## 29. EOCENE TO EARLY MIOCENE BENTHIC FORAMINIFERA<sup>1</sup> DSDP LEG 39, SOUTH ATLANTIC

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## INTRODUCTION

Few reports of benthic foraminiferal faunas from deep-sea cores of the Tertiary have been published. Notable exceptions are the works of Berggren (1972, 1975), Douglas (1973), and Vincent et al. (1974) on samples taken by the Deep Sea Drilling Project. Older works, providing the reference faunas for these deeper, open marine sections include Beckmann (1953), Bandy (1970), Cushman and Renz (1948), Cushman and Stainforth (1945), Palmer (1940), AGIP (1959), and Bermudez (1949): see Berggren and Phillips (1971) for a more extensive bibliography. Because of the time between publication of these two groups of works, and although some taxonomic revisions are presently in progress (for example, Tjalsma, personal communication), there is currently a lack of standardized and updated taxonomy. Consequently, the faunas reported here are given names directly from the older literature and the source of each name is listed in the Appendix. When the taxonomy is revised it will then be reasonably simple to incorporate the taxa listed in this report.

Benthic foraminifera were studied from the Tertiary of Sites 356, 357, 358, and 359 (Table 1), and those—both the smaller and larger forms—from Site 357 are treated in greater detail. Coring gaps, hiatuses, and preservational effects resulted in less complete sections at the other sites.

Presently, one of the crucial problems in the study of benthic foraminifera, particularly those of the geologic past, is to reinterpret their distribution patterns in terms of chemical, physical, and/or biological parameters. The seemingly straightforward explanation of water depth as a controlling factor has been questioned in recent years (Streeter, 1973; Douglas, 1973). Thus, one of the purposes of this study is to document faunal changes at this site with accompanying temperature fluctuations determined from oxygen isotope ratios.

Stratigraphic and evolutionary conclusions from this sort of study are few, as appearances and disappearances at the site may be ecological rather than evolutionary events.

### **SITE 357**

Site 357 lies approximately 30°S, 30°W at a present water depth of 2086 meters. The site is within the

present depth range of the North Atlantic Deep Water on the eastern flank of the Rio Grande Rise (Figure 1).

Reconstruction of South Atlantic plate motions and spreading (Ladd, 1974) indicates that in the early Tertiary the site lay farther south and moved gradually northward as the Tertiary progressed. It is now in the subtropical zone, but may have been within the warmer subtropical zone during the warmer periods of the early Tertiary.

The stratigraphic distrubutions of key benthic species from the Eocene into the Miocene are shown in Figure 2. Most discontinuities in the stratigraphic ranges result from the fact that an aliquot, not the entire sample, was picked for benthic foraminifera.

The faunas of Site 357 are very similar to those reported from the Pacific by Douglas (1973). The most obvious differences are (1) the Pacific samples lack lagenids, which are present and are occasionally abundant at Site 357; and (2) the greater significance of pleurostomellids at Site 357. The faunas examined in this study are otherwise remarkably similar in content and diversity in both areas from Eocene into early Miocene time.

#### Larger Benthic Foraminifera

A shallow water fauna of larger benthic foraminifera accompanied a volcanic sequence of rocks and sediments in Core 25. This displaced fauna, along with the volcanic material, undoubtedly moved downslope from a topographic high adjacent to the site. These larger foraminifera are shown in Plate 1.

Significant among the typically middle Eocene fauna was the presence of operculinid nummulites. Nummulites are rare outside the eastern Tethys (including the Mediterranean); in fact, only two groups are known to have colonized the Caribbean (Blondeau, 1968). Because of the latitude of the Rio Grande Rise in the early Tertiary, it could hardly have been a "stepping stone" for the trans-Atlantic migration of larger benthics. Therefore, it seems larger benthic foraminifera reached the Rio Grande Rise via the South American shelf.

The total fauna is strongly reminiscent of the middle Eocene (Lutetian) larger foraminiferal faunas of Italy (AGIP, 1959). Although specific identifications have not yet been made, the genera present include: *Linderina, Sphaerogypsina, Pseudophragmina,* operculinid nummulites, *Fabiania, Discocyclina,* and lepidocyclinids, as well as rotalids, bryozoa, and calcareous algae.

Planktonic foraminifera were mixed in with the larger benthic foraminifera. They were apparently contemporaneous with the sediment containing the volcanic rocks and other invertebrate fossils. No other larger foraminifera were found.

