

## 23. FORAMINIFERA, LEG 19, DEEP SEA DRILLING PROJECT<sup>1</sup>

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### INTRODUCTION

Significant numbers of indigenous foraminifera were found at seven of the eleven sites drilled on Leg 19. Six of these, Sites 184, 185, 188, 189, 190, and 191, are in the Bering Sea. The seventh, Site 192, is at the top of Meiji Guyot in the northwest Pacific Ocean south of the Aleutian Islands.

The foraminifera found at each of these sites is discussed in the preceding site reports. This section synthesizes foraminiferal biostratigraphy at Leg 19 sites and explores some of the paleoclimatic implications of the foraminiferal assemblages.

It was necessary to apply several methods to disaggregate the sediment samples. Unconsolidated samples from the upper parts of the holes usually disaggregated readily when boiled in a 15% solution of hydrogen peroxide. However, deeper in the holes the samples become semiconsolidated and resist this treatment. Boiling in the strong detergent, Quaternary-O, was tried for these latter samples without noticeable success. In order to disaggregate them sufficiently for study, it was usually necessary to use mechanical methods, either breaking lumps apart with fingers or brushing them against the screen. Highly indurated sediment of lithologic Units B and C was disaggregated by placing thoroughly dried samples into varsol or kerosene for several hours and then boiling them in water.

All samples were washed on a 63 $\mu$  mesh sieve, but studies were carried out only on the fraction retained on a 125 $\mu$  mesh sieve. Checks of the fraction passing through the 125 $\mu$  sieve showed it to contain up to approximately 30% of *Globorotalia (Turborotalia) pachyderma* populations. Species of planktonic foraminifera so small that most would be lost through a 125 $\mu$  sieve (for example, *Globigerina quinqueloba* and *Globigerinita uvula*) were never found to be common in checks of the finer fraction.

Tables 1 to 7 show estimates of abundance for planktonic species and for total planktonic foraminifera and hyaline, porcelaneous, and arenaceous benthic foraminifera. Indigenous foraminifera are extremely rare at the four deepest sites: Sites 183 (4718 m), 186 (4522 m), 187 (4577 m), and 193 (4811 m). A few examples of displaced assemblages at Sites 183 and 186 are discussed in Chapters 2 and 5. At other sites there are usually a few arenaceous tests throughout, but occurrences of calcareous tests are sporadic. The Quaternary is characterized by sharp fluctuations in abundance from common or abundant to zero, often within the same section of a core. In contrast, the Pliocene and upper Miocene is exceptionally poor in

calcareous foraminifera, particularly planktonics. Within the Bering Sea the only representative assemblages of planktonic forms below the Quaternary are from Site 184, Cores 14 and 16. At Site 192, from south of the Bering Sea, planktonic forms are slightly better represented in cores older than Quaternary, but the record is, nevertheless, very discontinuous.

Tables 1 to 7 also show estimates of the state of preservation of planktonic foraminifera tests. Tests from the upper parts of the holes exhibit a different style of preservation than tests from the lower parts of the holes. In the upper parts of the holes quality of preservation is a function of solution effects which are pronounced on most assemblages of planktonic tests. In the lower parts of the holes quality of preservation is limited by recrystallization and compression. Recrystallization occurs only at Site 192. From Core 28 downward at this site all calcareous tests appear infilled with calcareous material and recrystallized so that fine morphological details are often obscured. Compression is observed from Core 28 downward at Site 192 and throughout lithologic Unit B at sites within the Bering Sea. In Unit B, within the Bering Sea, tests of *Martinottiella communis*, an arenaceous form, are usually compressed completely flat and other arenaceous tests are to some degree distorted; however, calcareous tests are affected little if at all. In the lower parts of Site 192 calcareous tests are affected also. Planktonic tests appear more susceptible to compression than benthic tests, but both are affected. The degree of compression varies from sample to sample and, in some, all planktonic tests have been completely flattened and are therefore unidentifiable.

### GENERAL BIOSTRATIGRAPHIC UNITS

Because the record is discontinuous, because planktonic foraminifera are often scarce where they do occur, and because diversity is always low, as is typical in high latitudes, zonation of foraminiferal assemblages on the fine scale customary in tropical areas cannot be approached. Instead the stratigraphic succession is subdivided into seven units each characterized by a particular association of species (Figure 1). From known ranges of the species and assisted by biostratigraphic control from other kinds of microfossils, these units can be associated with broad increments of geologic time. All seven units are represented at Site 192. Only Units I to III, and the upper part of Unit IV, can be recognized in the sections at other Leg 19 sites, because the other sites did not sample foraminifera-bearing sections as old as the other units.

**Unit VII:** Part of Core 4A, core catcher, and the part of Core 5A above basalt at Site 192 have yielded a rich Maestrichtian nannofossil assemblage but only four poorly preserved planktonic foraminifera: *Globotruncana* sp. (1 specimen) and *Heterhelix* sp. (3 specimens).

<sup>1</sup>Contribution No. 689 from the Department of Oceanography, University of Washington.

TABLE 1  
Data on Occurrences of Foraminifera at Site 184<sup>1</sup>

Depth Below Sea Floor (m)	Core, Section, Interval (cm)	Preservation	Benthics - Arenaceous	- Porcelaneous	- Hyaline	Planktonics	<i>Globorotalia (T.) pachyderma</i> (Form A)	<i>Globorotalia (T.) pachyderma</i> (Form B)	<i>Globigerina bulloides</i>	<i>Globorotalia (T.) scitula</i>	<i>Globigerina quinqueloba</i>	<i>Globigerinita glutinata</i>	<i>Globigerinita uvula</i>	<i>Globorotalia (T.) cf. subretacea</i>	<i>Martinottiella communis</i>	Age
1.0	1-1(100-102)	P	R	O	C	A	A		C		R					Upper Pleistocene
3.8	1-3(80-82)		F	O	R	O										
132.1	2-3(110-112)		O	O	R	O										
149.8	3-3(80-82)		R	O	O	O										
168.8	4-3(80-82)		R	O	O	O										
205.8	6-3(80-82)		O	O	VR	O										
224.8	7-3(80-82)	P	F	VR	C	R		R	R							
280.8	10-3(80-82)		F	O	O	O										
299.8	11-3(80-82)		F	O	O	O									X	
335.2	12-2(78-80)		F	O	O	O									X	
344.2	13-2(78-80)		R	O	O	O									X	
385.2	14-4(66-68)	M	R	VR	VR	C						R	C			
428.6	16-2(10-12)	M	F	R	C	C						R	R	C	X	
502.7	18-1(80-82)		R	O	R	O									X	
540.8	20-3(80-82)		R	O	VR	O									X	
708.5	2B-1(148-150)		F	O	VR	O									X	
745.2	3B-1(122-126)		C	R	C	R	VR	VR							X	
823.0	5B-3(95-97)		R	O	O	O									X	
874.4	7B-1(43-46)		O	O	R	O										
878.0	7B-3(95-97)		R	O	F	O										
891.5	8B(CC)		O	O	O	O										
900.3	9B-5(127-129)		O	O	O	O										

