

16. EOCENE-OLIGOCENE SUBTROPICAL PLANKTONIC FORAMINIFERS AT SITE 841¹

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ABSTRACT

A middle Eocene to lower Oligocene sedimentary sequence was drilled at Site 841 in the Tonga forearc region during Ocean Drilling Program Leg 135. A 56-m-thick sequence of volcanic sandstone, spanning from Cores 135-841B-41R to -47R (549.1 to 605 mbsf), unconformably overlies rhyolitic volcanic basement. The middle Eocene planktonic foraminifer assemblages (P Zone ?), which occur in association with larger benthic foraminifers, include spinose species of *Acarinina*, *Morozovella*, and *Truncorotaloides*, but their abundance is low. Late Eocene and early Oligocene faunas are abundant and show the highest diversity of the Paleogene sequence drilled at this site. They have been assigned to Zones P15–16 and P18, respectively. The Eocene/Oligocene boundary was not recognized because of a hiatus in which Zone P17 (37.2–36.6 Ma) was missing. Another hiatus is recorded in the interval between the middle and late Eocene, spanning at least 1.8 Ma.

Paleogene assemblages of Site 841 contain equal numbers of warm- and cool-water species, an attribute of the warm middle-latitude Paleogene fauna of the Atlantic Ocean. In particular, common to high abundances of cool-water taxa, such as *Globorotaloides*, *Catapsydrax*, *Tenuitella*, and small globigerinids, may be related to the opening of a shallow seaway south of Tasmania permitting the influx of cool Indian Ocean waters into the South Pacific before the late Eocene (approximately 37 Ma).

INTRODUCTION

This paper presents the results of a study of Paleogene planktonic foraminifers recovered from Site 841, which was drilled into the Tonga forearc region during Ocean Drilling Program (ODP) Leg 135. Site 841 is located (Fig. 1) just west of the trench slope break, approximately 55 km west of the axis of the Tonga Trench and 60 km east of the Tonga Ridge, about 140 km south-southwest of Site 840. The water depth at this site is 4809.8 m, below the carbonate compensation depth (CCD).

Two holes were drilled at Site 841. Sediments recovered consist of a 605-m-thick sequence of clay, vitric siltstone and sandstone, volcanic conglomerate and breccia, and calcareous volcanic sandstone. The sediments overlie an igneous basement composed of rhyolitic volcanic rocks. At this site, a thick middle Pleistocene to upper Miocene sequence continues down to 467.8 mbsf. This sequence is faulted against middle Miocene volcanoclastic sediments. Below 549 mbsf, lower Oligocene to middle Eocene sediments are present (Fig. 2).

GENERAL LITHOSTRATIGRAPHY OF HOLE 841B

Sedimentary Sequence and Geological Age

The sedimentary sequence penetrated at Hole 841B was divided into five lithologic units (Parson, Hawkins, Allan, et al., 1992; Fig. 2). Recovery below 72 mbsf was poor (approximately 40%).

Unit I (0–56 mbsf) consists of structureless clay interbedded with very thin- to medium-bedded vitric sand and silt turbidites and thin fallout tephra. Unit II (56–333 mbsf, 277 m thick) displays a thick sequence of turbidites composed of thin- to thick-bedded vitric siltstone and sandstone. Unit II is characterized by increases in the proportion of sandstone beds, bed thicknesses, and grain size downcore. This turbidite sequence overlies a 125-m-thick sequence of poorly sorted, matrix-supported, volcanic conglomerate and breccia, interbedded with vitric siltstone and sandstone (Unit III, 333–458 mbsf).

These sediments are interpreted as debris flows and proximal turbidites, based on their sedimentary structures. Although Unit I is dated as middle Pleistocene and Units II and III are assignable to the late Miocene, many intervals are barren of calcareous flora and fauna because of dissolution, indicating that the depth of Site 841 was at or near the CCD throughout the deposition of Units I, II, and III. In particular, the first major barren interval separates the middle Pleistocene from the upper Miocene.

Unit IV (458–549 mbsf) comprises a 91-m-thick turbidite sequence of volcanic sandstone and siltstone, possibly deposited on a submarine fan. This unit is characterized by an overall coarsening downsequence. A volcanic conglomerate near the base of the unit is interpreted as a proximal facies. Unit IV is separated from the overlying unit by a fault breccia. This unit is moderately deformed, and meso- and microscopic high-angle normal faults and fractures are common. Planktonic foraminifer fossils are present consistently throughout this interval, yielding abundant specimens of *Orbulina*, *Globigerinoides*, *Globoquadrina*, and *Globigerina*, with minor components of *Globorotalia*, *Sphaeroidinella*, and *Cassigerinella*. The presence of *Praeorbulina*, *Orbulina suturalis*, *Globorotalia peripheroronda*, and *G. archeomenardii* indicates Zones N8 and N9 of Blow (1969), which are early middle Miocene in age (Chaproniere and Nishi, this volume). The preservation and abundance of specimens varies from moderate and common to poor and rare (Fig. 2), and fragmented and deformed specimens occur commonly throughout this interval.

The lowermost unit, Unit V (549–605 mbsf), is a 56-m-thick sequence of volcanic sandstone with thin interbeds of claystone. Total recovery was 18.35 m, representing 37% of the stratigraphic section. This unit is dated as middle Eocene to early Oligocene, and the boundary between Units IV and V is thought to be an unconformity spanning approximately 13 m.y. from the early Oligocene to the early middle Miocene. These beds are faulted against a rhyolitic complex. The following four lithologies were recognized in this unit (Parson, Hawkins, Allen, et al., 1992; Fig. 3).

Lithology A (Interval 135-841B-41R-3, 113 cm, to -42R-1, 42 cm; 549.1–554.7 mbsf) consists of a poorly sorted, matrix-supported volcanic conglomerate that is interbedded with thin, wavy, and bioturbated volcanic sandstone beds. The conglomerate beds contain mafic rock fragments, intraformational clasts of sedimentary rocks, and silicic volcanic rocks.

¹ Hawkins, J., Parson, L., Allan, J., et al., 1994. *Proc. ODP, Sci. Results*, 135: College Station, TX (Ocean Drilling Program).

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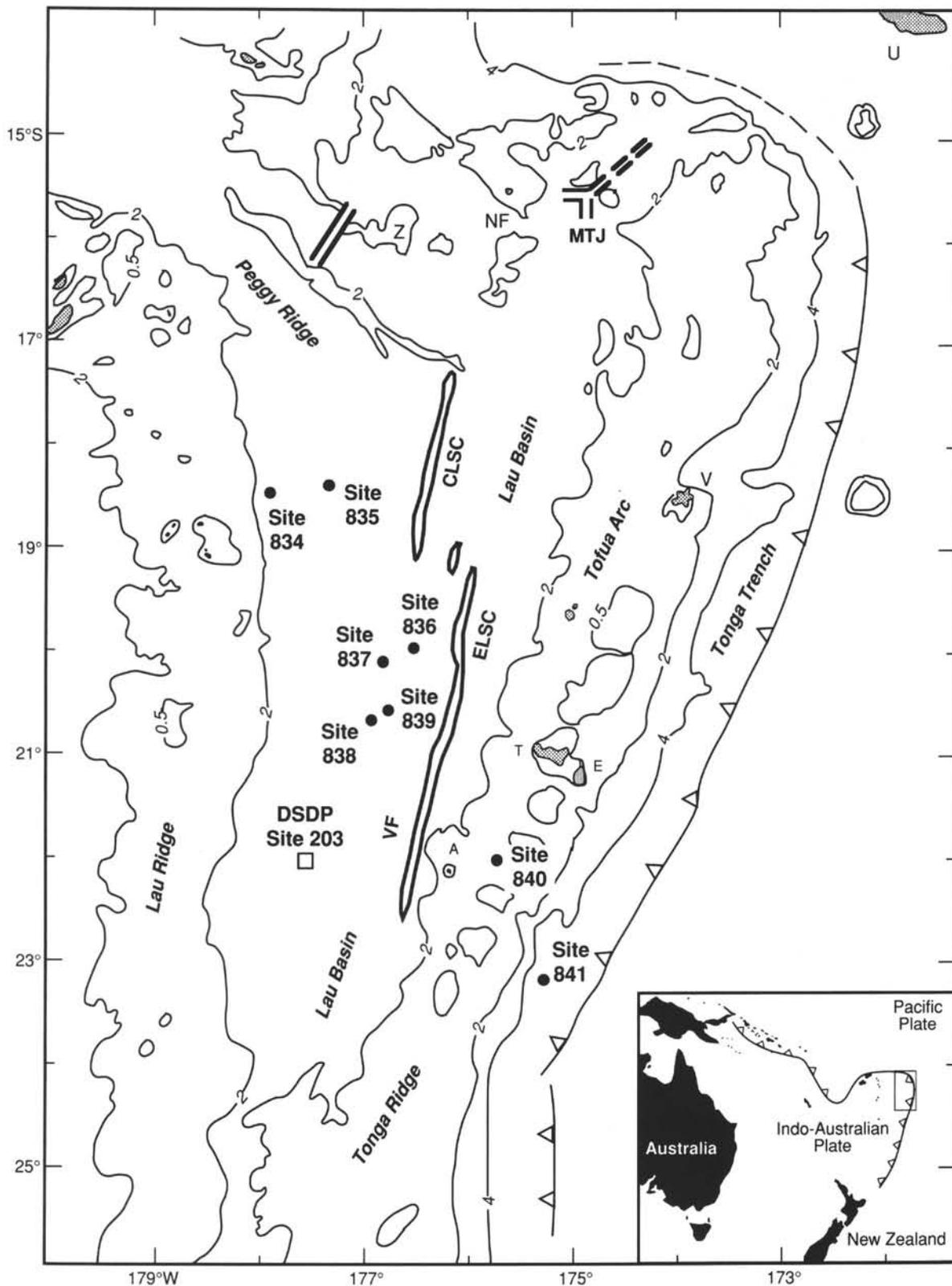
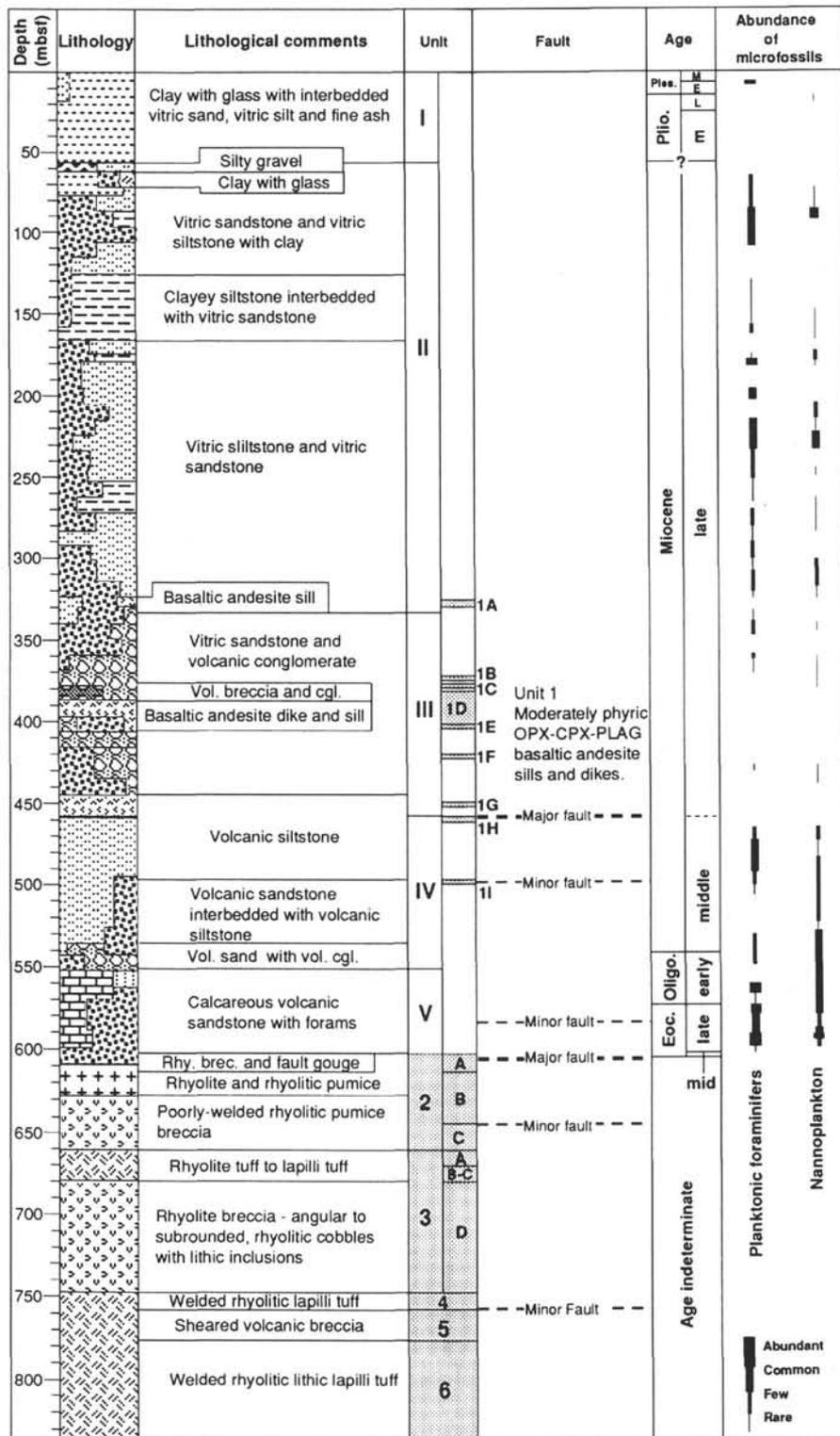


Figure 1. Regional setting for the Leg 135 drill sites showing the major geologic features of the Tonga Trench and Lau Basin system. Site 203, drilled during the Deep Sea Drilling Project (DSDP), is also shown. Z is Zephyr Shoal. Islands shown are as follows: T = Tongatapu, E = 'Eua, V = Vava'u, NF = Niufo'ou, and U = Upolu. Locations of the Central Lau and Eastern Lau spreading centers, Valu Fa Ridge, and Mangatolu Triple Junction are shown as CLSC, ELSC, VF, and MTJ, respectively. Depths are in kilometers.



