

27. CENOZOIC PLANKTONIC FORAMINIFERA FROM THE EASTERN EQUATORIAL PACIFIC OCEAN

Ansis G. Kaneps, Scripps Institution of Oceanography, La Jolla, California

INTRODUCTION

Leg 16 of the Deep Sea Drilling Project cored two sedimentologically, paleontologically, and paleoenvironmentally distinct regions. The division of the present paper into two parts, one on the late Cenozoic of the Panama Basin (Sites DSDP 155, 157, and 158)¹ and the other on the mid-Cenozoic of the west flank of the East Pacific Rise (Sites DSDP 159-162)², reflects the fact that there is little in common between the two regions so far as the planktonic foraminifera are concerned. Pertinent data for Leg 16 sites are given in Table 1.

TABLE 1

Location and Water Depth of Sites DSDP 155, 156, 157, and 158

Site	Geographical Area	Latitude	Longitude	Water Depth (m)
155	Coiba Ridge	06° 07.38'N	81° 02.62'W	2752
156	Carnegie Ridge	01° 40.80'S	85° 24.06'W	2369
157	Carnegie Ridge	01° 45.70'S	85° 54.17'W	2591
158	Cocos Ridge	06° 37.36'N	85° 14.16'W	1953

The Panama Basin sites were drilled in sediment-filled troughs or catchments on the Coiba, Carnegie, and Cocos ridges and recovered thick sequences of Middle and upper Miocene to upper Pleistocene calcareous-siliceous pelagic ooze. Sedimentation rates are high, up to 60 m/m.y., and are reflected by the dominantly gray and green colors which indicate deposition in a region of high organic productivity. Foraminifera are present throughout and are moderately well to well preserved except in a basal zone of diagenetic alteration, in which foraminifera are crushed and infilled with silica, and in a zone of apparent dissolution at the middle-upper Miocene boundary.

The East Pacific Rise sites were drilled through interbedded coccolith chalks, brown clay, and radiolarian ooze of mid-Cenozoic (middle Eocene to middle Miocene) age. Younger sediments are highly condensed or missing. The planktonic foraminiferal assemblages of these sites are characterized by sporadic occurrence and a high degree of dissolution, with only the most resistant forms preserved. This probably reflects the fact that these sites were drilled

along the northernmost margin of the equatorial Pacific high productivity belt, where the equatorial calcareous oozes pass into the barren clays that underlie the North Pacific Central Water Mass. Consequently, detailed foraminiferal biostratigraphy was not possible at these sites, and age determinations had to rely on nannofossils and Radiolaria.

The zonation used in the present report is a combination of zones from Bolli (1957, 1966a), Blow (1969), and Jenkins and Orr (1972). For the mid-Cenozoic of the East Pacific Rise sites, the zonal sequence of Bolli (1957, 1966a) was recognized, but only two of the zones (*Globorotalia opima opima* and *G. kugleri* Zones) could be positively identified by means of their marker fossils; the remainder were inferred to be present by negative evidence or position in sequence. Because of the dissolution problem, the refinements of the zonation of Blow (1969) could not be recognized.

For the Panama Basin sites, the middle and upper Miocene zonation is fairly orthodox, comprising the *Globorotalia fohsi* s.l. to *G. acostaensis* zones of Bolli (1966a) and Zones N.10 through N.17 of Blow (1969). Owing to the scarcity or absence of many of the species commonly used as markers for the Pliocene-Pleistocene, a new zonal scheme had to be devised for this part of the section in the Panama Basin. This zonal scheme is intended only for the purpose of intra-basin correlation and may not be applicable elsewhere, although some of the zonal boundary datums seem to be chronostratigraphically highly reliable. The "zone" that corresponds to the upper Pleistocene was left unnamed for lack of a zonal name that is not already occupied.

METHODS

Samples for shore-based study were cleaned ultrasonically, ensuring foraminiferal tests completely clean of matrix. Samples were dried for 24 hours at 105°C, weighed, and allowed to disperse in a water-Calgon solution. After dispersal was as complete as possible in this initial step, the sample was ultrasonically agitated for a few seconds and washed through a 62.5 μ sieve. This step removed most of the matrix. The residue was again placed in a water-Calgon solution and the ultrasonic cleaning repeated for a few seconds. This second cleaning, in most cases, removed all traces of adherent matrix. It has been found that stirring the sample during the ultrasonic cleaning greatly speeds dispersal of the matrix and probably reduces test breakage due to prolonged sonification. The cleaned residue was then sieved, dried, and weighed and the percentage by weight of >62.5 μ residue (which generally consists of the tests of foraminifera, Radiolaria, and diatoms) calculated. The curves showing this parameter are given in subsequent parts of this chapter.

¹At Site DSDP 156, only a meter or so of Pleistocene or Recent foraminiferal ooze was recovered before the bit entered a ferromanganese crust and the hole was abandoned. This site will not be discussed further.

²The Cenozoic section at Site DSDP 163 is completely barren of calcareous fossils. The foraminifera from the thick upper Cretaceous chalk sequence at this site are discussed in Chapter 33 (Pessagno and Longoria) in this volume.

The residues, one per core section generally and at closer intervals near biostratigraphic boundaries, were examined and species presence or absence noted. No attempt was made to estimate abundance inasmuch as the marker species are generally very scarce and in most cases had to be specifically sought within rather monotonous assemblages of long-ranging forms. Before microscopic examination, it was also found necessary to sieve the dried residues through a 149 μ sieve to remove the radiolarians and diatoms which in most cases are more abundant than, and mask, the foraminifera.

PANAMA BASIN

Locations of the Panama Basin sites are shown in Figure 1 and their biostratigraphic and time-stratigraphic correlation in Figure 2. Sites DSDP 157 and 158 were continuously cored from the surface to basaltic basement. Coring at DSDP 155 was begun at a depth of 434 meters below the sediment surface, a level within the *Globorotalia acostaensis* Zone (upper Miocene), and continued to basement, which is overlain by sediments of the *Globorotalia fohsi fohsi* Zone (middle Miocene), the oldest recovered in the Panama Basin. The section above the continuously cored interval was sampled in three sidewall cores; Core 13 recovered sediments of the *Globorotalia plesiotumida* Zone (upper Miocene), and Cores 14 and 15, sediments of the *Globorotalia tumida* Zone (lower Pliocene). The following discussion will concern itself mainly with the continuously cored sites, 157 and 158, and attention will be focused mainly on the late Miocene to Pleistocene since this part of the section is still the least understood in terms of planktonic foraminiferal biostratigraphy. DSDP 155 is of interest mainly for its display of the diagenetic processes that have affected the planktonic foraminifera; these are discussed and illustrated in a subsequent section.

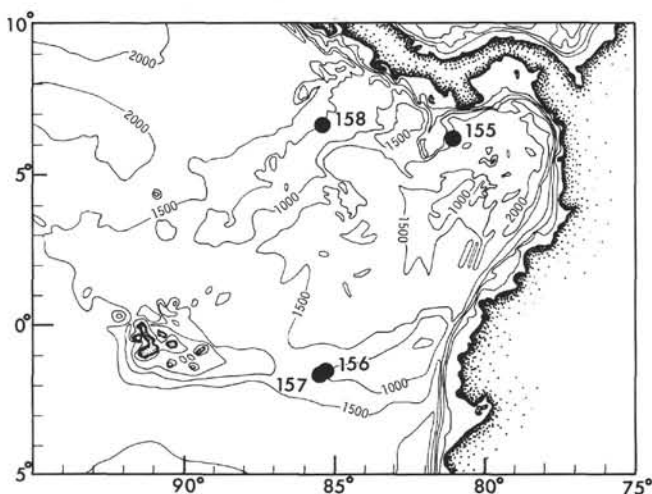


Figure 1. Location of Leg 16 sites in the Panama Basin.

Definition of Zones

For the middle and upper Miocene of the Panama Basin, the zones of Bolli (1966a), up through the *Globorotalia acostaensis* Zone, were used. The next higher zone is the *Globorotalia plesiotumida* (N.17) Zone of Blow (1969); along with the basal part of the overlying *Globorotalia tumida* Zone (here defined), it represents the uppermost Miocene. Definition of zones above the *G. plesiotumida* Zone are described as follows:

Globorotalia tumida Zone

Base: First appearance of *G. tumida*.

Top: Change in coiling direction of *Pulleniatina primalis* from left below to right above.

Characterization: Interval with *Globorotalia tumida* and left-coiling *P. primalis*.

Age: Late Miocene/Early Pliocene.

Remarks: This zone is probably equivalent to the combined Zones N.18/N.19 of Blow (1969) as *Globorotalia pseudopima*, the marker for Zone N.20, appears near its top. Zones N.18 and N.19 were not distinguished because *Sphaeroidinella dehiscens*, the marker for N.19, first occurs a very short distance above the first occurrence of *G. tumida*, rendering N. 18 a short interval, probably of subzonal rank.

This is at variance with Jenkins and Orr (1972), who recognize quite a long interval with *G. tumida* but without *S. dehiscens* (their *G. tumida* Zone). However, it has been noted before (Hays et al., 1969, p. 1499) that the first abundant occurrence of *S. dehiscens* (their Datum V) has previously been mistaken for its first phyletic occurrence. The former is located in equatorial Pacific and Indian Ocean cores at the top of the Mammoth event (~3 m.y.) of the Gauss normal series, while the latter occurs considerably lower in the section (at least 4.5 m.y.). A similar situation was seen in the Panama Basin cores. At DSDP 158, *S. dehiscens* first appears shortly above the base of the *G. tumida* Zone but remains scarce and sporadic in occurrence until within the overlying *Globoquadrina altispira* Zone (see below), where it becomes common and is consistently present to the top of the section. At DSDP 157, the pattern of occurrence of *S. dehiscens* is similar, except that it was not seen at all below a point within the *G. altispira* Zone, where it occurs sporadically; its only interval of consistent occurrence at this site bridges the *Globorotalia limbata*/*Pulleniatina obliquiloculata* zonal boundary (see below).

The top of the *G. tumida* Zone of the present study is defined by distinct, easily recognizable coiling change of *Pulleniatina primalis* from left below to right above. This is the initial coiling change of *Pulleniatina*, and is succeeded by additional coiling changes higher in the section. A similar initial shift from left to right coiling was detected by Hays et al. (1969) in equatorial Pacific and Indian Ocean cores and was located paleomagnetically just above the "A" event of the Gilbert reversed series. A similar shift has been documented by Bolli (1964, 1966b) and Bolli and Bermudez (1965) in land sections from the Caribbean area and Indonesia. It must be emphasized, however, that if the chronological scheme of the Panama Basin sections is correct (details of this chronology are given in chapter 30), then the coiling shift in the Panama Basin cores is significantly older than the one seen in equatorial Pacific sections farther west, lying probably within the lower split of event C of the Gilbert reversed series. The diachronous nature of the initial coiling shift of *Pulleniatina* is supported by the later history of coiling changes of the genus, which does not match that reported by Hays et al. (1969).

