

31. MIDDLE EOCENE TO HOLOCENE BENTHIC FORAMINIFER ASSEMBLAGES FROM THE KERGUELEN PLATEAU (SOUTHERN INDIAN OCEAN)¹

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ABSTRACT

Middle Eocene to Holocene benthic foraminifers were studied in sediments from Sites 736, 738, and 744 (Kerguelen Plateau). Significant faunal changes took place in the middle Eocene, late Eocene/early Oligocene, middle Miocene, and late Miocene. The benthic assemblages are characterized by gradual species replacements. Assemblage boundaries are defined where first appearance datums (FAD's) and last appearance datums (LAD's) concentrate. The Eocene fauna was dominated by *Nuttallides truempyi*. Buliminids became important at the end of the Eocene and in the early Oligocene *Nuttallides umbonifera* became dominant. The FAD of *N. umbonifera* is coeval with the onset of the first paleoceanographic indications, such as ice rafted material, of Antarctic glaciation. The establishment of the Antarctic Circumpolar Current in the middle Oligocene is reflected at Site 738 by an erosional hiatus. The increase in relative abundance of *Nuttallides umbonifera* at Site 744 during the same interval indicates cold, carbonate-corrosive bottom water. *Epistominella exigua* dominates the bathyal to abyssal upper Miocene to Holocene sediments at Sites 744 and 738, preferring the high supply of organic matter associated with increased upwelling near the Antarctic convergence. Site 736 has a benthic fauna, highly diluted by biosiliceous sedimentation. Significant increases of benthic foraminiferal numbers may indicate changes of the Polar Front during Pliocene/Pleistocene time.

INTRODUCTION

Many deep-water benthic foraminifers are cosmopolitan organisms and their paleontological ranges cover large time spans. Therefore they are not so useful in detailed biostratigraphy as planktonic microfossil groups. Benthic foraminifers are, however, good paleoenvironmental indicators. Marine benthic assemblages are exposed to changing bottom water configurations, as well as to variations in the supply of organic matter due to fluctuations in biological surface productivity. High-latitude areas are of special interest for the study of the impact of paleoenvironmental changes on organisms, because these regions are presently major sources of bottom water masses. In addition, they are characterized by extreme ecological conditions, and they are greatly affected by glacial changes during the Cenozoic.

Ocean Drilling Program (ODP) Leg 119 drilled at six sites along a latitudinal transect across the Kerguelen Plateau, three of which were used in the present study (Fig. 1). This paper concentrates on distinct assemblages and times of faunal change of middle Eocene to Holocene benthic foraminifers. Detailed paleoceanographic discussions based on isotope data are given for the Paleogene and early Miocene by Barrera and Huber (this volume) and for the middle Miocene by Woodruff and Chambers (this volume).

Present surface water masses around Antarctica are influenced by the Antarctic Circumpolar Current (ACC). Sedimentation around Antarctica is altered by the position of the Polar Front which separates biosiliceous sediments in antarctic waters to the south and calcareous sediments in subantarctic waters to the north (Gordon, 1971). Site 736 in middle bathyal depth (629 m water depth) on the northern part of the plateau is beneath the modern Polar Front. Sites 744 (2307 m water depth) and 738 (2253 m water depth) in upper abyssal depth (for the bathymetric

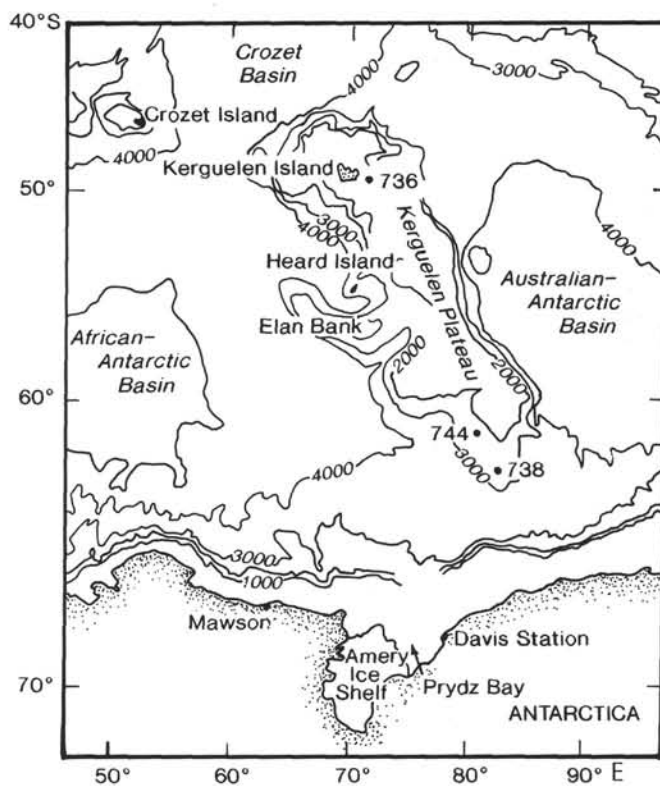


Figure 1. Location map of Sites 736, 738, and 744 on the Kerguelen Plateau. Bathymetry in meters.

division; see Berggren and Miller, 1989) are south of the Polar Front, and are influenced by Circumpolar Deep Water (CPDW) (Lindenberg and Auras, 1984).

Paleogene through Neogene bathyal to abyssal benthic foraminifer assemblages have been studied to a great extent (e.g., Tjalsma, 1983; Tjalsma and Lohmann, 1983; Miller, 1983; Thomas, 1985, 1986a, 1986c; Miller and Katz, 1987). The most

¹ Barron, J., Larsen, B., et al., 1991. *Proc. ODP, Sci. Results*, 119: College Station, TX (Ocean Drilling Program).

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suitable data of comparison for the assemblage changes discussed here are the results of ODP Leg 120 which are in preparation (A. Mackensen, pers. comm. 1989). Leg 120 drilled the central and southern part of the Kerguelen Plateau and recovered Upper Cretaceous to Holocene sediments (Schlich et al., 1988). Late Cenozoic benthic species of the Ninetyeast Ridge were studied by Boltovskoy (1978). Shallow-water benthic foraminifers from the upper Oligocene to Pleistocene were recorded at Deep Sea Drilling Project (DSDP) Site 270 (Leckie and Webb, 1985). Tertiary benthic foraminifers were described from DSDP Leg 74 on the Walvis Ridge (Boersma, 1984). A continuous benthic foraminiferal record from the Maestrichtian through Neogene of southern high latitudes was recovered during ODP Leg 113 from the Maud Rise in the Weddell Sea (Thomas, 1990). There, large parts of the upper Neogene section are missing as a result of unconformities and calcium carbonate dissolution.

Results of several studies, performed on Quaternary benthic foraminifers and their relationships to bottom water masses in the Indian Ocean (Corliss, 1979a, 1979b; Peterson, 1984), can be used to predict environmental/faunal relationships in the past, presuming that species are responding in a similar manner to ecological parameters through time.

MATERIALS AND METHODS

Benthic foraminifers from three sites on the Kerguelen Plateau were studied (Fig. 1). Site 736 (49°24.12'S, 71°39.61'E; water depth 629 m), located on the northern plateau, recovered upper Pliocene to Holocene sediments. Samples (10 cm³) were taken at 1.50 m intervals. Core recovery averaged 100% at Hole 736B, 58% at Hole 736A, and 20% at Hole 736C. Site 744 (61°34.65'S, 80°35.46'E; water depth 2307.8 m) and Site 738 (62°42.54'S, 82°47.24'E; water depth 2252.5 m) are located on the southern plateau, and recovered upper Eocene to Quaternary (Site 744) and lower Turonian to Quaternary (Site 738) sediments. Samples spaced at 1.50 m were studied from both sites for the Neogene sections; core-catcher samples only were available from sediments older than Miocene. At Site 738 only Hole 738B, which reaches into the middle Eocene, was studied; for the late Cretaceous to Paleocene fauna, see Huber (this volume). Hole 738B had good core recovery of 79% with an almost full recovery in the upper 108 m below seafloor (mbsf). Site 744 reached full recovery in Hole 744B which covers the upper 80 mbsf and in Hole 744A for Cores 119-744A-10H to 119-744A-20H.

The biochronology of Barron et al. (this volume), based on the time scale of Berggren et al. (1985), was used to establish a biostratigraphic time frame. The planktonic foraminiferal zonation is obtained from Huber (this volume) and Barron et al. (this volume). The biostratigraphy as derived from all fossil groups revealed a number of unconformities. An unconformity is present in Core 738B-2H, spanning most of the upper Pliocene and lower Pleistocene. Parts of the lower Oligocene through upper Miocene (Section 119-738B-3H-3) are also not represented in sediments. Another unconformity is present at the middle/upper Eocene boundary at Site 738. Site 744 was drilled in a comparable water depth in the hope of recovering the missing lower Oligocene to upper Miocene section. The continuous section of fossiliferous sediments recovered at this site complements the record of Site 738, and both sites offer a base for comparison of benthic foraminifer assemblages. An unconformity in Site 744 of about 5 m.y. duration is present in latest Miocene to Pliocene time (Barron et al., this volume).

Samples were washed through a 0.063 mm sieve and the residue dried. The entire size fraction >0.063 mm was analyzed to ensure the inclusion of the large number of small species (Schröder et al., 1987). In samples with a high abundance of foraminifers a split of approximately 200–300 specimens was

identified and counted. In numerous sections, especially at Site 736, foraminifers are rare. In samples with at least 100 specimens the more abundant species are expressed in relative abundance.

Useful publications for taxonomic species identification were Cushman and Parker (1947), Parker (1964), Boltovskoy (1978), Berggren and Aubert (1976), Thomas (1985, 1986c), Tjalsma and Lohmann (1983), Miller (1983), Miller and Katz (1987), Morkhoven et al. (1986), and Loeblich and Tappan (1987).

RESULTS

Abundance and Preservation

Site 736 recovered 370 m of diatom ooze with a varying input of volcanic debris and a small, nonvolcanic terrestrial component. The benthic assemblage is characterized by extreme fluctuations in total number of specimens. Barren sections are interrupted by sudden increases to over 8000 individuals per 10 cm³ (Fig. 2). The Quaternary interval generally has a more abundant benthic fauna than the Pliocene interval. All samples below 310 mbsf (Core 119-736C-12R) are barren of foraminifers. The short,

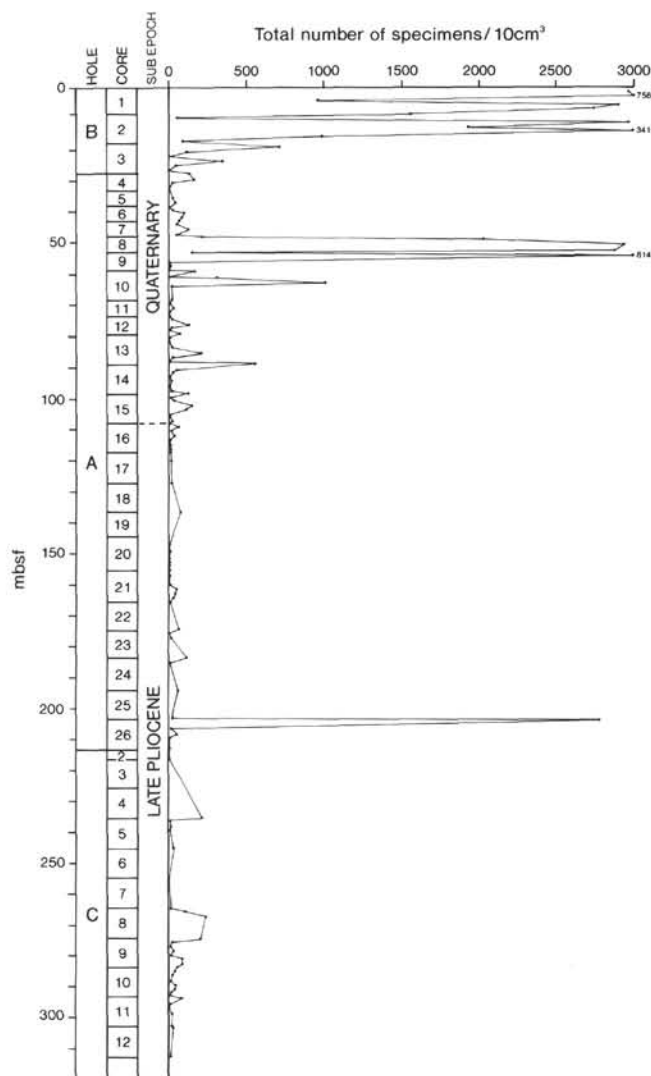


Figure 2. Absolute abundance of benthic foraminifers per 10 cm³ at Site 736.

dramatic increases of benthic specimens do not show a periodic pattern. Unfortunately the foraminiferal record is too sparse and scattered to attempt to obtain stable isotope data. The presence of planktonic foraminifers varies in a similar manner from the domination of the studied size fraction to a complete absence. All foraminifers are generally well preserved throughout the entire sequence, but show signs of corrosion on SEM photographs.

