23. PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY AND PALEOCEANOGRAPHY OF THE JAPAN TRENCH, LEG 57, DEEP SEA DRILLING PROJECT

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ABSTRACT

During Leg 57 of the Deep Sea Drilling Project four sites were drilled on the landward slope of the Japan Trench at 39° and 40°N latitude. Only three of the four sites (438, 439, and 440) yielded planktonic foraminiferal faunas providing a discontinuous late Cenozoic biostratigraphic record. The severe calcium carbonate dissolution in these sections is probably due to deposition beneath the CCD and to incursions of cold subarctic subsurface currents, low in salinity and high in oxygen, during periods of climatic cooling. Such intervals of dissolution are observed in Sites 438 and 440 during the late Miocene to early Pliocene and latest Pliocene to early Pleistocene. Paleoclimatic analysis based on coiling ratio of *Neogloboquadrina pachyderma* and faunal assemblages suggest a cold late Miocene to early Pliocene interval followed by warmer temperatures during the early to middle Pliocene. A cooling trend appears at about 2.4 m.y. to about 2.0 m.y., correlating with a cold interval recognized in other North Pacific deep sea sites. Severe dissolution between 0.9 and 1.5 m.y. suggests deteriorating climatic conditions at this time. A glacial maximum at 1.0 to 1.2 m.y. for the North Pacific has been previously documented in deep sea sections. Dextral-sinistral populations of *N. pachyderma* suggest brief warming trends at 0.9 (base of Jaramillo) and 0.7 m.y. (base of Brunhes). Cool temperatures are indicated between 0.6 and 0.4 m.y., followed by a warming trend between 0.4 and 0.2 m.y.

Planktonic foraminiferal zonation and placement of zonal boundaries are difficult in the Leg 57 sites owing to dissolution intervals resulting in discontinuous ranges of species. Despite these difficulties, a number of datum levels can be recognized and the faunal sequences correlated with similar sequences at Sites 310 and 296. Zonation of Leg 57 sites in terms of the zonations and datum levels proposed by Asano et al. (1975) and Oda (1977) provides difficulties owing both to absence and/or rarity of index taxa and to discontinuous ranges. However, the *Globoquadrina asanoi* first and last appearance datums can be recognized. The evolutionary morphotypes of *Globorotalia inflata* (primitive and modern varieties), *G. inflata praeinflata*, and the two late Pleistocene occurrences of *N. pachyderma* form 2 provide useful datum planes in these mid-latitude faunas of the North Pacific.

INTRODUCTION

During Legs 56 and 57 of the Deep Sea Drilling Project the active convergent margin encompassing the Japan Trench (Figure 1, A) was studied. A total of four sites were cored on Leg 57, penetrating 4834 meters of sediment and yielding a total of 1521 meters of recovered cores (Figure 1, B; Table 1). The cored sections provide relatively continuous upper Cenozoic sequences containing faunal assemblages which can largely be correlated with those of other mid-to-high latitude faunal sequences in the North Pacific. Lower Cenozoic sequences are more discontinuous because of disconformities, discontinuous coring, and dissolution of both calcareous and siliceous faunas.

A total of 526 samples were analyzed to determine the planktonic foraminiferal biostratigraphy. Abundance of planktonic foraminifers is sporadic, ranging from common to rare in upper Pliocene to Pleistocene sections. In addition, preservation ranges from good to poor because of dissolution at various levels. In all lower Pliocene sections planktonic foraminifers are rare to absent and marginally preserved because of dissolution. Upper Miocene sequences yielded few samples, with moderately preserved planktonic faunas within isolated thin calcareous layers in these generally diatomaceous sequences. Throughout the sedimentary sequences drilled on Leg 57, nannofossils, like planktonic foraminifers, are present in varying abundances, whereas diatoms and radiolarians are common throughout the sediments being

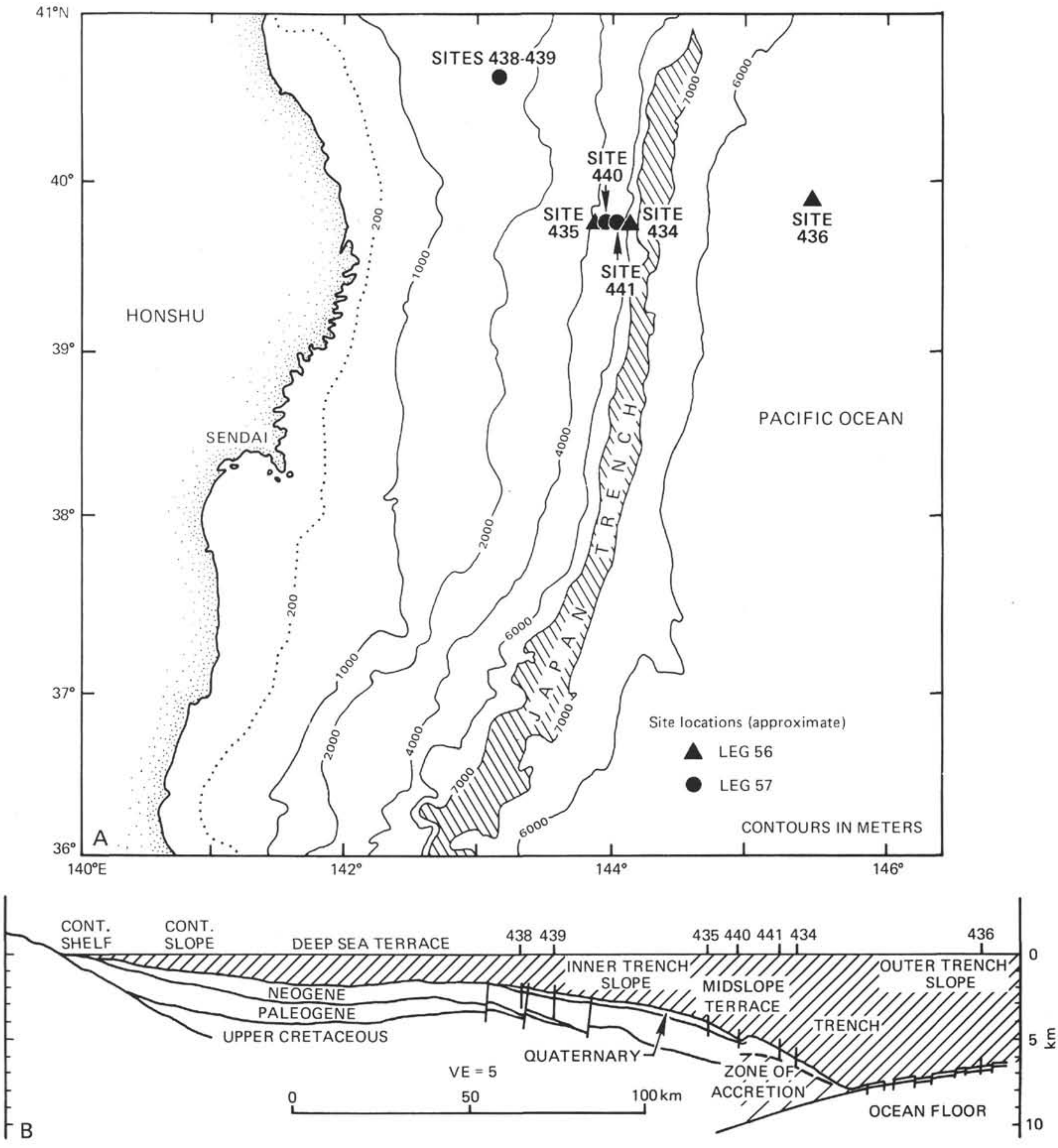


Figure 1. A. *Location of DSDP Leg 57 sites and major current circulation.* B. *Schematic cross section showing drill site locations for DSDP Legs 56 and 57.*

entire lower Miocene to Pleistocene sequences but are extremely rare in all lower Cenozoic sections. The presence of these microfossil groups permits comparison and correlation of biostratigraphic zones based on each of these groups at a relatively high latitude in the northwestern Pacific.

The location of the Legs 56 and 57 sites beneath the mixing zone of the cold Oyashio and the warm Kuroshio

TABLE 1
Leg 57 Site Data

Hole	Latitude	Longitude	Sub-Bottom Depth (m)	Penetration (m)	Total Core Recovered (m)	Oldest Sediment Cored
438	40°37.75'N	143°13.90'E	1552	109.5	81.9	Lower Pliocene
438A	40°37.79'N	143°14.15'E	1558	878.0	555.3	Middle Miocene
438B	40°37.80'N	143°14.80'E	1564	1040.7	192.6	Lower Miocene
439	40°37.61'N	143°18.63'E	1656	1157.5	163.0	Upper Cretaceous
440	39°44.13'N	143°55.74'E	4509	73.0	50.4	Pleistocene
440A	39°44.13'N	143°55.74'E	4509	139.5	33.5	Pleistocene
440B	39°44.13'N	143°55.74'E	4509	814.0	401.9	Upper Miocene
441	39°45.05'N	144°04.55'E	5655	293.0	16.6	Lower Pliocene
441A	39°45.05'N	143°04.59'E	5644	662.0	19.7	Upper Miocene
441B	39°45.08'N	144°04.60'E	5635	687.0	5.5	Upper Miocene

Current systems (Figure 1, A) provides a complex environment for planktonic groups. Northward or southward shifting of these water masses in response to climatic oscillations is reflected in the temperature-sensitive subarctic and temperate planktonic foraminiferal faunas deposited at these sites and in the sporadic incursions of warm subtropical faunal elements during warm climatic intervals. These climatic oscillations are also sensed in other microfossil groups. The various levels of calcium carbonate dissolution during the late Cenozoic may also be a response to these climatic oscillations associated with incursions of low salinity arctic cold bottom waters and subsurface currents. It is interesting to note that these dissolution intervals are also associated with periods of volcanic activity and high rates of sedimentation.

This study presents the planktonic foraminiferal biostratigraphy and paleoclimatic interpretation of Leg 57 sites, the stratigraphic ranges of important species, and abundance plots for Sites 438 and 440. Age-diagnostic species and temperature-sensitive faunal assemblages are discussed and correlated with similar faunas at DSDP Sites 173, 310, and 296 in the North Pacific. Correlation of Leg 57 sites with the onshore sections of Japan is discussed in the final section of this report. Characteristic faunas are illustrated in Plates 1 through 4.

METHODS

Samples of approximately 20 cubic cm were washed through a 250-mesh screen (62 μm) and dried. Unconsolidated sediments were soaked in water, and, when necessary, disaggregation was aided by the addition of small amounts of hydrogen peroxide. Hydrogen peroxide was routinely added to more consolidated sediments. The hard, black, fissile shale (Cretaceous) encountered at the bottom of Hole 439 was disaggregated by adding Quaternary O to the solution and boiling for several hours.

Because occurrences of planktonic foraminifers were sporadic, useful quantitative analysis was possible only for Site 438. Qualitative analysis of species abundance were made for Site 440 with the following notation regarding abundance: Abundant (A), more than 30 specimens; common (C), 15 to 30 specimens; few (F), 5 to 15 specimens; rare (R), fewer than 5 specimens. For preservation, G is good; M, moderate; P, poor. Labeling of samples follows DSDP convention: hole-core-section (interval in cm).

MID-LATITUDE FAUNAS IN THE NORTH PACIFIC

The standard zonation of Blow (1969) and Berggren and Van Couvering (1974) cannot be directly applied to mid-to-high latitude sections of the North Pacific owing to absence or rarity of subtropical index species. In this paper the familiar N zones are used for the reader's convenience and are approximations based on mid-to-high latitude species which have been tied to the paleomagnetic record, other microfossil datum levels, and the standard zonation at other mid-latitude sites (Keller and Ingle, in press; Ingle, 1973; Keller, 1978a, 1978b; Vincent, 1975).

