

Planktonic Foraminiferal Biostratigraphy of the Late Cenozoic Sedimentary Sequence, Central Honshu, Japan

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ABSTRACT

Stratigraphic changes of planktonic foraminiferal assemblages in the Boso Peninsula, the Kakegawa area, and the Takasaki area situated along the Pacific side of central Honshu, Japan have been analyzed. These land-based sections provide a valuable record of planktonic foraminiferal events which took place during the Late Cenozoic in the middle latitude region of the North Pacific. Especially, the Boso section in which foraminifera are generally abundant and well preserved with prominent planktonic forms represents the most complete stratigraphic succession in the present study. The Boso section is also suitable for constructing the paleomagnetic stratigraphy as well as the biostratigraphy, because tuff beds frequently intercalated in the sequence serve as good keys for determining the stratigraphic position of samples from separate outcrops with considerable accuracy. Thirteen planktonic foraminiferal levels on the basis of first and last occurrences and three distinct levels defined by the coiling direction shift in the genus *Pulleniatina* are useful for stratigraphic correlation of the Middle Miocene to Pleistocene sequence distributed in the regions on the western Pacific side of Japan. They may not be applicable elsewhere, although some of these events seem to be important for a time-stratigraphic correlation of widely separate localities. The magnetic polarity sequence determined by measuring detrital remanent magnetization of samples from the same section of the Boso Peninsula of the present study is interpreted on the basis of six principal levels of the planktonic foraminifera, in comparison to a combined planktonic foraminiferal biostratigraphy and magnetostratigraphy established in deep-sea cores in the equatorial Pacific covering the time span from the Magnetic Epoch 5 to the Brunhes Normal Epoch. Climatic fluctuation within the Pleistocene on the basis of the vertical changes of the planktonic foraminiferal assemblages in the Boso sequence which were dated in terms of the paleomagnetic scale shows a warming trend across the Olduvai Event. A cooling trend, denoted by the upward decrease in the abundance of warm-water fauna associated with an increased abundance of cold-water fauna and influx of sinistral coiling *Globigerina pachyderma* in varying frequency, occurs shortly before the Jaramillo Event prior to the onset of the severe cooling in the earlier part of the Brunhes Normal Epoch. This may mark the initiation of mid-latitude glaciation.

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INTRODUCTION

As the water temperature is known to influence primarily the latitudinal distribution of modern planktonic foraminiferal species, a planktonic microfossil zonation applicable to worldwide correlation in finely discriminated time intervals cannot be established until the stratigraphic ranges of species occurring in different latitudes are more completely investigated. Stratigraphic sections in the middle latitude are important, because there is an increased likelihood of finding interdigitation of sediments containing discrete faunal assemblages representing latitudinally distal zones.

The present paper covers Late Cenozoic sections in three separate areas situated along the Pacific side of central Honshu, Japan. These sections are the Boso Peninsula in Chiba Prefecture, Kakegawa area in Shizuoka Prefecture, and Takasaki area in Gunma Prefecture (Fig. 1). They are selected because: (1) the Boso section represents an almost continuous stratigraphic succession covering from the Middle Miocene to Pleistocene; (2) the Kakegawa section is one of the most intensively studied sequences in Japan both geologically and paleontologically, and the stratigraphic units established there are frequently used as the standard of reference for stratigraphic correlation of Neogene sediments on the Pacific side of Japan, and (3) the Takasaki section represents sedimentary sequences distributed in the northern Kanto region, in comparison to the Boso section which represents the southern Kanto region. These sections in three areas yield commonly planktonic foraminifera throughout and then merit detailed biostratigraphic and paleoceanographic investigations, because they are among a few available land-based sections containing faunas of temperate waters in the middle latitude region of the North Pacific.

The main purpose of the present paper is of fourfold: (1) determination of the stratigraphic ranges of planktonic foraminiferal species; (2) selection of foraminiferal events useful for correlation of Middle Miocene to Pleistocene sequences distributed on the Pacific side of central Honshu; (3) establishment of biostratigraphic zonation based on these events, and (4) interareal correlation of the biostratigraphic sequences established in three separate areas treated in the present study.

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GEOLOGIC SETTING AND MATERIAL

Three major areas were chosen for the systematic sampling to study the distribution of planktonic foraminifera during the Late Cenozoic in representative sedimentary basins of Japan. Following notes describe the localities of the samples as well as provide brief outlines of the stratigraphy of the areas treated in the present study.

1. BOSO PENINSULA

A thick series of marine sedimentary strata containing various kinds of fossils yields an almost complete record of the Late Cenozoic history in the Boso Peninsula, which is located in the southern part of the Kanto region in central Honshu, Japan (Fig. 1). There are many contributions published on the Cenozoic geology and paleontology of the peninsula since the later part of the last century. Most of the Late Cenozoic sedimentary rocks are developed to the north of the broad anticlinal zone, the so-called "Tanzawa-Mineoka Zone" (Koike, 1952), which extends from Hota in the west to Amatsu in the east with a general trend of WNW-ESE direction in the southern part of the peninsula. The sediments are classified into the Sakuma, Toyo-oka, Kazusa and Shimosa Groups in order of decreasing age. The Sakuma Group (Otuka and Koike, 1949) comprising the Nakahara and the superjacent Amatsu Formations overlies with unconformity the Hota Group (Otuka and Koike, *op. cit.*) which was assigned to the Oligocene based upon the occurrence of such mollusks as *Portlandia watasei* (Kanehara), *Periploma besshoensis* (Yokoyama) and others (Hatai and Koike, 1957). According to Nakagawa (1962), the Nakahara Formation can be correlated with the Kinone Formation in the eastern part of the peninsula. The Sakuma Group is locally unconformably overlain by the Toyo-oka Group which comprises the Kiyosumi and the overlying Anno Formations. In the eastern part of the peninsula where the sections discussed in the present study are located, however, the Kiyosumi Formation conformably overlies the Amatsu Formation (Kimura, 1974). The Anno Formation is overlain unconformably by the Kurotaki Formation which forms the basal part of the Kazusa Group. The unconformity is known as the "Kurotaki Unconformity" (Koike, 1952). The Kazusa Group (Ida *et al.*, 1956) is distributed over

