Fryer, P., Pearce, J. A., Stokking, L. B., et al., 1992
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 125

4. MIDDLE EOCENE TO EARLY OLIGOCENE FORAMINIFERS FROM THE IZU-BONIN FOREARC, HOLE 786A[1]

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ABSTRACT

Drilling at Site 786, located in the center of the Izu-Bonin forearc basin, penetrated an apparently continuous section of middle Eocene/lower Oligocene volcaniclastic breccias and nannofossil oozes. Planktonic foraminiferal faunas underwent a gradual transition from relatively high-diversity middle Eocene through late Eocene tropical or warm-water assemblages to a cooler-water, less diverse assemblage during the early Oligocene.

In the cosmopolitan benthic foraminiferal faunas, the major transition occurred during the early late Eocene. Middle Eocene benthic assemblages resembling the bathyal "*Lenticulina*" fauna (characterized by *Osangularia mexicana, Cibicidoides eocaenus,* and several buliminid species) changed to an upper Eocene abyssal "*Globocassidulina subglobosa*" fauna (characterized by *Cibicidoides praemundulus, Globocassidulina subglobosa, Gyroidinoides girardanus, Oridorsalis umbonatus,* and *Siphonodosaria aculeata*). Even though no large, abrupt faunal changes appear to have been associated with the assumed Eocene/Oligocene boundary, benthic species turnover continued through the late Eocene and into the early Oligocene. This resulted in a slightly lower diversity early Oligocene fauna dominated by three species: *Laevidentalina* sp., *Bulimina jarvisi,* and *Gyroidinoides girardanus.*

The progression from a middle Eocene bathyal "*Lenticulina*" fauna, rather than an abyssal "*Nuttallides truempyi*" fauna, to an abyssal "*Globocassidulina subglobosa*" fauna during the early late Eocene, suggests that a bathymetric deepening occurred at Site 786. Increased water depths may have resulted from tectonic subsidence.

INTRODUCTION

In the Pacific, the middle Eocene to early Oligocene interval witnessed extensive change in foraminiferal generic composition and diversity (Corliss, 1981; Keller, 1983a, 1983b, 1986b). It is now accepted that these changes occurred as a series of short stepwise events (Prothero, 1989), rather than as the single abrupt extinction inferred by Pomerol and Premoli-Silva (1986).

At Site 786 (31° 52′48″N, 141° 13′58″ E, Fig. 1) in the center of the Izu-Bonin forearc basin, a cored interval of middle Eocene to lower Oligocene sediments was recovered. The middle Eocene to lower Oligocene interval (Sections 125-786A-10X-5, 33–40 cm, through -12X-CC; Fig. 2) has a thickness of 20.95 m, and despite poor recovery in the lowermost core, 125-786A-12X, reasonable biostratigraphic control is attained. The foraminiferal record from Hole 786A complements that from Deep Sea Drilling Project (DSDP) Sites 445 and 446 (Echols, 1980) and details deep-water faunas in a juvenile arc environment.

The aims of this study are to: (1) document the foraminiferal assemblages from Eocene to lower Oligocene sediments in Hole 786A in the Izu-Bonin forearc and examine the benthic foraminiferal turnover during this time interval and (2) to compare the foraminiferal faunas with those from coeval deep-water deposits elsewhere in order to place the fauna in a global biogeographic context. Deep-sea drilling sites that penetrate Eocene to Oligocene sediments are present throughout the Atlantic Ocean (Tjalsma and Lohmann, 1983; Miller et al., 1985), Indian Ocean (Davies, Luyendyk, et al., 1974), and Pacific Ocean (Corliss, 1981). In the Pacific Ocean, few drill sites have intersected a continuous Eocene to Oligocene sedimentary section (Keller, 1986a). Many of the Pacific DSDP sites contain both Eocene and Oligocene sediments (e.g., Sites 208, 210, and 287), but the lower Oligocene is missing often due to poor recovery, hiatuses, and low carbonate preservation. Two DSDP sites, Site 292 (Keller, 1983a, 1983b; Corliss et al., 1984) and Site 592 (Kennett et al., 1985), have been extensively studied and represent the best Eocene to Oligocene reference sections for the southwest and equatorial Pacific regions.

Previous drilling results (i.e., DSDP Legs 6, 7, 20, 31, 58, 59, and 60) in the northwest Pacific did not yield a useable marine Eocene/Oligocene section. Most often the basement is younger than Miocene or a hiatus is present between Oligocene and Cretaceous strata. Only Sites 445 and 446 (DSDP Leg 58, northern Kyushu-Palau Ridge area) penetrated significant thicknesses of Eocene and Oligocene sediments. The results of Echols (1980) preliminary study on these sites are not detailed enough to provide useful data on Eocene/Oligocene faunal changes in the area drilled.

METHODS AND RESULTS

For laboratory analysis, nine friable, relatively carbonate-rich samples were used for detailed foraminiferal studies (see Fig. 2 for stratigraphic position). Each sample, of about 10–15 cm^3 of sediment, was disaggregated and washed with water over a >63-μm mesh sieve. Where preservation allowed, at least 300 foraminiferal specimens were systematically picked and sorted from the >63-μm fraction. The single poorly preserved sample (Sample 125-786A-11X-1, 100–109 cm) was selectively picked. Typical specimens of each species were photographed as secondary electron images using a Philips 505 scanning electron microscope, set at 20–25 kV.

General Faunal Characteristics

The planktonic and benthic foraminifers found in the studied section are typically cosmopolitan in character. The species are documented in the Appendix and shown in Plates 1–7. Foraminifers are the most common skeletal elements of the >63-μm fraction. Throughout the studied section planktonic foraminifers constitute between 94% and 99% of the total foraminiferal assemblage.

Foraminiferal diversity, expressed simply as number of species recovered from each sample, changed through time (Tables 1 and 2). Benthic foraminiferal species diversity rose steadily during the early middle Eocene through late Eocene and began to decrease during the

[1]Fryer, P., Pearce, J. A., Stokking, L. B., et al., 1992. *Proc. ODP, Sci. Results,* 125: College Station, TX (Ocean Drilling Program).

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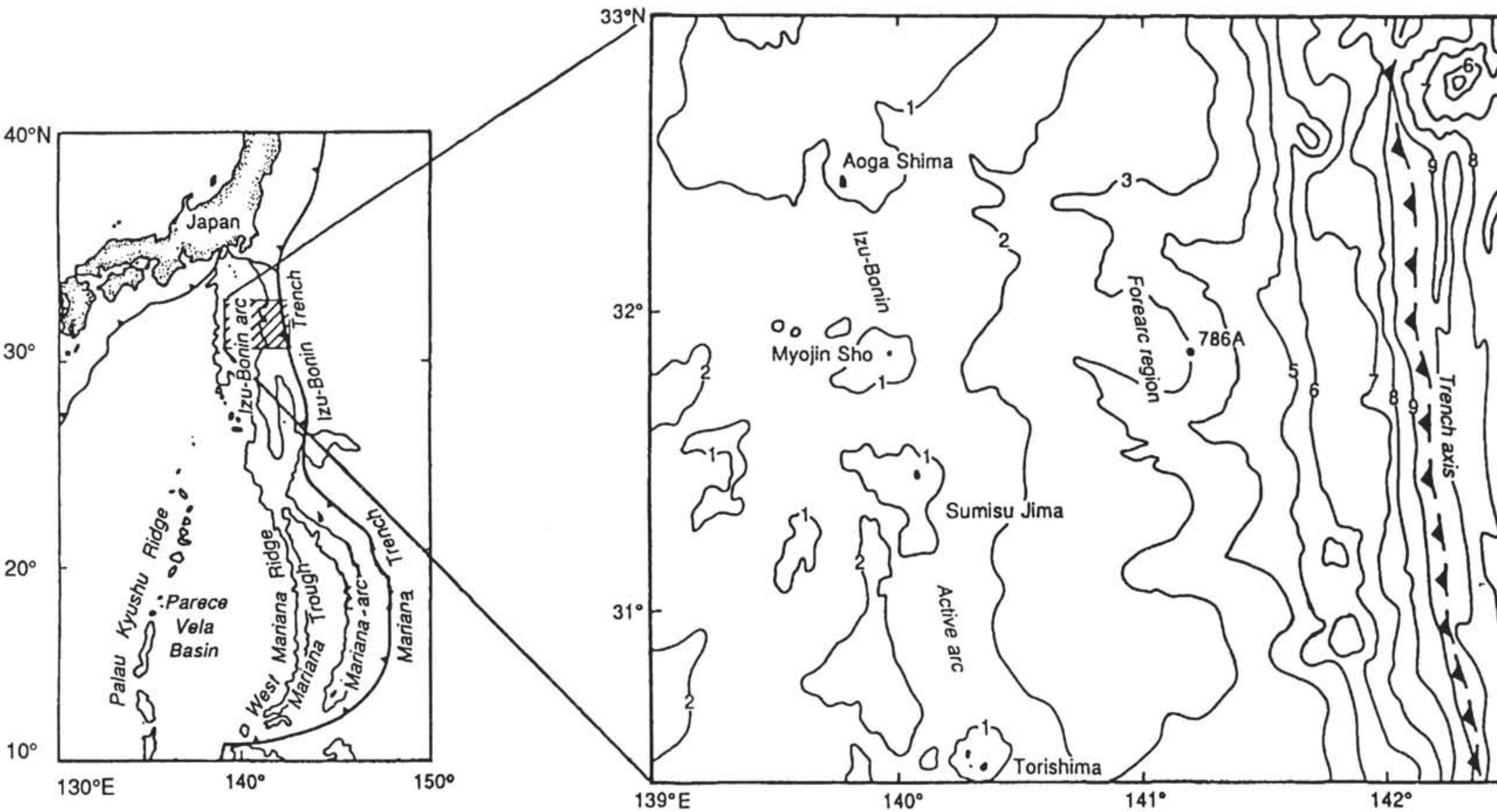

Figure 1. Location of Site 786 in the Izu-Bonin forearc. Adapted from Fryer, Pearce, Stokking, et al. (1990). Bathymetric contours are in kilometers.

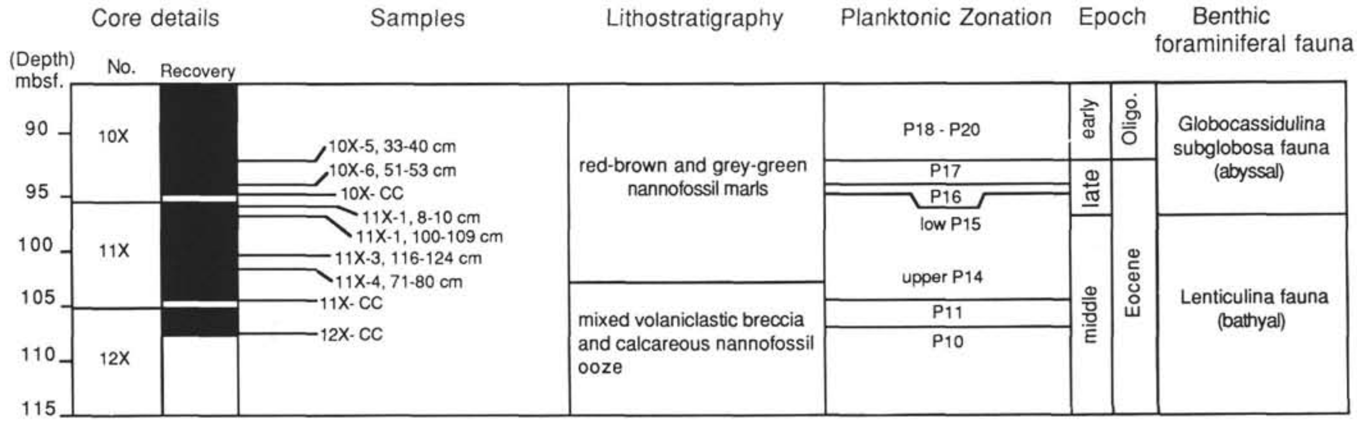

Figure 2. Position of samples in Hole 786A with lithostratigraphy, planktonic foraminiferal zonation, and benthic foraminiferal faunas.

Table 1. Distribution of planktonic foraminifers in Hole 786A.

