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29. MIOCENE BENTHIC FORAMINIFERS AT SITES 794, 795, AND 797 IN THE SEA OF JAPAN WITH REFERENCE TO THE FORAM SHARP LINE IN THE HONSHU ARC[1]

Ritsuo Nomura[2]

ABSTRACT

Benthic foraminifers from ODP Sites 794 and 797 (Yamato Basin) and Site 795 (Japan Basin) were investigated to clarify the Miocene paleoceanography and paleobathymetry of the Sea of Japan. Miocene benthic foraminifers from the three sites are generally characterized by agglutinated deep-water species apparently living below calcium carbonate compensation depth (CCD), except for faunas indicative of environments above the CCD in the early middle Miocene (~14 to ~17 Ma) and redeposited faunas in upper Miocene sediments. Based on species occurrences, the following assemblage zones are recognized from lower to upper horizons: at Site 794, the *Chilostomella oolina/Cyclammina* sp. C and the *Spirosigmoilinella compressa/Martinottiella communis* Zones; at Site 795, the *Martinottiella communis,* the *Oridorsalis umbonatus/Cibicidoides wuellerstorfi,* the *Martinottiella communis/Cribrostomoides* cf. *crassimargo,* and the *Cyclammina ezoensis* Zones; at Site 797, the *Cyclammina* sp. A/*Cyclammina*? sp., the *Gyroidina orbicularis/Gyroidinoides planulatus,* the *Cibicidoides wuellerstorfi,* and the *Martinottiella communis/Globobulimina pupoides* Zones and two barren intervals below the *Cyclammina* sp. A/*Cyclammina*? sp. Zone and between the *Cibicidoides wuellerstorfi* and the *Martinottiella communis/Globobulimina pupoides* Zones, respectively.

Benthic faunal changes are principally reflected by variations in the ratio between agglutinated and calcareous tests. Dominantly calcareous faunas developed in the early middle Miocene at Sites 794 and 797 and in the middle middle Miocene at Site 795. The first appearance of a dominantly calcareous fauna in the *G. orbicularis/G. planulatus* Zone at 17.1 Ma suggests a change from low-oxygen to high-oxygen bottom water. This paleoceanographic change was likely caused by widening of the Proto-Japan Sea in a tensional stress field. Thus, the significant opening of a basin along with the Pacific deep waters in the Sea of Japan is considered to have occurred at 17.1 Ma.

On the basis of an appearance of a barren interval and/or agglutinated fauna during the middle Miocene, two significant benthic foraminifer events are recognized in the Sea of Japan. The First Foram Sharp Line (1st FSL), representing an abrupt change from calcareous to agglutinated faunas, appears at 14.4 Ma at Site 794 and 14.3 Ma at Site 797. These ages are also close to the ages obtained for occurrence of the FSL in onshore Miocene sequences in the Honshu arc. The coeval appearance of the 1st FSL in the Yamato Basin and along the Sea of Japan coast indicates that the uplift of backbone ranges of the Honshu arc resulted in oxygen-deficient bottom water in the evolving back-arc basin. Uplift was likely associated with the clockwise rotation of the Japanese Islands. The Second Foram Sharp Line (2nd FSL) at Site 795 is estimated to occur at 11.2 Ma, which is about 3 m.y. later than the first FSL at Sites 794 and 797. These differences between the Yamato and Japan Basins suggest that sub-basins in the Sea of Japan did not respond simultaneously to changes in deep-water masses and currents. Paleotopographic features were changed dramatically through the back-arc opening process. The FSL at Site 795 may be related to global paleoceanographic changes and rather than caused by local silled basin effects. Thus, two types of the FSL are recognized in the Miocene Sea of Japan, which express both global and provincial paleoceanographic events.

INTRODUCTION

The Tertiary system along the coast of the Sea of Japan has been studied for over 60 years, both for oil exploration and for basic science. In general, the Tertiary system in the Japanese Islands is characterized by a differentiation into several basins caused by the location in an active or collision-margin setting. In order to correlate sediments among various basins, benthic foraminifers have been studied and regional zones have been proposed; e.g., Southwest Honshu (Tai, 1959), Central Honshu (Chiji, 1961), and Northeast Honshu (Matsunaga, 1963). In particular, the benthic foraminiferal zonation of Northeast Honshu is well correlated with planktonic foraminiferal zonation (Maiya, 1978). Using these biostratigraphic works, many workers have discussed the paleoenvironmental history of the coast of the Sea of Japan. Of special significance, Tai (1963, 1985, 1988) recognized a major middle Miocene benthic foraminiferal faunal change. He defines the Foram Sharp Line (FSL), which is expressed as the abrupt change from a diversified warm-water fauna to a low-diversity agglutinated fauna. This faunal change is thought to signify one of the most important paleoceanographic changes in the development of the Sea of Japan. Because these earlier studies were restricted to onshore or coastal sequences, it has been possible to corroborate the FSL hypothesis in the larger Sea of Japan region.

At Sites 794, 795, and 797 a nearly continuous record of Miocene sedimentation in the Sea of Japan was recovered. Recovery of these sediments permits us to compare the sedimentation histories between the Japanese Islands and the Sea of Japan proper and to discuss paleoceanographic changes in the Sea of Japan in much more detail than heretofore possible. The objectives of this paper are to document the occurrence of Miocene benthic foraminifers at ODP Sites 794, 795, and 797 and to discuss the FSL in relation to the opening event of the Japanese Islands (Otofuji and Matsuda, 1983, 1984; Otofuji et al., 1985a, b, c, 1986; Hamano and Tosha, 1985; Hayashida and Torii, 1988; Hayashida et al., 1991; Tamaki, 1985, 1988). Particularly, the FSL identified at Sites 794 and 797 can be correlated with geologic events identified in the Southwest Honshu arc (e.g., Nomura, 1989).

MATERIALS AND METHODS

Samples analyzed herein were taken from cores drilled during Leg 127 in order to examine the Miocene paleoceanography using benthic foraminiferal analysis. Sites 794 (2811 m present water depth) and 797 (2862 m present water depth) are both situated in the Yamato Basin (Fig. 1). Site 794 is located in the northeast Yamato Basin; Site 797 is on the base of the southern slope of the Yamato Rise. Site 795 (3298 m present water depth) is located in the northernmost Japan Basin (Fig. 1).

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[1] Pisciotto, K. A., Ingle, J. C., Jr., von Breymann, M. T., Barron, J., et al., 1992. *Proc. ODP, Sci. Results,* 127/128, Pt. 1: College Station, TX (Ocean Drilling Program).

[2] Department of Earth Sciences, Faculty of Education, Shimane University, Matsue, 690, Japan.

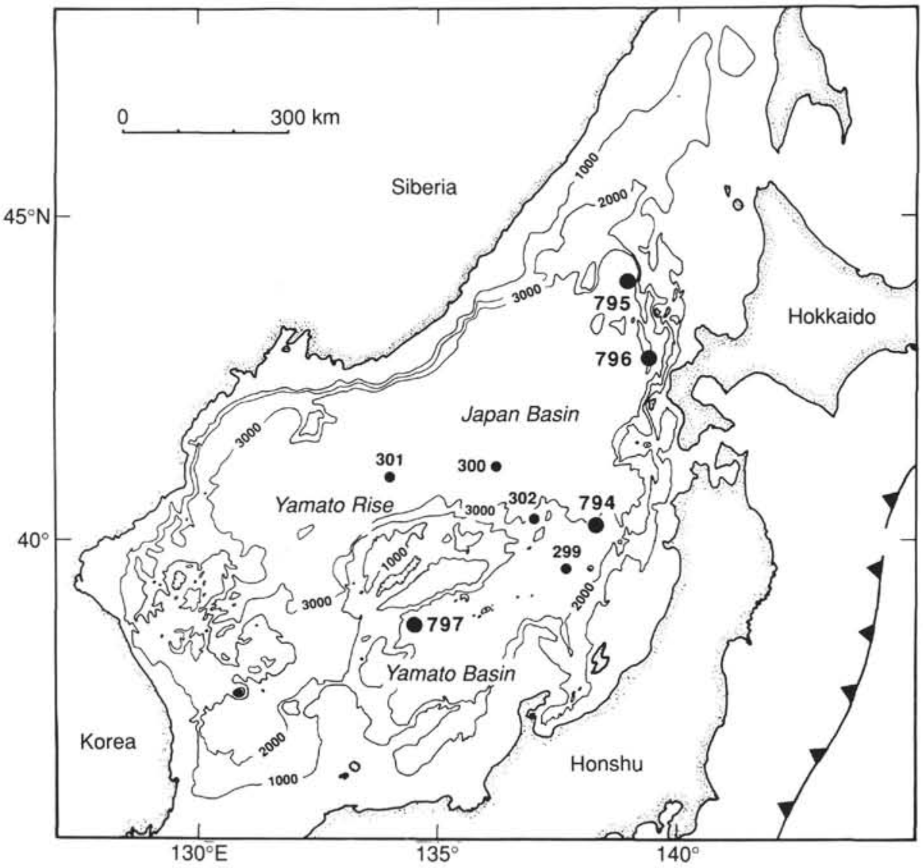

Figure 1. Location map of Sites 794, 795, and 797 in the Sea of Japan.

Sample intervals in lower to lower middle Miocene sediments are sufficient to establish faunal changes, although the preservation of foraminiferal specimens is not good. Some agglutinated taxa such as *Cribrostomoides, Cyclammina,* and *Eggerella* are commonly deformed, and calcareous overgrowths on calcareous foraminiferal tests occur in the lower middle and middle Miocene calcareous-rich sediments. Such bad foraminiferal preservation makes it difficult to analyze stable isotopes in foraminiferal tests. In addition, foraminiferal number and species number per unit sediments (cm^3) are generally low, which also limits use of a quantitative multivariate analysis. Relative percentages of each taxon are shown in Tables 1–3, but tubular agglutinated tests such as *Bathysiphon,* although common, were not counted in this study. Similarly, *Martinottiella communis* is characterized by a tubular test that is easily broken. However, its frequency was established by counting only the early tests with a proloculus. Sample horizons from each ODP site are shown in Figures 2–4 along with lithologies, other microfossil zones, and geologic ages as given in Tamaki, Pisciotto, Allan, et al. (1990) and Barnes (this volume).

The volume of each sample from Holes 794B, 795B, 797B, and 797C was first measured and then washed with warm water on a 63 µm sieve. However, samples that did not easily disaggregate were dried in an oven at 70°C, and a supersaturated Na_2SO_4 solution and naphtha was applied to aid breakdown. The latter two methods are alternately applied; first the samples were bathed in supersaturated Na_2SO_4 solution about 1 hr and the Na_2SO_4 solution decanted. Samples were dried at room temperature to allow growth of Na_2SO_4 crystals for 1 or 2 days and washed again with hot water on a sieve. Next, the hot and dried rock residues were bathed in naphtha until cool. Hot water was again poured onto the residues, and they were boiled on a hot plate for 2 or 3 hr. By these methods, most rock fragments were disaggregated, except for hard siliceous rocks and calcareous concretions.

Benthic foraminifers were picked from the 149 µm size fraction. Sample size varies from 1 to 319 specimens. A cluster analysis based on Dice's coefficient (= c/a + b) was used to compare sample similarity, where a and b are the number of species in each of the two samples being compared and c is the number of species that occur concurrently in both samples.

LITHOSTRATIGRAPHY

Variations in Miocene benthic foraminiferal faunas correspond directly to lithological divisions. Specifically, abundances of calcareous or agglutinated foraminifers are stratigraphically well correlated with the carbonate content of sediments. The lithological units discussed below are distinguished in the Miocene sediments at Sites 794, 795, and 797 on the basis of mineralogy, grain size, microfossil abundance, and bedding characteristics (Tamaki, Pisciotto, Allan, et al., 1990).

At Site 794, four lithological units are recognized: Unit II (Subunit IIA, 92.3–216.9 mbsf; Subunit IIB, 216.9–293.5 mbsf) consists of diatom clay and diatom ooze; Unit III (Subunits IIIA, 293.5–351.3 mbsf; Subunit IIIB, 347.8–491.7 mbsf) is composed of clay or claystone with silica of opal-CT; Unit IV (491.7–520.6 mbsf) is recognized by blue-gray to grayish-green or dark gray tuff, lapilli tuff, and claystone with or without

Table 1. Benthic foraminiferal distribution (%) at Site 794.

Holes 794A and 794B Section Interval (cm)	794A- 19X-4 4–8	3R-4 84–88	794B- 19R-1 82–83	19R-3 43–45	19R-4 37–39	20R-1 139–143	20R-4 7–11	24R-1 17–19	24R-4 126–129	25R-1 38–39	26R-1 24–26
Ammodiscus concinnus							1.7				
Ammodiscus macilentus	4.0		10.1			6.7	5.1	1.2	2.4	1.7	1.9
Ammodiscus sp.				5.0	2.6						
Ammosphaeroidina? sp.			2.9								
Ammovertellina sp.			1.4								1.2
Bathysiphon spp.	+		+	+		+	+			+	
Chilostomella oolina						2.5		16.9	23.0	10.5	
Cribrostomoides cf. *crassimargo*				10.0		10.0		3.0		1.1	
Cyclammina cancellata	4.0				5.1	5.8				1.1	0.6
Cyclammina pusilla						0.8			2.4	5.0	
Cyclammina sp. C	12.0						3.4	0.6	19.8	15.5	17.4
Cyclammina? sp.				5.0	38.5	12.5	7.7				
Dentalina spp.										1.7	
Eggerella bradyi							2.6		1.6		
Eggerella sp. B											6.2
Epistominella sp.										4.4	
Fissurina spp.									0.8		
Fursenkoina ishikiensis									1.6		
Fursenkoina sp.									0.8		
Gaudryinella? sp.										1.1	
Globobulimina sp.									2.4		
Globobulimina sp. indet.									1.6		
Globocassidulina globosa (s.l.)	8.0										
Globocassidulina sp. B						0.8		0.6			
Gyroidina orbicularis										0.6	
Gyroidina spp.								0.6		0.6	
Gyroidinoides planulatus									2.4		
Haplophragmoides sp. A										8.8	6.8
Haplophragmoides? sp.			11.6			2.5				1.1	1.2
Hopkinsina sp.										1.1	
Marginulina cf. *glabra*										0.6	
Martinottiella communis	28.0	100.0	11.6	25.0	5.1	45.0	15.4	1.2	5.6	3.3	5.0
Miliolinella sp.								0.6			
Nodosaria longiscata									0.8		
Nodosaria sp.									2.4		
Nonionella miocenica						2.5			8.7	1.7	
Nonionella stella								1.8			
Nonionella? sp.								1.2			
Nonionellina labradorica								0.6	2.4		
Plectina? sp.					2.6						
Plectina nipponica			8.7					3.0		3.3	
Psammosphaera compressa			1.4							1.7	
Pullenia bulloides										3.3	
Pullenia sp.									0.8	0.6	
Recurvoides? sp.											0.6
Rhabdammina sp.			+			+	+			+	+
Saccammina sphaerica									0.8		
Schizammina sp.											
Spiroplectammina sp.			+			0.8	+		+		
Spirosigmoilinella compressa			15.9		10.3	1.7	1.7	0.6	2.4	1.7	6.8
Thalmannammina cf. *parkerae*					10.3			9.6	1.6	2.2	30.4
Tosaia hanzawai									0.8	0.6	
Trochammina? sp.			4.3								
Uvigerina cf. *proboscidea*								2.4			
Uvigerina sp.									0.8		
Valvulineria cf. *masudai*									4.0	1.7	
Miscellaneous taxa	44.0		31.9	55.0	25.6	8.3	62.4	56.0	10.3	25.4	21.7

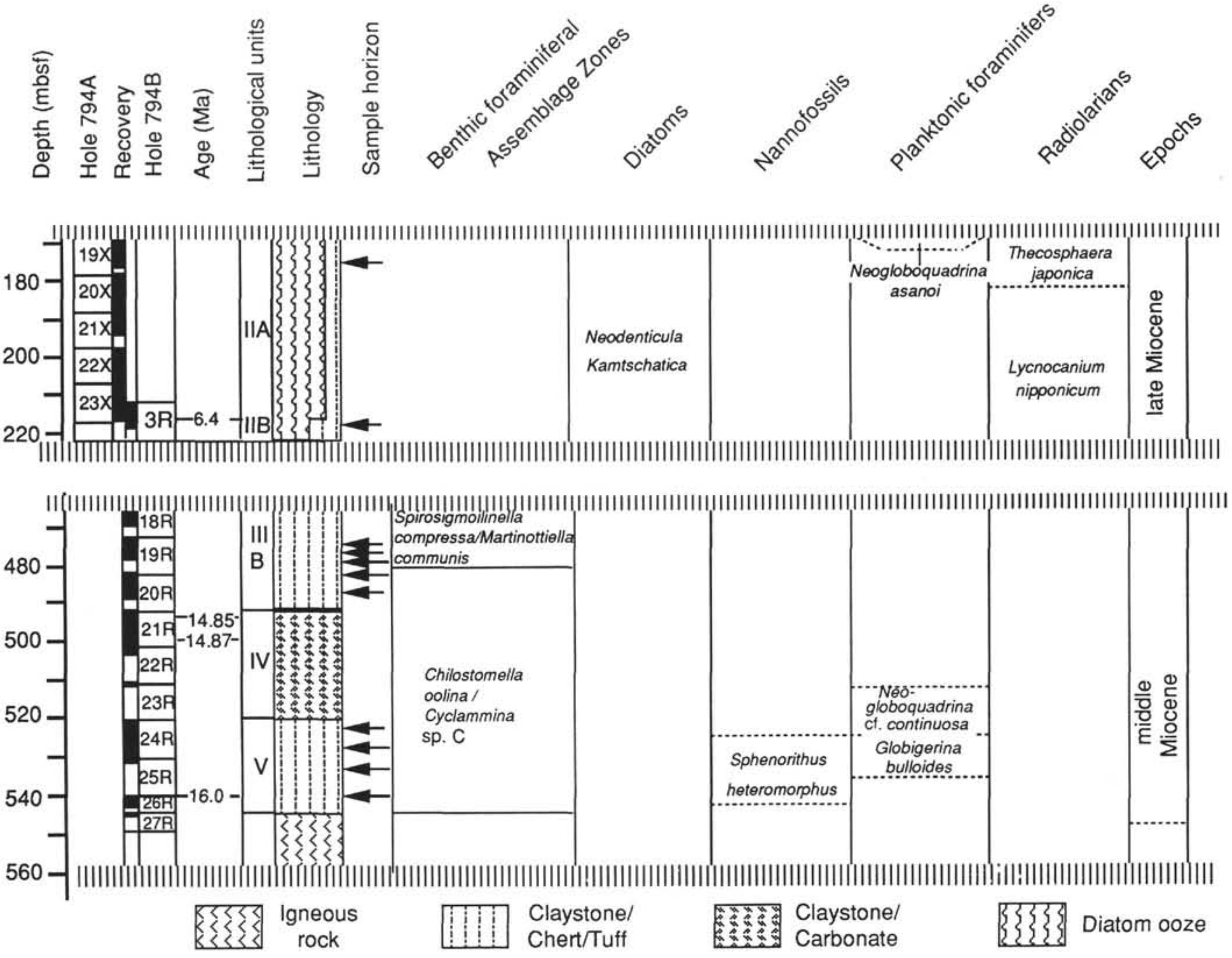

Figure 2. Sample horizons, benthic foraminiferal zones, lithological units, and diatom, nannofossil, planktonic foraminifer, and radiolarian zones at Site 794. Arrows indicate the sample horizons.

lamination and bioturbation; Unit V (520.6–544.3 mbsf) consists of moderately bioturbated claystone with glauconitic claystone and contains diagenetic dolomite and ankerite.

At Site 795, the Miocene argillaceous sediments are divided into two lithological units: Unit IV (Subunit IVA, 325–413 mbsf; Subunit IVB, 413–665 mbsf) consists of bioturbated siliceous claystone and silty siliceous claystone with chert and porcellanite; Unit V (665–685 mbsf) consists of claystone and altered fine to coarse-grained "blue" tuff.

At Site 797, the Miocene sediments are divided into three lithological units: Unit III (224–301.5 mbsf) includes upper upper Miocene diatom clay and siltstone; Units IV (Subunit IVA, 301.5–350 mbsf; Subunit IVB, 350–426.6 mbsf) consists of upper Miocene to upper middle Miocene claystone, silty claystone, and siliceous claystone; Unit V (426.6–627.3 mbsf) consists of lower middle Miocene to lower Miocene siliceous claystone, phosphatic and calcareous claystone, and tuff; Unit VI (646.9–900.1 mbsf) consists of interbedded sandstone, siltstone, and silty claystone. Lithological Unit VI is also characterized by the alternation of volcaniclastic and carbonaceous siltstone, sandstone, and silty claystone and also interbedded with basalt.

RESULTS

Site 794

Species Ranges

Although volcanic ashes (lithological Unit IV) are intercalated in the mudstone between 491 and 520 mbsf (lithological Units V and IIIB), calcareous foraminifers such as *Chilostomella oolina, Nonionella miocenica,* and *Globocassidulina* sp. C occur almost continuously through Sample 127-794B-20R-1, 139–143 cm (483.39 mbsf) (Fig. 5). *Gyroidina orbicularis, Valvulineria masudai, Gyroidinoides planulatus,* and *Nonionella stella* are rare and their occurrences are restricted to lithostratigraphic Unit V. Agglutinated foraminifers are generally long ranging. For example, *Martinottiella communis* is found in all samples examined at Site 794. The occurrences of *Thalmannammina* and *Cyclammina pusilla* are similar to the upper range of calcareous foraminifers.

Abundance

Abundances of the most common species at Site 794 are shown in Figure 6. *Chilostomella oolina* occupies over 10% of the fauna at

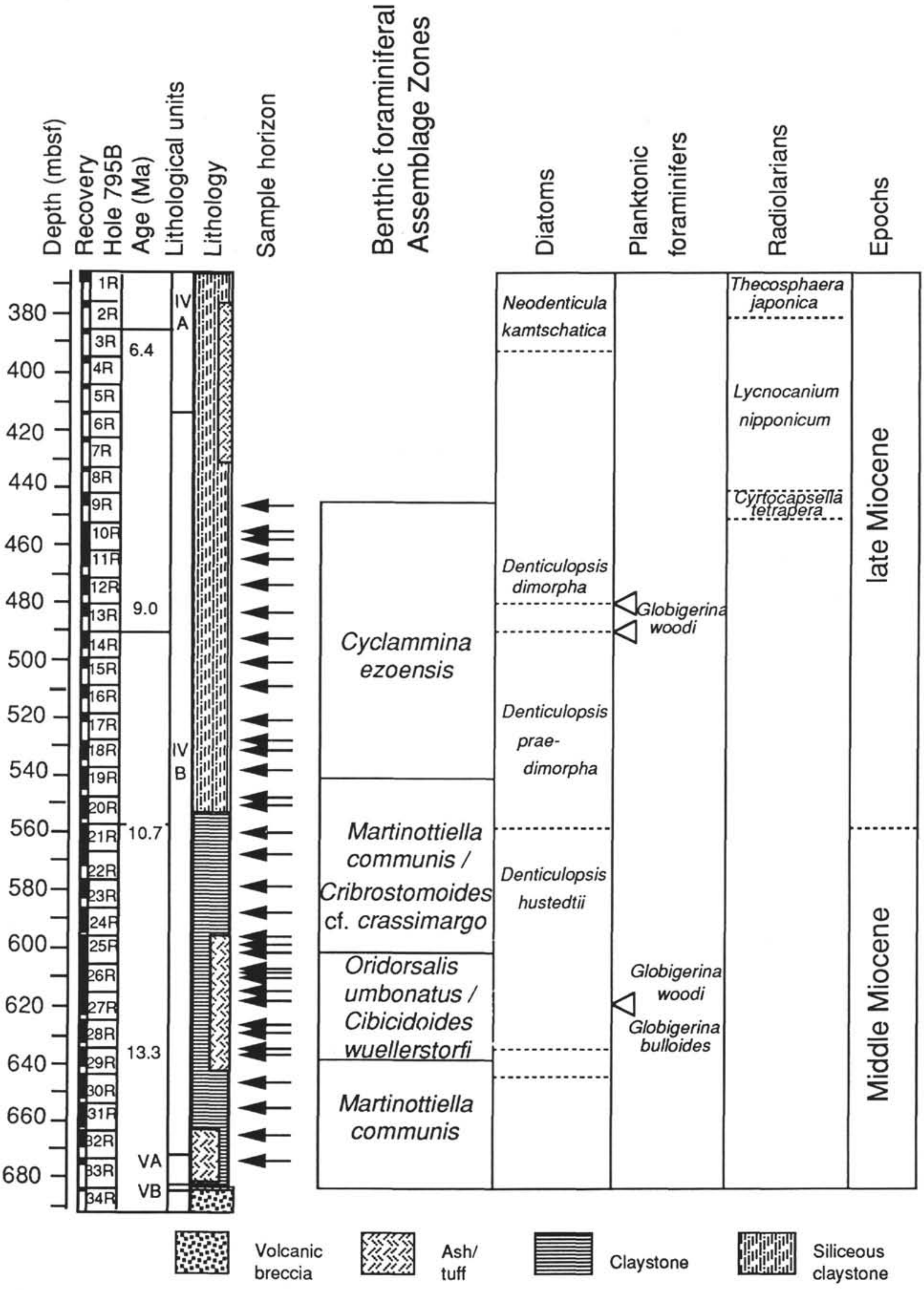

Figure 3. Sample horizons, benthic foraminiferal zones, lithological units, and diatom, nannofossil, planktonic foraminifer, and radiolarian zones at Site 795. Arrows indicate the sample horizons.