Detailed quantitative studies of Site 173 in the Northeast Pacific (Ingle, 1973; Keller, 1978b), Site 310 in the Central Pacific (Vincent, 1975; Keller, 1978a), and Site 296 in the Northwest Pacific (Ujiie, 1975; Keller, 1979c) have provided continuous late Neogene biostratigraphic and paleoclimatic records for the mid-latitudes of the North Pacific. I have recently correlated these sites based on quantitative analysis of planktonic foraminifers and proposed 11 datum levels for the Pliocene–Pleistocene sequences of these mid-latitude sites of the North Pacific (Table 2 and Keller, 1979a). Of particular interest to the Leg 57 sites are the faunal records of Site 310, on Hess Rise, and Site 296, on Kyushu Ridge, south of Japan. DSDP Site 310 has temperate to transitional faunal assemblages very similar to those found at Sites 438 and 440. DSDP Site 296 has subtropical to transitional faunal assemblages deposited beneath the Kuroshio Current system which also influenced faunal deposition in the Japan Trench sites.

A generalized comparison of the ranges of important species present at DSDP Sites 173, 310, 296, and the Japan Trench sites is presented in Figure 2. Correlation to the paleomagnetic scale is based on diatom correla-

TABLE 2
Planktonic Foraminiferal Datum Levels and Paleoclimatic Events in the North Pacific DSDP Sites 173, 310, and 296

Foraminiferal Horizons	Hole 296 Section (Time in m.y.)	Hole 310 Section (Time in m.y.)	Hole 173 Section (Time in m.y.)
Neogloboquadrina			
N. pachyderma f2,		2-2 (0.6–0.7)	4-3 (0.6–0.7)
N. pachyderma f2,		2-4 (0.9–0.92)	5, CC (0.9–0.92)
Cold event$_4$	5-3 (1.2)	3-2 (1.2)	6, CC (1.2–1.3)
Globorotalia			
G. truncatulinoides ↑	7, CC (1.8)	3-6 (1.8)	
Cold event$_3$	9-2 (2.2–2.4)	4-1–4-3 (1.9–2.3)	9-3–10-2 (1.9–2.2)
G. inflata modern var. ↑	9-1 (2.1–2.2)	4-3 (2.2)	9-5 (2.0)
G. inflata praeinflata ↑	10-2 (2.5–2.6)	4, CC (2.6)	12-1 (2.4)
G. inflata prim. var. ↑	11-4 (3.2)	5-6 (3.2–3.3)	13-2 (2.8)
G. venezuelana ↓	10, CC (2.7)	5-2 (2.7)	12-4 (2.6)
Globoquadrina			
G. dehiscens ↑	13-2 (3.5–3.6)	6-3 (3.6)	
Cold event$_2$	11, CC (3.2–3.4)	6-1 (3.3–3.4)	12, CC–13-1 (2.7–2.8)
Globorotalia			
G. margaritae ↓	13-2 (3.5–3.6)	6-5 (3.7–3.8)	
G. praescitula ↓	13-2 (3.5–3.6)	6-5 (3.7–3.8)	
G. crassaformis ↑	15-4 (4.2–4.4)	7-2 (4.2–4.4)	14, CC (4.2–4.4)
G. puncticulata ↑	15-4 (4.2–4.4)	7-2 (4.2–4.4)	14, CC (4.2–4.4)
G. tumida ↑	17, CC (5.0–5.1)	7-3 (5.0–5.1)	
Cold event$_1$	17-5 (>4.9)	7-3 (>5.0)	15-1 (>4.5)

Note: Correlations of foraminiferal datums with the paleomagnetic-radiometric time scale is based in part on correlation with diatom datum levels and correlations of the paleomagnetic stratigraphy to Site 173 (Burckle and Opdyke, 1977; Burckle, 1978) as well as on extrapolations from sediment rate curves based on diatom, nannofossil, and radiolarian datum levels which have been tied to the paleomagnetic-radiometric time scale. These foraminiferal datums have been discussed at length (Keller, 1979a).

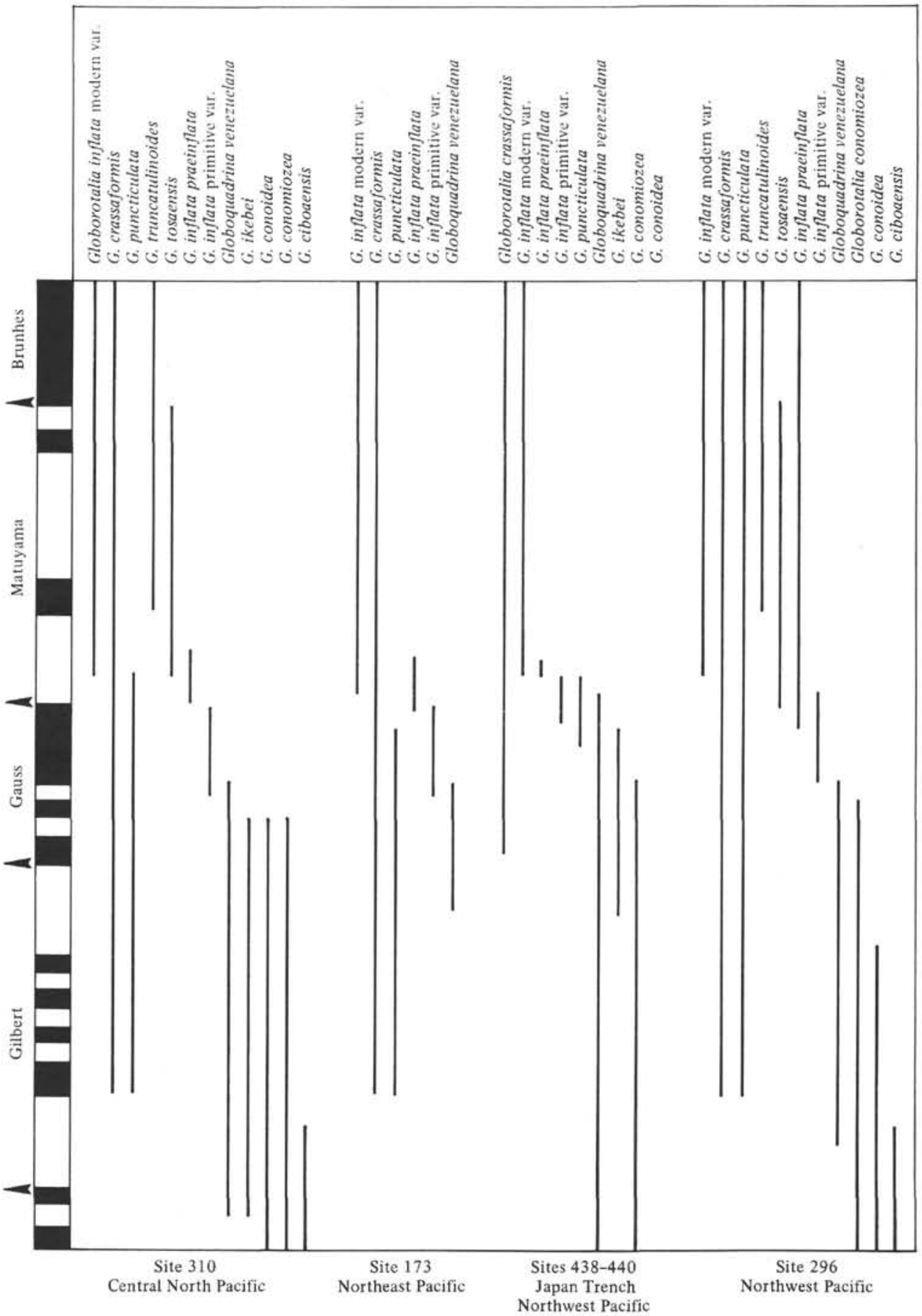


Figure 2. *Ranges of important planktonic foraminiferal species at Sites 173, 310, 296, and Leg 57 sites and generalized paleomagnetic scale (after LaBrecque et al., 1977). Correlation to the paleomagnetic scale is based on diatom correlations by Burckle and Opdyke (1977) and planktonic foraminifers (Keller, 1979a). (D = diatom, N = nannofossil, R = radiolaria, F = foraminifera.)*

tions by Burckle and Opdyke (1977) and correlations of planktonic foraminifers by Keller (1979a).

Site 438

Site 438 was drilled on the outer slope of a deep sea terrace 170 km seaward of the tectonically active Tohoku island arc. The primary objectives at Site 438 were (1) to obtain a Neogene and possibly Paleogene history of the continental shelf in terms of age, paleoenvironment, and tectonic history; (2) to determine the seaward extent of the continental crust; and (3) to date the age of the continental crust. Three holes were drilled at this site, Holes 438, 438A, and 438B, reaching 110 meters, 878 meters, and 1040 meters, respectively, the oldest of lower Miocene age. The acoustic basement, thought to represent the boundary of the continental crust between the Japan Trench and the continental shelf, was not reached. Thus we did not achieve Objectives (2) and (3).

The 110 meters of upper Pliocene to Pleistocene sediments penetrated in Hole 438 consist of sandy, silty clay with erratic pebbles. Hole 438A cored through relatively uniform diatomaceous silt and clay sections ranging from lower Miocene to Pleistocene. Hole 438B consists of lower Miocene to upper Miocene diatomaceous claystone. Volcanic detritus is found throughout Site 438 sections, but most volcanic ash layers are concentrated in sediments of early Miocene and latest Miocene through Pleistocene.

Planktonic foraminifers at Site 438 range from abundant to rare and are generally absent during cyclic intervals of intense dissolution. Preservation follows a similar pattern: Where foraminifers are abundant, they are relatively well preserved, and where they are rare they are poorly preserved. Based on microfossil data and extrapolation from sediment rate curves (see biostratigraphic synthesis, this volume) the following dates for intervals of intense calcium carbonate dissolution are estimated: 0.9 to 2.43 m.y., 2.8 to 3.0(?) m.y., 3.2 to 3.3(?) m.y., 3.5 to 5.5 m.y., 6.0 to 10.0(?) m.y., 12.0 to lower Miocene (Table 3, Figure 2). Extrapolated dates are marked with a questionmark. In the following discussion absolute dates are based on microfossil datum levels; F = foraminifera, N = nannofossil (Shaffer, this volume), D = diatom (Barron, this volume), R = radiolaria (Reynolds, this volume).

Hole 438

Planktonic foraminifers are common to abundant during the latest Pleistocene (0.9 m.y. [N, D] - Holocene), absent owing to intense dissolution between 0.9 m.y.(N, D) and 2.43 m.y.(D), and rare to few between 2.43 m.y.(D) and 2.8(?) m.y.(F) (Table 4). Quantitative analysis indicates that the late Pleistocene is dominated by *Neogloboquadrina pachyderma*, species of *Globigerina*, and by *Globorotalia inflata*. Almost exclusively sinistrally coiling *N. pachyderma* constitute more than 70 per cent of the fauna to about 0.25 m.y. (D, N), suggesting a cool latest Pleistocene interval. Less abundant (50%) but still sinistrally coiling *N. pachyderma* and increased abundance of *G. inflata* indicate slightly warmer temperatures between 0.25 (N,D) and 0.9 m.y. (D,N). No paleoclimatic trend can be determined from the few to rare occurrences of planktonic foraminifers in the upper Pliocene sediments.

