36. PLEISTOCENE AND PLIOCENE FORAMINIFERA FROM THE SEA OF JAPAN, LEG 31, DEEP SEA DRILLING PROJECT

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ABSTRACT

Pleistocene and Pliocene planktonic foraminiferal faunas found at Sites 299, 300, 301, and 302 in the Sea of Japan are dominated by *Neogloboquadrina pachyderma* and *Globigerina bulloides s.l.* including *G. umbilicata.* Minor accessory species include *Globigerina quinqueloba*, *Globigerinita glutinata*, *G. uvula*, and *Globorotalia scitula.* These species form a subarctic biofacies characteristic of upper Pliocene through Recent deposits in much of the sea. Only sparse faunas were recovered at Sites 300, 301, and 302, but quantitative analysis of a fair to good Pleistocene sequence at Site 299 in the Toyama Channel clearly records significant planktonic foraminiferal events correlative with the initiation of severe cooling at 900,000 yr B.P. and a significant interglacial warming about 500,000 yr B.P. Unusual paleooceanographic and geochemical environments have been created in this sea during glacial maxima and minima due to unusually shallow basin sills which, together with a relatively shallow calcium carbonate compensation depth (CCD), account for the virtual absence of calcareous foraminiferal assemblages from major portions of the sediments penetrated at Leg 31 sites in the Sea of Japan.

INTRODUCTION

The Sea of Japan represents one of the several marginal basin complexes formed during Tertiary episodes of increased subduction and back-arc extension in the western Pacific (Coleman, 1973). However, the Sea of Japan is bathymetrically and oceanographically more isolated than most of these seas including the adjacent Sea of Okhotsk which formed during the same Neogene tectonic pulse. A major objective of Leg 31 was to probe the sedimentary and tectonic history of the Sea of Japan with the expectation that study of temperature-sensitive planktonic microfossils would reveal variations in the paleoclimatic and paleooceanographic history of the Sea. In fact, studies of planktonic foraminifera from bathyal Neogene[1] marine sediments exposed along the northwestern coast of Honshu have already demonstrated that significant variations in surface-water temperature have occurred within this area during the early Miocene through Pleistocene period (Saito, 1963; Takayanagi and Oba, 1966; Huzioka et al., 1970; Asano et al., 1969; Saito and Maiya, 1973). These variations were in response to the combined effects of paleoclimatic events and tectonic adjustment of margins, sills, and straits during evolution of the Sea (Minato et al., 1965).

Unfortunately, calcareous foraminifera proved to be sparse or absent in most of the sediments recovered from Leg 31 sites in the Sea of Japan (Figure 1, Tables 1 and 2). Moreover, the presence of significant amounts of ethane at Sites 299 and 301 and caving sand at Site 300 forced abandonment of these sites prior to penetration of Miocene sediments. Thus, the results of foraminiferal analysis in the Sea of Japan are disappointing in terms of the original cruise objectives. Nevertheless, a fair to good sequence of Pleistocene planktonic foraminifera was recovered at Site 299 (Figure 1) allowing quantitative biofacies analysis and providing a heretofore unavailable record of major paleooceanographic variations during this period of climatic extremes. Pleistocene events are of special importance in the Sea of Japan due to its unusual oceanographic and bathymetric setting at a mid- to high-latitude position particularly sensitive to climatic fluctuations.

Bathymetry and Oceanography

The present unusual oceanographic environment of the Sea of Japan has been summarized by Hidaka (1966). Although over one-quarter of the sea is presently deeper than 3000 meters (Figure 1), it is bathymetrically and topographically isolated from the adjacent Pacific Ocean by narrow straits and extremely shallow sills between Honshu and Hokkaido (130 m), Hokkaido and Sakhalin (55 m), Honshu and Korea (130 m),[2] and

[1]Neogene, as used in this report, includes the Miocene through Pleistocene period.

[2]Narrow channels in the Tsushima Straits reach depths of 250 meters (Ujiié, 1973), but were likely sediment filled during lower stands of sea level.

