

Riv. Ital. Paleont.	v. 88	n. 1	pp. 113-132	tav. 3-5	Ottobre 1982
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**THE OLIGOCENE/MIOCENE BOUNDARY  
IN THE EQUATORIAL ATLANTIC DSDP SITE 354.  
RESULTS OF STUDIES ON PLANKTIC FORAMINIFERA  
AND CALCAREOUS NANNOFOSSILS**

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*Key-words:* Biostratigraphy, planktic Foraminifera, calcareous nannofossils, Oligocene/Miocene boundary, Equatorial Atlantic.

*Abstract.* A first order correlation between planktic foraminiferal and calcareous nannofossil events of DSDP Site 354 in the Equatorial Atlantic is presented. Within the 323 m thick, discontinuously cored section, 30 samples have been studied. In the Oligocene-Miocene sediments 57 different species of planktic Foraminifera and 51 species of calcareous nannofossils have been identified, and 6 foraminiferal zones and 7 nannofossil zones recognized. Besides the generally used biostratigraphic markers, some additional calcareous nannofossil events are considered for a further subdivision of the interval studied.

*Riassunto.* Nel presente lavoro vengono riportati i risultati dello studio biostratigrafico dei Foraminiferi planctonici e dei nannofossili calcarei nell'intervallo oligocenico-miocenico del Site 354 (Leg 39 del DSDP), ubicato nell'Atlantico equatoriale. Viene inoltre presentata la correlazione di primo grado tra le zonature basate sui due gruppi di organismi. In base alle 57 specie di Foraminiferi e alle 51 specie di nannofossili individuate nei 30 campioni analizzati, è stato possibile distinguere nella sezione oligocenico-miocenica 6 zone a Foraminiferi planctonici e 7 zone a nannofossili. A causa di una campionatura intermittente nell'intervallo studiato sono state riscontrate diverse lacune.

### Introduction

A poor availability of stratigraphic markers characterizes the Oligocene/Miocene boundary. The low evolutionary rates and the low total diversity during this time interval in different groups of marine organisms are thought to be the consequence of the lack of marked climatic/oceanographic changes, as indicated by the small variations in oxygen and carbon isotopes of calcareous plankton (Shackleton & Kennet, 1975; Boersma & Shackleton, 1977; Vergnaud-Grazzini, in Cati et al., 1981; Biolzi in preparation).

The improvement in biochronology, in relation to the Paleogene/Neogene (Oligocene/Miocene) boundary, and the choice of a boundary stratotype section are the main goals towards which the international Working Group on Paleogene/Neogene boundary (established in the past few years) is working (Cati et al., 1981). Correlation of biostratigraphic events concerning planktic and benthic Foraminifera, calcareous nannofossils, Radiolaria and Silicoflagellates can be used as clue for obtaining datum planes and good stratigraphic

resolution in the critical interval. The present study is a part of a large biostratigraphic project on several Deep Sea Sites and some land sections from tropical, subtropical and temperate areas in the Oligocene-Miocene interval. Since DSDP Site 354 seems from the literature "to contain a good Oligocene/Miocene boundary sequence worth studying further" (Perch-Nielsen, in Beckmann et al., 1981), the selection of the Ceara Rise section for research into Oligocene-Miocene stratigraphy seems well-founded.

#### **Material studied.**

The investigation presented here is based on material taken from cores provided by the Deep Sea Drilling Project, Leg 39.

At site 354 in the equatorial North Atlantic Ocean (05° 53.95' N, 44° 11.78' W), the Ceara Rise was drilled in October 1975 to a water depth of 4052 metres. The whole stratigraphic sequence ranges from Holocene to upper Cretaceous. The lower Miocene to middle Oligocene interval is contained in cores 7 (sample 7-1, 95-97) to 12 (sample 12-1, 70-72). As a result of a policy of discontinuous coring a good deal of sediment was not collected between adjacent cores. Within the 323 metres of total thickness only 37.5 m of sediments have been recovered. Besides that, part of the section is probably missing in cores 7 and 9 (see further in text). All the biostratigraphic zones are represented in the lower and middle part of the section, but the sediments belonging to planktic foraminiferal Zones N.6 and N.7 of Blow (1969) and calcareous nannofossil Zones NN3 and NN4 of Martini (1971) are missing in core 7.

Sediments from core 7 to 11 have a uniform lithology consisting of pale blue-green foraminiferal-nannofossil chalk, with interbedded foraminiferal chalk in the upper section, and contorted zeolitic layers and clay-pebble breccias in the lower portion. Core 12 consists of green-gray, zeolitic, diatomaceous chalk with common pyrite (Supko, Perch-Nielsen et al., 1977).

Planktic Foraminifera and calcareous nannofossil assemblages are typical of a tropical, open marine environment. The benthic fauna indicates a lower bathyal to abyssal depth (Boersma, 1977b).

Preservation and abundance of Foraminifera, in the interval considered in this investigation, vary from sample to sample from well preserved and rich to very poor with dissolution effects. Calcareous nannofossils are common to abundant in all samples studied. Preservation is moderate, the coccoliths sometimes being affected by overgrowth.

#### **Previous studies.**

The scientific results of DSDP Site 354 were published in Supko, Perch-Nielsen et al. (1977). The Cenozoic planktic Foraminifera were studied by

Boersma (1977a) who used the zonal scheme of Berggren (1972). The calcareous nannofossils were listed by Perch-Nielsen (1977a), who mainly followed the zonation of Martini (1971) and Bukry (1973).

