3. PALEOGENE PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY OF DSDP HOLE 398D, LEG 47B, VIGO SEAMOUNT, SPAIN

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INTRODUCTION

This paper discusses the Paleogene portion of the sedimentary succession recovered at Hole 398D (40° 57.6′ N, 10°43.1′ W), drilled during Leg 47B near Vigo Seamount.

The interval from the base of the Paleogene (Sample 41-3, 38-40 cm) to the base of the Miocene (top of Core 13) is represented by a continuously cored, 270-meter-thick sequence (from 527.5 to 796.9 m sub-bottom). Recovery was generally good (close to 80%) except for Cores 14, 16 through 18, and 25, in which recovery was poor to very poor.

The main lithotypes in this interval are microturbidites a few centimeters to one-half meter thick with scattered breccias and slumps. Microclasts and clasts are mainly biogenous with minor amounts of terrigenous materials. Consequently, the biostratigraphic signal is disturbed to highly disturbed throughout (i.e., Cores 32 Core 22).

BIOSTRATIGRAPHY AND CHRONOSTRATIGRAPHY

More than 300 samples were examined. The planktonic foraminiferal contents from fractions >63 μm were analyzed semiquantitatively. Range charts with the vertical distribution of the main taxa were constructed only for the lower portion from Cores 41 through 33 (Figure 1, back pocket). From Cores 32 through 13, because of abundant reworking and/or limited amounts of planktonic foraminifers at some levels, only a few biostratigraphic events and the associated assemblages recorded in this interval have been plotted (Figures 2 and 3).

Relative frequencies of benthic foraminifers, radiolarians, sponge spicules, fish debris, and ostracodes along with the main mineral components (micas, quartz, glauconite, etc.) also were plotted.

Despite the large number of samples, the poor state of preservation and the reworking of the planktonic foraminiferal faunas prevented us from recognizing all the biostratigraphic subdivisions from this time interval.

The zonal scheme used here is that proposed on the basis of tropical faunas by Bolli (1966a, b) and Premoli Silva and Bolli (1973) for the Paleocene-Eocene, and by Blow (1969) for the Oligocene.

Taxonomy of planktonic foraminifers is kept at a conservative level (see also Stainforth et al., 1975) at least for the generic names present-day classifications are still incomplete; for this reason, we preferred an older but more consistent approach. This does not apply to species and subspecies concepts on which general agreement exists.

As shown in Figures 1 to 4, we can recognize the following planktonic foraminiferal zones (from bottom to top) in Hole 398D:

1) Scattered, relatively well preserved, small globigerinids and heterohelicids attributable to the *Globigerina eugubina* Zone (Plate 1, Figure 2) are first encountered in Sample 41-3, 38-40 cm, along with a relatively abundant benthic foraminiferal assemblage. Sigal (this volume) points out that a similar fauna is present in Sample 41-5, 58-60 cm. Our samples from Sections 4 and 5 of this core do not yield any Tertiary globigerinids and heterohelicids. This zone extends up to Sample 41-2, 35-37 cm.

A lithologic break occurs in Sample 41-2, 40-42 cm where the poor, scarce residues of the lower portion of Core 41 are replaced by nannofossil chalk rich in planktonic foraminifers. As shown in Figure 1, planktonic foraminifers are unevenly distributed in the section and occur mainly in the coarser layers of the turbiditic sequences.

2) Above Sample 41-2, 35-37 cm, the coarser layers yield rich planktonic foraminiferal assemblages belonging to the *Globorotalia pseudobulloides* Zone with scattered reworked globotruncanids. These alternate with finer sediment levels still containing foraminifers of the *Globigerina eugubina* Zone. The same alternation of levels attributed to the *Globorotalia pseudobulloides* Zone occurs as high as the bottom of Core 40.

3) Sample 40, CC to Sample 40-3, 122-124 cm is attributable to the *Globorotalia trinidadensis* Zone. The zonal marker (Plate 1, Figure 6) is randomly present in the richer levels which alternate with layers yielding only a few benthic foraminifers. Assemblages are mostly dissolved or very poorly preserved.

4) At Sample 40-3, 84-86 cm, *Globorotalia uncinata* first occurs (Plate 1, Figure 8). The homonymous zone also is represented in the remaining part of Core 40 where poorly fossiliferous levels are recorded.

5) *Globorotalia angulata*, zonal marker of the overlying zone, is present only in the lower part of Core 39. Reworking is locally prominent, e.g., Sample 39-4, 65-71 cm.

	Recovery (m)	Core	Section	Interval (cm)	Planktonic Foraminiferal Assemblages	Diagnostic Planktonic Foraminifers	Planktonic foraminifers	Benthic foraminifers	Ostracods	Radiolarians	Sponges	Fish debris	Megafossils M/E/B	Quartz – Mica	Glauconite	Calcite	Reworking	Preservation	Zones	Age
613.0	7.52	22	1	27-29	*Gr. bullbrooki, Gl. inaequispira, Gl. galavisi, Globigerinatheka* spp., *Gl. yeguaensis, Gl. corpulenta, Gl. frontosa, Gl. linaperta* s. str.		|	x		○	●	x		○	|			□	*Globorotalia cerroazulensis* s. l./ *Globigerinatheka seminvoluta*	LATE EOCENE
			2	26-28			|	x		○	●			○			x	□		
			3	29-31			x	x		●	○	x		○				★		
			4	31-33			x	x		●	○	x		○				★		
			5	20-22			x	x		●	●	x	B	x				★		
				121-123				x		●	●	x		○				□		
622.5	5.52	23	1	23-25	*Gl. senni, Gr. bullbrooki, Gr. crassata, Gl. gortanii, C. pera*	*Gr. cerroazulensis* s. l.	x	x	|	●	●			○				★		
				139-141			|	x		○	○			x				□	*Truncorotaloides rohri*	
			2	67-69			○	|	|	●	○			○	x		x	★		
			3	113-115			○	|		●	○			○	x			★		
			4	76-78				x		●	○	x		x				□		
632.0	9.02	24	1	111-112	*Gr. bullbrooki, T. rohri, Gl. yeguaensis, Catapsydrax* spp., *Gl. frontosa, Hantkenina* spp., *Globigerinatheka* spp., *Gr. lehneri, Gr. spinuloinflata, Gl. senni, Gl. higginsi*		○	x		●	○			x				★		
			2	78-80				|		●	○			x				□		
			3	87-89			|	x		●	○	x		x				□		
			4	82-84			x	x	|	●	○	x		x				□		
			5	55-57			|	|		x	x							□		
			6	93-95		*Gl. linaperta* s. s., *Gr. lehneri*	●	x	|	x	x	x		x				★		
			CC				|	x	|	●	●	x		x			x	★	*Orbulinoides beckmanni*	
641.5	1.55	25	1	25-27	*Gr. bullbrooki, Gl. senni, Gr. spinuloinflata, Gl. yeguaensis, Globigerinatheka* spp.		○	x	|	●	●	x		○				★		
			CC				x	x		●	●	x		x				★		
651.0	9.66	26	1	58-60	*Gr. bullbrooki, Gl. senni, Gr. spinuloinflata, Gr. spinulosa, Gr. pentacamerata, Gl. corpulenta, Gl. linaperta* s. l., *Gl. frontosa, Hantkenina* spp., *Globigerinatheka* spp. (C), *Ph. micra*		x	x		●	●	x		x	|			★		
				64-66		*Gl. cryptomphala, Catapaydrax* spp.	●	x	|	x	x	x		x				☆		
			2	114-116			|	|						○				□	---?----?--- *Globorotalia lehneri*	
			3	27-29			○	x	|			x	E	○		○		☆		
				49-51			○	x	|			x	M	○		○		☆		
			4	32-34			x	|					B	●		○	x	★		
			5	48-50			x	○				x		●	|			★		
			6	32-34			○	x	|			x		○	|		x	☆		
			7	33-35			○	○						○				★		
660.5	7.56	27	1	54-56	*Gr. bullbrooki* (C), *Gr. aragonensis, Gl. senni* (C), *Gr. crassata, Gl. inaequispira, Gl. linaperta* s. l.		○	|						○				★		
			2	47-49			x	x						○				★		
			3	74-76			x	○						○				★	---?----?---	