<sup>1</sup>Number of individuals in samples corresponding to estimates of abundance are: VR (very rare), 1; R (rare), 2-10; F (few), 11-50; C (common), 51-500; A (abundant), 501-2000; VA (very abundant), more than 2000. X indicates occurrences of *Martinottiella communis*. State of preservation is estimated for planktonic foraminifera: P (poor), M (moderate), G (good).

**Unit VI:** Two samples of Core 4A, Site 192, contain *Acarinina primitiva* (Finley), *A. spinuloinflata* (Bandy), *A. soldadoensis* (Bronnimann), *Morozovella lensiformis* (Subbotina), *Globigerina triangularis* White (v. rare), and *Globigerina linaperta* Finley (v. rare), an assemblage indicating a late early Eocene age. Planktonic foraminifera were originally common, but many are badly compressed so that only a few undistorted tests could be isolated. Calcareous nannoplankton indicate an age no older than late early Eocene for this core.

**Unit V:** In Cores 29 through 2A, Site 192, five samples have been found to contain planktonic foraminifera. In three of them *Globorotaloides suteri* Bolli is the only identifiable species and in another *Globigerinita dissimilis* (Cushman and Bermudez) is the only identifiable species. The assemblages of these four samples appear monospecific, but other species now damaged beyond recognition could have been present originally. The fifth sample, from Core 35, contains *Globigerinita unicava* (Bolli, Loeblich, and Tappan), *Globigerina angiporoides* Hornibrook, and *G. ciperoensis* Bolli (?). *Globigerina angiporoides* indicates that Core 35 is upper Eocene or lower Oligocene. The other

species range from the upper Eocene into the lower Miocene.

**Unit IV:** The catcher of Core 28, Site 192, is regarded as approximating the boundary between the lower and middle Miocene (Zones N8/N9) because it contains *Globorotaloides suteri*, a species that extends to the top of the lower Miocene, in association with *Globigerina bulloides* d'Orbigny, *Globigerinita glutinata* (Egger), and *Globorotalia (Turborotalia) scitula scitula* (Brady), species ranging from the base of the middle Miocene to the Recent. From Core 28 upward to Core 17, Site 192, there are occurrences of the latter three species, of *Globigerinita uvula* (Ehrenberg) and *Globorotalia (T.) pachyderma* (Ehrenberg), which also extend to the Recent, and of *G. (T.) continua* Blow, *G. (T.) cf. continua*, and *Globigerina paraboloides* Blow, which do not.

*Globorotalia (T.) continua* (Core 22) and *G. (T.) cf. continua* (Cores 21 and 18) include individuals in which the terminal chamber is larger than the preceding chambers and of normal shape and also individuals in which the terminal chamber is smaller than the penultimate and hood-shaped. The latter forms strongly resemble *G. (T.)*

TABLE 2  
Data on Occurrences of Foraminifera at Site 185<sup>1</sup>

Depth Below Sea Floor (m)	Core, Section, Interval (cm)	Preservation	Benthics – Arenaceous	– Porcelaneous	– Hyaline	Planktonics	<i>Globorotalia</i> (T.) <i>pachyderma</i> (Form A)	<i>Globorotalia</i> (T.) <i>pachyderma</i> (Form B)	<i>Globigerina bulloides</i>	<i>Globorotalia</i> (T.) <i>scitula</i>	<i>Globigerina quinqueloba</i>	<i>Globigerinita quinqueloba</i>	<i>Globigerinita uvula</i>	<i>Martinottiella communis</i>	<i>G.</i> (T.) <i>pachyderma</i> – % sinistral	<i>G.</i> (T.) <i>pachyderma</i> – No. if <100	Age	
0.8	1-1(82-84)	P	O	R	C	C	C		F						98	62	Upper	Pleistocene
9.8	2-1(82-84)	M	O	R	C	C	C		R						100	66		
17.3	3-1(130-132)	P	R	O	C	A	A		C						100			
37.3	4-2(82-84)	M	R	VR	C	C	F		R			VR			96	47	Middle	Pleistocene
65.3	5-2(82-84)		R	O	F	R	VR		R									
93.3	6-2(82-84)	M	F	O	C	C	F	F	F						38	65	Lower	Pleistocene
96.3	6-4(82-84)		O	O	C	O												
130.3	7-1(130-132)		O	O	F	R			R								Upper	Pliocene
132.8	7-3(82-84)		F	O	F	R		R	VR				X					
170.8	8-3(80-82)		R	O	O	O											Lower	Pliocene
173.5	8-5(145-147)		F	O	O	O							X					
225.3	10-3(30-32)		R	O	O	O							X				Upper	Mio.
226.2	10-3(120-122)		F	O	O	O							X					

<sup>1</sup> For key to symbols, see Table 1.

*pachyderma* in ventral view, but they are distinguished by a slightly conical profile in edge view. *Globorotalia* (T.) *pachyderma* is restricted to individuals that are approximately equally biconvex in edge view. Within Unit IV of Site 192, it is reported only from Cores 17 and 18. The coiling direction of all three of these species is strongly sinistral.

Occurrence of *G. (T.) continuosa*, which ranges upward to the middle part of the upper Miocene (to within Zone 17 according to Blow, 1969), indicates that the Miocene-Pliocene boundary is higher than Core 22 at Site 192. Sinistral *G. (T.) pachyderma* indicates possible correlation of Cores 17 and 18, Site 192, with the upper Miocene of sinistral *G. (T.) pachyderma* recognized in southern California (Ingle, 1967), Japan (Asano et al., 1969), and New Zealand (Jenkins, 1967). At Site 192, these occurrences are consistent with the placement of the Miocene-Pliocene boundary by siliceous microfossils.

Rare sinistral *G. (T.) pachyderma* in Unit B of Sites 184 (Core 3B) and 189 (Core 13), occurring below the Miocene-Pliocene boundary as recognized with siliceous microfossils, suggests the presence of the upper part of Unit IV at these sites.