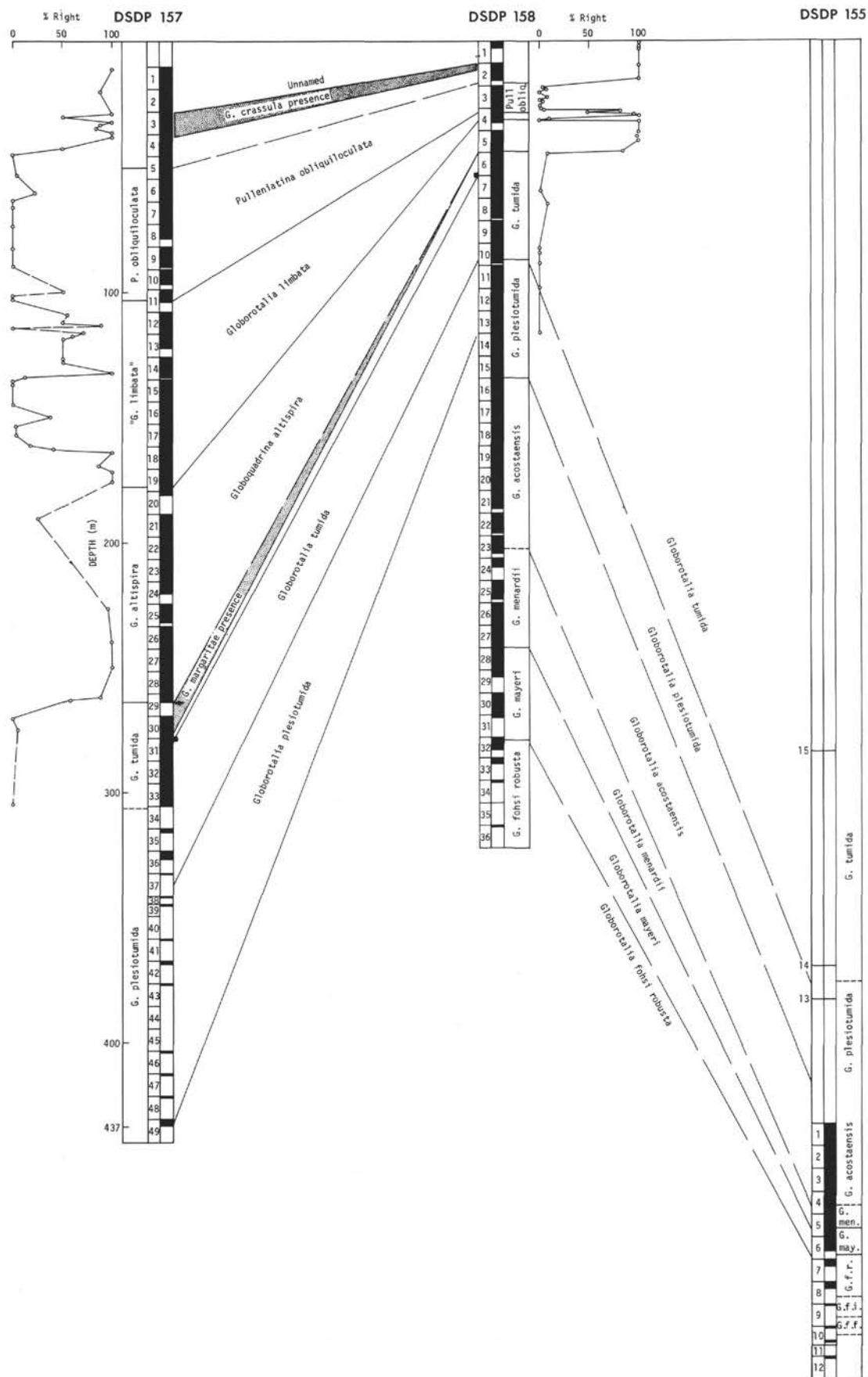


Figure 2. Biostratigraphic correlation of Sites DSDP 155, 157, and 158.

Globoquadrina altispira Zone

Base: Coiling change of *Pulleniatina primalis* from left below to right above.

Top: Extinction of *G. altispira*.

Characterization: Interval with *G. altispira* and without left-coiling *Pulleniatina* (although there may be a slight reversion to left coiling near the top of the zone).

Age: Mostly early Pliocene; upper part, late Pliocene according to nanofossils (Bukry, this volume).

Remarks: *Globoquadrina altispira* was chosen as a zonal marker because it seems to be one of a few species whose extinction horizon, for all practical purposes, seems to be isochronous in tropical-subtropical areas. Within the upper part of the *G. altispira* Zone is a sequence of paleontological events identical to that reported by Hays et al. (1969) and seen by me in cores from the Blake Plateau (Kaneps, 1970, unpublished thesis): (a) the extinction of *G. altispira* follows a short distance above that of *Sphaeroidinella seminulina* s.l. (= *Sphaeroidinellopsis* auct.); (b) the end of the range of *G. altispira* slightly overlaps the range of *Globorotalia tosaensis*³; and (c) at DSDP 158 there is also a slight overlap in the ranges of *G. altispira* and *Globigerinoides fistulosus*; the latter is not well represented at DSDP 157. Though differing in detail, a similar sequence of events was recorded by Jenkins and Orr (1972).

The *Globoquadrina altispira* Zone is largely equivalent to Blow's (1969) Zone N.20 and includes the basal part of his Zone N.21 (but see Theyer, 1972, which may necessitate redefinition of this part of Blow's zonation). It is also equivalent to the *G. tumida* (part) and *Sphaeroidinella dehiscens* Zone of Jenkins and Orr (1972) and includes the basal part of their *Globigerinoides fistulosus* Zone.

Globorotalia limbata Zone

Base: Extinction of *Globoquadrina altispira*.

Top: Extinction of *G. limbata*.

Characterization: Interval with *G. limbata* but without *G. altispira*.

Age: Late Pliocene.

Remarks: The concept of *Globorotalia limbata* used here is that of Blow (1969) in his Plate 7, Figures 4-6; not that represented by the lectotype designated by Banner and Blow (1960, Pl. 5, Fig. 3), which seems to be *Globorotalia menardii* with a reduced last chamber, as pointed out by these authors. The form referred to *G. limbata* is one of a branch of the *Globorotalia menardii* lineage which is recorded in the Panama Basin sections from the upper Miocene (base of *G. plesiotumida* Zone) to the uppermost Pliocene; a similar range for this form was observed in Blake Plateau cores (Kaneps, 1970, unpublished thesis) and at Atlantic DSDP sites (Parker, in press). It is distinguished from *Globorotalia menardii* by

(a) its preference for right coiling throughout most of its range, (b) weaker peripheral lobulation, which, along with a slower increase in the radius of the spire, gives the test a more circular outline, (c) lack or only weak development of the coarse secondary calcification of the apertural region developed by *G. menardii*, *G. tumida*, and other species of *Globorotalia* (d) a wider umbilicus, and (e) a tendency for a larger number of chambers in the final whorl (a trend developed to an extreme in *G. multicamerata* Cushman and Jarvis, which is an offshoot of the *G. limbata* branch). *G. limbata*, as here interpreted, probably includes such forms as *G. pseudomiocenica* Bolli and Bermudez (= ?*G. merotumida* Blow; see Parker, in press) and *G. fijiensis* Cushman.

In the Panama Basin sites, *G. limbata* disappears just below the extinction levels of *Globigerinoides fistulosus* and *Discoaster brouweri* and several meters above the extinction horizon of *Globigerinoides extremus*. In the Atlantic, *G. limbata* s.l. (including such forms as *G. miocenica*, *G. exilis* and *Globorotalia* sp. A of Kaneps, 1970, all of which seem to have evolved independently in the Atlantic after complete emergence of the Isthmus of Panama) has a similar range. *G. limbata*, itself, evolves into *G. miocenica* in the late Pliocene of the Atlantic and, to *G. exilis* via *G. multicamerata* and *G. pertenuis*. Both *G. miocenica* and *G. exilis* persist almost to what is currently regarded as the Pliocene/Pleistocene boundary (see Berggren, 1968, for details of the upper limits of these species as related to paleomagnetic stratigraphy, where *G. exilis* = "*G. fimbriata*" and *G. pertenuis* = "*G. cf. G. multicamerata*").

The *G. limbata* Zone of the present paper is equivalent to most of the *Globigerinoides fistulosus* Zone of Jenkins and Orr (1972), probably to the *G. exilis*/*G. miocenica* Zone of Bolli (1970), and to Zone N.21 of Blow (1969) as currently defined in subtropical sequences.

Pulleniatina obliquiloculata Zone

Base: Extinction of *Globorotalia limbata*.

Top: Reduction in abundance of *Pulleniatina obliquiloculata*, which is coincidental with a shift from dominantly left-coiling to dominantly right-coiling of this species.

Characterization: Interval with right-coiling, relatively common *Pulleniatina* but without *G. limbata*.

Age: Mostly early Pleistocene; basal part late Pliocene according to present definition.

Remarks: This zone is probably of utility only in the Panama Basin. As pointed out above, the coiling history of *Pulleniatina* in the Panama Basin does not show a history of shifts similar to that farther to the west (Hays et al., 1969).

The reduction in abundance of *Pulleniatina* at the top of this zone is similar to that described by Berggren (1968) in North Atlantic piston core Chain 61 (171), where it occurs at the top of the Jaramillo normal event of the Matuyama reversed series. This is in good agreement with its position as determined by the carbonate chronology developed in Chapter 30. Berggren (1968) interprets the reduction of *Pulleniatina* at this point, along with simultaneous increases in abundance of two cool water forms, as indicative of the first severe

³It should be noted here that this first occurrence of *Globorotalia tosaensis* is probably a local first occurrence since it has recently been reported by Theyer (1972) that this species and its descendant first appear in the lower Pliocene of cores from south of Australia. It thus seems that this lineage may be a southern hemisphere one that only later invaded the subtropics and the northern hemisphere.

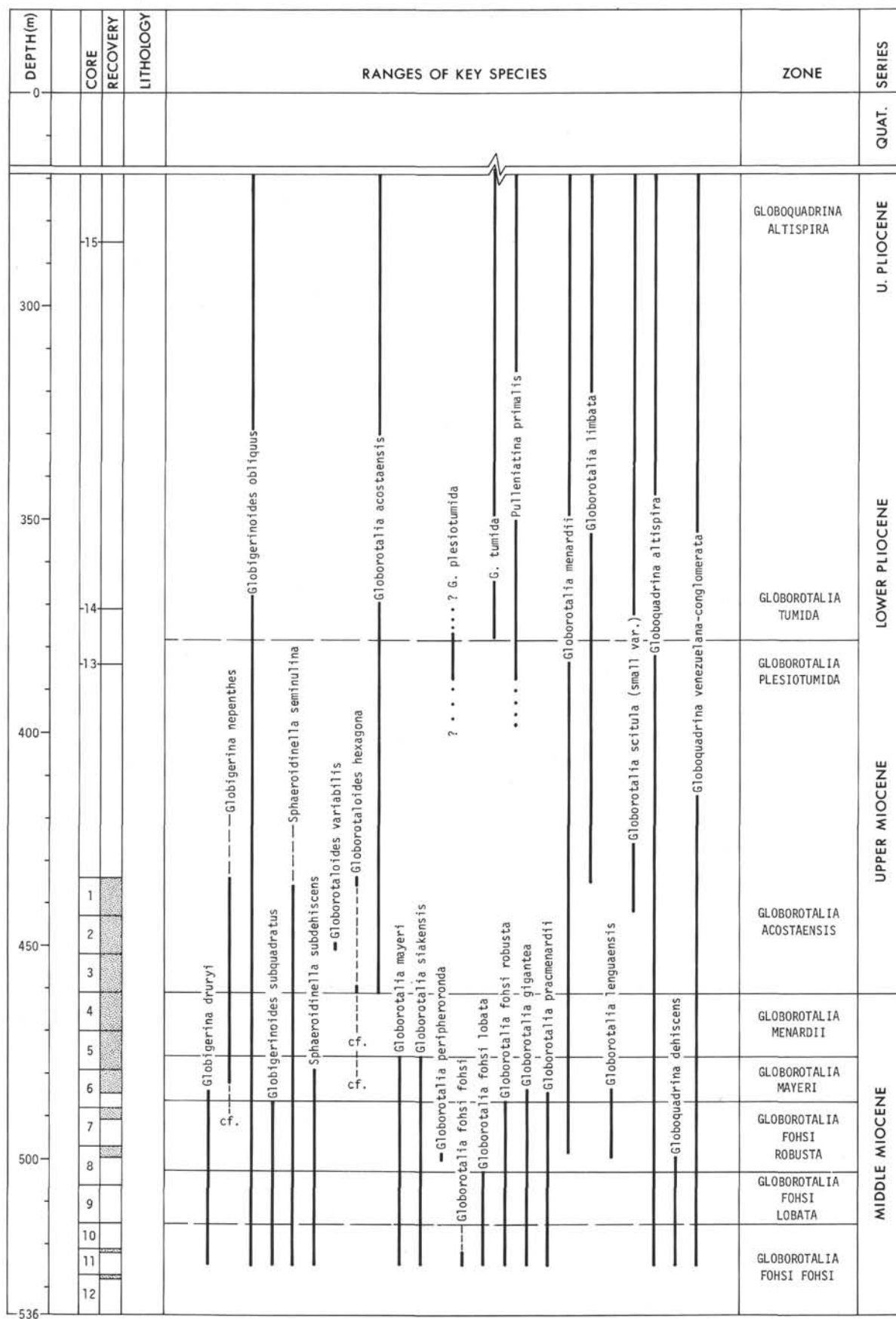


Figure 3. Ranges of key species of planktonic foraminifera at Site DSDP 155.

cooling of the classical glacial Pleistocene (Selli, 1967; Hays and Berggren, 1971). The reduction in abundance of *Pulleniatina* is much more pronounced at DSDP 158 than at DSDP 157; at the latter site the genus is never abundant.