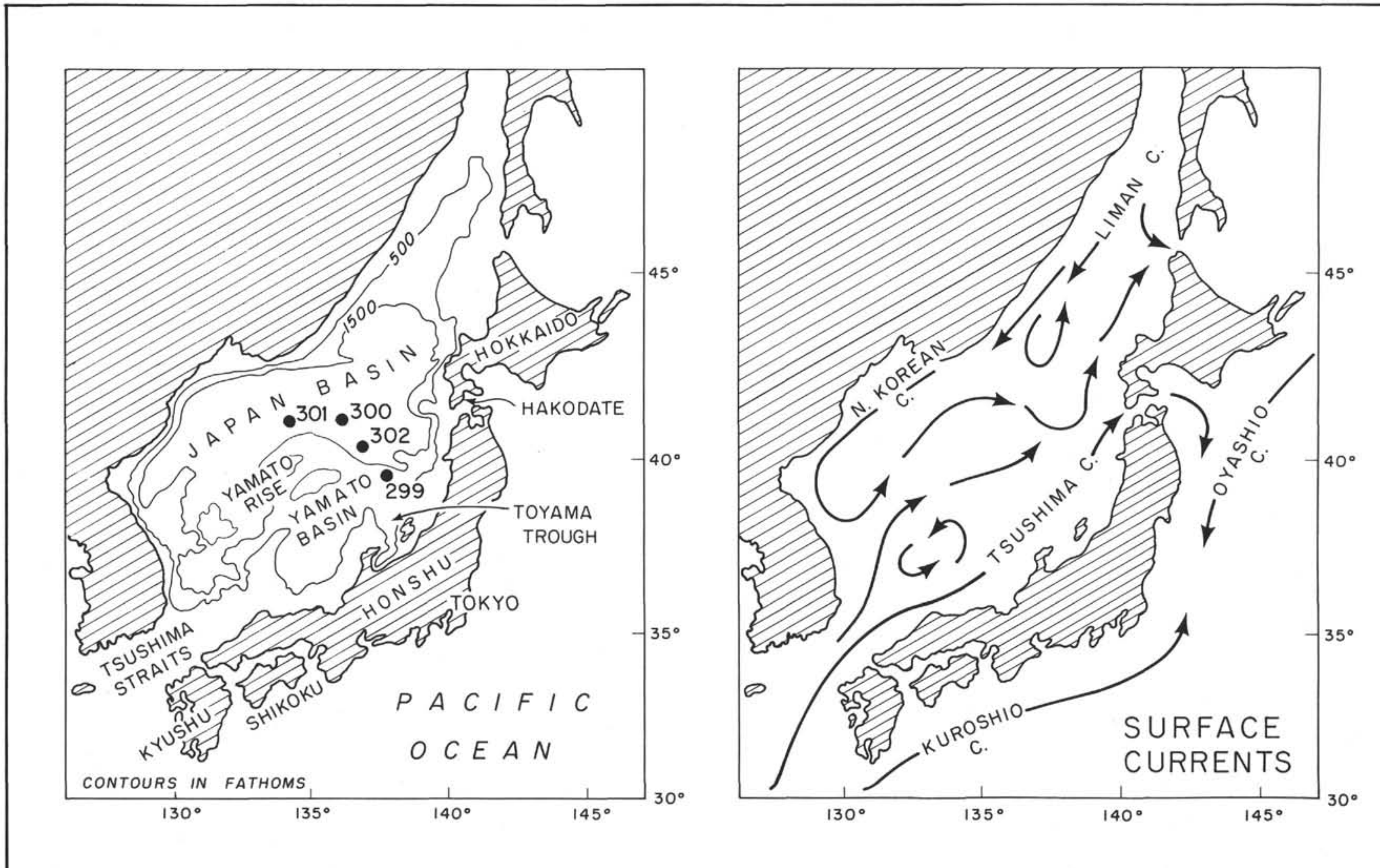

Figure 1. *Location map of the Sea of Japan area showing location of Leg 31 drilling sites; a second diagram illustrates the principal surface currents operating in the Japan Sea area and adjacent Pacific.*

TABLE 1
Leg 31 Sea of Japan Site Data

Site	Location	Depth Below Sea Level (m)	Maximum Penetration Below Sea Floor (m)
299	39°29.69'N 137°39.72'E	2599	532
300	41°02.96'N 136°06.30'E	3427	117
301	41°03.75'N 134°02.86'E	3520	497
302	40°20.13'N 136°54.01'E	2399	531.5

Sakhalin and the Asian mainland (12 m) as noted by Niino et al. (1969).

These shallow sills combine with a severe winter climate[3] in the northern portions of the sea to produce an extremely cold, but highly oxygenated water mass. Some subtropical water enters the sea from the south as a branch of the Kuroshio Current termed the Tsushima Current (Figure 1), and contains a warm temperate-subtropical planktonic biofacies (Ujiie, 1973). However, the dominant highly oxygenated cold surface waters formed in the northern areas under severe winter conditions[3] travel south as the Liman Current and ultimately sink. As they sink, they continually maintain a sill-full body of water exhibiting a uniform temperature of only 0.2°C, an oxygen content of 5.3 ml/l, and a relatively low salinity of 34‰, thus creating an unusual sediment-water interface capable of producing brown muds ("red clay") at relatively shallow depths (Niino et al., 1969). The surface sediments also display unusually low organic carbon values considering the high productivity in the sea. In addition, Ujiié and Ichikura (1973) provide clear evidence of a relatively shallow CCD in the sea of about 1500 meters[4] attesting to the aggressive nature of the resident bottom water.

Ujiié and Ichikura (1973) also emphasize the inescapable conclusion that eustatically lowered sea levels coincident with Plio-Pleistocene glacial maxima must have completely isolated the Sea.[5] All access through the present straits was undoubtedly severed when sea level dropped to -150 meters (Milliman and Emery, 1968) creating a truly unique environment ultimately producing reducing bottom conditions due to expansion and duration of sea ice, loss of exchange with the Pacific, and sluggish bottom circulation. This latter environment presents the geochemical inverse of conditions prevailing during the transitional (Recent) and interglacial periods. In fact, foraminiferal and geochemical ananysis of upper Pleistocene sediments from the sea provide ample evidence that reducing conditions were indeed the rule during glacial episodes (miyake et al., 1968; Ujiié and Ichikura, 1973).

[3]Including the presence of sea ice from November through April (Hidaka, 1966).

[4]Average depth of the CCD at 35°N in the Pacific is about 3500 meters (Berger, 1971).