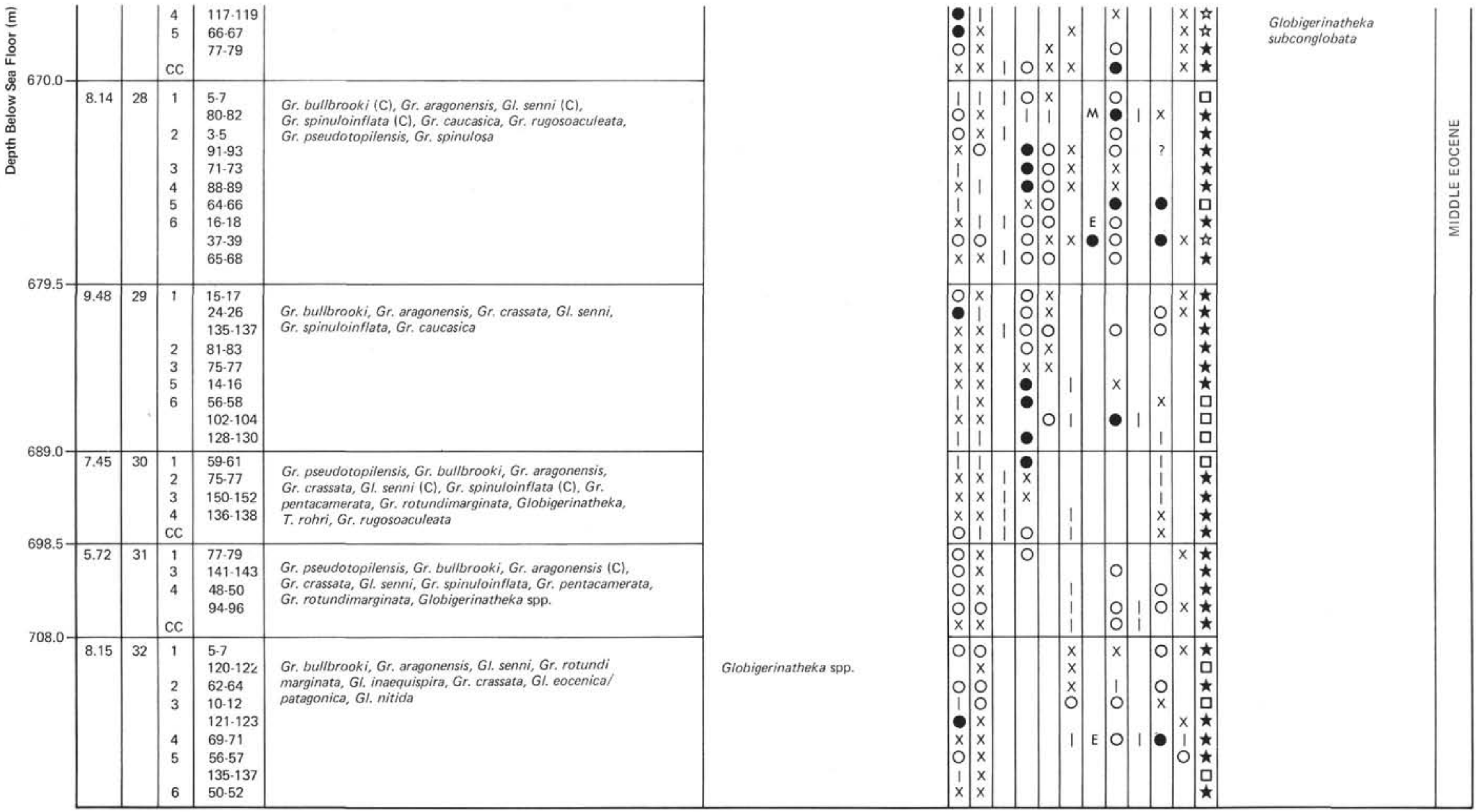

Figure 2. *Distribution of selected planktonic foraminifers in Hole 398D, late to middle Eocene.*

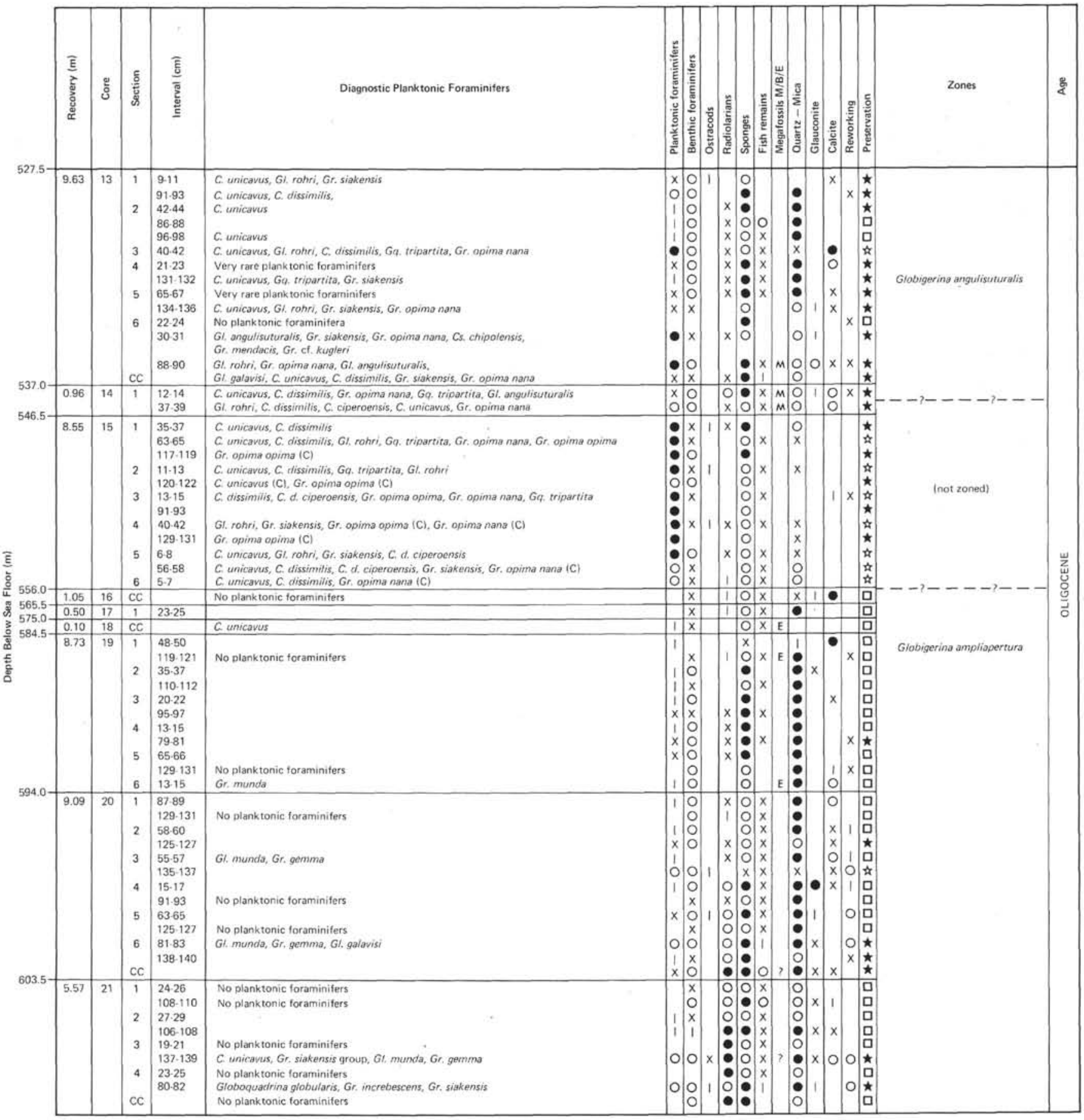

Figure 3. *Distribution of selected planktonic foraminifers in Hole 398D, late to early Oligocene.*

6) The interval from Sample 39-3, 131-133 cm to the top of Core 38 is in the *Globorotalia pusilla pusilla* Zone. However, most of Core 38 is barren of planktonic foraminifers.

7) The *Globorotalia pseudomenardii* Zone is relatively well documented from the base of Core 37 to sample 37-1, 117-119 cm. Above this level, planktonic foraminifers become very rare. One sample (36-3, 124-126 cm) still contains rare specimens of the zonal marker (Plate 1, Figure 10) and they are considered to be in place. Consequently this zone extends up to this level.