**Unit III:** In Cores 15, 13, and 12, Site 192, there are occurrences of *Globigerina bulloides* and *G. (T.) cf. G. (T.) subcretacea* (Lomnicki) associated, in Core 13, with less frequent *G. (T.) suteri* Catalano and Sprovieri. *G. (T.) pachyderma* is not recorded from this interval.

Presence of *G. (T.) cf. G. (T.) subcretacea* in Cores 14 and 16 of Site 184 indicate the occurrence of Unit III there also. In both Sites 184 and 192, Unit III occurs near the

Miocene-Pliocene boundary recognized by siliceous microfossils.

**Unit II and Unit I:** These two units are characterized by the occurrence of modern subarctic species only. *Globorotalia* (T.) *pachyderma* is usually dominant and *Globigerina bulloides* is the only other planktonic species that occurs at high relative frequencies. *Globorotalia* (T.) *scitula*, *Globigerinita uvula*, *G. glutinata*, and *Globigerina quinqueloba* Natland are often present at very low frequencies. *Globoquadrina dutertrei* (d'Orbigny) has been found in only one sample. Planktonic assemblages of Unit II and Unit I differ only in the coiling of populations of *G. (T.) pachyderma*. This species coils dominantly in the dextral direction in Unit II and dominantly in the sinistral direction in Unit I.

Trends in the coiling of *G. (T.) pachyderma* can be determined only schematically at Leg 19 sites because cores are often separated by long uncored intervals and because populations of this species large enough for accurate determination of coiling preference are infrequent. Fortunately, however, diatoms are common throughout and their biostratigraphy provides a time framework within which coiling trends of *G. (T.) pachyderma* can be understood (Figure 2). In the *Denticula seminula* diatom zone (upper Pleistocene) and the upper part of the *Rhizosolenia curvirostris* Zone (middle Pleistocene), *G. (T.) pachyderma* is more than 97% sinistral in samples of more than 100 tests and more than 90% sinistral in samples of more than 25 tests. In the middle part of the *R. curvirostris* Zone, sinistral tests fall below 90% of the total and near the boundary between the *R. curvirostris* Zone and the *Actinocyclus oculatus* Zone (lower Pleistocene), they fall

TABLE 3  
Data on Occurrences of Foraminifera at Site 188<sup>1</sup>

Depth Below Sea Floor (m)	Core, Section, Interval (cm)	Preservation	Benthics - Arenaceous	Porcelaneous	Hyaline	Planktonics	<i>Globorotalia (T.) pachyderma</i> (Form A)	<i>Globorotalia (T.) pachyderma</i> (Form B)	<i>Globigerina bulloides</i>	<i>Globorotalia (T.) scitula</i>	<i>Globigerina quinqueloba</i>	<i>Globigerinita glutinata</i>	<i>Globigerinita uvula</i>	<i>Martinottiella communis</i>	% sinistral <i>G. (T.) pachyderma</i>	No. <i>G. (T.) pachyderma</i> if < 100	Age	
0.7	1-1(69-72)	M	F	R	C	VA	VA	C		R	C				100		Upper	Pleistocene
1.0	1-1(106-108)	M	O	R	C	VA	VA	VA		F	C				99			
1.5	2-1(50-52)	M	O	O	F	C	C	F							100			
5.4	2-3(140-142)	P	O	O	O	F	F											
31.5	3-2(2-4)	M	O	VR	C	VA	VA	C							99			
35.9	3-4(140-142)	P	O	O	R	F	F	R										
60.4	4-1(140-142)	M	F	O	C	A	A	C							98			
63.4	4-3(140-142)	M	O	O	O	C	C	R							98			
88.8	5-2(30-32)	M	VR	O	C	VA	VA	C	C						96			
91.4	5-3(140-142)	P	R	O	F	C	C	F	R						99			
91.5	5(CC)	G	F	O	C	VA	VA	A	A						92			
124.8	6-1(80-82)	M	F	F	C	VA	VA	A	A	R	C				81			
125.0	6-1(101-103)		O	O	F	R	R											
126.1	6-2(64-66)		O	O	A	R	R	VR										
129.9	6-4(140-142)		R	O	VR	R	VR	VR	VR									
130.0	6(CC)	M	R	R	F	A	A	C	C	R					86			
171.1	7-1(10-12)		R	O	VR	O												
178.4	7-5(140-142)	M	R	O	R	C	F	F	F						34	41		
180	7(CC)	M	R	R	C	A	C	A	C		R				29			
227.1	8-1(10-12)		R	O	F	R		R										
235.9	8-6(140-142)		O	O	R	O												
236	8(CC)	M	R	O	R	F	R	F	R						6	35		
283.1	9-1(10-12)		R	O	O	O												
292.0	10(CC)		R	O	O	O												
331.5	11(CC)		R	O	O	O												
426.5	12(CC)		O	O	O	O												
602.5	17(CC)		R	O	O	O												

<sup>1</sup> For key to symbols, see Table 1.

below 50% of the total; that is, the populations are dominantly dextral. A population of *G. (T.) pachyderma* from the top of the *Thalassiosira zalzalinae* Zone (upper Pliocene) at Site 192 is also dextral. No populations of *G. (T.) pachyderma* from the upper Pliocene at Bering Sea sites is large enough for determination of coiling preference.

A change from dextral to sinistral populations of *G. (T.) pachyderma* across the boundary between the *A. oculatus* and *R. curvirostris* diatom zones is in agreement with the findings of Kent et al. (1971). These authors studied core V20-119 from the subarctic North Pacific south of the Aleutian Islands (45°57'N; 168°47'E). In that core the coiling change occurs across the Jaramillo Normal paleomagnetic event which previously was associated with this diatom zonal boundary by Donahue (1970). A change from dextral to sinistral populations occurring at about the same time has also been reported from DSDP Site 36 at about 41°N latitude in the northeast Pacific Ocean (Olsson, 1971)

and from southern California land sections at about 34°N by Bandy and Wilcoxon (1970).