Core, section: Interval (cm from top of section):	10X-5 33–40	10X-6 51–53	10X-CC	11X-1 8–10	11X-1 100–109	11X-3 116–124	11X-4 71–80	11X-CC	12X-CC
GLOBIGERINIDA									
Catapsydracidae									
Catapsydrax dissimilis	F	F	F	R	F	R	R	R?	R?
Globorotaloides carcoselleensis	—	—	—	—	—	—	R	—	—
Subbotina eocaena	C	F	C	C	C	C	F	F	F
Subbotina euapertura	C	F	C	F	C	C	F	—	—
Subbotina linaperta	—	—	F	C	C	C	C	C	C
Globigerinidae									
Globigerina sp. A	—	R	—	—	—	—	—	—	—
Globigerina corpulenta	F	F	C	C	C	C	C	R?	R?
Globigerina tripartita	R	—	—	—	—	—	—	—	—
Globigerina praeturritilina	F	F	—	—	—	—	—	—	—
Globigerinatheka mexicana cf. *barri*	—	—	—	—	—	F	F	—	—
Globigerinatheka mexicana mexicana	—	—	—	—	—	F	F	F	—
Globanomalinidae									
Cribrohantkenina inflata	—	—	R	—	—	—	—	—	—
Hantkenina alabamensis	—	—	F	F	F	F	R	R?	R
Pseudohastigerina micra	—	—	R	R	F	F	F	F	F
Pseudohastigerina naguewichensis	—	R	R	—	—	—	—	—	—
Truncorotaloididae									
Acarinina bullbrooki	—	—	—	—	—	—	—	F	C
Morozovella aragonensis	—	—	—	—	—	—	—	F	F
Morozovella spinulosa	—	—	—	—	—	—	F	—	—
Globorotaliidae									
Turborotalia cerroazulensis cocoaensis	—	R	F	A	C	C	C	—	F
Turborotalia cerroazulensis pomeroli	—	—	—	—	C	C	C	—	—
Preservation	Good	Good	Moderate	Moderate	Poor	Moderate	Moderate	Moderate	Moderate
Diversity	7	10	11	9	10	12	13	10	10

Notes: Species abundances are subjectively evaluated as rare (R), few (F), common (C), and abundant (A). Absences are indicated by dashes (—). Preservation of foraminifers is ranked as poor, moderate, and good. Diversity is the total number of planktonic species in the assemblage. Sample positions are shown in Figure 2.

latest Eocene and early Oligocene. In contrast to this trend, the number of planktonic foraminiferal species peaked in the early middle Eocene and, except for a small peak in the late Eocene, generally decreased through the early Oligocene.

Planktonic Foraminifers

Provincialism

Using foraminiferal evidence from DSDP sites in the northeast and southwest Pacific Ocean, Sancetta (1979), described temperate and tropical province planktonic foraminiferal assemblages in the middle and upper Eocene Pacific Ocean. The middle and upper Eocene assemblages in Hole 786A appear to contain species from both the tropical and temperate province faunas as defined by Sancetta (1979). Tropical planktonic foraminiferal species appear to be the most common. Temperate province species located in Hole 786A include common *Subbotina linaperta*, with fewer *Catapsydrax dissimilis*, *Globigerinatheka mexicana mexicana*, and *Globigerinatheka mex-icana* cf. *barri*. Tropical province species in studied planktonic assem-blages include *Subbotina eocaena, Turborotalia cerroazulensis pomeroli* (= synom. partim. *Globorotalia centralis,* Toumarkine and Luterbacher, 1985), *Turborotalia cerroazulensis cocoaensis, Morozovella spinulosa, Pseudohastigerina micra, Pseudohastigerina naguewichensis, Hantkenina alabamensis, and Cribrohantkenina inflata.*

Comparison of the lower Oligocene planktonic foraminiferal assemblage from Hole 786A with the faunal assemblage provinces described by Sancetta (1979) for the lower Oligocene Pacific Ocean shows that faunal elements of the transitional province are dominant. The transitional province planktonic foraminiferal species present in the lower Oligocene in Hole 786A include common *Subbotina eocaena*, with lesser numbers of *Catapsydrax dissimilis* and *Globigerina tripartita.* As described by Sancetta (1979) *Subbotina euapertura* is the only early Oligocene tropical province species present.

Zonation and Age

The biostratigraphic subdivision and chronostratigraphy of Cores 125-786A-10X through -12X is shown in Figure 2. Wherever possible the first appearance datums (FAD) and last appearance datums (LAD), detailed in the revised tropical planktonic foraminiferal zonation of Berggren and Miller (1988) and applied to the chronometric scale of Berggren et al. (1985), are used. Berggren and Miller (1988, p. 364) has shown their tropical zonation to be applicable as far north and south as the subtropics, between the latitudes 47° N (Krasheninnikov, 1979) and 30° S (Boersma, 1977; Pujol, 1983). For species ranges (Table 1) not described by Berggren and Miller (1988), those of Toumarkine and Luterbacher (1985, Eocene species) and Bolli and Saunders (1985, Oligocene species) are used.

Poor sediment recovery allowed only a single sample (Sample 125-786A-12X-CC) to be taken from the lowermost core (-12X). Here, the earliest middle Eocene planktonic foraminiferal fauna is dominated by *Acarinina bullbrooki* and typical middle Eocene *Subbotina* species (e.g., *S. eoceana* and *S. linaperta).* The rare presence of *Hantkenina* sp. and *Morozovella aragonensis* confines the sample to within Zones P10 to P11 (earliest middle Eocene; ca. 52.0–46.0 Ma).

Sample 125-786A-11X-CC contains many of the planktonic foraminifers present in the previous sample. The first appearance of *Globigerinatheka mexicana mexicana* and the presence of *Morozovella aragonensis* confines the age of Sample 125-786A-11X-CC to the middle Eocene (Zone P11; ca. 49.0–46.0 Ma).

In Sample 125-786A-11X-4, 71–80 cm, the presence of *Morozovella spinulosa* and *Turborotalia cerroazulensis cocoaensis* confines the sample to the upper part of Zone P14 (late middle Eocene; ca. 42.2–41.3 Ma). Between Samples 125-786A-11X-CC and -11X-4, 71–80 cm, a disconformity encompassing Zones P12 to lower P14 may be present. There is no sedimentary evidence suggesting this and these zones could be incorporated in a condensed sequence between the sampled intervals. Toumarkine and Luterbacher (1985, p. 97, fig. 6) noted that the first occurrence of *T. cerroazulensis cocoaensis* may be in the upper part of Zone P14, thus overlapping with the latter part of the *M. spinulosa* range. The planktonic assemblage from this sample is composed mostly of *T. cerroazulensis pomeroli, T. cerroazulensis cocoaensis,* and *Subbotina* species, with less common *Globigerinatheka mexicana mexicana, Globigerinatheka mexicana* cf. *barri,* and rare *M. spinulosa.*

A late middle to earliest late Eocene (upper Zone P14 to lower Zone P15; ca. 42.2–39.6 Ma) planktonic foraminiferal fauna occurs in Sample 125-786A-11X-3, 116–124 cm. Dominated by species of *Turborotalia* and *Subbotina,* the age of the sample is constrained by *T. cerroazulensis cocoaensis* and the last appearance of *G. mexicana mexicana.*

Samples 125-786A-11X-1, 100–109 cm, and -11X-1, 8–10 cm, are dominated by *Subbotina* species with less common *Turborotalia* species, *Hantkenina alabamensis,* and *Pseudohastigerina micra.* Based on the occurrence of *Subbotina linaperta* and *T. cerroazulensis cocoaensis,* these samples are dated as latest middle to late Eocene (upper Zone P14 to Zone P16; ca. 42.2–37.1 Ma).

A late Eocene (Zone P16) planktonic foraminiferal fauna occurs in Sample 125-786A-10X-CC and includes mostly *Subbotina* species and *T. cerroazulensis cocoaensis* with less common *Hantkenina alabamensis* and rare *Cribrohantkenina inflata.* The last appearance of *P. micra* also occurs in this sample as does the first appearance of *Pseudohastigerina nageuwichensis.*

Sample 125-786A-10X-6, 51–53 cm, is dated as late Eocene (Zone P17; ca. 37.1–36.6 Ma). based on a planktonic foraminiferal fauna (10 species) comprising abundant long-ranging *Subbotina* species and *Globigerina* species and a few individuals of *T. cerroazulensis cocoaensis* and *P. naguewichensis. Cribrohantkenina inflata* is absent from the assemblage.

The uppermost sample (Sample 125-786A-10X-5, 33–40 cm) contains the lowest diversity fauna in the examined section. This sample is tentatively assigned an age of early Oligocene (Zones P18 to P20; ca. 36.6–31.6 Ma). based on an exclusively globigerinacean fauna. An absence of the marker species described by Berggren and Miller (1988) and Bolli and Saunders (1985) (e.g., *Chilogeumbelina cubensis, Pseudohastigerina* species, and *Cassigerinella chipolensis*) precludes a more accurate zonal determination. The tentative age constraints are based on the disappearance of *T. cerroazulensis* s.l., suggesting a maximum age limit younger than Zone P17, and a minimum age of Zone P20 using the absence of *Globorotalia angulisuturalis* (FAD Zone P21; Berggren and Miller, 1988). Using nannofossils, the early Oligocene age determination by Xu and Wise (this volume) of Sample 125-786A-10X-5, 14–15 cm, in close proximity upsection to Sample 125-786A-10X-5, 33–40 cm, agrees with the author's age determination of early Oligocene based on planktonic foraminifers.

Benthic Foraminifers

Benthic foraminifers are present in low frequencies throughout the studied section, and commonly form between 1% and 6% of the total foraminiferal assemblage (see Table 2). Benthic assemblages in Hole 786A contain many species, described by van Morkhoven et al. (1986) and Tjalsma and Lohmann (1983) as deep-water cosmopolitan forms, which have been documented from most of the major oceanic basins (e.g., Atlantic Ocean: Tjalsma and Lohmann, 1983, and Miller et al., 1985; Pacific Ocean: Corliss, 1981; and Indian Ocean: Davies, Luyendyk, et al., 1974). Onshore sections with similar faunas are best represented by the Oceanic Formation of Barbados, documented by Wood et al. (1985).

Tjalsma and Lohmann (1983) described a "*Lenticulina*" fauna, interpreted as bathyal, characterized by *Lenticulina* spp., *Bulimina* spp., and *Osangularia mexicana* and an abyssal "*Globocassidulina subglobosa*" fauna composed of *Oridorsalis umbonatus, Gyroidinoides* spp., *Cibicidoides praemundulus, Stilostomella aculeata,* and *Globocassidulina subglobosa.*

In Hole 786A, assemblages resembling the "*Lenticulina*" fauna (i.e., with *Osangularia mexicana, Cibicidoides eoceanus, Vulvulina spinosa,* and several *Bulimina* species) are present in Samples 125-786A-12X-CC to -11X-1, 8–10 cm (earliest middle Eocene through latest middle to late Eocene). The *Globocassidulina subglobosa* fauna, characterized by *Cibicidoides praemundulus, Globocassidulina subglobosa, Gyroidinoides girardanus, Oridorsalis umbonatus,* and *Siphonodosaria aculeata,* is present in the remaining upper Eocene to lower Oligocene part of the section (Samples 125-786A-10X-CC through -10X-5, 33–40 cm).

Throughout the studied section, benthic foraminiferal faunas are dominated by long-ranging, geographically widespread buliminid and rotaliid species (e.g., *Bulimina jarvisi, Cibicidoides eocaenus, Cibicidoides praemundulus, Globocassidulina subglobosa, Gyroidinoides girardanus, Laevidentalina* sp., *Osangularia mexicana, Siphonodosaria aculeata,* and *Siphonodosaria* sp. cf. *S. verneuili*). The remaining orders, Lituolida and Nodosariida, are numerically and taxonomically poorly represented. Even though most species were long-ranging in

Table 2. Distribution of species of Lituolida, Nodosariida, Buliminida, and Rotaliida in Hole 786A.

