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

G. J. Milner

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 volcanioclastic 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.

The progression from a middle Eocene benthyal "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 a 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 from those from similar 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 cm³ 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...
Figure 1. Location of Site 786 in the Izu-Bonin forearc. Adapted from Fryer, Pearce, Stokking, et al. (1990). Bathymetric contours are in kilometers.
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 foraminifer 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 linaperla, with fewer Catapsydrax dissimilis, Globigerinatheka mexicana mexicana, and Globigerinatheka mexicana cf. barri. Tropical province species in studied planktonic assemblages include Subbotina eocaena, Turborotalia cerroazulensis pomeroli (= synom. partim. Globorotalia centralis,

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

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<tr>
<th>Core, section:</th>
<th>10X-5</th>
<th>10X-6</th>
<th>10X-CC</th>
<th>11X-1</th>
<th>11X-1</th>
<th>11X-3</th>
<th>11X-4</th>
<th>11X-CC</th>
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<tbody>
<tr>
<td>Interval (cm from top of section):</td>
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<td>8-10</td>
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<td>116-124</td>
<td>71-80</td>
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</table>

**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.
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Comparison of the lower Oligocene planktonic foraminiferal assemblage from Hole 786A with the faunal assemblages 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 less common Hantkenina abalamosenis, and Cribrohankevinai inflata.

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) have 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 Acorinirina bullbrooki and typical middle Eocene Subbotina species (e.g., S. eocaena and S. lineaperta). The rare presence of Hantkenina sp. and Morozenella 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 Morozenella 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 Morozenella 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 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 peneroli, 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 abalamosenis, and Pseudohastigerina micro. 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 abalamosenis and rare Cribrohankevinai inflata. The last appearance of S. micro also occurs in this sample as does the first appearance of Pseudohastigerina nagaweichensis.

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. nagaweichensis. Cribrohankevinai 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., Chilogeumbeina 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 angustiusculus (FAD Zone P21; Berggren and Miller, 1988). Using nanofossils, 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 Oosangula mexicana and an abyssal “Globocassidulina subglobosa” fauna composed of Orbulosiris umbonatus, Gyroidinoides spp., Cibicidoides praemundulus, Stilostomella acetala, and Globocassidulina subglobosa.

In Hole 786A, assemblages resembling the “Lenticulina” fauna (i.e., with Oosangula mexicana, Cibicidoides eocaeanus, Valvulina 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 girardinus, Orbulosiris umbonatus, and Siphonodosaria acetala, 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 eocaeanus, Cibicidoides praemundulus, Globocassidulina subglobosa, Gyroidinoides girardinus, Laevidentalina sp., Oosangula mexicana, Siphonodosaria acetala, and Siphonodosaria sp. cf. S. verneuilli). The remaining orders, Lituloida and Nodosariida, are numerically and taxonomically poorly represented. Even though most species were long-ranging in...
Table 2. Distribution of species of Lituolida, Nodosarida, Buliminida, and Rotaliida in Hole 786A.

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**LITUOLIDA**

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**NODOSARIDA**

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**BULIMINIDA**

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<td>Ellipsiodina sp.</td>
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<td>F</td>
<td>R</td>
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<td>R</td>
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**Stilostomellidae**

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<td>A</td>
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<td>—</td>
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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 *Anomalinaeoides* sp., *Buliminella grata spinosa*, *Bulimina jarvisi*, and three species: *Laevidentalina* rotaliid species remain unaffected. *Buliminida, six species of Nodosariida, and one species of Lituolida*. Twenty-five taxa make their last appearance in Samples 125-786A-10X-CC to -11X-CC, and these may be due to the progressive restriction of these forms to depths greater than approximately 1000 m, which is lower bathyal. The absence or reduced preservation of benthic foraminifers belonging to the bathyal *"Lenticulina"* fauna described by Tjalsma and Lohmann (1983; ca. 1000-2000 m) 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 middle Eocene (Gibson, 1989), and the bathymetric zonation adopted by van Morkhoven et al. (1986). Based on the upper and lower depth limits described 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

### Table 2 (continued)

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**ROTAIIIDA**

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**Preservation**

- Good
- Moderate
- Poor

**Diversity**

- 20
- 25
- 13
- 14
- 7
- 5

**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.
abyssal depths. Foraminifers more typical of the shallower “Lenticulina” fauna (i.e., Osangularia mexicana, Bulimina species, and Cibicidoides eoceneus) 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* assemblage was present at this time. This fauna probably reflects lower benthal water depths. The transition from a benthal “Lenticulina” fauna to an abyssal *Globocassidulina subglobosa* fauna suggests that in Hole 786A, the depositional environment deepened from lower benthal (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 foraminifera 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 Rankin (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 is correct then subsidence in parts of the forearc of the Izu-Bonin arc system may have begun as early as early late Eocene.

