6. NEOGENE PLANKTONIC FORAMINIFERS FROM THE CENTRAL NORTH PACIFIC, DEEP SEA DRILLING PROJECT LEG 62¹

Edith Vincent, Scripps Institution of Oceanography, La Jolla, California

ABSTRACT

Two sites (463 and 466) drilled during Deep Sea Drilling Project Leg 62 in the central North Pacific yielded substantial Neogene calcareous sequences. At Site 463, in the Mid-Pacific Mountains, a very condensed upper Miocene to Pleistocene section accumulated at an average rate of 3 m/m.y., whereas at Site 466, on southern Hess Rise, a welldeveloped Pliocene-Pleistocene sequence accumulated at an average rate of 15 m/m.y. The latter sequence provides a valuable complement to that of nearby Site 310, on central Hess Rise. An abrupt change in sedimentary regime occurred about 4.2 m.y. ago on Hess Rise, from very slow deposition or non-deposition during the early Neogene, to more-normal pelagic sedimentation during the rest of the Neogene and Pleistocene. At both Sites 463 and 466, as at other drilling sites of the central North Pacific, the lower few meters of the Neogene section contain mixed sediments, which include common reworked Eocene foraminifers and abundant phillipsite and are separated from underlying sediments by a major unconformity (equivalent to a time span of about 20 m.y. or more).

Site 463 lies under the central area of the subtropical central water mass, whereas Site 466 lies under its northern part, near the boundary with transitional waters. Planktonic-foraminifer faunas at Site 463 are dominated by *Globigerinoides ruber*, and those at Site 466 by right-coiling *Neogloboquadrina pachyderma* and globorotaliids of the *G. conoidea* and *G. inflata* groups. Climate-induced shifting of water masses throughout the Plio-Pleistocene is recorded at Site 466, as well as at other mid-latitude sites of the North Pacific. During two intense coolings in the middle Pliocene ($\sim 3.1 \text{ m.y.}$ ago) and in the late Pleistocene ($\sim 0.8 \text{ m.y.}$ ago), left-coiling *N. pachyderma* migrated south over southern Hess Rise. Short-term fluctuations in carbonate content correlatable over the equatorial Pacific and central Hess Rise are not detected in the carbonate stratigraphies of Sites 466 and 463 established with a sampling interval of about 70,000 and 500,000 years, respectively.

INTRODUCTION

One of the main objectives of DSDP Leg 62 was to recover Mesozoic and Cenozoic pelagic calcareous sediments at various latitudes of the North Pacific for paleoenvironmental reconstruction of this basin. Four sites (463, 464, 465, and 466) were continuously cored on the Mid-Pacific Mountains and on Hess Rise (Table 1; Fig. 1), which are among the very few structural units of the North Pacific sufficiently elevated above the abyssal sea floor to yield carbonate sections. Those two physiographic features, together with Shatsky Rise, had been drilled previously during Leg 32 (Table 1). Neogene calcareous sequences were recovered at three sites during this leg. Site 313, in the northeastern Mid-Pacific Mountains, is of little biostratigraphic and paleoceanographic value, because of discontinuous coring and because the site is a locale of slumping where mixed redeposited sediments accumulate. Sites 305 and 310, on Shatsky Rise and Hess Rise, respectively, yielded valuable records of late Neogene planktonic-foraminifer and paleoceanographic events. The location of these two sites in an area intermediate between subtropical and temperate regions (Fig. 1) makes them ideal for recording the shifting of water masses through time. However, Neogene sections recovered at Sites 305 and 310 are incomplete, and we hoped to obtain more-complete Neogene sequences during Leg 62. Furthermore, by sampling additional sites at latitudes lower and higher than those of Sites 305 and 310, we expected to refine Neogene biostratigraphic correlations between subtropical and temperate areas, allowing a detailed paleoceanographic reconstruction of the western North Pacific for the time interval. We fell short of this objective, however, because the recovery of condensed sections with major hiatuses at all Leg 62 sites precludes biostratigraphic and paleoceanographic investigation of the entire Neogene. However, a well-developed Plio-Pleistocene calcareous sequence was recovered at Site 466, on southern Hess Rise; this sequence provides a valuable complement to that of nearby Site 310.

METHODS

Samples of approximately 10 cm^3 were taken, using a sampling interval of about 1.5 meters. Calcium carbonate content was measured by a gasometric technique. The samples were then washed through a 63-µm sieve. Dried samples were weighed before and after washing, to obtain the percentage of sand-sized components. Calcium carbonate and coarse-fraction percentages are given in Tables 2 through 5.

Samples from Sites 463 and 466 were divided into two sieve fractions of greater and less than 149 μ m; the coarser of these two fractions was used for abundance estimates of planktonic foraminifers. A quantitative analysis was conducted only in the stratigraphically highest samples of these two sites (Table 6), and abundances of planktonic species in the remainder of the sequences were visually estimated (Tables 7 and 8). Because of the preliminary nature of this report, however, the species lists in these tables are not exhaustive.

The stratigraphic ranges of diagnostic taxa at Sites 463 and 466 are plotted against sub-bottom depths and zonations of various fossil groups (Figs. 2 and 3). Neogene foraminifer data from other North Pacific drilling sites, published by various authors (see Table 1), were compared with those obtained at Sites 463 and 466.

¹ Initial Reports of the Deep Sea Drilling Project, Volume 62.

Table 1. Location of DSDP sites used in this study and source of data on late Neogene planktonic foraminifers.

Leg	Site	Latitude	Longitude	Water Depth (m)	Physiographic Province	Neogene Planktonic-Foraminifer Data
62	463	21°21′N	174°40'E	2525	Northwestern Mid-Pacific Mountains	This paper
62	464	39°51'N	173°53'E	4637	Northern Hess Rise	This paper
62	465	33°49'N	178°55'E	2161	Southern Hess Rise	This paper
62	466	34°11'N	179°15'E	2665	Southern Hess Rise	This paper
32	305	32°00'N	157°51'E	2903	Shatsky Rise	Vincent (1975, 1977a)
32	310	36°52′N	176°54′E	3516	Central Hess Rise	Vincent (1975, 1977a); Keller (1978a,c, 1979b,c)
32	313	20°10'N	170°57'W	3484	Northeastern Mid-Pacific Mountains	Vincent (1975)
31	296	29°20'N	133°31'E	2920	Palau-Kyushu Ridge	Ujiie (1975); Keller (1979a,b,c)
18	173	39°57′N	125°27′W	2927	Continental slope south of Mendocino Ridge	Ingle (1973a,b, 1977a,b); Keller (1978a,b, 1979b,c)
16	157	1°45′S	85°54'W	2591	Carnegie Ridge	Kaneps (1973); Keigwin (1976)
16	158	6°37′N	85°14′W	1953	Cocos Ridge	Kaneps (1973); Keigwin (1976)
5	36	40°59′N	130°06′W	3273	Abyssal hills north of Mendocino Ridge	Olsson and Goll (1970); Olsson (1971, 1974)



Figure 1. Location of DSDP sites and distribution of summer sea-surface temperatures (°C), living faunal assemblages, and major surface currents in the North Pacific (after Bradshaw, 1959; Vincent, 1975).

PLANKTONIC-FORAMINIFER ZONATION

Blow's (1969) planktonic-foraminifer zonation established in tropical areas was found applicable at Site 463 in the Mid-Pacific Mountains, but not to the Pliocene sequences of Sites 465 and 466, on southern Hess Rise, whose faunas are dominated by mid-latitude forms. Pliocene zonations established for the Atlantic (e.g., Berggren, 1973; Parker, 1973; Poore and Berggren, 1975) are not entirely applicable to other oceanic areas. Zonations have been developed for mid-latitude sequences of the Pacific (e.g., Jenkins, 1967, 1971; Kennett, 1973; Kennett and Vella, 1975; Keller, 1979c). It appears, however, that the applicability of these zonations in their entirety is very local, and that a new zonal scheme has to be devised for almost every site studied. The multiplicity of such zonal schemes results in confusion, because the same name applies to zones equivalent to a different time interval in different areas. For this reason, I prefer to use datum levels rather than a zonal scheme for age assignments of the Pliocene sections of southern Hess Rise.

Following Jenkins (1966, 1971) and Hornibrook and Edwards (1971), the datum-level concept has been emphasized in biostratigraphy during the last decade. Highresolution biochronologic frameworks have been developed recently for the late Neogene by the integration of FADs (First Appearance Datums) and LADs (Last Appearance Datums) of species from various fossil groups directly calibrated to the radiometric-magnetic time scale, or whose ages were approximated by extrapolation from sedimentation rates (e.g., Berggren and Van Couvering, 1974; Ryan et al., 1974). Selected datum levels for various fossil groups are reported in Figures 4 to 7 and serve as a basis for sedimentation-rate estimates.

Table 2. Percentages of	calcium	carbonate a	and coarse
fraction in Neogene	sedimen	ts from Site	463.

Sample	Sub-bottom Depth	CaCO3	Fraction $> 63 \ \mu m$
(interval in ein)	(11)	(30)	(30)
463-1-1, 100-102	1.01	80.2	13.7
1-2, 37-39	1.88	77.0	25.3
1-3, 37-39	3.38	77.8	23.4
1-4, 37-39	4.88	82.7	18.3
2-1, 38-40	5.89	83.9	18.1
2-2, 38-40	7.39	88.7	16.5
2-3, 38-40	8.89	89.2	10.8
2-4, 38-40	10.39	88.8	15.7
2-5, 38-40	11.89	89.1	7.9
2-7, 38-40	14.89	88.2	2.8
3-1, 28-30	15.29	85.7	2.8
3-2, 28-30	16.79	84.8	4.0
3-3, 28-30	18.29	83.0	3.0
3-4, 28-30	19.79	88.9	3.9
3-5, 28-30	21.29	90.6	4.2
3-6, 28-30	22.79	94.7	4.7
4-1, 48-50	24.99	93.5	4.9
4-2, 48-50	26.49	92.0	23.3
4-3, 48-50	27.99	87.3	2.4
4-4, 48-50	29.49	80.8	62.5
4-5, 48-50	30.99	92.6	14.5
4-6, 48-50	32.49	94.9	5.1
4-CC	34.00	95.0	7.4

Table 3. Percentages of	calcium carbonate and coarse
fraction in Neogene	sediments from Site 464.