Core, section: Interval (cm):	10X-5 33–40	10X-6 51–53	10X-CC	11X-1 8–10	11X-1 100–109	11X-3 116–124	11X-4 71–80	11X-CC	12X-CC
LITUOLIDA									
Eggerellidae									
Karreriella subglabra	R	—	—	—	—	—	—	—	—
Spiroplectaminidae									
Spiroplectammina sp.	R	—	—	—	—	—	—	—	—
Vulvulina spinosa	—	F	F	—	R	R	—	—	—
NODOSARIIDA									
Ellipsolagenidae									
Oolina sp.	—	—	—	—	R	—	—	R	—
Palliolatella sp.	—	—	—	R	—	—	—	—	—
Pseudofissurina crassicarinata	—	R	—	—	—	—	—	—	—
?*Pseudoolina* sp. cf. *P. bouei*	R	—	—	—	—	—	—	—	—
Lagenidae									
?*Pygmaeoseistron* sp.	R	—	—	—	—	—	—	—	—
Nodosariidae									
Chrysalogonium sp.	—	—	R	—	—	—	—	—	—
Laevidentalina sp.	A	—	—	—	—	—	—	—	—
Plectofrondicularia paucicostata	—	—	R	R	—	—	—	—	—
Pseudonodosaria sp.	—	R	—	—	—	—	—	R	—
Pyramidulina sp.	R	F	A	F	R	R	—	—	—
Polymorphinidae									
Guttulina problema	—	—	R	R	—	—	—	—	—
Vaginulinidae									
Astacolus sp.	—	R	—	—	—	—	—	—	—
Lenticulina sp.	—	—	—	—	R	—	—	—	—
BULIMINIDA									
Buliminidae									
Bulimina sp.	—	R	—	—	—	—	—	—	—
Bulimina alazanensis	—	R	—	R	—	—	—	—	R
Bulimina glomarchallengeri	—	—	—	R	—	—	—	—	—
Bulimina jarvisi	A	—	R	R	R	R	R	—	—
Globobulimina sp.	R	—	—	—	—	—	—	—	—
?*Protoglobobulimina* sp.	R	—	—	—	—	—	—	—	—
Buliminellidae									
Buliminella grata	—	F	R	R	R	—	R	—	R
Buliminella grata spinosa	—	R	—	—	—	R	—	R	—
Quadratobuliminella pyramidalis	—	R	—	—	—	—	—	—	—
Cassidulinidae									
Cassidulina havanensis	—	R	F	F	—	—	—	—	—
Globocassidulina subglobosa	R	C	F	F	C	—	—	—	—
Pleurostomellidae									
?*Ellipsodimorphina* sp.	—	—	R	—	—	—	—	—	—
Ellipsoglandulina sp.	—	—	R	—	—	—	—	—	—
Ellipsoidina sp.	—	—	R	—	—	—	—	—	—
Nodosarella sp.	—	—	—	—	—	—	R	—	—
Pleurostomella sp.	—	R	—	—	—	R	—	—	—
Pleurostomella acuta	R	F	R	—	R	F	—	—	—
Pleurostomella bierigi	—	F	R	R	—	—	R	—	—
Pleurostomella sp. cf. *P. brevis*	—	—	R	—	—	—	—	R	
Pleurostomella incrassata	—	—	R	—	—	—	—	—	—
Stilostomellidae									
Nodogenerina sp. A	—	—	R	—	—	—	—	—	—
Nodogenerina sp. B	—	—	R	R	—	—	—	—	—
?*Siphonodosaria* sp.	R	—	—	—	—	—	—	—	—
Siphonodosaria sp.	R	—	—	—	—	—	—	—	—
Siphonodosaria cf. *aculeata*	—	C	A	—	—	F	—	—	—
Siphonodosaria sp. cf. *S. verneuili*	—	F	—	C	—	—	—	C	—
?*Stilostomella* sp.	R	—	—	—	—	—	—	—	—
Stilostomella subspinosa	—	—	R	F	—	—	—	—	—

Table 2 (continued).

Core, section: Interval (cm):	10X-5 33–40	10X-6 51–53	10X-CC	11X-1 8–10	11X-1 100–109	11X-3 116–124	11X-4 71–80	11X-CC	12X-CC
ROTALIIDA									
Epistomariidae									
Nuttallides truempyi	—	—	—	—	—	F	—	—	—
Gavelinellidae									
?Gyroidinoides sp.	—	—	—	R	—	—	—	—	—
Gyroidinoides girardanus	A	A	F	F	F	—	—	—	F
Heterolepidae									
Anomalinoides sp.	—	—	—	—	—	R	—	—	—
Nonionidae									
Pullenia bulloides	F	F	—	—	—	R	—	—	—
Pullenia quinqueloba	R	R	—	—	—	—	—	—	—
Oridorsalidae									
Oridorsalis umbonatus	C	A	C	F	—	—	R	—	R
Osangulariidae									
Osangularia mexicana	R	R	F	C	R	C	C	—	—
Parrelloididae									
Cibicidoides eocaenus	R	R	R	C	F	F	—	R	R
Cibicidoides praemundulus	A	F	R	—	F	F	F	R	R
Preservation	Good	Good	Moderate	Moderate	Poor	Moderate	Moderate	Moderate	Moderate
Diversity	20	23	25	20	13	14	7	5	8

Notes: Species abundances are subjectively evaluated as rare (R), few (F), common (C), and abundant (A). Absences are indicated by dashes (—). Sample positions are shown in Figure 2.

Hole 786A, two episodes of benthic foraminiferal diversification took place during the middle Eocene to early Oligocene. The first, during the middle Eocene (Samples 125-786A-11X-CC to -11X-3, 116–124 cm), involved the appearance of the buliminid and rotaliid species *Anomalinoides* sp., *Bulimina jarvisi, Buliminella grata spinosa, Nodosarella* sp., *Nuttallides truempyi, Osangularia mexicana, Pleurostomella* spp., *Pullenia bulloides,* and *Siphonodosaria aculeata.* The nodosariid (*Pseudonodosaria* sp., *Pyramidulina* sp., and *Oolina* sp.) and lituolid species (*Vulvulina spinosa*), which do not have representatives in the basal sample (125-786A-12X-CC), begin to appear in low numbers in this first period of faunal diversification. The second and larger diversification involved the introduction of 14 previously unrecorded species of benthic foraminifers and occurred during the latest middle to late Eocene (Zones [upper] P14 to P16; Samples 125-786A-11X-1, 8–10 cm, to -10X-CC). These first appearances include a total of nine buliminid species: *Cassidulina havanensis, ?Ellipsodimorphina* sp., *Ellipsoidina* sp., *Ellipsoglandulina* sp., *Pleurostomella* sp., *Pleurostomella acuta, Pleurostomella bierigi, Pleurostomella* sp. cf. *P. brevis,* and *Pleurostomella incrassata.* Other orders are represented by the first appearance of a single rotaliid species, *?Gyroidinoides* sp., and four species of nodosariids: *Palliolatella* sp., *Chrysalogonium* sp., *Plectofrondicularia paucicostata,* and *Guttulina problema.* After this late Eocene peak in diversity (in Sample 125-786A-10X-CC) the benthic faunal diversity falls slightly. Twenty-five taxa make their last appearance in Samples 125-786A-10X-CC and -10X-6, 51–53 cm; this includes 18 species of Buliminida, six species of Nodosariida, and one species of Lituolida. In contrast to the large number of extinctions, only three species are added in this interval, the rotaliid *Pullenia quinqueloba* and the nodosariids *Lenticulina* sp. and *Pseudofissurina crassicarinata.* The rotaliid species remain unaffected.

By the early Oligocene (Sample 125-786A-10X-5, 33–40 cm) the specific composition of the benthic foraminiferal fauna had changed. From the peak-diversity buliminid-dominated faunas of the late Eocene only 11 species remained. This new benthic fauna is dominated by three species: *Laevidentalina* sp., *Bulimina jarvisi,* and *Gyroidinoides girardanus.* The overall composition of the benthic fauna is only slightly less diverse (20 species) compared to the late Eocene (25 species in Sample 125-786A-10X-CC and 23 species in Sample 125-786A-10X-6, 51–53 cm). Many of the species in the Oligocene sample are represented by one or two individuals. Benthic forms that first appeared during the early Oligocene are the lituolids *Karreriella subglabra* and *Spiroplectammina* sp., the nodosariid species *?Pseudoolina* sp. cf. *P. bouei, Laevidentalina* sp., *?Pygmaeoseistron* sp., and buliminids *?Siphonodosaria* sp., *Siphonodosaria* sp., and *Stilostomella* sp. Rotaliid species representation shows little change from the late Eocene, though rotaliid species become relatively less abundant.

Paleobathymetric Regime

Using modern analogues (Murray, 1973), applied to the Paleogene (Gibson, 1989), and the bathymetric zonation adopted by van Morkhoven et al. (1986), the proportion of planktonic foraminifers in this studied section (94%–99%) suggests a paleobathymetry of at least upper bathyal (>150 m). For the middle Eocene this depth estimate is confirmed by the presence of benthic foraminifers belonging to the bathyal "*Lenticulina*" fauna described by Tjalsma and Lohmann (1983; ca. 1000–2000 m). Using the upper depth limits described by van Morkhoven et al. (1986), the presence of *Cibicidoides praemundulus* suggests a depth of greater than approximately 1000 m, which is lower bathyal. The absence or reduced presence of deeper water or abyssal forms (e.g., *Nuttallides truempyi*) may be due to the progressive restriction of these forms to depths greater than 2000 m (Tjalsma and Lohmann, 1983, text-fig. 55) during the middle Eocene. Depths may have increased by the late Eocene. In the lower upper Eocene, the abyssal "*Globocassidulina subglobosa*" fauna of Tjalsma and Lohmann (1983; ca. 2000–4000+ m) is the dominant assemblage continuing across the Eocene/Oligocene boundary into the lower Oligocene. This suggested transition from a lower bathyal to abyssal bathymetry is also supported by the increased relative abundance of *C. praemundulus* during the late Eocene/early Oligocene, noted by van Morkhoven et al. (1986) to be greatest at abyssal depths. Foraminifers more typical of the shallower "*Lenticulina*" fauna (i.e., *Osangularia mexicana, Bulimina* species, and *Cibicidoides eoceanus*) are still present, but in lesser abundances.

DISCUSSION AND CONCLUSIONS

Benthic foraminiferal evidence from Hole 786A shows that no real "faunal crisis" (Kennett and Shackleton, 1976), associated with benthic foraminifers at or near the Eocene/Oligocene boundary, took place in this area. Considerable benthic foraminiferal changes did occur, however, between the middle Eocene and lower Oligocene in Hole 786A. Corliss (1979, 1981), Tjalsma (1982), Tjalsma and Lohmann (1983), and Miller et al. (1985) have suggested that gradual variations in generic composition rather than large changes in generic diversity took place. At the deep-water DSDP sites examined by the above-mentioned authors the major middle Eocene to early Oligocene benthic foraminiferal change was the replacement of the middle Eocene abyssal "*Nuttallides* spp." assemblage with a late Eocene abyssal "*Globocassidulina subglobosa*" assemblage (e.g., Tjalsma and Lohmann, 1983, Miller et al., 1985) at or near the middle/late Eocene boundary. However, in Hole 786A a "*Lenticulina*" fauna with only a minor presence of *N. truempyi* represents the middle to early late Eocene. According to Tjalsma and Lohmann (1983) and van Morkhoven et al. (1986), this fauna probably reflects lower bathyal water depths. The transition from a bathyal "*Lenticulina*" fauna to an abyssal "*Globocassidulina subglobosa*" fauna suggests that in Hole 786A, the depositional environment deepened from lower bathyal (1000 m to approximately 2000 m) during the middle Eocene to an abyssal (>2000 m) during the late Eocene. This change in bathymetry was probably associated with tectonic subsidence in the outer forearc high. Sea-level curves for the middle to late Eocene, as defined by Haq et al. (1987), show decreasing sea levels for this time, which is contrary to the increase in sea levels needed to justify the deepening bathymetry in Hole 786A.

Evidence from Hole 786A appears to agree with the suggestion by Hussong and Uyeda (1981), who cited evidence using an Eocene-Oligocene sedimentary sequence at Site 460 at 6500 m depth, that subsidence can occur in a forearc setting. Even though they found no depth-definitive benthic foraminifers in association with these sediments it was noted the section was similar to coeval sediments in shallower drilled holes. They also suggested that subsidence in forearc terranes may not be uncommon and described cases from the Japan, Mariana, and Middle America arc systems, including benthic foraminiferal evidence from the Japan Trench (DSDP Sites 438 and 439) by Keller (1980). However, Karig and Ranken (1983) concluded that the Mariana forearc did not undergo significant subsidence, a view subsequently agreed with by Fryer, Pearce, Stokking, et al. (1990). If the evidence put forward by Hussong and Uyeda (1981) and Keller (1980) is correct then subsidence in parts of the forearc of the Izu-Bonin arc system may have begun as early as early late Eocene as suggested from the benthic foraminiferal evidence in Hole 786A.

ACKNOWLEDGMENTS

I am grateful to the Ocean Drilling Program and Australian Secretariat of the Ocean Drilling Program for inviting me to participate as a shipboard scientist on Leg 125. Special thanks are due to Dr. Patrick Coleman, Dr. David Haig, Dr. George Chaproniere, Dr. Johanna Resig, David Lynch, Darren Ferdinando, and Lorraine Stevens for their helpful discussions and reviews of the manuscript and to the Electron Microscopy Centre of the University of Western Australia for facilitating my use of a scanning electron microscope.

