

## 17. STRATIGRAPHY AND PLANKTONIC FORAMINIFERS OF CENOZOIC DEPOSITS OF THE BAY OF BISCAY AND ROCKALL PLATEAU, DSDP LEG 48

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### INTRODUCTION

During DSDP Leg 48 of the *Glomar Challenger*, drilling in the Bay of Biscay and on the Rockall Plateau at eight sites (399-406) (Figure 1) penetrated Cenozoic sediments of various thickness and stratigraphic completeness.

Zonal stratigraphy of Cenozoic deposits in the tropical belt of the world oceans has been thoroughly studied by means of planktonic foraminifers, but Cenozoic stratigraphy of higher latitudes is considerably less known. Because of the proximity of the Bay of Biscay to the Paris and Aquitain basins where stratotypes of some Paleogene and lower Miocene stages are already established, drilling in the Bay of Biscay and Rockall Plateau was important for elucidating (through planktonic foraminifers) the Cenozoic zonal and chronostratigraphic scale and the Cenozoic geologic history of the northeastern Atlantic Ocean.

The results of investigations of Leg 48 significantly supplement the findings of Leg 12 (Laughton, Berggren, et al., 1972; Berggren, 1972a, b, 1974; Poore and Berggren, 1975) on Cenozoic stratigraphy of the area. In the present study, 753 samples were taken for micropaleontological analysis; the number of samples studied in each of the holes is presented in Table 1.

### STRATIGRAPHY OF CENOZOIC SEDIMENTS IN THE SITES

The stratigraphy and planktonic foraminiferal assemblages of Cenozoic sediments (Figures 2 and 3) of the Bay of Biscay and Rockall Plateau are distinguished by a number of features.

#### Bay of Biscay

In the north of the Bay of Biscay the drilling was carried out on the lower part of the continental slope at the base of the Meriadzek Terrace (Sites 399 and 400), where the water depth reaches almost 4.4 kilometers, and at much lesser depths in the middle part of the continental slope near the margin of the Meriadzek Terrace (Site 401), and to the north of this escarpment (Site 402).

#### Sites 399 and 400

Continuous coring at Site 400 (except for the interval 9.0-74.5 m within Quaternary sediments) produced an excellent stratigraphic record, 635 meters thick. The Cenozoic section commences with upper Paleocene sediments unconformably resting on Upper Cretaceous (Maestrichtian) deposits. The upper Paleocene-lowermost Eocene (*Globorotalia formosa* Zone) consists of yellowish calcareous claystones and greenish gray clay chalk. The balance of the lower Eocene and the middle Eocene section are com-

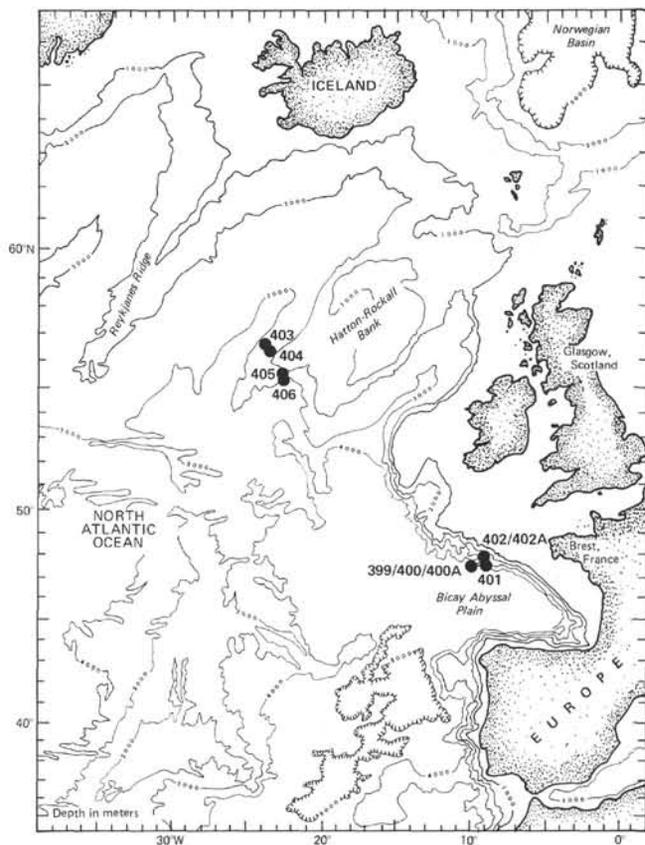


Figure 1. Location of Sites drilled on Leg 48.

TABLE 1  
Data on Sites of Leg 48

Hole	Latitude (N)	Longitude (W)	Water Depth (m)	Penetration (m)	Thickness of Cenozoic (m)	Number of Samples Examined
399	47° 23.4'	09° 13.3'	4399	72.5	72.5	10
400	47° 22.9'	09° 11.9'	4399	9	9	7
400A	47° 22.9'	09° 11.9'	4399	777.5	635	190
401	47° 25.65'	08° 48.62'	2495	341	236.5	75
402	47° 52.48'	08° 50.44'	2339.5	137	137	15
402A	47° 52.48'	08° 50.44'	2339.5	469.5	175	19
403	56° 08.31'	23° 17.64'	2301	489	489	117
404	56° 03.13'	23° 14.95'	2306	389	389	56
405	55° 20.18'	22° 03.49'	2958	407	407	125
406	55° 15.50'	22° 05.41'	2911	841	841	139

posed of greenish gray siliceous mudstones with abundant radiolarians, sponge spicules, and interbeds of porcellanites. Oligocene sediments comprise yellowish and yellowish gray siliceous nannofossil chalk with abundant radiolarians and sponge spicules, the latter sometimes to abundant that the sediment is transformed into spongolite.

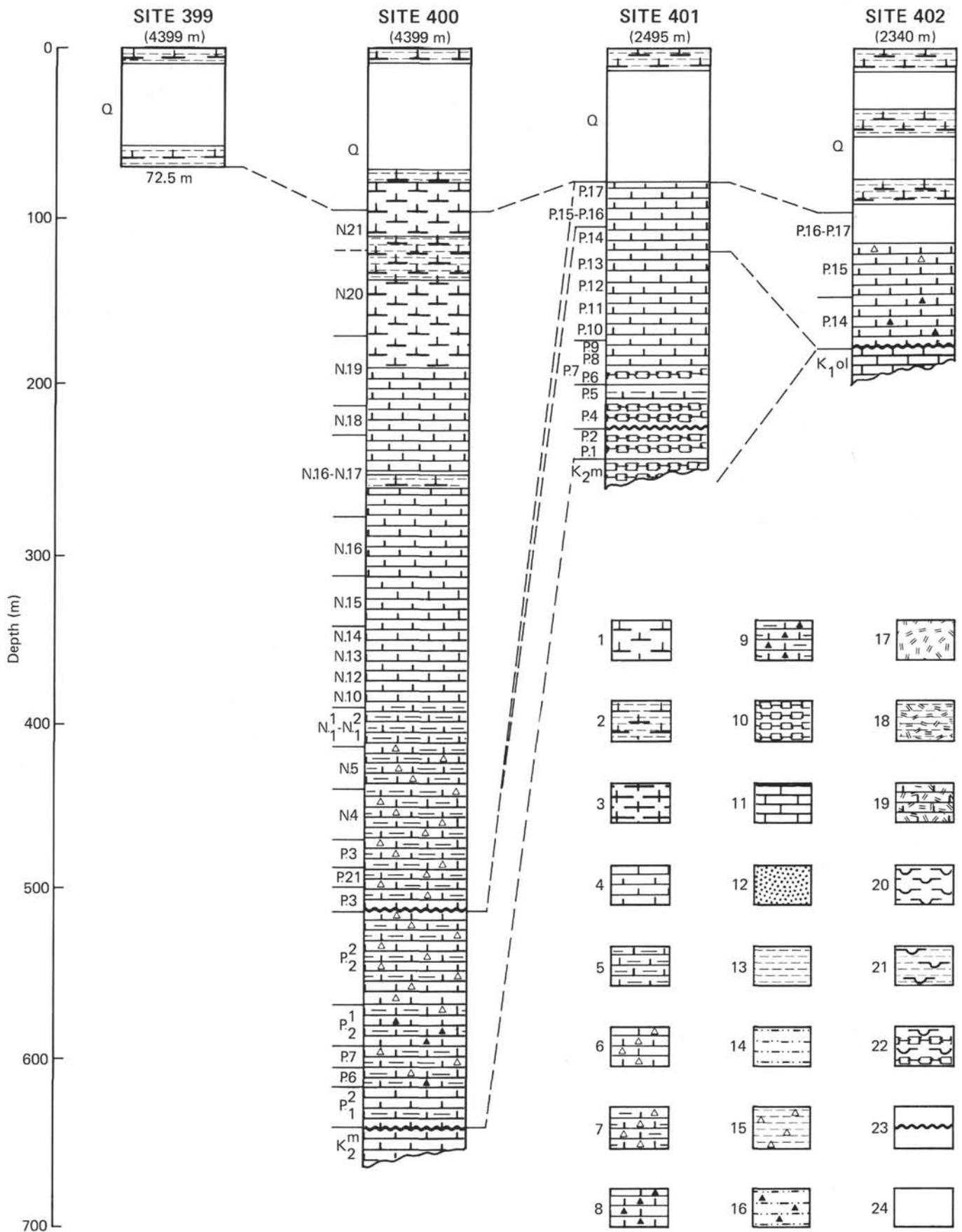


Figure 2. Stratigraphic correlation of the Cenozoic sediments penetrated by the DSDP holes in the Bay of Biscay. Stratigraphic symbols:  $K_{1al}$  – Lower Cretaceous, Albian;  $K_2 m$  – Upper Cretaceous, Maestrichtian;  $P_1?$  – Paleocene?;  $P_1^2$  – Upper Paleocene;  $P_2^1$  – Lower Eocene;  $P_2^2$  – Middle Eocene;  $P_2^3$  – Upper Eocene;  $P_3$  – Oligocene;  $N_1^1$  – Lower Miocene;  $N_1^2$  – Middle Miocene;  $N_2$  – Pliocene;  $Q$  – Quaternary; Zones:  $P.1$  – Globorotalia trinidadensis;  $P.2$  – Acarinina uncinata;  $P.4$  – Globorotalia pseudomenardii;  $P.5$  – Globorotalia velascoensis;  $P.6$  – Globorotalia subbotinae;  $P.7$  – Globorotalia formosa;  $P.8$  – Globorotalia aragonensis;  $P.9$  – Globorotalia palmerae;  $P.10$  – Hantkenina aragonensis s.l.;  $P.11$  – Globigerapsis kugleri;  $P.12$  – Globorotalia lehneri;  $P.13$  – Orbulinoides beckmanni;  $P.14$  – Truncorotaloides rohri;  $P.15$  – Globigerapsis semiinvoluta;  $P.16$  – Globorotalia cocoaensis;  $P.17$  – Globigerina gortanii-Globorotalia centralis;  $P.21$  – Globorotalia opima;  $P.22$  – Globigerina ciperoensis;  $N.4$  – Globigerinoides primordius-Globorotalia kugleri;  $N.5$  – Globigerinita dissimilis;  $N.8$  – Praeorbulina glomerata;  $N.9$  – Orbulina suturalis-Globorotalia peripheroronda;  $N.10$  – Globorotalia peripheroacuta;  $N.12$  – Globorotalia fohsi lobata;  $N.13$  – Sphaeroidinellopsis subdehiscens-Globigerina druryi;  $N.14$  – Globigerina nepenthes-Globorotalia siakensis;  $N.15$  – Globorotalia continua;  $N.16$  – Globorotalia merotumida;  $N.17$  – Globorotalia plesiotumida;  $N.18$  – Globorotalia margaritae margaritae;  $N.19$  – Globorotalia margaritae evoluta;  $N.20$  – Globorotalia miocenica;  $N.21$  – Globorotalia tosaensis;  $N_{2cr}$  – layers with Globorotalia crassaformis;  $N_{2inf}$  layers with Globorotalia inflata. Lithologic symbols: 1 – nanno ooze, 2 – clayey nanno ooze, 3 – nanno foraminiferal ooze, 4 – nanno chalk, 5 – clayey nanno chalk, 6 – nanno chalk with siliceous organisms, 7 – clayey nanno chalk with siliceous organisms, 8 – silicified chalk, 9 – silicified clayey chalk, 10 – compact nanno chalk, 11 – limestone, 12 – sandstone, 13 – clay and claystone, 14 – aleuritic clay and claystone, 15 – clay with siliceous organisms, 16 – silicified aleuritic clay, 17 – tuff, 18 – clayey tuff, 19 – tuffaceous nanno chalk, 20 – diatomite, 21 – diatomite clay, 22 – diatomite compact nanno chalk, 23 – disconformities, 24 – uncoded intervals.

