12. PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY AND PALEOENVIRONMENTAL INTERPRETATION OF PALEogene FAunas FROM THE SUBANTARCTIC TRANSECT, LEG 114

Marisa Nocchi, Emanuela Amici, and Isabella Premoli Silva

ABSTRACT

Paleogene planktonic foraminifers recovered during ODP Leg 114 in the subantarctic region exhibit a cosmopolitan character at the opening of the Paleocene, and then they evolve similarly to faunas from lower latitudes. They begin to differentiate from lower latitude faunas by the early late Paleocene when large morphozoellids disappear from the region and cool deep-water-dwelling Globorotalioides appear much earlier than at lower latitudes. By early Eocene time large morphozoellids immigrate into the subantarctic area during the warmest episode of the entire Eocene. From that time up to the end of the middle Eocene planktonic foraminiferal faunas exhibit a temperate character, as indicated by the abundance of common acarininids. At the same time dissolution at depth causes depauperated planktonic faunas at the deeper sites. A new warming episode during the late Eocene is marked by the immigration of Globigerinatheka venterbacheri into the subantarctic region. The cooling trend during the late Eocene causes a progressive decrease in species richness, which only sporadically is less than 10 species. The early Oligocene is also characterized by relatively rich planktonic faunas, but after that time the western subantarctic region is occasionally invaded by few planktonic foraminiferal species. These immigrations coincide with the warmer episodes on the climatic curve, such as Zones P21a and P22-“N4.”

Beginning in late early Eocene and through the Oligocene eastern subantarctic planktonic foraminiferal faunas exhibit a much warmer character than those from the western side and are more similar to warm temperate faunas. Therefore, the eastern faunas provide a more refined biostratigraphy. Oligocene time is characterized by a trend toward a warmer climate; however, this trend was reversed in the early Miocene.

A dissolution event, possibly coeval with an erosional event, occurs within Zone P21b across the subantarctic region.

INTRODUCTION

The seven sites (698 through 704) drilled during Ocean Drilling Program (ODP) Leg 114 in the subantarctic South Atlantic Ocean are located in the wide passageway linking the South Atlantic to the Weddell Sea Basin (Fig. 1A). The water depths of the various sites range from 2138 to 4636.7 m (Table 1). An almost continuous Upper Cretaceous to Holocene sedimentary sequence is represented by carbonate and siliceous biofacies along a west-east longitudinal transect across the Mid-Atlantic Ridge (Fig. 1B). Sites 698 through 702 were drilled on the western side and Sites 703 and 704 on the eastern side of the Mid-Atlantic Ridge. They are located on basement rises and in basins underlain by oceanic crust extending between the eastern end of the Maurice Ewing Bank on the west to the western termination of the Agulhas Plateau on the east, which represent the tips of South American and South African continental crust, respectively.

Rifting of the South Atlantic probably was initiated during the Late Jurassic (approximately 180 Ma) while seafloor spreading began in the Early Cretaceous. The rate of formation of South Atlantic oceanic crust increased from 75 until 35 Ma, in the early Oligocene (Sclater and McKenzie, 1973), when the investigated area reached its present latitudinal position. At present, the subantarctic southern Atlantic is a tectonically stable oceanic area south of the Falkland-Agulhas Fracture Zone and north of the triple junction of the South American, South African, and Antarctic plates.

Based on reconstruction of the spreading centers (LaBrecque, 1986; LaBrecque and Hayes, 1979), during the Paleogene some major tectonic events changed the physiography of the Falkland-Agulhas passageway:

1. In the early Paleocene Zone P1 the presence of a barrier at depth partially prevented deep-water circulation between the South Atlantic and the Weddell Sea basins. Such a barrier, at water depths of possibly less than 2000 m, was created during the Late Cretaceous by the westward shift of the ridge axis in the Agulhas basin.

2. During the late Paleocene a new spreading center formed between the Islas Orcadas Rise and Meteor Rise aseismic ridges, two conjugate features now on the western and eastern flanks of the Mid-Atlantic Ridge, respectively.

3. In middle Eocene Zones P11-12 the beginning of the formation of a large basin, about 1500 km wide, between the two aforementioned aseismic ridges was caused by continuous spreading and thermal tectonic subsidence and allowed deeper currents to flow northward.

Moreover, during the Paleogene several plate tectonic events had a strong influence on circulation on a global scale. Among these are the increasing separation of Australia from Antarctica (Weissel and Hayes, 1972) during the Eocene, which created a stronger circulation system on the Pacific side of Antarctica and the clearance of shallow-water barriers between the southern end of the South Tasman Rise and Antarctica in the early Oligocene and between the Campbell Plateau and Antarctica in the late Oligocene (Kennett, 1977, 1978). The deep clearance of the Drake Passage along the Shackleton Fracture Zone was completed by 23 Ma (early Miocene) (Barker and Burrell, 1977). The latter event re-
Figure 1. A. Location of Leg 114 sites in the subantarctic South Atlantic. B. West-east longitudinal transect across the Mid-Atlantic Ridge.

Table 1. Location and water depth of Leg 114 sites.

<table>
<thead>
<tr>
<th>Hole</th>
<th>Latitude</th>
<th>Longitude</th>
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<th>Total penetration (mbsf)</th>
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<td>07°25.231'E</td>
<td>2532.3</td>
<td>671.7</td>
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</table>

moved the last physiographic barrier to a full circum-Antarctic circulation system.

The drill sites are located at present-day latitudes of 51°S to 46°S (Table 1). Sites 698 through 702, to the west of the Mid-Atlantic Ridge, are within the Polar Front Zone and belong to the Subantarctic bioprovince (Bé and Tolderlund, 1971), and thus to the high latitudes, which in the Southern Hemisphere include water masses south of 50°S (Kennett, 1978). The Antarctic Convergence today sharply separates a southern bioprovince—characterized by widespread erosion at depth related to cold, aggressive bottom waters, the accumulation of ice-rafted material, and biogenic silica production—from a northern province, where calcareous sediments predominate (Kennett, 1977).

The abundance of Paleocene to Eocene age calcareous sediments recovered at the drill sites indicates that environmental conditions in the area investigated by Leg 114 were much warmer than at present and similar to those presently recorded north of the Antarctic Convergence. Through the remainder of the Paleogene, paleoclimatic and paleoceanographic conditions reflect a progressively cooler climate. Oceanwide cooling event(s) resulted in biotic changes that, in turn, produced an accumulation of different types of sediments (from calcareous to siliceous) (Keigwin and Corliss, 1986; Krasheninnikov and Basov, 1986; Boersma et al., 1987).

The aims of the Leg 114 drilling program were (1) to link regional tectonic events to the opening of the gateway that allowed the antarctic cold waters to flow northward into the Argentine Basin through the Falkland-Agulhas Fracture Zone and (2) to reconstruct the evolution of the climatic conditions that resulted in the disappearance of carbonate-rich biofacies indicative of warmer conditions and their replacement by silica-rich biofacies.
Lower Paleocene to upper Eocene sediments yielded rich planktonic foraminiferal assemblages, only slightly affected by dissolution, at Site 702, which is located on a basement high and has a low subsidence rate. Calcareous biofacies were truncated by an erosional event during the late Eocene to the west of the Mid-Atlantic Ridge, while to the east they persisted into the Oligocene and early Miocene. Thus, if both sides of the Mid-Atlantic Ridge are considered, a composite Paleogene record is completely represented by calcareous biofacies and planktonic foraminifers that are present throughout.

In general, the planktonic foraminiferal assemblages are enriched in thick-walled, high-latitude index species (high dominance), whereas thermostrophic species have shorter ranges and/or disappear earlier than at lower latitude (Boersma and Premoli Silva, 1983; Boersma et al., 1987; Premoli Silva and Boersma, 1988). Planktonic foraminiferal distributions, nevertheless, do allow reliable correlation with the lower latitude standard zonation.

Precise age assignment of the basement or plate tectonic events, however, needs the combined potential biostratigraphic resolution of both calcareous planktonic groups, calcareous nannofossils and planktonic foraminifers.

METHODS

The present study is based on the examination of core catcher samples and one sample taken per section. Sample volume was about 10 cm³. All samples were soaked in a solution of 5% hydrogen peroxide and boiled for 10 min when necessary, and then they were washed on a 40-µm sieve and dried under a heat lamp. The washed residues were sieved and split into two size fractions: >150 and 150-40 µm.

One of the major problems in studying planktonic foraminifers from a high-latitude ocean environment is selective solution affecting planktonic foraminifers, which removes numerous, typically age-diagnostic taxa (e.g., Tournamire, 1978; Premoli Silva and Boersma, 1988). Thus, we have tried to collect as much information as possible in order to reconstruct the original biocoenosis.

In order to obtain a more complete record from such high-latitude material, in addition to species identification, species abundance was quantitatively estimated on the size fraction >150 µm. We evenly spread an aliquot of each >150-µm residue twice over a picking tray with a standard 60-square grid. Abundances were estimated relative to the total planktonic foraminiferal assemblage by counting specimens on randomly chosen grid squares. Five categories are distinguished and plotted in the range charts or used for reconstructing the abundance curves:

- S = one to three specimens,
- R = rare (less than 3%),
- F = few (3%-15%),
- C = common (15%-30%),
- A = abundant (more than 30% and dominant).

Only semiquantitative analyses were performed on the <150-µm size fraction of each sample. Estimates concern the most significant groups of small planktonic foraminifers, the chilonguembelinids, planorotalitids, pseudohastigerinids, and nenuellids, and some diagnostic species, generally of larger size, but confined to the <150-µm size fraction for ecologic reasons. The total abundance of planktonic foraminifers relative to other biogenic constituents was similarly estimated.

The occurrence and abundance of selected species and groups have been plotted for Sites 698, 699, 700, 702, and 703 against the biostratigraphic framework and time scales of Berggren et al. (1985) in Tables 2 through 6.

The major biostratigraphic events were plotted against sub-bottom depth, recovery, and the standard zonal scheme to construct synthetic lithologic logs for each site (Fig. 2). Weight percentages of the washed residue vs. original sample weight; species diversity (Jenkins, 1968) including some informal groups (see Appendix); the planktonic foraminifer/planktonic foraminifer + siliceous organism ratio; and subbotinid + acarininid (S/SA) ratio—the latter two on washed residues >150 µm—were also plotted (Figs. 3 through 13). These values were estimated in the same quantitative way as described previously. Moreover, the estimation of the S/SA ratio in the size fraction <150 µm at Site 702 yielded the best preserved assemblages and provided a direct calibration between magnetostratigraphy and biostratigraphy.

Special attention was also devoted to the state of preservation of planktonic foraminifers. Although it was impossible to apply the solution ranking facies identified by Berger and von Rad (1972) because of climatic exclusion of several solution-susceptible taxa, three solution "stages" were recognized based on etching and fragmentation of foraminiferal tests (see Table 2).

Reworking was a serious problem only at the two eastern sites. Among the indigenous forms, we considered reworked are those taxa that, after their local extinction preceded by a gradual decrease in abundance, reappeared at much younger levels. This criterion could not be applied to immigrant forms, such as subtropical warmer species, whose occurrence was already irregular and random. In this case we could rely only on their different stratigraphic range, if any.

Downhole contamination was not indicated in the range charts, but it was a serious problem at some portions of Sites 703 and 704, where soupy material was recovered and the age differences among planktonic assemblages were minimal.

SITE DESCRIPTION

Preliminary biostatigraphic data from each subantarctic site are included in the Leg 114 Initial Reports volume (Ciesielski, Kristoffersen, et al., 1988). This chapter is concerned primarily with the major characteristics of the planktonic foraminiferal assemblages, their distribution, and the intensity of dissolution at each site.

Site 698

Site 698 is located near the eastern edge of the shallowest portion of the Northeast Georgia Rise, an oceanic plateau of mid-Cretaceous to Paleogene age. This site is approximately 60 to 100 km south of the mean present-day site of the Antarctic Convergence Zone. The primary objectives at Site 698 were mainly tectonic and paleogeographic in nature, with the aim of evaluating the influence of the Northeast Georgia Rise as a Late Cretaceous–Paleogene obstruction to deep-water interchange between the Weddell and South Atlantic basins.

An apparently complete, 190-m-thick sequence of pelagic, carbonate-rich sediments of Campanian to late early Eocene (Zone P9) age was recovered above basement at Site 698. The Paleogene portion spans about three-fifths of the entire sedimentary sequence and is truncated by a major hiatus spanning the remaining portion of the Eocene up to the Pliocene–Pleistocene.

The Paleogene sequence consists of nannofossil chalk at the Cretaceous/Paleocene boundary grading upward to a nannofossil ooze. The calcium carbonate content is as high as 90%, indicating that dilution by terrigenous and/or biogenic silica is minimal throughout the Paleocene and early Eocene age interval.

Planktonic foraminifers are common to abundant and dominate other pelagic organisms (Table 2 and Figs. 3 and 4). Radiolarians are generally rare to few except in the lower part
of Zone P4 and in Zone P9, where they are more abundant (Fig. 4). Chert nodules are scattered throughout, suggesting that siliceous organisms were possibly more common than apparent in the washed residues. Planktonic foraminiferal tests are extensively recrystallized in the lower Paleocene. From the upper Paleocene up to the uppermost lower Eocene, planktonic foraminifers are moderately to well preserved, with sporadic occurrences of slight corrosion by dissolution. The depositional environment is interpreted to have been always above the foraminiferal lysocline. This interpretation is in agreement with the water depth estimate based on benthic foraminifers, from 750 m in the late Paleocene to 1000 m in the latest early Eocene (Katz and Miller, this volume). There is no evidence of reworking.

Because of poor recovery, especially in the lower portion of the Paleocene, some biozones, such as Zones Palpha, P2, P3a, P3b, and the transition between Zones P4 and P5, could not be documented. As indicated by calcareous nannofossils, Zone Palpa may be missing because of a hiatus (Ciesielski, Kristoffersen, et al., 1988). Although the occurrence of other short hiatuses cannot be ruled out, the succession of foraminiferal events appears to be regularly spaced.

The Paleocene/Eocene boundary, placed according to calcareous nannofossil data and marked by the first occurrence (FO) of Planorotalites pseudoscutulatus, could be documented only at Site 698. The Eocene sequence ends within the Morozovella crater Zone (mainly Zone P9), of which the upper part is truncated by the aforementioned major hiatus.

Planktonic foraminiferal species diversity (= species richness) increases from the Paleocene to the lower Eocene (Fig. 4) with a mean of 25 species and a maximum diversity of 43 species. The S/S A ratio varies from high percentages of round-chambered acarininids and subangular biconvex morozovellids in Zone P8.

Site 699

Site 699, drilled on the northeastern slope of the Northeast Georgia Rise, was selected to (1) obtain a continuously cored sedimentary sequence of Late Cretaceous to Neogene age, (2) record the history of deep-water communication between the Weddell and Georgia basins and the South Atlantic Basin, and (3) document the development of the Antarctic Circumpolar Current. The recovered section ranges in age from late Paleocene (Zone P4) to Pleistocene. Paleogene sediments are 415 m thick within the total 518 m drilled.