[5]A major Pleistocene tectonic pulse compounds the eustatic effects with the Tsushima Straits perhaps nonexistent in the early Pleistocene restricting access to the northern straits (Minato et al., 1965, p. 325).

Abundance and Preservation of Plio-Pleistocene Foraminifera

The abrupt and almost total absence of calcareous benthonic and planktonic foraminifera within major portions of the stratigraphic columns at Sites 299, 301, and 302 (Table 2) is in all likelihood a reflection of one or both of the Quaternary oceanographic extremes noted above. Sediments barren of foraminifera at these sites commonly contain framboidal pyrite indicative of the reducing bottom conditions envisioned for glacial

TABLE 2
Samples Barren of Foraminifera at Sites 299, 301, and 302
(Interval in cm)

Site 299	Site 299	Site 301	Site 302
1-1, 45-47	19, CC	2-1, 85-87	2-3, 50-52
1-2, 40-42	20-1, 130-132	2-4, 30-32	2-4, 75-77
1-2, 110-112	20-2, 70-72	2-5, 110-112	2-6, 80-82
1-3, 14-16	20, CC	2-6, 109-111	3-6, 130-132
1-5, 110-112	21-1, 55-57	2, CC	3, CC
2-1, 140-142	21, CC	3-1, 118-120	4-2, 100-102
2-4, 60-62	22-2, 40-42	3, CC	4-4, 125-127
3-3, 70-72	22-3, 50-52	4-2, 75-77	4, CC
3-4, 70-72	22-4, 40-42	4, CC	5-2, 140-142
4-2, 35-37	22, CC	5-3, 34-36	5-4, 100-102
5-2, 87-89	23, CC	5, CC	5, CC
6-2, 55-57	24-1, 113-115	7 (heat flow)	6, CC
7-2, 50-52	24, CC	7, CC	7-2, 70-72
7-3, 48-50	25-1, 42-44	8-1, 80-82	7-5, 50-52
7-4, 96-98	25, CC	8, CC	7, CC
9-2, 55-57	26-1, 85-87	9-1, 133-135	8-2, 70-72
9-5, 25-27	26, CC	9, CC	8-5, 60-62
10-2, 7-9	28-1, 147-149	10-1, 20-22	8, CC
10-5, 30-32	28, CC	11-1, 84-86	9-1, 40-42
10, CC	29-1, 108-110	11, CC	9, CC
11-2, 40-42	29, CC	12, CC	10-2, 70-72
11-4, 41-43	30-1, 79-81	13-1, 71-73	10-5, 70-72
11-5, 13-15	30-3, 70-72	13, CC	10, CC
11, CC	30-5, 32-34	14-1, 80-82	11-2, 70-72
12-2, 54-56	30, CC	14, CC	11-4, 70-72
12-3, 50-52	31-1, 68-70	15-1, 50-52	11, CC
12-4, 13-15	31, CC	15-3, 80-82	12-1, 90-92
12-5, 55-57	32-2, 47-49	15, CC	12-3, 70-72
13-3, 127-129	32, CC	16-1, 93-95	12, CC
13-4, 90-92	33-1, 64-66	16, CC	13-1, 100-102
13-5, 25-27	33, CC	16-1, 93-95	13, CC
13, CC	34-1, 146-148	17-1, 47-49	14-2, 70-72
14-4, 86-88	35-1, 136-138	17, CC	14-4, 70-72
14-5, 90-92	35-2, 84-86	18-2, 37-39	14, CC
14, CC	35, CC	18, CC	15-1, 100-102
16-1, 90-92	36-2, 48-50	19-1, 94-96	16-1, 100-102
16-2, 120-122	36, CC	19-4, 60-62	17-1, 96-98
16-4, 85-87	37-1, 128-130	19, CC	17-2, 8-10
17-2, 70-72	37-2, 84-86	20-1, 80-82	17, CC
18-2, 87-89	37-3, 57-59	20-4, 52-54	
18-4, 60-62	37, CC	20, CC	
18, CC	38-1, 34-36		
19-1, 72-74	38-2, 25-27		
19-2, 45-47	38-3, 36-38		
19-3, 20-22	38-4, 99-101		
19-4, 40-42	38-6, 87-89		
19-5, 34-36			

maxima. Siliceous planktonic debris were little effected by these events (Koizumi, this volume; Ling, this volume). Alternately, absence of calcareous foraminifera in inter- or preglacial horizons within these same sequences probably reflects dissolution by aggressive bottom water due to a shallow CCD similar to modern conditions. The only well-preserved Pleistocene planktonic foraminiferal sequence recovered (Site 299) may owe its existence primarily to burial and protection by rapidly deposited submarine fan deposits in the Toyama Channel (Chapter 10, this volume).

Calcareous benthonic foraminifera occur sporadically along with planktonic specimens, but are only occasionally common and well preserved (Table 3). Most benthonic specimens encountered appear to represent specimens displaced from littoral, neritic, and upper bathyal depths via downslope redeposition, although some in situ lower bathyal species are present (Tables 4 and 5). Rare arenaceous specimens constitute the only foraminifera within major portions of the sedimentary columns at these same sites.