The following estimated radiometric ages are suggested for Hole 438, based on first and last appearances of key species and correlation with the paleomagnetic and radiometric scale as outlined in Table 2. The first appearance of *Globorotalia inflata praeinflata* occurs in Section 438-9-4, suggesting a date of 2.5 to 2.6 m.y. (*G. inflata praeinflata* was formerly called *G. inflata* trans. var. by Keller (1978a, 1978b, 1978c).) Such a date is also approximated by the last appearance of the nannofossil *Discoaster tamalis* within this interval (Shaffer, this volume). *Globorotalia inflata* primitive var. first appears in Section 438-10-2, suggesting an age of 2.8 to 3.0 m.y. However, dissolution below this interval indicates that this may not be the true first appearance of this species. In fact, diatom faunas suggest that Core 12 is no older than 2.8 to 3.0 m.y. (Barron, this volume).

Hole 438A

The sedimentary sequence recovered in this hole spans the early Miocene to the Pleistocene. The sporadic occurrence of planktonic foraminifers throughout this sequence is probably due to calcium carbonate dissolution, dilution due to high rates of sedimentation, and periods of volcanic activity, particularly during the late Miocene to early Pliocene and Pleistocene. Table 3 records the quantitative distribution of planktonic foraminifers in Hole 438A. The major dissolution intervals (i.e., the occurrence of fewer than 10 specimens) encompass early to middle Miocene 13.0 m.y.(N), latest Miocene to about 6.0 m.y.(D), latest Miocene 5.6 m.y.(N, D) to early Pliocene, and latest Pliocene 2.4 m.y.(D) to early Pleistocene 0.9 m.y.(N, F). The latter two intervals of dissolution are also present in Hole 438.

Dissolution cycles within Hole 438A make it difficult to assign absolute dates for planktonic foraminifers, because discontinuity in ranges of species causes uncertainty in determining first and last appearances of age-diagnostic taxa. However, characteristic faunal assemblages permit some conclusions regarding the age and paleoclimatic implications of these sections. The stratigraphic ranges of important taxa have been plotted in Figure 3 along with the coiling direction of *Neogloboquadrina pachyderma*, the cumulative distribution of dominant species, and the number of species present in each sample. Planktonic foraminifers are absent throughout lower to middle Miocene strata. Late Miocene assemblages (Zone N16) occur in Sections 438A-59,CC through 438A-52 and contain *Globorotalia merotumida*, *G. conoidea*, *G. lenguaensis*, *G.* cf. *scitula*, *Globoquadrina altispira*, *G. dehiscens*, *Globigerinoides triloba*, *Neogloboquadrina continuosa*, and *N. pachyderma* (Figure 2, Table 3). The latest Miocene Zone N17 is present in Sections 438A-45,CC through 438A-36,CC and is characterized by the last appearance of *Globoquadrina dehiscens*, *Globorotalia cibaoensis*, *G. lenguaensis*, *G. menardii*, *Neogloboquadrina continuosa*, *G. nepenthes*, and *N. pachyderma* (Figure 2). The Miocene/Pliocene boundary falls within a dissolution interval spanning the interval encompassed by Zone N18 as well.

Early Pliocene sediments are indicated by the last appearance of *Globigerina nepenthes* in Section 438A-24,CC. This species has a variable last appearance in mid-to-high latitudes ranging from 4.0 m.y. at Site 310 to 3.5 m.y. at Site 296. It may be reasonable to assume that the last appearance of this species in Hole 438A also falls within the time interval 3.5 to 4.0 m.y. Characteristic early Pliocene (N19) faunas are also present between Sections 438A-20,CC and 438A-11,CC (Figure 2, Table 3). *Globorotalia conomiozea* ranges through Core 12. The last appearance of this species at Sites 310

TABLE 3
Distribution of Planktonic Foraminifers in Hole 438A

Age	Datum Levels	Zonation	Sample (Interval in cm)	*Globigerina apertura*	*G. bulloides*	*G. cf. concinna*	*G. druryi*	*G. falconensis*	*G. foliata*	*G. incompta*	*G. parabulloides*	*G. praebulloides*	*G. praedigitata*	*G. quadrilatera*	*G. quinqueloba*	*G. rubescens*	*G. umbilicata*	*Globigerinita glutinata*	*G. uvula*	*Globigerinoides obliquus*	*G. sacculifer*	*G. triloba*	*Globorotalia conoidea*	*G. conomiozea*	*G. cibaoensis*	*G. crassaformis*
Pleistocene	0.25 N	N.22	438A-1-1, 30–34		100									23												
	0.9 N.F		2-4, 68–70		23						2			4	5											
	0.7 D		2,CC											Dissolution												
	0.9 D		3,CC																							
			4-5, 12–16																							
	2.0–2.2 F		4,CC		9						2			10	10	2		1								
			5-1, 100–102		1									1												
	2.43 D		5-3, 61–64		26												4	2								
			5-4, 18–22		4				1		1			3			1		2							
			5-5, 15–17		10						1			1			3		1							
			5,CC		13																					
		N.21	6,CC			7								1												
			7-2, 20–22			2																				
			7,CC		40	35			3		17			5			3	9	2							2
			8-5, 28–32		10	11			1	2	2						3									
			8,CC		19	30		2	1	2					2		2	4	2							
			9,CC			3																				
			10-4, 12–14			3																				
	3.0 N		10,CC																							1
			11-2, 29–33		9	20		1			3			3			5	4								
			11,CC		175	65					18			47	1		10	7	3							
			12-1, 20–24	2	85	40					14			19			8	13	4			1		1		1
			12-2, 12–14		11	11					3			5												
Pliocene			12,CC		43	25								27			3	2								
			13-2, 19–22																							
			13-4, 19–23																					1		
			13,CC																							
			14-5, 26–30		6	2								4			2				1					
			15,CC		7	5											3									
		N.19	16-4, 36–39		40	36					2		1	4			3	1		2				1		
			16,CC																							
	3.5F		17,CC		3									1												
			18-2, 10–14		1																					
			18-4, 10–14											1										1		
			18,CC		1									1										2		
			20,CC		4			1																2		
			21-2, 30–34																							
			24-5, 10–12																							
	3.5–4.0 F		24,CC		2																					
			25,CC		1		4				3			1												
	4.5 N.D		26-3, 20–24																							
Miocene	5.3 D		36,CC																							
	5.6 N		37,CC		1																					
	6.6 N		38,CC		6		12																			
		N.17	39,CC				10																			
			40,CC				7					2														
	6.0 D		41,CC																							
	7.0 D		43,CC																							
			44-4, 50–54		1							1		3											2	
	7.0–7.5		45,CC									1													2	
	N.D		46,CC																							
		N.16	52-5, 36–38																							
			52,CC				4					16	1					11			1	4	11	2		
	11.0 N		55,CC																							
			56,CC		1							12		6				1			1	1	8	4		
			57-4, 31–35		8							52		14				4				1				
			57,CC	2								30		18				4				4				
			59,CC									1		1								1				
	13.0 N		60,CC									3														
			61,CC									5						1								
			62,CC											Dissolution												
			86,CC																							

Note: D = diatom (Barron, this volume), N = nannofossil (Shaffer, this volume), R = radiolaria (Reynolds, this volume), F = foraminifera. Preservation: P = poor, M = moderate, G = good.

TABLE 3 – *Continued*

G. juanai	G. inflata modern var.	G. lenguaensis	G. merotumida	G. menardii	G. paralenguaensis	G. puncticulata	G. ikebei	G. cf. scitula	G. scitula	G. tumida	Globoquadrina altispira	G. dehiscens	G. larmeui	G. venezuelana	Neogloboquadrina cf. acostaensis	N. continuosa	N. cf. continuosa	N. dutertrei	N. humerosa	Globigerina nepenthes	N. pachyderma sinistral	N. pachyderma dextral	N. pachyderma f2	Globoquadrina asanoi	Pachyderma–dutertrei intergrade	Orbulina universa	O. suturalis	Sphaeroidinella subdehiscens	No. Foraminifers Counted	Preservation
																					552	2							677	G
	16																				129	16	2			1			198	G

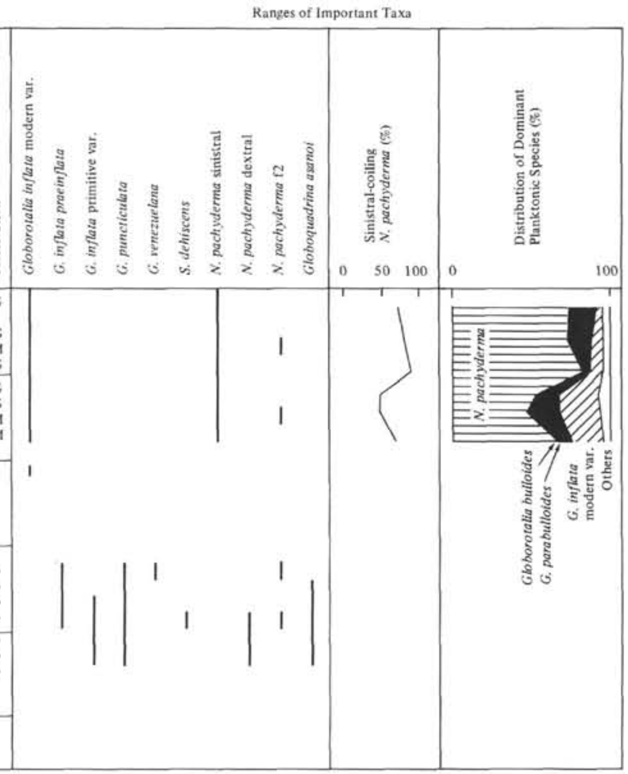
Dissolution

G. juanai	G. inflata modern var.	G. lenguaensis	G. merotumida	G. menardii	G. paralenguaensis	G. puncticulata	G. ikebei	G. cf. scitula	G. scitula	G. tumida	Globoquadrina altispira	G. dehiscens	G. larmeui	G. venezuelana	Neogloboquadrina cf. acostaensis	N. continuosa	N. cf. continuosa	N. dutertrei	N. humerosa	Globigerina nepenthes	N. pachyderma sinistral	N. pachyderma dextral	N. pachyderma f2	Globoquadrina asanoi	Pachyderma–dutertrei intergrade	Orbulina universa	O. suturalis	Sphaeroidinella subdehiscens	No. Foraminifers Counted	Preservation
	1					4			2												3	18	6	25	5				99	M
						2								1								6	3	12					26	M
																			2			29	24	15					102	M
						1								3					1			16	24	18					75	M
						4	3							6								14	14	6					63	M
						2			1					3								22		22	3				66	P
						1								1				2				2		2	2				18	P
																													2	P
							6															25	12						159	G
							5												2			15		2		2	1		56	M
							3															63		3					133	G
																													3	P
																						4							7	P
																						1	1			1			4	P
							2														5	4	9						65	G
							33								2							11	25	74	26	5			502	G
							68		1										1			13	27		3	4	2		307	G
							28							1									1			1			61	M
							55	1														14	11	9	5	5			200	M
																							2						2	P
							2																						3	P
							1																						1	P
1							16			1												6	1	2					42	M
							2																						17	M
2							136																6			11	1		246	G
							1																						1	P
							1															1							5	P
																													1	P
																													2	P
																					4								8	P
																													7	P
																				1	3								6	P
								3									7				2					1			22	P
																													1	P
				1												16					3							1	39	M
																17				1	17								45	P
		2											1			20					17								49	P
																													7	P
																					1								4	P
			1					14								11					3					1			80	P
								1																					1	P
				1				8							1	6					2							1	53	P
		2	3	1	1							3				75					30							1	195	P
											1		5			7					27								99	P
												1										2?							6	P
																													3	P
																													6	P