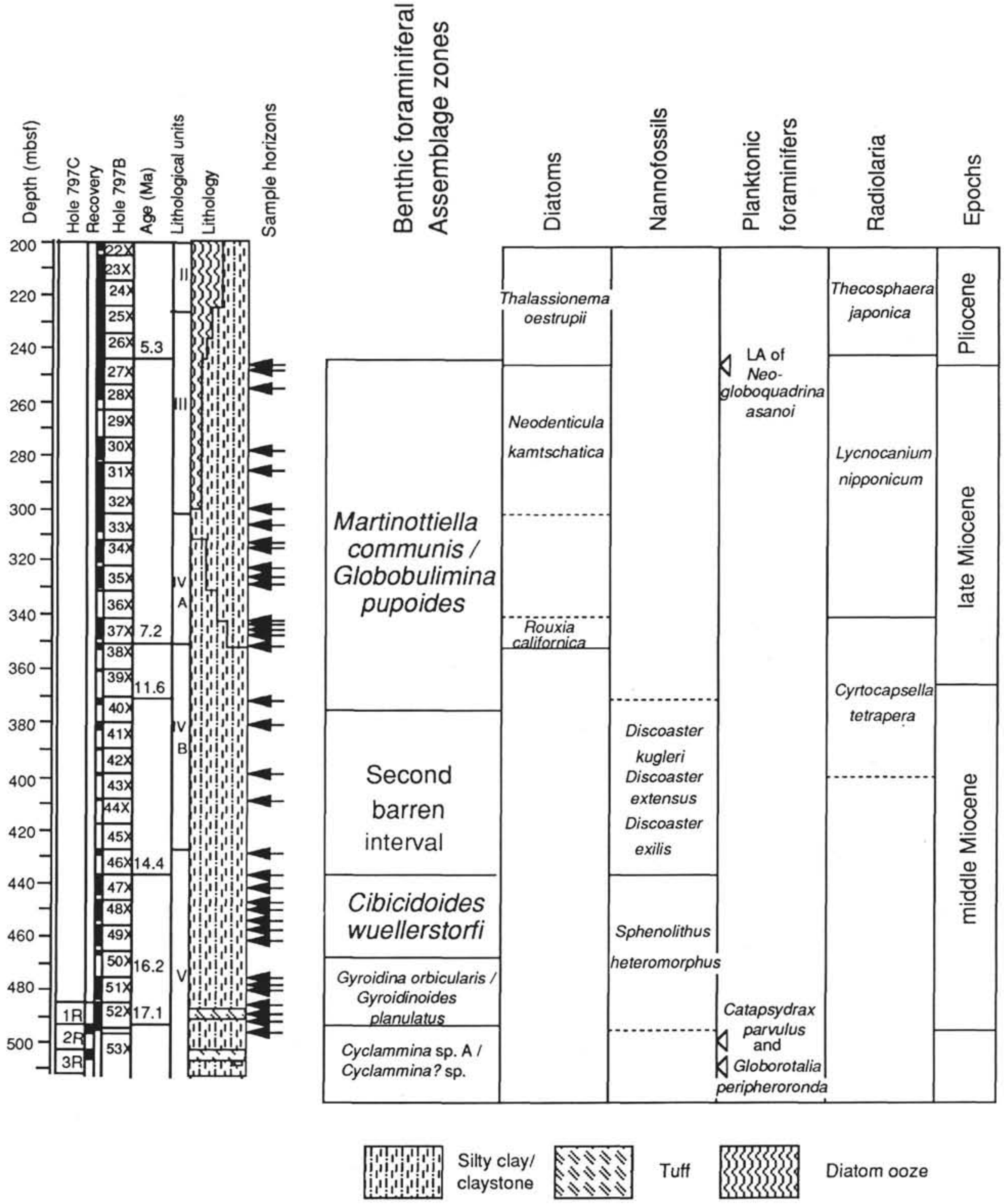

Figure 4. Sample horizons, benthic foraminiferal zones, lithological units, and diatom, nannofossil, planktonic foraminifer, and radiolarian zones at Site 797. Arrows indicate the sample horizons.

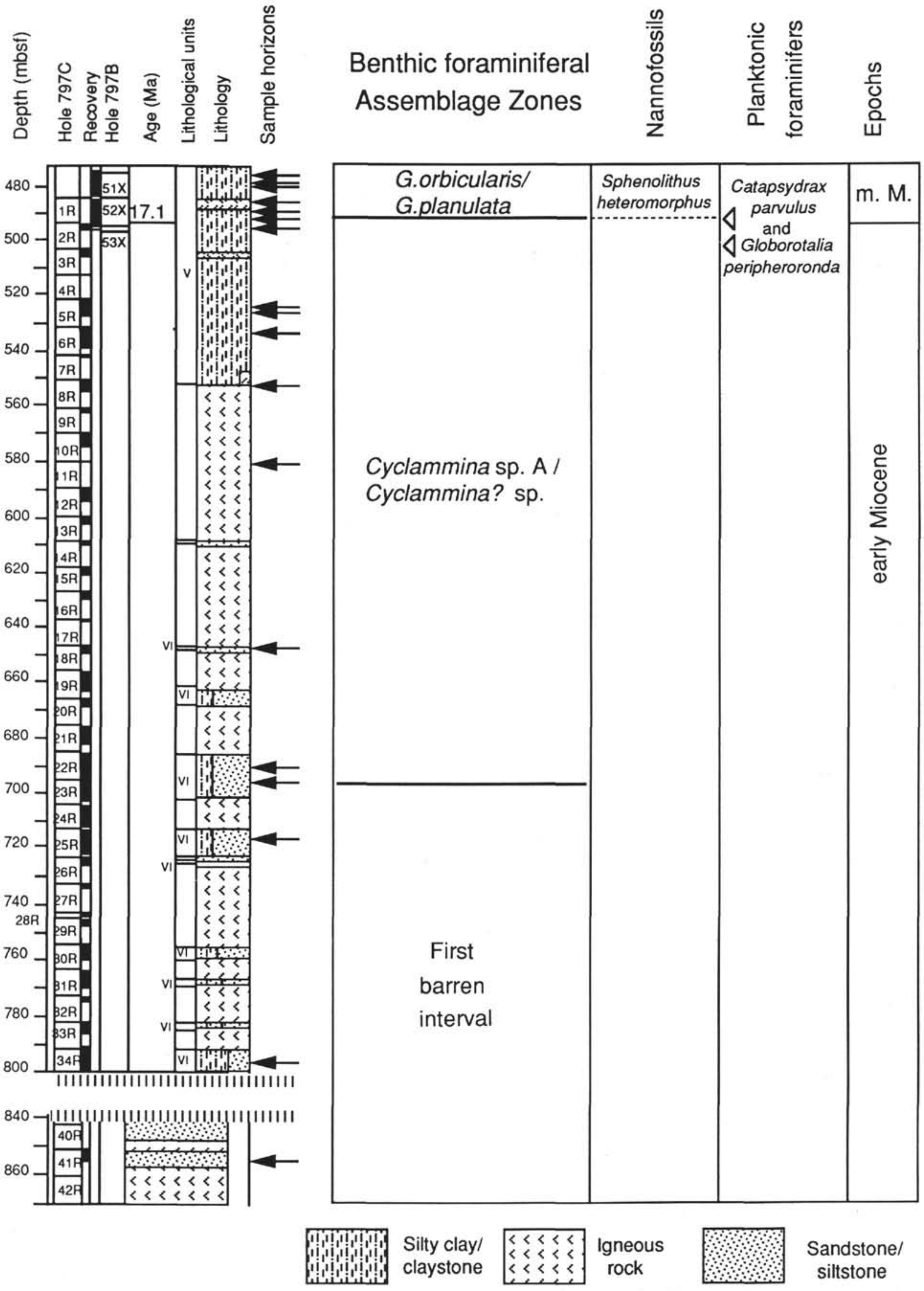

Figure 4 (continued).

Table 2. Benthic foraminiferal distribution (%) at Site 795.

Hole 795B Section Interval (cm)	795B- 9R-3 71–75	10R-3 50–52	10R-5 50–52	11R-4 50-52	12R-3 46–50	13R-3 48–52	14R-3 50–52	15R-2 57–61	16R-1 42–45	17R-2 42–43	18R-1 48–50	18R-3 44–46	19R-2 42–43	20R-1 41–45
Ammobaculites spp.											0.9			
Ammodiscus macilentus		0.9	4.3	0.9				1.7	3.8	4.5	4.9	4.4	3.8	2.3
Ammodiscus sp. A						1.0								
Ammodiscus tenuis					0.7	11.4	1.0				1.3			
Ammosphaeroidina spp.		2.6												
Ammovertellina sp.			1.1											
Anomalinoides sp.														
Astrononion sp.														
Bathysiphon spp.	+	+		+		+	+	+			+			
Bermudezina aminaensis							2.1	5.1			3.1	2.2		
Bulimina rostrata														
Bulimina striata														
Cibicidoides bradyi														
Cibicidoides wuellerstorfi														
Cibicidoides sp.					0.7									
Cribrostomoides cf. *crassimargo*				6.5		11.4	10.3	19.2	3.8	24.7	28.0	11.7	7.7	5.7
Cribrostomoides sp.														
Cyclammina cancellata	15.2	1.8	5.4	2.8			4.1	1.3			2.2			3.4
Cyclammina ezoensis			9.8		31.0	7.6	2.1				1.3			5.7
Cyclammina cf. *japonica*														
Cyclammina orbicularis			13.0	2.8				0.4						
Cyclammina pusilla				0.9		1.0			1.9			1.5	3.8	
Cyclammina sp.	21.2		6.5	14.8		6.7	1.0	0.9	1.9	5.6	0.4	2.9	3.8	6.8
Cyclammina? sp.								0.4		5.6	4.9			
Discammina compressa											1.1	1.3	0.7	
Discammina? sp.														
Eggerella bradyi					2.8	18.1	6.2	9.4	5.7					3.4
Elphidium cf. *bartletti*														
Elphidium cf. *perforatum*														
Elphidium sp.														
Fissurina marginata														
Fissurina marginata (compressed)														
Fissurina sp. A														
Fissurina spp.														
Glandulina cf. *nipponica*														
Globobulimina perversa														
Globobulimina pupoides														
Globobulimina sp.														
Globocassidulina globosa (s.l.)					0.7	2.9								
Gyroidina orbicularis														
Gyroidinoides planulatus														
Haplophragmoides sp.								1.0			3.4	1.3		
Haplophragmoides? sp.									0.4	1.9			0.7	
Hippocrepinella variabilis														
Hippocrepinella? sp.									0.4					
Hormosina sp.												0.9		
Lenticulina spp.														
Marginulina sp.														
Martinottiella communis	39.4	71.1	41.3	69.4	40.8	21.9	21.6	45.3	71.7	42.7	0.9	65.0	46.2	42.0
Martinottiella sp. A														

520.77–530.68 mbsf and attains 23% of the total fauna at Sample 127-794B-24R-4, 126–129 cm (526.36 mbsf). *Cyclammina* sp. and *Spirosigmoilinella compressa* attain peak abundances in lithological Unit IIIB, but they do not exhibit continuously high abundance through this unit. *Cyclammina* sp. C and *Thalmannammina* cf. *parkerae* are most abundant in lithological Unit V, though they are rare in some samples. The proportion of *Martinottiella communis* is generally high in the upper Miocene (lithological Unit II) and comprises up to 100% of the fauna; indeed upper Miocene faunas are characterized by a low number of species and individuals (0.9–1.3 species and 1.3–12.1 individuals/cm^3).

Figure 7 illustrates the species number, individuals/cm^3, as well as species occurrences determined using the sedimentation rate per 1000 yr. As clearly shown in this figure, higher numbers of both foraminiferal species and individuals characterize lithological Unit V, lower numbers occurring in Units IIIB and II, particularly in Unit II.

Calcareous vs. Agglutinated Foraminifers

A distinct peak in calcareous foraminifers represented by *Chilostomella oolina* is found at 526.36 mbsf, attaining 55% of the total fauna (Fig. 8). The high abundance of calcareous foraminifers

Table 2 (continued).

Hole 795B Section Interval (cm)	795B- 9R-3 71–75	10R-3 50–52	10R-5 50-52	11R-4 50-52	12R-3 46–50	13R-3 48–52	14R-3 50–52	15R-2 57–61	16R-1 42–45	17R-2 42–43	18R-1 48–50	18R-3 44–46	19R-2 42–43	20R-1 41–45
Melonis nikobarense														
Melonis pompilioides														
Nodosaria sp.						1.0								
Oolina sp. A		0.9			0.7									
Oolina sp. B														
Oolina sp.														
Oridorsalis umbonatus														
Plectina nipponica											0.4		3.8	
Proteonina compressa												0.7		2.3
Proteonina cf. *compressa*														
Pullenia bulloides														
Pullenia quinqueloba														
Pullenia salisburyi														
Pyrgo sp.														
Pyrgo? sp.														
Quadrimorphina sp.														
Quinqueloculina sp.														
Reophax spp.											0.4			
Reophax? sp.														
Rhabdammina spp.			+		+	+	+	+	+		+			+
Saccammina cf. *sphaerica*														
Schizammina sp.			+								+	+		
Sphaeroidina japonica														
Sphaeroidina sp.														
Spirosigmoilinella compressa														
Stilostomella sp.														
Technitella sp.														
Textularia sp.														
Thalmannammina cf. *parkerae*														
Thalmannammina? sp.							4.1	2.1			5.8			
Trochammina cf. *globigeriniformis*		3.5					1.0							
Trochammina? sp.														
Uvigerina proboscidea														
Valvulinerina sp.														
Miscellaneous taxa	24.2	19.3	18.5	1.9	22.5	17.1	46.4	13.1	10.5	15.0	40.8	8.1	29.3	28.4

changes abruptly between Samples 127-794B-20R-4, 7–11 cm, and 127-794B-24R-1, 17–19 cm.

Site 795

Species Ranges

The stratigraphic distribution of benthic foraminifers at Site 795 is shown in Figure 9. Except for sporadic occurrences of *Elphidium bartletti* and *Globocassidulina globosa* s.l., the occurrences of calcareous foraminifers are restricted to a short interval from Sample 127-795B-29R-3, 116–120 cm (639.46 mbsf), to 795B-25R-4, 23–26 cm (601.43 mbsf). Among the calcareous foraminifers, *Gyroidina orbicularis* is long ranging at this site. *Elphidium bartletti,* which is believed to be a shallow faunal element of northern seas, is badly preserved and suggests downward transport of a portion of the fauna.

Agglutinated foraminifers are generally also long ranging, as shown by *Cribrostomoides* cf. *crassimargo, Ammodiscus macilentus,* and *Martinottiella communis. Cyclammina pusilla, C. ezoensis,* and *C. cancellata* occur in the late Miocene, and the occurrence of *Thalmannammina* cf. *parkerae* extends to the upper Miocene. *Spirosigmoilinella compressa* occurs from lithological Unit VA, although its last or stratigraphically highest appearance is coincident with that of many calcareous taxa.

Abundance

Abundances of the most common species are shown in Figure 10. Peak abundances (>10%) of calcareous foraminifers such as *Cibicidoides wuellerstorfi, Gyroidina orbicularis, Gyroidinoides planulatus, Oridorsalis umbonatus,* and *Uvigerina proboscidea* are restricted to the middle part of lithological Unit IVB. *Uvigerina proboscidea* attains 25% of the total assemblage within a restricted horizon (Sample 127-795B-28R-2, 118–119 cm; 628.38 mbsf).

Martinottiella communis and *Eggerella bradyi* consistently occur in abundance throughout middle to upper Miocene strata. *Cribrostomoides* cf. *crassimargo* attains generally high abundance in the late Miocene. Agglutinated foraminifers are generally common at Site 795; their abundances, indicated by both individuals/cm^3 and individuals/cm^3/k.y. are particularly high in the late Miocene (Fig. 11). Except for the peak interval in the middle Miocene, species numbers per cubic centimeter do not show distinct variations in Hole 795B. However, a slight increase in species number/cm^3/k.y. is detected in the late Miocene.

Calcareous vs. Agglutinated Foraminifers

The relative abundance of calcareous versus agglutinated foraminifers shows an increased relationship. Relatively high abun-

Table 2 (continued).

Hole 795B Section Interval (cm)	20R-4 41–45	21R-3 39–43	22R-1 44–48	23R-2 37–41	24R-2 32–36	25R-1 33–37	25R-3 43–46	25R-4 23–26	26R-2 38–41	26R-3 57–61	26R-6 102–105	27R-1 114–118	27R-3 114–118
Ammobaculites spp.		0.8											
Ammodiscus macilentus	2.3	1.7	0.9	11.8	7.5	2.2			0.8			0.8	
Ammodiscus sp. A													
Ammodiscus tenuis	0.8				1.9								
Ammosphaeroidina spp.													
Ammovertellina sp.													
Anomalinoides sp.								2.5					
Astrononion sp.								1.3					
Bathysiphon spp.	+		+	+	+		+		+		+		
Bermudezina aminaensis		6.7											
Bulimina rostrata													
Bulimina striata													
Cibicidoides bradyi												3.1	
Cibicidoides wuellerstorfi								13.8	5.4		5.0	6.1	
Cibicidoides sp.													5.6
Cribrostomoides cf. *crassimargo*	8.4	3.4	2.7	8.8	1.9		6.7			2.9	10.0	1.5	
Cribrostomoides sp.								1.3		2.9		1.5	
Cyclammina cancellata	6.1								1.6			3.1	
Cyclammina ezoensis													
Cyclammina cf. *japonica*													
Cyclammina orbicularis													
Cyclammina pusilla													
Cyclammina sp.				5.9					4.7	5.7		6.1	2.8
Cyclammina? sp.		1.7			1.9	6.5	3.3						
Discammina compressa				0.9			4.3						
Discammina? sp.	1.1	0.8											
Eggerella bradyi	4.6	8.4	12.4	5.9	5.7	19.6	13.3	7.5	9.3			10.7	2.8
Elphidium cf. *bartletti*	0.8					2.2							
Elphidium cf. *perforatum*									2.3			5.3	
Elphidium sp.													
Fissurina marginata							3.3		0.8			0.8	
Fissurina marginata (compressed)													
Fissurina sp. A											5.0	0.8	
Fissurina spp.							3.3		1.6				
Glandulina cf. *nipponica*													
Globobulimina perversa								6.3	0.8		5.0	2.3	
Globobulimina pupoides									5.4			2.3	
Globobulimina sp.	0.8	0.8					3.3					1.5	
Globocassidulina globosa (s.l.)													
Gyroidina orbicularis							3.3	7.5	3.1		15.0	7.6	2.8
Gyroidinoides planulatus								6.3				3.1	
Haplophragmoides sp.							4.3						
Haplophragmoides? sp.		0.8											
Hippocrepinella variabilis				0.9		1.9	2.2						
Hippocrepinella? sp.													
Hormosina sp.			0.8						2.5	9.3	17.1		
Lenticulina spp.												0.8	2.8
Marginulina sp.													
Martinottiella communis	48.1	60.5	61.1	50.0	32.1	26.1	13.3	12.5	14.7	48.6	15.0	16.8	52.8
Martinottiella sp. A								1.3	0.8				

dances of calcareous fauna are found within the interval of 601.43-637.96 mbsf (Sample 127-795B-25R-4, 23–26 cm, to 29R-3, 116–120 cm) (Fig. 12).

Site 797

Species Ranges

The stratigraphic distributions of benthic foraminifers at Site 797 are shown in Figures 13 and 14. Benthic foraminifers are rare or absent in lithological Unit VI, which includes intercalated igneous rocks; however, juvenile forms of *Cyclammina cancellata, Ammovertellina, Haplophragmoides,* and *Ammodiscus macilentus* are rarely and sporadically found in this unit. Diversified foraminifers, both calcareous and agglutinated, are developed in lithological Unit V, particularly between 436.65 and 492.5 mbsf. The lower half of this interval (475.41–492.5 mbsf) is characterized by high species number/cm^3, with significant occurrences of *Globocassidulina* sp. A, *Cibicidoides* sp. B, *Cribrostomoides* cf. *crassimargo, Cyclammina pusilla, Uvigerina miocenica,* and *Valvulineria masudai.* The first appearance of *Cibicidoides wuellerstorfi* is estimated to occur at

Table 2 (continued).

Hole 795B Section Interval (cm)	20R-4 41–45	21R-3 39–43	22R-1 44–48	23R-2 37–41	24R-2 32–36	25R-1 33–37	25R-3 43–46	25R-4 23–26	26R-2 38–41	26R-3 57–61	26R-6 102–105	27R-1 114–118	27R-3 114–118
Melonis nikobarense												0.8	
Melonis pompilioides											10.0		
Nodosaria sp.									0.8				
Oolina sp. A								1.3					
Oolina sp. B									0.8				
Oolina sp.						2.2						0.8	
Oridorsalis umbonatus									14.0		5.0	8.4	
Plectina nipponica					1.9								
Proteonina compressa	2.3			2.9	3.8							0.8	
Proteonina cf. *compressa*			1.8										
Pullenia bulloides													
Pullenia quinqueloba												3.1	
Pullenia salisburyi												0.8	
Pyrgo sp.												1.5	
Pyrgo? sp.									0.8				
Quadrimorphina sp.								1.3					
Quinqueloculina sp.													
Reophax spp.													
Reophax? sp.						2.2							
Rhabdammina spp.		+	+			+		+	+	+		+	+
Saccammina cf. *sphaerica*												0.8	
Schizammina sp.	+	+	+	+		+							
Sphaeroidina japonica													
Sphaeroidina sp.									0.8				
Spirosigmoilinella compressa									4.7			0.8	
Stilostomella sp.											5.0		
Technitella sp.		0.8											
Textularia sp.			0.9										
Thalmannammina cf. *parkerae*			0.8	0.9						3.1	5.7		3.8
Thalmannammina? sp.										2.9			
Trochammina cf. *globigeriniformis*													
Trochammina? sp.	0.8											1.5	
Uvigerina proboscidea	2.3							25.0	7.8				
Valvulinerina sp.									0.8				
Miscellaneous taxa	21.8	13.6	18.7	12.1	43.4	37.2	39.1	12.5	16.1	24.7	2.1	6.9	26.7

15.3 Ma in this site, which is similar to its first appearance in the open Pacific Ocean at about 15.0–14.9 Ma (Thomas and Vincent, 1987). Both calcareous and agglutinated foraminifers disappear or here interrupt occurrences in the interval between 379.34 and 426.88 mbsf; 127-797B-41X-1, 34–38 cm, to 127-797B-44X-1, 36–40 cm, which is correlative with lithological Unit IVB. However, a few specimens of *Martinottiella communis* are found in this latter interval.

Benthic foraminifers are again found in the upper part of lithological Units IV and III. However, some species such as *Cibicidoides wuellerstorfi* and *Pullenia bulloides* disappear within lithological Unit IVA. *Gyroidinoides planulatus* and *Globobulimina pupoides* continue to occur in upper Miocene strata.

Sample 127-797B-31X-3, 50–54 cm, contains abundant calcareous foraminifers including *Buccella* cf. *kuromatsunaiensis, Cibicides* cf. *refulgens, Elphidium* cf. *jenseni, E. subarcticum, Grabratella subopercularis,* and *I. helenae.* In spite of the high diversity of this assemblage, the bad preservation and the inclusion of typical shallow- water species such as *G. subopercularis, B.* cf. *kuromatsunaiensis,* and *E.* cf. *jenseni* indicate redeposition of this fauna from shallower depths.

Abundance

Abundance of the most common species is shown in Figure 15; foraminiferal diversities and abundance/k.y. are shown in Figure 16. Both species number and individuals per cubic centimeter are generally high in lithological Unit V. Species number/cm^3 exhibits a single peak in Sample 127-797B-51X-5, 51–53 cm, whereas individuals/cm^3 form several peaks in this unit. The peak in diversity in Sample 127-797B-31X-3, 50–54 cm, noted above suggests the influence of reworked foraminifers. Thus, with the exception of the high-diversity interval in early middle Miocene, benthic foraminifers are characterized by low diversity throughout the Miocene (Fig. 16).

Early and late Miocene foraminifers are generally characterized by high relative abundances of *Cyclammina* sp. A, *Thalmannammina* cf. *parkerae,* and *Martinottiella communis.* Specifically, the following species form peaks of relative abundance in the late Miocene: *Valvulineria masudai, Pullenia bulloides, Cibicidoides* sp. A, *C. wuellerstorfi,* and *Globobulimina perversa.* Although *Gyroidina orbicularis* and *Gyroidinoides planulatus* are relatively abundant in the late Miocene, they are most abundant in the early middle Miocene, characterized by calcareous foraminifers.

Calcareous vs. Agglutinated Foraminifers

High relative abundances of calcareous foraminifers are consistently found between 436.65 and 488 mbsf (Sample 127-797B-47X-1, 45–49 cm, to 127-797B-52X-3, 50–54 cm), calcareous foraminifers attaining 100% of individual faunas (Fig. 17). In addition, calcareous foramini-

Table 2 (continued).

Hole 795B Section Interval (cm)	28R-2 118–119	28R-4 117–119	29R-2 116–120	29R-3 116–120	30R-2 110–112	31R-1 112–114	32R-1 106-107	33R-1 106–109
Ammobaculites spp.								1.3
Ammodiscus macilentus	8.2	14.3	5.1		5.4	3.6	2.2	
Ammodiscus sp. A								
Ammodiscus tenuis							4.3	
Ammosphaeroidina spp.		2.0					1.1	
Ammovertellina sp.								
Anomalinoides sp.								
Astrononion sp.								
Bathysiphon spp.	+	+					+	+
Bermudezina aminaensis					5.4	7.1		
Bulimina rostrata			0.6					
Bulimina striata		2.0	1.3					
Cibicidoides bradyi	8.2	2.0	2.6	0.8				
Cibicidoides wuellerstorfi	4.9	6.1	7.1					
Cibicidoides sp.	1.6			0.8				
Cribrostomoides cf. *crassimargo*			3.8	8.5	8.1	3.6	4.3	6.3
Cribrostomoides sp.	1.6		0.6					
Cyclammina cancellata			0.6					
Cyclammina ezoensis								
Cyclammina cf. *japonica*								1.3
Cyclammina orbicularis								
Cyclammina pusilla								
Cyclammina sp.			1.9				1.1	
Cyclammina? sp.		4.1		0.8			1.1	
Discammina compressa								
Discammina? sp.	8.3							
Eggerella bradyi	6.6	6.1	12.8	18.5	5.4	3.6	4.3	6.3
Elphidium cf. *bartletti*								
Elphidium cf. *perforatum*	4.9		3.2					
Elphidium sp.	1.6							
Fissurina marginata								
Fissurina marginata (compressed)	1.6							
Fissurina sp. A		2.0						
Fissurina spp.								
Glandulina cf. *nipponica*			0.6					
Globobulimina perversa			1.3					
Globobulimina pupoides		2.0	2.6					
Globobulimina sp.								
Globocassidulina globosa (s.l.)								
Gyroidina orbicularis		2.0	3.8					
Gyroidinoides planulatus	13.1	8.2	1.3					
Haplophragmoides sp.								
Haplophragmoides? sp.								
Hippocrepinella variabilis								1.1
Hippocrepinella? sp.								
Hormosina sp.				0.6	0.8			
Lenticulina spp.			0.6					
Marginulina sp.			0.6					
Martinottiella communis	23.0	14.3	19.9	60.8	40.5	57.1	45.7	70.0
Martinottiella sp. A			0.6					

fers are greater than 90% in several horizons of the upper Miocene, although some of their assemblages represent species redeposited from shallower environments.