The *P. obliquiloculata* Zone of this study is equivalent to the lower half of the *P. obliquiloculata* Zone of Jenkins and Orr (1972), who include the entire Pleistocene within their zone. It is also probably equivalent to the *Globorotalia truncatulinoides* cf. *tosaensis* Zone of Bolli (1970) and to Zone N.22 of Blow (1969) as currently defined in tropical-subtropical sequences. In general, the *G. tosaensis-truncatulinoides* lineage has played a prominent role in the zonation of the stratigraphic interval under consideration. However, both species are absent at DSDP 158 and at DSDP 157. *G. tosaensis* was seen only near the top of the *Globorotalia altispira* Zone, and *G. truncatulinoides* was seen in only one sample from the upper Pleistocene. The generally poor representation of the *G. tosaensis-truncatulinoides* lineage in tropical areas (Hays et al., 1969) and in the Mediterranean (Bayliss, 1969), plus the recorded occurrence of both species in the lower Pliocene (Theyer, 1972), makes necessary a reassessment of their use in world-wide biostratigraphy.

Boundaries

In theory, it would have been preferable not to pick the series boundaries between the Miocene, Pliocene, and Pleistocene because, as yet, no reliable foraminiferal criteria exist for extending them far beyond their type areas in the Mediterranean. However, for the sake of intra- and interdisciplinary communication, the selection of boundaries becomes almost mandatory. The boundaries, as used here, are based on nannofossil biostratigraphy.

MIocene-PLIOCENE BOUNDARY

According to nannofossil biostratigraphy, this boundary, based on the lowest datable sediment overlying Messinian evaporites at Site DSDP 132 in the Tyrrhenian Basin, lies within the *Ceratolithus amplifiscus* Subzone of the *C. tricorniculatus* Zone (Bukry, in press). Bukry, in the present volume (Chapter 26), has placed the Miocene-Pliocene boundary at the base of the *C. amplifiscus* Subzone although the carbonate chronology (Chapter 30) indicates that only the upper two-thirds of the subzone is represented at DSDP 132. Thus, the placement of the boundary in DSDP 157 is probably too low but is retained here for convenience. This level falls within the lower part of the *Globorotalia tumida* Zone of the present zonal scheme.

The only foraminiferal criterion advanced to date for recognition of the Mio-Pliocene boundary is the initial appearance of *Sphaeroidinella dehiscentis*, which, according to Blow (1969), occurs somewhat above the base of the Trubi marl of Sicily of early Pliocene (Zanclian) age.) This places the boundary somewhat below the base of his Zone N.19. However, Parker (in press), who restudied samples from the Trubi, was not able to confirm the presence of *S. dehiscentis* in this section, leaving open the question of a positive foraminiferal correlation between Mediterranean and extra-Mediterranean regions. Nonetheless, in DSDP 158, accepting the placement of the Miocene-Pliocene

boundary at the base of the *C. amplifiscus* Subzone rather than within it, *dehiscentis* appears first in the lowermost Pliocene, as proposed by Blow.

PLIOCENE-PLEISTOCENE BOUNDARY

Except for Saito's (1969) recognition of the extinction horizon of *Globigerinoides obliquus* at the Plio-Pleistocene boundary in the Le Castella section (Parker, in press, places this horizon somewhat below the boundary), there are no reliable paleontological criteria for the recognition of this boundary outside of its type section. Hence, the boundary adopted here is the conventional one for deep-sea sections: extinction of the genus *Discoaster*. At DSDP 157, the extinction horizon of *Globigerinoides obliquus* s.l. is a considerable distance—nearly 20 meters—below that of *Discoaster*, although part of this may be due to upward reworking of *Discoaster*. In other sections (Saito, 1969), *Discoaster* and *G. obliquus* seem to have similar upper limits, in the vicinity of, or within, the Olduvai paleomagnetic event.

Ever since Banner and Blow (1965b) recognized their Zone N.22 (*Globorotalia truncatulinoides* Partial-range Zone) in the stratotype Calabrian at Santa Maria di Catanzaro, it has been assumed that Zone N.22 corresponds to the basal Pleistocene and that, therefore, the evolutionary transition from *G. tosaensis* to *G. truncatulinoides* marks the Pliocene-Pleistocene boundary. However, Bayliss (1969) has shown that at the Catanzaro section, *G. truncatulinoides* is very poorly represented—several specimens which first occur some 30 meters above the boundary—and that *G. tosaensis* probably does not occur at all. Moreover, Theyer's (1972) recent finding of *G. truncatulinoides* and *G. tosaensis* in the basal Pliocene of cores from south of Australia makes a basal Pleistocene, or even a late Pliocene (see Kaneps, 1970), age for the *G. truncatulinoides* evolution datum extremely doubtful. Although Berggren (1968) described the evolutionary transition from *G. tosaensis* to *G. truncatulinoides* as occurring in the Olduvai event of a core from the North Atlantic, Parker (in press) finds that his *G. tosaensis* is actually referable to Blow's *G. crassaformis ronda*. Thus, all evidence seems to indicate that the "*G. truncatulinoides* Datum" should be used with great caution and only in local correlation.

It must be pointed out, in addition, that equating the *Discoaster* extinction datum and the Plio-Pleistocene boundary is purely a convention inasmuch as a *Discoaster* extinction has not been established in the Plio-Pleistocene sections of the Mediterranean region owing to extensive reworking of discoasters throughout the sections (Roth, personal communication).

Biostratigraphy

The distribution of key species of planktonic foraminifera at Sites DSDP 155, 157, and 158 is shown in Tables 2, 3, and 4, respectively, and their stratigraphic ranges at DSDP 155, 157, and 158 on Figures 3, 4, and 5. Only those species are charted which were judged to have biostratigraphic significance.

In general, the Panama Basin faunal assemblages are distinct from coeval open-ocean sequences in that they are rather monotonous, being dominated by members of the

TABLE 2
Distribution of Planktonic Foraminifera at Site DSDP 155

Age	PLIO.	Zone	Core	Section	Sample Interval (cm)	<i>G. druryi</i>	<i>G. nepenthes</i>	<i>Globigerinoides bollii</i>	<i>G. conglobatus</i>	<i>G. gomitulus</i>	<i>G. ruber</i>	<i>G. ruber var.</i>	<i>G. obliquus</i>	<i>G. subquadratus</i>	<i>Sphaeroidinella seminulina</i>	<i>S. subdehiscens</i>	<i>Globorotaloides variabilis</i>	<i>G. hexagona</i>	<i>Globorotalia acostaensis</i>	<i>Globorotalia mayeri</i>	<i>G. siakensis</i>	<i>G. peripheroronda</i>	<i>G. fohsi fohsi</i>	<i>G. fohsi lobata</i>	<i>G. fohsi robusta</i>	<i>G. gigantea</i>	<i>G. praemenardii</i>	<i>G. menardii</i>	<i>G. limbata s.l.</i>	<i>G. linguatensis</i>	<i>G. scitula (small var.)</i>	<i>Globoquadrina altispira</i>	<i>G. dehiscens</i>	<i>G. venezuelana-conglomerata</i>		
																																			<i>G. alt.</i>	<i>G. tum.</i>
LATE MIOCENE		<i>G. acostaensis</i>	1	1																																
			3	(05-127)																																
			4	(125-127)																																
			5	(124-126)																																
			6	(124-126)																																
			2	1	(124-126)																															
			2	(124-126)																																
			3	(130-132)																																
			4	(124-126)																																
			5	(110-112)																																
			6	(119-121)																																
			3	1	(112-114)																															
			2	(124-126)																																
			3	(124-126)																																
			4	(124-126)																																
			5	(124-126)																																
			6	(123-125)																																
			4	1	(124-126)																															
			3	(125-127)																																
			5	(119-121)																																
			6	(123-125)																																
MIDDLE MIOCENE		<i>G. menardii</i>	5	1	(113-115)																															
			2	(114-117)																																
			3	(110-113)																																
			4	(111-114)																																
		<i>G. mayeri</i>	5	(120-123)																																
			6	(113-116)																																
			1	(120-122)																																
			2	(120-122)																																
			3	(130-132)																																
		<i>G. fohsi robusta</i>	4	(120-122)																																
			CC	(120-122)																																
			7	1																																
			2	(122-124)																																
			CC	(122-124)																																
			8	1																																
<i>G. fohsi robusta</i>	2	(108-110)																																		
	CC	(119-122)																																		
	9	CC																																		
	11	1																																		
<i>G.f.f.</i>	12	CC	(101-103)																																	

LATE PLIOCENE		PLEISTOCENE	
<i>G. limbata</i>		<i>P. obliquiloculata</i>	
12	1 1-10	1 122-124	1 125-127
	2 1-10	2 122-124	2 123-125
	3 1-10	3 122-124	3 120-122
	4 1-10	4 124-126	4 56-53
	5 1-10	5 122-124	5 115-117
	6 1-10	6 122-124	6 120-122
13	1 62-64	7 1 129-131	7 1 129-131
	2 120-122	2 121-123	2 121-123
	4 36-38	3 122-124	3 122-124
	6 121-123	4 122-124	4 122-124
		5 52-54	5 52-54
		6 1-10	6 1-10
		8 1 122-124	8 1 122-124
		2 119-121	2 119-121
		3 122-124	3 122-124
		4 124-126	4 124-126
		9 1 112-114	9 1 112-114
		2 122-124	2 122-124
		3 120-123	3 120-123
		4 122-124	4 122-124
		5 107-109	5 107-109
		6 122-124	6 122-124
		10 1 123-125	10 1 123-125
		2 123-124	2 123-124
		3 123-125	3 123-125
		4 124-126	4 124-126
		11 1 122-124	11 1 122-124
		2 137-139	2 137-139
		3 30-33	3 30-33
		4 120-123	4 120-123
		12 1 1-10	12 1 1-10
		2 1-10	2 1-10
		3 1-10	3 1-10
		4 1-10	4 1-10
		5 1-10	5 1-10
		6 1-10	6 1-10
		13 1 62-64	13 1 62-64
		2 120-122	2 120-122
		4 36-38	4 36-38
		6 121-123	6 121-123

[illegible]

[illegible]

TABLE 4
Distribution of Planktonic Foraminifera at Site DSDP 158

[illegible]