Dissolution

TABLE 4
Distribution of Planktonic Foraminifers, Ranges of Important Taxa, and Cumulative Distribution of Dominant Species in Hole 438

Age	Datum Levels	Zonation	Sample (Interval in cm)	*Globigerina apertura*	*G. bulloides*	*G. foliata*	*G. incompta*	*G. parabulloides*	*G. praedigitata*	*G. quinqueloba*	*G. quadrilatera*	*G. umbilicata*	*Globigerinita glutinata*	*Globorotalia crassaformis*	*G. hirsuta*	*G. inflata* modern var.	*G. inflata praeinflata*	*G. inflata* primitive var.	*G. puncticulata*	*G. scitula*	*Globoquadrina venezuelana*	*Neogloboquadrina pachyderma* sinistral	*N. pachyderma* dextral	*N. pachyderma* f2	*G. asanoi*	*N. dutertrei*	*Orbulina universa*	*Sphaeroidinella subdehiscens*	No. Foraminifers Counted	Preservation
Pleistocene		N 23	438-1-2, 115–120		62						13					10						250	1						336	G
		N 22	1-3, 10–14		1																								1	
	0.25 D		2-2, 31–33		28			2		11	7				2	12						210							272	G
	0.25 N		2-4, 70–74		1			5								18						10	1						35	M
			2,CC					3			1			1		13						120							138	G
	0.4 R		3-2, 28–32		37	1	2	27			11					58						155	2			1			294	G
			3-4, 10–14		10			12			8		3			50				1		86	1						171	G
			3-5, 20–24		6			1			4	1		1		14						1		1			1		30	M
			3-6, 43–47		5						1					12						35							53	M
	0.9 D, N		3,CC																											
	0.9 R		5-1, 30–34													1													1	
	1.6 R		5-2, 40–42					1																					1	
	1.6 N		5,CC	Dissolution																										
Pliocene		N 21	7-1, 14–20																											
			7,CC																											
			8-1, 114–118																							1			1	
			8-2, 12–14			1					2	1					5		8		6			13		3			39	P
			8-6, 116–120		1						2		1	1				2	4			1			3				18	P
			9-3, 130–134															1											1	P
	2.5? F		9-4, 130–134	1	1			1		1							4		5				5	3	3			1	25	P
			10-1, 58–60								1																		1	P
			10-2, 134–136					1		1			1					1	1	1			5		2				13	P
			10,CC									1																	1	P
			11-1, 120–122																											
			11-6, 120–124									1																		
			11,CC	Dissolution																										
			12-1, 28–30																											
	2.8 R		12,CC																											



Note: D = diatom (Barron, this volume), N = nannofossil (Shaffer, this volume), R = radiolaria (Reynolds, this volume), F = foraminifera.
Preservation: P = poor, M = moderate, G = good.

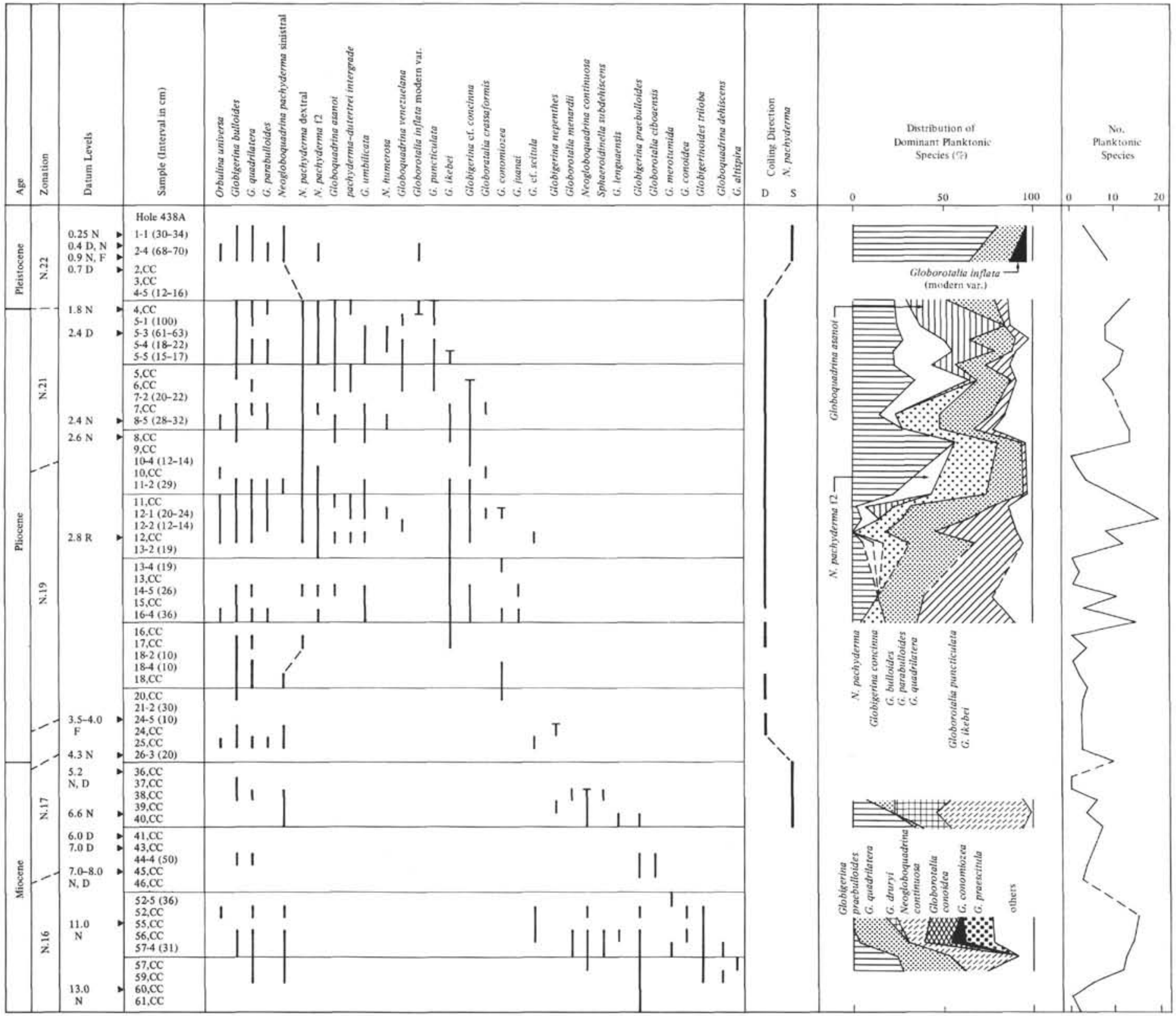


Figure 3. *Stratigraphic ranges of key taxa, cumulative distribution of dominant planktonic species, number of planktonic species, and coiling direction of* Neogloboquadrina pachyderma *in Hole 438A. (D = diatom [Barron, this volume], N = nannofossil [Shaffer, this volume], R = radiolaria [Reynolds, this volume], F = foraminifera.)*

and 296 is approximately at 3.5 m.y. and 3.0 m.y., respectively, suggesting an age of between 3.0 and 3.5 m.y. for the last appearance in Hole 438A. This date is supported by the last appearance of the nannofossil *Reticulofenestra pseudoumbilicata* in Section 438A-10,CC which is dated at 3.0 m.y. (Table 3 and Shaffer, this volume). Other characteristic early Pliocene species in Hole 438A are *Globorotalia juanai, G. ikebei, Globoquadrina venezuelana, N. pachyderma* form 2, and *G. asanoi* (Figure 2, Table 3). (*G. asanoi* was formerly called *N. pachyderma* form 3 by Keller [1978a, 1978b, 1978c]).

In mid-to-high latitude faunas the N19/N21 boundary is approximated by the first appearance of primitive forms of *Globorotalia inflata* associated with a marked cool event dated about 3.0 m.y. (Keller, 1978a). In Hole 438A this interval may occur in Cores 9 and 10, which are severely dissolved and contain only rare specimens (Figure 2, Table 3). Late Pliocene (N21) faunas are present between Sections 438A-10 and 438A-4,CC and include *Globorotalia puncticulata* (extinct in Section 438A-4,CC), *Globoquadrina venezuelana, G. asanoi, N. humerosa, N. pachyderma* form 2, and dextrally coiling *N. pachyderma. Globorotalia inflata* modern var. appears first in Section 438A-4,CC along with the last appearance of *G. puncticulata*, suggesting an age of 2.0 to 2.2 m.y. (Table 3). Abundance of dextrally coiling *N. pachyderma* and abundant form 2 and *G. asanoi* also suggest that the faunas in Section 438A-4,CC are of late Pliocene age. The interval between Core 4, Section 5 and Core 3 is barren of planktonic foraminifers.

Section 438A-2-4 is marked by predominantly sinistrally coiling *N. pachyderma* and rare form 2, suggesting that this occurrence corresponds to the 0.9 m.y. datum of this morphotype (Table 2). Such a date is also suggested by the presence of small *Gephyrocapsa* nannofossils (Shaffer, this volume). Thus the Pliocene/Pleistocene boundary falls within the dissolved interval following Core 4,CC, similar to the dissolved interval that characterized this boundary in Hole 438. The sedimentary sequence recovered in Hole 438B is barren of planktonic foraminifers.

Site 439

Because drilling failed to reach the acoustic basement at Site 438, Site 439 was drilled. The Neogene sedimentary and biostratigraphic record had been obtained at Site 438; therefore Site 439 was interval-cored through the early Miocene sections and the remaining sections cored to the acoustic basement. The oldest sediment recovered, a black fissile shale, was dated, by the presence of benthonic foraminifers, as Upper Cretaceous and will be discussed in a separate chapter.

Only one sample (439-1,CC) in this sedimentary sequence yielded a planktonic foraminiferal fauna. The following species are present in this sample: *Globigerina praebulloides, G. quadrilatera, G. woodi, Globoquadrina dehiscens, Globorotalia conoidea, G.* cf. *scitula, Globigerinoides triloba, Neogloboquadrina continuosa* and *N. pachyderma*. These species suggest an upper Miocene age for the top of this sequence as do the diatoms, radiolarians, and nannofossils present in this interval (Barron, Reynolds, Shaffer, this volume). Rare specimens of *Catapsydrax unicavus* are present in Cores 14 and 15, suggesting that this interval is no younger than lower Miocene. This date is confirmed by other microfossil groups, including benthic foraminifers (Keller, this volume).

Site 440

Site 440 was drilled on the midslope terrace (Figure 1,B) at a water depth of 4509 meters. The primary objective at this site was to investigate the zone of imbricated accretionary material which is theoretically presumed to exist on the landward wall of trenches. Microfossil data from Leg 57 sites do not support the presence of an imbricated accretionary wedge.