Sample (interval in cm)	Sub-bottom Depth (m)	CaCO3 (%)	Fraction >63 μm (%)
464-2-1, 100-102	4.51	25.1	3.8
2-2, 58-60	5.59	39.1	3.7
2-3, 58-60	7.09	10.8	4.3
2-4, 58-60	8.59	23.3	4.2
2-5, 58-60	10.09	17.7	6.1
2-6, 58-60	11.59	6.2	6.6
2-7, 21-23	12.72	6.6	6.7
3-1, 50-54	13.52	13.4	6.1
3-2, 50-54	15.01	8.8	10.2
3-3, 50-54	16.51	2.5	6.3
8-154 (8		3.0	
3-4, 50-54	18.01	11.9	10.4
3-5, 50-54	19.52	0.0	5.3
Contract 2.4 - Tool And And And A		0.6	
3-6, 50-54	21.02	0.2	3.2
4-2, 78-82	24.80	2.3	2.7
4-3, 118-122	26.70	0.0	3.0
4-4, 40-44	27.42	0.5	2.2
4-5, 48-52	29.00	0.0	3.9
5-1, 40-44	32.42	0.0	3.9
5-2, 40-42	33.91	0.0	2.8
5-3, 40-44	35.42	0.0	2.6
5-4, 40-44	36.92	0.1	5.7
5-5, 40-44	38.42	0.1	1.4

Slight differences occur in the chronology proposed by various authors for the paleomagnetic "time scale", depending on the methodology used for estimating ages of paleomagnetic-epoch boundaries (e.g., Opdyke, 1972; Berggren and Van Couvering, 1974; Opdyke et al., 1974; Ryan et al., 1974; Theyer and Hammond, 1974, folTable 4. Percentages of calcium carbonate and coarse fraction in Neogene sediments from Site 465.

Sample (interval in cm)	Sub-bottom Depth (m)	CaCO3 (%)	Fraction >63 μm
465-1-1, 12-14	0.13	83.3	33.0
1-1, 46-48	0.47	85.6	28.9
1-1, 80-82	0.81	84.3	35.7
2-1, 14-16	1.15	82.6	38.2
2-1, 81-83	1.82	82.4	37.5
2-1, 136-138	2.37	86.8	34.5
2-2, 21-23	2.72	89.3	19.1
2-2, 82-84	3.33	91.4	6.7
2-2, 136-138	3.87	91.6	6.9
2-3, 30-32	4.31	91.2	5.9
2-4, 30-32	5.81	89.1	6.8
2-5, 70-72	7.71	94.4	7.3

lowed by Theyer et al., 1978; La Brecque et al., 1977; Mankinen and Dalrymple, 1979). These various schemes have been used by various authors for assigning ages to biostratigraphic datums calibrated to the magnetic time scale. Slight discrepancies thus occur in absolute ages assigned by different workers to the same biostratigraphic event occupying a specific position in the magnetostratigraphic sequence. This should be kept in mind in reading "absolute age" values given in this paper. which may be slightly off, although an attempt has been made to follow Mankinen and Dalrymple's (1979) paleomagnetic time scale (see upper scale in Fig. 7) for age assignments. More important than these values are the positions of biostratigraphic events in the magnetostratigraphic sequence, as well as their positions relative to other biostratigraphic events. As pointed out by Theyer et al. (1978, p. 380), "at the present stage, the most important facet is not so much the absolute chronology, but the *direct* (that is, within the same material) calibration of the biostratigraphic events against an independent system of discrete events of global character, such as magnetic reversals."

BIOSTRATIGRAPHY

Site 463

A 34-meter-thick section of upper Miocene to Quaternary nannofossil ooze was recovered at Site 463. Although condensed, the sequence appears continuous. The lower 5 meters of this Neogene section contains a mixture of reworked sediments of early and middle Miocene, Oligocene, Eocene, and Late Cretaceous ages. These mixed sediments unconformably overlie Oligocene sediments. The hiatus, which spans the entire middle and lower Miocene and uppermost Oligocene, is equivalent to a time span of about 16 m.y.

Foraminifers are the dominant constituent of the coarse fractions. They are moderately well to well preserved in the Pleistocene, well preserved in the upper Pliocene, and poorly preserved in the lower Pliocene and upper Miocene, as evidenced in this interval by a significant amount of fragmentation and concentration of solution-resistant species. Benthic species never con-

Table 5. Percentages of calcium carbonate and coarse fraction in Neogene sediments from Site 466.

	Sub-bottom		
Sample	Depth	CaCO ₃	Fraction
(interval in cm)	(m)	(%)	>63 µm
466-1-1, 18-20	0.19	79.0	7.0
1-1, 44-46	0.45	76.3	12.6
1-1, 67-69	0.68	79.7	15.2
1-1, 116-118	1.17	76.2	6.4
1-2, 50-52	2.01	72.6	8.7
1-2, 100-102	2.51	56.7	5.5
1-3, 50-52	3.51	70.6	4.0
1-3, 100-102	4.01	74.8	5.8
1-4, 72-74	5.23	90.5	4.0
1-5, 50-52	6.51	79.9	5.2
1-5, 100-102	7.01	86.3	4.2
1-6, 50-52	8.01	87.9	4.0
2-1, 50-52	8.51	81.9	6.9
2-1, 100-102	9.01	80.5	5.2
2-2, 50-52	10.01	79.1	7.5
2-2, 100-102	10.51	74.0	16.0
2-3, 100-102	12.01	76.6	13.8
2-4, 50-52	13.01	81.1	8.7
2-4, 100-102	13.51	83.6	10.5
2-5, 50-52	14.51	74.7	14.4
2-5, 100-102	15.01	75.5	17.6
2-6, 50-52	16.01	68.6	15.4
2-0, 100-102	16.51	/5.5	14.2
3-1, 97-99	18.04	82.4	20.0
3-2, 53-55	19.54	81.3	11.8
3-2, 97-99	19.98	81.8	13.8
3-3, 53-55	21.04	79.6	13.0
3-3, 97-99	21.48	84.8	14.5
3-4, 53-55	22.54	87.3	4.6
3-4, 97-99	22.98	81.6	8.7
3-3, 33-33	24.04	80.2	0.3
4-1, 50-52	27.51	73.2	17.7
4-1, 100-102	28.01	78.8	14.8
4-2, 50-52	29.01	87.9	8.9
4-2, 100-102	29.51	84.0	8.8
5-1, 50-52	37.01	87.2	7.7
5-1, 100-102	37.51	88.4	8.1
5-2, 50-52 5-2, 100-102	38.51	89.0	3.5
5-3, 50-52	40.01	91.3	4.7
5-3, 100-102	40.51	90.9	4.2
5-4, 50-52	41.51	89.5	5.9
5-4, 100-102	42.01	90.7	5.9
5-5, 50-52	43.01	92.1	1.8
5-5, 100-102	43.51	89.0	3.0
6-1, 30-32 6-1, 110-112	40.31	88.0	15.8
6-2, 30-32	47.11	89.7	3.5
6-2, 110-112	48.61	86.1	6.6
6-3, 30-32	49.31	85.0	4.3
6-3, 110-112	50.11	84.1	5.5
6-4, 30-32	50.81	82.6	3.0
6-4, 110-112	51.61	88.5	5.3
6-5, 30-32	52.31	87.8	20.4
6-6, 30-32	53.81	78.0	13.6
6-6, 110-112	54.61	79.0	19.1
6-7, 15-19	55.17	90.3	7.9
7-1, 30-32	55.81	90.7	3.3
7-1, 110-112	56.61	91.2	3.8
7-2, 30-32	57.31	88.7	4.0
7-2, 110-112	58.11	75.6	4.3
1-5, 30-32	38.81	89.4	3.8

Table 5. (Continued).

Sample (interval in cm)	Sub-bottom Depth (m)	CaCO3 (%)	Fraction >63 μm
7-3, 110-112	59.61	87.4	4.9
7-4, 30-32	60.31	82.6	7.0
7-4, 110-112	61.11	79.5	7.4
7-5, 30-32	61.81		7.7
7-5, 110-112	62.61	94.9	1.0
7-6, 30-32	63.31	95.1	1.3
7-6, 110-112	64.11	96.2	0.8
7-7, 16-18	64.67	95.6	2.3

stitute more than about 3% of the total foraminifer fauna. Occasional ostracodes and echinoid spines are minor components of the coarse fraction.

The Plio-Pleistocene boundary defined at its Sicilian stratotype has been correlated into deep-sea sediments to a level equivalent to, or slightly younger than, the top of the Olduvai normal Paleomagnetic Event, thus being dated approximately at 1.6 m.y. (Haq et al., 1977). A number of paleontologic events have been shown to be closely associated with the Olduvai in paleomagnetically dated deep-sea cores. These events include the LADs of Globigerinoides obliguus and G. fistulosus at the top or just above the Olduvai, the LAD of Discoaster brouweri near the top of the Olduvai, and the FAD of Globorotalia truncatulinoides just below the base of the Olduvai (Berggren et al., 1967; Hays et al., 1969; Hays and Berggren, 1971; Gartner, 1973, 1977; Saito et al., 1975; Haq et al., 1977). The Plio/Pleistocene boundary at Site 463 is placed at approximately 4.5 meters, between Sections 3 and 4 of Core 1, at the level of the first occurrence of Globorotalia truncatulinoides (marking the N22/N21 foraminifer boundary) and of the last occurrences of Discoaster brouweri (marking the NN19/NN18 nannofossil boundary) and Globigerinoides fistulosus. Globigerinoides obliquus last occurs just above this level. As throughout the tropical Indo-Pacific, the last appearance of Globorotalia limbata coincides with the Plio/Pleistocene boundary (see Vincent, 1977b).

The FAD of Globorotalia tosaensis, which defines the base of Zone N21 and approximates the upper/ lower Pliocene boundary, occurs in the lower part of Core 2. The development of G. tosaensis from G. crassaformis was observed in a paleomagnetically dated core from the subtropical Indian Ocean (V20-163) in the lower part of the Gauss interval, typical G. tosaensis appearing first in the core just below the Mammoth event $(\sim 3.2 \text{ m.y.})$, very slightly above the first appearance of Globigerinoides fistulosus and below the extinction levels of Sphaeroidinellopsis spp. and Globoquadrina altispira (Hays et al., 1969; Bandy, 1975). The two latter events occur in this core between the Mammoth and the Kaena events (~3.0 m.y.). At Site 463, G. tosaensis and G. fistulosus first appear in Core 2, Section 4, at the same level as the disappearance of G. altispira. This horizon also coincides with the top of the continuous range of common occurrence of Sphaeroidinellopsis spp. (scattered rare occurrences of this genus, however,