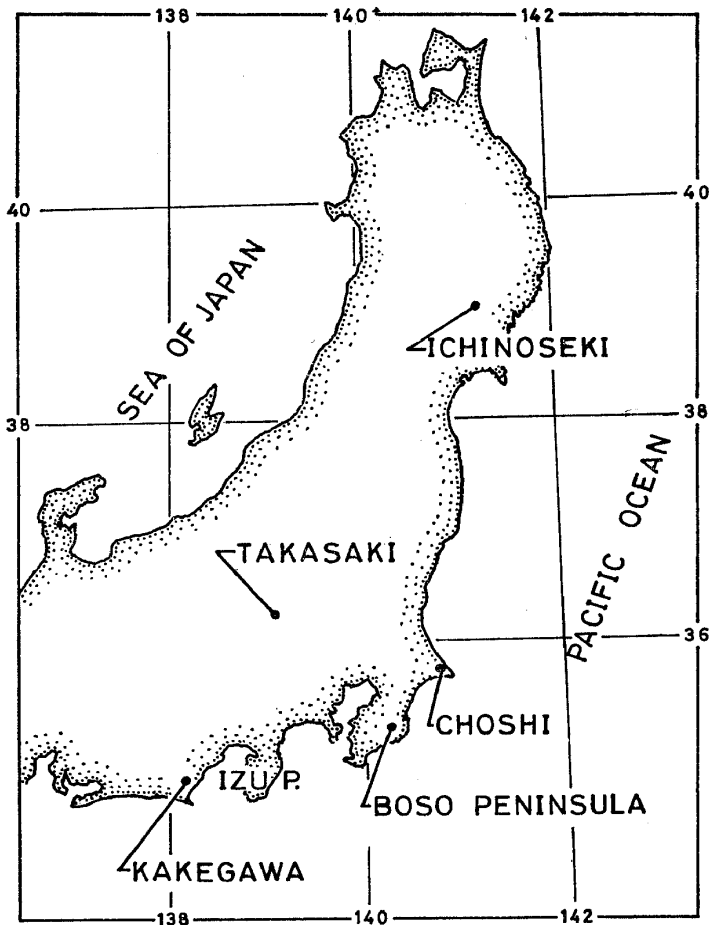


Fig. 1. Map of Japan showing the areas referred in the text.

the northern part of the peninsula, forming a homoclinal structure which dips to the north. The Late Cenozoic sediments on the peninsula are suitable for a paleontological study because many pyroclastic layers intercalated in the sequence serve as good keys for determining the stratigraphic position of samples from separate outcrops. Especially, a detailed lithostratigraphic study on the Kazusa Group by means of the pyroclastic layers was made by Mitsunashi *et al.* (1959) and the stratigraphic sequence of this region was summarized in the geologic map sheet "Futtsu-Otaki" (Mitsunashi *et al.*, 1961). This sheet almost covers all the area treated in the present study, where the Kazusa Group is distributed. Based upon a tephrochronological study, it became clear that the lower part of the Kazusa Group converges and thins westward, but thickens eastward where it attains more than 1000 m in thickness. Thus, the lower formations of the group unconformably overlies the Toyo-oka Group in the eastern area, and the younger ones progressively overlap the Toyo-oka Group in the western area, and the Kurotaki Formation of the Kazusa Group represents the basal and/or marginal conglomeratic facies of the group (Fig. 2). Consequently, the section along the Yoro River in the central part and that along the eastern part of the peninsula present the most continuous stratigraphic sequence.

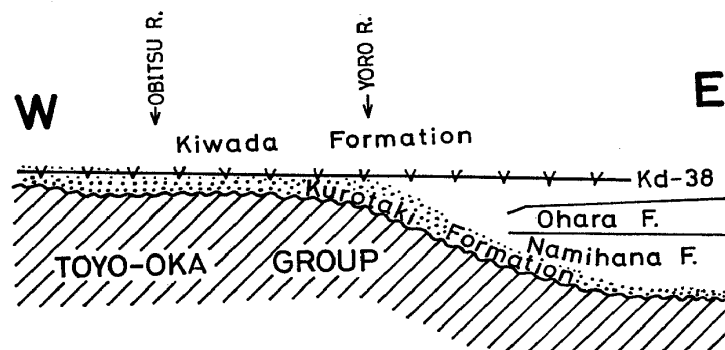


Fig. 2. Schematic cross section showing the lower part of the Kazusa Group overlying the Toyo-oka Group with unconformity (Kurotaki Unconformity) of the Boso Peninsula.

The stratigraphic sequence of the Late Cenozoic sediments is summarized as follows in descending order.

<i>Stratigraphic unit</i>	<i>Lithology</i>	<i>Thickness in meter</i>
Superjacent unit: Shimosa Group		
Kasamori Formation	Silty fine-grained sandstone and sandy siltstone.	150
Mandano Formation	Sandstone and pebbly-to-cobbly conglomerate, in many places cross-bedded.	40
Chonan Formation	Alternation of sandstone and siltstone intercalated with layers of tuff.	75
Kakinokidai Formation	Fine-grained sandstone and sandy siltstone intercalated with layers of tuff.	75
Kokumoto Formation	Alternation of sandy siltstone and sandstone intercalated with layers of tuff.	340
Umegase Formation	Sandstone intercalated with layers of siltstone and tuff. Middle part with granular conglomerate.	520
Otadai Formation	Alternation of siltstone and sandstone intercalated with layers of tuff.	420
Kiwada Formation	Massive bluish gray siltstone intercalated with layers of sandstone and tuff.	770
Ohara Formation	Alternation of siltstone and sandstone intercalated with layers of tuff.	160
Namihana Formation	Siltstone and sandstone intercalated with layers of tuff. Lower part dominated by sandstone.	420
Kurotaki Formation	Conglomerate and tuffaceous sandstone intercalated with thin layers of siltstone.	30
..... Unconformity		
Anno Formation	Alternation of tuffaceous sandstone and siltstone intercalated many tuff layers. Uppermost part dominated by tuffaceous sandstone.	600
Kiyosumi Formation	Yellowish brown medium- to fine-grained sandstone with intercalated layers of siltstone and tuff. Lower part dominated by tuffaceous sandstone.	500
Amatsu Formation	The dark bluish-gray massive siltstone intercalated with tuff layers in the lower part, whereas alternation of tuffaceous sandstone and siltstone with interbedded layers of tuff in the upper part. Uppermost part dominated by scoria, pumice and tuffaceous sandstone.	1050
Kinone Formation	Dark-gray siltstone with sandstone and tuff layers and with conglomerate in the basal part.	150
..... Unconformity		
Subjacent unit: Hota Group (Oligocene ?)		

