

# 11. LATE CRETACEOUS TO EOCENE PLANKTONIC FORAMINIFERA AND STRATIGRAPHY OF LEG 15 SITES IN THE CARIBBEAN SEA

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## INTRODUCTION

The major aims of Leg 15 of DSDP – to drill down to acoustic basement in as many sites as possible and to attempt to recover a complete sedimentary succession – were both successfully fulfilled. The present report covers the older part of the sedimentary succession recovered during this leg, with special reference to its foraminiferal content.

Only the six sites where the Late Eocene to latest Turonian sediments were recovered have been considered in this report (see Figure 1). The cores recovered from Sites 146 and 149 together form a more or less complete succession of Late Turonian to Late Eocene.

Problems concerning the Cretaceous-Tertiary boundary, selective solution at depths, and the variations in the sedimentation rates are dealt with.

The shipboard work on foraminifera of Sites 146 to 154 was carried out jointly by both authors irrespective of the age of penetrated strata. For the preparation of this initial report, however, the part of Cretaceous to Late Eocene was studied and written largely by Premoli Silva, that on Oligocene to Recent by Bolli.

The foraminiferal specimens figured on Plates 4 to 10 are deposited at the Natural History Museum, Basel, under the numbers C-29458 to C-29498.

## ZONAL SUBDIVISION BASED ON PLANKTONIC FORAMINIFERA

A considerable number of planktonic foraminiferal zonations have been proposed for the Late Cretaceous and Paleogene. Personal preference or regional peculiarities play an important role in the choice of the zonation scheme used by various authors. However, all zonations are based on the same important biostratigraphic datum levels. Figures 2 and 4 show some of these zonations, correlated with the scheme used in the present report (see also Figures 3 and 5).

We have used essentially the same subdivisions introduced by Bolli (1957a, b, 1966) for Trinidad, with minor modifications which became necessary due to taxonomic changes or to improve the original scheme on the basis of new findings.

From bottom to top, the zones are as follows.

### Late Cretaceous (see Figures 2 and 3)

#### *Globotruncana schneegansi* Zone

**Definition:** Interval with the zonal marker from the last occurrence of *Globotruncana helvetica* to the first occurrence of *Globotruncana concavata*.

**Remarks:** *Globotruncana sigali*, *G. renzi*, *G. inornata*, *Clavibergella simplex*, *Hastigerinoides alexanderi* and some species of *Globigerinelloides* are particularly frequent in this zone. In the upper part some specimens transitional to *G. fornicata* occur together with *G. concavata primitiva*.

#### *Globotruncana concavata concavata* Zone

**Definition:** Interval from the first occurrence of the zonal marker to the first evolutionary occurrence of *Globotruncana concavata carinata*.

**Remarks:** Most of the species characteristic for the underlying zone become extinct within this zone. *G. angusticarinata*, *G. coronata*, *G. linneiana*, *G. lapparenti* together with the first representatives of *Rugoglobigerina* characterize this zone.

#### *Globotruncana concavata carinata* Zone

**Definition:** Range of the zonal marker.

**Remarks:** This corresponds to the *Globotruncana fornicata* Zone of Bolli (1957a) and probably to *Globotruncana concavata concavata* Zone of Barr (1972). *G. arca* has its first occurrence at the base of this zone; *G. fornicata* is very frequent. *G. concavata*, *G. angusticarinata*, *G. coronata*, *Hedbergella delrioensis*, *Rugoglobigerina pilula* do not extend beyond the upper boundary of the zone. No overlap seems to exist with *G. elevata* and *G. concavata* group, but this possibility could not be completely excluded because of the poor preservation of the planktonic assemblages of this interval.

#### *Globotruncana elevata* Zone

**Definition:** Interval with the zonal marker from the first occurrence of the zonal marker to the first occurrence of *Globotruncana calcarata*.

**Remarks:** In this zone many species have their first occurrence, i.e., *G. stuartiformis*, *Heterohelix pulchra*, *Pseudoguembelina costulata*, *Rugoglobigerina rugosa*, *Globigerinelloides prairiehillensis*, and *G. yaucoensis*. In the uppermost part of the zone *G. elevata subspinosa*, *G. "tricarinata"*, and *Heterohelix punctulata* make their first appearance. This zone covers a very long time span. However, we did not find any event to subdivide it.

#### *Globotruncana calcarata* Zone

**Definition:** Range of the zonal marker.

**Remarks:** Many species have their first occurrence in this zone including *G. ventricosa*, *G. gagnebini*, *G. subcircumnodifer*, *G. havanensis*, and *G. plummerae*.

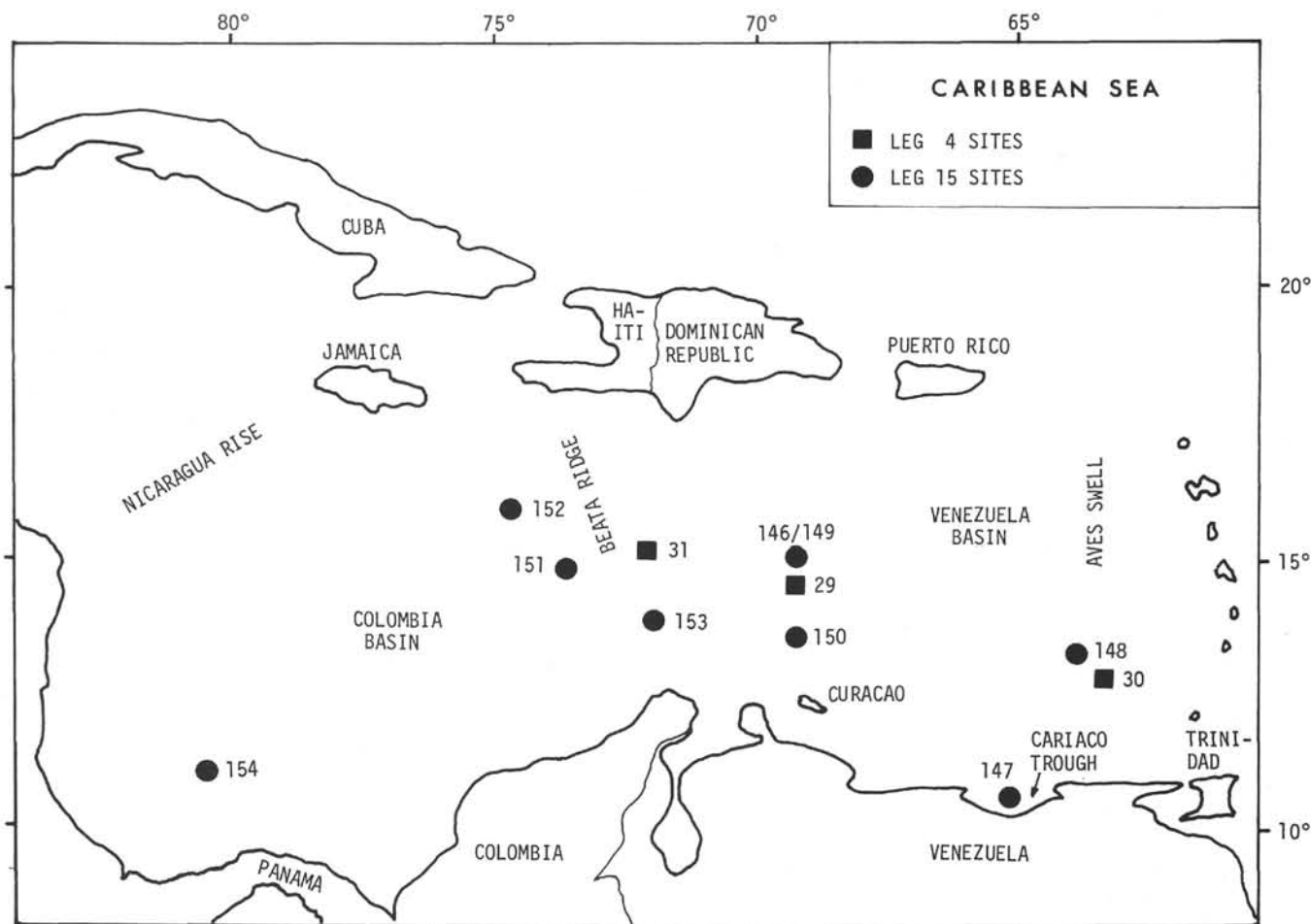


Figure 1. Location of Legs 4 and 15 sites in the Caribbean Sea.

#### Globotruncana "tricarinata" Zone

**Definition:** Interval with the zonal marker from the last occurrence of *Globotruncana calcarata* to the first occurrence of *Globotruncana gansseri*.

**Remarks:** The definition and name of this biostratigraphic interval have changed many times in recent years. The changes are connected with taxonomic problems concerning the identification of the zonal marker. Pessagno (1967), for instance, considers *G. tricarinata* a junior synonym of *G. linneiana*, thus he excluded this taxon from his zonal scheme. Recently, Cita (in Cita and Gartner, 1971), who accepted this synonymy, named this interval *Globotruncana arca* Zone.

We prefer not to change the name of the zone at the present.

Species that first appeared in the underlying zones are very frequent, such as *G. plummerae*, *G. caliciformis*, *G. subcircumnodifer*, *Rugoglobigerina rugosa*, and *Pseudoguembelina costulata*. In the topmost part *G. aegyptiaca* may also occur.

#### Globotruncana gansseri Zone

**Definition:** Interval from the first occurrence of the zonal marker to the first occurrence of *Globotruncana contusa*.

**Remarks:** Within this zone many species make their first appearance. Close to the base, *Pseudoguembelina excolata* evolves from *P. costulata*, and *G. subpennyi*, *Abathomphalus intermedius*. *G. subcircumnodifer*, *G. plummerae*, and *G. bulloides* gradually decrease in number upwards, being replaced by *G. caliciformis* and *G. subpennyi*.

#### Globotruncana contusa Zone

**Definition:** Interval from the first occurrence of the zonal marker to the first occurrence of *Abathomphalus mayaroensis*.

**Remarks:** During the time span of this zone a marked change in the assemblage occurred. The underlying zone is dominated by the "rugose" *Globotruncanae* such as *G. subcircumnodifer*, *G. subpennyi*, etc., while in this zone *Rugoglobigerinae*, large *Heterohelicidae*, and *G. contusa* are more important. *G. conica*, *G. trinidadensis*, *Racemi-guembelina fructicosa*, and some *Pseudotextularia* occur for the first time in this zone. The change is rapid, but not abrupt.

#### Abathomphalus mayaroensis Zone

**Definition:** Range of the zonal marker.

**Remarks:** Close to the base of this zone *G. gansseri* becomes extinct.

AGE	present paper Leg XV	CARIBBEAN Bolli 1957a, 1966	W. COASTAL PLAIN Pessagno, 1967	NORTHERN ATLANTIC DSDP Leg 2 Cita & Gartner, 1971	LYBIA Barr, 1972	SOUTHERN FRANCE Porthault, in press	TUNISIA Sigal, 1967	SOUTHERN ALPS Casati & Tomai, 1969	GENERALIZED ZONATION van Hinte, 1972
Maastrichtian	Late	Abathomphalus mayaroensis	Abathomphalus mayaroensis	Abathomphalus mayaroensis	Abathomphalus mayaroensis		Globotruncana mayaroensis et Globotruncana contusa	Abathomphalus mayaroensis	Globotruncanella mayaroensis
	Middle	Globotruncana contusa	Globotruncana gansseri	Globotruncana gansseri	not cored	Globotruncana gansseri	Globotruncana Stuarti et Coniques	Globotruncana stuarti	Globotruncana contusa
		Globotruncana gansseri							Globotruncana gansseri
Early	Globotruncana "tricarinata"	Globotruncana lapparenti tricarinata	Rugotruncana subcircummodifer	Globotruncana arca	Globotruncana			Globotruncana scutilla	
CAMPANIAN		Globotruncana calcarata	Globotruncana calcarata	Globotruncana calcarata	Globotruncana calcarata	tricarinata	?	Globotruncana calcarata	Globotruncana calcarata
		Globotruncana elevata	Globotruncana stuarti s.t.	Globotruncana elevata	Globotruncana elevata	?	?		Globotruncana elevata et stuartiformis
SANTONIAN	Late	Globotruncana concavata carinata	Globotruncana fornicata	Globotruncana fornicata	Globotruncana concavata concavata	St. 3	Globotruncana concavata	Globotruncana carinata	Globotruncana concavata (G. sigali - G. fornicata)
	Early	Globotruncana concavata concavata	Globotruncana concavata	Margino- truncancana concavata	Globotruncana concavata cyrenaica	St. 2 St. 1 Co2 ?			
CONIACIAN	Late	Globotruncana schneegansi	Globotruncana schneegansi	Marginotruncana renzi	Globotruncana sigali	Co1 ?	"grandes Rosalines plates"	Globotruncana renzi/ Globotruncana sigali	Globotruncana renzi
	Early								
TURONIAN	Late					Tu5			

Figure 2. Some Late Cretaceous published planktonic foraminiferal zonations correlated with the scheme used in the present report.

ABSOLUTE AGE	AGE	ZONES	SELECTED	DATUM-LEVELS
65 m.y.	MAASTRICHTIAN	Late	← T extinction of all planktonic fauna	
			← J. <i>Abathomphalus mayaroensis</i>	
		Middle	← J. <i>Racemiguembelina fructifera</i>	
			← J. <i>Rugoglobigerina rotundata</i> , <i>Globotruncana trinidadensis</i>	
			← J. <i>Globotruncana contusa</i>	
Early	← J. <i>Abathomphalus intermedius</i>			
71 m.y.	CAMPANIAN	← J. <i>Pseudoguembelina excolata</i>		
		← J. <i>Globotruncana gansseri</i>		
75 m.y.	SANTONIAN	← J. <i>Globotruncana aegyptiaca</i>		
		← T <i>Globotruncana calcarata</i>		
		← J. <i>Globotruncana calcarata</i>		
82 m.y.	CONIACIAN	← J. <i>Globotruncana calcarata</i>		
		← J. <i>Globotruncana elevata</i> , <i>Globotruncana stuartiformis</i>		
91 m.y.	TURONIAN	← J. <i>Pseudoguembelina costulata</i>		
		← J. <i>Globotruncana elevata</i> , <i>Globotruncana stuartiformis</i>		

Figure 3. Late Cretaceous zonation scheme and datum levels of index species.

#### Paleocene (see Figures 4 and 5)

##### *Globigerina eugubina* Zone

**Definition:** Interval from the first occurrence of the zonal marker to the first occurrence of *Globorotalia pseudobulloides*.

**Remarks:** This zone is characterized by a small-sized assemblage. The species are few but represented by a great number of specimens.

##### *Globorotalia pseudobulloides* Zone

**Definition:** Interval from the first occurrence of the zonal marker to the first occurrence of *Globorotalia trinidadensis*.

**Remarks:** In this zone *Globigerina daubjergensis* is particularly frequent. This zone is poorly represented in the Leg 15 cores.

##### *Globorotalia trinidadensis* Zone

**Definition:** Interval from the first occurrence of the zonal marker to the first occurrence of *Globorotalia uncinata*.

**Remarks:** During this interval the planktonic foraminiferal assemblage diversifies. *G. praecursoria*, *G. inconstans*, *G. compressa*, *G. schachdagica* occur for the first time in this zone. The zonal marker is frequently very common.

##### *Globorotalia uncinata* Zone

**Definition:** Interval from the first occurrence of the zonal marker to the first occurrence of *Globorotalia angulata*.

**Remarks:** In this interval the zonal marker and *G. praecursoria* are particularly frequent, while *G. trinidadensis* gradually decreases upwards. *G. daubjergensis* disappears within the zone.

##### *Globorotalia angulata* Zone

**Definition:** Interval from the first occurrence of the zonal marker to the first occurrence of *Globorotalia pusilla pusilla*.

**Remarks:** The zonal marker rapidly evolves and is well represented. *G. indolensis*, and *G. perclara* also occur, appearing at the same time as the zonal marker. *G. uncinata* disappears at about the middle of the zone, while in the upper part *G. simulatilis* and forms intermediate between *G. compressa* and *Pseudohastigerina wilcoxensis* first occur. *G. compressa* is quite frequent.

##### *Globorotalia pusilla pusilla* Zone

**Definition:** Interval from the first occurrence of the zonal marker to the first occurrence of *Globorotalia pseudomenardii*.

**Remarks:** This interval is characterized by a marked change in the total aspect of the assemblage. Species such as *G. inconstans*, *G. indolensis*, *G. spiralis* have disappeared. *G. conicotruncata* evolves from *G. angulata*, and *G. chapmani*, *G. cf. kolkidica*, and *G. triangularis* are recorded for the first time along with the zonal marker. Additional taxa that first occur at different levels within this zone are *G. acuta*, *G. velascoensis*, *G. quadrata*, *G. pusilla laevigata* and *G. tadjikistanensis* appear in the upper part of the zone.

##### *Globorotalia pseudomenardii* Zone

**Definition:** Range of the zonal marker.

**Remarks:** This zone could not be identified in any of the Caribbean sites. Poor recovery and/or facies exclusion (dominantly siliceous sedimentation) may account for this fact.

##### *Globorotalia velascoensis* Zone

**Definition:** Interval with the zonal marker from the last occurrence of *Globorotalia pseudomenardii* to the last occurrence of the zonal marker.

**Remarks:** Many species make their first appearance within this zone, of which the most important are *G. wilcoxensis*, *G. gracilis*, *G. marginodentata*, *G. guatemalensis*, *G. subbotinae*, *G. planoconica*, *G. primitiva*. All of them are particularly frequent in the overlying zone. Very frequent are also *G. acuta*, *G. triangularis*, *G. soldadoensis*, and *G. soldadoensis angulosa*. In the upper levels *G. edgari* n. sp. also occurs.

#### Eocene (see Figures 4 and 5)

##### *Globorotalia edgari* Zone

**Definition:** Interval with the zonal marker from the last occurrence of *Globorotalia velascoensis* to the last occurrence of the zonal marker.

**Remarks:** This interval lacking in Trinidad has been named differently by various authors. It corresponds to the *Globorotalia aequa* Zone of Luterbacher (1964), to the

AGE	present paper Leq XV	CARIBBEAN Bollí, 1957b, 1966	CENTRAL APENNINES Luterbacher, 1964	SOUTHERN URSS Strat. Commission, 1963	SYRIA, EGYPT Krasheninnikov, 1969, 1965		EGYPT Beckman et al., 1969	NORTHERN ITALY Luterbacher, in press	General Scheme Berggren, 1969		
Eocene	Middle	Hantkenina aragonensis	Hantkenina aragonensis	Globorotalia bullbrookii	Acarinina crassaformis	Acarinina bullbrookii	Hantkenina aragonensis	Globorotalia bullbrookii	Hantkenina aragonensis		
	Early	Globorotalia palmerae	Globorotalia palmerae	Globorotalia aragonensis	Globorotalia aragonensis	Globorotalia aragonensis	Acarinina pentacamerata	Globorotalia aragonensis	Globorotalia pentacamerata	P9	
		Globorotalia aragonensis	Globorotalia aragonensis				Globorotalia aragonensis		Globorotalia aragonensis	P8	
		Globorotalia formosa formosa	Globorotalia formosa formosa	Globorotalia formosa formosa/ Globorotalia subbotinae	Globorotalia subbotinae	Globorotalia marginodentata	Globorotalia marginodentata	Globorotalia formosa formosa	Globorotalia formosa formosa	P7	
		Globorotalia subbotinae	Globorotalia rex	Globorotalia aegua		Globorotalia subbotinae	Globorotalia subbotinae	?	Globorotalia subbotinae	Globorotalia subbotinae	P6
		Globorotalia edgari	?			Globorotalia subbotinae	Globorotalia subbotinae	Globorotalia subbotinae	Globorotalia subbotinae	Globorotalia subbotinae	
Paleocene	Late	Globorotalia velascoensis	Globorotalia velascoensis	Globorotalia velascoensis	Acarinina subsphaerica	Acarinina acarinata	Globorotalia velascoensis	Globorotalia velascoensis	P5		
		Globorotalia pseudomenardii	Globorotalia pseudomenardii	Globorotalia pseudomenardii		Acarinina subsphaerica		Globorotalia pseudomenardii	P4		
	Middle	Globorotalia pusilla pusilla	Globorotalia pusilla pusilla	Globorotalia pusilla pusilla	Globorotalia angulata	Globorotalia tadjikistanensis	Globorotalia conicotruncata	Globorotalia conicotruncata	Globorotalia pusilla pusilla	P3	
		Globorotalia angulata	Globorotalia uncinata	Globorotalia uncinata		Globorotalia conicotruncata	Globorotalia angulata	Globorotalia angulata	Globorotalia angulata		
		Globorotalia uncinata				Acarinina inconstans	Acarinina uncinata	Globorotalia uncinata	P2		
	Early	Globorotalia trinidadensis	Globorotalia trinidadensis	Globorotalia trinidadensis	Globigerina trivialis/ G. daubjergensis	Globigerina trieculinoides/ G. daubjergensis	Globigerina trinidadensis	Globorotalia trinidadensis	P1		
		Globorotalia pseudobulloides	Globorotalia pseudobulloides	Globorotalia pseudobulloides/ Globigerina daubjergensis	Globorotalia compressa	Globorotalia pseudobulloides Eoglobigerina eobulloides	Globorotalia pseudobulloides	Globorotalia pseudobulloides			
		Globigerina eugubina	Globigerina eugubina	Globigerina eugubina	Eoglobigerina taurica	Globigerina eugubina	Globigerina eugubina	Globigerina eugubina			

Figure 4. Some Paleocene-Early Eocene published planktonic foraminiferal zonation correlated with the scheme used in the present report.

ABSOLUTE AGE	AGE	ZONES	SELECTED DATUM-LEVELS
48 m.y.	Middle	Hantkenina aragonensis	↑ Hantkenina aragonensis
		Globorotalia palmerae	↑ Globigerinatheka, Globigerinita
	Early	Globorotalia aragonensis	↑ Globorotalia formosa formosa
		Globorotalia formosa formosa	↑ Globigerina taroubaensis
		Globorotalia subbotinae	↑ Globorotalia aragonensis
		Globorotalia edgari	↑ Globorotalia formosa formosa
54 m.y.	Late	Globorotalia velascoensis	↑ Globorotalia velascoensis
		Globorotalia pseudomenardii	↑ Globorotalia edgari, Globorotalia subbotinae
	Middle	Globorotalia pusilla pusilla	↑ Globorotalia pseudomenardii
		Globorotalia angulata	↑ Globorotalia pusilla pusilla
		Globorotalia uncinata	↑ Globorotalia comico truncata
		Globorotalia trinidadensis	↑ Globorotalia uncinata
Early	Globorotalia pseudobulloidis	↑ Globorotalia trinidadensis	
	Globigerina eugubina	↑ Globigerina daubjergensis, Globorotalia pseudobulloidis	
		↑ Globigerina eugubina	
65 m.y.			