		F	auna >149 μ m				Fauna >63 µn	Fauna 2	>175 µm	
	Site 313 1-1, 100-102 cm	Site 463 1-1, 100-102 cm	Site 305 1-2, 100-102 cm	Site 466 1-1, 18-20 cm	Site 310 1-1, 5-7 cm	Site 296 1-1, 84–86 cm	Site 310 1-1, 68-70 cm	Site 173 1-1, 107–109 cm	Site 158 1-1, 100 cm	Site 157 1-1, 100 cm
Group A										
Globoquadrina conglomerata		0.4								<5
Globorotalia theyeri				0.8						
Globorotalia cultrata	0.6	0.4				0.3			20-30	5-10
Globigerinoides conglobatus	3.2	7.0							< 5	< 5
Pulleniatina obliguiloculata						0.6			< 5	< 5
Globorotalia tumida	55.6	6.3		0.8		0.6			5-10	< 5
Globigerinoides sacculifer		14.1		0.8		3.5			< 5	< 5
Globigerinella siphonifera	0.5	3.5		0.4		1.5			< 5	< 5
Globigerinoides ruber	6.7	51.2	3.6	5.5	1.5	6.6			5-10	< 5
Sphaeroidinella dehiscens	24.0	0.4								
Globorotaloides hexagonus	2110	011		1.2					< 5	
Globigering glutingta			5.0	12	5 2	6.6	6	4	<5	<5
Globorotalia crassaformis	2.9	1.2	5.0		5.12	0.0	č	1966		<5
Globorotalia hirsuta		1.12	1.4	0.8						
Globorotalia truncatulinoides		3.5	0.5	7.9	4.5	43				
Globiaering falconensis		5.5	41	3.6	4.2	8.5	2	4	<5	<5
Orbuling universa	5.8		6.3	1.2	2.2	0.0	ĩ	2		
Globigaring digitata	13	2.5	0.5	1.2	20.20	0.7	÷	2	~5	~5
Neogloboguadring dutertrei	1.5	5.5		2.0		2.5			30-40	> 50
Globorotalia inflata		2.0	52.0	28.5	20.9	7.5	3		50-40	250
Cloborotalia taitula		2.0	1.4	20.5	20.9	0.0	1			
Neogloboguadzing pachudarma		0.4	17.4	28.6	47.0	0.9	16	74	~5	~5
Clabinging and the pachyaerma		0.4	15.0	20.0	47.0	0.9	10	74	-5	
Globigerina quinqueloba		1.0	0 (24	12.4	5.8		4	< 5	5 10
Globigerina bulloides		1.2	8.0	2.4	15.4	2.0	5	4	< 3	5-10
Miscellaneous		4.0		13.5		14.2	0			
Group B										
Globoturborotalita rubescens						1.7		1		
Turborotalita humilis						5.2				
Globigerinita iota						14.4	2			
Globigerinita uvula						2.0	25	1		
Group C										
Example (whole texts	20.59	31.10	1.67	0.60	1.08		2	1222	- 1.0	~1
riaginents/whole tests,	20.58	1.10	1.07	0.09	1.08		_	_	~1.0	<1
Parthia foreminifers	52.4	2.0	10.0	11.0	0.0				< 10	< 10
Dediclosions	54.4	3.0	19.0	26.1	9.0				< 40	< 40
IN AUTO DALLATIS			1.4	20.1	41.7					

Table 6. Faunal composition in the highest samples recovered at Sites 463 and 466 and other North Pacific and equatorial Pacific DSDP Sites.

Note: Data for Sites 305, 310, and 313 (fauna > 149 μ m) are from Vincent (1975); for Sites 296, 310, and 173 (fauna > 63 μ m) from Keller (1978b,c, 1979a); for Sites 157 and 158 (fauna > 175 μ m) from Keigwin (1976); (the sign — is used where data are not given). In the first two categories, the sites are arranged from left to right in order of increasing latitudes. Taxonomy follows that of Vincent and Berger (in press). Relative frequencies of planktonic-foraminifer species are expressed as percentages of the total planktonic-foraminifer fauna (percentage classes with a 5 or 10% increment are given for Sites 157 and 158). Planktonic species are ranked from top to bottom in order of decreasing habitat temperature according to Parker and Berger (1971) and Coulbourn et al. (1980). Group A: planktonic species > 149 μ m. Group B: planktonic foraminifer fagments to unfragmented planktonic foraminifers; percentages of benthic foraminifers in total foraminifer population; popu

Table 7. Distribution of N	Neogene planktonic	foraminifers at	Site 463.
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Series	Zone	Sample (interval in cm)	Preservation	Unfragmented Planktonic Foraminifers	Planktonic-Foraminifer Fragments	Benthic Foraminifers	Globigerina bulloides	"Globigerina" nepenthes	Globigerinella siphonifera	Globigerinita glutinata	Globigerinoides conglobatus	G. fistulosus	G. obliquus	G. ruber	G. sacculifer	Globoquadrina altispira	G. conglomerata	G. dehiscens	G. venezuelana	Globorotalia crassaformis	G. cultrata	G. inflata	G. limbata	G. scitula	G. tosaensis	G. truncatulinoides	G. tumida	Globorotaloides hexagonus	Neogloboquadrina acostaensis	N. dutertrei	N. pachyderma	Orbulina universa	Sphaeroidinella dehiscens	Sphaeroidinellopsis seminulina	S. subdehiscens
Pleist.	N23-N22	1-1, 100-102 1-2, 37-39 1-3, 37-39	M M M	A A A	C C A	R R R	Р	P	C C C		C C C		R	C C C	C C C					P P R	P P C	P		P P P		C C C	C C R			P P P	Ρ	R	C C R		Ρ
upper Pliocene	N21	1-4, 37-39 2-1, 38-40 2-2, 38-40 2-3, 38-40 2-4, 38-40	M M G G G	C A A A A	A A C C C	R R R R R	Р		R R R	R	C C	P R P	R R R C	C C C	CCCCC	R			R	C C R R	C R R R	P P	P R P	P P P	P R P		R R R R	Р		P P		R R R	R R R		R P
lower Pliocene	N18 to N19-N20	2-5, 38-40 2-7, 38-40 3-1, 28-30 3-2, 28-30 3-3, 28-30	M P P P	00000	A A A A A	R R R R R		С	R		C C		C R R	C R	C R	C R			R R	R	R R R R		P P	Р			R C P					C C C C C R	Ρ	R R R C	RCCCC
upper Miocene	N14 to N19-N20	3-4, 28-30 3-5, 28-30 3-6, 28-30 4-1, 48-50 4-2, 48-50 4-3, 48-50 4-4, 48-50 4-5, 48-50 4-6, 48-50	P P P P P P P M	C C C C C A R A A C	A A A A C A C C R	R R R R R R R R R R R R		CCCC			C C C C		R R R	R P	R C R	R P		R R	RRRR	- 1	Rew	ork	ed	Eoc	ene	: an	d O	ligc	P	ie fa	P	R R R as		R R R C	CCCC

Preservation: G, good; M, moderate; P, poor. Frequency: A, abundant; C, common; R, rare; P, present.

are found higher in the section throughout the upper Pliocene and Pleistocene); thus, there is good agreement between mid-Pliocene foraminifer events of paleomagnetically dated cores and those at Site 463 (although the stratigraphic sequence at the latter site is somewhat condensed), which allows an age assignment of about 3.0 m.y. for the interval represented by Core 2, Section 4.

The poor preservation of the lower Pliocene section, which eliminates diagnostic species, precludes a detailed biostratigraphy of this interval. The first appearance of *Sphaeroidinella dehiscens*, which defines the base of Zone N19, has been recorded in paleomagnetically dated tropical cores in the lower Gilbert (~4.9 m.y.), slightly above the Miocene/Pliocene boundary (Saito et al., 1975). This event appears to be delayed at Site 463 as at many other sites in subtropical to temperate areas of the Indo-Pacific (see Vincent, 1977b). *S. dehiscens* first occurs here in Core 2, Section 5, near the upper/ lower Pliocene boundary.

The LAD of "Globigerina" nepenthes has been recorded in paleomagnetically dated cores near the top of the Gilbert A event ($\sim 3.8 \text{ m.y.}$), the FAD of Globorotalia tumida in the lowermost Gilbert ($\sim 5.1 \text{ m.y.}$), and the LAD of Globoquadrina dehiscens just above the top of Epoch 5 ($\sim 5.2 \text{ m.y.}$) (Hays et al., 1969; Saito et al., 1975). The latter two datums approximate the Mio/Pliocene boundary. The evolutionary development of G. tumida cannot be observed at Site 463, where this taxon is very rare in the lower part of its range. At the level of its initial occurrence, however (in Core 3, Section 3), primitive specimens are present. This horizon is thought to approximate here the Mio/Pliocene boundary, in agreement with nannofossil data. On the other hand, the last appearances of "G". nepenthes and G. dehiscens in Sections 3 and 6 of Core 3, respectively, appear to be biostratigraphically too low (see Fig. 8).

It is not possible to make a precise age assignment for the autochthonous sediments of the mixed interval in Core 4 at the base of the Neogene section. This interval is not older than late Miocene, as indicated from nannofossil data (Zone NN11). The poorly preserved planktonic-foraminifer fauna contains common "G". *nepenthes, Sphaeroidinellopsis seminulina*, and S. subdehiscens, indicating a zonal interval from N14 to N19-N20 (middle Miocene to lower Pliocene), and commonly includes reworked Oligocene and Eocene assemblages, as well as a few Upper Cretaceous species.

Site 464

A 36-meter-thick section of siliceous and clayey Neogene sediments was recovered at Site 464 (Cores 1-5), which lies near the CCD, at 4600-meters water

					-															_	<u> </u>	_		_			_					_	_	_		
Series	Sample (interval in cm)	Unfragmented Planktonic Foraminifers	Planktonic-Foraminifer Fragments	Benthic Foraminifers	Globigerina bulloides	G. falconensis	"Globigerina" nepenthes	Globigerinella siphonifera	Globigerinoides conglobatus	G. obliques	G. ruber	G. sacculifer	Globoauadrina altispira	G. venezuelana	Clobandalla annoidan	Gioborotatta conotaea Gi crassoformis	G autrota	O. cuinaid	O. nilsuid	G. inflata	G. limbata	G. margaritae	G. puncticulata	G. scitula	G. sphericomiozea	G. theyeri	G. tosaensis	G. truncatulinoides	G. tumida	Globorotaloides hexagonus	Neogloboquadrina dutertrei	N. pachyderma	Orbulina universa	Sphaeroidinella dehiscens	Sphaeroidmellopsis seminulina	S. subdehiscens
Pleistocene	$\begin{array}{c} 1\text{-1, } 18\text{-}20\\ 1\text{-1, } 44\text{-}46\\ 1\text{-1, } 67\text{-}69\\ 1\text{-1, } 116\text{-}118\\ 1\text{-}2, 50\text{-}52\\ 1\text{-}2, 100\text{-}102\\ 1\text{-}3, 50\text{-}52\\ 1\text{-}3, 100\text{-}102\\ 1\text{-}4, 11\text{-}13\\ 1\text{-}4, 72\text{-}74\\ 1\text{-}5, 50\text{-}52\\ 1\text{-}5, 100\text{-}102\\ 1\text{-}6, 50\text{-}52\\ 2\text{-}1, 50\text{-}52\\ 2\text{-}1, 50\text{-}52\\ 2\text{-}1, 50\text{-}52\\ 2\text{-}3, 50\text{-}52\\ 2\text{-}3, 50\text{-}52\\ 2\text{-}3, 50\text{-}52\\ 2\text{-}4, 50\text{-}52\\ 2\text{-}5, 50\text{-}52\\ 2\text{-}6, 50\text{-}52\\ 3\text{-}1, 53\text{-}55\\ 3\text{-}1, 97\text{-}99\\ 3\text{-}2, 53\text{-}55\\ 3\text{-}3, 53\text{-}55\\ 3\text{-}4, 53\text{-}55\\ 3\text{-}5, 53\text$	CCCCCCRRRCCCCRRRCCCCCCCCCCCCCC	CRRRRAAARRCRRCRRRRRCCCCCCC	C C C C C C C R C R R R R R R R R R R R	R R C R R P P R R R P R C C C C C C C C	R R R	1 Mai	P R R P R R	P P P P	PP	RRPPPP PR PPR PPP PR PPP	R R P				P C C C C R R P C C C R A A C C C C R C C C C C C R C C C C	F		2	CACCCRCCACAAAAAACACACCCCCCC				R R P P R R P P R P P P		P C	R P P	CRCRRRPR RRRCRPP CR P	RR PPRRP	P P P	P R R R P P R R R R	C A A R R R A C C A A A A A A C C A C C R R R R	R P P R R R P P R R R R R R P P R R R P P R R R P P R	P P P R R P		
upper Pliocene	4-1, 50-52 4-2, 50-52 5-1, 50-52 5-2, 50-52 5-3, 50-52 5-3, 100-102 5-4, 50-52 5-5, 50-52 6-1, 30-32	C C C R R R C R R C R R	C C C R C R C R C R	R R R R R R R R R R R R R	R R R P R			P P P P P P P	P P P		P P P P	P P P	C R P	P R R C R		C R C A A A C C				C C A C R C A R C A R				P P P R			Ρ	С	P P P P		C P R R R R	RRRPPPRR	R R R R R R R R R R	P P P		PP
lower Pliocene	6-2, 30-32 6-3, 30-32 6-4, 30-32 7-1, 30-32 7-2, 30-32 7-2, 110-112 7-3, 30-32 7-4, 30-32 7-5, 30-32 7-5, 110-112 7-6, 30-32 7-7, 116-118	R R R R R R R R R R R R R R R R R R R	R A C C C A R C A	R R R R R R R R R	R R R P P R R R R	P P	Р	Р	Р	P P	P P	P R P P P P P P P	P P	P P P P						R	P	P P porke	P R P P	P P Dlig	cf.	ne a	and	Eo	P P R P cen	e fa	P C R R R R	R R	R R R R R R R R R	Р		P R R P R R R R R R