- Lithologic codes:
- Clay/claystone
 - Sand/sandstone
 - Volcanic ash/tuff
 - Silt/siltstone
 - Gravel
 - Volcanic conglomerate
 - Silty clay/clayey silt
 - Calcium carbonate
 - Volcanic breccia
 - Sandy clay/clayey sand
 - Acid igneous
 - Basic igneous

Figure 2. Generalized lithologic summary for Site 841. Since this core displays low recovery, the lithologic column has been expanded vertically to make the complete column. True recovery of Site 841 was described in Parson, Hawkins, Allan, et al. (1992).

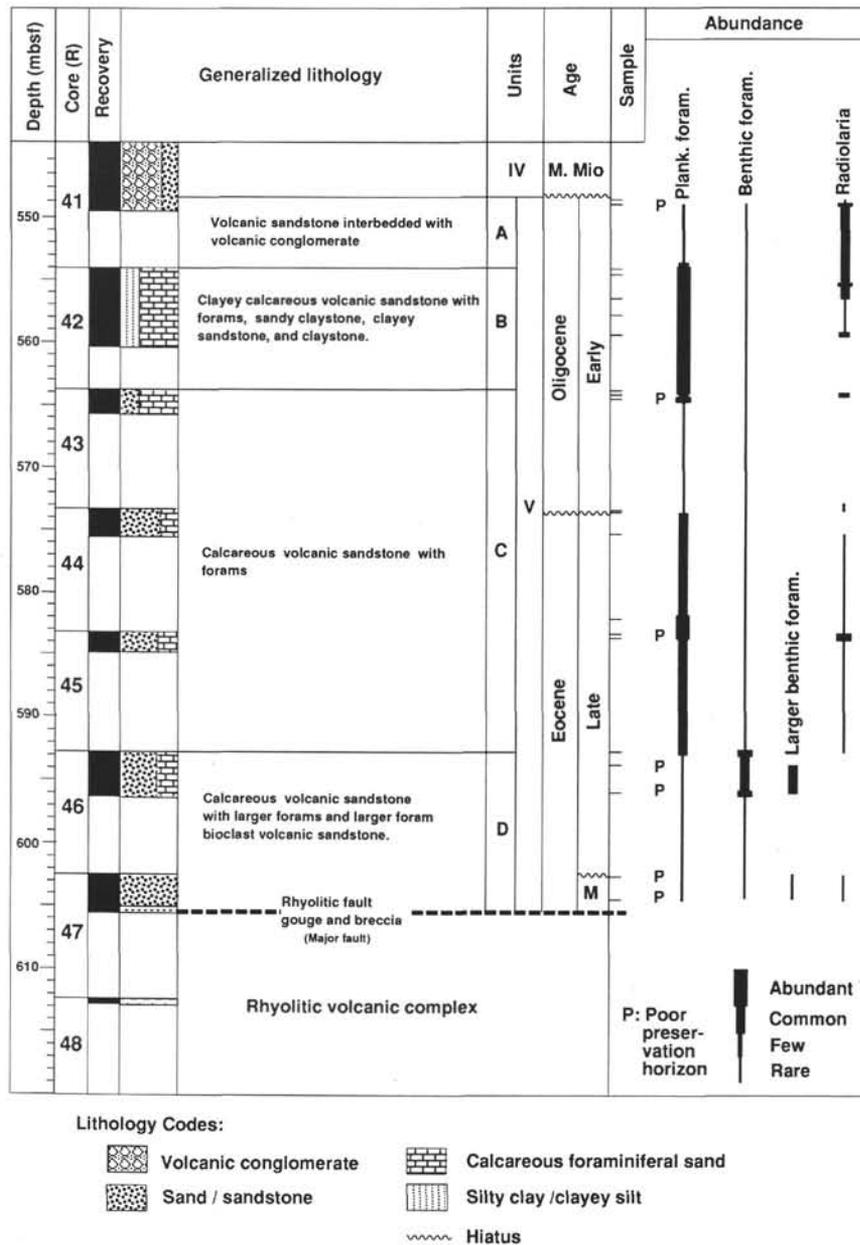


Figure 3. Stratigraphic summary of the Paleogene sequence for Site 841, showing core recovery, unit boundaries, abundances of foraminifers and radiolarians, and sampling levels. Abundances are based on specimen counts of microfossils on a picking tray using disaggregated samples; this figure does not include data on larger benthic foraminifers studied in thin section.

Lithology B (Intervals 135-841B-42R-1, 42 cm, through -42R-CC; 554.7–564 mbsf) is dominant in the upper part of this unit. It is composed of clayey calcareous volcanic sandstone, sandy claystone, and claystone with foraminifers. The clayey sand beds are generally medium- to coarse-grained and are normally graded with subrounded grains of mafic rock fragments and crystals, whereas the sandy claystone and claystone are usually structureless. These beds are heavily bioturbated, and primary sedimentary structures and bedding are frequently absent.

Lithology C (Cores 135-841B-43R through -45R; 564–592.9 mbsf) consists of calcareous volcanic sandstone with foraminifers, which dominate the middle part of this unit. These sediments are bioturbated, with common *Zoophycos* burrows, especially in Core 135-841B-45R. The volcanic sandstone is usually fine grained and

structureless, but thick beds ranging from 1 to 8 cm in thickness show normal grading. Abundant granules and pebbles up to 6 mm in diameter within a sandstone occur in Core 135-841B-43R.

Lithology D (Cores 135-841B-46R to -47R; 592.9–605 mbsf) is characterized by volcanic sandstone containing abundant larger benthic foraminifers together with calcareous algae.

Volcanic Sequence

Two major igneous sequences were encountered in Hole 841B. The first (Unit 1, 324.76–497.68 mbsf) is a series of thin basaltic andesite dikes or sills (0.07–8 m thick) within the upper Miocene volcanic siltstone and sandstone (Fig. 2). This sill or dike sequence is divided into nine subunits. The intrusive relationship was indicated

by the presence of chilled margins and hyaloclastite breccias on the igneous rocks and indurated sediments at the contact.

The second major igneous sequence (Units 2 through 6) is the basement rhyolitic volcanic complex of uncertain age. No microfossils were found from the basement rock sequence, which is in fault contact with the middle Eocene shallow-water carbonates of Unit V (Figs. 2–3). The rhyolitic assemblage is characterized by a very high silica (76%–80% SiO₂) and very low potassium (0.4%–1.6% K₂O) content. The volcanic-rock series includes rhyolites, rhyolitic tuff, breccia, welded tuff, and lapilli tuff. It is interpreted that these rocks were formed subaerially or in a very-shallow-water environment. This complex constitutes the lower 210 m section of Hole 841B (Parson, Hawkins, Allen, et al., 1992).

EOCENE TO OLIGOCENE BIOSTRATIGRAPHY

Methods

The planktonic foraminifer biostratigraphy presented in this paper is based on 21 samples from Cores 135-841B-41R to -47R. Because the sediments encountered in the lower part of Hole 841B were consolidated or indurated, samples were taken from cores as a solid piece measuring approximately 1–4 cm². One half of each rock piece was disaggregated by using a sodium sulfite (Na₂SO₃) solution or a petroleum solvent (Varsol or naphtha). For this technique, samples are thoroughly dried and then soaked with solvent while still hot. The soaked sediments were then left, in the case of the Na₂SO₃ solution methods, for 1 or 2 weeks. After samples were broken down to small pieces, they were boiled in water containing a small quantity of sodium metaphosphate until complete disaggregation occurred. Disaggregated samples were then washed over a 250-mesh screen (62- μ m opening) with water and the residue oven dried.

At first, dried residues were scattered on a picking tray to evaluate the abundance of foraminifers and radiolarians for each sample. For estimates of species abundance, the following scale was used: R = rare (1–5 tests on tray), F = few (6–10 tests on tray), C = common (11–25 tests on tray), and A = abundant (more than 25 tests on tray). The preservation state of the planktonic foraminifers is described as follows: G = good (little or no fragmentation), M = moderate (some signs of fragmentation or alteration), P = poor (severe fragmentation or alteration) (Fig. 3).

For analyses of planktonic foraminifers, dried samples were sieved through a 120-mesh screen (125- μ m opening) and divided into coarse (>125 μ m) and fine (<125 μ m) fractions. An aliquot of 200–300 specimens of each fraction was split with a microsampler and used for biostratigraphic and quantitative faunal analysis. All specimens were picked from the sample aliquot in each fraction and the species were identified. In core-catcher samples and in the case when the number of specimens was fewer than 200, the total number of specimens of both fractions was used for quantitative analyses.

FORAMINIFER BIOSTRATIGRAPHY AND ZONES

Larger Benthic Foraminifers

Reworked Eocene large benthic foraminifers are scattered throughout Unit III (Cores 135-841B-22R to -30R, lower part of upper Miocene). Cores 135-841B-46R and -47R (lithology D of Unit V) also contain larger foraminifers, including *Amphistegina waiareka*, *Asterigerina tectoria*, *Asterocyclina matazensis*, *Discocyclina omphala*, and *Operculina pacifica*, as well as associated planktonic foraminifers and coralline algae and bryozoans (Chaproniere, this volume). Larger foraminifers gradually increase in number downcore from the top of Core 135-841B-36R of Unit III to Sample 135-841B-46R-CC of Unit V and become rare in underlying Core 135-841B-47R. Larger foraminifers are most concentrated in Sample 135-841B-46R-CC (Fig. 3). The larger foraminifer assemblage from Cores 135-841B-46R and -47R is distinctly tropical. The absence of *Pellatispira* places this assemblage in the East Indian Letter Stages Ta₃ to Tb, which is

equivalent to planktonic foraminifer Zones P10 to P15 (Chaproniere, this volume; Fig. 4).

Planktonic Foraminifers

At Site 841, the 56-m-thick Paleogene sedimentary sequence consists of 52 m of upper Eocene to lower Oligocene calcareous volcanic sandstone unconformably overlying 4 m of middle Eocene sandstones with larger foraminifers. On the basis of biostratigraphic study, Core 135-841B-47R is assigned to the middle Eocene, Cores 135-841B-46R through -44R are dated as late Eocene, and Cores 135-841B-43R to -41R are determined to be early Oligocene (Figs. 2–3). The distribution of planktonic foraminifers in Cores 135-841B-41R to -47R is plotted in Figure 5 and Tables 1–2.

Middle Eocene (Core 135-841B-47R)

Throughout Core 135-841B-47R, radiolarians and foraminifers are generally rare or absent. Moderately to poorly preserved specimens of planktonic foraminifers were recorded in this interval (Fig. 3). They include such species as *Acarinina densa*, *A. spinuloinflata*, *Morozovella spinulosa*, and *Truncorotaloides topilensis*, in addition to *Turborotalia cerroazulensis cerroazulensis*, *Catapsydrax howei*, *Globigerinatheka mexicana mexicana*, and *Planorotalites renzi*.

In tropical to subtropical regions, the middle Eocene faunas are characterized by spinose species of *Acarinina*, *Morozovella*, and *Truncorotaloides*. Although species of these genera disappear synchronously at the top of the *Truncorotaloides rohri* Zone and Zone P14 (e.g., Blow, 1969; Toumarkine and Luterbacher, 1985; Premoli Silva and Boersma, 1988) or diachronously within Zone P15 (Fig. 4), *M. spinulosa* and *T. topilensis* disappear at or just above Zone P14. Therefore, this faunal assemblage belongs to Zone P14 or older.

Upper Eocene (Cores 135-841B-46R to -44R)

The preservation and abundance of planktonic foraminifers in this interval vary from poor and rare (Core 135-841B-46R) to fairly good to common (Cores 135-841B-45R and -44R). Benthic foraminifers are common in samples from Core 135-841-46R and in Section 135-841B-45R-CC, but they are rare to absent in other layers. Radiolarians are rare to absent except in Section 135-841B-45R-1 (Fig. 3).

The planktonic foraminifer faunas are characterized by species of *Globigerinatheka* and *Hantkenina* and by subspecies of *Turborotalia cerroazulensis* and *Subbotina linaperta*. Other diagnostic species in this interval are *Catapsydrax africanus*, *Pseudohastigerina wilcoxensis*, *P. danvillensis*, *Chiloguembelina martini*, and *Planorotalites* sp. The co-occurrence of *T. cerroazulensis cocoaensis* and *Globigerinatheka subconglobata luterbacheri* enables a correlation with Zones P15 to P16 of Blow (1969) and Berggren and Miller (1988). According to the detailed biostratigraphic and paleomagnetic studies of Nocchi et al. (1986) and Nocchi et al. (1988), the first appearance datum (FAD) of *Turborotalia cerroazulensis cocoaensis* occurs close to the base of Chron C16N, whereas *Globigerinatheka subconglobata luterbacheri* disappears just above Chron C15. The upper Eocene interval at this site is, therefore, referable to Chrons C16R and C15R, which range in age from 37.2 to 39.2 Ma. The following late Eocene species disappear above Sample 135-841B-44R-1, 17–20 cm: *Globigerinatheka index tropicalis*, *T. cerroazulensis cerroazulensis*, *Globigerinatheka* cf. *semiinvoluta*, *G. index index*, *G. subconglobata luterbacheri*, and *Subbotina linaperta*. However, in Sample 135-841B-43R-CC, just above this level, species are rare, but include "*Globigerina*" *pseudovenezuelana*, *Dentoglobigerina tripartita*, and *D. galavisi* without late Eocene species; these are attributable to lower Oligocene Zone P18. The latest Eocene Zone P17 of Berggren and Miller (1988) that spans approximately 1 m.y. is presumably missing at this site based on the last occurrence of *G. subconglobata luterbacheri* in Section 135-841B-44R-1. Another major unconformity is present between the

Table 1 (continued).