Figure 5. Paleocene-Early Eocene zonation scheme and datum levels of index species.

lower part of *Globorotalia subbotinae* Zone of the same author (in press), etc. (see Figure 4).

This interval is characterized by the abundance of the "spinose-keeled" *Globorotaliae* such as *G. gracilis*, *G. marginodentata*, *G. subbotinae*, *G. acuta*, *G. aequa*, and by the group of *G. soldadoensis*. In the upper part of the zone *G. intermedia* and *G. turgida* make their first appearance. The zonal marker is generally well represented and disappears quite abruptly.

#### *Globorotalia subbotinae* Zone

**Definition:** Interval with the zonal marker from the last occurrence of *Globorotalia edgari* to the first occurrence of *Globorotalia aragonensis*.

**Remarks:** This zone corresponds to the *Globorotalia rex* Zone of Bolli (1957b, 1966), to the *Globorotalia formosa formosa*/*Globorotalia subbotinae* Zone of Luterbacher (1964), and to the upper part of *Globorotalia subbotinae* Zone of Luterbacher (in press).

The assemblage is very similar to that of the underlying zone. *G. intermedia* and *G. pseudotopilensis* (= *Acarinina* group of Russian authors) become important in the upper part of the zone.

#### *Globorotalia formosa formosa* Zone

**Definition:** Interval with the zonal marker from the first occurrence of *Globorotalia aragonensis* to the first occurrence of *Globigerina taroubaensis*.

**Remarks:** The zonal marker is generally not well represented, while *G. aragonensis* rapidly increases in number. The "spinose-keeled" *Globorotaliae* and *G. soldadoensis* group, occurring in the underlying zones, rapidly decrease in abundance while *G. intermedia* and *G. pseudotopilensis* become more and more frequent. *G. quetra* and *G. rotundimarginata* also occur.

The other Eocene zones based on planktonic foraminifera could not be identified in the Caribbean drill sites as this interval yields only very poor foraminiferal assemblages.

### CHRONOSTRATIGRAPHIC CORRELATIONS

#### Cretaceous

At present it is not possible to suggest a satisfactory correlation between the foraminiferal zonation and the standard zonation based on Ammonites, because a) Ammonites are generally very rare in the Late Cretaceous sediments, b) other molluscs are facies controlled and not as significant as Ammonites, c) rich and well-preserved foraminiferal assemblages frequently are not present along with megafossils. Moreover, the Late Cretaceous mollusc assemblages have not been well studied and then only from spot localities and not from continuous stratigraphic successions.

The Late Cretaceous stages were established mostly in France. The stratotypes seldom yield significant assemblages which are not facies controlled. In most cases they are represented by badly exposed sections consisting of shallow-water epicontinental sediments where the planktonic foraminiferal assemblages are very poor. Moreover, there are considerable disagreements as to the stage boundaries between specialists of different fossil groups. For instance, the *Globotruncana elevata* Zone may be referred to the Santonian on the basis of Belemnite stratigraphy (Barr, 1972), while a correlation with the Ammonite zonation places the same foraminiferal zone in the Campanian (Porthault, in press; Sigal, 1967).

In the last few years some authors have tried to tackle this problem by extending their investigations outside the classical localities into other basins where more continuous marine sections could be studied. The "Fosse Vocontienne" in Southern France seems better suited because a well-exposed and complete succession of pelagic sediments spanning the time interval from Early Cretaceous to the Late Campanian is present in this section. Both Ammonites and planktonic foraminifera are represented.

Figure 6 shows the correlations between the standard Ammonite zonation of Sigal (1967) and planktonic foraminiferal zones on the basis of new Ammonite assemblages reported from Southern France (Donze, Porthault et al., 1970; Porthault, in press) and including the recent Ammonite findings in Morocco and Northern Spain (Lehmann, 1962; Wiedmann, personal communication, April, 1972).

AGE	AMMONITE ZONES after Sigal, 1967	AMMONITE ASSEMBLAGES Southern France, Morocco, Northern Spain	PLANKTONIC FORAMINIFERAL ZONES (present paper)	ABSOLUTE AGE
MAASTRICHTIAN	neubergicus		Abathomphalus mayaroensis	65 m.y.
	constrictus-triolens		Globotruncana contusa	
			Globotruncana gansseri	
			Globotruncana "tricarinata"	
CAMPANIAN	polyplocum		Globotruncana calcavata	71 m.y.
	vari-delawarensis	Hoplitoplacenticeras vari	Globotruncana elevata	
		Delawarella delawarensis		
	biolorsatum	Placenticeras bidorsatum		
SANTONIAN	syrtale-isculensis	Placenticeras syrtale/isculensis	Globotruncana concavata carinata	76 m.y.
	texanus	Texanites texanus	Globotruncana concavata concavata	
CONIACIAN	emscheris	Parabeuahites emscheris Paratexanites, Gandry ceras sp. Hemitissotia turzoi		82 m.y.
	haberfellneri	Barroisiceras haberfellneri		
TURONIAN Late	ornatissimus-bizeti- deveriai	Peroniceras spp. Romaniceras sp.	Globotruncana schneegansi	91 m.y.

Figure 6. Tentative correlation between the standard Ammonite zonation and the planktonic foraminiferal zones. Data on Ammonites are from: Southern France, after Donze, Porthault et al., 1970; Porthault, personal communication, June, 1972. Morocco, after Lehmann, 1962; Wiedmann, personal communication, April, 1972. Northern Spain, Wiedmann, personal communication, April, 1972.

The discrepancies existing in the literature with reference to the scheme illustrated in Figure 6 may probably be due to erroneous identification of the Ammonites. For instance, Lehmann (1962) attributes the upper part of his "Zone à grandes Rosalines" (= *Globotruncana schneegansi* Zone) to the Coniacian on the basis of the Ammonite content sampled in the Tarfaya section (Morocco). According to Wiedmann (personal communication, April, 1972) the topmost sample (n. T 473) of the "Zone à grandes Rosalines" from the section cited above yielded an Ammonite assemblage of Late Turonian age and not Coniacian as suggested by Collignon (footnote in Lehmann, 1962). Thus, the overlying *Globotruncana concavata concavata* Zone of the same section predates the Santonian at least in its lower part and is extended to the Coniacian.

This interpretation is in agreement not only with Porthault's view concerning the relative distribution of planktonic foraminifera versus Ammonites in Southern France, but also with Sigal (1967) and de Klasz (1961) with reference to their findings in Tunisia and Gabon respectively.

Another discrepancy concerns the age of the boundary between the *Globotruncana concavata carinata* and *Globotruncana elevata* zones. Marie (1961) reported *Globotruncana elevata* from the Late Cretaceous of Corbières (France, north of Pyrenees) from the same levels that also yielded an important mollusc fauna, which was attributed to the lower part of Late Santonian. In contrast, according to Porthault (personal communication, June, 1972), the

vertical range of *Globotruncana elevata* is mostly Campanian with a possible occurrence in the topmost levels of the Santonian. The overlap between *Globotruncana elevata* and *Globotruncana concavata carinata* is probably of very short duration and close to the Santonian-Campanian boundary. The above interpretation is also in agreement with the relative distribution of planktonic foraminifera and Ammonites in Morocco (Lehmann, 1962), in Tunisia (Sigal, 1967), and in Northern Spain (Wiedmann, personal communication, April, 1972). It would seem that the mollusc fauna from Corbières probably needs restudying.

On the Caribbean sites we can attribute the *Globotruncana concavata carinata* Zone to the Late Santonian. However, we are not able to establish exactly the age of the underlying zones. We know that *Globotruncana concavata concavata* is recorded from layers referable to the Coniacian on the basis of the Ammonite content—more precisely from Early Coniacian of Southern France and of Gabon (Donze, Porthault et al., 1970; de Klasz, 1961)—and that the *Globotruncana schneegansi* Zone straddles the boundary between the Coniacian and Turonian stages (Porthault, personal communication, April 1972). However, we do not know where the Santonian-Coniacian boundary should be placed with reference to the *Globotruncana concavata* Zone. Sediments suitable for detailed biostratigraphic investigations are not available from Leg 15 sites; solution and mechanical disturbances are accentuated in this part of the succession.

### Lower Tertiary

In the Paleocene and Eocene, correlation problems are essentially limited to the boundary between Paleocene and Eocene. The ambiguous original definition of the Paleocene leaves several possibilities open for placing the Paleocene-Eocene boundary. In the present report the boundary under discussion is considered as coincident with the boundary between the *Globorotalia velascoensis* and *Globorotalia edgari* zones.

As shown in Figures 4 and 5 the name of the stages will not be used in the present paper for subdividing the Paleocene. We consider that at the present time correlations between stages and planktonic foraminiferal zones would be unsatisfactory because of the lack of good stratigraphic data in the stratotype areas.

### DISCONTINUITIES IN THE STRATIGRAPHIC RECORD

As reported in the site reports a complete succession from the latest Turonian to the Late Eocene has been recovered only at Sites 146 and 149 in the Venezuelan Basin. At other drill sites gaps of sedimentation of different magnitude occur (see Figure 7). The most important gap is observed at Site 150 where the entire Paleocene, the Maestrichtian, Campanian, and Late Santonian are not represented, which represents a duration of about 25 m.y. Most of the Eocene and the entire Oligocene are also lacking, only a few meters of lowest Eocene age being present at Site 150. These gaps in sedimentation suggest a location on a rise during at least part of the Late Cretaceous and most of the Paleogene in contrast with the present physiographic setting in a basin some 450 meters deep. The inferred location resulted in sediment removal by current action and/or gravity sliding. Unfortunately poor core recovery and/or disturbance of the sediments in the cores prevent an interpretation of the nature of the possibly unconformable contacts. The existence of hardground cannot be ruled out; however, we did not find positive evidence of this phenomenon.

A comparison of the stratigraphic sections, as recorded in three drill sites illustrated in Figure 8 (foldout in pocket at back of volume), shows that the gaps become less pronounced in a northerly direction, though the present-day water depth decreases in that direction. Thus, Sites 146 and 149, which together offer a thick and more or less uninterrupted section, with evidence of redeposited layers, is to us the expression of deposition in a basin, while Site 150 with its important gaps, a strongly reduced section, and no evidence of redeposited material suggests a depositional environment on a submarine rise.

The gap in sedimentation at Site 151 is accompanied by hardground from the Early Paleocene (*Globorotalia trinidadensis* Zone) to the Late Santonian (*Globotruncana concavata carinata* Zone). The corresponding duration is estimated to be about 10 m.y. At the same site, the Late Paleocene and most of the Middle Paleocene are also missing. The duration of this gap is estimated to be 5 to 6 m.y. Only a few meters of sediments represent the Early Eocene (*Globorotalia edgari* and *Globorotalia formosa formosa* zones) (with a short gap between them). The remaining Eocene sediments are completely lacking, which

would represent a duration of 14 to 15 m.y. The site under discussion was drilled on the southern part of the Beata Ridge, in a water depth of about 2000 meters. The succession described above also includes a well-recognizable hardground, suggesting deposition on a seamount or submarine rise.

Minor gaps are also present at Site 153, located at a depth of about 4000 meters at the eastern foot of the Beata Ridge. Most of the Middle and Late Maestrichtian (about 4 m.y.) are lacking, the *Globigerina eugubina* horizon directly overlying sediments of early Middle Maestrichtian (*Globotruncana gansseri* Zone) age. The contact is obviously unconformable and an intraformational breccia is observed, suggesting submarine movements. The occurrence of zeolites, siliceous clay, etc., poor in calcitic, organogenic content in the overlying sediments suggests that for the post-*Globigerina eugubina* succession, the stratigraphic record at Site 153 represents deposition occurring in a deep basin, well below the Carbonate Compensation Depth.

The poor recovery from the *Globotruncana "tricarinata"* Zone down to the bottom of the hole prevents good control of the stratigraphic record. Our assumption on its completeness is mainly based on the sediment thickness, which compares well with that recorded at Site 146.

The succession at Site 152 is the richest in carbonates recorded in the Caribbean. It is located on the Nicaragua Rise, at a depth of 3900 meters. Unfortunately, the cored interval is limited from the Campanian to the Early Eocene. A gap of three zones overlying the *Globigerina eugubina* horizon exists, the corresponding duration being about 4 m.y. However, poor core recovery (only 0.8 m) may lead to an overestimation of the duration of this gap. Higher in the section, the *Globorotalia pseudomenardii* Zone is not represented, however, this may possibly be due to facies exclusion.

### AGE OF THE SEDIMENTS IN CONTACT WITH MAFIC IGNEOUS ROCKS

Igneous rocks were recovered at Sites 146 (Cores 41-44), 150 (Cores 11 and 12), and 153 (Cores 19 and 20). In these three locations dolerites and basalts are directly overlain by sediments referable to the *Globotruncana schneegansi* Zone, of latest Turonian-earliest Coniacian age. According to the most recent time scales (Larson and Pitman, 1972), the absolute age of these sediments can be estimated to be about 90 m.y. These mafic igneous rocks represent acoustic basement in the Venezuelan Basin. The calcareous sediments are more or less indurated near the contact with the igneous rocks. At Site 146 the limestone appears slightly metamorphosed for a thickness of about 1 meter.

At all the locations considered above, the fossil content of the sediments in contact with the basement is abundant and as diversified as in the overlying layers. No indication of a depth of deposition shallower than that indicated for the higher portion of sediments was found. The benthonic foraminifera are poor and belong to the same taxa as recorded from overlying layers. Only at Site 150 was a slightly greater abundance of benthonic foraminifera recorded; however, this is not considered a valid argument in favor of a shallower environment.



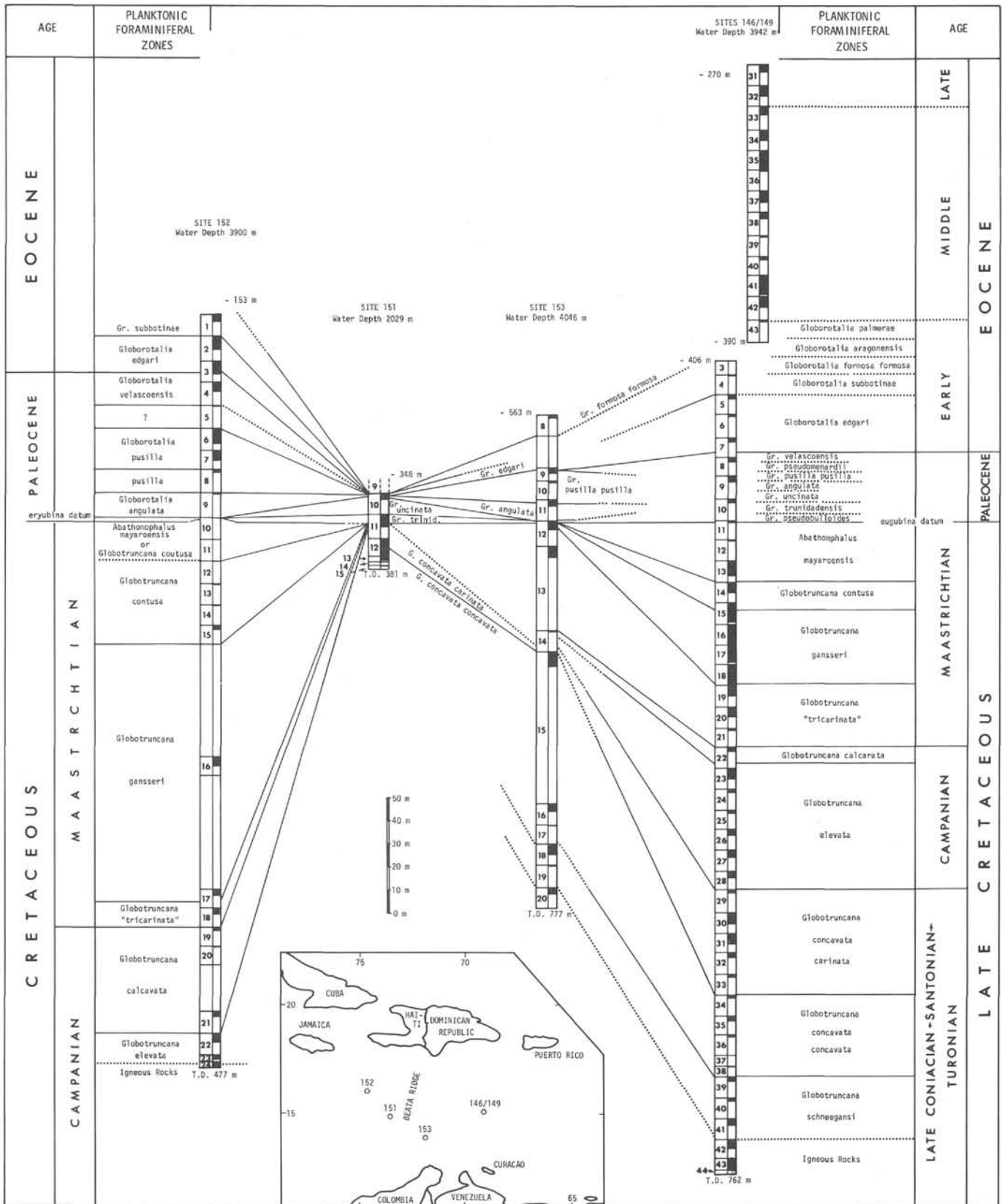


Figure 7. West-east stratigraphic correlation of the Eocene-Cretaceous cores in Sites 152, 151, 153, and 146-149.

Igneous rocks were also recovered at Site 151 (Cores 13-15) and Site 152 (Cores 23 and 24). In the former, the sediments resting on diabase are highly disturbed and are of mixed lithology, containing mixed foraminiferal assemblages which have different states of preservation. They can be attributed to the *Globotruncana concavata concavata* Zone, Late Coniacian or Early Santonian (82-85 m.y.), but the presence of older sediments can not be ruled out.

In the latter site, the igneous rocks are associated with large fragments of metamorphosed limestones of reddish to brown color, which yield a foraminiferal assemblage of *Globotruncana elevata* Zone of Middle Campanian age, about 73 m.y. old.

#### THE CRETACEOUS-TERTIARY BOUNDARY AND THE CARBONATE CRISIS OF THE LATE MAESTRICHTIAN

The Cretaceous-Tertiary boundary was cored in all the drill sites considered in this chapter. The boundary occurs at the following positions:

Site 146, Core 11, Section 1, between 131 and 139 cm (see Figure 9);

Site 150, within Core 7;

Site 151, Core 11, Section 6, at 130 cm (see Plate 1);

Site 152, Core 10, Section 1, at 142 cm (see Plate 3, Figure 2);

Site 153, Core 12, Section 1, between 92 and 102 cm (see Plate 3, Figure 3).

Only at Site 150 was recovery poor at the passage, and here only mixed assemblages were recovered due to drilling disturbance. In the remaining drill sites, sediments of the lowermost Tertiary and the topmost part of the Cretaceous are contained in a single section of a single core. In all cases, the sediments are semiconsolidated or consolidated. The figures on Plates 1 to 3 illustrate the contact as observed at various sites.

The contact is very sharp at Sites 151 and 152 and disturbed at Sites 146 and 153.

**Site 146**—Some *Globigerina*-bearing silty layers alternate with brownish gray marly layers. The former are probably redeposited and contain different assemblages belonging to the *Globorotalia pseudobulloides* Zone, to the *Globigerina eugubina* Zone, and to a general Late Cretaceous age, possibly *Abathomphalus mayaroensis* Zone (these assemblages, unlike the former, are very poor). The stratigraphic superposition is not certain. The marly layers, brownish gray in color, contain only few benthonic foraminifera.

**Site 151**—A 15-cm thick layer contains sediments representing a relatively long time span of more than 10 m.y. This obviously involves a considerable gap in sedimentation, from the latest Santonian (*Globotruncana concavata carinata* Zone) to the Early Paleocene (*Globorotalia trinidadensis* Zone). The layer consists of a heterogeneous microbreccia, the elements of which are interpreted as fragments of one or more ancient hardgrounds eventually destroyed. Both the clasts and the cement were subsequently partially silicified (see Plate 2).

**Site 152**—A distinct break occurs between the homogeneous *Globigerina eugubina* chalk and the underlying burrowed, possibly redeposited marls rich in Late Maestrichtian foraminiferal assemblages. Erosion by drilling operations at the top of the Cretaceous cannot be ruled out (see Plate 3, Figure 2).

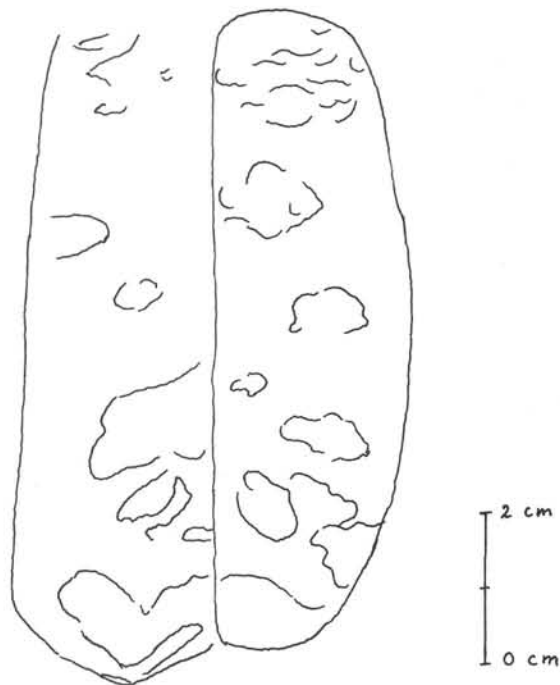


Figure 9. Sketch of the layer containing the Cretaceous-Tertiary boundary at Site 146, Core 11, Section 1, 131-138 cm. Dark lines delimit the silty foraminiferal-rich lenses and/or layers, irregularly alternating with the foraminiferal-poor brownish gray marly layers. Planktonic foraminiferal assemblages become progressively older from top to bottom, namely from the *Globorotalia pseudobulloides* Zone, via *Globigerina eugubina* Zone, of earliest Paleocene to Late Maestrichtian *Abathomphalus mayaroensis* Zone. Because of redeposited character of sediments the boundary cannot be exactly fixed.

**Site 153**—A 10-cm thick breccia consists of predominant lowermost Tertiary elements with few fragments of argillaceous micrite yielding Late Cretaceous assemblages.

In all the drill sites considered here, the passage from the Cretaceous to the Tertiary is modified by some external factors. We could not recover an undisturbed succession of sediments, such as may be found on land. Also in other DSDP holes where the Cretaceous-Tertiary boundary has been cored, namely Site 20C in the South Atlantic (Leg 3) and Site 47.2 in the equatorial Pacific (Leg 6), definitely undisturbed successions could not be recovered. In the former, *Globigerina*- and *Globotruncana*-bearing layers occurred interbedded for some meters. It could not be determined whether this is due to drilling disturbances or to slumping during sediment deposition. In the latter site the core containing the boundary is highly disturbed.