The Nakahara Formation, which is a correlative unit in the west with the Kinone Formation, consists of shallow marine sediments bearing larger foraminifera such as *Nephrolepidina*, *Miogypsina*, and *Amphistegina*. According to Saito (1963), the planktonic foraminiferal assemblage from the Nakahara Formation is judged to be correlative with the *Globigerinatella insueta*/*Globigerinoides bisphericus* Subzone, although *Globigerinatella insueta* is lacking. The Amatsu Formation contains marine molluscan fauna such as

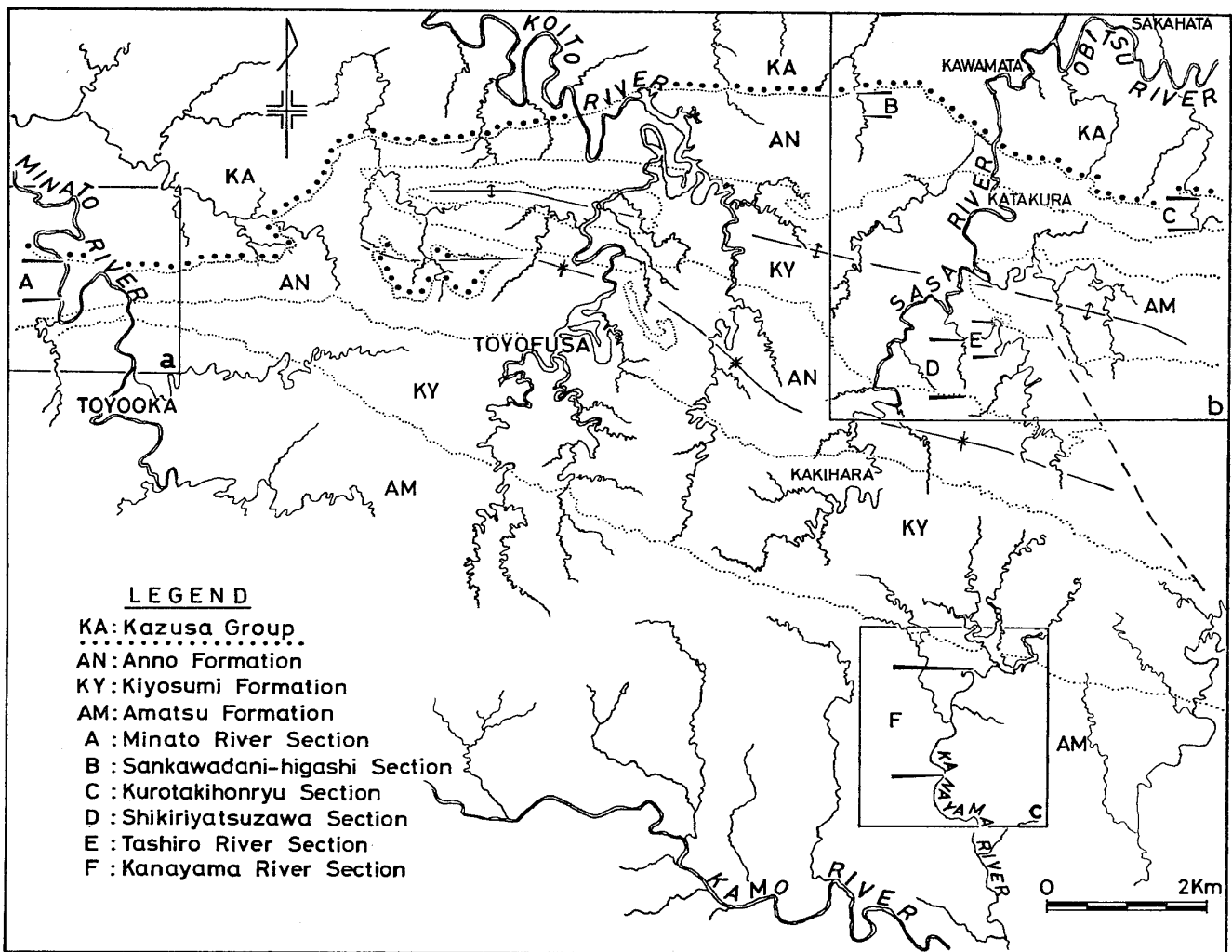


Fig. 4. Geologic map of the central part of the Boso Peninsula. Details of the enclosed areas (a), (b) and (c) are shown in Figs. 5(a), 5(b) and 5(c), respectively.

the Kazusa Group have been established for correlation of both surface and subsurface sections for natural gas exploration (Ishiwada, 1958; Ishiwada *et al.*, 1962). Ishiwada (1964) attempted to make paleontological interpretations of the biofacies of the Kazusa Group based upon a comparative study with the Recent benthonic foraminiferal assemblages in the seas off the Pacific coast of Japan. He also suggested that the faunal assemblages of the Kazusa Group are related to those of the Recent mixed Kuroshio-Oyashio region, ranging from the neritic to the bathyal zone. Aoki (1963, 1968), from his foraminiferal study, demonstrated that the change in the vertical sequence of the benthonic foraminiferal assemblages of the sedimentary basin indicates a regressive phase or shallowing from the lower bathyal to the middle or even to the upper shelf. Thus the Kazusa Group, from the previous studies, represents a series of sediments that accumulated during the course of a gradual marine regression. Many suggestions about the age of the Kazusa Group, based upon studies on various kinds of fossils and paleomagnetism, will be discussed in the later part of the present paper.