8) In Sample 35-6, 72-74 cm, the co-occurrence of *Globorotalia velascoensis*, (Plate 1, Figure 11), *G. subbotinae, G. marginodentata*, and *G. edgari* marks the upper part of the *Globorotalia velascoensis* Zone. Some *Globorotalia pseudomenardii* are still present, but they are interpreted as being reworked: *G. pseudomenardii* does not overlap with *G. marginodentata* and *G. subbotinae*. The boundary between the *G. velascoensis*

Age		Foraminiferal Zones		Site 398	Site 118	Site 119
OLIGOCENE	late	P.22	*Globigerina angulisuturalis*	Cores 13 to 15	Hiatus	Cores 12(?) to 14
		P.21	*Globigerina angulisuturalis/Globorotalia opima opima*			Cores 15 to 16
	early	P.20	*Globigerina ampliapertura*	Cores 16 to 21		
		P.19	*Gl. sellii/Pseudohastigerina barbadoensis*			Cores 17 to 18
		P.18	*Globigerina tapuriensis*	? Hiatus ?		? ?
EOCENE	late	P.17 P.16	*Globorotalia cerroazulensis* s. l.	Core 22 to Sample 23-1, 23-25 cm		Hiatus
		P.15	*Globigerinatheka semiinvoluta*			
	middle	P.14	*Truncorotaloides rohri*	Samples 23-1, 139-141 cm to 24-6, 93-95 cm		
		P.13	*Orbulinoides beckmanni*	Samples 24,CC to 26-1, 5-7 cm		
		P.12	*Globorotalia lehneri*	Samples 26-1, 114-116 cm to 32-1, 5-7 cm		Section 19-1
		P.11	*Globigerinatheka subconglobata*			Section 19-2 to Core 22
		P.10	*Hantkenina aragonensis*	Hiatus	Cores 12, 2-145 to 14-1	
	early	P.9	*Globorotalia pentacamerata*		Hiatus	Core 23
		P.8	*Globorotalia aragonensis*			Not recovered
		P.7	*Globorotalia formosa formosa*	Core 33 to Sample 34-2, 26-28 cm	Section 14-2	
		P.6	*Globorotalia subbotinae*	Samples 34-2, 102-104 cm to 35-1, 83-85 cm	Samples 14,CC to 15,CC	Core 24
			Globorotalia edgari	Samples 35-2, 16-18 cm to 35-4, 108-110 cm	Cores 16(?) to 17(?)	
PALEOCENE	late	P.5	*Globorotalia velascoensis*	Sample 35-5, 137-139 cm to 39-4, to ?	Cores 18 to 21	Cores 25 to 27
		P.4	*Globorotalia pseudomenardii*	Samples 37-1, 117-119 cm to 37,CC	Basement	Cores 28 to 30
	middle	P.3	*Globorotalia pusilla pusilla*	Core 38 to Sample 39-4, 131-133 cm		Cores 31 to 39
			Globorotalia angulata	Samples 39-4, 65-71 cm 115-117 cm		
		P.2	*Globorotalia uncinata*	Samples 40-1, 7-9 cm to 40-3, 84-86 cm		Core 40
	early	P.1	*Globorotalia trinidadensis*	Samples 40-3, 122-124 cm to 40-7, 28-30 cm		
			Globorotalia pseudobulloides	Samples 40,CC to 41-2, 15-17 cm		
			Globigerina eugubina	Samples 41-2, 33-35 cm to 41-4, 0-42 cm		

Figure 4. *Paleogene sediments recovered at Sites 398, 118, and 119, drilled off the Iberian Peninsula, plotted against planktonic foraminiferal zonal scheme and age (zonation after Bolli, 1966; Premoli Silva and Bolli, 1973; Blow, 1969). Uncertain zonal designations and presumed hiatuses are indicated by question marks and dashed lines.*

Zone and *G. pseudomenardii* Zone cannot be located precisely because the two topmost sections of Core 36 do not contain planktonic foraminifers. *G. velascoensis* disappears above Sample 35-5, 137-139 cm.

9) The *Globorotalia edgari* Zone is short, from Sample 34-4, 108-110 cm to Sample 34-2, 89-91 cm.

10) The next recognizable zone is the *Globorotalia subbotinae* Zone, spanning from Sample 35-2, 16-18 cm to Sample 34-2, 102-104 cm. In this interval, reworking of Cretaceous materials is almost absent and faunas are moderately well preserved.

11) The interval from Sample 34-2, 26-28 cm to the top of Core 33 represents the *Globorotalia formosa* Zone. Faunas are abundant and moderately well preserved. Reworking of Cretaceous forms appears again in Core 33. Some of the keeled globorotaliids (i.e., *G. gracilis, G. marginodentata*) are absent in the topmost section of Core 33. This suggests either an increase of dissolution or that the top of Core 33 is referable to the overlying *Globorotalia aragonensis* Zone. However, the species (*Globorotalia pentcamerata*) whose appearance marks the beginning of the zone is not present.

12) Starting from the base of Core 32 to Core 22 inclusive, planktonic foraminiferal faunas are monotonous. They consist of *Globigerina senni, Globorotalia bullbrooki, G. spinuloinflata,* and *G. spinulosa* in differing amounts from sample to sample. Their preservation varies from very highly dissolved to moderately pre-

served. They are characteristic of the middle Eocene, but in most cases this assemblage shows clear evidence of being displaced in turbiditic layers. Reworking is so common that the biostratigraphic events are difficult to detect. Nevertheless, the following occurrences could have some biostratigraphic significance. They are as follows (from bottom to top): (a) The appearance of *Globigerinatheka* spp. in Sample 32-1, 5-7 cm marks the presence of the *Globigerinatheka subconglobata* Zone. (b) The occurrence of *Globigerina crypthomphala* and of the first *Catapsydrax* in Sample 26-1, 64-66 cm suggests the *Orbulinoides beckmanni* Zone (see Blow, 1969). (c) The occurrence of *Globigerina linaperta* s. str. in Sample 24-6, 93-95 cm could mark the presence of the *Truncorotaloides rohri* Zone (personal observation). (d) Forms belonging to the *Globorotalia cerroazulensis* lineage close to *G. cerroazulensis* s. str. from Sample 23-1, 23-25 cm is characteristic of the transition between the *Truncorotaloides rohri* and *Globigerinatheka semiinvoluta* zones (see Toumarkine and Bolli, 1970). This is consistent with the occurrence of few specimens of *Globigerina gortanii* and *Catapsydrax pera*.

13) Cores 21 and 20 are poor to barren in planktonic foraminifers. However, few levels (i.e., Samples 21-4, 80-82 cm and 21-3, 137-139 cm) yield rare specimens of *Globoquadrina globularis* (Plate 1, Figures 15 and 16), *G. increbescens* Plate 1, Figure 14), *Catapsydrax unicavus, Globorotalia siakensis* group, *"Globigerina" munda, Globorotalia gemma*, and large globigerinids. No zonal designation can be established for this interval. However, *G. globularis* and *G. siakensis* are recorded from zones younger than the *Globorotalia cerroazulensis* Zone: according to Blow, 1969, and Berggren and Andurer, 1973, they would appear within the *Globigerina ampliapertura* Zone (i.e., P. 20). Reworking of mid-Eocene planktonic faunas (if present) is less prominent than in the underlying cores.

14) Cores 19 through 16 contain only rare benthic foraminifers but are rich in sponge spicules. Recovery was very poor in Cores 18 through 16. No zonal designation can be made.

15) Most of Core 15 consists of a six-meter-thick marly nannofossil chalk layer which has been interpreted as belonging to a slump. Those calcareous sediments yield a rich, moderately preserved, planktonic foraminiferal fauna attributable to the *Globigerina ampliapertura* Zone on the basis of the occurrence of *Globorotalia opima opima, G. siakensis* group, and *Catapsydrax dissimilis ciperoensis*, and on the absence of *Globigerina angulisuturalis*. The topmost section is barren of planktonic foraminifers as were the previous cores.

16) In Sample 14-1, 12-14 cm, *Globigerina angulisuturalis* (Plate 1, Figure 17) first occurs associated with *Globorotalia siakensis, Catapsydrax dissimilis, Globorotalia opima nana*, and *Globoquadrina tripartita*. *Globorotalia opima opima* is absent. The assemblage is partially dissolved and core recovery was poor (Core 14 has only one section). Therefore, Core 14 is tentatively placed in the *Globigerina angulisuturalis* Zone.

17) The lower part of Core 13 (Sample 13-6, 88-90 cm) contains few specimens of *Globigerina angulisuturalis* and forms close to *Globorotalia kugleri*. This assemblage is attributable to the younger part of the *Globigerina angulisuturalis* Zone.

On the basis of what was discussed above, all the Paleocene biozones were recovered at Hole 398D. However, the paleontological record is discontinuous and frequently interrupted by intervals in which planktonic foraminifers are rare or absent. In particular, only the topmost part of the *Globorotalia velascoensis* Zone is documented; i.e., Sections 35-6 and 35-5. Approximately one meter of clay without planktonic foraminifers overlies the *G. velascoensis* Zone and underlies the *Globorotalia edgari* Zone, which belongs to the lower Eocene (Caro et al., 1975). Within this interval, we place the Paleocene/Eocene boundary. The *Globorotalia edgari* Zone is followed by the *G. subbotinae* and *G. formosa* zones. They represent the lower and middle part of the lower Eocene (Section 35-2 through Core 33).

