later *G. dehiscens* are abundant in most samples. During periods of temperature change there appear to be fluctuations in the abundance of globoquadrinids relative to the genera *Globigerina* and *Catapsydrax*. For example during times of temperature increase *Catapsydrax* decreases in abundance and *Globigerina woodi* increases. Such fluctuations during one period of temperature increase in the early Miocene are shown by Boersma and Shackleton (this volume).

The unusual, large planktonic species, *Globigerinoides mitra*, is present, usually accompanying *Globigerinopsis* spp., from Zone N.7 through the Miocene. *Globigerinoides mitra* becomes particularly abundant at the top of the Miocene (for example, Section 3-6).

A unique, spiny form, resembling both the Paleogene genus *Acarinina* and the Neogene genus *Globoquadrina* appears for a short time in Cores 9 and 10 (Plate 2). Its spines are actually elongate, sometimes multiple pustules distributed very densely over the test. This form appears just during the temperature maximum as recorded in the early Miocene planktonic foraminifera (see Boersma and Shackleton, this volume.)

In the best preserved samples tiny biserial forms belonging to the Neogene genus *Streptochilus* occur. They occur in abundance only in Core 15, Section 2, but are fairly common in samples from the uppermost Oligocene into the upper Miocene. These forms are planktonic, as shown by their ^{18}O values.

DSDP Leg 3 Sites

Figure 4 shows the planktonic foraminiferal zones recovered at Site 357 as well as from several other western Atlantic sites. Hiatuses versus coring gaps are differentiated to show that the only hiatus consistent among these sites occurs across the Eocene/Oligocene boundary. Most all other Paleogene zones were recovered at one site or another. The extensive coring gaps in the Neogene allow for little comparison between sites. However, thick Oligocene and early Miocene sequences are common to most of these sites.

Paleoecology of Sites 356 and 357

The proximity of Sites 356 and 357 suggests that they may have been subject to the same sort of changing oceanographic conditions through time. As stated before, the sequence of events in the planktonic faunas, including change in dominance from one genus to another, occurs apparently simultaneously at Site 356 and 357. We can then briefly reconstruct the changing

Figure 7. *(Continued)*.

Core	Foraminiferal and Nannofossil Zones (this volume)		Subtropical Zonation Kennett (1973)	New Zealand Zonation Jenkins (1971)	Foraminiferal Zones Berggren (this volume)		
1	NN17-19	N23	*Globorotalia truncatulinoides*	*Globorotalia inflata*	N23		
		N22	*G. truncatulinoides-tosaensis*		N22		
2	NN16	N19	*Globorotalia inflata*			P1 3	
	NN13-15		*Globorotalia crassaformis*	*Globoratalia miozea Spheneomiozea*		P1 2	
	NN12		*Globorotalia punticulata*		c	P1 1	
3			*Globorotalia margaritae*	?	b		
					a		
4	unzoned	late Miocene	? *Globigerina nepenthes*	? *Globorotalia miotumida*	*Globorotalia conomiozea-Globorotalia mediterranea*		
5	NN6-7						
		N13-N14	*Globorotalia mayeri*	*Globorotalia mayeri*	N14		
					N13		
6	NN4-5	N12-N11			N12		
			Orbulina suturalis	*Orbulina suturalis*	N11		
		N7-N8			N7-8		
7	NN3						
8	NN3?	N6	*Globigerinoides trilobus*	*Globigerinoides trilobus*			
9	NN2						
10	NN1	N5		*Globigerina woodi-connecta*			
11				*Globigerina woodii*			
12		N4		*Globoquadrina dehiscens*			
13				*Globigerina euapertura* (Oligocene)			
14							

Figure 8. *Comparison of the temperature zonation (Kennett, 1973) and high latitude zonation (Jenkins, 1973) with the zonation of Berggren (1972) as recognized at Site 357. Nannofossil zones (Perch-Nielsen, this volume) and planktonic foraminiferal zonations (Berggren, this volume) are included for the sake of comparison.*

oceanographic scenario as reflected in the changing planktonic faunas.

