Barker, P. F., Kennett, J. P., et al., 1990
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 113

34. ANTARCTIC PALEOGENE PLANKTONIC FORAMINIFER BIOSTRATIGRAPHY: ODP LEG 113, SITES 689 AND 690[1]

Lowell D. Stott[2,3] and James P. Kennett[2]

ABSTRACT

ODP Leg 113 drilled the first nearly continuous pre-Neogene calcareous biogenic sequence from the Antarctic Ocean at Sites 689 and 690. At 65°S, these are probably the highest latitude calcareous sequences available in the Southern Hemisphere deep oceans. Together these two sites provide a nearly complete planktonic foraminifer history for the Late Cretaceous through late Oligocene. Planktonic foraminifers are abundant and generally well preserved from the Upper Cretaceous to the Eocene. Abundances and the quality of preservation are reduced during the Oligocene as calcareous microfossil groups are progressively replaced by siliceous groups. The Neogene is marked by only rare, isolated occurrences of planktonic foraminifers, the most conspicuous of which are of Quaternary age.

The diversity of planktonic foraminifers was low following the mass extinction event at the Cretaceous/Paleogene boundary. The lowermost Paleogene fossil assemblages following the mass extinction event closely resemble those of lower latitudes. During the middle Paleocene, a "high latitude" assemblage developed that lacked species found at lower latitudes, particularly the early morozovellids. The diversity increased during the late Paleocene through evolutionary radiation in conjunction with warm conditions at high latitudes. Diversity remained high in the Antarctic throughout most of the early and early middle Eocene. Subbotinids and acarininids dominated the assemblages along with various *Planorotalites* species. At no time, however, did any of the large-keeled morozovellids, the hantkeninids, or the globigerapsids characteristic of the low latitudes inhabit the Antarctic Ocean. Beginning in the late middle Eocene, planktonic foraminifer diversity was reduced due to the extinction of the acarininids and several *Subbotina* and *Planorotalites* species. In the upper Eocene the fossil assemblages exhibit even lower diversity and are dominated by three to four species. These changes correspond to the beginning of a long-term climatic cooling trend that is also recorded in the stable isotopic records. Further reduction in diversity occurred across the Eocene/Oligocene boundary in response to continued cooling and increased $CaCO_3$ dissolution. At that time siliceous microfossils began to appear in increasing abundance.

A new planktonic foraminifer biostratigraphy has been developed for the Weddell Sea area, Antarctica. Fourteen biozones are defined on the basis of distinct biohorizons used to mark the top and bottom of each zone, and are intercalibrated with magnetostratigraphy. This stratigraphy has been correlated with the well-established low-latitude zonations.

INTRODUCTION

ODP Leg 113 Sites 689 and 690 were drilled at ~65°S on Maud Rise in the Weddell Sea, Antarctica (Fig. 1). Together these two sites provide the first opportunity to document Antarctic Cenozoic planktonic foraminifers from high-quality biogenic sequences and to establish, for the first time, a planktonic foraminifer biostratigraphy for the Antarctic Ocean. It is likely that this biostratigraphy will be applicable to other parts of the Antarctic Ocean, but this will need confirmation by the examination of sequences in other sections. Previously, Cenozoic sediments containing planktonic foraminifer assemblages were available only from short piston cores (see Lazarus et al., 1987) or somewhat longer drilled sequences in clastic sedimentary facies (Kaneps, 1975; Webb and Wrenn, 1982; Leckie and Webb, 1986; Webb, 1986; Webb et al., 1986). Consequently, the Antarctic biostratigraphic and biogeographic and paleoecologic history could only be inferred from a few fragmented records. The two Maud Rise sites provide a nearly complete composite planktonic foraminifer record for the Paleogene, whereas the Neogene is composed primarily of biosiliceous sediments with only rare occurrences of planktonic foraminifers (Barker, Kennett, et al., 1988). The Cretaceous planktonic foraminifer assemblages have been described by Huber (this volume). This contribution concerns the Paleogene planktonic foraminifer biostratigraphy and Cenozoic foraminifer history of Maud Rise Holes 689B and 690B.

Existing low-latitude biostratigraphic zonations could not be used because most low-latitude index species are absent in the Antarctic record. This includes, for example, the large, keeled morozovellids in the Paleocene and early Eocene, the hantkeninids and the globigerapsids of the middle and late Eocene. The Oligocene is similarly devoid of low-latitude marker species. The faunas observed in the Maud Rise sequences are similar to those described from the middle latitudes of the South Atlantic, Australia, New Zealand, and deep-sea sequences of the Southwest Pacific. The sequence of first and last appearances of these taxa is similar to that observed in the Southwest Pacific where biostratigraphic zonations have previously been applied (Carter, 1959; Jenkins, 1966, 1971, 1974, 1975; Ludbrook and Lindsay, 1969; McGowran and Lindsay, 1969; Srinivasan and Kennett, 1981; Jenkins and Srinivasan, 1985). Although it is possible to recognize several of the previously defined middle-latitude planktonic foraminifer zones in the Maud Rise sequences, all zones are not present in the sequence. Furthermore, the ranges of several zonal species are not clearly distinguished because of rarity of specimens or their sporadic occurrences, resulting in considerable uncertainty in the placement of the zonal boundaries. For these reasons, a new biostratigraphic zonation has been developed for the Maud Rise sequences, the boundaries of which are more easily and precisely placed than those of existing middle-latitude zonations. In this report we identify 16 planktonic foraminifer datum levels that are used to delineate a new Paleo-

[1] Barker, P. F., Kennett, J. P., et al., 1990. *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program).

[2] Marine Science Institute and Department of Geological Sciences, University of California, Santa Barbara, Santa Barbara, CA 93106.

[3] Present address: Department of Geological Sciences, University of Southern California, Los Angeles, CA 90089-0740.

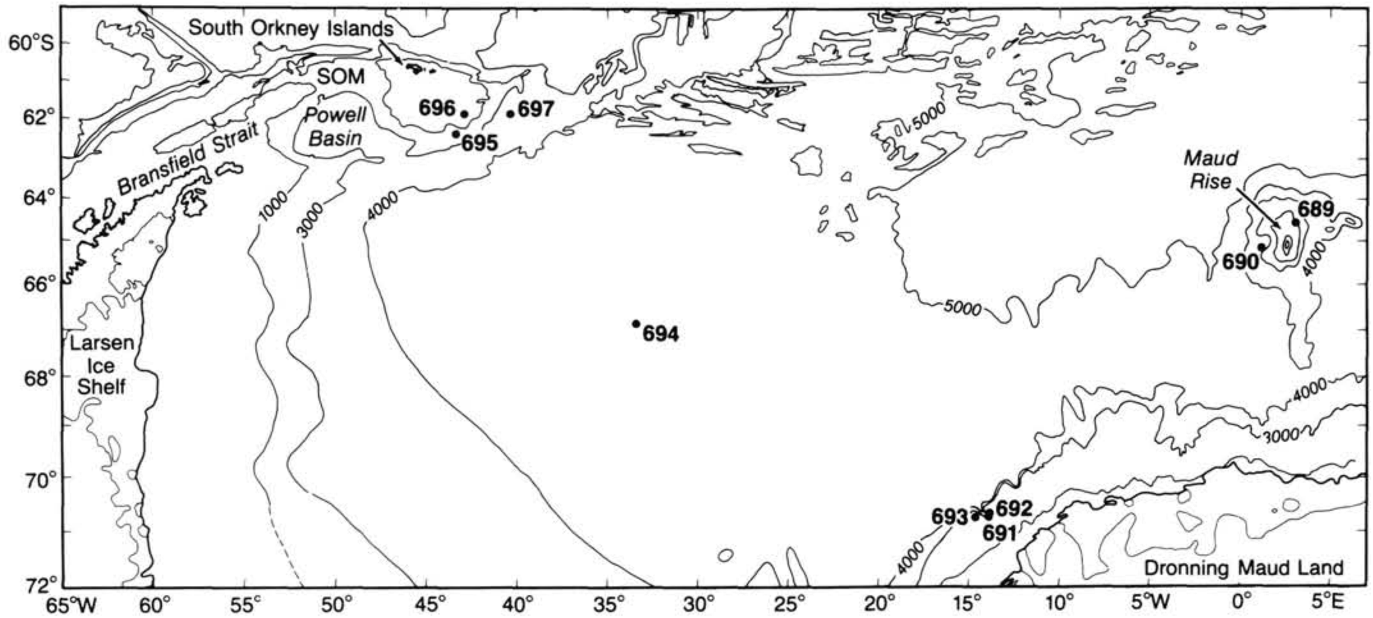

Figure 1. Location of ODP Leg 113 Sites, Weddell Sea, Antarctica. Bathymetry shown in meters. SOM = South Orkney microcontinent.

gene biostratigraphic zonation in the Maud Rise sequences. These datum levels are calibrated to magnetostratigraphy (Hamilton, this volume; and Spieß, this volume) in order to provide a chronologic framework that will facilitate interregional correlations. However, because the middle-latitude zonations have not been intercalibrated with magnetostratigraphy it is not yet possible to determine if the zonal boundaries recognized here are correlative with those in the Southwest Pacific. Because of the latitudinal and faunal differences, it is possible that diachroneity exists between the Weddell Sea and the Southwest Pacific biozones. Therefore, we have not attempted any stratigraphic correlation between these zonations.

METHODS

Samples discussed herein were prepared for study as described in Stott and Kennett (this volume, chapter 47). Assemblage composition is described nonquantitatively in terms of the most abundant species observed in a random sample of ~300–500 specimens from the >63-μm size fraction. Relative abundances are recorded in terms of Abundant, Common, Few, and Rare (as described in the "Methods" section, Barker, Kennett et al., 1988) and recorded in the accompanying range charts (Appendixes I, II). Quantitative determinations were made only for the intervals spanning the Cretaceous/Paleogene (K/P) boundary in Holes 689B and 690C. In these intervals ~300–400 specimens were identified and counted in the >63-μm size after they were split with a microsplitter.

The generic classification used in this study largely follows that of Loeblich and Tappan (1988). The generic assignment of certain species is not clear; however, in these instances taxonomic notes are provided to clarify the usage. Species identifications were made using a wide range of literature, but descriptions of particular value were those of Jenkins (1971), Stainforth et al. (1975), Blow (1979), and Berggren (1977). Taxonomic notes are provided where appropriate to outline differences in usage with previous workers.

The quality of preservation of assemblages is also noted in the range charts, and is described in the following way:

E = excellent, no breakage or dissolution, and no evidence of recrystallization.

G = good, some breakage or minor dissolution, but no evidence of recrystallization.

M = moderate, breakage and/or dissolution common but no evidence of recrystallization.

P = poor, breakage and/or dissolution with possible recrystallization.

SITE DESCRIPTIONS

Site 689

Four holes were drilled at Site 689 in 2080 m of water near the crest of Maud Rise. Only Hole 689B provides a nearly continuous sequence through the Cenozoic and Upper Cretaceous. Sediments were cored to a depth of 229.44 m below the seafloor (mbsf), averaging 77% recovery. The APC (Advanced Hydraulic Piston Corer) was used from the top of the hole down to Core 113-689B-21H, which reached the middle Eocene, after which the XCB (Extended Core Barrel) was used to the bottom of the hole. In general, the Paleogene is marked by foraminifer-bearing, calcareous nannofossil ooze and chalk. The ooze/chalk transition does not form a sharp boundary in this hole. Chalk first occurs as thin, 2–3-cm-thick zones in Core 113-689B-21H (middle Eocene) at approximately 190 mbsf. Below this, the abundance and thickness of these chalk zones increase downward to the base of Core 113-689B-25X, beyond which the sequence is entirely nannofossil chalk. The abundances of planktonic foraminifers decreases notably in the Miocene, where biosiliceous sediments progressively replace calcareous nannofossils and planktonic foraminifers. Planktonic foraminifers are essentially absent from the middle and upper Neogene except for abundant occurrences in the Pleistocene sequences at the top of the hole.

Site 690

Three holes were drilled at Site 690 in 2914 m of water on the flank of Maud Rise, 116 km southwest of Hole 689B. Hole 690B was cored with the APC and provides a biogenic record to 213.4 mbsf (Core 113-690B-25H) with close to 100% recovery. Sediments below 213.4 mbsf were recovered with the XCB. Hole 690C was cored to 83.6 mbsf (Core 113-690C-9H) to overlap sequences of Hole 690B. The hole was then washed to 204.2 mbsf and cored to 321.2 mbsf. Core recovery averaged 100% in the

APC portion of Hole 690C and 76% in the XCB portion. The lithologies of Site 690 are similar to those of Site 689. Differences occur as a result of the differing water depths, creating differences in dissolution or winnowing of the sediments. In particular, the Paleogene of Site 690 contains a distinct terrigenous component not found at Site 689. The absence of this terrigenous component at Site 689 is enigmatic but may suggest that current activity differentially winnowed these clays from sediments in the shallower location. The lower sedimentation rates observed in Hole 689B compared to Site 690 may be further evidence for this (Barker, Kennett, et al., 1988).

BIOSTRATIGRAPHY

Planktonic foraminifer occurrences in Holes 689B, 690B, and 690C are summarized in the accompanying range charts (Appendixes I, II). Sixteen distinct planktonic foraminifer datum levels are identified and used to subdivide the Antarctic sequences into 14 biozones (Fig. 2). These datum levels are first occurrences (FAD) or last occurrences (LAD) of species that are common to abundant. Their first and last occurrences are conspicuous and easily identified. Each datum level defines the base or top of the biostratigraphic zone. Two types of biozones have been employed, the Interval Zone (Hedberg, 1976) and Partial Range Zone (sensu Berggren and Miller, 1988). The Partial Range Zone delimits those strata characterized by the partial range of a taxon. The upper and lower boundaries of the zone are defined by the first and/or last occurrence of species other than that used in the zonal name.

Numeric designations are also applied to each of the new Antarctic biozones to facilitate their use. An alphabetic prefix attached to the numeric designation (i.e., A) indicates Antarctic, the region for which the zone was developed. P included in the prefix indicates that the zone is from the Paleogene. For example, Zone AP1 refers to the Antarctic Paleogene Zone 1. It precedes Zone AP2, which in turn precedes Zone AP3, etc.

ZONAL DEFINITIONS

Eoglobigerina fringa Partial Range Zone (APα)

Definition. Partial range of the nominate taxon from the last occurrence of *Abathomphalus mayaroensis* (base = K/P boundary) to the initial "common" occurrence of *Subbotina pseudobulloides* (top).

Remarks. The zone is characterized by the occurrence of very small simple morphotypes including *E. fringa, Eoglobigerina eobulloides, "Globorotalia" polycamera, Eoglobigerina edita, Eoglobigerina trivialis, Subbotina minutula, Guembelitria cretacea*, and *Chiloguembelina taurica. Parvularugoglobigerina eugubina* was initially identified from this zone in Holes 689B and 690C (Barker, Kennett, et al., 1988). However, subsequent work using the scanning electron microscope (SEM) revealed that none of the small specimens observed in the basal Paleocene sediments exhibit the highly arched aperture characteristic of *P. eugubina* (Smit, 1977, 1979). Nonetheless, a distinct iridium anomaly at the boundary between the Paleogene and Cretaceous in Hole 690C (Michel et al., this volume) indicates that the lowermost Paleogene is present and that the absence of *P. eugubina* cannot be attributed to the presence of any hiatus.

The first common occurrence of *S. pseudobulloides* is approximately 31 cm above the iridium anomaly near the base of Chron 29N as described by Hamilton (this volume) in Hole 690C. Although bioturbation disrupted the stratigraphic succession, it is clear that the first common occurrence of *S. pseudobulloides* is above the interval characterized by abundant *E. fringa* and other minute species typical of the basal Paleocene. Therefore, although *P. eugubina* is not present in these assemblages, Zone APα appears to be equivalent to the *Globigerina eugubina* Zone of Luterbacher and Premoli-Silva (1964) and Zone P1a (Smit, 1982; Berggren et al., 1985) or Zone Pα (Blow, 1979; Berggren and Miller, 1988).

Subbotina pseudobulloides Interval Zone (AP1)

Definition. Interval between the initial "common" occurrence of *S. pseudobulloides* and the initial occurrence of *Planorotalites imitatus*.

Remarks. This lower Paleogene zone is characterized by the initial occurrence of several new genera and species. These include, for example, *Subbotina pseudobulloides, Subbotina triloculinoides, Globoconusa daubjergensis*, and *Planorotalites*. The succession of these forms within the zone provides criteria with which to further subdivide the zone into the following:

Globoconusa daubjergensis Partial Range Subzone (AP1a)

Definition. Partial range of the nominate taxon from the initial common occurrence of *S. pseudobulloides* (base) to the initial occurrence of *Subbotina inconstans* (top).