The Oligocene/Miocene boundary was placed on foraminiferal evidence, between Sections 9-2 and 9-3. Boersma (1977a) places the boundary "on the basis of the overlap between *Globigerina angulisuturalis* and *Globorotalia kugleri*, immediately below the abundant occurrence of *Globigerinoides primordius*". This level is 4 metres higher than that at which the boundary is placed in the present study, where it coincides with the first appearance of *Globorotalia kugleri* s.s. and with the extinction of *Sphenolithus ciperoensis*, between samples 9, cc and 9-5, 70-72 cm. In Supko, Perch-Nielsen et al. (1977), the correlation between foraminiferal and coccolith zonations follows Berggren's (1972), except for the lower boundary of *Sphenolithus predistentus* Zone, NP23. A complete review of the state-of-the-art of the Oligocene/Miocene boundary is given in the results of the Paleogene/Neogene/Boundary Working Group (Cati et al., 1981).

### Biostratigraphy

Several zonal schemes based on planktic Foraminifera have been proposed in the past years for Atlantic Cenozoic sediments: Bolli (1957, 1966), Banner and Blow (1965), Blow (1969), Berggren (1972), Stainforth et al. (1975), among others. Low-latitude coccolith biostratigraphic zonation schemes accepted world-wide for Cenozoic sediments include those of Martini (1971), Bukry (1973, 1975) and Okada and Bukry (1980). On the following pages the author will refer to Blow (1969) for the planktic foraminiferal zonation and to Martini (1971) for the calcareous nannofossil zonation. Some references are also made to Bolli (1966), Bukry (1973, 1975) and Okada and Bukry (1980).

#### Planktic Foraminifera.

The distribution of planktic Foraminifera is shown in Fig. 1. Broadly the section is divisible into a lower part (up to sample 9-5, 70-72 cm) dominated by an assemblage of long-ranging, large, four-chambered *Globigerinas*, which are mostly assigned to the *G. pseudovenezuelana* - *venezuelana* - *euapertura* group and of *Globorotalia opima opima*, and into an upper part, above the first appearance of *Globorotalia kugleri* which is characterized by a more rapidly evolving and better diversified fauna.

Approximately but not simultaneously as *Globigerina ampliapertura* disappears from the assemblage, *Globorotalia opima opima* appears and persists through most of the Oligocene section.

Blow's (1969, p.217) assumption that "the first appearance of *Globigerina angulisuturalis* has been found to follow upon the extinction of *Globigerina*

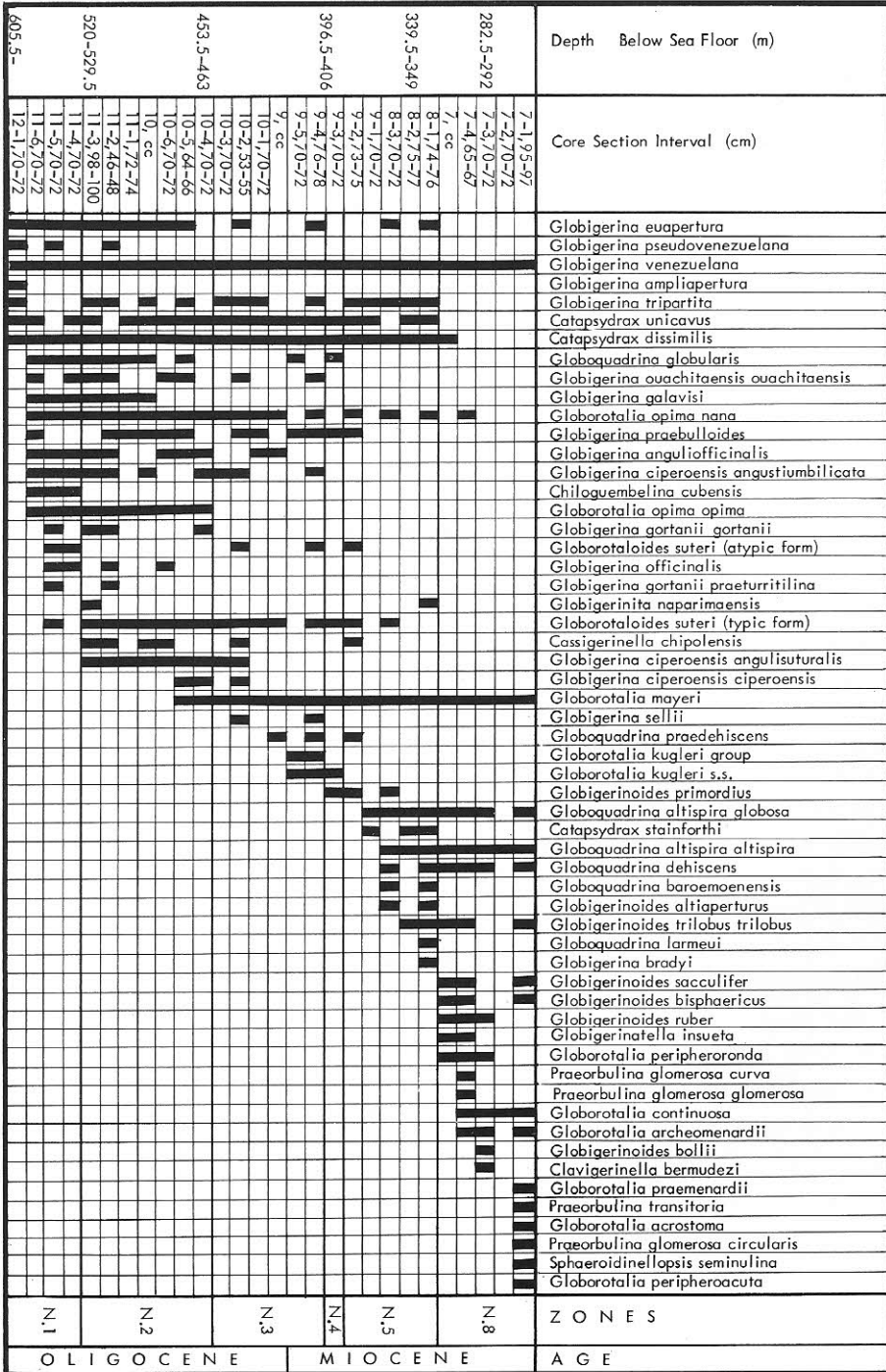


Fig. 1 — Distribution of middle Oligocene-early Miocene planktic Foraminifera of DSDP Site 354.