Site 356 lay in the subtropical zone at the beginning of the Tertiary. Contrary to the suggestion of Worsley (1974) that the CCD lay in the photoic zone across the Cretaceous/Tertiary boundary, rich faunas of planktonic foraminifera were accumulating during the very earliest Tertiary at a water depth close to 2000 meters (based on a highly speculative model of continuous sinking for this site). Paleocene faunas are rich and well-preserved and attest to the stability of the site at this time as well as to moderate temperatures in the Paleocene, in the subtropical zone. Site 357 records a temperature of close to 16° for surface zone waters in the Paleocene, top of Zone P.1 (Boersma and Shackleton, this volume).

A fairly continuous Paleocene sequence (at least to Zone P.3) accumulated at both sites, although preservation is markedly different between the two sites. At this time both sites must have been moving gradually northward.

The hiatus from the later Paleocene across the Paleocene/Eocene boundary suggests a change in bottom circulation vigor at this time. Loss of sediments of this age is anomalous with respect to other areas of the Atlantic, where rich foraminiferal faunas of earliest Eocene age are preserved in abundance (Premoli-Silva, in preparation). The elimination of keeled forms (Zone P.7) may reflect either the loss of their niche in the water column with the cooling temperatures, and/or solution. As the keeled globorotaliids and *Chiloguembelina* consistently record the warmest temperatures of the Eocene species tested (Boersma and Shackleton, this volume) their resistance to solution may be low, and thus they may be lost from sediment earlier than the cooler-dwelling acarininids, for example. However, the event does imply changed movement and stratification of water masses during a cooler episode in the early Eocene. The marked increase in the siliceous component of the sediment and the increase in induration are further indications of an altered water mass. The later appearance of radiolarians at Site 356 than Site 357 may reflect increased surface productivity in this general geographic area by Zone P.8, which at least, at Site 356 continues into Zone P.12, but is much reduced by the later middle Eocene.

The first appearance of bullate forms at both sites occurs in Zone P.8 just prior to the temperature decline in the Eocene. The later appearance of *A. pseudotopilensis* and eventually *Truncorotaloides* spp. coincides at Site 357 with a temporary temperature rise. This may also be the case at Site 356 which contains correlative faunal events.

The later middle Eocene at Site 356 contains diverse, well-preserved faunas accompanied by radiolarians and diatoms. The section at this site ends low in Zone P.13; thus, the faunal changes characterizing the coolest intervals of the later Eocene at 357 do not have their analogs here.

The early Miocene at Site 356 so resembles that at Site 357 that temperature events at 357 can be extrapolated to Site 356 also. At Site 357 a temperature increase in the surface zone is reflected in the first appearance of open-apertured, abundant *Globigerinoides altiaperturus* and unusual spinose morphotypes. A change in the ratio of *Globigerina woodi* to *Catapsydrax* spp. results in the increased dominance of the *G. woodi* group. As *G. woodi* is much less abundant at Site 356, the primary difference between the two sites is the greater abundance of higher latitude species in the early Miocene of Site 357. Nevertheless, the first appearance of *G. altiaperturus* in abundance and the spinose species suggest a temperature increase in Zone N.6 also at Site 356.

The extensive hiatus at Site 356 spanning the remainder of the Miocene and early Pliocene, includes the middle Miocene hiatus common to the South Atlantic. The hiatus at Site 356 may then in part be related to a rise of the CCD and increased vigor of bottom circulation (Berger and von Rad, 1972) causing the removal of the middle Miocene in several areas of the South Atlantic (see Figure 4).

At Site 357 the Miocene section is complicated and not easily interpreted. After an extensive lower Miocene, parts of the middle and upper Miocene are absent; however, the middle Miocene is better represented at Site 357 than at Site 356. As Site 357 is not within the path of true bottom water, other erosional forces must be considered responsible for the erosion at this site.

SITE 358

From the Cretaceous into the middle Eocene four distinctive faunas occur in the sediments at Site 358. These are:

1) planktonic and benthic faunas together, but low in species and in small residues; faunas are reduced by dissolution and species show evidence of solution; called a *near lysocline fauna*;

2) faunas containing only benthic foraminifera, and occasional fragments of the planktonic foraminifera that were there before dissolution took its toll; calcareous nannofossils would typically be preserved also in such a sample; called *near CCD sample*;

3) residue containing no foraminifera, but a mineral residue: called the *below CCD sample*;

4) typical open marine planktonic and benthic faunas slightly reduced in diversity by solution and/or recrystallization during diagenesis; called *above lysocline fauna*.