Methods and Procedures

All samples examined were collected by H. Ujiié onboard *Glomar Challenger*. Sample labeling procedures and designations are explained in Chapter 1, Introduction (this volume). Samples obtained generally consist of 10 cc of sediment, although core-catcher samples generally consist of larger amounts of material. Unconsolidated samples were prepared by soaking in water with the occasional addition of small amounts of hydrogen peroxide to aid disaggregation. In a few cases kerosene treatment was used to break down more consolidated mudrock. Disaggregated samples were routinely washed through a 250-mesh (0.62μ openings) screen, dried, and examined.

Quantitative analyses were made of planktonic foraminiferal faunas at Sites 299, 301, and 302; only Site 299 provided a significant number of assemblages for meaningful stratigraphic analysis. Species abundances are reported as percent of total planktonic specimens counted in a given sample; percentages were not calculated for samples containing less than 20 specimens. Qualitative notations regarding the abundance of foraminifera in each sample are as follows: A = abundant (more than 100 specimens), C = common (26-100 specimens), F = few (10-25 specimens), R = rare (less than 10 specimens). Samples examined which proved to be barren of foraminifera are listed in Table 2. Preservation of foraminifera is noted as follows: G = good, M = moderate, and P = poor.

SITE 299

Site 299 is located in a channel extending west from the mouth of the Toyama Trough within the Yamato Basin (Figure 1). This bathymetric feature is the conduit for a significant amount of the terrigenous debris currently filling the Sea of Japan (Hilde and Wageman, 1973; Chapter 10, this volume). The 532-meter thick section penetrated consists of an alternating series of Quaternary channel, levee, and overbank deposits associated with the developing trough and channel system (Bouma, this volume).

TABLE 3
Abundance[a] and Stratigraphic Distribution Planktonic Foraminifera, Site 299, Sea of Japan

Sample (Interval in cm)	Abundance	Preservation	*Globigerina bulloides s.l.*[b]	*Globigerina bulloides umbilicata*	*Globigerina quinqueloba*	*Globigerinita glutinata*	*Globigerinita uvula*	*Globorotalia scitula*	*Neogloboquadrina pachyderma*	(% Sinistral Specimens)	No. Specimens Counted	Zone	Age[c]
1-1, 110-112	R	M			X		X		X	(X)	8		
1-3, 100-102	A	M	28	7	2				62	(100)	134		
1-4, 30-32	C	M	27	9	1				62	(100)	149		
1-4, 100-102	A	M	17						83	(99)	168		
1-5, 40-42	A	M	21	5	2				71	(98)	214		
1-6, 20-22	R	P	X						X	(X)	21		
1-6, 111-113	A	M	1						99	(99)	135		
1, CC	A	G	46	10	3				41	(100)	190		
2-2, 90-92	R	P							X	(X)	1		
2, CC	A	M	10		5				85	(94)	100		
3-2, 90-92	R	P							X	(X)	7		
3, CC	R	M	20	2					78	(95)	49		
4-1, 120-122	R	P				X					2		
4-3, 3-5	A	M	12	1	1				86	(99)	183		
4-3, 22-24	R	P				X					1		
4-3, 41-43	A	G	15	2	X		X		82	(99)	171		
4-4, 54-56	A	G	11	6	3		3		77	(99)	231		
4, CC	C	G	7	1	4				88	(100)	115	N23	
5-1, 72-74	F	M		X			X		X	(X)	17		
5-3, 61-63	F	M	19	1	10				70	(84)	70		
5-5, 15-17	R	M							X	(X)	5		
5, CC	A	G	15	1	3				81	(100)	143		
6-1, 93-95	R	M			X	X			X	(X)	4		
6-3, 63-65	R	P							X	(X)	2		
6-4, 48-50	A	G	13		1	X			85	(18)	172		
6, CC	A	G	26	5	X				68	(58)	155		
7-1, 83-85	C	G	1		2				97	(88)	162		PLEISTOCENE
7, CC	R	P							X	(X)	2		
8, CC	C	M	1						99	(89)	176		
9-1, 40-42	C	M	2	1	1				96	(86)	108		
9-3, 20-22	F	M	9		9		X		82	(75)	82		
9-4, 21-23	R	P							X	(X)	1		
10-3, 125-127	F	M	17	3					80	(0)	30		
10-4, 25-27	C	P	12						88	(X)	177		
11-1, 30-32	R	M	X						X	(0)	2		
11-3, 40-42	R	P							X	(X)	1		
12-1, 105-107	R	P	X						X	(0)	6		
12, CC	R	P	X								1		
13-1, 80-82	R	P	15		12		X		73	(2)	26		
13-2, 40-42	R	P	26		32		3		39	(17)	31		
13-3, 20-22	R	P	X		X						2		
14-1, 60-62	A	M	78	12	2				8	(6)	195		
14-2, 50-52	A	M	80	2	2				16	(0)	182	N22	
14-3, 20-22	A	M	73	5	7				16	(3)	197		
15-1, 64-66	R	P	X		X		X				9		
15-4, 50-52	R	P	X	X	X						11		
15-5, 103-105	C	G	44	4	13			X	31	(23)	250		
16, CC	F	M	24		19				57	(17)	21		
17-4, 90-92	F	M	26		15				59	(0)	41	N21/20?	PLIOCENE
17, CC	R	P			X						1		
18-1, 133-135	F	M	21		19				60	(8)	83		
18-3, 64-66	R	P	X		X				X	(0)	8		
31-2, 38-40	F	M	36	31					33	(62)	39	↓	

[a]Species abundance given as percentage of total planktonic population; X = less than 1%
[b]*Globigerina bulloides s.* includes *G. bulloides quadrilatera* .
[c]Age based in part on diatom zonation of Koizumi (1974, this volume).