<sup>&</sup>lt;sup>1</sup>The author has expressed strong preference for using "foraminifera" rather than the common form "foraminifer." Although the DSDP editors feel that the common form of the word is preferable in English, and for consistency have decided to use it in the Initial Reports, they accede here to the author's wishes.

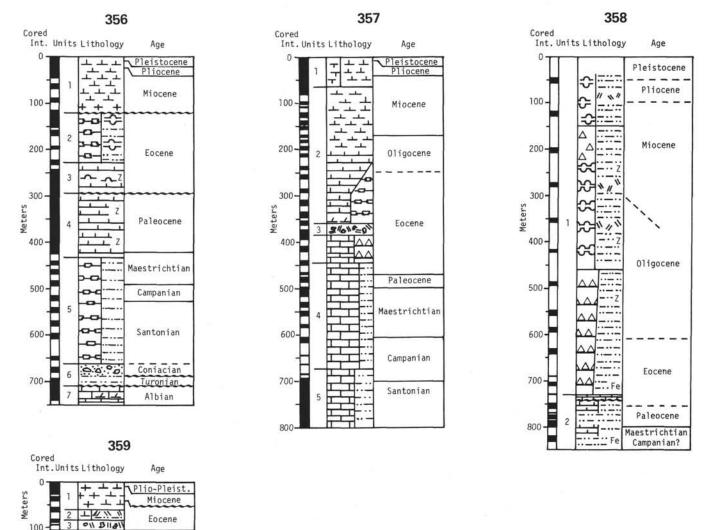


Figure 1. Location maps and biostratigraphic column drilled during Leg 39. (Reconstructions from McCoy and Zimmerman, this volume.)

Site	Present Latitude	Present Longitude	Present Water Depth (m)	Age of Oldest Recovered Sediments	Cored (m)	Recovery (%)
356	28°17′S	41°05′W	3175	Late Albian	333	76
357	30° 00' S	35° 33'W	2086	Santonian	209	73
358	37° 39' S	35° 57'W	4962	Late Campanian	28	59
359	34° 59' S	4°29′W	1655	Late Eocene	27	55

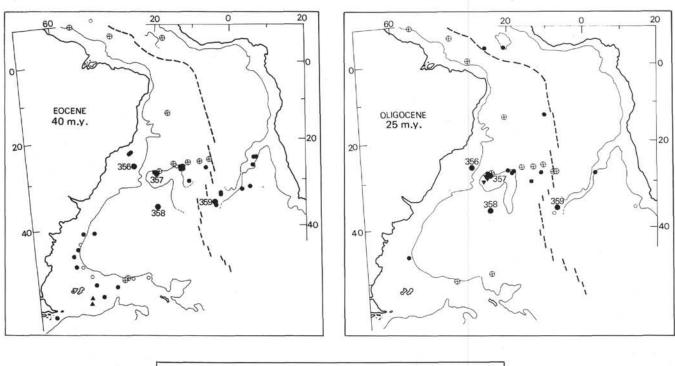
### Stratigraphic Distributions of Key Species

Based on the ranges of species at Site 357, a table of age-restricted species in the South Atlantic has been assembled (Table 2). At Site 357 the number of species restricted to a given epoch approximates the number of species restricted to the key time periods of Douglas (1973). It is perhaps too early to interpret the evolutionary changes in Tertiary benthic foraminifera without careful group-by-group studies and taxonomic revisions.

#### **SITE 356**

Benthic foraminifera are generally rare in most samples at Site 356. Levels subjected to slight

#### EOCENE TO EARLY MIOCENE BENTHIC FORAMINIFERA



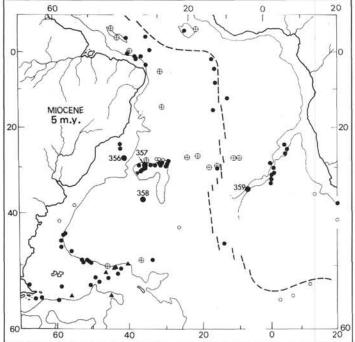


Figure 1. (Continued).

dissolution, not surprisingly, have larger benthic foraminiferal faunas. The Eocene sediments at Site 356, however, contain levels with exceptional degrees of dissolution and diagenetic alteration which also destroyed the benthic foraminifera. Faunas from selected intervals are shown in Figure 3.