Elements of the dissolved planktonic faunas are shown in Plate 2; the planktonics include primarily acarininids and globigerinids.

Using these broad categories and plotting the fluctuations of these faunas against the calculated depth of the site results in the data presented in Table 2.

For this table the faunas, as described briefly above, were briefly listed according to which core or level they characterized. The ages are taken from the zonation and age scale of Berggren (1972), but are based primarily on ages given by the calcareous nannofossils (see site chapter, Site 358) as the foraminifera are not diagnostic.

TABLE 2

Estimates of the Paleo-CCD and Foraminiferal Lysocline Based on a
Continuous Sinking Model for Site 358 in the Argentine Basin

Core	Age (m.y.)	Calculated Depth (m)	Type Fauna	Lysocline Level	Approximate CCD
10	49	4100	Below CCD		>4100
11	49	4100	Below CCD	<4100	<4100
11, CC	49	4100	Near CCD	<4100	near 4100
12-2	52	3800	Near lysocline	near 3800	
12, CC	52	3800	Below CCD		<3800
13-1	60	3600	Near CCD		near 3600
13-4	60	3600	Near lysocline	near 3600	
13, CC	60	3600	Near CCD	<3600	near 3600
14-4	60	3600	Below CCD		<3600
14-15	63	3500	Near CCD	<3500	>3500 (near)
15	65	3300	Below CCD		<3300
15-16	67	3200	Near lysocline	near 3200	
16, CC	70	2700	Above lysocline	>2700	

Site 358 was drilled on basement estimated to lie between magnetic anomalies 32 and 33 (Ladd, 1974). As the drilling at the site stopped approximately 50 meters above basement (see Site 358 Site Summary) as judged from the seismic profiles, and the oldest fossils at the site are latest Campanian/early Maestrichtian in age, we can use a rough estimate of 2700 meters for the depth of the site at the ridge in the latest Campanian. From the age/depth relationships inherent in the McKenzie-Sclater (1971) model it is then possible to derive the depths of the site at various times as follows:

Core 16, 70 m.y. early Maestrichtian, = 2700 meters
Core 15, 67 m.y., middle Maestrichtian, = 3200 meters
Core 14, 60 m.y., NP.4 (nanno zone) = 3500 meters, etc.

From the table it is apparent that after the early Maestrichtian, this site continuously intersects either a paleolysocline or a paleo-CCD, and the times of intersection give evidence of the paleodepths of those oceanographic features in the early Tertiary and latest Cretaceous at this site (Table 2).

Comparison of our estimates of the CCD with those published by Berger and Winterer (1974) and Ramsay (1974) shows that estimates from Site 358 are consistently shallower than those proposed by Ramsay. According to his estimates for the early Tertiary of the Atlantic, our site would always have lain above his compensation depth and should not show this degree of dissolution, even in the late Eocene when according to our interpretation, Site 358 sank permanently below the CCD.

Berger and Winterer's estimates for the central Atlantic begin at 50 m.y. and thus overlap by but 7 m.y. with the time of carbonate deposition at our site. Their estimates for the paleo-CCD at close to 3600-3800 meters between 50 and 45 m.y. accord well with the estimates from Site 358 except in the case of our Core 11, whose faunas indicated deposition closer to the CCD which, if the depth estimates are nearly accurate, would have lain closer to 4100 meters than Berger and Winterer's estimated 3600 meters.

Our site is considered to have sunk permanently below the CCD by the later Eocene. At this time, the CCD presumably was located below 4300 meters. Differences between estimates from Site 358 and estimates of Berger and Winterer or Ramsay may result from the roughness of this estimate based on an average depth near the ridge or from the fact that this area of the South Atlantic had different CCD depths than the general estimates because of its position at higher latitude and within the direct influence of the bottom waters generated around Antarctica.

SITE 359

Because of the large coring gaps at this site, only small sections of any one age were recovered. The Miocene-Pliocene recovered at this site resembled that at Site 357. This is not surprising as the two sites lie at approximately the same latitude.