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Date of initial receipt: 19 October 1990
Date of acceptance: 5 June 1991
Ms 125B-143

APPENDIX

Taxonomic Notes

Foraminifers recorded from Hole 786A are classified under the orders recognized by Haynes (1981), and the families and genera diagnosed by Loeblich and Tappan (1988). For each species the original nomenclature is cited (following Ellis and Messina, 1940, et seq.) and, where relevant, remarks are made concerning the taxonomy and/or previously recognized occurrences. References are included with those of the main text.

Order LITUOLIDA
Family EGGERELLIDAE
Genus *KARRERIELLA*

Karreriella subglabra (Gümbel)
(Plate 1, Fig. 1)

1868 *Gaudryina subglabra* Gümbel, p. 602, pl. 1, figs. 4a–b.
1983 *Karreriella subglabra*, Tjalsma and Lohmann, p. 34, pl. 9, fig. 1a–b.

Remarks. This species, represented by a single specimen from lower Oligocene, Sample 125-786A-10X-5, 33–40 cm, is described by Tjalsma and Lohmann (1983) as a common element of the deep-water Eocene benthic assemblages.

Family SPIROPLECTAMMINIDAE
Genus *SPIROPLECTAMMINA*

Spiroplectammina sp.
(Plate 1, Fig. 2)

Remarks. All the specimens found consisted only of the later biserially arranged part of the test. The lack of the coiled initial chambers precludes any specific identification.

Genus *VULVULINA*

Vulvulina spinosa Cushman
(Plate 1, Fig. 3)

1927 *Vulvulina spinosa* Cushman, p. 111, pl. 23, fig. 1 [*fide* Ellis and Messina].
1983 *Vulvulina spinosa*, Tjalsma and Lohmann, p. 38, pl. 10, figs. 4a–5b.

Remarks. Described by Tjalsma and Lohmann (1983) as a common middle early Eocene to Oligocene deep-water form, this species is sporadically present in the upper Eocene to lower Oligocene samples.

Order NODOSARIIDA
Family ELLIPSOLAGENIDAE
Genus *OOLINA*

Oolina sp.
(Plate 1, Fig. 4)

1985 *Globulina* sp., Grünig, p. 263, pl. 6, figs. 10, 11.

Genus *PALLIOLATELLA*

Palliolatella sp.
(Plate 1, Fig. 5)

Remarks. This specimen appears similar to *Entosolenia crumenata* Cushman (1935), but the individual found and figured here has a more laterally compressed test with less prominent secondary keels on either side of a broader and wider median keel.

Genus *PSEUDOFISSURINA*

Pseudofissurina crassicarinata Bandy
(Plate 1, Fig. 6)

1949 *Fissurina crassicarinata* Bandy, p. 64, pl. 9, fig. 6 [*fide* Ellis and Messina].

Genus ?*PSEUDOOLINA*

?*Pseudoolina* sp. cf. *P. bouei* Karrer
(Plate 1, Fig. 7)

1877 *Fissurina bouei* Karrer, p. 378, pl. 16b, fig. 19 [*fide* Ellis and Messina].

Remarks. The specimen figured here is most like *F. bouei* with fewer ribs on the lower half of the test while *F. multicosta* Karrer, 1877 has a greater number of ribs that tend to bifurcate.

Family LAGENIDAE
Genus *PYGMAEOSEISTRON*

?*Pygmaeoseistron* sp.
(Plate 1, Fig. 8)

Family NODOSARIIDAE
Genus *CHRYSALOGONIUM*

Chrysalogonium sp.
(Plate 1, Fig. 9)

Genus *LAEVIDENTALINA*

Laevidentalina sp.
(Plate 1, Fig. 10)

Genus *PLECTOFRONDICULARIA*

Plectofrondicularia paucicostata Cushman and Jarvis
(Plate 1, Fig. 11)

1929 *Plectofrondicularia paucicostata* Cushman and Jarvis, p. 10, pl. 2, figs. 11–13 [*fide* Ellis and Messina].
1986 *Plectofrondicularia paucicostata*, van Morkhoven et al., p. 273, pl. 91, figs. 1a–2c.

Remarks. Described by van Morkhoven et al. (1986) as a middle bathyal to abyssal form ranging from middle Eocene Zone P12 through early Oligocene Zone P20, this species was found in the upper Eocene Samples 125-786A-10X-CC and -11X-1, 8–10 cm.

Genus *PSEUDONODOSARIA*

Pseudonodosaria sp.
(Plate 1, Fig. 12)

Genus *PYRAMIDULINA*

Pyramidulina sp.
(Plate 1, Fig. 13)

Family POLYMORPHINIDAE
Genus *GUTTULINA*

Guttulina problema (d'Orbigny)
(Plate 1, Fig. 14)

1846 *Polymorphina (Guttiline) problema* d'Orbigny, p. 266, pl. 12, figs. 26–28 [*fide* Ellis and Messina].

Family VAGINULINIDAE
Genus *ASTACOLUS*

Astacolus sp.
(Plate 1, Fig. 15)

Genus *LENTICULINA*

Lenticulina sp.
(Plate 2, Figs. 1, 2)

Remarks. The single specimen found in Sample 125-786A-11X-1, 100–109 cm, displays an atypical aperture which maybe a growth aberration resulting from predatory boring.

Order BULIMINIDA
Family BULIMINIDAE
Genus *BULIMINA*

Bulimina alazanensis Cushman
(Plate 2, Fig. 3)

1927 *Bulimina alazanensis* Cushman, p. 161, pl. 25, fig. 4.
1983 *Bulimina alazanensis,* Tjalsma and Lohmann, p. 24, pl. 14, fig. 4.

Remarks. This species had a rare scattered occurrence from early middle Eocene (Sample 125-786A-12X-CC) to latest Eocene (Sample 125-786A-10X-6, 51–53 cm).

Bulimina glomarchallengeri Tjalsma and Lohmann
(Plate 2, Fig. 4)

1983 *Bulimina glomarchallengeri* Tjalsma and Lohmann, p. 25, pl. 13, figs. 9a–b.
1986 *Bulimina glomarchallengeri,* van Morkhoven et al., p. 243, pl. 82A–B, figs. 1–4c, 1–3.

Remarks. This species represented by a single specimen from Sample 125-786A-11X-1, 8–10 cm, has a reduced adapical spine and a greater area covered by fine longitudinal costae compared to the specimens figured by van Morkhoven et al. (1986).

Bulimina jarvisi Cushman and Parker
(Plate 2, Fig. 5)

1936 *Bulimina jarvisi* Cushman and Parker, p. 39, pl. 7, figs. 1a–c [*fide* Ellis and Messina].
1986 *Bulimina jarvisi,* van Morkhoven et al., p. 184, pl. 62, figs. 1–5.

Remarks. As described by van Morkhoven et al. (1986) *B.jarvisi* is often difficult to distinguish from *B. semicostata* Nutall. The specimens figured in this study have been named *B. jarvisi* because of their large test size and loop-shaped aperture, whereas individuals of *B. semicostata* tend to have smaller, more triangular tests. This species present in low numbers throughout the section became abundant in the early Oligocene (represented by Sample 125-786A-10X-5, 33–40 cm).

Genus *GLOBOBULIMINA*

Globobulimina sp.
(Plate 2, Fig. 6)

Family BULIMINELLIDAE
Genus *BULIMINELLA*

Buliminella grata Parker and Bermudez
(Plate 2, Figs. 7, 8)

1937 *Buliminella grata* Parker and Bermudez, p. 515, pl. 59, figs. 6a–c [*fide* Ellis and Messina].
1983 *Buliminella grata,* Tjalsma and Lohmann, p. 26, pl. 12, figs. 7a–b.

Remarks. These specimens most resemble those figured by Tjalsma and Lohmann (1983) with their smooth test wall as compared to the granulose walls of the individuals figured by Berggren and Aubert (1983).

Buliminella grata spinosa Parker and Bermudez
(Plate 2, Fig. 9)

1937 *Buliminella grata spinosa* Parker and Bermudez, p. 516, pl. 59, fig. 7 [*fide* Ellis and Messina].
1983 *Buliminella grata spinosa,* Tjalsma and Lohmann, pl. 12, figs. 8a–b.

Genus *QUADRATOBULIMINELLA*

Quadratobuliminella pyramidalis de Klasz
(Plate 2, Fig. 10)

1953 *Quadratobuliminella pyramidalis* de Klasz, p. 435, text-fig. 1a–2c.
1983 *Quadratobuliminella pyramidalis,* Tjalsma and Lohmann, p. 19, pl. 12, fig. 6a–b.

Family CASSIDULINIDAE
Genus *CASSIDULINA*

Cassidulina havanensis Cushman and Bermudez
(Plate 2, Fig. 11)

1936 *Cassidulina havanensis* Cushman and Bermudez, p. 36, pl. 6, fig. 11 [*fide* Ellis and Messina].
1985 *Cassidulina havanensis,* Wood et al., p. 184, pl. 1, figs. 14–16.

Remarks. This species is present only in the late middle Eocene and late Eocene samples of this study.

Genus *GLOBOCASSIDULINA*

Globocassidulina subglobosa (Hantken)
(Plate 2, Figs. 12, 13)

1875 *Cassidulina globosa* Hantken, p. 64, pl. 16, figs. 2a–b [*fide* Ellis and Messina].
1983 *Globocassidulina globosa,* Berggren and Aubert, pl. 14, figs. 5–7.

Remarks. This species first appeared in the late middle Eocene (Sample 125-786A-11X-1, 100–109 cm) and became abundant in the early Oligocene. Tjalsma and Lohmann (1983) described this species as an abyssal component of their late Eocene *Globocassidulina subglobosa* fauna deep-water fauna.

Family PLEUROSTOMELLIDAE
Genus *ELLIPSODIMORPHINA*

?*Ellipsodimorphina* sp.
(Plate 2, Fig. 14)

Genus *ELLIPSOGLANDULINA*

Ellipsoglandulina sp.
(Plate 2, Fig. 15)

Genus *ELLIPSOIDINA*

Ellipsoidina sp. A
(Plate 3, Fig. 1)

Ellipsoidina sp. B
(Plate 3, Fig. 2)

Genus *NODOSARELLA*

Nodosarella sp.
(Plate 3, Fig. 3)

Genus *PLEUROSTOMELLA*

Pleurostomella sp.
(Plate 3, Fig. 4)

Pleurostomella acuta Hantken
(Plate 3, Fig. 5)

1875 *Pleurostomella acuta* Hantken, p. 44, pl. 13, fig. 18 [*fide* Ellis and Messina].
1983 *Pleurostomella acuta,* Miller, p. 439, pl. 4, fig. 7.

Pleurostomella bierigi Palmer and Bermudez
(Plate 3, Fig. 6)

1936 *Pleurostomella bierigi* Palmer and Bermudez, p. 224, pl. 294, pl. 17, figs. 7–8 [*fide* Ellis and Messina].

Pleurostomella sp. cf. *P. brevis* Schwager
(Plate 3, Fig. 7)

1866 *Pleurostomella brevis* Schwager, p. 239, pl. 6, fig. 81 [*fide* Ellis and Messina].

Pleurostomella incrassata Hantken
(Plate 3, Fig. 8)

1883 *Pleurostomella incrassata* Hantken, p. 146, pl. 1, figs. 4a–b, 7a–b [*fide* Ellis and Messina].
1987 *Pleurostomella incrassata,* Hulsbos, p. 531, pl. 5, fig. 10.

Family STILOSTOMELLIDAE
Genus *NODOGENERINA*

Nodogenerina sp. A
(Plate 3, Fig. 9)

Nodogenerina sp. B
(Plate 3, Fig. 10)

Genus *SIPHONODOSARIA*

?*Siphonodosaria* sp.
(Plate 3, Fig. 11)

Siphonodosaria sp.
(Plate 3, Fig. 12)

Siphonodosaria aculeata (Cushman and Jarvis)
(Plate 3, Fig. 13)

1948 *Ellipsonodosaria nuttalli* Cushman and Jarvis var. *aculeata* Cushman and Renz, p. 32, pl. 6, fig. 10.
1983 *Stilostomella aculeata,* Tjalsma and Lohmann, p. 36, pl. 14, fig. 12.