Characteristic of Site 738 are the Quaternary to upper Pliocene calcareous diatom ooze; a decreased calcareous component during the upper Pliocene to upper Miocene; an abrupt change into nannofossil ooze down to the middle Eocene, and the presence of calcareous chalk and limestone below the middle Eocene. Benthic foraminifers are rare compared to the number of planktonic foraminifers, but the numbers are in most sections sufficient for a quantitative study. The interval above an unconformity separating the upper Miocene from the lower Oligocene (Samples 119-738B-2H-6; 115–120 cm, to 119-738B-3H-2; 80–85 cm) is barren of calcareous species, but contains rare agglutinated specimens. These samples have an increased terrigenous mineral component and contain abundant diatoms and radiolarian tests in the >0.063 mm size fraction. Agglutinated tests and pebble-sized particles have ferromanganese coatings, indicating a high oxygen content of the waters and a slow sedimentation rate. This suggests the presence of an erosional surface. The preservation of benthic foraminifers throughout the Eocene to Neogene sediments is generally good, but specimens show some signs of corrosion such as a rough surface of the test and broken chambers.

Site 744 contains highly fossiliferous sediments, consisting of a calcareous diatom ooze in the Pliocene/Pleistocene sequence, and nannofossil ooze from the Eocene to Miocene. Benthic foraminifers are present in varying numbers, but generally common throughout the entire sequence. Specimens are well preserved. In the middle part of the Pliocene (Sample 119-744B-2H-5, 25–27 cm; 15.75 mbsf) numbers of planktonic and benthic foraminifers decrease drastically for a short interval. The residue is dominated by mineral grains, large-sized diatom and radiolarian tests, and rare agglutinated foraminiferal specimens. The lithological sequences at Sites 744 and 738 are similar phenomena within an equivalent age sequence.

Foraminiferal Changes

The entire benthic foraminiferal assemblage of the studied material contains a total of more than 200 species. Benthic assemblages are commonly dominated by a small number of taxa, and the fluctuations in relative abundances in this continuous record indicate paleoenvironmental changes. Precise biostratigraphic ranges for a large number of rare species cannot be determined. In addition, the confusing taxonomy of benthic foraminifers and the different size fractions used do not facilitate a comparison between different studies (Boltovskoy, 1978, 1980; Thomas, 1990). At this point the identification of numerous species is still in progress, and this study concentrates on the more common species.

Five benthic assemblages are recognized in the middle Eocene to Quaternary sequence of Sites 738 and 744. Their boundaries are marked through FAD's and LAD's in a defined interval. These faunal changes are assigned to one particular sample by choosing the LAD's of certain species. The assemblage boundaries, however, are marked in some cases by a transitional zone, where a gradual change in species composition takes place. The middle bathyal Pliocene/Pleistocene assemblage represented in Site 736 differs from these five assemblages and is discussed separately.

Site 738

Sites 738 and 744 have to be discussed in close association because Site 744 includes the interval that was not deposited at Site 738 due to a hiatus. The following five assemblages and their ages derived from the correlation with planktonic microfossil groups (Barron, et al., this volume) are recognized:

- Assemblage 1: latest Miocene to Quaternary
- Assemblage 2: late middle Miocene to early late Miocene
- Assemblage 3: early Oligocene to middle Miocene
- Assemblage 4: latest middle Eocene to late Eocene
- Assemblage 5: early middle Eocene to late middle Eocene

Drilling at Site 738 recovered lower Turonian to Pleistocene sediments, however, only middle Eocene to Quaternary benthic foraminifers are described here. Assemblages 1 and 3–5 are present whereas Assemblage 2 is missing because of an unconformity. Many FAD's and LAD's are questionable because of the unconformities. Therefore, a positioning of the upper boundary of Assemblage 3 and the lower boundary of Assemblage 1 is not precise. Changes of selected dominant species are illustrated in Figure 3 and biostratigraphic ranges of species are shown in Figure 4. Appendix A is an alphabetical list of those species in Figure 4; Appendix B is a list of all identified species.

Assemblage 5: early middle Eocene to late middle Eocene

The lower boundary of Assemblage 5 cannot be defined because no samples were studied below Sample 119-738B-24X-CC (214.3 mbsf). The upper boundary of this assemblage is chosen at the LAD of *Alabamina dissonata*, *Anomalina spissiformis*, *Bolivina huneri*, and *Bulimina basistriata* var. *nuda* in Sample 119-738B-10H-CC (85 mbsf). Several other species have a LAD within this interval. The FAD's of these species do not occur within the studied sequence and their exact ranges have to remain uncertain. The assemblage is dominated by *Nuttallides truempyi*, *Bulimina thanetensis*, *Bulimina simplex*, *Stilostomella* spp., and *Orthomorphina antillea*.

Assemblage 4: latest middle Eocene to late Eocene

Assemblage 4 ranges from Sample 119-738B-9H-CC (80 mbsf) to Sample 119-738B-5H-CC (42 mbsf). The upper boundary of Assemblage 4 is represented by a transitional zone, which includes several LAD's of important species. The relatively large intervals between samples (only core-catcher samples were used) possibly prohibit an exact positioning of the boundary. The last occurrence of *N. truempyi* appears in the uppermost Eocene (Sample 119-738B-6H-CC; 51.50 mbsf). *Orthomorphina havanensis* has its LAD slightly higher. *Bulimina semicostata* shows a short range within the upper Eocene. *Nonion havanensis* and *Neoeponides lunata* disappear at the Eocene/Oligocene boundary. Some LAD's cannot be determined because of a suggested hiatus at the middle/upper Eocene boundary. The range of *B. simplex*, a species ranging into the Oligocene at Site 744, *Bulimina elongata*, and *Stilostomella gracillima* may be affected by a lower Oligocene hiatus. No major extinction event occurs at the Eocene/Oligocene boundary, but rather a more gradual faunal change takes place.

Assemblage 3: early Oligocene

Assemblage 3 is only represented by two samples in the lower Oligocene (Sample 119-738B-4H-CC; 32.50 mbsf and 119-738B-3H-CC; 23 mbsf). The upper part is missing because of a large hiatus in this interval. Most of the representative species of the Oligocene sequence, which were identified at Site 744, are miss-

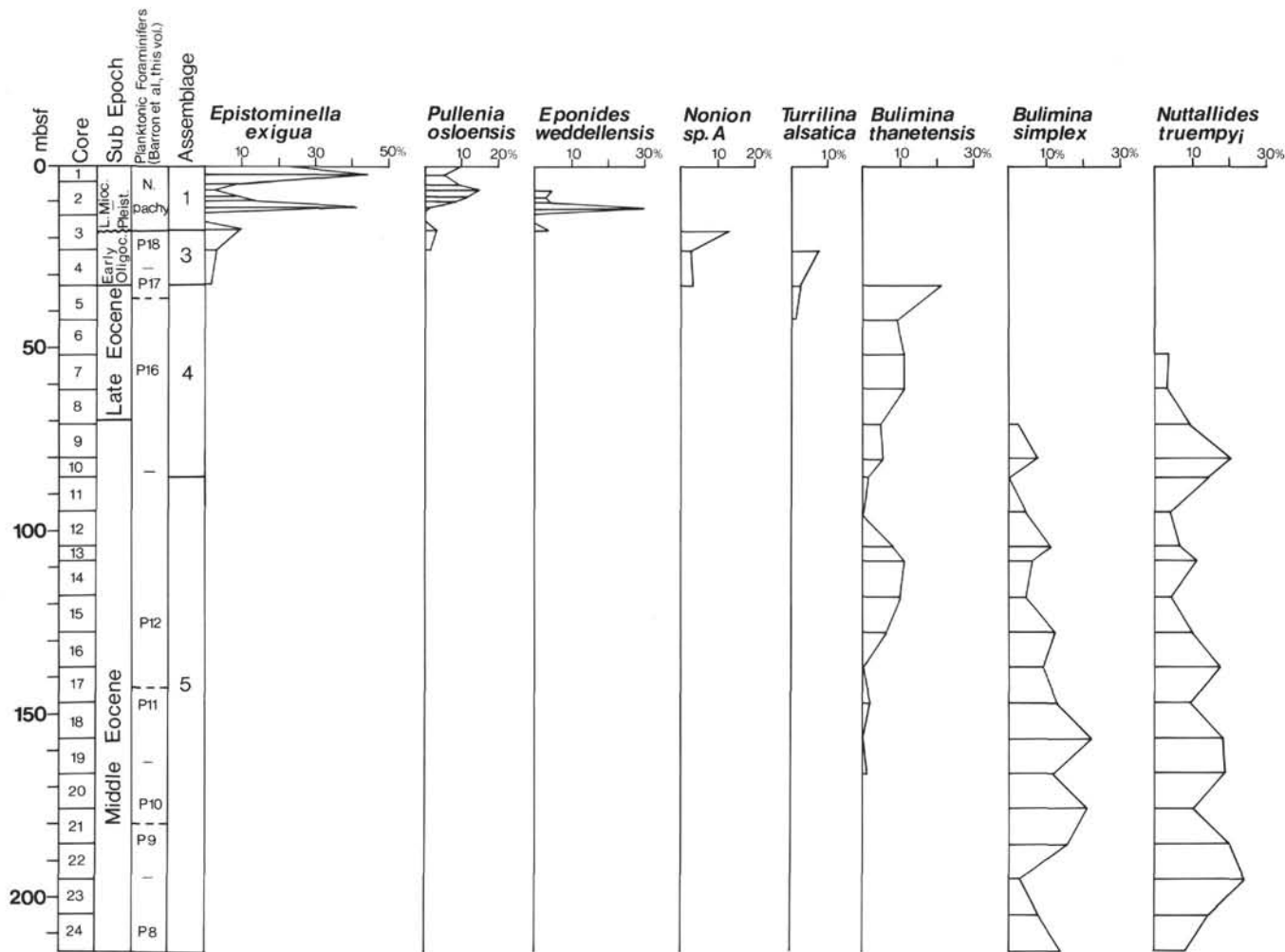


Figure 3. Relative abundance of selected species at Site 738, including all studied samples of Hole 738B.

ing. Common species such as *Nuttallides umbonifera*, *Laticarina pauperata*, and *Gyroidina* spp. occur rarely. The interval is characterized by the short range of *Turrilina alsatica* and *Nonion* sp. A. A large group of taxa disappears at the hiatus and therefore has unknown LAD's at Site 738. These species are *Bulimina thanetensis*, *Orthomorphina antillea*, *Bolivinopsis cubensis*, *Stilostomella subspinosa*, *Cibicidoides ungerianus*, and *Astronion umbilicatum*.

Assemblage 1: late Miocene to Pleistocene

Assemblage 1 ranges from Sample 119-738B-3H-3, 90–94 cm (17.40 mbsf), to the mud-line sample, spanning the upper Miocene to Holocene. Dominant species are *Epistominella exigua*, *Epistominella vitrea* and *Pullenia osloensis*. *Eponides weddellensis* is common in the upper Miocene. The FAD's of most species in this assemblage cannot be determined due to the hiatus at the lower boundary.

Site 744

Drilling at Site 744 recovered upper Eocene to Holocene sediments and the benthic foraminiferal fauna is represented by Assemblage 4 to Assemblage 1. Figure 5 shows the relative abundances of abundant species that dominate the distinct benthic assemblages. Biostratigraphic ranges of selected species are shown in Figure 6 (Appendix A is an alphabetical list of those species in Fig. 6).

Assemblage 4: late Eocene

The lower boundary of Assemblage 4 cannot be defined at this site; only three samples were studied within the upper Eocene. The upper boundary of this assemblage is drawn in Sample 119-744A-18H-CC (157.1 mbsf) just below the Eocene/Oligocene boundary. This boundary, comparable to Site 738, is not marked by an abrupt turnover of species but rather by a gradual change in species composition. *Nuttallides truempyi*, an important Eocene marker (Tjalsma and Lohmann, 1983), has its LAD in Sample 119-744A-20H-CC. Other LAD's below the Eocene/Oligocene boundary are of *Stilostomella gracillima* and *Osangularia mexicana*. Species that have their LAD just below the boundary are *Hanzaweia ammophila*, *Gyroidinoides globosus*, and *Gavelinella semicibrata*. Dominant species are *Bulimina simplex* (Fig. 4), *Stilostomella* spp., *Cibicidoides ungerianus*, and *Orthomorphina antillea*.

Assemblage 3: Early Oligocene to late middle Miocene

Assemblage 3 ranges from Sample 119-744A-17H-CC (147.6 mbsf) to Sample 119-744B-7H-5, 120–125 cm (57.20 mbsf). The lower Oligocene is marked by the short range and relatively high abundance of *Turrilina alsatica* (Fig. 5). The upper boundary is placed at the LAD of *Bolivinopsis cubensis* in the upper middle Miocene (Sample 119-744B-7H-5, 120–125 cm). *Nuttallides umbonifera*, *Astronion umbilicatum*, and *Epistominella ex-*

igua, three important species in the upper Paleogene and Neogene, have their FAD's within the Oligocene. *N. umbonifera* dominates throughout the assemblage. *Stilostomella* spp. and *Bigeneria nodulosa* are common, but their ranges extend beyond the discussed sequence.