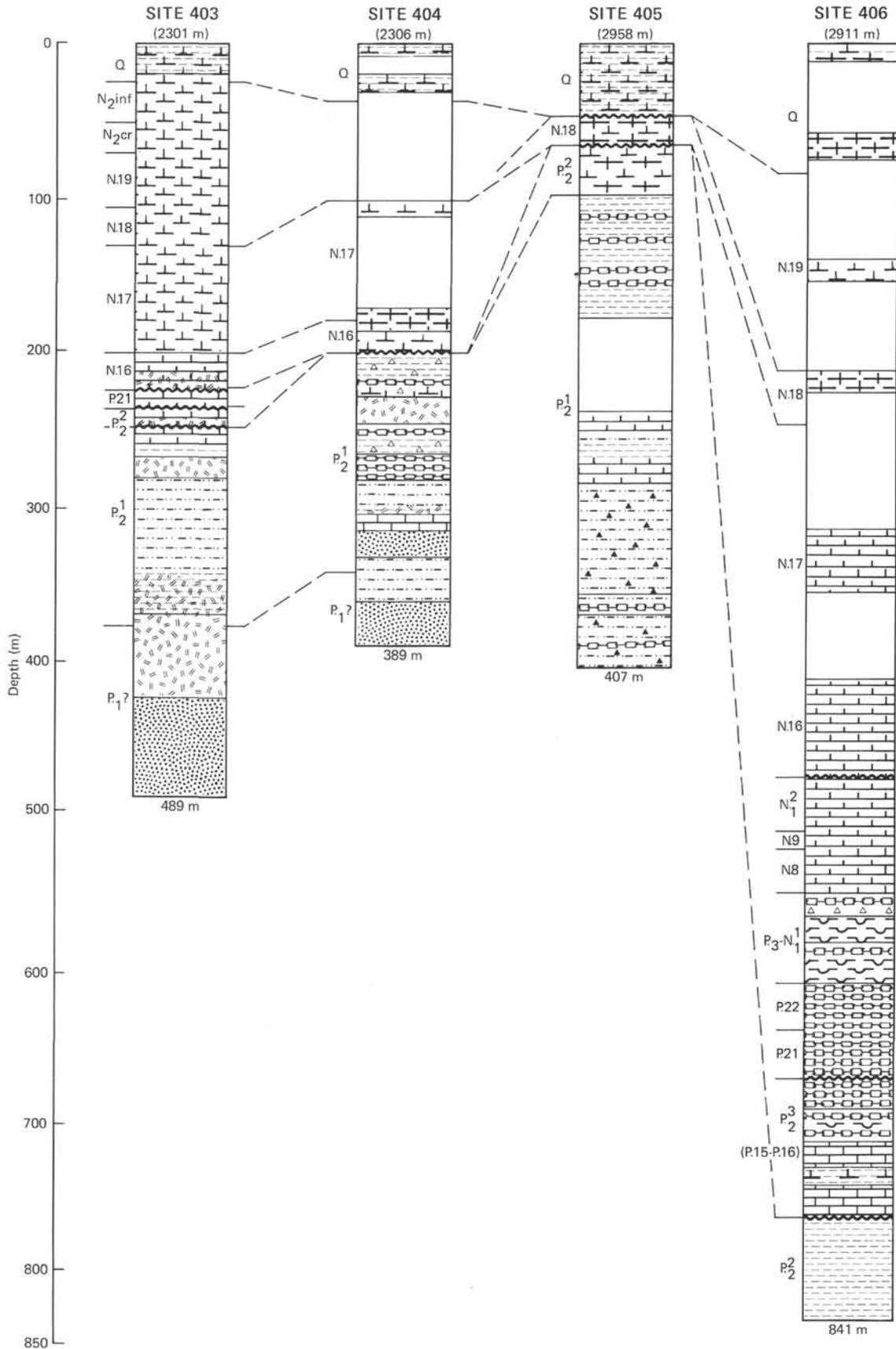


Figure 3. Stratigraphic correlation of the Cenozoic sediments penetrated by the DSDP holes on the Rockall Plateau. The same legend as for Figure 2.

Lower Miocene deposits consist of alternating pale gray clayey chalk, nannofossil chalk, and calcareous claystones frequently enriched with remains of siliceous organisms (radiolarians, sponges). The lower Miocene-Quaternary are represented by pale gray and greenish nannofossil chalk and oozes and clayey nannofossil chalk and oozes.

Planktonic foraminifers from Cenozoic deep-water sediments at Site 400 were strongly affected by selective dissolution, especially in Paleogene and lower Miocene sediments; in this interval only a few zones can be established. In middle Miocene-Quaternary sediments planktonic foraminifers are more abundant, the entire succession of zones being recognizable because the foraminiferal assemblages are composed mostly of resistant species.

### Paleocene

Upper Paleocene deposits (thickness, 27 m; Samples 58, CC to 59-1, 57-59 cm) contain rare specimens of *Globorotalia* aff. *velascoensis*, *Acarinina acarinata*, *A. mckannai*, *A. sp.*, and *Globigerina nana*.

### Eocene

Eocene deposits, (thickness, 93 m) are represented by a lower and a middle subseries; upper Eocene sediments are absent thus marking a hiatus below the overlying lower Oligocene beds.

Two early Eocene zones are identified: (1) the *Globorotalia subbotinae* Zone (Sample 57, CC) with the index species, *G. aff. edgari*, *Acarinina pseudotopilensis*, *A. acarinata*, *A. mckannai*, *Globigerina nana*, *G. compressaformis*. The microfauna appears to originate from the layers transitional to the upper Paleocene; (2) the *Globorotalia formosa* Zone (Sample 56-2, 39-41 cm), an assemblage of planktonic foraminifers that includes common *Globorotalia formosa gracilis*, *G. marginodentata*, *G. subbotinae*, *Acarinina pseudotopilensis* and rare *Globorotalia* aff. *formosa formosa*, *Acarinina camerata*, *A. mckannai*, and *A. intermedia*.

In the interval from Sample 54-1, 146-148 cm to Sample 55-2, 58-60 cm (which contains enormous radiolarian accumulations) only sporadic *Acarinina pentacamerata*, *A. interposita*, *Globigerina eocaenica*, and *G. pseudoecaena* were observed. These sediments tentatively can be assigned to the upper part of the lower Eocene (*Globorotalia aragonensis* and *G. palmerae* zones).

The middle Eocene is characterized by a poor planktonic foraminiferal assemblage. The boundary between the lower and middle Eocene tentatively is drawn in the interval between Samples 54-1, 146-148 cm and 53-1, 86-89 cm, the latter yielding, for the first time, rare specimens of *Acarinina bullbrooki*. In the interval from Sample 52-1, 123-126 cm to Sample 53-1, 86-89 cm planktonic foraminifers are sporadic; *Acarinina bullbrooki*, *A. triplex*, *A. pentacamerata*, and *Globigerina sp.* occur therein. From Sample 51-4, 58-62 cm to Sample 51-7, 8-11 cm they become more diverse and include *Acarinina bullbrooki*, *A. triplex*, *A. pentacamerata*, *Globigerina boweri*, *G. pseudoecaena*, *G. senni*, *Globorotalia frontosa*, and *G. aragonensis*, which denote a middle Eocene age.

In Samples 51-3, 58-61 cm; 51-2, 120-122 cm; and 51-1, 45-48 cm rare *Acarinina rotundimarginata* were found; the age of these sediments is not older than the *Globigerapsis kugleri* Zone (likely close to the age of sediments transitional to the *Globorotalia lehneri* Zone). The interval from Sample 47-6, 122-126 cm to Sample 50-4, 104-105 cm contains rare specimens of *Acarinina bullbrooki*, *A. sp.*, *Globorotalia frontosa*, *Globigerapsis kugleri*, *G. index*, *Globigerina sp.* Although these do not allow a specific age determination within the middle Eocene, it is possible that the interval contains, in addition to the upper part of the middle Eocene, some upper Eocene as well.

### Oligocene

Oligocene deposits in the interval from Sample 45-5, 63-65 cm to Sample 47-2, 138-140 cm are characterized by poor associations of *Globigerina prasaepis*, *G. officinalis*, *G. ouachitaensis*, *G. galavisi*, and *Globigerinita unicava*. In the basal layers, reworked middle Eocene foraminifers were identified.

The *Globorotalia opima* Zone in the interval from Sample 43-5, 20-22 cm to Sample 45-4, 92-94 cm, is readily distinguished despite the foraminifers being rare; it contains *Globorotalia opima*, *G. nana*, *Globigerinita unicava*, *Globigerina venezuelana*, *G. praebulloides leroyi*, *G. ouachitaensis*, and *G. tripartita*.

The same species, but without *Globorotalia opima*, are developed higher in the section in the interval from Sample 43-1, 37-39 cm to Sample 43-4, 27-31 cm, indicating uppermost Oligocene.

The thickness of the Oligocene section is at least 60 meters; Oligocene and lower Miocene deposits are separated by an 18.5-meter interval in which there was poor core recovery (Cores 42 and 41). Siliceous sponge spicules are extremely abundant in the Oligocene sediments.

### Miocene

The absence of such species as *Globigerina ciperoensis* and *G. angulisuturalis* in the upper Oligocene, and *Globigerinoides primordius* in the lower Miocene makes establishment of the Oligocene/Miocene boundary difficult. It is tentatively drawn below Sample 41-1, 38-40 cm, a foraminiferal assemblage of the *Globigerinoides primordius-Globorotalia kugleri* Zone is developed. This assemblage consists of *Globorotalia kugleri*, *G. nana*, *G. siakensis*, *Globigerina venezuelana*, *G. praebulloides*, *G. juvenilis*, *G. woodi*, *Globigerinita stainforthi*, *G. unicava*, *G. dissimilis*, and *Globoquadrina* aff. *praedeheiscens*.

In the interval from Sample 39-1, 79-81 cm to Sample 32-2, 58-60 cm the few specimens recovered testify only to belonging to sediments of lower Miocene age. Radiolarians and siliceous sponge spicules here are abundant.

Higher in the section (from Sample 37-1, 29-31 cm to Sample 38-1, 68-70 cm) the *Globigerinita dissimilis* Zone is clearly demarcated. It contains *Globigerinoides trilobus*, *G. altiapertura*, *Globoquadrina praedeheiscens*, *G. altispira*, *Globigerinita dissimilis*, *G. unicava*, *G. stainforthi*, *Globigerina juvenilis*, *G. bradyi*, *G. angustumbilicata*, *G. venezuelana*, *Globorotalia siakensis*, *G. continuosa*, and *G. aff. peripheroronda*.

Overlying sediments in the interval from Sample 35-1, 70-72 cm to Sample 36-2, 8-10 cm contain rare specimens of *Globorotalia peripheronda*, *G. siakensis*, *Globorotalia altispira*, *Globigerina druryi*, *G. juvenilis*, and *Globigerinoides trilobus*. The age of these sediments lies within the upper part of the lower Miocene (the *Globigerinita stainforthi*-*Praeorbulina glomerosa* zones) and the lowermost part of the middle Miocene (the *Orbulina suturalis*-*Globorotalia peripheronda* Zone), if the section is continuous. The thickness of lower Miocene and, likely, middle Miocene basal layers is 57.5 meters.

Higher in the middle Miocene, the following zones, almost the entire succession, can be observed, from the base upward: the *Globorotalia peripheroacuta* Zone (Sample 34, CC) with the index species, *G. siakensis*, *G. peripheronda*, *G. continuosa*, *G. praemenardii*, *Orbulina suturalis*, *Globigerinoides trilobus*, *Globoquadrina dehiscens*, *G. altispira*, and *Sphaeroidinellopsis seminulina*.

Core 33 yielded no recovery; this interval appears to correspond to the *Globorotalia fohsi fohsi* Zone.

The *Globorotalia fohsi lobata* Zone (from Sample 31-1, 138-140 cm to Sample 32-2, 6-8 cm) with an assemblage including the index species, *G. fohsi fohsi*, *G. siakensis*, *G. continuosa*, *G. obesa*, *G. scitula*, *Orbulina suturalis*, *O. universa*, *Sphaeroidinellopsis seminulina*, *Globigerinita siphonifera*, *Globoquadrina dehiscens*, *G. altispira*, *Globigerina bollii*, *G. juvenilis*, *G. foliata*, *G. druryi*, *Globigerinoides trilobus*, and *Globigerinita glutinata*.

The *Sphaeroidinellopsis subdehiscens*-*Globigerina druryi* Zone (Sample 30-1, 86-88 cm): its assemblage consists of numerous *Globorotalia siakensis* combined with rare *Sphaeroidinellopsis subdehiscens*, *Globigerina juvenilis*, *G. druryi*, *Globigerinita glutinata*, *Globoquadrina dehiscens*, *Orbulina suturalis*, and *Globorotalia continuosa*.

The *Globigerina nepenthes*-*Globorotalia siakensis* Zone (Sample 29-1, 145-147 cm) in which rare *G. nepenthes* and small *Globorotalia menardii* appear: other foraminifers are similar to those of the previous zone except *G. druryi* is absent.

The thickness of middle Miocene deposits is about 66 meters.

All upper Miocene zones have been distinguished but the poor specific composition of foraminifers (especially in the upper part of this age) prevents precise establishment of the boundaries.

The *Globorotalia continuosa* Zone (from Sample 25-3, 59-61 cm to Sample 28, CC) contains numerous *G. continuosa* associated with rarer *G. menardii* (small forms), *Globigerina nepenthes*, *G. bulloides*, *G. bollii*, *G. quinqueloba*, *Globigerinita glutinata*, *Orbulina universa*, *O. suturalis*, *Globoquadrina dehiscens*, *G. altispira*, *Sphaeroidinellopsis subdehiscens*, and *S. seminulina*. No *Globorotalia siakensis* specimens were found here.

The *Globorotalia merotumida* Zone (from Sample 22-4, 80-82 cm to Sample 25-2, 59-61 cm) is characterized by the index species, *G. acostaensis*, *G. menardii*, *G. languaensis*, *G. scitula*, *Orbulina universa*, *Globigerina bulloides*, *G. nepenthes*, *G. quinqueloba*, *Globoquadrina dehiscens*, *G. altispira*, *Sphaeroidinellopsis seminulina*, *S.*

*subdehiscens*, *Globigerinita glutinata*, *G. uvula*, *Globigerinoides trilobus*, and *G. bollii*.

Deposits in the interval from Sample 17-1, 25-27 cm to Sample 22-3, 80-82 cm should be attributed to the undifferentiated *Globorotalia merotumida*-*Globorotalia plesiotumida* zones. In it planktonic foraminifers are rare and poorly preserved. They include *Orbulina universa*, *Globigerina bulloides*, *G. nepenthes*, *G. quinqueloba*, *G. juvenilis*, *Globorotalia acostaensis*, *G. scitula*, *Sphaeroidinellopsis seminulina*, *S. subdehiscens*, *Globigerinita glutinata*, *G. uvula*, and *Globorotaloides hexagonus*. In the upper part of this interval sporadic specimens of *Neogloboquadrina dutertrei* appear, suggesting the presence of the *Globorotalia plesiotumida* Zone.

The uppermost Miocene (from Sample 15-2, 84-86 cm to Sample 16-1, 63-65 cm) is capped with the *Globorotalia margaritae margaritae* Zone characterized by the index species, *G. acostaensis*, *Neogloboquadrina dutertrei*, *Orbulina universa*, *Globigerina bulloides*, *Globigerinita glutinata*, *Globorotaloides hexagonus*, *Globigerinoides obliquus*, and *Sphaeroidinellopsis seminulina*. Upper Miocene deposits are 122 meters thick. Total thickness of the entire Miocene is 245.5 meters.