The lower portion of the sequence, about 180 m thick, consists of nannofossil chalk, ranging in age from late Paleocene through late Eocene, grading upward into a siliceous nannofossil ooze with an increase of the biosiliceous components. The carbonate fraction ranges from 70% in the lower to middle Eocene, shows strong fluctuations (between 75% and 0%) from the upper Eocene to Oligocene, and disappears almost completely at 85 m below sea floor (mbsf), just above the Oligocene/Miocene boundary. Paleogene sediments are mainly pelagic, mostly biogenic, except the basal 21 m of upper Paleocene sediments, which displays a high clay content. The clay source is supposed to be located in the southern Andean Cordillera with clay dispersed as a thick nepheloid

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4 After this paper was accepted for publication, new palaeomagnetic data were produced, especially for Site 699. The new data were unavailable for modifying Figure 5 and Table 3, which accordingly lack precise locations of the magnetic chrons identified in the sequences. This accounts for the discrepancies among the text and figures for the early to middle Eocene boundary (19 October 1990).
either a cold-temperate to subpolar climate or secondary diver-
ing to Jenkins (1968, 1973) species diversity less than 12 indicates
sp. recorded in the lower middle
Whiteinella
well as by calcareous nannofossils (Crux, this volume).
last occurrence (LO) of
at Site 699, as
702 (approximately 70 m thick). This is corroborated by the
the thickness of coeval sediments recorded at Sites 700 and
Eocene (Table 3, in back pocket).
Paragloborotalia opima nana
closeness of the F0 of
and the
Eocene age are too thin (only 20 m thick) in comparison with
hypothesis is based on the fact that sediments of late middle
possibly occurs at the middle to late Eocene boundary. This
the presence of a widespread unconformity in the South
Poor recovery prevents us from either proving or disproving
content is only 60% on average. The Zone P4 carbonate low
Max. 237 µm; in contrast, benthic foraminifers increase in
abundance (= near lysocline fauna; Boersma, 1977).
content is moderate with signs of only slight dissolution. By the
preservation of the planktonic foraminifers.
Reworked foraminifers are apparently absent except for
rare Cretaceous Whiteinella sp. recorded in the lower middle
Eocene (Table 3, in back pocket).
Within the lower Eocene and in the lower middle Eocene
species diversity is high (more than 20 species), decreasing to
less than 10 species in the Oligocene, when they occur. Accord-
ing to Jenkins (1968, 1973) species diversity less than 12 indicates
either a cold-temperate to subpolar climate or secondary diver-
sity caused by dissolution (Orr and Jenkins, 1977). Comparison
of species diversity curves from Sites 699 and 702, located at the
same latitude and during the same time interval, indicates that
low diversity at Site 699 is secondary and caused by selective, 
destructive solution. Moreover, in the middle Eocene several
species belonging to the biconvex morozovellids, small acarin-
id, and the pseudohastigerinids disappear earlier than at Sites
700 and 702. These disappearances are also interpreted as local
events related to dissolution.
The S/SA ratio ranges about 50% on average in the lower
Eocene and decreases suddenly within Zone P11 where spe-
cies diversity is very low (Fig. 6) due to the marked domi-
nance of A. primitiva, a very solution-resistant species. The
S/SA ratio then increases rapidly up to 100% after the extinc-
tion of A. primitiva.
At this site a 20-m-thick Morozovella crater Zone (cor-
responding to mainly Zone P9) was identified. The LO of M.
crater is within Chron 21R (Hailwood and Clement, this
volume).
In conclusion, Site 699 shows an increasing dissolution of
calcareous organisms, and thus, it is not adequate to depict
the global cooling event, recognized in the Oligocene, by
means of planktonic foraminifers.
Site 700
Site 700 was drilled in the western region of the East
Georgia Rise. The objectives for Site 700 were complementary
to those reported for Site 699.
The 465-m-thick sequence consists of pelagic carbonate
sediments rich in planktonic foraminifers, ranging in age from
late Turonian to late middle Eocene, overlain by 25 m of
Pliocene-Pleistocene diatom ooze. The Paleogene section
occupies about two-thirds of the entire sequence, and the
sediments have been affected by progressive lithification with
depth, from nanofossil ooze to nannofossil chalk, micritic
nannofossil chalk, and indurated chalk. Through the entire
Paleogene sequence the carbonate content is almost constant
(approximately 80%) except for a single level in upper Pa-
leocene Zone P4 where carbonate content drops to 1% and
another interval of late middle Eocene age in which carbonate
content is only 60% on average. The Zone P4 carbonate low
corresponds to a siliceous-bearing claystone horizon. Chert
nODULES occur only at the top of Zone P4.
Most of the Paleocene sediments yield abundant radiolar-
ians, whereas planktonic foraminifers are abundant only in the
lower to middle part of Zone P1b (Table 4, back pocket, and
Figs. 7 and 8). Radiolarians constitute the entire planktonic
microfauna in the Zone P4 claystone layer. planktonic for-
aminifers again become very abundant and dominant through-
out the Eocene sequence whereas radiolarians are rare. Only
at the top of the sequence does the radiolarian content
increase again.
Within the Paleocene, preservation of planktonic foramin-
ifers ranges from poor to moderate as a result of strong
recrystallization without any etching. The occurrence of abun-
dant siliceous organisms does not seem to have affected the
preservation of the planktonic foraminifers.
Above the Paleocene, planktonic foraminiferal preserva-
tion is moderate with signs of only slight dissolution. By the
upper middle Eocene evidence of dissolution suddenly be-
comes very strong: most of the foraminiferal tests are frag-
ment with few whole specimens preserved in the size
fraction >150 µm; in contrast, benthic foraminifers increase in
abundance (= near lysocline fauna; Boersma, 1977).
According to the benthic assemblages, the water depth at
Site 700 is estimated to have been nearly 2200 m in the early
Paleocene, then deepening down to 2500 m by latest early
Eocene (Katz and Miller, this volume). Thus, it was above the
Table 2. Stratigraphic ranges and relative abundances of Paleogene planktonic foraminifers and other selected organisms in Hole 698A.

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<tr>
<th>Age</th>
<th>Planktonic foraminiferal zone</th>
<th>Core-top depth (mbsf)</th>
<th>Core, section, interval (cm)</th>
<th>Preservation</th>
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<th>Globorotaliids aff compressa</th>
<th>Globorotaliids ( \approx ) 15 μm</th>
<th>Subbotinae ( \approx ) 15 μm</th>
<th>Subbotinae ( \approx ) 30 μm</th>
<th>Subbotinae ( \approx ) 50 μm</th>
<th>Subbotinae ( \approx ) 90 μm</th>
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<td></td>
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<td>89.50</td>
<td>11R-CC</td>
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<td>12R-1, 115-117 13R-CC</td>
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<td>(A) F R R R F C F A</td>
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Species diversity ranges from 12 in the Paleocene, to 25-42 from lower Eocene Zone P6b up to the lower middle Eocene, then fluctuates between 11 and 27 in middle Eocene Zones P11-12, and finally decreases to value less than 10 in the upper middle Eocene. Diversity and percentage figures suggest that planktonic foraminifers were the dominant organisms in the early and early middle Eocene (Fig. 8).
Eocene Zones P11-12, but their abundance depends upon dissolution that does not affect the very solution-resistant *Acarinina primitiva*. A *Morozovella crater* Zone at least 10 m thick is also recorded at this site. Biofacies evolution at Site 700 is comparable to that at nearby Site 699. The only difference between the two sites is that at the latter species diversity is lower in the uppermost lower Eocene and decreases earlier in middle Eocene Zone P10.

Paleomagnetic analyses carried out at Site 700 provide correlation points for the Paleocene (Ciesielski, Kristoffersen, et al., 1988; Hailwood and Clement, this volume). Paleocene Sample 114-700B-36R-2, 68-70 cm, which belongs to Zone P1b and contains *Subbotina pseudobulloides*, falls within Chron 29N, and the FO of *"Morozovella" incinata*, which equates to the base of Zone P2, occurs just below the boundary between Chrons 27N and 26R (63.14 Ma). For additional calibration of Paleocene foraminiferal datums to the paleomagnetic record of Hole 700B, see Hailwood and Clement (this volume).

**Site 701**

Site 701 was drilled on the western flank of the Mid-Atlantic Ridge, about 160 km east of the Islas Orcadas Rise on oceanic crust of middle Eocene age. The major object-
Table 2 (continued).

<table>
<thead>
<tr>
<th>Age</th>
<th>Planktonic foraminiferal zone</th>
<th>Core-top depth (mbsf)</th>
<th>Core, section, interval (cm)</th>
<th>Preservation</th>
<th>Dissolution</th>
<th>&quot;Globotruncana&quot; sp.</th>
<th>Acarinina bulbilenta</th>
<th>A. pseudotopolensis</th>
<th>A. spinuloinflata</th>
<th>A. sp. cf. spinulina</th>
<th>A. helvetica</th>
<th>Cribroforaminella sp.</th>
<th>Subbotina angulata</th>
<th>Subbotina equiloba</th>
<th>Pseudolithostrotion sp.</th>
<th>A. rutarum</th>
<th>A. sp. cf. rutarum</th>
<th>P. dilatata</th>
<th>Cribroforaminella avicula</th>
<th>&quot;Morozo-</th>
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</tbody>
</table>

Note: Abundance: S = very rare or single specimen; R = rare; F = few; C = common; A = abundant. Preservation: G = good; M = moderate; P = poor. Dissolution: blank = test without etching of chambers; 1 = slight to medium etching of chambers; 2 = strong etching of chambers; 3 = most specimens broken. Also, r = reworked; ? = doubtful occurrences; ( ) = specimens occur only in the <150-µm size fraction.

The sequence is about 480 m thick, spanning the early middle Eocene (Zone P10-base Zone P11) to the Pleistocene; the 100-m-thick lower part is Paleogene in age. Carbonate biofacies are restricted to a 70-m section at the bottom of the sequence. Uphole, the sediments grade from indurated nanofossil chalk with an average carbonate content of 80% to an alternation of nanofossil oozes, siliceous oozes, and clays. Upward, only siliceous biofacies occur.

Planktonic foraminifers are abundant and moderately preserved only in the lowermost 5-m-thick sediment section, between Samples 114-701C-49X-CC and 114-701C-49X-3, 135–137 cm. A distribution chart and synthetic logs, therefore, were not constructed because of the few samples containing planktonic foraminifers.

The assemblages contain rare Acarinina pseudotopolensis, Acarinina bulbilenta, Acarinina spinuloinflata, "Morozo-
globigerinid tests, which disappear in Sample 114-701C-48X-
foraminiferal Zone P10 is reported to overlap with nannofossil
in comparison with the thick Oligocene sequence recorded at
with a hiatus between the early and late Oligocene, is very thin
assemblages are too depleted for any further interpretation.

tion-resistant species, at Site 701. Planktonic foraminiferal
could explain the absence of
on the basis of calcareous nannoflora (Crux, this volume)
explained as due to dissolution.

foraminifers become very rare and are represented by only the
solutions-resistant species A. primitiva, which persists up to
Sample 114-701C-49X-1. The last rare planktonic
foraminifers are represented by fragments of unidentified
globigerinid tests, which disappear in Sample 114-701C-48X-
CC (443 mbsf).

From the early middle Eocene, when the water depth at
Site 701 was clearly above the foraminiferal lysocline, disso-
lution increased in such a way as to fragment, and then
destroy completely, the foraminiferal tests from a 30-40-m
section of sediments. The foraminiferal lysocline was defi-
nitely above the seafloor during the late Eocene. The low
species diversity in the last samples, as mentioned previously,
is interpreted as due to dissolution.

A hiatus detected between the middle and the late Eocene
on the basis of calcareous nannoflora (Crux, this volume)
could explain the absence of Globigerinatkeha index, a solu-
tion-resistant species, at Site 701. Planktonic foraminiferal
assemblages are too depleted for any further interpretation.

The sequence of siliceous-bearly clay of Oligocene age,
with a hiatus between the early and late Oligocene, is very thin
in comparison with the thick Oligocene sequence recorded at
Site 699 (approximately 50 m at Site 701 vs. approximately 200
m at Site 699). This would suggest that deep erosional currents
were strongly active at the location of Site 701 during the
Oligocene.

The contribution of planktonic foraminifers to the history
of this important gateway area is limited to the initial phase of
sedimentation, dated as early middle Eocene and at a water
depth of less than 3000 m.

Site 702

Site 702 is located on the central part of the Islas Orcadas
Rise, a north-northwest-trending aseismic ridge more than
1000 m above the adjacent seafloor. The Islas Orcadas and
Meteor rises were conjugate features prior to seafloor spreading
that separated them in the Eocene. One of the major
objectives of this site was to investigate the influence of the
shallow Islas Orcadas and Meteor rises on oceanic water-mass
communication between the southern high-latitude region and
the South Atlantic.

At Site 702 the sedimentary sequence is represented essen-
tially by pelagic carbonates, 273 m thick, ranging in age from
late Paleocene (Zone P3) to late Eocene, topped by a 22-m-
monic diatom muds and nannofossil and siliceous
ozes, ranging in age from late Miocene to Pleistocene.

Paleogene sediments grade from indurated chalks with
interbedded cherts in the lower part upward to chalks and
nannofossil oozes. The carbonate content is consistently
between 88% and 95%. Clay is present only at the bottom of
the sequence, attributed to the lower part of Zone P3, where
the carbonate content is lower also (mean value of 60%). In
the clay-rich interval radiolarians are more abundant than
planktonic foraminifers (Figs. 9 and 10). In late Paleocene
Zone P4 planktonic foraminifers seem to be more abundant in
comparison with the other sites, but the poor recovery can be
misleading. Above the clayey layer of Zone P3, planktonic
foraminifers are abundant and dominate throughout, whereas
radiolarians are absent in the lower Eocene. Radiolarians
reappear again in the lower middle Eocene, but they are never
abundant except at two levels in the upper Eocene.

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Figure 3. Paleogene planktonic foraminiferal zonation, Hole 698A.
Planktonic foraminifers are poorly preserved in the lower part of the sequence, due to the diagenetic processes of compaction, and moderately well preserved upward. Heavy etching of chambers is observed only in the uppermost middle Eocene and upper Eocene, but planktonic foraminifers are always abundant.

On the whole, the bulk of the carbonate sediments deposited during the Paleogene indicates uniform environmental conditions and biogenic accumulation always well above the foraminiferal lysocline. According to benthic foraminifers the water depth at Site 702 changed from 1600 m by early late Paleocene to about 2000 m in the early middle Eocene (Katz and Miller, this volume).

Species diversity was high from the late Paleocene onward, reaching the maximum number of species in the late early Eocene; from the early middle Eocene mean species diversity decreased and fluctuated (Fig. 10). Although calcareous biofacies exhibit some degree of dissolution associated with the decrease in species diversity beginning in early middle to late Eocene, dissolution effects are much less evident than at Sites 699 and 700.

Good paleomagnetic signals allow us to calibrate several events that have been used to identify the standard biozona
tion (see correlation by Berggren et al., 1985). According to Ciesielski, Kristoffersen, et al. (1988) and Clement and Hallwood (this volume), the following chron could be recognized:

- 157 mbsf within Core 114-702B-17X: Chron 21N/20R boundary (48.75 Ma), which falls within the basal part of Zone P12;
- 113 mbsf within Core 114-702B-13X: Chron 20R/20N boundary (46.17 Ma), which correlates with the P11/12 zonal boundary;
- 98.70 mbsf within Core 114-702B-11X: Chron 20N/19R boundary (44.66 Ma), which falls within Zone P12;
- 86.50 mbsf within Core 114-702B-10X: Chron 19R/19N boundary (44.06 Ma), which falls within Zone P12;
- 84.76 mbsf within Core 114-648B-10X: Chron 19N/18R boundary (43.60 Ma), which falls within Zone P12; and
- 71.90 mbsf within Core 114-702B-8X: Chron 18R/18N boundary (42.73 Ma), which straddles the Zone P12-13/P14 boundary.

At 154 mbsf, just above the Chron 21N/20R boundary, the planorotalitids disappear; thus their local last occurrence is an early P11 zonal event. Between 113.72 and 115.20 mbsf (46.19-46.28 Ma), less than 2 m below the Chron 20R/20N boundary, the FO of Globigerinatheka index is a late P11 zonal event. Within Chron 20N, and thus in the lower part of Zone P12, the biconvex morozovellids and the previously common Guembelitria disappear, while Acarinina bullbrooki disappears (44.13-43.99 Ma) about 5 m above them. Close to the Chron 18R/18N boundary, which is just below the P13/14 zonal boundary, the disappearance of "Globigerinatheka" seni and Pseudohastigerina danvillensis is recorded. In the uppermost part of Zone P12, as here inferred, common Subbotina linaperta occurs. Very rare specimens of S. linaperta are recorded much earlier in the sequence (lower part of Zone P12) (Table 5, back pocket). At Site 702 the LO of Acarinina primitiva occurs about 24 m above the Chron 18R/18N boundary, thus much higher than the P13/14 zonal boundary. Consequently, the LO of A. primitiva cannot be a P13 zonal event, as suggested by Edwards and Hoskins (1982), being very close, if not coincident, with the P14/15 zonal boundary at Site 702.

A few reworked Cretaceous Globigerinelloides and Heterohelix were found in late Paleocene and early Eocene age strata.

Major hiatuses are not present in the Paleogene, but minor hiatuses between the upper Paleocene and lower Eocene and
**Figure 5.** Paleogene planktonic foraminiferal zonation, Hole 699A.
<table>
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<th>Depth (m)</th>
<th>Core</th>
<th>Recovery</th>
<th>Residue &gt;40 µm (% of initial weight)</th>
<th>Diversity (number of species)</th>
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Figure 6. Selected parameters plotted against depth to depict changes in biofacies deposition at Hole 699A.
## PLANKTONIC FORAMINIFERAL PALEogene BIOstratigraphy

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**Figure 7.** Paleogene planktonic foraminiferal zonation, Hole 700B.
Figure 8. Selected parameters plotted against depth to depict changes in biofacies deposition at Hole 700B.
between Zones P7 and P8 cannot be ruled out due to poor recovery. A hiatus occurring at the lower/middle Eocene boundary has removed most of Chron 21R (Clement and Hailwood, this volume). A major hiatus truncates the Paleogene section at the level of Zone P15 or basal Zone P16 (nannofossil Zone NP18), identified on the basis of the occurrence of small round-chambered acarininids (see "Biostratigraphy" section). The Morozovella crater Zone spans 20 m of sediments at this site.