Assemblage 2: late middle to early late Miocene

Assemblage 2 includes Sample 119-744B-7H-4, 120–125 cm (55.70 mbsf), to Sample 119-744B-4H-7, 25–27 cm (30.75 mbsf), and is defined by a number of short-ranging taxa which are relatively abundant and have their FAD's and LAD's within the upper middle Miocene to the uppermost Miocene interval. This group includes *Sigmoilina edwardsi*, *Eponides* sp. A, *Quinqueloculina venusta*, *Spiroloculina depressa*, *Ophthalmidium pusillum*, and *Uvigerina proposcidea*. Important LAD's of longer ranging taxa in this zone are of *B. nodulosa* (Sample 119-744B-5H-1, 125–130 cm; 32.25 mbsf) and *N. umbonifera* (Sample 119-744B-5H-3, 125–130 cm; 35.25 mbsf). The assemblage is dominated by *Bolivina thalmani* (Fig. 5) which has its FAD in the upper lower Miocene (Sample 119-744B-9H-4, 125–130 cm; 74.75 mbsf).

Assemblage 1: latest Miocene to Quaternary

Assemblage 1 ranges from Sample 119-744B-4H-6, 25–27 cm (29.25 mbsf) to the mud-line sample and is dominated by *E. exigua* and *Epistominella vitrea*. Both taxa reach their highest relative abundance in the Quaternary (Fig. 5). Several consistently present species with long ranges have their LAD's in the uppermost Pliocene to lower Pleistocene: *Laticarinina pauperata*, *Uvigerina peregrina*, *Pleurostomella obtusa*, *Bolivina thalmani* and others (Fig. 6). Typical Quaternary species are *Nonionella iridea* and *Triloculina oblonga*.

Comparison of Site 744 and 738

Combination of the sections cored at Sites 738 and Site 744 includes a complete benthic record from the middle Eocene to the Quaternary. The sites are at a similar water depth and approximately 250 km apart. A correlation of assemblage boundaries is illustrated in Figure 7. Assemblage 1, ranging from the uppermost Miocene to Holocene, is represented at both sites, although in a more compressed interval at Site 738 due to hiatuses. A short barren zone in this interval, indicating an erosional surface, is present at both sites. *Epistominella exigua*, *E. vitrea*, and *Pullenia osloensis* dominate both assemblages. The increase in abundance of *Eponides weddellensis* in the upper Miocene occurs at both sites, but it is more pronounced at Site 738.

At Site 744, Assemblage 2, ranging through late middle Miocene to early late Miocene time, is well developed and has a large number of species. This assemblage is missing at Site 738, due to a hiatus. *Bolivina thalmani*, abundant at Site 744, is absent at Site 738. *Nuttallides umbonifera* is abundant at Site 744, but is reduced at Site 738 to two rare occurrences in the lower Miocene and lower Oligocene.

Assemblage 3 characterizes the lower Oligocene to middle Miocene sequence. Only the lowermost Oligocene is present at both sites, whereas the upper Oligocene to middle Miocene interval occurs only at Site 744. The lower Oligocene is marked at both locations by the short range of *Turrilina alsatica* complemented by *Nonion* sp. A. The occurrence of *T. alsatica* compares with high numbers of this taxon at Site 689, where it has its FAD in the late Eocene (Thomas, 1990). The late Oligocene/early Miocene relative abundance increase of *Bulimina simplex* together with common occurrences of *Astrononion umbilicatum* and *Nuttallides umbonifera*, is lacking at Site 738 because of the hiatus.

Assemblage 4 is well developed at Site 738, but is represented only in the lowermost two samples of Site 744. The uppermost Eocene is dominated by buliminids. Site 744 has high numbers of *B. simplex* and Site 738 has high numbers of *Bulimina thanensis*. Assemblage 5 is only documented at Site 738 and is dominated by *Nuttallides truempyi*.

A comparison of the ranges of individual species between Sites 744 and 738 is problematical due to the impossibility of establishing the LAD's of many species in the upper Oligocene to middle Miocene interval, where an unconformity is present at Site 738. Certain differences in LAD's of species occur at the Eocene/Oligocene boundary, but the rarity of these species and the large sample intervals make a comparison doubtful.

During the studied interval, Sites 738 and 744 represent a middle bathyal to abyssal depositional environment with a deepening trend from the Eocene to Neogene. The high relative abundance of *N. truempyi* suggests for the Eocene a lower to middle bathyal paleo water depth (Morkhoven et al., 1986). The Oligocene fauna with high numbers of *N. umbonifera*, *E. exigua*, and *Cibicidoides mundulus* imply a lower bathyal paleo-environment of 1000–2000 m. The Neogene section is placed into the upper abyssal bathymetric range (2000–3000 m) with typical modern deep-water species such as *E. exigua*, *Oridorsalis umbonatus*, and *Cibicidoides wuellerstorfi*.

Site 736

Site 736 was drilled in middle bathyal water depth. The foraminifer assemblage is less diverse and differs in species composition in comparison with the same time interval at Sites 738 and 744 at an upper abyssal depth. Over the short time interval recovered, no significant assemblage changes occurred. Changes of the most common species are expressed in relative abundance (Fig. 8). Most dominant species occur over the entire sequence, although with extreme changes in absolute abundance. The uppermost 20 mbsf are dominated by *Bulimina aculeata*, *Nonionella iridea*, and *Fursenkoina* spp. Less common species are *Stainforthia complanata* and *Bolivina pseudopunctata*. Below 20 mbsf *Cassidulina oblonga*, *Angulogerina earlandi*, and *Sphaeroidina bulloides* are abundant. *Pullenia bulloides* and *Eponides pusillus* are common. These species occur sporadically throughout the Pliocene with high peaks in single samples followed by barren intervals. Below 300 mbsf all samples were barren of benthic foraminifers. The species composition suggests a middle bathyal paleo water depth throughout the late Pliocene to Holocene similar to the present water depth of Site 736.

A similar foraminiferal assemblage was observed by Mackensen et al. (in press), who studied living and dead Holocene faunas in the Eastern Weddell Sea, where *Trifarina angulosa* (*Angulogerina earlandi* in this study) is correlated with coarse sediment at a water depth of 1500 m, where the biotope is well oxygenated and noncorrosive to calcium carbonate because of bottom currents. These conditions preserve this species in the dead assemblage and provide a high potential for fossilization (Mackensen et al., in press). At Site 736 this species occurs sporadically, but then in high numbers throughout the Pliocene/Pleistocene. *N. iridea* and *B. aculeata* are considered infaunal species and are associated in the Weddell Sea with a high supply of organic matter in a fine substrate. In the dead assemblage a few centimeters below the surface, the tests are dissolved because of the high organic carbon content (Mackensen et al., in press). Both species occur at Site 736 in the upper 10 mbsf. *N. iridea* disappears below this interval whereas *B. aculeata* shows another high abundance (up to 50%) at 285 mbsf.

Another study for comparison was performed on surface samples along a transect west of Heard Island (Lindenberg and

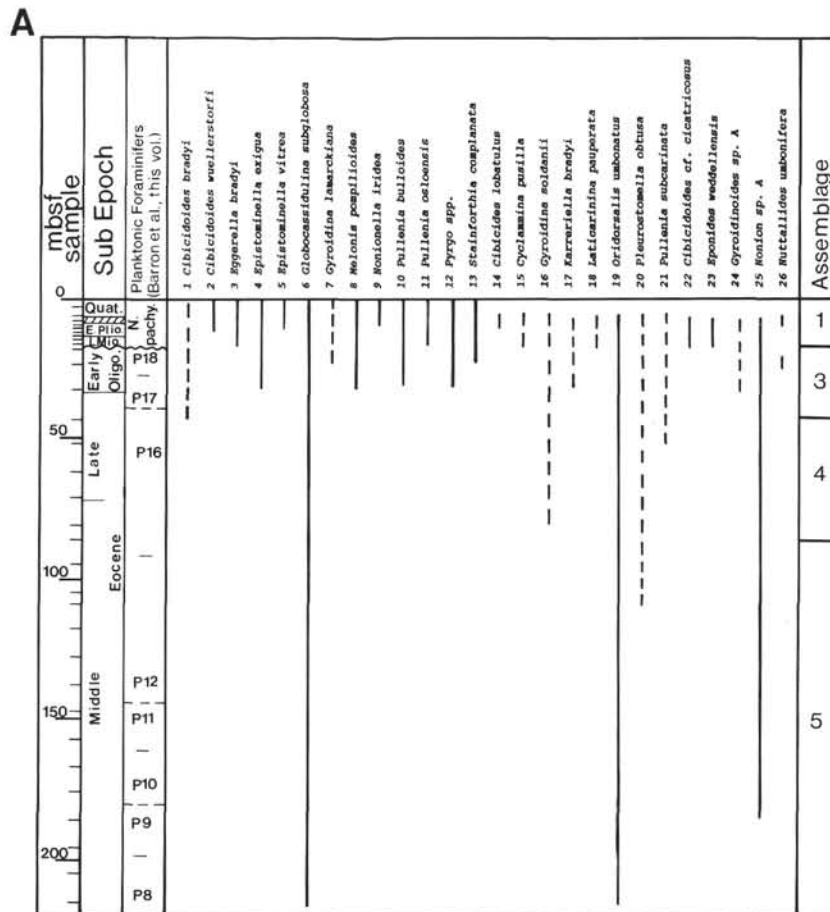


Figure 4. Vertical ranges of selected benthic species at Hole 738B. Species are arranged according to their last appearance. A solid line represents a continuous, frequent, common, or abundant occurrence (> 2% relative abundance); a broken line represents an irregular, rare occurrence (< 2% relative abundance). For an alphabetical species list, see Appendix A.

Auras, 1984). *B. aculeata* and *A. earlandi* were dominant at a middle bathyal water depth.

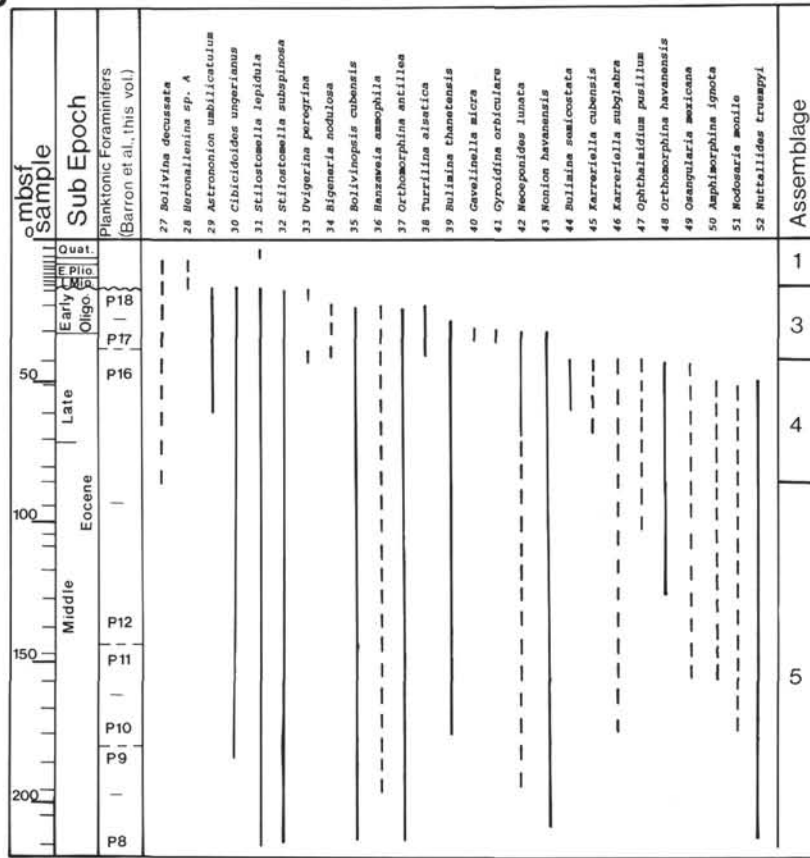
DISCUSSION

Benthic foraminifer assemblages from the Pliocene/Pleistocene section on the northern Kerguelen Plateau and from the same interval on the southern plateau indicate two different environments. Site 736 is located beneath the present Antarctic Convergence, a major water-mass boundary, associated with increased rates of upwelling and, consequently, a high production of planktonic biomass. This is reflected in the rapid sedimentation rate of biosiliceous tests, reaching a minimum of 140 m/m.y. during the Pliocene and 54 m/m.y. during the Quaternary (Barron, Larsen, et al., 1989). The high production of siliceous organisms means an increased nutrient supply in the form of organic matter for benthic foraminifers. On the other hand, high siliceous sedimentation rates dilute the foraminiferal component, which is reflected by the numerous barren intervals, especially in the Pliocene. Dissolution of calcium carbonate because of the high supply of organic matter could also be a factor influencing the foraminiferal assemblage. This cause is suggested for large barren intervals during the middle Miocene to Pleistocene of the Maud Rise (Thomas, 1990). The present calcareous foraminiferal tests of numerous delicate species at Site 736 do not show signs of corrosion. Present-day oceanographic conditions in this region were established in the latest Miocene to

early Pliocene (Kemp et al., 1975; Barron, Larsen, et al., 1989). Small shifts of the Polar Front in the past caused detectable changes in the composition of the sediment. The observed short pulses of increased numbers of foraminifers at Site 736 may be an indication of either the stronger influence of subantarctic waters or the decreased surface productivity and consequently decreased dilution of the calcareous component or increased preservation of foraminiferal tests. It has been suggested that a low diversity Neogene assemblage dominated by *Bulimina aculeata* may represent oceanographic conditions with a high supply of organic matter (Mackensen et al., in press). This situation compares with that at Site 736, where *B. aculeata* dominates the upper 10 m of sediment.