PALEODEPTH

Except for infrequent redeposited assemblages found in the middle to late Miocene, benthic foraminifers at Sites 794, 795, and 797 are generally characterized by deep or bathyal faunas. The principal species recognized include *Cibicidoides wuellerstorfi, C. bradyi, Oridorsalis umbonatus, Eggerella bradyi, Uvigerina proboscidea,* and species of *Melonis* and *Gyroidina.* These latter taxa are noted by Boltovskoy (1984) as typical deep-sea assemblages of the modern world ocean inhabiting water depths of 2500 to 4000 m.

It is well known that agglutinated foraminifers comprise more than 90% of the total fauna at depths deeper than about 1000 m in the modern Sea of Japan. According to Ujiie and Ichikura (1973), the calcium carbonate compensation depth (CCD) of the modern Sea of Japan is estimated to be at a depth of about 1437 to 1596 m. More recently, Matoba and Honma (1986) estimated the CCD to be at

Table 2 (continued).

Hole 795B Section Interval (cm)	28R-2 118–119	28R-4 117–119	29R-2 116–120	29R-3 116–120	30R-2 110–112	31R-1 112–114	32R-1 106-107	33R-1 106–109
Melonis nikobarense								
Melonis pompilioides								
Nodosaria sp.								
Oolina sp. A				0.8				
Oolina sp. B								
Oolina sp.			0.6					
Oridorsalis umbonatus	1.6	4.1	11.5	3.8				
Plectina nipponica								
Proteonina compressa								
Proteonina cf. *compressa*								
Pullenia bulloides	3.3	2.0						
Pullenia quinqueloba								
Pullenia salisburyi			0.6					
Pyrgo sp.			0.6					
Pyrgo? sp.								
Quadrimorphina sp.								
Quinqueloculina sp.		2.0	0.6					
Reophax spp.			0.6					
Reophax? sp.								
Rhabdammina spp.	+		+	+	+	+	+	+
Saccammina cf. *sphaerica*	3.3		0.6					
Schizammina sp.	+		+					
Sphaeroidina japonica			0.6					
Sphaeroidina sp.		2.0						
Spirosigmoilinella compressa				2.3			20.7	13.8
Stilostomella sp.			1.9					
Technitella sp.								
Textularia sp.								
Thalmannammina cf. *parkerae*								
Thalmannammina? sp.								
Trochammina cf. *globigeriniformis*			1.3					
Trochammina? sp.								
Uvigerina proboscidea			3.8					
Valvulinerina sp.								
Miscellaneous taxa	8.1	24.5	5.8	2.4	34.4	25.0	15.2	0.2

1850 m off Tsugaru Peninsula, Northeast Japan. These data suggest that the Miocene agglutinated faunas found at Sites 794, 795, and 797 represent water depths greater than the local CCD. However, the CCD in the Pacific and Indian oceans oscillated between approximately 3500 and 5000 m during the Miocene, becoming shallower in the early and middle Miocene (van Andel, 1975; Petersen and Backman, 1990). These latter depths are much deeper than the modern CCD in the Sea of Japan. Calcareous faunas are obviously indicative of depths shallower than the CCD. The occurrences of dominantly agglutinated faunas in Miocene sediments in the Sea of Japan suggest that the CCD in the marginal sea is much different from the open ocean Cenozoic CCD history. Thus, paleodepths based on CCD records from the open ocean are not reliable in this setting. Many local environmental factors may influence the CCD in the Sea of Japan; moreover, the difference between the Yamato and Japan basins may be a result of different rates of supply of calcium carbonate to deep water in these areas.

Aside from foraminiferal wall types (e.g., agglutinated versus calcareous tests), the following species and genera, although limited in number, permit paleodepth estimates. *Ammodiscus macilentus* occurs commonly at the three ODP sites and is morphologically similar to Recent *A. gullmarensis* reported by Matoba and Honma (1986) as abundant at 1850 m in the modern Sea of Japan. *Thalmannammina* cf. *parkerae* is similar to Recent *T. parkerae*, a species which is very abundant at depths greater than 1000 m. *Spirosigmoilinella compressa* is similar to *Silicosigmoilina abyssalica,* which is common in modern deep regions of the Sea of Japan (Inoue, 1980; Ujiie et al., 1983). Matoba and Honma (1986), for example, report that *S. abyssalica* forms peak abundances at depths of 1850 to 2300 m in the modern Sea of Japan. Both *Cibicidoides wuellerstorfi* and *C. bradyi* are commonly reported from lower bathyal depths in the open ocean, although their occurrences are not common in the modern Sea of Japan. *Cibicidoides wuellerstorfi* is noted as having an upper depth limit of about 1800–1900 m on the continental margin of the northeastern United States and being very abundant deeper than 3000 m in the Gulf of California (van Morkhoven et al., 1986). *Cibicidoides bradyi* occurs at abyssal depths (van Morkhoven et al., 1986). In addition, Thompson (1980) reported the following dominant species from the Japan Trench area: Calcareous taxa *Chilostomella oolina, Nonionellina labradorica,* and *Melonis pompilioides* from depths of 1800–3300 m in depth and agglutinated species such as *Eggerella bradyi, Saccammina sphaerica,* and *Martinottiella communis* from 3300 to 6000 m.

On the basis of these data, the oldest sediments (lithological Unit V) at Sites 794 and 795 were likely deposited at lower bathyal to upper abyssal depths (1000–3000 m) based on van Morkhoven et al. (1986)'s depth divisions. At Site 797, the foraminiferal occurrences

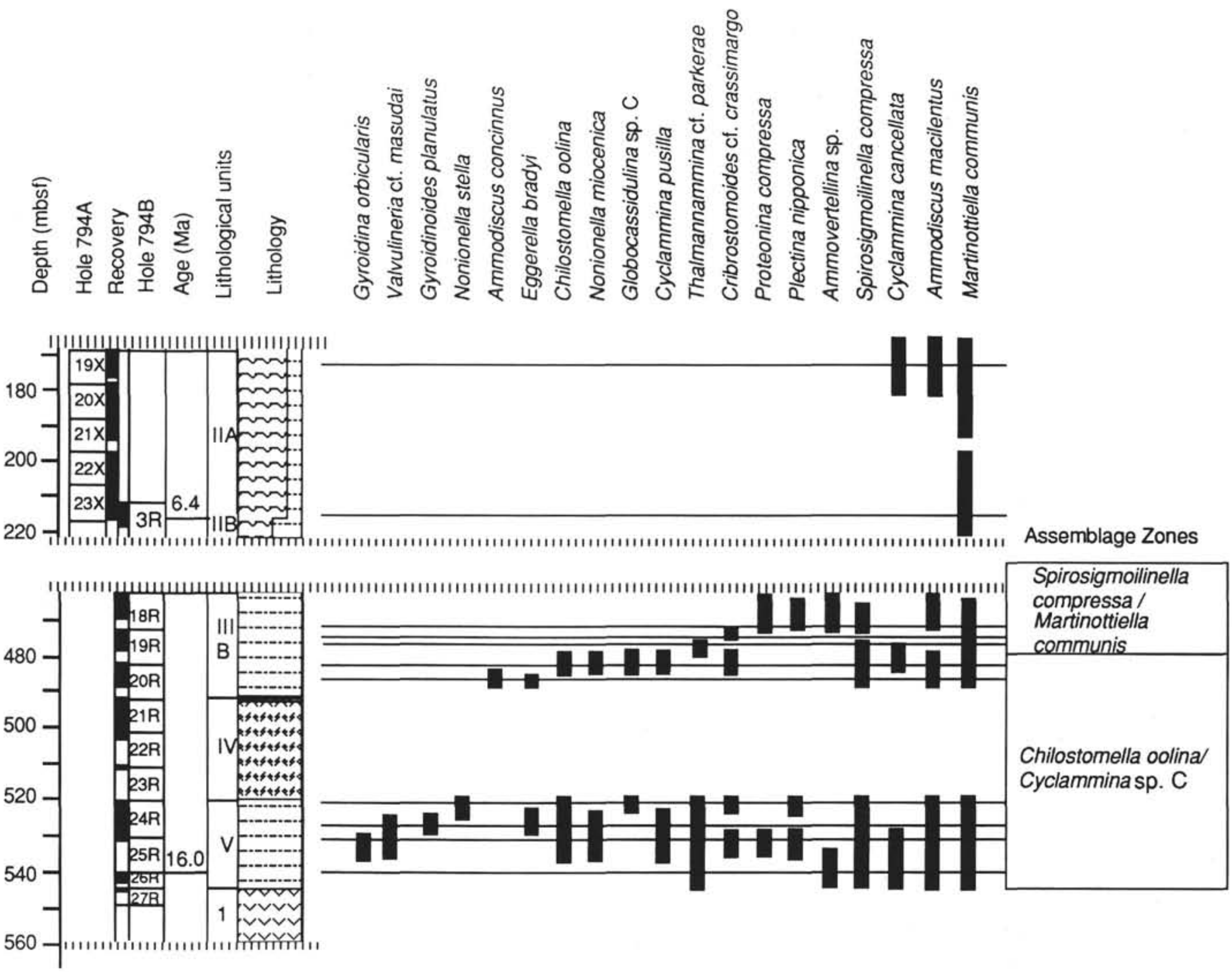

Figure 5. Stratigraphic distribution of benthic foraminifers from Site 794.

are much reduced below lithological Units V to VI, but the first appearances of *T.* cf. *parkerae* at 22R-5, 146–150 cm (692.5 mbsf), and *A. macilentus* at 18R-1, 130–134 cm (647.8 mbsf), also indicate the lower bathyal to upper abyssal depths. *Bathysiphon* sp., which occurs from Sample 127-797C-41R-CC (30–34 cm), does not suggest paleodepth but rather is interpreted to represent an oxygen-deficient marine bottom environment formed in the early Miocene.

THE FORAM SHARP LINE

The Foram Sharp Line (FSL) was introduced by Tai (1963) to define a horizon showing a distinct faunal change in the middle Miocene sequences of the Sea of Japan borderland region. The term "Foram" is abbreviated from the adjective "foraminiferal." This horizon or FSL was originally defined as the abrupt change from diversified calcareous and agglutinated foraminifers to a low-diversity fauna consisting only of agglutinated foraminifers or in some cases, a barren interval (Fig. 18). According to Tai (1963, 1985, 1988) and Serova and Tai (1977), a similar faunal change is present not only in Japan but also in Korea (Pohan Basin) as well as in Sakhalin and Kamchatka sequences facing the Okhotsku Sea. This characteristic faunal change or FSL is most typically shown in the middle Miocene sequences of Southwest Honshu. Faunas stratigraphically below the FSL consist of tropical to subtropical shallow water forms of *Miogypsina* and *Operculina* and forms such as *Uvigerina, Stilostomella, Nonion, Trifarina, Buccella, Gaudryina, Bolivina, Bulimina, Hanzawaia,* and *Cibicides.* In contrast, the faunas stratigraphically above the FSL consist mainly of *Bathysiphon, Haplophragmoides, Cyclammina, Gaudryina, Martinottiella, Sigmoilina,* and *Trochammina* (Tai, 1985).

Tai (1985) stated that all these areas do not consistently show the same specific changes in faunal composition across the FSL. However, with respect to the change of faunal diversity they always exhibit a drastic change from higher to lower diversities across the FSL. Following Tai's (1963) definition, the FSL is recognizable at 14.4 Ma at Site 794, 11.2 Ma at Site 795, and 14.3 Ma at Site 797 (Fig. 19). Onshore, the ages of the FSL have been estimated at about 14–15 Ma from Northeast and Southwest Honshu (Maiya and Inoue, 1981; Maiya, 1988; Nomura, in press). Thus, the position of the FSL at ODP sites in the Yamato Basin correlate well with the onshore occurrences. Alternatively, the FSL in the Japan Basin occurs about 3 m.y. later, and a time lag of the FSL is assumed from southern to northern sites. However, the FSL (11.2 Ma) at Site 795 appears in cooler temperatures of water mass in the northern Sea of Japan, because disappearance of the warm-water planktonic fauna from the onshore sequences occurred at the N11/12 boundary (about 12.8 Ma) (Maiya and Inoue, 1981; Fig. 20). Thus, the FSL at Site 795 occurred in water masses different from those of Sites 794 and 797. This indicates that the

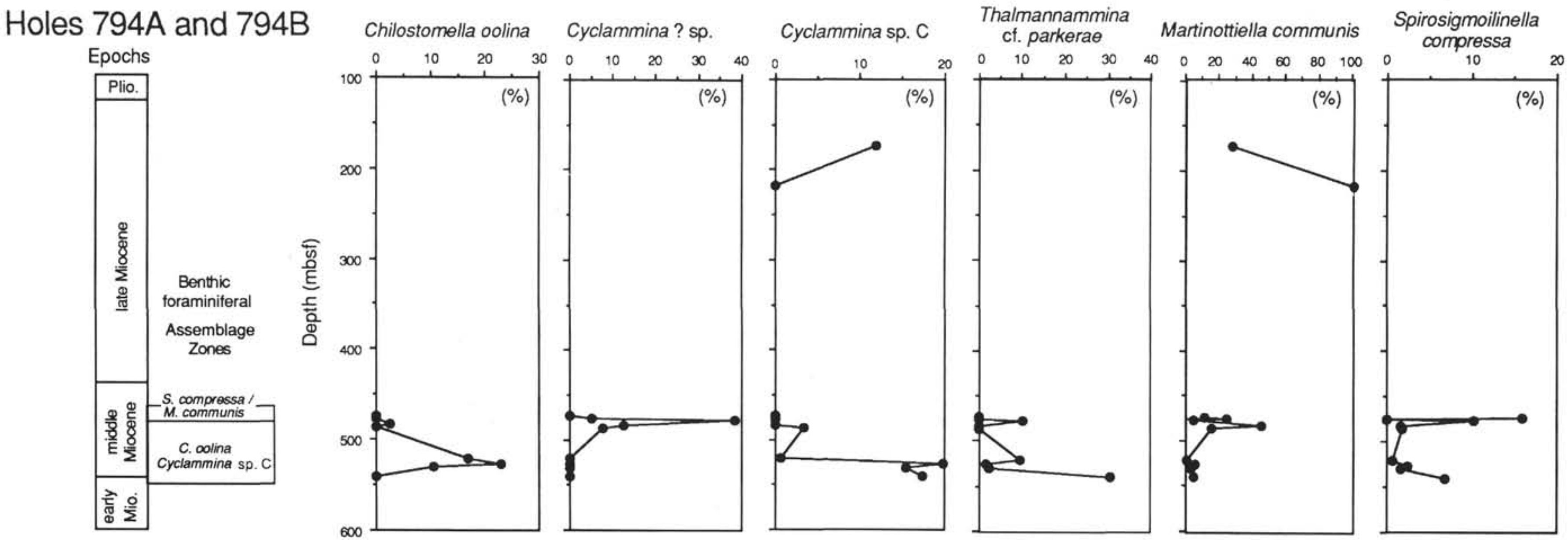

Figure 6. Frequency distribution of dominant benthic foraminifers from Site 794 in terms of percent of total benthic foraminifer population.

Table 3. Benthic foraminiferal distribution (%) at Site 797.

Holes 797B and 797C Section Interval (cm)	797B- 27X-3 52–57	27X-4 52–57	28X-1 51–56	30X-5 52–57	31X-3 50–54	32X-6 51–55	33X-4 52–54	34X-1 52–56	34X-3 50–54	35X-1 51–55	35X-4 50–54	35X-6 50–54	37X-1 52–56
Ammodiscus macilentus													
Ammodiscus sp. A													
Ammodiscus spp.													
Ammodiscus tenuis													
Ammosphaeroidina sp.									1.69				
Ammovertellina													
Astrononion sp.													
Bathysiphon spp.	+			+							+		+
Brizalina sp.													
Buccella cf. *kuromatsunaiensis*					3.11								
Bulimina cf. *rostrata*													
Bulimina sp.													
Bulimina striata													
Bulimina cf. *striata*													
Chilostomella oolina									40.68		0.78		
Cibicides cf. *refulgens*					35.11								
Cibicides sp.									6.78				
Cibicidoides? sp.													
Cibicidoides bradyi													
Cibicidoides sp.					0.44						0.78		
Cibicidoides sp. A													
Cibicidoides sp. B													
Cibicidoides wuellerstorfi							8.00				2.33		
Cribrostomoides? sp.	16.67								1.69				
Cribrostomoides cf. *crassimargo*													
Cyclammina? sp.													
Cyclammina cancellata				14.29									
Cyclammina orbicularis													
Cyclammina pusilla													
Cyclammina sp. A													
Dentalina insecta													
Dentalina sp.													
Dentalina? sp.													
Eggerella sp. A													
Elphidium cf. *jenseni*					0.44								
Elphidium spp.					0.44								
Elphidium subarcticum					10.22								
Evolvocassidulina kuwanoi													
Fissurina marginata													
Fissurina orbignyana					0.44								
Fissurina sp. A					0.44								
Fursenkoina sp. A													
Gavelinopsis sp.					1.33								
Glabratella suboperculosis					1.33								
Globobulimina perversa											0.78		
Globobulimina cf. *perversa*													
Globobulimina pupoides				28.57		50.00	28.00		1.69	40.00	7.75		50.00
Globobulimina spp.						50.00					0.78	20.00	
Globocassidulina globosa (s.l.)					5.33						1.55		
Globocassidulina sp. A													
Glomospira sp.													
Gyroidina orbicularis					0.44						3.10		
Gyroidinoides planulatus				28.57					10.17		14.73		
Gyroidinoides cf. *planulatus*													
Hippocrepinella?													
Hormosina spp.													
Islandiella cf. *compressa*					6.67								
Islandiella helenae					20.89								
Islandiella sp. A													
Lagena cf. *apiopleura*					0.44								
Lenticulina spp.											0.78		
Marginulina sp.													
Martinottiella communis	66.67	100.00	92.86				12.00	50.00	10.17			20.00	
Martinottiella cf. *communis*													
Melonis nikobarense													

Table 3 (continued).

Holes 797B and 797C Section Interval (cm)	797B- 27X-3 52–57	27X-4 52–57	28X-1 51–56	30X-5 52–57	31X-3 50–54	32X-6 51–55	33X-4 52–54	34X-1 52–56	34X-3 50–54	35X-1 51–55	35X-4 50–54	35X-6 50–54	37X-1 52–56
Melonis pompilioides													
Miliolinella sp.													
Nodosaria? sp.													
Nonionellina labradorica													
Nonionella									5.08				
Nonionella cf. *miocenica*											2.33		
Nonionella stella													
Oolina globosa			7.14										
Oolina hexagona													
Oolina? sp.													
Oridorsalis umbonatus											51.16		
Oridorsalis spp.							4.00						
Parafissulina sp.													
Planodiscorbis sp.													
Plectina nipponica													
Plectina? sp.													
Proteonina sp.													
Proteonina? sp.													
Pullenia bulloides							4.00				1.55		
Pullenia quinqueloba													
Pullenia salisburyi				28.57									
Pullenia subcarinata									1.69	10.00	1.55		
Pullenia cf. *subcarinata*											1.55		
Pullenia sp.									1.69				
Pullenia? sp.													
Pyrgo cf. *vespertilio*													
Pyrgo murrhina													
Pyrgo spp.										10.00	0.78		
Quadrimorphina sp.							4.00						
Quinqueloculina cf. *seminula*											3.88		
Quinqueloculina vulgaris													
Quinqueloculina sp. A													
Quinqueloculina sp. B													
Quinqueloculina spp.													
Quinqueloculina? sp.											0.78		
Recurvoides? sp.													
Reophax excentricus													
Reophax spp.													
Reophax? sp.													
Rhabdammina spp.												+	
Saccammina sp.													
Saracenaria sp.													
Schizammina sp.									+				
Sphaeroidina cf. *compacta*					0.44								
Sphaeroidina japonica													
Sphaeroidina cf. *japonica*													
Spirosigmoilinella compressa													
Spirosigmoilinella? sp.								50.00					
Thalmannammina cf. *parkerae*													
Tosaia hanzawai													
Trifarina sp.					11.56								
Triloculina sp.											0.78		
Trochammina sp.													
Uvigerina cf. *modeloensis*													
Uvigerina cf. *segundoensis*													
Uvigerina proboscidea					0.44						1.55		
Uvigerina cf. *proboscidea*													
Uvigerina sp.													
Valvulineria cf. *sadonica*										20.00			
Valvulineria masudai													
Valvulineria spp.									1.69				
Miscellaneous taxa	16.67				0.44		40.00		16.95	20.00	0.78	60.00	50.00

Table 3 (continued).

Holes 797B and 797C Section Interval (cm)	37X–2 48–52	37X–3 51–55	37X–4 51–55	38X–1 50–54	40X–2 35–39	41X–1 34–38	43X–1 35–39	44X–1 36–40	46X–1 28–32	47X–1 45–49	47X–3 52–56	48X–1 68–72	48X–2 53–57
Ammodiscus macilentus										1.26		0.49	0.38
Ammodiscus sp. A												1.46	
Ammodiscus spp.													0.38
Ammodiscus tenuis													
Ammosphaeroidina sp.													
Ammovertellina										0.63		1.46	0.38
Astrononion sp.													
Bathysiphon spp.	+			+	+				+			+	+
Brizalina sp.													
Buccella cf. *kuromatsunaiensis*													
Bulimina cf. *rostrata*										0.63			
Bulimina sp.													
Bulimina striata													1.51
Bulimina cf. *striata*												0.49	
Chilostomella oolina				6.25									
Cibicides cf. *refulgens*													
Cibicides sp.			7.69										
Cibicidoides? sp.													
Cibicidoides bradyi													4.91
Cibicidoides sp.					0.62								
Cibicidoides sp. A										27.04	18.54	8.25	2.26
Cibicidoides sp. B													
Cibicidoides wuellerstorfi		25.00			14.29					43.40	48.31	67.48	55.85
Cribrostomoides? sp.													
Cribrostomoides cf. *crassimargo*													
Cyclammina? sp.							33.33						
Cyclammina cancellata													
Cyclammina orbicularis													
Cyclammina pusilla													
Cyclammina sp. A													9.06
Dentalina insecta													
Dentalina sp.													
Dentalina? sp.												0.49	
Eggerella sp. A													
Elphidium cf. *jenseni*													
Elphidium spp.													0.38
Elphidium subarcticum													
Evolvocassidulina kuwanoi													
Fissurina marginata													1.89
Fissurina orbignyana													
Fissurina sp. A					0.62							0.97	0.38
Fursenkoina sp. A													
Gavelinopsis sp.													
Glabratella suboperculosis													
Globobulimina perversa													
Globobulimina cf. *perversa*													0.38
Globobulimina pupoides			7.69								1.69		1.13
Globobulimina spp.													
Globocassidulina globosa (s.l.)										6.92	8.43	5.83	4.53
Globocassidulina sp. A													
Glomospira sp.												0.49	
Gyroidina orbicularis		50.00			8.07					0.63	1.12	4.37	1.51
Gyroidinoides planulatus		25.00			4.97					1.26	1.69		1.89
Gyroidinoides cf. *planulatus*												0.49	
Hippocrepinella?										0.63			
Hormosina spp.													
Islandiella cf. *compressa*													
Islandiella helenae													
Islandiella sp. A													
Lagena cf. *apiopleura*													
Lenticulina spp.					0.62					0.63			0.38
Marginulina sp.													
Martinottiella communis	60.00			56.25	8.07	4.35		28.57		2.52			
Martinottiella cf. *communis*			23.08									0.97	
Melonis nikobarense					0.62						3.93	2.43	0.38

Table 3 (continued).

Holes 797B and 797C Section Interval (cm)	37X–2 48–52	37X–3 51–55	37X–4 51–55	38X–1 50–54	40X–2 35–39	41X–1 34–38	43X–1 35–39	44X–1 36–40	46X–1 28–32	47X–1 45–49	47X–3 52–56	48X–1 68–72	48X–2 53–57
Melonis pompilioides			15.38		5.59								
Miliolinella sp.													
Nodosaria? sp.													
Nonionellina labradorica													
Nonionella										0.63			
Nonionella cf. *miocenica*													
Nonionella stella													
Oolina globosa					0.62								
Oolina hexagona													0.38
Oolina? sp.													
Oridorsalis umbonatus					6.83					0.63	2.81	0.49	4.91
Oridorsalis spp.													
Parafissulina sp.													
Planodiscorbis sp.													
Plectina nipponica													
Plectina? sp.													
Proteonina sp.													
Proteonina? sp.													
Pullenia bulloides	10.00				1.24					3.77	5.06	0.97	2.64
Pullenia quinqueloba					0.62								
Pullenia salisburyi										1.89	7.30		2.26
Pullenia subcarinata					0.62								
Pullenia cf. *subcarinata*												0.49	
Pullenia sp.													
Pullenia? sp.													
Pyrgo cf. *vespertilio*													
Pyrgo murrhina													
Pyrgo spp.													
Quadrimorphina sp.													
Quinqueloculina cf. *seminula*													
Quinqueloculina vulgaris													1.51
Quinqueloculina sp. A													
Quinqueloculina sp. B													
Quinqueloculina spp.					0.62								0.38
Quinqueloculina? sp.													
Recurvoides? sp.													
Reophax excentricus													
Reophax spp.													
Reophax? sp.													
Rhabdammina spp.													
Saccammina sp.				18.75									
Saracenaria sp.													
Schizammina sp.													
Sphaeroidina cf. *compacta*													
Sphaeroidina japonica													
Sphaeroidina cf. *japonica*										1.26			
Spirosigmoilinella compressa										2.52			
Spirosigmoilinella? sp.	10.00											0.49	
Thalmannammina cf. *parkerae*												0.49	
Tosaia hanzawai					0.62								
Trifarina sp.													
Triloculina sp.													
Trochammina sp.													
Uvigerina cf. *modeloensis*													
Uvigerina cf. *segundoensis*													
Uvigerina proboscidea					42.24								
Uvigerina cf. *proboscidea*										1.89	0.56		
Uvigerina sp.													
Valvulineria cf. *sadonica*													
Valvulineria masudai													
Valvulineria spp.			7.69										0.38
Miscellaneous taxa	20.00		38.46	18.75	3.11	95.65	66.67	71.43		1.89	0.56	1.46	

Table 3 (continued).