Globigerina (Ga.) senilis	Globigerina spp.	Globigerina sp.1	Globigerinatheka index Index	Globigerinatheka index tropicalis	Globigerinatheka index tropicalis (high-spined)	Globigerinatheka mexicana barri	Globigerinatheka mexicana mexicana	Globigerinatheka subconglobatus luterbacheri	Globigerinatheka cf. seminivolula	Globigerinella obesa	Globorotaloides suteri	Globorotaloides perimicrus	Hantkenina alabamensis	Molozovella spinulosa	Paragloborotalia optima nana	Planorbialites renzi (Boll)	Planorbialites sp. 1 (low-trochoid)	Planorbialites sp. 2 (high-trochoid)	Pseudohastigerina barbaensis	Pseudohastigerina darvillensis	Pseudohastigerina micra	Pseudohastigerina wilcoxensis	Subbotina angiporoides	Subbotina brevis	Subbotina corpulenta	Subbotina eocaena	Subbotina gortanii	Subbotina linaperta	Subbotina utilisindex	Subbotina yeguaensis	Tenuitella munda	Tenuitella postretacea	Truncorotaloides topilensis	Turborotalia centralis	Turborotalia cerroazulensis cerroazulensis	Turborotalia cerroazulensis coccaensis	Turborotalia increbescens	Total					
																																								0			
										5	27				12			3	6	3																			1	17			
										3	32				77				37	13	1	3	21																8	390			
										11	52				33				140	51																			1	563			
										9	142				48			12	190	69																			24	370			
										5	44				16				28	5	10	4	6	2	18														2	405			
										5	62				13				67	22																				5	318		
										9	36				14				21	14	6																			11	309		
										14	206				17				79	73	14																			2	719		
										4	55				30				18	19	2	2	5	7																20	434		
										5					2				1	6	5	8	1																	12	169		
										46					8				57	5																					3	231	
										3									2	1	6	3	4	2	4	1															17	265	
										2					4	21				59	22	3																			6	246	
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abundant species is *Globigerinatheka index tropicalis*. It exceeds 10% of the assemblage and attains a maximum abundance of 17%. The various subspecies of *Turborotalia cerroazulensis* also occur in fairly high abundance (>10%) in some samples. Among the subspecies, *T. cerroazulensis cerroazulensis* is the most common, and its highest abundance (28%) is recorded in Sample 135-841B-44R-2, 28–31 cm. High-spined subbotinids (*Subbotina corpulenta* and *S. gortanii*) and the *Dentoglobigerina tripartita* group (*D. tripartita*, *D. tapuriensis*, and *D. sellii*) occur consistently throughout the upper Eocene, but their abundances are less than 7% (generally 1%–3%). Low-spined subbotinids (*Subbotina eocaena* and *S. yeguaensis*), large globigerinid groups (“*Globigerina*” *euapertura* and “*Globigerina*” *pseudovenezuelana*), and *Dentoglobigerina* (*D. galavisi*) increase in the uppermost part of Core 135-841B-44R-1 where *S. yeguaensis* and *D. galavisi* attain a peak abundance of approximately 20%. *Hantkenina* is rare and scattered throughout the sequence.

The fine fractions (<125 μm) are dominated by *Pseudohastigerina*, often reaching more than 20% with a maximum of 72% in the uppermost Eocene Sample 135-841B-44R-1, 17–20 cm. Other dominant components include *Catapsydrax*, *Globigerina*, *Globorotaloides*, and *Chiloguembelina*, but these are generally less than 20%. The populations of such dominant groups as *Globigerinatheka* and *T. cerroazulensis* in coarse fractions are rare (<4%) in the fine fractions.

Lower Oligocene

Planktonic foraminifer faunas in the coarse fractions (>125 μm) are dominated by large globigerinid groups, along with less common *Catapsydrax*, *Dentoglobigerina*, “*Globigerina*” *ampliapertura* group, and *Globorotaloides* (Fig. 6). The following species increase in abundance downsection through the Oligocene sequence: “*G.*” *ampliapertura*, *Turborotalia increbescens*, *Dentoglobigerina galavisi*, “*Globigerina*” *euapertura*, *Subbotina angiporoides*, *Dentoglobigerina tripartita* groups, and *Globorotaloides suteri*.

One of the characteristic features in this interval is a high abundance of “*G.*” *ampliapertura* groups (“*Globigerina*” *ampliapertura* and *Turborotalia increbescens*). “*G.*” *ampliapertura* attains approximately 30% in the lower part, whereas *T. increbescens* first occurs in the Oligocene sequence and does not exceed 10% (Fig. 6). The *Dentoglobigerina tripartita* group displays an abundance peak at the same levels, but this species is generally less than 10%. “*G.*” *euapertura* and *D. galavisi* are consistently present and fluctuate in abundance from 7% to 15%. *Catapsydrax* decreases slightly upward; *C. unicavus* is most common (<9%), and others do not exceed 5%.

The fine fractions (<125 μm) are dominated by *Pseudohastigerina micra* and *G. suteri*. Their abundances fluctuate from 6% to 29% but attain approximately 20% in many samples. Although *Cassigerinella*

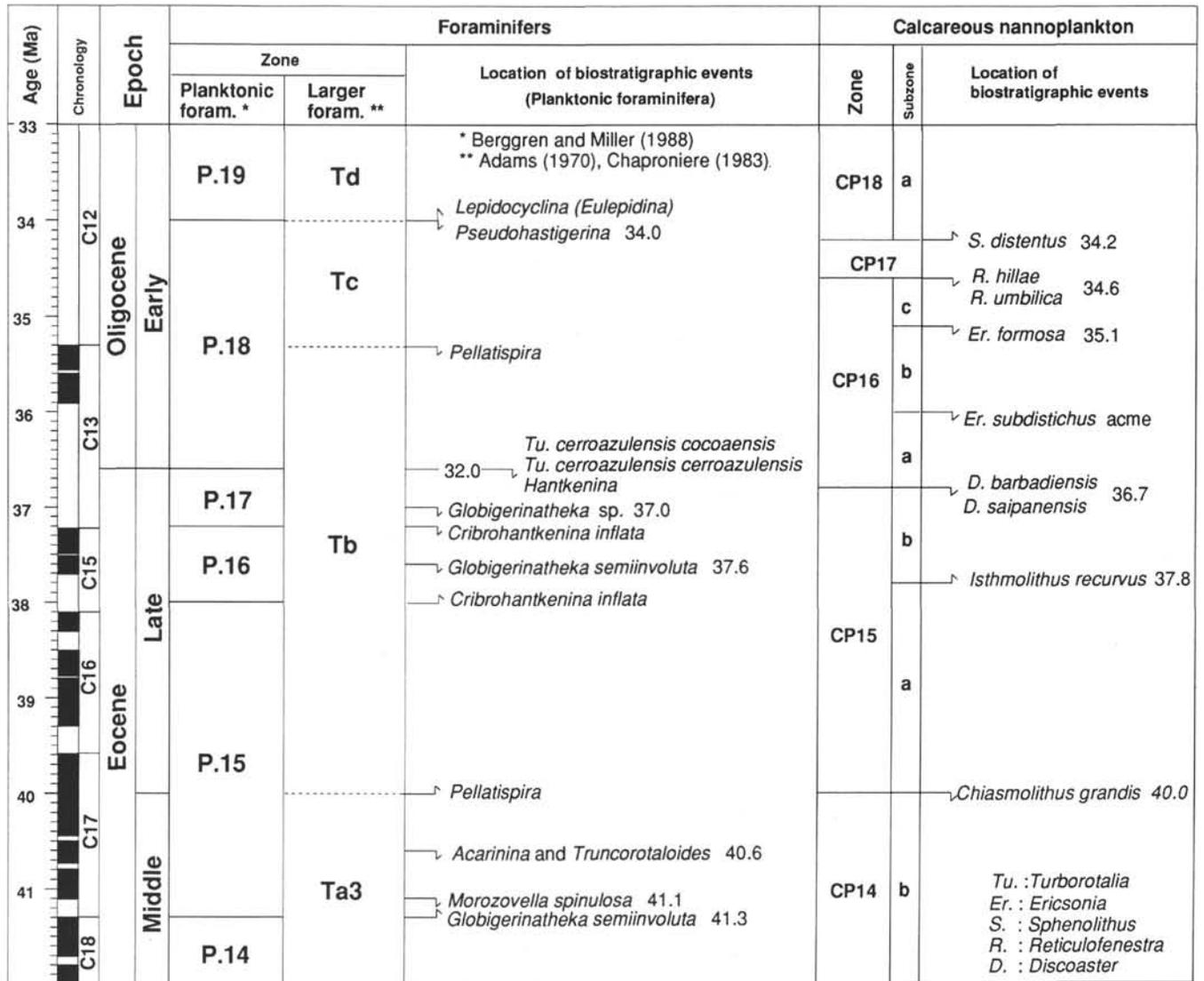


Figure 4. Biostratigraphic standard for the Paleogene sequence of Leg 135. Age (in Ma) and magnetostratigraphic scale are adopted from Berggren et al. (1985) and Aubry et al. (1988), planktonic foraminifer zones from Berggren and Miller (1988), larger foraminifer zones from Adams (1970, 1984) and Chaproniere (1981, 1983), and nannoplankton zones from Okada and Bukry (1980).

chipolensis is a useful marker species in the earliest Oligocene, its occurrence is rare (1%–2%) and sporadic. *Chiloguembelina cubensis* increases upward through the Oligocene sequence and exceeds 10% in the upper part. *Tenuitella* and *Paragloborotalia nana* also display the same trend and exceed 5% in the upper part of Core 135-841B-42R. Except for the *D. tripartita* group and the low-spired subbotinids, the dominant species in the coarse fractions are present in reduced numbers in the fine fractions.

DISCUSSION

Bioprovince Indexes of the Paleogene Ocean

In the Southwest Pacific today, there are a number of surface-water masses bounded by oceanographic fronts that are marked by distinctive planktonic faunas and floras. They are arranged with a distinct latitudinal zonality (Kennett and von der Borch, 1986). This floral and faunal latitudinal differentiation (provincialism) existed throughout the Cenozoic, the composition changing with time (e.g., Haq et al., 1977; Premoli Silva and Boersma, 1988). These changes have

involved both major latitudinal shifts of assemblages and major evolutionary change between old and new dominant groups, altering the make-up of the assemblages. In particular, the latitudinal migration of warm- and cool-water taxa has been interpreted as being caused by major climatic fluctuations and controlled mainly by a changing latitudinal thermal gradient (Haq et al., 1977; Murphy and Kennett, 1986). Shifts of low-latitude (warm) assemblages toward high latitudes reflect warming periods, whereas invasions of high-latitude (cool) assemblages toward low latitudes indicate cooling.

In Paleogene time the bioprovincialism and migration of the faunas have been recognized by a series of bioprovincial studies in the Atlantic province (Boersma and Premoli Silva, 1986; Premoli Silva and Boersma, 1988, 1989; Spezzaferri and Premoli Silva, 1991). During the early late Eocene, for example, lower latitude faunas were dominated by such taxa as *Globigerinatheka*, *Subbotina*, *Pseudohastigerina*, and subspecies of the *Turborotalia cerroazulensis* lineage, all previously typical of middle latitudes and of gyre margins (Boersma and Premoli Silva, 1986; Premoli Silva and Boersma, 1988). These bioprovincial studies have also revealed the existence