*ampliapertura* so closely that these two events may be regarded as being virtually synchronous for practical purposes of correlation" is not confirmed here since *Globigerina angulisuturalis* has been found at an approximately 4.5 m higher level above the extinction of *Globigerina ampliapertura*, which is however recorded only in the lowermost sample studied.

*Globigerina anguliofficialis* from which *Globigerina angulisuturalis* evolved (Blow, 1969) ranges from Zone N.1 to Zone N.3 and persists to slightly higher level than *G. angulisuturalis*.

*Globorotalia opima opima* is present with both subspecies *nana* and *opima*. Intermediate stages between the small and the large forms are represented in the population but only the specimens larger than approximately 35 $\mu$  are assigned to *Globorotalia opima opima* (Bolli, pers.comun.).

The abrupt extinction of *Globorotalia opima opima* marks the upper boundary of Zone N.2 while *Globorotalia opima nana* ranges higher through most of the section. Well preserved specimens of *Globorotalia kugleri* s.s. have been found in three samples from core 9 (Plate 3, fig. 1, 2). Similiar forms, but with only 6 chambers of a more globular form, are assigned to the *G. kugleri* group.

The total range of *G. kugleri* was used by Bolli (1957, 1966) to define the homonymous zone, and by Banner and Blow (1965) to define Zone N.4. Blow (1969) considered the co-occurrence of *G. kugleri* and *Globigerinoides primordius* to characterize the *Globigerinoides quadrilobatus primordius/Globorotalia kugleri* Zone, N.4.

*Globigerinoides primordius*, the stratigraphic reliability of which recently came under discussion (Meulenkamp, 1975; Lamb & Stainforth, 1976; Rögl, in Cati et al., 1981), occurs here within the range of *Globorotalia kugleri*. The appearance of *Globoquadrina dehiscens dehiscens* within the *Globorotalia kugleri* Zone and of *Globigerinoides altiapertura* at the level of extinction of *Globorotalia kugleri*, considered as two important datum planes in the Oligocene/Miocene biostratigraphy (Rögl, in Cati et al., 1981), are not confirmed here since the two species only appear together with *Globoquadrina altispira altispira* at a higher level within Zone N. 5.

*Globigerinatella insueta* appears late in the sequence together with *Globigerinoides bisphaericus* (Zone N. 8). The simultaneity of the two events is however not proved since the hiatus below sample 7, cc could affect the first occurrence of the two species.

The boundary between the *Catapsydrax dissimilis* and *Catapsydrax stainforthi* Zones of Bolli (1966), which should be placed, according to the author, at the level of the first appearance of *Globigerinatella insueta*, is not shown in the biostratigraphic scheme given here. Consequently the two zones are not separated. Zones N. 6 and N. 7 of Blow (1969) are absent because the first appearance of *Globigerinatella insueta* and the extinction of *Catapsydrax*

*dissimilis*, which should define the base of N. 6 and N. 7 respectively, occur only after the appearance of *Globigerinoides bisphaericus*. The hiatus which affects the relationships among the stratigraphic events between cores 8 and 7 is probably due to coring problems. The evidence of a "drilling-effect" is also displayed in the aspect of the core which consists, in this section, mostly of broken pieces. Core 7 is placed in Zone N. 8 because of the presence of *Globigerinatella insueta*, *Globigerinoides bisphaericus*, *Praeorbulina glomerosa*, *Globorotalia peripheroronda*, *Globorotalia archeomenardii* and the absence of *Orbulina*.

#### Calcareous nannofossils.

The distribution and the relative abundance of calcareous nannofossils in the middle Oligocene-lower Miocene sediments of the Ceara Rise section are shown in Fig. 2, and interpreted according to the Standard Zonation of Martini (1971) (NP, NN Zones). Some references are made to Bukry (1973, 1975) with the new code-number designation introduced by Okada and Bukry (1980) (CP, CN Zones). Approximately 50 nannofossil species have been identified and no reworked forms have been found.

Above the top of Zone NP22, marked by the extinction of *Reticulofenestra umbilica* and *Helicosphaera reticulata*, the complete sequence of *Sphenolithus predistentus*, *S. distentus* and *S. ciperoensis* provides a good zonal subdivision of the sediments of cores 11 and 10. The last occurrence of *Sphenolithus ciperoensis* is used to define the top of Zone NP25.

*Helicosphaera recta* and *Dictyococcites bisecta*, in Fig. 2, are rare and were not found in all samples below their last occurrence in sample 9, cc which is also the level at which *Sphenolithus ciperoensis* disappears.

The co-occurrence of these three events is probably due to the fact that a considerable part of the section between samples 9, cc and 9-5, 70-72 cm may be missing, since core 9 may have been collected from anywhere between 349 m and 406 m, where the 9 cc, probably comes from (Perch-Nielsen, pers. comun.). The last occurrence of *Zygrhablithus bijugatus* is considered a good marker for the upper boundary of Zone NP25 in high latitudes. *Z. bijugatus* here occurs only sporadically and becomes extinct slightly above *Sphenolithus ciperoensis* in NN1. *Triquetrorhabdulus carinatus* ranges from NP23 on through most of the section and its extinction has been used to define the upper boundary of the *Discoaster druggii* Zone, NN2. Some quite well preserved specimens of *D. druggii* were found in NN2 (Plate 5, fig. 1). Since the two events used by Martini (1971) to define the boundaries NN3-NN4 and NN4-NN5 (extinction of *Sphenolithus belemnus* and extinction of *Helicosphaera ampliapertura* respectively) occur simultaneously in sample 7, cc, the Zones NN3 and NN4 of the Standard Zonation are missing between samples 7, cc and 7-4, 65-67 cm (same explanation as before for core 9).