The recovered sediments of the southern Kerguelen Plateau (Sites 738 and 744) document several changes within the benthic foraminiferal assemblage during Eocene to Quaternary time. The Eocene fauna was dominated by *Nuttallides truempyi*, which had a worldwide distribution in lower Cretaceous to Eocene deep-water sediments (Tjalsma and Lohmann, 1983; Miller et al., 1984). This species was replaced in the late Eocene by several *Bulimina* species. Above the Eocene/Oligocene boundary *Nuttallides umbonifera* appeared and increased in relative abundance in the middle early Oligocene. Other long-ranging taxa with a broad bathymetric distribution, such as *Oridorsalis umbonatus*, *Globocassidulina subglobosa*, *Gyroidina* spp., and *Pullenia bulloides*, complement this assemblage. A similar fau-

B



C

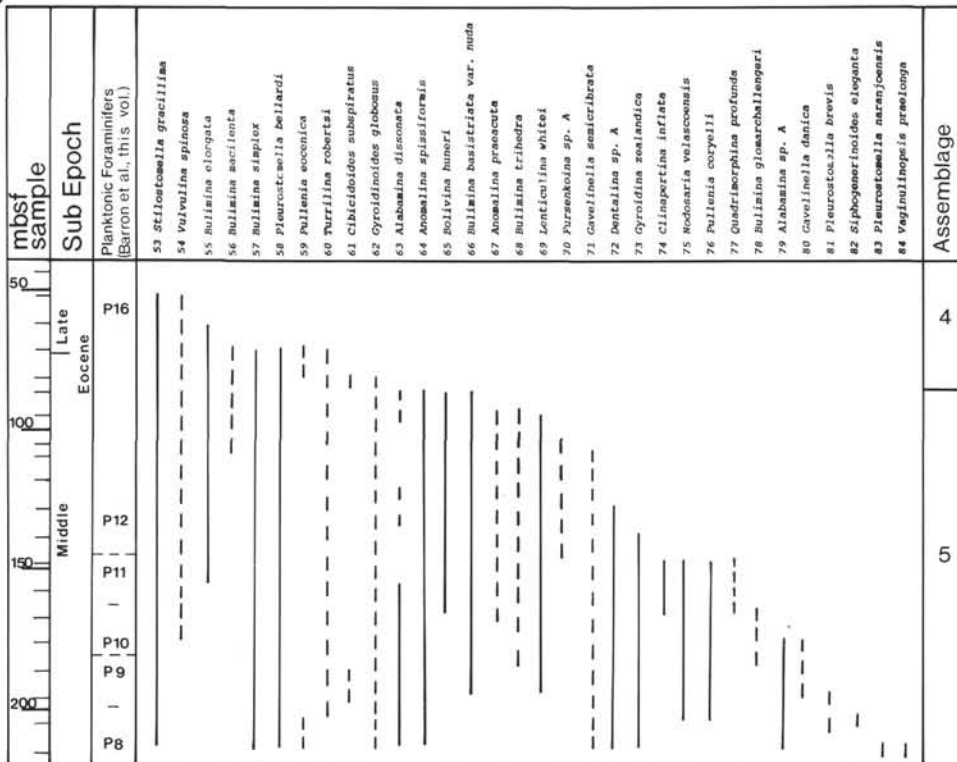


Figure 4 (continued).

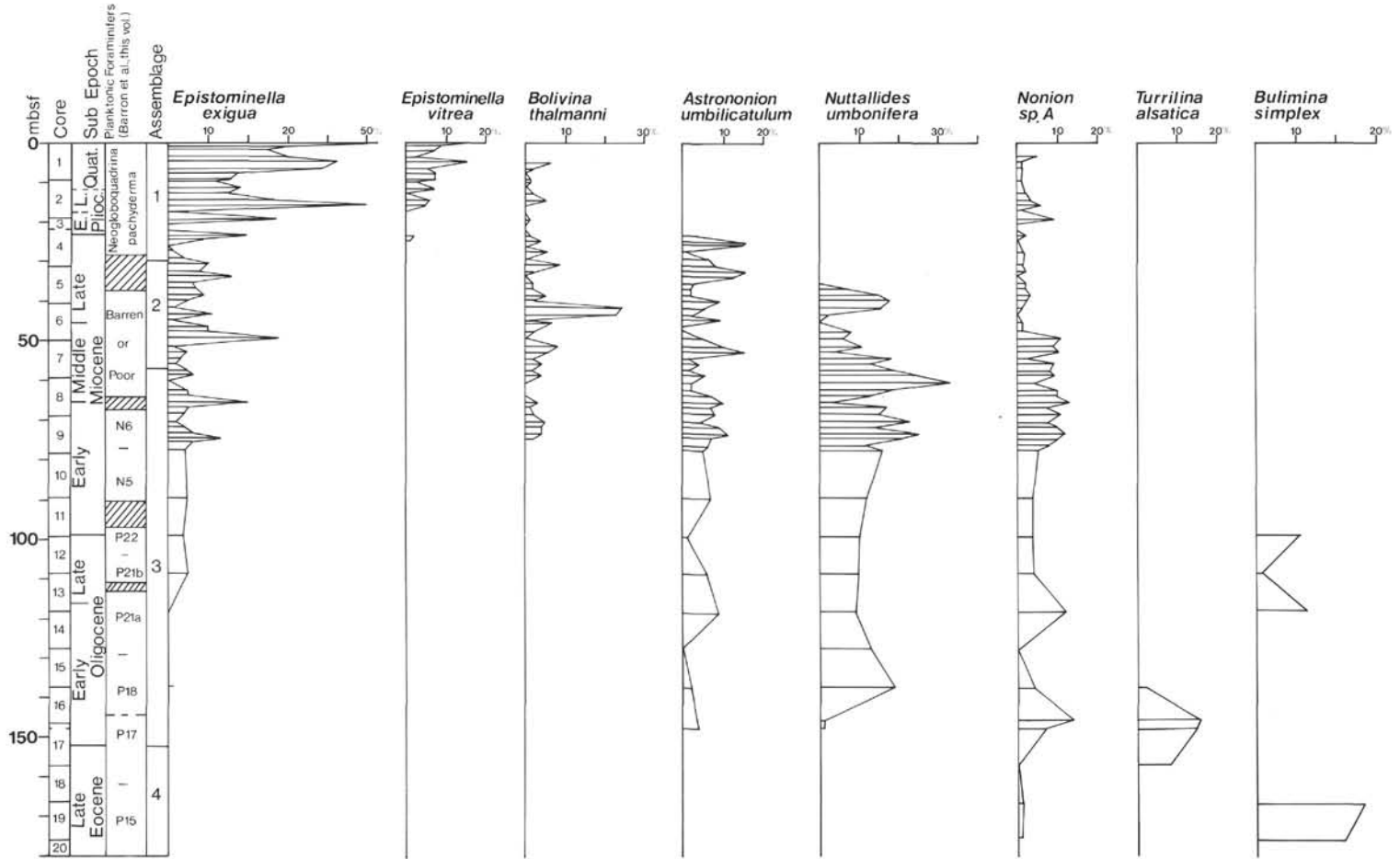


Figure 5. Relative abundance of selected species at Site 744, including all studied samples from Hole 744B (Cores 1H-9H) and from Hole 744A (Cores 10H-20H).

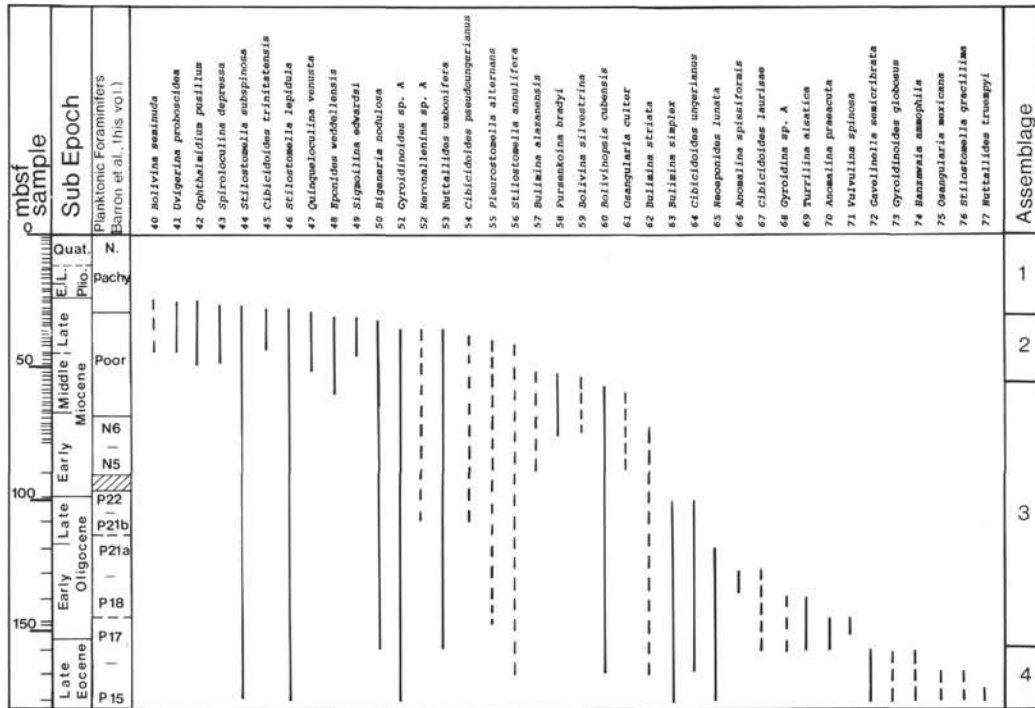
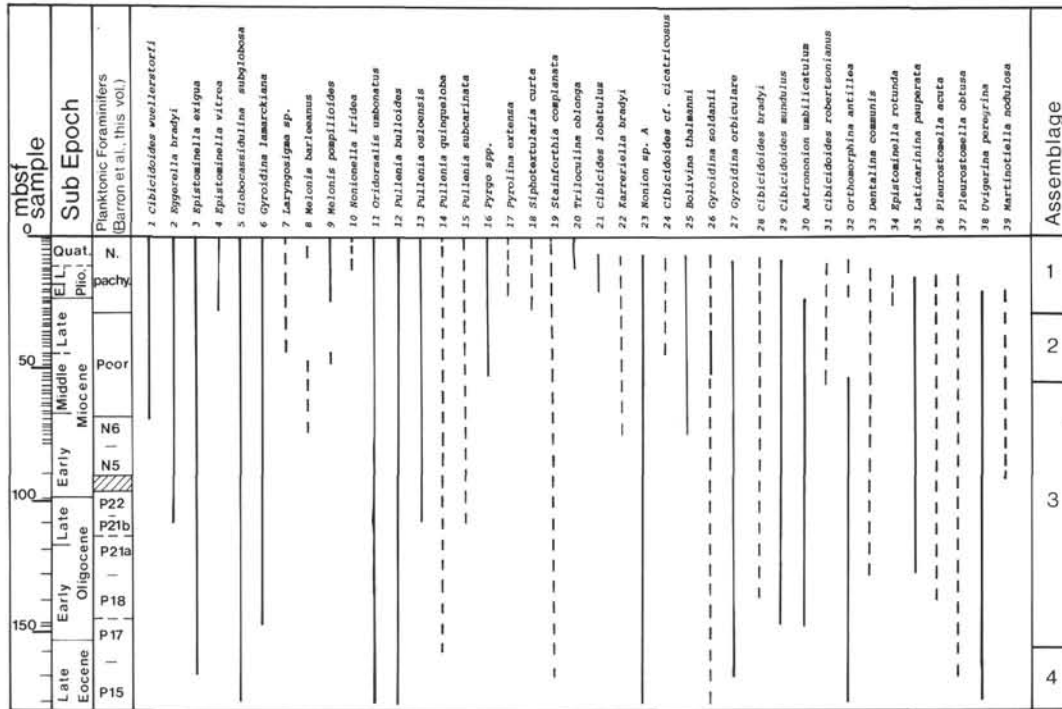


Figure 6. Vertical ranges of selected benthic species at Site 744. Species are arranged according to their last appearance. A solid line represents a continuous, frequent, common, or abundant (> 2% relative abundance); a broken line represents an irregular, rare occurrence (< 2% relative abundance). For an alphabetical species list, see Appendix A.

nal change at the end of the Eocene was described from the Bay of Biscay and explained by a bottom water change from old, warm, and carbonate corrosive to younger, colder and more vigorously circulating bottom water of Arctic origin (Miller et al., 1984).