Thus consistent evidence is offered by DSDP drill sites in different parts of the world oceans that the abrupt change at the Cretaceous-Tertiary boundary is more accentuated in deep-sea basins than in many land sections, which at first sight is the opposite of what should be expected. The events which resulted in the abrupt change of the organic life at the end of the Cretaceous were apparently more effective on the water masses on the open oceans than on the near shore and shelf areas.

According to Tappan (1968) a continuing climatic deterioration occurred during Maestrichtian time. She suggested that the atmospheric oxygen depletion increased the CO<sub>2</sub> content in the ocean, strongly reducing the upwelling and resulting in a change of pH in the water masses. Worsley (1971) suggested that the submarine solution of carbonates increased with upward migration of the Carbonate Compensation Depth through the Late Maestrichtian. The CCD supposedly approached the surface of the oceans near the Cretaceous-Tertiary boundary (see also Hay, 1970). Planktonic organisms, especially the phytoplankton, were directly affected and massive extinctions occurred at that time.

The interruption of the phytoplankton productivity rapidly affected all the organisms in the food chain. Worsley suggested further that only close to the shelves can a continuous record across the Cretaceous-Tertiary boundary be expected. This is in agreement with what is recorded on land, where sections are rich in planktonic organisms up to the top of the Cretaceous.

We can conclude that, as observed by Worsley, at the end of the Cretaceous the Carbonate Compensation Depth was shallower than in previous times. However, we cannot conclude that it reached the surface of the ocean, because the sections outcropping on land yield very rich assemblages, including all the components of a normal pelagic fauna.

According to Sliter (1972), a water column some hundred meters thick is needed for a complete and well-diversified fauna characteristic for the slope and deep-water facies to develop (see also Douglas, 1971). This is in contrast with the idea of CCD reaching close to the surface of the ocean.

The Paleocene Epoch is never represented by continuous, carbonate-rich successions in the Caribbean sites. Siliceous clays, or cherts, can cover this interval in part or completely. Foraminiferal oozes are limited to some definite levels. It is worthwhile mentioning that the sediments representing the interval just above the *Globigerina eugubina* Zone are never calcareous<sup>1</sup>; they are either lacking as at Site 151, or are represented by sediments very poor in carbonates, as at Sites 146 and 153.

If we accept that the Carbonate Compensation Depth migrated upwards during the Late Cretaceous, we should not expect to find carbonate-rich sediments at the bottom of the Tertiary; a finite duration being necessary to renew normal productivity in the oceans (see Worsley, 1971). Thus, we can conclude that the presence of the *Globigerina eugubina*-bearing layers is anomalous, suggesting that they may have slumped from locations above the Lysocline.

<sup>1</sup>In more complete landbased sections which are not affected by carbonate dissolution (e.g., Central Apennines, Southern Alps), the faunas of the *Globigerina eugubina* Zone grade upwards into the assemblages of the *Globorotalia pseudobulloides* Zone. In these sections, it can be readily demonstrated that the assemblages of the *Globigerina eugubina* Zone are not dwarfed and residual relicts of topmost Cretaceous age, but represent the stock of small globigerinids from which the Paleogene planktonic foraminifera evolved (see Luterbacher and Premoli Silva, 1964, and Premoli Silva and Luterbacher, 1966).

## PROBLEMS OF SOLUTION

During the last few years a number of scientists have paid special attention to the problems of solution of calcium carbonate at depth, especially solution of calcitic tests of planktonic organisms, such as foraminifera and calcareous nannofossils.

Experimental investigations were made by Peterson (1966) on calcite spherules and by Berger (1970, 1971, 1972) on Recent and Subrecent planktonic foraminifera.

The problems of solution affecting fossil sediments became evident during the study of DSDP cores. Cita (1971a, b) on Leg 2 and Hsu and Andrews (1970) on Leg 3 tried to interpret the Cenozoic fossil record in the light of the experimental data available on solution of calcite tests.

After the Pacific legs, where older sediments were recovered in abundance, Douglas (1971) studied in detail the solution affecting the Late Cretaceous foraminiferal assemblages. According to him, "As a general rule the globigerina-shaped taxa are less resistant than the majority of heterohelicids and heterohelicids are less resistant than keeled species." Three different groups could be differentiated as being least to most resistant: 1) juveniles and small, thin-walled fragile species; 2) the medium-sized species with little or no ornamentation; 3) the large thick-walled and strongly ornamented species. The last group includes *Rugoglobigerina*, *Racemiguembelina*, *Pseudotextularia*, *Globotruncana contusa*, *Abathomphalus intermedius*, and *Globotruncana havanensis*. Only few heterohelicids could be preserved in highly dissolved facies along with the benthonic foraminifera and calcareous nannoplankton.

Berger and von Rad (1972) on the basis of Leg 14 material, improved the classification of different states of preservation in the foraminifera. They established a new scale of solution facies based on Recent foraminifera, which can be applied in general to the older sediments. In Figure 10 the schedule on recent solution facies and the coarser scale for the older sediments as put forward by Berger and von Rad are presented.

### Late Cretaceous

As far as the Late Cretaceous sediments from the Caribbean are concerned, we found some intervals to be completely devoid of planktonic foraminifera, e.g., in Site 146, Cores 11 (pars), 12, and 13 (pars); Site 153, Cores 12 and 13 (pars). The absence of calcitic tests is interpreted as the result of solution at depth (pelagic sediments being accumulated on the sea floor close to the compensation depth of calcite). Other intervals contained only impoverished foraminiferal assemblages.

These assemblages selected according to differential resistance to solution on various taxa are as follows.

**Site 152:** Only the uppermost 10 cm referable to the Late Maestrichtian (Core 10, Section 1, 142-150 cm) yield an anomalous assemblage characterized by (a) very frequent *Heterohelicidae* (mostly *Pseudoguembelina* and *Racemiguembelina*); (b) very frequent and large *Rugoglobigerinae*; (c) very rare *Globotruncana elevata*, *G. stuartiformis*, *G. leupoldi*, and *G. trinidadensis*; (d) rather fre-

quent *Globotruncana aegyptiaca* and *Abathomphalus intermedius*; and (e) no *Globotruncana contusa*, *G. conica*, or *G. gansseri* (see Figure 19).

According to Douglas (1971), the presence of rare single-keeled globotruncanids along with high frequency of costate heterohelicids, rugoglobigerinids, and *Abathomphalus intermedius* indicates a strong effect of solution on the assemblage described above, which could be compared to high solution facies group N.3 of Douglas' scheme.

The only discrepancy is the absence of *Globotruncana contusa*, which is considered a resistant species, and should be present in the considered time interval. Its resistance to solution is probably weaker than previously suspected as compared to the taxa referred to the same group.

According to Berger and von Rad's general scale, the assemblage of Site 152 represents a facies between "L- and R-facies"; it is poor in keeled forms and rich in *Heterohelicidae* and *Rugoglobigerinae*.

**Site 146:** Core 13, Section 4, 41-43 cm — only *Heterohelicidae*, with few specimens of *Rugoglobigerina rugosa* and *Abathomphalus intermedius*; Core 13, Section 5 — very frequent *Globotruncanae* with only small *Heterohelicidae* and rare *Rugoglobigerinae* (the only recorded taxon is *R. rugosa*); Core 13 CC — rare *Globotruncanae*, some *Abathomphalus mayaroensis*, a few *Heterohelicidae*.

Downwards, in the Middle and Late Maestrichtian, the assemblages are dominated by *Globotruncanae*, also including rugose forms, while the genus *Rugoglobigerina*, mostly represented by *R. rugosa*, is poorly represented. Among the *Heterohelicidae*, *Pseudoguembelina excolata* and *P. costulata* are the dominant taxa. The remaining species that occur in this time interval, such as *Pseudotextularia elegans*, are only sporadically represented, while fish remains are always frequent. Only in the lower part of the *Globotruncana "tricarinata"* and in the *Globotruncana calcarata* zones, the assemblages give the impression of being complete in all their components.

From Core 23 down to Core 41 all the planktonic foraminifera are badly preserved, squeezed, and dissolved. Radiolaria, on the other hand, are very abundant.

Only the topmost part of the succession (to the catcher sample of Core 13) is similar to Douglas' group N.3 and to the assemblages recorded at Site 152 (= L-/R-facies of Berger and von Rad, see Figure 10). For the remaining part of the Maestrichtian, the assemblages are not comparable with any existing scheme.

Redeposition processes were particularly active during this interval at Site 146. Carbonate-rich sediments are interbedded with carbonate-poor layers, yielding well-preserved but not complete planktonic foraminiferal and poor benthonic assemblages, respectively. This facies association suggests a flow of carbonate-rich sediments from shallower depths into a region very close to the Carbonate Compensation Depth (where the carbonates became almost completely dissolved). Thus, we consider most of these forms as redeposited. Sorting could also be considered as a possible control of the apparent anomaly. However, this assumption is unrealistic, since species having the same size as those absent in the assemblages are well represented.

Again, the absence of resistant species such as *Rugoglobigerina* and the small faunal diversity of the *Heterohelicidae* together with the normal development of other groups (in the carbonate-rich layers) suggests that perhaps the problem could be explained by provincialism of some species and/or by the distribution patterns related to water depth. The planktonic foraminiferal assemblages from Site 146 are characteristic for a deep-water environment.

We can conclude that carbonate solution at depth cannot be responsible, alone, for the peculiar characters offered by these faunas. Some other factors have to be considered, i.e., volcanic activity (igneous minerals are frequent in the sediments), diagenetic processes, etc.

FS Criteria	Approximate Loss Per Cent	Coarse Scale
1 Foraminifera undissolved (aragonitic pteropods present)	0	"P-facies" (Plenty of delicate forms, Preserved assemblage, FS ≅ 1 to 3), "L-facies" (Lowered abundance of delicate forms, Lysocline zone, maximum secondary diversity; FS ≅ 4), "R-facies" (Rare delicate forms, Resistant forms greatly enriched; FS ≅ 5 to 6), "N-facies" (No delicate forms, Nannofossils relatively enriched; FS ≅ 7 to 9).
2 <i>Hastigerina</i> present. Many globigerinids bear spines. R < 5%.	~10	
3 More spined than non-spined species. 5% < R < 25%	<50	
4 Maximum equitability of assemblage. 25% < R < 50%.	50-80	
5 Solution obvious. Whole tests > fragments. R > 50%.	80-90	
6 Fragments > whole tests. Plankt. whole tests > calc. benth. f.	>90	
7 Calcareous benthonics > planktonics. (Plankt. ≠ 0).	>95	
8 No whole planktonics. Calcareous benthonics present.	>98	
9 Fragments of calcareous foraminifera only.	>99	
X No calcareous fragments.	100	

Figure 10. Solution facies schemes based on recent and fossil foraminiferal assemblages respectively (after Berger and Von Rad, 1972).

During Campanian, Santonian, and part of Coniacian time, the water masses were apparently under-saturated in calcium carbonate, but very rich in silica. Planktonic foraminiferal faunas are very rare and poorly preserved, attributable to the solution facies FS = 8 to 9 of Berger and von Rad's scheme (below the Lysocline).

Different kinds of solution facies are represented in the Late Cretaceous cores of Site 153, from "N-facies" (FS=9) of Core 12, Section 1, 104-106 cm, to "L-facies" (FS=4 to 5) of Core 13, Sections 2 and 4. In some sandy levels that are rich in volcanic material (Core 18, Section 4, 10-14 cm and 112-115 cm), no organic remains at all are present. The foraminiferal assemblages from Core 15 down to the bottom of the hole are always silicified to a greater or lesser degree, particularly in Core 18.

Radiolaria are very badly preserved, sometimes frequent at some levels, and essentially dissolved in the remaining parts (see Berger and von Rad, 1972, p. 804).

The sediments are generally strongly indurated, commonly silicified, and very resistant to disaggregation. Often only a study in thin section was possible (Plate 3, Figures 4 and 5). Almost all kinds of cherts distinguished by Berger and von Rad are represented in the cores of Site 153 considered here.

### Tertiary

At Site 146 all the Paleocene sediments are devoid of planktonic foraminifera and generally very poor in calcium carbonate. Core 9, particularly, and part of Core 10 are devoid of calcareous fragments and calcareous nannoplankton.

At Site 153, during the Paleocene, almost the same environmental conditions as at Site 146 are repeated, however, silica plays a more important role in the sediment accumulation. A few levels of Middle Paleocene age are found, yielding poor foraminiferal assemblages of *Globorotalia pusilla* Zone and *Globorotalia angulata* Zone age. Thick incrustated or pachyform tests are present in some samples of Core 11 (see Figure 22). Among these forms *Globorotalia pseudobulloides* is undoubtedly the most resistant. It has a pachyform test and is the only species present in Core 12, Section 1, 69-71 cm (many specimens).

We interpret the succession as deposited very close to, and locally below the Carbonate Compensation Depth, and corresponding to FS=6 to 9 of Berger and von Rad's solution facies scheme.

Similarly, at Site 152 siliceous sediments cover, for a limited period, the interval corresponding to the *Globorotalia pseudomenardii* Zone. Radiolaria are present throughout the Paleocene though they are never abundant.

It is difficult to explain how in the middle part of a succession, apparently very rich in carbonates, the planktonic foraminifera became abruptly destroyed. This unusual phenomenon invokes some other mechanisms than the normal dissolution at depth. According to Berger and von Rad, processes of mobilization and migration of silica could be involved to explain the occurrence of siliceous sediments instead of carbonate-rich layers. However, the reasons for the occurrence of nodules or layers of accreted silica at certain levels are still poorly understood (see Heath and Moberly, 1971).

The lowermost Eocene is represented in all the drill sites by carbonate-rich sediments, yielding very well preserved planktonic foraminiferal assemblages belonging to an undissolved facies.

The interval from the Early Eocene *Globorotalia formosa formosa* Zone to the top of the Eocene is represented by indurated radiolarian oozes, silicified limestones, and cherts. The carbonate content decreases upwards. In the lower part of the section the assemblages are very poor indeed. Some *Globorotalia*, such as *G. spinuloinflata* and *G. pseudotopilensis*, *Globigerina turgida* and *G. senni* are present at the base (Cores 42 to 37). Moving up in the section, the faunal diversity decreases together with the faunal abundance. In Cores 36 up to 33 only *Globigerina senni* remains, and in the last (uppermost), Cores 32 and 31, planktonic foraminifera are absent.

The taxa recorded above are essentially the most resistant to solution. It should be pointed out that the species preserved have thickly incrustated tests, and that *Globigerina senni* has a particularly thick pachyform test, like that of *Globorotalia pseudobulloides* in the Early Paleocene (see above), and *Globigerina nepenthes* in the Late Miocene (see Berger and von Rad, 1972).

According to Berger and von Rad's solution facies scheme, all the succession of Site 149 described above belongs to the "N-facies" (from FS=7 in the oldest part to FS=9 in the last two cores considered here).

### RATES OF SEDIMENTATION

The rate of sedimentation can be calculated only in a continuous succession, without gaps. This is realized only in the stratigraphic record recovered at Site 146 and Site 149 in the Venezuela Basin. From the base of the Tertiary down to the oldest sediments overlying acoustic basement, we have a column of sediments some 260 meters thick. The corresponding time, from Late Turonian (age of the oldest sediments) to the base of the Tertiary, is close to 25 m.y. according to the recently updated time scale. The overall rate of sedimentation is about 1 cm/10<sup>3</sup>y, a figure in agreement with normal carbonate-rich oceanic sediments. However, the rate at Site 146 and Site 149 cannot be considered constant because the sedimentation was not homogeneous in the interval considered.

The rate of sedimentation for the various intervals is as follows:

Eocene	0.9 cm/10 <sup>3</sup> y
Paleocene + Latest Maestrichtian	0.4-0.5 cm/10 <sup>3</sup> y
Maestrichtian + Latest Campanian	1.5 cm/10 <sup>3</sup> y
Campanian	1.2 cm/10 <sup>3</sup> y
Santonian + Coniacian + Latest Turonian	0.9 cm/10 <sup>3</sup> y

The highest values (1.5 cm/10<sup>3</sup>y in the Maestrichtian-Late Campanian; 1.2 cm/10<sup>3</sup>y in the Campanian) are recorded in carbonate-rich sediments deposited during periods of high productivity and faunal diversity. The lowest (0.4 cm/10<sup>3</sup>y) is recorded in the "carbonate crisis" of the latest Cretaceous-Early Tertiary (see pertinent section).

The rate of 1.5 cm/10<sup>3</sup>y for the Middle and Early Maestrichtian has to be considered an average of high and low values of carbonate-rich redeposited layers and of interbedded carbonate-poor layers, respectively. This average is within the limits of the pelagic sedimentation and it has almost the same value which characterizes periods of high productivity.

At Site 152 for the interval between the base of the *Globotruncana calcarata* Zone and the *Globotruncana contusa* Zone (about 110 m from Core 13 to Core 22) the rate of sedimentation is more than twice that observed at Site 146.

At Site 153 we can consider only a part of the Late Cretaceous succession from the latest Turonian *Globotruncana schneegansi* Zone to the Maestrichtian *Globotruncana gansseri* Zone, where the record is supposed to be continuous. The rate here is lower than at Site 146: in the lowest part (*Globotruncana schneegansi* Zone) it is very close to 1 cm/10<sup>3</sup>y, but in the overlying part it is very low — close to 0.2 cm/10<sup>3</sup>y. The sediments in this part of the stratigraphic column are represented by strongly indurated siliceous limestones.

Figure 11 shows graphically the rates of sedimentation evaluated for Sites 146, 152, and 153. In the remaining drill sites we have too many gaps to evaluate the rates of sedimentation.

We can conclude that the rates of sediment deposition found in the Caribbean sites are in agreement with the values known for pelagic successions elsewhere.

#### BENTHONIC ASSEMBLAGES

The benthonic foraminiferal assemblages in the Caribbean sites are generally poor both in species and specimens, as is to be expected in pelagic sediments. They change very slowly through time, similar assemblages being found in the Paleocene, Maestrichtian, Campanian, and part of the Santonian, with only minor differences. From the latest Turonian to the early Santonian, species of the genera *Aragonia*, *Lenticulina*, *Stensiöina*, etc., differ from those recorded stratigraphically higher. Shortage of time prevented a thorough study of these forms. Generally speaking, they are quite well preserved. Some pyrite spots or holes often exist together with volcanic minerals in specimens recovered from Sites 146 and 153. In some cases they also appear to be affected by solution. From our preliminary investigations it seems that some benthonic species are more sensitive to solution at depth than others. The succession from readily dissolved to more resistant forms is tentatively indicated from top to bottom as follows:

*Reussella szajnochae*,  
*Stensiöina* spp.,  
*Aragonia* ssp.,  
*Eponides*, *Gavelinella*,  
*Gyroidina*, *Osangularia*, *Cibicides*, *Allomorphina*,  
*Pleurostomellidae*, *Lagenidae*, and  
 agglutinated forms.

From a preliminary examination, the benthonic assemblages appear similar to those from land sections of the same age. However, we noticed the rarity of taxa of stratigraphic value, such as *Neoflabellina* and *Bolivinooides*, in the sediments investigated. These genera, unlike those

cited above, did not live in deep waters, their absence, therefore, is ecologically controlled. The other taxa recorded are normally found in deep-sea sediments including the mesolytic facies (ca. 200 meters or less above the Carbonate Compensation Depth, Hsu and Andrews, 1970), where the planktonic foraminifera are strongly affected by solution and constitute less than 3 percent of the assemblage (Cita, 1971b).

Besides foraminifera, the bottom-living fauna contains ostracods, both smooth shelled and ornamented, echinoid spines, fish teeth, and bones. These remains are never abundant and represent a minor constituent of the fossil assemblages, with the exception of fish debris, which is relatively common in the *Globotruncana concavata carinata* Zone of Sites 151 and 146, in the *Globotruncana concavata concavata* Zone of Site 150, and in the Middle Maestrichtian of Site 146. The minor groups were not investigated in detail but are tabulated in the range charts of each drill site.

#### NOTES ON PALEOGEOGRAPHIC DISTRIBUTION OF THE PLANKTONIC FORAMINIFERA

According to earlier works, both the Late Cretaceous and the Paleocene-Eocene foraminifera recorded in the cores of the Caribbean Sea are typically open-ocean, warm-water assemblages and show high diversification, when not impoverished by external factors.

Keeled species of globotruncanids in the Late Cretaceous and of globorotaliids in the Late Paleocene-Early Eocene are well represented and generally dominant. The very high plankton/benthos ratio also speaks in favor of open oceanic conditions. No evidence of shallow deposition could be found in the Caribbean deep-sea cores; not even in the redeposited layers at Sites 146 and 153.

In the Late Turonian-Early Coniacian the planktonic foraminiferal assemblages are dominated by characteristic forms such as *Globotruncana sigali*, *G. schneegansi*, and *G. renzi*, but a number of *G. cachensis* specimens, which is an endemic form of the Pacific area (according to Douglas, 1972), occur in three different sites in the Caribbean, in particular Site 146, Core 41 (where it is frequent), Site 150, Cores 9 and 10, and Site 153, Core 19, suggesting a connection between the Pacific and Caribbean regions during this time.

From the Late Campanian-to-Middle Maestrichtian, the Caribbean faunas were very rich in "rugose" *Globotruncana*, such as *G. subcircumnodifer* and *G. subpennyi*, along with *G. gagnebini* and *G. gansseri*, similar to the assemblages recorded by Pessagno (1967) from the southwestern Gulf Coastal Plain and to those reported by Gandolfi (1955) from Colombia. Outside the Central American regions, similar Late Cretaceous assemblages have been described from Libya in the East (Barr, 1972) and from the equatorial Pacific in the West (Douglas, 1971), substantiating the conclusion that the Late Cretaceous planktonic foraminifera were arranged in latitudinal bands (Douglas, 1972).