Remarks. This species, sporadically present in low numbers in the middle Eocene, increased in abundance to form a significant component of the benthic fauna in the late Eocene. Tjalsma and Lohmann (1983) described this species of this genus as a component of their late Eocene abyssal *Globocassidulina subglobosa* fauna.

Siphonodosaria sp. cf. *S. verneuili* (d'Orbigny)
(Plate 3, Fig. 14)

1846 *Dentalina verneuili* d'Orbigny, p. 48, pl. 2, figs. 7–8 [*fide* Ellis and Messina].
1976 *Stilostomella verneuili,* Berggren and Aubert, p. 314, pl. 1, fig. 6.

Remarks. Described by Berggren and Aubert (1976) as characteristic of late Paleogene bathyal assemblages, individuals of this species, often consisting of poorly preserved broken tests, are commonly found in Samples 125-786A-12X-CC and 125-786A-11X-1, 100–109 cm.

Genus *STILOSTOMELLA*

Stilostomella subspinosa (Cushman)
(Plate 3, Fig. 15)

1943 *Ellipsonodosaria subspinosa* Cushman, p. 92, pl. 16, figs. 6–7b [*fide* Ellis and Messina].
1983 *Stilostomella subspinosa,* Tjalsma and Lohmann, p. 36, pl. 14, figs. 16–17.

Order ROTALIIDA
Family EPISTOMARIIDAE
Genus *NUTTALLIDES*

Nuttallides truempyi (Nuttall)
(Plate 4, Figs. 1, 2)

1930 *Eponides truempyi* Nuttall, p. 287, pl. 24, figs. 9–13 [*fide* Ellis and Messina].
1986 *Nuttallides truempyi,* van Morkhoven et al., p. 288, pl. 96A–D.

Remarks. This species, represented in this study by a few individuals found in Sample 125-786A-11X-3, 116–124 cm, is described by Tjalsma and Lohmann (1983) as becoming restricted to deeper water environments by the middle to late Eocene.

Family GAVELINELLIDAE
Genus *GYROIDINOIDES*

?*Gyroidinoides* sp.
(Plate 4, Fig. 7)

Gyroidinoides girardanus (Reuss)
(Plate 4, Figs. 3, 4)

1851 *Rotalina girardana* Reuss, p. 73, pl. 5, fig. 34 [*fide* Ellis and Messina].
1984 *Gyroidinoides girardanus,* Clark and Wright, p. 464, pl. 7, figs. 4a–c.

Remarks. This species, sporadically present in low numbers throughout the Eocene-Oligocene section, increases in abundance to form a significant component of the benthic fauna in the lower most lower Oligocene, Sample 125-786A-10X-6, 51–53 cm. Tjalsma and Lohmann (1983) described this species of this genus as a component of their late Eocene abyssal *Globocassidulina subglobosa* fauna.

Family HETEROLEPIDAE
Genus *ANOMALINOIDES*

Anomalinoides sp.
(Plate 4, Figs. 5, 6)

Remarks. This species comprises a single specimen found in Sample 125-786-11X-3, 116–124 cm. The specimen has a low trochospiral test with 7–8 chambers in final whorl. The spiral side is coarsely perforate and the umbilicus deep and central. Sutures become more deeply incised towards the final chamber.

Family NONIONIDAE
Genus *PULLENIA*

Pullenia bulloides (d'Orbigny)
(Plate 4, Fig. 8)

1846 *Nonionina bulloides* d'Orbigny, p. 107, pl. 5, figs. 9–10 [*fide* Ellis and Messina].
1985 *Pullenia bulloides*, Miller, Curry and Ostermann, p. 538, pl. 7, fig. 3.

Pullenia quinqueloba (Reuss)
(Plate 4, Fig. 9)

1851 *Nonionina quinqueloba* Reuss, p. 71, pl. 5, figs. 31a–b [*fide* Ellis and Messina].
1987 *Pullenia quinqueloba*, Hulsbos, p. 531, pl. 2, fig. 11–12.

Family ORIDORSALIDAE
Genus *ORIDORSALIS*

Oridorsalis umbonatus (Reuss)
(Plate 4, Figs. 10, 11)

1851 *Rotalina umbonata* Reuss, p. 75, pl. 5, fig. 35 [*fide* Ellis and Messina].
1983 *Oridorsalis umbonatus*, Miller, pl. 4, figs. 14–15.

Remarks. This species, described by Tjalsma and Lohmann (1983) as an element of their abyssal *Globocassidulina subglobosa* fauna, is sporadically present in low to moderate numbers throughout the middle to upper Eocene part of the section and increases in abundance to form a significant part of the benthic fauna in the lower Oligocene sample.

Family OSANGULARIIDAE
Genus *OSANGULARIA*

Osangularia mexicana (Cole)
(Plate 4, Figs. 12, 13)

1927 *Pulvinulinella culter* (Parker and Jones) var. *mexicana* Cole, p. 31, pl. 1 figs. 15–16 [*fide* Ellis and Messina].
1983 *Osangularia mexicana*, Tjalsma and Lohmann, p. 35, pl. 20, fig. 6.

Remarks. Present in low amounts throughout the studied section, this species was described by Tjalsma and Lohmann (1983) as a bathyal element of their *Lenticulina* fauna.

Family PARRELLOIDIDAE
Genus *CIBICIDOIDES*

Cibicidoides eocaenus (Gümbel)
(Plate 5, Figs. 1, 2)

1868 *Rotalina eocaena* Gümbel, p. 650, pl. 2, figs. 87a–b [*fide* Ellis and Messina].
1986 *Cibicidoides eocaenus*, van Morkhoven et al., p. 256, pl. 86A–B, figs. 1–4b, 1a–2c.

Remarks. This species, designated by van Morkhoven et al. (1986) to encompass *Cibicidoides tuxpamensis* is commonly present in the lower–middle Eocene to lower Oligocene samples examined.

Cibicidoides praemundulus Berggren and Miller
(Plate 5, Figs. 3, 4)

1986 *Cibicidoides praemundulus*, van Morkhoven et al., p. 264, pl. 87, figs. 1a–2b.

Remarks. This species, described as a separate species from the Miocene species *Cibicidoides ungerianus* (d'Orbigny) and as a bathyal to abyssal form by van Morkhoven et al. (1986), is present in small percentages in most samples examined from the lower middle Eocene to lower Oligocene. Tjalsma and Lohmann (1983) included this species as part of their abyssal *Globocassidulina subglobosa* fauna.

Order GLOBIGERINIDA
Family CATAPSYDRACIDAE
Genus *CATAPSYDRAX*

Catapsydrax dissimilis (Cushman and Bermudez)
(Plate 5, Fig. 5)

1937 *Globigerina dissimilis* Cushman and Bermudez, p. 25, pl. 3, figs. 4–6.
1985 *Catapsydrax dissimilis*, Bolli and Saunders, p. 186, figs. 17.1–4.

Genus *GLOBOROTALOIDES*
Globorotaloides carcoselleensis Toumarkine and Bolli
(Plate 5, Fig. 6)

1975 Globorotaloides carcoselleensis Toumarkine and Bolli, p. 81, pl. 5, fig. 24.
1985 *Globorotaloides carcoselleensis*, Toumarkine and Luterbacher, p. 150, figs. 41.9–16.

Genus *SUBBOTINA*

Subbotina eocaena (Gümbel)
(Plate 5, Fig. 11)

1868 *Globigerina eocaena* Gümbel, p. 662, pl. 2, figs. 109a–c.
1981 *Globigerina eocaena*, Stainforth and Lamb, p. 20, pl. 1, figs. 2a–c.

Subbotina euapertura (Jenkins)
(Plate 5, Fig. 12)

1960 *Globigerina euapertura* Jenkins, p. 351, pl. 1, figs. 8a–c.
1985 *Globigerina euapertura*, Bolli and Saunders, p. 180, figs. 21a–c.

Subbotina linaperta Finlay
(Plate 6, Fig. 1)

1939 *Globigerina linaperta* Finlay, p. 125, pl. 13, figs. 54–57 [*fide* Ellis and Messina].
1981 *Globigerina linaperta*, Stainforth and Lamb, p. 19, pl. 1, figs. 1a–b.

Family GLOBIGERINIDA
Genus *GLOBIGERINA*

Globigerina sp. A
(Plate 5, Fig. 7)

Globigerina corpulenta Subbotina
(Plate 5, Fig. 8)

1953 *Globigerina corpulenta* Subbotina, p. 76, pl. 9, figs. 5a–c.
1981 *Globigerina corpulenta*, Stainforth and Lamb, p. 21, pl. 1, figs. 3a–4c.

Globigerina praeturritilina Blow and Banner
(Plate 5, Figs. 9, 10)

1962 *Globigerina praeturritilina* Blow and Banner, p. 99, pl. 13, figs. A–C.
1985 *Globigerina praeturritilina*, Bolli and Saunders, p. 177, figs. 17.18a–b.

Globigerina tripartita Koch
(Plate 6, Fig. 2)

1926 *Globigerina bulloides* var. *tripartita* Koch, p. 746, pl. 737, figs. 21a–b [*fide* Ellis and Messina].
1985 *Globigerina bulloides* var. *tripartita*, Bolli and Saunders, p. 181, figs. 14.13a–c.

Genus *GLOBIGERINATHEKA*

Globigerinatheka mexicana mexicana Cushman
(Plate 6, Fig. 3)

1925a *Globigerinatheka mexicana mexicana* Cushman, p. 61, pl. 22, figs. 6a–c.
1985 *Globigerinatheka mexicana mexicana,* Toumarkine and Luterbacher, p. 112, figs, 37.16–17, 39.33–39.

Globigerinatheka mexicana cf. *barri* Brönnimann
(Plate 6, Fig. 4)

1952 *Globigerinatheka mexicana barri* Brönnimann, p. 27, text figs. 3a–c.
1985 *Globigerinatheka mexicana barri,* Toumarkine and Luterbacher, p. 144, figs. 37.15, 39.23–32.

Family GLOBANOMALINIDAE
Genus *CRIBROHANTKENINA*

Cribrohantkenina inflata (Howe)
(Plate 6, Figs. 5, 6)

1928 *Hantkenina inflata* Howe, p. 14, pl. 14, fig. 2.
1985 *Cribrohantkenina inflata,* Toumarkine and Luterbacher, p. 125, figs. 26.1–7.

Genus *HANTKENINA*

Hantkenina alabamensis Cushman
(Plate 6, Figs. 7, 8)

1925b *Hantkenina alabamensis* Cushman, p. 3, pl. 1, fig. 1 [*fide* Ellis and Messina].
1950 *Hantkenina alabamensis* Brönnimann, p. 414, pl. 56, figs. 10, 14–16.

Genus *PSEUDOHASTIGERINA*

Pseudohastigerina micra (Cole)
(Plate 6, Figs. 9, 10)

1927 *Nonion micrus* Cole, p. 22, pl. 5, fig. 12 [*fide* Ellis and Messina].
1985 *Pseudohastigerina micra,* Toumarkine and Luterbacher, p. 118, figs. 21.1–8.

Pseudohastigerina naguewichensis (Myatliuk)
(Plate 6, Figs. 11, 12)

1950 *Globigerinella naguewichensis* Myatliuk, p. 281, pl. 4, fig. 4a–b [*fide* Ellis and Messina].
1985 *Pseudohastigerina naguewichensis,* Toumarkine and Luterbacher, p. 119, figs. 21.10–16.

Family TRUNCOROTALOIDIDAE
Genus *ACARININA*

Acarinina bullbrooki (Bolli)
(Plate 7, Figs. 1, 2)

1957 *Globorotalia bullbrooki* Bolli, p. 167, pl. 38, figs. 5a–b.
1985 *Acarinina bullbrooki,* Toumarkine and Luterbacher, p. 130, figs. 29.4–10.

Genus *MOROZOVELLA*

Morozovella aragonensis (Nuttall)
(Plate 7, Figs. 3, 4)

1930 *Globorotalia aragonensis* Nuttall, p. 238, pl. 24, figs. 6–8, 10–11.
1977 *Morozovella aragonensis,* Berggren, p. 244, chart 9.

Morozovella spinulosa (Cushman)
(Plate 7, Fig. 5, 6)

1927 *Globorotalia spinulosa* Cushman, p. 114, pl. 23, figs. 4a–c.
1985 *Morozovella aragonensis,* Toumarkine and Luterbacher, p. 130, figs. 30.1–8.