Holes 797B and 797C Section Interval (cm)	48X-4 56–60	49X-2 50–54	49X-4 52–56	51X-1 51–53	51X-3 51–53	51X-5 51–53	52X-1 45–49	52X-3 50–54	52X-6 50–54	797C- 2R-2 28–32	5R-2 76–80	5R-4 39–43	6R-1 56–60
Ammodiscus macilentus				2.88	1.12	0.47			3.57		7.95		1.94
Ammodiscus sp. A												1.22	
Ammodiscus spp.													
Ammodiscus tenuis	10.53	3.88				1.42					3.41	6.10	3.23
Ammosphaeroidina sp.													
Ammovertellina		0.97								3.19	2.27	6.10	0.65
Astrononion sp.								0.34					
Bathysiphon spp.	+	+				+	+		+		+	+	
Brizalina sp.							0.89						
Buccella cf. *kuromatsunaiensis*													
Bulimina cf. *rostrata*													
Bulimina sp.								0.68					
Bulimina striata								4.10				1.22	
Bulimina cf. *striata*													
Chilostomella oolina						0.95	7.14	8.19	2.38	0.32			
Cibicides cf. *refulgens*													
Cibicides sp.						0.47							
Cibicidoides? sp.													
Cibicidoides bradyi					3.35	1.42			1.19				
Cibicidoides sp.													
Cibicidoides sp. A		18.45	42.86		15.64	6.64	7.14	0.34				1.22	
Cibicidoides sp. B				20.86		0.95							
Cibicidoides wuellerstorfi	15.79	23.30											
Cribrostomoides? sp.					1.12				2.38				
Cribrostomoides cf. *crassimargo*				2.16	0.56	3.32	1.79		4.76	2.56			0.65
Cyclammina? sp.		1.94		0.72		3.79	0.89			2.24	13.07		10.32
Cyclammina cancellata												4.88	3.87
Cyclammina orbicularis						0.47							
Cyclammina pusilla				2.88	6.70				15.48				
Cyclammina sp. A					0.56				2.38	25.24	31.82	59.76	42.58
Dentalina insecta						0.95							
Dentalina sp.					1.12	0.47		1.02					
Dentalina? sp.		2.91											
Eggerella sp. A									11.90				
Elphidium cf. *jenseni*													
Elphidium spp.							0.89						
Elphidium subarcticum													
Evolvocassidulina kuwanoi						0.95		1.02					
Fissurina marginata					1.12								
Fissurina orbignyana					1.12	0.95							
Fissurina sp. A				2.16		0.95							
Fursenkoina sp. A								2.73					
Gavelinopsis sp.													
Glabratella suboperculosis													
Globobulimina perversa				4.32	0.56	2.37	14.29	4.44					
Globobulimina cf. *perversa*					0.56		0.89					1.22	
Globobulimina pupoides		7.77		2.88			2.68	14.33	2.38				
Globobulimina spp.		1.94		2.16	4.47	1.42		0.34					
Globocassidulina globosa (s.l.)				0.72	2.79				1.19			2.44	
Globocassidulina sp. A					0.56			3.75					
Glomospira sp.													
Gyroidina orbicularis	10.53	4.85	14.29	5.76	13.41	5.69	2.68	3.07					
Gyroidinoides planulatus		5.83		3.60		10.90	3.57	15.36	3.57			2.44	
Gyroidinoides cf. *planulatus*													
Hippocrepinella?											0.57		
Hormosina spp.										0.64			
Islandiella cf. *compressa*													
Islandiella helenae													
Islandiella sp. A					1.12		3.57						
Lagena cf. *apiopleura*													
Lenticulina spp.						0.47		0.34					
Marginulina sp.						0.95		0.34					
Martinottiella communis	15.79	0.97	14.29	3.60	20.11		0.89		3.57	10.22			
Martinottiella cf. *communis*													
Melonis nikobarense		4.85			1.12	1.90							

Table 3 (continued).

Holes 797B and 797C Section Interval (cm)	48X-4 56–60	49X-2 50–54	49X-4 52–56	51X-1 51–53	51X-3 51–53	51X-5 51–53	52X-1 45–49	52X-3 50–54	52X-6 50–54	797C- 2R-2 28–32	5R-2 76–80	5R-4 39–43	6R-1 56–60
Melonis pompilioides				5.76	0.56					0.32			
Miliolinella sp.						0.47							
Nodosaria? sp.						0.47							
Nonionellina labradorica							0.89	1.71					
Nonionella		0.97											
Nonionella cf. *miocenica*					0.56	0.47							
Nonionella stella							5.36						
Oolina globosa													
Oolina hexagona								0.34					
Oolina? sp.				0.72									
Oridorsalis umbonatus	10.53	1.94			7.26	1.42	5.36			0.64			
Oridorsalis spp.					0.56								
Parafissulina sp.						0.47							
Planodiscorbis sp.							1.79						
Plectina nipponica									4.76				
Plectina? sp.						0.95							
Proteonina sp.													
Proteonina? sp.						0.95							
Pullenia bulloides		8.74		17.27	3.35	9.00	5.36	13.65	4.76				
Pullenia quinqueloba				0.72		0.47	3.57		1.19				
Pullenia salisburyi					1.12								
Pullenia subcarinata	21.05	4.85		2.16		3.79	3.57	2.39	1.19				
Pullenia cf. *subcarinata*													
Pullenia sp.													
Pullenia? sp.								0.68					
Pyrgo cf. *vespertilio*						0.95							
Pyrgo murrhina						2.37	1.79						
Pyrgo spp.				0.72	0.56		0.89						
Quadrimorphina sp.													
Quinqueloculina cf. *seminula*													
Quinqueloculina vulgaris													
Quinqueloculina sp. A						2.37							
Quinqueloculina sp. B						0.95							
Quinqueloculina spp.		2.91				0.95							
Quinqueloculina? sp.						0.47							
Recurvoides? sp.									2.38				
Reophax excentricus					0.56								
Reophax spp.						1.42					1.14		
Reophax? sp.						0.95					0.57		
Rhabdammina spp.								+	+	+	+	+	+
Saccammina sp.													
Saracenaria sp.							0.89						
Schizammina sp.										+			+
Sphaeroidina cf. *compacta*													
Sphaeroidina japonica						0.47	6.25						
Sphaeroidina cf. *japonica*													
Spirosigmoilinella compressa					3.91					9.90	12.50	2.44	
Spirosigmoilinella? sp.		0.97											
Thalmannammina cf. *parkerae*										34.82	10.80	3.66	12.26
Tosaia hanzawai				0.72		5.21	0.89						
Trifarina sp.													
Triloculina sp.													
Trochammina sp.											0.57		
Uvigerina cf. *modeloensis*				0.72	0.56								
Uvigerina cf. *segundoensis*							1.79						
Uvigerina proboscidea					1.12		0.89	1.37					
Uvigerina cf. *proboscidea*													
Uvigerina sp.												1.22	
Valvulineria cf. *sadonica*													
Valvulineria masudai				2.88		10.43	2.68	18.43	4.76			4.88	
Valvulineria spp.		0.97											
Miscellaneous taxa	15.79	0.97	28.57	13.67	2.79	7.11	10.71	1.02	26.19	9.90	15.34	1.22	24.52

Table 3 (continued).

Holes 797B and 797C Section Interval (cm)	8R-1 94–98	11R-1 42–46	18R-1 130–134	22R-5 146–150	23R-2 14–18	25R-4 85–89	34R-6 146–150	41R-CC 30–34
Ammodiscus macilentus	2.08		3.23					
Ammodiscus sp. A								
Ammodiscus spp.								
Ammodiscus tenuis								
Ammosphaeroidina sp.								
Ammovertellina		6.58						
Astrononion sp.								
Bathysiphon spp.	+		+	+	+	+	+	+
Brizalina sp.								
Buccella cf. *kuromatsunaiensis*								
Bulimina cf. *rostrata*								
Bulimina sp.								
Bulimina striata								
Bulimina cf. *striata*								
Chilostomella oolina								
Cibicides cf. *refulgens*								
Cibicides sp.								
Cibicidoides? sp.								
Cibicidoides bradyi								
Cibicidoides sp.								
Cibicidoides sp. A								
Cibicidoides sp. B								
Cibicidoides wuellerstorfi								
Cribrostomoides? sp.				7.14	50.00			
Cribrostomoides cf. *crassimargo*								
Cyclammina? sp.			12.90					
Cyclammina cancellata	2.50	2.63						
Cyclammina orbicularis								
Cyclammina pusilla								
Cyclammina sp. A	65.83	63.16		10.71				
Dentalina insecta								
Dentalina sp.								
Dentalina? sp.								
Eggerella sp. A								
Elphidium cf. *jenseni*								
Elphidium spp.								
Elphidium subarcticum								
Evolvocassidulina kuwanoi								
Fissurina marginata								
Fissurina orbignyana								
Fissurina sp. A								
Fursenkoina sp. A								
Gavelinopsis sp.								
Glabratella suboperculosis								
Globobulimina perversa								
Globobulimina cf. *perversa*								
Globobulimina pupoides								
Globobulimina spp.								
Globocassidulina globosa (s.l.)								
Globocassidulina sp. A								
Glomospira sp.								
Gyroidina orbicularis								
Gyroidinoides planulatus								
Gyroidinoides cf. *planulatus*								
Hippocrepinella?	0.42							
Hormosina spp.	0.83							
Islandiella cf. *compressa*								
Islandiella helenae								
Islandiella sp. A								
Lagena cf. *apiopleura*								
Lenticulina spp.								
Marginulina sp.								
Martinottiella communis	19.17							
Martinottiella cf. *communis*								
Melonis nikobarense								

Table 3 (continued).

Holes 797B and 797C Section Interval (cm)	8R-1 94–98	11R-1 42–46	18R-1 130–134	22R-5 146–150	23R-2 14–18	25R-4 85–89	34R-6 146–150	41R-CC 30–34
Melonis pompilioides								
Miliolinella sp.								
Nodosaria? sp.								
Nonionellina labradorica								
Nonionella								
Nonionella cf. *miocenica*								
Nonionella stella								
Oolina globosa								
Oolina hexagona								
Oolina? sp.								
Oridorsalis umbonatus								
Oridorsalis spp.								
Parafissulina sp.								
Planodiscorbis sp.								
Plectina nipponica								
Plectina? sp.								
Proteonina sp.			3.23					
Proteonina? sp.			3.23					
Pullenia bulloides								
Pullenia quinqueloba								
Pullenia salisburyi								
Pullenia subcarinata								
Pullenia cf. *subcarinata*								
Pullenia sp.								
Pullenia? sp.								
Pyrgo cf. *vespertilio*								
Pyrgo murrhina								
Pyrgo spp.								
Quadrimorphina sp.								
Quinqueloculina cf. *seminula*								
Quinqueloculina vulgaris								
Quinqueloculina sp. A								
Quinqueloculina sp. B								
Quinqueloculina spp.								
Quinqueloculina? sp.								
Recurvoides? sp.					50.00	20.00		
Reophax excentricus								
Reophax spp.								
Reophax? sp.								
Rhabdammina spp.	+			+	+	+		
Saccammina sp.								
Saracenaria sp.								
Schizammina sp.	+							
Sphaeroidina cf. *compacta*								
Sphaeroidina japonica								
Sphaeroidina cf. *japonica*								
Spirosigmoilinella compressa								
Spirosigmoilinella? sp.								
Thalmannammina cf. *parkerae*	0.42		16.13	7.14				
Tosaia hanzawai								
Trifarina sp.								
Triloculina sp.								
Trochammina sp.								
Uvigerina cf. *modeloensis*								
Uvigerina cf. *segundoensis*								
Uvigerina proboscidea								
Uvigerina cf. *proboscidea*								
Uvigerina sp.								
Valvulineria cf. *sadonica*								
Valvulineria masudai								
Valvulineria spp.								
Miscellaneous taxa	8.75	27.63	61.29	75.00		80.00		

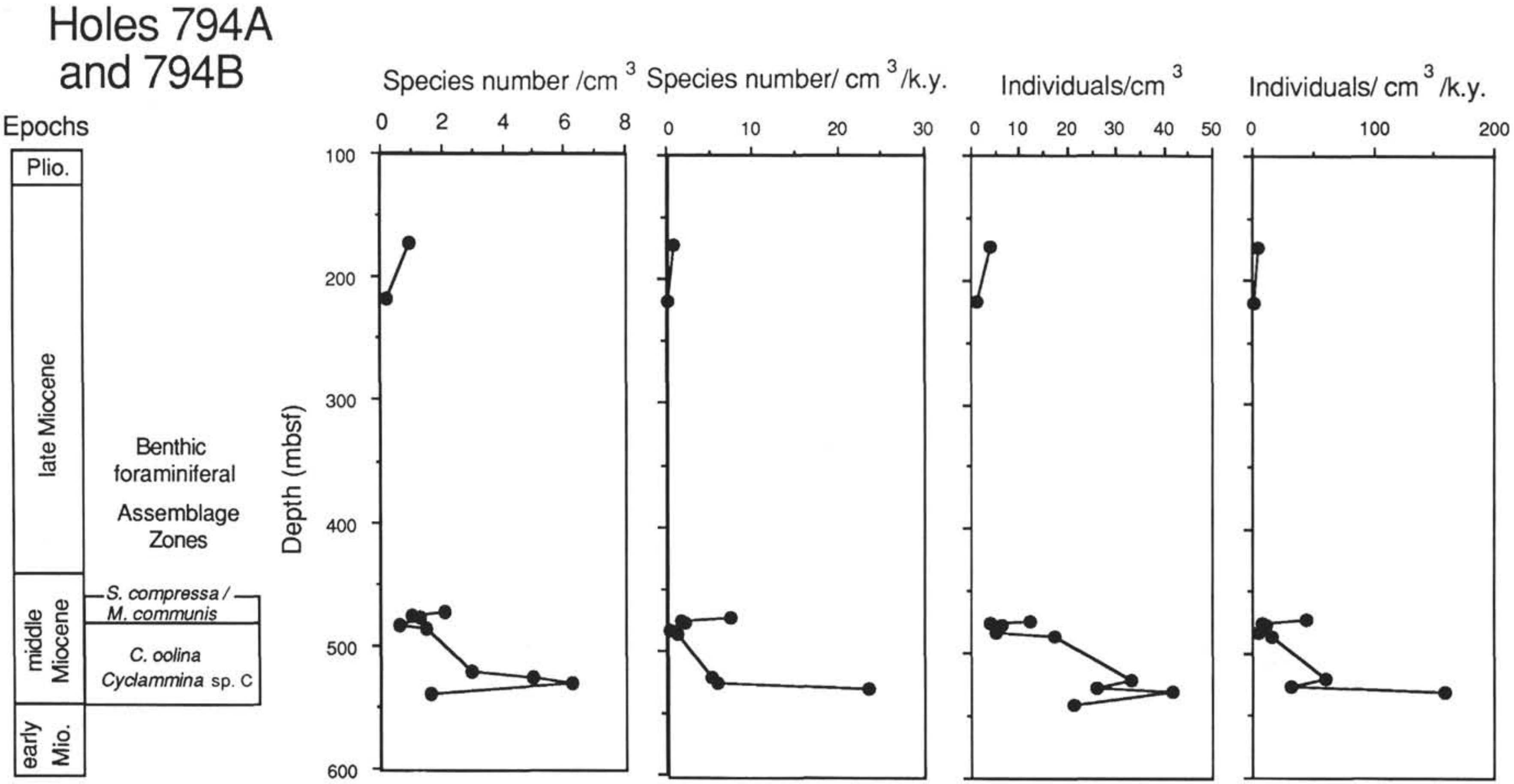

Figure 7. Species diversity in terms of species number, species number per cm^3, and species number per k.y. at Site 794.

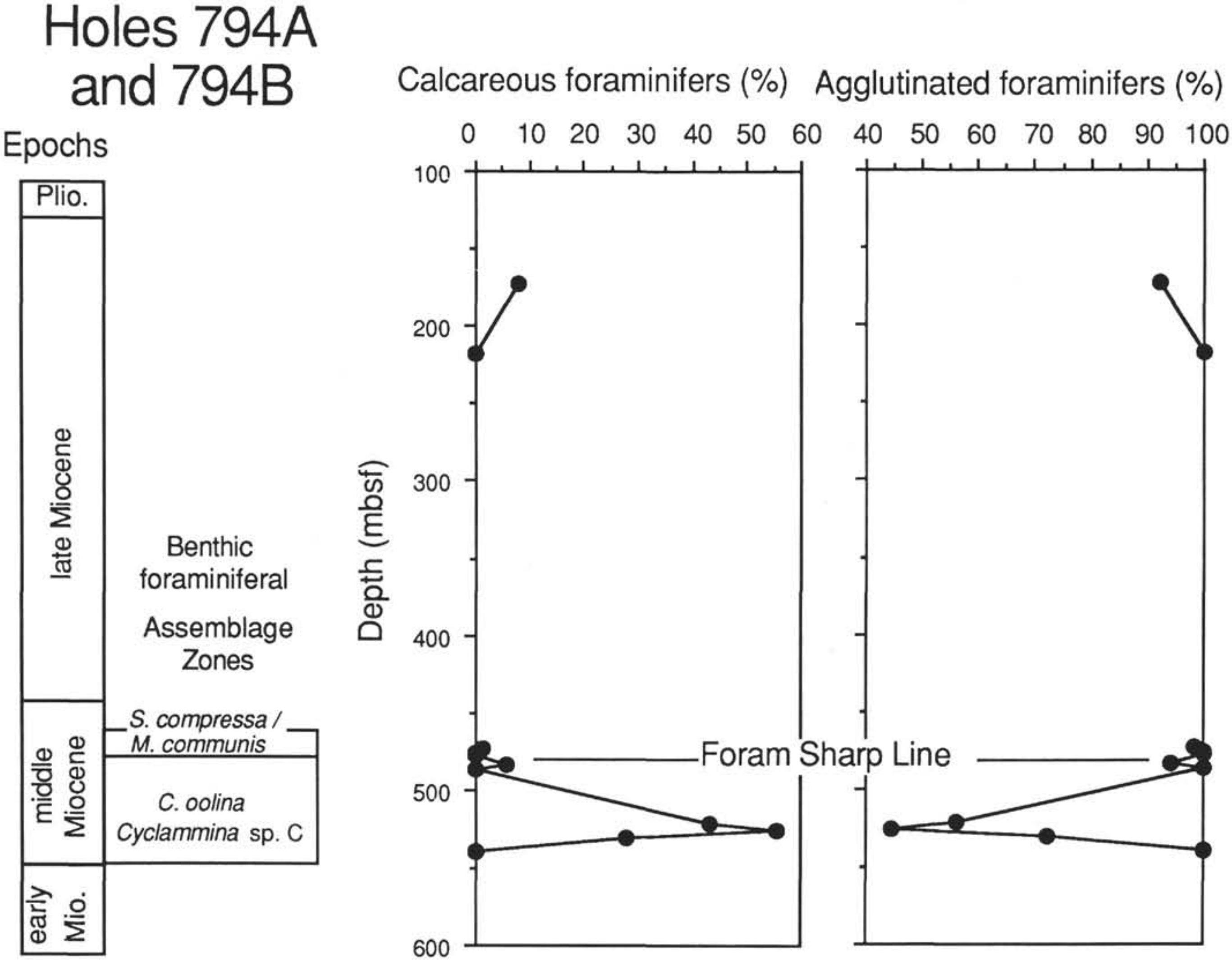

Figure 8. Stratigraphic distribution of calcareous and agglutinated foraminifers at Site 794.

different age of the FSL between the Japan and Yamato basins is not due to a time lag alone. For these reasons, the FSL at 14–15 Ma is here called the first FSL and that at 11.2 Ma is the second FSL.

Appearance of the FSL at Sites 794, 795, and 797 reveals that anoxic bottom water formed throughout the Sea of Japan in middle Miocene time, which can be explained by a silled basin model applied for the FSL from Southwest Honshu (Nomura, 1989, in press). This event may also relate to a global extinction event of deep-water benthic foraminifers recognized by Berggren and Miller (1989). Both of these ideas offer possible explanations for the nature of the FSL. However, on the basis of the distribution of the first FSL restricted to the back-arc region, it should be related to the tectonic movement of the Islands arc.

BENTHIC FORAMINIFERAL ZONES

Site 794

On the basis of the occurrence of calcareous foraminifers and their abundance, two assemblage zones are recognized at Site 794 (Figs. 2 and 5). The first, the *Chilostomella oolina/Cyclammina* sp. C Assemblage Zone, consists of the lower part of the middle Miocene and is characterized by an abundant occurrence of *C. oolina, Cyclammina* sp. C, and *Thalmannammina* cf. *parkerae.* The upper boundary of this zone is defined by the disappearance of *C. oolina, Nonionella miocenica, Globocassidulina* sp. C, and *Cyclammina pusilla* between 127-794B-19R-4, 37–39 cm (477.17 mbsf), and 127-794B-20R-1, 139–143 cm (483.39 mbsf).

The second, the *Spirosigmoilinella compressa/Martinottiella communis* Assemblage Zone, is characterized by an abundant occurrence of *Cyclammina*? sp., *M. communis,* and *S. compressa.* The upper boundary of this zone is not defined because of insufficient materials in the upper middle Miocene to upper Miocene. The lower boundary of this zone is defined by the disappearance of calcareous foraminifers.

Site 795

Three assemblage zones are recognized at Site 795 (Figs. 3 and 9).

Martinottiella communis Assemblage Zone: This zone is characterized by the presence of agglutinated foraminifers such as *M. communis, Eggerella bradyi,* and *Cribrostomoides* cf. *crassimargo.* The upper boundary of this zone is defined by the horizon just below the appearance of *Cibicidoides bradyi* and *Oridorsalis umbonatus* at Sample 127-795B-29R-3, 116–120 cm (639.46 mbsf).

Oridorsalis umbonatus/Cibicidoides wuellerstorfi Assemblage Zone: This zone is characterized by the interval of abundant calcareous foraminifers including *C. wuellerstorfi, Gyroidina orbicularis, Gyroidinoides planulatus,* and *Oridorsalis umbonatus.* The upper boundary of this zone is defined by the disappearance

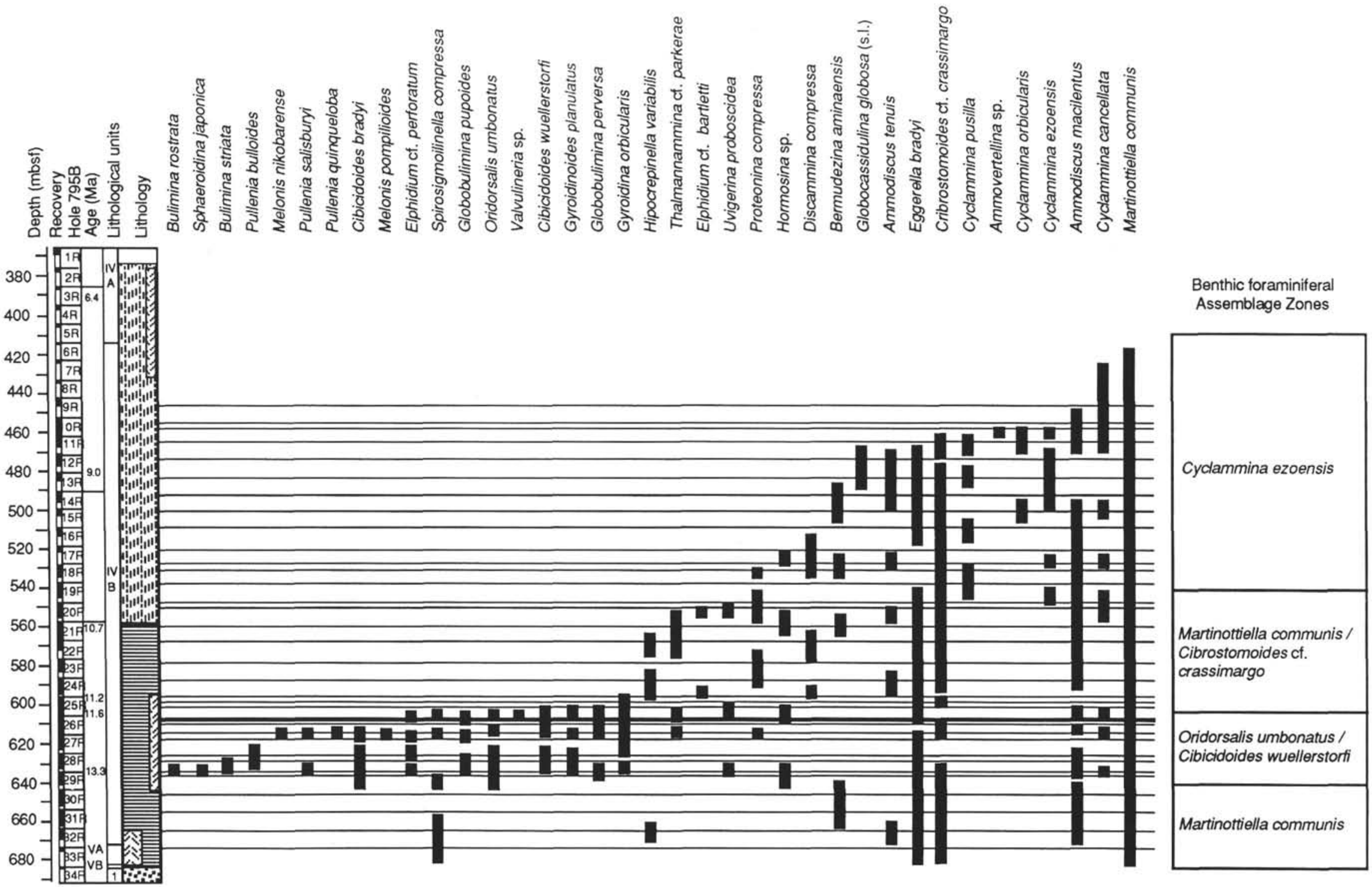

Figure 9. Stratigraphic distribution of benthic foraminifers from Site 795.