Comparison with the more northern assemblages from the Northern Atlantic at lat. 32°37'N described by Cita (in Cita and Gartner, 1971, Site 10) reveals that these planktonic foraminiferal assemblages are less and/or differently diversified when compared with those of Leg 15, e.g., heterohelicids and rugoglobigerinids are more diversified

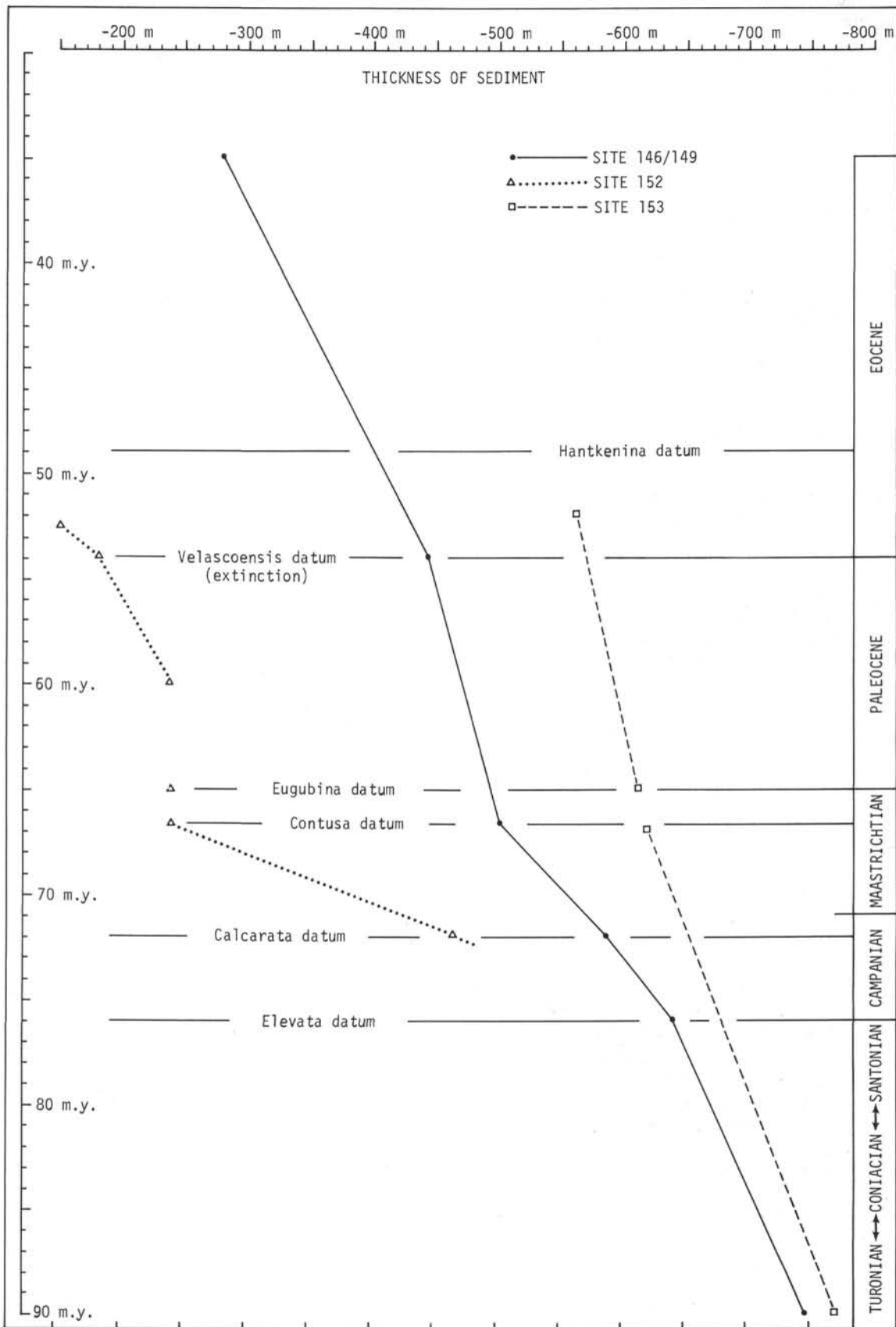


Figure 11. Graphic representation of age versus thickness of sediments at Sites 146-149, 152, and 153, based on planktonic foraminiferal zonation.

but the "rugose" globotruncanids are absent. Similar differences are observed when the Caribbean planktonic foraminiferal faunas are compared with the planktonic foraminiferal content yielded by the land sections outcropping in many European countries. The latter, at times richer, assemblages might be considered cooler than the former, and possibly belong to the northern Tethyan subprovince of Davids (reported by Berggren and Hollister, in press).

At the beginning of the Tertiary, the planktonic foraminiferal fauna shows poor diversification, but because it is essentially cosmopolitan, it extends to both the low and the high latitudes (see also Berggren and Hollister, in press). After the advent of the Tertiary, in a very short time, a marked diversification of the faunas occurred, and, as in Late Cretaceous time, bioprovinces were oriented along latitudinal bands. The highly diversified planktonic foraminiferal assemblages from the Caribbean area belong to the tropical Tethyan province, which extended equatorially from the Pacific in the West to the Crimea and Caucasus in the East.

#### THE DISTRIBUTION OF FORAMINIFERA IN THE SITES

##### Site 146 and Site 149 (Figures 9 and 12 to 15)

Site 146: 15°06.99'N, 69°22.67'W. Hole 146A: 15°06.99'N, 69°22.74'W. Site 149: 15°06.25'N, 69°21.85'W. Center of Venezuelan Basin, about 40 km N of Site 29 (Leg 4). Water depth 3949 and 3972 meters (approximately 300 m shallower than Site 29).

Site 146: Spot-cores 1 and 2 at 96 to 105 meters and 254 to 263 meters continuous coring from 406 to 762 meters (Cores 36-44). The interval 701 to 762 meters (Cores 36-44) was drilled with a new bit after successful reentry. 145.6 meters (39%) of the 374 meters cored were recovered.

Hole 146A: A missed reentry attempt drilled to 96 meters with a core taken at 87 to 96 meters.

Site 149: Continuous coring (43 cores) to 390 meters with 239.9 meters (57%) recovery.

##### Site 146

This site was continuously cored from 406 meters below bottom to the total depth of 762 meters reached in Core 44. In the upper part of the succession rich and generally well preserved planktonic foraminiferal assemblages are present (Cores 5 and 6 and Core 7, Section 1, 48-51 cm) and can be placed in the Early Eocene *Globorotalia edgari* Zone. Above these cores and below them down to Core 11, Section 1, 128 cm, the foraminiferal microfauna is comprised of few benthonic foraminifera or is completely dissolved due to solution.

Between 128 and 135 cm in Core 11, Section 1, rich calcareous sediments are encountered once again. Redeposited layers very rich in planktonic foraminifera are interbedded with tan-colored clays yielding only poor benthonic assemblages. Among the planktonic faunas three different assemblages are present. These are typical of (a) the *Globorotalia pseudobulloides* Zone; (b) the *Globigerina eugubina* Zone which has the most frequent and best

preserved specimens; and (c) possibly the *Abathomphalus mayaroensis* Zone, which is very poor in microfauna. The assemblages (a) and (b) are Early Paleocene, and (c) is Late Cretaceous. The Cretaceous-Tertiary boundary falls within these 12 cm (Figure 9).

Below 135 cm of Core 11, Section 1, down to Core 13, Section 4, only few benthonic foraminifera are present. The oldest sediments recovered at Site 146 are chalks, marls, limestones, and sandy-textured radiolarian/foraminiferal limestones. The marls yield poor assemblages with few benthonic and very poorly preserved planktonic foraminifera. These are generally represented by few specimens, frequently flattened, distorted, and partly corroded. The smaller forms, when present, are less damaged than the larger ones.

The sandy-textured limestones are rich to very rich in planktonic foraminifera of all sizes, frequently empty-shelled, but very rarely well preserved. However, calcareous nanofossils are not present in these coarse-textured limestones.

The planktonic foraminiferal fauna is rich in *Globotruncaninae*, while *Rugoglobigerinae* are generally rare and represented by few specimens of *R. rugosa*. In some levels (Core 17, Section 4) rugoglobigerinids are less frequent than *Globigerinelloides*. Among the heterohellicids, *Pseudoguembelina excolata* and *P. costulata* are dominant.

From Core 18 to Core 23, Section 1, we have a succession of relatively undisturbed sediments rich in carbonate. It yields very rich, diversified, and well-preserved assemblages. The dominant forms differ in each sample, suggesting that one is dealing with redeposited layers. Radiolaria can be present and may be very frequent at times.

From Core 23, Section 2, to the bottom of Core 39 planktonic foraminifera are generally rare, very poorly preserved, frequently dissolved, and flattened. In contrast, Radiolaria are always abundant, though not often well preserved. Some redeposited layers may also be present here (Plate 3, Figure 6).

A rich and abundant planktonic foraminiferal fauna is present in the last core (41) overlying the igneous rocks. It is in part silicified and poorly preserved.

The benthonic assemblages are generally poor in species and specimens and are uniform over a very long period. The same species may be present from the Campanian-Maestrichtian to Paleocene. Late Turonian to Santonian benthonic assemblages, however, contain different species.

The preservation of the benthos is generally good, the tests being frequently filled by pyrite and with black pyrite spots on their surface.

The most frequent species belong to *Reussella*, *Stensiöina*, *Aragonia*, *Eponides*, *Gavelinella*, *Gyroidina*, *Osangularia*, *Cibicides*, *Allomorphina*, *Pleurostomella*, *Lagenidae*, and agglutinated forms. These genera can live in rather deep water. Cita (1971a, b) cited the same benthonic assemblages in sediments where the planktonic foraminifera are strongly affected by solution and constitute less than 3 per cent of the total fauna (FS=8 to 9 of Berger and von Rad's scheme).

If the marls described above as containing very poor benthonic assemblages were deposited below the Lysocline



LEG 15 SITE 146				DIAGNOSTIC PLANKTONIC FORAMINIFERA	planktonic foraminifera benthonic foraminifera radiolaria ostracods fish teeth/bones preservation of foraminifera	ZONE	AGE
DEPTH BELOW SEA FLOOR IN METERS	RECOVERY IN METERS	CORE NUMBER	SAMPLE INVESTIGATED INTERVAL IN CM				
406-413	.1	3		no foraminifera		Globorotalia subbotinae or Globorotalia edgari	EOCENE
413-422	.2	4		no foraminifera			
422-431	2.5	5	50-53	Gr. acuta, Gr. edgari, Gr. gracilis, Gr. guatemalensis, Gr. intermedia, Gr. marginodentata, Gr. planoconica, Gr. subbotinae, Gr. wilcoxensis, Gl. soldadoensis, Gl. soldadoensis angulosa, Gl. turgida, Psh. cf. wilcoxensis	●   +		
			148-150	Gr. acuta, Gr. edgari, Gr. gracilis, Gr. guatemalensis, Gr. intermedia, Gr. marginodentata, Gr. planoconica, Gr. subbotinae, Gr. wilcoxensis, Gl. soldadoensis, Gl. soldadoensis angulosa, Psh. cf. wilcoxensis	●   +	Globorotalia edgari	
431-440	1.5	6	68-72 (within)	Gr. acuta, Gr. edgari, Gr. gracilis, Gr. guatemalensis, Gr. intermedia, Gr. marginodentata, Gr. planoconica, Gr. subbotinae, Gr. wilcoxensis, Gl. soldadoensis, Gl. soldadoensis angulosa, Psh. cf. wilcoxensis	●     +		
			CC (bottom)	few silicified planktonic foraminifera	x x *		
440-449	1.5	7	35-37	very rare benthonic foraminifera			
			48-51	Gr. acuta, Gr. edgari, Gr. gracilis, Gr. guatemalensis, Gr. intermedia, Gr. marginodentata, Gr. planoconica, Gr. subbotinae, Gr. wilcoxensis, Gl. soldadoensis, Gl. soldadoensis angulosa, Psh. cf. wilcoxensis	●       *		
			148-150	no foraminifera			
			CC	no foraminifera			
449-458	3.0	8		no foraminifera or very rare benthonic foraminifera	x		PALEOCENE
458-467	3.3	9		no foraminifera	x		
467-476	2.2	10		no foraminifera	●		
476-485	2.3	11	0-128	no foraminifera	●		
			128-138	planktonic foraminifera concentrated in lenses belong to three different assemblages yielding: 1 - Gr. pseudobulloides, Gr. inconstans, Gl. daubjergensis; 2 - Gl. eugubina, Gl. fringa, Woodringia hornerstownensis; 3 - few Globotruncanas (identified in thin section)	● ○     +	Globorotalia pseudobulloides Globigerina eugubina	
			143-145	few benthonic foraminifera	x x x *		
				few benthonic foraminifera	x x   x *		
485-494	.3	12		few benthonic foraminifera	x     *		MAAST- RICHTIAN

LEGEND: Frequency of fauna: | very few  
x few  
○ common  
● abundant  
Preservation of foraminifera: + not affected  
+ affected slightly  
\* damaged  
\* strongly damaged  
\* destroyed

Figure 12. Distribution of selected planktonic foraminifera in Site 146, Early Eocene to latest Maestrichtian.

in solution facies FS=8 to 9 of Berger and von Rad's scheme, then it is reasonable to assume that the interbedded layers, containing almost 100 per cent of planktonic foraminifera showing almost no effects of solution, were redeposited by bottom and/or turbidity currents. The absence of nannofossils in the layers containing the rich foraminiferal assemblages is in agreement with this idea; because of their smaller size they can be winnowed out more readily, while the coarser fraction composed of foraminiferal and radiolarian tests is left behind.

This mechanism would account for the high accumulation rate of planktonic foraminifera, while rapid deposition of the transported material may explain why the tests of globotruncanids, etc., are not affected by solution, as they would otherwise be at these depths.

The source of transported material was presumably not too distant and included pelagic sediments deposited above the Lysocline and chronologically at about the same time as the sediments deposited directly on the deep-sea floor. The location of this source may have been nearby slopes of some rise, where soft sediments could be easily involved in sliding and slumping producing turbidity currents.

Finally, many minerals of volcanic origin such as biotite, feldspar, apatite, etc., are frequently associated with the rich planktonic assemblages.

Site 149

The stratigraphic succession recovered at this site and considered here (Cores 31 to 42) is represented mostly by

silicified limestones very rich in Radiolaria and very poor in carbonates. Only few benthonic foraminifera are present in the Late Eocene (Cores 31 and 32). *Globigerina senni* with a typical pachyform test is the only representative of planktonic foraminifera from Core 33 to Core 36. The carbonate content increases downwards and some other species such as *Globorotalia spinuloinflata*, *G. pseudotopilensis*, and *Globigerina turgida* appear in Core 37. The relative percentage of *Globigerina senni* decreases downwards, while other species become gradually more frequent. Tests become thick and recrystallized. Few benthonic specimens are always present, as in the earliest cores.

Selective solution played an important role in the preservation of planktonic foraminiferal faunas described from this site. The planktonic foraminifera, when present, always have pachyform or thickly incrustated tests, suggesting that these forms are more resistant to dissolution. We can conclude that the foraminiferal assemblages of this site belong to the high ranges of solution facies (FS=8 to 9, according to Berger and von Rad's solution values).

Site 150 (Figure 16)

14°30.69'N, 69°21.35'W. Venezuelan Basin, about 35 km S of Site 29 (Leg 4), where seismic profiles recorded an anomalous thinning of all sediment layers above Horizon B. Water depth 4545 meters.

Site 150: Spot core at 49 to 58 meters, continuous coring from 77 to 114 meters (Cores 2-5) and 127 to 180





LEG 15  
SITE 149

DEPTH BELOW SEA FLOOR IN METERS	RECOVERY IN METERS	CORE NUMBER	SECTION NUMBER	SAMPLE INVESTIGATED INTERVAL IN CM	DIAGNOSTIC PLANKTONIC FORAMINIFERA	PRESERVATION OF FORAMINIFERA					ZONE	AGE
						planktonic foraminifera	benthonic foraminifera	radiolaria	ostracods	preservation of foraminifera		
270-279	3.0	31	1	69-71			●	●	●	●	NO ZONE	Eocene
			2	44-46 CC	few benthonic foraminifera		●	●	●	●		
279-288	4.7	32	1	146-148			●	●	●	●	NO ZONE	Eocene
			2	107-109			●	●	●	●		
			3	57-59	few benthonic foraminifera		●	●	●	●		
			4	62-64 CC			●	●	●	●		
288-298	3.0	33	1	98-100			●	●	●	●	NO ZONE	Eocene
			2	31-33 CC	Globigerina senni and few benthonic foraminifera		●	●	●	●		
298-307	3.7	34	1	100-102			●	●	●	●	NO ZONE	Eocene
			2	44-46			●	●	●	●		
			3	59-61 CC	Globigerina senni and few benthonic foraminifera		●	●	●	●		
307-316	9.0	35	1	50-52			●	●	●	●	NO ZONE	Eocene
			2	35-37			●	●	●	●		
			3	28-30			●	●	●	●		
			4	58-60	Globigerina senni and few benthonic foraminifera		●	●	●	●		
			5	66-68			●	●	●	●		
			6	88-90			●	●	●	●		
316-325	.6	36	1	107-109	Globigerina senni and few benthonic foraminifera		●	●	●	●	NO ZONE	Eocene
			2	20-22			●	●	●	●		
325-334	5.1	37	1	124-126		X	X	●	●	●	NO ZONE	Eocene
			2	20-22		X	X	●	●	●		
			3	59-61	Gr.spinuloinflata, Gr.pseudotopilensis, Gl.senni, Gl.turgida, and few benthonic foraminifera	X	X	●	●	●		
			4	58-60 CC		X	X	●	●	●		
334-344	3.2	38	2	41-43		X	X	●	●	●	NO ZONE	Eocene
			3	36-38	Gr.spinuloinflata, Gr.pseudotopilensis, Gl.senni, Gl.turgida, and few benthonic foraminifera	X	X	●	●	●		
				84-86		X	X	●	●	●		
344-353	.5	39	1	117-119 CC	Gr.spinuloinflata, Gr.pseudotopilensis, Gl.senni, Gl.turgida, and few benthonic foraminifera	X	X	●	●	●	NO ZONE	Eocene
			2	22-24 CC	Gr.spinuloinflata, Gr.pseudotopilensis, Gl.senni, Gl.turgida, and few benthonic foraminifera	X	X	●	●	●		
353-362	1.6	40	1	60-62		X	X	●	●	●	NO ZONE	Eocene
			2	22-24 CC	Gr.spinuloinflata, Gr.pseudotopilensis, Gl.senni, Gl.turgida, and few benthonic foraminifera	X	X	●	●	●		
			3	47-49		X	X	●	●	●		
			4	56-58		X	X	●	●	●		
			5	71-73		X	X	●	●	●		
			6	16-18 CC		X	X	●	●	●		
362-371	8.0	41	1	64-66		X	X	●	●	●	NO ZONE	Eocene
			2	41-43		X	X	●	●	●		
			3	47-49		X	X	●	●	●		
			4	56-58	Gr.spinuloinflata, Gr.pseudotopilensis, Gl.senni, Gl.turgida, Gl.eocaena, Globigerinita sp., and few benthonic foraminifera	X	X	●	●	●		
371-381	5.0	42	2	18-20		X	X	●	●	●	NO ZONE	Eocene
			3	18-20	Gr.spinuloinflata, Gr.pseudotopilensis, Gr.rotundimarginata, Gl.senni, Gl.turgida, Gl.eocaena, Globigerinita sp., and few benthonic foraminifera	X	X	●	●	●		
			4	18-20		X	X	●	●	●		
				CC		X	X	●	●	●		

LEGEND: Frequency of fauna: | very few, X few, O common, ● abundant. Preservation of foraminifera: + not affected, \* affected, \* damaged, \* strongly damaged, ■ destroyed.

Figure 15. Distribution of selected planktonic foraminifera in Site 149.

The same faunas also occur in the mixture of Core 7, and the presence of a few specimens of *Stensiöina exculpta gracilis* in the core catcher of this core indicates that Late Cretaceous sediments were reached at the bottom.

The lower part of the sedimentary succession (Cores 9 and 10) just overlying the igneous rocks is in contrast very rich in planktonic foraminifera, frequently well preserved and highly diversified.

The assemblages recorded belong to the *Globotruncana concavata concavata* Zone (only the upper part of Core 9), and to the *Globotruncana schneegansi* Zone (the remaining part of Core 9 and Core 10), Coniacian and Late Turonian in age. Some beautiful specimens of *Schackoina cenomana* and *S. multispinata*, complete with spines, are

present in some levels of Core 10. *Hastigerinoides alexanderi*, *Clavhedbergella simplex*, and *C. moremani* are particularly frequent in the same core.

The above foraminiferal data, together with the data on the calcareous nannofossils and Radiolaria, indicate that there are at least two and possibly three sedimentary hiatuses in the section cored at Site 150.

Continuous coring began with Core 2 (77 to 86 m), and Early Miocene was found through Core 5 (105 to 114 m). Core 2A (at 119 m) contains an Early Eocene fauna. Thus the Oligocene and most of the Eocene are missing. Cores 6 to 8 (127 to 150 m) contain Late Cretaceous chert, with no evidence for Paleocene. Core 9 (150 to 159 m) contains Coniacian foraminifera and calcareous nannofossils, and





thin, dark clayey layer at 148 to 150 cm, which contains few but diversified planktonic foraminifera of the *Globotruncana concavata carinata* Zone, Late Santonian, with many fish remains filled with glauconite. The catcher sample of Core 11 falls in the same zone but is richer in planktonic foraminifera.

The sediments of Cores 12 and 13 are highly disturbed, consisting predominantly of dark olive clay, but mixed throughout with different lithologies. Lenses of indurated sediments may yield rich planktonic assemblages, or may be totally barren, such as fragments of hardground and green sediments. Two different assemblages belonging to the *Globotruncana concavata carinata* Zone (above) and to the *Globotruncana concavata concavata* Zone (below), both Santonian, were identified in this mixture.

The state of preservation of the foraminifera varies: some are silicified, others calcitic but recrystallized, some excessively dissolved.

We can conclude that at Site 151 the Early Oligocene, Late, Middle, and the uppermost part of the Early Eocene are missing, which corresponds to a time span of about 23 m.y. The earliest Eocene is represented by a few centimeters. Below this, only a part of the Early and Middle Paleocene are present. The remainder of the Early Paleocene and Maestrichtian and Campanian are also absent, corresponding to a time interval of about 14 m.y.

#### Lithologic Description of the Hardground in Core 11, Section 6, 135-148 cm, and the Catcher Sample of Core 11 (Plates 1, 2, and Plate 3, Figure 1)

The layer between 135 and 148 cm of Core 11, Section 6, consists of a heterogeneous microbreccia, the elements of which are hematitic crust fragments, hematitic mud pebbles, sometimes altered to limonite, and small spots of phosphatic marls. The groundmass is mostly siliceous and only partially calcitic. The most important components are micro- and mega-quartz and chalcedony, which replaced secondarily both the lithic elements and the original calcitic cement. The presence among the lithic elements of a number of iron crust fragments suggests that one or more hardground was formed during the long time interval when no deposition occurred (current action later destroyed the original layers, the fragments of which were cemented by calcite, secondarily replaced by silica).

The catcher sample of Core 11 consists of graded beds. The coarse fraction of these beds contains planktonic foraminifera as clastics, while the fine fraction is clayey and strongly impregnated by iron oxides. The color ranges from ochre (coarse layers) to dark red (fine layers). Its deposition is probably connected with the presence of currents.