An important change in the planktonic foraminiferal assemblages occurs between the top of Core 33 and the base of Core 32. There is no evidence of the *Globorotalia aragonensis* Zone and the overlying *Globorotalia pentacamerata* Zone. Consequently, a gap in sedimentation seems to span the upper part of the lower Eocene. This hypothesis is consistent with the occurrence of the first *Globigerinatheka* representatives, which mark the second zone of the middle Eocene, in the topmost part of Core 32.

Although the interval from Cores 32 to 22 is depositionally highly disturbed and abundant reworking masks zonal boundaries, the scattered occurrence of discrete diagnostic taxa through the sequence suggests that all the zonal assemblages of the middle Eocene were deposited at least up-slope of the area. Representatives of the *Globorotalia cerroazulensis* lineage are recorded in Section 23-1; consequently, a transition between the *Truncorotaloides rohri* (youngest of the middle Eocene) and *Globigerinatheka semiinvoluta* (oldest of the late Eocene) zones is suggested. According to this interpretation, we can infer that (a) the boundary between the middle and upper Eocene could fall in the topmost part of Core 23 or between Cores 23 and 22; and (b) considering that Core 21 is Oligocene, only Core 22 could span the upper Eocene.

The presence of *Globoquadrina globularis* (see Plate 1, Figures 15 and 16) and *Globorotalia siakensis* in Sample 21-4, 80-82 cm, which according to Blow (1969) and Berggren and Amdurer (1973) never occur before Zone P. 20, suggests a middle Oligocene age for Core 21. Consequently, a gap in sedimentation spanning at least the lowermost Oligocene Zones P. 18 and P. 19 is inferred. Such a gap also could extend into the upper Eocene; however the data from Core 22 are too poor to confirm this.

This interpretation is in disagreement with the calcareous nannoplankton data which supports placing the Eocene/Oligocene boundary at Section 19-20.

Despite the incompleteness of the paleontological record, the identification of foraminiferal zones (*Globigerina ampliapertura* and *Globigerina angulisturalis*) testifies that middle and upper Oligocene sediments were deposited in the area (from Section 15, CC through Core 13).

REMARKS ON SEDIMENT CHARACTERISTICS

Reworked and Displaced Material

During the Paleogene, reworking and downslope displacement were important processes affecting sedimentation at Hole 398D. The following comments are provided:

a) Downslope displacement and reworking from older formations are the two sedimentary processes affecting the pelagic sediments. The first process resulted in displaced material which is penecontemporaneous or only a little older than the autochthonous material (i.e., one zone into the next one)as occurs in the lower part of the Paleocene. For the second process, continuing erosion involved progressively older sediments which are mainly Cretaceous (Maestrichtian to Albian).

Some radiolarians also seem to be reworked. These are the forms which are silicified and possibly zeolitized, and whole preservation looks poor in comparison with those interpreted as being autochthonous (see Figure 5).

b) Shallow-water debris are frequent components of the coarser layers of the turbiditic sequences. Among those are fragments of mollusks, bryozoa, echinoids, and foraminifers (including larger foraminifers) and smaller shallow-water benthics (like large agglutinants, *Cibicides*, costate bolivinids, etc.) Those coarser layers are more common in Cores 32 through 26.

c) Terrigenous components consisting of quartz (opaque) grains, crystalline rock fragments, iron-ore, mica, and pyrite are also present in the coarser layers, mainly is association with displaced shallow-water faunas. In a few cases, the inorganic material is not associated with shallow-water debris, as in Core 13.

d) Glauconite can be very abundant (Sample 20-4 15-17 cm) and appears to be directly related to the amount of displaced shallow-water material (e.g., gastropod molds, etc.).

Changes in Vertical Distribution of Clastic Components

On the basis of the washed-residue content and considering the sedimentological aspects of the deposits, the following changes of Paleocene clastic component distribution can be detected (from bottom to top):

a) During the Paleocene and the lower Eocene (from Sample 41-3, 38-40 cm to the top of Core 33), sediments are mainly biogenic carbonates alternating with some levels poor to devoid of planktonic foraminifers. Allochthonous materials are frequently present, mainly derived from the erosion of Mesozoic pelagic successions: in the lower Paleocene, reworking involves Maestrichtian sediments: during the lower Eocene, reworked material also can belong to the upper Albian, i.e., *Planomalina buxtorfi* was found in Sample 33-3, 81-83 cm (Premoli Silva and Boersma, 1977).

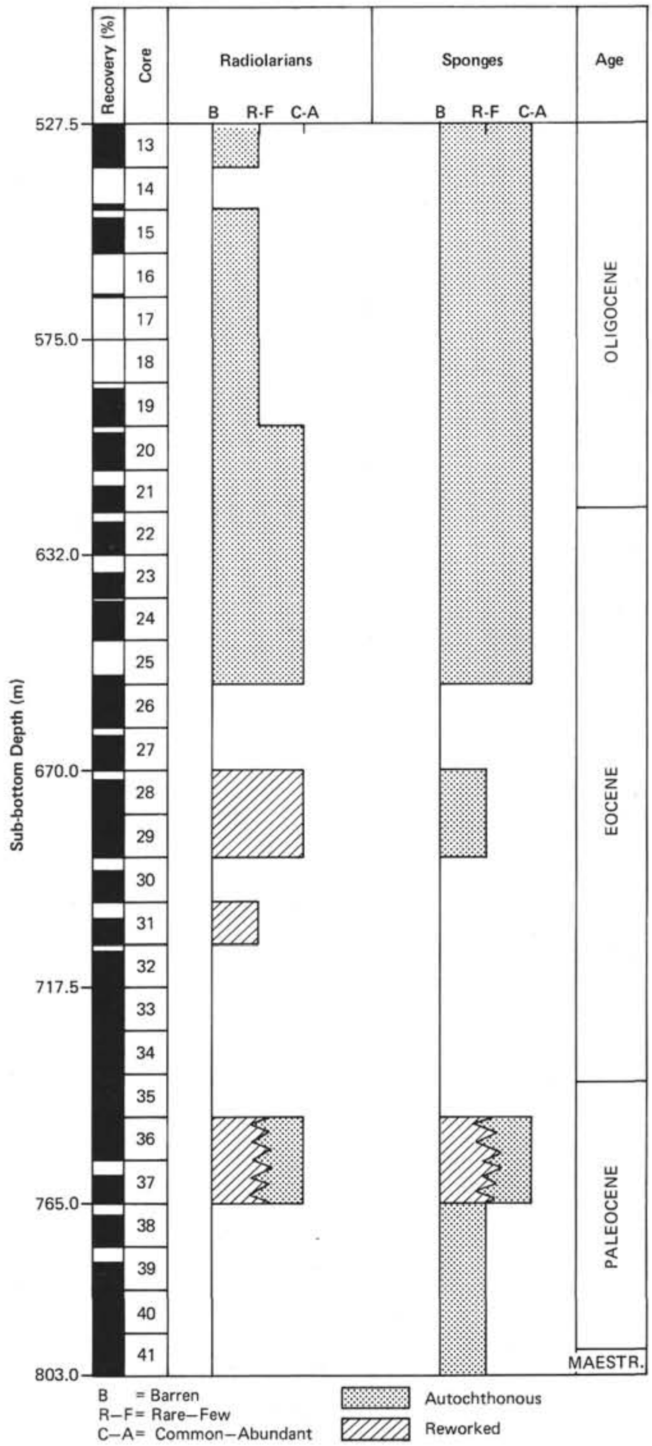

Figure 5. *Distribution and frequency of biogenic silica at Hole 398D during the Paleogene.*

Displaced levels from zone to zone are mainly concentrated in the lower Paleocene and in Core 35. The debris of shallow-water forms were recorded in small amounts only in Cores 39 and 38.

b) From Cores 32 through 26, sediments are represented by rhythmic turbiditic sequence 5 to 50 cm thick, sometimes with basal breccias. They are generally rich in calcium carbonates. Displaced shallow-water debris including mollusks, bryozoa, and large foraminifers are common components of the coarser layers, (i.e., *Nummulites* was recorded in Sample 26-4, 35 cm). The fine-grained levels finally contain mainly displaced planktonic foraminifers and/or silicified radiolarians.

c) From Cores 25 to 20, sedimentation is still mainly turbiditic. However, calcium carbonate content decreases abruptly particularly in the finest fractions (<150 μm) whose components are abundant well-preserved radiolarians and sponge spicules with minor amount of mica. Reworked planktonic foraminifers are still present, though concentrated in the coarser layers and in lesser amounts than in the underlying interval.