Family GLOBOROTALIIDAE
Genus *TURBOROTALIA*

Turborotalia cerroazulensis cocoaensis (Cushman)
(Plate 7, Figs. 7, 8, 9)

1928 *Globorotalia cerroazulensis cocoaensis* Cushman, p. 75, pl. 10, figs. 3a–c.
1985 *Turborotalia cerroazulensis cocoaensis,* Toumarkine and Luterbacher, p. 138, figs. 34.2, 36.10–12.

Turborotalia cerroazulensis pomeroli (Toumarkine and Bolli)
(Plate 7, Figs. 10, 11)

1970 *Globorotalia cerroazulensis pomeroli* Toumarkine and Bolli, p. 140, pl. 1, fig. 13.
1985 *Turborotalia cerroazulensis pomeroli,*Toumarkine and Luterbacher, p. 137, figs. 34.9, 35.4–9.

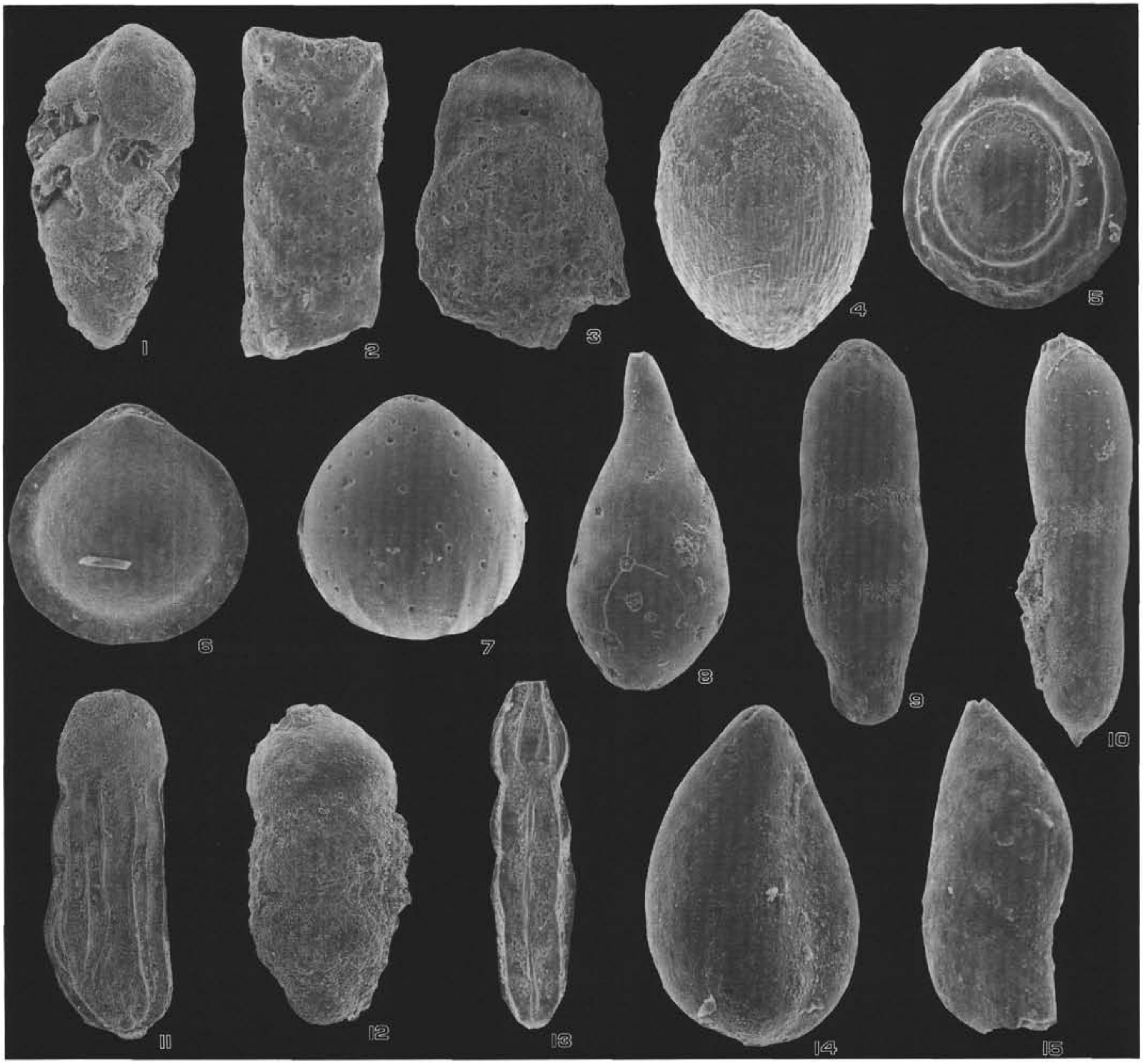

Plate 1. **1.** *Karreriella subglabra* (Gümbel), Sample 125-786A-10X-5, 33–40 cm, ×98. **2.** *Spiroplectammina* sp., Sample 125-786A-10X-5, 33–40 cm, ×197. **3.** *Vulvulina spinosa* Cushman, Sample 125-786A-10X-6, 51–53 cm. **4.** *Oolina* sp., Sample 125-786A-11X-1, 100–109 cm, ×151. **5.** *Palliolatella* sp., Sample 125-786A-11X-1, 8–10 cm, × 112. **6.** *Pseudofissurina crassicarinata* Bandy, Sample 125-786A-10X-6, 51–53 cm, × 181. **7.** ?*Pseudoolina* sp. cf. *P. bouei* Karrer, Sample 125-786A-10X-5, 33–40 cm, × 206. **8.** ?*Pygmaeoseistron* sp., Sample 125-786A-10X-5, 33–40 cm, × 102. **9.** *Chrysalogonium* sp., Sample 125-786A-10X-CC, × 139. **10.** *Laevidentalina* sp., Sample 125-786A-10X-5, 33–40 cm, × 112. **11.** *Plectofrondicularia paucicostata* Cushman and Jarvis, Sample 125-786A-10X-CC, ×122. **12.** *Pseudonodosaria* sp., Sample 125-786A-11X-CC, ×67. **13.** *Pyramidulina* sp., Sample 125-786A-10X-CC, ×122 **14.** *Guttulina problema* (d'Orbigny), Sample 125-786A-10X-CC, ×224. **15.** *Astacolus* sp., Sample 125-786A-10X-6, 51–53 cm, ×224.

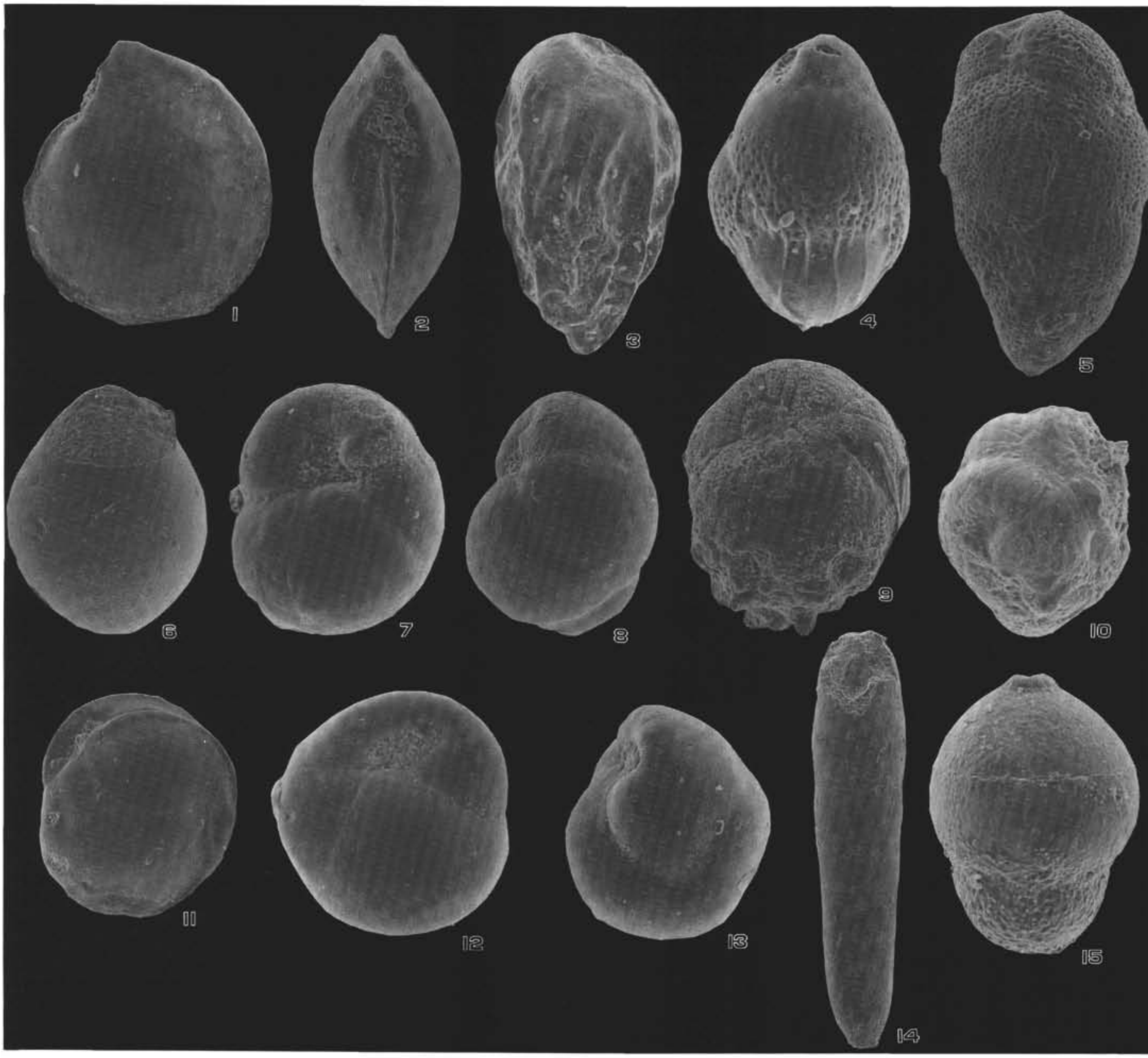

Plate 2. **1, 2.** *Lenticulina* sp., (1) Sample 125-786A-11X-1, 100–109 cm, ×150, (2) Sample 125-786A-11X-1, 100–109 cm, ×171. **3.** *Bulimina alazanensis* Cushman, Sample 125-786A-10X-6, 51–53 cm, ×287. **4.** *Bulimina glomarchallengeri* Tjalsma and Lohmann, Sample 125-786A-11X-1, 8–10 cm, ×287. **5.** *Bulimina jarvisi* Cushman and Parker, Sample 125-786A-10X-5, 33–40 cm, ×164. **6.** *Globobulimina* sp., Sample 125-786A-10X-5, 33–40 cm, ×164. **7, 8.** *Buliminella grata* Parker and Bermudez, (7) Sample 125-786A-11X-4, 71–80 cm, ×203, (8) Sample 125-786A-11X-4, 71–80 cm, ×185. **9.** *Buliminella grata spinosa* Parker and Bermudez, Sample 125-786A-10X-6, 51–53 cm, ×187. **10.** *Quadratobuliminella pyramidalis* de Klasz, Sample 125-786A-10X-6, 51–53 cm, ×164. **11.** *Cassidulina havanensis* Cushman and Bermudez, Sample 125-786A-10X-CC, ×85. **12, 13.** *Globocassidulina subglobosa* (Hantken), (12) Sample 125-786A-10X-CC, ×194, (13) Sample 125-786A-10X-CC, ×194. **14.** ?*Ellipsodimorphina* sp., Sample 125-786A-10X-CC, ×75. **15.** *Ellipsoglandulina* sp., Sample 125-786A-10X-CC, ×132.