The described faunal change at the Eocene/Oligocene boundary is a gradual one without a distinct diversity change. The upper Eocene has a larger number of LAD's whereas the lower Oligocene is marked by more FAD's. This trend has also been described from many other studied localities (Tjalsma and Loh-

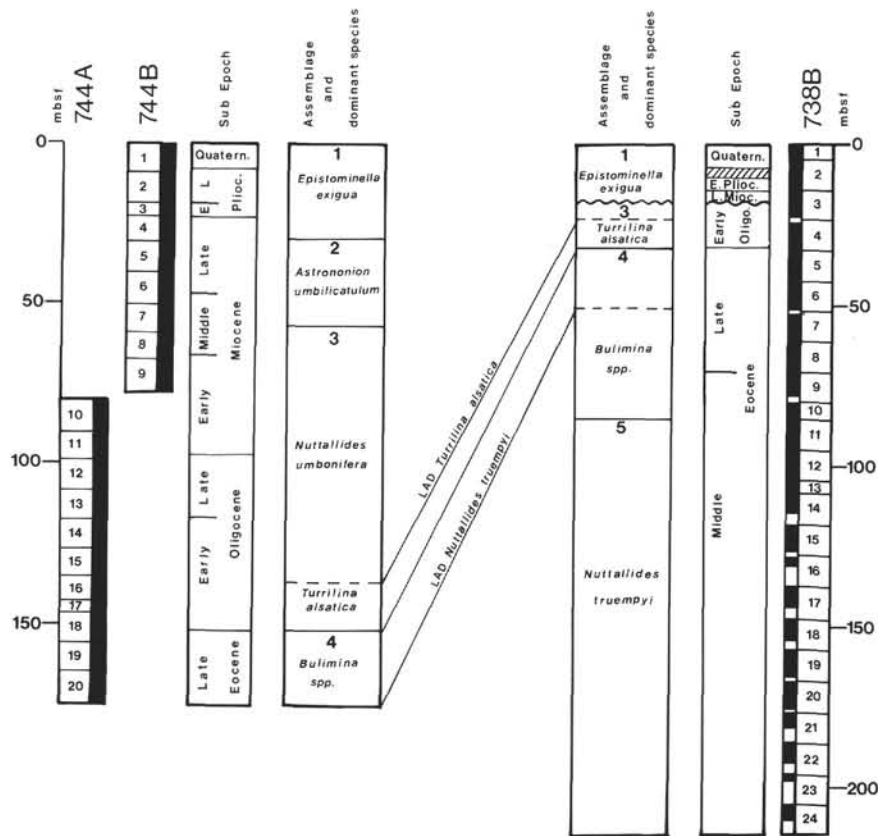


Figure 7. Comparison of benthic foraminiferal assemblages and their dominant species recovered at Sites 738 and 744. The boundary between Assemblage 3 and 4, and the LAD of *Turrilina alsatica* and *Nuttallides truempyi* are correlated.

mann, 1983; Miller et al., 1984; Corliss, 1981; Corliss et al., 1984; Thomas, 1990). The series of LAD's through middle to late Eocene times suggests a gradual climate deterioration and oxygen isotope data from DSDP Site 277 in the Southwest Pacific imply the beginning of increased bottom water circulation in the middle to late Eocene and a temperature drop just above the Eocene/Oligocene boundary (Corliss, 1981).

Sites 738 and 744 are located south of the Antarctic Convergence in Antarctic waters, in the area influenced by the Antarctic Circumpolar Current, the major ocean current circulating around Antarctica. The time of the initiation of this current has been dated to the earliest Miocene by Barker and Burrell (1982). Based on DSDP Leg 29 data from the South Tasman Rise earliest signs of the ACC were present in middle to late Oligocene sediments of about 30 m.y. (Kennett et al., 1974). This event is followed by a long period of worldwide deep-sea erosion creating a hiatus in the upper Oligocene and lower Neogene. The present data indicate a paleoceanographic change in the early Oligocene at the Kerguelen Plateau, possibly related to the initiation of the ACC. Strong erosional bottom current activity is reflected at Site 738 by the middle Oligocene to Miocene unconformity. The almost complete record, despite several small unconformities during that time interval at Site 744, 250 km farther north, suggests less erosion by the current, possibly due to local topographic barriers.

Nuttallides umbonifera dominates the Oligocene to middle Miocene sequence at Site 744. The occurrence of this species is well documented in all oceans and it is found to be more resistant to carbonate corrosive bottom water (Bremer and Lohmann, 1982; Corliss, 1979a, 1979b; Miller and Katz, 1987;

Mackensen et al., in press). Since late Oligocene time *N. umbonifera* has coexisted with *Epistominella exigua*, an epibenthic species, as reported from recent faunas (Gooday, 1988). *E. exigua* shows large fluctuations, however, increasing up to the Quaternary, whereas *N. umbonifera* disappears in the late Miocene. This faunal change between dominant species suggest paleoceanographic changes in terms of calcium carbonate saturation (Mackensen et al., in press). The epibenthic life position of *E. exigua* also makes the species less vulnerable to carbonate-aggressive pore-water chemistry, which is created by high flux of organic matter. The increasing dominance of this species is coeval with the move of the Polar Front and a high production of biosiliceous sedimentation providing an increased supply of organic matter to the sediment. Furthermore *E. exigua* has a preference for areas with a high food supply (Mackensen et al., 1985).

Another faunal change occurring in the middle Miocene has also been recognized in the North Atlantic (Schnitker, 1984; Miller and Katz, 1987; Thomas, 1986b, 1986c). These changes have been related to either a decrease in temperature as documented by changes in oxygen isotope values (Schnitker, 1984; Douglas and Woodruff, 1981; Woodruff, 1985) or to increased primary productivity (Miller and Katz, 1987). This faunal change occurs in the equatorial Pacific somewhat earlier in the early to middle Miocene (Thomas, 1985; Douglas and Woodruff, 1981; Woodruff, 1985) and appears to be the result of an increase in surface productivity which creates a variable corrosivity of the bottom water (Thomas and Vincent, 1987). Stable isotope data of this particular interval in preparation will shed some light on this question (Woodruff and Chambers, this volume).

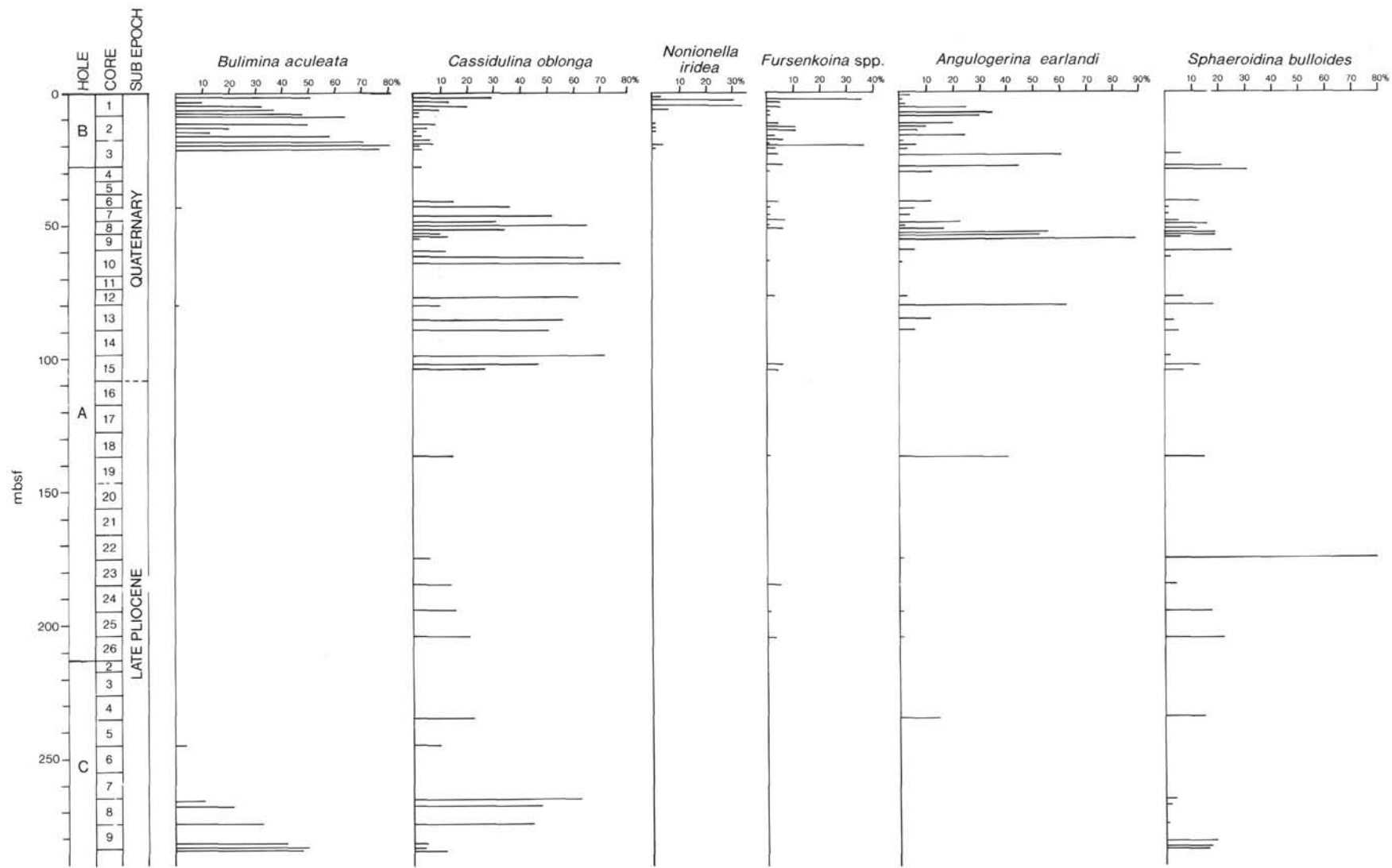


Figure 8. Relative abundance of selected species at Site 736, including all samples with a minimum of 100 specimens per 10 cm³.

It has been argued that the modern deep-sea benthic foraminiferal fauna developed during the early Oligocene and that no major faunal turnover took place since that time (Boltovskoy, 1980; Boltovskoy and Boltovskoy, 1988). The results of Sites 738 and 744 partly support this theory. Many taxa that appear at the Eocene/Oligocene boundary have ranges through to the Holocene. These species are not affected by the described faunal change in the middle Miocene. Assemblage 2 is marked by additional short-ranging species, which occur fairly commonly for a short period of time. No comparable fauna in other parts of the deep-sea record was found. It remains questionable which paleoenvironmental conditions were favored by these species.

CONCLUSIONS

1. The upper Pliocene to Quaternary section at Site 736 on the northern Kerguelen Plateau beneath the modern-day Polar Front is marked by short pulses of high absolute abundances of benthic foraminifers interrupted by barren intervals. The absence of foraminifers is associated with high-productivity zones of biosiliceous phytoplankton. It is still questionable if these intervals can be correlated with local shifts of the Polar Front.

2. The Holocene assemblage is dominated by *Bulimina aculeata*. This species is connected with a high supply of organic matter, which prevents the preservation of these tests in the fossil record. More resistant species such as *Angulogerina earlandi* remain downcore and become the dominant taxa.

3. Together, Sites 738 and 744 provide an almost continuous record of the Eocene to Holocene age. Five benthic assemblages are defined in this time interval. The transitions between assemblages are gradational and are not marked by large extinction events.

4. The Eocene fauna is dominated by *Nuttallides truempyi*. During the late Eocene the genus *Bulimina* took over, and at the end of the Eocene many long-ranging taxa became established. These broad faunal changes of dominant constituents were recognized in other oceans.

5. The establishment of the Antarctic Circumpolar Current in the early Oligocene caused long-term erosion at Site 738 as a result of the development of strong bottom currents. At Site 744 this paleoceanographic change is connected with the beginning of a cold, more carbonate-corrosive watermass which is suggested by the increase in relative abundance of *Nuttallides umbonifera* in the early Oligocene. This event follows the first signs of glaciation in Antarctica during the early Oligocene, which may have precipitated the large faunal turnover at the Eocene/Oligocene boundary.

6. The upper Miocene to Quaternary interval is dominated by *Epistominella exigua*. This species prefers a high nutrient supply and as an epibenthic species shows resistance against corrosive sediment, which favors preservation. The establishment of the Polar Front since late Miocene time provided these conditions and *E. exigua* increased in abundance.

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APPENDIX A

Alphabetical list of all species shown in Figure 4 (range chart Site 738).