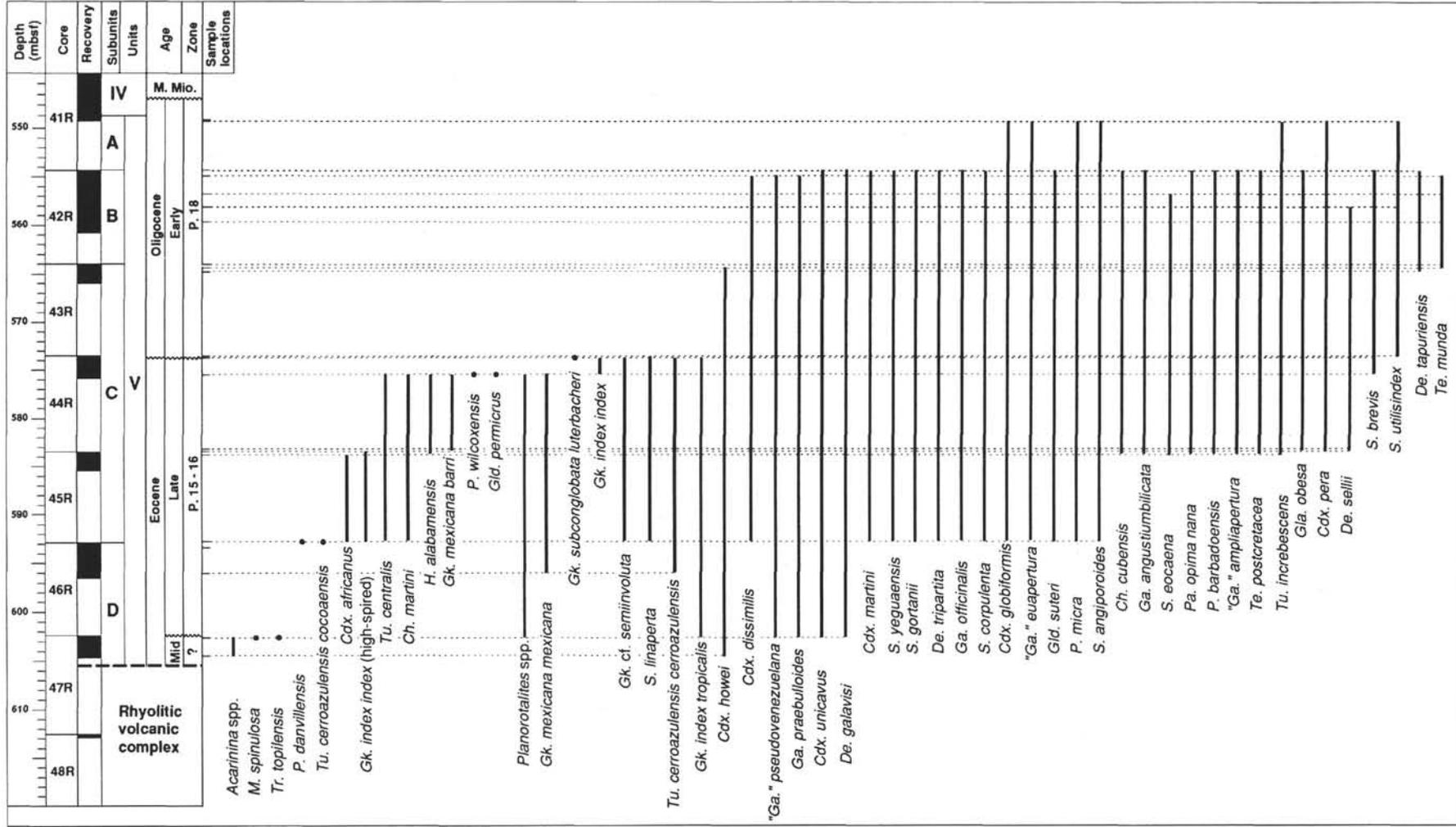


Figure 5. Stratigraphic distribution of planktonic foraminifers throughout the Paleogene sequence at Site 841. *Cdx.* = *Catapsydrax*, *Ch.* = *Chiloguembelina*, *De.* = *Dentoglobigerina*, *Ga.* = *Globigerina*, *Gk.* = *Globigerinatheka*, *Gla.* = *Globigerinella*, *Gld.* = *Globorotaloides*, *H.* = *Hantkenina*, *M.* = *Morozovella*, *Pa.* = *Paragloborotalia*, *P.* = *Pseudohastigerina*, *S.* = *Subbotina*, *Te.* = *Tenuitella*, *Tr.* = *Truncorotaloides*, and *Tu.* = *Turborotalia*.

Table 3. List of planktonic groups used in this paper (after Premoli Silva and Boersma, 1988).

Group	Species	Group	Species
1.	<i>Acarinina spinulosa</i> lineage <i>Acarinina densa</i> (Cushman) <i>Acarinina bullbrooki</i> (Bolli)	12.	<i>Hantkeninids</i> <i>Hantkenina alabamensis</i> Cushman
2.	<i>Heterohelicids</i> <i>Cassigerinella chipolensis</i> (Cushman and Ponton)	13.	<i>Weakly muricocarinata morozovellids</i> <i>Morozovella spinulosa</i> (Cushman)
3.	<i>Catapsydrax</i> <i>Catapsydrax africanus</i> (Blow and Banner) <i>Catapsydrax dissimilis</i> (Cushman and Bermúdez) <i>Catapsydrax globiformis</i> (Blow and Banner) <i>Catapsydrax martini</i> (Blow and Banner) <i>Catapsydrax pera</i> (Todd) <i>Catapsydrax unicus</i> Bolli, Loeblich, and Tappan	14.	<i>Planorotalites</i> <i>Planorotalites renzi</i> (Bolli)
4.	<i>Biserial heterohelicids</i> <i>Chiloguembelina cubensis</i> (Palmer) <i>Chiloguembelina martini</i> (Pijpers)	15.	<i>Pseudohastigerina</i> <i>Pseudohastigerina barbadoensis</i> Blow <i>Pseudohastigerina micra</i> (Cole) <i>Pseudohastigerina wilcoxensis</i> (Cushman and Ponton)
5.	<i>Dentoglobigerina</i> <i>Dentoglobigerina galavisi</i> (Bermúdez)	16.	<i>Subbotina linaperta</i> group <i>Subbotina angiporoides</i> (Hornibrook) <i>Subbotina brevis</i> Jenkins <i>Subbotina linaperta</i> (Finlay) <i>Subbotina utilisindex</i> (Jenkins and Orr)
6.	<i>Dentoglobigerina tripartita</i> group <i>Dentoglobigerina sellii</i> (Borsetti) <i>Dentoglobigerina tapuriensis</i> (Blow and Banner) <i>Dentoglobigerina tripartita</i> Koch	17.	<i>Low-spined subbotinids</i> <i>Subbotina cocaena</i> (Gümbel) <i>Subbotina yeguaensis</i> (Weinzierl and Applin)
7.	" <i>Globigerina</i> " <i>ampliapertura</i> Bolli " <i>Globigerina</i> " <i>ampliapertura</i> Bolli <i>Turborotalia increbescens</i> (Bandy)	18.	<i>High-spined subbotinids</i> <i>Subbotina gortanii</i> (Borsetti) <i>Subbotina corpulenta</i> (Subbotina)
8.	<i>Globigerina</i> s. str. <i>Globigerina angustiumbilitata</i> Bolli <i>Globigerina officinalis</i> Subbotina <i>Globigerina ouachitaensis ouachitaensis</i> Howe and Wallace <i>Globigerina senilis</i> Bandy	19.	<i>Turborotalia cerroazulensis</i> lineage <i>Turborotalia centralis</i> (Cushman and Bermúdez) <i>Turborotalia cerroazulensis cerroazulensis</i> (Cole) <i>Turborotalia cerroazulensis cocoaensis</i> (Cushman)
9.	Large <i>globigerines</i> " <i>Globigerina</i> " <i>euapertura</i> Jenkins " <i>Globigerina</i> " <i>pseudovenezuelana</i> (Blow and Banner)	20.	<i>Globigerinella</i> <i>Globigerinella obesa</i> (Bolli)
10.	<i>Globigerinatheka</i> <i>Globigerinatheka index</i> (Finlay) <i>Globigerinatheka mexicana barri</i> Brönnimann <i>Globigerinatheka mexicana mexicana</i> (Cushman) <i>Globigerinatheka</i> cf. <i>semiinvoluta</i> (Keijzer) <i>Globigerinatheka subconglobata luterbacheri</i> Bolli <i>Globigerinatheka tropicalis</i> (Blow and Banner)	21.	<i>Paragloborotalia opima</i> group <i>Paragloborotalia opima nana</i> (Bolli)
11.	<i>Globorotaloides</i> <i>Globorotaloides suteri</i> Bolli	22.	<i>Tenuitella</i> <i>Tenuitella munda</i> Jenkins <i>Tenuitella postcretacea</i> (Myatliuk)

located at about 50° to 70°S, the planktonic foraminifer assemblages of the two groups are very similar, suggesting that the oceanographic front between the biogeographic provinces had not yet developed (Murphy and Kennett, 1986; Kennett and von der Borch, 1986).

However, the differences between the planktonic faunal assemblages of the northern (286/288/829/828/841) and southern (277/281/282/593/592) sites are distinct, and each assemblage represents the tropical-subtropical bioprovince and the temperate-subantarctic bioprovince, respectively, during the late Eocene to early Oligocene. Presumably, the oceanographic boundary was located at about 40°S latitude between Sites 592 and 841 (Fig. 7).

The first high-latitude, surface-water communication between the southern Indian and South Pacific oceans occurred in the latest Eocene across the shallow, subsiding South Tasman Rise. This opening permitted the passage of cool Indian Ocean waters into the South Pacific, leading to a cooling of waters in the South Pacific and an initial decoupling of the warm-subtropical gyre from the Southern Ocean (Kennett, 1977; Kennett and von der Borch, 1986; Murphy and Kennett, 1986). The presence of two latitudinal bioprovinces in the late Eocene to early Oligocene, therefore, implies that the opening of this seaway and the subsequent influx of the cool Circum-Antarctic Current occurred sometime before the late Eocene (about 37 Ma). Common to high abundances of cool-water species such as *Globorotaloides suteri*, *Catapsydrax*, *Tenuitella*, and small *globigerinids* at Site 841 may indicate the influx of a cold-water spike reaching into fairly northern regions of the subtropical bioprovince.

CONCLUSIONS

The lowermost sedimentary sequence, Unit V (549–605 mbsf), at Site 841 is a 56-m-thick sequence of middle Eocene to lower Oligocene volcanic sandstone with thin interbeds of claystone. This unit is overlain unconformably by a lower middle Miocene sequence, referable to Zones N8 and N9, with a hiatus spanning approximately 13 m.y.

The middle Eocene fauna (Core 135-841B-47R) includes *Acarinina densa*, *A. spinuloinflata*, *Morozovella spinulosa*, and *Truncorotaloides topilensis*, with additional species of *Turborotalia cerroazulensis cerroazulensis*, *Catapsydrax howei*, *Globigerinatheka mexicana mexicana*, and *Planorotalites renzi*.

This assemblage is referable to Zone P14 or older. Late Eocene faunas (from Cores 135-841B-46R to -44R) are characterized by species of *Globigerinatheka*, *Hantkenina*, subspecies of *Turborotalia cerroazulensis*, and *Subbotina linaperta*. The co-occurrence of *T. cerroazulensis cocoaensis* and *Globigerinatheka subconglobata luterbacheri* indicates Zones P15 to P16. The early Oligocene faunas (from Cores 135-841B-43R to -41R) include large numbers of *Pseudohastigerina*, *Chiloguembelina*, *Dentoglobigerina*, *Subbotina*, *Globigerina*, and *Catapsydrax*, indicative of Zone P18.

Two hiatuses are recognized in the Eocene interval of Site 841. An unconformity is present between the middle and upper Eocene, with a stratigraphic gap spanning approximately 1.8 m.y. at least, whereas a small hiatus separates the upper Eocene sequence from the lower Oligocene, with the uppermost Eocene Zone P17 (about 1 m.y. interval) missing.

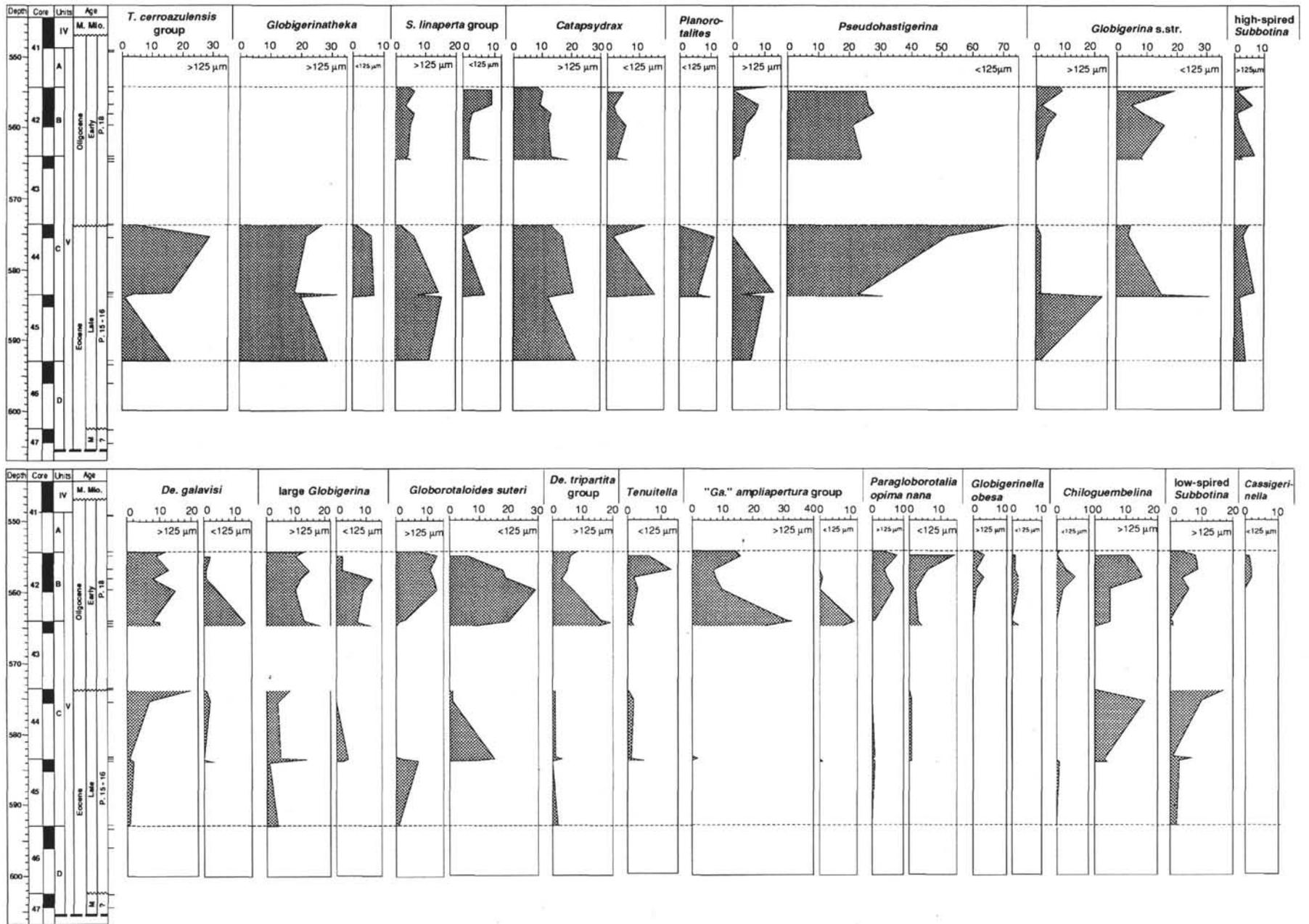


Figure 6. Abundance percentage curves of groups of late Eocene to early Oligocene planktonic foraminifers in Hole 841B. Results of coarse fraction (>125 μm) analyses are shown on the left, and data on fine fraction (<125 μm) analyses are on the right. Small samples (<100 specimens) were not included in this figure.