The foraminiferal samples were systematically collected from the Boso sections by the present author (Fig. 3). Fig. 4 shows six selected sections for the lower sequence which is

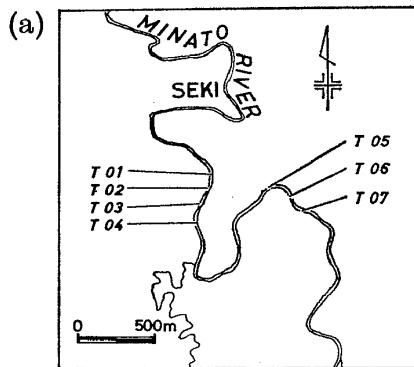
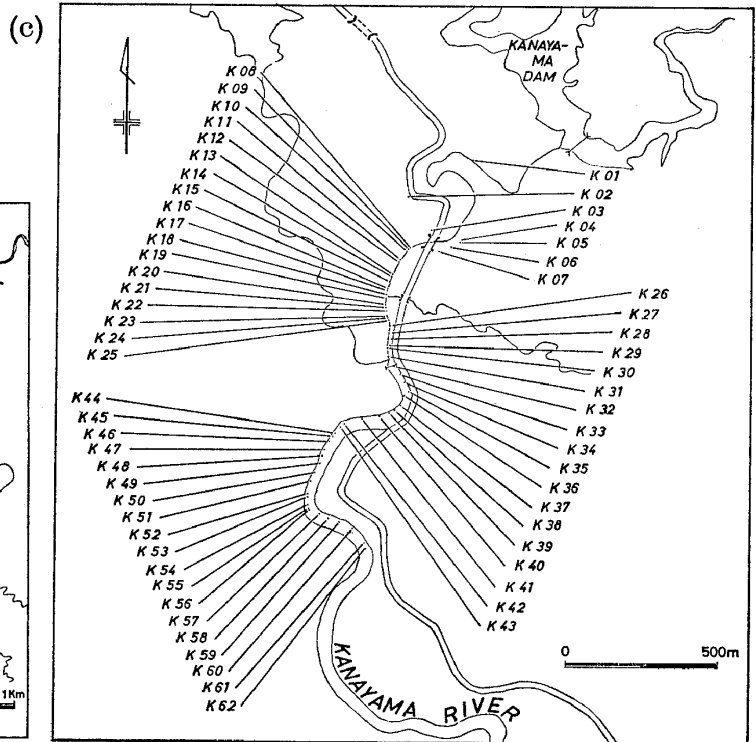
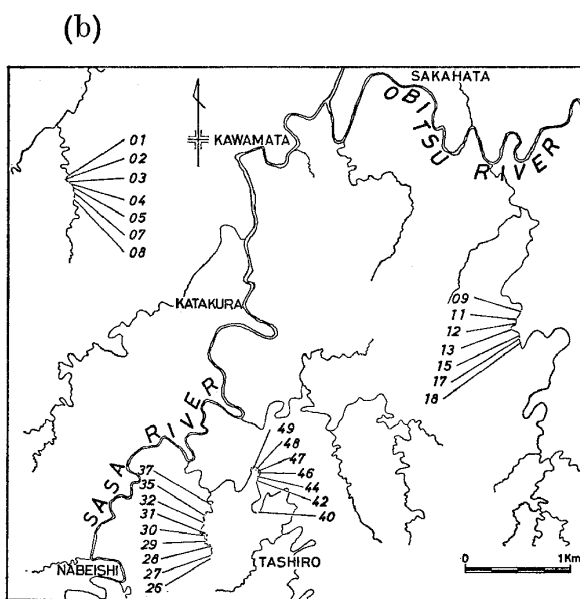


Fig. 5(a). Sample location map showing the Minato River section (Section A in Fig. 4).

Fig. 5(b) Sample location map showing the Sankawadani-higashi, Kurotaki-honryu, Shikiriya-suzawa and Tashiro River sections (Sections B, C, D and E in Fig. 4).

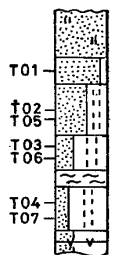
Fig. 5(c). Sample location map showing the Kanayama River section (Section F in Fig. 4).



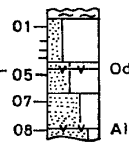
unconformably overlain by the Kazusa Group. The Kanayama River section lies along the Kanayama River in the northern part of Kamogawa City. It comprises the Kinone and the main part of the Amatsu Formations, attaining about 1200 m in thickness. The Tashiro River and the Shikiriya-suzawa sections are situated along the Tashiro River and the Shikiriya-suzawa, a tributary of the Sasa River flowing through the southern part of Katakura Town. These sections include the uppermost part of the Amatsu and the Kiyosumi Formations and attains approximately 650 m in thickness. The Kurotaki-honryu and the Sankawadani-higashi sections lie along the Kurotaki-honryu in the southern part of Sakahata Town and the Sankawadani-higashi valley in the western part of Kawamata Town, attaining approximately 400 m in thickness. The Minato River section, which includes the upper part of the Anno Formation, lies along the middle Minato River in the northern part of Toyo-oka Town, and attains about 300 m in thickness.