Within Section 20-3, radiolarians abruptly decrease and sponge spicules are the main component of the finest fractions of the turbiditic sequences (see Figure 2). Radiolarians, sponge spicules, and rare benthic foraminifers are the only autochthonous forms from Core 32 upwards.

d) Above Core 20, turbidites become less frequent as reflected by a remarkable decrease in evidence of reworking. Sediments are still poor in calcium carbonate and rich in sponge spicules, except for the 6-meter-thick nannofossil chalk layer in Core 15 which is interpreted as representing downslope slumping.

e) Terrigenous and calcareous biogenic materials again become relatively important in the last core considered here (Core 13). Rhythmic turbidites are not well-defined in this core, but sponge spicules are still the most important component of the fraction <63μm.

Depth of Deposition

In evaluating the water depth at which the Paleogene turbiditic sequence was deposited, the following observations must be considered. Turbidites even of small thickness are representative of Bouma's sequence, except for the interval from Core 32 through Core 26 in which the rhythmic sequences are less complete. Several sets of samples have been collected specifically to control the sequence and grain size distribution.

The hemipelagites and the pelitic layers (Te) consist of clay, rare benthic foraminifers, and occasionally radiolarians and spicules. The calcium carbonate content can be low (1%) or moderately high (10 to 30%). The weight of the >63 μm fraction (washed residue) relative to the total weight of the dry unwashed sample is in per cent very low, mainly less than 1 or close to 1 per cent. A low correlation between $CaCO_3$ content and weight of washed residue suggests that in some cases the presence of nannofossils must account for the relatively high carbonate content (see Table 1). Two types of hemipelagic and/or finest grain (i.e., Te) levels can be distinguished. They are characterized by (a) low weight of the 63 μm fraction and low carbonate content (i.e., Sample 29-6, 24-26 cm), (b) low weight of the 63 μm fraction but higher carbonate content (i.e., Sample 38-2, 54-56 cm). The former is representative of a deposit close to the carbonate compensation depth, (CCD); the latter could represent the tail, of a turbidite rich in nannofossils deposited in an environment close to the CCD or, if the calcareous nannoplankton are autochthonous, a less-dissolved stage comparable to Facies 8 to 9 of Berger and von Rad (1972).

The carbonate poor hemipelagic levels are distributed throughout the Paleogene succession. Autochthonous material is represented by rare benthic foraminifers and sponge spicules associated with abundant rads in the late Paleocene and middle-late Eocene. Only during the Oligocene can rare planktonic foraminifers with evidence of strong dissolution be considered in place. Those biotopes are characteristic of depths well below the lysocline and sometimes intersecting the carbonate compensation line. The inferred water depth at Hole 398D (presently at 3900 meter depth), based on the subsidence curve, was close to 2500 meters at the Cretaceous/Paleocene boundary and deepened 1000 meters by the end of the Oligocene. If these values are correct, then the CCD curve previously constructed for the North Atlantic (Berger and von Rad, 1972) is 1000 meters too deep. According to these authors, the CCD in the North Atlantic was at ~ 3600 meters in the early Eocene and close to 4500 meters at the end of the Oligocene.

Based on these interpretations, the carbonate-rich layers must be considered resedimented and their fossil content allochthonous. This interpretation also can be applied to the upper Paleocene-lower Eocene interval, which (although indicative of more homogeneous sedimentation) shows the 1-meter-thick clayey layer (Section 35-5 to 35-4) that also testifies the water depth at Hole 398D during this period was below the CCD. Moreover, Cores 35 and 34 show some evidence of possible slump deposits on a large scale, which is consistent with the hypothesis that all carbonates have been redeposited.

Rate of Sedimentation

The poorly detailed biostratigraphic subdivisions associated with the inaccurate time scale prevents us from accurately calculating the Paleogene sedimentation rate. A rough estimation of the accumulation rates is presented in Figure 6 on the basis of epoch boundary (Berggren, 1972).

These rates are relatively low and comparable to those normally associated with deep-sea pelagic sedimentation. This is in disagreement with the turbiditic type of sequences recorded at Hole 398D during the Paleogene. The highest rates recorded in the middle Eocene interval are 1.5 cm/1000 years and reflect the larger turbiditic input. These low rates must be as-

TABLE 1
Paleogene Study Results for DSDP Site 398

Sample (Interval in cm)	Total Weight (g)	Weight 63 µm Fraction (g)	63 µm (%)	$CaCO_3$ (%)	Lithological Description	Principal Components
13-3, 74-76	14.3367	0.0498	0.35	53.5	Siliceous marly nannofossil chalk	SP, QTZ, PL pdis.
14-1, 12-14	14.6053	0.0629	0.43	67.0	Quartzose nannofossil chalk	PL pdis., SP, QTZ
15-3, 99-101	23.0371	0.1130	0.49	73.0	Marly nannofossil chalk	PL pdis., SP, QTZ
19-4, 83-85	11.2808	0.1070	0.95	22.0	Quartzose calcareous sandy mudstone	QTZ, SP, B
20-4, 17-19	13.2617	0.0412	0.31	3.0	Quartzose mudstone	QTZ, SP
20-6, 83-85	18.3642	0.1170	0.64	18.0	Siliceous calcareous mudstone	SP, RW
21-4, 80-82	15.2768	0.1027	0.67	28.0	Siliceous marly nannofossil chalk	SP, PL pdis., RD ?
22-1, 27-29	15.4326	0.0448	0.29	6.5	Siliceous mudstone	RD, SP, B (rr)
22-2, 95-97	16.9724	2.1087	12.42	32.0	Calcareous siliceous sandstone	RW, RD, SP
22-4, 67-69	22.5852	0.1498	0.66	10.5	Radiolarian marly nannofossil chalk	RW (A), RD
23-3, 99-101	13.3807	0.1534	1.14	12.0	Radiolarian calcareous siltstone	RD, B
24-3, 7-9	15.6487	0.0602	0.38	26.0	Siliceous marly chalk	RD (A), RW, B
25-1, 23-25	14.8394	0.0723	0.48	32.0	Siliceous nannofossil chalk	RD (A), B
26-4, 118-120	24.9083	0.0313	0.12	5.5	Quartzose mudstone	QTZ (A), B
27-4, 78-80	15.5097	0.2247	1.45	30.0	Quartzose calcareous mudstone	QTZ (A), RW (C)
28-4, 62-64	21.7663	0.2789	1.28	31.0	Calcareous siltstone	RD sil.
29-2, 93-95	23.1452	0.1075	0.46	51.0	Calcareous quartzose mudstone	RD sil. B, QTZ
29-6, 24-26	13.9426	0.0030	0.02	1.0	Silty mudstone	RD sil. (r)
30-4, 123-125	23.8400	–	–	37.0	Calcareous mudstone	–
31-2, 34-36	20.4550	0.2301	1.12	47.5	Marly nannofossil chalk	RD sil., RW
32-1, 8-10	17.7183	0.0367	0.20	54.5	Marly nannofossil chalk	RW (A)
32-5, 54-56	16.9096	0.0274	0.16	54.5	Sandy nannofossil chalk	RW (A)
34-1, 11-13	27.1974	0.9734	3.58	73.5	Marly nannofossil foraminiferal chalk	PL (A)
34-4, 14-16	15.6854	0.7602	4.84	82.5	Marly nannofossil foraminiferal chalk	PL (A)
35-4, 39-41	11.9501	0.7752	6.48	74.0	Marly nannofossil foraminiferal chalk	PL (A)
36-2, 82-84	23.0654	0.2738	1.19	43.5	Marly nannofossil chalk	RD sil., B
37-2, 49-51	17.7110	0.1203	0.68	43.5	Siliceous marly nannofossil chalk	RD, RD sil., PL (r)
37-4, 57-59	21.2585	0.5576	2.62	66.0	Marly nannofossil chalk	RD sil., PL (r)
38-2, 54-56	21.1949	0.0254	0.12	32.5	Marly nannofossil chalk	B pdis., QTZ
39-2, 61-63	13.2553	0.0051	0.04	47.0	Marly nannofossil chalk	B pdis.