**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.

**REFERENCES**


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, pi. 1, figs. 4a-b.
1983 Karreriella subglabra, Tjalsma and Lohmann, p. 34, pi. 9, figs. 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, pi. 23, fig. 1 [fide Ellis and Messina].
1983 Vulvulina spinosa, Tjalsma and Lohmann, p. 38, pi. 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

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

Pygmaeosistron 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 paucicosta Cushman and Jarvis

(Plate 1, Fig. 11)

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

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 (Guttuline) 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

1937 *Buliminella grata* Parker and Bermudez, p. 515, pi. 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).

*Quadratobuliminella*

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

Genus QUADRATOBULIMINELLA

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

*Globobulimina*

1937 *Bulimina alazanensis* Cushman, p. 161, pi. 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 gionarchallengeri* Tjalsma and Lohmann  
(Plate 2, Fig. 4)

1983 *Bulimina gionarchallengeri* Tjalsma and Lohmann, p. 25, pl. 13, figs. 9a–b.
1986 *Bulimina gionarchallengeri*, van Morkhoven et al., p. 243, pl. 82A–B, figs. 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 Bermudez, p. 36, pi. 6, fig. 11 [fide Ellis and Messina].
1985 *Bulimina jarvisi*, Wood et al., p. 184, pi. 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, pi. 16, figs. 2a–b [fide Ellis and Messina].
1983 *Globocassidulina subglobosa*, 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. A  
(Plate 3, Fig. 1)

Ellipsoglandulina 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, pi. 13, fig. 18 [fide Ellis and Messina].
  
  1983 *Pleurostomella acuta*, Miller, p. 439, pi. 4, fig. 7.

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

  1936 *Pleurostomella bierigi* Palmer and Bermudez, p. 224, pi. 294, pi. 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, pi. 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 **SIPHONOSDOSARIA**

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

* Siphonodosaria sp.
  
  (Plate 3, Fig. 12)

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

  1948 *Ellipsonodosaria nutalli* Cushman and Jarvis var. *aculeata* Cushman and Renz, p. 32, pl. 6, fig. 10.

  1983 *Stilostomella aculeata*, Tjalsma and Lohmann, p. 36, pl. 14, figs. 16-17.

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 middle Eocene. Tjalsma and Lohmann (1983) described the species of this genus as comprising a significant 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 abyssal 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. 6-7 [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)

  1851 *Rotalina girardana* Reuss, p. 73, pi. 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 middle Eocene. Tjalsma and Lohmann (1983) described this species of this genus as comprising a significant 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 125-786A-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**

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.
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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 ungonatus (Reuss)
(Plate 4, Figs. 10, 11)

1851 Rotula ungonata Reuss, p. 75, pl. 5, fig. 35 [fide Ellis and Messina].
1983 Oridorsalis ungonatus, Miller, pl. 4, figs. 14–15.

Remarks. This species, described by Tjalma and Lohmann (1983) as an element of their abyssal Globocassidulinia 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, Tjalma and Lohmann, p. 35, pl. 20, fig. 6.

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

Family PARRELLOIDIDAE
Genus CIBICIDOIDS

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

1868 Rotula 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 tusamensis 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. 254, 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. Tjalma and Lohmann (1983) included this species as part of their abyssal Globocassidulinia subglobosa fauna.

Order GLOBIGERINIDIA
Family CATAPSYDRACIDAE
Genus CATAPSYDRA

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

1937 Globigerina dissipitilita Cushman and Bermudez, p. 25, pl. 3, figs. 4–6.

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 xapertura (Jenkins)
(Plate 5, Fig. 12)

1960 Globigerina xapertura Jenkins, p. 351, pl. 1, figs. 8a–c.
1985 Globigerina xapertura, 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 GLOBIGERINIDAE

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

1962 Globigerina praeterritilina Blow and Banner, p. 99, pl. 13, figs. A–C.
1985 Globigerina praeterritilina, 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].

Genus GLOBIGERINA

Globigerinatheka mexicana mexicana Cushman
(Plate 6, Fig. 3)
FORAMINIFERS FROM HOLE 786A

1925a Globigerinatheka mexicana mexicana Cushman, p. 61, pl. 22, figs. 6a–c.

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.

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].

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

1950 Globigerinella naguewichensis Myahtuk, 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 Acarina bullbrooki, Toumarkine and Luterbacher, p. 130, figs. 29.4–10.

Genus MOROZOVELLA
Monzoavella 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 cerwazulensis cocoaensis (Cushman)
(Plate 7, Figs. 7, 8, 9)

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

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

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