Fig. 6. Columnar sections indicating the stratigraphic positions of samples. The sample locations are designated on the left side column. The letters appeared on the right side column show the positions of key beds. Localities of two samples (25 and 21) from the lowermost part of the Anno Formation are shown in Fig. 7. →

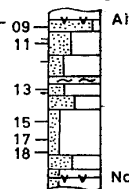
Minato Section



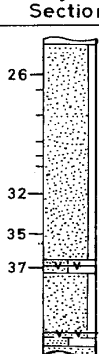
Sankawadani-higashi Section



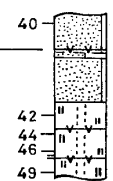
Kurotakihonryu Section



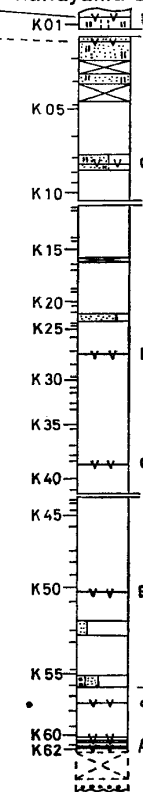
Shikiryatsuzawa Section












Tashiro Section

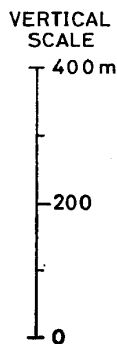


Kanayama Section



LEGEND

-  siltstone
-  sandy siltstone
-  sandstone
-  alternation of siltstone & sandstone
-  tuffaceous sandstone
-  conglomerate
-  intraformational deformation
-  key bed
-  fault



ANNO FORMATION

KIYOSUMI FORMATION

AMATSU FORMATION

KINONE FORMATION

TOYO-OKA GROUP

SAKUMA GROUP

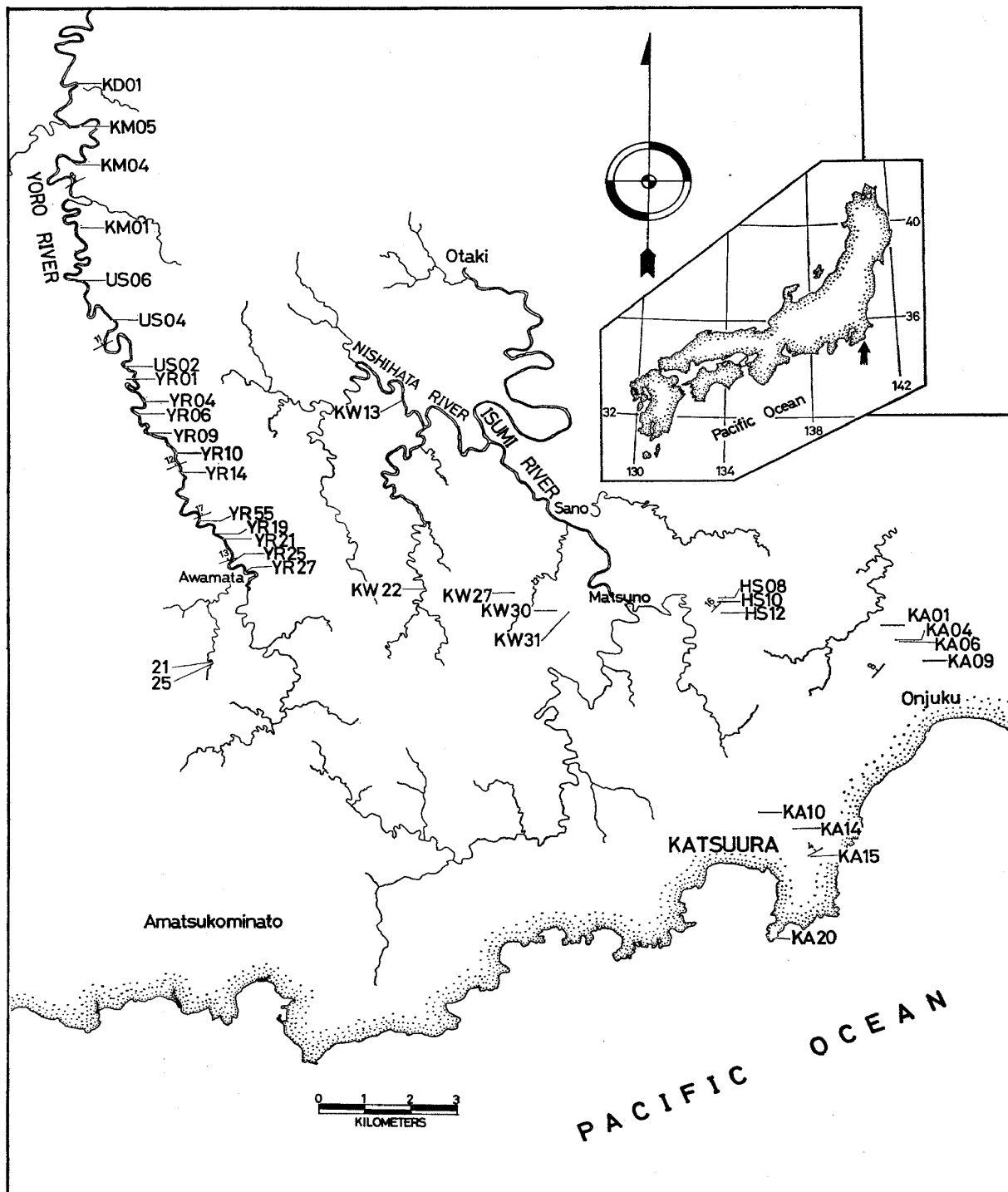


Fig. 7. Location map of samples obtained from along the Yoro River and from the eastern part of the Boso Peninsula.

Except for the Minato River section, the sections were correlated with one another on the basis of pyroclastic key beds by Kimura (1974) who carried out a paleomagnetic survey on the same sections.