Table 8. Distribution of Neogene planktonic foraminifers at Site 466.

Frequency: A, abundant; C, common; R, rare; P, present.



Figure 2. Neogene biostratigraphy, calcium carbonate content, and coarse-fraction content at Site 463.

depth. This section overlies Upper Cretaceous to Eocene brown clay.

This Neogene sequence is virtually barren of planktonic foraminifers and was dated by siliceous microfossils and by poorly preserved calcareous nannofossils.

Coarse fractions contain pumice fragments in Core 1, and very abundant radiolarians and diatoms in the interval from Core 2 through Core 5, Section 3, together with rare sponge spicules, fish teeth, and volcanic glass. Only occasional foraminifers were found. A few specimens of *Neogloboquadrina dutertrei* and *Globorotalia inflata* occur in Core 2, Section 1; one specimen of *Globigerinita glutinata* in Core 2, CC; a few specimens of *Globigerina bulloides* and right-coiling *Neogloboquadrina pachyderma* in Core 3, Section 2; and two specimens, one each of *Sphaeroidinellopsis seminulina* and *Sphaeroidinellopsis subdehiscens*, in Core 4, Section 1.

Site 465

Undisturbed Neogene sediments were recovered only in the upper 4.5 meters (Core 1 and the upper part of Core 2) at Site 465. They consist of a highly condensed Pleistocene and Pliocene sequence of nannofossil ooze which overlies a 3.5-meter-thick interval (lower part of Core 2) of mixed Pliocene, Eocene, and Paleocene sediments. These mixed sediments in turn overlie upper Paleocene sediments. The major hiatus spans nearly 50 m.y.

Foraminifers are abundant and moderately well preserved in the upper part of the sequence, down to Core 2, Section 2. Throughout the remainder of Core 2, foraminifers are rare and poorly preserved, with a large amount of fragmentation. Phillipsite is common in the mixed interval containing reworked sediments in the lower part of Core 2.

The planktonic assemblages are dominated by globorotaliids characteristic of middle latitudes. *Globorotalia inflata* is abundant from the top of the section down to 1.8 meters (Sample 2-1, 81–83 cm), and less common with primitive forms in the interval from 1.8 to 3.3 meters (Samples 2-1, 81–83 cm through 2-2, 82–84 cm). Below that level, which probably approximates the upper/lower Pliocene boundary, *G. inflata* is absent and *G. conoidea* s.l. is common. *G. crassaformis* is common in the interval from 2.7 to 4.3 meters (Samples 2-2, 21–23 cm through 2-4, 30–32 cm).

A detailed study of the Neogene planktonic fauna recovered at Site 465 was not attempted, because of the little biostratigraphic and paleoceanographic value of



Figure 3. Neogene biostratigraphy, calcium carbonate content, and coarse-fraction content at Site 466.

nulation	
1.y.)	

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	Paleontological Event*	Position in Cores	Sub-Bottom Depth (m)	Position within Magnetostratigraphy	Approximate Age (m.y.)	Average Acc Rate (m	cumulation /m.y.)
1	T Globigerinoides obliquus					2 20	
2	T Globigerinoides fistulosus	-		Within or near		2.39	
3	T Discoaster brouweri	- 1-3, 34 cm to 1-4, 37 cm	4.5	(see text)	1.88		
4	B Globorotalia truncatulinoides						
5	NN16/NN15 boundary = T Reticulofenestra pseudoumbilica	2-5, 43 cm to 2-7, 42 cm	11.93-15	Upper Gauss (Gartner, 1973)	2.8	5.25	
6	T Globoquadrina altispira					\backslash	
7	T Sphaeroidinellopsis spp.		10.38	Near Mammoth event (see text)		\backslash	3.27
8	B Globorotalia rosaensis	- 2-4, 38 cm			ca 3.0		
9	B Globigerinoides fistulosus						
10	NN14/NN13 boundary = B Discoaster asymetricus	2,CC to 3-1, 33 cm	15-15.3	Base Gilbert A (Gartner, 1973)	3.95	3.0	
11	NN13/NN12 boundary = B Ceratolithus rugosus	3-1, 33 cm to 3-2, 33 cm	15.3-16.83	Within Gilbert C (Gartner, 1973)	4.56		
12	B Globorotalia tumida	3-3, 28 cm to 3-4, 38 cm	18.28-19.88	Lowermost Gilbert (Saito et al., 1975)	5.1		
13	NN12/NN11 boundary = T Discoaster quinqueramus	3-2, 33 cm to 3-3, 33 cm	~18	Near top of reversed event in Epoch 5 (Gartner, 1973)	5.5	>	
14	T "Globigerina" nepenthes	3-2, 28 cm to 3-3, 28 cm	16.78-18.28	Near top of Gilbert A (Hays et al., 1969)	3.8		
15	T Globoquadrina dehiscens	3-6, 28 cm to 4-1, 48 cm	23.08 - 24.98	Just above top of Epoch 5 (Saito et al., 1975)	5.2		

T = top; B = bottom

Figure 4. Average sediment-accumulation rates at Site 463. Nannofossil data from Schmidt (this,volume). Ages according to Mankinen and Dalrymple's (1979) paleomagnetic time scale.

Paleontological Event*		Position in Cores and Sub-bottom Depth (m)		Calibration to Paleomagnetic Time Scale					
		Sample in Which Event Occurs	Next Higher or Lower Sample	Magnetostratigraphic Position	Reference**	Approximate Age*** (m.y.)	Average Accumulation (m/m.y		erage lation Rate 'm.y.)
1	T Axoprunum angelinum (R)	1-1, 79 cm (0.79 m)	1-1, 15 cm (0.15 m)	Middle Brunhes	1, 2	0.44			
2	T Nitzchia reinholdii (D)	2-2, 130 cm (10.30 m)	2-1, 130 cm (9.30 m)	Lower Brunhes	3	0.65	7.2	13.0	
3	T Eucyrtidium matuyamai (R)	3-1, 77 cm (18.27 m)	2,CC (17.50 m)	Base of Jaramillo	4	0.98			
4	B Eucyrtidium matuyamai (R)	3-5, 77 cm (24.37 m)	3,CC (27.00 m)	Near base of Olduvai	4	1.88			
5	T Stichocorys peregrina (R)	5-1, 30 cm (36.80 m)	4,CC (36.50 m)	Midway in normal upper Gauss	5,6	2.67	T		15.5
6	T Globoquadrina altispira (F)		Midd	Middle Gauss	(see text) ca 3.0				
7	T Sphaeroidinellopsis spp. (F)	5-3, 50 (40 m) to 6-1, 30 (46.30 m)				ca 3.0	17.8		
8	B Globorotalia inflata (F)								
9	T. "Globigerina" nepenthes (F)				(- 20			
10	B Discoaster asymmetricus (N) (Base of NN14)	7-4, 30 cm (60.30 m)		Gilbert A	(see text)	ca 3.9	\square		

* T = top; B = bottom; R = radiolarian (Schaaf, this volume); D = diatom (Sancetta, this volume); N = calcareous nannofossil

(Schmidt, this volume); F = foraminifer (this paper).
** References: 1, Hays and Shackleton (1976); 2, Morley and Shackleton (1978); 3, Burckle (1977); 4, Hays (1970); 5, Saito et al. (1975); 6, Theyer et al. (1978).

*** Ages follow Mankinen and Dalrymple's (1979) paleomagnetic time scale.

Figure 5. Average sediment-accumulation rates at Site 466.