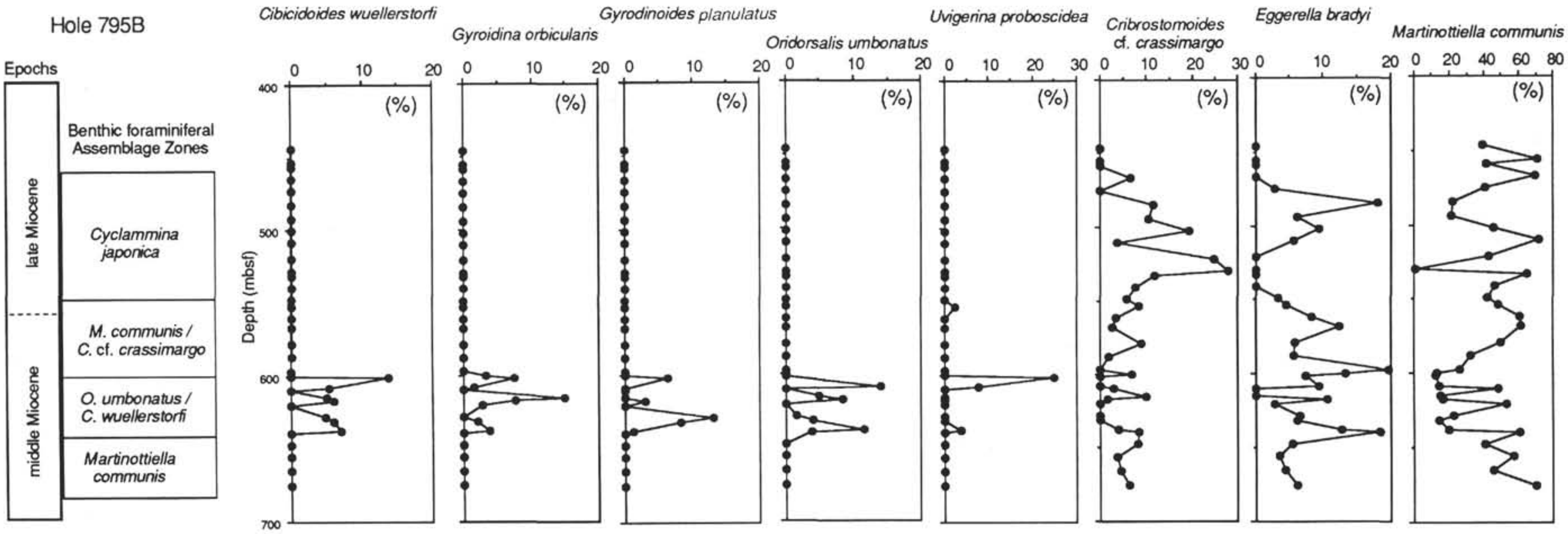

Figure 10. Frequency distribution of dominant benthic foraminifers from Site 795 in terms of percent of total population.

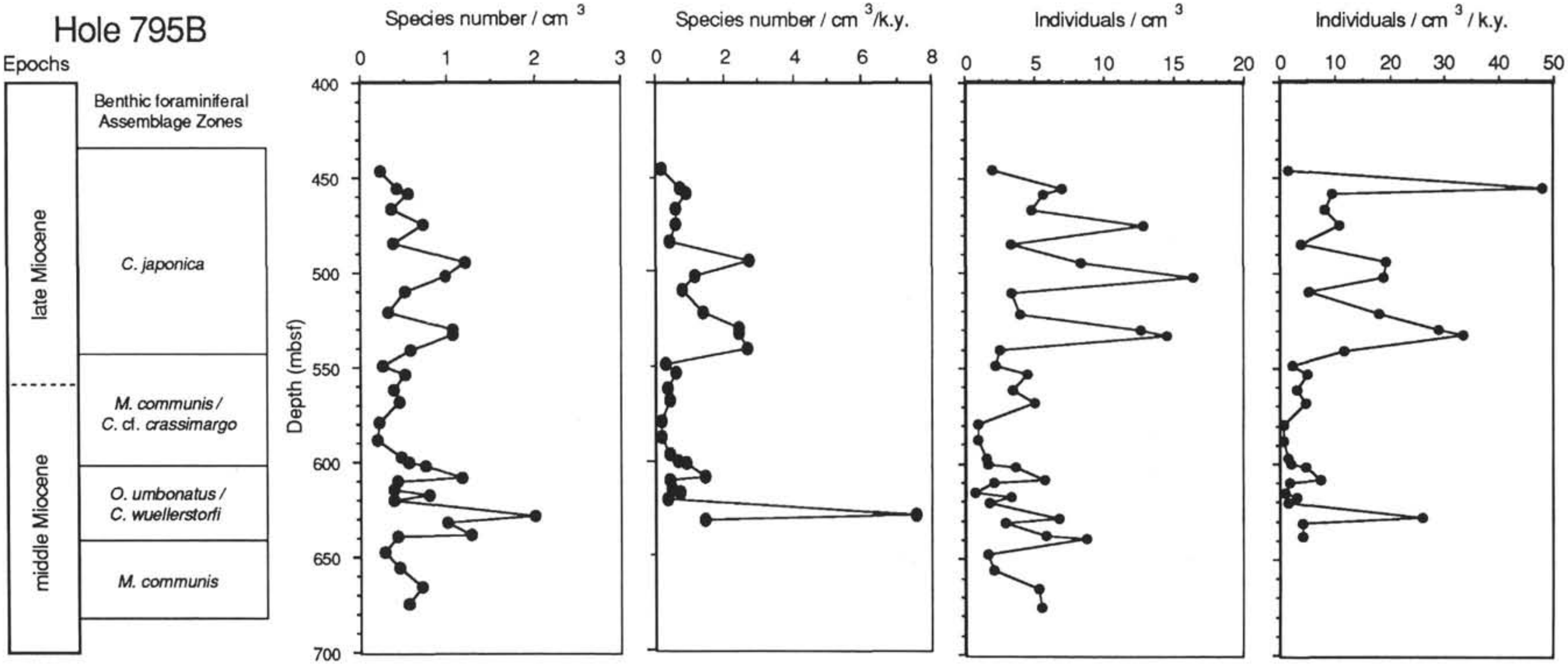

Figure 11. Species diversity in terms of species number, species number per cm^3, and species number per k.y. from Site 795.

of *O. umbonatus* and *C. wuellerstorfi* between Samples 127-795B-25R-3, 43–46 cm (600.13 mbsf), and 795B-25R-4, 23–26 cm (601.43 mbsf).

Martinottiella communis/Cribrostomoides cf. *crassimargo* Assemblage Zone: This zone consists of agglutinated foraminifers in association with very limited calcareous foraminifers. The base of this zone is defined by the disappearance of *O. umbonatus* and *C. wuellerstorfi*. The upper boundary is defined by the horizon below the appearance of *Cyclammina ezoensis* at Sample 127-795B-19R-2, 42–43 cm (540.62 mbsf).

Cyclammina ezoensis Assemblage Zone: This zone is defined by common occurrence of *Cyclammina ezoensis* and well-developed agglutinated foraminifers at the interval of 127-795B-19R-2, 42–43 cm (540.62 mbsf), to 127-795B-10R-5, 50–52 cm (458.5 mbsf).

Site 797

Seven benthic foraminiferal assemblage zones are recognized at Site 797 (Figs. 4, 13, and 14).

First barren interval: First barren interval develops in the range of Sample 127-797C-41R-CC (856.14 mbsf) to 797C-23R-2, 14–18 cm (696.24 mbsf). Broken and badly preserved *Bathysiphon*? sp. in Sample 127-797C-41R-CC indicates an early Miocene marine environment.

Cyclammina sp. A/*Cyclammina*? sp. Assemblage Zone: This zone is characterized by the occurrence of *Cyclammina* sp. A, *Cyclammina?* sp., *Thalmannammina* cf. *parkerae*, and *Ammodiscus macilentus*. In general, foraminiferal diversities are low in this zone. The upper boundary of this zone is defined by the appearance of *Cibicidoides bradyi, Globobulimina perversa,* and *Pullenia bulloides* in Sample 127-797B-52X-6, 50–54 cm (492.5 mbsf).

Gyroidina orbicularis/Gyroidinoides planulatus Assemblage Zone: This zone is characterized by a high diversity of calcareous foraminifers. The upper boundary of this zone is defined by the disappearance of several calcareous foraminifers such as *Cibicidoides* sp. B, *Uvigerina* cf. *modeloensis,* and *Valvulineria masudai* between Samples 127-797B-49X-4, 52–56 cm (460.52 mbsf), and 127-797B-51X-1, 51–53 cm (475.41 mbsf).

Cibicidoides wuellerstorfi Assemblage Zone: This zone is defined by an abundant occurrence of *C. wuellerstorfi, Cyclammina* sp. A, and *Pullenia bulloides* and is characterized by a high number of calcareous foraminifers. The upper boundary of this zone is defined by the disappearance of foraminifers between Samples 127-797B-46X-1, 28–32 cm, and 127-797B-47X-1, 45–49 cm (426.98–436.55 mbsf).

Second barren interval: This interval ranges from the horizon below Sample 127-797B-41X-1, 34–38 cm (379.34 mbsf), to the

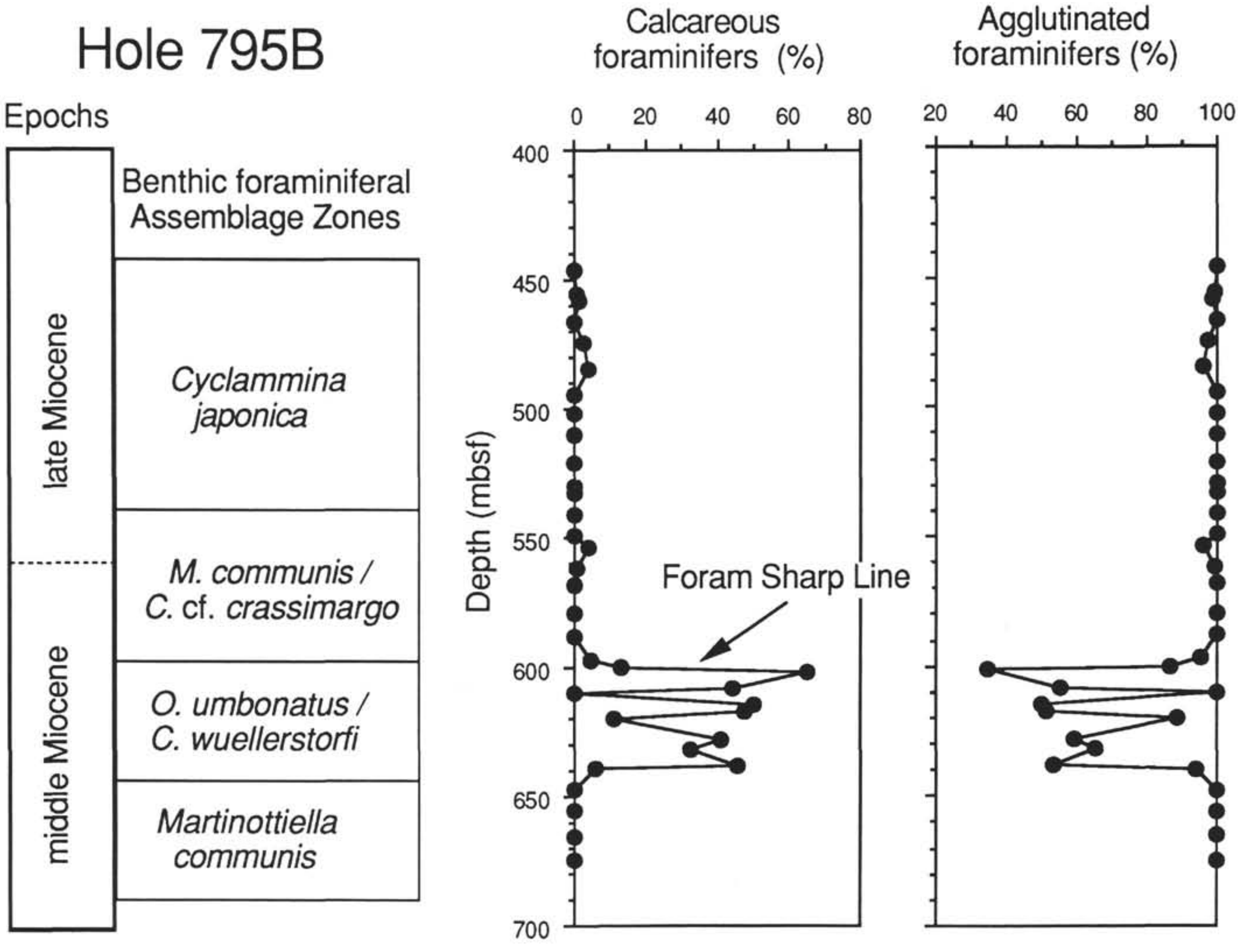

Figure 12. Stratigraphic distribution of calcareous and agglutinated foraminifers at Site 795.

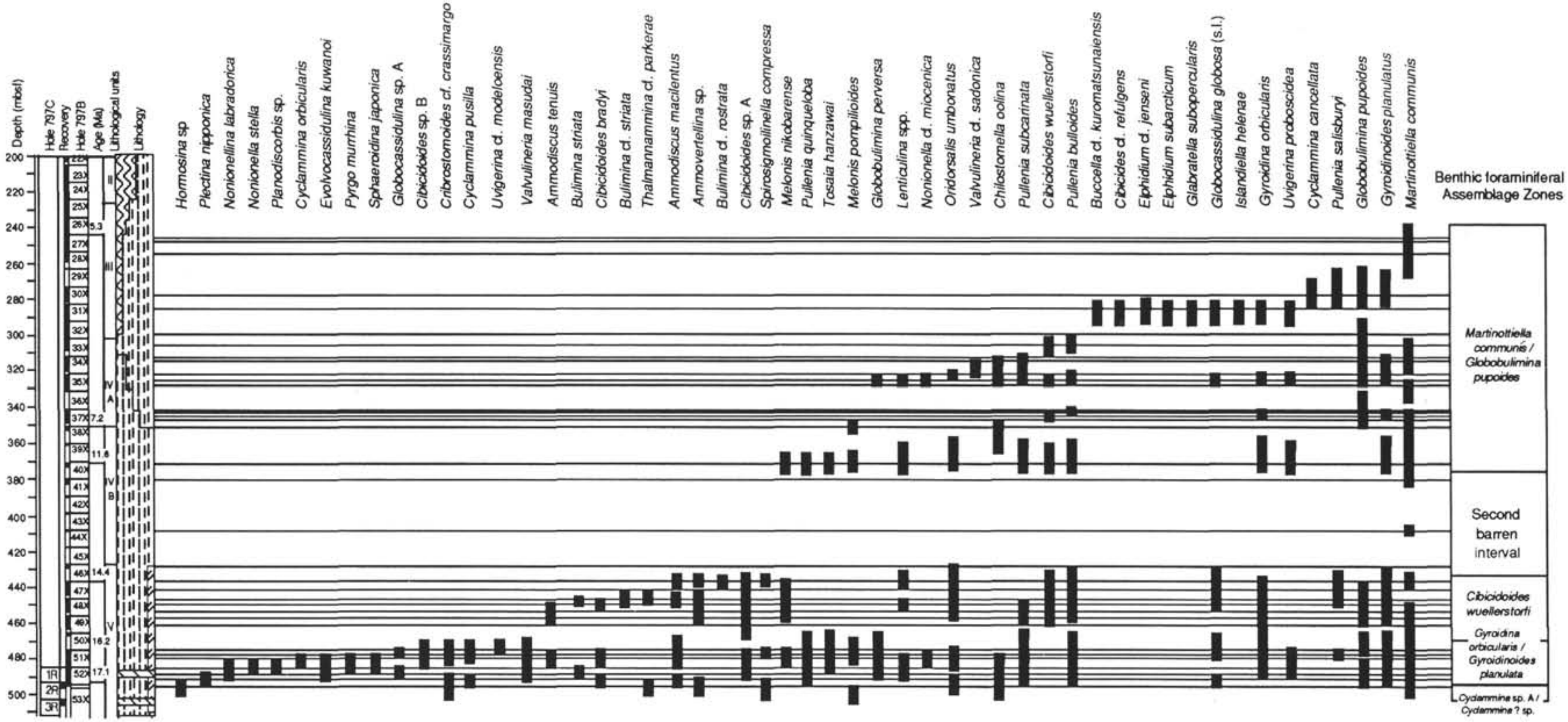

Figure 13. Middle to upper Miocene stratigraphic distribution of benthic foraminifers from Site 797.

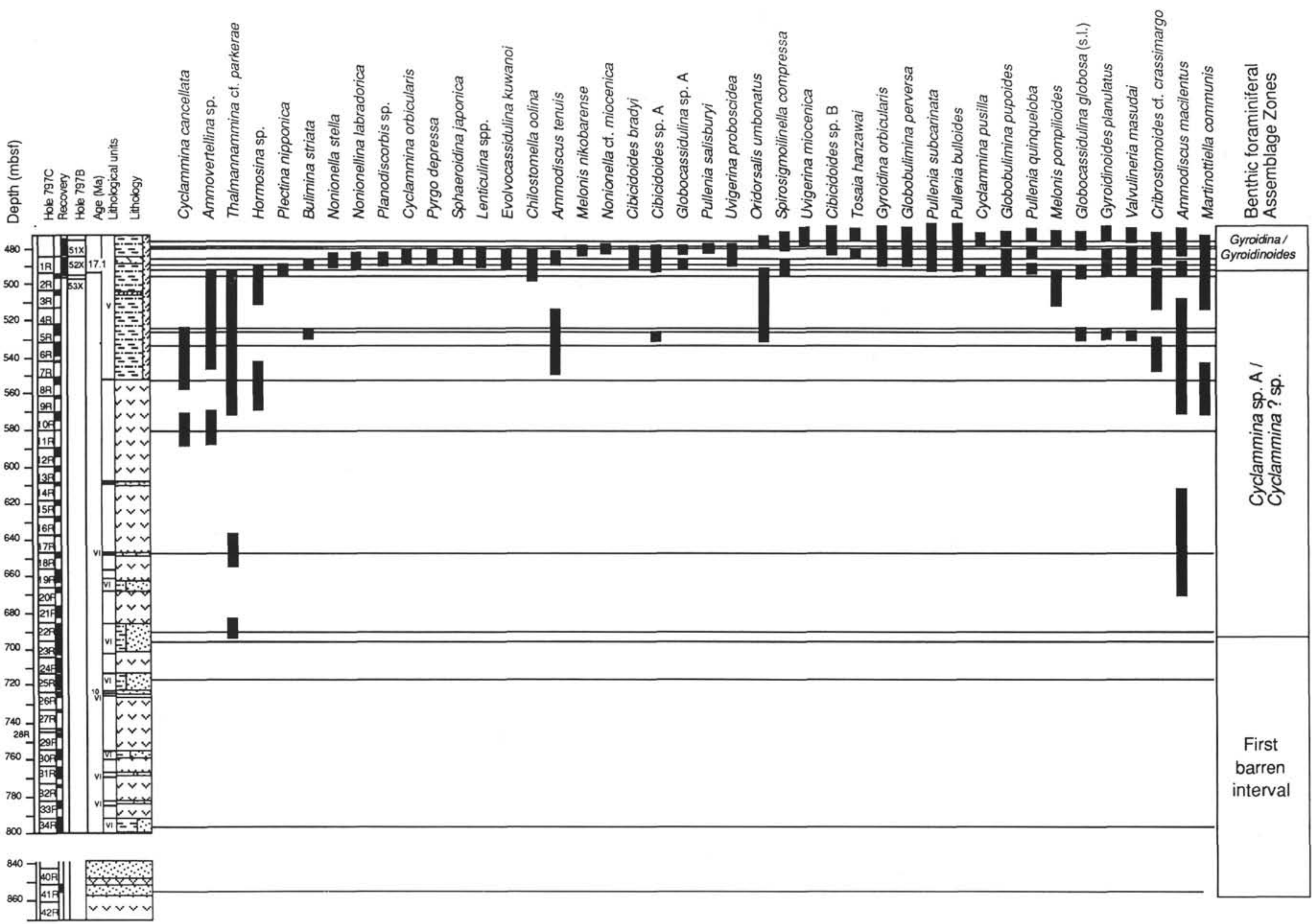

Figure 14. Lower to lower middle Miocene stratigraphic distribution of benthic foraminifers from Site 797.

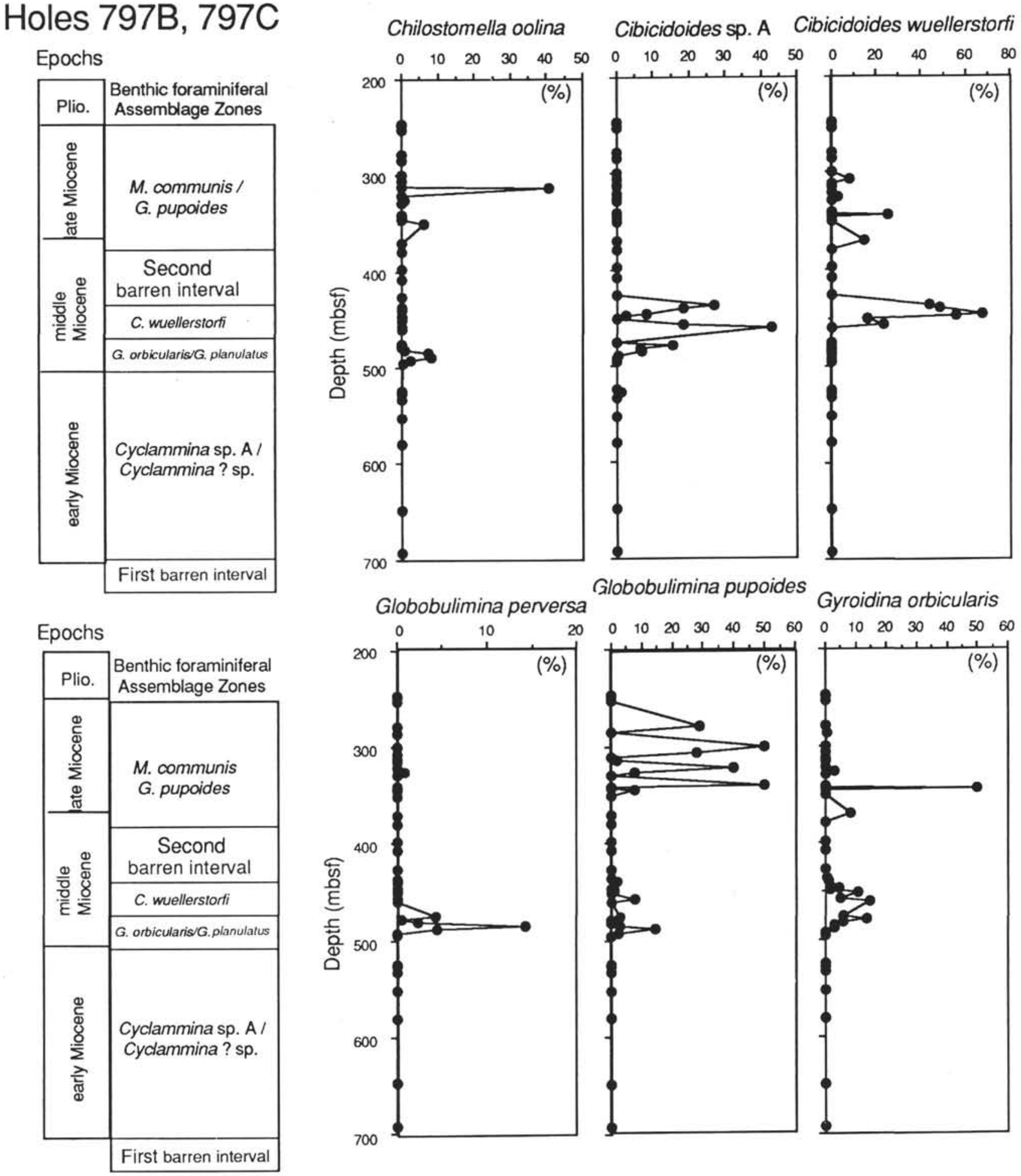

Figure 15. Frequency distribution of dominant benthic foraminifers from Site 797 in terms of percent of total benthic foraminifer population.

horizon above Sample 127-797B-47X-1, 45–49 cm (436.66 mbsf). Occurrence of benthic foraminifers is very limited; only *Martinottiella communis* is found in this interval.

Martinottiella communis/Globobulimina pupoides Assemblage Zone: The lower boundary of this zone is defined by the appearance of both agglutinated and calcareous foraminifers such as *Uvigerina proboscidea, Cibicidoides wuellerstorfi,* and *Martinottiella communis* in Sample 127-797B-40X-2, 35–39 cm (370.31 mbsf). This zone is principally characterized by low numbers of species and specimens of agglutinated foraminifers.