Because a complex of morphological characteristics distinguishes dextral *G. (T.) pachyderma* populations occurring below the middle part of the middle Pleistocene, this form has been designated Form B to distinguish it in Tables 1 to 7 from dominantly sinistral *G. (T.) pachyderma* populations. The latter is designated Form A. Excluding diminutive terminal chambers, Form B (Plate I, Figures 4-7) typically has four, or slightly less than four chambers in umbilical view in contrast to Form A (Plate I, Figures 1-3) which has four to five chambers. Also Form B is usually larger and often has distinctly coarser pores than Form A. Both Form A and Form B may have thick walls, but some individuals of Form B have relatively thin walls. Tests in which the characteristics of Form B are fully developed disappear a short distance above the level at which the frequency of sinistral tests becomes greater than 90%. The



TABLE 4  
Data on Occurrences of Foraminifera at Site 189<sup>1</sup>

Depth Below Sea Floor (m)	Core, Section, Interval (cm)	Preservation	Benthics - Arenaceous	- Porcelaneous	- Hyaline	Planktonics	<i>Globorotalia (T.) pachyderma</i> (Form A)	<i>Globorotalia (T.) pachyderma</i> (Form B)	<i>Globigerina bulloides</i>	<i>Globorotalia (T.) scitula</i>	<i>Globigerina quinqueloba</i>	<i>Globigerinita glutinata</i>	<i>Globigerinita uvula</i>	<i>Martinottiella communis</i>	% sinistral <i>G. (T.) pachyderma</i>	No. <i>G. (T.) pachyderma</i> if < 100	Age			
0.4	1-1(43-45)	P	F	O	F	A	C	C							100		Upper	Pleistocene		
2.3	1-2(76-78)	P	R	R	F	A	A	C							99					
3.7	1-3(72-74)		VR	O	O	O														
4.9	1-4(40-42)		VR	O	O	O														
5.3	1-4(76-78)		VR	O	O	VR	VR													
6.7	1-5(68-70)		VR	O	O	O														
45.8	3-1(76-78)	M	O	O	R	F	F	R	R						97	35	Middle			
47.3	3-2(76-78)		O	O	O	R	R													
48.2	3-3(15-17)		O	O	R	O														
49.1	3-3(110-112)	M	O	O	F	C	C	F	F		R				90					
50.3	3-4(76-78)	P	R	O	R	C	C	R	R						90	98				
51.8	3-5(76-78)	M	R	O	F	A	A	C	F						87					
53.2	3-6(73-75)	P	R	VR	VR	F	F	R							91					
85.3	4-2(76-78)	M	R	F	F	C	F	C	F						10		Lower			
86.7	4-3(65-67)	M	O	O	R	F	R	F	R						21	14				
88.6	4-4(60-62)		O	O	O	O														
147.8	5-1(76-78)		R	O	O	O														
149.2	5-2(68-70)		R	O	O	VR	?													
150.8	5-3(76-78)		R	VR	R	VR		VR												
153.0	5(CC)		R	O	R	O														
212.9	6-1(90-92)		O	O	O	O														
214.3	6-2(76-78)		O	O	O	O														
215.0	6(CC)		O	O	O	O														
300.5	7(CC)		O	O	O	O														
644.8	11-3(76-78)		R	O	O	O														
726.0	13-1(101-103)		F	O	R	R	R							?	100	3	Pliocene or Upper Miocene			
778.5	15(CC)		O	O	O	O														
802.6	16-3(62-64)		F	O	O	O								X						
830.0	18(CC)		F	O	O	O														
867.0	20-2(97-98)		F	O	O	O								X						

<sup>1</sup>For key to symbols, see Table 1.

infrequent dextral tests at higher levels are similar in characteristics other than coiling direction to sinistral tests.

Morphological characteristics associated with dextral and sinistral populations of *G. (T.) pachyderma* at Leg 19 sites are not the same as those reported at DSDP Site 36 from farther south in the northeast Pacific. Olsson (1971) found that at Site 36 sinistral *G. (T.) pachyderma* varies little. It has four chambers in umbilical view rather than varying from four to five as does Form A at Leg 19 sites. Furthermore, dextral populations of Site 36 have four and one-half to five chambers in umbilical view, not four, or slightly less than four, as has Form B at Leg 19 sites. These comparisons indicate a variability in space and time of *G. (T.) pachyderma* populations within the North Pacific area that is still poorly understood. A more complete documentation of this variability, based on samples widely distributed in the North Pacific area, is needed to determine

relationships of North Pacific forms to South Pacific and Arctic forms of this species described by Kennett (1968, 1970).

#### BIOSTRATIGRAPHIC SIGNIFICANCE OF *MARTINOTTIELLA COMMUNIS*

Calcareous planktonic and benthic foraminifera are so infrequent in Pliocene and Miocene strata of the Bering Sea that their use for correlation between sites is severely limited. In contrast, arenaceous foraminifera occur relatively consistently in the same interval. Unfortunately, there are few arenaceous species in most samples. One of these, however, *Martinottiella communis* d'Orbigny, is useful biostratigraphically because it occurs very consistently in Miocene and lower Pliocene strata of Bering Sea sites and Site 192 but becomes extinct in the middle part of the Pliocene near the boundary between the *Denticula*