Remarks. The zone is characterized by the common co-occurrence of *S. pseudobulloides* and *G. daubjergensis*. Rare occurrences of *S. pseudobulloides* are observed lower in the section; however, these may be due to downward mixing by bioturbation. The first common occurrence (FCOD) of *S. pseudobulloides* is a more sharply defined and easily identified position for the base of this zone than is its first occurrence datum level. The magnetostratigraphically calibrated age of the *S. pseudobulloides* FCOD in Hole 690C (see below) also agrees with age estimates in other South Atlantic sequences (Poore et al., 1984). The base of this subzone is, therefore, equivalent to the base of Zone P1 (= base of *Subbotina pseudobulloides–Globoconusa daubjergensis* Zone) of Berggren (1969). Berggren and Miller (1988) suggested that the first occurrence of *S. pseudobulloides* and *G. daubjergensis* are essentially coeval, although Blow (1979) noted that the latter species appeared slightly earlier in Zone Pα. In both Maud Rise sequences, *G. daubjergensis* occurs just below the first common occurrence of *S. pseudobulloides*. Because bioturbation may have disrupted the natural stratigraphic succession in this lowermost Paleocene interval we are not able to distinguish whether the earlier occurrence of *G. daubjergensis* in the Maud Rise sequences is an artifact of the bioturbation. Other evidence indicates that this is likely. For example, the first occurrence of *Subbotina triloculinoides* is in both Maud Rise sequences near the base of the *S. pseudobulloides* Zone. Berggren and Miller (1988) pointed out that in most sequences the first occurrence of *S. pseudobulloides* precedes that of *S. triloculinoides*. They further suggested that the records where this is not the case probably can be attributed to misidentification of *Subbotina trivialis* for *S. triloculinoides*. We have identified both *S. trivialis* and *S. triloculinoides* in intervals near the base of the *S. pseudobulloides* Zone (AP1a) which suggests that the anomalously early occurrence of *S. triloculinoides* resulted from bioturbation. *Planorotalites compressus* first appears in the Maud Rise sequences in the lower part of the *S. pseudobulloides* Zone. This too is contrary to the normal succession of these two species (see Berggren and Miller, 1988). From the above, it appears that the threefold subdivision of the basal Paleocene, based on the succession of *S. pseudobulloides, S. triloculinoides*, and *P. compressus* used by Berggren (1969), cannot be applied to the Maud Rise sequences.

Subbotina inconstans Interval Subzone (AP1b)

Definition. Interval from the first occurrence of the nominate taxon (base) to the initial occurrence of *"Planorotalites" imitatus* (top).

Remarks. *G. daubjergensis* and *S. inconstans* dominate the planktonic foraminifer assemblages in this zone. The last occurrence of *P. compressus* occurs within the zone just below that of *G. daubjergensis*. *Igorina spiralis* occurs for the first time within the upper portion of the zone. The assemblages observed in this zone are similar to those described from Subzone P1c in middle-latitude sequences (Boersma and Premoli-Silva, 1983). The primary difference is the apparent absence in the Antarctic of *Morozovella trinidadensis*, the proposed descendant of *S. inconstans*. Preliminary identification of *Morozovella trinidadensis* from the Maud Rise sequences (Barker, Kennett, et al., 1988) was based upon slightly curved spiral sutures in some specimens. Some workers have argued that this is not sufficient criteria to identify the species (Corfield and Shackleton, 1988). Subsequently, we have not been able to identify, even with the SEM, the small muricae near the apertures of these specimens, which would be definitive evidence for *M. trinidadensis* (Corfield and Shackleton, 1988). This indicates that either the species did not inhabit the southern high latitudes or, alternatively, the distinction of *M. trinidadensis* from *S. inconstans* is untenable as suggested by Blow (1979).

"Planorotalites" imitatus Interval Zone (AP2)

Definition. Interval from the initial occurrence of the nominate taxon (base) to the initial occurrence of *Muricoglobigerina mckannai* (top).

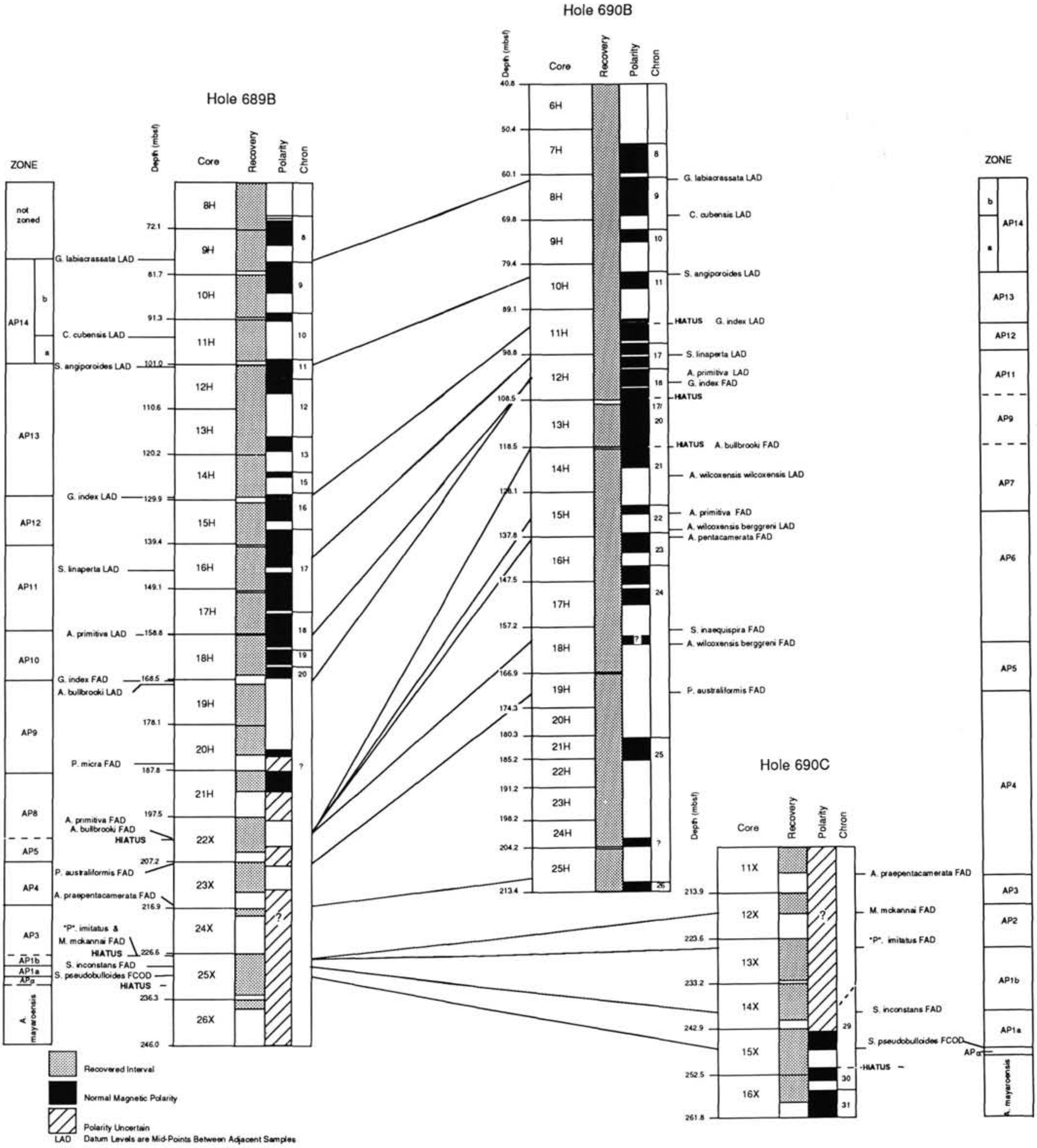

Figure 2. Summary of core recovery and magnetic-polarity stratigraphy as measured by Spieß (this volume) and Hamilton (this volume). The Antarctic planktonic foraminiferal datum levels used to delineate the new Antarctic biostratigraphy are shown for each site along with the zonal designations. The datum levels are used to correlate the two sites (connecting lines) and to illustrate the intervals which are either condensed or missing due to a hiatus. For example note that in Hole 690B the interval encompassing Zones AP6 through AP7 are missing in Hole 689B. Also note that the interval encompassing Zones AP8 through AP9 in Hole 689B appear to be condensed and truncated between two hiatuses in Hole 690B.

Remarks. The upper portion of this zone is truncated by a coring gap in Core 113-690C-12X. The first occurrence of *M. mckannai*, therefore, is extrapolated to a position midway between the two sample intervals that bracket its first occurrence. Except for the addition of "*P.*" *imitatus*, the fossil assemblages in this zone resemble those of the preceding *S. inconstans* Subzone.

Muricoglobigerina mckannai Interval Zone (AP3)

Definition. Interval from the initial occurrence of the nominate taxon to the initial occurrence of *A. praepentacamerata*.

Remarks. In addition to *M. mckannai*, the fossil assemblages typical of this zone include *S. pseudobulloides, S. triloculinoides, Igorina spiralis, S. triangularis*, and "*P.*" *imitatus*.

Acarinina praepentacamerata Interval Zone (AP4)

Definition. Interval from the initial occurrence of the nominate taxon (base) to the first occurrence of *Planorotalites australiformis* (top).

Remarks. The base of the zone is characterized by abundant subbotinids including *S. triangularis, S. inconstans* and primitive acarininids such as *Acarinina esnaensis* (= *Acarinina carinata* of some authors). *Acarinina praepentacamerata* is rare in the lower part of the zone but easily recognized. Other small acarininids and morozovellids become important within the zone, including *Morozovella convexa, M. nicoli*, and *M. djanensis*. The assemblages of this zone are distinctive in containing several morozovellid species, the presence of which in the Antarctic ocean may reflect the incursion of warmer waters during the late Paleocene (Boersma and Premoli-Silva, 1983; Premoli-Silva and Boersma, 1988). However, because none of the typical keeled *Morozovella* species occur, it is difficult to correlate this zone precisely with the upper Paleocene low-latitude zones.

Blow (1979) used the first occurrence of *A. soldadoensis* to define the base of the *Muricoglobigerina soldadoensis soldadoensis/Globorotalia* (*Morozovella*) *velasocensis pasionensis* Zone, which he termed a concurrent range Zone (= P5), although the zone was based on the first occurrence of *M. soldadoensis* at its base. The absence of *M. velascoensis* precludes the identification of any such concurrent range zone. However, the initial occurrence of *A. soldadoensis* lies above the base of the AP4 Zone, slightly below the initial occurrence of *Planorotalites australiformis* and *Acarinina wilcoxensis berggreni*. The AP4 Zone appears, therefore, to be approximately equivalent to the P4–P5 zones in low latitudes.

Planorotalites australiformis Interval Zone (AP5)

Definition. Interval from the initial occurrence of the nominate taxon (base) to the initial occurrence of *Acarinina wilcoxensis berggreni* (top).

Remarks. The occurrence of the nominate species, together with *A. soldadoensis* and *Muricoglobigerina aquiensis*, forms a distinctive assemblage that lacks the small morozovellids typical of the preceding zone.

Acarinina wilcoxensis berggreni Interval Zone (AP6)

Definition. Interval from the initial occurrence of the nominate taxon (base) to the initial occurrence of *Acarinina primitiva* (top).

Remarks. The lower part of the zone includes the first occurrence of *Subbotina inaequispira* as well as rare *Morozovella aequa*. Two other distinctive species appear for the first time within the zone. These are referred to as *Globigerina* sp. A (large) and *Globigerina*? sp. B (with small bulla). Although the taxonomy of these morphotypes is not clear, their presence in the fossil assemblage helps to distinguish the zone.

Subdivision of this zone is appropriate because it is relatively long. *Acarinina pentacamerata* first appears near the top of the zone. In the low latitudes, the initial occurrence of this species delineates the boundary between Blow's P8 and P9 zones. However, magnetochronostratigraphic calibration of this datum level is lacking (Aubry et al., 1988). Based on the initial occurrence of *A. pentacamerata*, the *A. wilcoxensis berggreni* Zone has been subdivided into the two subzones as follows:

Subbotina inaequispira Partial Range Subzone (AP6a)

Definition. Interval from the initial occurrence of *A. wilcoxensis berggreni* (base) to the initial occurrence of *A. pentacamerata* (top).

Remarks. *S. inaequispira* becomes an important component in the assemblages of this zone following its initial occurrence near the base of the zone.

Acarinina pentacamerata Interval Subzone (AP6b)

Definition. Interval from the initial occurrence of the nominate taxon (base) to the initial occurrence of *A. primitiva* (top).

Acarinina primitiva Interval Zone (AP7)

Definition. Interval from the initial occurrence of the nominate taxon (base) to the initial occurrence of *Acarinina bullbrooki* (provisional top).

Remarks. *A. primitiva* is rare near the base of its range, but is generally large and easily identified. Within the zone, the species forms a high proportion of the assemblage. The zone is also marked by the continued abundance of *S. inaequispira* and *S. eoceanica/patagonica. Subbotina linaperta* becomes abundant near the base of the zone and is a conspicuous and dominant element throughout the remainder of its range. Typical acarininids occurring within the zone include *Acarinina collactea, Acarinina wilcoxensis wilcoxensis*, and *Acarinina pseudotopilensis*.

The upper boundary of the zone is provisional, being placed at the initial occurrence of *Acarinina bullbrooki*. The initial occurrence of the species coincides with a hiatus in both of the Maud Rise sequences, precluding detailed resolution of the biostratigraphy in this interval (Fig. 2).

Acarinina bullbrooki Interval Zone (AP8)

Definition. Interval from the initial occurrence of *A. bullbrooki* (provisional base) to the initial occurrence of *Pseudohastigerina micra* (top).

Remarks. The base of the zone is provisionally placed at the initial occurrence of the nominate taxa for the reason given above. *Acarinina bullbrooki*, together with the morphologically similar *A. spinuloinflata* and *Acarinina matthewsae*, form conspicuous elements of the assemblages within this zone. The subbotinids common to Zone AP7 continue to contribute significantly to the fossil assemblages within this zone.

Pseudohastigerina micra Interval Zone (AP9)

Definition. Interval from the initial occurrence of *P. micra* (base) to the initial occurrence of *Globigerinatheka index* (top).

Remarks. The zone is characterized by the continued occurrence of abundant *A. bullbrooki* and related forms. *P. micra* is common to abundant above its initial occurrence and produces a distinctive change from the assemblages of the previous zone.

Acarinina collactea Partial Range Zone (AP10)

Definition. Partial range of the nominate taxa from the initial occurrence of *Globigerinatheka index* (base) to the last occurrence of *Acarinina primitiva* (top).

Remarks. The nominate taxon dominates the assemblages of this zone together with *G. index, A. primitiva*, and *Subbotina linaperta. Subbotina angiporoides* occurs for the first time within this zone.

Globigerinatheka index Partial Range Zone (AP11)

Definition. Partial range of the nominate taxa from the last occurrence of *A. primitiva* (base) to the last occurrence of *S. linaperta* (top).

Remarks. The top of this zone is marked by a distinct reduction in planktonic foraminifer diversity. It is at about this horizon that the muricate acarininids last occur in the Antarctic. *Globigerinatheka index, S. angiporoides, S. linaperta*, and *Globorotaloides suteri* dominate the assemblages of this zone.

Globorotaloides suteri Partial Range Zone (AP12)

Definition. Interval from the last occurrence of *S. linaperta* (base) to the last occurrence of *G. index* (top).

Remarks. The last occurrence of *S. linaperta* may vary latitudinally (Jenkins, 1971; Premoli-Silva and Boersma, 1988). At lower latitudes the species has been recorded in sediments as young as early Oligocene (Keller, 1983). At middle latitudes, this species last occurred near the Eocene/Oligocene boundary (Jenkins, 1971; 1974). In the Antarctic, the last occurrence of this taxon was even earlier, well below the Eocene/Oligocene boundary (see below). Nonetheless, the last occurrence of *S. linaperta* forms a conspicuous datum level in the Antarctic Ocean.

Subbotina angiporoides Interval Zone (AP13)

Definition. Interval from the last occurrence of *G. index* (base) to the last occurrence of the nominate taxon (top).

Remarks. *G. suteri* and *Subbotina angiporoides* dominate the planktonic foraminifer assemblages within this zone. Rare *Tenuitella munda* and *Globigerina officinalis* also occur discontinuously throughout the zone.

Globigerina labiacrassata Interval Zone (AP14)

Definition. Interval from the last occurrence of *S. angiporoides* to the last occurrence of the nominate taxon.

Remarks. This zone is subdivided into two subzones on the basis of the last occurrence of *Chiloguembelina cubensis*. This species was used to mark the boundary between the early and late Oligocene by Berggren et al. (1985). Its last occurrence appears to be isochronous interregionally and therefore forms a useful correlation marker (Hess et al., 1989). However, in some sequences *C. cubensis* does not occur continuously throughout its range and becomes rare in assemblages near the top of its range. For this reason it is possible for the last occurrence of this species to be mislocated. If the last occurrence of *C. cubensis* is mislocated or has been disrupted by reworking or bioturbation, the AP12 Zone remains useful in its broader sense.

Chiloguembelina cubensis Interval Subzone (AP14a)

Definition. Interval from the last occurrence of *S. angiporoides* (base) to the last occurrence of *Chiloguembelina cubensis* (base).

Globigerina euapertura Partial Range Subzone (AP14b)

Definition. Partial range of the nominate taxon from the last occurrence of *C. cubensis* to the last occurrence of *G. labiacrassata*.