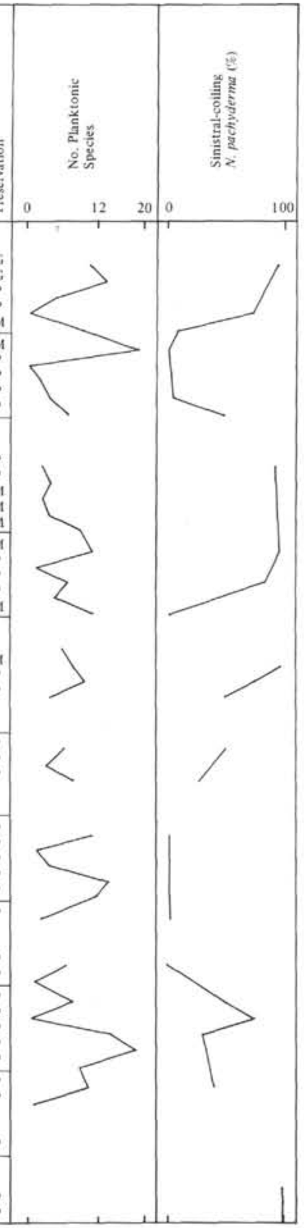
More than 800 meters of sediments were cored in three holes representing uniform hemipelagic siliceous mudstones similar in composition to sediments at Sites 438 and 439 farther upslope. These sediments represent a relatively continuous upper Miocene to Pleistocene sequence comparable to that in Hole 438A. Planktonic foraminifers, where present, range from rare to common and are generally moderately to poorly preserved, suggesting deposition at or near the calcium carbonate compensation depth (CCD). Intervals of calcium carbonate dissolution occur in the upper Miocene through middle Pliocene and uppermost Pliocene to lower Pleistocene sediments. These dissolution intervals correspond in time to similar $CaCO_3$ dissolved intervals in Hole 438A. Table 5 records the relative abundance of planktonic foraminifers, the number of planktonic species, and percent age of sinistrally coiling *Neogloboquadrina pachyderma* at Site 440. Stratigraphic ranges of important species are represented in Figure 4.

Planktonic foraminifers are rare to absent throughout the upper Miocene to upper Pliocene until about 2.4 m.y. (the last appearance of *Denticula kamtschatica* occurred in Section 440-24,CC, Barron, this volume). Rare planktonic foraminifers in Sections 440-53-3 and 440-58-3 suggest an age at or near the Miocene/Pliocene boundary. The species present are *Globigerina praebulloides, N. continuosa,* and typical late Miocene to early Pliocene sinistrally coiled forms of *N. pachyderma*. Section 440-28,CC contains species of definite Pliocene age, probably upper part of Zone N19. The species present include *Globorotalia crassaformis* and *G. tumida*. The first occurrence of *G. inflata* primitive var., which marks the N19/N21 boundary in mid-latitudes of the North Pacific (Keller, 1978a), occurs in Section 440-24-2 just above the diatom datum level *D. kamtschatica* (2.43 m.y.) (Table 5, Figure 4). Below this interval Cores 24,CC to 28,CC are barren of planktonic foraminifers; it is assumed that the N19/N21 boundary falls within this dissolution interval. Modern forms of *G. inflata* first appear in Section 440-21-4 suggesting an age of 2.0 to 2.2 m.y. (Table 2) for this interval. Severe dissolution during the early Pleistocene does not permit placement of the Pliocene/Pleistocene boundary. However, based on radiolarian and nannofossil data this boundary is assumed to fall at or near the dissolution interval in Core 19 or Core 18.

TABLE 5

Relative Abundance of Planktonic Foraminifers, Number of Planktonic Species, and Percentage of Sinistrally Coiling *Neogloboquadrina pachyderma* at Site 440

Age	Datum Levels	Zonation	Sample (interval in cm)	Globigerina bulloides	G. falconensis	G. foliata	G. incompta	G. parabulloides	G. praebulloides	G. praedigitata	G. quadrilatera	G. quinqueloba	G. rubescens	G. umbilicata	Globigerinita glutinata	G. uvula	Globigerinoides obliquus	G. ruber	G. sacculifer	G. triloba	Globorotalia crassaformis	G. inflata modern var.	G. inflata praeinflata	G. inflata primitive var.	G. scitula	G. tosaensis	G. truncatulinoides	G. tumida	Globoquadrina venezuelana	Neogloboquadrina cf. acostaensis	N. cf. continuosa	N. dutertrei	N. humerosa	N. pachyderma sinistral	N. pachyderma dextral	N. pachyderma f2	Globoquadrina asanoi	Pachyderma-dutertrei intergrade	Orbulina universa	Pulleniatina obliquiloculata	P. okinawaensis	Abundance	Preservation
			Hole 440																																								
Pleistocene		N22	1-3, 110-114	●		○		●			◕							◐				●					◐					○		◐	◐			◐				A	G
Pleistocene		N22	1,CC	◕				◐			◐				◐			◐				●			◐							○		●	○	◐			○		○	A	G
Pleistocene		N22	2,CC	◐						○												○												◐	○							F	P
Pleistocene		N22	3,CC																			○																				R	P
Pleistocene		N22	4-5, 130-134	◐				◐			○	○			◐							●												◐	●					○	○	C	M
Pleistocene		N22	4,CC	◐		○	○	◕		○	○	○	○		◐			○	○			◐			◐		○					○			●				○	○	○	C	M
Pleistocene		N22	6-4, 52-54																																○							R	P
Pleistocene	0.25 D	N22	6,CC	○																		○													○							R	P
Pleistocene		N22	7,CC	○				○														○													○							R	P
Pleistocene		N22	8,CC	○				○														○												◐	◕							C	P
			Hole 440A																																								
Pleistocene		N22	2,CC																			○												◐	○							R	P
Pleistocene	0.4 R	N22	3,CC	○				○														○												○								R	P
Pleistocene	0.4 D, N	N22	4,CC					◐														◕												◕								C	M
Pleistocene		N22	5,CC	○				○							○																			◐								F	M
Pleistocene		N22	5-6, 145-149	◐		○		○			◐			○	○							●										○		●								C	M
Pleistocene		N22	6,CC	◕				◕			◐				○			○	○			◕			○							◐		●								C	M
Pleistocene		N22	7-2, 83-87																			◕												○								F	P
Pleistocene		N22	7-3, 20-24					○				○						○				◐												◐	○							F	P
Pleistocene		N22	7-4, 60-64								○											○												○	○							R	P
Pleistocene	0.63 D	N22	7,CC				○	○			○	◐			◐							◕					○								●			○		○		C	M
			Hole 440B																																								
Pleistocene		N22	1,CC	○				○			○										○	●										◐		◕				○				C	M
Pleistocene	0.7 F	N22	3,CC	○				○			○	○									○	○												●	◐	◐						R	P
Pleistocene		N22	4,CC					○																		○									○	◐						R	P
Pleistocene		N22	5-1, 40-44																																								
Pleistocene		N22	7-1, 50-54																																								
Pleistocene		N22	7-2, 40-44					○														◐						○						○	○	◐						R	P
Pleistocene		N22	7-3, 29-33																			○						○						○	○							R	P
Pleistocene	0.9 F, D, N, R	N22	7,CC	○							○					○					○	◐												◕	●	●						C	P
Pleistocene		N22	8-2, 125-129																																								
Pleistocene		N22	12,CC																																								
Pleistocene		N22	13-3, 10-14	◐			○	◐				○			○		○	○				◕													●	○		○				C	P
Pleistocene	1.5 N	N22	15,CC					○														◐																				R	P
Pleistocene		N22	16-5, 8-12	○								○			○									○																		R	P
Pleistocene		N22	16,CC	◐			○	◐			○	○		○	○	○		○		○		◐						○							○	○						F	P
Pleistocene		N22	17-2, 12-16	○		○	○	○			◐	○			○	◐			○			◐													○							F	P
Pleistocene		N22	17,CC				○				○																								○							R	P
Pleistocene		N22	18-2, 30-34																																								
Pleistocene	1.6 D	N22	18,CC																																								
Pleistocene	1.6 R	N21	19-3, 8-10	○				◐			◐	○										◐		○											●							F	P
Pliocene		N21	19,CC	○																		○																				R	P
Pliocene	2.0 D	N21	20-3, 8-12	○				○			○											○			○									○	○	○						R	P
Pliocene		N21	20-6, 30-34																			○							?													R	P
Pliocene		N21	21-3, 15-19	○	○			○			◐						○	○			○	○			○				○	○				●	◐		●	○				C	P
Pliocene	2.0-2.2 F	N21	21-4, 24-28	●			◐	●			◕	○			◕			○		○		◐	○	◐		○						○	○	◕	●		●		○			C	P
Pliocene		N21	22,CC	○				○			○				○									◕	○			○							◐							R	P
Pliocene		N21	23-2, 12-16			○		○							○			○			○			◕				○						◐	◕	◐						F	P
Pliocene		N21	24-2, 15-19																					○																		R	P
Pliocene	2.4 D	N21	24,CC																																								
Pliocene		N21	27,CC																																								
Pliocene		N21	28,CC				○	○													◕			○				○					○		○							R	P
Pliocene		N17	29-2, 19-21																																								
Pliocene		N17	52,CC																																								
Miocene[a]	5.2 D	N17	53-3, 30-34						○																									●								R	P
Miocene[a]		N17	58-3, 2-7																												○			◐	○							R	P



Note: D = diatom (Barron, this volume), N = nannofossil (Shaffer, this volume), R = radiolaria (Reynolds, this volume), F = foraminifera. Number of specimens estimated: ○ < 5, ◐ 5-15, ◕ 15-30, ● > specimens. Abundance: A = abundant, C = common, F = few, R = rare. Preservation: P = poor, M = moderate, G = good.

[a]Miocene.

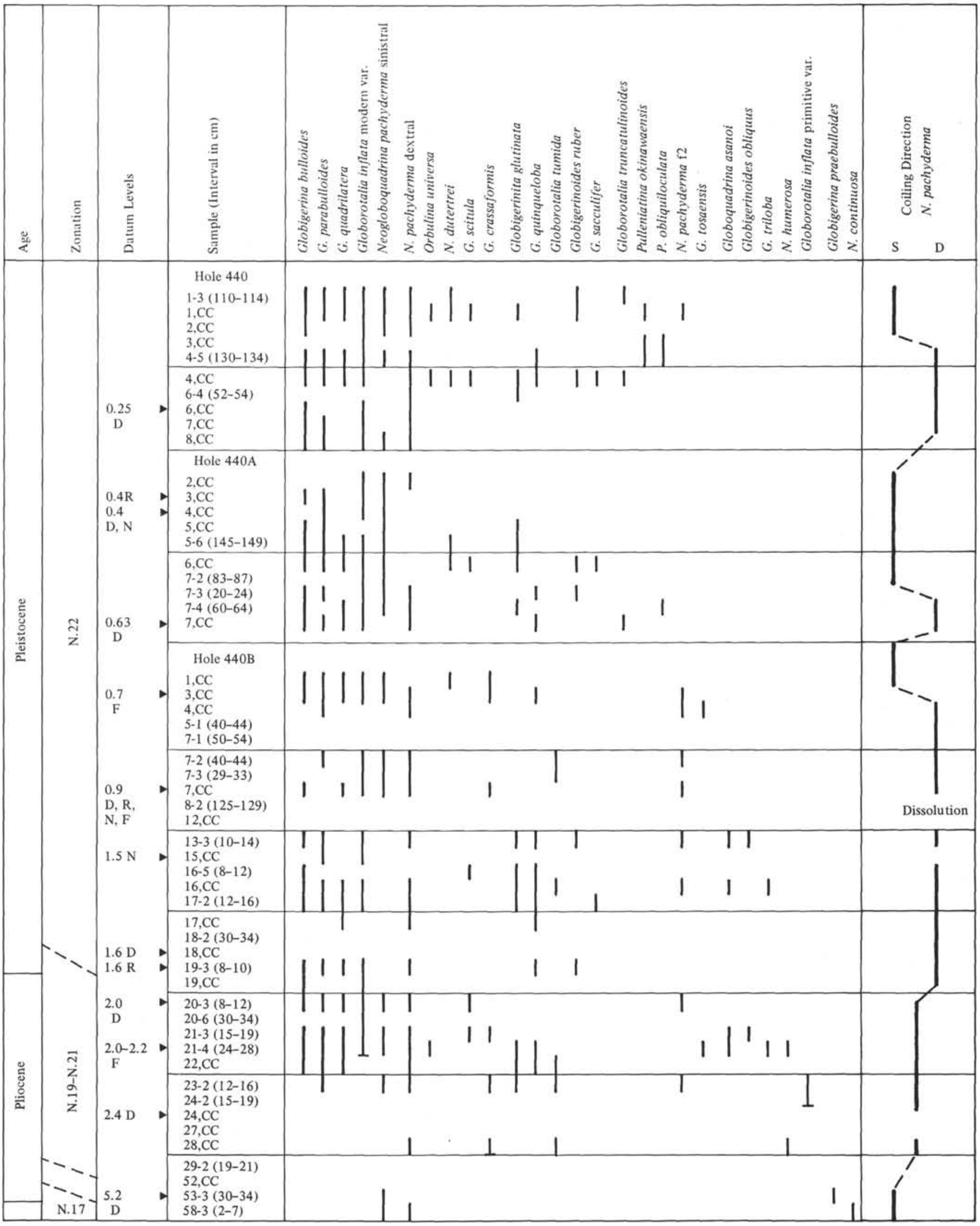


Figure 4. *Stratigraphic ranges of key taxa and coiling ranges of* Neogloboquadrina pachyderma *in Holes 440, 440A, and 440B. (D = diatom [Barron, this volume], N = nannofossil [Shaffer, this volume], R = radiolaria [Reynolds, this volume], F = foraminifera.)*