Paleontological Event*		Position in Cores and Sub-bottom Depth (m)		Calibration to Paleomagnetic Time Scale			Average	
		Sample in Which Event Occurs	Next Higher or Lower Sample	Magnetostratigraphic Position	References*	Approximate Age*** (m.y.)	Ra (m/n	te 1.y.)
1	T Axoprunum angelinum (R) ^a	1-3, 110 cm (4.10 m)	1-2, 40 cm (1.90 m)	Middle Brunhes	1, 2	0.44		
2	T Nitzschia reinholdii (D) ^b	2-2, 130 cm (7.80 m)	1-4, 149 cm (4.99 m)	Lower Brunhes	3	0.65	14.8	
3	T Mesocena elliptica (S) ^C	2-2, 20 cm (6.70 m)	1-4, 27 cm (4.77 m)	Middle of reversed interval between Jaramillo and Brunhes	3	0.82		
4	T Eucyrtidium matuyamai (R) ^a	2,CC (14.50 m)	2-4, 103 cm (10.53 m)	Base Jaramillo	4	0.98	>	12.8
5	B Mesocena elliptica (S) ^c	3-3, 20 cm (17.60 m)	3-6, 20 cm (22.20 m)	Upper reversed interval between Jaramillo and Olduvai	3	1.3	10.6	
6	B Pseudoeunotia doliolus (D) ^b	3,CC (24.0 m)	4-2, 101 cm (26.61 m)	Lower Olduvai	3, 5	1.8		
7	B Eucyrtidium matuyamai (R) ^a	3,CC (24.0 m)	4-1, 50 cm (24.5 m)	Near base of Olduvai	4	1.88	>	
8	B Globorotalia truncatulinoides (F) ^d	3-6, 123 cm (23.23 m)	3,CC (24.0 m)	Just below Olduvai	6	1.9		
9	T Thalassiosira convexa (D) ^{b,e}	4-4, 80 cm (30.80 m)	4-2, 101 cm (26.61 m)	Midway between Gauss/Matuyama boundary and base of Olduvai	5	2.26	12.3	
10	T Nitzschia jouseae (D) ^e	5-1, 60 cm (34.10 m)	4-4, 80 cm (30.80 m)	Midway in normal upper Gauss	5	2.67	1210	
11	T Stichocorys peregrina (R) ^a	5-2, 122 cm (36.22 m)	5-1, 124 cm (34.74 m)	Midway in normal upper Gauss	6, 7	2.67		11.5
12	B Lamprocyrtis heteroporos (R) ^a	7-1, 133 cm (53.83 m)	7-3, 125 cm (56.75 m)	Just below Gilbert B	8	4.3	>	
13	B Nitzchia jouseae (D) ^f	~ 54 m		Upper Gilbert C	9, 10	4.45		
14	B Ceratolithus rugosus (N) ^g	7-2, 73 cm (54.73 m)	7-3, 90 cm (56.4 m)	Within Gilbert C	11	4.56	0.5	
15	B Coscinodiscus nodulifer var. cyclopus (D) ^f	7-3 (56.5 m)		Base Gilbert C	12	4.71	>	n.y.
16	T Thalassiosira miocenica (D) ^f	7-3 (56.5 m)		Lower reversed Gilbert	10	4.92		~0.4 п
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17	T Dictyocha navicula (S) ¹	7-3 (56.5 m)		Lower reversed Gilbert	12	4.95		iatus	
18	T Asterolampra acutiloba (D) ^f	7-4 (57.6 m)		Top Epoch 5	10	5.26	>	<u></u> т	
19	B Dictyocha navicula (S) ^f	~ 58 m		Upper Epoch 5	12	5.3	Ţ		
20	T Nitzschia miocenica (D) ^f	7-5 (59.6 m)		Top reversed event of Epoch 5	10	5.43			
21	T Thalassiosira praeconvexa (D) ^f	7-5 (60.0 m)		Midway in normal lower Epoch 5	10	5.64	4.9	10.2	
22	B Thalassiosira convexa var. aspinosa (D) ^f	7-6 (61.7 m)		Upper Epoch 6	10	5.85]	10.2	
23	B Thalassiosira miocenica (D) ^f	8-1 (62.5 m)		Upper Epoch 6	10	5.95	>		
24	B Thalassiosira praeconvexa (D) ^f	8-4 (66.6 m)		Middle Epoch 6	10	6.20	17.5		
25	B Stichocorys peregrina (R) ^a	8-4, 124 cm (67.74 m)	8-5, 125 cm (69.25 m)	Middle Epoch 6	7	6.25	\searrow		3.0
26	B Nitzchia miocenica (D) ^f	8-9 (67.5 m)		Middle Epoch 7	10	7.12			
27	T Thalassiosira burckliana (D) ^f	8-5 (69.3 m)		Lower Epoch 7	10	7.48	1		
28	T Ommatartus hughesi (R) ^a	8-5, 125 cm (69.25 m)	8-4, 124 cm (67.74 m)	Uppermost Enosh 0	7	10000	1.0		
29	B Ommatartus penultimus (R) ^a	8-5, 125 cm (69.25 m)	8-6, 100 cm (70.5 m)	Oppermost Epoen 9	1	8.63		0	
30	T Discoaster hamatus (N) ^g	9-3, 50 cm (75.0 m)	9-3, 122 cm (75.72 m)	Middle Epoch 10	13	10.6	1		
31	B Discoaster hamatus (N) ^g	9-5, 49 cm (77.99 m)	9-5, 123 cm (78.73 m)	Lower Epoch 12	13	12.3			
32	B Catinaster coalitus (N) ^g	9-5, 123 cm (78.73 m)	9-6, 149 cm (80.49 m)	Lower Epoch 12	13	12.4	>		

* T = top; B = bottom; R = radiolarian; D = diatom; S = silicoflagellate; F = foraminifer; N = calcareous nannofossil.

Data Source: a. Foreman (1975); b. Koizumi (1975); c. Bukry (1978); d. Vincent (1975); e. J. Barron (pers. comm.); f. L. Burckle (pers. comm.); g. Bukry (1975).

** References: 1. Hays and Shackleton (1976); 2. Morley and Shackleton (1978); 3. Burckle (1977); 4. Hays (1970); 5. Burckle and Trainer (1979); 6. Saito et al. (1975); 7. Theyer et al. (1978); 8. Casey and Reynolds (1980); 9. Burckle and Opdyke (1977); 10. Burckle (1978); 11. Gartner (1973); 12. Burckle (pers. comm.); 13. Ryan et al. (1974).

*** Ages follow Mankinen and Dalrymple's (1979) paleomagnetic time scale.

Figure 6. Average sediment-accumulation rates at Site 310.

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Figure 7. Sedimentation-rate curves for Sites 463, 466, and 310.



Figure 8. Correlation of the Plio-Pleistocene sequences at Sites 310 and 466.

this fauna, owing to the highly condensed nature of the sequence. In this respect the well-developed Plio-Pleistocene sequence at nearby Site 466 is much more valuable.

Site 466

A 65-meter-thick Neogene section of nannofossil ooze, representing an apparently complete sequence

from the upper Pleistocene to the lower Pliocene, was penetrated at Site 466. The lower 5 meters of the Pliocene section contains a mixture of reworked sediments of middle and late Miocene, Oligocene, Eocene, and Late Cretaceous ages. These mixed sediments unconformably overlie upper Eocene sediments. The hiatus, which spans the entire Oligocene and Miocene, is equivalent to a time span of about 34 m.y.

Foraminifers are the dominant constituent of the coarse fractions. They are moderately well preserved in the Pleistocene and upper Pliocene (with an interval of poor preservation in the upper Pleistocene, within Sections 2 and 3 of Core 1), and poorly preserved in the lower Pliocene. Benthic species constitute about 10% of the total foraminifer fauna in the upper part of Core 1, and less than 5% throughout the remainder of the sequence. Other minor components of the coarse fractions include rare radiolarians and occasional ostracodes, throughout the sequence. Pyrite is common in Core 5, Section 3. Phillipsite is abundant at the base of the Neogene section in Core 7, associated with the reworked sediments. All transitions were observed between large (about 500 µm) twinned crystal aggregates with excellent terminations and roughly spherical aggregates in which the terminations have been severely abraded. The delicate crystal terminations protruding from many of the aggregates indicate that the phillipsite formed in situ, but the rounding of some aggregates also suggests some mechanical abrasion.

Globorotalia truncatulinoides first appears in the uppermost part of Core 1, just below the Plio/Pleistocene boundary, placed in the lowermost part of Core 3, at the FAD of the radiolarian species Eucyrtidium matuyamai, which defines the Lamprocyrtis heteroporos/E. matuyamai zonal boundary. This siliceous-fossil event occurs in paleomagnetically dated cores of the North Pacific near the base of the Olduvai (Hays, 1970). The N22/N21 boundary, marked by the FAD of G. truncatulinoides, is the only zonal boundary from Blow's (1969) scheme recognizable here.

The first occurrence of Globorotalia tosaensis in the upper part of Core 4, just slightly below the FAD of G. truncatulinoides, is not a biostratigraphic marker utilizable at Site 466, because it is much higher than the level of first evolutionary appearance of this species. Because of the delayed appearance of G. tosaensis at various mid-latitude drilling sites in the North Pacific, the base of Zone N21 at these sites was equated by Vincent (1975) and Keller (1978c, 1979a) to the first occurrence level of Globorotalia inflata. These two species appear to have evolved almost simultaneously, and their first occurrence has often been recorded at the same level in stratigraphic sequences from various areas (see Vincent, 1977b). G. tosaensis, however, apparently evolved slightly prior to G. inflata, as evidenced by Cita's (1973) observations of rare G. tosaensis together with forms transitional between G. inflata and its ancestor G. puncticulata in the Mediterranean.

The evolutionary transition from G. puncticulata to Globorotalia inflata has been observed in the southwest Pacific (Kennett, 1973) and in the North Atlantic (Berggren and Amdurer, 1973; Poore and Berggren, 1974) at or just below the NN16/NN15 nannofossil zonal boundary. This boundary (marked by the LAD of *Reticulofenestra pseudoumbilica*) falls into the upper Gauss (Gartner, 1973; Ryan et al. 1974), being slightly younger (~2.5-2.8 m.y.) than the extinction level of Sphaeroidinellopsis spp. and Globoquadrina altispira (~3.0 m.y.). It thus appears that the FAD of G. inflata in the middle Gauss is slightly younger than the FAD of G. tosaensis (~3.2 m.y.), slightly older than the LAD of R. pseudoumbilica (~2.8 m.y.), and very close in age to the LAD of Sphaeroidinellopsis spp. and G. altispira (~3.0 m.y.).

Globorotalia inflata first appears simultaneously or very slightly above the disappearance of Globorotalia conoidea and G. conomiozea at mid-latitude sites of the North Pacific (Olsson, 1971; Vincent, 1975; Keller, 1978c, 1979a) and South Atlantic (Berggren, 1977a,b). These two species are closely related. The 4- to $4\frac{1}{2}$ chambered, high angulo-conical G. conomiozea apparently evolved from the $4\frac{1}{2}$ - to 5-chambered, moderately angulo-conical G. conoidea in the late Miocene (Kennett, 1966).

There are two concepts regarding the ancestry of Globorotalia puncticulata. Kennett (1966, 1973), followed by Kennett and Vella (1975) and Scott (1979), interprets G. puncticulata as derived from G. conomiozea by reduction in the conical angle and loss of the peripheral keel. Doubts have been expressed on the existence of such an evolutionary trend in planktonic foraminifers, which commonly develop a keel, but rarely (if at all) lose one (Blow, 1969; Berggren, 1977a). Berggren (1977a), following the concept of the "Mediterranean school" (see references in Berggren, 1977a), who interpret G. puncticulata as derived from an unkeeled ancestral form, suggested Globorotalia cibaoensis as the direct ancestor of G. puncticulata. The FAD of G. puncticulata occurs in the lower Pliocene, within the B and C events of the Gilbert ($\sim 4.4 \text{ m.y.}$), slightly above the FAD of the nannofossil Ceratolithus rugosus, which occurs in the C event of the Gilbert (~4.7 m.y.) (Gartner, 1973; Cita and Gartner, 1973; Ryan et al., 1974).

Members of the G. conoidea-G. conomiozea and the G. puncticulata-G. inflata groups have been utilized in late Neogene biostratigraphy of temperate areas throughout the world ocean (e.g., [South Pacific] Hornibrook, 1958; Kennett, 1966, 1967, 1973; Jenkins, 1967, 1971; Collen and Vella, 1973; Kennett and Watkins, 1974; Kennett and Vella, 1975; [North Pacific] Olsson, 1971; Ikebe et al., 1972; Vincent, 1975; Maiya et al., 1976; Ikebe, 1977; Oda, 1977; Keller, 1978c, 1979a; [Indian Ocean] Bandy, 1975; Vincent, 1977a,b; [North Atlantic] Cita, 1971; Berggren, 1972; Berggren and Amdurer, 1973; Poore and Berggren, 1974, 1975; Poore, 1979; [South Atlantic] Berggren, 1977a,b; [Mediterranean] Bertolino et al., 1968; Bizon and Bizon, 1972; Cita, 1973, 1975; D'Onofrio et al., 1975; Zachariasse, 1975). Taxonomic reviews of members of this foraminifer plexus have been presented, and their relationships to a biochronologic framework has been discussed (see Berggren and Amdurer, 1973; Poore and Berggren, 1974; Ryan et al., 1974; Berggren, 1977a).