Many species occurring at Site 356 are also found at Site 357. Site 356, however, must have lain in water depths between 2000-3000 meters and apparently was deeper than Site 357 throughout the Tertiary. Several features of the Site 356 faunas distinguish them from those of Site 357:

1) Persistent greater abundance of spinose rectilinear forms and abundance of rectilinear forms;

2) Greater abundance of Nuttallides truempyi;

3) Lack of the large specimens typical of some Site 357 residues deposited during cooling episodes;

4) Presence of *Pulvinulinella*, even in highly dissolved faunas;

5) Lack of Uvigerina species except U. cf. auberiana;

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Figure 2. Stratigraphic ranges (Eocene-lower Miocene) of selected benthic foraminifera of DSDP Leg 39, Site 357.

6) Low abundances of *Cibicides* spp., anomalinids, and bolivinids.

#### Faunas

Faunas at Site 356 in the early Eocene are dominated by a *Pleurostomella-Nuttallides* fauna which, according to Bandy (1970), characterizes the abyssal zone during the early Paleogene.

Later, faunas at Site 356 evolve from a *Pleuro-stomella-Nuttallides* fauna to ones dominated by *Pleurostomella-Stilostomella* including *S. gracillima*, *S. consobrina*, *S. abyssorum*, and *S. aculeata*; planktonic foraminifera are rare. This type of fauna containing few benthics, primarily the rectilinear species and

dominated by *Stilostomella*, is typical in certain levels of the Oceanic Formation of Barbados which contain radiolarians, few benthics and few or no planktonic foraminifera.

The lack of planktonic foraminifera is probably the result of dissolution in the Oceanic Formation as well as at Site 356. At Site 356 the majority of in situ benthic foraminifera were also lost from the sediments deposited in water depths of only from 2000 to 2500 meters during the latter part of the Eocene.

One interval with an influx of species more typical of Site 357, including the *Robulus occidentalis* group and *Bulimina jarvisi*, occurs in Core 10, section 2 to sample 9, CC. The interval is characterized by improved

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Figure 2. (Continued).

preservation up section beginning in Core 10, and an influx of radiolarians and diatoms. It corresponds to planktonic forminiferal Zone P8 of the middle Eocene. These forms may be displaced or are a result of downslope migration of faunas. At this time at Site 357 there is a significant increase both in the near surface and bottom temperatures. Presumably a similar temperature change occurred at Site 356, and the warming could have resulted in downslope displacement of water masses, migration of the robulinids and buliminids, as well as the decreased ratio of spiny and rectilinear to rotaloid species.

Throughout the rest of the Eocene at Site 356, rectilinear and spinose forms dominate the faunas. In

strongly dissolved samples only pieces of lagenids, pleurostomellids, and stilostomellids are found; *Nuttallides truempyi* is absent. Lagenids become increasingly more abundant higher in the section.

Early Miocene faunas in Cores 3 and 4 strongly resemble those of the Eocene. Spiny stilostomellids, pleurostomellids, and lagenids dominate these sparse faunas. These faunas probably lived in water depths of greater than 2500 meters but less than 3000 meters.

Pulvinulinella persists even in the most dissolved and recrystallized faunas at Site 356. According to Loeblich and Tappan (1964), Pulvinulinella is a junior synonym of Epistominella. Interestingly, the Recent species, E. exigua is characteristic of greatest depths (Streeter,

Eocene	Oligocene	Miocene
Robulus oblonga	Cibicides perlucidus	Plaunlina renzi
Gyroidina planulata	Pyrulina extensa	Robulus alatolimbatus
Anomalinoides affinis	Bulimina semicostata	
Nuttallides truempyi	Pleurostomella alazanensis	5
	Laticarinina bullbroki	
	Anomalina aragonensis	
Species Restricted to Key 7	Time Intervals at Site 357	
Middle Eocene-	Late Oligocene-	Eocene-
Middle Eocene- ate Oligocene	Late Oligocene- early Miocene	Eocene- early Oligocene
ate Oligocene	early Miocene	early Oligocene Chrysalogonium

#### TABLE 2 Species Restricted to an Epoch at Site 357

Uvigerina cf. auberiana	Pullenia bulloides	
Globocassidulina subglobosa	Pullenia quinqueloba	
Oridorsalis umbonatus	Stilostomella abyssorum	

1976, personal communication) and is found in Recent faunas from piston cores taken in deep water of the circum-Antarctic region (unpublished data). This genus appears to have high dissolution resistance and to have occurred in cold deep waters both in the Eocene and the Recent.