Remarks. *Globigerina euapertura* does not occur continuously within the zone but is conspicuous when present. The zone is also characterized by the common occurrences of *Globigerina labiacrassata, Globigerina juvenilis, Globorotaloides suteri*, and *Catapsydrax unicavus*. In some instances where dissolution has severely altered the assemblages, the latter two species are the only planktonic foraminifers observed, due to their resistance to dissolution.

CHRONOSTRATIGRAPHIC CALIBRATION

Berggren et al. (1985) integrated the tropical zonations with magnetostratigraphy, using high-temperature radiometric age determinations to calibrate certain polarity intervals. The ranges of Paleogene planktonic foraminifer species and the placement of Paleogene chronostratigraphic boundaries using biostratigraphic criteria has been discussed by various authors (Berggren and Miller, 1988; Premoli-Silva and Boersma, 1988; Tourmarkine and Luterbacher, 1985; Blow, 1979; Stainforth et al., 1975; Premoli-Silva and Bolli, 1973; Bolli, 1966; Jenkins, 1971). Many of the datum levels used to mark the major chronostratigraphic subdivisions at lower latitudes do not appear in the Antarctic record. However, several major biostratigraphic events that occurred during the Paleogene provide global chronologic markers. Such events include the mass-extinction event at the Cretaceous/Paleogene boundary, the last occurrence of coarsely muricate acarininids near the end of the middle Eocene, and the last occurrence of biserial heterohelicids in the middle Oligocene. Events such as these, when correlated to the magnetostratigraphy of Holes 689B and 690B/690C, can be used to identify polarity patterns which match those of the standard magnetochronostratigraphic record of Berggren et al. (1985). With these major tie points, the other Antarctic datum levels can be correlated with the magnetostratigraphy, and a biochronostratigraphic framework can be developed for the Antarctic.

Cretaceous/Paleogene Boundary

The mass-extinction event at the Cretaceous/Paleogene (K/P) boundary has been correlated with the younger part of magnetochron 29R in deep-sea sequences (e.g., Alvarez et al., 1977; Lowrie et al., 1977; Poore et al., 1984; Monechi et al., 1985; see also Berggren et al., 1985). In continuous sections, this horizon is also marked by a distinct iridium anomaly (e.g., Alvarez et al., 1980; Hsü et al., 1982; Alvarez et al., 1984; Michel et al., 1985).

In Hole 690C, the Cretaceous/Paleogene boundary occurs in Section 113-690C-15X-4 and is marked by a distinct color change (Barker, Kennett, et al., 1988) from white nannofossil ooze/chalk to brown clay-bearing nannofossil ooze. Within the time represented by this color change, planktonic foraminifers typical of the Upper Cretaceous *A. mayaroensis* Zone became extinct. However, because the interval has been bioturbated, the color change and the "extinction event" do not form a distinct horizon. It is spread out over several tens of centimeters. To identify the position of the K/P boundary the abundance of Cretaceous and Paleogene planktonic foraminifer species were determined quantitatively, as discussed earlier. The boundary is placed at the point where Paleogene species become dominant (>50%) over Cretaceous species (Fig. 3). The Cretaceous species, including *Globigerinoides multispinatus, Heterohelix globulosa*, and *Hedbergella monmouthensis*, were replaced by assemblages characterized by *E. fringa, Eoglobigerina eobulloides*, and small heterohelicids within a 10-cm interval between Samples 113-690C-15X-4, 45–47 cm, and -15X-4, 35–37 cm. Michel et al. (this volume) also identified elevated concentrations of iridium (1566 ± 222‰) within this same interval (Sample 113-690C-15X-4, 39–40 cm).

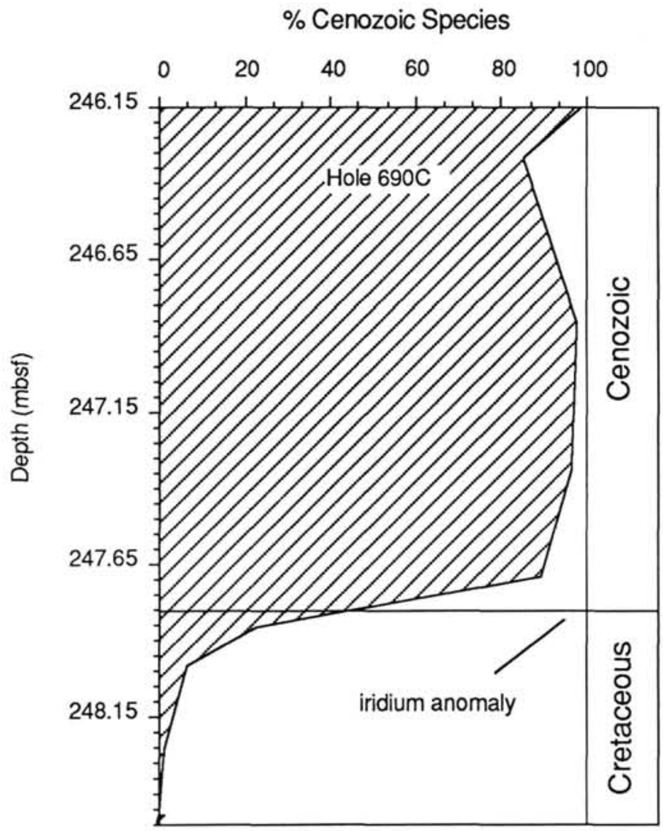

Figure 3. Plot of relative percentage of Tertiary (Cenozoic) vs. Cretaceous species in samples across the Cretaceous/Tertiary transition interval in Hole 690C. Bioturbation has mixed Cretaceous and Tertiary species through the interval marked by a distinct color change and elevated concentrations of iridium (Michel et al., this volume). The biostratigraphic boundary is placed at the horizon where Tertiary species form greater than 50% of the species present. This horizon occurs within 5 cm of a peak in the concentration of iridium (indicated by a line). Tertiary and Cretaceous species are listed under "Species List and Taxonomic Notes."

The extinction horizon and the iridium anomaly both occur within a reversed magnetic polarity zone (Hamilton, this volume). At ~40 cm above the biostratigraphically identified K/P boundary, the magnetic polarity is normal. This polarity pattern is similar to that described for the Gubbio section (Alvarez et al., 1977) and other deep-sea sequences (Peterson et al., 1984; Bleil, 1985), correlating to the Chron 29N/29R boundary of standard magnetochronology (Berggren et al., 1985).

The Cretaceous/Paleogene boundary can also be identified at Site 689 within Core 113-689B-25X at a distinct color change. However, at this site, the change is from Cretaceous white nannofossil chalk to Paleogene green clay-bearing nannofossil chalk. The boundary is similar to that of Hole 690C, with latest Cretaceous species and early Paleogene species mixed across a broad interval by bioturbation. An assessment of the abundances of Cretaceous vs. Paleogene specimens through the interval indicates that the boundary occurs between Samples 113-689B-25X-5, 79–81 cm, and -25X-5, 91–94 cm (233.45 mbsf). The latter sample contains species attributable to Zone APα. Michel et al. (this volume) did not identify any elevated iridium concentrations through the K/P boundary transition at this site, suggesting that erosion or nondeposition has affected the K/P boundary. The magnetostratigraphy of Hole 689B through this interval is too poor to evaluate the duration of the hiatus. However, because the fauna immediately above the boundary is similar to that of Hole 690C it appears that little of the lowermost Paleogene is missing.

Paleocene/Eocene Boundary

In low-latitude sequences, the Paleocene/Eocene boundary is identified by the last occurrence of *Morozovella velascoensis*, which marks the boundary between Zones P6a and P6b (Berggren et al., 1985; Berggren and Miller, 1988). It has also been suggested that the first evolutionary appearance of *Pseudohastigerina wilcoxensis* from its ancestor *Planorotalites chapmani* appears in the uppermost part of the tropical Subzone P6a, and thus close to the Paleocene/Eocene boundary (Jenkins, 1971; Berggren et al., 1985). Blow suggested that the first appearance of *Acarinina wilcoxensis berggreni* slightly preceded the first appearance of *P. wilcoxensis*, but he used the FAD of the former species to mark the base of Zone P7, which correlates with the boundary of Zones P6a/P6b and the Paleocene/Eocene boundary of Berggren and Miller (1988). According to Berggren et al. (1985), the P6a/P6b boundary correlates to the lower reversed part of Chron 25R, dated as 57.8 Ma.

Morozovella velascoensis does not occur in the Maud Rise sequences. The first recognizable *A. wilcoxensis berggreni* occurs in Core 113-690B-18X between Samples 113-690B-18X-1, 36–40 cm, and -18X-4, 36–39 cm (159.44 mbsf). *Pseudohastigerina wilcoxensis* is rare in the Maud Rise sequences. It is observed only rarely in Core 113-690B-16H through -15H. Forms typical of *P. chapmani* were not observed in the intervals below the initial occurrence of *P. wilcoxensis*. It appears, therefore, that the evolutionary development of *P. wilcoxensis* from *P. chapmani* does not provide a viable datum level in the Antarctic for the Paleocene/Eocene boundary.

The magnetostratigraphy of Hole 690B (Spieß, this volume) between Cores 113-690B-17H and -25H matches closely that of Chrons 24 through 25 in the standard magnetostratigraphic time scale of Berggren et al. (1985). The long reversed interval that characterizes Chron 24 and the Paleocene/Eocene transition is apparently expanded in this sequence, extending from Cores 113-690B-17H to -23H (Fig. 2). Assuming a constant sedimentation rate from the top of Chron 25N (58.7 Ma) to the base of Chron 24N (56.10 Ma) and by extrapolating between these polarity datum levels, the magnetostratigraphically correlated Paleocene/Eocene boundary (57.8 Ma of Berggren et al., 1985) occurs at 173.20 mbsf. This correlates with the middle of the AP4 Zone. The initial appearance of *A. wilcoxensis berggreni* therefore took place approximately 0.4 to 0.8 m.y. later than the Paleocene/Eocene boundary recognized by Berggren et al. (1985). The *P. australiformis* FAD occurs at 171.38 mbsf in Hole 690B, a level closer to the magnetostratigraphically defined Paleocene/Eocene boundary.

Aubry et al. (1988) recently suggested that the chronology of the Paleocene/Eocene boundary was higher within Chron 24R, equivalent to 57.0 Ma based on revised paleomagnetic calibrations of the low-latitude biostratigraphies. Accordingly, the Paleocene/Eocene boundary in Hole 690B, based on magnetostratigraphy, would be placed at 165 mbsf. This is approximately the level of the boundary between Zones AP4 and AP5, and hence with the initial occurrence of *A. wilcoxensis berggreni.*

Early/Middle Eocene Boundary

Various biostratigraphic criteria have been used to recognize the early/middle Eocene boundary (Berggren et al., 1985). The first appearance of *Hantkenina* spp. is often used for low-latitude sequences (Berggren and Miller, 1988). However, this group is restricted to tropical and subtropical latitudes. No *Hantkenina* spp. are recorded in the Maud Rise sequences. The first appearance of *Pseudohastigerina micra* may also approximate the lower/middle Eocene boundary in middle-latitude sections (Premoli-Silva and Boersma, 1988). However, we know of no record where this datum level has previously been calibrated magnetostratigraphically. Berggren et al. (1985) correlated the *Hantkenina* FAD (Zone P9/P10 boundary) and the early/middle Eocene boundary with the top of Chron 22N at 52 Ma. Notwithstanding the potential difficulty in identifying the first evolutionary appearance of *P. micra* (cf. Blow, 1979), the first occurrence of this taxon in the Maud Rise sequences can be readily identified in Core 113-689B-21H just below a short normal polarity event at 183 mbsf between the first and last occurrences of *A. bullbrooki*. Blow (1979) considered *A. bullbrooki* to range from the base of his P9 Zone to the top of Zone P11. According to Berggren and Miller (1988), this interval includes the base of Chron 20R through the base of Chron 22R. The polarity pattern below the short normal event at 183 mbsf in Hole 689B is not well constrained (Spieß, this volume). However, the polarity pattern above this level correlates closely with the long reversed polarity portion of Chron 20 and the multiple normal events of the middle middle to late middle Eocene (Berggren et al., 1985). The short normal event associated with the *P. micra* FAD at 183 mbsf is correlated with the younger part of Chron 21N, equivalent to a magnetostratigraphic age of 49 Ma, and therefore is too young to approximate the early/middle Eocene boundary.

In Hole 690B the polarity pattern below 21N appears to be well delineated (Fig. 2). Chron 22N occurs within Core 113-690B-15H below a long reversed interval characteristic of lower Chron 21 (Berggren et al., 1985). At the base of Core 113-690B-15H, *A. pentacamerata* first appears in the sequence and is associated with the top of another normal polarity event. Aubry et al. (1988) recently suggested that the initial occurrence of *A. pentacamerata* (= base of P8 Zone) approximately correlates with the top of Chron 23N. In Hole 690B the initial occurrence of *A. pentacamerata* is also used to identify the top of Chron 23. On this basis, the younger normal event in Core 113-690B-15H noted above is correlated with Chron 22 of the Berggren et al. (1985) time scale. The early/middle Eocene boundary is placed at the top of that normal event. Consequently, it appears that the initial occurrence of *A. primitiva* closely approximates, although it is slightly older than, the boundary between the early and middle Eocene (Figs. 2, 4).

Middle/Late Eocene Boundary

The chronostratigraphic placement of the middle/late Eocene boundary in relation to established biostratigraphic criteria is still equivocal (Berggren et al., 1985). The end of the middle Eocene, although not necessarily the middle/late Eocene boundary, is marked worldwide by the extinction of most muricate planktonic species (Stainforth et al., 1975; Berggren et al., 1985; Premoli-Silva and Boersma, 1988). The first appearance of *Globigerinatheka semiinvoluta* also occurred near the end of the middle Eocene, although slightly below the *Acarinina* LAD. Berggren et al. (1985) chose to place the middle/late Eocene boundary in the latter part of Chron 17 with an age of 40.0 Ma, slightly postdating the *Acarinina* LAD.

At Maud Rise the last occurrence of the acarininids can be correlated to a paleomagnetic record in Hole 689B where the sequence is expanded relative to that of Hole 690B (see below). In Hole 689B the acarininids last appear in the top of Core 113-689B-18H in the middle of a long normal polarity zone that extends from the middle of Core 113-689B-17H to the upper part of Core 113-689B-18H (Fig. 2). The lower part of Core 113-689B-18H is marked by two shorter normal polarity intervals separated by similarly short reversed intervals. This same pattern characterizes Chrons 18–20N in the standard time scale of Berggren et al. (1985). The *Acarinina* LAD in the Antarctic record can, therefore, be correlated approximately with the normal subchron of Chron 18-2. This is equivalent to a magnetostratigraphic age of 42.0 Ma on the Berggren et al. (1985) time scale. On the basis of this age assignment, the middle/upper Eocene boundary occurs slightly higher in the sequence.

The last occurrence of *Subbotina linaperta* in Hole 689B is in Core 113-689B-16H, just above the acarininid LAD, near the top of a relatively long normal event corresponding to that of Chron 17N-1 in the Berggren et al. (1985) time scale. Above this horizon, in Core 113-689B-15H, the planktonic foraminifer assemblages are composed of typical late Eocene forms such as *S. angiporoides, G. index, G. suteri*, and *T. insolita*. The middle/late Eocene boundary is correlated with the top of Chron 17N-1 in Core 113-689B-16H, associated with the last occurrence of *S. linaperta*.

Eocene/Oligocene Boundary

Various criteria have been used to delineate the biostratigraphic placement of the Eocene/Oligocene boundary. In low latitudes the boundary "interval" can be identified by the last occurrence of hantkeninids and *Turborotalia cerroazulensis* s.l., just prior to the short magnetic normal events in Chron 13 (see discussion by Nocchi et al., 1986). However, the precise age of these magnetochrons and the age of the Eocene/Oligocene boundary remain equivocal (see Berggren et al., 1985; Montanari et al., 1985; Odin, 1986; Berggren and Miller, 1988; Premoli-Silva and Boersma, 1988; Aubry et al., 1988). Berggren et al. (1985) placed the chronostratigraphic boundary within the relatively long magnetic reversed interval of Chron 13, which they estimated to be 36.6 Ma.

Recent investigations using high-resolution $^{87}Sr/^{86}Sr$ stratigraphy calibrated to deep-sea magnetostratigraphy (Hess et al., 1989) have demonstrated that the *Globigerinatheka* LAD occurred isochronously in the Pacific and Atlantic oceans at 37 Ma. This age slightly predates the magnetobiostratigraphically correlated Eocene/Oligocene boundary, which is considered to be at 36.6 Ma (Berggren et al., 1985), but provides a means of identifying the paleomagnetic pattern across the boundary in the Maud Rise sites.