Vincent (1975) did not differentiate G. conoidea and G. conomiozea in her North Pacific study, owing to the difficulty of distinguishing the number of chambers in heavily encrusted forms, and referred both forms to G. conoidea s.l., whereas Keller (1978c, 1979a) differentiated both species. For the sake of consistency with my previous work, and also because the ambiguity as to the

At Site 466, G. inflata first appears in the upper part of Core 6, slightly above the disappearance of G. conoidea s.l., as also at Sites 36, 296, 305, and 310. This horizon falls at Site 466 in the Sphaeropyle langii radiolarian zone of Foreman (1975), as also at Sites 305 and 310, but in a lower stratigraphic position with respect to the nannofossil zonation-that is, within NN14 at Site 466, instead of the Discoaster tamalis Zone (equivalent to NN16) at Sites 296, 305, and 310 (Bukry, 1975; Ellis, 1975). At Site 466, the first G. inflata slightly precedes the disappearance of Sphaeroidinellopsis spp. and Globoquadrina altispira, as at Site 296 and 305 (at the latter site the appearance of G. inflata is coincidental with the disappearance of G. altispira, slightly below the disappearance of Sphaeroidinellopsis spp.). At Site 310, however, G. inflata first appears above the disappearance of Sphaeroidinellopsis spp., as at Sites 36 and 173.

The difference in the relative position of these two foraminifer levels (the appearance of G. inflata on the one hand, and the disappearance of Sphaeroidinellopsis spp. and G. altispira on the other hand) at various North Pacific sites probably results from a latitudinal effect. Modern populations of Globoquadrina conglomerata, the direct descendant of G. altispira, show a narrow temperature tolerance, with maximum concentration along a narrow equatorial belt (Bradshaw, 1959; Coulbourn et al., 1980). G. altispira, which probably had a similar habitat preference, is indeed absent in the Pliocene of the higher-latitude Sites 310, 173, and 36. The upper range of the warm-water forms Sphaeroidinellopsis spp. possibly could be curtailed at these three sites. However, the direct descendant of these forms, Sphaeroidinella dehiscens, today exhibits a latitudinal range much wider than that of G. conglomerata; also, the last occurrence of Sphaeroidinellopsis spp. appears to be a reliable datum throughout a wide latitudinal range. Its stratigraphic position relative to the LAD of R. pseudoumbilica is consistent in various oceanic areas. Both these datum levels occur close to each other, or are coincidental, in the equatorial Pacific, as well as in the Atlantic and Mediterranean (Gartner, 1973; Saito et al., 1975; Mazzei et al., 1979). The last occurrence level of Sphaeroidinellopsis spp. occupies the same position at mid-latitude Site 310 as in equatorial Pacific cores, with respect to carbonate stratigraphy (Vincent, this volume). Thus, if the LAD of Sphaeroidinellopsis spp. is a reliable datum at all North Pacific sites mentioned, G. inflata would have migrated to Sites 310, 36, and 173 later than the time of its appearance at lowerlatitude Sites 296, 305, and 466. Keller (1979b) noted that the initial appearance of G. inflata at several North Pacific sites is associated with a marked cool event. From age estimates based on sedimentation-rate extrapolations, she concluded that this event is diachronous, and apparently occurred later at Site 173 than at Sites 310 and 296. Modern populations of G. inflata show a narrow tolerance to surface-water temperature variations. Living populations of this species in the North Pacific are restricted to the subtropical central fauna (see Fig. 1), with an optimum surface-water temperature range between 21 and 22°C (Bradshaw, 1959). In North Pacific surface sediments, *G. inflata* dominates only the northern periphery of this faunal province (Coulbourn et al., 1980).

It should be noted that the LAD of Sphaeroidinellopsis spp. is difficult to pinpoint in some sedimentary sections, because of scattered, rare occurrences of S. subdehiscens well above the top of its consistent common occurrence, as for example at Site 463 (see above) and at Site 305 (Vincent, 1975). Notwithstanding, the appearance level of G. inflata needs to be calibrated to a system of events independent of planktonic foraminifers, in order to precisely evaluate migration trends. In this respect, further detailed studies of mid-Pliocene sequential events in other fossil groups at Site 466 may provide useful information.

From the foregoing discussion, it appears that it is difficult to pinpoint the upper/lower Pliocene boundary at Site 466 on the basis of foraminifer data. However, the 3.0 m.y. horizon can be placed in the interval from Core 5, Section 3 (level of *G. altispira* last occurrence) through Core 6, Section 1 (level of *G. inflata* first occurrence), in agreement with radiolarian data. The radiolarian species *Stichocorys peregrina*, whose extinction level has been calibrated to the upper Gauss ($\sim 2.6 \text{ m.y.}$) (Theyer et al., 1978), last occurs slightly above, in the uppermost part of Core 5.

Morphological trends in *G. inflata* from primitive $3\frac{1}{2}$ - to 4-chambered forms with a rather quadrate equatorial outline to modern 3-chambered forms with a rounded outline and highly glassy wall have been described by Vincent (1975) and Keller (1978c). Primitive subquadrate forms of this species occur at Site 466 in the lower part of its range throughout Core 5. Only rare occurrences of forms referable to *G. puncticulata* were noted in Cores 6 and 7.

As at Site 463, Sphaeroidinella dehiscens shows a delayed first appearance at Site 466, where it first occurs at approximately 56 meters, a level equivalent to an age of about 3.6 m.y., judging from sedimentation-rate extrapolations (see Fig. 7). Globorotalia margaritae and "G". nepenthes last occur together in Core 7, Section 4, just above the mixed interval. At Site 296, the last occurrences of these two species also coincide, whereas at Site 310 G. margaritae ranges above "G". nepenthes and at Site 305 "G". nepenthes ranges above G. margaritae. G. margaritae and "G". nepenthes extinction levels in the subtropical Indian Ocean correlate with the Gilbert/Gauss boundary ($\sim 3.4 \text{ m.y.}$) and the top of the Gilbert A event (~3.8 m.y.), respectively (Hays et al., 1969). Vincent (1975; this volume) and Keller (1979c) have shown from evidence based on sedimentation rate extrapolation and carbonate stratigraphy that these two species disappear slightly earlier at mid-latitude sites of the North Pacific. Nannofossil data (Bukry, 1975; Ellis, 1975; Schmidt, this volume) suggest that these two species disappeared later at Site 296 (within nannofossil Zone NN15) than at Site 466 (within NN14) and Sites

310 and 305 (within Zones NN13 and NN12). It thus appears that sediments in Sample 7-4, 30-32 cm at Site 466, just above the mixed interval, which include both G. margaritae and "G". nepenthes, have a minimum age of about 3.8 m.y. (age of LAD of "G". nepenthes), but are probably slightly older. They are not older, how ever, than the base of the NN14 Zone, defined by the FAD of Discoaster asymmetricus, which occurs in paleomagnetically dated cores just below the base of the Gilbert A event (~4.0 m.y.) (Gartner, 1973).

The mixed interval at the base of the Neogene section (the remainder of Core 7) belongs to nannofossil Zone NN14. The autochthonous lower Pliocene planktonicforaminifer fauna is poorly preserved and mixed with abundant reworked Oligocene and Eocene assemblages and rare Cretaceous species. Elimination of diagnostic species precludes a precise age assignment for the autochthonous fauna. However, the presence of *Globorotalia crassaformis* throughout the interval indicates an age not older than early Pliocene.

The first occurrences of G. crassaformis and G. puncticulata are often coincidental in the lower Pliocene in sedimentary sequences of various areas (see discussion in Vincent, 1977b, p. 527). Some workers consider that G. crassaformis developed earlier than G. puncticulata in the latest Miocene (Blow, 1969; A. Kaneps, pers. comm.). However, Berggren (1977a) suggests that G. crassaformis evolved from primitive G. puncticulata during the early Pliocene. Both species appear together at a number of mid-latitude sites of the North Pacific, and their level of appearance was equated at these sites to the N18/N19 zonal boundary by Vincent (1975) and Keller (1978c, 1979a). This level coincides also with the appearance of the radiolarian species Lamprocyrtis heteroporos at Sites 310 and 173 (Vincent, 1975). The earliest appearance of this radiolarian species has been dated by paleomagnetism just below the Gilbert B event (~4.25 m.y.) (Casey and Reynolds, 1980). Thus, it is probable that sediments of the mixed interval at the base of the Neogene section of Site 466 are not older than about 4.2 m.y., an inference supported by sedimentation-rate extrapolations (see below).

SEDIMENTATION RATES

Absolute ages assigned to selected planktonic faunal and floral datum levels at Sites 463, 466, and 310 (Figs. 4–6) are plotted against sub-bottom depths in Figure 7.

At Site 463, there is good agreement between nannofossil and foraminifer data for placing the base of the Olduvai event (which approximates the Plio/Pleistocene boundary) at 4.5 meters (between Sections 3 and 4 of Core 1). It thus appears that the Pleistocene section at Site 463 accumulated at an average rate of about 2.4 m/m.y. Although very condensed, this section appears to be continuous, as shown by a complete nannofossil zonal sequence. The co-occurrence of several foraminifer datums at approximately 10.5 meters allows placement of the upper/lower Pliocene boundary at this level (between Sections 3 and 4 of Core 2), in disagreement, however, with the position of the NN16/NN15 nannofossil zonal boundary, located slightly lower in the section. The entire upper Pliocene sequence accumulated at Site 463 at an average rate of about 5.3 m/m.y.

Based on nannofossil data at Site 463, the lower Pliocene and upper Miocene section down to 18 meters accumulated at an average rate of approximately 3 m/m.y. The sedimentation-rate curve constructed from this value allows placement of the Miocene/Pliocene boundary at 18.2 meters, approximately the same level as the first appearance of *Globorotalia tumida*. The last occurrence levels of "*Globigerina*" nepenthes and *Globoquadrina dehiscens* are significantly offset to the left of the sedimentation-rate curve (Fig. 7), indicating that these two species disappeared here at a level stratigraphically lower than their level of extinction.

The average rate of accumulation for the entire sequence from 0 to 18 meters at Site 463 is about 3.3 m/m.y. Assuming that the remainder of the Neogene section down to 34 meters accumulated at the same average rate, an age of about 10 m.y. can be inferred for the base of the Neogene sequence directly above the unconformity. This date approximates that of the base of Zone NN11, in lowermost Epoch 9 (Ryan et al., 1974). However, it is possible that, because of fast accumulation of reworked sediments, the base of the Neogene sequence is younger and belongs to a higher stratigraphic level in Zone NN11.