[illegible]



G. menardii

TABLE 4 - Continued

MIDDLE MIOCENE										Age
										Zone
										Core
										Section
										Sample Interval (cm)
										<i>Globigerina apertura</i>
										<i>G. calida</i>
										<i>G. druryi</i>
										<i>G. nepenthes</i>
										<i>Globigerinoides bollii</i>
										<i>G. conglobatus</i>
										<i>G. gomitulus</i>
										<i>G. ruber</i>
										<i>G. ruber</i> var.
										<i>G. obliquus</i>
										<i>G. extremus</i>
										<i>G. subquadratus</i>
										<i>G. hystericus</i>
										<i>G. fistulosus</i>
										<i>Sphaeroidinella seminulina</i>
										<i>S. subdehiscens</i>
										<i>S. kochi</i>
										<i>S. paenedehiscens</i>
										<i>S. dehiscens</i>
										<i>Pulleniatina S</i>
										<i>Pulleniatina D</i>
										<i>P. primalis</i>
										<i>P. spectabilis</i>
										<i>P. obliquiloculata</i>
										<i>Globorotaloides variabilis</i>
										<i>G. hexagona</i>
										<i>G. sp. cf. G. hexagona</i>
										<i>Globorotalia acostaensis</i>
										<i>G. humerosa</i>
										" <i>G. multiloba</i> "
										<i>G. pseudonipina</i>
										<i>Neogloboquadrina dutertrei</i>
										<i>Globorotalia mayeri</i>
										<i>G. siakensis</i>
										<i>G. peripheroronda</i>
										<i>G. fohsi fohsi</i>
										<i>G. fohsi lobata</i>
										<i>G. fohsi robusta</i>
										<i>G. gigantea</i>
										<i>G. praemenardii</i>
										<i>G. menardii</i>
										<i>G. limbata</i> s.l.
										<i>G. multicamerata</i>
										<i>G. pleistotumida</i>
										<i>G. tumida</i>
										<i>G. linguaensis</i>
										<i>G. margaritae</i>
										<i>G. crassaformis</i>
										<i>G. toazensis</i>
										<i>G. truncatulinoides</i>
										<i>G. crassula</i>
										<i>G. puncticulata</i>
										<i>G. scitula</i>
										<i>G. scitula</i> (small var.)
										<i>G. scitula</i> (angular)
										<i>Globoquadrina altispira</i>
										<i>G. dehiscens</i>
										<i>G. venezuelana-conglomerata</i>
										<i>G. pseudofofolata</i>

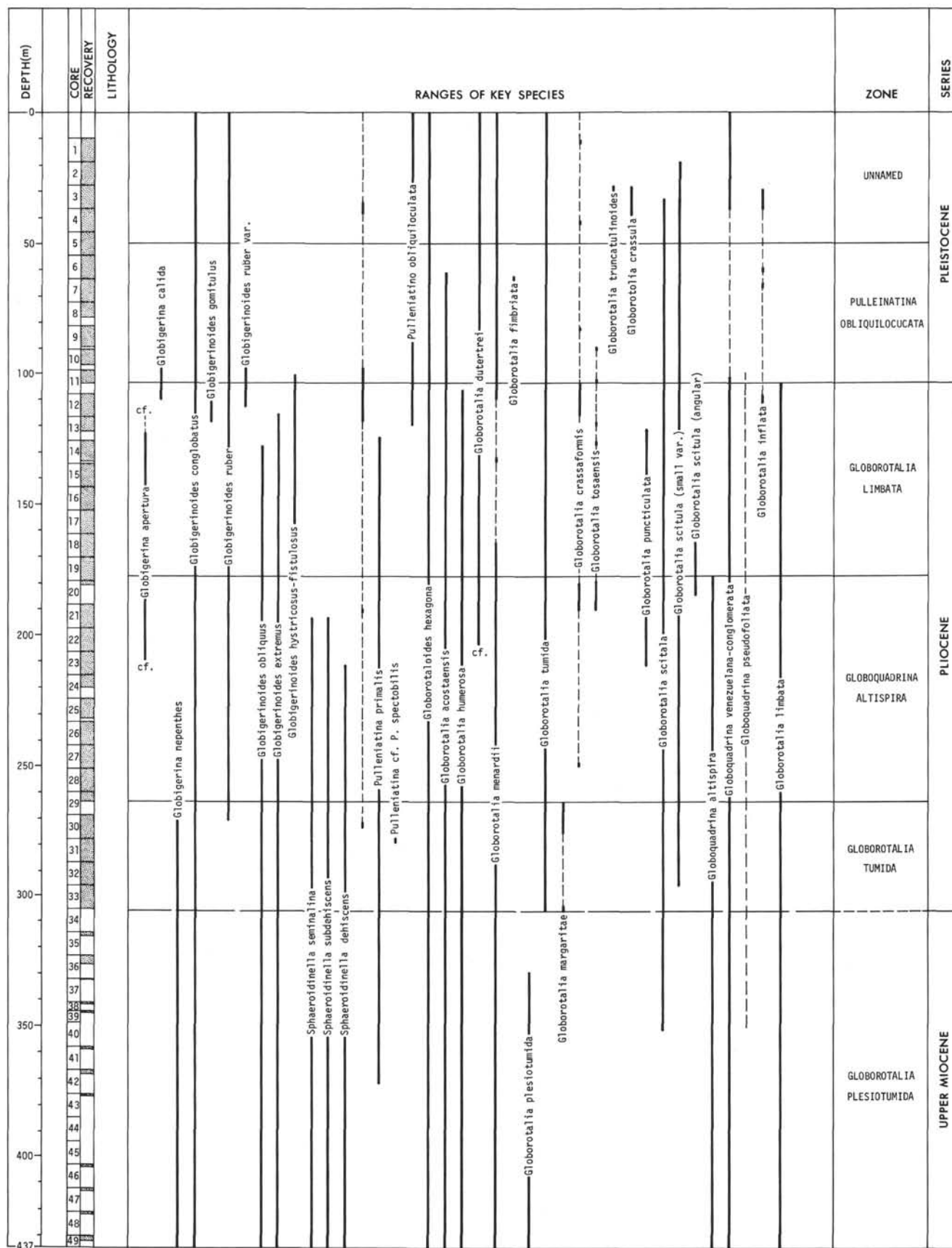


Figure 4. Ranges of key species of planktonic foraminifera at Site DSDP 157.



Globorotalia acostaensis-humerosa-dutertrei group. In comparison to this group, most of the commonly used marker species for the Pliocene and Pleistocene are rare or absent.

The two continuously cored sites, 157 and 158, are also quite distinct from each other faunally. DSDP 158 has a distinctly more tropical aspect than DSDP 157 as evidenced by species which are present at DSDP 158 but which are rare or absent at DSDP 157, and vice versa (see Notes on Species Section). This difference between the two sites, fairly closely spaced geographically, can be accounted for by the fact that DSDP 157 is mainly under the influence of Peru Current while DSDP 158 lies under the equatorial countercurrent.

SITE 155

At this site, the only one on Leg 16 not cored continuously, coring was begun at a depth of 434 meters below bottom and continued to basement (at 519 meters). Three sidewall cores were obtained while pulling the drill string out of the hole (Cores 13, 14, and 15). The section recovered in the continuously cored interval encompasses the *Globorotalia fohsi fohsi* Zone at the bottom to the *Globorotalia acostaensis* Zone at the top. The sidewall cores recovered the *Globorotalia plesiotumida* Zone (Core 13) and the *G. tumida* Zone (Cores 14 and 15).

A detailed study of this section was not made other than to recognize the presence of the middle and upper Miocene zones of Bolli (1966a). Preservation is generally poor in the continuously cored section owing to test crushing and flattening, which is probably a result of diagenetic silica mobilization. Most broken tests were seen to be filled with silica. The postulated process is a penecontemporaneous mobilization of biogenous silica. This would remove part of the structural framework of the sediment causing partial void collapse (empty interiors of foraminiferal tests) and migration of the silica into these voids. Similar foraminiferal preservation was seen in the basal portions of Sites DSDP 157 and 158, and this mode of preservation may be peculiar to the diagenetic environment in rapidly deposited calcareous-siliceous cores.

SITE 157

At Site DSDP 157, continuously cored from the surface to a total depth of 437 meters, an apparently continuous section, ranging in age from late Miocene (*Globorotalia plesiotumida* Zone) immediately above basalt to late Pleistocene at the top, was recovered. The planktonic foraminifera are generally moderately well to well preserved throughout, but increasing sediment induration from Core 39 downward made the obtaining of representative faunas difficult. Below Core 38, the only sample which yielded a fairly good assemblage was the core catcher of Core 48. In addition, foraminifera are nowhere abundant in the section and are outweighed by the siliceous microfossils. The sand-size ($>62.5\mu$) fraction analyses show that foraminifera through most of the section, except for the uppermost portion, do not constitute more than one or two percent by weight of the sediment.

If the carbonate chronology for this site is valid (see Chapter 30), then the average sedimentation rate for DSDP

157 is about 60 m/m.y. Also, it can be seen that the upper 40,000 y., or so, of the section were not recovered. It is possible that this part of the section may be missing at the sea floor, but a part of it was probably bypassed during spudding in, as Hole 157A recovered stratigraphically higher sediments, but still not a complete section.

The foraminiferal assemblages of DSDP 157 are characterized by their peculiar mixture of high- and low-latitude forms, coupled with a scarcity or absence of what must be regarded as mid-latitude forms. The assemblages are monotonous, being dominated by members of the *Globorotalia acostaensis-pseudopima-humerosa-dutertrei* group of related species. If each member of this evolving lineage (Parker, 1967) represents adaptation to similar environmental conditions, then the dominance of the lineage throughout the section suggests that the oceanographic environment at DSDP 157 has not changed radically since the initiation of deposition at this site. Along with the lineage occur such species as *Globorotalia menardii*, *G. tumida*, *Pulleniatina* (tropical), and *Globigerina bulloides* (temperate); but other typical members of late Cenozoic assemblages are extremely scarce or missing (*Globorotalia margaritae*, *G. crassaformis* group, *G. inflata*, *Globigerina nepenthes*, *Globorotalia multicamerata*, and as reported for DSDP sites farther north by Olsson and Goll, 1970, *G. miozea*). This presence of high- and low-latitude species but absence of mid-latitude forms is probably a result of the location of Site 157 in an area of mixing of two current systems: the tropical equatorial Pacific countercurrent and the cool-water Peru current.

SITE 158

An apparently continuous section from middle Miocene to upper Pliocene (*Globorotalia fohsi robusta* Zone to lower *Globorotalia limbata* Zone), to lower *Globorotalia limbata* Zone), disconformably overlain by about 30 meters of upper Pliocene and Pleistocene sediments, was cored at DSDP 158. The hiatus superimposes the uppermost part of the *Globorotalia limbata* Zone of the upper Pliocene on the lower *Globoquadrina altispira* Zone; it occurs between Sections 2 and 3 of Core 4 and is marked by the simultaneous disappearance of *Globigerinoides obliquus*, *G. extremus*, *Sphaeroidinella seminulina*, *S. subdehiscens*, and *Globorotalia multicamerata*.

In general, tests of planktonic foraminifera are well preserved but, as at DSDP 157, are not very abundant. As at DSDP 155, a zone of carbonate dissolution occurs in Cores 24 through 27 in which age-diagnostic species are not preserved. This zone is nearly identical, or identical, in stratigraphic position to the zone of dissolution at DSDP 155; it straddles the *Globorotalia acostaensis/G. menardii* zonal boundary (boundary between the middle and upper Miocene).