- 63 *Alabamina dissonata*
 79 *Alabamina* sp. A
 50 *Amphimorphina ignota*
 67 *Anomalina praeacuta*
 64 *Anomalina spissiformis*
 29 *Astrononion umbilicatum*
 34 *Bigeneria nodulosa*
 27 *Bolivina decussata*
 65 *Bolivina huneri*
 35 *Bolivinopsis cubensis*
 66 *Bulimina basistriata* var. *nuda*
 55 *Bulimina elongata*
 78 *Bulimina glomarchallengeri*
 56 *Bulimina macilenta*
 44 *Bulimina semicostata*
 57 *Bulimina simplex*
 39 *Bulimina thanetensis*
 68 *Bulimina trihedra*
 14 *Cibicides lobatulus*
 1 *Cibicidoides bradyi*
 22 *Cibicidoides* cf. *cicatricosus*
 61 *Cibicidoides subspiratus*
 2 *Cibicidoides wuellerstorfi*
 30 *Cibicidoides ungerianus*
 74 *Clinapertina inflata*
 15 *Cyclammia pusilla*
 72 *Dentalina* sp. A
 3 *Eggerella bradyi*
 4 *Epistominella exigua*
 5 *Epistominella vitrea*
 23 *Eponides weddellensis*
 70 *Fursenkoina* sp. A
 80 *Gavelinella danica*
 40 *Gavelinella micra*
 71 *Gavelinella semicribata*
 6 *Globocassidulina subglobosa*
 7 *Gyroidina lamarckiana*
 41 *Gyroidina orbiculare*
 16 *Gyroidina soldanii*
 73 *Gyroidina zelandica*
 62 *Gyroidinoides globosus*
 61 *Gyroidinoides subspiratus*
 24 *Gyroidinoides* sp. A
 36 *Hanzawaia ammophila*
 28 *Heronallenina* sp. A
 17 *Karreriella bradyi*
 45 *Karreriella cubensis*
 46 *Karreriella subglabra*
 18 *Laticarinina pauperata*
 69 *Lenticulina whitei*
 8 *Melonis pompilioides*
 42 *Neoponides lunata*
 51 *Nodosaria monile*
 75 *Nodosaria velascoensis*
 43 *Nonion havanensis*
 25 *Nonion* sp. A
 9 *Nonionella iridea*
 26 *Nuttallides umbonifera*
 52 *Nuttallides truempyi*
 47 *Ophthalmidium pusillum*
 19 *Oridorsalis umbonatus*
 37 *Orthomorphina antillea*
 48 *Orthomorphina havanensis*
 49 *Osangularia mexicana*
 58 *Pleurostomella bellardi*
 81 *Pleurostomella brevis*
 83 *Pleurostomella naranjoensis*
 20 *Pleurostomella obtusa*

Date of initial receipt: 19 December 1989

Date of acceptance: 19 July 1990

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- 10 *Pullenia bulloides*
 76 *Pullenia coryelli*
 59 *Pullenia eocenica*
 11 *Pullenia osloensis*
 21 *Pullenia subcarinata*
 12 *Pyrgo* spp.
 77 *Quadriformina profunda*
 82 *Siphogenerinoides elongata*
 13 *Stainforthia complanata*
 53 *Stilostomella gracillima*
 31 *Stilostomella lepidula*
 32 *Stilostomella subspinosa*
 38 *Turrilina alsatica*
 60 *Turrilina robertsi*
 33 *Uvigerina peregrina*
 84 *Vaginulinopsis praelonga*
 54 *Vulvulina spinosa*

Alphabetical list of all species shown in Figure 6 (range chart Site 744).

- 70 *Anomalina praeacuata*
 66 *Anomalina spissiformis*
 30 *Astrononion umbilicatum*
 50 *Bigeneria nodulosa*
 40 *Bolivina seminuda*
 59 *Bolivina silvestrina*
 25 *Bolivina thalmani*
 60 *Bolivinopsis cubensis*
 57 *Bulimina alazanensis*
 63 *Bulimina simplex*
 62 *Bulimina striata*
 21 *Cibicides lobatulus*
 28 *Cibicidoides bradyi*
 24 *Cibicidoides* cf. *cicatricosus*
 67 *Cibicidoides laurisiae*
 29 *Cibicidoides mundulus*
 54 *Cibicidoides pseudoungerianus*
 31 *Cibicidoides robertsonianus*
 45 *Cibicidoides trinitatis*
 64 *Cibicidoides ungerianus*
 1 *Cibicidoides wuellerstorfi*
 33 *Dentalina communis*
 2 *Eggerella bradyi*
 3 *Epistominella exigua*
 34 *Epistominella rotunda*
 4 *Epistominella vitrea*
 48 *Eponides weddellensis*
 58 *Fursenkoina bradyi*
 72 *Gavelinella semicibrata*
 5 *Globocassidulina subglobosa*
 6 *Gyroidina lamarckiana*
 27 *Gyroidina orbiculare*
 26 *Gyroidina soldanii*
 68 *Gyroidina* sp. A
 73 *Gyroidinoides globosus*
 51 *Gyroidinoides* sp. A
 74 *Hanzawaia ammophila*
 52 *Heronallenina* sp. A
 22 *Karrerella bradyi*
 7 *Laryngosigma* sp.
 35 *Laticarinina pauperata*
 39 *Martinotiella nodulosa*
 8 *Melonis barleeanus*
 9 *Melonis pompilioides*
 65 *Neoepionides lunata*
 23 *Nonion* sp. A
 10 *Nonionella iridea*
 77 *Nuttallides truempyi*
 53 *Nuttallides umbonifera*
 42 *Ophthalmidium pusillum*
 11 *Oridorsalis umbonatus*
 32 *Orthomorphina antillea*
 61 *Osangularia culter*
 75 *Osangularia mexicana*
 36 *Pleurostomella acuta*

- 55 *Pleurostomella alternans*
 37 *Pleurostomella obtusa*
 12 *Pullenia bulloides*
 13 *Pullenia osloensis*
 14 *Pullenia quinqueloba*
 15 *Pullenia subcarinata*
 16 *Pyrgo* spp.
 17 *Pyrolina extensa*
 47 *Quinqueloculina venusta*
 49 *Sigmoilina edwardsi*
 18 *Siphotextularia curta*
 43 *Spiroloculina depressa*
 19 *Stainforthia complanata*
 56 *Stilostomella annulifera*
 76 *Stilostomella gracillima*
 46 *Stilostomella lepidula*
 4 *Stilostomella subspinosa*
 20 *Triloculina oblonga*
 69 *Turrilina alsatica*
 38 *Uvigerina peregrina*
 41 *Uvigerina proboscidea*
 71 *Vulvulina spinosa*

APPENDIX B

Alphabetical list of all identified species. Numerous taxa with still unknown generic identification are not included.

- Alabamina creta* (Finlay) = *Pulvinulinella creta* Finlay
Alabamina dissonata (Cushman and Renz) = *Pulvinulinella atlantiae* Renz var. *dissonata* Cushman and Renz
Alabamina sp.
Ammonia sp.
Amphicoryna hirsuta (d'Orbigny) = *Nodosaria hirsuta* d'Orbigny
Amphimorphina ignota Cushman and Siegfus
Amphimorphina sp.
Angulogerina earlandi Parr
Anomalina globosa Chapman and Parr
Anomalina praeacuata Vasilenko
Anomalina sp.
Anomalina spissiformis Cushman and Stainforth
Anomalinoides pseudogrosserugosus (Colon) = *Anomalina pseudogrosserugosa* Colon
Anomalinoides sp.
Astrononion echolsi Kennett
Astrononion pusillum Hornibrook
Astrononion umbilicatum Uchiro
Bathysiphon sp.
Bigeneria nodulosa d'Orbigny
Bolivina decussata Brady
Bolivina globulosa Cushman
Bolivina huneri Howe
Bolivina pseudopunctata Höglund
Bolivina seminuda Cushman
Bolivina silvestrina Cushman
Bolivina striatula Cushman
Bolivina thalmani Renz
Bolivina sp.
Bolivinopsis cubensis (Cushman and Bermudez) = *Spiroplectoides cubensis* Cushman and Bermudez
Brizalina spinescens (Cushman) = *Bolivina spinescens* Cushman
Bulimina aculeata d'Orbigny
Bulimina alazanensis Cushman
Bulimina basistriata var. *nuda* Howe and Wallace
Bulimina bradbury Martin
Bulimina elongata d'Orbigny
Bulimina exilis Brady
Bulimina glomarchallengeri Tjalsma and Lohmann
Bulimina impendens Parker and Bermudez
Bulimina macilenta Cushman and Parker
Bulimina marginata d'Orbigny
Bulimina semicostata Nuttall
Bulimina simplex Terquem
Bulimina striata d'Orbigny
Bulimina thanetensis Cushman and Parker
Bulimina translucens Parker

- Bulimina trihedra* Cushman
Buliminella grata Parker and Bermudez
Cassidella bradyi (Cushman) = *Virgulina bradyi* Cushman
Cassidulina laevigata d'Orbigny
Cassidulina oblonga Reuss
Cibicides lobatulus (Walker and Jacob) = *Nautilus lobatulus* Walker and Jacob
Cibicoides aknerianus (d'Orbigny) = *Rotalina akneriana* d'Orbigny
Cibicoides bradyi (Trauth) = *Truncatulina bradyi* Trauth
Cibicoides cf. *cicatricosus* (Schwager) = *Anomalina cicatricosa* Schwager
Cibicoides grimsdalei (Nuttall) = *Cibicides grimsdalei* Nuttall
Cibicoides haitiensis (Coryell and Rivero) = *Cibicides robertsonianus* (Brady) var. *haitiensis* Coryell
Cibicoides laurissae (Mallory) = *Cibicides laurissae* Mallory
Cibicoides mundulus (Brady, Parker and Jones) = *Truncatulina mundula* Brady, Parker and Jones
Cibicoides perlucida (Nuttall) = *Cibicides perlucida* Nuttall
Cibicoides pseudoungerianus (Cushman) = *Truncatulina pseudoungeriana* Cushman
Cibicoides robertsonianus (Brady) = *Truncatulina robertsoniana* Brady
Cibicoides subspiratus (Nuttall) = *Cibicides subspiratus* Nuttall
Cibicoides trinitatensis (Nuttall) = *Truncatulina trinitatensis* Nuttall
Cibicoides tuxpamensis (Cole) = *Cibicides tuxpamensis* Cole
Cibicides ungerianus (d'Orbigny) = *Rotalina ungeriana* d'Orbigny
Cibicoides wuellerstorfi (Schwager) = *Anomalina wuellerstorfi* Schwager
Clavulina sp.
Clinapertina inflata Tjalsma and Lohmann
Cribostrum subglobosus (Sars) = *Lituola subglobosa* Sars
Cyclamina pusilla Brady
Cystamina argentea Earland
Dentalina communis d'Orbigny
Dentalina ittai Loeblich and Tappan
Dentalina pauperata d'Orbigny
Dentalina reussi Neugeboren
Dentalina spp.
Discorbis sp.
Eggerella bradyi (Cushman) = *Verneuilina bradyi* Cushman
Ehrenbergina carinata Eade
Ehrenbergina sp. A
Epistominella exigua (Brady) = *Pulvinulina exigua* Brady
Epistominella rotunda (Husezima and Maruhashi) = *Eponides rotundus* Husezima and Maruhashi
Epistominella rugosa (Phleger and Parker) = *Cibicides rugosa* Phleger and Parker
Epistominella vitrea Parker
Eponides weddellensis Earland
Eponides pusillus Parr
Eponides sp. A
Francesita advena (Cushman) = *Virgulina advena* Cushman
Francesita sp. A
Fronicularia sp.
Fursenkoina bradyi (Cushman) = *Virgulina bradyi* Cushman
Fursenkoina ciperana (Cushman and Stainforth) = *Virgulina ciperana* Cushman and Stainforth
Fursenkoina cylindrica (Cushman and Bermudez) = *Virgulina cylindrica* Cushman and Bermudez
Fursenkoina earlandi (Cushman) = *Virgulina earlandi* Cushman
Fursenkoina fusiformis (Williamson) = *Bulimina pupoides* var. *fusiformis* Williamson
Fursenkoina sp. A
Gaudryina laevigata Franke
Gavelinella capitata (Gümpel) = *Rotalina capitata* Gümpel
Gavelinella danica (Brotzen) = *Cibicides danica* Brotzen
Gavelinella micra (Bermudez) = *Cibicides micrus* Bermudez
Gavelinella semicibrata (Beckmann) = *Anomalina pompilioides* Galloway and Heminway var. *semicibrata* Beckmann
Glandulina antarctica Parr
Glandulina sp.
Globobulimina pacifica Galloway and Wissler
Globocassidulina subglobosa (Brady) = *Cassidulina subglobosa* Brady
Gyroidina lamarckiana (d'Orbigny) = *Rotalina lamarckiana* d'Orbigny
Gyroidina soldani d'Orbigny
Gyroidina zelandica Finlay
Gyroidinoides globosus (Hagenow) = *Nonionina globosa* Hagenow
Gyroidinoides spp.
Hanzawaia ammophila (Gümpel) = *Rotalia ammophila* Gümpel
Heronallenina sp. A
Heronallenina sp. B
Hormosina pilulifer Brady
Hyperammina sp.
Karrerella bradyi (Cushman) = *Gaudryina bradyi* Cushman
Karrerella chapapotensis (Cole) = *Textularia chapapotensis* Cole
Karrerella cubensis Cushman and Bermudez
Karrerella subglabra (Gümpel) = *Gaudryina subglabra* Gümpel
Karrerella sp.
Kyphopyxa sp.
Lagena spp.
Laryngosigma spp.
Laticarinina pauperata (Parker and Jones) = *Pulvinulina repanda* Fichtel and Moll var. *menardii* d'Orbigny subvar. *pauperata* Parker and Jones
Lenticulina cultrata d'Orbigny
Lenticulina whitei Tjalsma and Lohmann
Lenticulina spp.
Marginulina obesa Cushman
Marginulina sp.
Martinoiella nodulosa (Cushman) = *Clavulina nodulosa* Cushman
Melonis affine (Reuss) = *Nonionina affinis* Reuss
Melonis barleeanus (Williamson) = *Nonionina barleeana* Williamson
Melonis pompilioides (Fichtel and Moll) = *Nautilus pompilioides* Fichtel and Moll
Miliammina arenacea (Chapman) = *Miliolina oblonga* (Montagu) var. *arenacea* Chapman
Neoeponides lunata (Brotzen) = cf. *Eponides lunata* Brotzen
Nodosaria limbata d'Orbigny
Nodosaria monile Hagenow
Nodosaria sulcata Nilsen
Nodosaria velascoensis Cushman
Nodosaria vertebralis (Batsch) = *Nautilus vertebralis* Batsch
Nonion grateloupi (d'Orbigny) = *Nonionina grateloupi* d'Orbigny
Nonion havanensis Cushman and Bermudez
Nonion sp. A
Nonion sp. B
Nonionella iridea Heron-Allen and Earland
Nonionellina sp.
Nuttallides truempyi (Nuttall) = *Eponides truempyi* Nuttall
Nuttallides umbonifera (Cushman) = *Pulvinulinella umbonifera* Cushman
Oolina spp.
Ophthalmidium pusillum (Earland) = *Spiroloculina pusilla* Earland
Oridorsalis umbonatus (Reuss) = *Rotalina umbonata* Reuss
Oridorsalis spp.
Orthomorphina antillea (Cushman) = *Nodosaria antillea* Cushman
Orthomorphina challengeriana (Thalman) = *Nodogenerina challengeriana* Thalman
Orthomorphina glandigena (Schwager) = *Nodosaria glandigena* Schwager
Orthomorphina havanensis (Cushman and Bermudez) = *Nodogenerina havanensis* Cushman and Bermudez
Orthomorphina himerensis (de Amicis) = *Nodosaria himerensis* de Amicis
Orthomorphina perversa (Schwager) = *Nodosaria perversa* Schwager
Osangularia culter (Parker and Jones) = *Planorbulina culter* Parker and Jones
Osangularia mexicana (Cole) = *Pulvinulinella culter* Parker and Jones var. *mexicana* Cole
Parafissurina spp.
Pleurostomella acuminata Cushman
Pleurostomella acuta Hantken
Pleurostomella alternans Schwager