TABLE 5  
Data on Occurrences of Foraminifera at Site 190<sup>1</sup>

Depth Below Sea Floor (m)	Core, Section, Interval (cm)	Preservation	Benthics - Arenaceous	Porcelaneous	Hyaline	Planktonics	<i>Globorotalia (T.) pachyderma</i> (Form A)	<i>Globorotalia (T.) pachyderma</i> (Form B)	<i>Globigerina bulloides</i>	<i>Globorotalia (T.) scitula</i>	<i>Globigerina quinqueloba</i>	<i>Globigerinita glutinata</i>	<i>Globigerinita uvula</i>	<i>Martinottiella communis</i>	% sinistral <i>G. (T.) pachyderma</i>	No. <i>G. (T.) pachyderma</i> if <100	Age	
0.4	1-1(43-45)	-	F	O	O	O												
0.9	1-1(85-87)	P	O	VR	C	F	F		R						97	38	Upper	
1.8	1-2(27-29)	-	VR	O	R	O												
3.4	1-3(40-42)	-	O	O	R	F	R		R									
5.1	1-4(60-62)	-	VR	O	R	F	F		VR					100	10			
6.5	1-5(50-52)	M	O	VR	VR	C	F		F					100	42			
6.5	2-1(53-55)	M	O	O	O	R	R		R									
8.6	2-2(105-107)		O	O	VR	O												
16.4	3-1(140-142)		O	O	O	R	R		R									
16.8	3-2(30-32)		O	O	O	O												
18.3	3-3(30-32)		O	O	O	O												
19.8	3-4(30-32)		O	O	O	O												
24.6	4-1(60-62)		R	O	O	O												
25.8	4-2(30-32)		R	O	O	O												
27.3	4-3(30-32)		O	O	R	O												
28.6	4-4(11-13)	M	O	O	C	A	A		C		R			100			Middle	
33.4	5-1(40-42)	P	R	R	R	F	F		F					100	17			
34.8	5-2(30-32)	M	VR	VR	VR	C	C		C					98				
36.3	5-3(33-35)	P	R	O	O	F	F		R					100	13			
37.8	5-4(30-32)		O	O	O	O												
39.3	5-5(30-32)	M	O	O	R	C	C		C		VR			100				
40.8	5-6(30-32)		O	O	O	O												
43.3	6-1(30-32)	M	VR	O	R	F	F	VR	R					97	39			
45.3	6-2(78-80)	P	O	O	R	F	R		R					100	9			
47.1	6-3(110-112)	P	O	O	R	C	C	R	R					96	68			
48.3	6-4(84-86)		O	O	O	O												
49.6	6-5(62-64)	P	O	O	R	R	R											
77.4	7-2(90-92)	M	O	O	F	C	C	C	R					47				
81.7	7-5(74-76)	M	VR	O	R	C	C	F	F					65				
82.5	7(CC)		O	O	O	O												
87.9	8-3(88-90)		R	O	O	O												
112.9	9-1(88-90)	P	O	O	O	C	F	F	R					35	46		Lower	
116.2	9-3(120-122)		O	O	O	O												
116.5	9(CC)		O	O	R	R		R	R					0	7			
152.7	10-2(120-122)		R	O	O	O												
200.8	11-3(80-82)		O	O	R	O											Upper	
228.8	12-3(80-82)	M	VR	R	R	F	R	R	R	VR				20	10			
328.9	13-1(88-90)		O	O	O	O											Lower	
332.5	13(CC)		F	O	O	O								X			Upper	
423.2	14-2(65-67)		VR	O	O	O								X				
430.0	14(CC)		R	O	O	VR								X				
610.5	15(CC)		R	O	O	O												
618.0	16(CC)		R	O	O	O								X			?	

<sup>1</sup>For key to symbols, see Table 1.

*kamchatica* (lower Pliocene) and *Thalassiosira zalzelinae* (upper Pliocene) diatom zones. At Sites 184 and 185 its highest occurrence is just above this diatom zonal boundary and at Sites 192 and 190 it is just below it. *Martinottiella communis* does not occur at Sites 183, 186, and 187, which lack indigenous foraminifera in significant numbers, except in displaced middle Miocene material at Site 186. Also *M.*

*communis* was not found at Site 191 which is not known with certainty to have reached strata equivalent to the *D. kamchatica* Zone because cores from levels below the *T. zalzelinae* Zone lack significant identifiable diatoms. Cores at Site 189 also become unfossiliferous with reference to diatoms in the *T. zalzelinae* Zone, but occurrence of *M. communis* near the bottom of the hole at this site (Cores 16

TABLE 6  
Data on Occurrences of Foraminifera at Site 191<sup>1</sup>

Depth Below Sea Floor (m)	Core, Section Interval (cm)	Preservation	Benthics - Arenaceous	Porcelaneous	Hyaline	Planktonics	<i>Globorotalia (T.) pachyderma</i> (Form A)	<i>Globorotalia (T.) pachyderma</i> (Form B)	<i>Globigerina bulloides</i>	<i>Globorotalia (T.) scitula</i>	<i>Globigerina quinqueloba</i>	<i>Globigerinita glutinata</i>	<i>Globigerinita uvula</i>	<i>Martinottiella communis</i>	% sinistral <i>G. (T.) pachyderma</i>	No. <i>G. (T.) pachyderma</i> if <100	Age
23.0	1A(CC)	M	R	F	C	C	C		C						97		Upper Pleistocene
27.5	2A(CC)	M	R	O	C	C	C		C						99		
50.0	4A(CC)		O	O	O	O											
0.0	1(CC)		R	R	F	F	R		R								
5.5	2(CC)	M	O	O	F	F	F		R						67	12	
87.0	4(CC)	M	O	R	F	F	F		R						100	10	
143.0	5(CC)		VR	O	VR	O											
174.0	6(CC)	G	O	R	O	A	A		C	R					96		
230.0	7(CC)		R	O	R	F	R	R	VR						75	12	
277.0	8(CC)		O	O	VR	VR	VR										
322.5	9(CC)	M	R	VR	R	C	R	C	F						33	89	
388.5	10(CC)		O	VR	R	VR			VR								
523.0	12(CC)		O	O	O	O											Upper Pliocene ?

<sup>1</sup>For key to symbols, see Table 1.

and 20) indicate that strata equivalent to or older than *D. kamtschatica* Zone were reached. Within the Bering Sea the *D. kamtschatica* Zone was sampled and found barren of *M. communis* only at Site 188. The lowest occurrence of *M. communis* at Site 192 is lower Miocene or Oligocene (Core 30).

### PALEOCLIMATOLOGY

Across most of the North Pacific, the southern boundary of the subarctic fauna of planktonic foraminifera is at about 45°N and therefore more than 800 kilometers from the most southern of Leg 19 sites. Because the sites, at present, are remote from this faunal boundary and are separated from the arctic regions by the Alaskan-Siberian landmass, broached only by the narrow Bering Strait, it is presumed that in times past the planktonic faunas overlying them have been insensitive to all but the most important paleoclimatic changes. Therefore, it is believed that some paleoclimatic interpretations can be made from the record of changing assemblages of fossil planktonic foraminifera, although much of that record consists only of sporadic occurrences in sections that are otherwise lacking in planktonic foraminifera. Paleoclimatic interpretations of assemblages will be discussed from youngest to oldest because that is the order of increasing uncertainty. This uncertainty arises because, increasingly with age, interpretations must rely upon inferences about the latitudinal distribution of species that are extinct. An additional complication is that the records older than upper Miocene are all from Site 192. This site is located on the North

Pacific crustal plate believed to have moved long distances from more southern latitudes during the Tertiary.