### Pliocene

As in case of the Miocene section, it is difficult to subdivide the Pliocene because many genera and species of planktonic foraminifers are absent as a result of selective dissolution. Only the *Globorotalia margaritae evoluta* Zone (from Sample 11-1, 95-97 cm to Sample 15-1, 114-116 cm) is reliably identified, with the index species, *G. margaritae margaritae*, *G. puncticulata*, *G. crassaformis ronda*, *G. crassaformis oceanica*, *G. inflata*, *G. acostaensis*, *G. scitula*, *G. hirsuta*, *Orbulina universa*, *Globigerina bulloides*, *G. nepenthes*, *G. concinna*, *G. quinqueloba*, *G. megastoma*, *Neogloboquadrina dutertrei*, *Globorotaloides hexagonus*, *Globigerinita glutinata*, *G. uvula*, *Turborotalita iota*, and sporadic specimens of *Sphaeroidinellopsis subdehiscens*, *Globigerinoides sacculifer*, *G. trilobus*, *G. ruber*, *G. obliquus obliquus*, and *G. obliquus extremus*. The top of the zone is drawn above Sample 11-1, 95-97 cm in which the last rare specimens of *Globorotalia margaritae evoluta* were recognized, although disappearance of this species may have been caused by ecological or taphonomic factors.

In the interval from Sample 3-5, 92-94 cm to Sample 10-3, 27-29 cm the specific composition of the fauna includes *Globorotalia crassaformis* s.l., *G. inflata*, *G. scitula*, *Globigerina bulloides*, *G. concinna*, *G. megastoma*, *G. quinqueloba*, *Globigerinita uvula*, *G. glutinata*, *Orbulina universa*, *Globorotaloides hexagonus*, *Neogloboquadrina dutertrei*, *Turborotalita iota*, *Globigerinita siphonifera*, *Sphaeroidinella dehiscens*, *Globigerinoides sacculifer*, *G. pyramidalis*, and *G. trilobus* are extremely rare. The interval corresponds to the *Globorotalia miocenica* and *Globorotalia tosaensis* zones. In Sample 4-5, 57-59 cm two small specimens of *Globorotalia miocenica* were identified, indicating that the interval from Sample 4-5, 57-59 cm to Sample 10-3, 27-29 cm involves the *Globorotalia miocenica* Zone. Such zones

established by means of such rare findings hardly can be considered reliable.

The total recorded thickness of Pliocene deposits is 113 meters.

#### Quaternary

At Site 400 the thickness of Quaternary sediments is 96.5 meters, but cores were recovered only from the upper 9 meters and lower 22 meters of sediments of this interval. A similar circumstance occurred at Site 399, where the interval of 8 to 63 meters was penetrated without recovery. The zonal stratigraphy of the complete Quaternary section, the *Globorotalia truncatulinoides* Zone, is not possible in this area.

The Pliocene/Quaternary boundary was drawn beneath Sample 400A-3-2, 78-80 cm, where small specimens of *Globorotalia truncatulinoides* were recognized, but the boundary may be somewhat lower because the species is sporadic in the interval. It is completely absent in Samples 400A-3-1, 51-53 cm; 2-6, 33-35 cm; 2-5, 71-73 cm; 2-4, 91-93 cm; 2-3, 116-118 cm; 2-1, 78-80 cm; 1, CC, and rare in Samples 400A-2-2, 90-92 cm and 1-1, 85-87 cm.

Quaternary sediments in the interval between Sample 400A-1-1, 85-87 cm and Sample 400A-3-2, 78-80 cm are characterized by numerous *Globorotalia inflata*, *G. crassaformis crassaformis*, *G. crassaformis oceanica*, *G. scitula*, *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *G. megastoma*, *G. quadrilatera*, *Globigerinita uvula*, *G. glutinata*, *Globorotaloides hexagonus*, *Orbulina universa*, *Globigerinella siphonifera*, *Turborotalita iota*, and *Neogloboquadrina dutertrei*. *N. pachyderma* occurs in subordinate amounts. In Sample 2-3, 116-118 cm there are sporadic *Globigerinoides conglobatus*, and in Sample 1-1, 85-87 cm, occasional *Globorotalia tosaensis*. In some samples of Cores 400A-1 and 2, rare *Globorotalia crassaformis hessi* were recognized. As it can be seen the foraminiferal composition is impoverished. The ratio among *Globorotalia inflata*, *G. crassaformis* s.l., *Globigerina bulloides*, *Orbulina universa*, and *Neogloboquadrina pachyderma* in the samples studied noticeably varies, evidently reflecting climatic fluctuations. Sample 400A-2-2, 90-92 cm is characterized by a higher content of *Neogloboquadrina pachyderma*. The sediments should be assigned to the *Globorotalia crassaformis viola* and *Globorotalia crassaformis hessi* sub-zones. The sediments and planktonic foraminifers of Core 2 in Hole 399 are of the same age.

The surface layer of the Quaternary sediments penetrated at Sites 399 and 400, the lower part is characterized by a poor, cold-water assemblage of planktonic foraminifers, *Neogloboquadrina pachyderma* being predominant among them. These sediments were formed under conditions of the late Pleistocene glaciation (from Samples 399-1-2, 85-87 cm to 399-1-6, 20-22 cm, and from Samples 400-1-3, 90-92 cm to 400-1-6, 90-92 cm).

The uppermost part of the Quaternary layer, 1.5 to 2.5 meters thick, contains a rich warm water (temperate) assemblage of planktonic foraminifers with common *Globorotalia inflata*, *Neogloboquadrina dutertrei*, *Globigerina bulloides*, *G. megastoma*, *G. quadrilatera*, *G. quinqueloba*, *Globigerinita glutinata*, *Orbulina universa*,

and much less frequent *Globorotalia truncatulinoides*, *G. crassaformis*, *G. scitula*, *G. bermudezi*, *G. cavernula*, *Globigerinoides ruber* (pink and white), *G. pyramidalis*, *Globigerina rubescens* (pink and white), *G. aff. calida calida*, *Globigerinella siphonifera*, *Globigerinita uvula*, *Turborotalita iota*, and *Neogloboquadrina pachyderma*. This microfauna is peculiar to relatively warm climatic conditions of the postglaciation (Holocene).

#### Site 401

In this hole Cenozoic deposits, about 236.5 meters thick, were drilled with continuous coring, except for the interval from 9.5 meters down to 84.5 meters. The Cenozoic (Danian stage) is conformably underlain by the Upper Cretaceous *Abathomphalus mayaroensis* Zone (Maestrichtian). Unfortunately, due to poor recovery, the basal part of the Danian stage, containing minute thin-walled *Globigerinas*, was not recognized in this section. Speculatively, we may assume a hiatus here, but its length was negligible.

The Paleocene and lower Eocene section consists of yellowish and brown nannofossil chalk, nannofossil-foraminiferal chalk and slightly argillaceous chalk. Middle and upper Eocene sediments are composed of greenish gray and light greenish nannofossil and nannofossil-foraminiferal chalk frequently enriched with radiolarians and sponge spicules. Above the 75-meter interval drilled without coring are Quaternary clayey calcareous oozes. A considerable part (possibly all) of the Oligocene and Neogene section is absent at Site 401.

The excellent fauna of planktonic foraminifers provides ready zonal subdivision of Paleocene and Eocene deposits.

#### Paleocene

The following zones have been identified in the Paleocene section: the *Globorotalia trinidadensis* Zone (from Sample 17-2, 60-63 cm to Sample 17-3, 8-10 cm) (Danian stage) with the index species, *G. pseudobulloides*, *G. compressa*, *Globigerina triloculinoides*, *G. varianta*, *G. trivialis*, *G. daubjergensis*, and *Chiloguembelina midwayensis*.

The *Acarinina uncinata* Zone (Sample 17-1, 118-120 cm) with the index species, *A. spiralis*, *A. inconstans*, *A. sp.*, *Globorotalia compressa*, *G. pseudobulloides*, *G. quadrata*, *Globigerina triloculinoides*, and *G. varianta*.

The *Globorotalia pseudomenardii* Zone (from Sample 16-1, 22-25 cm to Sample 16-3, 15-18 cm) with numerous specimens of the zonal species associated with *G. velascoensis*, *G. laevigata*, *Acarinina mckannai*, *A. intermedia*, *Globigerina nana*, and *G. velascoensis*. The section lacks deposits of the *Globorotalia angulata* Zone and, perhaps, the lower part of the *Globorotalia pseudomenardii* Zone.

The *Globorotalia velascoensis* Zone (from Sample 14-1, 129-132 cm to Sample 14-5, 7-10 cm) including the index species, *G. acuta*, *G. aequa*, *G. hispidicidaris*, *Acarinina soldadoensis*, *A. acarinata*, *A. intermedia*, *A. primitiva*, *A. mckannai*, *Globigerina velascoensis*, *G. nana*, *G. quadriloculinoides*, and *G. compressaformis*. There was no recovery in Core 15.

Thickness of the Paleocene section (including the Danian stage) is 38 meters.

### Eocene

Eocene sediments are characterized by abundant, excellently preserved planktonic foraminifers.

The lower Eocene section at Site 401 comprises four zones:

The *Globorotalia subbotinae* Zone s.l. with numerous *G. subbotinae*, *G. marginodentata*, *G. wilcoxensis*, *Acarinina pseudotopilensis*, *Globigerina eocaenica*, *G. compressaformis*, with rarer *Globorotalia formosa gracilis*, *G. aequa*, *G. aff. planoconica*, *Acarinina esnaensis*, *A. acarinata*, *A. soldadoensis*, *A. mckannai*, *Globigerina nana*, and *Pseudohastigerina wilcoxensis*. It encompasses the interval from Sample 13-3, 27-30 cm to Sample 13-5, 43-45 cm. The *Globorotalia subbotinae* Zone s.l. can be subdivided into two sub-zones: *Globorotalia subbotinae* s. str. with predominance of the index species and *G. aequa* (Sample 13-5, 43-45 cm) and the *Globorotalia marginodentata* Sub-zone where the index species and *G. formosa gracilis* are characteristic (Samples 13-4, 25-29 cm and 13-3, 27-30 cm).

The *Globorotalia formosa* Zone (from Sample 12-5, 55-57 cm to Sample 13-2, 50-53 cm) with numerous *G. formosa formosa*, *G. lensiformis*, *Acarinina pseudotopilensis*, *Globigerina eocaenica* accompanied by rarer *Globorotalia formosa gracilis*, *G. marksi*, *G. marginodentata*, *Acarinina soldadoensis angulosa*, *A. interposita*, *A. triplex*, *A. acarinata*, *A. broedermanni*, and *Pseudohastigerina wilcoxensis*.

The *Globorotalia aragonensis* Zone (from Sample 12-1, 55-57 cm to Sample 12-4, 55-57 cm) containing numerous *G. aragonensis*, *Acarinina interposita*, *A. pseudotopilensis* and rarer *Acarinina pentacamerata*, *A. triplex*, *A. broedermanni*, *Globorotalia planoconica*, *Globigerina pseudoeocaena*, *G. eocaenica*, *Pseudohastigerina wilcoxensis*. *Globorotalia caucasica* and, in the lower part of the zone, *G. formosa formosa*, *G. lensiformis*, and *Acarinina acarinata* were observed as sporadic specimens. The lowest sample is characterized by transitional fauna from the *Globorotalia formosa* Zone into the *Globorotalia aragonensis* Zone.

The *Globorotalia palmerae* Zone (from Sample 11-4, 125-127 cm to Sample 11-5, 31-33 cm) with widely distributed *Acarinina pentacamerata*, *A. interposita*, *A. aspensis*, *A. broedermanni*, *Globorotalia caucasica*, *Globigerina pseudoeocaena*, and *Pseudohastigerina wilcoxensis* in combination with less numerous *Globorotalia aragonensis*, *G. planoconica*, *Acarinina triplex*, *A. pseudotopilensis*, *Globigerina eocaenica*, and *G. eocaena*.

The thickness of lower Eocene deposits is 24 meters.

The middle Eocene section includes the following zones:

The *Hantkenina aragonensis* Zone s.l. has a three-membered structure. The lower part (from Sample 11-1, 124-126 cm to Sample 11-2, 49-51 cm) is characterized by the appearance of *Acarinina bullbrooki*, *Globigerina boweri*, and *Pseudohastigerina micra*, accompanied by numerous *Globorotalia caucasica* and common *G. aragonensis*, *Acarinina aspensis*, *A.*

*pentacamerata*, *A. triplex*, *Globigerina senni*, *G. higginsii*, and *G. pseudoeocaena*. These are transitional layers from the lower to middle Eocene. *Acarinina bullbrooki* and *Globigerina boweri* are more numerous in the middle member of this zone (from Sample 10-2, 102-104 cm to Sample 10-7, 44-46 cm), where *Globorotalia spinulosa*, *G. aff. pseudomayeri*, *Globigerina posttriloculinoides* appear; *Globorotalia caucasica* and *G. aragonensis* are presented here by rare specimens. Other species include *Acarinina triplex*, *A. broedermanni*, *A. pentacamerata*, *A. aspensis*, *Globigerina higginsii*, *G. senni*, *G. eocaena*, *G. pseudoeocaena*, and *Pseudohastigerina micra*. The upper member of the zone, the *Hantkenina aragonensis* Zone s.str. (from Sample 9-1, 93-96 cm to Sample 10-1, 108-110 cm) is characterized by appearance of the index species, *Globorotalia renzi*, *Globigerapsis aff. index*, *Truncorotaloides aff. rohri*, and abundant *Acarinina bullbrooki*; *Globigerina boweri* is invariably present. Other species of planktonic foraminifers are the same as in the middle member of the zone, but *Globorotalia caucasica*, *G. aragonensis*, *Acarinina pentacamerata*, and *A. triplex* become rare. Thus, deposits of the *Hantkenina aragonensis* s.l. Zone are developed in the interval from Sample 9-1, 93-96 cm to Sample 11-2, 49-51 cm.

In the *Globigerapsis kugleri* Zone (from Sample 7-4, 117-119 cm to Sample 8-7, 67-69 cm) there appears the index species, *G. index*, *Globorotalia frontosa*, *Truncorotaloides topilensis*, *T. rohri* and rare *Acarinina rotundimarginata*, *Hantkenina liebusi*, and *H. lehneri*. Accompanying species are represented by numerous *Acarinina bullbrooki*, *Globigerina boweri*, and *Pseudohastigerina micra* with less frequent *Globorotalia spinulosa*, *G. renzi*, *G. aff. pseudomayeri*, *Acarinina aspensis*, *A. triplex*, *A. broedermanni*, *Globigerina senni*, *G. higginsii*; *G. pseudoeocaena*, and *G. posttriloculinoides*. In sediments from Sample 8-5, 32-34 cm to Sample 8-7, 67-69 cm, *Hantkenina aragonensis* and *Globigerapsis kugleri* were not present, but numerous specimens of *Globorotalia frontosa* and rare *Hantkenina liebusi* were recognized. The latter circumstance allows us to attribute tentatively the sediments of this interval to the *Globigerapsis kugleri* Zone.