- Pleurostomella bellardi* Hantken
Pleurostomella bolivinoidea Schubert
Pleurostomella brevis Schwager
Pleurostomella naranjoensis Cushman and Bermudez
Pleurostomella obtusa Berthelin
Pleurostomella tenuis Hantken
Psammosphaera fusca Schulze
Pullenia bulloides (d'Orbigny) = *Nonionina bulloides* d'Orbigny
Pullenia coryelli White
Pullenia eocenica Cushman and Siegfus
Pullenia osloensis Feyling-Hanssen
Pullenia quinqueloba (Reuss) = *Nonionina quinqueloba* Reuss
Pullenia salisbury Stewart and Stewart
Pullenia subcarinata (d'Orbigny) = *Nonionina subcarinata* d'Orbigny
Pyrgo depressa (d'Orbigny) = *Biloculina depressa* d'Orbigny
Pyrgo murrhina (Schwager) = *Biloculina murrhina* Schwager
Pyrgo nasuta Cushman
Pyrgo spp.
Pyrolina extensa (Cushman) = *Polymorphina extensa* Cushman
Pyrolina sp.
Quadriformina profunda Schnitker and Tjalsma
Quinqueloculina pygmaea Reuss
Quinqueloculina seminula (Linné) = *Serpula seminulum* Linné
Quinqueloculina venusta Karrer
Quinqueloculina sp.
Recurvoides contortus Earland
Reophax pilulifer Brady
Reticulophragmium orbicularis (Brady) = *Cyclammia orbicularis*
 Brady
Robulus rotulatus (Lamarck) = *Lenticulina rotulata* Lamarck
Sigmoilina edwardsi (Schlumberger)
Siphogenerinoides cf. *brevispinosa* Cushman
Siphonodosaria sp.
Siphotextularia curta (Cushman) = *Textularia flintii* var. *curta*
 Cushman
Sphaeroidina bulloides d'Orbigny
Spiroloculina antillarum d'Orbigny
Spiroloculina asperula Karrer
Spiroloculina depressa d'Orbigny
Spiroplectammia spectabilis (Grzybowski) = *Spiroplecta spectabilis*
 Grzybowski
Stainforthia complanata (Egger) = *Virgulina schreibersiana* Czjzek
 var. *complanata* Egger
Stilostomella annulifera (Cushman and Bermudez) = *Ellipsonodosaria*
annulifera Cushman and Bermudez
Stilostomella gracillima (Cushman and Jarvis) = *Ellipsonodosaria*
nuttalli var. *gracillima* Cushman and Jarvis
Stilostomella lepidula (Schwager) = *Nodosaria lepidula* Schwager
Stilostomella subspinosa (Cushman) = *Ellipsonodosaria subspinosa*
 Cushman
Textularia wiesneri Earland
Trifarina angulosa (Williamson) = *Uvigerina angulosa* Williamson
Trifarina bradyi Cushman
Triloculina oblonga (Montagu) = *Vermiculum oblongum* Montagu
Trochammia sp.
Turrilina alsatica Andreae
Turrilina robertsi (Howe and Ellis) = *Bulimina robertsi* Howe and
 Ellis
Uvigerina graciliformis Papp
Uvigerina havanensis Cushman and Bermudez
Uvigerina peregrina Cushman (group)
Uvigerina rippensis Cole
Uvigerina schencki Asano
Uvigerina semicostata Cushman
Uvigerina senticosa Cushman
Uvigerina spinicostata Cushman and Jarvis
Vaginulina subelegans Parr
Vaginulinopsis praelonga ten Dam
Vaginulinopsis tasmanica Parr
Valvulinaria laevigata Phleger and Parker
Vulvulina jarvisi Cushman
Vulvulina spinosa Cushman

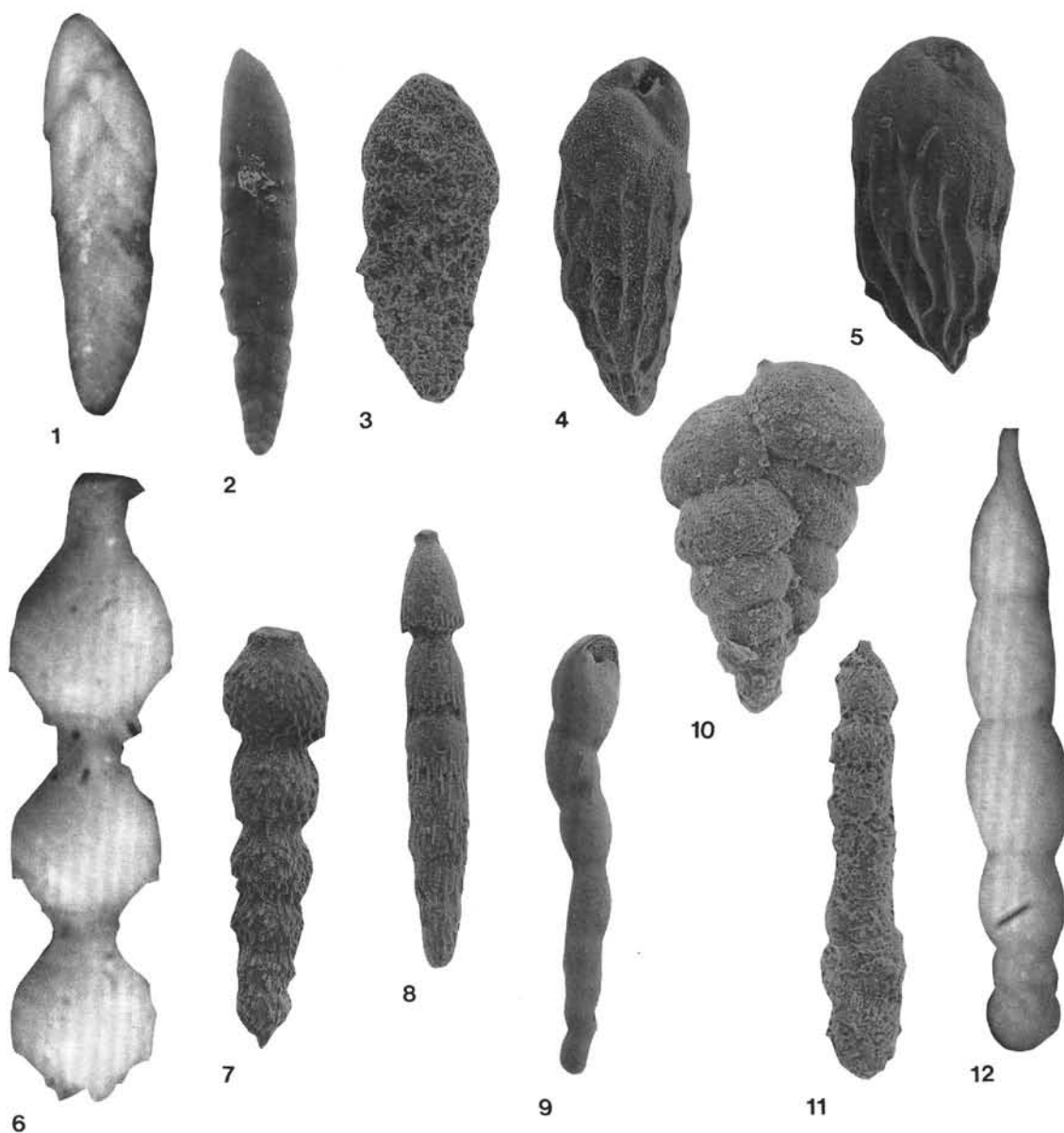


Plate 1. 1, 2. *Bolivina pseudopunctata* Höglund, Sample 119-736B-2H-4, 115-120 cm, $\times 451$. 3. *Bolivina thalmani* Renz, Sample 119-744B-6H-1, 125-130 cm, $\times 516$. 4. *Bulimina semicostata* Nuttall, Sample 119-738B-23X-CC, $\times 810$. 5. *Bulimina alazanensis* Cushman, Sample 119-744B-9H-4, 125-130 cm, $\times 561$. 6. *Stilostomella lepidula* (Schwager), Sample 119-738B-13H-CC, $\times 305$. 7. *Stilostomella subspinosa* (Cushman), Sample 119-738B-13H-CC, $\times 241$. 8. *Orthomorphina antillea* (Cushman), Sample 119-738B-11H-CC, $\times 437$. 9. *Pleurostomella obtusa* Berthelin, Sample 119-744A-14H-CC, $\times 271$. 10. *Karreriella cubensis* Cushman and Bermudez, Sample 119-738B-7H-CC, $\times 585$. 11. *Bigeneria nodulosa* d'Orbigny, Sample 119-744A-18H-CC, $\times 274$. 12. *Orthomorphina havanensis* (Cushman and Bermudez), Sample 119-738B-11H-CC, $\times 310$.