#### **SITE 359**

There is disagreement over the water depth in the late Eocene (P16) at Site 359 (Fodor et al., this volume; Boersma, this volume). The foraminiferal fauna listed below, rich in *Robulus* and large nodosarids, contains both a shallower and a deeper component (Table 3). The deeper component resembles faunas at Site 357, although the charactistic cosmopolitan species *Globocassidulina subglobosa, Nuttallides truempyi*, *Uvigerina spinicostata*, and *Pullenia bulloides* are not present. Apparently the deeper fauna is in place and the shallow water species were displaced downslope along with the volcanic materials.

#### PALEOTEMPERATURE AND BENTHONIC FORAMINIFERAL RESPONSE

Several indices were used to characterize benthonic faunas during times of temperature change:

Benthic Number (BN) as a simple measure of the abundance of benthic foraminifera, and hence the planktonic benthic ratio, the benthic number was estimated from a sample of standard weight. In a preliminary analysis such as this, this simple index gives a first approximation of the abundance of the benthics, although a total picking of the sample would be more reliable in any detailed analysis of the faunas.

The ratio of rectilinear forms to rotaloid forms was estimated by Douglas (1973) and has been investigated here, as changes in this index appear to coincide with changes in the oxygen isotope record and thus with paleotemperature changes at the site.

 TABLE 3

 Benthic Species From Site 359, Core 3

Species also present at Site 357	"Shallower" Species
Bulimina macilenta	Saracenaria hantkeni
B. jarvisi	Ellipsoglandulina glabra
Stilostomella abyssorum	Nonion chapapotense
Vulvuina spinulosa (elongate form)	Marginulina spp.
Robulus occidentalis Group	Chrysalogonium longiscatum
Pleurostomella acuta	Planulina cocoaensis
Oridorsalis umbonatus	Anomalina granosa
Pullenia quinqueloba	Dentalina jacksonensis
Uvigerina havanensis	Marginulina cf. cocoaensis
Anomalina semicribrata	Nodosaria latejugata
Osangularia mexicana	+ pelecypod fragments
Dentalina mucronata	bryogoan fragments
Cibicides pseudoungerians	hystrichospheres volcanic glass volcanic rock fragments

Spinosity is a marker of differing environments; it has been found that some genera respond to changing conditions by producing more spiney morphotypes. The degree of spinosity within a species as well as the number of spinose species does appear to change during times of temperature change. This is true of both the rectilinear hyaline and agglutinated foraminifera.

Diversity of benthic faunas changes irregularly, generally consistently with times of temperature change, but diversity in a standard sized sample is largely a function of the amount of planktonics accumulating at a site, as the greater planktonic abundance will affect both the BN and the diversity. However, as these values are not always parallel, there must be other factors affecting diversity at the site, particularly in closely spaces samples.

Generalists versus specialists. There are several deep marine species which may be called generalists and/or cosmopolitan. These species have long stratigraphic