Note: SP = sponge spicules, RD = autochthonous radiolarians, RD sil. = displaced silicified radiolarians, PL = autochthonous planktonic foraminifers, PL pdis. = partially dissolved planktonic foraminifers, RW = reworked planktonic foraminifers, B = benthic foraminifers, QTZ = quartz, (rr) = very rare, (r) = rare, (C) = common, (A) = abundant. Lithological descriptions are based on visual core description and on residual composition.

cribed partly to the effect of calcium carbonate solution which removes the planktonic foraminifers, and partly to the distal nature of the turbidites.

The very low values (0.16 cm/1000 years) calculated for the late Eocene (43 to 37.5 m.y.B.P.) are striking when one considers that the sediments are still turbiditic. The existence of a hiatus spanning the upper most Eocene and the lower part of the Oligocene ($\sim$ 4 m.y.), as suggested by our biostratigraphic observations, could account for an underestimated sedimentation rate.

COMPARISON WITH SITES 118 AND 119 (LEG 12)

Paleogene sediments were recovered at Sites 118 and 119 drilled in the western part of the Bay of Biscay some miles north of Vigo Seamount. Their stratigraphy is summarized in Figure 7 and the estimated rates of sedimentation are shown in Figure 8.

The comparison of the Paleogene successions from those sites with Hole 398D shows that their depositional histories differed (see Figures 4 and 9).

Their characteristics can be summarized as follows:

Site 118

Location: side of a basement high.

Type of deposits: pure pelagic with some non-deposition and/or erosion.

Site 119

Location: more basinal than Site 118.

Type of deposits: turbiditic sediments at the beginning of the Tertiary; by late Paleocene through Oligocene, pure pelagic with episodes of non-deposition and/or erosion.

Hole 398D

Location: deep sedimentary basin.

Type of deposits: very distal turbidites with differing supply rates, rare breccias and slumps.

Such differences between the sites reflect differing topographic settings and distances from the continental margins and/or supplying areas. The only characteristic common to the three sites is that the water depth was well below the lysocline and frequently intersected the CCD. Planktonic foraminiferal faunas are frequently dissolved.

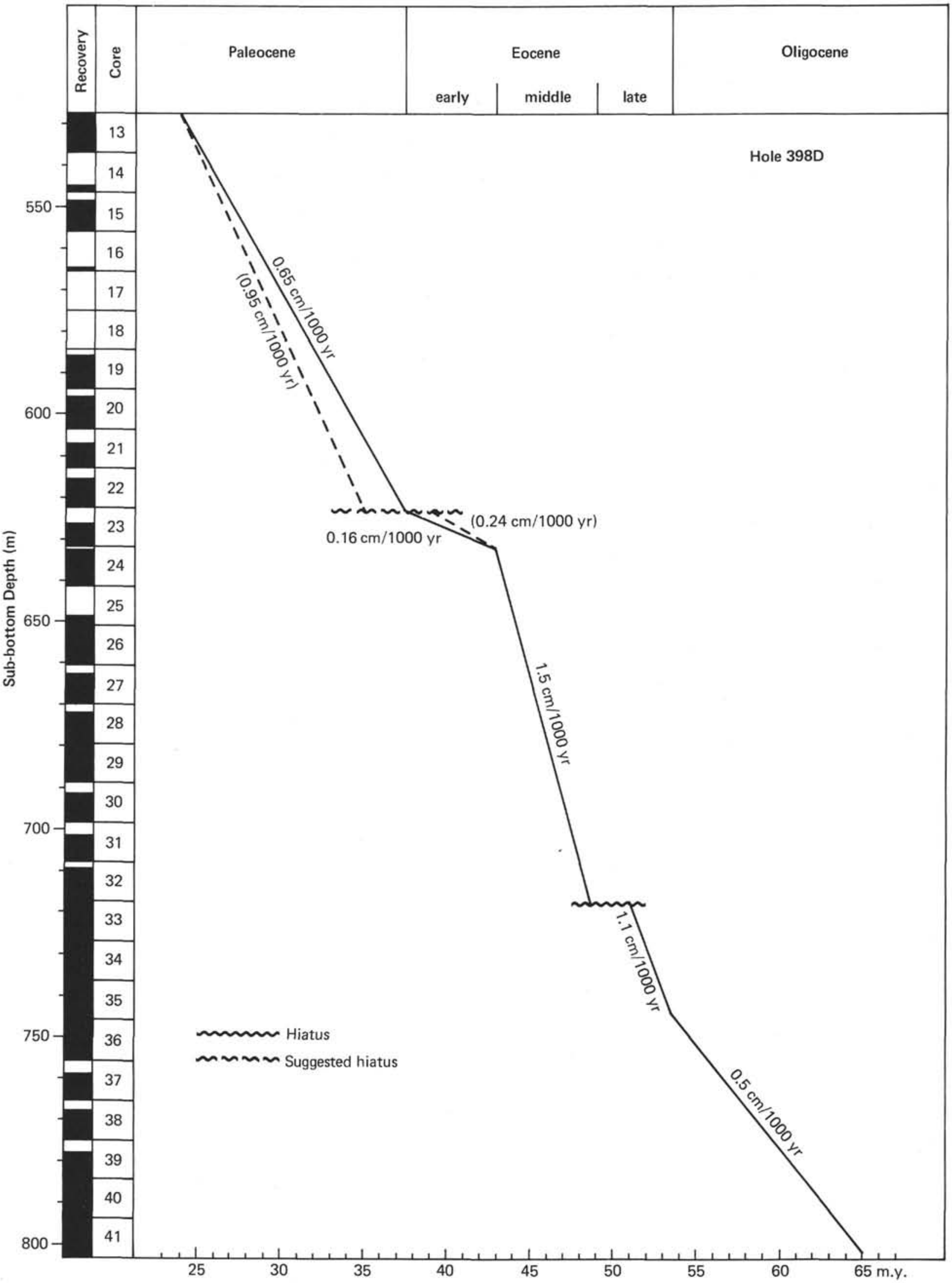

Figure 6. *Estimated Paleogene rate of sedimentation at Hole 398D. Dashed line represents the inferred sedimentation rate on the assumption of a 4-m.y. gap at the Eocene/Oligocene boundary. Time scale after Berggren (1972).*

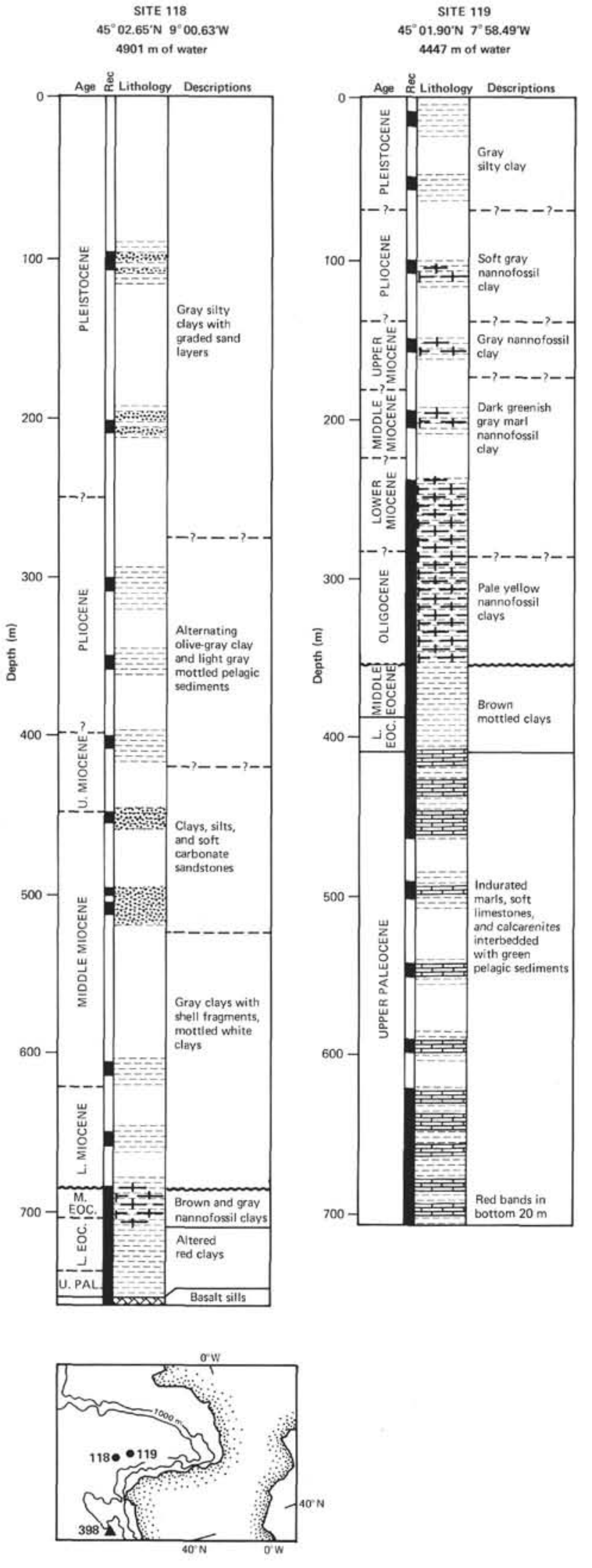

Figure 7. *Stratigraphy of Sites 118 and 119 in the Bay of Biscay (after Laughton et al., 1972a,b).*

Biogenous silica is distributed differently at the three sites. Sponge spicules, an abundant component of the autochthonous thanatocenosis at Hole 398D, are rarely recorded at the other two sites. Radiolarians never occur at the same level at the three sites (see Figure 9).