Depth Below Sea Floor (m)	Core Section Interval (cm)		
605.5-	12-1,70-72	C	Cyclicargolithus floridanus
		C	Coccolithus pelagicus
		F	Coccolithus eopelagicus
		R	Ericsonia obruta
		R	Helicosphaera recta
		R	Dityococcites bisecta
		C	Sphenolithus moriformis
		C	Helicosphaera compacta
		R	Helicosphaera reticulata
		F	Helicosphaera parallela
		R	Helicosphaera seminulum
		R	Helicosphaera bramlettei
		R	Coronocyclus nitescens
		R	Reticulofenestra umbilica
		R	Thoracosphaera sp.
		R	Discoaster deflandrei
		R	Sphenolithus predistentus
		R	Cyclicargolithus abisectus
		R	Sphenolithus distentus
		R	Triquetrorhabdulus carinatus
		R	Pontosphaera segmentata
		R	Helicosphaera perch-nielsenae
		R	Helicosphaera obliqua
		R	Sphenolithus pseudoradians
		R	Sphenolithus ciproensis
		R	Discoaster deflandrei, 5 arms
		R	Zygrhablithus bijugatus
		R	Sphenolithus delphix
		R	Sphenolithus conicus
		R	Pontosphaera sp.
		R	Reticulofenestra lockeri
		R	Coccolithus miopelagicus
		R	Cyclococcolithina leptopora
		R	Helicosphaera wilcoxanii
		R	Helicosphaera sp.
		R	Helicosphaera truempyi
		R	Shenolithus dissimilis
		R	Helicosphaera intermedia
		R	Pontosphaera multipora
		R	Sphenolithus neobabies
		R	Reticulofenestra pseudoumbilica
		R	Triquetrorhabdulus milowii
		R	Mastasterites sp.
		R	Discoaster druggii
		R	Discoaster sp., 6 arms
		R	Sphenolithus belemnus
		R	Cyclococcolithina macintyreii
		R	Helicosphaera ampliaptera
		R	Discoaster exilis
		R	Sphenolithus heteromorphus
		R	Helicosphaera granulata
			Martini (1971)
			ZONES
			AGE
520-529.5	11-4,70-72	C	Sphenolithus NP23
	11-3,98-100	C	Sphenolithus NP24
	11-2,46-48	C	Sphenolithus NP25
	11-1,72-74	C	Sphenolithus NP25
	10-6,70-72	C	Sphenolithus NP25
453.5-463	10-5,64-66	C	Sphenolithus NP25
	10-4,70-72	C	Sphenolithus NP25
	10-3,70-72	C	Sphenolithus NP25
	10-2,53-55	C	Sphenolithus NP25
	10-1,70-72	C	Sphenolithus NP25
396.5-406	9-5,70-72	C	Triquetrorhabdulus NN1
	9-4,76-78	C	Triquetrorhabdulus NN1
	9-3,70-72	C	Triquetrorhabdulus NN1
	9-2,73-75	C	Triquetrorhabdulus NN1
	9-1,70-72	C	Triquetrorhabdulus NN1
339.5-349	8-3,70-72	C	Discoaster NN2
	8-2,75-77	C	Discoaster NN2
	8-1,74-76	C	Discoaster NN2
282.5-292	7-4,63-67	C	Sphenolithus NN5
	7-3,70-72	C	Sphenolithus NN5
	7-2,70-72	C	Sphenolithus NN5
	7-1,95-97	C	Sphenolithus NN5
			OLIGOCENE
			MIOCENE
			AGE

Fig. 2 - Distribution and relative abundance of middle Oligocene-early Miocene calcareous nannofossils of DSDP Site 354 (C: common, F: few, R: rare).

The last (and only) occurrence of *Helicosphaera ampliaperta* and the first occurrence of *Discoaster exilis* in sample 7–4, 65–67 cm, are considered reliable enough data to assign the uppermost part of this sequence to NN5.

Bukry (1973, 1975) used the stratigraphic range of *Sphenolithus belemnos* to define the boundaries of the homonymous zone. Following this scheme, sample 7, cc (the only one where *S. belemnos* was found) is assigned to the *S. belemnos* Zone (CN2 of Okada & Bukry, 1980).

At the same level at which *S. belemnos* disappears the end of the *Discoaster deflandrei* acme and the extinction of the *Helicosphaera ampliaperta* define the base of the *Sphenolithus heteromorphus* Zone, CN4.

The *Helicosphaera ampliaperta* Zone, CN3 (the base of which is determined by the first appearance of *Sphenolithus heteromorphus* and the extinction of *Sphenolithus belemnos* and the top by the termination of the *Discoaster deflandrei* acme and the extinction of *Helicosphaera ampliaperta*) is not represented in the sequence considered here since the two events which should mark the upper boundary of CN3 coincide here with the top of CN2 (extinction of *Sphenolithus belemnos*). Perch-Nielsen considered the specimens of *Triquetrorhabdulus carinatus* contained in sample 7, cc too rare to use the extinction to define the upper boundary of NN2, and so assigned Section 8–1 to the *Discoaster druggii* Zone, NN2 and sample 7, cc to the *Sphenolithus belemnos* Zone, NN3. She assigned core 7, including Section 7–4 and above, to *Sphenolithus heteromorphus* Zone, NN5.

Since the associations found at Site 354 are quite good some thought has been given to possible additional stratigraphic indicators (first/last appearance: FAD/LAD). A few species having at Site 354 the first or the last appearance close to zonal boundaries are plotted in Fig. 3 together with the traditional zonal markers.