The last occurrence of *G. index* in Hole 689B is in Section 113-689B-14H-CC within a paleomagnetic normal zone that extends from near the base of Core 113-689B-14H (~128.5 mbsf) to the middle of Core 113-689B-15H (~133.5 mbsf). Below this horizon, the magnetostratigraphy of Hole 689B between Core 113-689B-15H and the middle of Core 113-689B-17H exhibits a pattern of long normals separated by several short reversals (Fig. 2). This pattern closely matches the late Eocene magnetostratigraphy in the Berggren et al. (1985) time scale. The *G. index* LAD is, therefore, correlated with the uppermost part of Chron 16N. Based on the age/polarity relationship in the Berggren et al. (1985) magnetostratigraphic time scale, this horizon corresponds to an age of 38.1 Ma, approximately 1 m.y. older than the strontium isotope age estimate. Even though the strontium isotope age model has a precision of ± 300 k.y., this age discrepancy suggests that there may be a problem in the calibration of the $^{87}Sr/^{86}Sr$ curve of Hess et al. (1989) near the Eocene/Oligocene boundary or that there is considerable fossil diachroneity between the middle and high latitudes.

In Hole 690B the *G. index* LAD also occurs within a normal magnetic interval in Core 113-690B-11H between 92.45 and 93.2 mbsf. The planktonic foraminifer assemblages within this interval, however, differ from those of Hole 689B close to the Eocene/Oligocene boundary, particularly in the abundance of *G. index*. In Hole 689B the abundance of *G. index* is common in the early part of its range and becomes rare to rare/absent in the middle part. At the end of its range, *G. index* is again common in the assemblages. In Hole 690B, however, this species never occurs abundantly above its initial occurrence, being present rarely and discontinuously in the assemblages. Because the samples are well preserved, the abundance pattern observed in Hole 690B cannot be attributed to dissolution. This suggests that a hiatus has truncated the upper part of the range of *G. index*. Most other late Eocene species are long-ranging and do not provide sufficient stratigraphic resolution to estimate the amount of sediment/time missing in Hole 690B. The correlation of the magnetostratigraphies of Hole 689B and Hole 690B to that of Berggren et al. (1985) indicates that the interval encompassing Chrons 13–15 and possibly the upper part of Chron 16N is missing from Hole 690B. The short normal polarity zone that includes the *G. index* LAD appears to be a concatenation of lower Chron 13N and the upper portion of Chron 16.

Magnetostratigraphic Calibration of Antarctic Planktonic Foraminifer Biostratigraphy

The Antarctic biostratigraphic zonation has been calibrated to magnetostratigraphy. Figure 2 shows the relationship between planktonic foraminifer datum levels and zonal boundaries vs. the magnetostratigraphic records of Spieß (this volume) and Hamilton (this volume). The interpretation of the reversal pattern is based on the recognition of polarity patterns that match those in the standard magnetochronostratigraphy of Berggren et al. (1985) using the chronostratigraphic datum levels discussed above as calibration points. These are shown as follows:

Zonal boundary	Depth* (mbsf) Site 689	Site 690	Chron
APα/AP1a *S. pseudobulloides* FCOD	231.89	247.47	Base C29N
AP1a/AP1b *S. inconstans* FAD	229.84	239.79	~Top C28N?
AP1b/AP2 "*P.*" *imitatus* FAD	Hiatus	226.64	Base C27N?
AP2/AP3 *M. mckannai* FAD	Hiatus	216.18	Lower C26R?
AP3/AP4 *A. praepentacamerata* FAD	215.06	210.58	Top C26N
AP4/AP5 *P. australiformis* FAD	207.92	170.64	Mid C24R
AP5/AP6a *A. wilcoxensis berggreni* FAD	Hiatus	159.45	Upper C24R
AP6a/AP6b *A. pentacamerata* FAD	Hiatus	137.98	C22R/C23N

Blow (1979) considered that *A. pentacamerata* ranges from the base of Zone P8a (= base Zone P6c of Berggren and Miller,

1988) to the top of Zone P9 (= middle P9 of Berggren, 1969, and Berggren and Miller, 1988). The FAD of this species would, therefore, correspond to the top of Chron 24N of Berggren et al. (1985). By contrast, Stainforth et al. (1975) and Toumarkine and Luterbacher (1985) considered the range of *A. pentacamerata* to be from the base of the *Morozovella aragonensis* Zone (= base P8 of Berggren and Miller, 1988) to the *Morozovella lehneri* Zone. In this interpretation, the FAD would correspond to the top of Chron 23N or lower Chron 22R. Aubry et al. (1988) recently revised the chronostratigraphic position of the *A. pentacamerata* FAD (= base P8 Zone), placing it "arbitrarily" at 54.0 Ma, which corresponds to the top of Chron 23N. In the Antarctic sequences *A. pentacamerata* first appears at the top of a normal polarity zone which we correlate with Chron 23N. The species last occurrence can be seen in Hole 689B, where it occurs only rarely at the base of Core 113-689B-20H, which may correspond to middle of Chron 20R.

AP6b/AP7 *A. primitiva* FAD	Hiatus	133.35	C22N/C22R

At Site 516 Pujol (1983) recorded the *A. primitiva* FAD in an interval Berggren et al. (1983) correlated with mid Chron 20, based evidently on the position of the nannofossil NP15/NP16 boundary. However, no biostratigraphic criteria were discussed in conjunction with the interpretation of that polarity record. The authors did note that the identification of normal "events" was difficult throughout the interval in question. Although Site 516 is at a lower latitude than Maud Rise, the evidence from Site 690B suggests that the interval including the *A. primitiva* FAD at Site 516 might correlate with Chron 22 rather than Chron 20.

AP7/AP8 *A. bullbrooki* FAD	Hiatus	Hiatus	Mid C21N??

Blow (1979) considered the range of this species to be from approximately the base of Zone P9, which is correlated with the top of Chron 23 by Berggren and Miller (1988). In the Antarctic, the initial occurrence of *A. primitiva* correlates approximately with the base of Chron 22N as discussed above. Because the *A. primitiva* FAD occurs prior to any occurrence of *A. bullbrooki* in Hole 690B, we have provisionally correlated the initial occurrence of *A. bullbrooki* with the middle of Chron 21. Above the hiatus the polarity pattern cannot be delineated unequivocally.

AP8/AP9 *P. micra* FAD	186.69	Hiatus	Mid C20R?-Top C21N
AP9/AP10 *G. index* FAD	168.61	Hiatus	C20/C20R

The initial occurrence of *G. index* in the Antarctic appears to correlate closely with the initial occurrence of the species at Site 516 based on the Berggren et al. (1983) interpretation of the polarity record. It also correlates with the first definite occurrence at Site 523 (Poore et al., 1984).

AP10/AP11 *A. primitiva* LAD	158.98	Hiatus	Mid C18N

Poore et al. (1984) recorded the last occurrence of *A. primitiva* in the interval interpreted to be upper Chron 18 at Site 523. Pujol (1983) also recorded the last occurrence of the species in an interval interpreted to be upper Chron 18 by Berggren et al. (1983). This datum level appears, therefore, to provide a useful cross-latitudinal correlation horizon within the Atlantic basin.

AP11/AP12 *S. linaperta* LAD	145.18	98.98	Mid C17N-1
AP12/AP13 *G. index* LAD	129.29	Hiatus	Top C16N
AP13/AP14a *S. angiporoides* LAD	101.75	82.03	Lower C11N

Berggren et al. (1985) also noted that this species last occurs at the top of C11N (= 32.0 Ma) in middle-latitude sequences.

AP14a/AP14b *C. cubensis* LAD	95.77	69.62	~Top C10N
Top AP14b *G. labiacrassata* LAD	79.22	61.79	C9N/C8R

*Depths are midpoints between adjacent samples.

The magnetostratigraphic correlations outlined above can be used to correlate the new Antarctic biostratigraphy to the low-latitude zonations which have also been chronostratigraphically calibrated (Berggren and Miller, 1988). This is summarized in Figure 4. The ranges of the Antarctic index species are summarized in Figure 5.

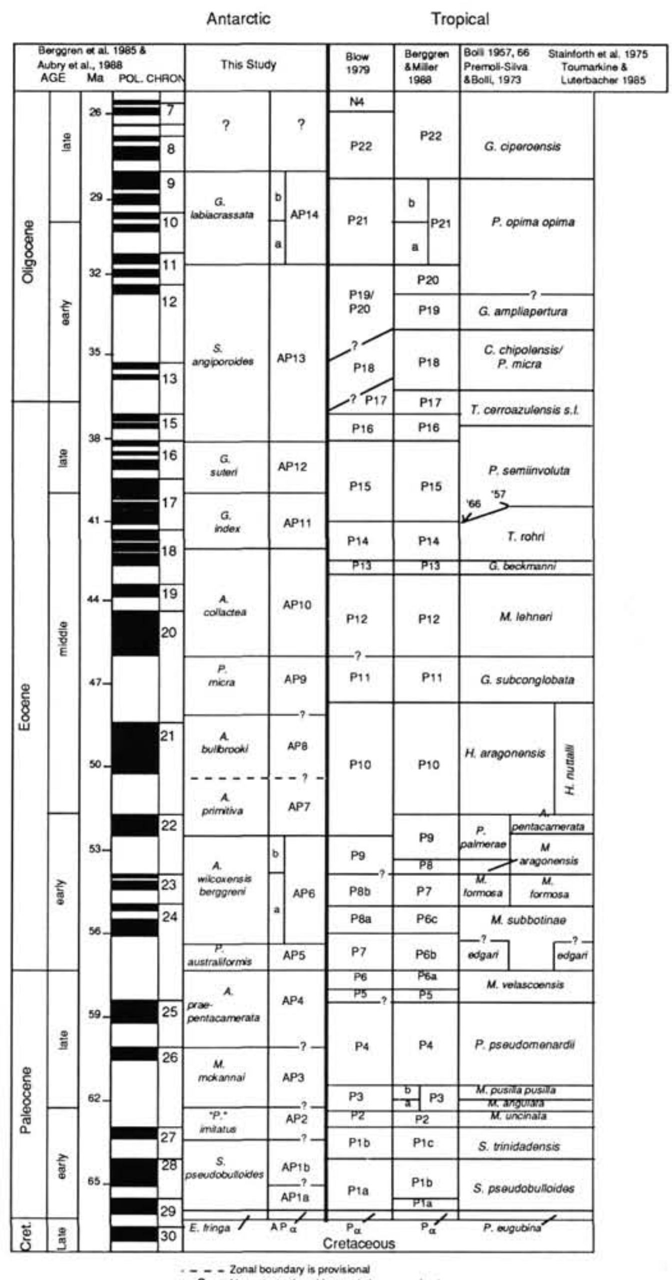

Figure 4. Correlation between the tropical zonations (summary after Berggren and Miller, 1988) and the new Antarctic planktonic foraminiferal biostratigraphy.

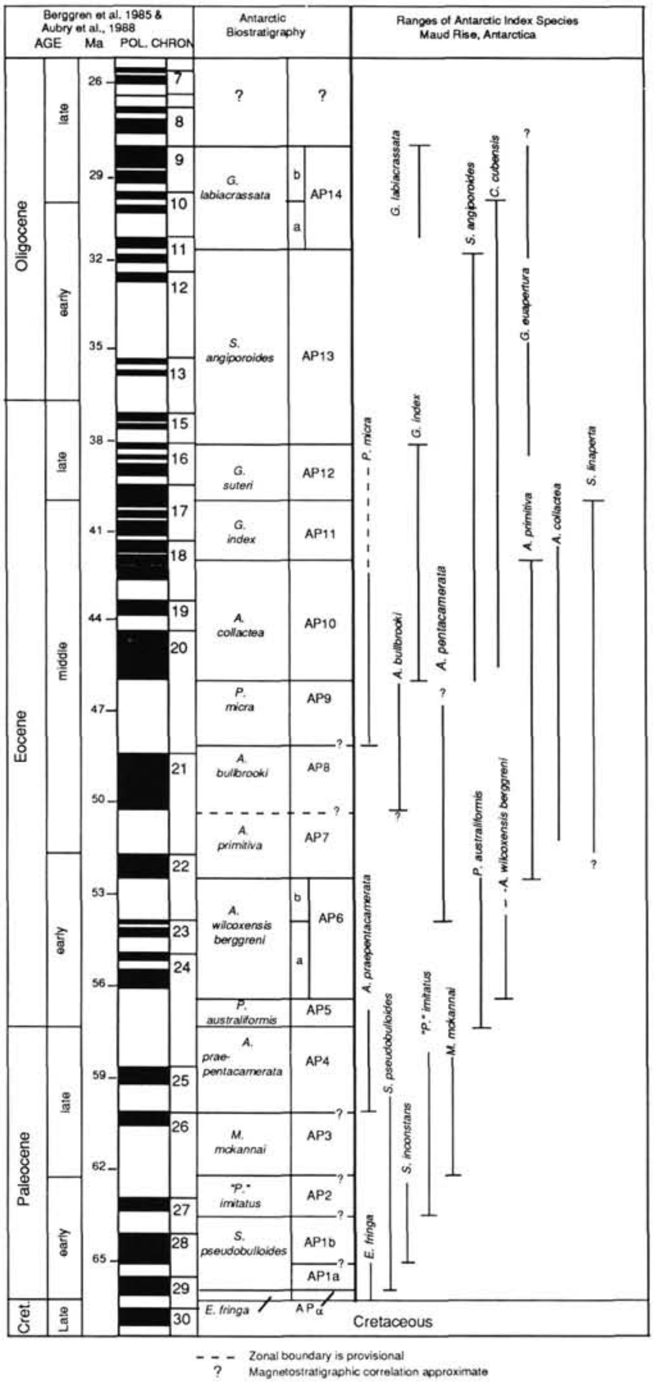

Figure 5. Ranges of Antarctic planktonic foraminiferal index species which have been used to define the zones.

SUMMARY

The recovery of continuous calcareous biogenic sequences at Sites 689 and 690 makes possible the study of Antarctic planktonic foraminifer biogeography and paleoecology through the entire Paleogene. The biostratigraphic and chronostratigraphic framework developed here is integral to those studies because it provides the time framework needed to determine sequence events and to make interregional correlations. Further work is needed, however, on many aspects of the taxonomy of Paleogene foraminifer assemblages at these high latitudes. The present study has elucidated only the major features of the planktonic foraminifers.

Together, Sites 689 and 690 provide a nearly complete planktonic foraminifer record for the Late Cretaceous through the late Oligocene. Planktonic foraminifers are abundant and generally well preserved from the Upper Cretaceous to the Eocene. Abundances and the quality of preservation are reduced for the Oligocene, as calcareous microfossil groups are progressively replaced by siliceous groups. The Neogene is marked by only rare, isolated occurrences of planktonic foraminifers, the most conspicuous of which are Quaternary.

Planktonic foraminifer diversity was very low in the region of Maud Rise for the first several hundred thousand years of the Paleogene following the Cretaceous/Paleogene boundary extinction event. Despite the low diversity in the lowermost Paleogene fossil assemblages, the species found in the Antarctic are similar to those recorded in middle and low latitudes. During the middle Paleocene, Antarctic lower latitude assemblages began to take on a distinct character, lacking some lower latitude forms such as the early morozovellids. However, the assemblages found in the Antarctic are similar to those observed from the Falkland Plateau (Tjalsma, 1977; see also Boersma and Premoli-Silva, 1983) and from higher latitude sequences of the Northern Hemisphere (Subbotina, 1953).

The diversity of planktonic foraminifers in the Antarctic increased significantly during the late Paleocene due to evolutionary radiation of several distinct lineages. These include the large acarininids and the smaller, biconvex morozovellids together with a variety of different subbotinid species. This evolutionary radiation probably was facilitated in the Antarctic by warmer conditions, as recorded in the stable isotopic records (Kennett and Stott, this volume).

Diversity remained high in the Antarctic throughout most of the early and early middle Eocene. Subbotinids and acarininids dominated the assemblages along with various *Planorotalites* species. At no time, however, did any of the large, keeled morozovellids, the hantkeninids, or the globigerapsids characteristic of the low to middle latitudes inhabit the Antarctic Ocean. Beginning in the late middle Eocene, planktonic foraminifer diversity was reduced as a result of the extinction of the acarininids, as well as several *Subbotina* and *Planorotalites* species. In the upper Eocene the fossil assemblages are dominated by three to four species. This lower diversity was associated with a climatic cooling trend that is recorded in the stable isotopic records from this interval (Kennett and Stott, this volume). During the late Eocene the Antarctic assemblages began to take on a "polar" character, marked by lower diversity than at the temperate latitudes. Nonetheless, calcareous fossils dominated the sediments on Maud Rise throughout the late Eocene. Further reduction in planktonic foraminifer diversity occurred across the Eocene/Oligocene boundary in response to continued cooling and the radiation of siliceous microfossils in the Antarctic Ocean. By the late Oligocene, siliceous microfossils became important sedimentary components on Maud Rise. Planktonic foraminifers are generally rare to common, and assemblages are composed of only two to three species.