					truempyi sp.	issiformis	hi 2 decurta	am sp.	Ammodiscus cf. glabiatus Globecassidulina subglobosa	Gyroidina girardana Dulminulinella atlantisae	a consobrina		2	Pleurosteomella subcylindrica Stilostomella gracillima	ensis	sp.	nexicana rohri	ь.	Cibicides pseudoungerians Lagena nuttali	a abyesorum	rvisi	roria	la altermans sevigata	ta	cronata	a moaesta dentalis	<i>visi</i>	Belivinopsis trinitatensis	umbonifera Loides	Ellipsoglandulina decurta	nqueloba	t.	Davard			sugu	um asperum	la acuta	. aubertana	utrysacuguntum sp.	ra arazanererere	sp.	bleekeri	
Epocn Series	Planktonic Zones	Core	Section	Centimeter interval	Nuttellides truempyi Gavelinella sp.	Anomalina spissiformis	Lagena rutschi Stilostomella decurta	Chrysalogonium sp.	Ammodiscus cf. glabiatus Globecassidulina subglob	Gyroidina girardana	stilostomella consobrina	S. aculeata	S. subspinosa	Fleurosteomella subcylina Stilostomella gracillima	Nonion havanensis	Karreriella sp.	Osangularia mexicana Nodogenerina rohri	Spirillina sp.	Cibicides pseu Lagena nuttali	Stilostomella abyssorum	Vulvulina jarvisi	Guttulina sororia	Pleurostomella alternans Glandulina laevigata	Balimina grata	Dentalina mucronata	striostometia moaesta Robulus occidentalis	Bulimina jarvisi	Belivinopsis	Oridorsalis unbonifera Pullenia bulloides	Ellipsogland	Pullenia quinqueloba	Nodosaretta sp.	ryruurna curvauura	Vaginulina sp.	Pyrulina sp.	Robulus oblongus	Chrysalogonium asperum	Pleurostomella acuta	Urigerina Ct. auberiana	D1 autoct and 1	Eleuroscomet. Boliving SD.	Angulogerina sp.	Bulimina cf. bleekeri	
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middle	P11 to P10	8 8 9 10	2 CC CC 2	60	x	×			××	× × ×	( X	× × ×		×	x		x			x					x x		x		x	x	x	x												
Eocene	P8	10 10 11 11	4 2 4	120 57 60	×	x			×		x	< x	x x		×		~ × ×	×		x		X	x x	x	x	x x		^	~ ·															
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Paleocene upper	P4	17 17	2	75 120	x x	x	××	×	x															1								_												

Figure 3. Occurrence of upper Paleocene-lower Miocene selected smaller benthic foraminifera, DSDP Leg 39, Site 356, Site 357.

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ranges, as well as wide vertical and geographic ranges. The number of these forms in populations appears to alter during times of temperature change, but these results are very preliminary.

The analysis of benthic foraminiferal response to paleotemperature changes at Site 357 are discussed in Boersma and Shackleton (this volume). The following conclusions can be reiterated:

1) that during times of significant change in the temperature signal, as recorded in the oxygen isotopes, there are interspecific as well as intraspecific responses in the benthic foraminifera. For example, at this depth during a cooling the benthic forams demonstrate increased spinosity, increased numbers of rectilinear species, increased numbers of benthic relative to planktonic foraminifera, increased number of generalists, or cosmopolitan species, and increased size of individuals;

2) that large individuals (for example, *Cibicides perlucidus*) were not necessarily redeposited, as the <sup>18</sup>O values may correspond to those of smaller species as well as to smaller individuals of the same species in a sample;

3) that the response of benthic faunas was not dependent upon sudden depth changes as the depth estimates from both ostracodes, and Cretaceous benthic foraminifera, are close to the present-day depth of the site.

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### APPENDIX

#### Fossil Name

Anomalina affinis Anomalina alazanesis Anomalina aragonensis Anomalina illingi Anomalina pompilioides Anomalina semicribrata Anomalina spissiformis Anomalina subbadensis Bolivina cf. alazanensis Bolivina tectiformis Bolivina tectiformis Bolivinopsis cubensis Bolivinopsis trinitatensis Bulimina alazanensis Bulimina jarvisi Bulimina macilenta Bulimina ovata Bulimina cf. pupoides Bulimina semicostata Cassidulina crassa Chrysalogonium asperum Chrysalogonium breviloculum Chrysalogonium cf. ciperense Chrysalogonium elongatum Chrysalogonium lanceolum Chrysalogonium tenuicostatum Cibicides coryelli Cibicides grimsdalei Cibicides io Cibicides perlucidus Cibicides pseudoungerians Cibicides trincherasensis Cibicides trinitatensis Dentalina cf. cocoaensis Dentalina cf. halk yardi Dentalina cf. inepta Dentalina jacksonensis Dentalina mucronata Dentalina soluta Dentalina cf. vertibralis Discorbis ciperense Dorothia biformis Ellipsonodosaria multicosta Entosolena longispina Entosolenia orbignyana Eponides umbonatus Globocassidulina subglobosa (Cassidulina subglobosa

(Cassidulina subglobosa Gyroidina jarvisi

Gyroidinoides altiformis

#### Reference

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Beckmann, 1953 Cushman and Renz, 1948 Beckmann, 1953