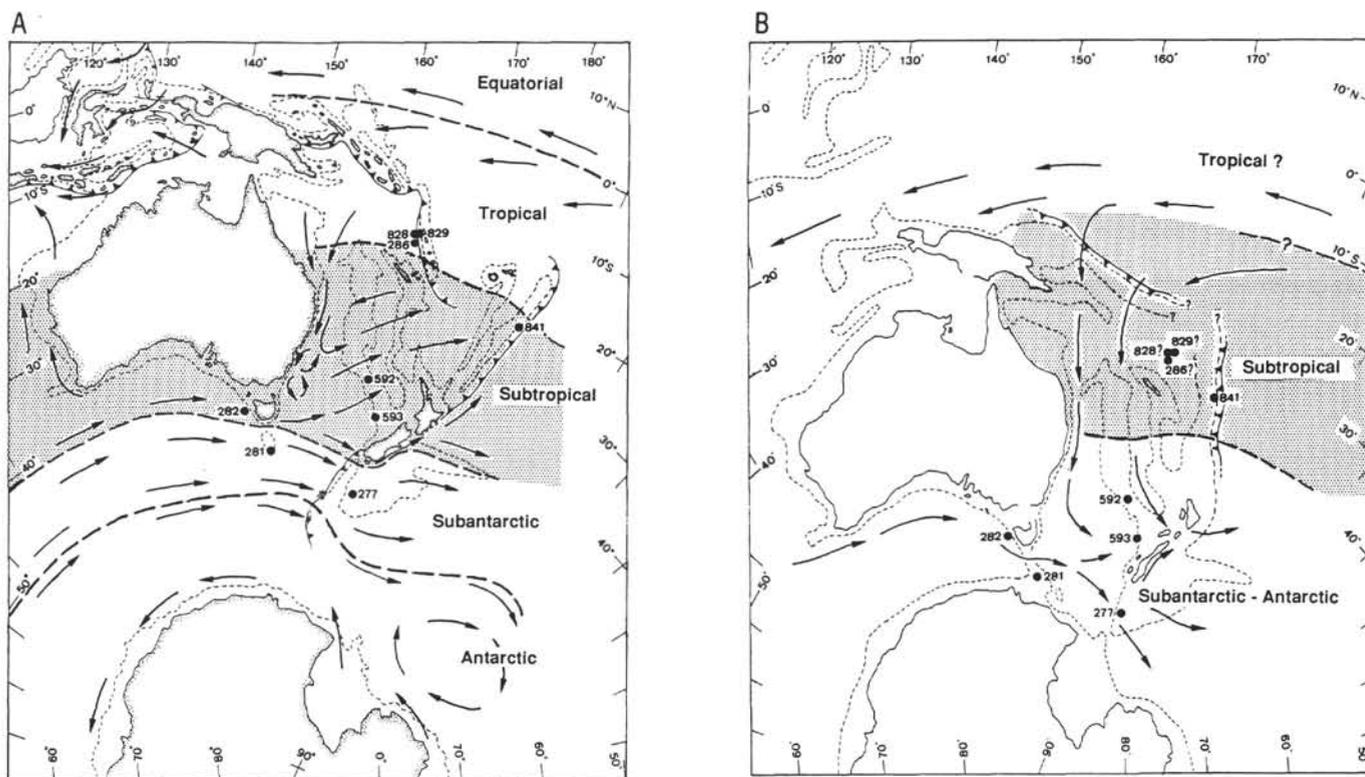


Figure 7. Present-day and Paleogene (late Eocene to early Oligocene) southwest Pacific surface-water circulation patterns. **A.** The modern ocean summarized from Edwards (1975), Murphy and Kennett (1986), and Kennett and von der Borch (1986). **B.** Proposed model for late Eocene to early Oligocene circulation pattern. The location of continents is based on Edwards (1975) and the circulation patterns of currents are modified from Murphy and Kennett (1986). Dotted areas show the subtropical biogeographic province.

The dominant taxa in the upper Eocene sequence are *Catapsydrax* (>12%) and *Globigerinatheka* (>18%). The lower Oligocene faunas in the coarse fractions (>125 μm) are dominated by large globigerinid groups, along with less common *Catapsydrax*, *Dentoglobigerina*, “*Globigerina*” *ampliapertura* group, and *Globorotaloides*. Abundances of these species generally exceed 10%. The most characteristic feature in the Oligocene is a rapid increase of the “*G.*” *ampliapertura* group in the coarse fractions. *Pseudohastigerina* dominates (>20%) assemblages in the fine fractions (<125 μm) throughout the upper Eocene to lower Oligocene.

In the middle to late Eocene, the presence of tropical-subtropical Indo-Pacific larger foraminifers indicates that Site 841 belongs to a tropical-subtropical bioprovince, but in the late Eocene the planktonic faunal assemblages began to include the cool-water taxa *Catapsydrax*, *Globorotaloides*, and *Globigerina*. In the Oligocene sequence, such typical warm-water indicators as *Dentoglobigerina tripartita* and *Cassigerinella* are rare or absent, whereas middle-latitude species (e.g., “*Globigerina*” *euapertura* and “*G.*” *ampliapertura*), and cooler province indicators increase. These characteristics imply that the Paleogene assemblages at Site 841 are referable to warm middle-latitude faunas.

The late Eocene faunal composition of Site 841 differs from that of more southern sites in the southwest Pacific Ocean. These differences suggest that the biogeographical boundary was located at about 40°S latitude, between Sites 592 and 841. The presence of two distinct assemblages suggests that the opening of a seaway between the Pacific and Indian oceans and subsequent influx of the cool Indian Ocean current occurred before the late Eocene (about 37 Ma).

SPECIES LIST AND TAXONOMIC NOTES

Species are listed in alphabetical order by genus. The generic and specific concepts and the species groups are those used by Premoli Silva and Boersma (1988, 1989) and Spezzaferri and Premoli Silva (1991); however, the taxo-

nomic positions of several species classification are retained as those reflecting our own concept in this paper. Reference is made to the most reliable illustrations reported in the literature available. All the specimens are deposited in the microfossil collection of the Department of Earth Sciences, Yamagata University, Yamagata, Japan.

- Acarinina densa* (Cushman) (Plate 1, Figs. 1–3). *Pulvinulina crassata* var. *densa* Cushman, 1925a, p. 300. Redrawn figures in Cifelli, 1972, pp. 157–159, text-figs. 1a–c.
- Acarinina spinuloinflata* (Bandy). *Globigerina spinuloinflata* Bandy, 1949, p. 122, pl. 23, figs. 1a–c.
- Cassigerinella chipolensis* (Cushman and Ponton) (Plate 1, Figs. 12–14). *Cassidulina chipolensis* Cushman and Ponton, 1932, p. 98, pl. 15, figs. 2a–c. *Cassigerinella chipolensis* (Cushman and Ponton) in Bolli, 1957b, p. 108, pl. 22, fig. 3.
- Catapsydrax africanus* (Blow and Banner) (Plate 3, Figs. 4–9).
- Globigerinita africana* Blow and Banner, 1962, pp. 105–106, pl. XV, figs. A–C, fig. 11, i–iv.
- Catapsydrax dissimilis* (Cushman and Bermúdez). *Globigerina dissimilis* Cushman and Bermúdez, 1937, pp. 25–26, pl. 3, figs. 4–6. *Catapsydrax dissimilis* (Cushman and Bermúdez) in Bolli, Loeblich, and Tappan, 1957, p. 36, pl. 7, figs. 6a–c and 7a–8c. *Globigerinita dissimilis dissimilis* (Cushman and Bermúdez) in Blow and Banner, 1962, pp. 106–107, pl. XIV, fig. D. *Globigerinita dissimilis ciproensis* Blow and Banner, 1962, pp. 107–108, pl. XIV, figs. A–C.
- Catapsydrax globiformis* (Blow and Banner) (Plate 2, Figs. 27–29). *Globigerinita globiformis* Blow and Banner, 1962, pp. 108–109, pl. XIV, figs. S–U.
- Catapsydrax howei* (Blow and Banner) (Plate 3, Figs. 1–3). *Globigerinita howei* Blow and Banner, 1962, pp. 109–110, pl. XIV, figs. P–R, text-figs. 11, x–xiv.
- Catapsydrax martini* (Blow and Banner) (Plate 3, Fig. 13). *Globigerinita martini martini* Blow and Banner, 1962, pp. 110–111, pl. XIV, fig. O.
- Globigerinita martini scandretti* Blow and Banner, 1962, pp. 111–112, pl. XIV, figs. V–X.
- Catapsydrax pera* (Todd) (Plate 3, Figs. 10–12). *Globigerina pera* Todd, 1957, p. 301, pl. 70, figs. 10–11. *Globigerinita pera* (Todd) in Blow and Banner, 1962, pp. 112–113, pl. XIV, figs. E–H.