The section along the Yoro River comprises the main part of the Kazusa Group which includes the stratigraphic interval from the main part of the Kiwada Formation to the

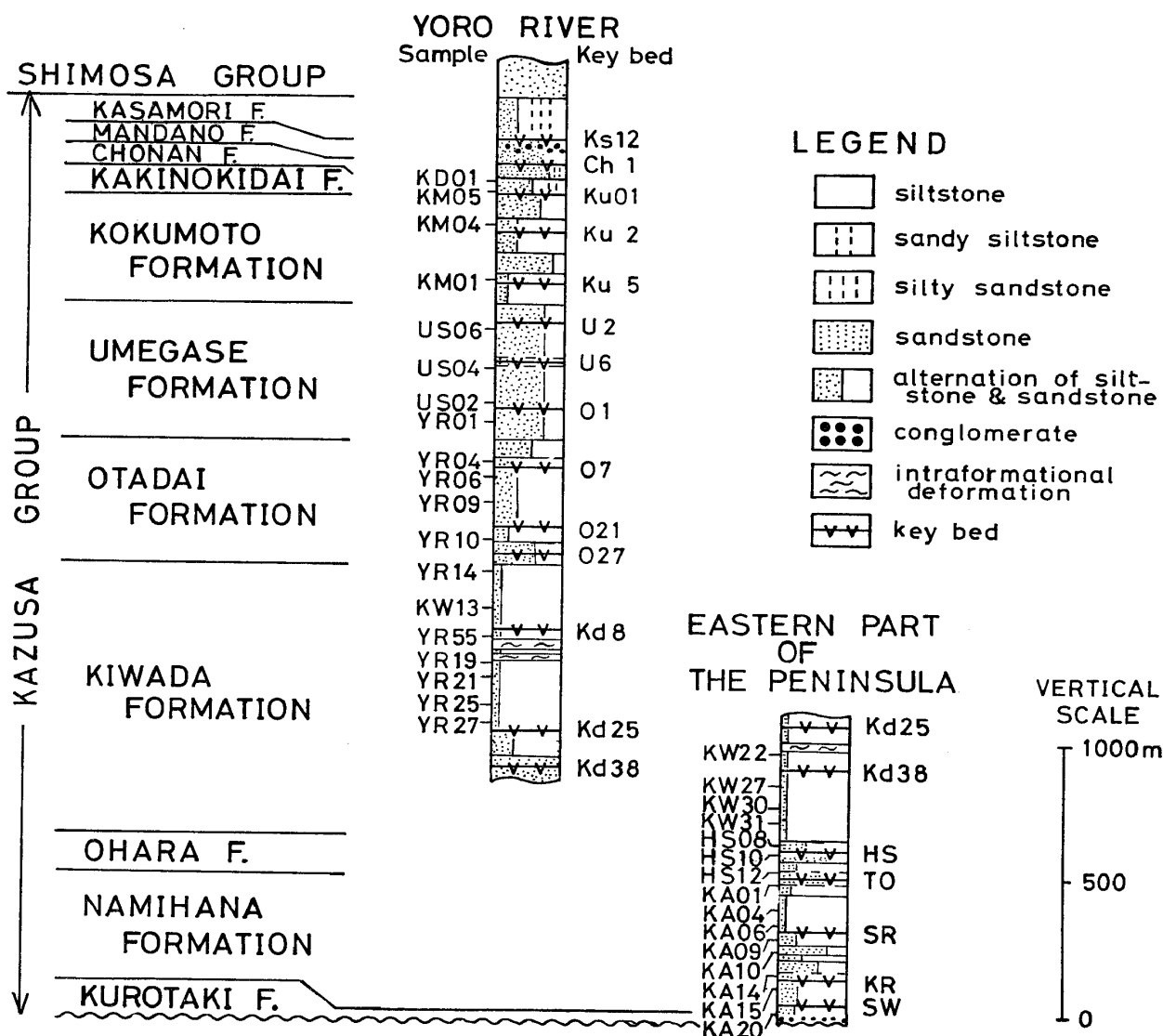


Fig. 8. Columnar sections indicating the stratigraphic positions of samples. The sample locations are designated on the left side column. The letters appeared on the right side column show the positions of key beds.

Kakinokidai Formation. The samples of the lower part of the Kazusa Group, from the Kurotaki to the lowermost part of the Kiyada Formations, were collected from the route running across the northern part of Onjuku Town and Katsuura City, because the lower part of the Kiyada and the Namihana Formations thin out along the Yoro River and in the western area of the river. These sections were correlated with one another by the pyroclastic key beds. The next younger formations of Chonan, Mandano, and Kasamori, representing the upper part of the Kazusa Group, were omitted from the present study, because no planktonic foraminifera were recovered owing to deep weathering.

Localities of the samples along the each section are shown in Figs. 5a-c and 7. Figs. 6 and 8 indicate the stratigraphic position of the samples on the respective columnar sections.

2. KAKEGAWA AREA

Late Cenozoic sediments of the Kakegawa area are well developed in the western hilly district of Shizuoka Prefecture between the lower courses of the Oi and Tenryu Rivers. The present area has attracted the interests of geologists and paleontologists. Through his detailed stratigraphic investigation on the Late Cenozoic sequence, Makiyama (1931, 1939, 1941) proposed a number of stages as a standard for Japanese Neogene based upon the molluscan fauna. The marine sequence consists of two sedimentary series, the one of early Neogene and the other of late Neogene. The older one is represented by the Mikasa Group of the Early Miocene age, equivalent to the *Globigerinita unicava* Zone through the *Globigerinatella insueta*/*Globigerinoides bisphericus* Subzone (Saito, 1960). On the other hand, the younger one is represented by the Sagara and the superjacent Kakegawa Groups. The Sagara Group, in the present area studied, exhibits a NE-SW general trend of structures, among which the Megami Anticline and the Hiki Syncline are the most prominent feature (Oda, 1971). The Megami Formation, which is unconformably overlain by the Sagara Group, is exposed from Tonokubo via Haibara to Megami as a core of the southward plunging anticline. The formation contains limestone beds, from which larger foraminifera such as *Nephrolepidina japonica* (Yabe), *N. angulosa* Provale, *Miogypsina globulina* (Michelotti), *Amphistegina radiata* (Fichtel and Moll), and other (Hanzawa, 1943; Matsumaru, 1971) were found at Nita in the northern part of the area of present study. Saito (1963) reported a planktonic foraminiferal assemblage belonging to the *G. insueta*/*G. bisphericus* Subzone from a quartzose-sandy siltstone interbedded with the limestone containing larger foraminifera. The Sagara Group is composed of the Sugegaya and the overlying Sagara Formations. It is conformably overlain by the Kakegawa Group consisting of three formations, Horinouchi, Hijikata, and Soga, in ascending order, in the northwestern limb of the Megami Anticline. The stratigraphic sequence of these units of the present area is summarized in descending order (Ujiié, 1963; Oda, 1971; Kato, 1973).