Special attention is given to:

– *Helicosphaera compacta* LAD, at the top of NP23/CP18 (Martini, 1971; Okada & Bukry, 1980) (see also Perch-Nielsen, 1977a, Site 357, and Perch-Nielsen, in Beckmann et al., 1981);

– *Sphenolithus predistentus* LAD, at the top of NP24 (see also Bramlette & Wilcoxon, 1967; Roth, 1973, Site 165A; Perch-Nielsen, 1977a, Site 357);

– *Reticulofenestra lockeri* and *Coccolithus miopelagicus* FAD, at and near the base of NP25, respectively;

– *Helicosphaera trümpyi* and *Sphenolithus dissimilis* FAD, at the base of NN1;

– *Sphenolithus dissimilis* and *Ericsonia obruta* LAD, within NN1;

– *Cyclococcolithina macintyeri* FAD, at the base of CN2.

#### Summary of biostratigraphic results.

The stratigraphic results and the first-order correlation between planktic



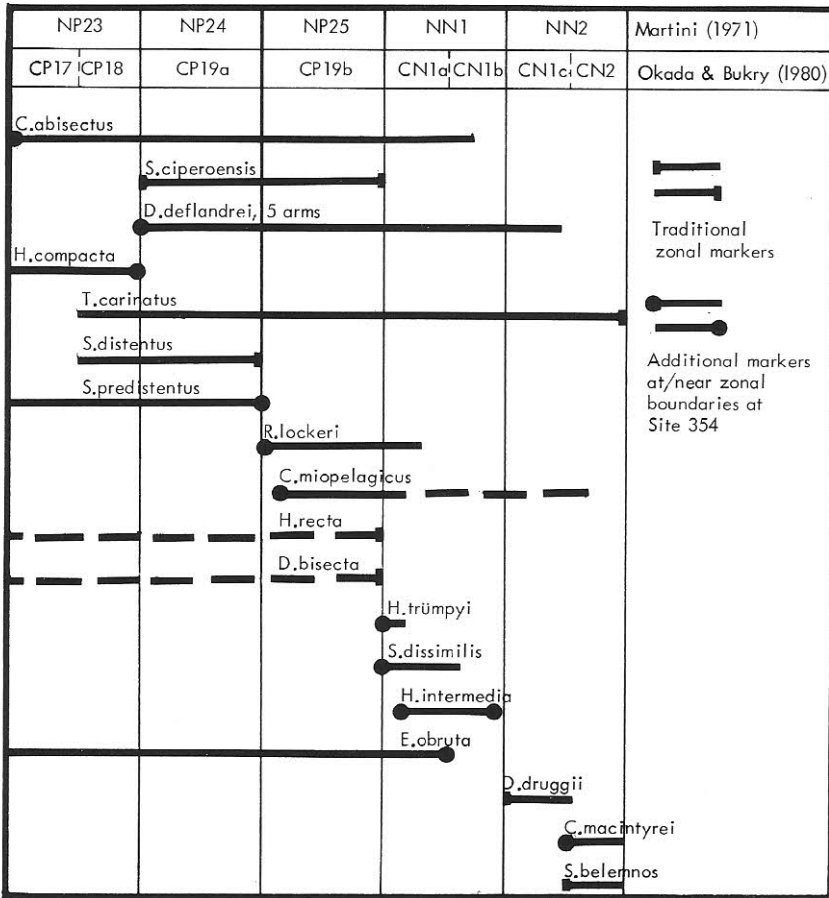


Fig. 3 — Traditional zonal markers and additional events at/near the zonal boundaries at Site 354.

foraminiferal and calcareous nannofossil zonations are summarized in Fig. 4. Foraminiferal ranges and nannofossil datum planes provide the most reliable scheme for a good correlation.

The following events occur at the same time:

- LAD of *Globigerina ampliapertura* and LAD of *Reticulofenestra umbilica* (Zone N.1/NP22);
- FAD of *Globorotalia opima opima* and FAD of *Sphenolithus distentus* (Zone N.1/NP23);
- FAD of *Globorotalia kugleri* and LAD of *Sphenolithus ciproensis*, *Helicosphaera recta* and *Dyctiococcites bisecta* (Zone N.3/NN1);
- FAD of *Globigerinoides primordius* and end of the *Cyclicargolithus abisectus* acme (Zone N. 4/NN1);
- FAD of *Globigerinoides bisphaericus* and FAD of *Sphenolithus belem-*

nos and *Helicosphaera ampliaperta* (Zone N.8/NN2).

The co-occurrence of the last events is however questionable; since the lower boundaries of the Zones N.8 and CN2 lie between two not continuous cores, the first appearance of *Globigerinoides bisphaericus*, *Sphenolithus belemnos* and *Helicosphaera ampliaperta* could have followed whichever sequence and be not synchronous at all. Into the same questionable account must be taken the boundaries between the Zones NP22/NP23 and CP16/CP17 which possibly lie anywhere in the 76 metres of not cored sediments.

The Oligocene/Miocene boundary is placed at the top of nannofossil Zone *Sphenolithus ciperoensis* (NP25 of Martini, 1971, and CP19 of Okada and Bukry, 1980). This horizon is marked by the last occurrence of *Sphenolithus ciperoensis*, *Helicosphaera recta* and *Dyctiococcites bisecta* and by the first occurrence of *Globorotalia kugleri* s.s. The boundary coincides with the base of foraminiferal Zone *Globorotalia kugleri* of Bolli (1957, 1966) and with the base of Zone N.4 of Banner and Blow (1965). It lies in the upper part of *Globigerina angulisuturalis* Zone (N.3) of Blow (1969) and coincides with the base of *Globigerinoides primordius* Zone of Bolli and Premoli Silva (1973).