The latest Pleistocene (0.63 m.y. [D] to Holocene) is represented in Holes 440 and 440A (Table 5). Microfossil correlations indicate that Section 440A-7,CC (0.63 m.y. [D]) correlates with Core 2 of Hole 440B (Barron, Shaffer, Reynolds, this volume). Unfortunately, Core 2 of Hole 440B is barren of planktonic foraminifers. However, Core 3 contains sinistral and dextral coiling *N. pachyderma* and *N. pachyderma* form 2, suggesting an age of about 0.7 m.y. (Table 2), which is quite in agreement with other microfossil data. A second occurrence of *N. pachyderma* form 2 occurs in Core 7 (440B), indicating an age of 0.9 m.y. for this interval. This datum concurs with the nannofossil and diatom datum levels of this age within this interval (Shaffer, Barron, both this volume).

Site 441

Site 441 was drilled at a water depth of 5516 meters, well below the level of the calcium carbonate compensation depth. The sedimentary sequence recovered here is barren of foraminifers.

PALEOCLIMATIC INTERPRETATION

It has been well documented that the late Neogene in the North Pacific is punctuated by a series of climatic oscillations (Ingle, 1973, 1976; Echols, 1973; Keller, 1978a, 1978b, 1979b, Shackleton and Opdyke, 1977). Detailed quantitative analysis of planktonic foraminifers combined with oxygen isotope stratigraphy have provided the following dates for cool climatic intervals in the North Pacific: late Miocene through early Pliocene (4.5 m.y.), an intense, short, cold event during the middle Pliocene at about 3.0 to 3.2 m.y.; two cold pulses during the latest Pliocene to the Plio/Pleistocene boundary at 2.5 to 2.6 m.y. and about 2.2 to 2.0 m.y.; early Pleistocene at about 1.0 to 1.2 m.y. and late Pleistocene oscillations (Shackleton and Opdyke, 1977; Keigwin, 1978; Kent et al., 1971; Keller, 1978b, 1979a). Planktonic foraminiferal faunas encountered in the late Neogene sequence of the Japan Trench appear to follow a similar pattern. However, faunal patterns in the Leg 57 sites are complicated by deposition beneath the mixing zone of the warm water Kuroshio Current and the cold water Oyashio Current systems. The most complicating factor in deciphering the paleoclimatic history in this region is the severe cyclic dissolution of calcium carbonate. This dissolution is due, in part, to deposition in deep undersaturated waters, such as at Sites 440 and 441; however, the shallow dissolution intervals may be a function of cold undersaturated subarctic subsurface currents of low salinity sweeping over the area during periods of climatic cooling. One might then assume that dissolution should correspond to periods of climatic cooling. In fact, some dissolution intervals do encompass cool paleoclimatic intervals such as the late Miocene to early Pliocene, late Pliocene, and early Pleistocene, but some do not. For instance, the early Pliocene interval to about 3.5 m.y. is known to have been a warm stable climatic period (Shackleton and Opdyke, 1977; Keigwin, 1978; Keller, 1978a, 1979a). In the Japan Trench sites this interval is almost entirely dissolved.

Because of dissolution intervals, no continuous picture regarding the paleoclimatic history of the Leg 57 sites can be made, but the following trends are apparent. Almost exclusively sinistrally coiling forms of *Neogloboquadrina pachyderma* dominate the late Pleistocene to 0.9 m.y. in Site 438. At Site 440 the late Pleistocene record is more complete, and a series of dextral and sinistral coiling intervals are present (Figure 4, Table 5). Sinistrally coiling *N. pachyderma* indicate a cool late Pleistocene interval, followed by dextral coiling forms indicating a warming trend to just above the radialarian datum of 0.44 m.y. (Reynolds, this volume). Sinistrally coiling *N. pachyderma* dominate again between 0.4(R) and 0.6(D) m.y. During early to late Pleistocene, dissolution is more severe, but available data indicate a warming trend at about 0.7(F) m.y., as indicated by sinistral-dextral coiling forms of *N. pachyderma*. Decidedly warmer temperatures are indicated at 0.9 m.y. (F, R, N) (N = nannofossil, Shaffer, this volume), as represented by predominantly dextrally coiling forms of *N. pachyderma* and *N. pachyderma* form 2. Echols (1973) reports similar warming trends at 0.7 and 0.9 m.y. in Leg 19 sites. In all sites the lower Pleistocene interval is barren of planktonic foraminifers. In Hole 440B the dissolution interval is most severe between 0.9 and 1.6 (?R) m.y., spanning Sections 440B-8 to 440B-12-4 (Table 5). As mentioned earlier, a distinct cold event can be recognized within North Pacific sections at about 1.0 to 1.2 m.y. The dissolution that marks this interval in the Japan Trench sites may be partly due to this period of climatic cooling.

The Plio/Pleistocene boundary in Site 440 is marked by sinistral-dextral forms of *N. pachyderma.* A coiling change to predominantly sinistral forms occurs at about 2.0 m.y. (D, F) (first appearance of *Globorotalia inflata* modern var.). This cool event is well in agreement with other North Pacific sites (Keller, 1978a). Dextral-sinistral coiling *N. pachyderma* suggest a warming trend below 2.43 m.y. (D). Warm temperatures during the early Pliocene are suggested by the abundant occurrence of *G. ikebei,* a temperate to transitional water mass species which has also been reported from early Pliocene sections of Leg 19 sites (Echols, 1973, *G. ikebei* = *G.* cf. *suterae*) and Site 310 (Keller, 1979b, *G. ikebei* included in *G. puncticulata*). Severe dissolution during lowermost Pliocene precludes paleoclimatic interpretation during this time interval. Late Miocene faunas of *N. pachyderma* are sinistrally coiled in all Leg 57 sites.

Notes on Species

Neogloboquadrina pachyderma form 2 and form 3 (form 3 = *Globoquadrina asanoi*)

Species useful for zonation in mid-to-high latitude faunas are forms here called *N. pachyderma* form 2 and one form formerly called *N. pachyderma* form 3 (Plate 2, Figs. 1-11; Plate 1, Figs. 14-16). These forms are considered to fall within the plexus of *Neogloboquadrina* and probably somewhere between *N. pachyderma* and *N. dutertrei.* Recently, Maiya and Takayanagi (1978) suggested that *N. pachyderma* form 3 is within the population of *G. asanoi*. Thus in this chapter *N. pachyderma* form 3 is now called *G. asanoi*. *N. pachyderma* form 2 and *G. asanoi* occur in varying abundances throughout the Pliocene, particularly during warmer climatic intervals (Keller, 1978c). Two isolated occurrences of *N. pachyderma* form 2 also appear in the Pleistocene and have been dated at 0.7 m.y. and 0.9 m.y. (Keller, 1979a; Keller and Ingle, in press). The distribution of these forms along the marginal northeastern Pacific has been recently discussed by Keller (1978c).

Globorotalia inflata primitive var.

The earliest forms of *Globorotalia inflata* in the North Pacific are small subquadrate forms with 3 to 3½ chambers and a flat dorsal side (Plate 3, figs. 5-8). These forms generally lack the luster characteristic of modern forms of *G. inflata*. They are easily identified, and their initial appearance marks a useful datum plane in mid-latitude sections of the North Pacific. At Sites 173, 310, and 296 the initial appearance of *G. inflata* primitive var. occurs at or near a marked cold event dated at 3.0 to 3.3 m.y. (Table 2), which also approximates the N19/N21 boundary in mid-latitude sections (Keller, 1978a, 1979a).

Globorotalia inflata modern var.

The first appearance of *Globorotalia inflata* modern var. is another biostratigraphically useful morphotype in mid-latitude sections of the North Pacific. Modern forms of *G. inflata* with 3 to 3½ and sometimes 4 inflated chambers, a more rounded periphery, and inflated convex dorsal side first appear at about 2.0 to 2.2 m.y. in North Pacific Sites 173, 310, and 296 (Keller, 1979a) (Table 2; Plate 3, figs. 1-3). This form is also present in Leg 57 sites, where the first appearance also approximates the 2.0 to 2.2 m.y. datum.

Globorotalia inflata praeinflata (= *G. inflata* trans. var.)

Globorotalia inflata praeinflata is a distinct morphotype with 4 to 5 globose chambers and a low, arched, inflata-like aperture or open umbilicus caused by positioning of the final chamber (Plate 3, fig. 4). This form was formerly called *G. inflata* transitional var. (Keller, 1978b, 1978c). However, recent discussions with Maiya and Takanyanagi (1978) suggest that this form is included in the species concept of *G. inflata praeinflata*. Within the subtropical to transitional water masses of Sites 310 and 296, this form initially appears at 2.5 to 2.6 m.y. (Keller, 1978a, 1979a). At the cool transitional Site 173, this form appears somewhat later—at about 2.4 to 2.5 m.y. (Keller, 1979a)—slightly below the last appearance of *Denticula kamtschatica*, which is dated 2.43 m.y. In the Leg 57 sites the first appearance of this form is also observed below the diatom datum level *D. kamtschatica*.

Correlation with Onshore Sequences of Japan

Late Cenozoic foraminiferal biostratigraphy of onshore marine sections in Japan has been studied by numerous workers—for example, Matoba, 1967, 1970, 1976; Oda, 1977; Ujiie et al., 1977; Takayanagi et al., 1976; Takayanagi and Saito, 1962; Takayanagi and Chiji, 1973; and Saito and Maiya, 1973. The biostratigraphy and chronostratigraphy of the Japanese Neogene have been summarized and planktonic foraminiferal datum levels and epoch boundaries discussed by Ikebe et al., 1976; Saito, 1976; and Asano et al., 1975. Some Japanese sections have been correlated with Mediterranean sections by means of magnetostratigraphic correlations (Nakagawa et al., 1977).