The *Globorotalia lehneri* Zone (from Sample 6-2, 137-139 cm to Sample 7-3, 118-120 cm) contains abundant *Acarinina rotundimarginata*, *A. bullbrooki*, *Truncorotaloides rohri*, *T. topilensis* and frequent *Globigerapsis index*, *G. kugleri*, *Globorotalia frontosa*, *G. spinulosa*, *Globigerina pseudoeocaena*, and *G. pseudoeocaena compacta*; *Hantkenina liebusi* and *H. lehneri*, though not numerous, are constantly present. Other species present are *Pseudohastigerina micra* and rare *Globorotalia aff. pseudomayeri*, *Globigerina boweri*, *G. senni*, and *Acarinina aspensis*. In the upper part of the zone *Hantkenina alabamensis* appears.

The *Orbulinoides beckmanni* Zone (from Sample 5-1, 119-121 cm to Sample 6-1, 89-92 cm) is characterized by the invariable presence of *Hantkenina alabamensis*, and the appearance of *Globorotalia centralis* and *Globigerina pseudovenezuelana*. Rather numerous are *Globigerina pseudoeocaena pseudoeocaena*, *G. pseudoeocaena compacta*, *Globigerapsis index*, *Truncorotaloides rohri*,

and *T. topilensis* accompanied by less frequent *Pseudohastigerina micra*, *Globorotalia frontosa*, *G. renzi*, *G. spinulosa*, *G. spinuloinflata*, and *Globigerinatheca barri*. In the lower part of the zone there are frequent *Acarinina bullbrooki* and *Acarinina rotundimarginata*, but they are less numerous higher up in the section. In Sample 5-1, 119-121 cm sporadic *Globorotalia lehneri* and *G. bolivariana* were found.

The *Truncorotaloides rohri* Zone (Sample 4, CC) assemblage includes *T. rohri*, *Globigerinatheca barri*, *Globigerapsis index*, *Globigerina galavisi*, *G. pseudovenezuelana*, *Globorotalia centralis*, *G. pomeroli*, *G. spinulosa*, and *Pseudohastigerina micra*. Rare *Globigerapsis tropicalis*, *Globorotalia cerroazulensis*, and *Globigerina angiporoides* are present in the sediments of the upper part of the zone. It is quite possible that the *Truncorotaloides rohri* and the *Orbulinoides beckmanni* zones are separated by a hiatus, but poor core recovery in Core 4 makes the solution of this question difficult. The thickness of the middle Eocene section is 71 meters.

A limited number of samples permits a suggested outline of the zonal subdivision of the upper Eocene:

Undifferentiated *Globigerapsis semiinvoluta* and *Globorotalia cocoaensis* zones (Sample 3-1, 30-32 cm) with *Globigerapsis tropicalis*, *Globorotalia centralis*, *Globigerina corpulenta*, *G. galavisi*, *G. tripartita*, *G. ouachitaensis*, *Pseudohastigerina micra*, and *P. barbadoensis*.

The *Globorotalia cocoaensis* Zone (Sample 2, CC) contains broken specimens of *Cribohantkenina inflata*, *Globigerapsis tropicalis*, *Globigerina corpulenta*, *G. galavisi*, *G. angiporoides*, *G. praebulloides*, and *Pseudohastigerina micra*.

The *Globigerina gortanii*-*Globorotalia centralis* Zone (Sample 2-1, 44-49 cm) contains a planktonic foraminiferal assemblage transitional from the upper Eocene to Oligocene and includes *Globigerina corpulenta*, *G. angiporoides*, *G. galavisi*, *G. tripartita*, *G. praebulloides*, *G. prasaepis*, *Globorotalia permicra*, *G. gemma*, *Globigerinita unicava*, *Globorotaloides suteri*, *Pseudohastigerina micra*, and *P. barbadoensis*. The thickness of the upper Eocene section is 19 meters and the total thickness of Eocene deposits at Site 401 is 114 meters.

#### Quaternary

Quaternary deposits, 9.5 meters thick, are subdivided into two parts. The lower (from Sample 1-3, 108-110 cm to Sample 1-6, 64-66 cm) is characterized by a poor assemblage where numerous *Neogloboquadrina pachyderma* are accompanied by rare *N. dutertrei*, *Globorotaloides hexagonus*, *Globigerinita glutinata*, *Globigerina bulloides*, *G. quadrilatera*, and *Globorotalia inflata*. The accumulation of sediments was proceeding under conditions of Pleistocene glaciation.

In the upper part (from Sample 1-1, 38-40 cm to Sample 1-2, 108-110 cm) the planktonic foraminifera are diverse with numerous *Globorotalia inflata*, *Neogloboquadrina dutertrei*, *Globigerina bulloides* accompanied by fewer *Globorotalia truncatulinoides*, *G. crassaformis*, *G. hirsuta*, *Neogloboquadrina pachyderma*, *Globigerinoides ruber*, *Orbulina universa*, *Globigerina quadrilatera*, *G.*

*megastoma*, *G. quinqueloba*, *Globigerinella siphonifera*, and *Globigerinita glutinata*. This microfauna reflects relatively warm water conditions of Holocene postglaciation.

#### Site 402

At this site the Cenozoic section is incomplete and totals approximately 175 meters in thickness. The upper middle and upper Eocene deposits are composed of greenish gray and pale green nannofossil oozes and chalk, sometimes clayey, with a high content of siliceous organisms (radiolarians, diatoms, sponges). This part of the section at Site 402 significantly supplements Site 401 where the zonal subdivision of the upper middle Eocene part and the upper Eocene can be only outlined. In the interval from 89.5 meters down to 118 meters there was no core recovery. Higher in the section occur Quaternary yellowish, gray, and gray greenish clayey nannofossil and nannofossil-foraminiferal oozes in which only three cores were taken.

The middle Eocene is represented by the *Truncorotaloides rohri* Zone (from Sample 402A-1-5, 65-68 cm to Sample 402A-4-3, 88-90 cm). Its foraminiferal assemblage consists of *T. rohri*, *Acarinina rugosoaculeata*, *Globigerina incretacea*, *G. azerbaijanica*, *G. galavisi*, *G. pseudovenezuelana*, *G. pseudocorpulenta*, *G. praebulloides*, *Globorotalia centralis*, *G. pomeroli*, *G. spinulosa*, *G. renzi*, *G. bolivariana*, *Pseudohastigerina micra*, *Globigerinita howei*, *Globigerapsis index*, *Globigerinatheca barri*, and *Guembelina* sp.; *Truncorotaloides topilensis*, *Hantkenina alabamensis*, and *Globorotalia lehneri* occur as rare specimens. *Globigerina pseudoecaena pseudoecaena* and *G. pseudoecaena compacta* are representative of the basal layers of the zone, *Globigerapsis tropicalis* being frequent in the upper part of the zone. The interval thickness is 32 meters.

The late Eocene *Globigerapsis semiinvoluta* Zone (from Sample 402-5-1, 123-126 cm to Sample 402-5-4, 33-36 cm and, stratigraphically lower, from Sample 402A-1-2, 28-30 cm to Sample 402A-1-4, 106-109 cm) is well established. The zone is characterized by *Globigerapsis tropicalis*, *G. index*, *Globigerinatheca* sp., *Globigerina corpulenta*, *G. galavisi*, *G. pseudovenezuelana*, *G. angiporoides*, *G. azerbaijanica*, *G. ouachitaensis*, *Pseudohastigerina micra*, *Globigerinita howei*, *Globorotalia centralis*, and *G. pomeroli*; the index species and *Globorotalia cerroazulensis* occur as sporadic specimens. Small specimens of *Acarinina* aff. *rugosoaculeata* were identified in the lower part of the zone. In Core 402-4 a core-catcher sample was recovered; the sediments are of late Eocene age, but they have not been analyzed by us. Visible thickness of the upper Eocene deposits is 25 meters.

The interval from 89.5 down to 118 meters sub-bottom was penetrated without recovery. Washings from there yielded, in addition to Quaternary foraminifera, the late Miocene and early Pliocene species *Globorotalia merotumida*, *G. plesiotumida*, *G. margaritae evoluta*, *Globoquadrina dehiscens*, and *G. altispira*. Either they are reworked Quaternary sediments, or some upper Miocene and lower Pliocene layers are present at the bottom of the interval. In any case, it appears that Oligocene and Neogene

deposits were almost completely destroyed by erosion at both Sites 401 and 402.

In the 89.5 meters of Quaternary sediments, three cores were taken. The sediments in the interval 42.0 to 89.5 meters (Samples 2-1, 18-20 cm and 3-1, 88-90 cm) contain the rather diverse assemblage of *Globorotalia truncatulinoides*, *G. inflata*, *G. crassaformis*, *G. hirsuta*, *Neogloboquadrina dutertrei*, *Orbulina universa*, *Globigerinoides ruber*, *Globigerina bulloides*, *G. megastoma*, and *G. quinqueloba*; specimens of *Neogloboquadrina pachyderma* are rare. In Sample 1-2, 113-115 cm planktonic foraminifers are compositionally poor, *N. pachyderma* being predominant; these sediments correspond to the time of Pleistocene glaciation. In the uppermost layer of sediments (Sample 1-1, 24-26 cm) the foraminifers are again diverse and abundant and include *Globorotalia truncatulinoides*, *G. inflata*, *Orbulina universa*, *Neogloboquadrina dutertrei*, *Globigerina bulloides*, *G. megastoma*, *G. quadrilatera*, *Globigerinoides ruber*, etc.; they are relatively warm water postglacial species, *Neogloboquadrina pachyderma* is in subordinate amounts.

### Rockall Plateau

Near the southwestern margin of Rockall Plateau the drilling was carried out in two regions: at the rifted margin of the plateau, roughly 30 kilometers east of the oldest magnetic anomaly (24) recorded in the adjacent ocean crust (Sites 403 and 404) and south of the transform fault which defines the southwestern margin of the plateau (Sites 405 and 406). Cenozoic stratigraphy at these four sites has much in common.

#### Site 403

The character of Cenozoic deposits at Site 403 is considerably varied. At the base of the section Paleocene-lower Eocene medium- and coarse-grained arkosic sandstones with interbeds of lignitic mudstones and tuffaceous siltstones occur. They are overlain by lapilli conglomerates, tuffs, tuffaceous mudstones, and mudstones also of the early Eocene age. The thickness of these terrigenous-volcanic deposits is 229 meters. Above them lie 37 meters of nannofossil and nannofossil-foraminiferal chalk of the early Eocene, middle Eocene, and Oligocene age, being separated by unconformities. The Oligocene sediments are overlain by 223 meters of nannofossil and nannofossil-foraminiferal chalk and oozes of late Miocene to Quaternary age. Late Pliocene-Quaternary oozes contain clay and ice-rafted pebbles and grains.

### Paleogene

Sediments at the base of the section (Cores 52 to 45) are devoid of organic remains; sporadic, poorly preserved benthic foraminifers (*Eponides*, *Valvulineria*, *Cibicides*, *Robulus*) and mollusk fragments appear in Cores 44, 43, and 42. These deposits are tentatively attributed to the Paleocene.

In Cores 41 to 39 benthic foraminifers are, as previously, sporadic, but their composition is somewhat more diverse (*Cibicides*, *Valvulineria*, *Nodosaria*, *Robulus*, *Lagena*, *Gyroidina*, *Alabamina*, *Pseudopolymorphina*). In Sample

41-1, 136-138 cm rare *Globigerina* sp. are present, and ostracodes appear.

Cores 38 to 29 also contain rare benthic foraminifers; in some samples they are completely absent. In Samples 38-4, 59-61 cm; 38-2, 77-81 cm; 38-1, 62-66 cm; 37-3, 106-110 cm; 37-1, 107-110 cm; and 29-1, 26-28 cm, although not numerous, they are diverse: *Anomalina*, *Cibicides*, *Eponides*, *Gyroidina*, *Valvulineria*, *Alabamina*, *Bulimina*, *Quinqueloculina*, *Glandulina*, *Pullenia*, *Robulus*, *Lenticulina*, *Marginulina*, *Nodosaria*, *Lagena*, *Dentalina*, *Textularia*. Planktonic foraminifers are extremely rare: *Globigerina nana* in Sample 38-4, 59-61 cm; *Globigerina* sp. and *Acarinina* sp. in Sample 29-1, 26-28 cm. Sediments in this interval show a general increase of diversity in organic remains; common are needles of sea urchins, bryozoa, ostracodes, and fragments of mollusks. On the basis of nannoplankton, the deposits are of early Eocene age (see Müller, this volume).

The first good assemblage of planktonic foraminifers was found in Sample 28-1, 25-27 cm. It contains rare small *Globigerina eocaenica*, *G. nana*, *G. sp.*, *Acarinina pseudotopilensis*, *A. acarinata*, *A. esnaensis*, *A. primitiva*, and *A. sp.* denoting an early Eocene age.

Sample 26-4, 12-15 cm is characterized by planktonic foraminifers of the upper middle Eocene, with numerous, but small *Globigerina pseudoeocaena*, and *G. sp.* in combination with rare *Acarinina rotundimarginata*, *A. sp.*, and *Globorotalia centralis*.

In the interval from Sample 26-3, 37-39 cm up to 26-1, 32-34 cm Oligocene planktonic foraminifers are numerous and rather diverse, the fauna comprising *Globorotalia opima*, *G. nana*, *Globigerina prasaepis*, *G. ouachitaensis*, *G. galavisi*, *G. angustumbilicata*, *G. pseudovenezuelana*, *Globorotaloides suteri*, and *Globigerinita unicava* (the *Globorotalia opima* Zone).

### Upper Miocene

The upper Miocene section, 114 meters thick, begins with sediments containing the *Globorotalia merotumida* Zone (from Sample 23-1, 55-57 cm to Sample 25-1, 3-5 cm). Its assemblage consists of enormous accumulations of *Globorotalia acostaensis* combined with lesser *G. miozea miozea*, *G. miozea cibaoensis*, *G. globorotaloidea*, *Globigerina bulloides*, *G. microstoma*, *G. quinqueloba*, *Orbulina universa*, and *Globoquadrina dehiscens*; sporadic specimens of *Globorotalia merotumida*, *G. menardii*, *G. cultrata*, *G. scitula*, *Globigerina nepenthes*, *G. juvenilis*, *Globigerinoides bollii*, and *Sphaeroidinellopsis seminulina* are present.