There is now abundant evidence for a pronounced global cooling trend, probably marking the initiation of continental glaciation in mid-latitudes, occurring over the time interval from slightly earlier than the Jaramillo Normal paleomagnetic event (0.9 m.y.) to about the boundary between the Matuyama Reversed and Brunhes Normal paleomagnetic epochs (0.7 m.y.). Kent et al. (1971) give a recent summary of this evidence. The coiling direction of *G. (T.) pachyderma* appears to be a sensitive indicator of this cooling trend in the north Pacific area. *Globorotalia (T.) pachyderma* coils sinistrally in the polar part of its range and dextrally in the more temperate part. In surface sediments the boundary between sinistral and dextral populations occurs at about 45°N in the north central Pacific (Parker, 1971) and between 35°N and 40°N in the northeastern Pacific (Ingle, 1967; Morin, 1971). At DSDP Site 36 in the northeastern Pacific at about 41°N, sinistral populations occur throughout the section above the Brunhes-Matuyama paleomagnetic boundary (Olsson, 1971). From the time of that magnetic reversal to the present, therefore, the faunal boundary has never been far north of its present position, although it shifted far to the south during cold cycles (Bandy, 1960). In the warmer early Pleistocene, however, dextral populations occurred throughout the North Pacific (Bandy and Wilcoxon, 1970; Kent et al., 1971; Olsson, 1971). Evidence from Leg 19 cores (Figure 2) shows that early Pleistocene populations were dominantly dextral in the Bering Sea, the most northern part of the Pacific Ocean. However, if any other







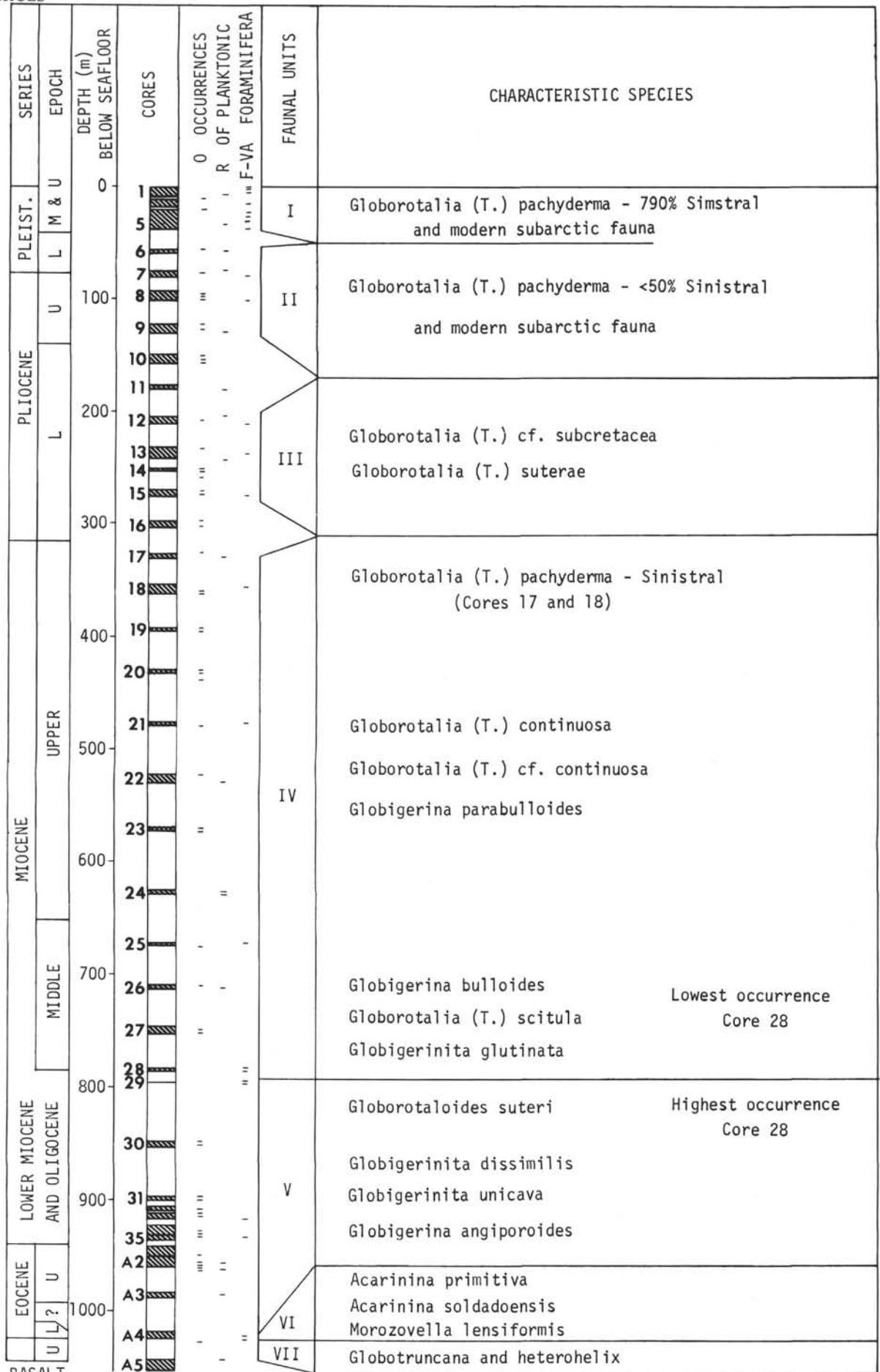


Figure 1. Sequence of planktonic foraminifera faunas at Site 192.