In Figure 10, S/SA ratio was plotted separately for the size fractions <150 and >150 µm. In the lower Eocene up to Zones P11/12, the acarininids are more abundant and diversified than the subbotinids in the finer fraction without domination by any species. By the upper middle Eocene the acarininids increase in abundance in the size fraction >150 µm, mainly because of the dominance of the large species *A. primitiva*. Considering both size fractions, the acarininids are abundant up to the middle to upper Eocene boundary.

The generally good preservation of planktonic foraminifers and the completeness of the Paleogene record at least up to the upper Eocene at Site 702 suggest that this site is the most suitable for biogeographic and paleoceanographic reconstructions.

Site 703

Site 703 was drilled on Meteor Rise, an aseismic ridge extending southwest from the Agulhas Fracture Zone.
Residue >40 µm (% of initial weight)

Planktonic foraminifers/
planktonic foraminifers +
siliceous organisms

Diversity (number of species)

Subbotinid / subbotinid +
acarininid

Figure 10. Selected parameters plotted against depth to depict changes in biofacies deposition at Holes 702A and 702B.

The site is presently located between the Subtropical Convergence and the Antarctic Convergence Zone, the northern edge of which is about 2.5° south of Site 703. One of the major objectives of this site was to investigate the influence of the shallow fracture zone on the oceanic communication between high and temperate latitudes in the South Atlantic.

At Site 703 the 377-m-thick sedimentary sequence consists predominantly of calcareous biogenic sediments, middle Eocene to Pleistocene in age, resting on volcanic rocks. However, significant biosiliceous input occurred in the late Eocene, late Oligocene, and early Miocene, and mass-flow deposits are common throughout the middle Eocene. The Paleogene section represents almost eight-ninths of the entire sequence. In the lowest part of the section, recovery was poor and discontinuous (Fig. 11). The common drilling disturbances are due to the occurrence of extremely variable lithotypes, including gravelly volcanic sand, volcanic tuff, and conglomerate.
## PLANKTONIC FORAMINIFERAL PALEogene BIOSTATIGRAPHY

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Figure 11. Paleogene planktonic foraminiferal zonation, Hole 703A.

249
cies, chert, basalt, quartz and granodiorite fragments, and
minor amounts of nannofossil chalk. Higher in the sequence
(above 250 mbsf) the main lithotypes are nannofossil oozes
containing mass-flow deposits of clay, sand, gravel, and
volcanic breccias, replaced by siliceous, foraminifer-bearing
nannofossil oozes in the uppermost part. The carbonate
content is 0% in the lowest part and increases abruptly above
300 mbsf; from this level upward CaCO₃ content is high on
average (80%). Lower carbonate content reflects the presence
of noncarbonate components, such as volcanic ash and silici-
aceous organisms, which are more abundant in residues >40
µm (Fig. 12).

Intensive downhole contamination of planktonic foraminifers
occurs in the bottom core, where well-preserved planktonic
foraminifers are extremely abundant and of mixed ages, al-
though the differences in age of the various taxa are minor.
Above Core 114-703A-23X (200 mbsf) planktonic foraminifers
are abundant to common throughout the remaining Paleogene
sequence except for some lower Oligocene levels where few
planktonic foraminifers were recovered (see Table 6, back
pocket, and Fig. 12). In the upper middle Eocene planktonic
foraminifers are more abundant than siliceous organisms, but by
the upper Eocene through the Oligocene–lower Miocene radio-
larians become a significant component of the microfaunas (Fig.
12).

Planktonic foraminifers are variably preserved throughout
the Paleogene sequence. Foraminiferal tests are well pre-
served without signs of dissolution in Core 114-703A-40X at
the bottom of the hole in the upper middle Eocene, alternat-
ingly slightly to strongly dissolved in the uppermost middle
Eocene and upper Eocene, and strongly dissolved in the lower
Oligocene. Foraminiferal preservation improves upslope in the
upper Oligocene Subzones P21a and P21b and in the interval
attributed to Zones P22-"N4," where planktonic foraminifers
are only slightly recrystallized. Preservation becomes poor again later in the lower Miocene.

Overall at Site 703 dissolution is not only extremely vari-
able, but is also randomly distributed through the section. It
does not, however, affect species diversity except in the early
Oligocene assemblages. Dissolution affects the sediments
differently than at Site 699.

On the basis of the good to moderate preservation of the
faunas at the bottom of the hole, the early middle Eocene
sedimentary depositional environment was well above the
foraminiferal lysocline. In contrast to the inferred deepening
of the CCD in the South Atlantic Ocean from the early Eocene
to late Oligocene (van Andel, 1975), at Site 703 the occurrence
of dissolved sediments from upper middle Eocene, at least
partially, and especially in the lower Oligocene must be
attributed to other causes independent of depth. This is
corroborated by the succession of regularly spaced bioevents
in the upper middle and upper Eocene that is strictly compa-
rable with that from Site 702, which is supposed to have
remained at an almost constant water depth.

From middle Eocene Core 114-703A-18X upward diatoms
are recorded in the HCl-insoluble residue, even when they are
not visible in washed residues. Between Cores 114-703A-20X
and 114-703A-32X (170 to 230 mbsf) they were possibly
present, but are now completely dissolved, as suggested by
the occurrence of clinoptilolite in the silty fraction. Therefore,
we suggest that the dissolution of planktonic foraminifers
(generally few in the size fraction >150 µm) could have
increased during episodes of increasing siliceous productivity
or for climatic reasons (Boersma, 1977).

Downhole contamination at the bottom (Core 114-703A-
40X) proved to be quite useful in indicating the character and
ages of planktonic foraminiferal faunas from a portion of the
sequence that was either poorly or not recovered.

At Site 703 reworking of planktonic foraminifers, espe-
cially pronounced in the lower Miocene, is indicated by the
common occurrence of middle Eocene taxa such as Acri-
rina primitiva, Acrarina rotundimarginata, Acrarina rugo-
soaculatea, Globigerinatheka index, the pseudohastigeri-

dids, the planorotalitids, and in minor amounts, Oligocene
forms (possibly the chiloguembelinids and Paragloborotalia
opima opima) found in Zone P22-"N4" and in the lower
Miocene.

Reworking during the middle Eocene is uncertain. Some
Planorotalites have been found above the FO of G. index. At
the studied sites west of Mid-Atlantic Ridge, the planorota-
litids are reported to disappear earlier than the FO of G. index,
which was also paleomagnetically calibrated. Thus, the plan-
rorotalitids could be reworked when mass flows were redepos-
ituted. Alternatively, because Site 703 is located at a lower
latitude than that of the other sites (Table 1), Planorotalites
could be in place, ranging up to the middle/late Eocene
boundary, as it does in middle and low latitudes.

As evidenced by the terrigenous and siliceous input, the
occurrence of mass flows, and common reworking of plank-
tonic foraminifers, the environment at Site 703 could be
characterized as rather unstable because of either up-slope
erosional events or strong bottom currents. This is in contrast
with the quieter deposition on the western sites.

Several hiatuses inferred from siliceous phytoplankton and
paleomagnetic data (Hailwood and Clement, this volume) are
not easily detectable at this site on the basis of planktonic
foraminifers as a result of reworking and mass slides.

In the middle Eocene species diversity is high (about 25 on
average) and rather constant, with fewer fluctuations than at
Site 702. While diversity fluctuates more in the upper Eocene,
species diversity is always >10. In the lower Oligocene
species diversity shows the lowest value, about 10, whereas it
markedly increases in the upper Oligocene–lower Miocene
(Fig. 12).

The acarininids increase in abundance in Core 114-703A-
21X, attributable to Zone P12, where the last biconvex moro-
zovellids occur, and then they drastically decrease after the A.
primitiva extinction. Only a few small, round-chambered
acarininids persist into the upper Eocene with the same trend
as at Site 702.

On the basis of paleomagnetic data (Hailwood and Clem-
ent, this volume) the Eocene/Oligocene boundary is estimated
to occur at about 122 mbsf via correlation to the Umbrian
sequences (Nocchi et al., 1986). Above the inferred Eocene/
Oligocene boundary we recorded the FO of small-sized spec-
imens named Catapsydrax cf. dissimilis and the LO of "Pra-
etenuitella” insolita.

Because the paleomagnetic data above Chron 12N are
somewhat difficult to interpret and because of the mixed
nature of planktonic foraminiferal faunas, most of the corre-
lations between biostratigraphic events and magnetic data
within the Oligocene interval should be considered tentative.

Subbotina angiporoides and Subbotina utilisindex, which
should fall within the lower part of Zone 21a, disappears in
Sample 114-703A-9H-CC (81 mbsf), about 2.5 m below a
proposed hiatus between Chrons 11N and 9R. P. opima opima
first occurs immediately above the Chron 9R/11N hiatus; how-
ever, its FO must be younger than the base of Chron 11N
and it should be considered an immigrant.

The chiloguembelinids strongly decrease in abundance
between Samples 114-703A-8H-2, 130–132 cm, and 114-703A-
8H-1, 130-132 cm, and disappear at Sample 114-703A-7H-4,
124–126 cm. Diatoms and paleomagnetic data suggest that a
 hiatus may be present at or near the level of the chiloguem-
belinid’s strong decrease, separating Chron 9N from Chron
8N (Hailwood and Clement, this volume). According to this
Figure 12. Selected parameters plotted against depth to depict changes in biofacies deposition at Hole 703A.
interpretation the P21a/21b zonal boundary, based on
chilloguembelinid extinction, is considered uncertain and
chilloguembelinids might be reworked above Sample 114-
703A-8H-2, 130–132 cm.

Site 704

Site 704 was drilled on the southern part of the Meteor
Rise, between the present Subtropical Convergence and the
Antarctic Convergence Zone. This site was located on a
region of the Meteor Rise where a maximum thickness of
Neogene and upper Paleogene sediments could be obtained in
order to provide a high-resolution paleoceanographic-paleo-
climatic record of an interval not well represented at the
previous Leg 114 sites.

A 670-m-thick mixed carbonate and biosiliceous sequence,
of early Oligocene to Pleistocene age, was obtained at Site
704. The Paleogene portion (120 m thick) represents only
about one-fifth of the entire sequence and consists of indu-
rated micritic nannofossil chalks, with little variation in lithol-
ogy, grading to nannofossil chalks in the lower Miocene.
Within the Oligocene, pelagic carbonate sediments predomi-
nate, with a CaCO₃ content up to 80% on average.

Planktonic foraminifers are abundant in the lower Oli-
gocene up to Zone P21a, become rare to few in the middle of
Zone P21b, and then increase again in abundance upward.
Radiolarians and other siliceous organisms are always com-
mon to abundant in washed residues, although their occur-
cence is not mentioned in the lithologic description (Ciesielki,

Preservation of planktonic foraminifers is poor, with signs of
dissolution evident in the lower part of Zone P21b. Poor preser-
vation and the decrease in planktonic foraminiferal abundance
are related to an increase in diatom abundance at about 600–650
mbsf; therefore, poor foraminiferal assemblages may be related
to an increase in siliceous productivity, possibly associated with
major late Oligocene climatic and oceanographic changes (e.g.,

Reworking of planktonic foraminifers occurs at various
intervals. At the bottom of the hole, in the lower part of Zone
P21a, abundant forms >300 µm in size, of middle to late
Eocene age, such as Acrarinina primitiva, Globigerinathea
index, and Subbotina linaperta, are reworked and well sorted.
This sorting can be attributed to winnowing or turbidity
currents. A. primitiva and the chilloguembelinids also occur
within the late Oligocene P22-“N4” zonal interval.

In the Paleogene section hiatuses are not easily recogniz-
able on the basis of planktonic foraminifers. In the interval
from Zone P21a through the P22-“N4” zonal interval we
record the same succession of events as at Site 703 (Fig. 13)
except that the Zone P21b is much thicker than at the previous
site (about 40 vs. <10 m).

A distribution chart and diagrams were not constructed for
Site 704 because of the poor preservation and reworking. The
sedimentation history at Site 704 is similar, however, to that of
the nearby, more elevated Site 703, except that the late Oligocene age sequence records a higher accumulation rate than at Site 703.

**BIOSTRATIGRAPHY**

Like modern planktonic foraminifers, Paleogene planktonic foraminifers are distributed in biogeographic zones paralleling latitude. Climatically induced expansion or contraction of these zones is reflected in changing foraminiferal distributions through the Paleogene (Boersma et al., 1987). Consequently, planktonic foraminiferal assemblages recovered in Leg 114 should represent the climatic evolution of the subantarctic region.

Paleogene planktonic foraminifers from the subantarctic transect display distributions strongly dependent upon their location at high latitudes.

In general, we can distinguish two major associations among the planktonic foraminiferal assemblages recovered during Leg 114: (1) “indigenous” faunas containing species or genera that are present with some continuity after their evolutionary appearance and (2) single species or a few species per genus that display discontinuous or stratigraphically very limited ranges and that are interpreted to have immigrated into the area, usually during warm periods. The latter are called “guests,” or “immigrants.” Indigenous faunas display lower diversity and high to very high dominance. Faunas containing immigrants have higher species diversity and, as expected, dominance decreases.

Because the forms indigenous to high latitudes are not only cosmopolitan species, but have longer stratigraphic ranges, biostratigraphic correlation with the low-latitude standard zonation must be based mainly on the warmer immigrants. Consequently, zoning is based on event stratigraphy, not datums, which produces a higher degree of uncertainty. This is strongly amplified in those parts of the stratigraphic column characterized by very poor recovery. Nevertheless, the lower latitude standard zonation (Berggren et al., 1985) was applied, as shown in Figure 14. The applicability of such a zonation is corroborated by the paleomagnetic stratigraphy of some of the sequences and by comparison with the paleobiogeographic reconstructions of the Paleogene Atlantic Ocean. The new data are not only in agreement with, but also complement, what has already been described from the Atlantic Ocean for this interval (Boersma and Shackleton, 1977; Haq et al., 1977; Boersma and Premoli Silva, 1983; Boersma et al., 1987; Premoli Silva and Boersma, 1988).

The taxonomy used in this paper is rather informal and mainly follows that proposed by Boersma and Premoli Silva (1983) and Premoli Silva and Boersma (1988, in press). This loose taxonomy reflects the numerous unsolved questions in Paleogene taxonomy remaining from the major treatment by Blow (1979).

**Early Paleocene**

**Zone P1a-1c**

The oldest Paleocene Subzone Palpha (= Planorotalitae eugubinus Zone) according to the calcareous nannofossil data seems to be missing because of a hiatus (Ciesielski, Kristoffersen, et al., 1988). The other three subzones have been recognized at Sites 698 and 700. The boundaries between them are based on the FO of the nominate taxa “Subbotina” pseudobulloides, Subbotina triloculinoides, and “Morozovella” trinidadensis, respectively. These boundaries, however, are somewhat uncertain in terms of sub-bottom depth at each site because of poor recovery.

Planktonic foraminiferal faunas are rich and diversified. The oldest P1b fauna consists of few to common chiloguembelinids (<150 µm), Globobaculina dautjergensis, common Subbotina triloculinoides, few “Subbotina” fringa, common “S.” pseudobulloides, few Planorotalitae praecompressus, Tenuitella reissi, and rare “Morozovella” edita. In Zone P1c, the chiloguembelinids are larger than 150 µm, and more abundant “S.” pseudobulloides is associated with rare “Morozovella” inconstans, few Planorotalitae compressus, Subbotina imitata, Subbotina triangularis, and rare “Morozovella” indolensis. The zonal marker, “Morozovella” trinidadensis, is very rare.

**Zone P2**

This zone was recorded only from Site 700; its presence or absence at Site 698 cannot be proved because of poor recovery. The assemblage of Zone P2 is similar to those of the previous zones, but is characterized by common “Morozovella,” the zonal marker, much rarer Globobaculina dautjergensis, small-sized chiloguembelinids (<150 µm), and by the FO of “Morozovella” praeursorius. A few “Morozovella” trinidadensis are still present.