Most of the results presented here are in good agreement with the criteria proposed by the Working Group on Paleogene/Neogene Boundary (Cati et al., 1981). The level of first appearance of *Globoquadrina dehiscens* falls within the range of *Globorotalia kugleri* in the Italian sections studied by the members of the Working Group. This level correlates with the top of the standard nannofossil Zone NP25 where the LADs of *Sphenolithus ciperoensis*, *Helicosphaera recta*, *Dyctiococcites dictyodus* and *Zygrhablithus bijugatus* are recognized. Therefore the first appearance of *Globoquadrina dehiscens* is one of the datum planes proposed by the Working Group at the Oligocene/Miocene boundary. *Globoquadrina dehiscens* is also found within the *Globorotalia kugleri* Zone in the equatorial Pacific and Indian Oceans (Bizon & Müller, 1979) and close to the Oligocene/Miocene boundary in New Zealand (Jenkins, 1971). In the classical Oligocene-Miocene Cipero Formation of Trinidad *Globoquadrina dehiscens* was reported from the *Catapsydrax stainforthi* Zone (Bolli, 1957, 1966), but it was more recently found already in the *Catapsydrax dissimilis* Zone (Bolli, pers. comun.). Since the Ceara Rise, where Site 354 was drilled, is geographically very close to Trinidad, the late appearance of *Globoquadrina dehiscens* (within the Zone N.5) was probably environmentally controlled.

#### Acknowledgements.

The Author is grateful to the Deep Sea Drilling Project for providing the material for this study. She wishes to express her sincere thanks to K. Perch-Nielsen who read and helpfully criticized an earlier draft, to H.M. Bolli, M. Toumarkine and J.P. Beckmann for reading and discussing the manuscript, to F. Steininger, F. Rögl and all the members of the Working Group on the Paleogene/Neogene Boundary for the stimulating discussions on biostratigraphic problems of the Oligocene-Miocene interval, to H.E. Franz and U. Gerber for the SEM and photographic work, and to G. Lister who improved the English text.

Sample	Ranges of significant Planktic Foraminifera		Planktic Foraminifer Zonation		Calcareous Nannofossil Zonation		Calcareous Nannofossil Datum Levels	AGE
	Bolli 1966	Blow 1969						
7-1,95-97			Gr. fohsi fohsi		NN5	S. heteromorphus CN 4		OLIGOCENE
7-2,70-72			Gr. fohsi peripheroranda	N,8		S. belemnos CN2		
7-3,70-72			Parasubulina dimerora		NN2	S. belemnos CN1c	T. carinatus, S. belemnos, H. ampliap., J. S. heterom., S. belemnos, H. ampliaperta	
7-4,65-67			Catapsydrax			D. druggii CN1c	D. druggii	
7, cc			Catapsydrax stamforthi					
8-1,74-76			Catapsydrax	N,5	NN1	D. deflandrei CN1b		
8-2,74-76			Catapsydrax dissimilis			T. carinatus CN1		
8-3,70-72			Globorotalia kugleri	N,4		C. abisectus CN1a	C. abisectus Acme	
8, cc			Globigerina coperoensis					
9-1,70-72			Globigerina coperoensis	N,3			S. ciproensis, H. recta, D. bisectus	
9-2,73-75			Globigerina ciproensis					
9-3,70-72					NP25	D. bisectus CP19b		
9-4,76-78						S. ciproensis CP19		
9-5,70-72								
9, cc								
10-1,70-72								
10-2,53-55								
10-3,70-72								
10-4,70-72								
10-5,64-66								
10-6,70-72								
10, cc								
11-1,72-74								
11-2,46-48								
11-3,98-100								
11-4,70-72								
11-5,70-72								
11-6,70-72								
11, cc								
12-1,70-72								

Fig. 4 — Summary of principal biostratigraphic events and correlation of planktic Foraminiferal and calcareous nannofossil zonations.

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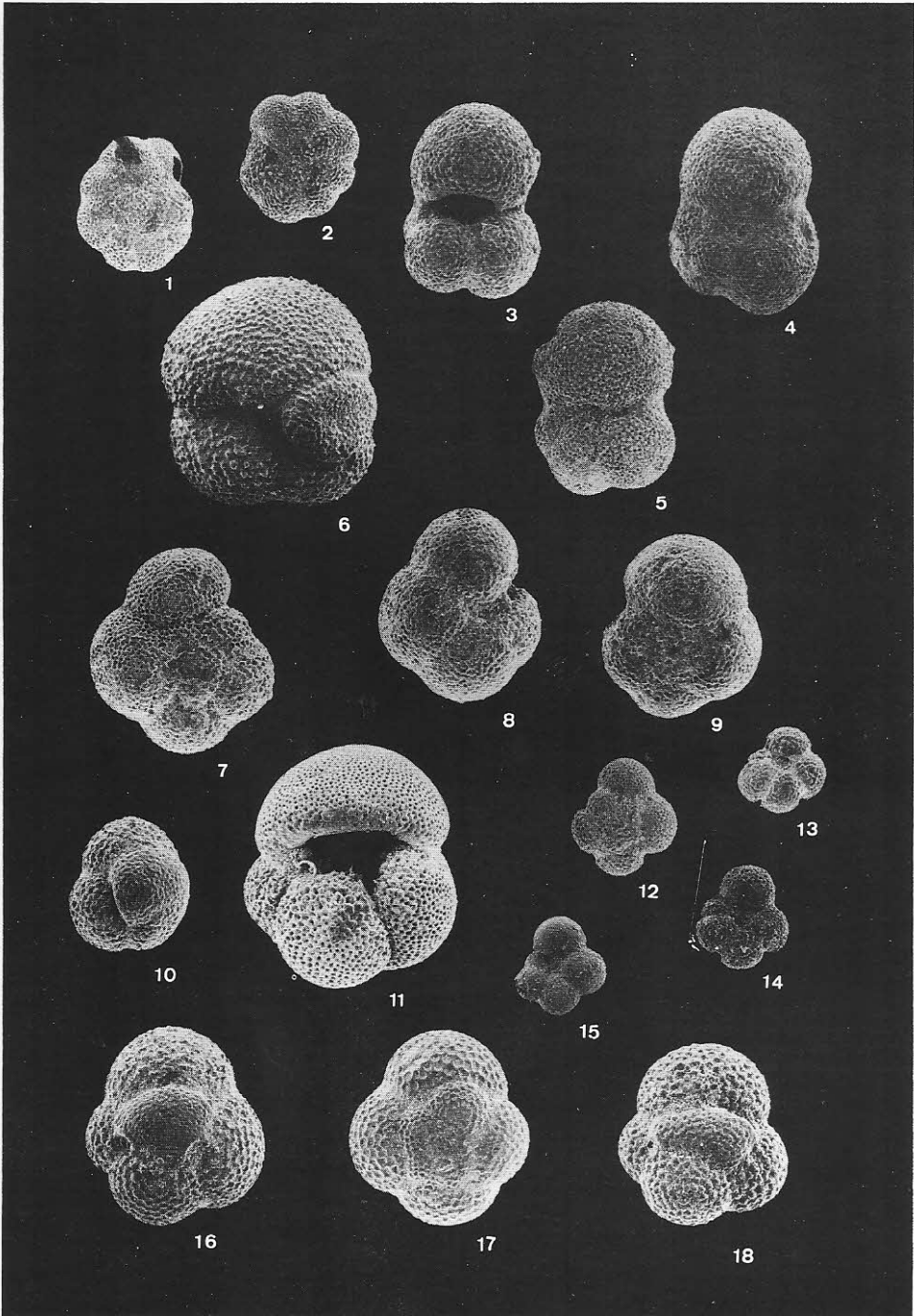
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## PLATE 3