<i>Stratigraphic Unit</i>	<i>Lithology</i>	<i>Thickness in meter</i>
Superjacent unit: Ogasayama Conglomerate		
..... Unconformity		
Soga Formation	Dark bluish gray fine- to medium-grained sandstone containing biotite.	200+
Hijikata Formation	Bluish gray massive siltstone with thin sandstone layers.	600
Horinouchi Formation	Alternation of fine-grained sandstone and sandy siltstone. Lower part dominated by sandstone. Three fine-grained key tuffs (Hotta, Iozumi, and Nishihirao tuff layers) and the Tamari Mudstone Member intercalated in the middle part. The Kamiyashiro (Abina) Conglomerate and the Kiriya Mudstone Members in the basal part.	2000
Sagara Formation	Alternation of bluish gray siltstone with interbedded layers of sandstone. The Wada and the Saguchi Conglomerate Members at the uppermost part.	1200+
Sugegaya Formation	The grading from conglomerate or coarse-grained sandstone into siltstone. The psammitic layers are thicker and coarser in the lower part with cross-lamination.	500
..... Unconformity		
Subjacent unit: Megami Formation (the Mikasa Group)		

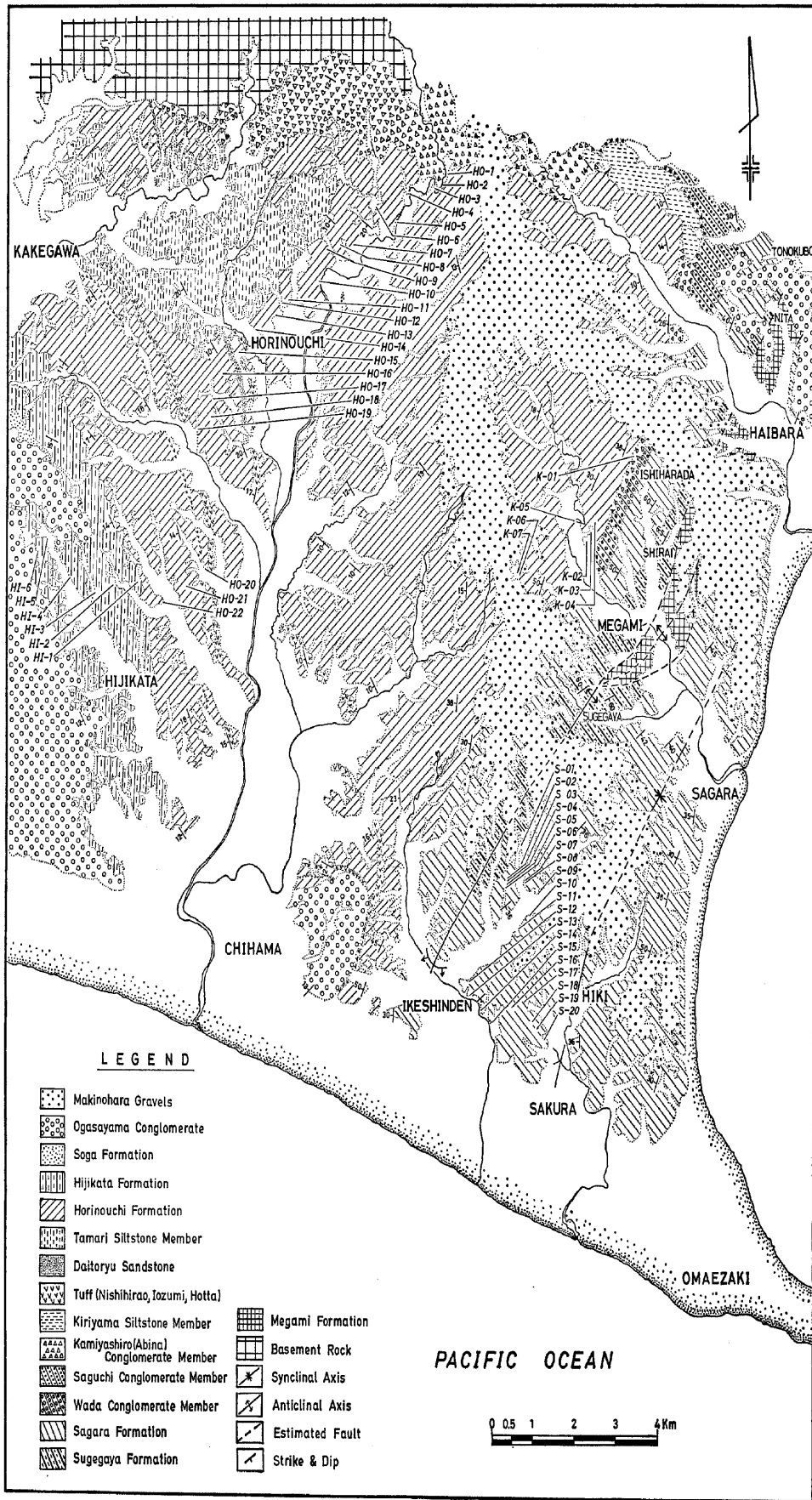


Fig. 9. Geologic map of the Kakegawa area showing the sample locations.

Saito (1963) proposed a planktonic foraminiferal zonation of the Kakegawa sequence. He assigned the Sagara and the Kakegawa Groups to the Miocene ranging from the *Globorotalia menardii menardii*/*Globigerina nepenthes* Zone to the *Sphaeroidinellopsis seminulina* Zone of Blow (1959). Recently, Oda (1971), Morozumi (1972), and Kato (1973) in their foraminiferal studies noted that the two groups should be assigned to Late Miocene through Pleistocene, ranging from the Zone N. 16 to Zone N. 22 of Blow (1969).