## EOCENE TO EARLY MIOCENE BENTHIC FORAMINIFERA

Gyroidinoides girardana Gyroidinoides planulata Karreriella alticamera Karreriella subcylindrica Lagena laevigata Lagena lagenoides Laticrinina bullbroki Martinottinella prytoda Nodogenerina rohri Nodosarella subnodosa Nodosaria longiscata Nonion havanenses Nonion pompiliodes Nuttallides truempyi Oridorsalis umbonatus Orthomorphina havanensis Orthomorphina havanensis Osangularia interrupta Osangularia mexicana Planulina renzi Plectofrondicularia Pleurostomella acuta Pleurostomella alazanensis Pleurostomella alternans Pleurostomellabellardii Pleurostomella bierigi Pleurostomella nuttalli Pleurostomella subcylindrica Pseudopolymorphina ovalis Pullenia bulloides Pullenia quinqueloba

Beckmann, 1953 Beckmann, 1953 Cushman and Stainforth, 1945 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Cushman and Stainforth, 1945 Cushman and Renz, 1948 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Cushman and Stainforth, 1945 Beckmann, 1953 Streeter (personal communication.) Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953

Pullenia riveroi Pulvinulinella mexicana Pvrulina extensa Robulus cf. alato limbatus Robulus oblonga (Cristellaria oblonga) Robulus occidentalis grp. Robulus plummerae Saracenaria cf. schenki Shenckiella petrosa Sigmomorphina cf. trinitatensis Sphaeroidina bulloides Stilostomella abyssorum Stilostomella annulifera Stilostomella caribea Stilostomella consobrina Stilostomella curvatura Stilostomella decurta Stilostomella gracillima Stilostomella modesta Stilostomella nuttalli Stilostomella seriata Stilostomella subspinosa Stilostomella verneuli Uvigerina cf. auberiana Uvigerina gallowayi Uvigerina cf. pygmaea Uvigerina spinicostata Uvigerina spinulosa Bulbulina jarvisi Vulvulina spinosa

Beckmann, 1953 Cushman and Stainforth, 1945 Beckmann, 1953 Cushman and Stainforth, 1945 Beckmann, 1953 Cushmann and Renz, 1948 Cushman and Stainforth, 1945 Cushman and Stainforth, 1945 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckamnn, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Beckmann, 1953 Boersma (in preparation) Cushman and Stainforth, 1945 Boersma (in preparation) Beckmann. 1953 Beckmann, 1953 Beckmann, 1953

Beckmann, 1953

# PLATE 1 All figures approximately ×40.

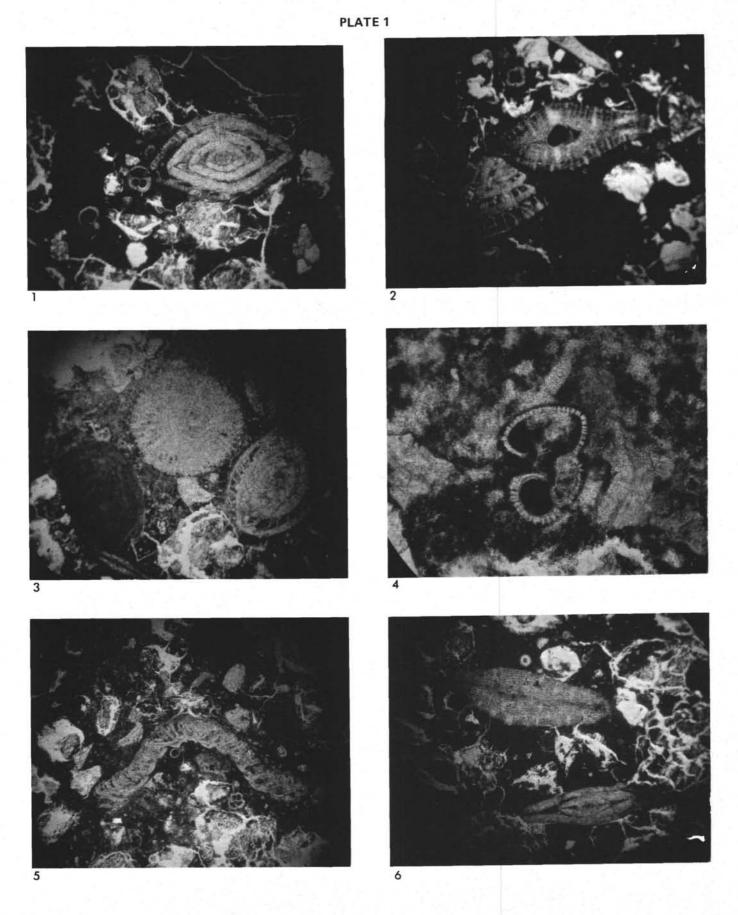
Figure 1	Nummulites sp., Site 357, Core 25.
Figure 2	Lepidocyclina sp., Site 357, Core 25.
Figure 3	Sphaeogypsina sp., Site 357, Core 25.
Figure 4	Truncorotaloides cf. peudotopliensis, Site 357, Core 25.
Figure 5	Fabiania sp., Site 357, Core 25.
Figure 6	Psedophragmina sp., Site 357, Core 25.