The entire Pleistocene sequence at Site 466, on Southern Hess Rise, accumulated at an average rate of 13 m/m.y., with some fluctuations, as indicated by siliceous faunal datums. The uppermost Pleistocene appears to be missing, as indicated by the last occurrence of Ax-oprunum angelinum as high as the uppermost part of Core 1. The upper Pleistocene down to the base of the Jaramillo magnetic event (approximated by the LAD of *E. matuyamai*) accumulated at an average rate of 18.2 m/m.y. (possibly with a higher rate, as this value does not take into account the missing uppermost Pleistocene), whereas the lower Pleistocene accumulated at a lower average rate of 7.2 m/m.y

The upper Pliocene and upper lower Pliocene down to the 60-meter level, which is assigned an age of 3.9 m.y. (between the minimum age of 3.8 m.y., equivalent to the LAD of *Globigerina nepenthes*, and a maximum age of 4.0 m.y., equivalent to the base of NN14), accumulated at Site 466 at an average rate of about 18 m/m.y., equivalent to that of the upper Pleistocene. The entire section from 0 to 60 meters accumulated at an average rate of 15.5 m/m.y. If we assume a constant sedimentation rate for the remainder of the Neogene section below 60 meters, the basal Neogene at Site 466 above the unconformity is approximately 4.2 m.y. old.

The entire Pleistocene section at Site 310, on central Hess Rise, accumulated at the same average rate as at nearby Site 466 to the south (~13 m/m.y.). As at Site 466, the average accumulation rate for the lower Pleistocene below the Jaramillo is lower (~11 m/m.y.) than for the upper Pleistocene (~15 m/m.y.). It appears,

however, from the stratigraphic position of the LAD of A. angelinum that the missing part of the uppermost Pleistocene is greater at Site 466 than at Site 310.

The upper Pliocene and upper lower Pliocene down to about 53 meters accumulated at Site 310 at an average rate of about 12 m.y. The rarity of reliable biostratigraphic datums between 30 and 53 meters prevents recognition of possible fluctuations in sedimentation rates within that interval. However, the stratigraphic position of magnetostratigraphic boundaries inferred from carbonate stratigraphy (Vincent, this volume) provide additional data points. The base of the Matuyama and the Gauss series, identified at approximately 31 and 45 meters, respectively, are in good agreement with the sedimentation-rate curve (Fig. 7).

Below 53 meters, the Neogene sedimentary sequence at Site 310 is greatly condensed. It includes a shorter hiatus spanning the Miocene/Pliocene boundary, and possibly others. A highly reduced average accumulation rate of about 3 m/m.y. is obtained for the entire upper and middle Miocene section.

The inflection point on the sedimentation-rate curve for Site 310 on central Hess Rise, at about 4.2 m.y. coincides with the beginning of Neogene sedimentation at Site 466, on southern Hess Rise. It thus appears that an abrupt change in sedimentary regime occurred about 4.2 m.y. ago on Hess Rise—a change from slow deposition or non-deposition during the early Neogene to normal pelagic sedimentation during the rest of the Neogene and Pleistocene.

PALEOCEANOGRAPHY

Paleoceanographic studies require detailed, quantitative faunal analyses which are beyond the scope of this paper. However, from semiquantitative analyses of the foraminifer faunas at Sites 463 and 466 and comparison with faunal distribution at other North Pacific sites some general paleoceanographic trends can be inferred.

Distribution patterns of planktonic foraminifers in the surface sediments of the North Pacific follow those of their living counterparts (Bradshaw, 1959; Coulbourn et al., 1980). These are closely related to the distribution of the surface waters, which have been divided into subarctic, transitional, central, and equatorial water masses (Sverdrup et al., 1942; Fig. 1).

Sites 463, 313, 466, and 305 lie under the central water mass, which is part of a large clockwise gyre containing a thick subtropical mixed layer characterized by the central fauna. The first two sites are in the center of this faunal province, the two others near its northern boundary. Site 296, in the westernmost North Pacific, is under the western extension of the subtropical gyre, beneath the warm-water Kuroshio, which brings tropical water to the north. Site 310 lies beneath the boundary of central and transitional water masses under the Kuroshio extension, in the vicinity of the mixing boundary of the Kuroshio extension and the Oyashio. Sites 173 and 36, in the eastern North Pacific, lie beneath the California Current, which brings cool subarctic waters south to about 24°N latitude in the marginal northeast Pacific (Ingle, 1973a,b). Sites 157 and 158 lie in the easternmost tropical Pacific, in the Panama Basin, a region of high productivity. Site 158 is an area dominated by the influence of the equatorial countercurrent, whereas Site 157 is under the influence of the equatorial divergence and the Peru-Chile current.

Faunal counts conducted on the faunas greater than 149 µm from the highest stratigraphic samples recovered at Sites 463 and 466 are reported on Table 6 together with those made from the same size fraction at Sites 305, 310, and 313 by Vincent (1975). The order of species listing on Table 6 follows the temperature ranking given by Parker and Berger (1971) and Coulbourn et al. (1980). These authors delineated planktonic-foraminifer distribution in surface sediments of the South and North Pacific by making quantitative analyses of the fauna greater than 149 µm; thus, their data are directly comparable to mine. Faunal counts from Keller (1978b,c, 1979a) and Keigwin (1976), obtained from the fractions greater than 63 μ m and 175 μ m, respectively, at other North Pacific drilling sites, are also reported on Table 6. However, these data are not directly comparable to mine, because the size fraction of the analyzed fauna biases the temperature aspect of an assemblage (Vincent and Berger, in press). It should be kept in mind that the stratigraphically highest samples quantitatively analyzed here may not represent modern sediments, because the tops of sedimentary sequences recovered by drilling are often missing. General latitudinal trends in the faunal distribution nevertheless can be distinguished.

In the central North Pacific, the planktonic-foraminifer assemblages at Sites 463 and 313 have a distinctly warmer aspect than those at Sites 466, 305, and 310. The fauna at Site 463 is dominated by Globigerinoides species. G. ruber, whose maximum concentrations in modern sediments coincide with the outline of the subtropical central faunal province (Coulbourn et al., 1980), is the main component and constitutes over 50% of the planktonic fauna, whereas the two tropical species G. sacculifer and G. conglobatus constitute 14 and 7%, respectively. The tropical species Globorotalia tumida is another significant component of the fauna, amounting to 6%. At Site 313, the faunal assemblage is significantly different from that at Site 463, because of pronounced carbonate dissolution, which results in selective elimination of species (Berger, 1968, 1970; Parker and Berger, 1971; Coulbourn et al., 1980). The solutionsusceptible species of Globigerinoides are largely eliminated at Site 313, whereas the warm-water resistant species G. tumida and Sphaeroidinella dehiscens dominate the fauna. The pronounced dissolution at Site 313 is also reflected in the high proportion of foraminifer fragments and of benthic species (Table 6), which are more resistant to solution than planktonic forms (Berger, 1971; Parker, 1971; Parker and Berger, 1971).

Foraminifer assemblages at Sites 305, 466, and 310 are dominated by *Globorotalia inflata* and *Neogloboquadrina pachyderma*. *G. inflata* characterizes the zooplankton of the central water mass (Bradshaw, 1959), but in surface sediments dominates only the northwestern periphery of this province (Coulbourn et al., 1980). At Site 305, in this area, *G. inflata* largely dominates the fauna, with a relative frequency of over 50%, whereas at Sites 466 and 310, to the east, this species constitute 28 to 21% of the fauna. Right-coiling *N. pachyderma* dominates faunal assemblages from the transitional province (Bradshaw, 1959; Coulbourn et al., 1980). This species constitutes 47% of the fauna at Site 310, and 29 and 14% respectively at Sites 466 and 305. *Globigerina bulloides*, an important constituent of the transitional and subarctic provinces (Bradshaw, 1959; Coulbourn et al., 1980), constitute 13% of the fauna at Site 310, but only 8 and 2% at Sites 305 and 466, respectively. *Globigerina falconensis*, a minor component of the northern subtropical central fauna (Coulbourn et al., 1980), makes up 4% of the assemblage at Sites 305 and 466, and is absent at Site 310.

Thus, it appears that the faunal composition in the top samples of drilled sequences in the central North Pacific reflects the faunal provincialism identified in the zooplankton and modern sediments. Site 310, at the boundary of the transitional and central provinces, contains an assemblage "cooler" than those from Sites 466 and 305, in the northern part of the central province. The latter assemblages are in turn cooler than the assemblage at Site 463, in the center of the central province. Coulbourn et al. (1980) have shown that the record of faunal provincialism in surface sediments of the North Pacific usually is obscured by dissolution at depths greater than 3300 meters. Sites 313 and 310 lie at water depths close to 3500 meters. Site 313 foraminifer assemblages indeed exhibit a strong dissolution effect, whereas those at Site 310 do not appear significantly altered. The proportion of foraminifer fragments and benthic species at Site 310 is of the same order of magnitude as at Sites 305 and 466, at water depths of 2900 and 2700 meters, respectively (Table 6).

The influence of the analyzed size fraction on the species composition of an assemblage is illustrated by comparing faunal counts at Site 310 from Vincent (1975) and Keller (1978c) (Table 6). The two dominant species, *N. pachyderma* and *G. inflata*, which respectively constitute 47 and 21% of the fauna greater than 149 μ m, constitute only 16 and 3% of the fauna greater than 63 μ m, whereas the small-sized species *Globigerinita uvula*, which is not present in the fauna greater than 149 μ m, constitutes 25% of the fauna greater than 63 μ m.

The faunal composition at Site 296 cannot be compared directly to that of Site 305, because of the different size fractions analyzed at these two sites. Faunal counts of a smaller size fraction at Site 296 result in an enrichment in small-sized species (*Globigerinita iota*, for example, which is absent in the fauna greater than 149 μ m at Site 305, makes up 14% of the fauna greater than 63 μ m at Site 296), and a depletion in large-sized species (*G. inflata*, which constitutes 52% of the fauna greater than 149 μ m at Site 305, constitutes only 8% of the fauna greater than 63 μ m at Site 296). However, the 8% value at Site 296 indicates the importance of *G. inflata* in this area.

The faunal assemblage at Site 173, under the cold California Current, is largely dominated by populations of *Neogloboquadrina pachyderma* (74% of the fauna greater than 63 μ m), of which 20% are sinistrally coiled.

Faunal counts made by Keigwin (1976) for the easternmost equatorial Pacific Sites 158 and 157 (in which the relative abundance of species is given according to percentage classes with a 5 or 10% increment; see Table 6) show the great dominance of *Neogloboquadrina dutertrei*, which characterizes upwelling areas off the American coast (Parker and Berger, 1971; Coulbourn et al., 1980), as well as the importance in this region of the equatorial species *Globorotalia cultrata*, whose maximum concentrations are between 0 and 10°N (Coulbourn et al., 1980).

Down-core variations in the relative abundance of planktonic foraminifers at each of the drilling sites listed in Table 6, together with changes in the coiling ratio of *Neogloboquadrina pachyderma*, reflect oscillations of surface-water masses across the North Pacific throughout the Neogene (Ingle, 1973a,b, 1977a,b; Vincent, 1975, 1977a,b; Keigwin, 1976; Keller, 1978a,b,c, 1979a,b; Sancetta, 1978). These recent studies of DSDP cores complement earlier studies of climatic oscillations in the North Pacific, based mainly on material from piston cores and (or) onshore sections of the circum-North Pacific (Bandy and Kolpack, 1963; Parker, 1964, 1967; Bandy, 1967, 1972; Ingle, 1967, 1972; Asano et al., 1969; Hays et al., 1969; Bandy and Ingle, 1970; Herman, 1970; Kent et al., 1971; Olsson, 1971, 1974).