- Catapsydrax unicavus* Bolli, Loeblich, and Tappan (Plate 3, Figs. 14–15). Bolli, Loeblich, and Tappan, 1957, p. 37, pl. 7, figs. 9a–c. *Globigerinita unicava unicava* (Bolli, Loeblich, and Tappan) in Blow and Banner, 1962, pp. 113–114, pl. XIV, figs. M–N. *Globigerinita unicava primitiva* Blow and Banner, 1962, pp. 113–114, pl. XIV, figs. M–N.
- Chiloguembelina cubensis* (Palmer) (Plate 1, Fig. 30–31). *Güembelina cubensis* Palmer, 1934, p. 74, text-figs. 1–6. *Chiloguembelina cubensis* (Palmer) in Beckmann, 1957, p. 89, pl. 21, fig. 21, text-fig. 14, figs. 5–8.
- Chiloguembelina martini* (Pijpers) (Plate 1, Fig. 32). *Textularia martini* Pijpers, 1933, p. 57, figs. 6–10. *Chiloguembelina martini* (Pijpers) in Beckmann, 1957, p. 89, pl. 21, fig. 14, text-figs. 4, figs. 4, 9–11, 14–18, and 20–23.
- Dentoglobigerina galavisi* (Bermúdez) (Plate 5, Figs. 10–12). *Globigerina galavisi* Bermúdez, 1961, pp. 1183–1184, pl. IV, fig. 3; Blow, 1979, p. 121, pl. 5, figs. 1–3. *Globigerina yeguaensis yeguaensis* Weinzierl and Applin in Blow and Banner, 1962, pp. 99–100, pl. XIII, figs. H–M.
- Dentoglobigerina sellii* (Borsetti) (Plate 5, Figs. 7–9). *Globoquadrina sellii* Borsetti, 1959, p. 209, pl. 1, figs. 3a–d. *Globigerina oligocaenica* Blow and Banner in Blow and Banner, 1962, pp. 88–89, pl. X, figs. G and L–N.
- Dentoglobigerina tapuriensis* (Blow and Banner) (Plate 5, Figs. 4–6). *Globigerina tripartita tapuriensis* Blow and Banner, 1962, pp. 97–98, pl. X, figs. H–K.
- Dentoglobigerina tripartita* Koch (Plate 5, Figs. 1–3). *Globigerina bulloides* d'Orbigny var. *tripartita* Koch, 1926, p. 746, text-figs. 21a–b. *Globigerina rohri* Bolli, 1957b, pp. 109 and 141–144, pl. 23, figs. 1a–4b. *Globigerina tripartita tripartita* Koch in Blow and Banner, 1962, pp. 96–97 and 141–144, pl. X, figs. A–F.
- "*Globigerina*" *ampliapertura* Bolli (Plate 4, Figs. 1–6). *Globigerina ampliapertura* Bolli, 1957b, p. 108, pl. 22, figs. 5–7. The distinct feature of this species is its large, distinctly high-arched aperture. However, the shape and position of aperture vary from asymmetrical and slightly extraumbilical-umbilical (*Globorotalia*-type) to symmetrical and umbilical (*Globigerina*-type), which results in difficulties of generic attribution for this species. *Globigerina pseudoampliapertura* proposed by Blow and Banner (1962) is distinguished from *G. ampliapertura* by the presence of a smooth, finely perforate wall. *G. pseudoampliapertura* is a low-latitude index for the Oligocene age (Premoli Silva and Boersma, 1988, 1989). Samples of Hole 841B yielded many specimens referable in morphology to *G. pseudoampliapertura*, but these forms were recognized as "*G.*" *ampliapertura* in this paper because of the possession of a slightly rough and pitted wall surface.
- Globigerina angustiumbilicata* Bolli (Plate 4, Figs. 25–27). *Globigerina ciperoensis angustiumbilicata* Bolli, 1957b, p. 109, pl. 22, figs. 12–13.
- "*Globigerina*" *euapertura* Jenkins (Plate 4, Figs. 10–12). *Globigerina euapertura* Jenkins, 1960, p. 351, pl. 1, figs. 8a–c. *Globigerina reticulata* Stache in Hornibrook, 1961, p. 146, text-figs. 4b–c, Jenkins, 1971, p. 147, pl. 15, figs. 457–461, pl. 16, fig. 462. *Globigerina ampliapertura euapertura* (Jenkins) in Blow and Banner, 1962, p. 84, pl. XI, figs. E–G. *Globigerina prasaepis* in Blow, 1969, pp. 321 and 382–383, pl. 10, fig. 13, pl. 18, figs. 3–7. This species differs from "*G.*" *ampliapertura* in possessing more depressed later chambers and in the low-arched, more slit-like aperture. Because some specimens display the slightly extraumbilical-umbilical apertural position, its generic attribution is uncertain. Although *Globigerina prasaepis* Blow is distinguished from "*G.*" *euapertura* by having a restricted aperture and a well-developed apertural lip (Blow, 1969), the specimens from this core include forms with or without a distinct apertural lip or rim and the apertural width is very variable. These features are found among specimens in Australia and New Zealand sections (Jenkins, 1971; Chaproniere, 1981). Therefore, it is difficult to separate *G. prasaepis* from "*G.*" *euapertura* by the criteria proposed by Blow (1969), and both are considered synonymous in this paper.
- Globigerina officinalis* Subbotina (Plate 5, Figs. 16–18). Subbotina, 1953, p. 78, pl. 11, figs. 1–7; Blow and Banner, 1962, p. 88, pl. IX, figs. A–C.
- Globigerina praebulloides* Blow (Plate 5, Figs. 25–27). Blow, 1959, pp. 180–181, pl. 8, figs. 47a–c, pl. 9, fig. 48. *Globigerina praebulloides praebulloides* Blow and Banner, 1962, pp. 92–93, pl. IX, figs. O–Q. *Globigerina praebulloides leroyi* Blow and Banner, 1962, p. 93, pl. IX, figs. R–T. *Globigerina praebulloides oclusa* Blow and Banner, 1962, pp. 93–94, pl. IX, figs. V–W.
- "*Globigerina*" *pseudovenezuelana* Blow and Banner (Plate 5, Figs. 22–24). *Globigerina yeguaensis pseudovenezuelana*. Blow and Banner, 1962, pp. 100–101, pl. XI, figs. J–L, N, and O. This species was classified by Blow (1979) as belonging to the genus *Dentoglobigerina*, which is characterized by possessing a triangular-shaped, portical-umbilical tooth. Because the specimens with these teeth were not found in samples recovered from Site 841, its generic attribution is retained in quotation marks.
- Globigerina senilis* Bandy (Plate 4, Figs. 13–15). *Globigerina ouachitaensis* Howe and Wallace var. *senilis* Bandy, 1949, p. 121, pl. 22, figs. 5a–c. *Globigerina senilis* Bandy in Blow and Banner, 1962, pp. 95–96, pl. XI, figs. R–U.
- Globigerinatheka index index* (Finlay) (Plate 2, Figs. 22–24). *Globigerinoides index index* Finlay, 1939, p. 125, pl. 14, figs. 85–88. *Globigerapsis index* (Finlay) in Bolli, 1957a, p. 165, pl. 36, figs. 14–18. *Globigerinatheka index index* (Finlay) in Bolli, 1972, pp. 124–126, text-figs. 51–57 and 63–64, pl. 1, figs. 1–4 and 6–7.
- Globigerinatheka index tropicalis* (Blow and Banner) (Plate 2, Figs. 4–9). *Globigerapsis tropicalis* Blow and Banner, 1962, pp. 124–125, pl. XV, figs. D–F; *Globigerinatheka index tropicalis* (Blow and Banner) in Bolli, 1972, pp. 127–128, text-figs. 58–60, pl. 3, figs. 1–24.
- Globigerinatheka mexicana barri* Brönnimann (Plate 2, Figs. 10–12 and 25–26). *Globigerinatheka barri* Brönnimann, 1952, p. 27, text-figs. 3a–c; *Globigerinatheka mexicana barri* Brönnimann in Bolli, 1972, p. 128, pl. 2, figs. 8–20, text-figs. 21–26.
- Globigerinatheka mexicana mexicana* (Cushman) (Plate 2, Figs. 13–15). *Globigerina mexicana* Cushman, 1925c, p. 6, pl. 1, fig. 8. *Globigerapsis mexicana* (Cushman) in Blow and Saito, 1968, pp. 357–360, text-figs. 1–4. *Globigerinatheka mexicana mexicana* (Cushman) in Bolli, 1972, p. 129, figs. 1–11, pl. 2, figs. 1–5.
- Globigerinatheka* cf. *semiinvoluta* (Keijzer), 1945 (Plate 2, Figs. 19–21). *Globigerinatheka semiinvoluta* is characterized by its hemispherical final chamber, which embraces nearly one-half of the earlier test and a high-arched circular aperture with distinct rim. This species is easily distinguished from other species of *Globigerinatheka* by its embracing final chambers, tightly coiled initial test, and fairly shallow and indistinct sutures. Specimens from this core, however, differ from typical forms in lacking large circular sutural apertures. Premoli Silva and Boersma (1988) demonstrated that *G. semiinvoluta* never exhibits well-developed supplementary apertures, and it is always smaller in size at middle latitudes than at low latitudes in the Atlantic province. These small aperture types are identified as *G. cf. semiinvoluta* in this paper.
- Globigerinatheka subconglobata luterbacheri* Bolli (Plate 2, Figs. 1–3). Bolli, 1972, pp. 132–133, text-figs. 47–50, pl. 1, figs. 17 and 22–25.
- Globigerinella obesa* (Bolli) (Plate 1, Figs. 36–38). *Globorotalia obesa* Bolli, 1957b, p. 119, pl. 29, figs. 2–3.
- Globorotaloides suteri* Bolli (Plate 1, Figs. 15–17). Bolli, 1957b, p. 117, pl. 27, figs. 9–13; Bolli, 1957a, p. 166, pl. 37, figs. 10–12; Blow and Banner, 1962, pp. 122–123, pl. XIII, figs. N–P.
- Globorotaloides permicra* (Blow and Banner). *Globorotalia (Turborotalia) permicra* Blow and Banner, 1962, p. 120, pl. XII, figs. N–P.
- Hantkenina alabamensis* Cushman (Plate 2, Figs. 16–18). Cushman, 1925b, p. 3, fig. 1, pl. 1, figs. 1–6, pl. 2, fig. 5; Bolli, Loeblich, and Tappan, 1957, p. 26, pl. 2, fig. 8; Blow and Banner, 1962, pp. 126–127, pl. XVI, figs. C, D, J, and K.
- Morozovella spinulosa* (Cushman) (Plate 1, Figs. 2–6). *Globorotalia spinulosa* Cushman, 1927, p. 114, pl. 23, fig. 4; Bolli, 1957a, p. 168, pl. 38, fig. 6–7. *Globorotalia (Morozovella) spinulosa spinulosa* Cushman in Blow, 1979, pp. 1013–1015, pl. 182, figs. 1–4, pl. 197, figs. 1–6.
- Paragloborotalia opima nana* (Bolli) (Plate 1, Figs. 39–41). *Globorotalia opima nana* Bolli, 1957b, p. 118, pl. 28, figs. 3a–c. *Globorotalia (Turborotalia) opima nana* Bolli in Blow and Banner, 1962, pp. 119–120, pl. XIII, figs. Q–S; Toumarkine and Luterbacher, 1985, pp. 202–203, text-fig. 26, figs. 15–20.
- Planorotalites renzi* (Bolli) (Plate 1, Figs. 9–11). *Globorotalia renzi* Bolli, 1957a, p. 168, pl. 38, fig. 3.
- Pseudohastigerina barbadoensis* Blow (Plate 1, Figs. 28–29). Blow, 1969, pp. 376 and 409–410, pl. 53, figs. 7–9, pl. 54, figs. 1–3. *Pseudohastigerina nagewichiensis barbadoensis* Blow, 1979, p. 763, pp. 1190–1191, pl. 246, figs. 2 and 6–7.
- Pseudohastigerina danvillensis* (Howe and Wallace) (Plate 1, Figs. 22–23). *Nonion danvillensis* Howe and Wallace, 1932, p. 51, pl. 9, figs. 3a–b.
- Pseudohastigerina micra* (Cole) (Plate 1, Figs. 24–27). *Nonion micrus* Cole, 1927, p. 22, pl. 5, fig. 12. *Hastigerina micra* (Cole). Bolli, 1957a, p. 161, pl. 35, figs. 1a–2b. *Pseudohastigerina micra* (Cole) in Banner and Blow, 1959, pp. 19–20, figs. 4g–i.
- Pseudohastigerina wilcoxensis* (Cushman and Ponton) (Plate 1, Figs. 18–21). *Nonion wilcoxensis* Cushman and Ponton, 1932, p. 64, pl. 8, fig. 11. *Pseudohastigerina wilcoxensis* (Cushman and Ponton) in Berggren et al.,

- 1967, pp. 278–280, text-figs. 2a–v, text-fig. 3, figs. 2a–5c, text-fig. 4, figs. 2a–5c.
- Subbotina angiporoides* (Hornibrook) (Plate 5, Figs. 28–30). *Globigerina angiporoides* Hornibrook, 1965, pp. 834–838, figs. 1–2.
- Subbotina brevis* (Jenkins) (Plate 4, Figs. 16–18). *Globigerina brevis* Jenkins, 1966, pp. 1100–1102, text-figs. 7–58 to –63.
- Subbotina corpulenta* (Subbotina) (Plate 4, Figs. 19–20). *Globigerina corpulenta* Subbotina, 1953, pp. 76–78, pl. IX, figs. 5–7, pl. X, figs. 2–4. *G. corpulenta* is distinguished from *G. eoacaena* by its somewhat rapidly enlarging chambers and its high-spired coiling. It differs from *G. gortanii* in having a low-spired coiling and more loosely arranged globular chambers. This species is characterized by morphologic variations with abnormal or bulla-like last chambers, as shown by Subbotina (1953, 1971) and Stainforth and Lamb (1981).
- Subbotina eoacaena* (Gümbel) (Plate 5, Figs. 19–21). *Globigerina eoacaena* Gümbel, 1868, p. 662, pl. 2, fig. 109; Subbotina, 1953, pl. VI, fig. 5, pl. VII, fig. 1. *Globigerina* (*Subbotina*) *eoacaena* Gümbel in Hang and Lindenbergh, 1966, pp. 342–358, figs. 1–4.
- Subbotina gortanii* (Borsetti) (Plate 4, Figs. 28–30). *Catapsydrax gortanii* Borsetti, 1959, pp. 205–212, pl. 1, fig. 1. *Globigerina turritilina turritilina* in Blow and Banner, 1962, pp. 98–99, pl. XIII, figs. D–G. *Globigerina turritilina praeturritilina* in Blow and Banner, 1962, p. 99, pl. 13, figs. A–C.
- Subbotina linaperta* (Finlay) (Plate 4, Figs. 22–24). *Globigerina linaperta* Finlay, 1939, p. 125, pl. 13, figs. 54–56. *Globigerina linaperta* Finlay in Hornibrook, 1958, pp. 33–34, pl. 1, figs. 19–21.
- Subbotina utilisindex* (Jenkins and Orr). *Globigerina utilisindex* Jenkins and Orr, 1973, pp. 133–135, pl. 1, figs. 1–3.
- Subbotina yeguaensis* (Weinzierl and Applin) (Plate 5, Figs. 13–15). *Globigerina yeguaensis* Weinzierl and Applin, 1929, p. 408, pl. 43, figs. 1a–b; Bolli, 1957a, p. 163, pl. 35, figs. 14a–15c. *Globigerina yeguaensis yeguaensis* Weinzierl and Applin in Blow and Banner, 1962, pp. 99–100, pl. XIII, figs. H, J, and K–M.
- Tenuitella munda* (Jenkins) (Plate 1, Figs. 33–35). *Globorotalia* (*Turborotalia*) *munda* Jenkins, 1966, pp. 1121–1122, text-fig. 14, figs. 126–133.
- Tenuitella postcretacea* (Myatliuk). *Globigerina postcretacea* Myatliuk, 1950, p. 280, pl. 4, fig. 3; Subbotina, 1953, pp. 60–61, pl. 2, figs. 16–20. *Globorotalia* (*Turborotalia*) *postcretacea* (Myatliuk) in Blow and Banner, 1962, pp. 120–121, pl. XII, figs. G–J.
- Truncorotaloides topilensis* (Cushman) (Plate 1, Figs. 7–8). *Globigerina topilensis* Cushman, 1925c, p. 7, pl. 1, fig. 9; Bolli, 1957a, p. 170, pl. 39, figs. 13–16b.
- Turborotalia centralis* (Cushman and Bermúdez) (Plate 3, Figs. 16–18). *Globorotalia centralis* Cushman and Bermúdez, 1937, pp. 26–27, pl. 2, figs. 62 and 64–65; Bolli, Loeblich, and Tappan, 1957, p. 41, pl. 10, figs. 4a–c.
- Turborotalia cerroazulensis cerroazulensis* (Cole) (Plate 3, Figs. 19–24). *Globigerina cerroazulensis* Cole, 1928, p. 17, pl. 1, figs. 11–13. *Globorotalia cerroazulensis cerroazulensis* (Cole) in Toumarkine and Bolli, 1970, p. 144, pl. 1, figs. 19–24.
- Turborotalia cerroazulensis cocoaensis* (Cushman) (Plate 3, Figs. 25–30). *Globorotalia cocoaensis* Cushman, 1928, p. 75, pl. 10, figs. 3a–c; Bolli, 1957a, pp. 169–170, pl. 39, figs. 5a–7b.
- Turborotalia increbescens* (Bandy) (Plate 4, Figs. 7–9). *Globigerina increbescens* Bandy, 1949, pp. 120–121, pl. 23, fig. 3. *Globorotalia* (*Turborotalia*) *increbescens* (Bandy) in Blow and Banner, 1962, pp. 118–119, pl. XIII, figs. T–V.
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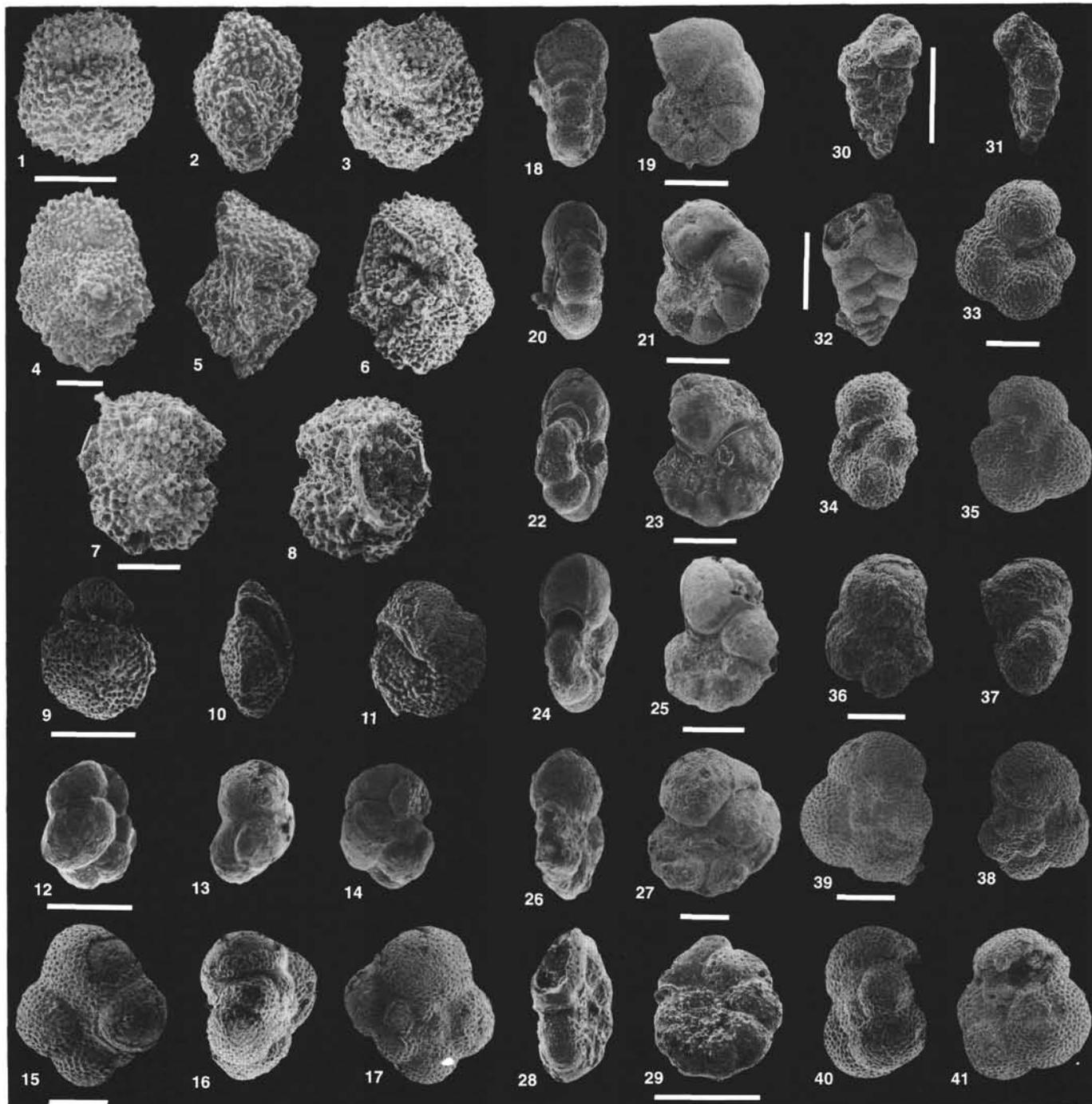