The correlation of these benthic zones is shown in Figure 20 along with correlation of benthic zones from Southwest Honshu and Northeast Honshu. Matsunaga's *Hopkinsina morimachiensis* Zone was originally defined by planktonic foraminifers, but Maiya (1978) re-

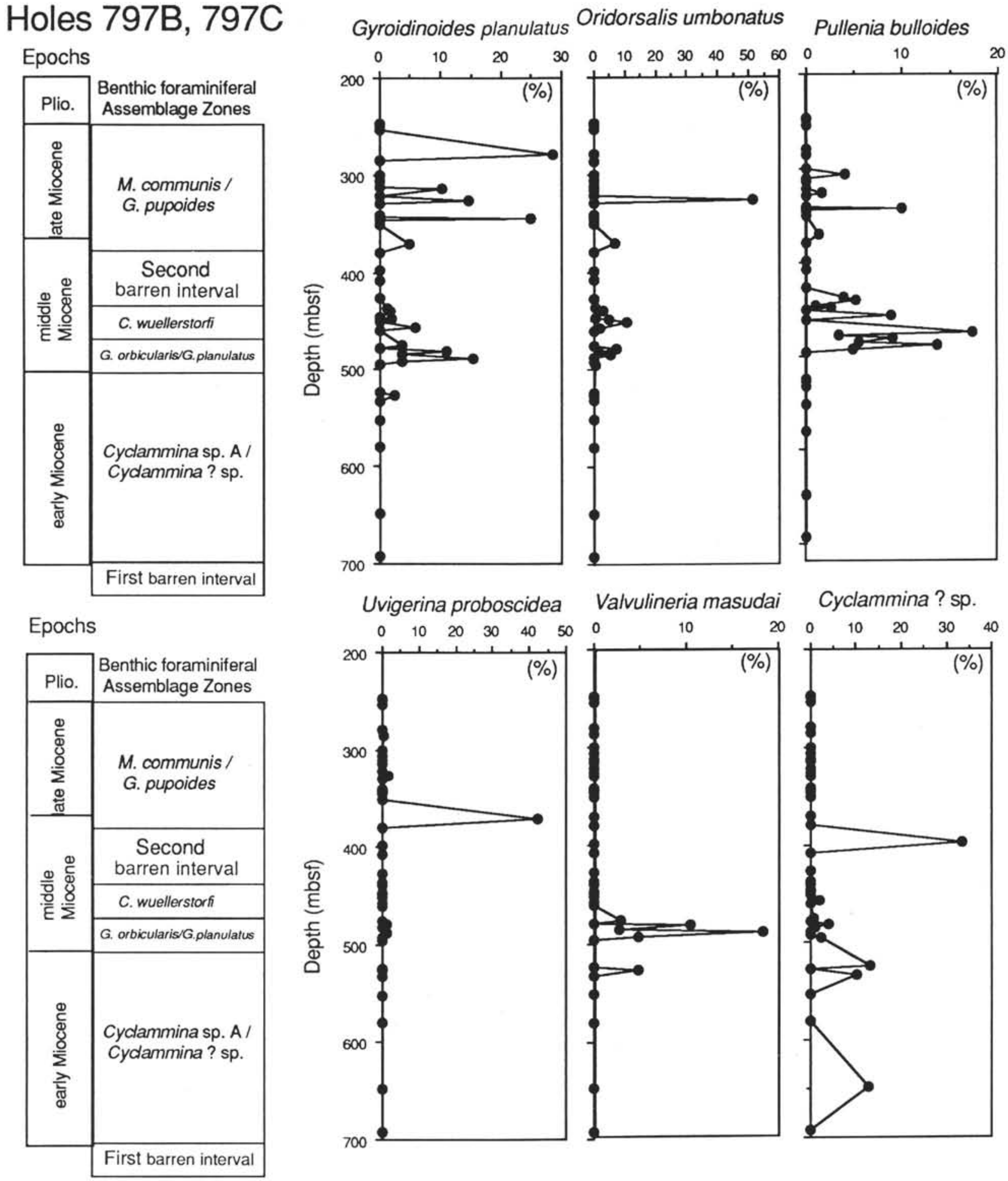

Figure 15 (continued).

vised it and correlated with his planktonic foraminiferal zone in the Niigata area.

CLUSTER ANALYSES

Seventy-eight samples from three sites were grouped into seven clusters in this study. The result of cluster analysis is shown in Figure 21 and the stratigraphic distributions of these groups are shown in Figure 22.

The horizon having the highest foraminiferal diversity below the FSL is mainly characterized by C or E clusters. C and E clusters occur alternately in two zones at Site 797 and one zone at Site 795. The D cluster is also characterized by a high abundance of calcareous foraminifers, but it consists primarily of reworked fauna. Other clusters such as B, F, and G are characterized by the agglutinated

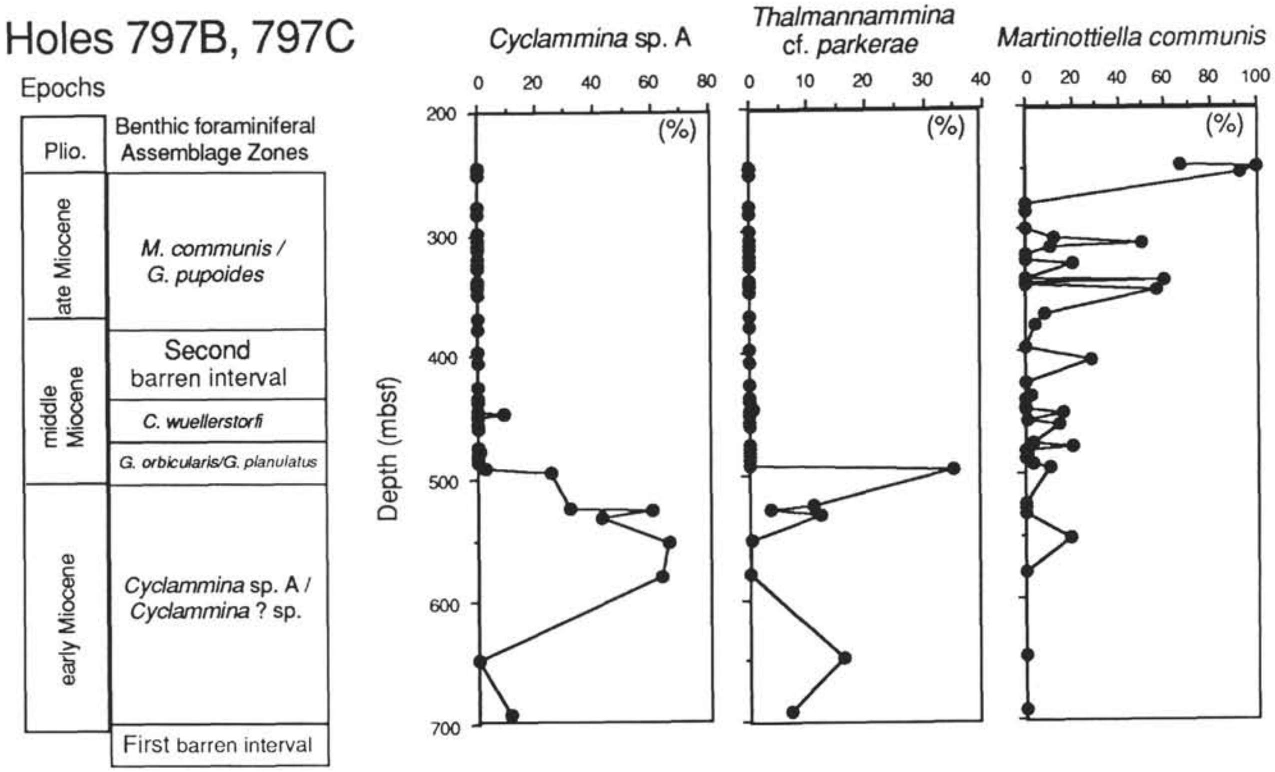

Figure 15 (continued).

foraminifers, although the A cluster contains a few calcareous foraminifers.

It should be noted that the C and E clusters at Site 795 appear during 11.2–13.3 Ma, an age that corresponds to the development of the second barren interval at Site 797 in the Yamato Basin. The second FSL at Site 795 is correlated with the top of the second barren interval at Site 797. Alternatively, B cluster does not appear at Site 797 prior to 14.3 Ma. This may be due to the local difference of deep-sea environment and suggests that paleoceanographic condition of earlier stages of the Sea of Japan is differentiated not only within the Yamato Basin but also between the Yamato and Japan Basins. These sorts of benthic distributional patterns depend primarily on local conditions, as noted by Boltovskoy (1987)

DISCUSSION

Timing of the Foram Sharp Line and Paleoceanography of the Sea of Japan

As is well known, tropical to subtropical shallow-marine faunas and subsequent deep-water faunas developed on pre-Tertiary basement and/or lower Miocene nonmarine sediments in the area of the Honshu arc. Therefore, contrasting early to early middle Miocene faunas are present at the Sea of Japan ODP sites and the onshore Sea of Japan coastal regions, despite the presence of similar faunas around the margins of the Sea of Japan. These differences largely reflect the different tectonic histories and water depths of these two fundamentally different areas of the Sea of Japan.

The planktonic foraminiferal *Globigerinoides sicanus*/*Praeorbulina glomerata* and *Globorotalia peripheroronda*/*Globorotalia quinifalcata* Zones of Maiya (1978) proposed for the Sea of Japan side of Northeast Honshu are correlated with the standard planktonic foraminifer N8 to N9 Zones. Maiya's two zones are also correlated with the lower two-thirds of the benthic foraminifer *Hopkinsina morimachiensis* Zone of Matsunaga (1963)(Fig. 19). In this zone, paleotopographic irregularity has been noted in the Niigata and Akita regions of northern Honshu. The *Hopkinsina morimachiensis* Zone includes diversified *Hopkinsina* species in association with the correlative shallower faunas, which include *Miogypsina, Operculina, Nephrolepidina,* and *Ammonia tochigiensis.* The deeper fauna in the *H. morimachiensis* Zone is characterized by the nominate taxon along with *Cyclammina* spp., *"Haplophragmoides"* spp., *Martinottiella communis, Uvigerina proboscidea, Gyroidina orbicularis, Melonis pomplioides, Cibicidoides wuellerstorfi, Pullenia bulloides,* and *Stilostomella lepidula* (Maiya, 1978; Matoba, 1984), which are considered to represent water depths of 1500–2000 m (Matoba, 1981). Even deeper water depths (>3500 m, 1500–2000 m, and 2000–3000 m) have been estimated for the inland area of Northeast Honshu (Guber and Ohmoto, 1978; Kitazato, 1979; Matoba, 1983). Thus, a range of paleodepths was formed during Zones N8–9 in the Northeast Honshu arc coincident with volcanic activity. In contrast, Miocene benthic foraminifers from the Southwest Honshu arc usually indicate sequential deepening of sedimentary basins. In the Bihoku Group of the inland area of Southwest Honshu, three zones of the *Miogypsina*–*Operculina,* the *Hanzawaia tagaensis*/*Heterolepa praecincta,* and the *Uvigerina segundoensis* s.l. are recognized from lower to upper horizons (Tai, 1959; Nomura, in press). Although these zones are not precisely dated because of limited age-indicative microfossils, it is clear that differential vertical movement in the basin commenced in the *Hanzawaia*/*Heterolepa* Zone assigned to upper N8 to N9 zones. These areas continue to deepen in the *Uvigerina* Zone and a barren interval (= the 2nd barren interval at Site 797; Fig. 20) (~300 m in paleodepth), coincident with the uplift of the Chugoku Backbone Range. Uplift of the Backbone Range prevented Pacific Deep Water from entering the paleo-Sea of Japan. The first FSL corresponds to the timing of the formation of stagnant bottom water in the inland area of Southwest Honshu (Nomura, 1989). The agglutinated fauna formed

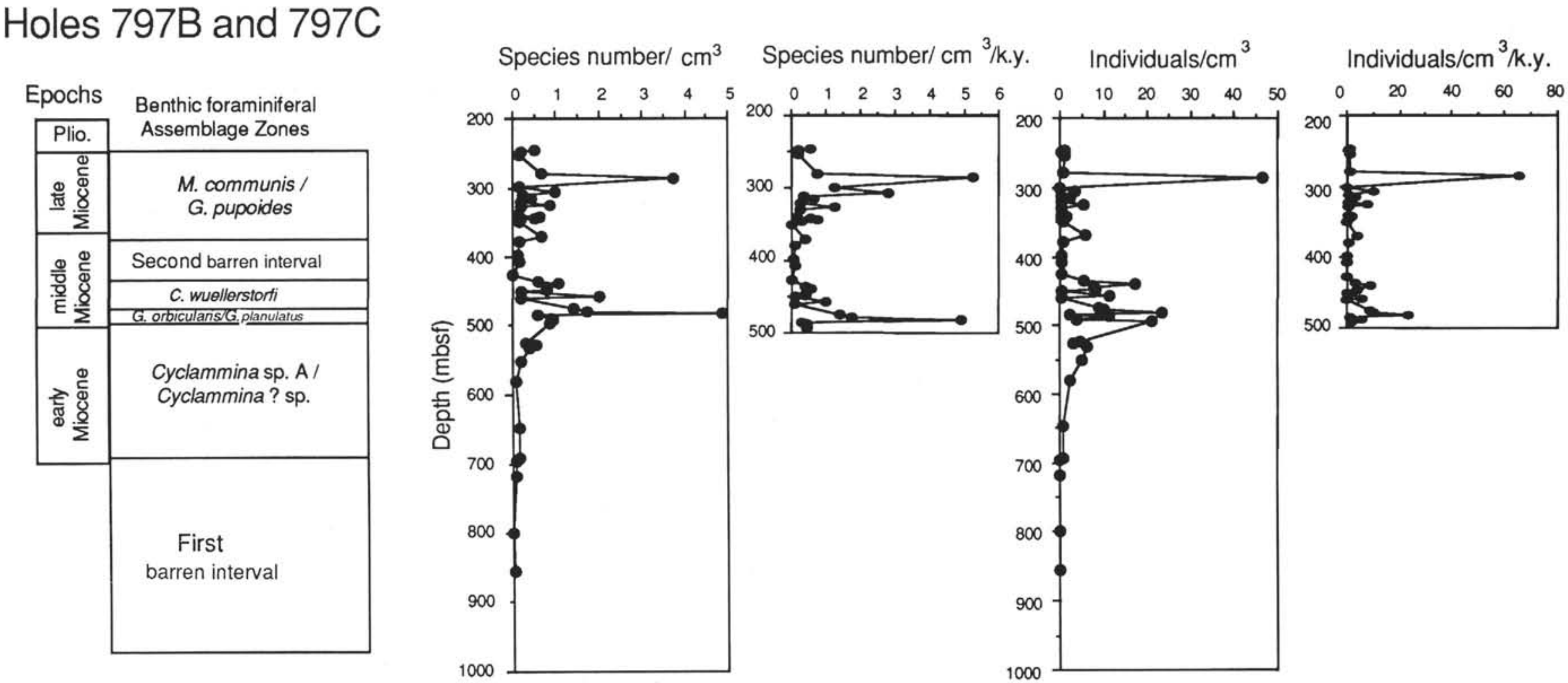

Figure 16. Species diversity in terms of species number, species number per cm^3, and species number per k.y. from Site 797.

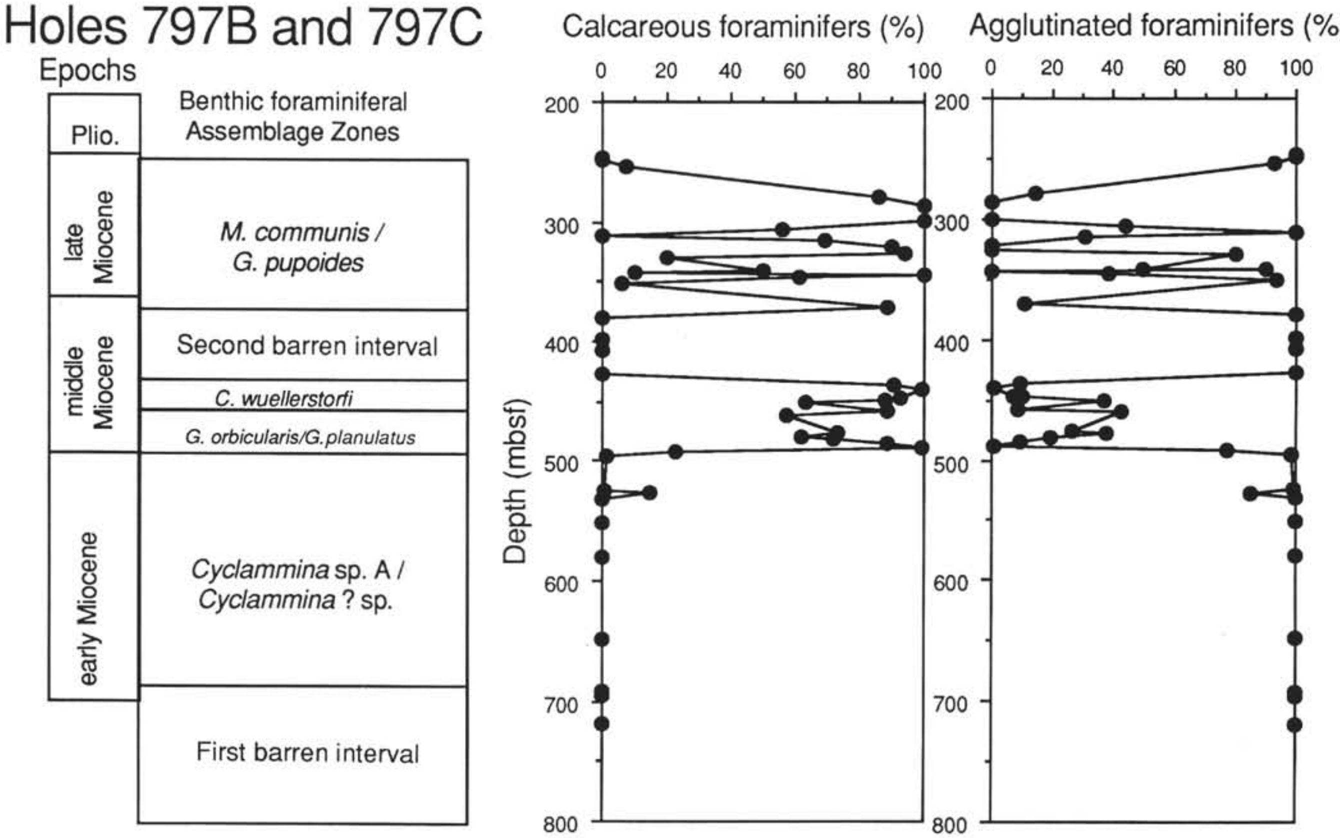

Figure 17. Stratigraphic distribution of calcareous and agglutinated foraminifers at Site 797.

in the Shimane Peninsula (Nomura, 1986a, b) and in the Yamato Basin are essentially coeval responses to this paleoceanographic change, which was a function of the uplift of the Backbone Range.

The appearance of an agglutinated fauna in the *Spirosigmoilinella compressa*/*Martinottiella communis* Zone at Site 794 correlates well with the appearance of the FSL in Northeast Honshu at the N9/10 boundary (Maiya, 1978). The dissolved oxygen content in bottom water largely determines the nature of the benthic fauna (Thompson et al., 1985); thus, the second barren interval likely reflects limited content of dissolved oxygen in bottom water. Critical oxygen content for the presence of a calcareous fauna is about 0.3 mL/L (Thompson et al., 1985). Oxygen supply into bottom water may also be regulated by local topographic features.

The idea of middle Miocene development of agglutinated foraminifers along the northern Sea of Japan coast as a function of the uplift of the Backbone Range of Northeast Honshu was originally proposed by Asano et al. (1969) and Maiya (1988). Specifically, Maiya (1988) suggests that faunal differentiation between the Sea of Japan and the Pacific sides occurred at N9 (15 Ma) due to lifting of the backbone range and the prevalence of cold-water species. This age is also coincident with the presumed vertical and horizontal movement of Southwest Honshu. On the basis of the rotation event of the Honshu arc (~15 Ma), Chinzei (1986) considered that the molluscan faunal change from warm- to cold-water taxa was caused by the closing of the Korea and Tsushima straits and by intrusion of northern cold water. A similar model has been applied to the benthic foraminiferal faunal change by Ujiie (1988), though he supposes that the Pacific water flow came through Central Honshu. However, the deep-water stagnation in the Sea of Japan cannot be explained solely by the closing of the above straits. Although I cannot identify particular straits for the Pacific deep-water inflow to the Sea of Japan, I assume that there were many channels prior to uplift of the Backbone Ranges.

The Second Foraminiferal Sharp Line, however, appears at 11.2 Ma at Site 795 in the Japan Basin. According to Maiya and Inoue (1981), the disappearance of warm-water planktonic foraminifers (a Planktonic Foram Sharp Surface defined by these latter authors) is stratigraphically very distinct and marks the introduction of cold-water planktonic foraminifers (the *Globorotalia pseudopachyderma*/*Globigerina woodi* Zone of Maiya (1978)) in the Sea of Japan. It is likely that cold deep water replaces the previous deep water at this time as marked by agglutinated foraminifers. Nevertheless, benthic foraminifers in the *O. umbonatus*/*C. wuellerstorfi* Zone at Site 795 indicate great similarity to those of the *C. wuellerstorfi* and the *G. orbicularis*/*G. planulatus* zones at Site 797 (Fig. 21). Increasingly oxic bottom water apparently began to form from about 11.6 Ma at Site 797. This age is surprisingly close to the appearance of the second FSL at Site 795 and suggests that the second FSL at Site 795 was not formed through the opening event of the Sea of Japan as in the case of the first FSL but rather may be related to a large-scale water mass change in the North Pacific Ocean. Woodruff (1985) suggested stepwise paleoceanographic changes in the Pacific Ocean during the Miocene. The changes are correlated with cooling of the deep Pacific Ocean due to Antarctic glacial expansion and are expressed by the clear isotopic changes at 14.5 Ma and 8–10 Ma. During these periods, benthic foraminifers change their distribution patterns in addition to origination and extinction of species. In particular, the late Miocene paleoceanographic event is related to the intensification of organic productivity by thermohaline circulation, which resulted in the development of low-oxygen deep water and an increase of deep-sea dissolution of calcareous matter. Although the timing of the Second FSL is not exactly the same as that of the latter paleoceanographic change,

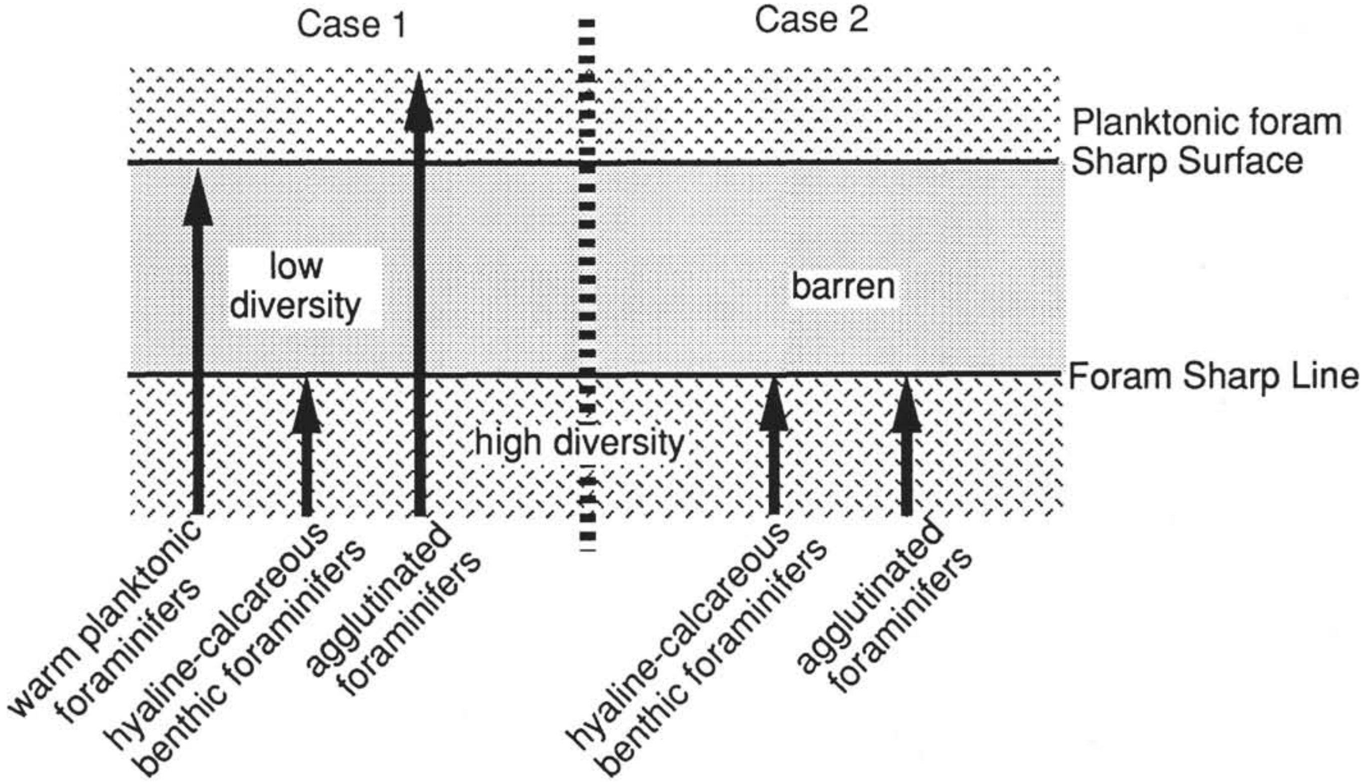

Figure 18. Conceptual diagram of the Foram Sharp Line (Tai, 1963) and the Planktonic Foram Sharp Surface (Maiya and Inoue, 1981). The Foram Sharp Line (FSL) is recognized as the stratigraphic horizon that changes from the high-diversity benthic fauna containing both hyaline-calcareous and agglutinated foraminifers to the low-diversity fauna consisting of agglutinated foraminifers (case 1) or barren interval (case 2). Both cases are defined as occurring in middle Miocene mudstone sequences. The Planktonic Foram Sharp Surface is the stratigraphic horizon characterized by the disappearance of warm planktonic foraminifers from the Sea of Japan borderland regions.

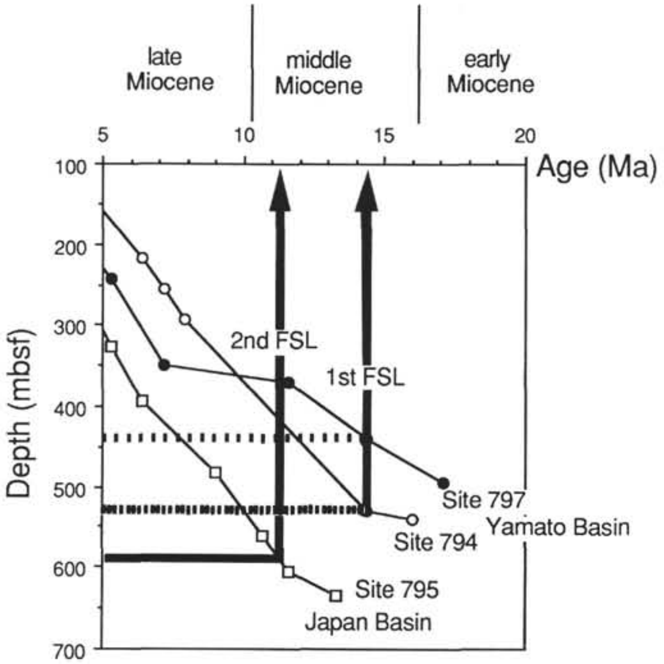

Figure 19. Age distribution of the Foram Sharp Lines (FSL) with respect to variations in rate of sediment accumulation. The First FSL appears at the 14–15 Ma interval at Sites 794 and 797. The Second FSL appears at 11.2 Ma at Site 795.

intensified thermohaline circulation with the development of North Atlantic Deep Water becomes more active at approximately 11 Ma (Woodruff and Savin, 1989). Northward movement of nutrient-rich intermediate water likely activated primary production through upwelling in the North Pacific Ocean. This global change of ocean bottom water may also be responsible for the increase of agglutinated foraminifers in marginal seas. After the late middle Miocene, lithological units represented by diatomaceous ooze and claystone prevailed at both Sites 795 and 797, which suggests that the active upwelling in the Sea of Japan begins from this time.