The *Globorotalia plesiotumida* Zone (from Sample 16-2, 120-122 cm to Sample 22-6, 62-64 cm) has numerous *G. conomiozea*, *G. miozea conoidea*, *G. pseudomiocenica* and rare small *G. aff. plesiotumida*. *G. acostaensis*, *G. globorotaloidea*, *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *Globigerinita glutinata*, and *G. uvula* continue to be numerous, accompanied by rare *Globorotalia scitula*, *Orbulina universa*, *Globigerina falconensis*, *G. nepenthes*, *G. decoraperta*, and *Sphaeroidinellopsis subdehiscens*.

The *Globorotalia margaritae margaritae* Zone (from Sample 13-1, 54-57 cm to Sample 14-2, 38-40 cm) is

characterized by common specimens of *G. margaritae primitiva* and *G. margaritae margaritae*. Widely distributed are *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *Orbulina universa*, *Globorotalia acostaensis*, and *G. globorotaloidea* accompanied by fewer *Globorotalia scitula*, *Globigerina decoraperta*, *Globigerinita glutinata*, and *G. uvula*.

### Pliocene

The *Globorotalia margaritae evoluta* Zone (from Sample 9-1, 95-97 cm to Sample 12-6, 106-108 cm) is clearly distinguishable. It is marked by the appearance of the index species accompanied by numerous *Globorotalia puncticulata*, *G. crassaformis ronda*, *G. crassaformis oceanica*, and rare *G. inflata*; *G. margaritae margaritae* and *Globoquadrina dehiscens* are still present. Other foraminifers are abundant: *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *Globigerinita glutinata*, *Globorotalia acostaensis*, *G. globorotaloidea* and rarer *Globorotalia humerosa*, *G. scitula*, *G. miozea conoidea*, *Neogloboquadrina dutertrei*, *Globigerinella siphonifera*, *Orbulina universa*, *Globigerina decoraperta*, *G. atlantica*, and *G. foliata*.

Among the sediments in this interval are chalk clasts of older (upper Miocene) age. In some samples planktonic foraminifers display distinct traces of sorting, and the sediment is regarded as being a calcareous turbidite.

The overlying Pliocene sediments contain the undifferentiated *Globorotalia miocenica*-*Globorotalia tosaensis* zones, and are characterized by *Globorotalia puncticulata*, *G. acostaensis*, *G. humerosa*, *G. globorotaloidea*, *G. scitula*, *G. inflata*, *G. crassula*, *G. crassaformis* (varieties — *crassaformis*, *ronda*, *oceanica*), *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *G. decoraperta*, *G. falconensis*, *Neogloboquadrina dutertrei*, *Orbulina universa*, *Globigerinella siphonifera*, *Globigerinita uvula*, and *G. glutinata*. The interval is divisible into two parts: (1) (from Sample 7-1, 128-130 cm to Sample 8-6, 101-103 cm) layers with abundant specimens of *G. crassaformis crassaformis*, *G. crassaformis oceanica*, and *G. crassaformis ronda* and rare specimens of *G. inflata*; (2) (from Sample 5-1, 55-57 cm to Sample 5-5, 108-110 cm) layers with numerous *Globorotalia inflata*, and rare to absent *G. crassaformis* s.l.

Total thickness of Pliocene deposits is 81 meters.

### Quaternary

The exact sub-bottom position of the Pliocene-Quaternary boundary has not been established because of poor recovery in Core 4 and the impoverished specific composition of planktonic foraminifers. Sample 4-1, 90-92 cm is characterized by numerous *Globorotalia inflata*, *G. crassaformis crassaformis*, *Globigerina bulloides*, *G. concinna*, and *G. quinqueloba* with rarer *Globorotalia scitula*, *Neogloboquadrina dutertrei*, *Orbulina universa*, *Globigerina decoraperta*, and *Globigerina glutinata*. Presence of infrequent *Globorotalia crassaformis viola* shows that the age of the sediments is confined to the late Pliocene (the *Globorotalia tosaensis* Zone) — early Quaternary (the *Globorotalia crassaformis viola* Sub-zone). The Pliocene/Pleistocene boundary is

likely to be within Core 4. Sample 3-3, 47-49 cm contains *Globorotalia truncatulinoides* and *G. crassaformis hessi*, and corresponds stratigraphically to higher layers of the Pleistocene (the *Globorotalia crassaformis hessi* Sub-zone).

Almost all typical species are found throughout the Quaternary sediments, i.e., *Globorotalia truncatulinoides*, *G. inflata*, *G. acostaensis*, *G. scitula*, *G. hirsuta*, *G. crassaformis crassaformis*, *ronda*, *G. crassula crassula*, *G. crassula viola*, *Neogloboquadrina pachyderma*, *N. dutertrei*, *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *G. microstoma*, *Orbulina universa*, *Globigerinella siphonifera*, *Globigerinita glutinata*, *G. uvula*, and *Turborotalita iota*. Only *Globorotalia crassaformis hessi* disappears in the middle Quaternary. However, the ratio of the major species in the faunas varies rather strongly, probably reflecting climatic fluctuations of the Quaternary time:

1) layers with numerous *Globorotalia inflata*, *G. crassaformis hessi*, *Globigerina bulloides*, *G. quinqueloba*, *Orbulina universa* and rare *Neogloboquadrina pachyderma* (Sample 3-3, 47-49 cm);

2) layers with the same foraminifers, but with numerous *N. pachyderma* (from Sample 2-6, 29-31 cm to Sample 3-2, 48-50 cm); *Globorotalia crassaformis hessi* was not recorded higher in the section;

3) layers with numerous *Globorotalia crassaformis crassaformis*, *G. inflata*, *Globigerina bulloides*, and rare *Neogloboquadrina pachyderma* (from Sample 2-4, 53-55 cm to Sample 2-5, 30-32 cm);

4) layers with abundant *N. pachyderma*, *Globigerina bulloides*, *G. quinqueloba*, and *Globorotalia inflata* (Sample 2-3, 20-22 cm);

5) layers with rare *Neogloboquadrina pachyderma* and various other planktonic foraminifers, including *Globigerinoides ruber* (from Sample 2-1, 24-26 cm to Sample 2-2, 119-121 cm);

6) layers with predominant *Neogloboquadrina pachyderma*, and other diverse species of planktonic foraminifers (from Sample 1-3, 57-59 cm to Sample 1-4, 13-15 cm);

7) layers with enormous amounts of *N. pachyderma* and rare other foraminifers (Sample 1-2, 27-29 cm).

The total thickness of Quaternary sediments is about 28 meters.

### Site 404

Because Site 404 is within 5 kilometers of Site 403, the Cenozoic stratigraphy of the two sites has much in common. The section at Site 404 commences with tuffaceous conglomerates, glauconitic sandstones, and tuffitic mudstones with rare interbeds of arenaceous limestones (Paleocene?-lower Eocene). There follows a unit of lower Eocene glauconitic and siliceous limestones, tuffs, and glauconitic mudstones, capped by silicified limestones and porcellanites with abundant radiolarians and sponge spicules. They in turn are overlain by nannofossil and nannofossil-foraminiferal oozes of the upper Miocene-Quaternary. In the Quaternary part the oozes contain vitric tuffs, ice-rafted pebbles, and grains. In contrast to Site 403, there are no middle Eocene and Oligocene deposits at Site 404.

### Paleogene

In basal layers of the terrigenous-tuffaceous succession (Cores 25 and 24) no fauna was found. Higher up (Cores 23-19) appear sporadic benthic foraminifers such as *Nonion*, *Nonionella*, *Cibicides*, *Discorbis*, *Valvulineria*, *Alabamina*, *Lenticulina*, *Nodosaria*, *Textularia*, *Polymorphina*, ostracodes, bryozoa, and echinoid remains. The diversity and abundance of benthic foraminifers increases upwards (Cores 18-10): *Cibicides*, *Anomalina*, *Glandulina*, *Lenticulina*, *Lagena*, *Marginulina*, *Nodosaria*, *Alabamina*, *Nonion*, *Siphonina*, *Eponides*, *Gyroidina*, *Reussella*, *Bolivina*, *Discorbis*, *Valvulineria*, *Pullenia*, *Bulimina*, *Uvigerina*; radiolarians, diatoms, and sponges appear here as well. Within this interval occur the first sporadic *Globigerina* sp. (Samples 17-2, 66-69 cm and 17-1, 82-84 cm). Sample 16-1, 32-34 cm contains numerous minute *Globigerina eocaenica*, *G. prolata*, *G. nana*, *G. sp.*, *Acarinina triplex*, and *A. sp.* (the lowermost Eocene). Samples 14-1, 1-3 cm and 10-1, 59-63 cm contain numerous *Globigerina collactea*, *G. eocaenica*, *G. prolata*, *G. turgida*, and *Acarinina pseudotopilensis* indicating that this interval is probably the upper part of the lower Eocene. Within silicified limestone (Samples 7-3, 55-58 cm and 7-2, 70-74 cm), associated with a mass of radiolarians and sponges, rare planktonic foraminifers were found, including *Acarinina pentacamerata*, *A. interposita*, *A. pseudotopilensis*, and *Globigerina pseudoeocaena* testifying to the belonging of sediments to the upper part of the lower Eocene.

Thickness of the Paleogene deposits at Site 404 is 190 meters.

### Upper Miocene

Two zones were recognized in sediments of this age:

The *Globorotalia merotumida* Zone (from Sample 5-1, 107-109 cm to Sample 6-1, 89-92 cm) with numerous *Globorotalia acostaensis*, *G. miozea miozea*, *G. miozea cibaoensis*, *Globigerina bulloides*, *G. decoraperta*, *G. concinna*, *G. quinqueloba*, rare *G. scitula*, *Orbulina universa*, *O. suturalis*, *Globoquadrina dehiscens*, *G. altispira*, *Globigerina foliata*, *Globigerinita glutinata*, and sporadic *Borbulina bilobata*, *Globorotalia menardii*, *G. obesa*, *G. globorotaloidea*, *Sphaeroidinellopsis seminulina*, and *S. subdehiscens*; and the *Globorotalia plesiotumida* Zone (from Sample 3-1, 83-86 cm to Sample 4-2, 23-26 cm) where appear *G. miozea conoidea*, *G. conomiozea*, *G. pseudomiocenica*, rare *G. plesiotumida*, accompanied by *G. acostaensis*, *G. globorotaloidea*, *G. scitula*, *G. humerosa*, *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *G. foliata*, *G. decoraperta*, *G. nepenthes*, *Orbulina universa*, *Globigerinita glutinata*, *Globoquadrina dehiscens*, *Sphaeroidinellopsis seminulina*, and *S. subdehiscens*.

The apparent thickness of the upper Miocene is 95 meters.

In the interval from 28 meters down to 104 meters there was no core recovery. The sediments of this interval most likely correspond to the uppermost Miocene and the Pliocene.

### Quaternary

In Quaternary sediments, 28 meters thick, only two cores were obtained, at the base and top of the section; in the interval from 9 meters down to 21.5 meters no cores were recovered. Variations of the specific composition of planktonic foraminifers reflect climatic fluctuations of the Quaternary time:

1) a relatively cold-water assemblage with abundant *Neogloboquadrina pachyderma*, common *Globorotalia inflata*, *G. crassaformis*, *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, and sporadic *Globorotalia truncatulinoides*, etc. (Sample 2-6, 34-36 cm);

2) a warm-water assemblage with various foraminifers including *Globorotalia crassaformis hessi*, *G. truncatulinoides*, *G. hirsuta*, *Orbulina universa*, etc.; *Neogloboquadrina pachyderma* are rare, and in some samples, practically absent (from Sample 2-1, 82-84 cm to Sample 2-6, 34-36 cm).

Especially frequent are variations in the foraminiferal composition in the surface 9 meters.

3) layers with *Neogloboquadrina pachyderma* and *Globigerina bulloides*, where other species are in subordinate amounts (Sample 1-6, 104-106 cm);

4) layers with abundant *Globigerina bulloides* and *G. quinqueloba* where *Globorotalia inflata* and *Neogloboquadrina pachyderma* are not numerous (Sample 1-5, 61-63 cm);

5) layers with enormous numbers of *Neogloboquadrina pachyderma*, but rare *Globigerina bulloides*, *G. quinqueloba*, *Orbulina universa*, *Globorotalia inflata*, and *G. crassaformis* (Sample 1-4, 129-131 cm);

6) layers with diverse foraminifers where *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, and *Globorotalia inflata* are predominant, and *Neogloboquadrina pachyderma* are in subordinate amounts (Sample 1-3, 129-131 cm);

7) layers with an enormous mass of *N. pachyderma* and *Globigerina bulloides* but other species are not numerous (from Sample 1-1, 42-44 cm to Sample 1-2, 13-15 cm).

Holocene (postglacial) sediments are absent at Sites 404 and 403.

### Site 405

This hole penetrated a stratigraphically incomplete section of Cenozoic sediments, 407 meters thick.

### Eocene

The section begins with a thick accumulation (307 m) of gray and greenish calcareous mudstones and silicified mudstones with some cherty interbeds. These sediments (from Sample 12-1, 136-138 cm to Sample 43-7, 4-6 cm) contain abundant remains of organisms with a siliceous skeleton (radiolarians, sponges, and, less frequently, diatoms). Planktonic foraminifers are not numerous and include *Acarinina triplex*, *A. pentacamerata*, *A. interposita*, *A. pseudotopilensis*, *A. aff. aspensis*, *Globorotalia planoconica*, *Pseudohastigerina wilcoxensis*, *Globigerina eocaenica*, *G. turgida*, and *G. aff.*

*pseudoeocaena*. The sediments belong to the upper part of the lower Eocene, within the *Globorotalia aragonensis* and *Globorotalia palmerae* zones. Many samples are devoid of planktonic foraminifers.

Higher, there is a unit (35 m thick) of yellowish gray nannofossil and nannofossil foraminiferal chalk with some interbeds of silicified chalk (from Sample 8-1, 118-120 cm to Sample 11-1, 16-18 cm). Radiolarians and sponges are abundant in some layers only. The variety of planktonic foraminifers is diverse, their numbers increasing upwards in the section. Included are *Acarinina bullbrooki*, *A. aspensis*, *A. pentacamerata*, *A. triplex*, *Globigerina boweri*, *G. senni*, *G. posttriloculinoides*, *G. pseudoeocaena*, *G. eocaena*, *Pseudohastigerina micra*, *Globorotalia bolivariana*, *G. caucasica*, and *G. aragonensis*, which are indicative of the basal part of the middle Eocene, most likely the lower part of the *Hantkenina aragonensis* Zone s.l., below the level of appearance of *H. aragonensis* itself (see Site 401).