Sedimentary sequences near water-mass boundaries are especially well suited to the recording of shifts of these water masses through time. In this respect, DSDP Site 310, on central Hess Rise, has an ideal location for recording the climatically induced migrations of subtropical and transitional water masses. Furthermore, the north-south migration of these water masses in the central North Pacific is not complicated by the asymmetric current circulation which characterizes the margins of the basin.

The well-known coiling preferences of *N. pachyderma* (Ericson, 1959; Bandy, 1960) have been used repeatedly for paleoclimatic studies in various areas of the Pacific realm. Sinistrally coiled forms are dominant in surface sediments beneath waters cooler than 10° C, whereas dextral forms are dominant in surface sediments beneath water warmer than 15° C. The abundance of left-coiling *N. pachyderma* on the North Pacific sea floor outlines the subarctic faunal province. The change in coiling direction of populations of this species occurs between latitudes 40° N and 30° N in the eastern North Pacific, and between 42° N and 40° N in the western North Pacific (Coulbourn et al., 1980).

Sporadic incursions of sinistral populations of *N. pachyderma* at mid-latitude sites of the North Pacific reflect southward shift of surface isotherms. Using the record of these incursions, as well as frequency oscillations in temperate and subtropical foraminifer assemblages, Keller (1978c, 1979b) identified four major cold intervals (labeled C1 to C4; see Fig. 8) in Plio-Pleistocene mid-latitude sequences of the North Pacific, which she correlated to paleoceanographic oscillations identified in the southwest Pacific (Kennett and Vella, 1975).

Cyclic variations in carbonate content have been identified in upper Neogene sequences of the equatorial Pacific, as well as at Site 310 (see Vincent, this volume). For the Pleistocene, the relationship of these carbonate cycles with paleoclimatic fluctuations has been well demonstrated (Arrhenius, 1952; Hays et al., 1969). Carbonate cycles extend back to the Miocene and show extreme excursions at certain times, which can be used for correlation over wide geographic areas. I discuss elsewhere (this volume) the significance of these excursions in relation to changes in isotopic composition of foraminifer shells and global paleoceanographic changes.

Calcium carbonate content at Sites 463 and 466 is plotted against sub-bottom depths in Figures 2 and 3. The curves show the same overall trend as at Site 310 (Vincent, this volume) that is, a slight upward-decreasing trend from a higher carbonate content in the upper Miocene and lower Pliocene to slightly lower values in the upper Pliocene, and minimum values in the upper Pleistocene. At Site 463, the carbonate content ranges from 75 to 95% with three minima intervals: one in the Pleistocene, one spanning the Miocene/Pliocene boundary, and one in the upper Miocene associated with reworked sediments. At Site 466, carbonate values throughout the Pliocene and lower Pleistocene show a range similar to that at Site 463 (75-95%), but there are more fluctuations than at the latter site. Carbonate values in the upper Pleistocene are lower at Site 466 than at Site 463, reaching a minimum of 55%.

The average level of calcium carbonate content in the Pliocene and lower Pleistocene at Site 310 is similar to that at Sites 466 and 463 for the same interval (75-95%), but at Site 310 there are short intervals with pronounced carbonate minima, reaching values as low as 40% or less. The lower average carbonate level in the upper Pleistocene at Site 310 (about 55%, with excursions as low as 35%) than at Sites 466 and 463 may be related to the greater water depth at the former site.

The pronounced dissolution spikes (labeled with a letter-number system according to their position within magnetic epochs) seen at Site 310, as well as in equatorial cores (see Vincent, this volume), have a very short duration-less than 100,000 years-and easily might be missed in carbonate stratigraphies established with a large sampling interval. The carbonate stratigraphic study of Site 310 was done with a 30-cm sampling interval, that of Site 466 with a 75- to 100-cm sampling interval, and that of Site 463 with a 150-cm sampling interval. Sampling at Site 310, where the average accumulation rate is 13 m/m.y., represents an interval of about 20,000 years between samples, whereas sampling at Site 466 (average accumulation rate of 15 m/m.y.) and Site 463 (average accumulation rate of 3.3 m/m.y.) represents intervals of about 60,000 and 500,000 years, respectively. These differences indeed are reflected in the general patterns of the carbonate curves. The curve for Site 463 shows more gentle undulations than that for Site 466, which is in turn less "noisy" than that for Site 310. Low-carbonate excursions are not as numerous and not as pronounced at Site 466 as at Site 310. Although some of the low-carbonate intervals at Site 466 probably correspond to intervals with carbonate minima at Site 310, a close correlation between these two nearby sites is not possible, whereas, if sampling density permits, a correlation from peak to peak is possible between widely distant carbonate sequences (see Vincent, this volume).

Fluctuations in coarse-fraction content (>63 μ m) at Sites 466 and 463 (Figs. 2 and 3) do not always show a correlation with those in CaCO₃ content. A significant increase in coarse fraction in the upper Miocene at Site 463 in Core 4 is associated with a decrease in CaCO₃ and with reworked sediments. An upward-increasing trend in coarse-fraction content at Site 463 throughout the upper Pliocene and Pleistocene appears to correspond to a decreasing trend in carbonate, although the increase in coarse fraction starts well below the decrease in carbonate. Such a relationship between coarse fraction and carbonate contents is not present in the upper Plio-Pleistocene sequence at Site 466.

It is of interest to note that at both Sites 463 and 466 there is no correlation between calcium carbonate content and foraminifer preservation in the upper Miocene and lower Pliocene sections. These stratigraphic intervals contain the most poorly preserved foraminifer faunas of the entire sedimentary sequences, and also the highest CaCO₃ content. In the Pleistocene, however, the interval with a minimum CaCO₃ in the upper part of the section contains foraminifer faunas more poorly preserved than those in the remainder of the Pleistocene (compare preservation data in Tables 6 and 7 with carbonate curves in Figs. 2 and 3).

A climatic cooling (cold event C1) in the earliest Pliocene is recorded in mid-latitude sequences of the North Pacific, as well as in the equatorial sequences of the Panama Basin. In equatorial sections, this event is associated with high-frequency calcium carbonate fluctuations and pronounced low-carbonate peaks. In midlatitude sections, the cool interval follows a hiatus spanning the Miocene/Pliocene boundary and is associated with dissolution-affected foraminifer assemblages.

An apparently continuous sequence occurs at Site 463 across the Miocene/Pliocene boundary. No record of cooling in that interval can be detected from the present data. However, the highly condensed nature of the Site 463 section makes this sedimentary sequence very poorly suited for paleoceanographic studies. Furthermore, this site being under the central part of the central water mass, shifting of this water mass over the site may not be reflected in significant faunal changes. An interval of decreased carbonate content in the upper part of Core 3 spans the Miocene/Pliocene boundary. Foraminifer faunas exhibit a dissolution facies throughout the upper Miocene and lower Pliocene. Such a dissolution facies is also shown by the lower Pliocene fauna at Site 466, where sedimentation started in the early Pliocene. No record of cooling is detectable in the poorly preserved lower Pliocene fauna at the base of this section. Biostratigraphic correlations with Site 310 (Fig. 8) show that the interval of cold event C1 is missing at Site 466.

A stable, warm climatic interval during the early Pliocene is followed in the mid-Pliocene by a pronounced cold event (C2), well recorded at all North Pacific and equatorial sites, which corresponds to the onset of northern-hemisphere glaciation. This climatic deterioration, which occurred in the middle Gauss near the Mammoth event, about 3.1 m.y. ago, is marked by a distinct enrichment in ¹⁸O of deep-sea benthic foraminifers in both equatorial and transitional provinces (Shackleton and Opdyke, 1977; Keigwin, 1979) and is associated with a pronounced carbonate minimum (GU 3). This cold event is recorded at Site 466 in the upper part of Core 6 by the presence of left-coiling *N. pachyderma*. As at other mid-latitude sites of the North Pacific, it corresponds here to the initial appearance of *G. inflata*. The dissolution spike GU 3 is not seen in the carbonate stratigraphy of this site.

Subsequently, fluctuating climatic conditions prevailed, as shown by the amplitude of the equatorial benthic oxygen-isotope record (Shackleton and Opdyke, 1977). The faunal record at Site 310 suggests a distinctly warm interval (Fig. 8) shortly after cool event C2, characterized (in Core 5, Section 4) by an increased abundance of globorotaliids and a decreased abundance of *N. pachyderma*. This interval correlates with a distinctly warm interval at Site 466, marked in the upper part of Core 5 by a pronounced decrease in *N. pachyderma* and a simultaneous increase in *Globoquadrina altispira* and *G. venezuelana*.

A major glaciation about 2.4 m.y. ago (just after the Gauss/Matuyama boundary) reflected in the benthic isotopic record of the equatorial and temperate North Pacific by a distinct ¹⁸O enrichment (Shackleton and Opdyke, 1977; Keigwin, 1979) is associated with a pronounced carbonate minimum (M21). A cooling of surface water (C3) recorded at mid-latitude sites of the North Pacific is not contemporaneous with the benthic isotopic event, but lags slightly behind it. This cooling event, recorded at Site 310 in the upper part of Core 4, is not identifiable from present data at Site 466, nor is dissolution spike M21. The wide unrecovered intervals in Cores 3 and 4 at the latter site may truncate the record corresponding to that time interval.

The pronounced dissolution spike M17 associated with the Olduvai event (close to the Pliocene/Pleistocene boundary) is not seen on the carbonate curves of Site 463 and 466, although carbonate values in the uppermost part of Core 4 at Site 466, just below the Plio/Pleistocene boundary, indicate a decreasing trend.

Fluctuating climatic conditions prevailed through much of the early Pleistocene, with a significant cooling about 1.2 m.y. ago recorded at mid-latitude North Pacific sites (C4), and throughout the marginal northeast Pacific. No record of cooling is detectable at Site 466 for that time interval, according to present data (Fig. 8).

Cooling became very intense between the Jaramillo and Brunhes about 0.8 m.y. ago. This pulse of profound cooling is observed in marine sections throughout the northeast Pacific margin. From that time on (after isotopic stage 22), glacial extremes were significantly more intense than in the early Pleistocene (Shackleton and Opdyke, 1976). At Site 310, the beginning of the pronounced cooling is recorded in the calcareous flora in Core 2, Section 3 (D. Bukry, pers. comm.) and is followed by two incursions of left-coiling *N. pachyderma* in Core 2, Section 1, and Core 1, Section 2, respectively. The beginning of the intense cooling is recorded at Site 466 in Core 2, Section 3, by a significant increase in abundance of *N. pachyderma*. The first incursion of left-coiling *N. pachyderma* at Site 310 corresponds to an incursion of this taxon at Site 466 as well (Core 1, Sections 4 and 5). The second incursion, however, which occurred after the extinction of *A. angelinum*, is not recorded at Site 466, where the top of the Pleistocene younger than the LAD of *A. angelinum* is mostly missing.

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