#### Site 152 (Figures 18, 19; Plate 3, Figure 2)

15°52.7'N, 74°36'W. Approximately 90 miles NW of Site 151 on the Nicaragua Rise, where two reflectors outcrop on the slope and a *Vema* piston core had retrieved Maestrichtian from the upper one; gave us the opportunity to core the Cretaceous-Tertiary boundary.

The site was continuously cored from 153 to 295 meters. A single core was obtained between 342 and 351 meters depth (Core 16). From 398 meters the section was

again continuously cored to a total depth of 477 meters. Water depth 3900 meters.

The succession recovered at Site 152, though not complete, contains some of the best preserved Early Paleogene-Late Cretaceous planktonic foraminiferal assemblages obtained in the Caribbean area. In particular, the preservation of Late Paleocene-Early Eocene faunas is so exceptional that features are recognizable here that are not readily detectable in material usually available. Of particular interest for instance are tiny secondary sutural apertures on the spiral and umbilical sides of *Globorotalia gracilis* and *G. wilcoxensis*.

Because of a fairly abrupt faunal change, a probable stratigraphic break was assumed to exist between the Paleocene *Globorotalia velascoensis* Zone and the Early Eocene *Globorotalia rex* Zone (= *Globorotalia subbotinae* Zone) when these zones were introduced in strata from Trinidad (Bolli, 1957b, p. 69). It would now appear that at least some of these missing strata are present in Cores 2 and 3 at Site 152.

The lower part of Core 3 and Core 4 contain a fauna typical of the *Globorotalia velascoensis* Zone. Core 2 and the upper part of Core 3 are devoid of typical *G. velascoensis* but contain a number of specimens of small sinistrally coiling *Globorotalia edgari* n. sp. that in some features appear to be close to this species.

The *Globorotalia pseudobulloides*, *Globorotalia trinidadensis*, and *Globorotalia uncinata* zones were not recorded in Site 152. Core 5, which is practically barren of foraminifera, may represent the time interval of the *Globorotalia pseudomenardii* Zone. Cores 6 to 8 are assigned to the *Globorotalia pusilla pusilla* Zone, and Core 9 to the *Globorotalia angulata* Zone (possibly only the lower part of this zone due to the common occurrence of *G. uncinata*).

The 25 cm of sediments recovered in Core 10 contain the contact between the earliest Tertiary and Late Cretaceous. At 127 to 141 cm a very rich, well-preserved fauna of minute globigerinids is present and is attributable to the *Globigerina eugubina* Zone of the oldest Paleocene distinguished up to now. The fauna found in this core shows better preservation than that from which this group of minute *Globigerina* species was originally described (Central Italy, Luterbacher and Premoli Silva, 1964).

From 142 to 150 cm a poor to rich, but partially dissolved planktonic foraminiferal assemblage of the Late Cretaceous *Globotruncana contusa* Zone is present.

The physical break at 142 cm suggests that some levels may be missing due to drilling disturbance.

The Late Cretaceous of this site ranges from the *Globotruncana elevata* Zone, overlying basalt, to the *Globotruncana contusa* Zone of the Middle Maestrichtian. The assemblages are well preserved with many specimens showing *tegillae* and *portici*. Of special interest is the presence of *Globotruncana gagnebini*, which occurs abundantly from the upper part of the *Globotruncana calcarata* Zone to the base of the *Globotruncana contusa* Zone. This species is rarely recorded in the literature. The evolution of *Globotruncana fornicata* into *G. contusa* through *G. caliciformis* may be followed in this sequence. The *Globo-*

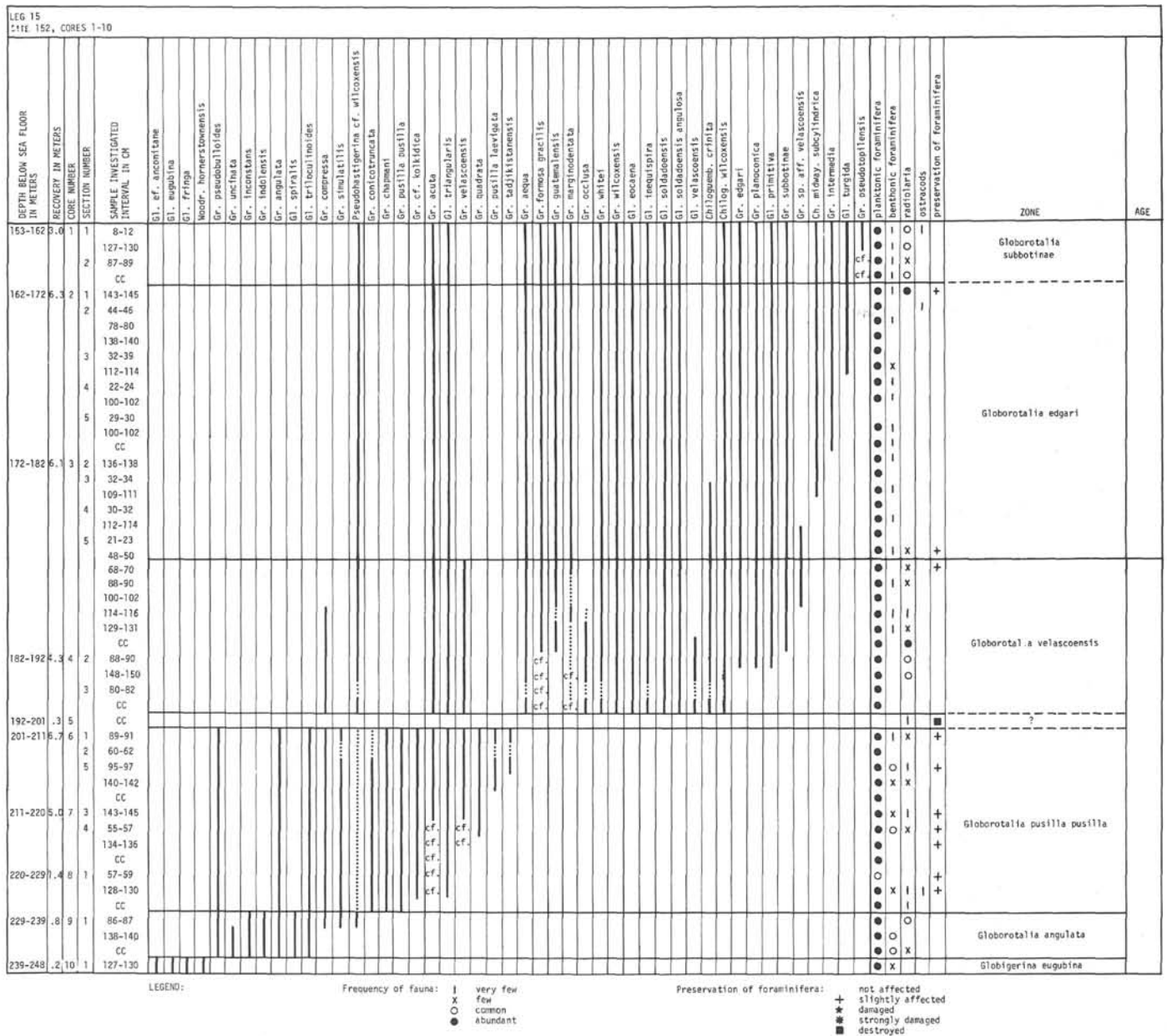


Figure 18. Distribution of selected planktonic foraminifera in Site 152, Early Eocene to earliest Paleocene.

*truncana calcarata* Zone is represented by a particularly thick sequence and considerably exceeds the average thickness known from other sections in the literature.

The faunas of the strongly indurated Cores 23 and 24 had to be identified by means of peels and thin sections.

**Site 153 (Figure 20; Plate 3, Figures 3 to 5)**

13°58.33'N, 72°26.08'W. At southern end of Beata Ridge where it is terminated by the Aruba Gap. Water depth 3932 meters.

The Pliocene, Miocene, and Oligocene were spot cored at intervals of about 100 meters to a depth of 563 meters (up to Core 8). Continuous coring took place from 586 meters to 619 meters (Cores 9 to 12), and from 731 meters to 767 meters (Cores 16 to 19). Core 13 covered an interval of 37 meters. Core 14 was a normal core (at 656 m) while Core 15 was taken during the drilling of 64 meters of sediments.

As coring was incomplete, analysis is difficult, but it is likely that stratigraphic gaps are present. For instance, Core 7 (at 499-508 m depth) yields a fauna of Middle Oligocene *Globigerina ampliapertura* Zone, Core 8 (at 563-572 m depth) is in the Early Eocene *Globorotalia formosa formosa* Zone. As in Site 151, the Late and Middle Eocene may be missing here or be much condensed.

Again, Late Maestrichtian is missing. An intraformational breccia occurs at the Cretaceous-Tertiary boundary containing micrite fragments rich in minute globigerinids of the *Globigerina eugubina* Zone, earliest Paleocene, and other rare fragments containing globotruncanids can be attributed to the Middle Maestrichtian *Globotruncana gansseri* Zone. There is also no evidence for Campanian-Santonian, which may be due to the spot coring and poor recovery, and not due to an actual gap in sedimentation.





LEG 15 SITE 153				DIAGNOSTIC PLANKTONIC FORAMINIFERA	planktonic foraminifera benthonic foraminifera radiolaria ostracods fish teeth/bones preservation of foraminifera	ZONE	AGE	
DEPTH BELOW SEA FLOOR IN METERS	RECOVERY IN METERS	CORE NUMBER	SECTION NUMBER					
563-572	1.2	8	1	98-100 CC Gr. aequa, Gr. aragonensis, Gr. broedermanni, Gr. formosa formosa, Gr. gracilis, Gr. intermedia, Gr. marginodentata, Gr. pseudotopilensis, Gr. rotundimarginata, Gr. subbotinae, Gr. wilcoxensis, Gl. eccaena, Gl. primitiva, Gl. soldadoensis group, Gl. turgida	● I I ● I I	★ ★	Globorotalia formosa formosa	Eocene
				B/9 center bit: early Eocene planktonic foraminiferal assemblage as above with much early Miocene, and Oligocene contamination	●	★		
586-591	2.3	9	1	103-105				Paleocene
			2	106-108	only few benthonic foraminifera	X O X X O X	★ ★	
				0-2	thin section containing a quite rich planktonic foram assemblage attributed to Globorotalia pusilla pusilla Zone	O I X	★	Globorotalia pusilla pusilla
				127-129 CC	some benthonic foraminifera	I O X X X X X X	★ ★ ★	
591-600	1.7	10	1	147-150	only few benthonic foraminifera			Paleocene
			2	16-21	thin section with isooriented calcified radiolaria and few benthonic foraminifera	I ●	★	
				116-119 CC	very few benthonic foraminifera	I ● I	★	Globorotalia pusilla pusilla
				600-609	some benthonic foraminifera and only two specimens of Globigerina sp.	I X O	★	
			11	133-137	some benthonic foraminifera	O X O	★	Globorotalia angulata
			2	79-81	Gr. angulata (frequent), Gr. chapmani, Gr. pseudobulloides (frequent), Gr. quadrata, Gl. triloculinoidea	X O X I I I X I	★ ★	
			3	81-83				Globorotalia angulata
				76-79	Gr. angulata, Gr. chapmani, Gr. confotruncata, Gr. pseudobulloides, Gr. pusilla pusilla, Gr. quadrata, Gr. simulatilis, Gl. triloculinoidea	● O I	★	
				126-128 CC	some benthonic foraminifera	O O O	★	Globorotalia angulata
				609-619	Gr. angulata, Gr. cf. confotruncata, Gr. inconstans, Gr. pseudobulloides, Gr. quadrata, Gr. simulatilis, Gl. triloculinoidea	O O ● I	★	
			12	69-71	only Gr. pseudobulloides and some benthonic foraminifera	I O X X	★	Globigerina eugubina
				71-74	some benthonic foraminifera	O I X	★	
				88-90		X X	★	Globotrucana gansseri
				90-102	Breccia consisting of micrite fragments sometime rich in small planktonic foraminiferal assemblage of Globigerina eugubina Zone, sometime containing very benthonic foraminifera, and more rarely specimens of Globotruncana and Heterohellicidae.	O X	★	
				104-106	few benthonic foraminifera	X X	■	Globotrucana gansseri
				132-134	planktonic foraminiferal assemblage, very badly preserved, mostly constituted by Heterohellicidae: Psg. costulata, Psg. excolata, Pst. elegans, Hx. carinata, Hx. palpebra, Hx. striata, Hd. petaloidea, Ab. intermedius, R. rugosa	X X I	★	
			2	137-139	Gt. aegyptiaca, Gt. arca, Gt. caliciformis, Gt. elevata, Gt. fornicata, Gt. gagnebini, Gt. gansseri, Gt. lapparenti, Gt. linneiana, Gt. leupoldi, Gt. plummerae, Gt. rosetta, Gt. stuartiformis (very frequent), Gt. subcircummodifer, Gt. subpenneyi, Gt. "tricarinata", Gt. ventricosa, R. rugosa, G. lloides prairiehillensis, Psg. costulata, Psg. excolata, Hx. punctulata	● X	★	Globotrucana "tricarinata"
			3	48-50	as in section 2, 137-139 cm, without Gt. gansseri and Psg. excolata	● I	★	
				75-79 CC	Gt. arca, Gt. caliciformis, Gt. elevata (very frequent), Gt. fornicata, Gt. gagnebini, Gt. lapparenti, Gt. linneiana, Gt. leupoldi, Gt. plummerae, Gt. rosetta, Gt. stuartiformis (very frequent), Gt. subcircummodifer, Gt. "tricarinata" (frequent), Gt. ventricosa (frequent), R. rugosa (frequent), G. lloides prairiehillensis, G. lloides yaucensis, Psg. costulata, Hx. punctulata	● I ● X ● I ● X I ● I	★ ★ ★ ★ ★	Globotrucana "tricarinata"
619-656	4.8	13	2	80-85				
			4	53-57 CC				Globotrucana concavata concavata
				656-667	few benthonic foraminifera	X ●	★	
			1	146-150				Globotrucana concavata concavata
				667-731	Gt. angusticarinata, Gt. concavata concavata, Gt. coronata, Gt. fornicata, Gt. linneiana, Hd. delrioensis, G. lloides asper, G. lloides caseyi, G. lloides ehrenbergi, Hastigerinoides alexanderi, Hx. reussi	O I O O I X O X X I	★ ★ ★	
			2	111-115 CC				Globotrucana concavata concavata
				731-740	Gt. angusticarinata, Gt. bulloides, Gt. concavata concavata, Gt. concavata primitiva, Gt. coronata, Gt. cf. fornicata, Gt. linneiana, Gt. marginata, Gt. renzi, Gt. aff. ventricosa, Hd. delrioensis, R. pilula, G. lloides asper, G. lloides caseyi, G. lloides ehrenbergi, Hx. reussi	O X X	★	
				CC	thin section containing the same assemblage as in section 2, 116-120 cm, with Gt. inornata	● I	★	Globotrucana schneegansi
				740-749	few benthonic foraminifera	X O ●	★	
			2	30-33	Gt. angusticarinata, Gt. concavata primitiva, Gt. coronata, Gt. cf. fornicata, Gt. inornata, Gt. lamellosa, Gt. linneiana, Gt. renzi, Gt. schneegansi, Gt. sigali, Whiteinella archaeocretacea, Hd. delrioensis, Hd. loetterlii, R. pilula, G. lloides asper, G. lloides caseyi, G. lloides ehrenbergi, Hx. reussi	● I O X O O O	★ ★ ★ ★	Globotrucana schneegansi
				88-91				
				100-103				Globotrucana schneegansi
				125-127				
			3	67-69				Globotrucana schneegansi
				133-135				
			4	10-14	no foraminifera		■	Globotrucana schneegansi
				112-115	no foraminifera		■	
				136-138	rare very badly preserved planktonic foraminifera and few benthonic foraminifera	I X	★	Globotrucana schneegansi
				758-767	Gt. cachensis, Gt. coronata, Gt. cf. fornicata, Gt. imbricata, Gt. inornata, Gt. lamellosa, Gt. renzi, Gt. schneegansi, Gt. sigali, Gt. tarfayensis, Whiteinella archaeocretacea, Hd. delrioensis, Hd. loetterlii, R. pilula, G. lloides asper, G. lloides caseyi, G. lloides ehrenbergi, Hx. reussi	● X	★	

LEGEND: Frequency of fauna: I very few, X few, O common, ● abundant. Preservation of foraminifera: + not affected, ★ affected, \* damaged, ■ strongly damaged, □ destroyed.

Figure 20. Distribution of selected planktonic foraminifera in Site 153.

Although we can recognize several zones, the planktonic foraminifera are seldom abundant. Only two levels yield abundant and well-preserved assemblages: a) the Early Eocene *Globorotalia formosa formosa* Zone; b) the lower part of the *Globotruncana gansseri* and the *Globotruncana "tricarinata"* zones, Middle-Early Maestrichtian. Radiolaria are conspicuously absent at these intervals (Figure 20).

Elsewhere in the succession the planktonic foraminifera are generally of poor preservation, frequently dissolved, and never abundant. In the Paleocene few assemblages belonging to the *Globorotalia pusilla pusilla* and to the *Globorotalia angulata* zones could be recognized (Core 9, Section 2, 0-2 cm; Core 11, Sections 2 and 3, and core catcher). Other levels yield only the species that are relatively more resistant to solution, such as *Globorotalia pseudobulloides*, or few benthonic foraminifera. Radiolaria are common to abundant, and some levels are particularly rich in fish remains.

Strongly indurated, silicified limestones and cherts were recovered in the lower part of Site 153. Excluding the layers described above which contain well-preserved assemblages, the state of preservation of the planktonic foraminifera of these sediments is generally very poor; often peels or thin sections were necessary for their investigation.

As in the other sites discussed in this paper, no radiolaria are present in the Coniacian-Late Turonian *Globotruncana schneegansi* Zone. In this interval foraminiferal tests are usually silicified and the silica that replaced the calcite is probably of volcanic origin — a fact suggested by the presence of abundant volcanic material in Core 18. The Coniacian-Late Turonian sediments of the zone mentioned above directly overlie the basalt.

#### TAXONOMIC NOTES

##### Cretaceous

The classification of the Family Globotruncanidae and related forms continues to be controversial, in particular for the generic and subgeneric position of some Late Cretaceous taxa (Hofker, 1956; Pessagno, 1967; Donze, Porthault et al., 1970; Barr, 1972).

Since the purpose of this report is to elucidate the stratigraphic record of the Leg 15 Caribbean sites by means of planktonic foraminifera, and not to discuss taxonomic viewpoints in detail, all the keeled species, with the exception of *A bathomphalus*, are described and tabulated under *Globotruncana*.

##### *Globotruncana calcarata* Cushman

*Globotruncana calcarata* Cushman, 1927, p. 115, pl. 23, figs. 10 a, b.

The spiral surface in this species, including the angle of the peripheral spines, tends to change from plane to slightly concave to plane to slightly convex. This development takes place within the *Globotruncana calcarata* Zone from Core 21 to Core 19 in Site 152.

##### *Globotruncana concavata* (Brotzen) group (Plate 5, Figures 9-12)

The three subspecies *primitiva*, *concavata*, and *carinata* are distinguished by the umbilical side becoming more and more convex from *primitiva* via *concavata* to *carinata*. Simultaneously the form of the chambers of the last whorl changes from almost spherical to highly conical with a subacute to keeled border surrounding the umbilicus. The number of chambers in the last whorl remains practically constant in all three subspecies. The spiral side becomes more and more concave from *primitiva* to *carinata*.

Many authors do not agree with this interpretation and hesitate to differentiate the three forms; others consider *primitiva* a junior synonym of *Globotruncana indica* (Jacob and Sastri), which however, is very poorly figured and described.

The ranges of the three subspecies differ but overlap. Based on the first appearance of the subspecies *concavata* and *carinata*, two zones of these names are distinguished in the Coniacian to Late Santonian. *G. concavata primitiva* has its first occurrence in the upper part of the latest Turonian-Early Coniacian *Globotruncana schneegansi* Zone.

##### *Globotruncana elevata* (Brotzen)

During its vertical range we can observe a large variability of the shape of *Globotruncana elevata*. In the upper part of the Campanian, preceding the appearance of *Globotruncana calcarata*, the equatorial periphery of the forms under examination becomes extremely lobulate and develops a pinched-out single keel resembling a spine. Pessagno (1960) considered this form as a separate taxon, namely *Globotruncana elevata subspinosa*, which he eliminated again later. Because of the short range that precedes and concurs with *G. calcarata* and for the characteristic morphology, the subspecies is here retained and tabulated separately.

##### *Globotruncana gagnebini* Tilev (Plate 6, Figures 2-6)

*Globotruncana gagnebini* Tilev, 1951, pp. 50-56, figs. 14-17, pl. 3, figs. 2-5.

Test trochospiral, plano-convex, spiral side flat or somewhat concave, umbilical side strongly convex. 10 chambers, 4-1/2 to 6 in the last whorl, rapidly increasing in height. Equatorial periphery slightly lobate. Chambers on spiral side petaloid, separated by curved and raised sutures; on umbilical side hemispherical to highly conical, separated by distinctly depressed and straight sutures increasing strongly in thickness. Final chamber more than twice the height of the first chamber of the last whorl. Umbilicus quite large and deep, sometimes surrounded by a rim. Wall calcareous with few pustules on spiral side, restricted to the first chambers, often very pustulose on the umbilical side. Pustules decrease in number towards the final chamber which is almost smooth. Closely spaced peripheral double keel with the upper one always present and well developed. The lower keel is quite variable, generally better developed in the first chambers of the last whorl but only weak in later ones, in particular the last chamber.

**Stratigraphic range:** Late Campanian to Middle Maestrichtian. From within the *Globotruncana calcarata* Zone to the base of the *Globotruncana contusa* Zone.

**Remarks:** The large variability in shape described by Tilev is present also in the Caribbean material. Because of this variability, the species has become highly controversial. Some authors consider it a junior synonym of *Globotruncana gansseri*, others (e.g., Pessagno, 1967) a junior synonym of *Globotruncana aegyptiaca*. Based on above description, *Globotruncana gagnebini* is here retained as an independent taxon.

It is very close to *G. gansseri* Bolli, but differs from Bolli's species in possessing a double keel, fewer and more petaloid shaped chambers (Plate 6, Figures 7-9), and a longer range.

It differs from *G. aegyptiaca* Nakkady by having a) chambers increasing less rapidly in diameter, but more rapidly in height; b) larger umbilicus; c) more spinose wall on the umbilical side; d) a second, well developed keel; e) spiral side flat to concave, instead of slightly convex; f) more than four chambers in the last whorl, these not being arranged at right angles to each other (like a cross).

*G. gagnebini* is close to *G. ventricosa* White from which it differs in having fewer chambers and a less angular side view, and in having two very close keels, the lower of which is poorly developed or absent in the final chamber (Plate 4, Figures 6-8).

##### *Globotruncana leupoldi* Bolli

*Globotruncana leupoldi* Bolli, 1945, p. 235, fig. 17.