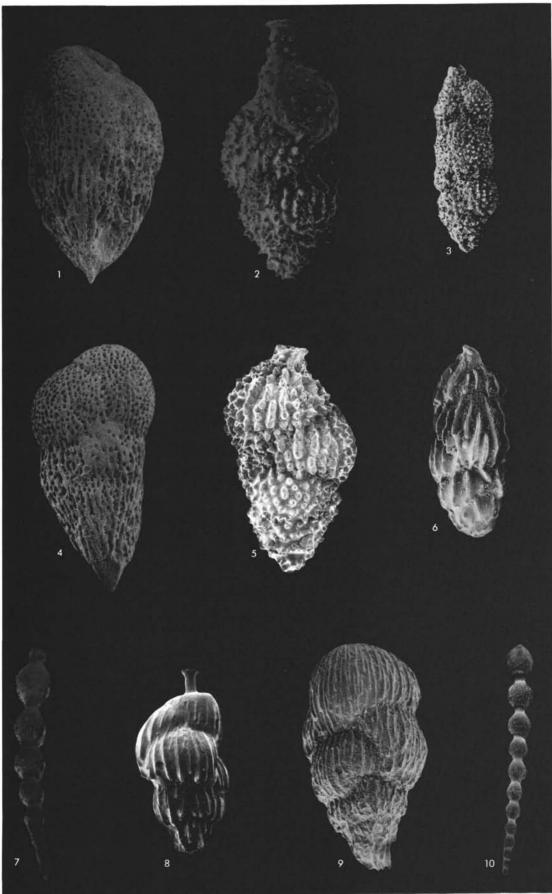
# PLATE 2

Figure 1	Bulimina jarvisi, Site 357, 23, CC ×252.
Figure 2	Uvigerina rippensis, Site 357, 23, CC, ×314.
Figure 3	Uvigerina sp., Site 357, 20, CC, ×297.
Figure 4	Bulimina jarvisi, Site 357, Core 20, Section 1, $\times 197$ .
Figure 5	Uvigerina rippensis, spiny form, Site 357, Core 20, Section 1, $\times 188$ .
Figure 6	Uvigerina rippensis, low costate form, Site 357, Core 21, Section 1, $\times 142$ .
Figure 7	Stilostomella aybssorum, Site 357, Core 19, Section 1, $\times$ 95.
Figure 8	Uvigerina spinulosa, Site 357, 18, CC, ×145.
Figure 9	Uvigerina spinulosa, spiny morphotype during temperature minimum; Site 357, Core 18, Section 1, $\times 206$ .
Figure 10	Stilostomella abyssorum, spiny morphotype during the temperature minimum; Site 357, Core 18, Section 1, $\times$ 56.

(see page 654)

# EOCENE TO EARLY MIOCENE BENTHIC FORAMINIFERA





# PLATE 3

Figure 1	Oridorsalis umbonatus, Site 357, 20, CC, ×289.
Figure 2	Oridorsalis umbonatus, side view, Site 357, 20, CC, $\times$ 480.
Figure 3	Pullenia bulloides, Site 357, Core 20, Section 1, $\times 278$ .
Figure 4	Globocassidulina subglobosa, Site 357, Core 20, Section 1, $\times 287$ .
Figure 5	Osangularia mexicana, Site 357, 18, CC, ×189.
Figure 6	Pullenia quinqueloba, Site 357, Core 18, Section 3, $\times 185$ .
Figures 7-9	Anomalina dorri var. aragonensis, Site 357, Core 18, Section 3, 7. ×215. 8. ×232. 9. ×228.

(see page 656)