Plate 1. Scale bar = 100 μm . 1–3. *Acarinina densa*, Sample 135-841B-47R-1, 66–70 cm (1, spiral view; 2, side view; 3, umbilical view). 4–6. *Morozovella spinulosa*, Sample 135-841B-47R-1, 66–70 cm (4, spiral view; 5, side view; 6, umbilical view). 7, 8. *Truncorotaloides topilensis*, Sample 135-841B-47R-1, 66–70 cm (7, spiral view; 8, umbilical view). 9–11. *Planorotalites renzi*, Sample 135-841B-47R-1, 66–70 cm (9, spiral view; 10, side view; 11, umbilical view). 12–14. *Cassigerinella chipolensis*, Sample 135-841B-42R-1, 92–96 cm (12, side view; 13, peripheral view; 14, side view). 15–17. *Globorotaloides suteri*, Sample 135-841B-42R-3, 80–83 cm (15, spiral view; 16, side view; 17, umbilical view). 18, 19. *Pseudohastigerina wilcoxensis*, Sample 135-841B-44R-2, 28–31 cm (18, apertural face; 19, lateral view). 20, 21. *Pseudohastigerina wilcoxensis*, Sample 135-841B-44R-2, 28–31 cm (20, apertural face; 21, lateral view). 22, 23. *Pseudohastigerina danvillensis*, Sample 135-841B-44R-2, 28–31 cm (22, apertural face; 23, lateral view). 24, 25. *Pseudohastigerina micra*, Sample 135-841B-45R-1, 60–65 cm (24, apertural face; 25, lateral view). 26, 27. *Pseudohastigerina micra*, Sample 135-841B-45R-1, 25–28 cm (26, apertural face; 27, lateral view). 28, 29. *Pseudohastigerina barbadoensis*, Sample 135-841B-45R-1, 60–65 cm (28, apertural face; 29, lateral view). 30, 31. *Chiloguembelina cubensis*, Sample 135-841B-45R-1, 25–28 cm (30, lateral view; 31, edge view). 32. *Chiloguembelina martini*, Sample 135-841B-44R-2, 28–31 cm, lateral view. 33–35. *Tenuitella munda*, Sample 135-841B-42R-1, 92–96 cm (33, umbilical view; 34, side view; 35, spiral view). 36–38. *Globigerinella obesa*, Sample 135-841B-42R-3, 80–83 cm (36, umbilical view; 37, side view; 38, spiral view). 39–41. *Paragloborotalia opima nana*, Sample 135-841B-42R-1, 92–96 cm (39, umbilical view; 40, side view; 41, spiral view).

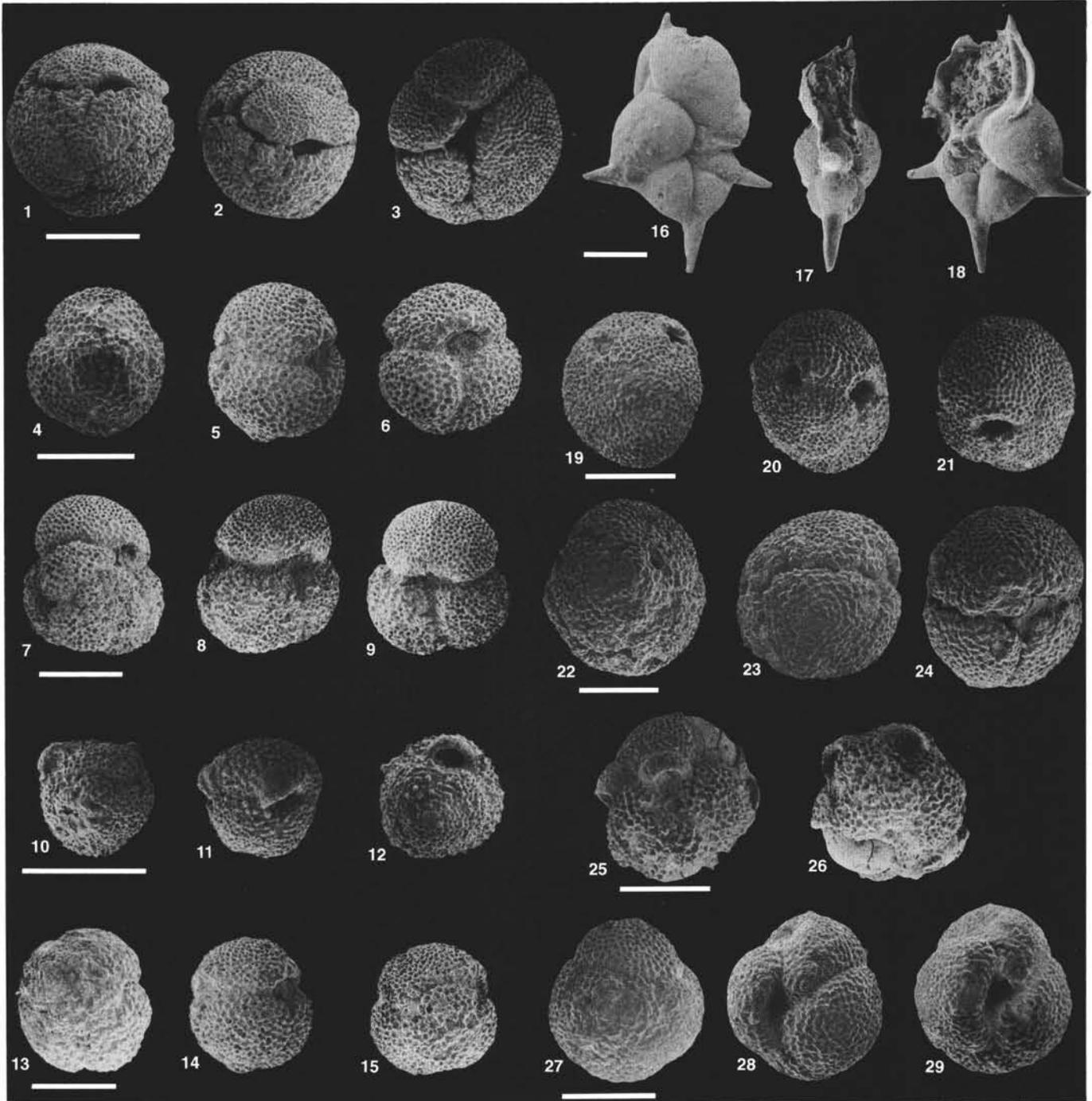


Plate 2. Scale bar = 200 μm . **1–3.** *Globigerinathea subconglobata luterbacheri*, Sample 135-841B-44R-1, 17–20 cm (1, spiral view; 2, side view; 3, umbilical view). **4–6.** *Globigerinathea index tropicalis*, Sample 135-841B-45R-1, 60–65 cm (4, spiral view; 5, side view; 6, umbilical view). **7–9.** *Globigerinathea index tropicalis*, Sample 135-841B-44R-2, 28–31 cm (7, spiral view; 8, side view; 9, umbilical view). **10–12.** *Globigerinathea mexicana barri*, Sample 135-841B-44R-2, 28–31 cm (10, spiral view; 11–12, side view). **13–15.** *Globigerinathea mexicana mexicana*, Sample 135-841B-45R-1, 60–65 cm (13, side view; 14, 15, spiral view). **16–18.** *Hantkenina alabamensis*, Sample 135-841B-45R-1, 60–65 cm (16, lateral view; 17, apertural face; 18, lateral view). **19–21.** *Globigerinathea* cf. *semiinvoluta*, Sample 135-841B-45R-1, 60–65 cm (19, spiral view; 20, side view; 21, umbilical view). **22–24.** *Globigerinathea index index*, Sample 135-841B-44R-2, 28–31 cm (22, spiral view; 23, side view; 24, umbilical view). **25, 26.** *Globigerinathea mexicana barri*, Sample 135-841B-45R-1, 60–65 cm, side view. **27–29.** *Catapsydrax globiformis*, Sample 135-841B-44R-2, 28–31 cm (27, spiral view; 28, side view; 29, umbilical view).