**Late Paleocene**

**Zone P3a**

In this zone, recorded at Sites 700 and 702 but again not at Site 698, the FO of Morozovella angulata, the index species,
is associated with the appearance of the other new taxa “Morozovella” schachdagica, rare Morozovella abundocamerata (at the top), Acarinina mckennai, and Acarinina praepentacamerata. Low-spired subbotinids, the chilougembelinids, Subbotina pseudobulloides, and Tenuitella reissi still make up the bulk of the assemblage. Rare “Morozovella” uncinata is still present at the base of the zone.

Zone P3b

The assemblages attributed to this subzone, from Sites 700 and 702, are similar to those from the previous zone except that species diversity increases with the appearance of the index species, Morozovella pusilla, and Morozovella simulatilis, “Morozovella” tadikistanensis djanensis, Acarinina nitida, Acarinata acarinata, and Planorotalites ehrenbergi, all of which are generally rare except for the last taxon. The bulk of the assemblages is still composed of the subbotinids, the chilougembelinids (also >150 µm)”S.” pseudobulloides, and much rarer T. reissi and Planorotalites compressus. When muricate forms, such as the acarininids and morozovellids, become much rarer, assemblages are dominated by the low-spired subbotinids or by A. mckennai. The large morozovellid lineage is represented by only M. abundocamerata.

Zone P4

The lower boundary of this zone, recorded in all four western sites (698, 699, 700, and 702), is marked by the appearance of a few Planorotalites pseudomenardii. This index species, however, is recorded only at the base of the zone, whereas P. compressus is the only planorotalid that occurs, although discontinuously, in the upper layers of the zone. “S.” pseudobulloides, already rare at the base of the zone, became extinct in the lower part of it.

Significant fluctuations in abundance of various taxa from layer to layer are first observed in Zone P4. The alternating faunas are: (1) Acarinina mckennai frequently associated with Acarinina subshphaerica, “Acarinina” aquensis, “Acarinina” chascanona, “Morozovella” tadikistanensis, and “M.” tadikistanensis djanensis; (2) the low-spired subbotinids including S. triloculoides, S. triangularis, Subbotina eocaenica, and Subbotina patagonica; and (3) the true acarininids (A. nitida, A. acarinata, and A. velascoensis). Assemblages also contain, but never in abundance, A. praepentacamerata, T. reissi, the chilougembelinids mainly of small size (<150 µm), “Morozovella” convexa, and, finally, a possible new species of Globorotaloides, identified here as Globorotaloides sp. 1, which appears in the middle to upper part of Zone P4 in the small fraction (<150 µm). Representatives of the large morozovellids are absent.

Zones P5-6a

The P5-6a zonal interval was recovered at Sites 698, 699, and 702.

The absence of Planorotalites pseudomenardii through most of Zone P4, however, prevented identification of the P4/5 zonal boundary according to the standard definition. Consequently, the beginning of Zone P5 was tentatively placed above the extinction level of Subbotina triloculoides, which is known to disappear close to the top of Zone P4 elsewhere. This is in agreement with the calcareous nannofossil data.

The youngest assemblages attributed to the Paleocene contain species of round-chambered acarininids inherited from the previous zones, except for A. subshphaerica, which is missing. Common species are “M.” tadikistanensis djanensis, which became extinct at the top of this interval; “M.” convexa and other biconvex morozovellids; the low-spired subbotinids, mainly S. triangularis and S. eocaenica–S. patagonica; Globorotaloides sp. 1; common chilougembelinids, including large-sized forms only at Site 698; and T. reissi, among others.

Important events in this interval are (1) the reappearance of Planorotalites represented by large-sized P. planonoconicus, P. australiformis; and P. chapmani (sensu Berggren et al., 1967); (2) the FO of Zeauginerina sp. at Site 698 among the biserial heterohelicids; and (3) the FO of sporadically common Acarinina interposita, Acarinata rotundimarginata, Acarinina rugosoaculeata, and Acarinina gravaelli. Large morozovellids, including Morozovella velascoensis, are missing. No layers show dominance of single groups.

Early Eocene

Zones P6b-7

This interval is recorded at Sites 698, 700, and 702.

The base of Zone P6b, equated to the Paleocene/Eocene boundary, is placed according to calcareous nannofossil data. In terms of planktonic foraminifers, this boundary seems to be marked by the FO of Planorotalites pseudosculptus associated with an overall increase in abundance of all planorotalids. Rare, small-sized Pseudeogastherina wilcoxensis occurs slightly higher, associated with Morozovella wilcoxensis.

Besides the abundant large and small-sized planorotalids, in this interval planktonic foraminiferal assemblages are characterized by abundant Acarinina acarinata, A. nitida, A. eocaenica, and A. soldadoensis particularly in the fine fraction (<150 µm), by large-sized Chilougembelina midwayensis, by common “A.” aquensis and “A.” chascanona, and by “M.” convexa. “A.” mckennai is the only large-sized, round-chambered acarininids present, but it decreases drastically in abundance. A few Globorotaloides sp. 1 and Globorotaloides sp. (Pl. 1, Figs. 13–15) occur also in the fraction >150 µm.

Peculiar to this interval is the occurrence of a few large morozovellids, represented by the species Morozovella marginodentata, Morozovella subbotinae, and very rare Morozovella gracilla and Morozovella aequa. Low-spired subbotinids, enriched by the appearance of Subbotina eocaenica irreguralis and Subbotina pseudoecaenae may be more abundant in some levels, but they never are so dominant as in some horizons of Zone P4. “Globorotalia” praecentralis occurs in some abundance in a single horizon, then disappears.

Zone P8

The lower boundary of this zone is placed at the level of the FO of Acarinina pentacamerata, which is mainly confined to the lower part of the zone and occurs only sporadically in any abundance. This zone, represented in all the western drill sites, is characterized by a major change in planktonic foraminiferal assemblages, which become dominated by Acarinina primitiva and its overgrown morphotype, attributed to Murigoglobergina senni by Blow (1979). At the beginning of this acme, several new species appear in almost all genera or groups, resulting in a large increase in specific diversity. In particular, there are the appearances of Acarinina pseudoplilens, A. triplex, and later A. praepontticus among the subquadrate acarininids; of Morozovella lensiformis, M. dolabrata, and very rare Morozovella aragonensis along with M. subbotinae among the large morozovellids; of Subbotina inaequispira and S. pseudoecaenae compacta associated with the always common S. eocaenica–S. patagonica and S. pseudoecaenae irregularis among the low-spired subbotinids; of Globorotaloides turgida and Globorotaloides aff. suteri along with common, typically large-sized Globorotaloides sp. 1 among the globorotaloids; of the first representatives of the
high-spired subbotinids, Subbotina eocaena, Subbotina cor-
puenta, Subbotina lozanoi, and very rare Subbotina higgin-
si. and of common “Globigerinathenke,” very rare Pseudohasti-
gerina crisca, Acarinina bullbrooki, and small-sized “Mor-
zovella” brodermanni, among others. The small acarinids
are still very common in the fine fraction (<150 µm) where
they are associated with some Guembelitria. By contrast, the
planorotalitids tend to decrease in both abundance and size
upward and are more common in the <150-µm fraction.
Moreover, the chiloumbelids (always <150 µm in size), A.
aquisiens, A. chascanona, T. reissi, and biconvex moro-
zovellids all decrease in number.

Zone P9
This zone is also recorded in all western drill sites.
The lower boundary is placed at the FO of Morozovella
 crater, generally close to the FO of Pseudohastigerina da-
villensis. Zone P9 seems to correspond to most of the range of
M. crater, which, although never frequent, is continuously
recorded throughout this interval (Pujo and Sigal, 1979). This
correlation is corroborated by calcareous nannofossil (Crux,
this volume) and paleomagnetic data (Hailwood and Clement,
this volume).

The bulk of the P9 zonal assemblage is similar to that
described from Zone P8 with all the acarinids more abun-
dant in the fine fraction (<150 µm) except for A. primitiva,
which dominates the larger fraction (>150 µm). The species
first appearing in this interval are Catapsydrax taroubaensis
and Cassiginerellina amekiensis in the upper part. Biconvex
morozovellids become more common in the lower to middle
part of the zone, from where they decrease in number toward
the top. Acarinina aquisiens and associated forms become
rare and disappear at the top of the zone; the subbotinids,
in general, as Acarinina pseudotopilensis and Acarinina praepolipilensis, increase in abundance. Acarinina bullbrooki
remains very rare.

Middle Eocene
Zones P10-11
This zonal interval is recorded at Sites 699, 700, and 702,
wherese it is missing at Site 698 because of a large hiatus (see
“Site Description” section).

The lower boundary of Zone P10 is placed on the basis of
paleomagnetic data (Hailwood and Clement, this volume) and
falls within Chron 22N very close to the Chron 22N/21R
boundary (Lowrie et al., 1982; Napoleone et al., 1983).
Accordingly, Morozovella crater ranges up into the lower part
of this interval, in contrast with that reported in the literature
(Bolli et al., 1985), in which the disappearance of M. crater at
midlatitude is equated to the early to middle Eocene boundary
 [=Zone P9/10 boundary].

The boundaries between Zones P10 and P11 and the over-
ying Zone P12 could not be documented on the basis of
planktonic foraminiferal faunas or calcareous nannofossils,
because both groups are missing the index species. They were
placed through correlation of paleomagnetic data from Site
702 with other paleomagnetically calibrated sequences from
the South Atlantic (Tauxe et al., 1983) and land sections
(Lowrie et al., 1982; Napoleone et al., 1983). Accordingly, the
P10/11 zonal boundary would fall between Chrons 21N and
20R, whereas the P11/12 zonal boundary lies between Chrons
20R and 20N.

Planktonic foraminiferal assemblages attributed to Zone
P10 are characterized by abundant A. primitiva, the low-
spired subbotinids (S. pseudoecaena compacta, S. pseu-
doecaena irregularis, and S. eocaena-patagonica), some

Just above the boundary between Zones P10 and P11, defined
according to paleomagnetic data, all planorotalitids disappear.
Peculiar to Zone P11 is a general upward decrease in abundance
of most of the species inherited from Zone P10, except for the still abundant A. primitiva, the globorotaloid-
s, and, to a lesser extent, the low-spired subbotinids.

The upper part of Zone P11 is characterized by the FO of
Globigerinathenke index, Subbotina angiporoids, and Subbotina
utilisindex. The FO of G. index is here used for marking the
lower boundary of the late middle Eocene interval. The LO of
Planorotalites and the younger FO of G. index seem to be
recorded in the same order and are possibly coeval with the same
events recorded by McGowran (1986) in South Australia.

Zones P12-13
This interval could be identified at Sites 700 and 702.
As mentioned previously, the lower boundary of this
interval was placed according to paleomagnetic data. In terms
of planktonic foraminifers it occurs just above the FO of G.
index. The upper boundary, according to paleomagnetic data
from Site 702, is near the base of Chron 18N (Fig. 15).

Planktonic foraminiferal assemblages, still dominated by
Acarinina primitiva, are also characterized by the occurrence
of Acarinina bullbrooki, A. decepta, the low-spired subbot-
inids (S. pseudoecaena irregularis, S. angiporoids, and S.
utilisindex), rare high-spired subbotinids, the catapsydracids,
Globorotaloides suteri, few G. oregonensis, Globigerinathenke
index, and “G.” senni in the coarse fractions and by the small
round-chambered acarinids, the pseudohastigerinids, and
common chiloumbelids in the fine fractions (<150 µm).

In the lower to middle part of this interval, attributed to
Zone P12, the biconvex morozovellids reappear in some
abundance before becoming extinct. Moreover, Subbotina
eocaena and Guembelitria disappear, whereas the subbot-
inids of the S. angiporoids group increase in abundance
upward. Rare Acarinina spinoloinflata are recorded in this
interval.

In the upper part of this interval at Site 702, 5 m below the
Chron 18R/18N boundary, which is possibly still in Zone P12,
two closely spaced horizons are characterized by the occurrence
of common Catapsydrax africanus, allowing us to make a good
correlation between Sites 700 and 702. Accordingly, the
Eocene sequence at Site 700 is truncated at this level. At
Site 702, where this interval is complete, its uppermost part,
attributable to Zone P13, is characterized by a generalized
decrease in abundance of most of the previously common
taxa, such as the low-spired subbotinids, the small acarin-
idns, the pseudohastigerinids, and Acarinina bullbrooki and,
in contrast, by an increase in the abundance of Globigerinathenke
index, the Subbotina angiporoids group, and Subbotina
linaperta s. str., which appears in Zone P12. Acarinina
primitiva is still dominant.
The whole interval is also recorded at Sites 699 and 703; however, it cannot be distinguished from the overlying Zone P14 because of heavy dissolution at Site 699 and poor recovery at Site 703 (see "Site Description" section).

**Zone P14**

This zone is identified only at Site 702. Its lower boundary is defined by the previously mentioned paleomagnetic data. The upper boundary, however, is placed above the extinction level of *Acarinina primitiva*.

In this zone, planktonic foraminiferal assemblages gradually record the loss of the acarininids (represented only by *A. primitiva* and small round-chambered forms), the low-spired subbotinids, and *Pseudohastigerina micra*. "Globigerinatheka" senni and *Pseudohastigerina danvillensis* disappear at the base of the zone.

In general, planktonic foraminiferal assemblages are characterized by common globorotaloids, abundant *Globigerinatheka* index, common chiloguembelinids (<150 µm), the catapsydracids, the *S. angiporoide* group, *S. linaperta* s. str., and *S. eocaena* (commonly with abortive chambers). The tenuitellids are still represented only by *T. reissi*.

At Site 699, because of the strong dissolution affecting the upper middle Eocene strata, planktonic faunas consist only of solution-resistant species, such as few *A. primitiva*, *G. index*, and some catapsydracids. At Site 703, planktonic foraminiferal assemblages evolved similarly to those at Site 702. However, poor recovery, especially in the upper part of the *A. primitiva* range, associated with some reworking, prevented precise placement of the lower boundary of Zone P14 at this site.

**Late Eocene**

**Zone P15**

The base of Zone P15, corresponding to the LO of *Acarinina primitiva* and associated with a marked decrease in abundance of the small round-chambered acarininids, is here equated to the beginning of the late Eocene. This zone is tentatively separated from the other late Eocene zones, although the index forms or other standard criteria for separating it are missing in the Leg 114 record. The identification of Zone P15 at Sites 702 and 703 is based on the occurrence of rare specimens belonging to the small acarininids, the occurrence of which above the major extinction level of this muricate group is confined to the lower part of Zone P15 in other areas (Poore, 1984; Boersma et al., 1987; Parisi et al., 1988; Fremoli Silva and Boersma, 1988).

Planktonic foraminiferal assemblages contain very abundant *G. index*, common chiloguembelinids (also recorded sporadically in the >150-µm fraction), the globorotaloids, subbotinids with abortive chambers, catapsydracids, *Subbotina linaperta* s. str., the *S. angiporoide* group, and very rare *Pseudohastigerina micra*. A renewal among the tenuitellids was observed at the base of this zone with the appearance of *Tenuitella ciemenceae*, *Tenuitella gemma*, and *Tenuitella insolita* (only at Site 703) replacing the older *T. reissi* and rare *Praetenuitella*. Among the small acarininids, just above the base of the zone, the FO of *Acarinina aculeata* (= *Tenuitella aculeata* Auc.) is observed, whereas the other forms successively disappear upward: first *Acarinina collactea*, followed by *Acarinina mediczai*, and finally *A. rugosaclea* associated with *A. aculeata*. Except for the range of the latter taxon, the same succession of extinction events among the small acarininids was observed by McGowan (1986) in southern Australia.

Other events observed in Zone P15 are (1) a single horizon rich in *Globigerinatheka luterbacheri* along with the appearance of *Paragloborotalia optima nana*, which coincides with the LO of *Subbotina linaperta* s. str., and of the pseudohastigerinids in both sites, and (2) the FO of "Globigerina" ampliapertura at Site 702.

**Zones P16-17**

This interval, recorded only at Site 703, contains planktonic foraminiferal assemblages very similar to those described from the previous zone, except for the aforementioned disappearances. The assemblages are dominated by *G. index* up to Sample 114-703A-14H-CC, the only sample from that core. Moreover, the tenuitellids increase in abundance, the chiloguembelinids, a common component of the finest fraction, consistently occur in the >150-µm fraction also, and the *Subbotina angiporoide* group is common.

Because of poor sampling from Core 114-703A-14H as a result of drilling disturbances and the incomplete recovery of Core 114-703A-13H, the placement of the Eocene/Oligocene boundary, equated to the P17/18 zonal boundary, was inferred from paleomagnetic data. The identification of Chron 13N at the top of Core 114-703A-13H suggests that the Eocene/Oligocene boundary would fall lower in the missing portion of Core 114-703A-13H (Nocchi et al., 1986).