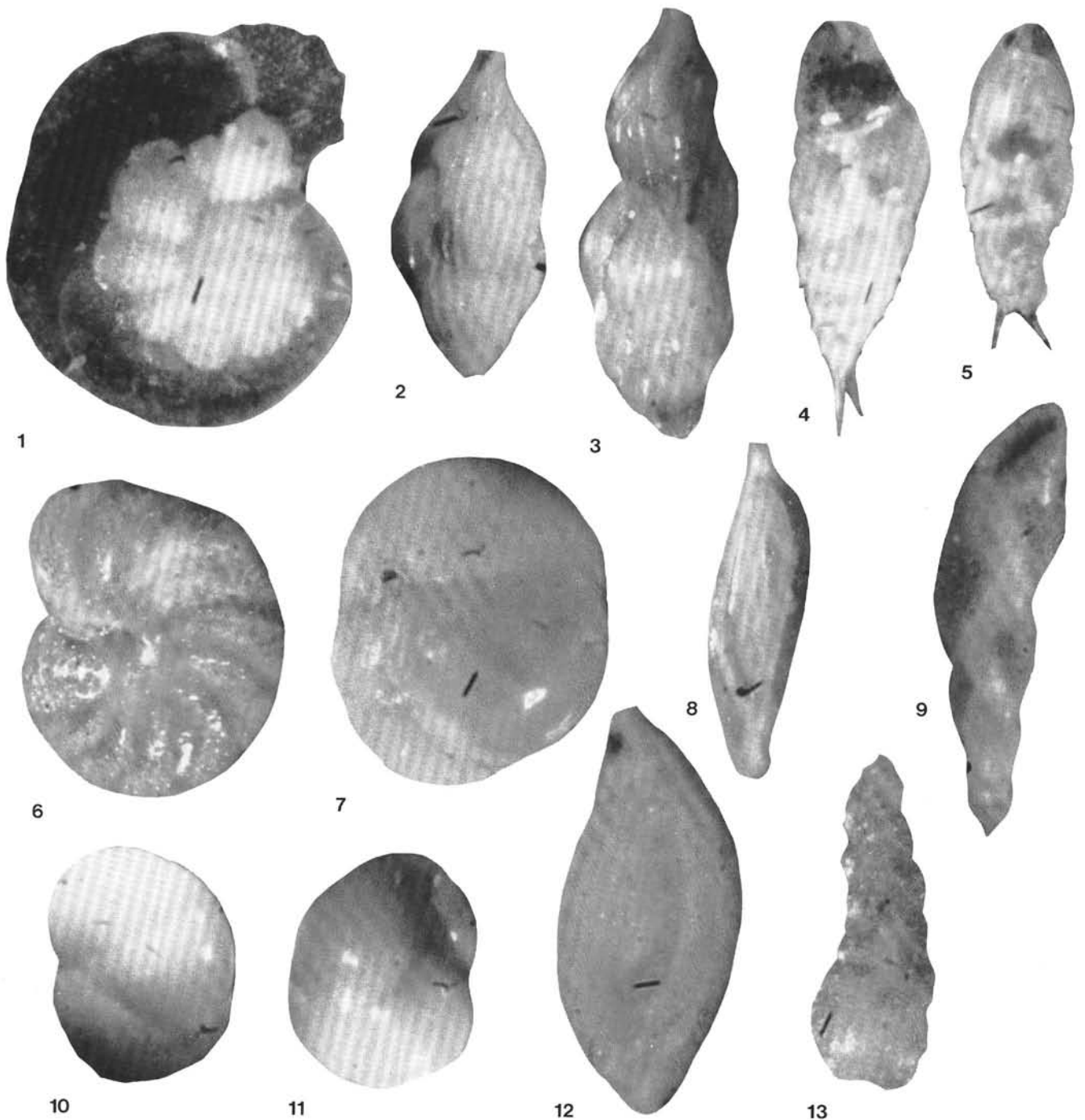


Plate 2. 1. *Laticarinina pauperata* (Parker and Jones), Sample 119-744B-7H-1, 120-125 cm, $\times 66$. 2, 3. *Angulogerina earlandi* Parr, Sample 119-736B-2H-2, 115-120 cm, $\times 85$. 4, 5. *Bulimina aculeata* d'Orbigny, Sample 119-736B-1H-1, 115-120 cm, $\times 175$. 6. *Melonis barleeanus* (Williamson), Sample 119-736B-2H-2, 115-120 cm, $\times 106$. 7. *Sphaeroidina bulloides* d'Orbigny, Sample 119-736C-10R-2, 115-120 cm, $\times 100$. 8. *Ophthalmidium pusillum* (Earland), Sample 119-744B-6H-3, 125-130 cm, $\times 197$. 9. *Stainforthia complanata* (Egger), Sample 119-736A-4H-1, 115-120 cm, $\times 210$. 10, 11. *Cassidulina oblonga* Reuss, Sample 119-736A-8H-CC, $\times 120$. 12. *Spiroloculina depressa* d'Orbigny, Sample 119-744B-6H-3, 125-130 cm, $\times 88$. 13. *Bolivinopsis cubensis* (Cushman and Bermudez), Sample 119-738B-12H-CC, $\times 156$.

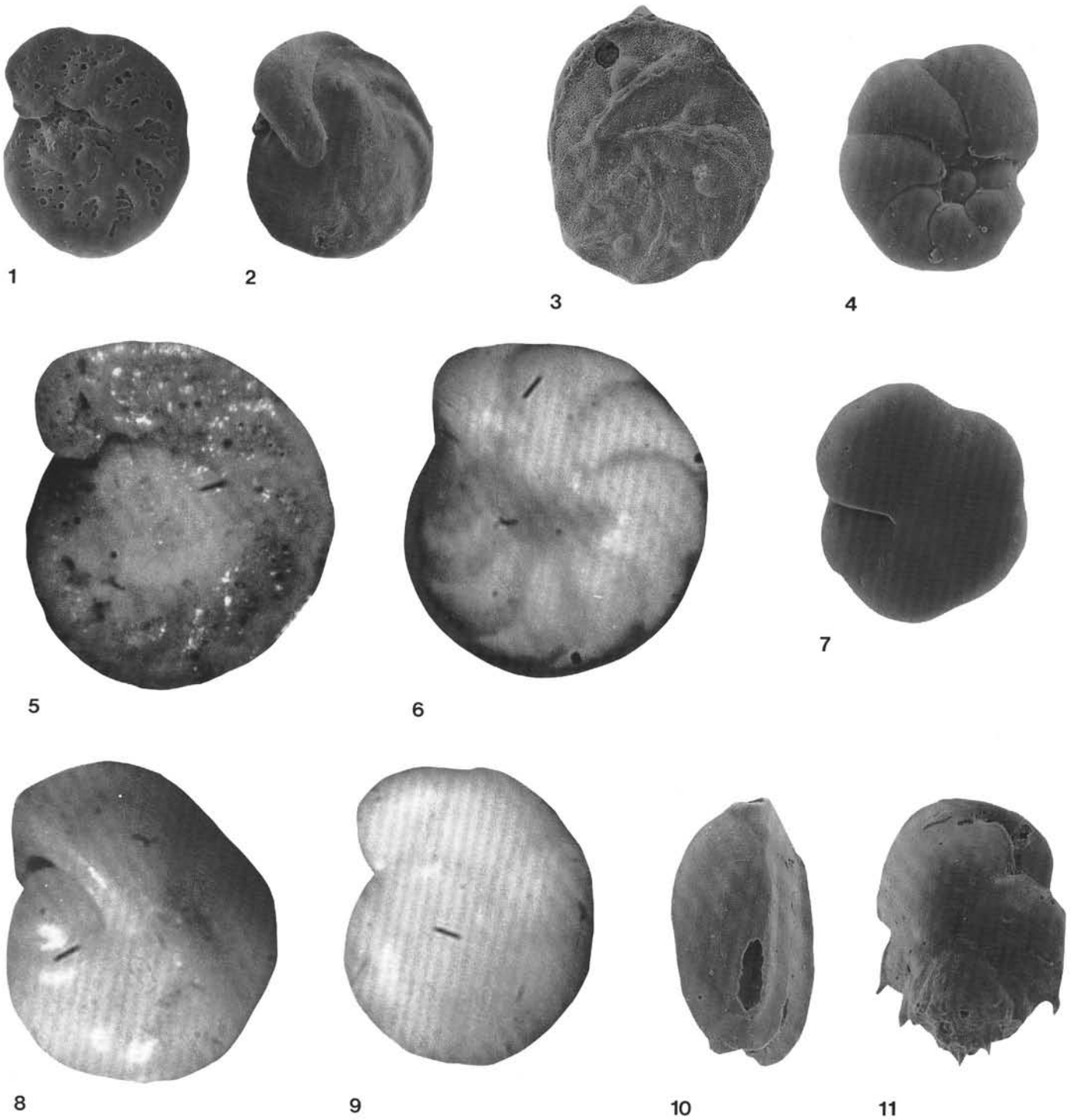


Plate 3. 1, 2. *Cibicoides wuellerstorfi* (Schwager), 1, spiral side, 2, umbilical side, Sample 119-744B-1H-3, 25-27 cm, $\times 195$. 3. *Heronallenia* sp. A, Sample 119-744B-7H-5, 120-125 cm, $\times 460$. 4. *Nonionella iridea* Heron-Allen and Earland, Sample 119-736B-1H-2, 115-120 cm, $\times 460$. 5, 6. *Cibicoides ungerianus* (d'Orbigny), 5, spiral side, 6, umbilical side, Sample 119-744A-19H-CC, $\times 380$. 7. *Pullenia osloensis* Feyling-Hanssen, Sample 119-744B-1H-2, 25-27 cm, $\times 491$. 8. *Pullenia subcarinata* (d'Orbigny), Sample 119-744B-6H-2, 125-130 cm, $\times 395$. 9. *Gyroidina lamarckiana* (d'Orbigny), Sample 119-744B-7H-3, 120-125 cm, $\times 166$. 10. *Quinqueloculina venusta* Karrer, Sample 119-744B-6H-4, 125-130 cm, $\times 304$. 11. *Ehrenbergina* sp. A, Sample 119-744B-7H-1, 120-125 cm, $\times 302$.

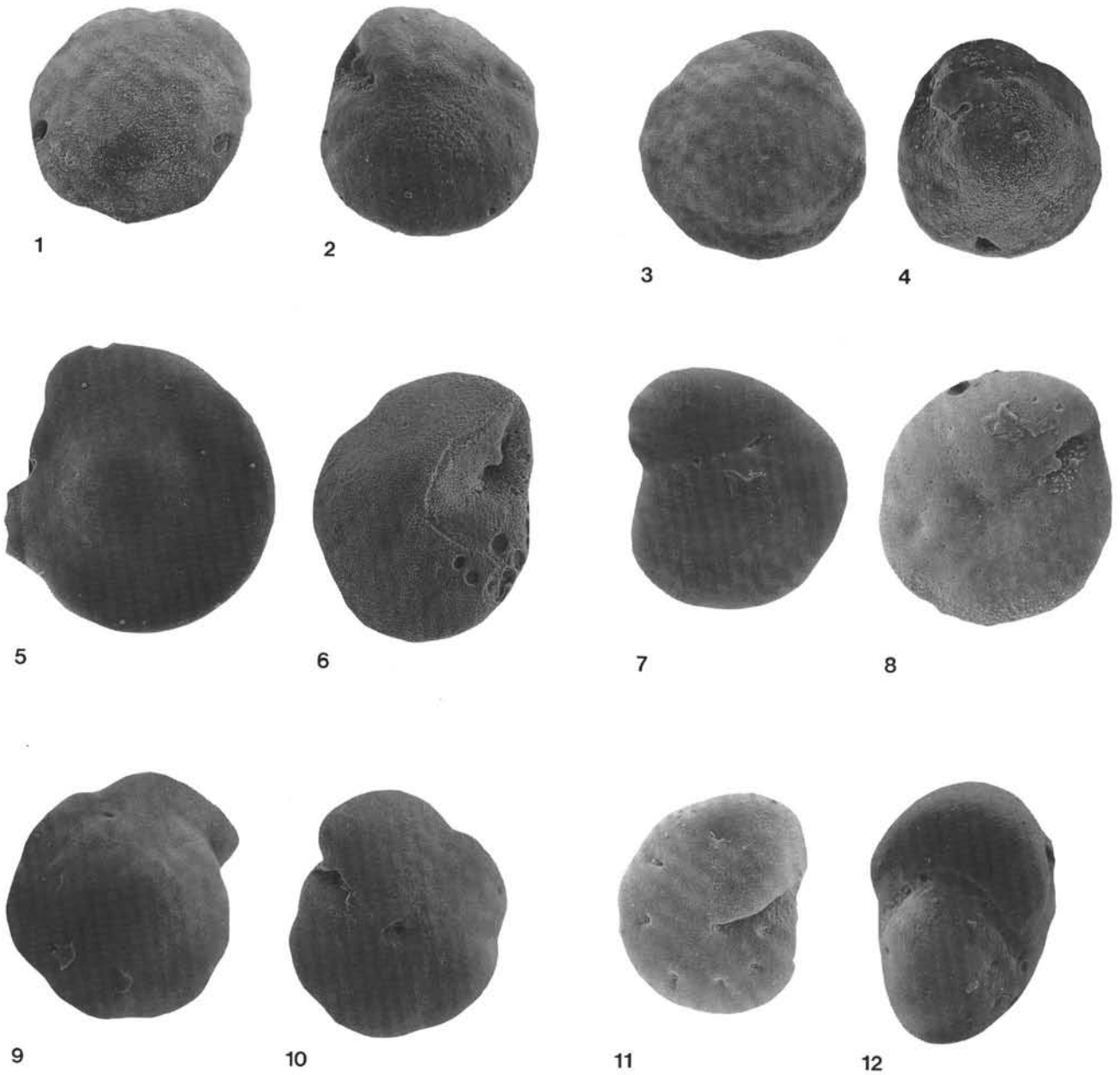


Plate 4. 1, 2. *Nuttallides umbonifera* (Cushman), 1, spiral side, 2, umbilical side, Sample 119-744B-7H-1, 120–125 cm, $\times 354$. 3, 4. *Nuttallides truempyi* (Nuttall), 3, spiral side, 4, umbilical side, Sample 119-738B-9H-CC, $\times 354$. 5, 6. *Epistominella exigua* (Brady), 5, spiral side, 6, umbilical side, Sample 119-744B-4H-2, 25–27 cm, $\times 459$. 7, 8. *Epistominella vitrea* Parker, 7, spiral side, 8, umbilical side, Sample 119-744B-1H-1, 2–4 cm, $\times 459$. 9, 10. *Oridorsalis umbonatus* (Reuss), 9, spiral side, 10, umbilical side, Sample 119-744A-12H-CC, $\times 453$. 11, 12. *Astrononion umbilicatum* Uchio, 11, side view, 12, aperture view, Sample 119-744B-7H-1, 120–125 cm, $\times 397$.