### Upper Miocene

Middle Eocene basal layers are overlain unconformably by bluish white nannofossil ooze belonging to the uppermost Miocene *Globorotalia margaritae margaritae* Zone (from Sample 6-1, 144-147 cm to Sample 7-1, 30-32 cm). Planktonic foraminifers present are *G. margaritae margaritae*, *G. acostaensis*, *G. scitula*, *G. globorotaloidea*, *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *Orbulina universa*, *Sphaeroidinellopsis subdehiscens*, and *Globigerinita glutinata*. The thickness of this zone is 19 meters.

### Quaternary

Quaternary greenish gray and pale gray nannofossil and nannofossil-foraminiferal oozes unconformably overlie upper Miocene sediments, their thickness being 46 meters. The oozes contain unsorted pebbles and grains of various petrographic composition (ice-rafted material).

The *Globorotalia truncatulinoides* Zone is characterized by the index species, *G. inflata*, *G. crassaformis*, *G. acostaensis*, *G. humerosa*, *G. scitula*, *G. crassula*, *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *Globigerinita glutinata*, *Orbulina universa*, *Globigerinella siphonifera*, and *Neogloboquadrina pachyderma*. The main components of planktonic foraminiferal assemblages occur in various ratios, reflecting the variations of Pleistocene climatic conditions. From base up:

1) a relatively warm water assemblage with diverse foraminifers with predominant *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *Globorotalia inflata* and rare specimens of *Neogloboquadrina pachyderma* (from Sample 4-1, 128-130 cm to Sample 5-4, 31-33 cm);

2) a relatively cold water assemblage, poor by specific composition containing equal numbers of *Neogloboquadrina pachyderma*, *Globorotalia inflata*, and *Globigerina bulloides* (Sample 3-3, 43-45 cm);

3) a temperate water assemblage with numerous *Globorotalia inflata*, *Globigerina bulloides*, *G. concinna*; *Neogloboquadrina pachyderma* remains common (Sample 3-2, 57-59 cm);

4) a relatively warm water assemblage with abundant *Globorotalia inflata*, *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, common *Orbulina universa*, less frequent *Globorotalia crassaformis*, and *G. scitula* and sporadic *Globigerinoides ruber* appear. Specimens of *Neogloboquadrina pachyderma* are not numerous (from Sample 2-5, 142-144 cm to Sample 3-1, 83-85 cm);

5) a relatively cold water assemblage with nearly equal amounts of *Neogloboquadrina pachyderma*, *Globorotalia inflata*, *Globigerina bulloides*, and *G. concinna* (Sample 2-4, 41-43 cm);

6) a cold water, almost monospecific assemblage consisting of many *Neogloboquadrina pachyderma* (Sample 2-3, 108-110 cm);

7) a relatively warm water assemblage with *Globorotalia inflata*, *G. crassaformis*, *G. acostaensis*, *Globigerina bulloides*, *G. concinna*, and *G. quinqueloba*; *Neogloboquadrina pachyderma* is present in subordinate amounts (from Sample 1-4, 130-132 cm to Sample 2-2, 133-135 cm);

8) a relatively cold water assemblage with abundant *Neogloboquadrina pachyderma*, but *Globorotalia inflata* and *Globigerina bulloides* are also common (Sample 1-3, 131-133 cm);

9) a relatively warm water assemblage with abundant *Globorotalia inflata*, *Globigerina bulloides*, *G. concinna*, frequent *Orbulina universa*, *Globorotalia acostaensis*, *G. crassaformis*, *G. scitula*, and sporadic *Globigerinoides ruber*; *Neogloboquadrina pachyderma* are in subordinate amounts (from Sample 1-1, 115-118 cm to Sample 1-2, 12-14 cm).

### Site 406

At Site 406, 841 meters of Cenozoic sediments were penetrated. The section begins with gray calcareous middle Eocene claystones, 66 meters thick, unconformably overlain by 93 meters of upper Eocene pale gray limestones and nannofossil chalk frequently enriched in radiolarians, sponge spicules, and passing into silicified limestones. Unconformably above these are 59 meters of pale gray nannofossil and nannofossil-foraminiferal Oligocene chalk. The upper Oligocene to lower Miocene beds, 56 meters thick, are greenish and yellowish, calcareous diatomites and chalk with enormous accumulations of siliceous organisms. A thick pile (557 m) of upper lower Miocene/Quaternary white and pale gray nannofossil oozes and chalk with some interbeds of nannofossil-foraminiferal oozes and chalk cap the section.

### Paleogene

The basal middle Eocene layers contain abundant *Pseudohastigerina micra* and less numerous *Acarinina bullbrooki*, *A. pentacamerata*, *A. sp.*, *Globigerina pseudoeocaena*, *G. posttriloculinoides*, and *G. sp.* The sediments (from Sample 46-2, 7-9 cm to Sample 50-1, 4-5 cm) most probably belong to the lower part of the *Hantkenina aragonensis* s.l. Zone.

Upper Eocene deposits (from Sample 36-2, 33-36 cm to Sample 45-5, 2-5 cm) contain rich assemblages of *Globigerina corpulenta*, *G. angiporoides*, *G. galavisi*, *G.*

*pseudovenezuelana*, *G. praebulloides*, *G. ouachitaensis*, *G. azerbaijanica*, *Globigerapsis tropicalis*, *G. index*, *Globigerinatheca* aff. *barri*, *G. sp.*, *Globorotaloides suteri*, *Globorotalia centralis*, *G. pomeroli*, and *Chiloguembelina* sp. Sporadic *Truncorotaloides rohri*, *T. topilensis*, and *Globigerinita howei* were recognized in basal layers (Sample 45-5, 2-5 cm). The lowermost deposits can be attributed to the undifferentiated *Globigerapsis semi-involuta* and *Globorotalia cocoaensis* zones. Where radiolarians and sponge spicules are abundant, the number of planktonic foraminifers abruptly decreases. In the mixed associations of foraminiferal assemblages either *Globigerina* or *Globigerapsis* predominates.

Lower Oligocene beds are absent. The overlying Oligocene sediments are subdivided into two zones: the *Globorotalia opima* Zone (from Sample 33-1, 133-135 cm to Sample 36-1, 36-39 cm) with abundant specimens of the index species and *Globorotaloides suteri*; they are accompanied by fewer *Globorotalia nana*, *G. sp.*, *Globigerina prasaepis*, *G. praebulloides*, *G. angustiumbilitata*, *G. officinalis*, *G. tripartita*, *G. aff. venezuelana*, and *G. aff. sellii*; the *Globigerina ciperoensis* Zone (from Sample 29-5, 7-10 cm to Sample 32-5, 68-71 cm) follows with *Globorotalia pseudokugleri*, *G. nana*, *Globorotaloides suteri*, *Globigerina praebulloides*, *G. tripartita*, *G. venezuelana*, *G. ouachitaensis*, *G. angustiumbilitata*, *G. brevispira*, *Globigerinita unicava*, *G. dissimilis*, and *G. stainforthi praestainforthi*. The key species of this zone, *Globigerina ciperoensis* and *G. angulisuturalis*, are missing and the age of the sediments is based on the assumption of the disappearance of *Globorotalia opima* and appearance of *G. pseudokugleri*.

### Miocene

It is not possible to draw the Oligocene/Miocene boundary by means of planktonic foraminifers. In the diatomites and diatom chalk of this interval (from Sample 25-1, 110-112 cm to Sample 29-3, 98-102 cm), they are rare and poor in systematic composition; the fauna consists of *Globigerina venezuelana*, *G. praebulloides*, *G. tripartita*, *Globigerinita stainforthi praestainforthi*, *G. dissimilis*, *G. unicava*, *Globoquadrina praedeheiscens*, and *Globorotalia siakensis* and is attributable to the undifferentiated upper Oligocene-lowermost Miocene.

Definitive lower Miocene begins with the uppermost part, the *Praeorbulina glomerosa* Zone (from Sample 20-3, 84-87 cm to Sample 24-1, 133-137 cm). Its foraminiferal assemblage consists of *P. glomerosa*, *P. transitoria*, *Globigerinoides bisphaerica*, *G. trilobus*, *G. subquadratus*, *Globorotalia siakensis*, *G. peripheroronda*, *G. scitula praescitula*, *G. minima*, *G. minutissima*, *G. obesa*, *Globigerina bollii*, *G. foliata*, *G. falconensis*, *G. juvenilis*, *G. bulbosa*, *Globigerinita naparimansensis*, *Globoquadrina dehiscens*, *G. altispira*, and *Sphaeroidinellopsis seminulina*. The usual distribution of the key species occurs with *Globigerinoides bisphaerica* and *Praeorbulina transitoria* first appearing, to be joined in the upper half of the zone by *Praeorbulina glomerosa* with the varieties *curva*, *glomerosa*, *circularis*.

The base of the middle Miocene is clearly fixed by the *Orbulina suturalis*-*Globorotalia peripheroronda* Zone (Interval from Sample 20-1, 34-37 cm to Sample 20-2, 129-133 cm), where these species are accompanied by *Globorotalia siakensis*, *G. scitula praescitula*, *G. miozea miozea*, *Biobulmina bilobata*, *Praeorbulina glomerosa glomerosa*, *P. glomerosa circularis*, *P. transitoria*, *Globoquadrina dehiscens*, *Globigerina juvenilis*, *G. bollii*, *G. foliata*, *G. falconensis*, *Globigerinoides trilobus*, and *Sphaeroidinellopsis seminulina*.

In the overlying middle Miocene sediments (from Sample 16-1, 52-55 cm to Sample 19-1, 27-30 cm) *Praeorbulina* disappears and *Globorotalia praemenardii* appears. The latter is accompanied by *G. siakensis*, *G. peripheroronda*, *G. miozea miozea*, *G. obesa*, *G. scitula scitula*, *G. scitula gigantea*, *Orbulina suturalis*, *Globigerina juvenilis*, *G. foliata*, *G. praebulloides*, *Globigerinoides trilobus*, *G. subquadratus*, *Globoquadrina dehiscens*, and *Sphaeroidinellopsis seminulina*. The upper part of these layers is marked by *Orbulina universa* and *Globorotalia* aff. *fohsi fohsi*. The basal layers can be attributed to the *Globorotalia peripheroacuta* Zone, although the zonal species itself is absent. The complete absence of species of the *Globorotalia fohsi* group prevents detailed subdivision of the interval but the upper age limit of these middle Miocene deposits is determined at the level of the disappearance of *Globorotalia praemenardii*, i.e., the top of the *Sphaeroidinellopsis subdehiscens*-*Globigerina druryi* Zone.

The middle/upper Miocene boundary is clearly marked with an unconformity.

The following zones are distinguished in the upper Miocene succession: the *Globorotalia continuosa* Zone with the index species, *Globorotalia miozea miozea*, *G. scitula*, *Globigerina bulloides*, *Orbulina universa*, *O. suturalis*, and rare specimens of *Globorotalia acostaensis*. Possibly the sediments in this interval (Sample 15-2, 113-115 cm) should be placed in the base of the next zone which is the *Globorotalia merotumida* Zone (from Sample 9-1, 140-142 cm to Sample 15-1, 119-121 cm). Its assemblage consists of abundant *Globorotalia acostaensis*, common *G. globorotaloidea*, *G. scitula*, *G. miozea miozea*, *G. miozea cibaoensis*, *Globigerina bulloides*, *G. concinna*, *G. juvenilis*, *G. quinqueloba*, *Orbulina universa*, *Globigerinita glutinata*, *G. uvula* and still rarer *Globorotalia merotumida*, *G. linguaensis*, *Globoquadrina dehiscens*, *G. altispira*, *Globigerinoides trilobus*, *G. obliquus obliquus*, *Globigerina nepenthes*, *G. microstoma*, *G. decoraperta*, *Sphaeroidinellopsis seminulina*, and *S. subdehiscens*.

The *Globorotalia plesiotumida* Zone follows (from Sample 6-1, 101-104 cm to Sample 8-7, 3-5 cm) with rare specimens of the index species and common *G. miozea conoidea*, *G. conomiozea*, and *G. pseudomiocenica*. Other foraminifers present are *Globorotalia acostaensis*, *G. globorotaloidea*, *G. scitula*, *G. aff. humerosa*, *Globigerina bulloides*, *G. quinqueloba*, *G. microstoma*, *G. nepenthes*, *G. atlantica*, *G. decoraperta*, *Orbulina universa*, *Globigerinita glutinata*, *G. uvula*, and *Sphaeroidinellopsis seminulina*.

The *Globorotalia margaritae margaritae* Zone (from Sample 4-1, 144-146 cm to Sample 4-2, 25-27 cm) with

numerous *G. margaritae margaritae*, *G. acostaensis*, *G. globorotaloidea*, *Globigerina bulloides*, *G. quinqueloba*, in combination with rarer *Globigerinita glutinata*, *G. uvula*, *Orbulina universa*, *Globorotalia scitula*, *G. humerosa*, *Globigerina microstoma*, and *G. concinna* caps the Miocene.

### Pliocene

Pliocene sediments are separated from those of the Miocene by a 66 meters interval wherein there was no recovery. The Pliocene sediments belong to the *Globorotalia margaritae evoluta* Zone (Sample 3-1, 80-82 cm), and are characterized by the index species, *G. margaritae margaritae*, *G. puncticulata*, *G. inflata*, *G. scitula*, *Globigerina bulloides*, *G. concinna*, *G. quinqueloba*, *Globigerinita glutinata*, and *Orbulina universa*.

### Quaternary

Another interval without recovery (66.5 m) separates Quaternary from Pliocene sediments. The apparent thickness of the Quaternary section is 71.5 meters; only two cores were recovered in the interval from 5 to 62 meters.

The lower part of the Quaternary oozes (from Sample 2-1, 144-146 cm to Sample 2-3, 86-87 cm) likely belongs to the *Globorotalia crassaformis hessi* Sub-zone. It is characterized by abundant *Globorotalia inflata*, *Globigerina bulloides*, and *G. quinqueloba* accompanied by rarer *Globorotalia crassaformis hessi*, *G. crassaformis crassaformis*, *G. puncticulata*, *G. scitula*, *G. crassula*, *Orbulina universa*, *Globigerinella siphonifera*, *Turborotalita humilis*, and *Neogloboquadrina pachyderma*.