*Globotruncana stephensoni* Pessagno, 1967, p. 270, pl. 69, figs. 1-7; pl. 96, figs. 5-6.

*Globotruncana leupoldi* Bolli, Caron, 1972, p. 555, pl. 2, figs. 1a-b.

The synonymy of *G. stephensoni* with *G. leupoldi* as proposed by Caron (1972) is accepted here. The ranges of both species are very similar.

##### *Globotruncana renzi* Gandolfi (Plate 5, Figures 7-8)

*Globotruncana renzi* Gandolfi, 1942, p. 124, text-figs. 45a-c; pl. 4, fig. 15.

Test biconvex, discoidal, small to medium in size, with well-developed second keel. 5 to 6 chambers in last whorl. Chambers petaloid, separated by raised and beaded sutures on the spiral side; on the umbilical side subrectangular in shape, bordered by raised and gently arcuate sutures. Umbilicus of medium size with apertural flaps in well-preserved specimens. Aperture umbilical. Wall covered by frequent pustules especially on umbilical side; wall of last chamber smooth.

**Globotruncana rosetta (Carsey)**

*Globotruncana rosetta* Carsey, 1926, p. 44, pl. 5, figs. 3a-c.

Pessagno's (1967) interpretation of *Globotruncana rosetta* (Carsey) is followed here.

**Globotruncana schneegansi Sigal**

(Plate 5, Figures 4-6)

*Globotruncana schneegansi* Sigal, 1952, p. 33, text-figs. 34a-c.

Sigal's description of this species is sketchy. As a consequence the taxon is often considered synonymous with other species (Pessagno, 1967; Donze, Porthault et al., 1970).

*G. schneegansi* is here identified as including forms with a biconvex test, 5 to 6 chambers in last whorl. Chambers on spiral side petaloid, regularly increasing in size, separated by arcuate and sometimes depressed, beaded sutures. Chambers subglobular on umbilical side, sutures depressed and gently arcuate to radial. Peripheral margin keeled, with a very close, second weak keel which can be present in the first chambers of last whorl. Umbilicus deep and of medium size. Aperture umbilical. Wall on spiral side with some pustules on the first chambers, smooth in the last, with small pustules on umbilical side.

**Globotruncana sigali Reichel**

(Plate 5, Figures 1-3)

*Globotruncana sigali* Reichel, 1950, p. 610, text-figs. 5-6; pl. 16, fig. 7; pl. 17, fig. 7.

Test biconvex, quite large, 12 to 15 chambers, in 2-1/2 to 3 whorls, rapidly increasing in size. Last chamber inflated in the umbilical side. Periphery gently lobate, generally single keeled; a second weak keel may be present in the first chambers of the last whorl. On spiral side, chambers elongate to broadly arcuate in shape, separated by raised, gently beaded curved sutures, surface irregularly undulate. On umbilical side, chambers subrectangular bordered by distinct keel surrounding umbilicus. Sutures generally raised, sometimes slightly depressed between penultimate and ultimate chambers. Umbilicus of medium size. Aperture umbilical. Wall generally smooth.

**Globotruncana "tricarinata" (Quereau)**

*Pulvinulina tricarinata* Quereau, 1893, p. 89, pl. 5, figs. 3a-d. (fide Ellis and Messina).

The trend from *G. linneiana* (d'Orbigny) to *G. ventricosa* White via *G. tricarinata*, with a progressive increase in height of the umbilical side can readily be followed in the Caribbean sections. *G. tricarinata* appears before *G. ventricosa*, in the upper part of the *Globotruncana elevata* Zone, Late Campanian; both taxa coexist during the Maestrichtian, where *tricarinata* is more common.

Pessagno (1967) considers *G. tricarinata* a junior synonym of *G. linneiana*; Cita (in Cita and Gartner, 1971) agrees with this interpretation. The most frequent among these *Globotruncana* species under discussion in the Caribbean Late Campanian-Middle Maestrichtian is *G. tricarinata* with a well-developed third keel surrounding the umbilicus. *G. linneiana* and *G. ventricosa* are often only very poorly represented. *G. tricarinata* is therefore retained here.

**Tertiary**

The taxonomy of the family Globorotaliidae and its genera is at present under review by a number of authors. For the time being we therefore prefer to use in this report the taxon *Globorotalia* for all forms with an umbilical-extraumbilical aperture, independent of the presence or absence of a peripheral keel and the wall structure, following the definition by Bolli et al. (1957).

**Globigerina eugubina Luterbacher and Premoli Silva**

(Plate 7, Figures 2-5)

*Globigerina eugubina* Luterbacher and Premoli Silva, 1964, p. 105, pl. 2, figs. 8a-c.

*Globigerina umbrica* Luterbacher and Premoli Silva, 1964, p. 106, pl. 2, figs. 2a-c.

*Globigerina sabina* Luterbacher and Premoli Silva, 1964, p. 108, pl. 2, figs. 1a-c, 6a-c, 7a-c.

Test very small, trochospiral, with a very low spire, consisting of 9 to 12 globular chambers in 2-1/2 whorls. 4-1/2 to 6 chambers in the last whorl separated by radial and depressed sutures on both the spiral and umbilical side. Umbilicus very small or absent. Aperture umbilical to extraumbilical like a comma-shaped arch, often bordered by a slit lip. Wall smooth, partly recrystallized.

**Remarks:** Based on the well-preserved material from the Caribbean drill sites, the species *G. umbrica* and *G. sabina* introduced in 1964 are here within the variability of *G. eugubina*.

Further studies will have to establish whether *Globigerina anconitana* Luterbacher and Premoli Silva is an extreme planispiral form of *G. eugubina*, or has to be regarded as a different taxon.

**Globorotalia edgari Premoli Silva and Bolli, n. sp.**

(Plate 7, Figures 10-12; Plate 8, Figures 1-12)

Test trochospiral with spiral side almost flat or very gently convex, the initial portion slightly elevated. Umbilical side strongly convex. 4-1/2 to 6 chambers in last whorl gradually increasing in size, on spiral side petaloid to elongate separated by distinct arcuate and flush sutures, generally indistinct in the inner whorl; on the umbilical side, chambers triangular rapidly increasing in height, separated by radial depressed sutures. Equatorial periphery with distinct keel, slightly elongate to circular, gently lobate. Umbilicus narrow and deep. Aperture a low arch, umbilical-extraumbilical with a distinct imperforate lip. Wall calcareous, perforate, with a number of pustules sparsely distributed, covering particularly the central portion of the spiral side, and the periphery of the last two chambers. Pustules, completely covering the early chambers of the last whorl of the umbilical side, decrease in number and size towards the last, which is almost smooth. In the antepenultimate and penultimate chambers, pustules are concentrated in the umbilical area. Coiling 98 percent sinistral.

**Largest diameter of holotype:** 0.21 mm.

**Stratigraphic range:** Latest Paleocene-earliest Eocene. Uppermost part of the *Globorotalia velascoensis* Zone to top of *Globorotalia edgari* Zone.

**Locality:** Holotype and paratypes from Leg 15, Site 152, Core 3, Section 2, 136-138 cm. Nicaragua Rise, Caribbean Sea (15°52.7'N, 74°36'W). *Globorotalia edgari* Zone, Early Eocene.

**Remarks:** The largest diameter of *G. edgari* n. sp. can vary from 0.2 to 0.25 mm. The largest specimens have also a more circular equatorial outline, due to the size of the final chamber, which can be less elongate than the penultimate one; the initial portion can be slightly elevated.

By its general test shape *Globorotalia edgari* n. sp. appears related to *Globorotalia velascoensis* (Cushman), but no phylogenetic connection between the two species has as yet been proved. *G. edgari* n. sp. differs from *G. velascoensis* in its smaller size (0.2-0.25 mm instead of about 0.5 mm), fewer and more elongate chambers in the last whorl, by a less distinct keel, a gently elevated initial portion, a narrower umbilicus, and a smooth wall covered by sparse pustules.

*G. edgari* n. sp. differs from *Globorotalia occlusa* Loeblich and Tappan in its smaller size, less convex spiral side, distinct pustules not only limited to the umbilical shoulder, a thinner keel, and a larger apertural arch.

The new species differs from *Globorotalia velascoensis parva* Rey in the smaller size, thinner keel, sutures not raised and the wall covered with sparse pustules.

*G. edgari* n. sp. shows some similarities with the topotype of *Globorotalia guatemalensis* Bermudez, as illustrated by Luterbacher (1964, figs. 116a-c). However, Bermudez's species has a subacute to rounded periphery, is never keeled, and is larger than *G. edgari*. The frequent specimens attributed to *G. guatemalensis*, present together with the new species in Site 152, have a uniform spinose wall and

are never keeled. *Globorotalia acuta* Toulmin is larger, and more strongly ornamented than *G. edgari*.

The species is named for Dr. N. Terence Edgar, Chief Scientist of the Deep Sea Drilling Project and Co-Chief Scientist of Leg 15.

#### Globorotaliids with Supplementary Apertures (Plates 9 and 10)

In the Late Paleocene-Early Eocene sediments recovered in the Caribbean drill sites, forms assigned to *Globorotalia gracilis* Bolli and *Globorotalia wilcoxensis* Cushman and Ponton, because of their excellent preservation, show supplementary apertures of two kinds:

1) Supplementary apertures on the spiral side, at the inner margin against the previous whorl, restricted to the later chambers of the last whorl, mostly to the penultimate and ultimate. As shown on Plate 9, Figures 1 to 10, these supplementary apertures are irregular in size and vary in shape. They may (Figures 5-8) or may not possess imperforate rims (Figures 1-4). The number per chamber varies from one (Figures 1-2) or two (Figures 3-4) to several (Figures 5-6).

2) Supplementary apertures along the outer side, between spiral periphery and umbilical rim; in the present material restricted to the ultimate chamber, along the suture with the penultimate. As in the spiral sutural apertures, number and size are variable, as can be seen in Figures 1 to 12 on Plate 10. Some may be only slightly larger than pores (Figures 1-4), others may be of distinctly larger size (Figures 5-12). All apertures are without rims. Of the numerous examined specimens only some possess this type of supplementary aperture.

**Remarks:** The forms with supplementary apertures described above are included here under the genus *Globorotalia* for the sake of convenience and to avoid lengthy discussions of taxonomic problems. A hierarchy of taxonomic criteria will have to be discussed before the various generic taxa can be qualified.

So far this type of supplementary aperture has been observed only in some well-preserved specimens from the *Globorotalia velascoensis* Zone, Late Paleocene, to the *Globorotalia subbotinae* Zone, Early Eocene, Leg 15, Sites 146, 151, 152, Caribbean Sea.

#### ACKNOWLEDGMENTS

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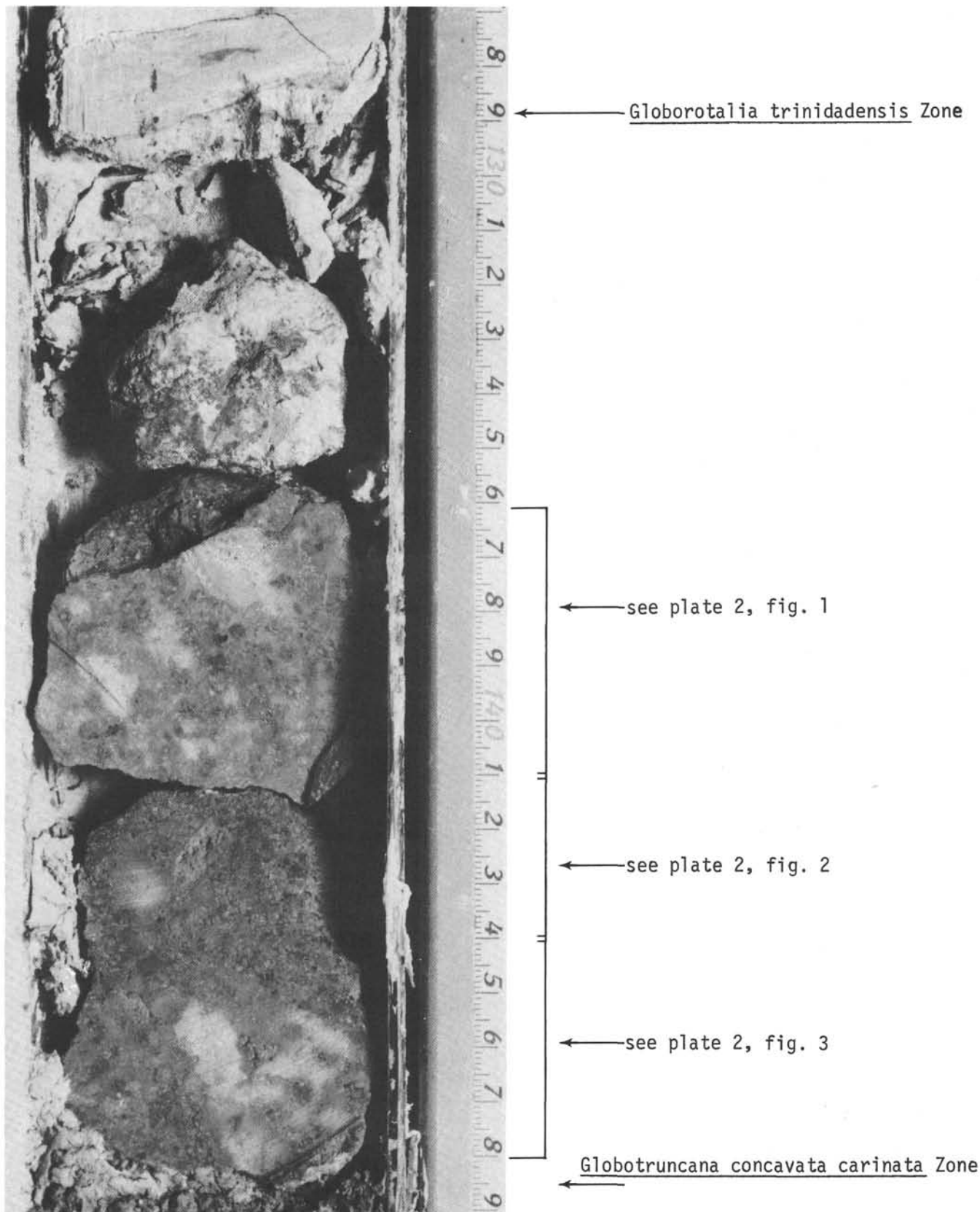
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PLATE 1



The hard ground at Site 151, Core 11, Section 6, 130-148 cm, between the *Globorotalia trinidadensis* Zone of early Paleocene and the *Globotruncana concavata carinata* Zone of late Santonian. The duration of this gap is estimated to be about 10 m.y.

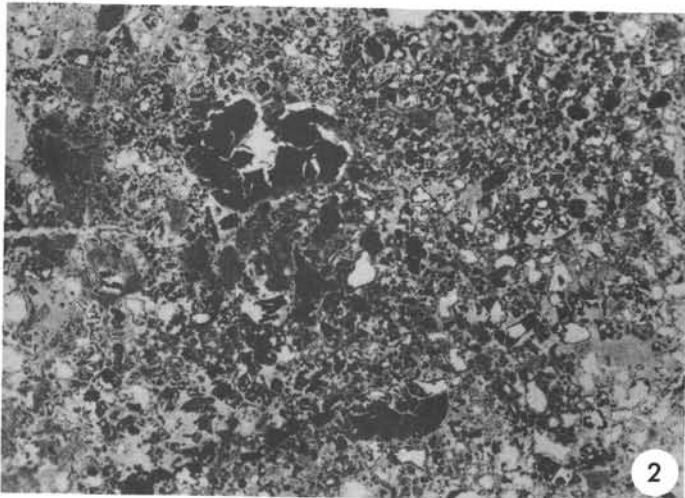


PLATE 2

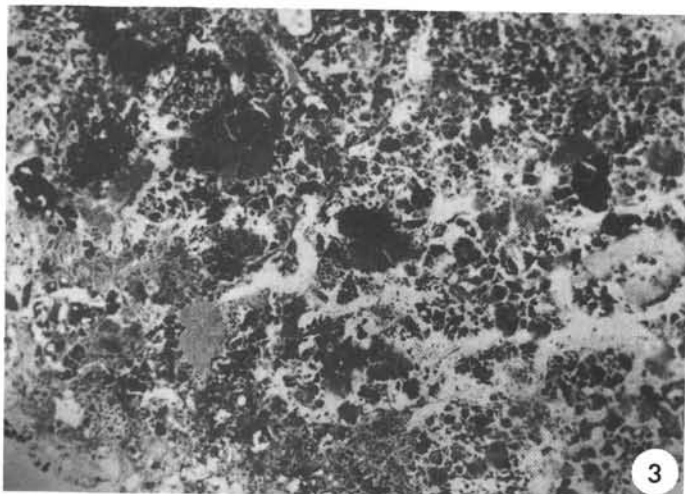


136-141 cm

Figures 1 to 3 show the microfacies of the hard ground illustrated in Plate 1. Fragments of the iron crusts are visible in the three figures (black areas). In addition, silica (white spots) and hematitic clay fragments (gray) are also present. The cement is mostly siliceous, with very little calcite.



141-144 cm



144-148 cm

PLATE 3

- Figure 1 The core catcher sample of Site 151, Core 11, below the hard ground illustrated in Plates 1 and 2. We can distinguish the graded beds that are very rich in planktonic foraminifera alternating with strongly impregnated hematitic layers, mostly clayey. Burrowing is visible in the upper part, while the bottom part is laminated.
- Figure 2 The contact between the Late Cretaceous and earliest Tertiary at Site 152, Core 10, Section 1, 142 cm. Homogeneous and carbonate-rich chalk (130-141 cm) yields a very rich assemblage of the *Globigerina eugubina* Zone, earliest Paleocene. The remaining part (142-150 cm) is less homogeneous, with a gray ash rich in feldspar and glass at bottom which grades upward to levels richer in carbonate and heavily burrowed. This part yields a rich, but partly dissolved, foraminiferal assemblage belonging to the late Maestrichtian, possibly lowermost part of the *Abathomphalus mayaroensis* Zone or to the upper part of *Globotruncana contusa* Zone.
- Figure 3 The breccia, representing the Cretaceous-Tertiary boundary at Site 153, Core 12, Section 1, 92-102 cm. The lowermost Tertiary elements, yielding an assemblage of the *Globigerina eugubina* Zone, are dominant, few fragments of argillaceous micrite contain rare Late Cretaceous planktonic foraminifera.
- Figures 4-5 Microfacies of silicified micrite at Site 153, Core 16, core catcher. Planktonic foraminifera are very abundant: two axial sections of *Globotruncana concavata concavata* are visible in Figure 5 and one of *Globotruncana renzi* in Figure 4. *Globotruncana concavata concavata* Zone, Coniacian. X60.
- Figure 6 Silicified limestone at Site 146, Core 38, core catcher. The tests of Radiolaria are completely destroyed. *Globotruncana concavata concavata* Zone, Coniacian. X60.

PLATE 3

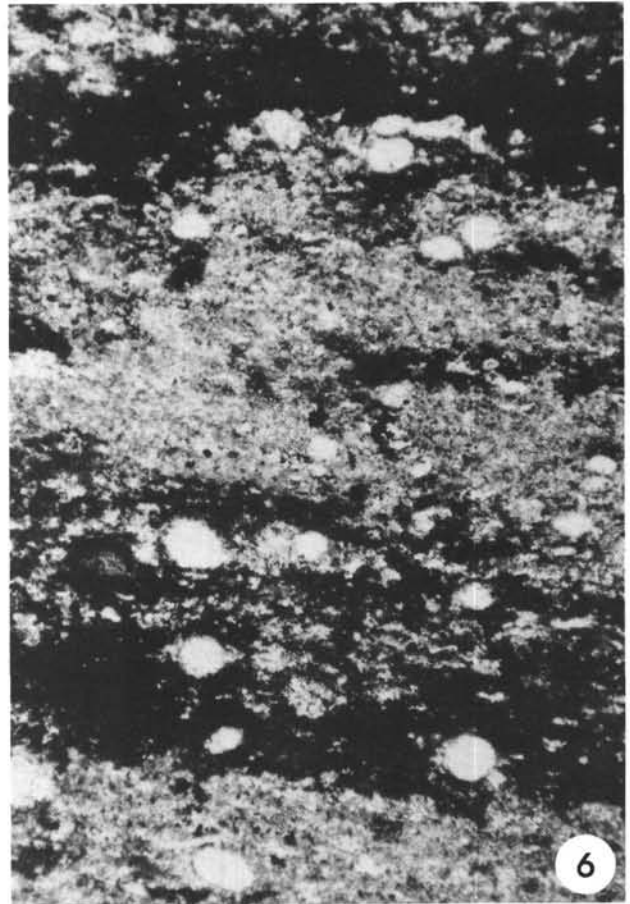
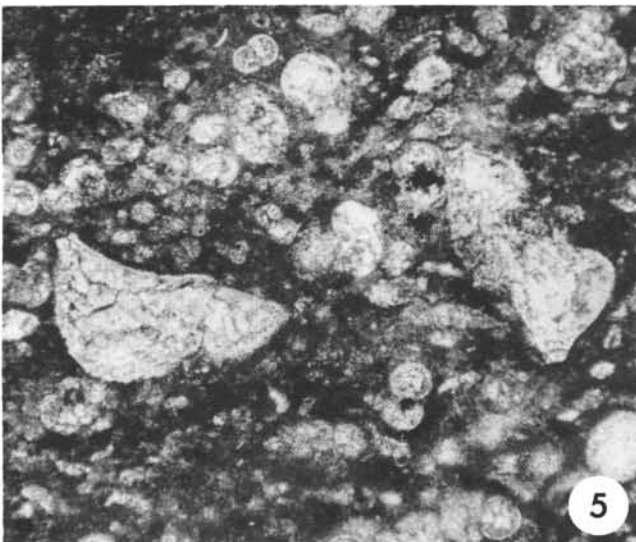
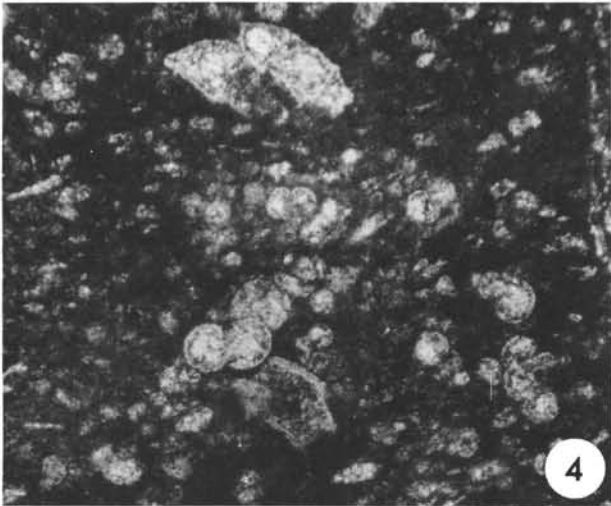
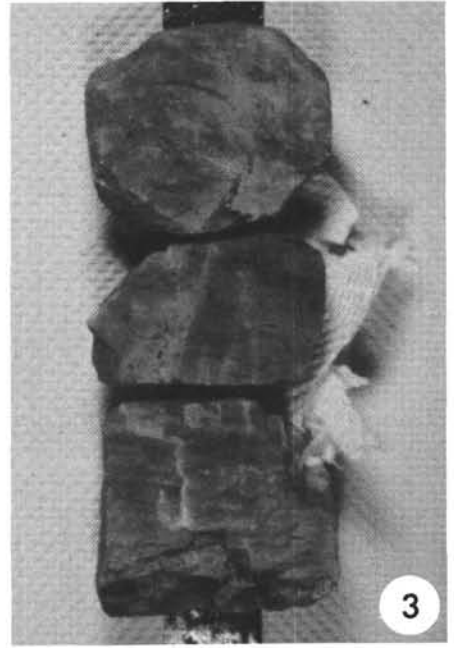
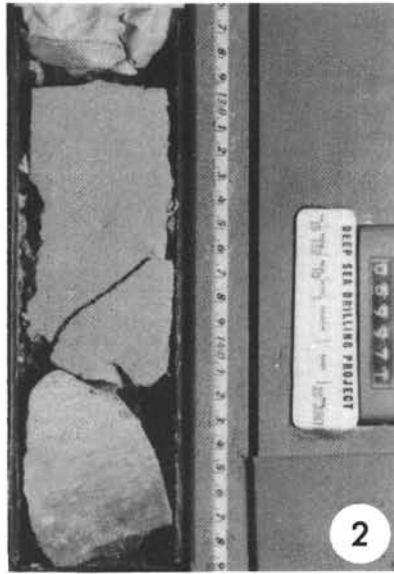
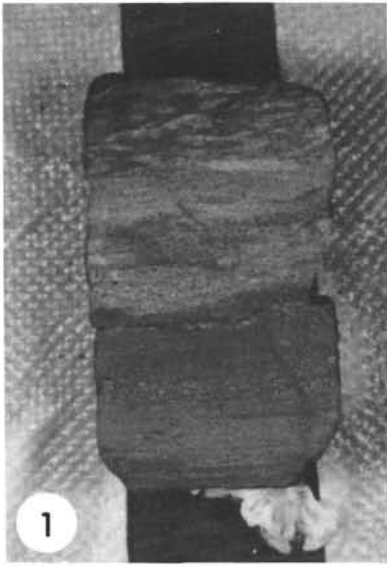