TABLE 4
Benthonic Foraminifera Identified at Site 299

Bolivina pisciformis Galloway and Morrey
Buccella frigida (Cushman)
Buliminella elegantissima (d'Orbigny)
Cassidulina minuta Cushman
Cassidulina norcrossi Cushman
Cassidulinoides sp.
Cibicides sp.
Elphidium clavatum (Cushman)
Elphidium frigidum Cushman
Elphidium incertum (Williamson)
Elphidium microgranulosa Galloway and Wissler
Epistominella exigua (Brady)
Epistominella pacifica (Cushman)
Fissurina spp.
Fursenkoina complanata (Egger)
Glandulina laevigata d'Orbigny
Globobulimina auriculata arctica Höglund
Lagena spp.
Melonis pompilioides (Fitchell and Moll)
Nonionella turgida (Williamson)
Nonionella spp.
Pyrgo sp.
Quinqueloculina cf. *nitida* Norvang
Triloculina sp.
Uvigerina peregrina Cushman

Although a significant portion of the sediments penetrated at Site 299 are barren of foraminifera, a relatively complete late Pleistocene planktonic foraminiferal sequence was recovered in the upper 170 meters (Cores 1 to 18) of the column (Figure 2) with an isolated Pliocene fauna in Core 31 (Table 3). Benthonic foraminifera are listed in Tables 4 and 5.

The Pleistocene faunas are dominated by alternating dextral and sinistral coiling populations of *Neogloboquadrina* ("*Globigerina*") *pachyderma* along with *Globigerina bulloides* and *G. bulloides umbilicata* (Figure 2). The single Pliocene fauna is dominated by *Globigerina bulloides*. Accessory species in the Pleistocene assemblages include *Globigerina quinqueloba*, *Globigerinita glutinata*, *G. uvula*, and *Globorotalia scitula*. This combined group of species is characteristic of cool temperate and subarctic biofacies currently living in the Sea of Japan and adjacent Sea of Okhotsk (Lipps and Warme, 1966) with the possible exception of *Globigerina bulloides umbilicata*[6] which may have become extinct in the latest Pleistocene (Ujiié and Ichikura, 1973; Ingle, 1973). These biofacies are clearly indicative of the late Pliocene through Recent interval in the North Pacific (Ingle, 1973), but a lack of critical transitional or subtropical species precludes definition of the Pliocene-Pleistocene boundary. Thus, reliance is placed on the better biostratigraphic resolution afforded by associated diatom floras (Koizumi, this volume) for placement of this epoch boundary between Cores 29 and 30 (Figure 2).

[6]Orr and Zaitzeff (1971) and Ujiié and Ichikura (1973) consider this morphotype to be a distinct species rather than an ecophenotypic variant.

TABLE 5
Abundance and Preservation of Benthonic Foraminifera at Sites 299, 301, and 302[a]

Sample (Interval in cm)	Abundance[b]	Preservation
Site 299		
1-1, 110-112	R	M
1-4, 30-32	R	M
1-5, 40-42	R	P
1-6, 111-113	R	G
1, CC	R	M
2-5, 90-92	R	M
4-3, 41-43	R	M
6-1, 93-95	R	G
6-3, 63-65	R	G
6-4, 48-50	F	M
7-1, 83-85	R	M
8-3, 125-127	R	P
8, CC	R	M
9-3, 20-22	C	G
10-4, 25-27	R	G
12-1, 105-107	R	P
13-1, 80-82	C	G
13-2, 40-42	C	G
13-3, 20-22	R	G
14-1, 60-62	R	M
14-2, 50-52	R	G
14-3, 20-22	R	G
15-1, 64-66	R	M
15-2, 49-51	R	M
15-3, 29-31	R	P
15-4, 50-52	R	M
15-5, 103-105	A	G
16-3, 107-109	R	P
16, CC	F	M
17-4, 90-92	R	G
17, CC	R	M
18-3, 64-66	R	P
31-2, 38-40	R	G
31, CC	R	M
38, CC	R	P (squashed Arenaceous sp.)
Site 301		
2-2, 40-42	R	M
2-3, 40-42	F	G
Site 302		
2-1, 95-97	R	M
2-2, 50-52	R	G
2-5, 70-72	R	M
2, CC	R	M
18-1, 77-79	R	P

[a]Samples barren of benthonic foraminifera omitted.

[b]Abundance designations as follows: R = rare, F = few, C = common, and A = abundant. Preservation designations as follows: P = poor, M = moderate, and G = good.