In the surface layers, 5 meters thick, two assemblages were observed. The lower (from Sample 1-2, 65-67 cm to Sample 1-3, 25-27 cm) abounds in *Neogloboquadrina pachyderma* associated with numerous *Globigerina bulloides*, *G. quinqueloba*, *Globigerinita glutinata* and rare *Globorotalia inflata*, *G. scitula*, *G. acostaensis*, *Orbulina universa*, and *Turborotalita humilis*, a relatively cold water microfauna.

The upper assemblage (Sample 1-1, 70-72 cm) reflects relatively warm water postglaciation (Holocene) conditions and consists of numerous *Orbulina universa*, *Globigerina bulloides*, *G. quinqueloba*, *Globigerinita glutinata*, *Globorotalia inflata*, *G. scitula*, *G. acostaensis*, *G. crassaformis*, *G. hirsuta*, and *Turborotalita humilis*; *Globorotalia truncatulinoides* was recognized and specimens of *Neogloboquadrina pachyderma* are rare.

## ECOLOGICAL AND CLIMATIC PECULIARITIES OF PLANKTONIC FORAMINIFERS

Throughout Cenozoic time the Bay of Biscay and Rockall Plateau areas were associated to various climatic belts and experienced changing climates from subtropical to temperate to boreal. The Cenozoic sediments in these areas were deposited at various depths, the local ecologies of which coupled with climate, affected the composition of the planktonic foraminiferal biotas. The combination of the above factors with selective diagenetic dissolution

determines the foraminiferal thanatocoenoses that are encountered in the sediments, but it is not always possible to differentiate which factor was the dominant influence.

The influence of selective dissolution on the systematic composition of foraminifers is well demonstrated at Site 400 (the present depth, 4399 m). Here, Eocene and Oligocene deep-water sediments are characterized mostly by representatives of *Acarinina* and non-keeled *Globorotalia*, the so-called *Turborotalia* such as *G. frontosa*, *G. opima*, *G. nana*, the related *Globigerina(?) boweri* and other species of *Globigerina* such as *Globigerinita unicava*. There are no keeled *Globorotalia*, some *Globigerina* species, and representatives of *Hantkenina*, *Globigerapsis*, *Globigerinatheca*, *Pseudohastigerina*, and *Truncorotaloides* which are widely developed in synchronous more shallow-water sediments of Sites 401 and 402.

In Neogene deep-water sediments of Site 400 *Globorotalia (Turborotalia)* with perforate peripheral margin are developed again, and include *G. kugleri*, *G. nana*, *G. continua*, *G. siakensis*, *G. peripheroronda*, *G. acostaensis*, *G. crassaformis*, *G. inflata*, *G. puncticulata*, and the phylogenetically related species of the *G. fohsi* group and *G. margaritae*. The common elements of this microfauna are *Neogloboquadrina dutertrei* and *N. pachyderma*, some species of *Globigerina* (*G. woodi*, *G. venezuelana*, *G. druryi*, *G. nepenthes*, *G. bulloides*) and comparatively rare *Globigerinita unicava*, *Sphaeroidinellopsis seminulina*, *S. subdehiscens*, *Globigerinita glutinata*, and *Globoquadrina dehiscens*. Representatives of keeled *Globorotalia* are very rare (i.e., *G. merotumida*). Noteworthy is the almost complete absence of *Globigerinoides* species, and extremely rare keeled *Globorotalia*, *Orbulina*, and *Praeorbulina*.

The quantitative distribution and qualitative diversity of planktonic foraminifers in deep-water sites such as Site 400, as compared to the more shallow-water Sites 401 to 406 was controlled by a number of local biogenic factors.

At Site 400, sediments of the lower part of the lower Eocene and the lower part of the lower Miocene, with rather diverse planktonic foraminiferal assemblages, are separated by sediments of the upper part of the lower Eocene, middle Eocene, and Oligocene, wherein foraminifers are rare or sometimes absent. In their stead, the sediments contain siliceous organisms, the development of which is probably related to upwelling of cold waters, rich in nutrients that stimulated a flourish of siliceous plankton and benthos. Selective dissolution of planktonic foraminifers was probably only secondary in accounting for their paucity.

A similar picture is observed at Site 406 where Oligocene sediments (the *Globorotalia opima* Zone) are separated from Miocene sediments (the *Praeorbulina glomerata* Zone), both with rich planktonic foraminiferal assemblages, by an interval of upper Oligocene-lower Miocene diatomites and diatom chalk characterized by abundant siliceous organisms and almost devoid of planktonic foraminifers. This flourish of siliceous organisms again is probably related to upwelling near the continental slope of the Rockall Plateau.

However, in deep-water sediments of Site 400 there are intervals (the upper part of the lower Miocene and the upper

part of the upper Miocene), where both siliceous and calcareous plankton are extremely rare. In this instance the scarcity or absence of planktonic foraminifers is most likely related to the lowering of the carbonate compensation depth.

The close relation of planktonic foraminifers to the depth of accumulation of carbonate sediments is obvious. At Site 406, middle Eocene shallow-water calcareous-clayey sediments contain a poor, dwarfish fauna of them. They are also of poor systematic composition and of small size in glauconitic limestones of the middle Eocene at Site 403, and in analogous sediments of the lower Eocene at Site 405. Such similarities cannot be explained simply by cold-water conditions in a temperate area, because normal faunas, although rather poor in systematic composition, are developed stratigraphically higher in typically pelagic calcareous oozes of the upper Eocene, Oligocene, and Neogene.

The influence of climate on distribution of planktonic foraminifers has become obvious only since Cenozoic deposits have been penetrated by DSDP holes throughout the North Atlantic, from the equatorial area to the Norwegian and Greenland Seas.

In the tropical belt, from the Equator to Latitude 28 degrees North, Paleogene planktonic foraminifers have been studied in both the western and the eastern sectors, and Neogene and Quaternary foraminiferal studies from the belt of the Mid-Atlantic Ridge (See *Initial Reports of the Deep Sea Drilling Project*, Legs 1, 2, 3, 4, 10, 11, 14, 15, 41).

In Paleogene time the Bay of Biscay was situated in the subtropical belt, probably near its northern margin. From the limited material from that area, it appears that Paleocene and lower Eocene planktonic foraminifers differed slightly from tropical microfauna in the absence of *Globorotalia occlusa*, *G. apantesma*, *G. imitata*, *G. trichotrocha*, *G. passionensis*, *G. elongata*, *G. quetra*, *G. marksi*, *Acarinina tribulosa*, *A. strabocella*, and *A. gravelli*.

In middle Eocene time the difference is pronounced, as evidenced by the absence of *Orbulinoides beckmanni*, *Globorotalia lehneri*, *Clavigerinella jarvisi*, *C. akersi*, *Hantkenina dumblei*, and *Globigerinita echinata*; by the wide distribution of *Acarinina* species, especially *A. rotundimarginata* and *A. bullbrooki*; in the frequent occurrence of *Hantkenina alabamensis*, *H. liebusi*, and *H. Lehneri*; by the morphological peculiarity of *Truncorotaloides rohri* and *T. topilensis* being frequently devoid of accessory apertures; and by the presence of numerous small *Globigerina* such as *G. incretacea*, *G. azerbaijanica*, and *G. pseudocorpulenta* in the *Truncorotaloides rohri* Zone. The abundant *Acarinina rotundimarginata* in the *Globorotalia lehneri* Zone and *Hantkenina alabamensis* in the *Orbulinoides beckmanni* Zone has not been observed in the tropical areas. Whereas, middle Eocene assemblages of the Bay of Biscay are very similar to the synchronous microfauna of the Crimea and North Caucasus, deposited approximately at the same latitude, the latter microfauna differs slightly by still greater impoverishment in the absence of *Hantkenina aragonensis*, *Globigerapsis kugleri*, *Globorotalia pseudomayeri*, *G. renzi*, and *G. spinulosa*.

Differences between tropical and subtropical assemblages are clearly recognized in the upper Eocene sediments of the Bay of Biscay where the entire group of *Globorotalia cerroazulensis* (*G. cerroazulensis*, *G. cocoaensis*, *G. cunialensis*), and *Hantkenina alabamensis* and *H. suprasuturalis* are absent, and *Globigerapsis semiinvoluta* and *Cribohantkenina inflata* only sporadic. If sporadic specimens of the latter two species are disregarded, the upper Eocene assemblages from the Bay of Biscay and the Crimean-Caucasian area are identical, both consisting of mass accumulations of large *Globigerina*, *Globigerapsis tropicalis*, and *G. index*.

Comparison of subtropical planktonic foraminifers from the Oligocene and Neogene of the Bay of Biscay to those of the tropical belt is rather difficult. At Sites 401 and 402 calcareous organogenic oozes of the Oligocene and Neogene were eroded, and at Site 400 they are represented by deep-water sediments. The impoverishment of the assemblages may have been caused by selective dissolution and/or climatic influence. Noteworthy is the presence of the *Globorotalia fohsi* group in the Miocene. The Pliocene microfauna is much richer, but *Sphaeroidinella*, *Pulleniatina*, *Candeina*, *Globigerinoides ruber*, *G. conglobatus*, *G. sacculifer*, *Globorotalia miocenica*, *G. exilis*, and *G. multicamerata* are not present. The *G. menardii* group is barely developed.

As already noted, meagerness of the planktonic foraminiferal assemblages of the lower Eocene of Rockall Plateau (the temperate belt) is probably due to shallow-water conditions of sediment accumulation. Upwards in the section they are replaced by normal calcareous pelagic sediments and the number of forms abruptly increases (middle Eocene of Site 405). The assemblage consists of representatives of *Aracinita*, *Globigerina* (including *G. boweri*), *Pseudohastigerina micra*, non-keeled *Globorotalia* (*G. bolivariana*); keeled *Globorotalia* (*G. caucasica*, *G. aragonensis*) are sporadic.

Excellent assemblages occur in the upper Eocene sediments of Rockall Plateau (Site 406). They consist of representatives of *Globigerina*, *Globigerapsis* (*G. tropicalis*, *G. index*), and rare non-keeled *Globorotalia* (*G. centralis*). Species of *Hantkenina*, *Cribohantkenina*, *Globigerapsis semiinvoluta* and the *Globorotalia cerroazulensis* group (*G. cerroazulensis*, *G. cocoaensis*, *G. cunialensis*) are entirely absent. These peculiarities distinguish upper Eocene assemblages of Rockall Plateau from those of the Bay of Biscay where sporadic *Globigerapsis semiinvoluta* and *Cribohantkenina inflata* are still present, and make them identical, in specific composition, to the upper Eocene associations of the Crimea and North Caucasus. But, whereas in the latter region almost every species occurs in equal numbers, in the paleocoenoses of Rockall Plateau *Globigerapsis tropicalis*, *Globigerina corpulenta*, *G. galavisi*, *G. praebulloides*, and sometimes *G. pseudovenezuelana* sharply predominate and other species are rare.

The Oligocene assemblages (the *Globorotalia opima* Zone) of the Rockall Plateau Sites 403 and 406 abound in some species such as non-keeled *Globorotalia* (*G. opima*, *G. nana*), *Globigerina praebulloides*, *Globorotaloides*

*suteri*, and *Globigerinita unicava*; other planktonic foraminifers are rare. As known, Septarian clays of North Europe, clays of the Carpathian Menilit Formation, calcareous and noncalcareous foliated shales of the Maicop Formation from Varna basin in Bulgaria to the Transcaspiian area are characterized by the fauna of small *Globigerina* (*G. officinalis*, *G. praebulloides*, *G. ouachitaensis*, *G. angustumbilicata*, etc.). The similar composition of Oligocene biotas of northern and eastern Europe has commonly been explained to result from general deterioration of climatic conditions in Oligocene time, and the relatively northern geographical position of the area. This explanation must be rejected because, much further north, in the Oligocene on Rockall Plateau, excellent assemblages of planktonic foraminifers are developed, including both the small and the large species of *Globigerina* and *Globorotalia* (*Turborotalia*). The presence of assemblages of minute Globigerinids in the Oligocene of northern and eastern Europe is related to the sandy-clayey, frequently slightly calcareous, sediments in which they accumulated.

The basal part of the lower Miocene on Rockall Plateau is composed of diatomites and diatomaceous chalk, and the nature of planktonic foraminifers for this unit is obscure. However, beginning in the upper part of the lower Miocene, the Neogene is characterized by abundant specimens, although the number of species is small. Five groups can be distinguished. Most prominent among them is: (1) the *Globorotalia* (*Turborotalia*) group with a rounded non-keeled peripheral margin (*G. siakensis*, *G. peripheroronda*, *G. obesa*, *G. continua*, *G. acostaensis*, *G. humerosa*, *G. globorotaloidea*, *G. crassaformis*). The author has never seen such enormous accumulations of *G. siakensis* in middle Miocene sediments, of *G. acostaensis* and *G. globorotaloidea* in upper Miocene sediments of the tropical and subtropical areas; (2) the *Globigerina* group (*G. juvenilis*, *G. falconensis*, *G. foliata*, *G. bulloides*, *G. concinna*, *G. quinqueloba*, and *G. megastoma*).

In the upper Miocene, Pliocene and Quaternary sediments these groups are supplemented by (3) a group of rather numerous *Globorotalia miozea miozea*, *G. miozea conoidea*, *G. conomiozea*, *G. puncticulata*, and *G. inflata*, observed in the subtropical area but rare or absent in tropical areas.

Stratigraphically important is (4) a group of eurythermal species, in small equal quantities of specimens developed in the tropical, subtropical and temperate-boreal belts. The group includes *Globorotalia miozea cibaoensis*, *G. praemenardii*, *G. pseudomiocenica*, *G. margaritae margaritae*, and *G. margaritae evoluta*.

Group (5) is composed of species occurring in subordinate numbers of specimens. It contains *Globoquadrina altispira*, *G. dehiscens*, *Globigerina nepenthes*, *Globigerinoides trilobus*, *G. subquadratus*, *G. bollii*, *Globorotalia merotumida*, *G. aff. plesiotumida*, *Sphaeroidinellopsis seminulina*, *S. subdehiscens*, *Globigerinoides bisphaerica*, *Praeorbulina transitoria*, *P. glomerosa*, *Orbulina suturalis*, *O. universa*, and others. Though they are seldom recognized, some of them are valuable stratigraphic markers as, for instance, in the

lower/middle Miocene of Rockall Plateau where the trend *Globigerinoides bisphaerica* – *Praeorbulina transitoria* – *P. glomerosa* – *Orbulina suturalis* – *O. universa* can be clearly traced.