In contrast to DSDP 157, the Pliocene-Pleistocene assemblages of DSDP 158 are much more tropical in aspect. They lack species such as *Globigerina bulloides*, *G. aperture*, and *Globorotalia puncticulata* and contain (a) more abundant representatives of the genus *Pulleniatina*, (b) better-developed *Globigerinoides fistulosus*, (c) more abundant *Sphaeroidinella*, which also ranges deeper in the section than at DSDP 157, and (d) *Pulleniatina spectabilis*.

Biostratigraphically, the lower portion of DSDP 158 is very similar to DSDP 155 except that the age of sediment above basalt at DSDP 158 is somewhat younger than at DSDP 155 (*Globorotalia fohsi robusta* Zone, as opposed to *G. fohsi fohsi* Zone at DSDP 155).

Although not distinguished in the present study because of its thinness, it was possible to detect the *Globigerinoides ruber* (= *G. subquadratus*) Zone of Bolli (1966b) at DSDP 158. This zone is defined as the interval of continuing occurrence of *G. subquadratus* above the extinction of *Globorotalia fohsi* s.l.. However, at DSDP 158, this interval is no more than a few meters in thickness, and at DSDP 155 it occurs in an unsampled interval between two cores.

NOTES ON SPECIES – PANAMA BASIN

Genus GLOBIGERINA d'Orbigny, 1826

Globigerina apertura Cushman, 1918

This species, undoubtedly closely related to *G. bulloides* d'Orbigny and distinguished from it by its large aperture, is present only at Site DSDP 157, discontinuously from the upper part of the *Globoquadrina altispina* Zone to the lower part of the *Globorotalia limbata* Zone. Inferences as to the paleoecological significance of *G. apertura* are of necessity speculative since it does not occur in modern faunas, but several factors suggest that it is probably a cool-water indicator. These are (a) its close affinity with *G. bulloides*, a species of known high latitude habitat; (b) the fact that it only occurs at the southern Site DSDP 147, whose fauna appears to be strongly influenced by the cool waters of the Peru current; and (c) it often cooccurs with *Globorotalia puncticulata*, a species which shows close affinity with *Globorotalia inflata*, another form which occurs in higher latitudes.

Globigerina bulloides d'Orbigny, 1839

This species is ubiquitous at the three Panama Basin sites and has consequently not been plotted on the distribution charts. It is one of the species which characterize the modern Panama Basin fauna (Bradshaw, 1959), thus, its past distribution accords well with its present day distribution.

Globigerina calida Parker, 1962

This species is very rare in the Panama Basin cores. It was seen in the uppermost sample (late Pleistocene) of DSDP 158, and its only interval of consistent occurrence straddles the Pliocene-Pleistocene boundary at Site DSDP 157.

Globigerina nepenthes Todd, 1957

This commonly used index to the late Miocene/early Pliocene is extremely scarce in the Panama Basin and occurs very sporadically so that no consistent pattern of occurrence, nor a consistent extinction horizon, could be determined.

Globigerina druryi Akers, 1955

This rather small *globigerinid* is distinctive because of its wide aperture and well developed apertural lip, which gives it close affinity to *G. nepenthes*. It was noted to occur from the bottom of the section (*Globorotalia fohsi fohsi* Zone) into the lower part of the *Globorotalia mayeri* Zone at DSDP 155 but was not seen in the equivalent interval at DSDP 158.

Genus GLOBIGERINOIDES Cushman, 1927

Globigerinoides conglobatus (Brady), 1879

At DSDP 158 this species has a consistent range from near the base of the *Globorotalia plesiotumida* Zone to the top of the section. At DSDP 157 its occurrence is sporadic, and it is not as common. This is consistent with the observation that *G. conglobatus* is a low-latitude species (Bradshaw, 1959; Bé, 1959; Bé and Hamlin, 1967; Parker, 1962).

Globigerinoides gomitulus Seguenza

This species is probably often combined with *G. conglobatus* Brady because of gross similarities in test morphology and wall

structure. The form distinguished here has a large test and granular surface like *G. conglobatus*, but the aperture is located over the suture between the penultimate and antepenultimate chambers (*ruber*-like), although it is often shifted to the left. In *G. conglobatus*, and some other species of *Globigerinoides*, the aperture is located more or less symmetrically over, and encompasses, the antepenultimate chamber and includes the two bounding sutures of this chamber (*obliquus*-like). This distinction between the two classes of primary aperture in *Globigerinoides* has previously been discussed by Bolli (1957).

G. conglobatus has a sporadic occurrence at DSDP 158 from near the top of the *Globorotalia tumida* Zone into the lower Pleistocene. At DSDP 157, it was seen only in two samples at the top of the Pliocene (*Globorotalia limbata* Zone).

Globigerinoides ruber (d'Orbigny), 1839

This species is distinguished from the middle Miocene homeomorph *G. subquadratus* Bronnimann. *G. ruber* first occurs within the lower part of the *Globorotalia plesiotumida* Zone, is sporadic in the upper Miocene and lower Pliocene, and then has a continuous range to the top of the section at Sites DSDP 157 and 158.

Globigerinoides subquadratus Bronnimann

At DSDP 158 this species, a homeomorph, or near-homeomorph, of *G. ruber*, occurs from the bottom of the section into the lowermost part of the *Globorotalia mayeri* Zone. At DSDP 155, it disappears at the base of this zone, but this is undoubtedly an expression of the phenomenon remarked on in the Introduction of this volume that lithological, time, and biostratigraphic boundaries in Deep Sea Drilling cores often fall between cores as a result of incomplete recovery of cored intervals. The extended range of *G. subquadratus* above the top of the *Globorotalia fohsi robusta* Zone at Site 155 probably occurs in the unrecovered gap between Cores 6 and 7. Nonetheless, it is apparent that in the Panama Basin, the extended range of *Globigerinoides subquadratus* above the extinction of *Globorotalia fohsi* is rather short; it is for this reason that the *G. ruber* (= *G. subquadratus*) Zone of Bolli (1966b, 1971) was not distinguished.

Globigerinoides obliquus Bolli, 1957

Globigerinoides extremus Bolli and Bermudez, 1965

These species are discussed together because they are obviously closely related, but it seems nonetheless worthwhile distinguishing the two taxonomically since their stratigraphic ranges are quite distinct. Whereas, the former occurs in the oldest Panama Basin samples, the latter does not appear until very near the top of the *Globorotalia acostaensis* Zone. Also, although both disappear near the Pliocene/Pleistocene boundary, a fact that may have some significance in the correlation of this boundary in extra-Mediterranean areas (Saito, 1969), *Globigerinoides* has a distinctly longer range than *G. obliquus*.

Globigerinoides fistulosus Schubert, 1910

In the present study, *G. hystricosus* Belford, 1962 was charted separately, although it is considered here to be a poorly developed phenotypic variant of *G. fistulosus*. It is, in essence, a *fistulosus* with poorly developed fistulose projections on the last chambers. Its stratigraphic range at DSDP 158 coincides with that of *G. fistulosus*, while at DSDP 157, *G. fistulosus* has a shorter range than "*G. hystricosus*." Both forms are rather scarce in the Panama Basin, and it seems that they represent a very marginal population, the one at DSDP 157 more so than the one at DSDP 158. Nonetheless, as in other areas, *G. fistulosus-hystricosus* seems to be a good index for the upper Pliocene. It disappears within the lower part of the *P. obliquiloculata* Zone at DSDP 157 and 158.

Globigerinoides ruber d'Orbigny, 1839, var.

This form is tentatively regarded as a variant of *Globigerinoides ruber*. It is a large form and superficially resembles *Globigerinoides obliquus* in the position of the primary aperture in the last one or two chambers. However, it can be seen that previous apertures are of the normal *ruber* type. This form has a short and very distinct range from the uppermost part of the *Globorotalia limbata* Zone into the lowermost part of the *P. obliquiloculata* Zone and may serve as a useful index to the vicinity of the Pliocene-Pleistocene

boundary. A similar occurrence has been noted by me in cores from the Blake Plateau and the equatorial Atlantic.

Genus SPHAEROIDINELLA Cushman, 1927

There seems to be no biostratigraphic or phylogenetic reasons for distinguishing more than one genus in this structurally, and probably phylogenetically, homogeneous group.

Sphaeroidinella dehiscens (Parker and Jones), 1865

This species occurs at DSDP 158 from very near the base of the *Globorotalia tumida* Zone to the top of the section. At DSDP 157, on the other hand, its first appearance is near the top of the *G. tumida* Zone, and it occurs rarely and sporadically throughout the rest of the section. This again probably reflects the paleo-oceanographic setting of the two sites: 158 dominated by the equatorial counter current, 157 by the Peru current. It is emphasized that the first occurrence noted here, and at piston core sites on the Blake Plateau (Kaneps, 1970), is nearly simultaneous with that of *Globorotalia tumida*; indicating that Blow's (1969) Zone N.19 is a very short interval, probably not worthy of zonal rank.

Sphaeroidinella seminulina (Schwager), 1866

Sphaeroidinella subdehiscens Blow, 1959

These two forms seem to be phenotypic variants although they are recognized as distinct species in the distribution charts. The only difference between them throughout their stratigraphic record seems to be the addition of a final pointed, oblique chamber, in *S. seminulina*, resulting in four chambers in the final whorl as opposed to *S. subdehiscens*, which normally has three chambers in the final whorl and lacks the bullet-shaped chamber of the former.

An interesting phenomenon, noted earlier (Kaneps, 1970), is the apparently adaptive loss of the cortical thickening by both of the forms near the end of their stratigraphic range. This results in forms that are otherwise identical morphologically to their predecessors with a cortex, but have, instead, a coarsely cancellate test surface. This phenomenon is noted for *seminulina*-*subdehiscens* throughout the range of these forms, but it is only at the end of their stratigraphic range that specimens lacking a cortex occur exclusively.

Sphaeroidinella paenedehiscens Blow, 1969

As distinguished in the present study, this species is essentially a *Sphaeroidinella dehiscens* that lacks a supplementary aperture and is no doubt the immediate ancestor of the latter. It has large, spherical chambers, usually three to a whorl, but the final chamber is usually somewhat oblique. Other than the lack of a supplementary aperture, the species is identical in all respects to Pliocene and early Pleistocene specimens of *Sphaeroidinella dehiscens*. It ranges at DSDP 158 from just below the top of the *Globorotalia acostaensis* Zone into the basal part of the *Globoquadrina altispira* Zone. In the (rather lengthy) interval of overlap in the ranges of *S. paenedehiscens* and *S. dehiscens*, the two are probably not distinct species but instead members of a population, some with, and some without, a supplementary aperture. At DSDP 157, as with *S. dehiscens*, the species is rare and sporadic in occurrence.

Genus PULLENIATINA Cushman, 1927

Owing to its solution resistance, apparently rather wide distribution (It occurs in fair abundance in the Panama Basin sites whereas other commonly used index species do not.), distinctive morphology, and test surface, this genus is one of the more useful taxa in late Cenozoic biostratigraphy. In addition, the genus undergoes a number of relatively sharp coiling changes throughout its history (see Figure 6), but in the Panama Basin the coiling shifts do not seem to match those documented by Hays et al. (1969). As in the foregoing lineage, *Pulleniatina* seems to have undergone gradual morphological changes during its evolution, and precise species limits are difficult to pinpoint. Hence, only the two species, *P. primalis* and *P. obliquiloculata*, were recognized, and the shift from one to the other is placed in the uppermost Pliocene, very near the Plio-Pleistocene boundary.

Of note is the occurrence of *Pulleniatina spectabilis* in the Panama Basin cores; the eastern-most record of this species to date.

Pulleniatina primalis Banner and Blow, 1967

This species is very rare in its lowermost occurrences; therefore, its level of first appearance is somewhat vague. At both DSDP 157 and 158, it was first observed in the *G. plesiotumida* Zone about a third of the way up from the base. Its evolution to *P. obliquiloculata* occurs near the top of the Pliocene.