Few planktonic foraminifers are recorded in the Miocene of the Maud Rise sequences. This was probably due to colder Antarctic surface waters, a higher carbonate compensation depth (CCD), and the dominance of siliceous microfossils. Nonetheless, planktonic foraminifers are recorded from several intervals. Of these, the most commonly observed are dissolution-resistant taxa such as *Catapsydrax*. The upper Miocene contains rare occurrences of *Globigerina bulloides, G. quinqueloboa*, and *Globorotalia scitula. Neogloboquadrina pachyderma* first appeared in the Antarctic during the late Miocene. During part of the

Quaternary *N. pachyderma* became abundant enough to form a calcareous ooze throughout shallow areas of the Weddell Sea (Barker, Kennett, et al., 1988). This unusual occurrence of foraminifer-rich sediments suggests that oceanic conditions (CCD, temperature, and nutrients) were favorable for the production and preservation of calcareous biogenic sediments, a clear reversal from the siliceous biogenic productivity that marked nearly all of the Neogene. Future investigations will attempt to quantify the biogeographic and paleoecologic history of the Antarctic foraminifers and to incorporate that work with similar studies of other fossil groups. It will also be possible to integrate the new planktonic foraminifer biostratigraphy with that of other fossil groups (Thomas et al., this volume) and thereby provide a comprehensive biostratigraphic record for the Antarctic.

SPECIES LIST AND TAXONOMIC NOTES

Species identified in the Antarctic sequences are noted below. Comments are included at several places to clarify interpretations of species usage and morphological characteristics. Because of space limitations, SEM illustrations are restricted to taxa of stratigraphic value or of distinctive character within the assemblages (Pls. 1-7).

Several of the more distinctive chiloguembelinids have been identified. The upper Paleocene through middle Eocene sequence contains several morphotypes identified as elongate or inflated on the range charts.

Chiloguembelina wilcoxensis (Cushman and Ponton) 1932 (Pl. 2, Fig. 2).

Chiloguembelina cubensis (Palmer) 1934 (Pl. 5, Fig. 10).

Chiloguembelina taurica Morozova 1961.

Eoglobigerina fringa (Subbotina) 1950 (Pl. 1, Figs. 5, 6). *E. fringa* is distinguished from *E. eobulloides* in having a more extraumbilically positioned aperture.

Eoglobigerina edita (Subbotina) 1953 (Pl. 1, Figs. 9, 10). The form illustrated here exhibits a bulla-like final chamber covering the apertural region.

Eoglobigerina eobulloides (Morozova) 1959 (Pl. 1, Fig. 7).

Eoglobigerina trivialis (Subbotina) 1953 (Pl. 2, Fig. 11).

"Globorotalia" (Turborotalia) polycamera (Chalilov) 1956 (Pl. 1, Figs. 1, 2). The generic and subgeneric designations for these small early Paleogene forms follow those of Blow (1979).

"Globorotalia" (Turborotalia) cf., tetragona (Morozova) 1961 (Pl. 1, Figs. 12, 13).

Globoconusa daubjergensis (Bronnimann) 1953 (Pl. 1, Figs. 8, 11).

Guembelitria cretacea Cushman 1933 (Pl. 2, Fig. 7).

Chiloguembelitria sp.? (Pl. 5, Fig. 9).

Globigerinita glutinata (Egger) 1893.

Globigerinita uvula (Ehrenberg) 1861.

Subbotina spp. The taxonomy of many Paleogene subbotinids is poorly understood. However, several distinct morphotypes can be distinguished consistently. No attempt was made to distinguish subspecies as described, for example, by Blow (1979).

Subbotina eocaenica (Terquem) 1882 sensu Blow (1979) (Pl. 3, Fig. 14). *S. eocaenica* and *S. patagonica* (Todd and Kniker) are not distinguished here.

Subbotina eoceana (Gumbel) 1868 (Pl. 7, Figs. 4, 5).

Subbotina inaequispira (Subbotina) 1953.

Subbotina inconstans (Subbotina) 1953 (Pl. 2, Figs. 5, 6). See comments under description of Zone AP1.

Subbotina pseudobulloides (Plummer) 1926 (Pl. 2, Figs. 13, 14).

Subbotina triangularis (White) 1928 (Pl. 3, Fig. 12).

Subbotina triloculinoides (Plummer) 1926 (Pl. 2, Fig. 12).

Subbotina varianta (Subbotina) 1953.

Subbotina angiporoides (Hornibrook) sensu Jenkins (1971) (Pl. 7, Fig. 3).

Subbotina angiporoides minima (Jenkins) 1966.

Subbotina moskovini (Shutskaya) 1953 (Pl. 1, Figs. 3, 4).

Subbotina linaperta (Finlay) 1939 sensu Jenkins (1971) (Pl. 7, Fig. 9).

Globigerina ampliapertura Bolli 1957. This form is rare in the Antarctic sequences.

Globigerina brevis Jenkins 1966. This short-ranging species is used in the southwest Pacific to mark the uppermost Eocene zone of Jenkins (1971). In the Antarctic sequences at Maud Rise, the species is rare and therefore difficult to use stratigraphically.

Globigerina bulloides d'Orbigny 1826.

Globigerina connecta Jenkins 1964.

Globigerina cryptomphala Glaessner 1937.

Globigerina euapertura Jenkins 1960 (Pl. 7, Fig. 2).

Globigerina juvenilis Bolli 1957.

Globigerina labiacrassata Jenkins 1966 (Pl. 7, Fig. 1).

Globigerina lozanoi Colom 1954 (Pl. 7, Figs. 6, 7).

Globigerina officinalis Subbotina 1953.

Globigerina ouachitaensis Howe and Wallace 1932.

Globigerina praebulloides Blow 1959.

Globigerina quinqueloba Natland 1938.

Globigerina woodi Jenkins 1960.

Globigerina sp. A. A globigerinid which is similar in test ultrastructure to the *G. lozanoi* group. However, this form exhibits fewer chambers and is more tightly coiled than *G. lozanoi.*

Globigerina sp. B (Pl. 5, Figs. 11-14). A very small form with typically 4 chambers in the final whorl. Most specimens exhibit a small bulla covering the aperture (Pl. 5, Fig. 11). Other forms, such as that shown (Pl. 5, Fig. 14), are higher spired and do not show the bulla-like umbilical chamber.

Igorina spiralis (Bolli) 1957 (Pl. 3, Fig. 7).

Muricoglobigerina aquiensis (Loeblich and Tappan) 1957 (Pl. 3, Figs. 2, 3).

Muricoglobigerina chascanona (Loeblich and Tappan) 1957.

Muricoglobigerina mckannai (White) 1928 (Pl. 3, Figs. 7, 8).

Muricoglobigerina soldadoensis soldadoensis (Bronnimann) 1952 (Pl. 3, Figs. 1, 5).

Muricoglobigerina soldadoensis angulosa (Bolli) 1957.

Acarinina aspensis (Colom) 1954.

Acarinina appressocamerata (Blow) 1979. Blow (1979) considered *A. appressocamerata* and *A. nitida* (= *A. subspherica* Subbotina) to be homeomorphic. We have followed this usage here.

Acarinina bullbrooki (Bolli) 1957 (Pl. 6, Figs. 5, 6). The distinction between *A. bullbrooki* and the similar *Acarinina matthewsae* follows the criteria of Blow (1979).

Acarinina camerata (Chalilov) 1956. See comments under *Acarinina interposita.*

Acarinina collactea (Finlay) 1939 (Pl. 6, Figs. 7, 8).

Acarinina esnaensis LeRoy 1953 (Pl. 4, Figs. 7, 8). See discussion under *Acarinina wilcoxensis* s.l.

Acarinina interposita Subbotina 1953 (Pl. 6, Figs. 3, 4). There is a close affinity between this species and *A. pentacamerata* and *A. camerata.* Nonetheless, because of the potential stratigraphic utility of *A. pentacamerata* we have attempted to distinguish these forms within the assemblages and have illustrated each here.

Acarinina matthewsae (Blow) 1979 (Pl. 6, Figs. 1, 2).

Acarinina nitida (Martin) 1943 (Pl. 4, Fig. 4).

Acarinina pentacamerata (Subbotina) 1953 (Pl. 6, Figs. 9, 10).

Acarinina praepentacamerata (Shutskaya) 1956 (Pl. 4, Figs. 9, 10).

Acarinina primitiva (Finlay) 1947 (Pl. 6, Figs. 11, 12).

Acarinina pseudotopilensis (Subbotina) 1953 (Pl. 4, Figs. 14, 15).

Acarinina rugosaculeata Subbotina 1953.

Acarinina spinuloinflata (Bandy) 1949. Identification of this form is based on the criteria outlined in Blow (1979).

Acarinina wilcoxensis (Cushman and Ponton) 1932 s.l. Despite the potential utility of this form for placing the approximate position of the Paleocene/Eocene boundary (Blow, 1979), the taxonomy of *A. wilcoxensis* is not clear. For example, Blow (1979) suggested that holotypes of *A. wilcoxensis* (Cushman and Ponton) and *Acarinina esnaensis* (LeRoy) are morphologically inseparable. He considered the former name to have priority. By contrast, Blow (1979) chose to subdivide several morphotypes within the range of *A. wilcoxensis* s.l. He suggested that a progressive flattening of the spiral surface characterized a bioseries beginning with *Acarinina acarinata* s.l. → *A. wilcoxensis wilcoxensis* (= *A. esnaensis*) → *Acarinina wilcoxensis berggreni* (El Naggar) → *A. wilcoxensis strabocella* (Loeblich and Tappan). *A. wilcoxensis strabocella* has a greater number of chambers in its final whorl. We recognize the same morphologic developmental pattern within the range of *A. wilcoxensis* s.l. in the Maud Rise sequences. However, we agree with Berggren (1977) in considering *A. esnaensis* a valid species from the middle to upper Paleocene that probably gave rise to *A. wilcoxensis*. We consider *A. esnaensis* to represent forms lacking spiral-surface flattening and whose apertures are interiomarginal umbilical in position rather than extraumbilical as in *A. wilcoxensis* s.l. On this basis we consider that *A. esnaensis* encompasses forms Blow referred to as *Acarinina acarinita* s.l. (Subbotina). The definition of *A. wilcoxensis* s.l. applied to Antarctic samples is, therefore, more consistent with the widely applied usage of *A. wilcoxensis* for those forms with flattened spiral surfaces that first appeared at or near the Paleocene/Eocene boundary (Stainforth et al., 1975; Berggren, 1977; Tjalsma, 1977; and *A. esnaensis* of Jenkins, 1971).

Acarinina wilcoxensis berggreni Blow 1979 (Pl. 4, Figs. 5, 6). See discussion under *A. wilcoxensis* s.l.

Acarinina wilcoxensis wilcoxensis Blow 1979 (Pl. 4, Figs. 1–3). Refers to forms with greater axial angularity than that of *A. wilcoxensis berggreni*. These forms lack the well-developed fused muricae along the margin, distinguishing them from *Acarinina quetra* Bolli. However, this form may represent a progressive stage in the evolutionary development of *A. quetra* as suggested by Berggren (1977).

Acarinina wilcoxensis strabocella Loeblich and Tappan 1957. Refers to forms similar to *A. wilcoxensis wilcoxensis*, but has additional chambers in the final whorl.

Acarinina velascoensis (Cushman) 1925 (Pl. 4, Figs. 12, 13). This species displays features common to many subbotinid species, including inflated chambers and an asymmetric, umbilical aperture. However, these forms clearly display muricae that distinguish them from other subbotinids. Therefore, we consider this a species of *Acarinina* rather than a subbotinid as suggested by Blow (1979).

Morozovella aequa (Cushman and Renz) 1942 (Pl. 6, Figs. 13–15).

Morozovella convexa (Subbotina) 1953 (Pl. 3, Figs. 5, 6).

Morozovella nicoli (Martin) 1943 (Pl. 4, Fig. 11).

Morozovella subbotinae (Morozova) 1939.

Morozovella tadjikistanensis (Bykova) 1953. Subbotina (1953) considered this species to belong to the acarininids, whereas Premoli-Silva and Boersma (1988) more recently suggested that it belongs with the morozovellids. The placement of this species and the other small and similar muricate forms is arbitrary. There is a need to clarify the taxonomy of this group, which forms such a distinctive assemblage in the upper Paleocene at higher latitudes.

Morozovella tadjikistanensis sp. cf., *djanensis* (Shutskaya). This form differs from *M. tadjikistanensis* in having radial rather than recurved spiral sutures.

Planorotalites australiformis (Jenkins) 1966 (Pl. 5, Figs. 1, 2). There appears to be considerable overlap in the concept of several species. *Planorotalites australiformis* Jenkins, *Planorotalites planoconicus* Subbotina (= *Planorotalites renzi* (Bolli) and *Planorotalites pseudoscitulus* Glaessner; cf. Jenkins, 1971; Tjalsma, 1977; Premoli-Silva and Boersma, 1988, and *P. ehrenbergi* Bolli (cf. Blow, 1979, p. 885) all resemble *Planorotalites pseudomenardii* but are generally smaller and lack a well-developed keel. The specimens referred to as *P. pseudomenardii* in the initial investigations of the Maud Rise material (Barker, Kennett, et al., 1988) based on the presence of a faint keel are now considered to be within the range of variability of *P. australiformis*. *Planorotalites planoconicus* is similar to *P. australiformis* and may fall within the range of variability of the latter. Notwithstanding the taxonomic uncertainties between the various morphotypes discussed above, the *P. australiformis* FAD forms a distinct and biostratigraphically useful horizon in the Antarctic sequences.

Planorotalites planoconicus (Subbotina) 1953. This species is distinguished from *A. australiformis* by having 4.5 to 5 chambers rather than 4 to 4.5 chambers in the final whorl and by having less lunate chambers (cf., Subbotina, 1953; pl. 17, figs. 4, 5).

Planorotalites chapmani (Parr) 1938.

Planorotalites compressus (Plummer) 1926 (Pl. 2, Figs. 8–10).

"Planorotalites" imitatus (Subbotina) 1953 (Pl. 3, Figs. 9, 10). See notes under *"P." imitatus* Zone.

Planorotalites pseudoimitatus (Blow) 1979. Many Maud Rise specimens exhibit the lobe-like extension that partially obscures the umbilicus. Blow (1979) noted that this feature is characteristic of many specimens of this species. The species is placed in *Planorotalites* because the test ultrastructure and coiling mode are similar to others in this group.

Pseudohastigerina micra (Cole, 1927) (Pl. 5, Figs. 7, 8).

Pseudohastigerina wilcoxensis (Cushman and Ponton, 1932) (Pl. 5, Figs. 5, 6).

Testacarinata inconspicua (Howe) 1939 (Pl. 7, Figs. 13, 14).

Globorotalia opima Bolli 1957.

Paragloborotalia nana (Bolli) 1957.

Tenuitella insolita (Jenkins) 1966. Jenkins (1966) originally considered this form to be a globorotalid and placed it in a subgenus he termed *Turborotalia* (Jenkins, 1971). It is considered here to be closely related to the *Tenuitella gemma–Tenuitella munda* group.

Tenuitella gemma (Jenkins) 1966 (Pl. 7, Fig. 10).

Tenuitella munda (Jenkins) 1966.

"Tenuitella" reissi (Loeblich and Tappan) 1957 (Pl. 5, Figs. 3, 4).

Neogloboquadrina pachyderma (Ehrenberg) 1861.

Catapsydrax dissimilis (Cushman and Bermudez) 1937.

Catapsydrax unicavus Bolli, Loeblich, and Tappan 1957.

Catapsydrax martini (Blow and Banner) 1962.

Catapsydrax echinatus Bolli 1957.

Globorotaloides turgida (Finlay) 1939.

Globorotaloides aff. *testarugosa* (Jenkins) 1960 (Pl. 7, Fig. 11).

Globorotaloides suteri Bolli 1957 (Pl. 7, Fig. 12).

Truncorotaloides sp. These forms occur in the upper Oligocene and may represent reworking.

Globigerinatheka index (Finlay) 1939 (Pl. 7, Fig. 8).

Cretaceous Species

Cretaceous species are illustrated in Huber (this volume).

Heterohelix dentata Stenestad 1968.
Heterohelix globulosa (Ehrenberg) 1840.
Heterohelix planata (Cushman) 1938.
Globigerinelloides multispinatus (Lalicker) 1948.
Globigerinelloides subcarinatus (Bronnimann).
Hedbergella monmouthensis (Olsson) 1960.
Hedbergella sliteri Huber 1989.
Archaeoglobigerina australis Huber 1989.
Rugotruncana circumnodifer (Finlay) 1940.
Globotruncanella petaloidea (Gandolfi) 1955.

Abathomphalus mayaroensis (Bolli) 1951.
Globotruncana subcircumnodifer (Gandolfi) 1955.

ACKNOWLEDGMENTS

We express appreciation to the shipboard scientific party for their contribution to the quality of the scientific results and to the ODP Leg 113 crew and technicians for their enthusiasm during the expedition. Reviews by W. Berggren and two anonymous reviewers were particularly useful. We also express appreciation to R. Olsson for information concerning the *Pseudohastigerina* datum. The careful technical assistance of D. Pak is gratefully acknowledged. The research was supported by USSAC grants FD 20103 and FD 20104 to L. Stott and J. Kennett and NSF grants (OCE 87-13391, OCE 88-17135, DPP 88-96183, and DPP 89-11554) to J. Kennett.