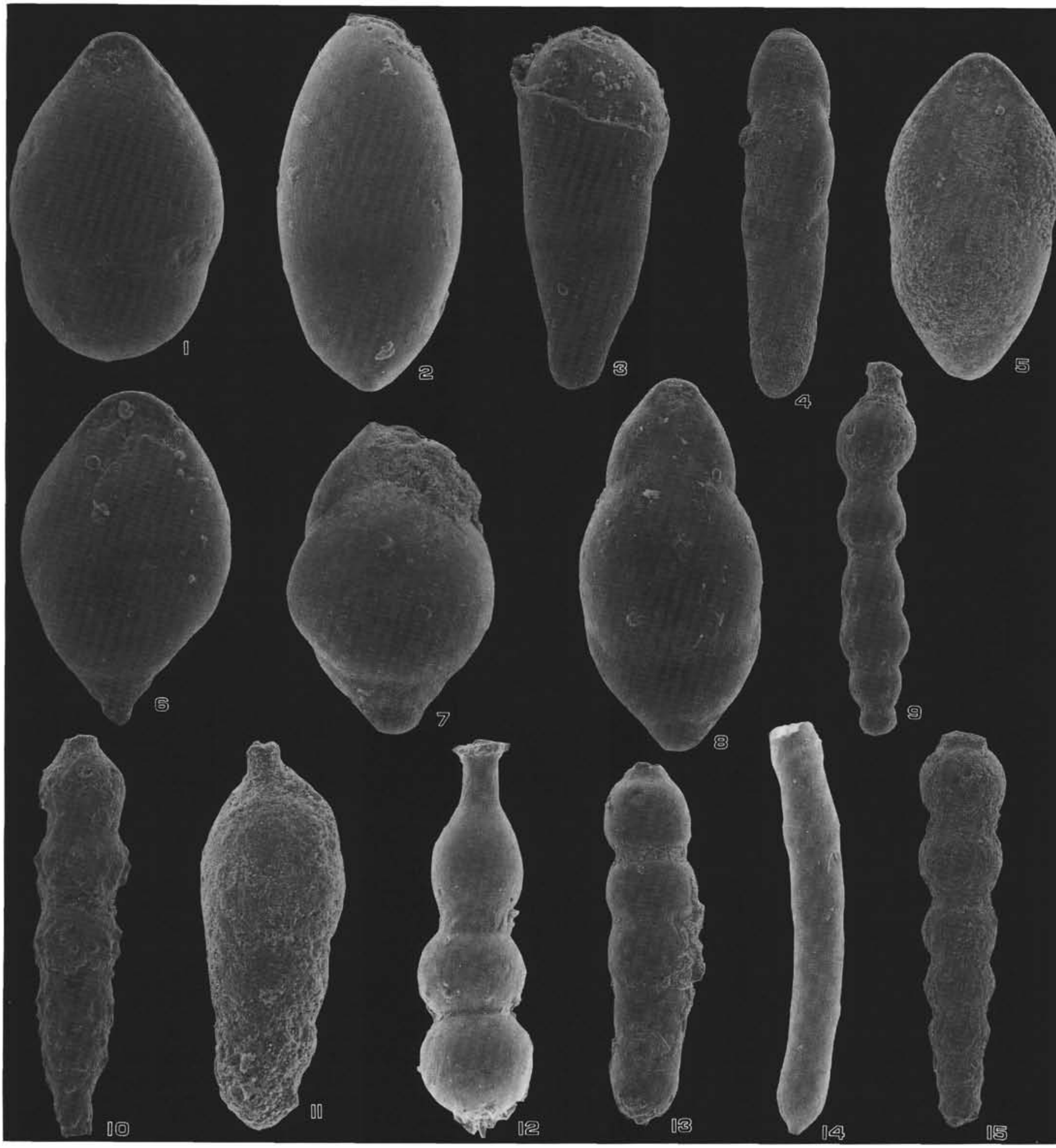

Plate 3. **1.** *Ellipsoidina* sp. A, Sample 125-786A-10X-CC, ×241. **2.** *Ellipsoidina* sp. B, Sample 125-786A-10X-5, 33–40 cm, ×105. **3.** *Nodosarella* sp., Sample 125-786A-11X-4, 71–80 cm, ×156. **4.** *Pleurostomella* sp., Sample 125-786A-10X-6, 51–53 cm, ×81.5. **5.** *Pleurostomella acuta* Hantken, Sample 125-786A-10X-6, 51–53 cm, ×221. **6.** *Pleurostomella bierigi* Palmer and Bermudez, Sample 125-786A-10X-CC, ×212. **7.** *Pleurostomella* sp. cf. *P. brevis* Schwager, Sample 125-786A-11X-1, 8–10 cm, × 221. **8.** *Pleurostomella incrassata* Hantken, Sample 125-786A-10X-CC, × 194. **9.** *Nodogenerina* sp. A, Sample 125-786A-10X-CC, ×94. **10.** *Nodogenerina* sp. B, Sample 125-786A-10X-CC, ×115. **11.** ?*Siphonodosaria* sp., Sample 125-786A-10X-5, 33–40 cm, × 156. **12.** *Siphonodosaria* sp., Sample 125-786A-10X-5, 33–40 cm, ×120. **13.** *Siphonodosaria aculeata* (Cushman and Jarvis), Sample 125-786A-10X-CC, ×97. **14.** *Siphonodosaria* sp. cf. *S. verneuili* (d'Orbigny), Sample 125-786A-10X-CC, ×55. **15.** *Stilostomella subspinosa* (Cushman), Sample 125-786A-11X-1, 8–10 cm, ×68.5.

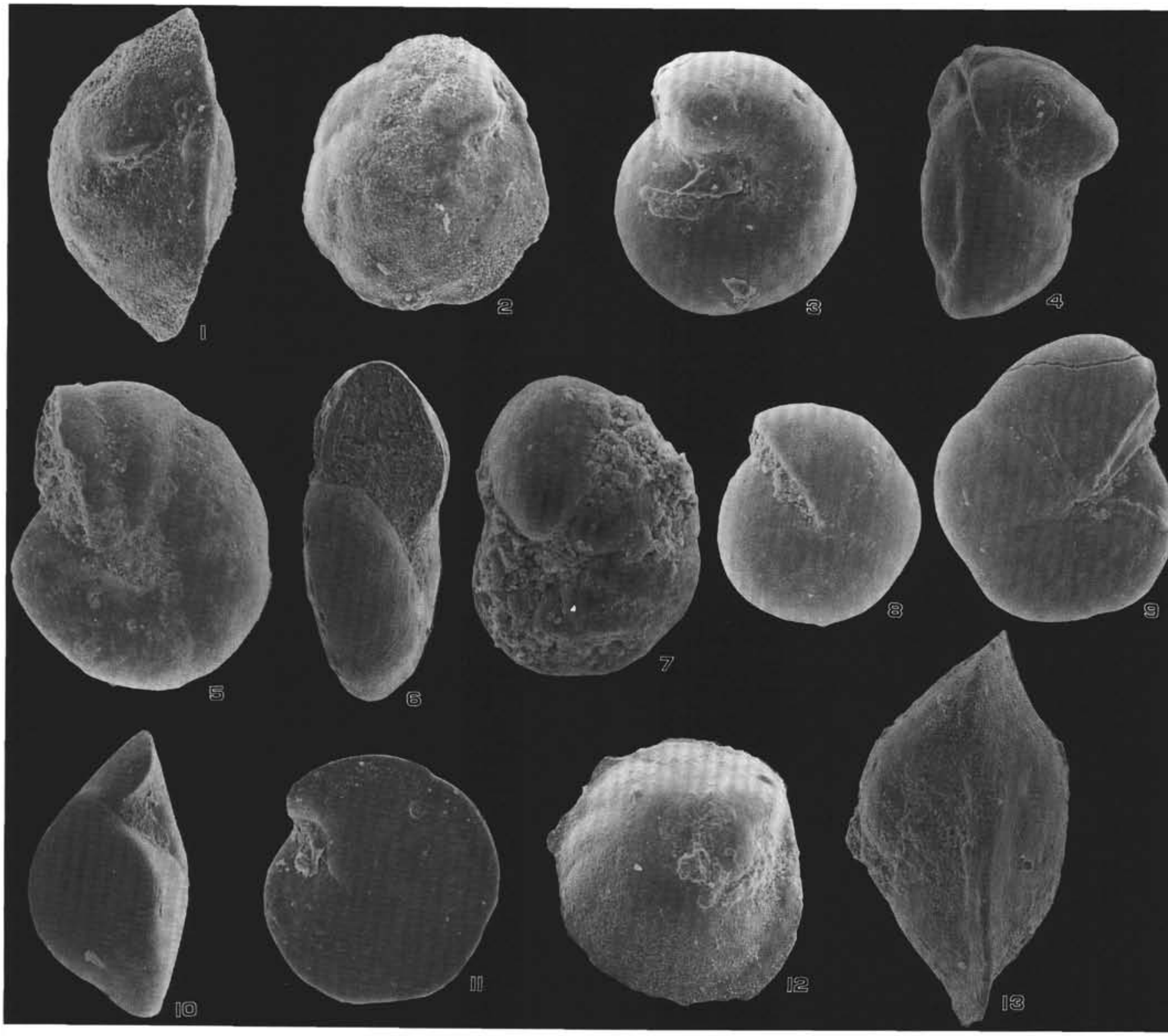

Plate 4. **1, 2.** *Nuttallides truempyi* (Nuttall), (1) Sample 125-786A-11X-3, 116–124 cm, × 224, (2) Sample 125-786A-11X-3, 116–124 cm, × 189. **3, 4.** *Gyroidinoides girardanus* (Reuss), (3) Sample 125-786A-10X-CC, × 107, (4) Sample 125-786A-10X-CC, × 112. **5, 6.** *Anomalinoides* sp., (5) Sample 125-786A-11X-3, 116–124 cm, ×181, (6) Sample 125-786A-11X-3, 116–124 cm, ×197. **7.** ?*Gyroidinoides* sp., Sample 125-786A-11X-1, 8–10 cm, ×303. **8.** *Pullenia bulloides* (d'Orbigny), Sample 125-786A-10X-5, 33–40 cm, ×166. **9.** *Pullenia quinqueloba* (Reuss), Sample 125-786A-10X-6, 51–53 cm, ×166. **10, 11.** *Oridorsalis umbonatus* (Reuss), (10) Sample 125-786A-10X-6, 51–53 cm, ×214, (11) Sample 125-786A-10X-6, 51–53 cm, × 181. **12, 13.** *Osangularia mexicana* (Cole), (12) Sample 125-786A-11X-1, 8–10 cm, ×94, (13) Sample 125-786A-11X-1, 8–10 cm, ×134.