Opening of the Sea of Japan: Benthic Foraminiferal Evidence

The theory for the opening of the Sea of Japan proposed by Otofuji and Matsuda (1983, 1984) and Otofuji et al. (1985a, c) calls for the Southwest Honshu arc to rotate clockwise to its present position at about 14–15 Ma. Counter-clockwise opening of the Northeast Honshu arc occurred at about 15–20 Ma (Hamano and Tosha, 1985) and at 11–21 Ma (Otofuji et al., 1985b, 1986). Coincident subsidence based on the benthic foraminiferal data discussed earlier supports a major geologic event at ~15 Ma. Subsidence suggests that a compressional stress field may have been present in the Japanese Islands among this time. Prior to N9 (about 16 Ma), however, there is no evidence of the compressional stress in Southwest Honshu based on benthic foraminiferal evidence. Distribution patterns of volcanic dikes support the idea that the Sea of Japan side of Southwest Honshu was positioned in the tensional stress field before 15 Ma (Tsunakawa and Takeuchi,

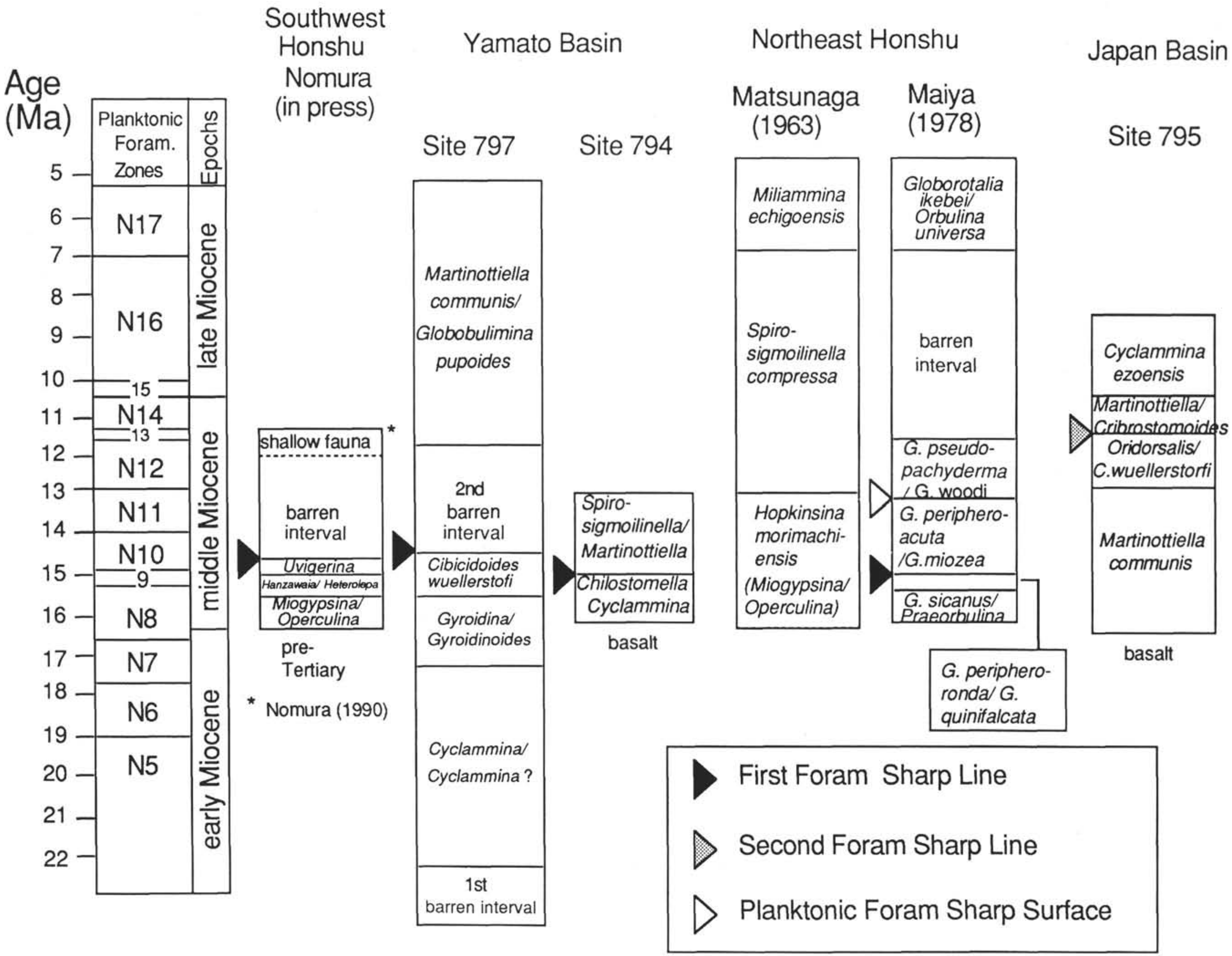

Figure 20. Correlation of benthic foraminiferal zones from Sites 794 795, and 797 with zones of Southwest Honshu (Nomura, in press) and Northeast Honshu (Matsunaga, 1963) and correlation with the planktonic foraminiferal zones of Maiya (1978).

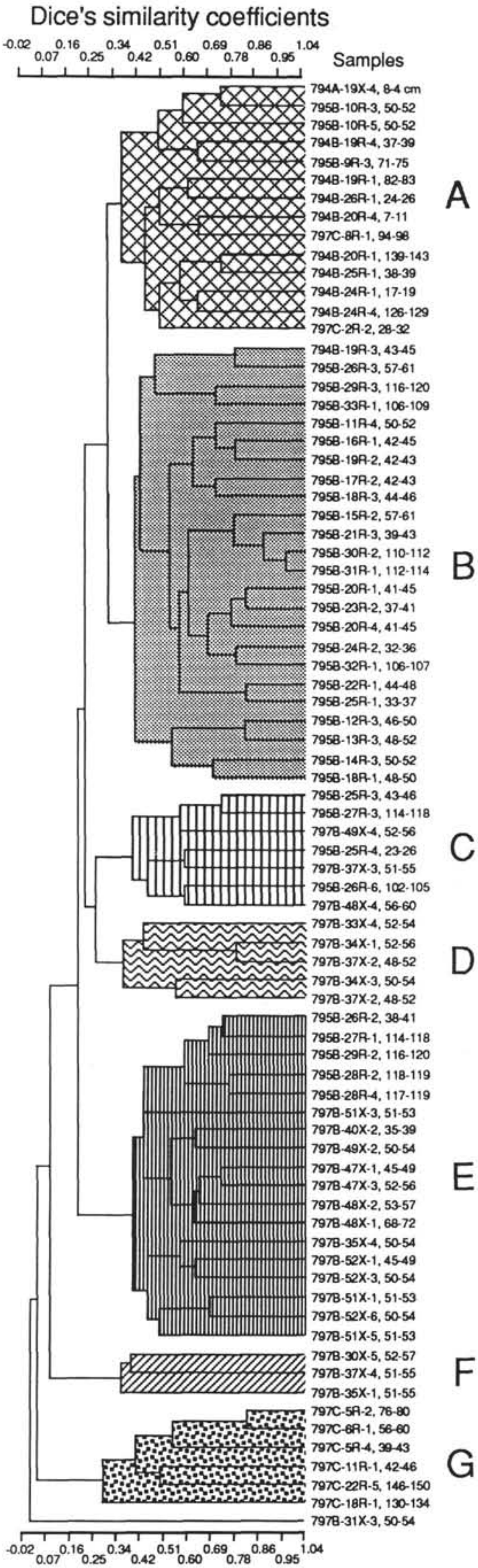

Figure 21. Cluster analysis at Sites 794, 795, and 797.

1983). In general, gradual deepening occurs in Southwest Honshu in association with a global marine transgression, which suggests that the Honshu arc was in a tensional stress field during this epoch (N8). After initial rifting, the Sea of Japan was positioned in the tensional stress field during the Miocene (Tamaki, 1985, 1988). In contrast to the movement of the Japanese Islands, the Sea of Japan sites show only gradual deepening of the oceanic basin during the Miocene, without signs of uplifting during N9. In order to explain the change of the stress field deduced from benthic faunal change, two opening processes proposed by Hayashida and Torii (1988) and Hayashida et al. (1991) may be more reasonable than a simple rotation of the Japanese Islands. The Japanese Islands moved southwardly in the first opening event at about 15–16 Ma and subsequently rotated to their present position during a short interval at about 15 Ma. This geophysical process fits the spreading model of Tamaki (1985, 1988). The timing of the separation of Japan from Asia is thought to have begun at about 16 Ma because the N8 Miocene marine transgression is widely recognized in various areas in the Japanese Islands, and no pre-N8 marine fossils have been recorded in the Sea of Japan borderland. Japanese paleontologists commonly believe that the presence of nonmarine or brackish sedimentary basins formed in the Sea of Japan area before the marine transgression (Koizumi, 1988). However, evidence from Site 797 clearly suggests that the Yamato Basin reached bathyal depths in the late early Miocene.

In order to explain such developmental processes of the Sea of Japan, a model derived from benthic foraminiferal changes is indicated in Figure 23. As shown in the zone boundary from the *Cyclammina* sp. A/*Cyclammina*? sp. Zone to the *Gyroidina*/*Gyroidinoides* Zone, a distinct faunal change occurred at 17.1 Ma. This zone boundary at 17.1 Ma is thought to indicate a change in oxygen content from low to high. After 17.1 Ma, calcareous foraminifers are abundant and suggest that the favorable ocean circulation developed in the Sea of Japan. Oxygen supply to bottom water should have been promoted by new water inflow into the Sea of Japan owing to the enlargement of the Sea of Japan. This interpretation indicates that the first opening of the Sea of Japan must have commenced at 17.1 Ma or earlier. Thus, the opening of the Sea of Japan occurred at least 1 m.y. earlier than previously thought (Hayashida et al., 1991; Chiji et al., 1989). The early Miocene Proto-Japan Sea may have been narrow, deep depressions with poor deep-water circulation, as interpreted by Tamaki, Pisciotto, Allan, et al. (1990).

The second phase in the opening of the Sea of Japan is related to the differential vertical movement of the Japanese Islands as previously mentioned. Toward the end of the initial opening, the first FSL marked the typically anoxic back-arc basins phase with oxygen-deficient bottom water. This paleoceanographic event was restricted to the Yamato Basin. Oxygenated deep water entered into the Japan Basin at about 13 Ma and continued up to about 11 Ma, as indicated by the fauna of the *O. umbonatus*/*C. wuellerstorfi* Zone, an age which may be related to the opening of the northern Yamato Basin. Although the Northeast Honshu arc is known to have gradually opened counterclockwise during 21–11 Ma (Hamano and Tosha, 1985; Otofuji et al., 1985b, 1986), further movement of Hokkaido and other small areas in the northern islands may have affected this faunal change.

CONCLUSIONS

1. Miocene benthic foraminifers from Sites 794 and 797 (Yamato Basin) and Site 795 (Japan Basin) were quantitatively analyzed. Two assemblage zones were identified at Site 794. Four assemblage zones and two barren intervals were identified at Site 797, and four assemblage zones at Site 795. The Miocene foraminifers from these sites are characterized by deep-water species, suggesting lower bathyal to upper abyssal depths. Major variations in the relative abundances of calcareous and agglutinated foraminifer are also recognized.

2. The Foram Sharp Line (FSL) is recognized at about 14.3 Ma at Site 797 and 14.4 Ma at Site 794, whereas the FSL at Site 795 is 11.2 Ma. The FSL at about 14.5 Ma is similar to the position of the FSL defined in onshore sequences of the Honshu arc and forms a useful stratigraphic criterion for correlating the Miocene strata. However, the FSL at Site 795 appears about 3 m.y. later and suggests that two FSL's occurred in the Miocene, the first FSL at about 14.5 Ma and the second at about 11.2 Ma.

3. The first FSL is related to the opening event of the Sea of Japan. Uplift of the backbone ranges of Honshu at about 15 Ma resulted in the formation of oxygen-deficient deep water in the back-arc basin as well as the inland area of Honshu by confining the inflow of the Pacific deep water. Subsidence indicates a compressional stress field in the Honshu arc and supports the ideas of a clockwise rotation of Southwest Honshu and a counter-clockwise rotation of Northeast Honshu.

4. Calcareous foraminifers become abundant at about 17.1 Ma at Site 797, which is the boundary between the *Cyclammina* sp. A/*Cyclammina*? sp. Zone and the *Gyroidina orbicularis*/*Gyroidinoides planulatus* Zone. This faunal change suggests that the bottom water of the Proto-Japan Sea changed from relatively oxygen poor to oxygen rich and geologically suggests the entrance of the oxygen-rich Pacific deep water by enlarging the Proto-Japan Sea. These late early Miocene deep-water faunas indicate that initial rifting and subsidence occurred at least 1 m.y. earlier than previously considered.

5. The second FSL may be related to a global paleoceanographic change caused by a deep-water cooling and the intensification of thermohaline circulation. Development of intermediate water from development of NADW occurred at about 11 Ma (Woodruff and Savin, 1989). This activated an upwelling and increased the organic productivity in the northern Pacific Ocean, which leads to a solution of calcareous foraminifers in deep sea. Diatom-rich sediments become more common above the second FSL.

6. At Site 795, calcareous foraminifers become common at about 13.3 Ma, which suggests that oxygenated deep water entered the Japan Basin while stagnant bottom water formed at Site 797. Therefore, the northernmost Japan Basin may have independently widened at about 13 Ma. This latter event suggests a complex topographic movement in the Sea of Japan during the Miocene time.

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I am very grateful to the shipboard party of Leg 127 for the time they devoted to sampling for this study. I thank Kensaku Tamaki for his kind invitation to study Miocene benthic foraminifers from Leg 127 cores. I prepared part of this study during a visit in Mexico, and I thank Adolfo Molina-Cruz for his courtesy during this period. I thank James Ingle and Martin Lagoe for critically reading the manuscript and for providing helpful suggestions.

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SPECIES REFERENCE LIST

All of the species and genera identified in this study are listed below.

Ammodiscus concinnus V. Kuznetzova, 1970.

Ammodiscus macilentus Chapman = *Ammodiscus incertus* (d'Orbigny) var. *macilenta* Chapman, 1904.

Ammodiscus tenuis Brady, 1881.

Ammodiscus spp.

Ammosphaeroidina sp.

Ammovertellina sp.

Astrononion spp.

Bathysiphon spp.

Bermudezina aminaensis Bermudez, 1949.

Brizalina spp.

Buccella cf. *kuromatsunaiensis* = cf. *Buccella kuromatsunaiensis* Shirai, 1960.

Bulimina rostrata Brady, 1884.

Bulimina striata d'Orbigny, 1826.

Bulimina spp.

Chilostomella oolina Schwager, 1878.

Cibicides cf. *refulgens* Montfort = cf. *Cibicides refulgens* Montfort, 1808.

Cibicides sp.

Cibicidoides bradyi (Trauth) = *Truncatulina bradyi* Trauth, 1918.

Cibicidoides wuellerstrofi (Schwager) = *Anomalina wuellerstorfi* Schwager, 1866.

Cibicidoides spp.

Cribrostomoides cf. *crassimargo* (Norman) = cf. *Haplophragmium crassimargo* Norman, 1892.

Cribrostomoides spp.

Cyclammina cancellata Brady, 1881.

Cyclammina ezoensis Asano, 1951.

Cyclammina cf. *japonica* Asano, 1950.

Cyclammina orbicularis Brady, 1881.

Cyclammina pusilla Brady, 1881.

Cyclammina spp.

Dentalina insecta (Schwager) = *Nodosaria insecta* Schwager, 1866.

Dentalina spp.

Discammina compressa (Goës) = *Lituolina irregularis* var. *compressa* Goës, 1882.

Eggerella bradyi (Cushman) = *Verneuilinella bradyi* Cushman, 1911.

Eggerella sp.

Elphidium bartletti Cushman = *Elphidium bartletti* Cushman, 1933.

Elphidium cf. *jenseni* (Cushman) = cf. *Polystomella jenseni* Cushman, 1924.

Elphidium cf. *perforatum* Nomura = cf. *Elphidium perforatum* Nomura, 1990.

Elphidium subarcticum Cushman, 1944.

Elphidium spp.

Epistominella sp.

Evolvocassidulina kawanoi (Matoba) = *Cassidulinoides kuwanoi* Matoba, 1967.

Fissurina spp.

Fissurina marginata (Montagu) = *Vermiculum marginatum* Montagu, 1803.

Fissurina orbignyana Seguenza, 1862.

Fursenkoina ishikiensis (Asano) = *Virgulina ishikiensis* Asano, 1949.

Fursenkoina spp.

Gaudryinella sp.

Gavelinopsis sp.

Glabratella subopercularis (Asano) = *Discorbis subopercularis* Asano, 1951.

Glandulina cf. *nipponica* = cf. *Glandulina nipponica* Asano, 1951.

Globobulimina perversa (Cushman) = *Bulimina pyrula* d'Orbigny var. *perversa* Cushman, 1921.

Globobulimina pupoides (d'Orbigny) = *Bulimina pupoides* d'Orbigny, 1846.

Globobulimina spp.

Globocassidulina globosa (Hantken) = *Cassidulina globosa* Hantken, 1875.

Globocassidulina spp.

Glomospira sp.

Gyroidina orbicularis d'Orbigny, 1826.

Gyroidinoides planulatus (Cushman and Renz) = *Gyroidina planulatus* Cushman and Renz, 1941.

Haplophragmoides spp.

Hippocrepinella variabilis Voloshinova, 1970.

Hopkinsina sp.
Hormosina spp.
Islandiella cf. *compressa* Nomura = cf. *Islandiella compressa* Nomura, 1983.
Islandiella helenae Feyling-Hanssen and Buzas, 1976.
Islandiella sp.
Lagena cf. *apiopleura* Loeblich and Tappan = cf. *Lagena apiopleura* Loeblich and Tappan, 1953.
Lenticulina spp.
Lituotuba sp.
Marginulina cf. *glabra* d'Orbigny = cf. *Marginulina glabra* d'Orbigny, 1826.
Marginulina sp.
Martinottiella communis (d'Orbigny) = *Clavulina communis* d'Orbigny, 1826.
Melonis nikobarense (Cushman) = *Nonion nikobarensis* Cushman, 1936.
Melonis pompilioides (Fichtel and Moll) = *Nautilus pompilioides* Fichtel and Moll, 1798.
Miliolinella sp.
Nodosaria longiscata d'Orbigny, 1846.
Nodosaria spp.
Nonionellina labradorica (Dawson) = *Nonionina labradorica* Dawson, 1860.
Nonionella miocenica Cushman, 1927.
Nonionella stella Cushman and Moyer = *Nonionella miocenica* Cushman var. *stella* Cushman and Moyer, 1930.
Nonionella spp.
Oolina globosa (Montagu) = *Vermiculum globosum* Montagu, 1803.
Oolina hexagona (Williamson) = *Entosolenia squamosa* (Montagu) var. *hexagona* Williamson, 1848.
Oolina spp.
Oridorsalis umbonatus (Reuss) = *Rotalia umbonata* Reuss, 1851.
Oridorsalis spp.
Parafissurina sp.
Planodiscorbis sp.
Plectina nipponica Asano, 1951.
Proteonina compressa Cushman and McCulloch, 1919.
Pullenia bulloides (d'Orbigny) = *Nonionina bulloides* d'Orbigny, 1846.
Pullenia quinqueloba (Reuss) = *Nonionina quinqueloba* Reuss, 1851.
Pullenia salisburyi R. E. and K. C. Stewart, 1930.
Pullenia subcarinata (d'Orbigny) = *Nonionina subcarinata* d'Orbigny, 1839.
Pullenia sp.
Pyrgo cf. *vespertilio* (Schlumberger) = cf. *Biloculina vespertilio* Schlumberger, 1891.
Pyrgo murrhina (Schwager) = *Biloculina murrhina* Schwager, 1866.
Pyrgo spp.
Quadrimorphina sp.
Quinqueloculina cf. *seminula* (Linnaeus) = cf. *Serpula seminulum* Linnaeus, 1767.
Quinqueloculina vulgaris d'Orbigny, 1826.
Quinqueloculina spp.
Recurvoides? sp.
Reophax excentricus Cushman, 1910.
Reophax spp.
Rhizammina sp.
Saccammina sphaerica Brady, 1881.
Saracenaria sp.
Schizammina sp.
Sphaeroidina cf. *compacta* Cushman and Todd = cf. *Sphaeroidina compacta* Cushman and Todd, 1949.
Sphaeroidina japonica Asano, 1953.
Spiroplectammina sp.
Spirosigmoilinella compressa Matsunaga, 1955.
Stilostomella sp.
Technitella sp.
Textularia sp.
Thalmannammina cf. *parkerae* (Uchio) = cf. *Recurvoides parkerae* Uchio, 1960.
Tosaia hanzawai Takayanagi, 1953.
Trochammina cf. *globigeriniformis* (Parker and Jones) = *Lituola nautiloidea* var. *globigeriniformis* Parker and Jones, 1865.
Trochammina sp.
Trifarina spp.
Triloculina sp.
Uvigerina cf. *segundoensis* Cushman and Galliher = cf. *Uvigerina segundoensis* Cushman and Galliher, 1934.
Uvigerina cf. *modeloensis* Cushman and Kleinpell = *Uvigerina modeloensis* Cushman and Kleinpell, 1934.
Uvigerina proboscidea Schwager, 1866.
Uvigerina spp.
Valvulineria cf. *sadonica* Asano = cf. *Valvulineria sadonica* Asano, 1951.
Valvulineria masudai Asano, 1953.
Valvulineria spp.

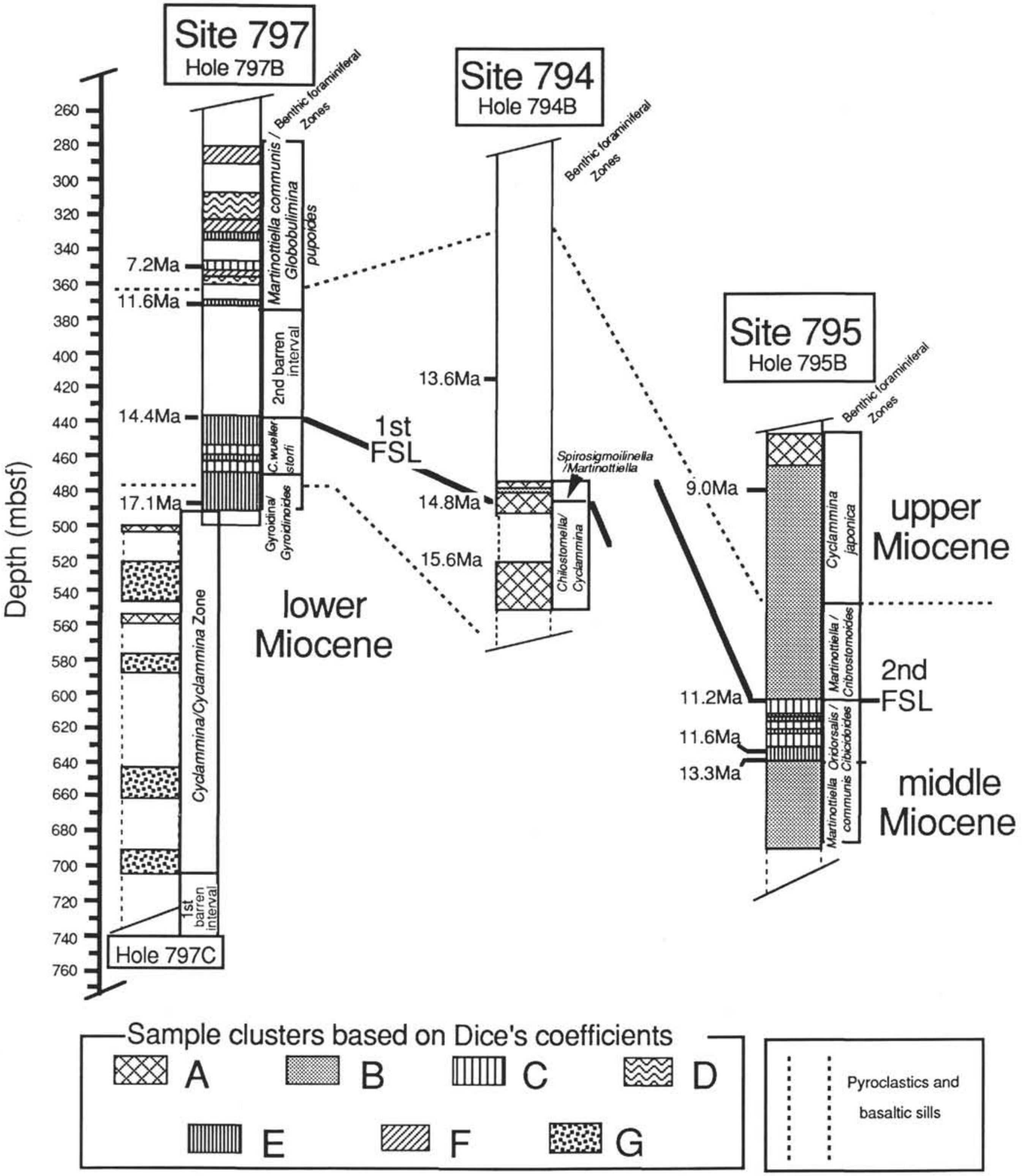

Figure 22. Distribution of sample clusters (A–G) at Sites 794, 795, and 797.