REFERENCES

Alvarez, W., Arthur, M. A., Fischer, A. G., Lowrie, W., Napoleone, G., Premoli-Silva, I., and Roggenthen, W. M., 1977. Upper Cretaceous-Paleocene magnetic stratigraphy at Gubbio, Italy. V. Type section for the Late Cretaceous-Paleocene geomagnetic reversal time scale. *Geol. Soc. Am. Bull.*, 88:383-389.

Alvarez, L., Alvarez, W., Asaro, F., and Michel, H., 1980. Extraterrestrial cause for the Cretaceous-Tertiary extinctions. *Science*, 208: 1095-1108.

Alvarez, W., Alvarez, L., Asaro, F., and Michel, H., 1984. The end of the Cretaceous: Sharp boundary or gradual transition?, *Science*, 223: 1183-1186.

Aubry, M.-P., Berggren, W. A., Kent, D. V., Flynn, J. J., Klitgord, K. D., Obradovich, J. D., and Prothero, D. R., 1988. Paleogene geochronology: An integrated approach. *Paleoceanography*, 3:707-742.

Barker, P. F., Kennett, J. P., et al., 1988. *Proc. ODP, Init. Repts.*, 113: College Station, TX (Ocean Drilling Program).

Berggren, W. A., 1969. Rates of evolution in some Cenozoic planktonic foraminifera. *Micropaleontology*, 15:351-365.

________, 1977. Atlas of Paleogene planktonic foraminifera. Some species of the genera *Subbotina, Planorotalites, Morozovella, Acarinina* and *Truncorotaloides*. *In* Ramsay, A.T.S. (Ed.), *Oceanic Micropaleontology*: London (Academic Press), 250-299.

Berggren, W. A., Aubry, M.-P., and Hamilton, N., 1983. Neogene magnetobiostratigraphy of DSDP Site 516 (Rio Grande Rise, South Atlantic). *In* Barker, P., Johnson, D., et al., *Init. Repts. DSDP*, 72: Washington (U.S. Govt. Printing Office), 675-706.

Berggren, W. A., Kent, D. V., and Flynn, J. J., 1985. Paleogene geochronology and chronostratigraphy. *In* Snelling, N. J. (Ed.), *The Chronology of the Geological Record*. Geol. Soc. London Mem., 10:141-195.

Berggren, W. A., and Miller, K. G., 1988. Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiochronology. *Micropaleontology*, 34:362-380.

Bleil, U., 1985. The magnetostratigraphy of northwest Pacific sediments, Deep Sea Drilling Project Leg 86. *In* Heath, G. R., Burckle, L. H., et al., *Init. Repts. DSDP*, 86: Washington (U.S. Govt. Printing Office), 441-458.

Bolli, H. M., 1957. The genera *Globigerina* and *Globorotalia* in the Paleocene-Lower Eocene Lizard Springs Formation of Trinidad. *In* Loeblich, A. R., Jr., Tappan, H., Beckmann, J. P., Bolli, H. M., Gallitelli, E. M., and Troelsen, J. C., *Studies in Foraminifera*. U.S. Nat. Mus. Bull., 215:97-124.

________, 1966. Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera. *Bolet. Infor. Assoc. Venez. Geol. Min. Pet.*, 9:3-32.

Blow, W. H., 1979. *The Cainozoic Globigerinida*, 3 vols: Leiden (E. J. Brill).

Boersma, A., and Premoli-Silva, I., 1983. Paleocene planktonic foraminiferal biogeography and the paleoceanography of the Atlantic Ocean. *Micropaleontolgy*, 29:355-381.

Carter, A. N., 1959. Guide to Foraminifera of the Tertiary stages in Victoria. *Austral. J. Mining Geol.*, 6:48-54.

Corfield, R. M., and Shackleton, N. J., 1988. Comment and Reply on "Danian faunal succession: Planktonic foraminiferal response to a changing marine environment". *Geology*, 16:378-379.

Hedberg, H. D. (Ed.), 1976. *International Stratigraphic Guide. A Guide to Stratigraphic Classification, Terminology, and Procedure*. New York (Wiley).

Hess, J., Stott, L. D., Bender, M., Schilling, J.-G., and Kennett, J. P., 1989. The Oligocene marine microfossil record; age assessments using strontium isotopes. *Paleoceanography*, 4:655-679.

Hsü, K. J., He, Q., McKenzie, J. A., Weissert, H., Perch-Nielsen, K., Oberhänsli, H., Kelts, K., LaBrecque, J., Tauxe, L., Krahenbuhl, U., Percival, S. F., Wright, R., Karpoff, A.-M., Petersen, N., Tucker, P., Poore, R. Z., Gombos, A. M., Pisciotto, K., Carman, M. F., and Schrieber, E., 1982. Mass mortality and its environmental and evolutionary consequences. *Science*, 216:249-256.

Jenkins, D. G., 1966. Planktonic foraminiferal zones and new taxa from the Danian to Lower Miocene of New Zealand: *N.Z. J. Geol. Geophys.*, 7:1088-1126.

________, 1971. New Zealand Cenozoic Planktonic Foraminifera. *N.Z. Geol. Surv., Paleontol. Bull.*, 42:1-278.

________, 1974. Paleogene planktonic foraminifera of New Zealand and the Austral region. *J. Foram. Res.*, 4:155-170.

________, 1975. Cenozoic planktonic foraminiferal biostratigraphy of the Southwestern Pacific and Tasman Sea, DSDP Leg 29. *In* Kennett, J. P., Houtz, R. E., et al., *Init. Repts. DSDP*, 29: Washington (U.S. Govt. Printing Office), 449-467.

Jenkins, D. G., and Srinivasan, M. S., 1985. Cenozoic planktonic foraminifers of the southwest Pacific. *In* Kennett, J. P., von der Borch, C. C., et al., *Init. Repts. DSDP*, 90: Washington (U.S. Govt. Printing Office), 795-834.

Kaneps, A. G., 1975. Cenozoic planktonic foraminifera from Antarctic deep-sea sediments, Leg 28, DSDP. *In* Hayes, D. E., Frakes, L. A., et al., *Init. Repts. DSDP*, 28: Washington (U.S. Govt. Printing Office), 573-584.

Keller, G., 1983. Biochronology and paleoclimatic implications of middle Eocene to Oligocene planktic foraminiferal faunas. *Mar. Micropaleontol.*, 7:463-486.

Kennett, J. P., 1973. Middle and late Cenozoic planktonic foraminiferal biostratigraphy of the southwest Pacific—DSDP Leg 21. *In* Burns, R. E., Andrews, J. E., et al., *Init. Repts. DSDP*, 21: Washington (U.S. Govt. Printing Office), 575-639.

Kennett, J. P., Houtz, R. E., et al., 1975. *Init. Repts. DSDP*, 29: Washington (U.S. Govt. Printing Office).

Lazarus, D., Pallant, A., and Hays, J. D., 1987. A data-base of Antarctic pre-Pleistocene sediment cores. *Woods Hole Ocean. Inst. Tech. Rept.*

Leckie, R. M., and Webb, P. N., 1986. Late Paleogene and Early Neogene foraminifera of DSDP Site 270, Ross Sea Antarctica. *In* Kennett, J. P., von der Borch, C. C., et al., *Init. Repts. DSDP*, 90: Washington (U.S. Govt. Printing Office), 1093-1142.

Loeblich, A. R., Jr., and Tappan, H., 1988. *Foraminiferal Genera and Their Classification*. New York (Van Nostrand).

Lowrie, W., Alvarez, W., Napoleone, G., Perch-Nielsen, K., Premoli-Silva, I., and Toumarkine, M., 1982. Paleogene magnetic stratigraphy in Umbrian pelagic carbonate rocks: The Contessa Sections, Gubbio. *Geol. Soc. Am. Bull.*, 93:414-432.

Ludbrook, N. H., and Lindsay, J. M., 1969. Tertiary foraminiferal zones in South Australia: *Internat. Conf. Plankt. Microfossils, 1st, Geneva, Proc.*, 2:366-375.

Luterbacher, H., and Premoli-Silva, I., 1964. Biostratigrafiea del limite Cretaceou-Terziario nell' Appennino Centale. *Rivista Italiana di Paleontologia e Stratigrafia*, 70:67-128.

McGowran, B., and Lindsay, J. M., 1969. A middle Eocene planktonic foraminiferal assemblage from Eucla Basin. *S. Austral. Dept. Mines Geol. Survey, Quart. Geol. Notes*, 30:2-10.

Michel, H., Asaro, F., Alvarez, W., and Alvarez, L., 1985. Elemental profile of iridium and other elements near the Cretaceous/Tertiary boundary in Hole 577B. *In* Heath, G. R., Burckle, L. H., et al., *Init. Repts. DSDP*, 86: Washington (U.S. Govt. Printing Office), 533-538.

Monechi, S., Bleil, U., Backman, J., 1985. Magnetobiochronology of Late Cretaceous-Paleogene and late Cenozoic pelagic sedimentary sequences from the northwest Pacific (Deep Sea Drilling Project, Leg 86, Site 577). *In* Heath, G. R., Burckle, L. H., et al., *Init. Repts. DSDP*, 86: Washington (U.S. Govt. Printing Office), 787-797.

Montanari, A., Drake, R., Bice, D. M., Alvarez, W., Curtis, H. G., Turrin, B., and DePaolo, D. J., 1985. Radiometric time scale for the upper Eocene and Oligocene based on K/Ar and Rb/Sr dating of volcanic biotites from the pelagic sequence of Gubbio, Italy. *Geology*, 13:596–599.

Nocchi, M., Parisi, G., Monaco, P., Monechi, S., Madile, M., Napoleone, G., Ripepe, M., Orlando, M., Premoli-Silva I., and Bice, D., 1986. The Eocene-Oligocene boundary in the Umbrian pelagic sequences, Italy. *In* Pomerol, C., and Premoli-Silva, I. (Eds.), *Terminal Eocene Events. Developments in Paleontology and Stratigraphy*: Amsterdam (Elsevier), 25–40.

Odin, G. S., 1986. Radiometric data across the Eocene-Oligocene transition: events and boundary. *In* Pomerol, C., and Premoli-Silva, I. (Eds.), *Terminal Eocene Events. Developments in Paleontology and Stratigraphy*: Amsterdam (Elsevier), 58–62.

Peterson, N., Heller, F., and Lowrie, W., 1984. Magnetostratigraphy of the Cretaceous/Tertiary geological boundary. *In* Hsü, K. J., LaBrecque, J. L., et al., *Init. Repts. DSDP*, 73: Washington (U.S. Govt. Printing Office), 645–655.

Poore, R. Z., Tauxe, L., Percival, S. F., Jr., LaBrecque, J. L., Wright, R., Petersen, N. P., Smith, C. C., Tucker, P., and Hsü, K. J., 1984. Late Cretaceous–Cenozoic magnetostratigraphic and biostratigraphic correlations for the South Atlantic Ocean, Deep Sea Drilling Project Leg 73. *In* Hsu, K. J., LaBrecque, J. L., et al., *Init. Repts. DSDP*, 73: Washington (U.S. Govt. Printing Office), 645–655.

Premoli-Silva, I., and Boersma A., 1988. Atlantic Eocene planktonic foraminiferal historical biogeography and paleohydrographic indices. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 687:315–356.

Premoli-Silva, I., and Bolli, H. M., 1973. Late Cretaceous to Eocene planktonic foraminifera and stratigraphy of Leg 15 sites in the Caribbean Sea. *In* Edgar, N. T., Saunders, J. B., et al., *Init. Repts. DSDP*, 15: Washington (U.S. Govt. Printing Office), 449–547.

Pujol, C., 1983. Cenozoic planktonic foraminiferal biostratigraphy of the southwestern Atlantic (Rio Grande Rise): Deep Sea Drilling Project Leg 72. *In* Barker, P. F., Carlson, R. L., Johnson, D. A., et al., *Init. Repts. DSDP*, 72: Washington (U.S. Govt. Printing Office), 623–673.

Smit, J., 1977. Discovery of a planktonic foraminiferal association between the *Abathomphalus mayaroensis* Zone and the *Globigerina eugubina* Zone at the Cretaceous/Tertiary boundary in the Barranco del Gredero (Caravaca, SE Spain). *Koninklijke Ned. Akad. Wet. Proc.*, Ser. B, 80:280–301.

———, 1979. The Cretaceous/Tertiary transition in the Barranco del Gredero, Spain. *In* Christensen, W. K., and Birkelund, T. (Eds.), *Cretaceous-Tertiary Boundary Events Symposium II*, Denmark (Univ. Copenhagen), 156–163.

———, 1982. Extinction and evolution of planktonic foraminifera after a major impact at the Cretaceous/Tertiary boundary. *In* Silver, L. T., and Schultz, P. H. (Eds.), *Geological Implications of Impacts and Large Asteroids and Comets on the Earth*. Geol. Soc. Am. Spec. Pap., 190:329–352.

Srinivasan, M. S., and Kennett, J. P., 1981. Neogene planktonic foraminiferal biostratigraphy and evolution: Equatorial to Subantarctic, South Pacific. *Mar. Micropaleontol.*, 6:499–533.

Stainforth, R. M., Lamb, J. L., Luterbacher, H., Beard, J. H., and Jeffords, R. M., 1975. *Cenozoic Planktonic Foraminifera Zonation and Characteristics of Index Forms.* Univ. Kansas Paleontol. Contrib., 62.

Subbotina, N. N., 1953. Fossil Foraminifera of the USSR: Globigerinidae, Hantkeninidae and Globorotalidae. *Trudy VNIGRI*, new series, 76 (in Russian). Trans. to English by E. Lees, Collet's Ltd., London and Wellingborough.

Tjalsma, R. C., 1977. Cenozoic foraminifera from the South Atlantic, DSDP Leg 36. *In* Barker, P. F., Dalziel, I.W.D., et al., *Init. Repts. DSDP*, 36: Washington (U.S. Govt. Printing Office), 493–517.

Toumarkine, M., and Luterbacher, H. P., 1985. Paleocene and Eocene planktonic foraminifera. *In* Bolli, H. M., Saunders, J. B., and Perch-Nielsen, K. D. (Eds.), *Plankton Stratigraphy*: Cambridge (Cambridge Univ. Press), 87–154.

Webb, P. N., 1986. Foraminifera (Late Cenozoic). *In* Barrett, P. J. (Ed.), *Antarctic Cenozoic History from the MSSTS-1 Drillhole, McMurdo Sound*: N.Z. Dept. Sci. Industr. Res. Bull., 237:127–129.

Webb, P. N., and Wrenn, J. H., 1982. Late Cenozoic micropaleontology and biostratigraphy of eastern Taylor Valley, Antarctica. *In* Craddock, C. (Ed.), *Antarctic Geoscience*: Madison (Univ. Wisconsin), 1117–1122.

Webb, P. N., Leckie, R. M., and Ward, B. L., 1986. Foraminifera (Late Oligocene). *In* Barrett, P. J. (Ed.), *Antarctic Cenozoic history from the MSSTS-1 drillhole, McMurdo Sound*: N.Z. Dept. Sci. Industr. Res. Bull., 237:115–125.