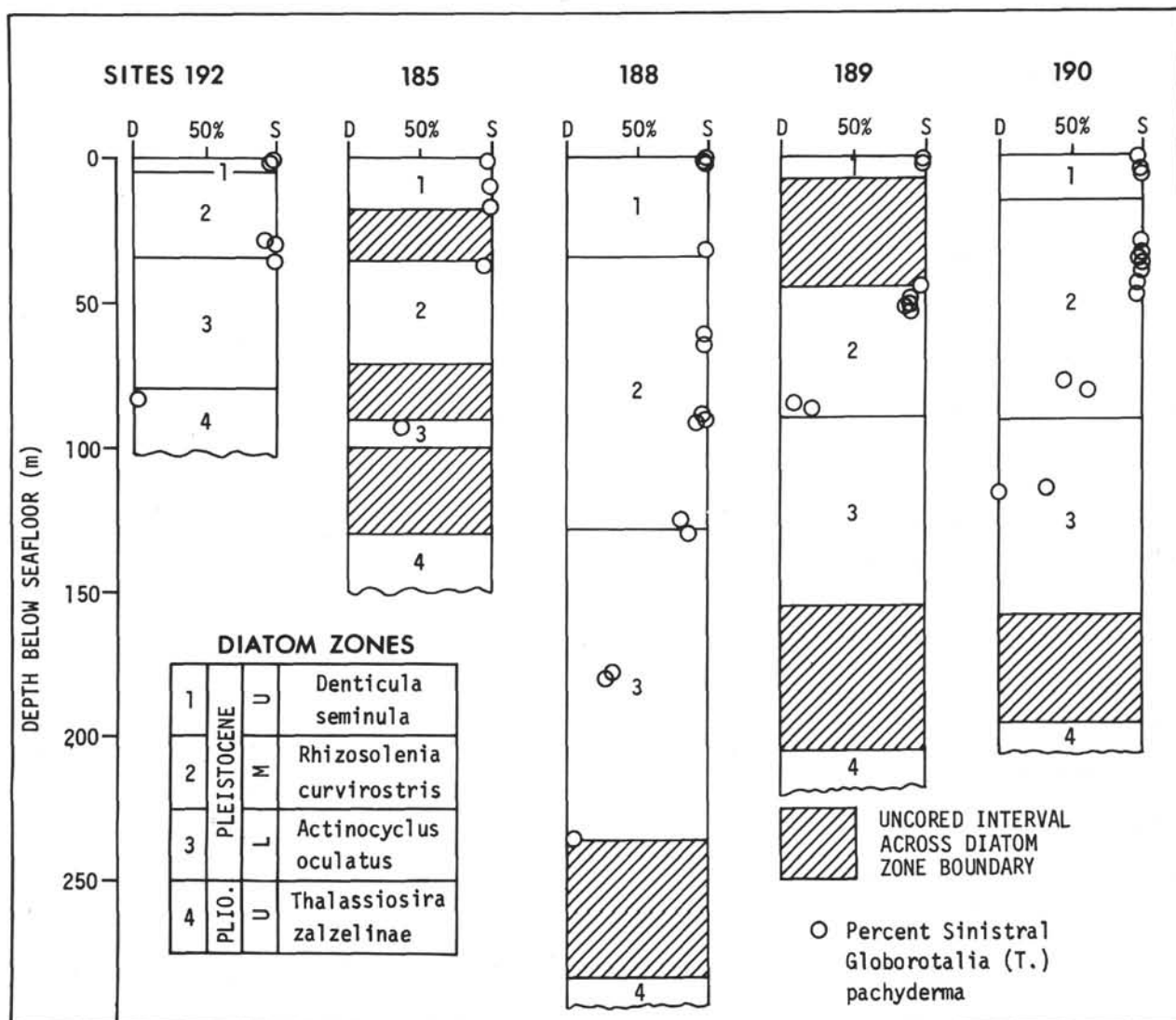


Figure 2. Coiling Ratio of *Globorotalia (T.) pachyderma* at five Leg 19 sites.

transitional zone planktonic foraminifer was associated with dextral *G. (T.) pachyderma* during the early Pleistocene in the Bering Sea, its remains have not been preserved in the material that has been examined. This suggests that the Bering Sea was relatively cool even in the early Pleistocene. Presence of ice-rafted material throughout the upper Pliocene and Pleistocene sections at Leg 19 sites supports this suggestion.

Planktonic foraminiferal assemblages in the lower part of the Pliocene at Site 192 also appear to indicate a climate more equitable than the present one. The high-latitude species *G. (T.) pachyderma* is absent here, although it occurs both in the upper Miocene and in upper Pliocene and Pleistocene assemblages. Further evidence for a warmer climate is the presence of *G. (T.) suterae*. This form resembles *G. (T.) puncticulata* (Deshayes), differing from it in its lower profile in edge view and its five, rather than four, chambers in the last whorl. *Globorotalia (T.) puncticulata* and other species similar to it morphologically, like *G. (T.) crassiformis* (Galloway and Wissler), have middle latitude distributions. This occurrence of *G. (T.) suterae*

can be compared to reports of *G. (T.) crassiformis* and *G. (T.) puncticulata* in the uppermost Miocene Montesano Formation and lower Pliocene Quinault Formation of Washington (Fowler in Ingle, 1967) that has been interpreted as evidence for an exceptionally warm cycle at this time (Ingle, 1967).

A relatively cool climate may be indicated by sinistral *G. (T.) pachyderma* occurring within the upper Miocene at Site 192. Sinistral *G. (T.) pachyderma* populations are known from the upper Miocene of the Southern California area (Ingle, 1967; Bandy and Ingle, 1970), of northern Japan (Asano et al., 1969), and of southeastern Alaska (Bandy et al., 1969). In the Yagatak Formation of southeastern Alaska they are associated with glacial marine sediments that provide physical evidence for cold climates at this time. However, upper Miocene glacial marine sediments have not been found in Leg 19 materials.

Sparse planktonic foraminiferal assemblages from the middle Miocene downward through the Oligocene retain the high-latitude aspect typical of assemblages at higher levels in the hole at Site 192. Probably because of the poor

quality of the record there is little evidence of the elements of low-latitude assemblages known to have invaded relatively high latitudes in the middle Miocene. This middle Miocene warm cycle is known to have been preceded by a cold cycle in the Oligocene during which ice-rafted sediments accumulated in subantarctic regions (Margolis and Kennett, 1971). The dominant species associated with these subantarctic ice-rafted sands, *Globigerinita dissimilis*, also occurs in a monospecific assemblage at Site 192, but there it is immediately below the boundary between the middle and lower Miocene and therefore probably within the lower Miocene. However, it has not been possible to adequately define the boundary between the Miocene and Oligocene at this site. Also occurring in apparent monospecific assemblages within the Oligocene-lower Miocene sequence at Site 192 are *Globigerinita unicava* and *Globorotaloides suteri*. This apparent low diversity suggests a cold climate. However, it is open to some question because many tests are crushed and could not be identified, therefore other species could be present. Another species from this interval, *Globigerina angiporoides*, is also reported associated with glacial marine sediments by Margolis and Kennett (1971) but from the upper Eocene rather than the Oligocene. Upper and middle Eocene sediments at Site 192 lack planktonic foraminifera.