(All figures x 75)

- Fig. 1, 2 — *Globorotalia kugleri* Bolli. 1) spiral view, 2) umbilical view. Sample 9-5, 70-72 cm. N. 3 Zone: Miocene.
- Fig. 3 - 5 — *Globigerinoides primordius* Blow & Banner. 3) umbilical view, 4, 5) spiral view. Sample 9-3, 70-72 cm. N. 4 Zone: Miocene.
- Fig. 6 — *Globigerina tripartita* Koch. Sample 10-5, 64-66 cm. N. 2 Zone: Oligocene.
- Fig. 7 - 9 — *Globorotalia opima opima* Bolli. 7, 9) spiral view, 8) umbilical view. Sample 11-1, 72-74 cm. N. 2 Zone: Oligocene.
- Fig. 10 — *Catapsydrax unicavus* Bolli, Loeblich & Tappan. Sample 11-1, 70-72 cm. N. 2 Zone: Oligocene.
- Fig. 11 — *Globigerina ampliapertura* Bolli. Sample 12-1, 70-72 cm. N. 1 Zone: Oligocene.
- Fig. 12 - 14 — *Globigerina ciperoensis angulisuturalis* Bolli. 12) spiral view, 13, 14) umbilical view. Sample 10-5, 64-66 cm. N. 2 Zone: Oligocene.
- Fig. 15 — *Globigerina ciperoensis angustiumbilocata* Bolli. Sample 11-4, 70-72 cm. N. 1 Zone: Oligocene.
- Fig. 16 - 18 — *Catapsydrax dissimilis* Cushman & Bermudez. 16, 18) umbilical view, 17) spiral view. Sample 10-5, 64-66 cm. N. 2 Zone: Oligocene.