Date of initial receipt: 1 March 1989
Date of acceptance: 21 July 1989
Ms 113B-121

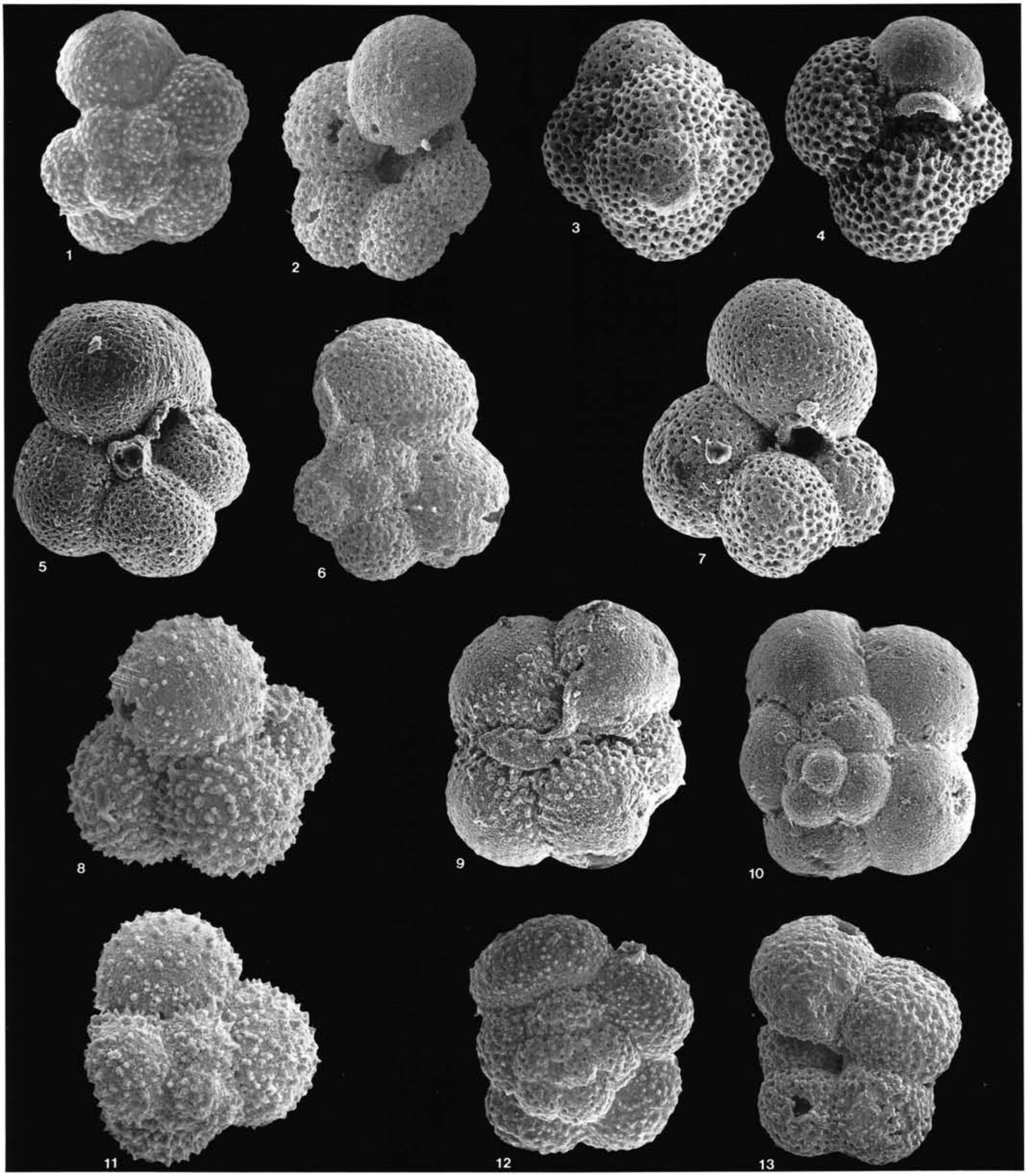

Plate 1. **1–2.** *"Globorotalia" (Turborotalia) polycamera*; (1) Sample 113-689B-25X-5, 48–50 cm, spiral view, ×540; (2) same specimen, umbilical view, ×540. **3–4.** *Subbotina moskovini*; (3) Sample 113-690C-15X-4, 28–30 cm, spiral view, ×200; (4) same specimen, umbilical view, ×200. **5–6.** *Eoglobigerina fringa*; (5) Sample 113-690C-15X-4, 28–30 cm, umbilical view, ×200; (6) same specimen, spiral view, ×200. **7.** *Eoglobigerina eobulloides*, Sample 113-690C-15X-4, 45–47 cm, umbilical view, ×200. **8, 11.** *Globoconusa daubjergensis*; (8) Sample 113-689B-25X-5, 48–50 cm, umbilical view, ×1084; (11) same specimen, spiral view, ×550. **9–10.** *Eoglobigerina edita*; (9) Sample 113-690C-15X-3, 95–97 cm, umbilical view, ×200; (10) same specimen, spiral view, ×200. **12–13.** *"Globorotalia" (Turborotalia) tetragona*; (12) Sample 113-690C-15X-4, 28–30 cm, spiral view, ×400; (13) same specimen, umbilical view, ×450.

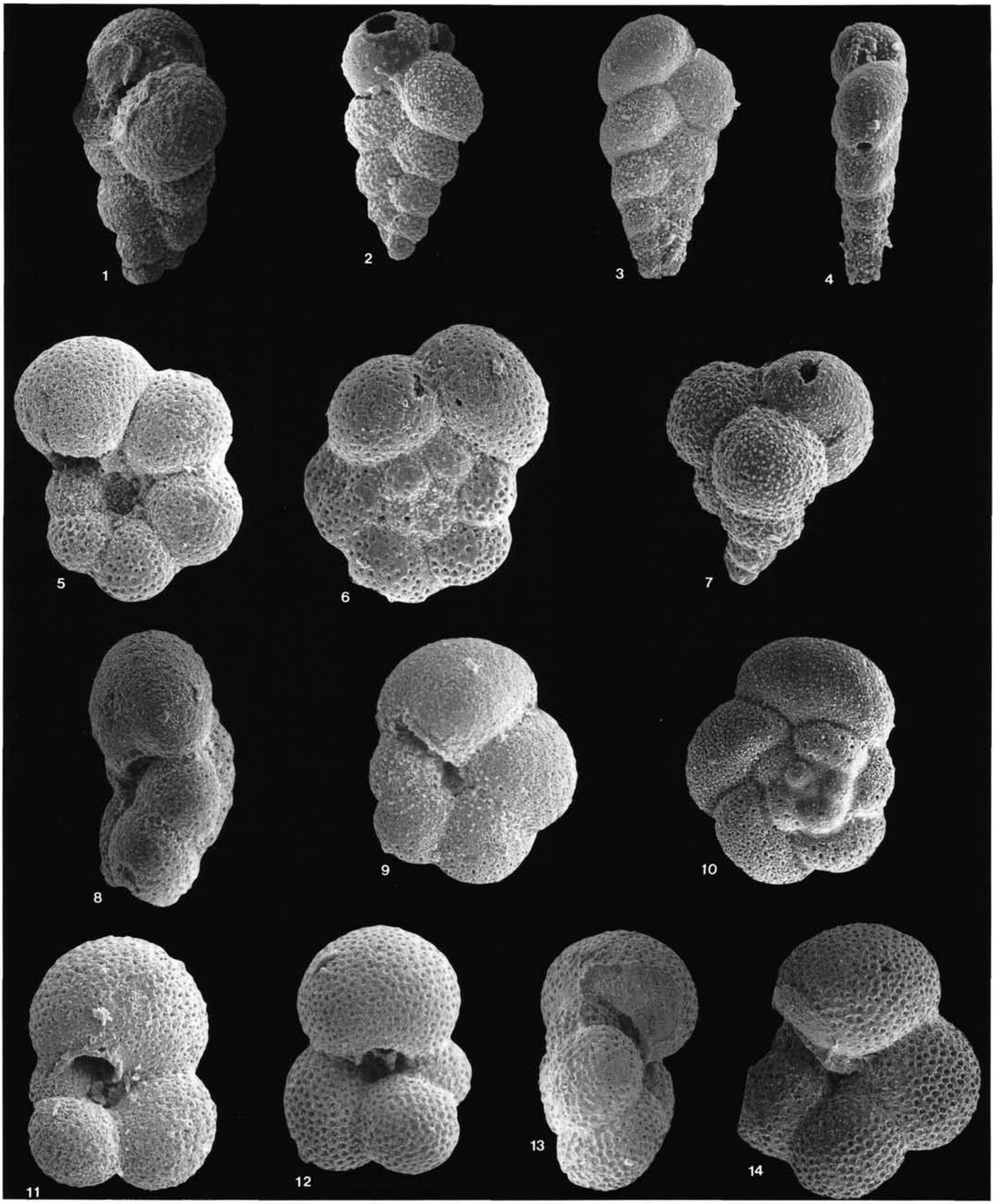

Plate 2. **1.** *Chiloguembelina taurica*; Sample 113-689B-25X-5, 48–50 cm, apertural view, ×340. **2.** *Chiloguembelina wilcoxensis*, Sample 113-689B-25X-5, 48–50 cm, side view, ×300. **3–4.** *Chiloguembelina* (elongate); (3) 113-689B-25X-5, 79–81 cm, side view, ×755; (4) same specimen, apertural view, ×380. **5–6.** *Subbotina inconstans*; (5) Sample 113-690C-14X-2, 36–40 cm, umbilical view, ×200; (6) same specimen, spiral view, ×200. **7.** *Guembelitria cretacea*, Sample 113-690C-15X-3, 41–45 cm, side view, ×200. **8–10.** *Planorotalites compressus*; (8) Sample 113-690C-15X-3, 41–45 cm, side view, ×200; (9) Sample 113-690C-14X-1, 110–114 cm, umbilical view, ×500; (10) Sample 113-690C-14X-1, 110–114 cm, spiral view, ×500. **11.** *Eoglobigerina trivialis*, Sample 113-690C-15X-2, 46–50 cm, umbilical view, ×260. **12.** *Subbotina triloculinoides*, Sample 113-690C-15X-2, 46–50 cm, umbilical view, ×300. **13–14.** *Subbotina pseudobulloides*; (13) Sample 113-690C-14X-3, 36–40 cm, side view, ×220; (14) same specimen, umbilical view, ×220.

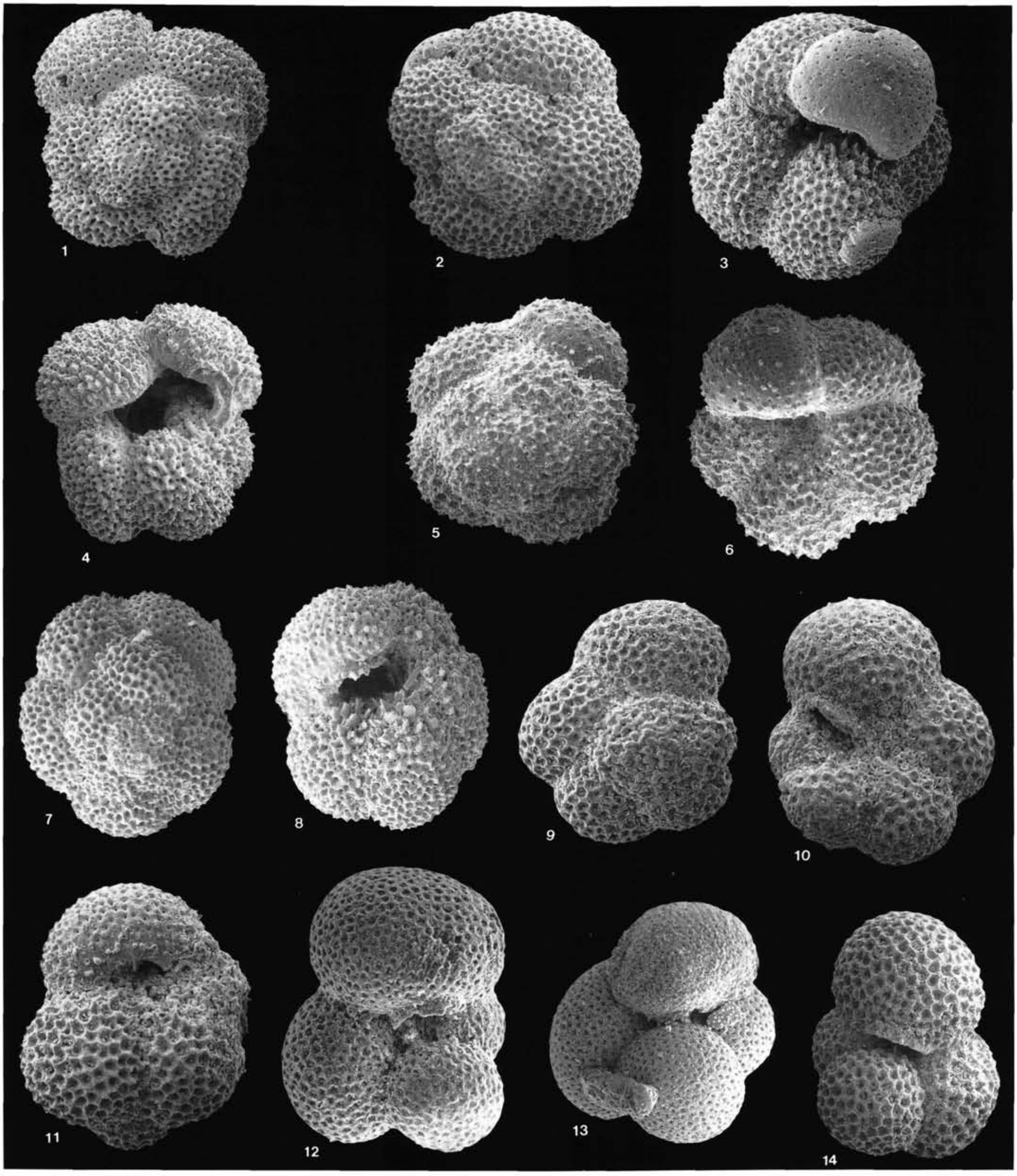

Plate 3. **1, 4.** *Muricoglobigerina soldadoensis soldadoensis*; (1) Sample 113-689B-22X-5, 110–114 cm, spiral view, ×180; (4) same specimen, umbilical view, ×180. **2–3.** *Muricoglobogerina aquiensis*; (2) Sample 113-689B-23X-1, 108–112 cm, spiral view, ×260; (3) same specimen, umbilical view, ×300. **5–6.** *Morozovella convexa*; (5) Sample 113-690B-19H-4, 36–40 cm, spiral view, ×280; (6) same specimen, umbilical view, ×280. **7–8.** *Muricoglobigerina mckannai*; (7) Sample 113-690B-17H-5, 36–40 cm, spiral view, ×250; (8) same specimen, umbilical view, ×250. **9–10.** *"Planorotalites" imitatus*; (9) Sample 113-689B-24X-CC, spiral view, ×330; (10) same specimen, umbilical view, ×330. **11.** *Igorina spiralis*, Sample 113-689B-24X-CC, umbilical view, ×330. **12.** *Subbotina triangularis*, Sample 113-690C-15X-3, 41–45 cm, umbilical view, ×200. **13.** *Subbotina* aff. *eocaenica*, Sample 113-689B-25X-5, 79–81 cm, umbilical view, ×240. **14.** *Subbotina eocaenica* sensu Blow, Sample 113-689B-15H-7, 35–39 cm, umbilical view, ×210.

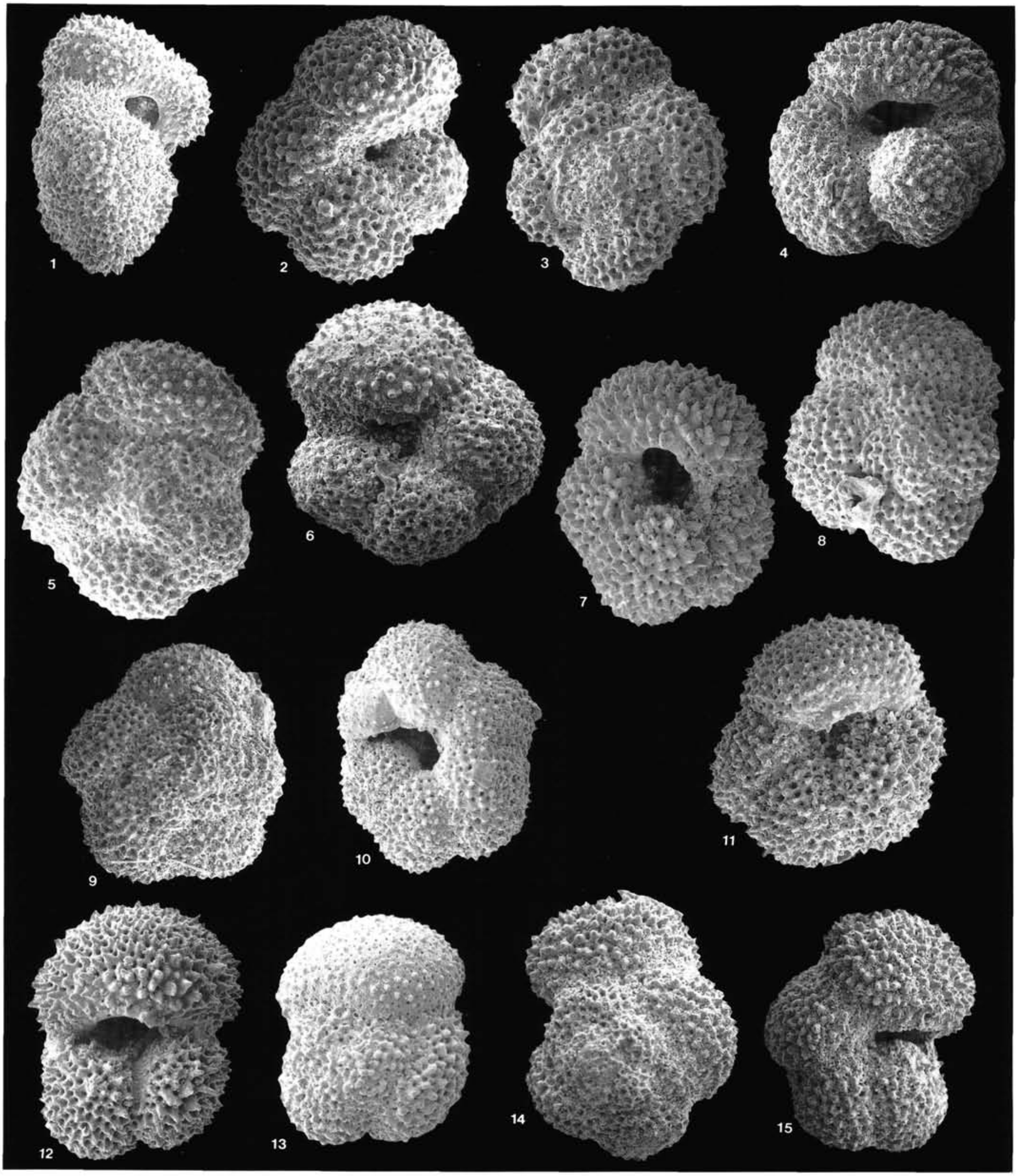

Plate 4. **1–3.** *Acarinina wilcoxensis wilcoxensis*; (1) Sample 113-690B-15X-4, 36–40 cm, side view, ×190; (2) Sample 113-690B-15H-3, 110–114 cm, umbilical view, ×300; (3) same specimen, spiral view, ×300. **4.** *Acarinina nitida*, Sample 113-690B-15H-3, 110–114 cm, umbilical view, ×210. **5–6.** *Acarinina wilcoxensis berggreni*; (5) Sample 113-689B-22X-2, 35–39 cm, spiral view, ×330; (6) same specimen, umbilical view, ×330. **7–8.** *Acarinina esnaensis*; (7) Sample 113-689B-22X-5, 110–114 cm, umbilical view, ×270; (8) same specimen, spiral view, ×270. **9–10.** *Acarinina praepentacamerata*; (9) Sample 113-689B-23X-1, 108–112 cm, spiral view, ×240; (10) same specimen, umbilical view, ×240. **11.** *Morozovella nicoli*, Sample 113-689B-23X-3, 108–112 cm, umbilical view, ×380. **12–13.** *Acarinina velascoensis*; (12) Sample 113-690B-17H-5, 36–40 cm, umbilical view, ×600; (13) Sample 113-689B-22X-5, 110–114 cm, spiral view, ×210. **14–15.** *Acarinina pseudotopolensis*; (14) Sample 113-689B-22X-1, 110–114 cm, spiral view, ×250; (15) same specimen, umbilical view, ×250.