No uniform zonation for mid-to-high latitude faunas of the North Pacific exists to date. A number of local zonations for the Northwest Pacific have been proposed, and most of these have been developed from onshore sections of Japan. These zonations are often based on abundance and coiling ratios of species as well as on first and last appearance datums (Shinbo and Maiya, 1971; Oda, 1977; Asano et al., 1975; Ujiie, 1976; Saito, 1976; Ikebe et al., 1976). The biostratigraphy of the Leg 57 sites has been based on datum levels and zonation proposed for the mid-latitudes of the North Pacific by Keller (1978a, 1979a), based on faunal sequences from Sites 173, 310, and 296.

In this section an attempt is made at correlating the biostratigraphy of the Leg 57 sites with the zonation proposed for the Pacific side of Japan by Asano et al. (1975) and datum levels proposed by Ikebe et al. (1976) and Oda (1977).

Table 6 compares the zonations proposed for the onshore sequences of the Pacific side of Japan and associated datum levels (Asano et al., 1975; Ikebe et al., 1976; Oda, 1977) with the zonation and datum levels proposed for mid-latitude sites of the North Pacific (Keller, 1978a, 1979a). Table 7 presents the biostratigraphic data of Leg 57 sites in terms of the zonation and datum levels of Asano et al. (1975), Oda (1977), and Ikebe et al. (1976). Important species present within each zone are marked in Column 3. Approximate dates for these foraminiferal events from Leg 57 sites are based on available microfossil datum levels and extrapolation from the sediment rate curves. Because *Pulleniatina* is only sporadically present in Hole 440A, its coiling changes are not useful for biostratigraphic correlations in the Japan Trench sites. The rare Pleistocene occurrences of *Pulleniatina* are all dextrally coiling.

The Pleistocene zones (N22) of Asano et al. (1975) and Oda (1977) can be recognized in Sites 438 and 440. The following important species occur in this interval: *Globorotalia tosaensis* L.A. (L.A. = last appearance), *G. truncatulinoides, Pulleniatina obliquiloculata,* and two occurrences of *Neogloboquadrina pachyderma* form 2 at 0.7 and 0.9 m.y. The continuous range of this form ends in the early Pleistocene.

Neither the *G. tosaensis/G. truncatulinoides,* or the *G. tosaensis* zone (N21) can be recognized at Leg 57 sites. The *Globoquadrina asanoi* L.A. datum level can be recognized here at about 2.0 to 2.2 m.y.

Zones *Sphaeroidinella dehiscens/G. tosaensis* and *G. miozea conoidea* to *Pulleniatina primalis/Globigerina*

TABLE 6
Planktonic Foraminiferal Zonation and Datum Levels of the Pacific Side of Japan and the Mid-Latitude Region of the North Pacific

N Zones (Blow [1969])	Pacific Side of Japan (Asano et al. [1975])	Central Honshu (Oda [1977])	Datum Levels, Japan (Asano et al. [1975], Ikebe et al. [1976], Oda [1977])	Mid-Latitude Region North Pacific (Keller [1978a, 1979a])	Datum Levels, North Pacific Mid-Latitudes (Keller [1978a, 1979a])
N22	*Pulleniatina obliquiloculata/Globorotalia truncatulinoides*	*G. truncatulinoides*	↧*G. tosaensis*	*G. truncatulinoides* *G. truncatulinoides/ G. tosaensis* overlap zone	↧*G. tosaensis* ←*N. pachyderma* f2 ←*N. pachyderma* f2 Cold event$_4$ •
N21	*G. tosaensis/ G. truncatulinoides*	*G. tosaensis*	↥*G. truncatulinoides* ↧*Globoquadrina asanoi*	*G. inflata* modern var. *G. inflata* trans. var.	↥*G. truncatulinoides* Cold event$_3$ • ↥*G. inflata* modern var.
		G. miozea conoidea	↧*Sphaeroidinellopsis* ↥*Globorotalia tosaensis* ↧*G. miozea conoidea*	*G. crassaformis/ G. puncticulata*	↥*G. praeinflata* ↧ Cold event$_2$ • ↥*G. inflata* prim. var.
N20	*Sphaeroidinella dehiscens/ G. tosaensis*		↧*G. margaritae* ↓*Globigerina nepenthes*		↧*G. margaritae* *Globigerina nepenthes*
N19		*Pulleniatina primalis/ Globigerina nepenthes*		*G. crassaformis/ G. conomiozea*	↥*Globorotalia puncticulata* *G. crassaformis*
N18	*G. tumida/ S. dehiscens*				↥*G. tumida* Cold event$_1$ •
N17	*G. tumida plesiotumida*	*Globorotalia tumida plesiotumida*	↥*Globorotalia tumida* ↥*P. primalis* ↥*G. tumida plesio tumida*		
N16	*G. tumida tumida merotumida*	*Globoquadrina dehiscens*			

nepenthes (N20–N19) cannot be recognized at Leg 57 sites. The *G. asanoi* F.A. (F.A. = first appearance) can be recognized at about 3.5 m.y.

Because of severe dissolution,the Miocene/Pliocene boundary and the early Pliocene Zone N18 are absent. Although the late Miocene index species *G. tumida plesiotumida,* which defines Zone N17 in Japanese sections, is also absent, characteristic late Miocene species of N17 are present (Table 7). *G. tumida merotumida,* which defines Zone N16 in Japanese sections, is present along with *G. lenguaensis, G. menardii, Globoquadrina altispira,* and *G. dehiscens.*

Difficulties in recognizing the Japanese zones in the Japan Trench sites are probably due to severe dissolution within these sections. Two (*G. asanoi* F.A. and L.A.) and possibly three (*Globorotalia tosaensis* L.A.) datum levels proposed by the Japanese workers can be recognized. The *Globoquadrina asanoi* datum levels combined with the faunal events of the two morphotypes of *Globorotalia inflata, G. inflata praeinflata,* and the two Pleistocene occurrences of *N. pachyderma* form 2 provide useful datum planes for the mid-latitudes of the North Pacific.

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TABLE 7
Biostratigraphic Data of Leg 57 Sites in Terms of the Zonations of Asano et al. (1975) and Oda (1977) and the Datum Levels of Keller (1978a, 1979a)

N Zone (Blow [1969])	Asano et al. (1975) / Oda (1977)	Occurrence of Important Species in Leg 57 Sites	Datum Levels (after Ikebe et al. [1976])	Datum Levels (after Keller) [1978a, 1979a])
N22	*Pulleniatina obliquiloculata Globorotalia truncatulinoides*	↧*G. tosaensis* (0.7 my) *G. truncatulinoides* *P. obliquiloculata* Two occurrences of *N. pachyderma* form 2	*Globorotalia tosaensis* ↧	←*N. pachyderma* f2 (0.7) ←*N. pachyderma* f2 (0.9)
	G. truncatulinoides			
N21	Zone not recognized	↧*Globoquadrina asanoi* (= *N. pachyderma* f3) ↧*Globorotalia puncticulata* *G. tosaensis* ↧*G. ikebei* ↥*G. inflata* modern var. ↥*G. inflata praeinflata* ↥*G. inflata* prim. var.	*Globoquadrina asanoi* ↧	↥*Globorotalia inflata* modern var. (2.0–2.2my) ↥*G. inflata* trans. var. (2.5–2.6 my) (= *G. inflata praeinflata)* ↥*G. inflata* prim. var. (2.8–3.0 my)
N20?	Zone not recognized	↧*G. conomiozea* *G. juanai*		
N19	Zone not recognized	↥*G. ikebei* ↥*G. asanoi* (= *N. pachyderma* f3)	*G. asanoi* ↥	
N18	Zone not present owing to dissolution			
N17	Zone not recognized	*Globigerina nepenthes* *Globorotalia ciboaensis* *G. lenguaensis* *G. menardii* *Neogloboquadrina acostaensis* *Sphaeroidinella subdehiscens*		
N16	*G. tumida merotumida*	*G. lenguaensis* *G. menardii* *Globoquadrina altispira* *G. dehiscens* *G. merotumida*		

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PLATE 1
(Bars represent 100 μm.)

Figure 1	*Globigerina parabulloides.* Sample 440-1-3. Pleistocene.
Figure 2	*Globigerina quadrilatera.* Sample 438A-6,CC. Upper Pliocene.
Figures 3, 4	*Globigerina rubescens.* Sample 440A-4,CC. Pleistocene.
Figure 5	*Globigerina foliata.* Sample 440-1-3. Pleistocene.
Figure 6	*Globigerina foliata.* Sample 440A-5-6. Pleistocene.
Figure 7	*Globigerina apertura.* Sample 438-9-4. Upper Pliocene.
Figure 8	*Globigerinita glutinata.* Sample 438-3-2. Pleistocene.
Figures 9, 10	*Globigerina umbilicata.* Sample 438A-6,CC. Upper Pliocene.
Figure 11	*Neogloboquadrina dutertrei.* Sample 440A-4,CC. Pleistocene.
Figure 12	*Neogloboquadrina dutertrei.* Sample 440B-21-4. Upper Pliocene.
Figure 13	*Neogloboquadrina pachyderma.* Sample 440B-16, CC. Upper Pliocene.
Figures 14, 15, 16	*Neogloboquadrina pachyderma* form 2 (encrusted). Sample 440B-7,CC. Upper Pleistocene.

PLATE 1

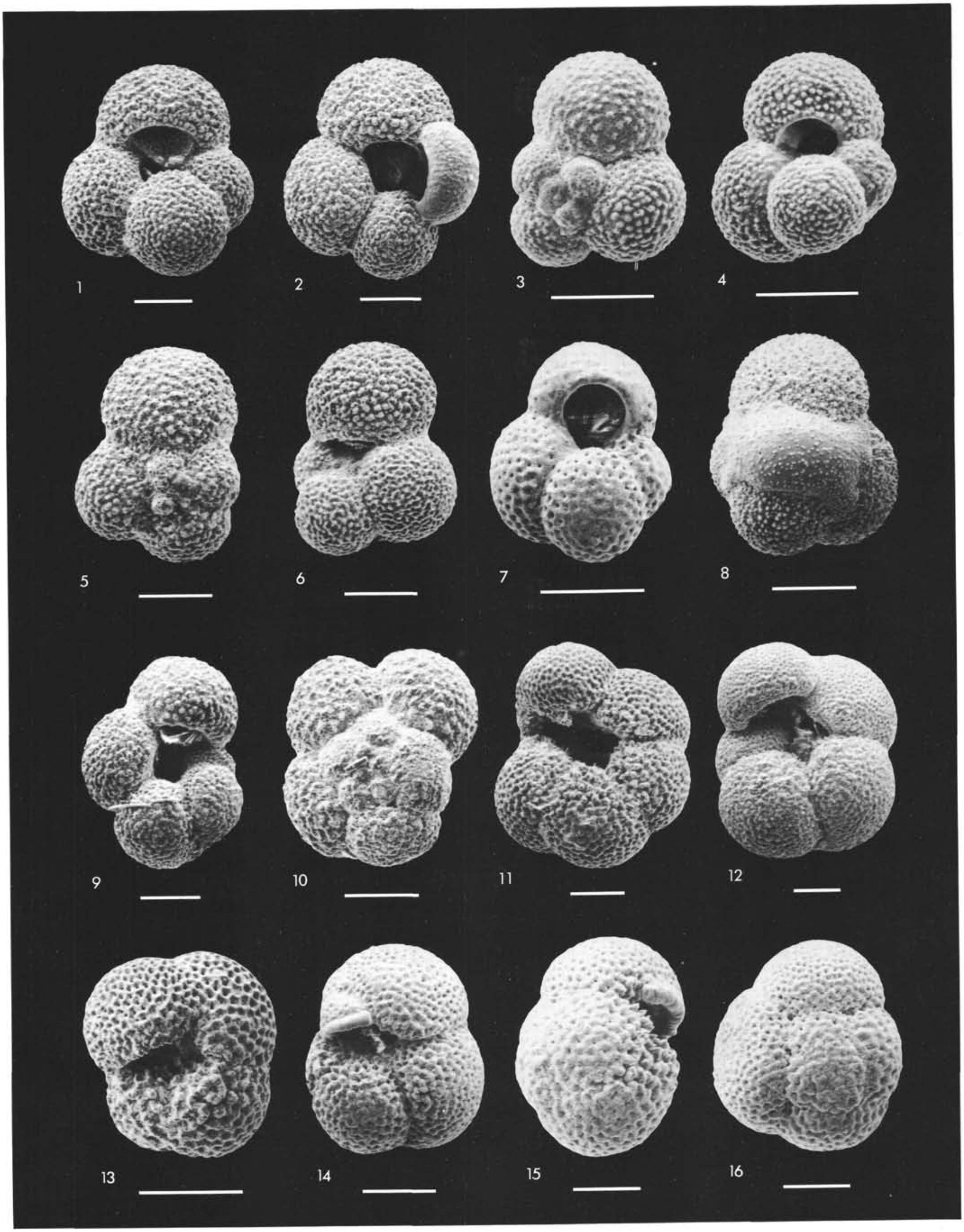

PLATE 2
(Bars represent 100 μm.)