Some similarities of the sedimentary patterns are recorded at Sites 119 and 398 during the Paleocene (turbidites deposited in both sites). However, the turbiditic supply was about 10 times larger at Site 119 than at Site 398, as reflected by sedimentation rates estimated at 4.6 cm/1000 years and 0.5 cm/1000, respectively.

As shown in Figure 4, non-deposition or erosional regime seems to have affected the three sites contemporaneously during the late Eocene, although the duration of the gap differs from one to the others (more than 20 m.y. at Site 118, only 4 m.y. at Site 398). The other gap involving the upper part of the lower Eocene seems to be restricted to Sites 118 and 398 although the poor recovery at Sites 118 and 119 prevents an accurate evaluation.

CONCLUSIONS

From our analyses, we conclude that a complete succession of Paleocene sediments was recovered from Hole 398D. If a gap in sedimentation marks the Cretaceous/Paleocene boundary, it only involves the upper part of the Cretaceous and not the basal Paleocene represented by the *Globigerina eugubina* Zone.

The overlying part of the Paleogene contains two interruptions in the sedimentary record: one spanning the upper part of the lower Eocene and the second at the Eocene/Oligocene boundary for a duration of about 2.5 m.y. and 4 m.y., respectively.

Although turbiditic sediments are distributed throughout Hole 398D, the middle Eocene (particularly its lower part) was characterized by the maximum turbiditic influx. By constrast, slumps are concentrated in two specific periods: the Paleocene-early Eocene and in the middle Oligocene. In the former, foraminiferal nannofossil chalk layers yield well-preserved planktonic foraminifers, whereas in the latter's layers contain dissolved foraminiferal assemblages.

Cretaceous foraminifer components are always present among the reworked material in various intervals, including the Oligocene, though in differing amounts. In the Oligocene, however, Cretaceous material may have been re-worked along with the middle Eocene sediments into which it was primarily eroded.

Distribution of biogenic silica, sponge spicules, and radiolarians suggests that the area of Site 398 was intermittently within or near a region of upwelling. Larger amounts of sponge spicules according to Lisitzin (1972) are recorded at the edge of the silica belts, belts which are characterized by the presence of radiolarians and/or diatoms.

Data from the eastern side of the North Atlantic are too scattered to further develop paleogeographical reconstructions.

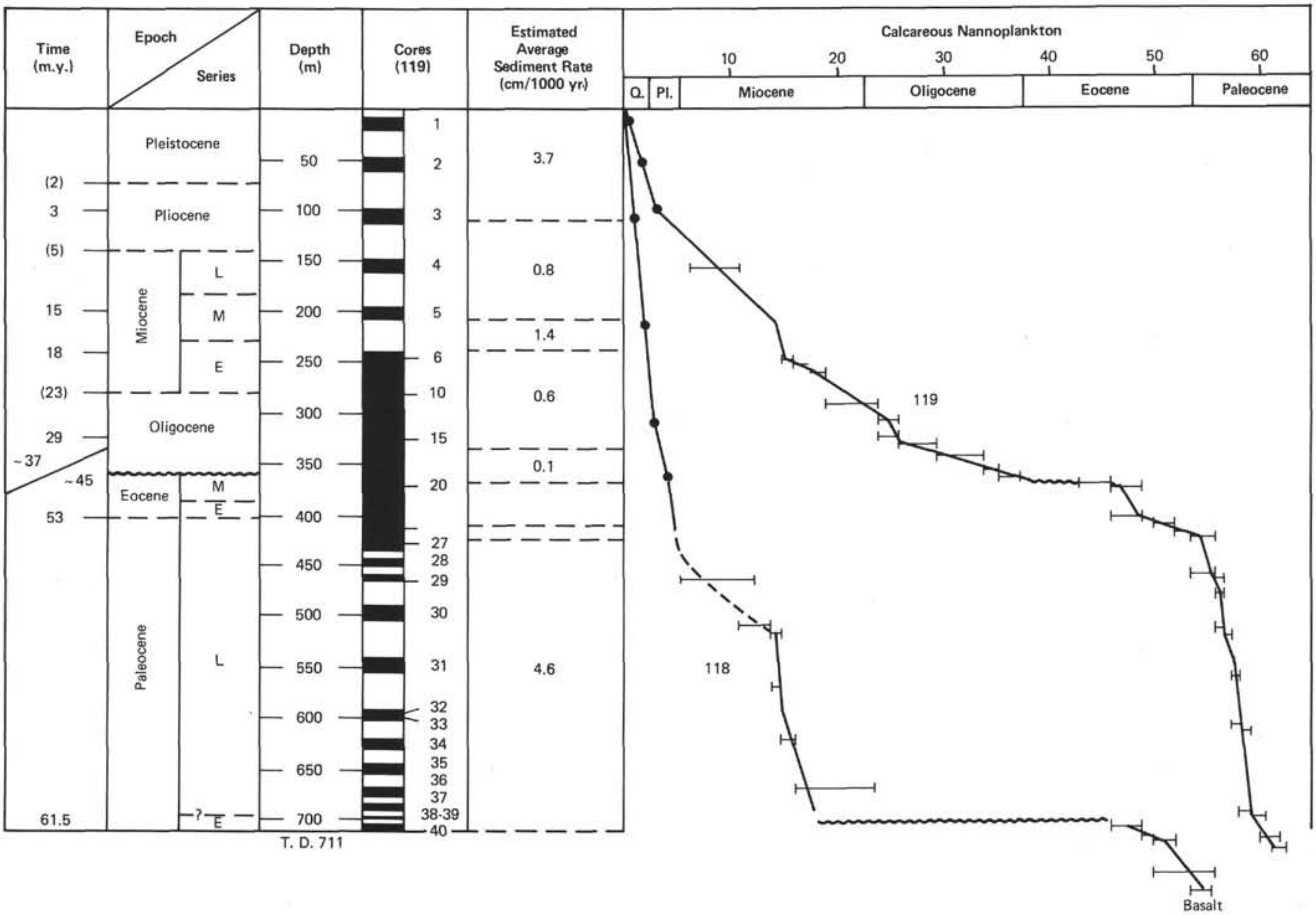

Figure 8. *Estimated average sedimentation rate of Sites 119 and 118, Bay of Biscay (after Laughton et al., 1972a,b).*