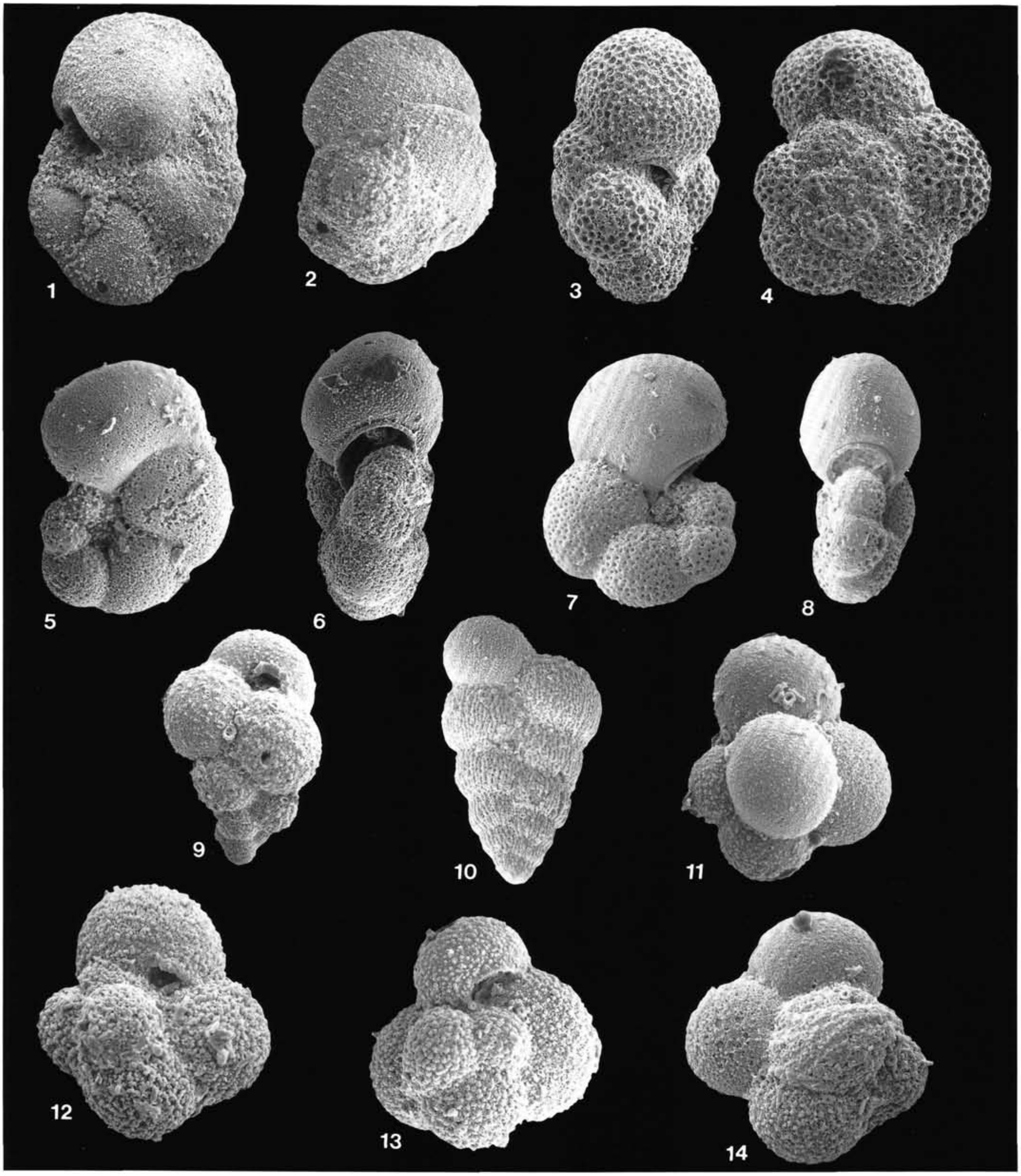

Plate 5. **1-2.** *Planorotalites australiformis*; (1) Sample 113-690B-18H-1, 36-40 cm, umbilical view, ×350; (2) same specimen, spiral view, ×270. **3-4.** *"Tenuitella" reissi*; (3) Sample 113-690B-15H-6, 36-40 cm, side view, ×500; (4) Sample 113-690B-15H-6, 36-40 cm, spiral view, ×500. **5-6.** *Pseudohastigerina wilcoxensis*; (5) Sample 113-690B-15H-4, 36-40 cm, spiral view, ×310; (6) same specimen, apertural view, ×280. **7-8.** *Pseudohastigerina micra*; (7) Sample 113-689B-20H-2, 35-39 cm, spiral view, ×270; (8) same specimen, apertural view, ×270. **9.** *Chiloguembelitria* sp., Sample 113-689B-20H-3, 35-39 cm, umbilical view, ×450. **10.** *Chiloguembelina cubensis*, Sample 113-689B-10H-4, 35-39 cm, side view, ×350. **11-14.** *Globigerina* sp. B; (11) Sample 113-689B-21H-1, 110-114 cm, bullate view, ×650; (12) Sample 113-689B-21H-1, 110-114 cm, umbilical view, ×650; (13) Sample 113-689B-21H-1, 110-114 cm, umbilical view, ×650; (14) Sample 113-689B-21H-1, 110-114 cm, spiral view, ×650.

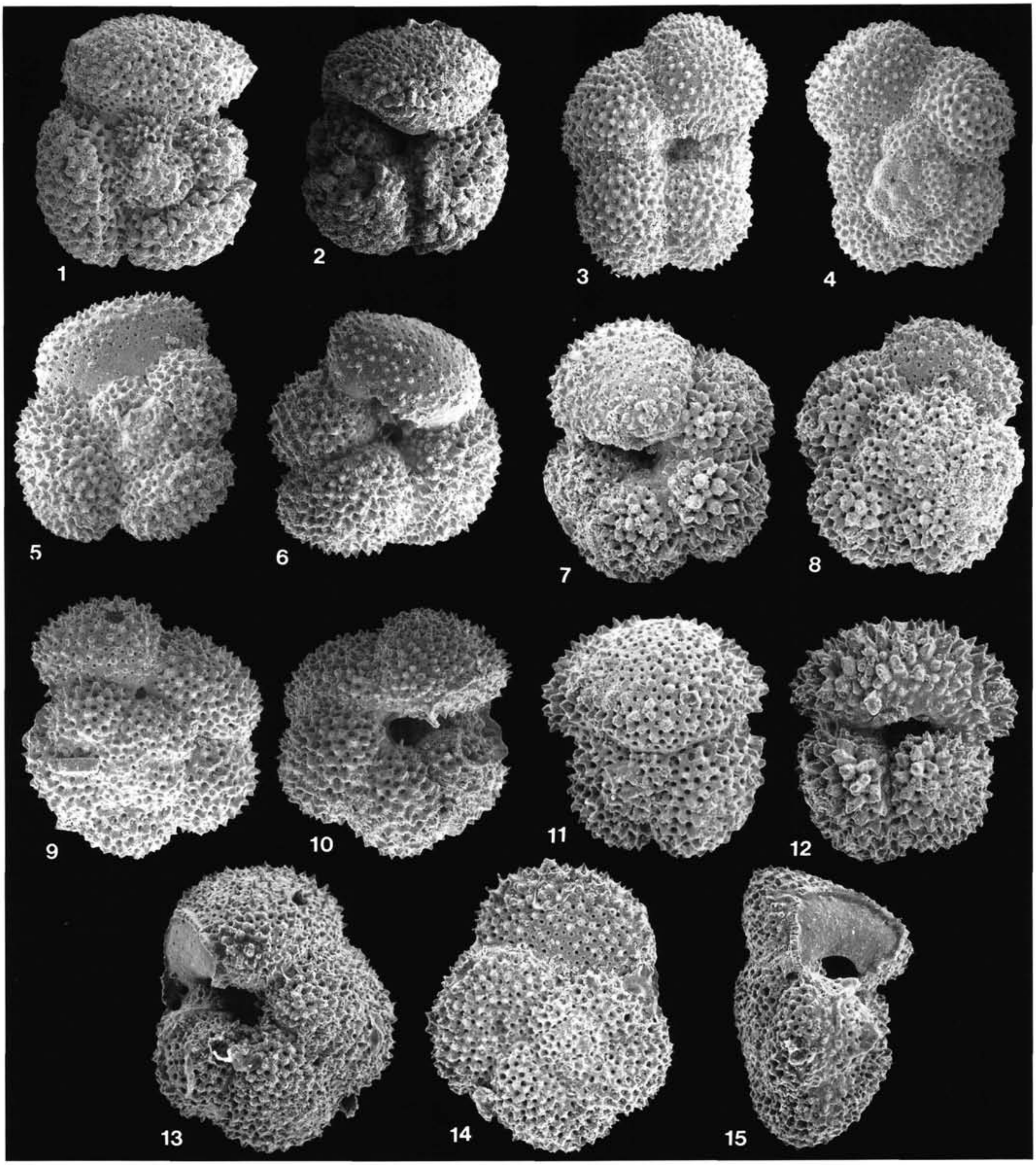

Plate 6. **1–2.** *Acarinina matthewsae*; (1) Sample 113-689B-19H-5, 35–39 cm, spiral view, ×160; (2) same specimen, umbilical view, ×160. **3–4.** *Acarinina interposita*; (3) Sample 113-689B-20H-3, 35–39 cm, umbilical view, ×250; (4) same specimen, spiral view, ×250. **5–6.** *Acarinina bullbrooki*; (5) Sample 113-689B-19H-5, 35–39 cm, spiral view, ×270; (6) same specimen, umbilical view, ×270. **7–8.** *Acarinina collactea*; (7) Sample 113-689B-21H-1, 110–114 cm, umbilical view, ×160; (8) same specimen, spiral view, ×160. **9–10.** *Acarinina pentacamerata*; (9) Sample 113-690B-15H-3, 110–114 cm, spiral view, ×300; (10) same specimen, umbilical view, ×300. **11–12.** *Acarinina primitiva*; (11) Sample 113-689B-21H-1, 110–114 cm, spiral view, ×160; (12) same specimen, umbilical view, ×160. **13–15.** *Morozovella aequa*; (13) Sample 113-690B-16H-7, 36–40 cm, umbilical view, ×160; (14) same specimen, spiral view, ×160; (15) same specimen, side view, ×160.

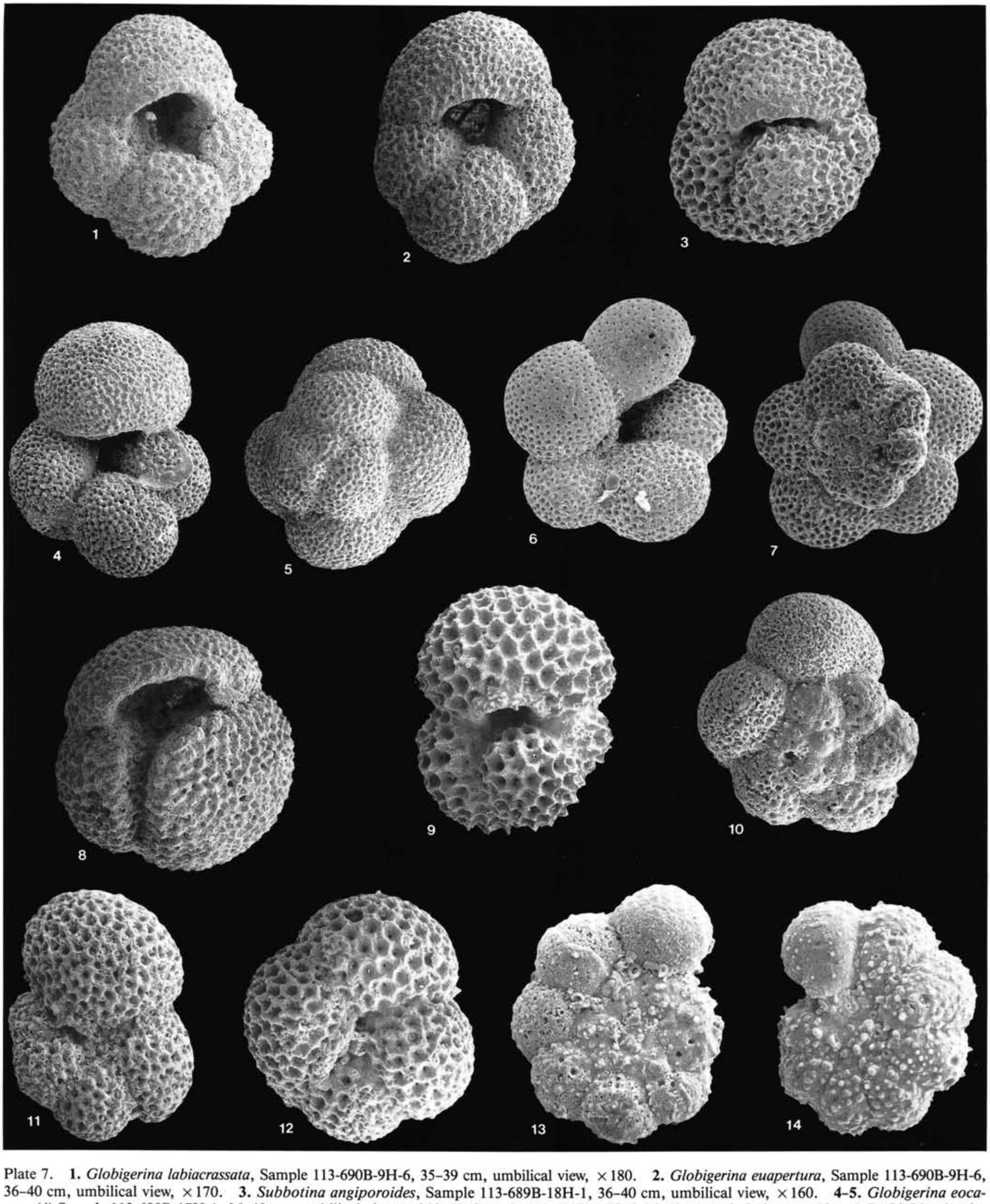

Plate 7. **1.** *Globigerina labiacrassata*, Sample 113-690B-9H-6, 35–39 cm, umbilical view, ×180. **2.** *Globigerina euapertura*, Sample 113-690B-9H-6, 36–40 cm, umbilical view, ×170. **3.** *Subbotina angiporoides*, Sample 113-689B-18H-1, 36–40 cm, umbilical view, ×160. **4–5.** *Globigerina eocaena*; (4) Sample 113-690B-17H-1, 36–40 cm, umbilical view, ×250; (5) Sample 113-690B-17H-5, 36–40 cm, spiral view, ×150. **6–7.** *Globigerina lozanoi*; (6) Sample 113-689B-17H-1, 36–40 cm, umbilical view, ×160; (7) same specimen, spiral view, ×160. **8.** *Globigerina index*, Sample 113-690B-12H-3, 36–40 cm, umbilical view, ×220. **9.** *Subbotina linaperta*, Sample 113-689B-17H-1, 35–37 cm, umbilical view, ×250. **10.** *Tenuitella gemma*, Sample 113-689B-17H-4, 35–37 cm, spiral view, ×420. **11.** *Globorotaloides* aff. *testarugosa*, Sample 113-689B-20H-3, 35–39 cm, umbilical view, ×260. **12.** *Globorotaloides suteri*, Sample 113-689B-17H-1, 35–37 cm, umbilical view, ×460. **13–14.** *Testicarinata inconspicua*; (13) Sample 113-689B-17H-6, 35–37 cm, spiral view, ×550; (14) Sample 113-689B-17H-6, 35–37 cm, umbilical view, ×550.