Pulleniatina spectabilis Parker, 1965

This species has a very limited occurrence in the Panama Basin. It was found in two samples from DSDP 158 (7-CC and 6-6, 121-124 cm) and in one from DSDP 157 (29-CC). Even the best-developed specimens (at 158-6-CC) are not typical (Parker, personal communication), but they have a definitely angled periphery and probably represent a marginal population of the species in the Panama Basin, apparently not its most environmentally optimal area. The specimens from DSDP 157 have only a very weakly angled periphery, but their identity with *P. spectabilis* is supported by their level of occurrence, which, on the basis of other faunal criteria, seems to be synchronous with that at DSDP 158.

Pulleniatina obliquiloculata Parker, Jones, and Brady, 1865

This species apparently developed from *P. primalis* in the late Pliocene (near the top of the *Globorotalia limbata* Zone). It is common in the *P. obliquiloculata* Zone (lower Pleistocene) but becomes scarce in the upper Pleistocene of the Panama Basin.

Genus GLOBOROTALOIDES Bolli, Loeblich, and Tappan, 1957

Globorotaloides hexagona (Natland)

Remarks: This species is included in the genus *Globorotaloides* because of its flat spiral mode of coiling and its coarsely cancellate test surface. This follows Parker (1967) and Blow (1969). *G. hexagona* in the Panama Basin ranges from the top of the *G. acostaensis* Zone to the Pleistocene. It presently occurs in the Pacific Ocean but has not been present in Atlantic faunas since the last interglacial (Parker, 1965). A variant of *G. hexagona* characterizes the uppermost Miocene and lower Pliocene (see below).

Globorotaloides cf. *G. hexagona*

Remarks: This species, or variant, is distinguished from *G. hexagona* by its generally larger size, and smoother, less coarsely cancellate test surface. It ranges from the uppermost part of the *G. plesiotumida* Zone through most of the *G. tumida* Zone at DSDP 158 and into the lower part of the *G. altispira* Zone at DSDP 157.

Genus GLOBOROTALIA Cushman, 1927

Globorotalia acostaensis Blow, 1959

Distinction of this species from *G. humerosa* follows Parker (1967). As with other gradually evolving lineages, which at any point in time consist, probably, of a single interbreeding population, distinction of the ancestor and descendant species during their interval of transition is difficult and artificial. Thus, the upper part of the range of *G. acostaensis* and the lower part of the range of *G. humerosa* is by necessity highly arbitrary. The *G. acostaensis* morphotype ranges into the upper Pliocene in the Panama Basin at DSDP 158 and into the lower Pleistocene, with one occurrence in the upper Pleistocene, at DSDP 157. Specifying a more exact upper limit would seem to imply more precision than is warranted.

Globorotalia humerosa Takayanagi and Saito, 1963

The arguments given above for some vagueness in specifying a precise stratigraphic range for *G. acostaensis* are equally true for *G. humerosa*, its descendant. The two were distinguished by the larger size, looser coiling, and consequently more chambers in the final whorl of *Globorotalia humerosa*. As such, this species was first recorded in the upper part of the *G. plesiotumida* Zone at DSDP 157 and 158, and morphotypes are seen as high as the lower Pleistocene.

Globorotalia dutertrei

This species is the end member of the gradually evolving *G. acostaensis-humerosa-dutertrei* lineage as proposed by Parker

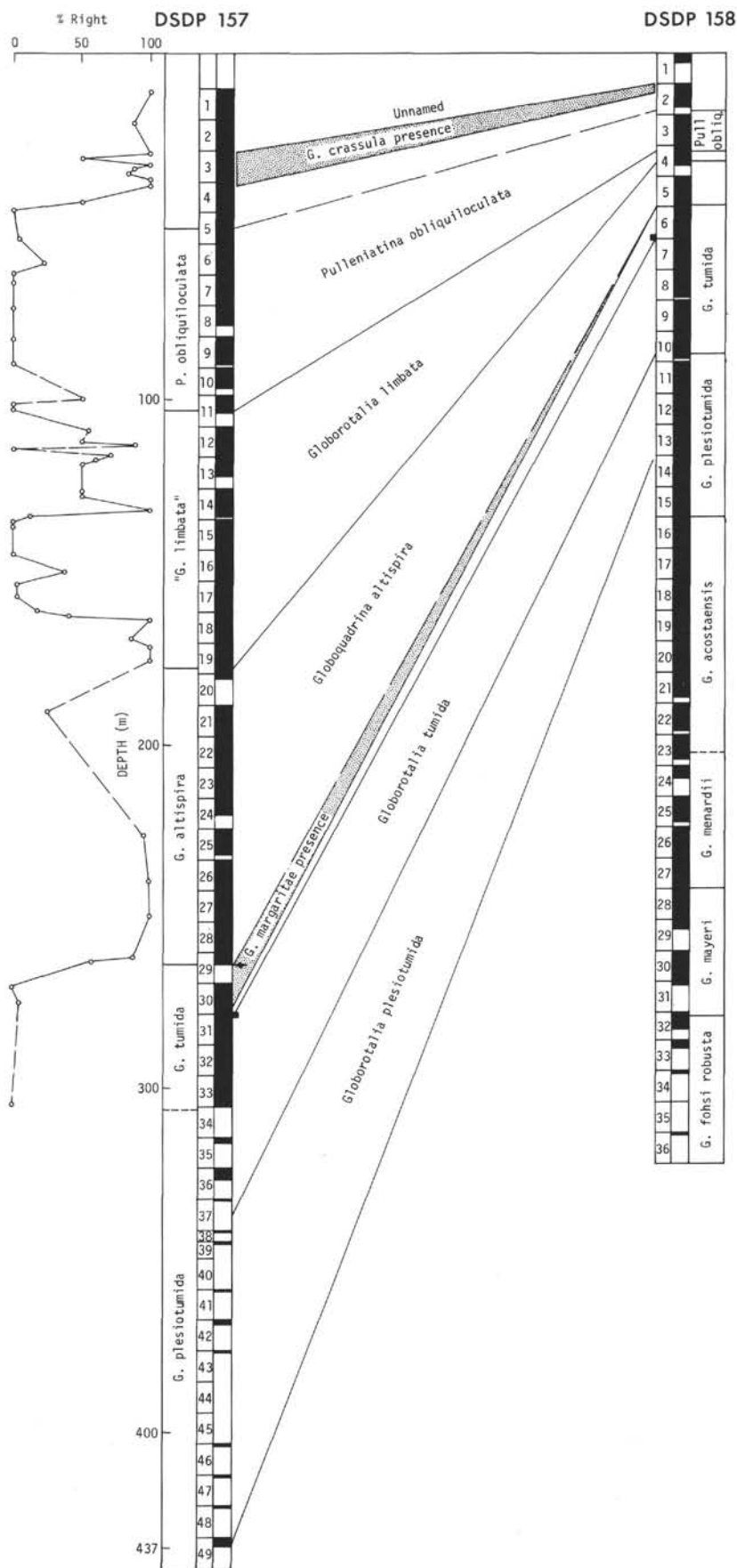


Figure 6. Coiling direction of *Pulleniatina* at Sites DSDP 157 and 158. Based on counts of entire population of *Pulleniatina* on one tray-spread. Number of specimens counted ranged from none to 200.

(1967). What are here considered to be "typical" specimens—large, with open umbilicus—first occur in the upper Pliocene, upper part of the *Globoquadrina altispira* Zone.

Globorotalia crassaformis Galloway and Wissler, 1927

Unlike in other areas of the world, this species is extremely rare in the Panama Basin sites. It was recorded in only one sample from DSDP 158 (4-2, 21-24 cm), from the uppermost Pliocene. It is somewhat more common at DSDP 157, being recorded as occurring sporadically from near the base of the *Globoquadrina altispira* Zone through the upper Pleistocene. Its only interval of consistent occurrence (though it is still extremely scarce) is across the *G. limbata*/*P. obliquiloculata* zonal boundary. It is clear that the presence of this species in the Panama Basin is only as a very marginal situation.

Globorotalia crassula Cushman

Parker (1972) regards *G. crassula* as *nomen dubium*. It is used in the present paper for those species of *globorotaliids* which are very much like *G. crassaformis* but have a flattened test. The test may be biconvex, concavo-convex, or plano-convex, and it may be unkeeled, partially keeled, or carinate.

Globorotalia inflata (d'Orbigny)

Remarks: This species was seen only at DSDP 157, ranging from the uppermost part of the *Globorotalia limbata* Zone to the upper Pleistocene. It is rare and occurs in scattered samples. Its brief interval of consistent occurrence in the upper Pleistocene at this site coincides with those of *Sphaeroidinella dehiscentis* and *Globorotalia crassula*; this may indicate a brief incursion into the Panama Basin of waters carrying a more diverse fauna than the endemic ones.

Globorotalia linguaensis Bolli, 1957

G. linguaensis was seen only as rare specimens in two samples from the *Globorotalia mayeri* Zone at DSDP 158.

Globorotalia margaritae Bolli and Bermudez, 1965

This species, used as a zonal marker elsewhere (Bolli and Bermudez, 1965; Bolli, 1966a, 1970), is extremely scarce in the Panama Basin and its interval of occurrence (uppermost part of *G. tumida* Zone and lowermost part of *G. altispira* Zone) is very brief and not representative of its range elsewhere. Its scarcity in the Indo-Pacific has been noted previously (Parker, 1967). However, the short interval of occurrence of *G. margaritae* makes a useful correlation datum for the Panama Basin.

Globorotalia tosaensis Takayanagi and Saito, 1963

Like many of the other index species in the Panama Basin, *G. tosaensis* is extremely scarce and occurs sporadically. It was not seen at DSDP 158 but occurs in scattered samples from the uppermost *G. altispira* Zone, the *G. limbata* Zone, and the lower *P. obliquiloculata* Zone. *G. tosaensis* and its close relative *G. truncatulinoides* are probably southern hemisphere species (see Theyer, 1972) that only reached the northern hemisphere in late Pliocene times. Their use in interregional biostratigraphy must be approached with caution.

Globorotalia truncatulinoides (d'Orbigny)

See remarks above for *G. tosaensis*. *G. truncatulinoides* was seen in one sample from the Pleistocene of DSDP 157.

Globorotalia puncticulata (Deshayes)

Remarks: The form here recognized is assigned only questionably to *G. puncticulata*. It has the same test morphology as the lectotype (Banner and Blow, 1960) but is small, with a smooth (glassy in well-preserved specimens), finely perforate wall; it is identical to *Globorotalia inflata* A of Bolli (1970). It was not seen at DSDP 158 but occurs in short intervals of four abundance in the upper half of the *G. altispira* Zone and through the *G. limbata* Zone at DSDP 157. Its sympathetic cooccurrence with *Globigerina apertura* in the *G. altispira* Zone may indicate incursions of cooler water into the Panama Basin area.

Globorotalia scitula (d'Orbigny)

Three varieties of *G. scitula* were distinguished in the present study: the typical variety (similar to the form present in surface

sediments); a small variety, distinguished solely by its small size; and an angular variety, distinguished by a less rounded equatorial margin and more flattened test. The last is probably sufficiently distinct to be regarded as a separate species. *G. scitula* (typical and small varieties) occur sporadically from the upper Miocene to the top of the section at DSDP 157 and 158, while the range of the angular variety is confined to the upper Miocene and Pliocene.