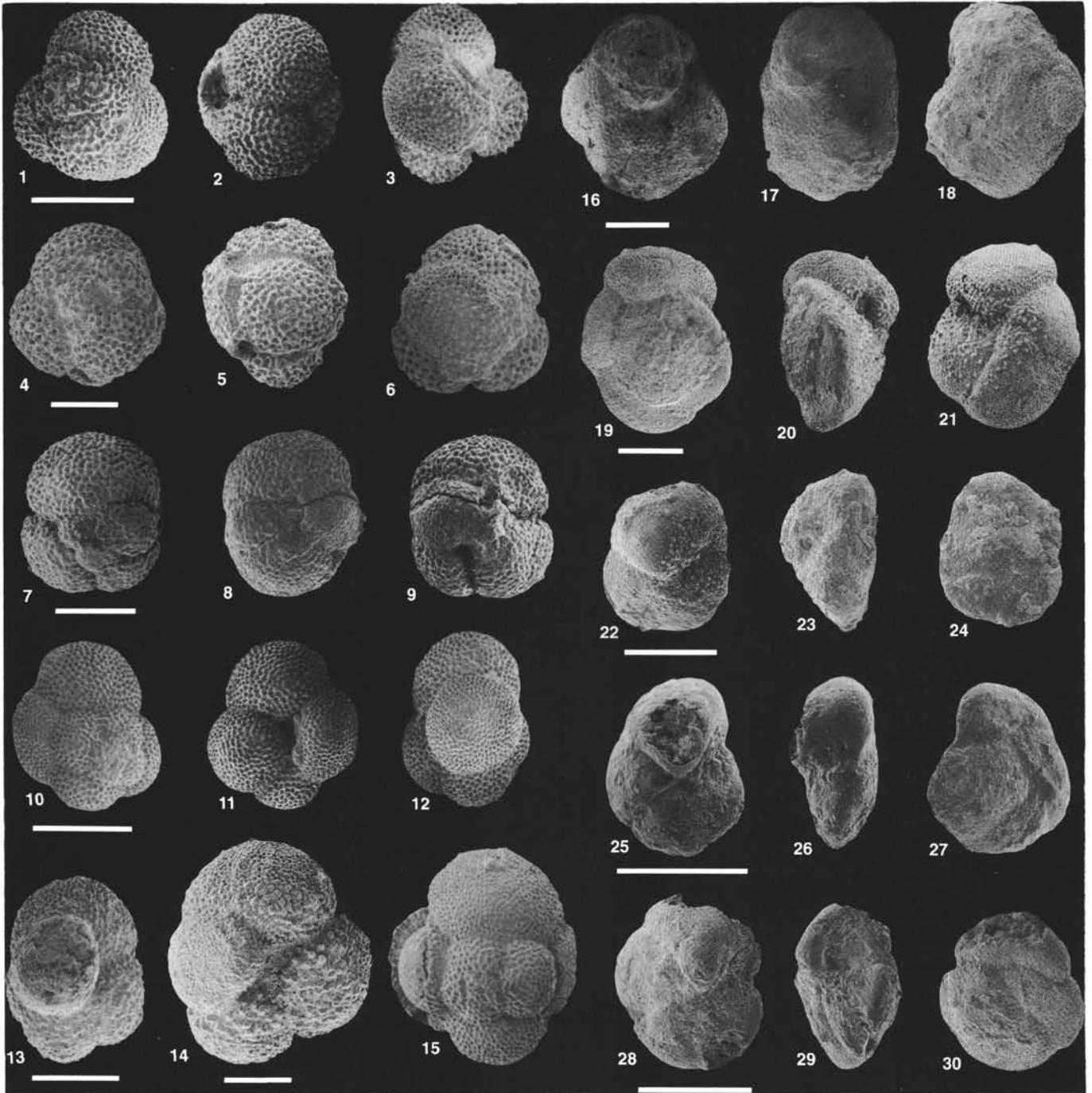


Plate 3. Scale bar = 200 μ m. 1–3. *Catapsydrax howei*, Sample 135-841B-44R-2, 28–31 cm (1, spiral view; 2, side view; 3, umbilical view). 4–6. *Catapsydrax africanus*, Sample 135-841B-45R-1, 60–65 cm (4, spiral view; 5, side view; 6, umbilical view). 7–9. *Catapsydrax africanus*, Sample 135-841B-44R-1, 17–21 cm (7, spiral view; 8, side view; 9, umbilical view). 10–12. *Catapsydrax pera*, Sample 135-841B-44R-1, 17–20 cm (10, spiral view; 11, side view; 12, umbilical view). 13. *Catapsydrax martini*, Sample 135-841B-42R-4, 89–93 cm, umbilical view. 14–15. *Catapsydrax unicavus*, Sample 135-841B-44R-2, 28–31 cm (14, umbilical view; 15, spiral view). 16–18. *Turborotalia centralis*, Sample 135-841B-45R-1, 25–28 cm (16, umbilical view; 17, side view; 18, spiral view). 19–21. *Turborotalia cerroazulensis cerroazulensis*, Sample 135-841B-44R-2, 28–31 cm (19, spiral view; 20, side view; 21, umbilical view). 22–24. *Turborotalia cerroazulensis cerroazulensis*, Section 135-841B-45R-CC (22, umbilical view; 23, side view; 24, spiral view). 25–27. *Turborotalia cerroazulensis cocoaensis*, Section 135-841B-45R-CC (25, umbilical view; 26, side view; 27, spiral view). 28–30. *Turborotalia cerroazulensis cocoaensis*, Section 135-841B-45R-CC (28, umbilical view; 29, side view; 30, spiral view).

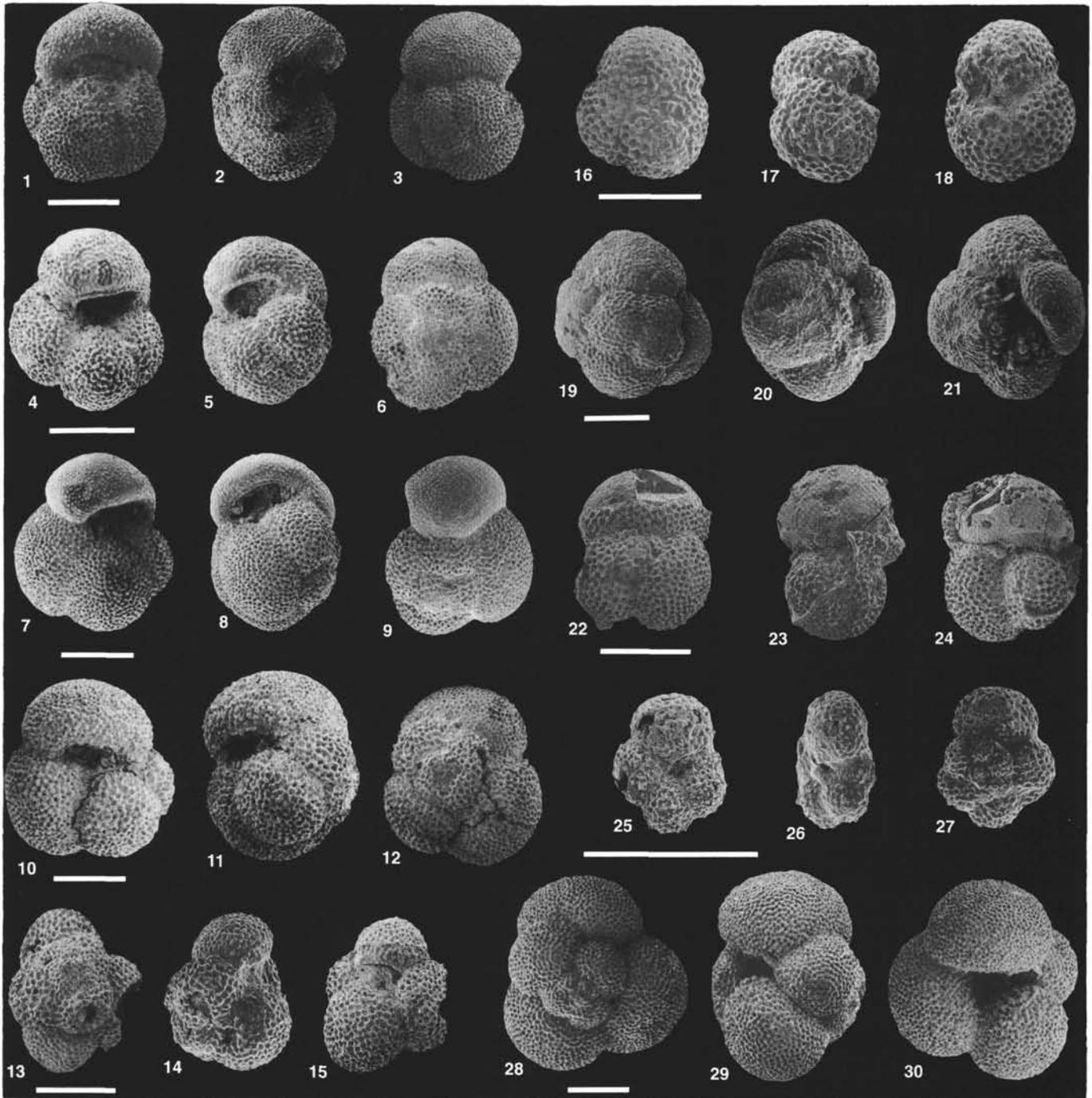


Plate 4. Scale bar = 200 μm . 1–3. *Globigerina ampliapertura*, Section 135-841B-41R-CC (1, umbilical view; 2, side view; 3, spiral view). 4–6. *Globigerina ampliapertura*, Section 135-841B-41R-CC (4, umbilical view; 5, side view; 6, spiral view). 7–9. *Turborotalia increbescens*, Section 135-841B-41R-CC (7, umbilical view; 8, side view; 9, spiral view). 10–12. *Globigerina euapertura*, Section 135-841B-41R-CC (10, umbilical view; 11, side view; 12, spiral view). 13–15. *Globigerina senilis*, Sample 135-841B-45R-1, 60–65 cm (13, spiral view; 14, side view; 15, umbilical view). 16–18. *Subbotina brevis*, Section 135-841B-41R-CC (16, spiral view; 17, side view; 18, umbilical view). 19–21. *Subbotina corpulenta*, Sample 135-841B-44R-2, 28–31 cm (19, spiral view; 20, side view; 21, umbilical view). 22–24. *Subbotina linaperta*, Sample 135-841B-44R-2, 28–31 cm (22, spiral view; 23, side view; 24, umbilical view). 25–27. *Globigerina angustiumbilitata*, Sample 135-841B-45R-1, 60–65 cm (25, umbilical view; 26, side view; 27, spiral view). 28–30. *Subbotina gortanii*, Section 135-841B-41R-CC (28, umbilical view; 29, side view; 30, spiral view).

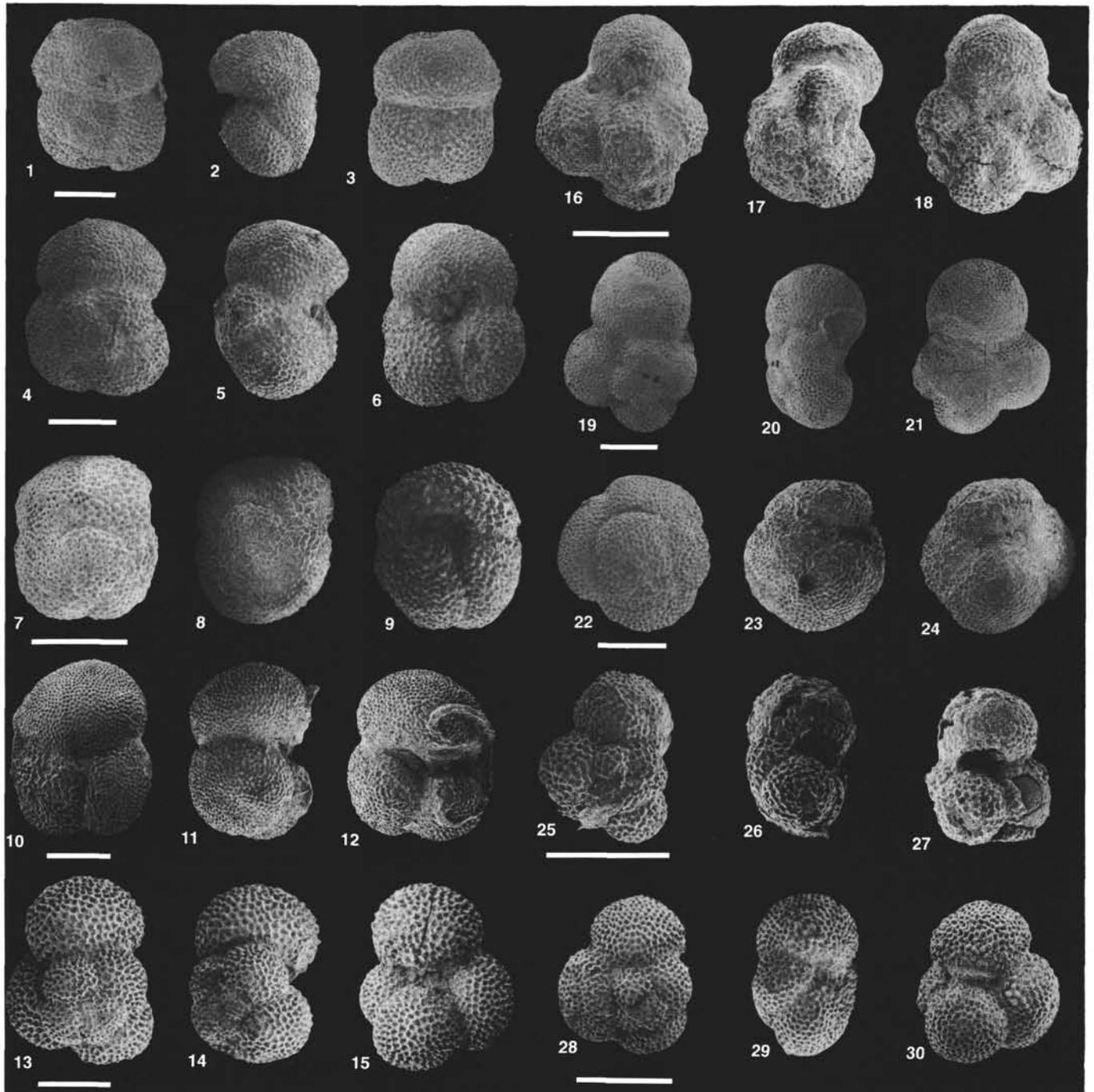


Plate 5. Scale bar = 200 μ m. **1–3.** *Dentoglobigerina tripartita*, Sample 135-841B-43R-1, 21–25 cm (1, spiral view; 2, side view; 3, umbilical view). **4–6.** *Dentoglobigerina tapuriensis*, Sample 135-841B-42R-1, 92–96 cm (4, spiral view; 5, side view; 6, umbilical view). **7–9.** *Dentoglobigerina sellii*, Sample 135-841B-43R-1, 21–25 cm (7, spiral view; 8, side view; 9, umbilical view). **10–12.** *Dentoglobigerina galavisi*, Sample 135-841B-44R-2, 28–31 cm (10, spiral view; 11, side view; 12, umbilical view). **13–15.** *Subbotina yeguaensis*, Sample 135-841B-44R-2, 28–31 cm (13, umbilical view; 14, side view; 15, spiral view). **16–18.** *Globigerina officinalis*, Sample 135-841B-45R-1, 25–28 cm (16, spiral view; 17, side view; 18, umbilical view). **19–21.** *Subbotina eocaena*, Sample 135-841B-44R-CC (19, spiral view; 20, side view; 21, umbilical view). **22–24.** “*Globigerina*” *pseudovenezuelana*, Sample 135-841B-44R-2, 28–31 cm (22, spiral view; 23, side view; 24, umbilical view). **25–27.** *Globigerina praebulloides*, Sample 135-841B-45R-1, 60–65 cm (25, spiral view; 26, side view; 27, umbilical view). **28–30.** *Subbotina angiporoides*, Sample 135-841B-44R-2, 28–31 cm (28, umbilical view; 29, side view; 30, spiral view).