PLATE 4

- Figures 1, 5 *Hastigerinoides alexanderi* (Cushman). Leg 15, Site 150, Core 10, Section 2, 48-50 cm. *Globo truncana schneegansi* Zone, latest Turonian. 1, X 100; 5, detail of the surface of penultimate tubular chamber, X 2000. (C-29458).
- Figures 2-4 *Clavhedbergella simplex* (Morrow). Leg 15, Site 150, Core 10, Section 2, 48-50 cm. *Globo truncana schneegansi* Zone, latest Turonian. 2, 3, X 150; 4, detail of penultimate clavate chamber of specimen in Figure 2, X 2000. (C-29459a-b).
- Figures 6-8 *Globo truncana ventricosa* White. Leg 15, Site 152, Core 19, Section 1, 27-33 cm. *Globo truncana calcarata* Zone, Late Campanian. Spiral, side, and umbilical views of same specimen, X 100. (C-29460).

PLATE 4

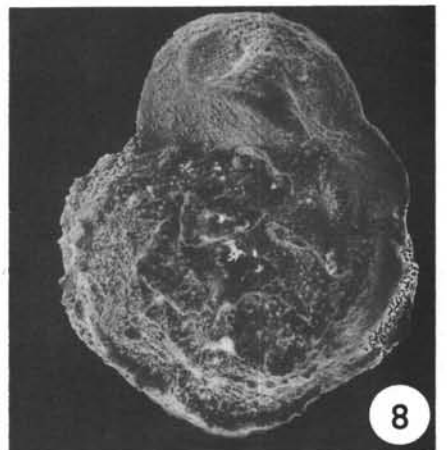
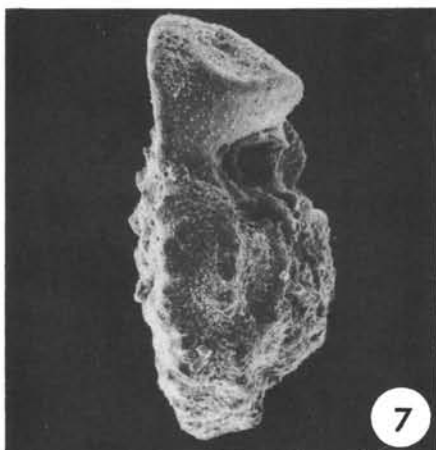
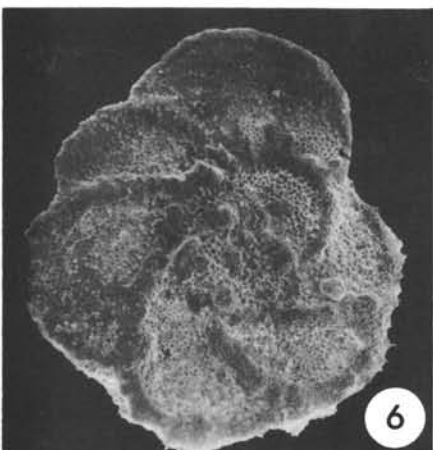
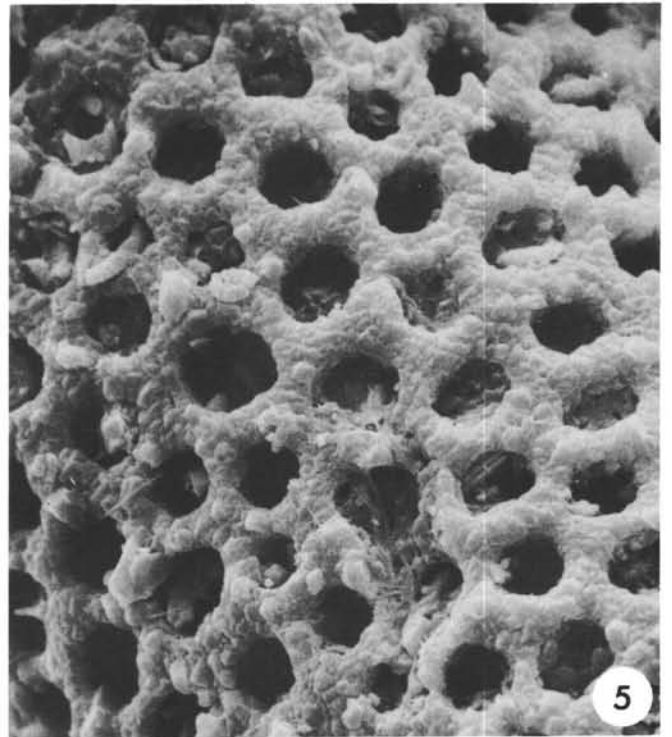
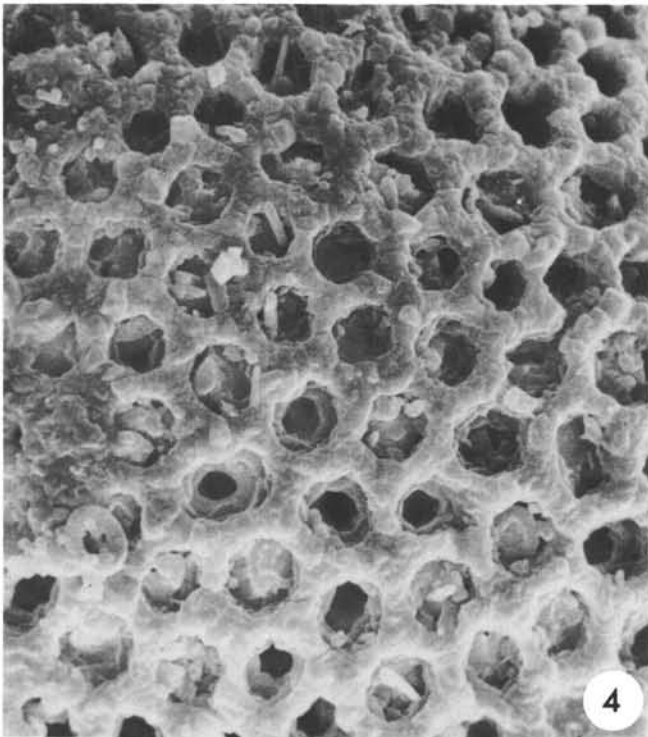
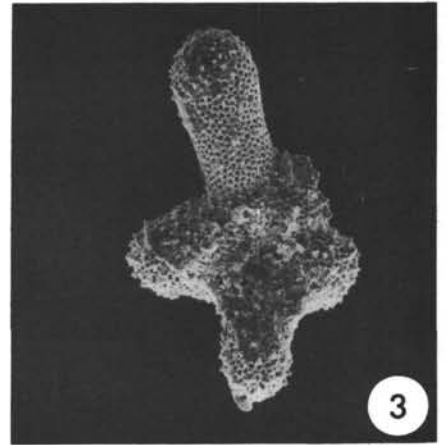
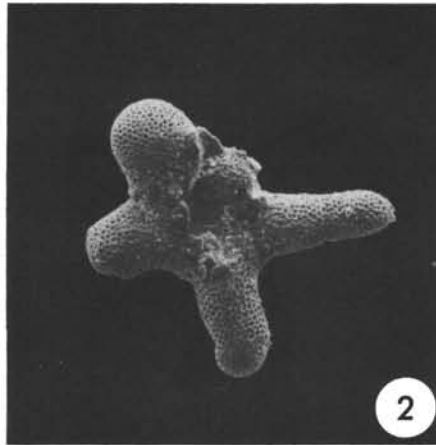
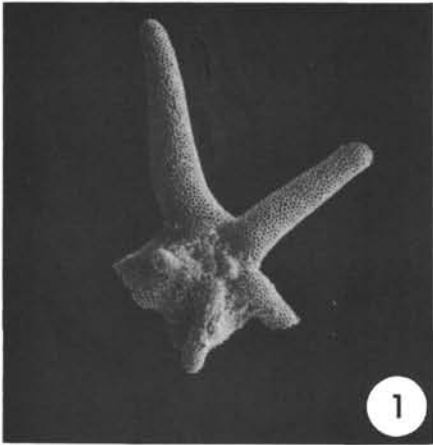


PLATE 5

- Figures 1-3 *Globotruncana sigali* Reichel. Leg 15, Site 150, Core 10, Section 2, 48-50 cm. *Globotruncana schneegansi* Zone, latest Turonian. Spiral, umbilical, and side views of the same specimen: 1, X 45; 2, X 50; 3, X 60. (C-29461).
- Figures 4-6 *Globotruncana schneegansi* Sigal. Leg 15, Site 150, Core 10, Section 2, 48-50 cm. *Globotruncana schneegansi* Zone, latest Turonian. 4, umbilical view, X 50; 5, detail of umbilical area, X 280; 6, side view, X 65, of the same specimen. (C-29462).
- Figures 7-8 *Globotruncana renzi* (Gandolfi). Leg 15, Site 150, Core 10, Section 2, 48-50 cm. *Globotruncana schneegansi* Zone, latest Turonian. 7, umbilical view, X 100; 8, side view, X 105, of the same specimen. (C-29463).
- Figures 9, 12 *Globotruncana concavata primitiva* Dalbiez. Leg 15, Site 150, Core 9, Section 1, 96-98 cm. *Globotruncana concavata concavata* Zone, Early Coniacian. 9, spiral view, X 85; 12, side view, X 90, of the same specimen. (C-19464).
- Figure 10 *Globotruncana concavata carinata* Dalbiez. Leg 15, Site 151, Core 12, Section 1, 0-2 cm. *Globotruncana concavata carinata* Zone, Late Santonian. Side view, X 100. (C-29465).
- Figure 11 *Globotruncana concavata concavata* (Brotzen). Leg 15, Site 150, Core 9, Section 1, 96-98 cm. *Globotruncana concavata concavata* Zone, Early Coniacian. Side view, X 100. (C-29466).

PLATE 5

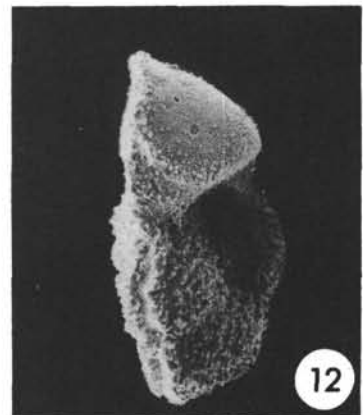
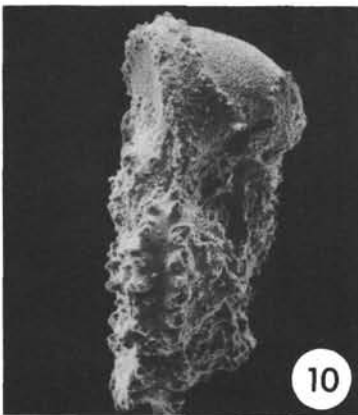
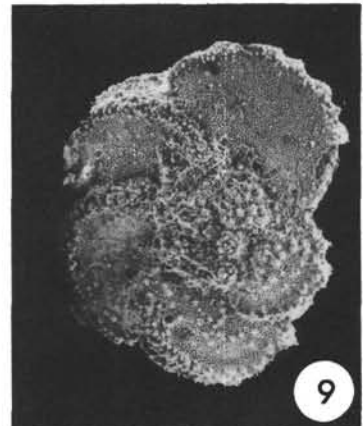
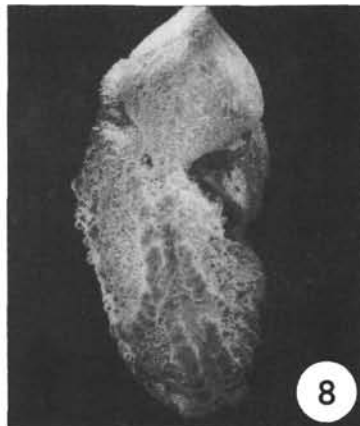
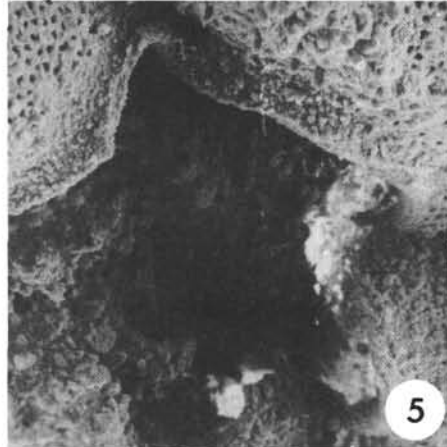
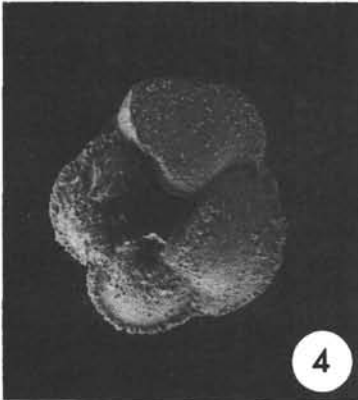
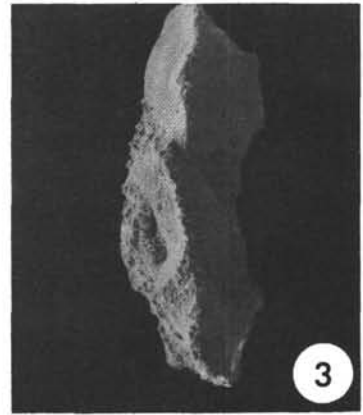
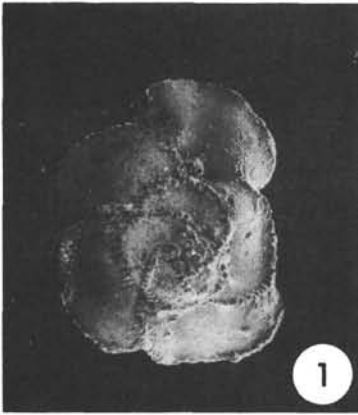


PLATE 6

- Figure 1 *Clavhedbergella moremani* (Cushman). Leg 15, Site 150, Core 10, Section 2, 48-50 cm. *Globotruncana schneegansi* Zone, latest Turonian. X 130. (C-29467).
- Figures 2-3 *Globotruncana gagnebini* Tilev. Leg 15, Site 152, Core 15, Section 2, 138-140 cm. *Globotruncana contusa* Zone, Middle Maestrichtian. 2, side view, X 120; 3, spiral view, X 115, of the same specimen. (C-29468).
- Figures 4-6 *Globotruncana gagnebini* Tilev. Leg 15, Site 152, Core 15, core catcher. *Globotruncana contusa* Zone, Middle Maestrichtian. 4, side view, X 100; 5, detail of Figure 6, X 250; 6, side view, X 100. (C-29469-70).
- Figures 7-9 *Globotruncana gansseri* Bolli. Leg 15, Site 152, Core 14, Section 1, 124-126 cm. *Globotruncana contusa* Zone, Middle Maestrichtian. 7, spiral view, X 100; 8, side view, X 100; 9, umbilical view, X 100. (C-19471a-c).
- Figures 10-12 *Woodringina hornerstownensis* Olsson group. Leg 15, Site 152, Core 10, Section 1, 127-130 cm. *Globigerina eugubina* Zone, earliest Paleocene. 10, X 500; 11, X 500; 12, detail of aperture of specimen in Figure 11, X 2000. (C-29472-73)



PLATE 6

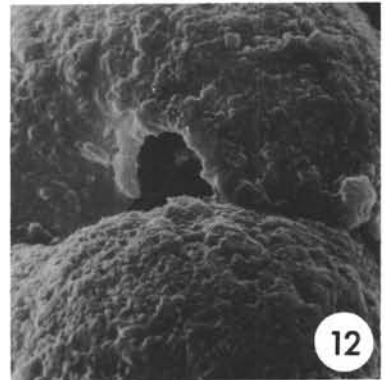
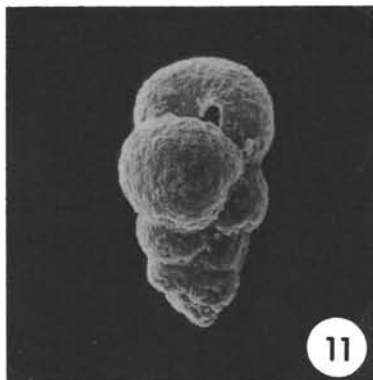
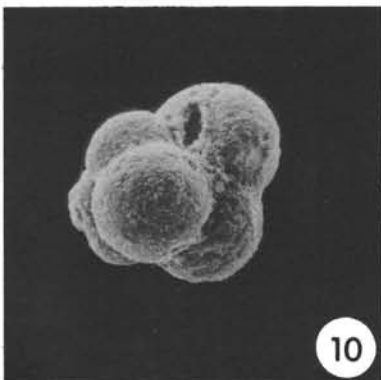
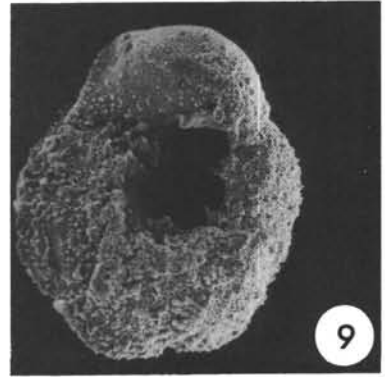
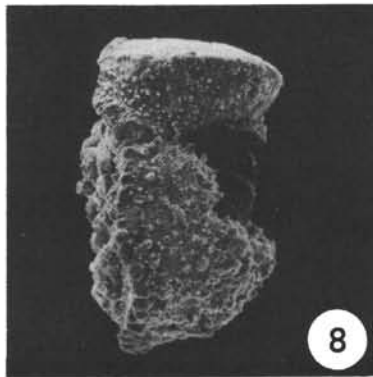
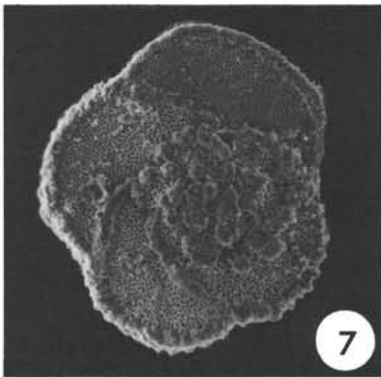
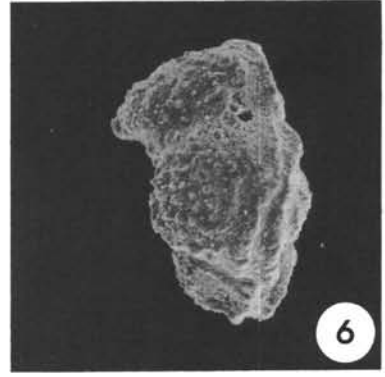
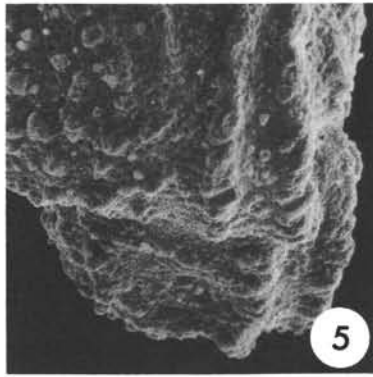
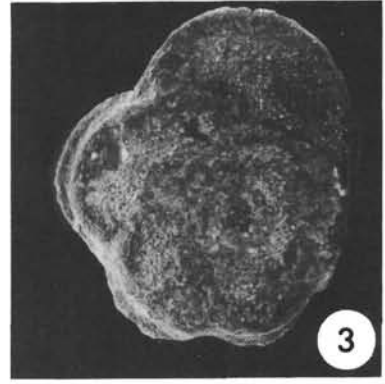
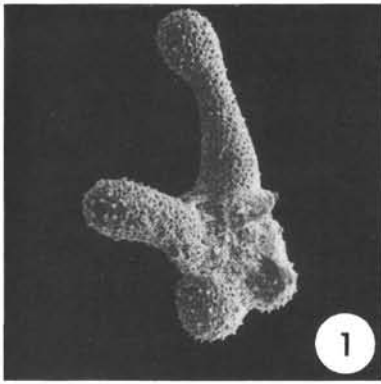


PLATE 7

- Figure 1 *Woodringina hornerstownensis* Olsson group. Leg 15, Site 152, Core 10, Section 1, 127-130 cm. *Globigerina eugubina* Zone, earliest Paleocene. X 500. (C-29474).
- Figures 2-4 *Globigerina eugubina* Luterbacher and Premoli Silva. Leg 15, Site 152, Core 10, Section 1, 127-130 cm. *Globigerina eugubina* Zone, earliest Paleocene. 2, spiral view, X 500; 3, detail of specimen in Figure 2, X 2000; 4, umbilical view, X 500. (C-29475-76).
- Figure 5 *Globigerina eugubina* Luterbacher and Premoli Silva. Leg 15, Site 152, Core 10, core catcher. *Globigerina eugubina* Zone, earliest Paleocene. Spiral view, X 500. (C-29477).
- Figures 6, 9 *Globigerina fringa* Subbotina. Leg 15, Site 152, Core 10, Section 1, 127-130 cm. *Globigerina eugubina* Zone, earliest Paleocene. 6, spiral view, X 500; 9, umbilical view, X 500. (C-29478).
- Figures 7-8 *Globigerina eugubina* group. Leg 15, Site 152, Core 10, Section 1, 127-130 cm. *Globigerina eugubina* Zone, earliest Paleocene. 7, umbilical view, X 500; 8, detail of the aperture of specimen in Figure 7, X 2000. (C-29479).
- Figures 10-12 *Globorotalia edgari* Premoli Silva and Bolli, n. sp. Leg 15, Site 152, Core 3, Section 2, 136-138 cm. *Globorotalia edgari* Zone, Early Eocene. Paratypes. 10, side view, X 150; 11, detail of the aperture of specimen in Figure 10, X 300; 12, side view, X 150. (C-29480-81).