Genus GLOBOQUADRINA Finlay

Globoquadrina altispira (Cushman and Jarvis)

Remarks: *G. altispira* ranges consistently and continuously throughout the Panama Basin sequences to its level of extinction at the top of its zone. This extinction horizon is regarded here to be a high reliability datum since *G. altispira*, based on its common occurrence in the Panama Basin, Indo-Pacific, and Atlantic Ocean (Kaneps, 1970, and personal observation of numerous pre-Pleistocene piston cores in the Lamont-Doherty collection), was, probably, a widely distributed, cosmopolitan species of fairly wide environmental tolerance. Its extinction horizon probably represents, therefore, a true phyletic extinction and may therefore represent for all practical purposes an isochronous surface.

Globoquadrina dehiscentis Chapman, Parr, and Collins

Remarks: This species occurs in the middle Miocene of Site DSDP 158; one occurrence was seen in the lower part of the *Globorotalia plesiotumida* Zone at this site. It was not observed at DSDP 157.

Globoquadrina venezuelana-conglomerata

Remarks: No attempt was made to distinguish these two closely related forms (Parker, 1967). They range consistently throughout the sections studied.

Globoquadrina pseudofoliolata Parker, 1967

Remarks: Specimens agreeing with Parker's illustrations of this species were seen only at DSDP 157, where it occurs sporadically from the uppermost Miocene through the upper Pliocene. Its only interval of fairly consistent occurrence is in the upper half of the *Globoquadrina altispira* Zone. Its absence at DSDP 158, and presence at DSDP 157, may indicate that it was a subtropical or temperate rather than tropical species.

EAST PACIFIC RISE

The last five of the Leg 16 sites (159 through 163) were drilled on the west flank of the East Pacific Rise in order to complete the series of sites drilled by Legs 5, 8, and 9 of the Deep Sea Drilling Project in this area. The sediments penetrated comprise pelagic brown clays, siliceous ooze, and highly calcareous nannofossil ooze. In even the most highly calcareous sections recovered, foraminifera are generally very scarce and greatly affected by solution. All sites were cored continuously from the sediment surface to basaltic basement. Sites DSDP 159 through 163 are shown in Figure 7, and pertinent data are given in Table 5.

Planktonic foraminiferal distribution charts are given for Sites DSDP 159, 160, and 161 (Tables 6, 7, 8). At Site 162, only the basal several meters of sediments contain an identifiable foraminiferal fauna; and the Cenozoic portion of Site 163 is entirely in a noncalcareous red clay or siliceous ooze facies; the Cretaceous foraminifera from this site are discussed in Chapters 32 and 33 of the present volume.

Zones

The foraminifer-bearing sediments recovered are of mid-Tertiary age (lower middle Eocene to lower Miocene). Because of the extensive solution that has affected all assemblages examined, only a very generalized zonal

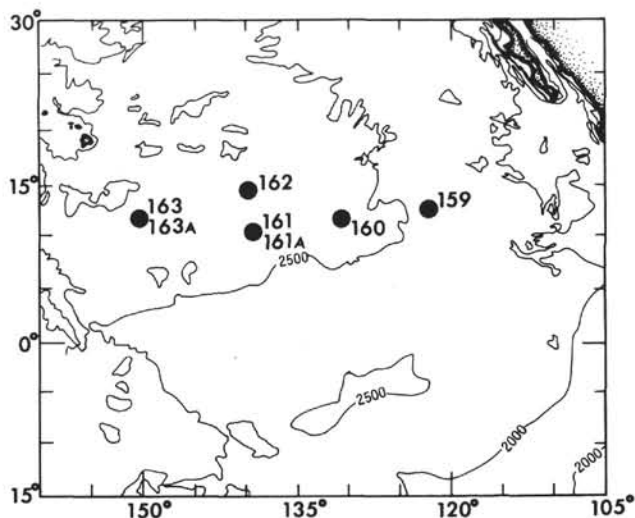


Figure 7. Location of Leg 16 sites on the west flank of the East Pacific Rise.

TABLE 5
Location and Water Depth of Sites 159-163

Site	Geographical Area	Latitude	Longitude	Water Depth (m)
159	a	12° 19.92'N	122° 17.27'W	4484
160	a	11° 42.27'N	130° 52.81'W	4940
161	a	10° 14.25'N	139° 57.21'W	4939
162	a	14° 52.19'N	140° 02.61'W	4854
163	b	11° 14.66'N	150° 17.52'W	5320

^aWest flank of East Pacific Rise between Clarion and Clipperton Fracture Zones.

^bAbyssal hill area between Clipperton and Clarion Fracture Zones.

scheme could be used. Essentially, it is the scheme of Bolli (1957) including his zones from the *Globigerina ampliapertura* Zone to the *Globigerinatella insueta* Zone. Only two of the zones, *Globorotalia opima* and *G. kugleri*, could be identified directly by the presence of their marker species. The remainder were judged to be present by negative evidence or position in sequences. At no single site is the entire zonal sequence present. This is due to (a) absence or condensation of the upper portion of the sedimentary sequences, and (b) the diachronous nature of the sediment/basalt contact.

Biostratigraphy

SITE 159

This site penetrated a condensed section of upper Oligocene to Pleistocene sediment, a little over 100 meters in thickness. The sediments at this site are predominantly in a noncalcareous facies and, owing to extensive solution, the planktonic foraminiferal biostratigraphy of this site is not definitive. Only the lower part of Core 9 and upper part of Core 10 yielded a fauna sufficiently well preserved to allow an unequivocal zonal assignment. This fauna includes *Globorotalia kugleri*, *Globigerinoides primordius*, *G. trilobus*, *Globigerina angustumilicata*, *G. officinalis*, *G. praebulloides occlusa*, *G. prasaepis*, *G. cf. G. sellii*, *G.*

venezuelana, *G. winkleri*, *Globorotalia mendacis*, *G. continuosa*, *G. pseudokugleri*, *G. siakensis*, *Globorotaloides suteri*, and others, which places it in the *Globorotalia kugleri* Zone of Bolli (1957). This is the most diverse and well-preserved assemblage at DSDP 159 although even here solution has been extensive.

Cores 1 through 4 are virtually devoid of foraminiferal carbonate, and the lack of diversity in the remainder of the section points to deposition in an environment of rapid solution. From Core 5 downward, the preserved fauna consists, in essence, of *Globorotalia siakensis* and related small globorotaliids along with *Globoquadrina venezuelana*. In addition, *Catapsydrax dissimilis* occurs commonly from Section 3 of Core 6 downward. Its absence above this level is most likely due to extinction and not solution as it seems to be a solution-resistant species based on its distribution at Sites DSDP 160 and 161; therefore, its disappearance is taken to mark the top of the *C. dissimilis/C. stainforthi* Zone and the base of the *Globigerinatella insueta* Zone.

The interval between the base of the *Globorotalia kugleri* Zone and basalt is assumed, on negative evidence, to belong to the *Globigerina ciperoensis* Zone. *Globorotalia opima*, the marker for the subjacent zone, is absent in this interval. On the basis of DSDP 160 and 161, it is a comparatively solution-resistant species. Its absence is therefore considered to be real, and not a result of removal by solution.

In addition to species named above, the following were identified in Cores 12 and 13: *Globorotalia pseudokugleri*, *G. mendacis*, *G. opima nana*, *G. continuosa* (?), *Catapsydrax unicavus*, *C. praestainforthi*, *Globorotaloides suteri*, *Globigerina prasaepis*, *G. tripartita*, and *G. cf. G. tripartita*.

SITE 160

As at Site DSDP 159, the planktonic foraminifera at DSDP 160 represent a dissolution facies even though the sediment below Core 4 is highly calcareous owing to an abundance of coccolith carbonate. The foraminiferal fauna of these sediments is numerically small and of very limited diversity.

Best preservation occurs in Cores 7, 8, and 9 where, in addition to the solution resistant forms *Globigerina prasaepis*, *Globorotalia opima*, and *Catapsydrax*, such species as *Globigerina galavisi*, *G. gortanii*, *G. sellii*, *G. Tapuriensis*, *G. tripartita*, and *G. winkleri* occur. The section is barren of foraminifera from about the middle of Core 5 upward.

Globorotalia opima is abundant from the bottom of the section upward to the top of Core 7. This abundance no doubt results from its being a solution-resistant form. Its disappearance is at the top of the *Globorotalia opima* Zone. The base of this zone is placed at the uppermost occurrence of *Globigerina ampliapertura* in the middle of Core 9. However, since *G. ampliapertura* seems to be a solution-prone species (only rare, poorly preserved or fragmentary specimens were seen), there is some uncertainty in this boundary. The remainder of the section above the *G. opima* Zone is placed in the *Globigerina ciperoensis* Zone on negative evidence (absence of *G. opima* and *G. ciperoensis* itself is not present).

Cores 10 and 11 are nearly devoid of foraminiferal tests, and preservation in Core 12 (CC) is again up to levels

encountered in Cores 7 through 9. The core catcher of Core 13 contains two lithologic types: a brown clay (probably in situ) and a white chalk, both thoroughly mixed with basalt chips. The recovered fauna from this sample is apparently from the chalk and appears to be derived from above by downhole slumping.

SITE 161

Two holes were drilled at DSDP 161 (161 to 126 m below bottom, and 161A from 128 to total depth of 245 meters). In addition, Core 1A was taken at a nominal depth of 63 to 72 meters to recover an unsampled gap left by Core 8 of DSDP 161; nannofossils and radiolarians show that this core is probably more likely stratigraphically equivalent to Cores 9 and/or 10 of DSDP 161.

At this site, poorly preserved foraminiferal assemblages of early and late Oligocene age were found. As at DSDP 159 and 160, they represent dissolution facies ranging from total dissolution to assemblages extensively modified by dissolution. Cores 1 through 4 are totally devoid of planktonic foraminifera. Cores 5 through 7 contain low-diversity assemblages characterized by *Catapsydrax* spp. and the last *Globorotalia opima* (in the core catcher of Core 7). The disappearance of the latter, inasmuch as it is a solution-resistant form, defines the top of the *Globorotalia opima* Zone. The biostratigraphy below this point is very unclear. Maximum diversity was found in Cores 10 and 11, in which rare specimens of the small globigerinids *G. praebulloides*, *G. leroyi*, *G. anguliofficialis* (?), *G. angulicentralis*, and *Chiloguembelina* were found along with *G. winkleri*, *G. sellii*, *G. galavisi*, and *G. tripartita*; this indicates a level still within the *G. opima* Zone. It was not possible to find the base of this zone. The only specimens of *Globigerina ampliapertura* were found in Cores 4A and 5A.

Diversity and preservation show a decline from Core 12 downward, and below Core 5A, the section is virtually barren (except for a very small and low-diversity assemblage in Core 8A which includes *Catapsydrax dissimilis* and *Globigerina pseudovenezuelana*).

It can be seen that detailed biostratigraphy of this site, as well as of other Leg 16 DSDP equatorial Pacific sites, by means of planktonic foraminifera is virtually impossible. All zonal boundaries should be regarded as tentative, or very rough approximations. These sites, as far as the planktonic foraminifera are concerned, will be most useful for the study of selective dissolution of mid-Tertiary assemblages and the history of fluctuations of the lysocline. The most solution-resistant taxa seem to be members of the genus *Catapsydrax*, and *Globorotalia opima*; while the least resistant are the small globigerinids (e.d., *G. ciperoensis*, *G. angulicentralis*, and others), *Chiloguembelina*, *Cassigerinella*, and *Pseudohastigerina*. *Globorotalia siakensis* and *Globigerina prasaepis* occur quite commonly at the equatorial Pacific sites and seem to be moderately solution-resistant.

SITE 162

Except for a few scattered and brief occurrences, planktonic foraminifera are absent from the section cored at Site 162. Foraminifera were found near the top of the

section (Cores 1 and 4) and just above basement (Core 17, Sections 2 through 4 and core-catcher).