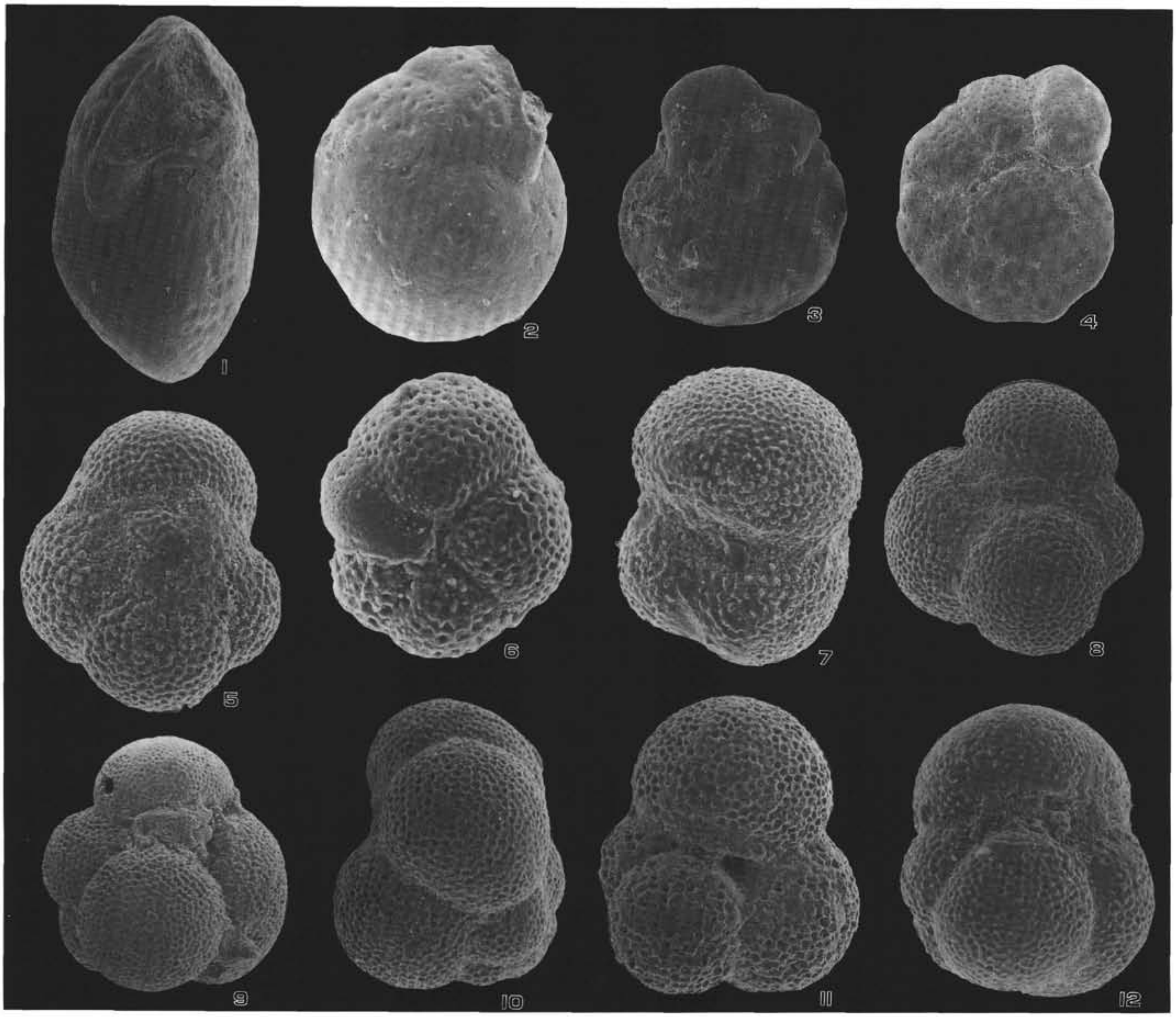

Plate 5. **1, 2.** *Cibicidoides eocaenus* (Gümbel), (1) Sample 125-786A-11X-1, 8–10 cm, ×98, (2) Sample 125-786A-11X-1, 8–10 cm, ×76. **3, 4.** *Cibicidoides praemundulus* Berggren and Miller, (3) Sample 125-786A-10X-5, 33–40 cm, ×98, (4) Sample 125-786A-10X-5, 33–40 cm, × 102. **5.** *Catapsydrax dissimilis* (Cushman and Bermudez), Sample 125-786A-11X-1, 8–10 cm, ×158. **6.** *Globorotaloides carcoselleensis* Toumarkine and Bolli, Sample 125-786A-11X-4, 71–80 cm, × 317. **7.** *Globigerina* sp. A, Sample 125-786A-10X-6, 51–53 cm, × 151. **8.** *Globigerina corpulenta* Subbotina, Sample 125-786A-10X-6, 51–53 cm, × 112. **9, 10.** *Globigerina praeturritilina* Blow and Banner, (9) Sample 125-786A-10X-6, 51–53 cm, ×90, (10) Sample 125-786A-10X-6, 51–53 cm, × 117. **11.** *Subbotina eocaena* Gümbel, Sample 125-786A-10X-5, 33–40 cm, × 145. **12.** *Subbotina euapertura* Jenkins, Sample 125-786A-10X-CC, × 139.

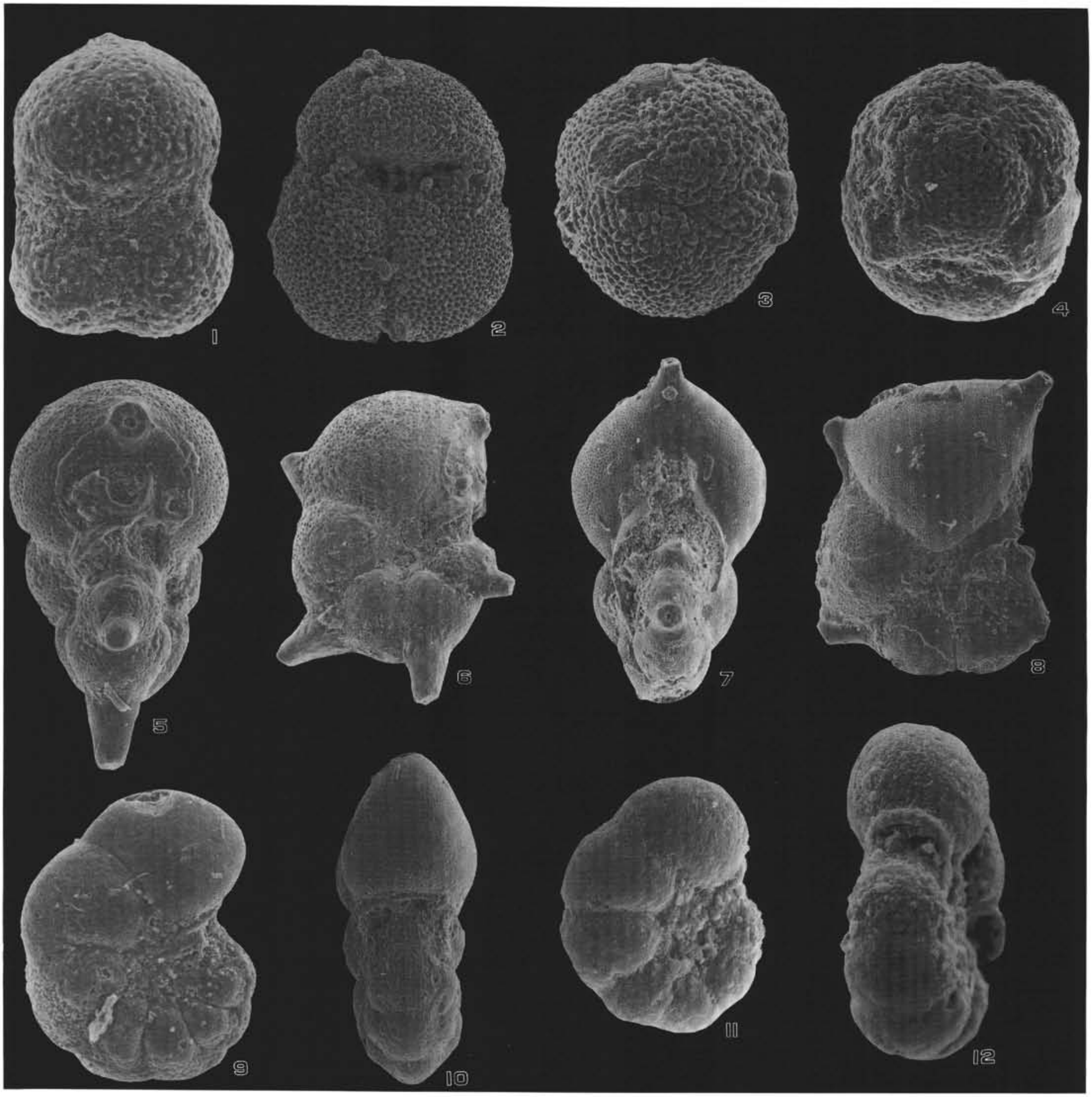

Plate 6. **1.** *Subbotina linaperta* Finlay, Sample 125-786A-11X-1, 8–10 cm, ×194. **2.** *Globigerina tripartita* Koch, Sample 125-786A-10X-5, 33–40 cm, ×106. **3.** *Globigerinatheka mexicana mexicana* (Cushman), Sample 125-786A-11X-4, 71–80 cm, ×178. **4.** *Globigerinatheka mexicana* cf. *barri* Brönnimann, Sample 125-786A-11X-4, 71–80 cm, ×150. **5, 6.** *Cribrohantkenina inflata* (Howe), (5) Sample 125-786A-10X-CC, ×178, (6) Sample 125-786A-10X-CC, ×137. **7, 8.** *Hantkenina alabamensis* Cushman, (7) Sample 125-786A-10X-CC, ×120, (8) Sample 125-786A-10X-CC, ×120. **9, 10.** *Pseudohastigerina micra* (Cole), (9) Sample 125-786A-11X-4, 71–80 cm, ×287, (10) Sample 125-786A-11X-4, 71–80 cm, ×312. **11, 12.** *Pseudohastigerina naguewichensis* (Myatliuk), (11) Sample 125-786A-10X-6, 51–53 cm, ×482, (12) Sample 125-786A-10X-6, 51–53 cm, ×680.

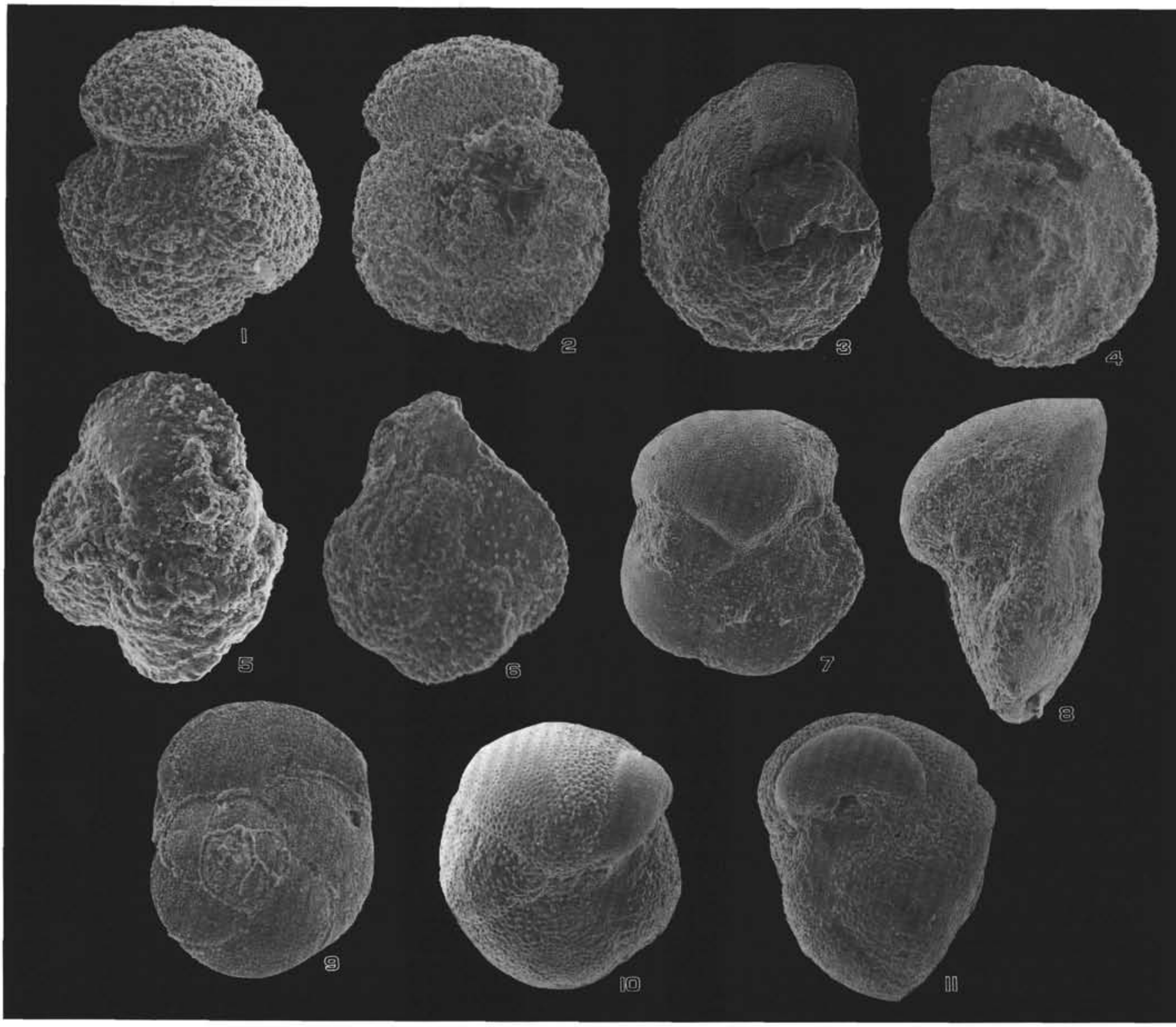

Plate 7. **1, 2.** *Acarinina bullbrooki* (Bolli), (1) Sample 125-786A-12X-CC, × 163, (2) Sample 125-786A-12X-CC, × 163. **3, 4.** *Morozovella aragonensis* (Nuttall), (3) Sample 125-786A-12X-CC, ×115, (4) Sample 125-786A-12X-CC, ×120. **5, 6.** *Morozovella spinulosa* Nuttall, (5) Sample 125-786A-11X-4, 71–80 cm, ×212, (6) Sample 125-786A-11X-4, 71–80 cm, ×194. **7, 8, 9.** *Turborotalia cerroazulensis cocoaensis* (Cushman), (7) Sample 125-786A-11X-1, 8–10 cm, ×115, (8) Sample 125-786A-11X-1, 8–10 cm, ×131, (9) Sample 125-786A-11X-1, 8–10 cm, ×170. **10, 11.** *Turborotalia cerroazulensis pomeroli* (Toumarkine and Bolli), (10) Sample 125-786A-11X-3, 116–124 cm, ×106, (11) Sample 125-786A-11X-3, 116–124 cm, ×106.