**Oligocene**

**Zones P18-20**

The placement of the Eocene/Oligocene boundary, and thus the base of Zone P18, within the missing portion of Core 114-703A-13H is confirmed by the FO of *Catapsydrax cf. dissimilis* in the core catcher, followed closely upward by the LO of "Praetenuitella" insolita, an event considered characteristic of the latest Eocene/earliest Oligocene. The upper boundary of this interval is placed just above the LO of "Globigerina" ampliapertura, the nominal marker of Zone P20. The absence of the index species at Site 703 prevented further subdivision of this interval.

Planktonic foraminiferal assemblages in this interval are less diversified than in the lower or upper parts of the Paleogene. Moreover, in the upper part of the interval species diversity decreases to less than 10 species.

The diversified tenuitellids are further enriched by new species such as *Tenuitella mundu* and *Tenuitella* cf. *pseudoedia* and by more abundant *T. gemma*. The chiloguembelinids are generally common in the <150-µm fraction and are rarer but constantly present in the coarse fractions. *Catapsydrax dissimilis*, *Catapsydrax unicus*us, the globorotaloids, and the *Subbotina angiporoide* group are among the most common components of the faunas. Moreover, in the lower part an acme of *Globorotaloides* sp. 1 and *G. oregonensis* was observed, in the middle to upper part of the interval "Globigerina" labacrasata becomes common, and few *Globigerina praebulloides* ocellus first appear in the upper part. "Globigerina" ampliapertura is rare and occurs discontinuously throughout.

**Zone P21a**

This zone is recorded at Site 703 and it is apparently complete at Site 704. The lower boundary is well defined by the LO of *G. ampliapertura* at both Sites 703 and 704. At Site 703 the upper boundary is placed tentatively at the level of the chiloguembelinid disappearance, whereas at Site 704 it is uncertain because of poor recovery.
Planktonic foraminiferal assemblages in this zone, together with most of the forms inherited from the previous interval, include *Paragloborotalia* *opima* *opima* and *P. opima* *nana*, common *G. labiacrassata*, and *Globigerina praebulloides*. In the lower part the *Subbotina* *angiporoides* group disappears. In the upper part several forms first appear: "Globigerina" *anguliofficinalis*, *Tenuitellinata* *angustiuberculata*, *Globigerinoides praestainforthi*, and *Casigerinella chipolensis* occur, each for a short interval with their ranges slightly overlapping.

**Zone P21b**

This zone is recorded at Sites 703 and 704. However, at Site 703 it is not completely represented, whereas sediment thickness (40 m) at Site 704 seems to suggest that Zone P21b might be represented in its entirety. Uncertainty in estimating the completeness of this zone at Site 704 is due to the occurrence of faunas depauperated by dissolution in most of this interval, the presence of reworking, poor recovery, and the fact that index species are rarely represented in the assemblages. Calibration of bioevents to magnetostratigraphy in this interval is too poor to increase biostratigraphic resolution. Tentatively, the upper boundary is placed at the FO of large-sized *Globigerina cипероensis* associated with "G." *anguliofficinalis*, which is followed shortly by the reappearance of *Paragloborotalia* *pseudocentralis* and *Globorotalia praebulloides* and *G. praebulloides* *occlusa*. At Site 704, the FO of *Globigerinina incrusta* and "Globigerina" *brazieri*. All of these species are known to be normal components of the youngest Oligocene faunas.

Planktonic foraminiferal assemblages contain abundant *Catapsydrax* (*C. dissimilis*, *C. dissimilis* *cipoensis*, and *C. unicus*), "Globigerina" *brazieri*, tenuitellids larger than 150 µm, *Tenuitellinata angustiuberculata*, *Globigerinoides praebulloides*, *G. praebulloides* *occlusa*, *G. ouachitensis*, "G." *anguliofficinalis*, and "G." euapertura. The zonal marker *P. opima opima* is present but never abundant.

**Zones P22-"N4"**

This interval is recorded from Sites 703 and 704. The two zones included in this interval could not be separated because of the absence of the entire *Globorotalia kugetleri* group, and thus of *G. kugetleri*, the appearance of which marks the beginning of Zone N4. The upper boundary of this interval was placed just below the FO of *Globoquadrina dehiscens* and *Globorotalioides zealandica*, which are considered Miocene index forms (Srinivasan and Kennet, 1983).

Planktonic foraminiferal assemblages consist of common catapsydracids, the globorotaloids, the tenuitellids (also >150 µm), *Paragloborotalia* *opima opima*, *P. pseudocentralis*, "Globigerina" *labiacrassata*, "G." *brazieri*, *Globigerina praebulloides*, *G. praebulloides* *occlusa*, *G. ouachitensis", "G." *anguliofficinalis*, and "G." euapertura. The zonal marker *P. opima opima* is present but never abundant.

**Early Miocene**

**Zones N4-5**

This interval is recorded at Sites 703 and 704. The two zones cannot be separated because of the absence of *Globorotalia kugetleri*. The lower boundary is placed at the FO of *Globoquadrina dehiscens*, whereas the upper boundary is placed according to the LO of *Catapsydrax dissimilis*. Planktonic foraminiferal assemblages are very similar to those described from the previous interval. Besides the occurrence of *G. dehiscens*, some new species appeared: *Globorotalia zealandica*, "Globigerina* woodii", and "G." *woodii* connecta. No *Globigerinoides* were found.

Above the LO of *Catapsydrax dissimilis*, a very short interval at Site 703 is tentatively attributed to Zone N6. Planktonic foraminifers are rare and affected by dissolution.

**Tentative High-Latitude Zonal Scheme**

Several authors have proposed biostratigraphic zonal schemes based on planktonic foraminifers for the high latitudes, especially in the Southern Hemisphere. None of these schemes fully apply to the Subantarctic Convergence Zone, where, as shown in this chapter, Paleogene planktonic foraminiferal assemblages exhibit, at least sporadically, a combination of low- and high-latitude index faunas. This fact allows us, first, to apply the lower latitude standard zonation, as previously described, and, second, to calibrate at least some tie-points from high-latitude zonal schemes to the standard zonation.

In Figure 15, the main planktonic foraminiferan events used for constructing the zonal scheme proposed here are plotted against age, local zonation, standard zones, and paleomagnetic data.

Austral Paleogene zonations that apply best to the subantarctic region are those proposed by Jenkins (1985) for the early and early middle Eocene and by Ludbrook and Lindsay (1969) for younger levels. While one zone at the Eocene/Oligocene boundary from Orr and Jenkins (1977) can be applied, the tentative zonation, shown in Figure 15, had to be completed with two new zones for the late Eocene and latest Oligocene, respectively. The former one, the *Subbotina utilis* index Zone (interval zone), partially replaces the previous *S. linaperta* Zone. The latter taxon had to be dropped as an index form because paleomagnetic calibration proved its range was different in southern Australia from in the subantarctic region. The second new zone is named "Globigerina" *brazieri* and spans the latest Oligocene—early Miocene. It corresponds to the interval between the LO of *Paragloborotalia opima opima*, associated locally with the FO of the nominal marker, and the FO of *Globoquadrina dehiscens*. The *Globigerinina incrusta* Zone of Jenkins (1985) was restricted to the early late Oligocene, because the nominal taxon is absent in the upper part of the sequences recovered during Leg 114. Moreover, the LO of *P. opima opima* was considered a first-order event. Another biostratigraphically useful event is the LO of "*Praetenuitella*" *insolita* (*= *Globorotalia insolita* in Orr and Jenkins, 1977). It was used for defining the upper boundary of the nominal zone, which was drawn as barely straddling the Eocene/Oligocene boundary. We suspect that this partial range zone could represent only the earliest Oligocene. Poor recovery in this interval from Leg 114 sites prevents the use of the LO of *Globoquadrina dehiscens* for marking the Eocene/Oligocene boundary as it does in the southwestern Pacific.

Finally, the standard zonation was easily applied to the Paleocene interval, because most of the key biostratigraphic events marking zonal boundaries are present in the Leg 114 sequences.

**CORRELATION**

**Intersite Correlation**

Several biostratigraphic events, based on first, last, or only occurrence of planktonic foraminiferal taxa, have been found to recur in the same stratigraphic order in the Paleogene sequences recovered during Leg 114. The most reliable succession of events is that based on the combined records from
Sites 702 and 703, which then provides a direct calibration to paleomagnetic stratigraphy. Such a succession of events was used as a framework to which all the other successions could be correlated. This allows us to demonstrate possible gaps, synchronicity and/or diachrony of some events from site to site, and changes in sedimentary features. Correlatable, age-diagnostic, or paleoenvironmentally significant events are plotted in Figure 16 against depth, standard planktonic biostratigraphy, and magnetostratigraphy.

Comparison among the various sites allows us to identify the following steps in the evolutionary history of the Atlantic subantarctic faunas:

1. Calcareous sedimentation characterized the opening of the Paleocene up through Zone P3a. Planktonic foraminiferal faunas evolved similarly to those from lower latitudes, except that some of the low-latitude index forms were less common in this area.

2. By the middle to early late Paleocene (Zones P3b-4), radiolarians appeared at the westernmost sites, whereas at Site 702 they were found to occur in small amounts only at the bottom of the hole. Planktonic foraminiferal assemblages started to evolve differently from their lower latitude counterparts. Large morozovellids temporarily disappeared, planorotalitids of the *P. pseudomenardii* group disappeared after a short acme of

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**Figure 15. Planktonic foraminiferal biozonal scheme, Leg 114.**

<table>
<thead>
<tr>
<th>AGE</th>
<th>LOCAL ZONES</th>
<th>STANDARD ZONES</th>
<th>PALEOMAGNETIC DATA</th>
<th>PLANKTONIC FORAMINIFERS EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>early Mocene</td>
<td><em>Globigerina</em> brazieri (4) (partial range zone)</td>
<td>N4</td>
<td></td>
<td>Globoquadrina dehiscens</td>
</tr>
<tr>
<td>late Oligocene</td>
<td><em>N4</em> or P22</td>
<td></td>
<td></td>
<td>Paragloborotalia</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><em>Globigerina</em> opima opima</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Chilostomellids</td>
</tr>
<tr>
<td>early Oligocene</td>
<td><em>Globigerina</em> euapertura (2) modified</td>
<td>P21b</td>
<td></td>
<td><em>Subbotina</em> angiporoides</td>
</tr>
<tr>
<td></td>
<td>(interval zone)</td>
<td></td>
<td></td>
<td><em>G.</em> ampliapertura</td>
</tr>
<tr>
<td>late Eocene</td>
<td><em>Globigerina labiacrassata</em> (2) (interval zone)</td>
<td>P11N</td>
<td></td>
<td><em>Praetenuitella</em> insolita</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Globigerinatheka index</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><em>Acarinina</em> aculeata and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>small rounded acarininids</td>
</tr>
<tr>
<td>late-middle Eocene</td>
<td><em>Globigerina</em> angiporoides (2) modified</td>
<td>P18</td>
<td></td>
<td>Acarinina primitiva</td>
</tr>
<tr>
<td></td>
<td>(partial range zone)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>late-middle Eocene</td>
<td><em>Subbotina</em> utilisindex (4) (interval zone)</td>
<td>P17P16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>early-middle Eocene</td>
<td><em>Globigerina</em> index (2) (partial range zone)</td>
<td>P12P13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>early-middle Eocene</td>
<td><em>Subbotina</em> primitiva (1) (interval zone)</td>
<td>P10P11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>early-mid Paleocene</td>
<td><em>Morozovella</em> crater (1) (total range zone)</td>
<td>P9P8P7</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>early-mid Paleocene</td>
<td><em>Pseudohastigerina</em> wilcoxensis (1) (partial range zone)</td>
<td>P6bP6aP4P3bP3aP2P1cP1b</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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(1) = Jenkins, 1985; (2) = Ludbrook and Lindsay, 1969; (3) = Orr and Jenkins, 1977; (4) = here suggested.
the nominate taxon early in Zone P4, and planktonic assem-
blages began exhibiting the dominance of one group vs. other
groups, which alternate from layer to layer. The first repre-
sentatives of the genus Globorotalioides appeared in this inter-
val, increasing slightly in abundance upward.

3. In the middle of Zone P4, sediments are enriched in clay
content. This thick interval at the westernmost sites thins
eastward, but it is also present at Site 701 on the isolated Islas
Orcadas Rise. Planktonic foraminifers in this layer are poorly
preserved.

4. At the end of the Paleocene, carbonate sedimentation
dominated. Radiolarians decreased in abundance, whereas
planktonic foraminifers increased in diversity. The planoro-
talitids reappeared, but were represented by different species,
mainly of smaller size than the P. pseudomenardii group.

5. From the beginning of the Eocene up to Zone P7,
planktonic foraminiferal assemblages displayed the highest
diversity and are the best preserved of the entire Paleogene
sequence. They include some immigrant large morozovellid
species, large-sized planorotalitids, and abundant and diver-
sified acarininids, associated with more abundant globorota-
loids, among others. Radiolarians are absent.

6. By early Eocene Zone P8, planktonic assemblages
were dominated by a single species, Acaninina primitiva, which
remained the most important species up to the middle to late
Eocene boundary.

7. The early Eocene closes at all sites with a marker level of
variable thickness, characterized by the occurrence of some abun-
dance of Morozovella crater. Above this level, no more large
morozovellids are recorded in the Atlantic subantarctic region.

8. With the beginning of the middle Eocene, dissolution of
the planktonic foraminiferal assemblages begins at Site 699,
whereas at nearby Site 700, at almost the same water pa-
leodepth, planktonic foraminifers are moderately well pre-
served. Calcareous sediments, recovered also at Site 701, the
deepest site drilled at the foot of the Islas Orcadas Rise, were
quickly replaced by predominantly siliceous sediments, which
persisted through the remainder of the Paleogene. According
to the calcareous nanofossil data, the sequence from Site 701
is affected by a hiatus spanning part of the middle Eocene.
Poor planktonic foraminiferal assemblages were also recov-
ered, but are mixed within a heterogeneous breccia at Site 703
on the Meteor Rise. At the other sites planktonic foraminifers
are abundant and fairly well preserved.

9. By early middle Eocene Zone P11, planktonic foramin-
iferal faunas began to change: the globorotaloidids increased in
abundance and size; the planorotalitids, already rare and of
small size at the end of the previous interval, definitely dis-
appeared; the Subbotina angiporoides group first occurred;
and by the end of Zone P11 Globigerinatheka index appeared.
Dissolution continued to heavily affect the planktonic faunas
at Site 699 and, to a lesser degree, those at Site 700. Radiol-
arians started to increase in abundance or were better pre-
served at Site 699, and they were also recorded in minor
amounts at Site 702.

10. By the beginning of the late middle Eocene, sedimen-
tary environments, which were relatively uniform during the
previous intervals, became different at each site. At Site 699
sediments became dominantly siliceous and carbonate content
decreased dramatically. A short hiatus at Site 699 encom-
passes the topmost part of the middle Eocene. At Site 700
carbonate content greatly decreased and planktonic assem-
blages, strongly affected by dissolution, consist only of a few
solution-resistant species. Radiolarians further increased in
abundance. The sequence is truncated at the level of the upper
part of Zone P12-13 by a major hiatus. At Site 701 the
predominantly siliceous sediments yield very few specimens
of the solution-resistant species A. primitiva. By contrast,
carbonate sedimentation continues at Site 702, but planktonic
foraminiferal assemblages, although rich in species, are
slightly dissolved. Radiolarians are always present, but never
abundant. At Site 703 carbonate sediments are dominant, but
are disturbed by mass-flows and slumps. Close to the end of
the middle Eocene, radiolarians also occurred on the eastern
side of the South Atlantic.

11. During the late Eocene carbonate sedimentation oc-
curred at three sites. At Site 699 dissolution is very strong and
planktonic foraminifers are rare. Siliceous input rapidly in-
creased there and predominated before the end of the Eocene.
At Site 701 planktonic foraminifers are recorded only as frag-
ments and the dominantly siliceous sediments became
enriched in clay. Sites 702 and 703 still were sites of carbon-
ate-rich sedimentation, which, however, at the former site is
truncked by a major hiatus at the level of Zone P15 (or
POSSIBLY the base of P16). Planktonic foraminiferal assem-
bilages are dominated by Globigerinatheka index, which
replaced A. primitiva as the dominant species after the middle
Eocene. The tenuitellids became an important constituent of
the faunas, chilogrammelinids are consistently found in the
Globigerinatheka luterbacheri allowed us to correlate the very distant
Sites 702 and 703. Although planktonic foraminifers are only
slightly affected by dissolution at Site 702, dissolution was
important, though variable, at Site 703, where radiolarians are
also more abundant.