Interestingly, warmer Pleistocene planktonic biofacies have been reported from the Oga Peninsula area of northern Honshu including assemblages within the Shibikawa Formation containing *Globorotalia truncatulinoides* (Takayanagi and Oba, 1966; Asano et al.,

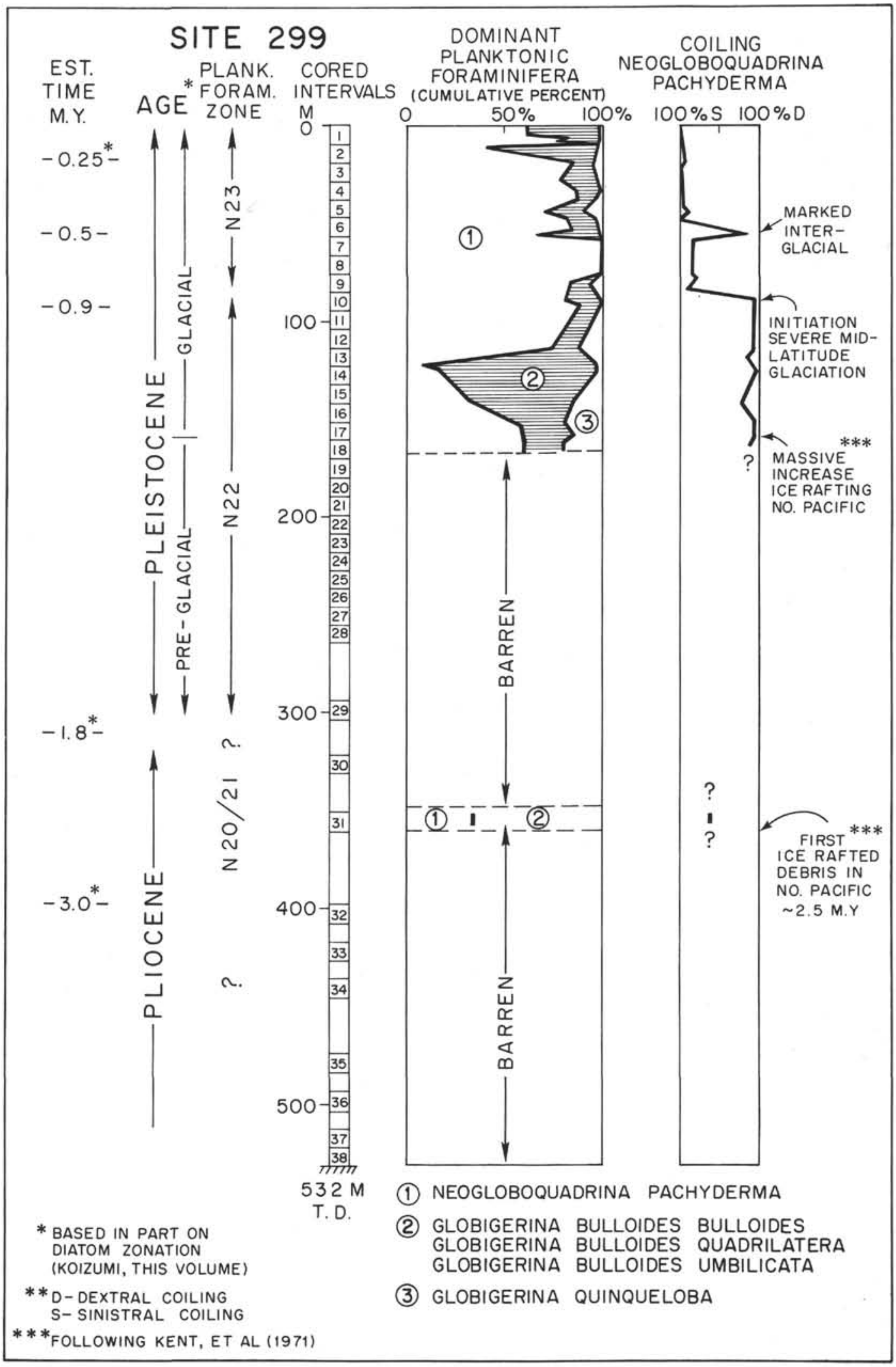

Figure 2. *Stratigraphic variation of Pleistocene and Pliocene planktonic foraminifera at Site 299, Yamato Basin, Sea of Japan. Note that estimated time in years before the present (B. P.) is based on correlation of diatom zonation and the paleomagnetic scale by Koizumi (this volume) and, correlation of planktonic foraminiferal evidence of the 900,000 yr B.P. cold event and 500,000 yr B.P. warm event noted by Kent et al (1971) in the open North Pacific.*

1969; Huzioka et al., 1970). These occurrences represent transitional and interglacial episodes during which the Tsushima Current allowed a warmer water biofacies to migrate as far north as 40°N along the eastern margin of the sea.

Paleooceanographic and Paleotemperature Record

Despite the limited species composition of the Plio-Pleistocene planktonic foraminiferal biofacies encountered at Site 299, they record several significant variations in surface temperature during the period represented. Coiling ratios of *Neogloboquadrina pachyderma* are particularly sensitive indicators of variation in surface temperature. The sustained presence of sinistral populations is indicative of water cooler than 10°C, whereas horizons dominated by totally dextral coiling populations represent warmer water than 15°C (Kennett, 1968; Bé and Toderland, 1971; Devereux et al., 1970; and references therein).[7] Coiling variations of this species at Site 299 demonstrate that at least four significant surface temperature events occurred within the mid to later Pleistocene in this area along with associated variations in species abundance and diversity (Figure 2).