Figures 1-5	*Neogloboquadrina pachyderma* form 2. Sample 438A-11,CC. Pliocene.
Figures 6-8	*Globoquadrina asanoi (=N. pachyderma* f3). Sample 438-9-4. Upper Pliocene.
Figures 9–11	*Globoquadrina asanoi (=N. pachyderma* f3). Sample 440B-21-4. Upper Pliocene.
Figures 12, 13	*Neogloboquadrina continuosa.* Sample 438A-39, CC. Upper Miocene.
Figures 14–16	*Pulleniatina obliquiloculata.* Sample 440-4-5. Pleistocene.

PLATE 2

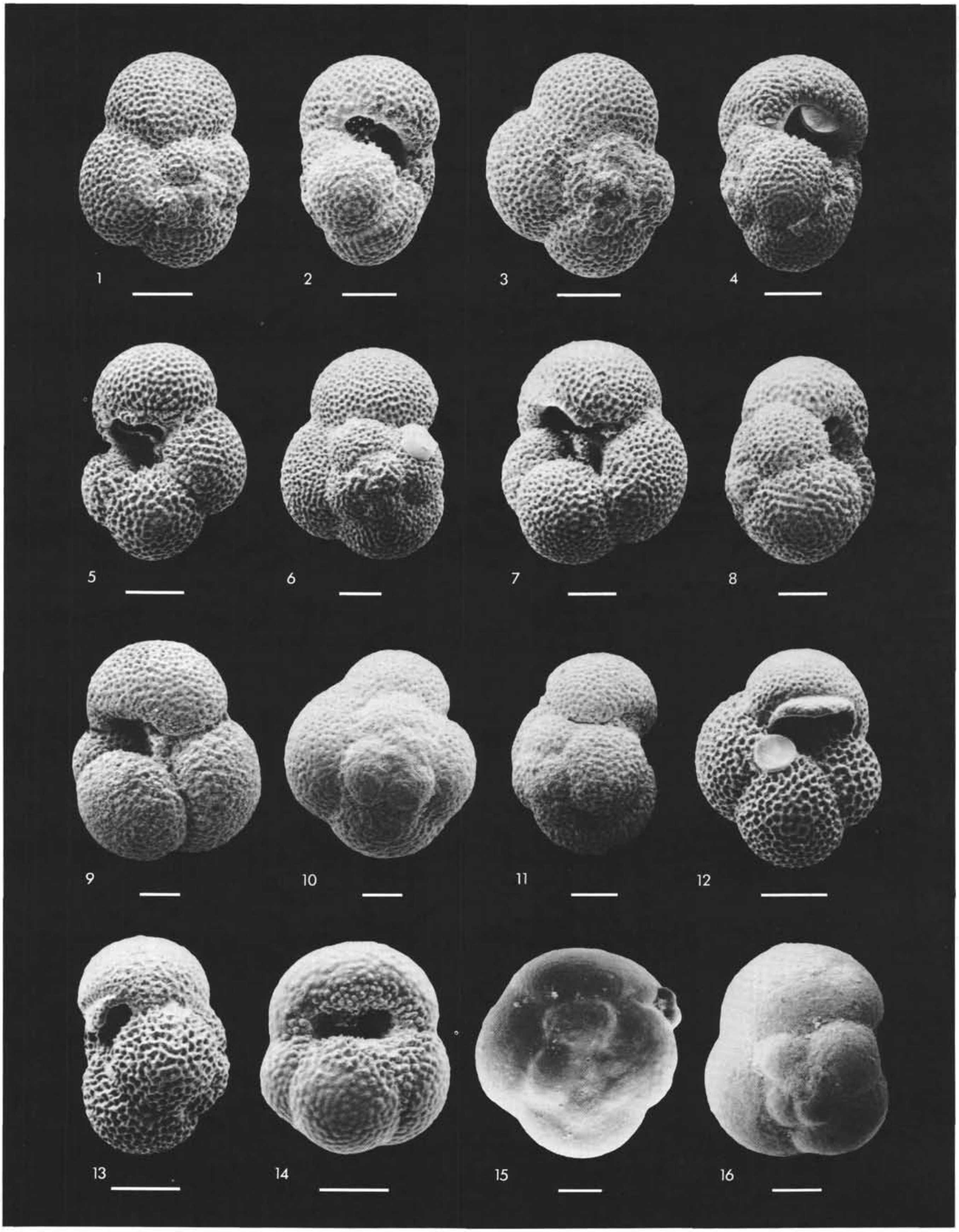

PLATE 3
(Bars represent 100 μm.)

Figure 1	*Globorotalia inflata* modern var. Sample 440-1-3. Pleistocene.
Figures 2, 3	*Globorotalia inflata* modern var. Sample 438-3-5. Pleistocene.
Figure 4	*Globorotalia inflata praeinflata*. Sample 438-9-4. Upper Pliocene.
Figures 5–8	*Globorotalia inflata* primitive var. Sample 440B-23-2. Pliocene.
Figures 9–11	*Globorotalia inflata* modern var. Sample 440B-17-2. Lower Pleistocene.
Figure 12	*Globorotalia crassaformis*. Sample 438-2,CC. Pleistocene.
Figures 13, 14	*Globorotalia truncatulinoides*. Sample 440-1-3. Pleistocene.
Figure 15	*Globorotalia tosaensis*. Sample 440B-21-4. Upper Pliocene.
Figure 16	*Globorotalia hirsuta*. Sample 438-2-2. Pleistocene.

PLATE 3

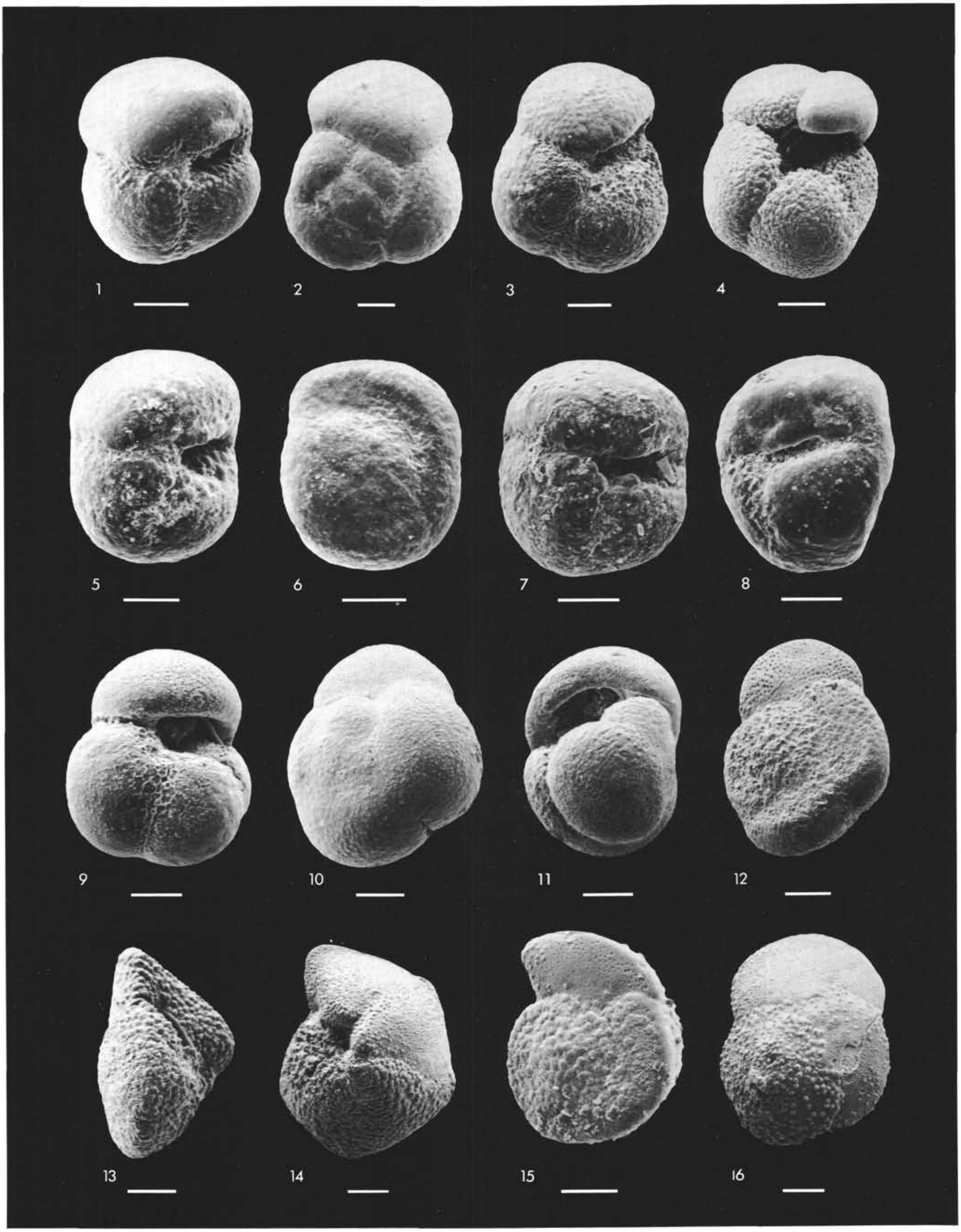

PLATE 4
(Bars represent 100 μm.)

Figure 1	*Globorotalia conoidea.* Sample 438A-56,CC. Upper Miocene.
Figures 2, 3	*Globorotalia conomiozea.* Sample 438A-12-1. Pliocene.
Figure 4	*Globorotalia conomiozea.* Sample 438A-52,CC. Upper Miocene.
Figure 5	*Globorotalia juanai.* Sample 438A-16-4. Pliocene.
Figures 6–8	*Globorotalia* cf. *scitula.* Sample 438A-52,CC. Upper Miocene.
Figure 9	*Globorotalia tumida.* Sample 440B-16,CC. Upper Pliocene.
Figure 10	*Globorotalia tumida.* Sample 440B-23-2. Upper Pliocene.
Figures 11, 12	*Globorotalia tumida merotumida.* Sample 438A-57-4. Upper Miocene.
Figure 13	*Globorotalia ikebei.* Sample 438A-11,CC. Pliocene.
Figures 14–16	*Globorotalia ikebei.* Sample 438-12-1. Pliocene.

PLATE 4