12. In the lower Oligocene up to Zone P20, very few plank-
tonic foraminifers were found in the dominantly siliceous sedi-
ments of Site 699. They are absent at Site 701, where siliceous
sediments dominate. The only site where planktonic foraminifers
of this age occur continuously is Site 703, where they are
frequent but species diversity is low. An acme of Globorota-
loides was observed and rare chilogrammelinids occur in the
>-150-µm fraction. Radiolarians are common.

13. In Zone P21a planktonic foraminifers are absent at Site
699, where the interval is represented by siliceous sediments.
At Site 701, a discrete hiatus, identified on the basis of
siliceous organisms, includes this interval zone. Planktonic
foraminiferal assemblages occur at Sites 703 and 704 associ-
at with abundant radiolarians. Planktonic foraminiferal div-
ersity increases, and the occurrence of the FO of “Globige-
rina” angulificinacis and short acmes of Cassigerinella
chipolensis and Guembelitria stavnensis, which partially over-
lap in the upper part of the zone, were recorded.

14. In Zone P21b radiolarians are common at Site 703, but
few at Site 704. At Site 703 the upper part of Zone P21b is
missing—or possibly all of the zone, as reworking makes
identification of the P21a/P21b boundary difficult—because of a
short hiatus. Just before the gap, a remarkable increase in
species diversity was noticed. At Site 704, Zone P21b is
apparently complete, but planktonic foraminifers are more
dissolved, especially at the level where sedimentation was
interrupted at Site 703.

15. The latest Oligocene is represented by siliceous sedi-
ments at Sites 699 and 701. A few species, including rare
Cassigerinella chipolensis, are, however, recorded at Site 699
in the upper part of the Paleogene sequence. At Sites 703 and
704 calcareous sediments are well represented. Planktonic
foraminiferal assemblages increase remarkably in diversity,
and some warmer species are recorded, including “Globige-
rina” ciperoensis, “G.” angulifinacis, Globocuoarinina
praedehiscens, a single Globigerinoides at Site 703, and a few
dentoglobigerinids, among others.
Figure 16. Intersite correlation of Leg 114. M-C = Maestrichtian-Campanian; P-P = Pliocene-Pleistocene; eE-IP = early Eocene–late Paleocene.
Figure 16 (continued).
16. The Miocene N4-5 zonal interval is the last interval included in this study. Planktonic foraminiferal assemblages from both Sites 703 and 704 are once more poorly diversified and are dominated by the catapsydracids, a cooler, less solution-susceptible group, but Globoroguembelina zealandica and Globorotalia zealandica were also recorded. Rare radiolarians occur at Site 703.

**Correlation with the Other High-Latitude Sites Drilled in the South Atlantic**

The seven holes drilled during Leg 114 fill the central gap of the South Atlantic transect from the Falkland Plateau (Holes 327–330, DSDP Leg 36; Sites 511–514, DSDP Leg 71) in the western South Atlantic to the Cape Basin (Holes 360 and 361, DSDP Leg 40) in the southeastern Atlantic (see Krasheninnikov and Basov, 1986).

A comparison between the Paleogene planktonic foraminiferal record from Leg 114 and those from previous Legs 36 (Tjalsma, 1977), 71 (Krasheninnikov and Basov, 1983), and 40 (Toumarkine, 1978) allows us to describe spatially and temporally the evolution of the South Atlantic latitudinal belt between 51°S (western side) and 45°S (eastern side) during the Paleogene.

During most of the Paleocene siliceous sediments predominated on both sides of the South Atlantic. On the western side of the Mid-Atlantic Ridge the more external areas, such as the Maurice Ewing Bank, the Malvinas Outer Basin, and the Argentine Basin, received major clay and siliceous input, discontinuities due to erosional events were common, and sedimentary sequences were more condensed than in the central area (Sites 698–702). On the eastern side of the Mid-Atlantic Ridge, in the Cape Basin, zeolitic clay with some fish remains was recovered at Site 360, located below the CCD. Paleocene sediments rich in carbonate were recorded on the Agulhas Plateau (Boersma and Premoli Silva, 1983) or much farther north at shallower depths than Site 360. Specifically, at Site 524 (29°S modern latitude) the Paleocene sequence appears complete and planktonic foraminiferal assemblages exhibit a clearly warm character.

In the subantarctic region, the oldest Paleogene carbonate-rich sediments were recovered at Site 329 (DSDP Leg 36), the shallowest site (1510 m water depth) drilled on the Falkland Plateau. These sediments yielded moderately rich planktonic foraminiferal assemblages of late Paleocene to early Eocene age that are very similar to those recovered from the western sites of Leg 114. At sites from both legs, late Paleocene large morozovellids are lacking and assemblages are dominated by the low-spired subbotinids, rounded-chambered large acarinids, the planorotalitids, rare “Morozovella” convexa, and Chilougbegemila wilcoxensis. The same species together with rare Morozovella subbotinae and M. aequa testify that the P6b-7 zonal interval recorded at Sites 698, 700, and 702 is at least partially represented also at Site 329.

Although early Eocene age sediments are very poor in carbonate on the Falkland Plateau and in the Cape Basin, planktonic foraminifers are strongly dissolved in late early Eocene Zone P9, as indicated by the co-occurrence of *Morozovella aragonensis* and *Morozovella cratert* (= *M. aragonensis caucasia* in Tjalsma, 1977; Toumarkine, 1978) associated with *A. primitiva* and “G.” senni in both areas at Sites 327 and 361, respectively.

In the western South Atlantic, middle Eocene sediments (about 90 m thick) containing planktonic foraminifers were recovered only from a shallower location (Site 512, 1846 m water depth) at the eastern margin of the Maurice Ewing Bank. At this site planktonic foraminiferal assemblages indicate that part of the interval corresponding to Zone P10 (the base is missing) and the entire Zone P11 up to possibly Zone P13, which are recorded in the sites here studied, are also present. The species recorded are *Acarinina primitiva*, rare *A. pseudopilensis* and *A. bulbrooki*, *Globorotaloides suteri*, Chilougbegemila cubensis, Subbotina angiporoides, *S. utilisindex* (= S. linaperta in Krasheninnikov and Basov, 1983), *Pseudohastigerina mira*, and *Globigerinatheka index* higher in the sequence. The well-preserved specimens illustrated by Krasheninnikov and Basov (1983) as *Globigerina bowieri* and *Globigerina frontosa* are common in our material, but are considered to belong to the genus *Subbotina*, based on their wall structure. A single specimen of *Hantkenina* was also found at Site 512, confirming that this taxon is mainly absent at high latitudes, independent of dissolution.

In the eastern Atlantic, at Site 361 (4549 m water depth) dissolution is still strong and results in a discontinuous planktonic record. Although planktonic foraminiferal assemblages are dominated by solution-resistant species, they contain some warmer taxa, such as *Acarinina bulbrooki*, *Morozovella spinulosa*, and representatives of the *Turborotalia cerroazulensis* lineage, which except for the former species were not recorded on the subantarctic sites. The middle Eocene record is more continuous at Site 360 and the warmer species recorded are more abundant in the assemblages than at Site 361. Beside those mentioned from Site 361, there are common and diversified *Globigerinatheka*, common *Acarinina bulbrooki* and A. spinuloinflata, *Turborotalia pomerolii*, and a few *Hantkenina*.

The major difference between planktonic foraminiferal assemblages from the Cape Basin and those from subantarctic sites is that the middle Eocene assemblages from the Cape Basin exhibit a much warmer character that makes them comparable to those from the Rio Grande Rise–Walvis Ridge region. Moreover, in the eastern Atlantic *S. angiporoides* and *Globorotaloides* occur later in the late Eocene and the genus *Globigerinatheka* exhibits higher species diversity.

Within the upper Eocene calcareous sediments are poorly represented on the Maurice Ewing Bank. At Site 511 planktonic foraminiferal assemblages are similar to those from the subantarctic transect except for the occurrence of *Globoroguembelina tripartita* and lower species diversity at Site 511, where sediments consist of diatom-nannofossil oozes.

At Site 360 in the eastern Atlantic, late Eocene assemblages contain several species in common with those recorded from Sites 702 and 703, such as *S. linaperta*, *S. eocaena*, *S. angiporoides*, *G. index*, *T. gemma*, *Globorotaloides suteri*, and *Globigerinatheka luterbacheri*. The latter species, however, is much more abundant and continuously present, “*Globigerina* brevis” occurs continuously in the upper part, and *Turborotalia pomerolii* and *Hantkenina* are present, whereas they have never been found in the subantarctic South Atlantic. At Site 361, late Eocene assemblages are recorded only in a very short interval between dissolved facies. Although they occur mixed together with some middle Eocene faunas, they contain some *Globoroguembelina tripartita* and *Denegalobigerina galavisii* in addition to *S. angiporoides*, few catapsydricids, and “*G.” brevis”. Again, the late Eocene assemblages have a warmer character in comparison with the subantarctic sites.

In the western South Atlantic, Oligocene sediments containing planktonic foraminifers were recovered at Sites 329 and 511 on Maurice Ewing Bank and on the Falkland Plateau, respectively, at depths shallower than at Site 699, and at Site 513 (4373 m water depth) on the lower flank of the Mid-Atlantic Ridge in the southeastern Argentine Basin, at approximately at the same latitude as Site 703. At each site planktonic foraminifers occur mainly in the lower Oligocene. In
PLANKTONIC FORAMINIFERAL PALEogene BIOSTRATIGRAPHY

fact, the late Oligocene/early Miocene age sediments grade upward from the nannofossil diatomaceous ooze or nannofossil ooze/chalk to diatom ooze. The assemblages from all these sites are similar to the lower diversity faunas found in the lower Oligocene at Site 703, including S. angiraporoides, S. utilisindex, Globorotaloides suteri, Chilaguzzella cubensis, Catapsyrrhax unicavus, C. dissimilis, "Globigerina" labiacroassa, Tenuitella munda, and T. gemma. However, in the lower Oligocene at Site 511 are forms such as Globigerina praebulloides, G. senilis, G. ouachitaensis, and T. angustiumbilicata, which occur later in the Oligocene (Zone P21) in our material, and "Globigerina" praseapis, which is absent at the subantarctic sites. At Site 329, the shallowest drilled along the Falkland Plateau—Cape Basin transect, the occurrence of Paragloborotalia opima nana, Globigerina praebulloides, "Globigerina" woodi, and "G." brazieri above the LO of S. angiraporoides suggests some similarity among this assemblage and the assemblages from Zone P21 and in the Zone P22-"N4" interval at Site 703.

Considering all the holes drilled during Legs 36, 71, and 114 west of the Mid-Atlantic Ridge, the planktonic foraminiferal record is confined to the early Oligocene time both on the plateau and in the basinal area north of Site 701. After that time planktonic foraminifers were almost totally absent from the sediments, indicating that the strong decrease of planktonic foraminiferal abundance by the late Oligocene—early Miocene may be related either to a climatic exclusion (cooling) or to an increase in dissolution at depth. On the whole, west of the Central Atlantic area studied here, Paleogene sediments yielding low-diversity planktonic foraminiferal faunas are patchy and discontinuous.

East of the Mid-Atlantic Ridge, the Oligocene to early Miocene stratigraphic interval from Sites 703 and 704 can be correlated with that at Site 360 in the Cape Basin. Within the lower Oligocene the planktonic faunas are similar except for the absence of the globotruncanids, Subbotina brevis, "Globigerina" euapertura, Paragloborotalia opima nana, Turborotalia increbescens, and Globorotaloides texturugosa in the subantarctic South Atlantic. In Zone P21 "Globigerina" euapertura, Paragloborotalia opima opima, P. opima nana, P. pseudomontana, and Globigerina praebulloides were recorded at both Sites 703 and 360. Moreover, above the chilaguzzellin extinction level, some events or occurrences are similar, such as the FO of Globigerinita juvenilia, "Globigerina" ciperoensis, and Tenuitellinatana angustiumbilicata. At Site 360 Cassigerinella chpolens also has a short range in Zone P21, but that occurs above the chilaguzzellin extinction instead of below it, as at Sites 703 and 704. "Globigerina" angulisuturalis is missing at all the sites, although its predecessor "Globigerina" angulocominos is present. Globocuvadrina dehiscens appears earlier at Site 360 than at Sites 703 and 704, where it was recorded in association with Globorotalia zealandica, a Miocene marker species. Sites 703 and 360 have several species in common in the lower Miocene, such as Catapsyrrhax dissimilis, "Globigerina" woodi and "G." woodi connecta, Globotruncanina dehiscens, Paragloborotalia pseudoncounsa, and Globorotalia zealandica, typical species restricted to cool austral waters (Jenkins, 1978b). The genus Globigerinoides, however, is represented by a single specimen, but Globorotalia kugleri is absent at the Meteor Rise sites. Once more, the Oligocene assemblages, although very similar in the areas of the Meteor Rise and the Cape Basin, exhibit a much warmer character in the Cape Basin than on Meteor Rise. This difference becomes more pronounced later in the Miocene. South of the site area investigated, Paleogene sequences were penetrated during Leg 113 in the Weddell Sea (Barker, Kennett, et al., 1988). Paleocene and Eocene pelagic calcareous ooze/chalks, yielding abundant and well-preserved planktonic foraminifers, were recovered at Sites 689 and 690 on the Maud Rise, an aseismic ridge at 64° and 65°S latitude, in water depths of 2080 and 2900 m. respectively. A preliminary comparison between Paleogene planktonic foraminiferal faunas recovered from Leg 113 and 114 indicates that the assemblages are very similar and display a similar evolution in the early Paleocene, confirming the cosmopolitan character of planktonic foraminifers at that time (Boersma and Premoli Silva, 1983). By Zone P3 time, the planktonic assemblages from the two areas started to differentiate. Zone P3 seems to be missing on the Maud Rise. In Zone P4, identified here on the basis of calcareous nannofossil content (Barker, Kennett, et al., 1988), the Maud Rise assemblages are rich in round-chambered acarininids associated with "Morozovella" convexa and "M." djannensis, but Planorotalites pseudomandadri is apparently missing. Zones P5-6a, also recalibrated via calcareous nannofossils, are characterized by large planorotalitids (not P. pseudomandadri, but P. pseudoscitulus) and round-chambered acarininids as at the subantarctic sites, and the early Eocene Zone P6b-7 Maud Rise assemblages are devoid of large morozovellids. Large planorotalitids are common and the FO of Pseudohastigerina wilcoxensis occurs slightly higher than the Paleocene/Eocene boundary, according to calcareous nannofossils, as at Site 698. The FO of Acarinina pentacamerata appears to be coeval with that from the subantarctic sites and should mark the base of Zone P8, but planktonic foraminifers from Site 690 did not register an increase in abundance of Acarina primitiva (= A. coalingensis Auct.). The absence of Morozovella crater in the late early Eocene age section at the Maud Rise sites prevents us from correlating between the two areas for that time. The remaining Eocene sequence at Sites 689 and 690 seems to contain planktonic faunas similar to those recorded in the subantarctic region, although species diversity is, in general, lower than in the subantarctic South Atlantic. The LO of the acarininids and of Globigerinathaka index, used for placing the middle to late Eocene boundary and the Eocene/Oligocene boundary, respectively, seem to be coeval or very close in time to those from the subantarctic sites.

From the late Eocene through the Oligocene in the Weddell Basin, siliceous biogenic facies progressively replaced the carbonate facies. Consequently, planktonic foraminifers became much less important, and species diversity was low. This sedimentary and microfaunal development is analogous to that recorded from the sequences penetrated at the western sites on the Mid-Atlantic Ridge during Leg 114.

CONCLUSIONS

Comparison of the occurrence and composition of Paleogene planktonic foraminiferal assemblages from the southernmost latitudes and from the lower latitude paleobiogeographic and paleoceanographic reconstructions in the Atlantic Ocean (e.g., Haq et al., 1977; Kennett, 1978; Boersma and Premoli Silva, 1983; Krasheninnikov and Basov, 1986; Boersma et al., 1987; Barker, Kennett, et al., 1988; Boersma and Premoli Silva, 1989) enhances our knowledge of the climatic evolution of Atlantic water masses during the Paleogene.