The earliest Pleistocene faunas present at Site 299 are characterized by dominantly dextrally coiling forms of *Neogloboquadrina pachyderma* and the *Globigerina bulloides s.l.* complex indicative of surface conditions similar to Recent conditions or slightly warmer. An abrupt and major event occurs in Core 9 with a change to dominantly sinistral coiling forms of *N. pachyderma* and a general increase in the relative abundance of this species indicating a significant drop in surface temperature. This event appears to correlate with the multiple evidence presented for initiation of intense mid-latitude glaciation and equatorward migration of the 10°C isotherm in the North Pacific at about 900,000 yr B.P. (Kent et al., 1971; Ingle, 1973), and in the Atlantic (Ruddimann, 1971). Moreover, a subsequent significant warming ("interglacial") is delimited by the appearance of dextral populations of *N. pachyderma* in Core 6. This is, in all likelihood, correlative with a similar event noted by Kent et al. (1971) in the open North Pacific and dated paleomagnetically as occurring between 530,000 and 460,000 yr B.P. The same major warming is also manifest in cores from the Antarctic area (Kennett, 1970). Severe glacial surface temperatures were apparently maintained in the sea for the remainder of the Pleistocene as recorded by the continual presence of sinistrally coiled specimens of *N. pachyderma* to the top of Hole 299 (Figure 2).

The Holocene-Pleistocene boundary was either not recovered or unrecognized at Site 299. This boundary is marked by a return to dominantly dextral coiling populations of *N. pachyderma* and other evidence of a pronounced increase in surface temperature at about 11,000 yr B.P. (Ujiié and Ichikura, 1973; Koizumi, 1970) coincident with an increase in surface temperatures in the marginal northeastern Pacific (Bandy, 1967; Griggs et al., 1970) and elsewhere (Berggren and Van Couvering, 1974).

Thus, the mid through later Pleistocene climatic record in the Sea of Japan is similar to that established in the adjacent open North Pacific and the world ocean in general, at least in terms of major events. Unfortunately, sediments barren of calcareous foraminifera obscure earliest Pleistocene and Pliocene events with the loss of calcium carbonate tests probably attributable to the effects of an unusually shallow CCD as discussed earlier. The only calcareous Pliocene foraminiferal fauna recovered at Site 299 is indicative of near-glacial surface temperatures (Figure 2) during a period known to include the first appearance of ice-rafted debris in the North Pacific (Kent et al., 1971). It appears the most definitive planktonic foraminiferal evidence of Pliocene and Miocene paleoclimates in the Sea of Japan is contained within the folded, exposed, and rapidly filled marginal basin sequences of northern Honshu, rather than in the adjacent more continuous but carbonate-poor deep-sea section.

SITE 300

Site 300 was drilled in the east central Japan Basin (or plain) in hopes of recovering a continuous biostratigraphic and sedimentologic record of Neogene and earlier (?) events in this deepest portion of the Sea of Japan (Figure 1). Unfortunately, caving sands and stuck drill pipe caused premature abandonment of this site after penetration to only 117 meters within a series of coarse turbidite sands representing part of the distributary system of the Toyama Trough, channel, and fan complex.

Analysis of core-catcher samples revealed moderately well preserved late Pleistocene (Holocene?) planktonic foraminifera with the faunas dominated by sinistrally coiled specimens of *Neogloboquadrina pachyderma* representative of a mean surface temperature cooler than that extant in the area today.

Benthonic foraminifera in these same samples were dominated by species displaced from littoral and neritic depths and redeposited at abyssal depths via the Toyama fan-channel system.

SITE 301

Site 301 was also located in the extensive Japan Basin (or plain) due west of the Yamato Rise (Figure 1) in hopes of recovering a similar section to that abandoned at Site 300. Drilling at this site penetrated 497 meters into the basin fill, with the column divisible into a 240.5-meter-thick upper Pliocene through Pleistocene unit of terrigenous clays and silts with sand and ash interbeds underlain by 256 meters of lower to upper Pliocene diatomaceous muds. Drilling was stopped at 497 meters when critical shows of ethane were encountered.

The only common and well preserved calcareous foraminifera at Site 301 were recovered from Core 2 (Tables 5 and 6) with planktonic assemblages again

[7]A well-established empirical relationship confirmed once again by recent studies in the Antarctic area (Kennett and Shackleton, 1974); although studies in progress are still in the throes of deciphering the relationship between *Neogloboquadrina dutertrei* (characteristically dextral) and *N. pachyderma* (Kennett and Srinivesan, 1974).

TABLE 6
Benthonic Foraminifera Identified at Site 301

Bolivina seminuda Cushman
Cassidulina limbata Cushman and Hughes
Cassidella schreibersiana Czjzek
Cyclammina sp. (broken)
Elphidium crispum (Linne)
Nonionella turgida (Williamson)
Quinqueloculina sp.

TABLE 7
Abundance[a] and Stratigraphic Distribution Pleistocene Planktonic Foraminifera Sites 301 and 302, Sea of Japan

Sample (Interval in cm)	Abundance	Preservation	*Globigerina bulloides bulloides*	*Globigerina bulloides quadrilatera*	*Globigerina bulloides umbilicata*	*Globigerina quinqueloba*	*Globigerinita glutinata*	*Globigerinita uvula*	*Neogloboquadrina pachyderma* (% Sinistral Specimens)	Number Specimens Counted
301-2-2, 40-42	C	G	8	7	X	34		X	48 (97)	140
301-2-3, 40-42	C	G	23	20	13	5			39 (92)	153
302-2-1, 95-97	C	F	34	2		X			64 (91)	176
302-2-2, 50-52	A	F	18	2	X	2			87 (90)	194
302-2-5, 70-72	A	G	15	3	5	3	X	X	73 (89)	153
302-2, CC	C	P	14	2		X			83 (90)	114
302-3-2, 15-17	C	F	36	5	1				57 (11)	128

[a]Species abundance given as percentage of total planktonic population; X = less than 1%

dominated by sinistral coiling populations of *Neogloboquadrina pachyderma* along with varying percentages of the *Globigerina bulloides* complex and minor accessory species (Table 7) representing the characteristic Plio-Pleistocene subarctic biofacies in the sea.