The assemblages at the top of the sequence are early Oligocene in age and show signs of extensive solution. The species recorded are *C. dissimilis*, *G. opima*, and one badly corroded specimen of *G. ampliapertura* (Core 1). The cooccurrence of the latter two taxa places the uppermost part of Site 162 in the *Globigerina ampliapertura* Zone.

Several specimens morphologically transitional between *G. ? angiporoides* and *G. opima* were found in Core 4, Section 5; and several specimens of *G. cf. G. opima nana* were found in the core-catcher of Core 15. These assemblages are not age-diagnostic.

In contrast to the above, Core 17 (Sections 2 to 4 and core-catcher) contains a well-preserved uppermost lower Eocene or lowermost middle Eocene assemblage. The species recorded from this interval are: *Globigerina limaperta*, *G. cf. G. prolata*, *G. cf. G. inaequispira*, *Acarinina aspensis*, *A. bullbrookii*, *Pseudohastigerina micra*, *Globorotalia cf. G. lehneri*, *G. broedermanni*, and *G. aragonensis*.

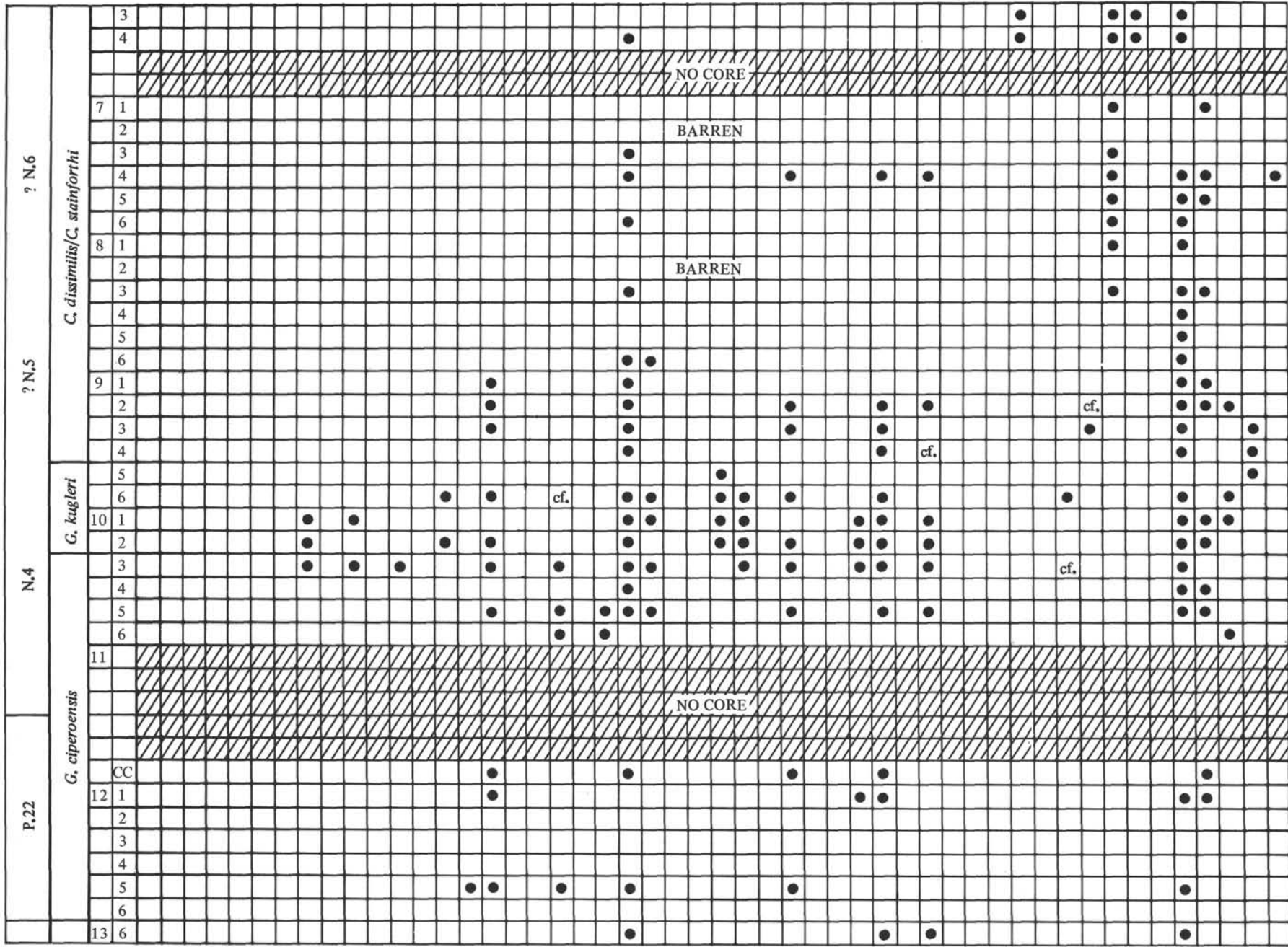
Owing to the absence of *G. palmerae*, *Hantkenina*, *Clavigerinella*, and *Globigerina frontosa*, this assemblage occupies a level intermediate between Bolli's (1957) *G. palmerae* and *H. aragonensis* zones.

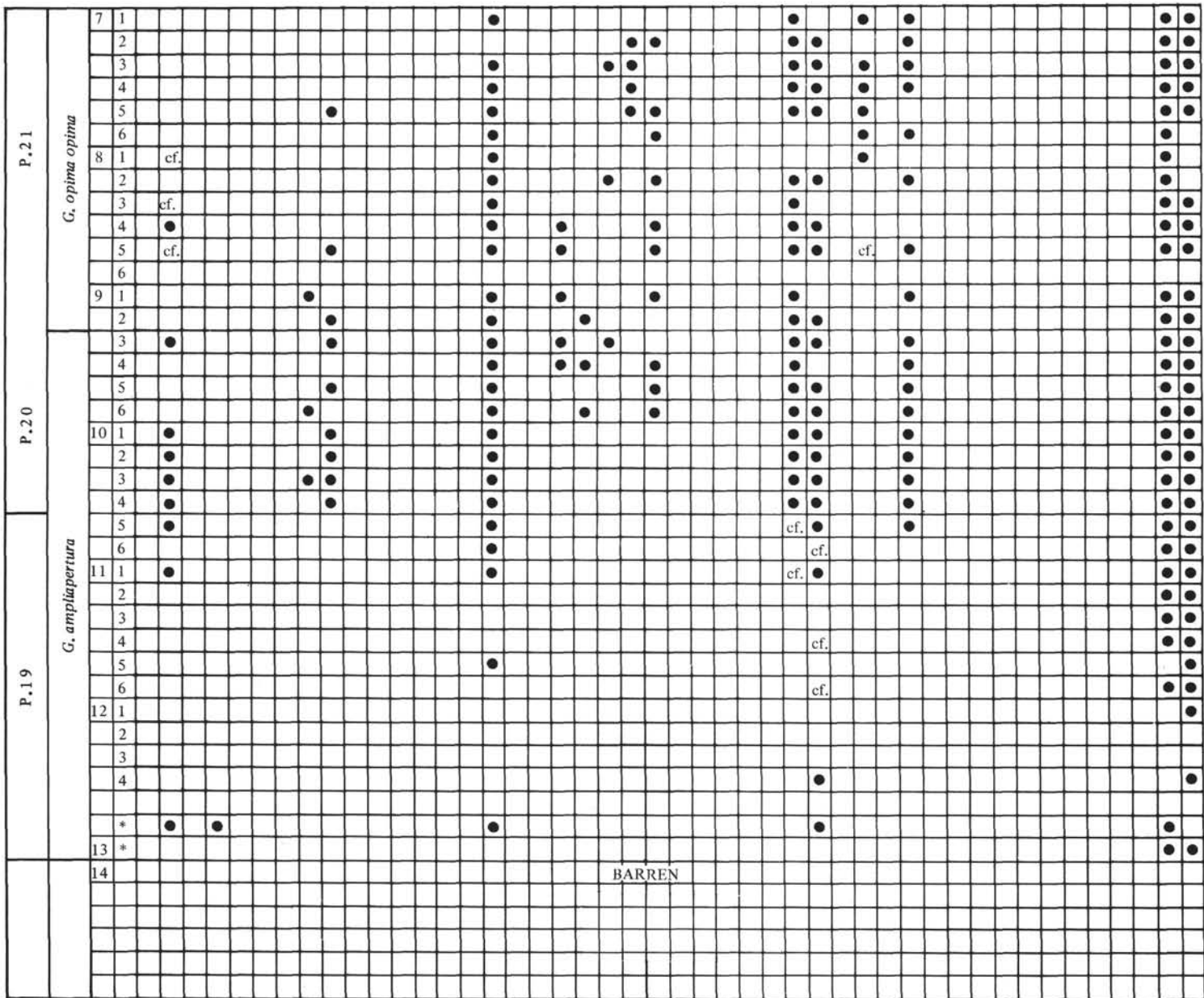
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TABLE 6
Distribution of Planktonic Foraminifera at Site DSDP 159

[illegible]





*Core Catcher

TABLE 8
Distribution of Planktonic Foraminifera at Site DSDP 161

Core	Section	<i>G. augustumbilicata</i>	<i>G. ampliaperiura</i>	<i>G. angiporoides</i>	<i>G. galavisi</i>	<i>G. gortanii</i>	<i>G. prasaepis</i>	<i>G. sellii</i>	<i>G. tapuriensis</i>	<i>G. tripartita</i>	<i>G. venezuelana</i>	<i>G. winkleri</i>	<i>G. opima</i>	<i>G. opima nana</i>	<i>G. siakensis</i>	<i>G. suteri</i>	<i>Chiloguembelina</i> spp.	<i>C. dissimilis</i>	<i>C. unicavus</i>	<i>G. sp. cf. winkleri</i>
5	1																			
	2																			
	3																			
	4																			
	5																			
	6																			
6	1						●				●				●					
	2																			
	6																			
7	1																			
	3	cf.			●	●				●	●			●	●	●		●	●	
	4																	●	●	
	CC						●				●		●	●	●			●	●	
9	1						●		●		●		●	●				●	●	
	2																			
	3	cf.				●	●				●		●	●				●		●
	4																			
	5						●				●		●	●				●	●	
	6																			
10	1						●	●		●	●		●	●	cf.	●		●	●	
	2																			
	3			●	●	●	●	●		cf.			●	●		●		●	●	●
	4																			
	5						●	●	●	●			●	●				●	●	●
	6																			
11	1																			
	2																			
	3						●		●				●	●				●	●	
	4																			
	5						●		●	●			●	●				●	●	●
	6																			
12	1						●						●	●		●		●	●	●
	4																			
	6						●						●	●		●		●	●	●
13	1																			
	2						●							●						
	3																			
	4						●											●	●	
	5																			
	6						●											●		
1A	1		●				●			●			●	●				●	●	
	2						●	●		●			●	●				●		
	3						●	●		●			●	●				●		
	4																			
	5																			
	6																			

Core	Section	<i>G. augustumbilicata</i>	<i>G. ampliaperiura</i>	<i>G. angiporoides</i>	<i>G. galavisi</i>	<i>G. gortanii</i>	<i>G. prasaepis</i>	<i>G. sellii</i>	<i>G. tapuriensis</i>	<i>G. tripartita</i>	<i>G. venezuelana</i>	<i>G. winkleri</i>	<i>G. opima</i>	<i>G. opima nana</i>	<i>G. siakensis</i>	<i>G. suteri</i>	<i>Chiloguembelina</i> spp.	<i>C. dissimilis</i>	<i>C. unicavus</i>	<i>G. sp. cf. winkleri</i>
2A	1						●			●			●					●	●	
	2																			
	3						●						●							
	4																			
	5												●					●		
	6																			
3A	1												●					●		
	2																			
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9A	1																			
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	4																			
	5																			
10A	1																			

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