The Paleocene opened with the occurrence of the cosmopolitan planktonic foraminiferal assemblages of Zone Palha (= P. eugubinus Zone) as far south as the Antarctic Ocean, despite distinct latitudinal paleotemperature gradients. During the remainder of the early Paleocene planktonic foraminiferal assemblages at such high latitudes exhibited the same evolutionary patterns recorded at lower latitudes. For example, species diversity among planktonic foraminifers increased as
it did at lower latitudes. Only the lower latitude tropical indices, such as the ancestral morozovellids, occur in lower percentages in these very high-latitude faunas than at lower latitudes. The beginning of provinciality in Zones P2 and P3a is marked by the absence or rarity of "Morozovella" uncinata and **M. angulata** in the Maud Rise faunas.

Zone P3b time is characterized by the occurrence of some radiolarians associated with poorly preserved planktonic foraminifers at subantarctic latitudes and is spanned by a short hiatus in the Antarctic region. These data suggest that the spurious temperature drop in Zone P3b, related to dissolution by Boersma and Premoli Silva (1983), is expressed in faunas and related to changes occurring around Antarctica.

Although during late Paleocene Zone P4 the overall diversity among planktonic foraminifers increased, differences among planktonic assemblages from the subantarctic to the Antarctic regions become more pronounced than those from lower latitudes; large morozovellids, already rare in the previous zone, are missing while consistently present in Zone P4 elsewhere in the Atlantic. **Planorotalites pseudomenardii** occurs very shortly only at subantarctic latitudes. The low-spired **subbotinids**, round-chambered **acarininids**, and rare biconvex morozovellids begin to fluctuate in abundance from layer to layer in the higher latitudes. The first representatives of the genus **Globorotaloides** were recorded earlier at the subantarctic sites, whereas rare **globorotaloids** occur at lower latitudes only by the late early Eocene (Fig. 17). The occurrence of the **Globorotaloides**, cooler dwelling forms (Boersma and Premoli Silva, 1986), would suggest that a new cooler niche opened at that time in these southern high latitudes several million years before it developed in low-latitude upwelling zones. A dissolution event in the middle of Zone P4 is evidenced by a clayey layer widespread in the subantarctic region, and radiolarians become common components of Zone P4 faunas.

In the latest Paleocene Zones P5-6b radiolarians become less abundant, whereas the biofacies are dominated by well-preserved, abundant planktonic foraminifers. Although large morozovellids are still missing, the assemblages are rich in small biconvex morozovellids, round-chambered acarininids, and common planorotalitids and globorotaloids (Fig. 17). It is at this time that planktonic foraminifers first occurred at locations closer to the South American continent on the Falkland Plateau. The resemblance of the faunas in subantarctic and Antarctic assemblages corroborates the idea of the extended influence of warm boundary currents at high latitudes near the end of the Paleocene (Boersma and Premoli Silva, 1983; Barker, Kennett, et al., 1988).

A warming trend during the early Eocene is confirmed by the immigration to the subantarctic region of some large morozovellids. This immigration of warm, low-latitude indices coincided with the warmest period of the entire Eocene (Savin, 1977; Boersma et al., 1987). Although large morozovellids apparently never reached the Antarctic Ocean, planktonic assemblages there are well-diversified and contain species similar to those in the subantarctic region. Warmer conditions continued through the remainder of the early Eocene up to Zone P9 in the southernmost regions, as indicated by the persistent occurrence of large morozovellids at least at subantarctic latitudes. Marked change in subantarctic faunal composition is evidenced by the dominance of **Acarinina primitiva**, a high-latitude marker species beginning by Zone P8. That this **Acarinina**-dominance event is not reported from the Antarctic region (Barker, Kennett, et al., 1988) may be related to the fact that studies of the latter region are still preliminary.

Latest early Eocene Zone P9 is a time of a paleobiogeographic uniformity throughout the entire subantarctic region. The high-latitude **Morozovella crater** Zone (mainly Zone P9) (Fig. 16) is recorded from the Falkland Plateau on the west to the Cape Basin on the east, the area where dissolution effects at last decreased at this time. The Antarctic region is still inhabited by warm faunas, although lacking the large morozovellids as in previous zones.

By the beginning of the middle Eocene, the previously uniform faunas become more heterogeneous. At intermediate-depth Site 699 in the East Georgia Basin planktonic foraminifers are dissolved, whereas in all other locations including the Antarctic region, planktonic assemblages are in general well diversified and moderately preserved up to the base of Zone P11. Within Zone P11 planktonic foraminiferal assemblages register a major change. The planorotalitids are replaced by new groups, such as the **Subbotina anguiformis** group, followed slightly later by **Globigerinatheka index**. The overall character of the planktonic foraminiferal faunas is still warm-temperate, as evidenced by the occurrence of several acarininids also in the Antarctic region. Radiolarians became important at the East Georgia Basin sites where dissolution also increased, and they occur in small amounts at the shallower Site 702.

The warm-temperate character of the foraminiferal faunas, still very diversified is maintained through the remainder of the middle Eocene. However, at the deeper sites dissolution drastically increased and planktonic foraminifers were replaced by radiolarians as the major constituent of planktonic assemblages. By Zone P12 dissolution, although slight, affected also the shallower sites and hiatuses, even of short duration, affected the deepest Site 701, already enriched in siliceous organisms.

By the late Eocene, following the extinction of the acarininids, species diversity drastically decreased across the southernmost latitude sites; however, planktonic foraminiferal faunas were still temperate in character. Planktonic foraminiferal assemblages are dominated by **G. index**, but the warmer forms for that time, such as the **Turborotalia cerroazulensis** group or the **dentoglobigerinids**, are generally missing. This trend is interrupted by a warmer event in late Zone P15/earliest Zone P16, as evidenced by the occurrence of **Globigerinatheka luterbacheri** and of rare **Globorotalia opima tripartita**. This event, however, seems confined only to the shallowest sites from the subantarctic region.

On the eastern side of the South Atlantic, after Zone P9, middle to late Eocene planktonic foraminiferal assemblages exhibit a much warmer character than their western counterparts. Consequently, the assemblages are more similar to those from the middle latitudes, even when affected by dissolution, as at the Cape Basin site. However, among the warmer water species, the turborotalitids are represented only by **T. pomeroli**, whereas the **T. cerroazulensis** lineage is missing.

Oligocene planktonic foraminifers occurred in the western South Atlantic mainly in the early Oligocene and at shallow depths. Where present, the assemblages consist only of cold, high-latitude indicators. On the contrary, in the eastern South Atlantic planktonic foraminifers are common or abundant, and a few subtropical species are present, as in the Eocene. The occurrence of rare **Cassigerinella chiplenensis**, **Guembelia stiavensis**, "**Globigerina**" anguliformis, and Parasubbotina opima opima indicates a warmer interval in Zone P21a also in the subantarctic region.

Of importance in the eastern Atlantic is the dissolution event within Zone P21b, which at some sites seems to be represented by an erosional event. Although the biostratigraphic calibration is not perfectly attained, it seems that a hiatus within siliceous sediments occurs at the same time also in the western South Atlantic at the deepest Hole 701.
Figure 17. Relative abundance of *Globorotaloides* sp. 1 and biconvex "morozovellids" at Sites 702 and 703.
Within the upper Oligocene Zones P22-"N4" planktonic foraminiferal faunas in the eastern Atlantic display evidence of a warming with a remarkable increase in species diversity and the occurrence of more abundant and diversified warmer indicators. Species composition again becomes more similar to those from lower latitudes. This warming event is registered also on the western side of the Mid-Atlantic Ridge by the occurrence of rare planktonic foraminifers, including few specimens of Cassigerinella, P. opima nana, and some globigerinids at shallow- and medium-depth sites. The preliminary data from the antarctic region do not allow us to state if the highest latitudes also experienced the immigration of planktonic foraminifers during this event.

The remarkable reverse of the late Oligocene warming trend in the early Miocene is evidenced by a drop in species diversity, the occurrence of species typical of the Pacific southern latitudes, and a new dissolution event.

**SPECIES LIST AND TAXONOMIC NOTES**

The generic and specific concepts and the species groups used by Boersma and Premoli Silva (1983), Boersma et al. (1987), and Premoli Silva and Boersma (1988) are retained herein, wherever possible. The comments and list of the species, which are in order of stratigraphic appearance in the distribution charts, are arranged in alphabetic order. The species figured in this paper are those rarely illustrated elsewhere or of stratigraphic interest. The identified species not here illustrated are referable to the indicated illustrations of other authors.

*Acarinina acarinata* Subbotina, 1953. (Pl. 1, Figs. 22, 23). Subbotina (1953), pl. XXII, figs. a4, b4, c4.

"Acarinina" aculeata (Jenkins, 1971) (= Globorotalia (Turborotalia) aculeata Jenkins, 1971), figs. 250-256.

*Acarinina appressocamerata* (Bolli, 1979) (= Globorotalia (Acarinina) Bolli). See Bolli, 1979, pl. 144, figs. 2, 4-9.

"Acarinina" aquinnis (Loeblich and Tappan, 1957) (= Globigerina aquinnis Loeblich and Tappan). See Loeblich and Tappan (1957), pl. 56, figs. 4a-6c.

*Acarinina bulbrooki* (Bolli, 1957) (= Globorotalia bulbrooki Bolli). See Bolli (1957a), pl. 38, figs. 4-5.

"Acarinina" chascanona (Loeblich and Tappan, 1957) (= Globigerina chascanona Loeblich and Tappan). See Loeblich and Tappan (1957), pl. 49, figs. 4-5c.

*Acarinina collactea* (Finlay, 1939) (= Globorotalia collactea Finlay). See Jenkins (1965), figs. 1-27. In our specimens secondary apertures on the dorsal side are not visible.


*Acarinina decepta* (Martin, 1943) (= Globigerina decepta Martin). See Martin (1943), pl. 7, figs. 2a-2c.

"Acarinina" echinata (Bolli, 1957) (= Catapsydrax echinata Bolli). See Bolli (1957a), pl. 37, figs. 2-5.

*Acarinina esnaensis* (Le Roy, 1953) (= Globigerina esnaensis Le Roy). (Pl. 1, Figs. 24-26). Le Roy (1953), pl. 6, figs. 8-10.

*Acarinina gravelli* (Brönnimann, 1952) (= Globigerina gravelli Brönnimann). See Brönnimann (1952), pl. 1, figs. 16-18.


*Acarinina intermedia* Subbotina, 1953. See Subbotina (1953), pl. XX, figs. 14-16.

*Acarinina interposita* Subbotina, 1953. See Subbotina (1953), pl. XXIII, figs. 7a, 7b, 7c.

secondary suturel apertures on the spiral side that occurs in the studied area.

Acarinina rotundimarginata Subbotina, 1953. See Subbotina (1953), pl. XXV, figs. 1–3.

Acarinina rugosocaerulea Subbotina, 1953. See Subbotina (1953), pl. XXV, figs. 4–5.

Acarinina soldadoensis (Brönnimann, 1952) (= Globigerina soldadoensis Brönnimann). See Sigal (1974), pl. 6, figs. 1a–1c.

Acarinina soldadoensis angulosa (Bolli, 1957) (= Globigerina soldadoensis Brönnimann subsp. angulosa Bolli). See Bolli (1957c), pl. 16, figs. 4–6.

Acarinina spinuloinflata (Bandy, 1949) (= Globigerina spinuloinflata Bandy). See Cifelli (1972), figs. 2a–2c.

Acarinina spiralis (Bolli, 1957) (= Globigerina spiralis Bolli). See Bolli (1957a), pl. 16, figs. 13–18.

Acarinina subsphaerica (Subbotina, 1947) (= Globigerina subsphaerica Subbotina). See Ellis and Messina (1940), figs. 23–28; Blow (1979), pl. 93, fig. 6; pl. 91, figs. 4–6.

Acarinina topilensis (Cushman, 1925) (= Globigerina topilensis Cushman). See Toumarkine and Luterbacher (1985), Fig. 33 (1–7).

“Acarinina” trichrotrocha (Loeblich and Tappan, 1957) (= Globorotalia trichrotrocha Loeblich and Tappan). See Loeblich and Tappan (1957), pl. 50, figs. 5a–5c.

Acarinina triplex Subbotina, 1953. See Subbotina (1953), pl. XXIII, figs. 1–5.

Acarinina velascoensis (Cushman, 1925) (= Globigerina velascoensis Cushman). See Sigal (1974), pl. 6, figs. 7a–7c.

Acarinina whitei (Weiss, 1955) (= Globigerina whitei Weiss). See Ellis and Messina (1940), figs. 1–3. This rare species has been found only in the upper Paleocene and is considered separate from A. rotundimarginata on the basis of its more angular axial periphery.

Cassigerinelloita amekiensis (Cushman and Ponton, 1932) (= Cassidulinina chiplonensis Cushman and Ponton). See Toumarkine and Luterbacher (1985). Fig. 16 (1–2).

Cassigerinelloita amekiensis Stolk, 1965. (Pl. 4, Figs. 1, 2). Stolk (1965), pl. 1, fig. 1. In agreement with Stolk’s suggestion, this species is probably related to Guembelitria, with which it is always associated in the Eocene, rather than to the genus Globigerinita as suggested by Blow (1979). In fact, the final apertures in Cassigerinelloita and Guembelitria are similar (Pl. 4, Fig. 3), and in both taxa no true umbilicus is present because the walls of the opposing chambers of each whorl join without leaving an umbilical cavity. The range of G. amekiensis is from uppermost Zone P9 to Zones P10-11, in agreement with the stratigraphic range reported by Stolk (1965) from southern Nigeria.

Catapsydrax africanus (Blow and Banner, 1962) (= Globigerinella africana Blow and Banner). See Blow and Banner (1962), pl. XV, figs. A–C.

Catapsydrax dissimilis (Cushman and Bermudez, 1937) (= Globigerinita dissimilis Cushman and Bermudez). See Blow and Banner (1962), pl. XIV, fig. d.

Catapsydrax cf. dissimilis. The specimens here included are smaller in size, with a tighter coiling and less lobulate periphery, than the typical C. dissimilis; however, they possess a clear bulla with two infralaminal accessory apertures. Catapsydrax dissimilis is considered to appear in the lower Oligocene (Molina, 1979).

Catapsydrax dissimilis ciperoensis (Blow and Banner, 1962) (= Globigerinita dissimilis ciperoensis Blow and Banner). See Blow and Banner (1962), pl. XIV, figs. A–C.

Catapsydrax globiformis (Blow and Banner, 1962) (= Globigerinita globiformis Blow and Banner). See Blow and Banner (1962), pl. XIV, figs. S–U.

Catapsydrax taroubaensis (Brönnimann, 1952) (= Globigerina taroubaensis). See Bolli (1957c), pl. 15, figs. 1, 2.

Catapsydrax unicavus Blow, Loeblich, and Tappan, 1957. See Bolli, Loeblich, and Tappan (1957), pl. 7, figs. 9a–9c. Only specimens very close to the holotype were included in C. unicus. They become abundant and clearly identifiable only in the Oligocene.

Chiloguembelina ciperoensis (Palmer, 1934) (= Guembelina ciperoensis Palmer). See Palmer (1934), figs. 1–6.

Chiloguembelina ciperoensis (Cushman and Ponton, 1932) (= Guembelina ciperoensis Cushman and Ponton). See Beckmann (1957), pl. 21, figs. 1–3, 6.

Chiloguembelina velascoensis (Cushman and Ponton, 1932) (= Guembelina velascoensis Roemer, 1838) (= Globigerina velascoensis Roemer). See Rögl (1985), fig. 4 (9–10).

Dentoguembelina pseudovenezuelana (Blow and Banner, 1962) (= Globigerina yeguaensis pseudovenezuelana Blow and Banner). See Blow and Banner (1962), pl. XI, figs. L–N, O.

“Globigerina” ampliapertura Bolli, 1957. See Bolli (1957b), pi. 22, figs. 5–6.


“Globigerina” brazieri (Jenkins, 1966) (= Globigerina brazieri Jenkins). (Pl. 5, Figs. 15–17). Jenkins (1985), p. 274, fig. 6 (20a–20c).

“Globigerina” ciperoensis Bolli, 1957. (Pl. 5, Fig. 9). Bolli (1957b), pi. 22, figs. 10a–10b.

“Globigerina” connecta Jenkins, 1964. See Kennett and Srinivasan (1983), pl. 8, figs. 1–3.

“Globigerina” euapertura Jenkins, 1960. See Jenkins (1985), fig. 6 (18a–18c).

“Globigerina” labiacrassata Jenkins, 1966. (Pl. 5, Figs. 11, 12). See Jenkins (1985), Fig. 6 (19a–19c).


Globigerinoides praebulloideos Blow, 1959. See Blow and Banner (1962), pl. IX, figs. O–Q.