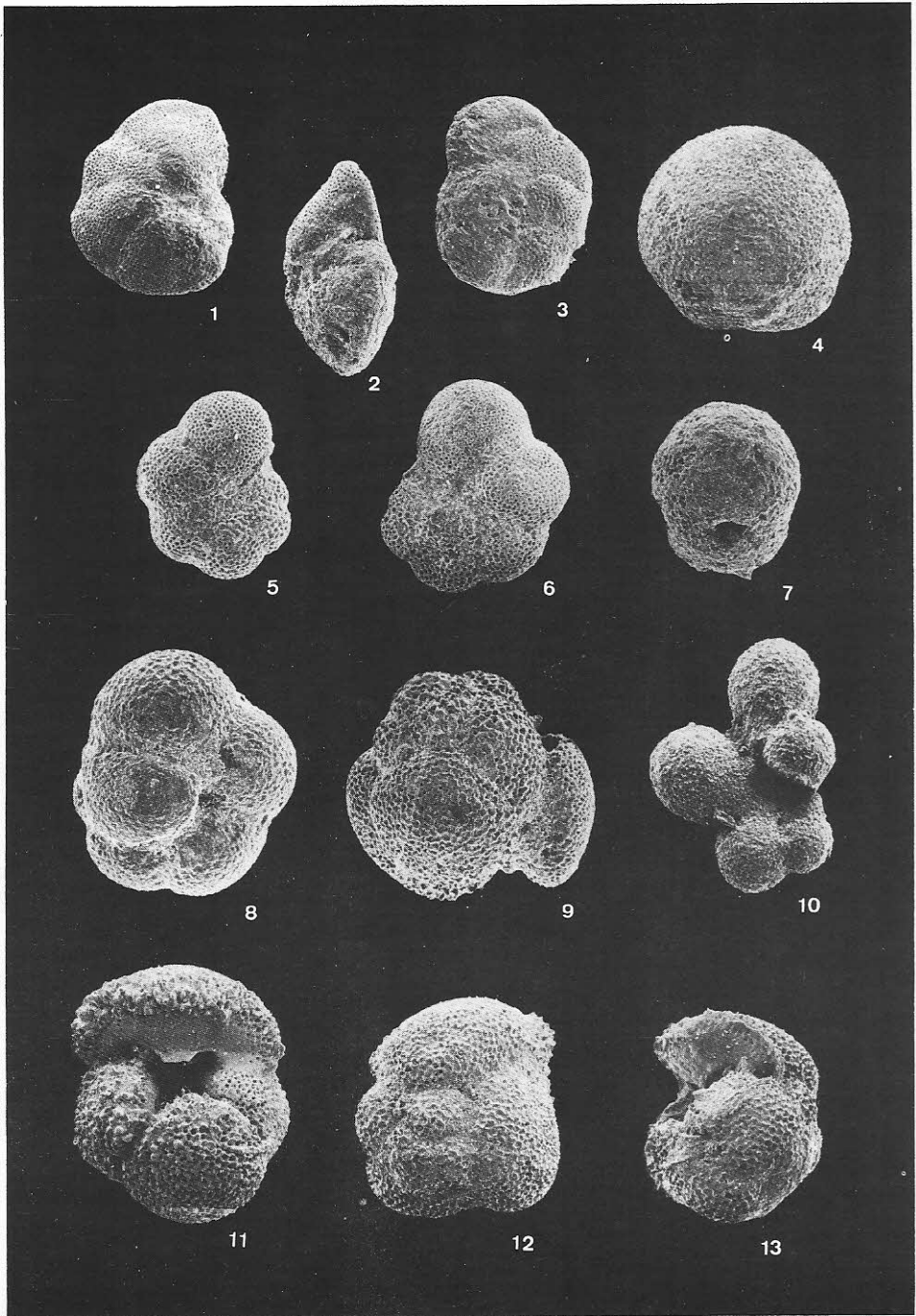


## PLATE 4

(All figures x 75, except Fig. 8 x 90)

- Fig. 1 - 3 — *Globorotalia foysi peripheroacuta* Blow & Banner. 1) umbilical view, 2) side view, 3) spiral view. Sample 7-1, 95-97 cm. N. 8 Zone: Miocene.
- Fig. 4 — *Praeorbulina glomerosa circularis* Blow. Sample 7-1, 95-97 cm. N. 8 Zone: Miocene.
- Fig. 5 - 6 — *Globorotalia mayeri* Cushman & Ellisor. 5) umbilical view, 6) spiral view. Sample 8-1, 74-76 cm. N. 5 Zone: Miocene.
- Fig. 7 — *Globigerinoides bisphaericus* Todd. Sample 7-1, 95-97 cm. N. 8 Zone: Miocene.
- Fig. 8 — *Catapsydrax stainforthi* Bolli, Loeblich & Tappan. Sample 8-2, 74-76 cm. N. 5 Zone: Miocene.
- Fig. 9 — *Globoquadrina altispira altispira* (Cushman & Jarvis). Sample 8-3, 70-72 cm. N. 5 Zone: Miocene.
- Fig. 10 — *Clavigerinella bermudezi* Bolli. Sample 7-3, 70-72 cm. N. 8 Zone: Miocene.
- Fig. 11 - 13 — *Globoquadrina dehiscens* (Chapman, Parr & Collins). 11) umbilical view, 12) spiral view, 13) side view. Sample 7-1, 95-97 cm. N. 8 Zone: Miocene.





## PLATE 5

- Fig. 1 — *Discoaster drugii* Bramlette & Wilcoxon. Sample 8-1, 74-76, x 1500.
- Fig. 2 — *Discoaster exilis* Martini & Bramlette. Sample 7-4, 65-67, x 2000.
- Fig. 3, 4 — *Helicosphaera ampliaperta* Bramlette & Wilcoxon. Sample 7, cc, 3) crossed nicols, 4) phase contrast, x 1500.
- Fig. 5, 6 — *Sphenolithus belemnos* Bramlette & Wilcoxon. Sample 7, cc, 5) long axis  $45^\circ$  to crossed nicols, 6) long axis  $0^\circ$  to crossed nicols, x 2000.
- Fig. 7, 8 — *Helicosphaera truempyi* Biolzi & Perch-Nielsen. Sample 9-5, 70-72, 7) crossed nicols, 8) phase contrast, x 2000.
- Fig. 9, 10 — *Sphenolithus heteromorphus* Deflandre. Sample 7-4, 65-67, 9) long axis  $45^\circ$  to crossed nicols, 10) long axis  $0^\circ$  to crossed nicols, x 2000.
- Fig. 11, 12 — *Helicosphaera bramlettei* Mueller. Sample 11-5, 70-72, 11) crossed nicols, 12) phase contrast, x 2000.
- Fig. 13, 14 — *Sphenolithus pseudoradians* Bramlette & Wilcoxon. Sample 11-5, 70-72, 13) long axis  $0^\circ$  to crossed nicols, 14) phase contrast, x 1500.
- Fig. 15, 16 — *Helicosphaera recta* (Haq) Martini. Sample 11-5, 70-72, 15) crossed nicols, 16) phase contrast, x 2000.
- Fig. 17, 18 — *Sphenolithus ciperensis* Bramlette & Wilcoxon. Sample 10-6, 70-72, 17) long axis  $45^\circ$  to crossed nicols, 18) long axis  $0^\circ$  to crossed nicols, x 2000.
- Fig. 19 — *Discoaster deflandrei*, 5 arms Bramlette & Riedel. Sample 9-5, 70-72, x 2000.
- Fig. 20 — *Ericsonia obruta* Perch-Nielsen. Sample 9-5, 70-72, x 2000.
- Fig. 21, 22 — *Sphenolithus distentus* (Martini) Bramlette & Wilcoxon. Sample 11-4, 70-72, 21) long axis  $45^\circ$  to crossed nicols, 22) long axis  $0^\circ$  to crossed nicols, x 2000.
- Fig. 23 — *Reticulofenestra umbilica* (Levin) Martini & Ritzkowski. Sample 12, cc, x 2000.
- Fig. 24 — *Triquetrorhabdulus carinatus* Martini. Sample 9-5, 70-72, x 2000.
- Fig. 25, 26 — *Sphenolithus predistentus* Bramlette & Wilcoxon. Sample 11-5, 70-72, 25) long axis  $45^\circ$  to crossed nicols, 26) long axis  $0^\circ$  to crossed nicols, x 2000.