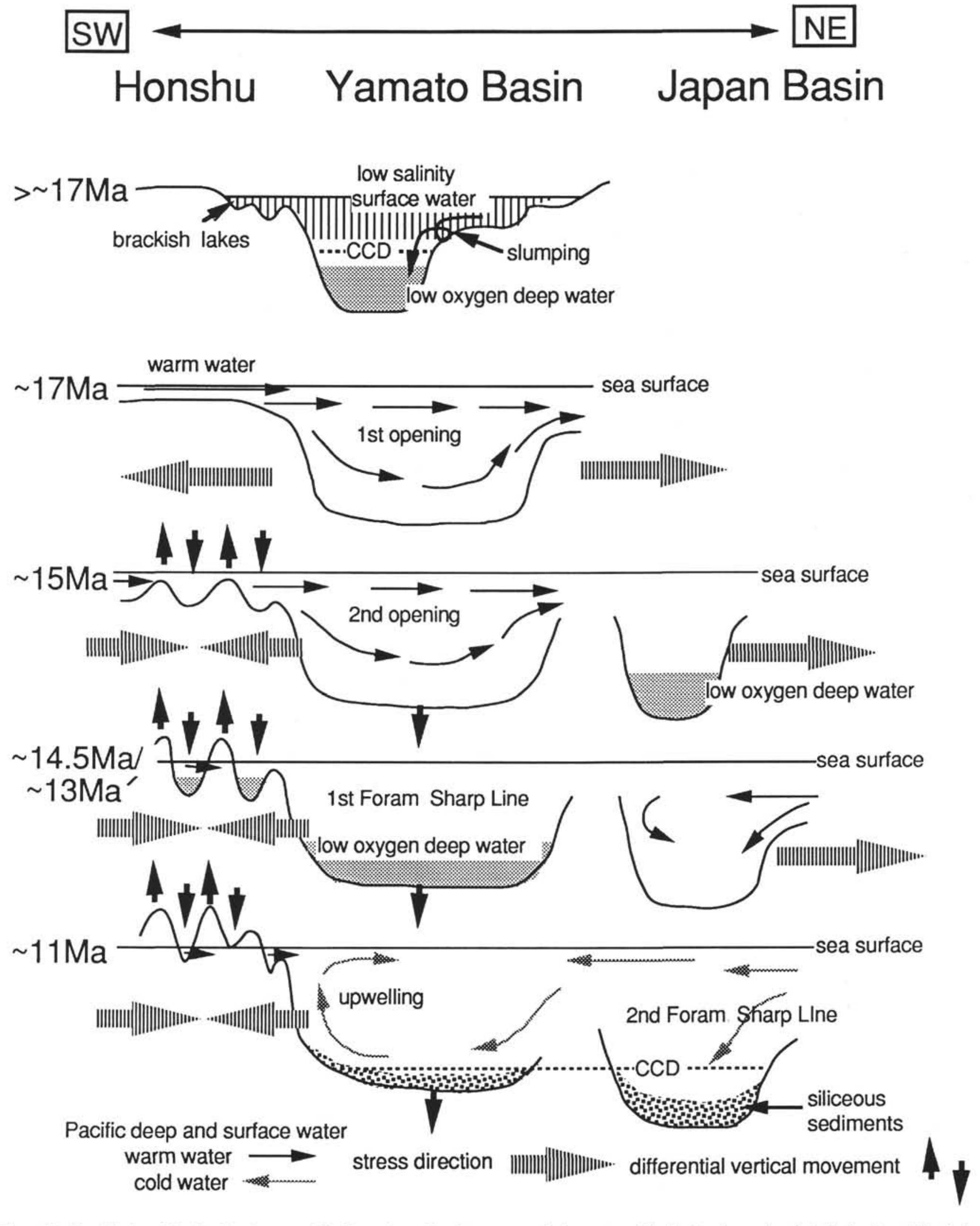

Figure 23. Simplified model of the development of the Japan Sea with reference to geologic events within the Honshu arc (particularly Southwest Honshu).

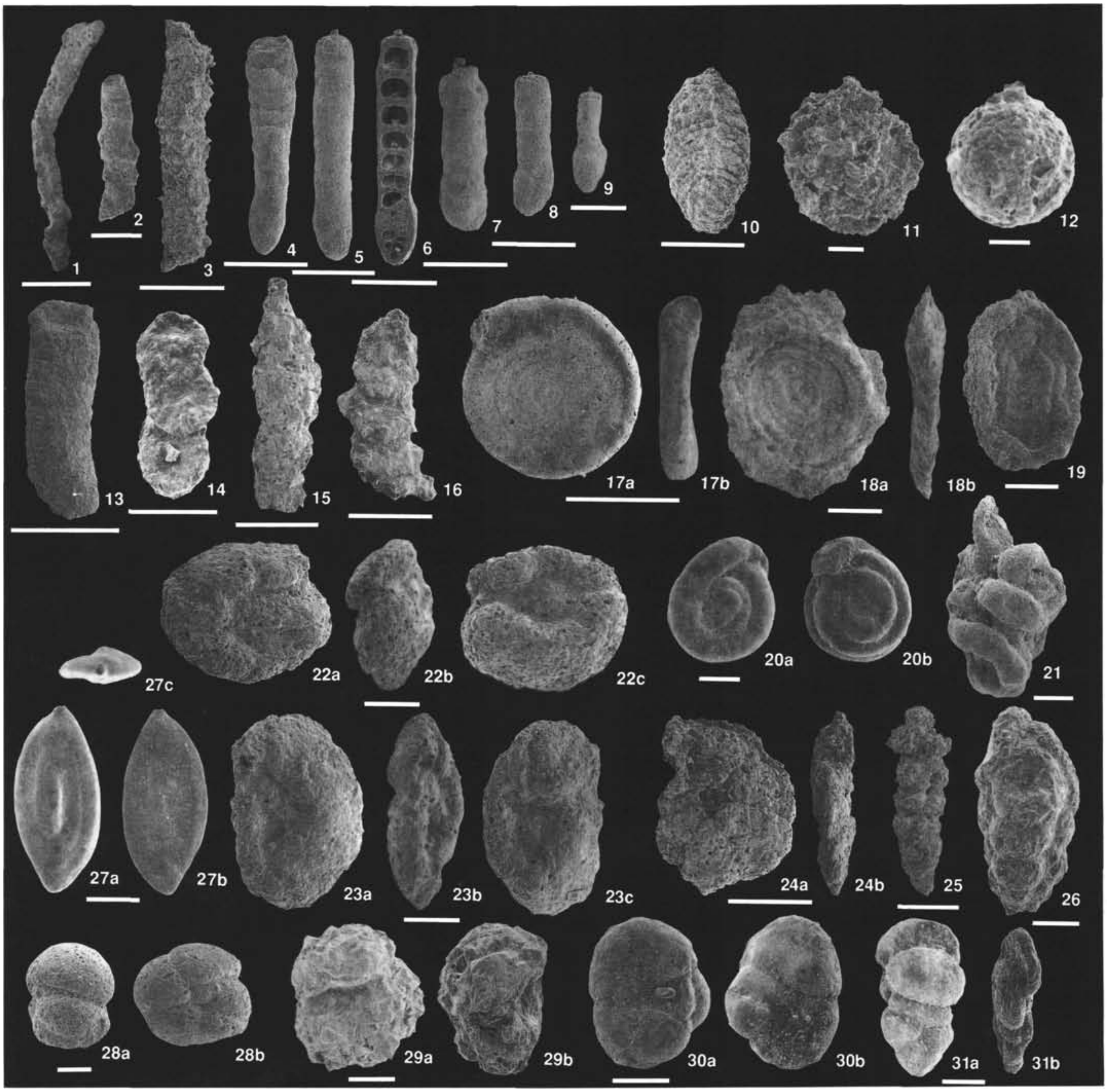

Plate 1. Scale = 100 µm. **1.** *Schizammina*? sp., 127-795B-18R-1, 48–50 cm. **2.** *Schizammina*? sp., 127-797C-6R-1, 56–60 cm. **3.** *Rhizammina* sp., 127-797C-5R-2, 76–80 cm. **4.** *Martinottiella communis*, 127-795B-19R-2, 42–43 cm. **5.** *Martinottiella communis*, 127-795B-20R-4, 41–45 cm. **6.** Dissected specimen of *Martinottiella communis*, 127-795B-22R-1, 44–48 cm. **7.** *Martinottiella communis*, 127-797B-40X-2, 35–39 cm. **8.** *Martinottiella communis*, 127-795B-15R-2, 57–61 cm. **9.** *Martinottiella communis*, 127-795B-24R-6, 17–21 cm. **10.** *Hippocrepinella variabilis*, 127-795B-15R-2, 57–61 cm. **11.** *Proteonina compressa*, 127-795B-18R-3, 44–46 cm. **12.** *Saccammina sphaerica*, 127-795B-27R-1, 114–118 cm. **13.** *Bathysiphon* sp., 127-797B-51X-5, 51–53 cm. **14.** *Plectina nipponica*, 127-797B-51X-5, 51–53 cm. **15.** *Reophax* sp., 127-795B-18R-1, 48–50 cm. **16.** *Reophax* sp., 127-797B-51X-5, 51–53 cm. **17a, b.** *Ammodiscus tenuis*, 127-797C-6R-1, 56–60 cm. **18a, b.** *Ammodiscus macilentus*, 127-795B-10R-5, 50–52 cm. **19.** *Ammodiscus tenuis*, 127-795B-18R-1, 48–50 cm. **20a, b, 21.** *Ammovertellina* sp., 127-797C-2R-2, 28–32 cm. **22a–c, 23a–c.** *Cribrostomoides* cf. *crassimargo*, 127-795B-18R-1, 48–50 cm. **24a, b.** *Haplophragmoides* sp., 127-795B-18R-1, 48–50 cm. **25.** *Bermudezina aminensis*, 127-795B-15R-2, 57–61 cm. **26.** *Eggrerella* sp., 127-797B-52X-6, 50–54 cm. **27a–c.** *Spirosigmoilinella compressa*, 127-795B-18R-3, 44–46 cm. **28a, b.** *Thalmannammina* cf. *parkerae*, 127-797C-2R-2, 28–32 cm. **29a, b.** *Trochammina* cf. *globigeriniformis*, 127-795B-10R-3, 50–52 cm. **30a, b.** *Ammosphaeroidina* sp., 127-795B-10R-3, 50–52 cm. **31a, b.** *Eggerella bradyi*, 127-795B-24R-2, 32–36 cm.

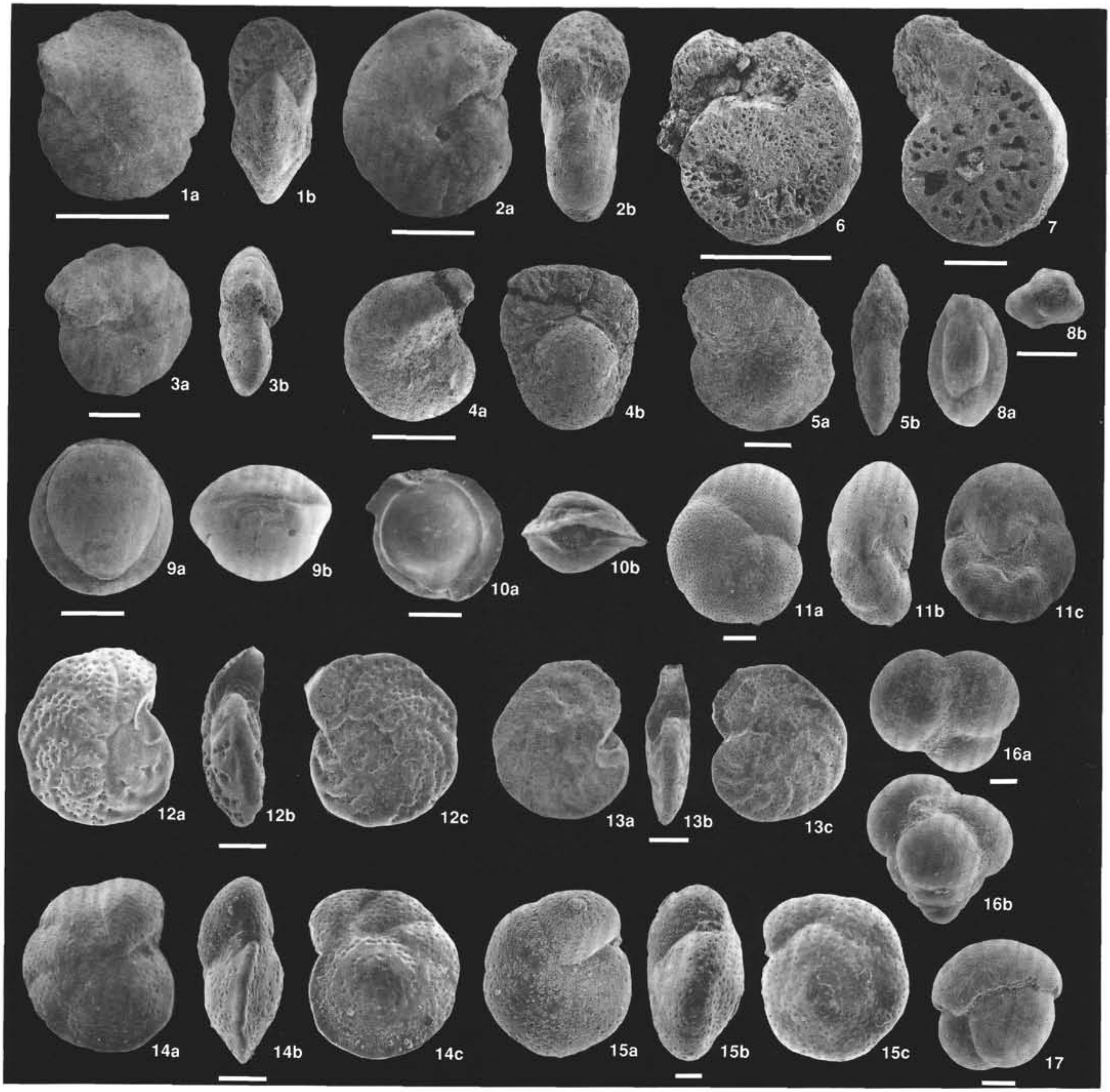

Plate 2. Scale = 100 µm. **1a, b.** *Cyclammina ezoensis,* 127-795B-12R-3, 46–50 cm. **2a, b.** *Cyclammina cancellata,* 127-797B-48X-2, 53–57 cm. **3a, b.** *Cyclammina* sp. A, 127-797C-5R-2, 76–80 cm. **4a, b.** *Cyclammina orbicularis,* 127-795B-10R-5, 50–52 cm. **5a, b.** *Cyclammina pusilla,* 127-797B-31X-3, 50–54 cm. **6.** Dissected specimen of *Cyclammina cancellata,* 127-795B-10R-5, 50–52 cm. **7.** Dissected specimen of *Cyclammina orbicularis,* 127-795B-10R-5, 50–52 cm. **8a, b.** *Quinqueloculina* sp., 127-797B-35X-4, 50–54 cm. **9a, b.** *Pyrgo* sp. 127-797B-51X-5, 51–53 cm. **10a, b.** *Pyrgo murrhina,* 127-797B-51X-5, 51–53 cm. **11a–c.** *Valvulineria masudai,* 127-797B-52X-3, 50–54 cm. **12a–c.** *Cibicidoides wuellerstorfi,* 127-797B-40X-2, 35–39 cm. **13a–c.** *Cibicidoides wuellerstorfi,* 127-797B-48X-1, 68–72 cm. **14a–c.** *Cibicidoides* sp. A, 127-797B-51X-5, 51–53 cm. **15a–c.** *Cibicidoides bradyi,* 127-797B-51X-5, 51–53 cm. **16a, b.** *Tosaia hanzawai,* 127-797B-51X-5, 51–53 cm. **17.** *Sphaeroidina japonica,* 127-797B-52X-1, 45–49 cm.

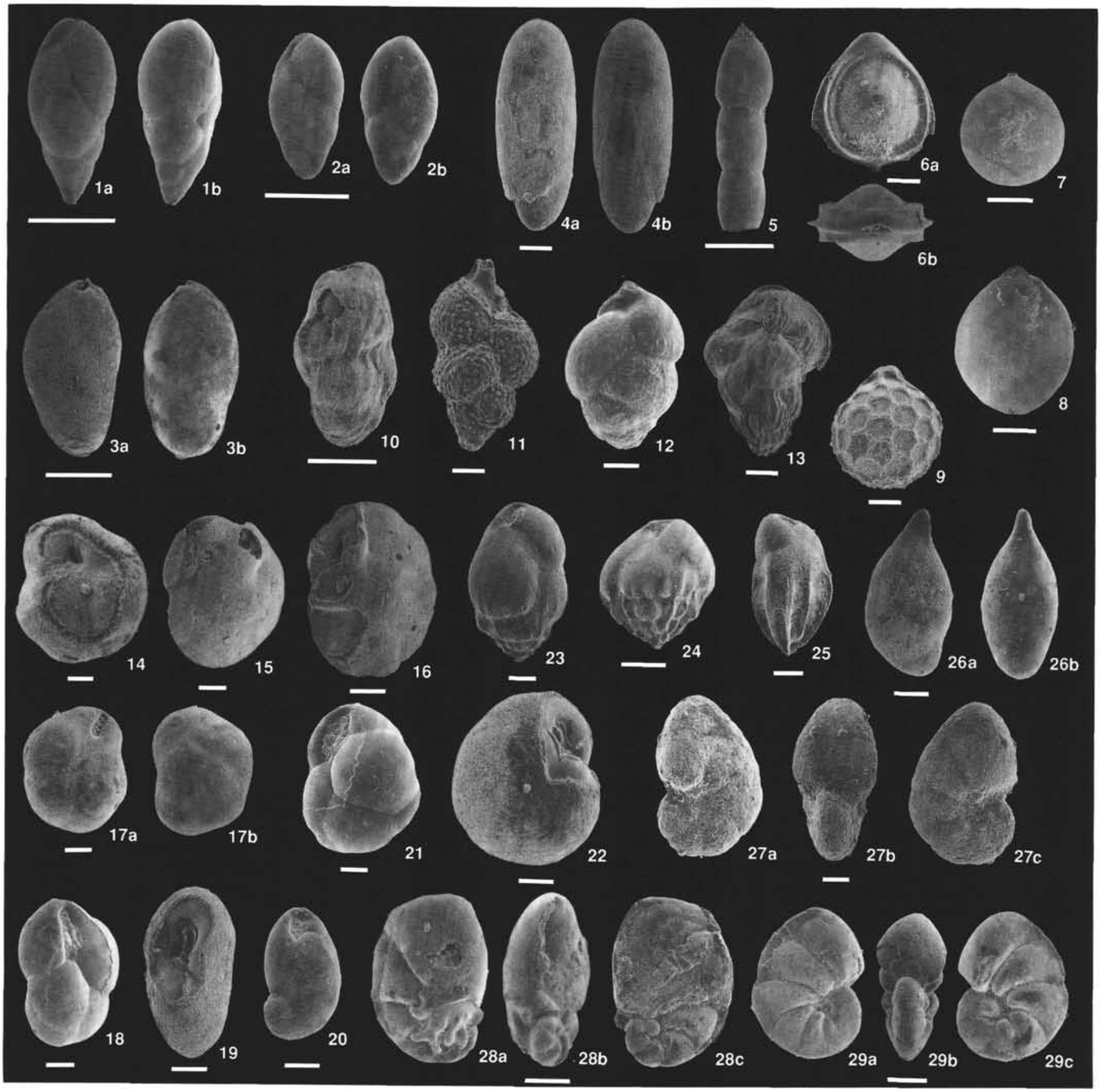

Plate 3. Scale = 100 µm. **1a, b, 2a, b.** *Globobulimina pupoides,* 127-797B-52X-3, 50–54 cm. **3a, b.** *Globobulimina perversa,* 127-797B-48X-2, 53–57 cm. **4a, b.** *Chilostomella oolina,* 127-797B-52X-3, 50–54 cm. **5.** *Dentalina* sp., 127-797B-51X-5, 51–53 cm. **6a, b.** *Fissurina orbignyana,* 127-797B-51X-3, 51–53 cm. **7.** *Oolina globosa,* 127-797B-28X-1, 51–56 cm. **8.** *Parafissurina* sp., 127-797B-51X-5, 51–53 cm. **9.** *Oolina hexagona,* 127-797B-48X-2, 53–57 cm. **10.** *Uvigerina miocenica,* 127-797B-51X-1, 51–53 cm. **11.** *Uvigerina proboscidea,* 127-797B-40X-2, 35–39 cm. **12.** *Uvigerina* cf. *modeloensis,* 127-797B-52X-3, 50–54 cm. **13.** *Trifarina* sp. 127-797B-31X-3, 50–54 cm. **14.** *Globocassidulina globosa* s.l., 127-797B-47X-1, 45–49 cm. **15.** *Islandiella* sp., 127-797B-52X-1, 45–49 cm. **16.** *Islandiella helenae,* 127-797B-31X-3, 50–54 cm. **17a, b.** *Globocassidulina globosa* s.l., 127-797B-31X-3, 50–54 cm. **18, 21.** *Globocassidulina* sp. A, 797B-52X-3, 50–54 cm. **19, 22.** *Islandiella* cf. *compressa,* 127-797B-31X-3, 50–54 cm. **20.** *Evolvocassidulina kuwanoi,* 127-797B-52X-3, 50–54 cm. **23.** *Bulimina striata,* 127-797B-52X-3, 50–54 cm. **24.** *Bulimina striata,* 127-797B-48X-2, 53–57 cm. **25.** *Bulimina rostrata,* 127-795B-29R-2, 116–120 cm. **26a, b.** *Marginulina* sp., 127-797B-51X-5, 51–53 cm. **27a–c.** *Nonionellina labradorica,* 127-797B-52X-3, 50–54 cm. **28a–c.** *Nonionella stella,* 127-797B-52X-3, 50–54 cm. **29a–c.** *Nonionella miocenica,* 127-797B-51X-3, 51–53 cm.

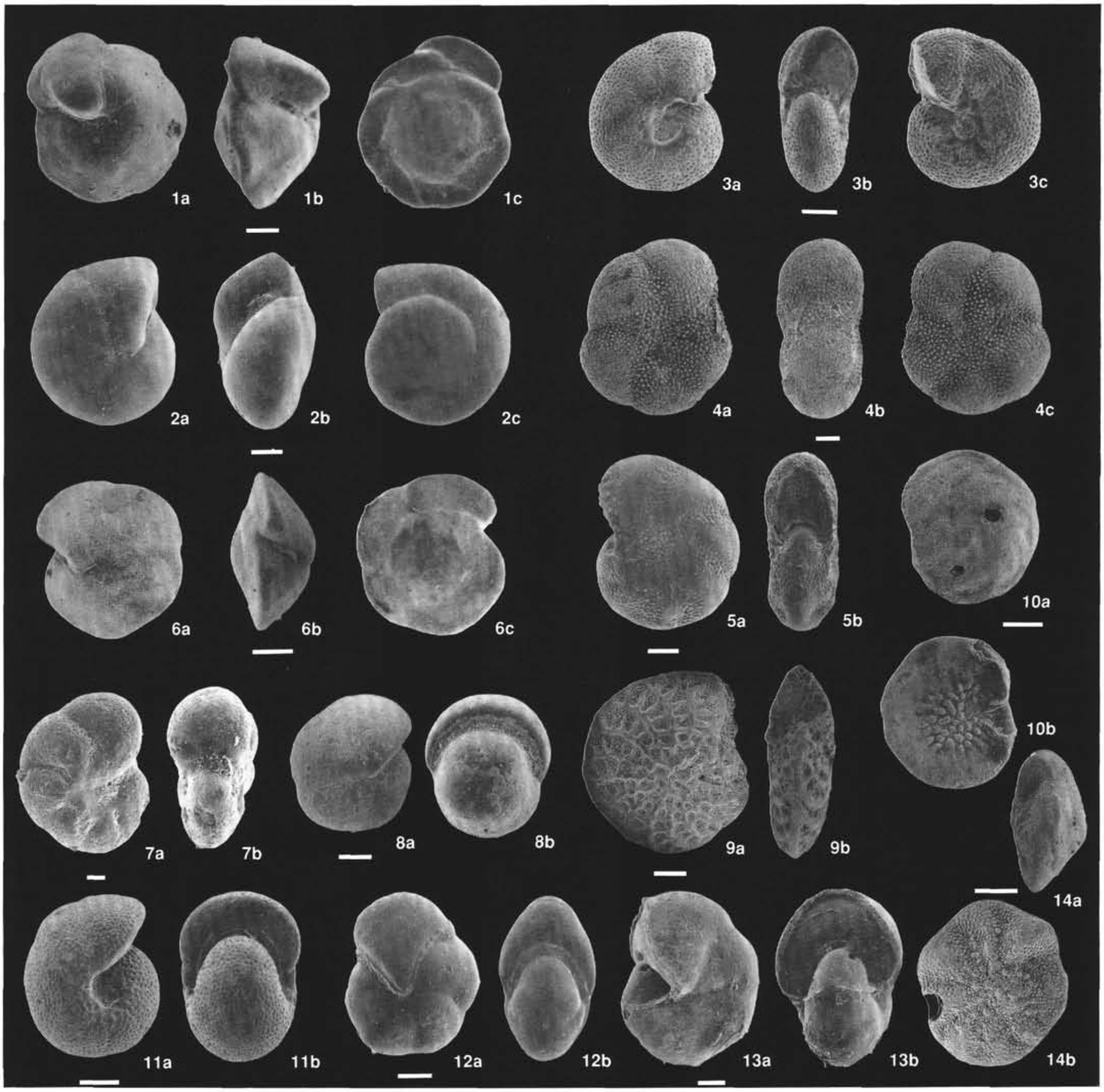

Plate 4. Scale = 100 µm. **1a–c.** *Gyroidina orbicularis,* 127-797B-51X-3, 51–53 cm. **2a–c.** *Gyroidinoides planulatus,* 127-797B-51X-5, 51–53 cm. **3a–c.** *Melonis nikobarense,* 127-797B-47X-3, 52–56 cm. **4a–c.** *Elphidium* cf. *perforatum,* 127-795B-29R-2, 116–120 cm. **5a, b.** *Elphidium subarcticum,* 127-797B-31X-3, 50–54 cm. **6a–c.** *Oridorsalis umbonatus,* 127-797B-52X-1, 45–49 cm. **7a, b.** *Astrononion* sp., 127-797B-52X-3, 50–54 cm. **8a, b.** *Pullenia bulloides,* 127-797B-52X-3, 50–54 cm. **9a, b.** *Elphidium jenseni,* 127-797B-31X-3, 50–54 cm. **10a, b.** *Glabratella subopercularis,* 127-797B-31X-3, 50–54 cm. **11a, b.** *Melonis pompilioides,* 127-797B-51X-1, 51–53 cm. **12a, b.** *Pullenia subcarinata,* 127-797B-52X-3, 50–54 cm. **13a, b.** *Pullenia salisburyi,* 127-797B-47X-3, 52–56 cm. **14a, b.** *Buccella* cf. *kuromatsunaiensis,* 127-797B-31X-3, 50–54 cm.