Globigerinoides praebulloideos leroi Blow and Banner, 1962. See Blow and Banner (1962), pl. IX, figs. R–T.

Globigerinoides praebulloideos occlusa Blow and Banner, 1962. See Blow and Banner (1962), pl. IX, figs. U–W.

“Globigerina” pseudodruryi Brönnimann and Resig, 1971. See Brönnimann and Resig (1971), pl. 7, figs. 1, 2.

Globigerinoides senilis Bandy, 1949. See Blow and Banner (1962), pl. XI, figs. R–U.

“Globigerina” veracuzaenana Hedberg, 1937. See Bolli and Saunders (1985), Fig. 13 (20).

“Globigerina” woodi s. str. Jenkins, 1960. See Chapronière (1988), pl. 1, 2. In our material it is quite difficult to keep separated from “Globigerina” labiacrassata specimens with almost a trilobate test and a large final chamber illustrated by Chapronière as G. woodi. We consider “G. woodi” to have a wider arched aperture and a thinner lip than “G. labiacrassata.”
"Globigerinatheka" senni (Beckmann, 1953) (= Sphaerooidinella senni Beckmann). (Pl. 3, Fig. 19). Tournam-
cline (1978), pl. 10, figs. 10–14. In our material there are several forms similar to Globigerina senni as illustrated by Tournam-
cline (1978), which have some morphological analogy with the compacted and thickened forms of A. primitiva. They differ from the latter by their rounded and lobate equatorial peripheral margin and by the shape of the umbilical area, which is more elongated and apparently without umbilical muricae.


Globigerinatheka incrusta Akers, 1955. (Pl. 5, Figs. 18–20). Aker (1955), pl. 65, figs. 2a–2d.

Globigerinatheca juvenilis (Bolli, 1957) (= Globigerina juvenilis Bolli). (Pl. 5, Figs. 3–5). Bolli (1957b), pl. 24, figs. 5, 6. In our material there are specimens without a bulla or with a bulla lacking sutural expansions; the spiral side can be more or less elevated with few high-spired forms tending to Globiger-

ina bradyi. The first occurrence is within Zone P21a.

Globoconusa daubrygensis (Brönniman, 1953) (= Globigerina daubrygensis Brönnimann). See Sigal (1974), pl. 3, figs. 1a–1c.


Globoquadrina dehiscens prae dehiscens Blow and Banner, 1962. (Pl. 5, Figs. 24–26). Blow and Banner (1962), pl. 15, figs. O–S. This species has a short range and it appears after the LO of Paragloborotalia opima opima. Its stratigraphic distribution is late Oligocene/early Miocene.

"Globorotalia" obtesa Bolli, 1957. See Bolli (1957b), pl. 29, figs. 2a–3.

"Globorotalia" praecentralis Blow, 1979. (Pl. 2, Figs. 20–25). Blow (1979), pl. 135, figs. 7–9; pl. 136, figs. 1–6.

"Globorotalia" aff. praecentralis Blow, 1979. (Pl. 1, Figs. 16–18). This specimens shows numerous chambers in the last whorl and a characteristic concave-convex axial profile. The closest form is "Globorotalia" centralis.

Globorotalia scitula praescitula Blow, 1959, See Kennett and Srivinasan (1983), pl. 25, figs. 4–6.

Globorotalia zealandicar Hornbrook, 1958. See Kennett and Srivinasan (1983), pl. 25, figs. 1–3.

Globorotaloides aff. carceselleensis Toumarkine and Bolli, 1975. See Toumarkine and Luterbacher (1985), Fig. 41 (9–16).

Globorotaloides oregonensis (McKeel and Lips, 1975) (= Subbotina oregonensis McKeel and Lips). (Pl. 6, Figs. 23–25). McKeel and Lips (1975), pl. 4, figs. 3e–3c. This form is considered to belong to the genus Globorotaloides because of the association of an initial globorotaliform coiling mode with globigerinid common inner chambers and a coarsely honey-
comb wall structure. It differs from Globorotaloides sp. 1 in having only three chambers in the last whorl. Its range is discontinuous; it first occurs in lower middle Eocene Zone P10 and ranges through Zone P11, and then it reappears in the lower Oligocene.

Globorotaloides praestainforthi (Blow, 1969) (= Globigera-

Globorotaloides suteri Bolli, 1957. See Bolli (1957b), pl. 27, figs. 9–13. Herein this form appears much earlier than in Trinidad (probably in Zones P10–11).

Globorotaloides aff. suteri Bolli, 1957. (Pl. 4, Figs. 4, 5). This form is common in the size fraction <150 µm from late Paleocene throughout middle Eocene. It differs from typical specimens of G. suteri because of a more oval axial profile in the smaller last chamber.
crater Zone) and becomes typical and increases in abundance in the lower middle Eocene.


**Pseudohastigerina sherkriverensis** Berggren, Olsson, and Reyment, 1967. (Pl. 2, Figs. 18, 19). Berggren et al. (1967), pl. 1, figs. 4a–4b.

**Pseudohastigerina wilcoxensis** (Cushman and Ponton, 1932) (= *Nonion wilcoxensis* Cushman and Ponton). See Berggren et al. (1967), text-fig. 2. In the studied area this species ranges from the base of the lower Eocene to the middle Eocene, although it is very rare in the middle Eocene.

**Subbotina angiporoides** (Hornibrook, 1965) (= *Globigerina angiporoides* Hornibrook). (Pl. 6, Fig. 18). Hornibrook (1965), pls. 1a–11, 2.


**Subbotina ayalai** (Bermudez, 1961) (= *Globigerina ayalai* Bermudez). See Bermudez (1961), pl. 1, figs. 4a–4c.

**Subbotina cf. azerbaidjanica** (Khaliilov, 1956) (= *Globigerina azerbaidjanica* Khaliilov). See Khaliilov (1956), pl. 4, figs. 1a–1c.

**Subbotina bakeri** (Cole, 1927) (= *Globigerina bakeri* Cole). See Bermudez (1961), pl. 1, figs. 5a–5c.

**Subbotina brevis** (Jenkins, 1966) (= *Globigerina brevis* Jenkins). See Jenkins (1985), fig. 6 (17a–17c). This form is very rare.

**Subbotina corpulenta** (Subbotina, 1953) (= *Globigerina corpulenta* Subbotina). See Subbotina (1953), pl. 10, figs. 1–4. The specimens attributed to this species tend to increase the height of the spire toward the top of the shell.

**Subbotina crassa** (Shutskaya, 1970) (= *Globigerina crassa* Shutskaya). See Shutskaya (1970), pl. 22, figs. 1a–1c; pl. 24, figs. 9a–9c.

**Subbotina crociapertura** Blow, 1979. See Blow (1979), pl. 176, figs. 1–9.

**Subbotina danica** (Bang, 1969) (= *Globigerina danica* Bang). See Bang (1969), pl. 1, figs. 1a–1c, 2a–2c, 3a–3c.

**Subbotina eobulloides** (Morozova, 1959) (= *Globigerina (Eoglobigerina) eobulloides* Morozova). See Ellis and Messina (1940), pl. 1a–1c.

**Subbotina eocaena** (Gumbel, 1868) (= *Globigerina eocaena* Gumbel). See Hagn and Lindenberg (1969), pl. 1, figs. 1a–1c. This species includes several specimens with a final chamber.

**Subbotina eocaena** (Terquem, 1882) (= *Globigerina eocaena* Terquem). (Pl. 6, Figs. 4–6). Subbotina (1953), p. XI, figs. 8–11. This form is not easily distinguished from **Subbotina utilisindex**, with which it coexists in Zones P11-12. The main difference between the two taxa consists in the nature of the aperture: **Subbotina eocaena** possesses a slightly arched, umbilical-extrambulacral aperture, with a moderately thin curved rim that never extends to the peripheral margin, whereas **Subbotina utilisindex** has a slitlike aperture or an elongate low arch that extends almost to the peripheral margin, with a straight and well-developed lip.

In the lower Eocene **Subbotina eocaena** is transitional to **Subbotina eocaena irregularis** whereas **Subbotina utilisindex**, which appears in the lower middle Eocene in this area, is related to **Subbotina angiporoides**.

**Subbotina eocaena irregularis** (Subbotina, 1953) (= *Globigerina eocaena var. irregularis* Subbotina). (Pl. 6, Figs. 7–9). Subbotina (1953), pl. XI, figs. 12a, 12b, 12c.

**Subbotina fringa** (Subbotina, 1953) (= *Globigerina fringa* Subbotina). See Subbotina (1953), pl. III, figs. 5a–5c, 4a–4c.

**Subbotina gortanii** (Borsetti, 1959) (= *Catapsydrax gortanii* Borsetti). See Borsetti (1959), pl. 1, figs. 1a–1c.

**Subbotina hagni** (Gohrbrandt, 1967) (= *Globigerina hagni* Gohrbrandt). See Toumarkine and Luterbacher (1985), fig. 42 (7–9).

**Subbotina higginsi** (Bolli, 1957) (= *Globigerinoides* higginsi Bolli). (Pl. 2, Fig. 17). Bolli (1957a), pl. 36, figs. 11–13. In the lower Eocene a few specimens display a morphology very close to that of *Globigerinoides* higginsi without clearly showing the secondary sutural apertures. They seem to be high-spired variants of **Subbotina lozanoi** (see Pl. 2, Figs. 13–16) in agreement with Blow (1979). These forms are confined to the lower Eocene.

**Subbotina ssp. hornibrooki** Brönniman, 1952) (= *Globigerina hornibrooki* Brönniman). See Blow (1979), pl. 124, figs. 7, 8.

**Subbotina ineququispira** (Subbotina, 1953) (= *Globigerina ineququispira* Subbotina). See Subbotina (1953), p. VI, figs. 1–4. The specimens herein found show a more restricted umbilical area than the holotype illustrated by Subbotina.

**Subbotina linaperta** group (Finlay, 1939) (= *Globigerina linaperta* Finlay). (Pl. 6, Figs. 26–31). Hornibrook (1958), pl. 1, figs. 19–21; Krasheninnikov and Basov (1983), pl. 2, figs. 8–11. The main characteristics of this species are the flattening of the last whorl to assume a kidney-shaped form, ellipsoidal in side view, and a very coarse hexagonal pore ridges. Aside from typical forms like the holotype, our material commonly contains specimens more tightly coiled with an aperture variably arched in the middle portion (Pl. 6, Figs. 26–28). They are similar to the variety of *S. linaperta* illustrated by Lindsay (1985, fig. 14) from type material. For the time being, all the illustrated morphotypes are included in the *S. linaperta* group. Further studies are needed to clarify the relationship among these forms. **Subbotina linaperta** s. str. and associated forms appeared in the late Eocene (Zones P12-13) and became extinct in the late Eocene.

**Subbotina lozanoi** (Colom, 1954) (= *Globigerina lozanoi* Colom). (Pl. 2, Figs. 13–16). Toumarkine and Luterbacher (1985), fig. 28 (6–11). Rare specimens have been attributed to **Subbotina lozanoi**, some of which show secondary sutural apertures (see Pl. 2, Fig. 16).

**Subbotina patagonica** (Todd and Kniker, 1952) (= *Globigerina patagonica* Todd and Kniker). (Pl. 6, Figs. 1–3). Todd and Kniker (1972), pl. 4, fig. 32. The main characteristics of this species are the size of the last chamber, which makes up almost half of the entire whorl, the highly arched primary aperture, and the finely cancellate wall. It has been found mainly in the lower Eocene, where it shows some relationship with the *S. eocaena* group.


**Subbotina pseudoeocaena compacta** (Subbotina, 1953) (= *Globigerina pseudoeocaena var. compacta* Subbotina). See Subbotina (1953), pl. V, figs. 3a, 3b, 3c.

**Subbotina pseudoeocaena** (Subbotina, 1953) (= *Globigerina pseudoeocaena var. pseudoeocaena* Subbotina). See Subbotina (1953), pl. V, figs. 1–2.

**Subbotina pseudoeocaena trilobata** (Subbotina, 1953) (= *Globigerina pseudoeocaena var. trilobata* Subbotina). See Subbotina (1953), pl. V, figs. 5a–5c.

**Subbotina ratusa** (Kopayevevich, 1970) (= *Globigerina ratusa* Kopayevevich). (Pl. 1, Figs. 27–28). Ellis and Messina (1940), pl. 3, figs. 2a–2c. This species is distinguished from *S. ineququispira* because the chambers in the last whorl remain uniform in size, the umbilical area is closed, and the coiling is tight.
PLANKTONIC FORAMINIFERAL PALEOGENE BIOSTRATIGRAPHY

Subbotina triangularis (White, 1928) (= Globigerina triangularis White). See Shutskaya (1970), pl. XXIII, figs. 1A–1B.

Subbotina utilisindex (Jenkins and Orr, 1973) (= Globigerina utilisindex Jenkins and Orr). (Pl. 1, Figs. 10–12, 16, 17). Jenkins and Orr (1973), pl. 1, figs. 1–6; pl. 2, figs. 1–9; pl. 3, figs. 1–3. The main characteristics of this species are the round final chamber and a finer wall structure than in the S. linaperta group. In topotypic material, S. utilisindex from subantarctic sites displays a consistently stiltlike appearance, located umbilically-extraumbilically, always bordered by a distinct imperforate lip, which allows us to link this species to S. angiporoides.

Subbotina yeguaensis (Weinzierl and Applin, 1929) (= Globigerina yeguaensis Weinzierl and Applin). Weinzierl and Applin (1929), pl. 43, figs. 1a–1b.

Tenuitella clemenciae (Bermudez, 1961) (= Turborotalia clemenciae Bermudez). (Pl. 5, Figs. 1, 2). Bermudez (1961), pi. 43, figs. 1a–1b.

Tenuitella gemma (Jenkins, 1971) (= Globorotalia (Turborotalia) gemma Jenkins). See Jenkins (1971), pl. 10, figs. 263–269.

Tenuitella minutissima (Bolli, 1957) (= globorotalia minutissima Bolli). See Li (1987), fig. 3 (16–18).


Tenuitella cf. pseudoeoida (Subbotina, 1960) (= Globigerina pseudoeoida Subbotina). See Ellis and Messina (1940), pl. 11, figs. 1–3.

Tenuitella reissi (Loeblich and Tappan, 1957) (= Globigerina ciperoensis Loeblich and Tappan). See Loeblich and Tappan (1957), pl. 50, figs. 3a–3c; pl. 58, figs. 3a–3c. This form displays a long range, from early Paleocene to middle Eocene.


Turborotalia cerroazulesensis frontosa (Subbotina, 1953) (= Globigerina frontina Subbotina). See Toumarkine and Luterbacher (1985), fig. 35 (16–18). This species is extremely rare in the subantarctic.

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Plate 1. Late Paleocene and early Eocene planktonic foraminifers. Scale bar = 100 µm. Different views of a specimen have the same magnification. 1–3. Planorotalites ehrenbergi; Sample 114-700B-30R-3, 130–132 cm; late Paleocene (P4), (1) ventral view (v. v.), (2) dorsal view (d. v.), (3) side view (s. v.). 4–6. Acarinina nitida transition to A. primitiva; Sample 114-698A-9R-1, 94–96 cm; late Paleocene (P5-6a), (4) v. v., (5) d. v., (6) s. v. 7–9. Planorotalites pseudomenardii; Sample 114-698A-11R-CC; late Paleocene (P4), (7) v. v., (8) d. v., (9) s. v. 10–12. Planorotalites pseudoscitulus elongatus; Sample 114-698A-6R-CC; early Eocene (P8), (10) v. v., (11) s. v. Other specimen (12) d. v. 13–15. Globorotaloides sp.; Sample 114-698A-8R-CC; early Eocene (P6-7), (13) v. v., (14) d. v., (15) s. v. 16–18. “Globorotalia” aff. praezensals; Sample 114-702B-23X-CC; early Eocene (P8), (16) v. v., (17) d. v., (18) s. v. 19–21. Acarinina nitida; Sample 114-699A-51X-CC; early Eocene (P8), (19) v. v. Other specimen (20) d. v. Other specimen (21) s. v. 22, 23. Acarinina acarinata; Sample 114-698A-6R-1, 110–112 cm; early Eocene (P8), (22) s. v., (23) v. v. 24–26. Acarinina esnaensis; Sample 114-698A-6R-CC; early Eocene (P8), (24) v. v., (25) d. v., (26) s. v. 27, 28. Subbotina ratusa; Sample 114-698A-4R-CC; early Eocene (P8), (27) v. v. Other specimen (28) d. v.