PLATE 7

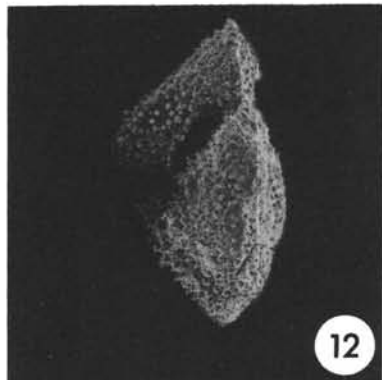
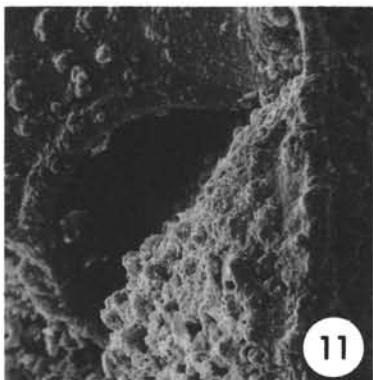
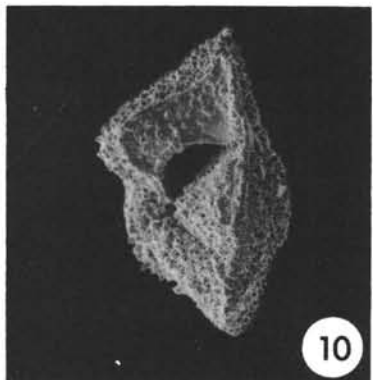
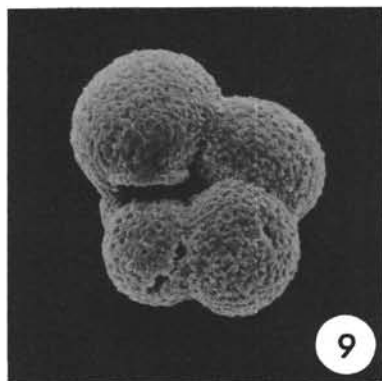
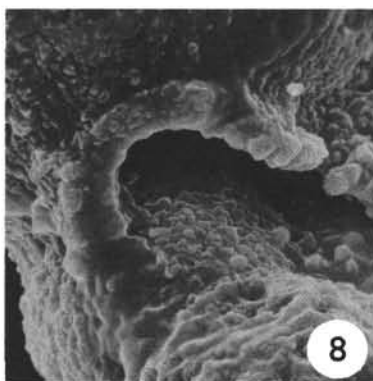
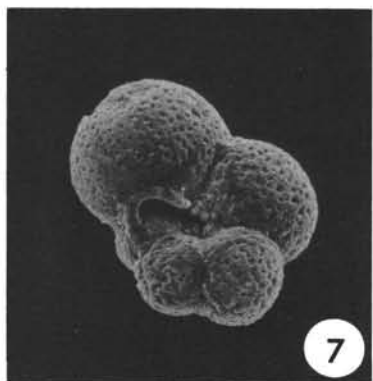
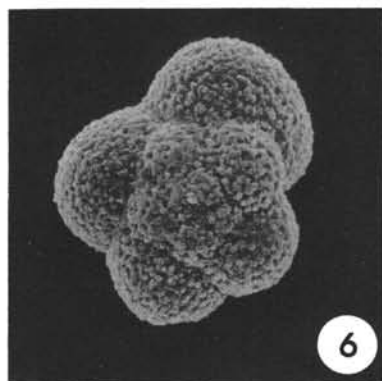
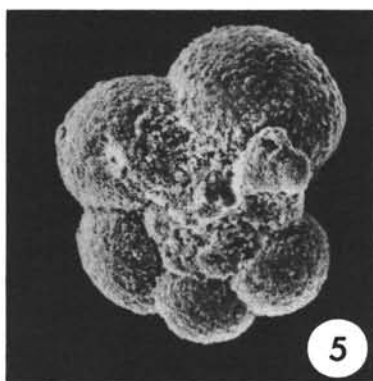
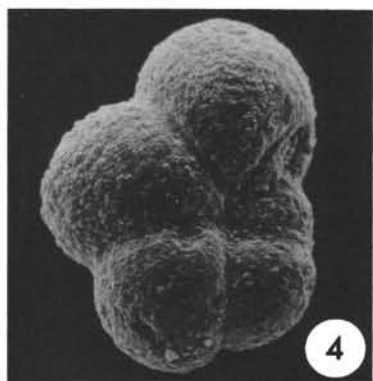
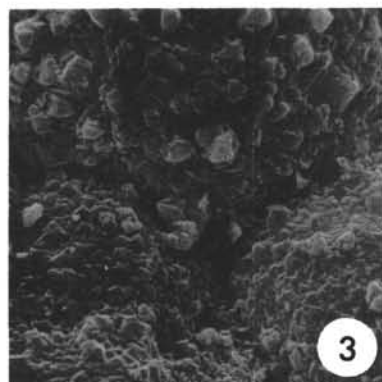
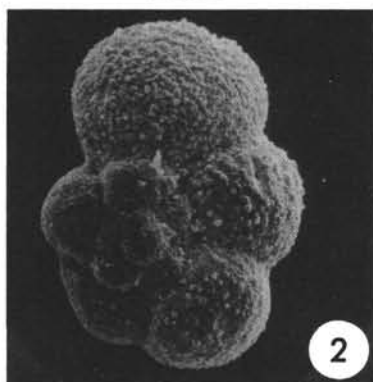
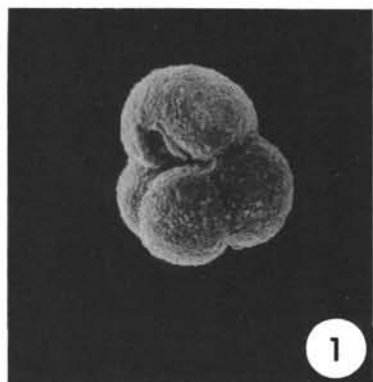


PLATE 8

- Figure 1 *Globorotalia edgari* Premoli Silva and Bolli, n. sp. Leg 15, Site 152, Core 3, Section 2, 136-138 cm. *Globorotalia edgari* Zone, Early Eocene. Holotype. Spiral view,  $\times 150$ . (C-29482).
- Figures 2-12 *Globorotalia edgari* Premoli Silva and Bolli, n. sp. Leg 15, Site 152, Core 3, 136-138 cm. Paratypes. 2, spiral view,  $\times 95$ ; 3, detail of the last chamber of specimen in Figure 2,  $\times 350$ ; 4, spiral view,  $\times 150$ ; 5 and 6, details of the last chamber of specimen in Figure 4,  $\times 750$  and  $\times 2500$  respectively; 7, umbilical view,  $\times 150$ ; 8, detail of the aperture of specimen in Figure 7,  $\times 400$ ; 9, umbilical view,  $\times 150$ ; 10, detail of the aperture of specimen in Figure 9,  $\times 500$ ; 11 and 12, details of the ante-penultimate chamber of specimen in Figure 9,  $\times 350$  and  $\times 1000$  respectively. (C-29483-86).

PLATE 8

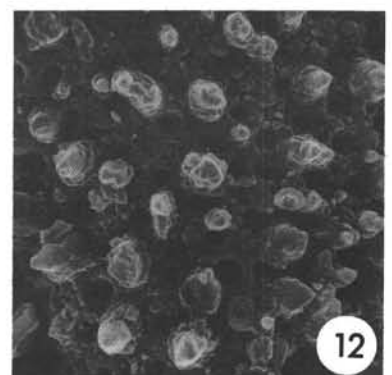
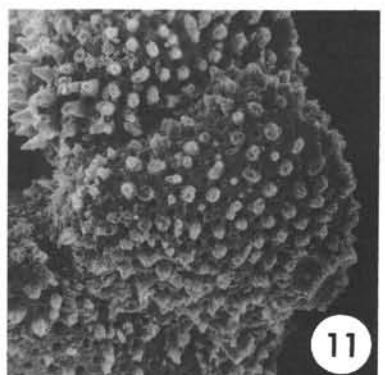
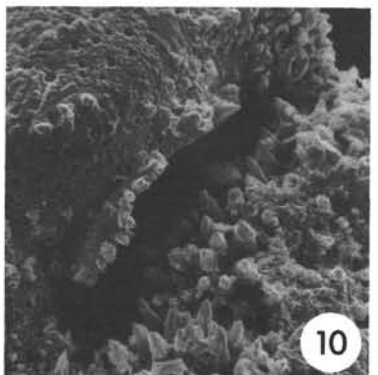
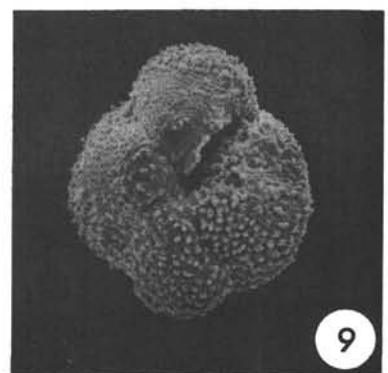
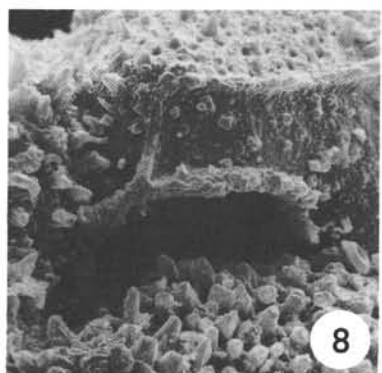
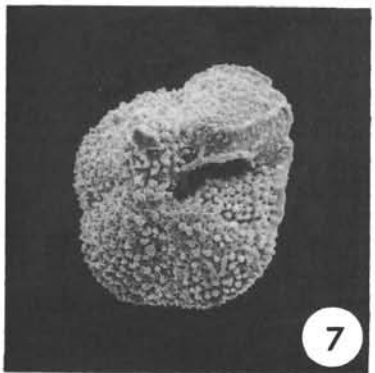
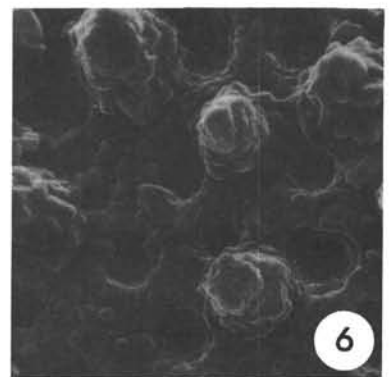
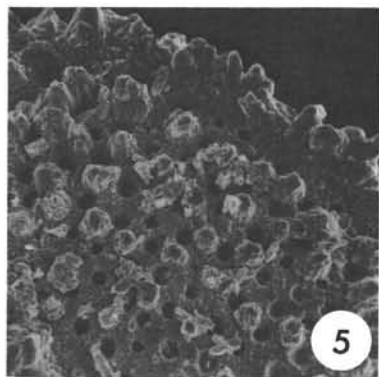
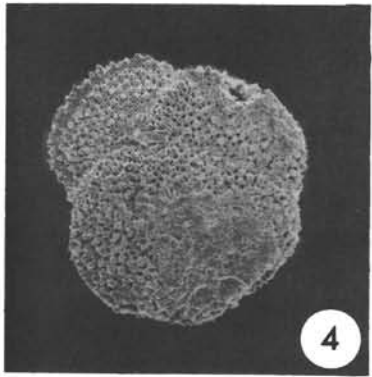
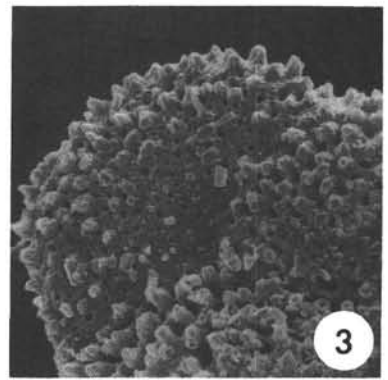
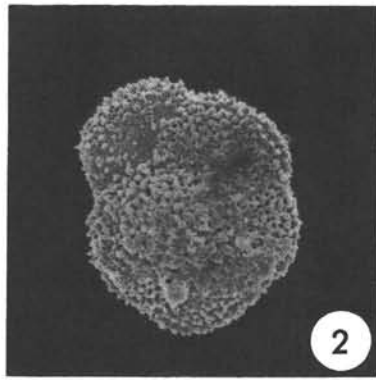
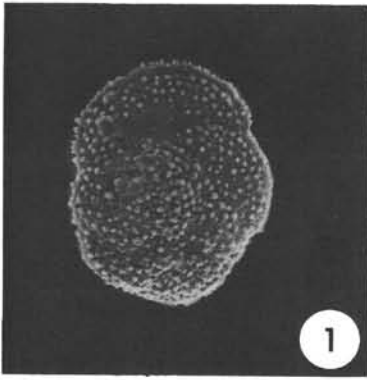


PLATE 9

Figures 1-4 *Globorotalia wilcoxensis* (Cushman and Ponton). 1, 3, spiral view with supplementary apertures along inner sutures of penultimate and ultimate chambers. Periphery of penultimate and ultimate chambers in 3 slightly acute and marked by prominent spines. 2, 4, details of 1 and 3, are as with supplementary apertures. 1, 3, X 100; 2, X 650; 4, X 250. (C-29487-88).

Figures 5-12 *Globorotalia gracilis* Bolli. 5, 7, spiral view with supplementary apertures along inner sutures of penultimate and ultimate chambers (both, X 85). Peripheral keel in 7 distinctly stronger than in 5. 6 and 8 are details of 5 and 7 respectively, showing spiral supplementary apertures; 6, X 250; 8, X 400. 9, umbilical view with umbilical side of ultimate chamber removed to make spiral supplementary apertures visible from inside, three of them visible, X 85. 10, detail of 9, largest of the three visible supplementary apertures, X 1000. 11, oblique umbilical view of a specimen with small ultimate chamber (upper left) practically closing off extra-umbilical portion of primary aperture, X 100. 12, detail of 11 showing pores on outer surface, coarse spines around umbilical area and peripheral keel formed of massive spines, X 200. (C-29489-92).

All specimens from Leg 15, Site 152, Core 1, Section 2, 87-89 cm. *Globorotalia subbotinae* Zone, Early Eocene.

PLATE 9

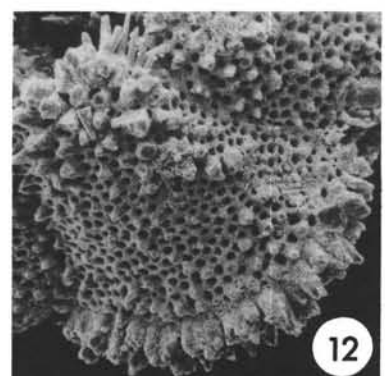
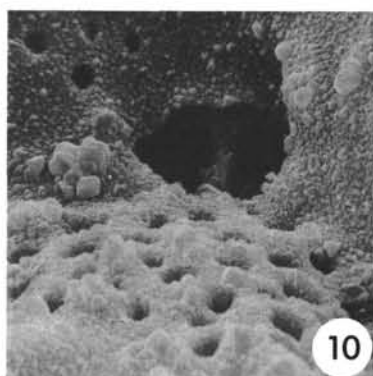
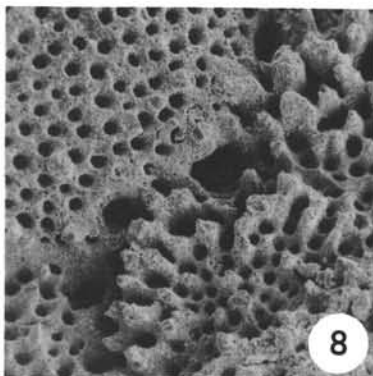
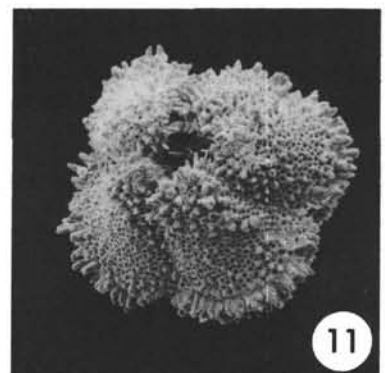
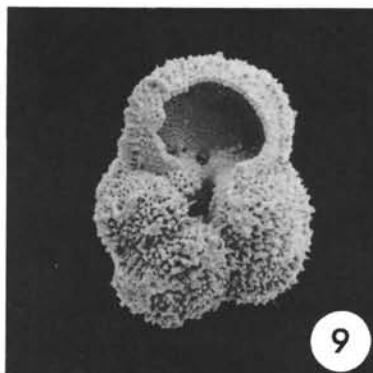
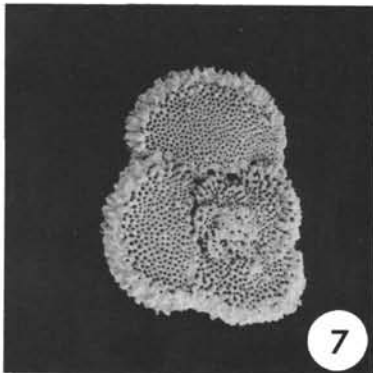
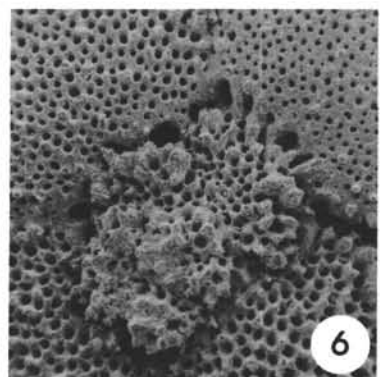
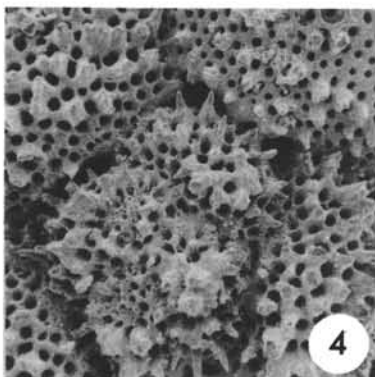
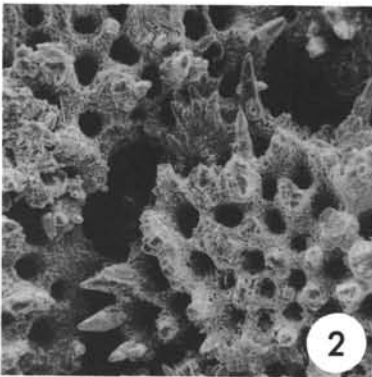
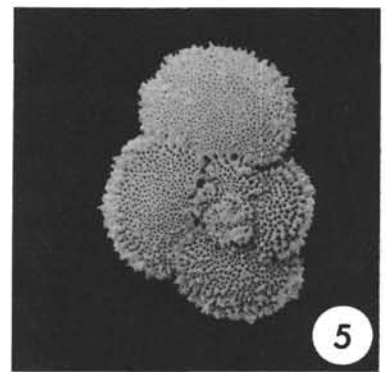
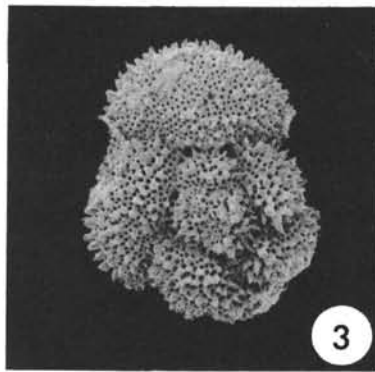
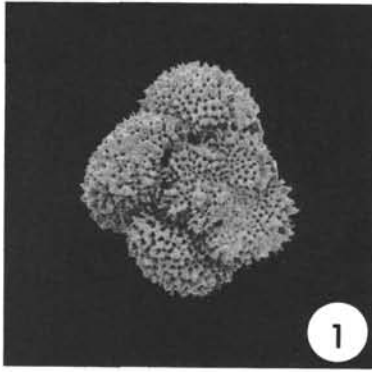


PLATE 10

Figures 1-12

*Globorotalia gracilis* Bolli. Specimens with last chambers possessing supplementary apertures on the outer umbilical side along suture with penultimate chamber. In addition to the primary umbilical-extraumbilical aperture, these specimens also possess supplementary spiral sutural apertures as shown on Plate 9. 1-2, specimens with sutural apertures only slightly larger than pores, but of more irregular shape. 1, side view of specimen with small supplementary apertures between penultimate and smaller ultimate (top) chamber, X 75; 2, detail of sutural area with the small supplementary apertures, X 250. 3-4, as in 1-2, with two small supplementary sutural apertures; 3, X 100; 4, X 500. 5-10, three specimens with larger supplementary sutural apertures. 5, specimen with one large supplementary aperture partially obscured by spines, X 75; 6, detail of 5, X 400; 7, specimen with six supplementary apertures, X 90; 8, detail of upper three supplementary apertures in 7, X 500; 9, specimen with three supplementary apertures, X 65, of which two are enlarged in 10, X 700. 11-12, 11, side view of penultimate (on left) and ultimate (center-right) chambers, with walls partially removed to make sutural apertures visible from inside (arrow), X 200; 12, detail of the two sutural apertures visible in 11, X 1000. (C-29492-98).

All specimens from Leg 15, Site 152, Core 1, Section 2, 87-89 cm. *Globorotalia subbotinae* Zone, Early Eocene.



PLATE 10