Interpretation of the early Eocene paleoclimate from planktonic assemblages in Core 4A at Site 192 is important because it has potential bearing on the magnitude of North Pacific plate movement. Given, for example, the path and rate of movement proposed by Jackson et al. (1972), Site 192 was located north of the present location of the Hawaiian Islands in the early Eocene, perhaps at about 35°N. If the early Eocene faunal distribution resembled that in the modern North Pacific Ocean, then early Eocene planktonic foraminiferal assemblages at Site 192 should be analogous to the modern central or subtropical fauna. This fauna differs markedly from the subarctic fauna, but lacks many species characteristic of tropical faunas (Bradshaw, 1957). Unfortunately, little is known about the early Eocene faunal distribution in the area because there is a dearth of modern studies of early Eocene planktonic foraminifera from land sections around the North Pacific. Another important constraint on interpretation of the early Eocene fauna at Site 192 is its state of preservation. Relatively few of the abundant planktonic tests have survived compression without distortion and therefore the original composition of the fauna is in doubt. Nevertheless, some attributes of this assemblage can be discerned from the character of the assemblage of undisturbed tests supplemented by examination of compressed tests; some comparisons of these attributes with those of assemblages of known paleolatitude can be made.

Some pertinent attributes of the early Eocene fauna at Site 192 are:

1) There are six identified species and probably three or four more that could not be identified because of poor preservation. This gives a probable total diversity of about ten species.

2) Either *Acarinina primitiva* or *A. spinuloinflata*, or both, greatly dominate the fauna.

3) Although *M. lensiformis* has an acute periphery and may be keeled, species with strongly developed keels, like *M. caucasica* Glaessner, are absent.

Of importance to interpreting this fauna is comparison with early Eocene faunas of Kamchatka; Site 192 is presently located nearby, but would have been far south of these in the early Eocene if large-scale North Pacific plate motion has occurred. The early Eocene fauna of Site 192 is correlative with either the upper part of *Globigerina turgida-Acarinina triplex* Zone or with the *Globigerina inaequispira-Globigerinella voluta* Zone of Kamchatka; these are local zones that have been briefly described by Serova (1967). Unfortunately, the general aspect of the fauna in these two zones in the Kamchatka sections are very different and therefore meaningful comparison depends upon more precise correlation than is now possible. The *Globigerina turgida-Acarinina triplex* Zone is relatively diverse, and many of the species that are listed as characteristic of it are either the same as those at Site 192 or considered to be synonyms or probable synonyms of these by some workers. (These, under names given by Serova, are: *Globigerina triangularis* White, *G. linaperta* Finley, *G. bullbrooki* Bolli, *Acarinina crassiformis* Galloway and Wissler, *Globigerina coalingensis* Cushman and Hanna.) In contrast, the *Globigerina inaequispira-Globigerinella voluta* Zone consists almost wholly of these two species and *Globigerina pseudoeocaena pseudoeocaena* Subbotina. It appears that if the Site 192 fauna correlates with the *G. turgida-A. triplex* Zone, then similarities are sufficient that latitudinal separation from Kamchatka in the early Eocene could be inferred only by careful comparisons that are not possible from available information. If, however, it correlates with the *G. inaequispira-G. voluta* Zone, differences are great and geographic separation is likely.

Other comparisons of interest are with subantarctic assemblages in deep-sea cores described by Margolis and Kennett (1971) and with those from DSDP Leg 6 from Shatsky Rise described by Blow (1971) and Krashennikov (1971). The subantarctic assemblages, which are probably a little older than those of Site 192, have a maximum of five species, are dominated at frequencies of 80 to 90% by *A. primitiva*, and include *M. aequa rex* (Martin). In comparison, Site 192 assemblages are slightly more diverse, include and may be dominated by *A. primitiva*, and include *M. lensiformis* which is morphologically similar to *M. aequa rex*. In contrast late early Eocene assemblages at Site 47.2 from Shatsky Rise, as described by Krashennikov (1971), are far more diverse and include strongly keeled species characteristic of tropical assemblages that do not occur at Site 192. Shatsky Rise is also located on the North Pacific plate and would have been transported from tropical latitudes since the early Eocene if Site 192 has been transported from subtropical latitudes.

These comparisons indicate that the early Eocene fauna of Site 192 has affinities with early Eocene high-latitude faunas, but they do not preclude it from being a subtropical fauna. In this regard, comparison with assemblages from North Atlantic surface sediments below the central part of the subtropical gyre are interesting. Ruddiman (1969) found these to be dominated at high frequencies by



*Globigerinoides ruber* d'Orbigny and in some cases to have a diversity of no more than ten species even though assemblages at the same latitude in the current gyre around the central part of the subtropical region were more diverse. It is possible that these North Atlantic assemblages are modern analogs of the early Eocene fauna at Site 192. Only from thorough study of the paleoecology of early Eocene planktonic foraminifera, and perhaps from study of better preserved assemblages on the North Pacific plate, will it be possible to tell.

Late Cretaceous rocks at the bottom of the section at Site 192 did not yield a representative assemblage of planktonic foraminifera. Therefore this group of fossils cannot contribute to inferences on the Late Cretaceous paleoclimate.

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PLATE 1

- Figures 1-6 *Globorotalia (Turborotalia) pachyderma* (Ehrenberg). 19 188-5, CC. X150; Middle Pleistocene. Figures 1-3 illustrate sinistral individuals and Figures 4-6 illustrate dextral ones.
- Figures 7, 8 *Globorotalia (Turborotalia) pachyderma* (Ehrenberg). 19-188-7, CC. X150; Early Pleistocene. Dextral individuals.
- Figures 9-12 *Globorotalia (Turborotalia) cf. G. (T.) subcretacea* (Lomnicki). 19-192-13-4, 20-22 cm. X150; Early Pliocene.
- Figures 13, 14 *Globorotalia (Turborotalia) suterae* Catalano and Sprovieri. 19-192-13-4, 20-22 cm. X150; Early Pliocene.
- Figure 15 *Globorotalia (Turborotalia) cf. G. (T.) continuosa* Blow. 19-192-21-1, 23-24 cm. X150; Late Miocene.

PLATE 1



1



2



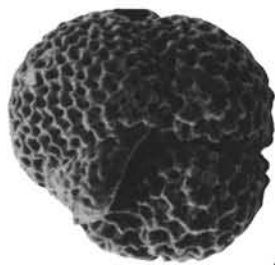
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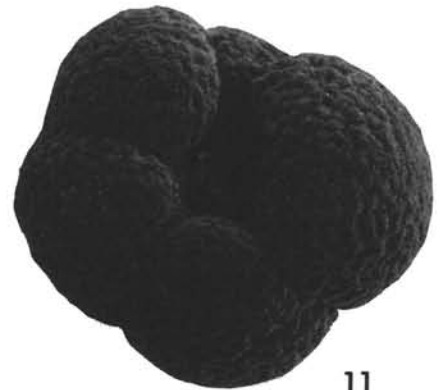
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