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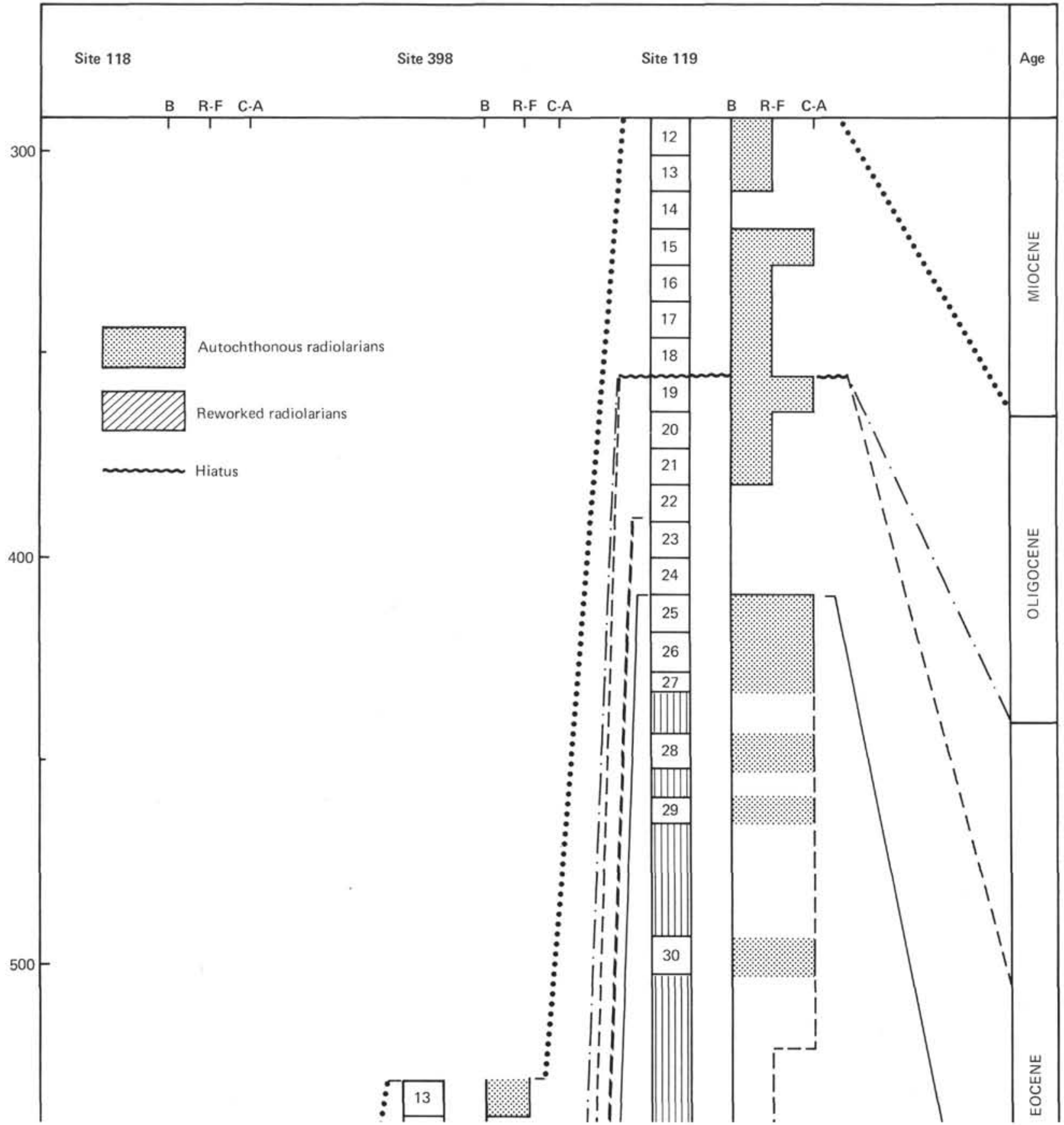

Site 118
Site 398
Site 119
Age
B R-F C-A
B R-F C-A
B R-F C-A
300
400
500
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
13
Autochthonous radiolarians
Reworked radiolarians
Hiatus
MIOCENE
OLIGOCENE
EOCENE

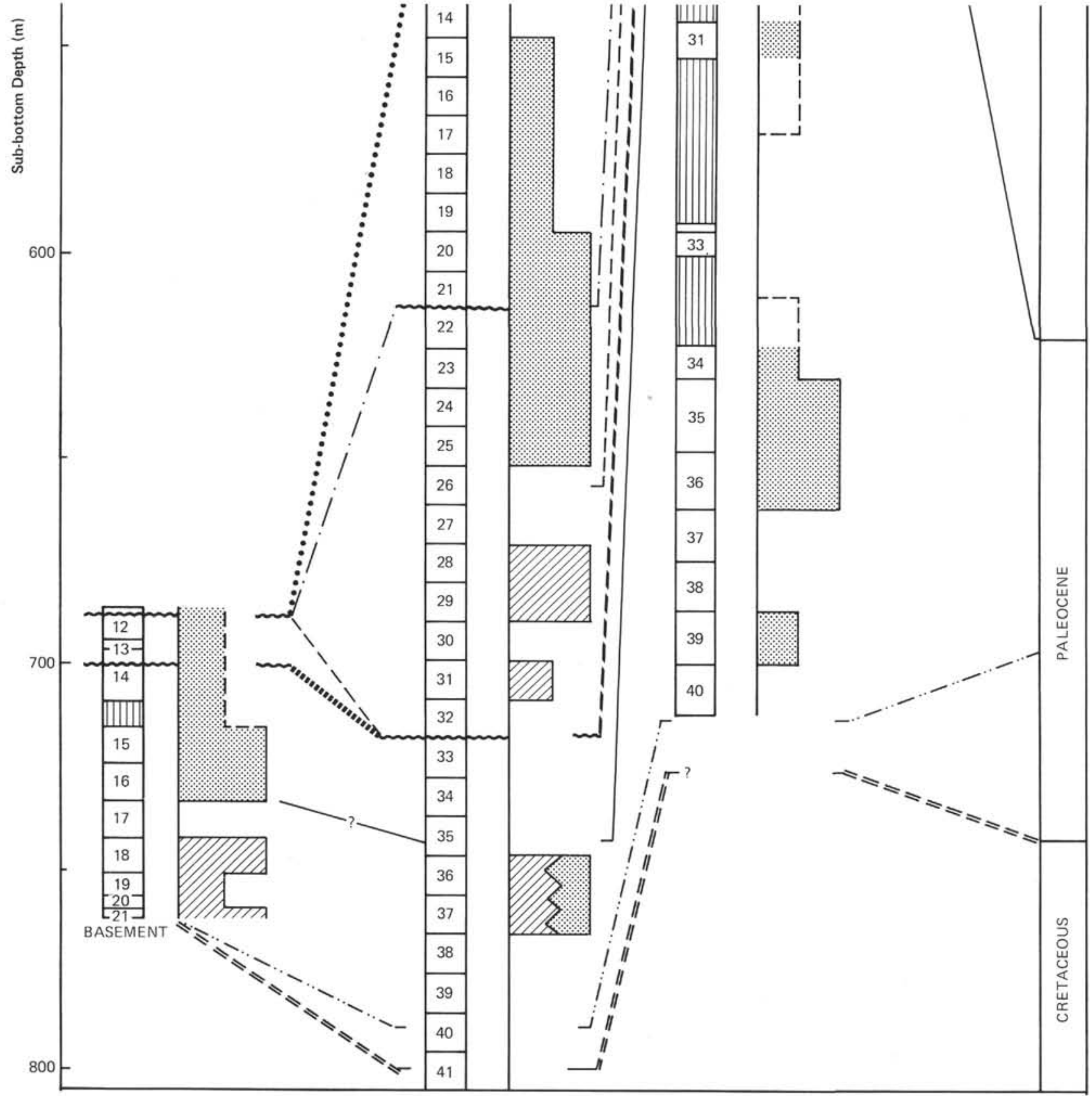

Figure 9. *Correlation between Site 398 and Sites 118 and 119 in the Bay of Biscay. Distribution and frequency of radiolarians are also plotted.*

PLATE 1

Figure 1	*Woodringina* spp. ×240. Sample 398D-41-2, 33-35 cm.
Figure 2	*Globigerina eugubina* Luterbacher and Premoli Silva ×240. Spiral view; Sample 41-2, 33-35 cm.
Figure 3	*Globorotalia uncinata* Bolli ×180. Umbilical view; Sample 398D-39-4, 65-71 cm.
Figures 4, 5	*Globigerina edita* Subbotina ×240. Spiral view; Sample 398D-41-2, 33-35 cm.
Figure 6	*Globorotalia trinidadensis* Bolli ×90. Spiral view; Sample 398D-39-4, 65-71 cm.
Figure 7	*Globorotalia inconstans* (Subbotina) ×90. Spiral view; Sample 398D-40, CC.
Figure 8	*Globorotalia praecursoria* (Morozova) ×90. Spiral view; Sample 398D-39-4, 65-71 cm.
Figure 9	*Globorotalia uncinata* Bolli ×90. Spiral view; Sample 398D-39-4, 65-71 cm.
Figure 10	*Globorotalia pseudomenardii* Bolli ×90. Spiral view; Sample 398D-35-5, 137-139 cm.
Figure 11	*Globorotalia velascoensis* (Cushman) ×100. Lateral view; Sample 398D-37, CC.
Figure 12	*Globorotalia caucasica* Glaessner ×45. Umbilical view; Sample 398D-29-1, 24-26 cm.
Figure 13	*Globorotalia lehneri* Cushman and Jarvis ×90. Umbilical view; Sample 398D-24-6, 93-95 cm.
Figure 14	*Globorotalia increbescens* (Bandy) ×45. Umbilical view; Sample 398D-21-4, 80-82 cm.
Figures 15, 16	*Globoquadrina globularis* Bermudez ×45. Umbilical view; Sample 398D-21-4, 80-82 cm.
Figure 17	*Globigerina angulisuturalis* Bolli ×90. Umbilical view; Sample 398D-14-1, 12-14 cm.

PLATE 1