Sparse benthonic foraminifera encountered at Site 301 all represent relatively shallow-water species deplaced into deeper water with the possible exception of a single broken specimen of *Cyclammina* (Table 6).

SITE 302

The final drilling site (302) on Leg 31 was located on the northern flank of the Yamato Rise, a prominent high in the south central portion of the Sea of Japan (Figure 1). It was hoped that the isolated nature of this feature might allow recovery of an especially complete biostratigraphic reference section undiluted by terrigenous debris. Unfortunately, calcareous microfossils again proved scarce due at least in part to a shallow CCD in the sea (Ujiié and Ichikura, 1973). However, a good Pleistocene and Pliocene siliceous sequence was recovered in the upper 352 meters of the 531.5-meter-thick section penetrated. A medical emergency ultimately forced early abandonment of this site and a minimal coring program in the lower 179 meters of the section.

Planktonic foraminifera were found in only the first three cores at Site 302, and all faunas are composed of the same Plio-Pleistocene subarctic biofacies encountered at other sites in the Sea (Tables 5, 6, and 7). Sinistrally coiled populations of *Neogloboquadrina pachyderma* dominate all but a single fauna in Core 3 which is characterized by a dextral population indicative of relatively warmer conditions than present during glacial maxima. All of these faunas are interpreted to be late Pleistocene in age on the basis of stratigraphic position and diatom zonation.

FAUNAL REFERENCE LIST

Listed below are references to the original description of each species of planktonic foraminifera mentioned in this report along with various taxonomic notes on selected species. All trinominals represent genus, species, and subspecies. Preferred modern names are followed by the original designation and reference.

Globigerina bulloides bulloides d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, v. 7, p. 277; Modeles no. 76.

Globigerina bulloides quadrilatera Galloway and Wissler = *Globigerina quadrilatera* Galloway and Wissler, 1927, J. Paleontol., v. 1, no. 1, p. 44, 84, pl. 7, fig. 11. This subspecies of *G. bulloides* is characterized by a diminutive fifth chamber in the final whorl. Recent populations of *G. bulloides* from the North Pacific region contain variable percentages of this form, and it has been recognized in bathyal Neogene sediments in California (Ingle, 1973).

Globigerina bulloides umbilicata Orr and Zaitzeff = *Globigerina umbilicata* Orr and Zaitzeff, 1971, J. Foram. Res., v. 1, no. 1, p. 18, pl. 1, fig. 1-3. This subspecies has been previously reported from Pleistocene sediments of the Sea of Japan (Ujiié and Ichikura, 1973) as well as from the Neogene of the northeastern Pacific (Ingle, 1973); significantly, it has not been reported in living populations of *G. bulloides* and thus may represent a reliable index to Pleistocene and older sediments in high-latitude areas of the northern hemisphere.

Globigerina quinqueloba Natland, 1938, Scripps Inst. Oceanogr., Bull., Tech. Serv., v. 4, no. 5, p. 149, pl. 6, fig. 7.

Globigerinita glutinata (Egger) = *Globigerina glutinata* Egger, 1895, K. Bayer Akad. Wiss., Math.-Phys. 11., Abh., v. 18, pt. 2, p. 371, pl. 13, fig. 19-21.

Globigerinita uvula (Ehrenberg) = *Polydexia uvula* Ehrenberg; 1861, K. Preuss, Akad. Wiss. Berlin, Monatsber., p. 276, 277, 308.

Globorotalia scitula (Brady) = *Pulvinulina scitula* Brady, 1882, Roy. Soc. Edinburgh, Proc., v. 11, p. 716.

Neogloboquadrina ("*Globigerina*") *pachyderma* (Ehrenberg) = *Aristospira pachyderma* Ehrenberg, 1861, K. Akad. Wiss. Berlin, Monatsber., p. 276, 277, 303. This species, formerly assigned to *Globigerina*, is placed in *Neogloboquadrina* on the basis of its nonspinose pitted wall and umbilical-extraumbilical position of its aperture as detailed by Bandy et al. (1967). The *N. pachyderma-dutertrei* plexus is currently under close study (Kennett and Srinivesan, 1974), and it is apparent from distributional and morphologic studies that these forms may well be related creating conflicts in taxonomic assignment in transitional areas between high- and low-latitude regions. Whatever the outcome of these studies, it is clear that sinistral coiling forms dominate in water masses where temperatures are cooler than 10°C and that dextral forms predominate within water masses warmer than 15°C in turn presenting reliable paleoclimatic indexes. Forms within the range of *N. incompta* Cifelli have been included within *N. pachyderma* of this report. This species forms the dominant member of Pleistocene planktonic foraminiferal biofacies within the Sea of Japan as demonstrated in this report and the work of Ujiié and Ichikura (1973).

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