The most interesting sequence of faunas is that of the Eocene. The planktonic faunas include *Hantkenina alabamensis*, *G. angiporoides*, *Chiloguembelina* sp., *Pseudohastigerina micra*, *Globorotalia "T." centralis*, *Catapsydrax unicavus*, *Globigerinatheka kugleri*, *Globigerinatheka barri*, and *Globorotalia "T." opima nana*. The outstanding feature of this fauna is the abundance of *H. alabamensis*.

Benthic faunas include many species also found at Site 357 as well as a significant component of presumably shallower water benthic foraminifera originally described from the Eocene of the American Gulf Coast (Cushman, 1935). The benthic fauna lacks the key genera *Nuttallides* and *Globocassidulina*, but has high numbers of *Robulus* and large rectilinear forms. Accompanying this fauna is some invertebrate debris, including bryozoan and pelecypod remains.

In order to lend some evidence toward the sinking history of this site, an estimate of the depth of Core 3 was made based on the benthic faunas as well as the high abundance of *Hantkenina*. Based on the problem of redeposited material, two solutions are possible. If the large benthics and invertebrates are out of place then the site could have lain at a depth less than 357; i.e., less than 1500 meters but greater than the shelf or upper slope. A realistic estimate then would be about 900 meters.

If, on the other hand, all the fauna is in place, then this site must have lain close to the shelf break or upper slope. The great abundance of planktonic fossils is hard to reconcile with this idea, although the prominence of *Hantkenina* is not. The depth of the site then in the late Eocene would have been closer 300 meters.

Paleotemperature measurements were made on benthic foraminifera from Site 359 (3, CC) as well as from Site 357 (Core 21, Section 1). According to the planktonic foraminifera, both samples belong to the late Eocene Zone P.16. At this time Site 357 has an estimated paleodepth of close to 1600 meters and a bottom temperature of 5.5°C ($+1.50^o/oo$). The bottom temperature at 359 was about 9.5°C ($+0.41^o/oo$). A 4°C temperature difference today in the water column would mean a depth difference of from 300-500 meters in the Atlantic and closer to 500 meters in the Pacific. The temperature differential, then, would place 359 not at outer shelf depths, but closer to 1000 meters.

The age of Core 3 based on nannofossils and foraminifera is approximately 41 m.y. The age reported by Fodor et al. (this volume) on the underlying volcanics (Core 4) is 40 ±1 m.y. Thus, given the degree of error in each estimate, the sediments in Core 3 and the underlying volcanic rocks are the same age. Fodor et al. consider the volcanics of subaerial origin. However, the foraminiferal evidence suggests that at 41 m.y. this site lay at bathyal depths, receiving redeposited shelf or slope material as well as volcanic ash from an adjacent volcanic source.

If the site lay close to 1000 meters in the late Eocene, it would have sunk those remaining 655 meters during the remainder of the Tertiary. This rate is reasonable according to a crustal subsidence model.

ACKNOWLEDGMENTS

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PLATE 1

Figures 1-3   Transitional forms to *Globoconusa daubjergensis*;
                Site 356, Core 29, Section 3.
                1. ×705.
                2. ×695.
                3. ×745.

Figures 4, 5   *Globigerina "Subbotina" triloculinoides*; Site 356,
                Core 29, Section 3.
                4. ×570.
                5. ×600.

Figures 6-8   *"Globigerina" eugubina*; Site 356, Core 29, Section
                3.
                6. ×500.
                7. ×475.
                8. ×500.

Figures 9-12   *"Globigerina" fringa*; Site 356, Core 29, Section 3.
                9. ×500.
                10. ×640.
                11. ×475.
                12. ×450.

PLATE 2

Figures 1, 2   *Acarinina primitiva*; Site 358, Core 12, Section 2,
                both ×248.

Figures 3, 4   Bullate *Globigerina trilocularis*; Site 358, Core 12,
                Section 2.
                3. ×232.
                4. ×193.

Figure 5   *Hantkenina alabamensis*; Site 359, 3, CC, ×128.

Figures 6, 7   *Globorotalia plesiotumida*; Site 357, 3, CC, ×270.

Figures 8-10   *Globoquadrina* sp., spiny form; Site 357, Core 10,
                Section 1.
                8, 9. ×137.
                10. ×116.

PLATE 1

PLATE 2