Impoverishment of some forms in Neogene/Quaternary sediments of Rockall Plateau is manifested in complete absence of *Globigerinatella*, *Cassigerinella*, *Candeina*, *Pulleniatina*, *Sphaeroidinella*, the *Globorotalia fohsi* group, the *Globorotalia menardii* group as well as *G. (Clavatorella) bermudezi*, *G. tumida*, *G. multicamerata*, *G. pertenuis*, *G. miocenica*, and *G. exilis*. In addition there is weak development of representatives of *Globigerinoides*, many species of which (*G. diminutus*, *G. obliquus*, *G. sacculifer*, *G. ruber*, and *G. conglobatus*) are absent.

As a whole, Eocene, Oligocene, and Neogene assemblages of planktonic foraminifers of the Rockall Plateau area are of clearly pronounced temperate character and, in the latest stages of the Pliocene/Quaternary time, they sometimes acquired temperate-boreal features.

Unfortunately, it is difficult to estimate every stage of impoverishment of planktonic foraminiferal assemblages in Paleogene and Neogene sections of the area because general deterioration of climatic conditions in some intervals of the Cenozoic (lower and middle Eocene, part of the Oligocene, and lower Miocene) do not yield definitive material.

Noteworthy is the bipolarity of planktonic foraminiferal distribution. *Globorotalia miozea miozea*, *G. miozea cibaoensis*, *G. miozea conoidea*, *G. conomiozea*, *G. puncticulata*, *G. inflata*, and *G. crassaformis*, peculiar to the upper Miocene and Pliocene of Rockall Plateau, are representative of synchronous sediments in the temperate belt of the Southern Hemisphere (DSDP Legs 28 and 29).

Comparison of Cenozoic planktonic foraminiferal assemblages of the tropical, subtropical, and temperate areas shows: (1) general specific diversity of planktonic foraminifers decreases northward; (2) the ratio of species in paleocoenoses varies; (3) in the main a limited group of species is peculiar to the temperate belt; (4) there are irregularities in species distribution along the stratigraphic section, where they are characterized not by their own biozones, but by epiboles (teilzones).

#### ZONAL STRATIGRAPHY OF CENOZOIC DEPOSITS OF THE BAY OF BISCAY AND THE ROCKALL PLATEAU

Numerous bionomic factors affect the systematic composition of planktonic foraminiferal assemblages in such diverse ways that the Tertiary faunal zones, regardless of whether they occur in the same or in different latitudes, are never identically represented by the same genera and species. Indeed it is not uncommon to find that the fauna of a particular zone lacks the index species. Obviously the stratigraphic value of a zone is much greater when the complex spatial diversity of its fauna is understood and used rather than depending upon a few individual elements within it or the appearance or disappearance of the index species. As a result of this regional variation in the taxonomic composition of fauna, independent zonal scales have been erected in different areas. In 1954 the Paleogene Committee of the USSR adopted the Unified Zonal Scale of Paleocene and Eocene (subtropical-temperate belt) for the

southern part of the USSR. The Oligocene and Miocene rocks of the southern USSR contain only marine intercalations separated by brackish and fresh water sediments. Zonal scales of Bolli (1957a, b, c) and Blow (1969) for the Paleogene and Neogene of the tropical and subtropical belts are well known and for the Cenozoic of Rockall Plateau (temperate-boreal area) an independent zonal scale has been created by Berggren (1972a).

For the Paleogene succession in the Bay of Biscay area, at least for middle and upper Eocene, the Crimean-Caucasian zonal scheme formally should be used. For the Neogene successions of the Bay of Biscay and Rockall Plateau, a zonation different to that of the standard tropical scale formally should be applied also. But the fact that some of the tropic elements are found in subtropic and temperate latitudes and the existence of sections with transitional microfaunas shows that the detailed Cenozoic zonal scale of the tropical zone is equally valid for the subtropical and temperate belts.

Zonal subdivisions, for the Cenozoic stratigraphy of the Bay of Biscay and Rockall Plateau, based on planktonic foraminifers, are summarized below. Figures 2 and 3 illustrate, respectively, the stratigraphic succession in the two areas. Because lower and middle Eocene sediments in the Rockall Plateau area are of shallow water-origin and poor in planktonic foraminifers, zonal units for sediments of these ages were recognized only in the Bay of Biscay.

Paleocene: the *Globorotalia trinidadensis* Zone, Site 401; the *Acarinina uncinata* Zone, Site 401; the *Globorotalia pseudomenardii* Zone, Site 401; the *Globorotalia velascoensis* Zone, Site 401. Because of a hiatus within Paleocene only the *Globorotalia pusilla* s.l. Zone was not recognized.

Lower Eocene: the *Globorotalia subbotinae* Zone, Sites 400 and 401; the *Globorotalia formosa* Zone, Sites 400 and 401; the *Globorotalia aragonensis* Zone, Site 401; the *Globorotalia palmerae* Zone, Site 401.

Middle Eocene: the *Hantkenina aragonensis* Zone s.l., Site 401; the *Globigerapsis kugleri* Zone, Site 401; the *Globorotalia lehneri* Zone, Site 401; the *Orbulinoides beckmanni* Zone, Site 401; the *Truncorotaloides rohri* Zone, Sites 401 and 402.

In the upper Eocene of the Bay of Biscay the following were singled out: the *Globigerapsis semiinvoluta* Zone, Site 402; the *Globorotalia cocoaensis* Zone, Site 401; the *Globorotalia centralis* – *Globigerina turritilina* Zone, Site 401. The two first zones cited have weak distinctions because the guide species of these zones are presented by rare specimens; on Rockall Plateau they were determined as an undifferentiated unit at Site 406.

The Oligocene sections both in the Bay of Biscay and on Rockall Plateau are stratigraphically incomplete. The *Globorotalia opima* Zone is very well defined in both regions (Sites 400, 403, and 406); the *Globigerina ciperoensis* Zone (without the index species) was determined on Rockall Plateau, Site 406.

The lower Miocene of the two given regions is characterized by sediments unfavorable for planktonic foraminifers. The *Globigerinoides primordius*-*Globorotalia kugleri* Zone and the *Globigerinita dissimilis* Zone were recognized in the Bay of Biscay, Site 400, and the

*Praeorbulina glomerosa* Zone, at Rockall Plateau, Site 406.

In the base of the middle Miocene at Rockall Plateau the *Orbulina suturalis*-*Globorotalia peripheroronda* Zone was recognized, Site 406. In the Bay of Biscay this stratigraphic interval is represented by sediments with rare planktonic foraminifers; here, overlying sediments of the middle Miocene contain the *Globorotalia peripheroacuta*, *Globorotalia fohsi lobata*, *Sphaeroidinellopsis subdehiscens*-*Globigerina druryi*, and *Globigerina nepenthes*-*Globorotalia siakensis* zones (Site 400). On Rockall Plateau sediments of the same age cannot be subdivided into zones (Site 406).

The whole succession of zonal units of the upper Miocene can be traced in the Bay of Biscay and on Rockall Plateau; it contains the *Globorotalia continua* Zone, Site 400 and, conditionally, Site 406; the *Globorotalia merotumida* Zone, Sites 400, 403, 404, and 406; the *Globorotalia plesiotumida* Zone, Sites 400, 403, 404, and 406; the *Globorotalia margaritae margaritae* Zone, Sites 400, 403, 405, and 406.

On Rockall Plateau the *Globorotalia merotumida* Zone is recognized by the occurrence of *Globorotalia miozea cibaoensis*, unknown in more ancient sediments, and for the determination of the *Globorotalia plesiotumida* Zone it is the appearance of *Globorotalia pseudomiocenica*, also unknown in the underlying sediments. In the *Globorotalia plesiotumida* Zone the species *G. pseudomiocenica* is accompanied by numerous *G. miozea conoidea*, and *G. conomiozea*. These three species are common also in the *Globorotalia margaritae margaritae* Zone, but there they associate with the index species.

In the Pliocene of the Bay of Biscay and on Rockall Plateau the *Globorotalia margaritae evoluta* Zone is very distinct at Sites 400, 403, and 406. On Rockall Plateau the index species of this zone is accompanied by abundant *Globorotalia puncticulata*. Younger sediments of the Pliocene of the Bay of Biscay (Site 400) are subdivided into the *Globorotalia miocenica* and *Globorotalia tosaensis* zones, but this subdivision is conditional on account of the poverty of the microfauna (evidently, in connection with selective dissolution). On Rockall Plateau (Site 403) the same stratigraphic interval cannot be separated into indicated zones due to the impoverishment of microfauna of the temperate belt. However, here, two local subdivisions are pronounced, layers with *Globorotalia crassaformis* and layers with *Globorotalia inflata*.

Comparison of stratigraphic subdivisions of the upper Miocene/Pliocene sediments of Rockall Plateau (the temperate belt of the Northern Hemisphere) with the Tasman Sea (the subtropical-temperate belt of the Southern Hemisphere), based on data of Kennett (1973), and Kennett and Vella (1975), reveals similarities. The upper Miocene/Pliocene sediments of the Tasman Sea are subdivided into the *Globorotalia continua*, *Globigerina nepenthes*, *Globorotalia conomiozea*, *Globorotalia margaritae*, *Globorotalia puncticulata*, *Globorotalia crassaformis*, and *Globorotalia inflata* zones. Thus, a bipolarity of the zonal stratigraphic scales of the upper Miocene and Pliocene is recognized. However, if the zones of the upper Miocene and lower Pliocene are based on the evolutionary development of planktonic foraminifers, establishment of the *Globorotalia crassaformis* and

*Globorotalia inflata* "zones" is based on epiboles of these two species. Coincidence, in general, of the stratigraphic scopes of the *Globorotalia crassaformis* layers and the *Globorotalia inflata* layers of the Northern Hemisphere and "zones" of the same name of the Southern Hemisphere suggests similar (universal) change of the climatic conditions, which determined, apparently, ecological flourishings (or subordinate position) of *Globorotalia crassaformis* and *G. inflata* in assemblages of planktonic foraminifers of the Northern and Southern temperate belts.

The Quaternary sediments correspond to the *Globorotalia truncatulinoides* Zone which was determined in all sites of the Bay of Biscay and Rockall Plateau. Paleontological data (ratio of planktonic foraminiferal species in their assemblages) in combination with the paleotemperature analysis ( $O^{16}/O^{18}$ ) should permit creation of the detailed climate-stratigraphy of Quaternary.

### SOME ASPECTS OF GEOLOGICAL HISTORY OF CENOZOIC

Numerous discontinuities and hiatuses exist in the Cenozoic successions of the Bay of Biscay and Rockall Plateau. Within the Paleogene section of the Rockall Plateau, at Site 403, the lower Eocene, middle Eocene, and Oligocene are separated by disconformities and considerable intervals of Paleogene sediments are missing. At Site 406 disconformities separate the middle Eocene, upper Eocene, and Oligocene. These gaps in the record reflect unstable conditions of sedimentation which existed not only during accumulation of shallow-water clayey tuffaceous sediments of Paleocene-early Eocene age, but continued into the late Eocene and Oligocene when accumulation of deeper water pelagic organogenic oozes took place.

A regional discontinuity separates the upper Miocene from older deposits. It is present at all sites on Rockall Plateau. Its regional character is emphasized by the fact that different zones of the upper Miocene (*Globorotalia continua*, *Globorotalia merotumida*, and *Globorotalia margaritae margaritae*) rest on sediments of different ages, i.e., middle Miocene (Site 406), Oligocene (Site 403), middle Eocene (Site 405), lower Eocene (Site 404). Even in two neighboring sites the age of sediments below this disconformity are widely diverse: Oligocene at Site 403 and lower Eocene at Site 404.

In contrast, sediments of the upper Miocene/Quaternary are remarkable for their stratigraphic completeness (Sites 403, 404 and 406); only in Site 405 do Quaternary oozes disconformably overlie the *Globorotalia margaritae margaritae* Zone (the uppermost Miocene), but this disconformity appears to be distinctly localized because, in the adjacent Site 406, the section is continuous.

Examination of the lithology and flora/fauna at sites on Rockall Plateau reveals significant interpretable information. The oldest Paleogene in Sites 403 and 404 (sandstones, tuffs, clays, lignitic clays), conditionally attributed to the upper Paleocene, lack faunal remains. Accumulation of these deposits evidently took place under subaerial conditions. Higher up, in basal Eocene layers are rare, sometimes rounded shells of benthic foraminifers and debris of mollusks; these sandstones, clays, and tuffs

probably should be considered to be littoral deposits. Overlying lower Eocene sediments are characterized by diverse benthic foraminifers, ostracodes, bryozoa, sponges, and sea urchins; rare planktonic foraminifers occur here. These sediments obviously accumulated in a sublittoral area.

Sediments of the upper part of the lower Eocene (within the limits of the *Globorotalia aragonensis* and *Globorotalia palmerae* zones) are distinguished by another type of microfauna, the bulk of which consists of abundant radiolarians. Occasionally planktonic foraminifers are numerous but their specific composition is impoverished because of the development of the radiolarian facies (Sites 404 and 405). Such a microfauna should be considered to be pelagic; their accumulation proceeded evidently at the margin of the shelf and in the upper part of the continental slope.

Analogous pelagic radiolarian-foraminiferal oozes are peculiar to the basal part of the middle Eocene (Sites 405 and 406), whereas exceptional pelagic foraminiferal and radiolarian-foraminiferal oozes were developed in the upper Eocene (Site 406) and Oligocene (Sites 403 and 406).

From this it is evident that subsidence of Rockall Plateau proceeded rather quickly, the amplitude of subsidence being equivalent to present-day depths of 2300 to 2900 meters.

The Cenozoic of the Bay of Biscay displays an irregular picture of the stratigraphic position of discontinuities, although sites are located close to each other. At Site 400 upper Paleocene rocks rest disconformably on the Maestrichtian; at Site 401 the contact of the Danian and Maestrichtian stages is essentially conformable, but higher up the section a gap within the Paleocene (between the *Acarinina uncinata* and *Globorotalia pseudomenardii* zones) is present; at Site 402 sediments of the upper part of the middle Eocene overlie those of the Lower Cretaceous (Albian).

At Site 400 Oligocene sediments rest disconformably on those of the middle Eocene but higher up, a continuous section of Oligocene, Neogene, and Quaternary follows; at Sites 401 and 402 sediments of this age are all but missing and the upper Eocene is directly overlain by Quaternary. For explanation of such a variegated picture of hiatuses and disconformities, it is difficult to find reasons.

The entire Cenozoic section of the Bay of Biscay is characterized by pelagic facies; the main subsidence of this region appears to have been a Mesozoic event.

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