Foraminiferal samples from the Sagara Formation to the Hijikata Formation which were used in this study were originally collected by the present author and M. Kato. The result of planktonic foraminiferal analyses, excluding the additional samples discussed in this study, has previously been reported by Oda (1971) and Kato (1973). Planktonic foraminifera from samples of the Sagara Formation, collected along the Shirai-Ishiharada route in the western limb of the Megami Anticline, are deformed and very poorly preserved to be identified, as already pointed out in the previous paper (Oda, 1971). In addition, the faunal succession from the Sagara to the Horinouchi Formations is interrupted by the coarse-grained facies void of planktonic foraminifera (the top conglomerate member of the Sagara Formation and the basal and/or marginal conglomerate member of the Horinouchi Formation). Consequently, samples to represent the Sagara Formation were collected along a route in the northern part of Ikeshinden in the eastern limb of the anticline, although a continuous stratigraphic sequence from the Sagara to the overlying Horinouchi Formations cannot be established directly. Thus, the stratigraphic gap between the highest sample of the Sagara Formation and the base of the Horinouchi Formation is not precisely determined. Fig. 9 shows localities of the samples treated in the present study in relation to the geology of the area.

3. TAKASAKI AREA

The Neogene sediments are well developed in the southwestern hilly site of Takasaki City, Gunma Prefecture in a generally homoclinal structure dipping to the north. Recently, Takayanagi *et al.* (1976) proposed a stratigraphic classification which is easily recognizable throughout the area. According to them, the stratigraphic sequence of the Neogene sediments of the area can be summarized as follows in order of increasing age:

<i>Stratigraphic Unit</i>	<i>Lithology</i>	<i>Thickness in meter</i>
	Superjacent unit: Akima Formation	
Unconformity.....	
Itahana Formation	Alternation of fine-grained sandstone, bluish gray siltstone, and pebbly conglomerate, in many places cross-bedded.	600
Haraichi Formation	Massive dark gray siltstone intercalated with many tuff layers in the upper part. Two key beds, Kitamura (4 m-thick sandy tuff with siltstone breccia) and Haraichi Tuff (bentonitic) in the basal part.	400
Ono Formation	Gray sandy siltstone, fine- to medium-grained tuffaceous sandstone and rhyolitic lapilli tuff. Upper and lower parts of the formation dominated by siltstone and sandstone, while the middle is represented by tuff layers. Some glauconites present in some of the tuff.	350
Idozawa Formation	Relatively massive gray sandy siltstone. Upper part intercalated with granular conglomerate and medium-grained sandstone, containing the larger foraminifera,	

	<i>Nephrolepidina</i> and <i>Miogypsina</i> .	375
Nukabe Formation	Thin-bedded alternation of medium-grained sandstone and siltstone. Kanohara Conglomerate Member, boulder to pebbly conglomerate, at the base.	450
.....Unconformity or fault.....		
Subjacent unit: Green schists, granites, and other Paleozoic and Mesozoic sediments.		

Saito (1963) recognized five foraminiferal zones on the basis of concurrent ranges of age-diagnostic species in the Takasaki sequence. These are, in ascending order, the *Globigerinatella insueta*/*Globigerinoides bisphericus* Subzone, *Globotalia fohsi barisanensis* Zone, *Globotalia fohsi fohsi* Zone, and *Globotalia bykovae* Zone. He noted that the last-named zone which was established on the basis of planktonic foraminifera from the upper part of the Ono Formation extending upward into the Itahana Formation is stratigraphically equivalent to the *Globotalia fohsi lobata* Zone, *Globotalia fohsi robusta* Zone, and *Globotalia mayeri*/*Globotalia linguaensis* Subzone established by Blow (1959) in Venezuela. Most recently, Takayanagi *et al.* (1976) proposed four zones based upon three kinds (planktonic foraminifera, Radiolaria, and calcareous nannoplankton) of microfossils occurring in the sequence ranging from the Early to Middle Miocene in age. They also suggested that the present sequence represents one cycle of sedimentation from the Idozawa to the Itahana Formations on the basis of biofacies changes.

The samples treated in the present study are the same as those of the previous report (Takayanagi *et al.*, 1976). Locations of the sections, and samples are shown on the geologic map (Fig. 10).

FIELD AND LABORATORY PROCEDURES

Each spot sample for the present study was collected from an interval of 10 cm in a stratigraphic section. Stratigraphic intervals between samples may vary, depending on the condition of outcrops, the suitability of materials for extracting planktonic foraminifera, and the importance of faunistic boundary. Only finer-grained layers were generally sampled from all formations in the present area.

In the laboratory each sample weighing 200 gr. was disaggregated with the use of sodium sulphate, wet-sieved on 200 mesh (74 μ opening) screen and oven dried at 120°C. The Naphtha method described by Maiya and Inoue (1973) was applied to very hard rock samples. Addition of sodium hexametaphosphate during a disaggregation process, however, must be done with extra care because the solution of sodium hexametaphosphate dissolves planktonic foraminiferal shells according to our experiment (Oda *et al.*, 1975). After the maceration, each sample was divided into a suitable volume depending upon the concentration of planktonic foraminifera. In many cases, 200-odd specimens of planktonic forms greater than 125 μ were picked up with a binocular microscope from an aliquot part.

BIOSTRATIGRAPHY

1. STRATIGRAPHIC DISTRIBUTION OF PLANKTONIC FORAMINIFERA

Stratigraphic distributions of planktonic foraminifera in the Boso, Kakegawa, and Takasaki areas are shown in Tables 1, 2, and 3, with indications of their relative abundance. Samples are arranged from left to right in order of decreasing age in each stratigraphic section. The abundance of each taxon is shown by a letter symbol as follow:

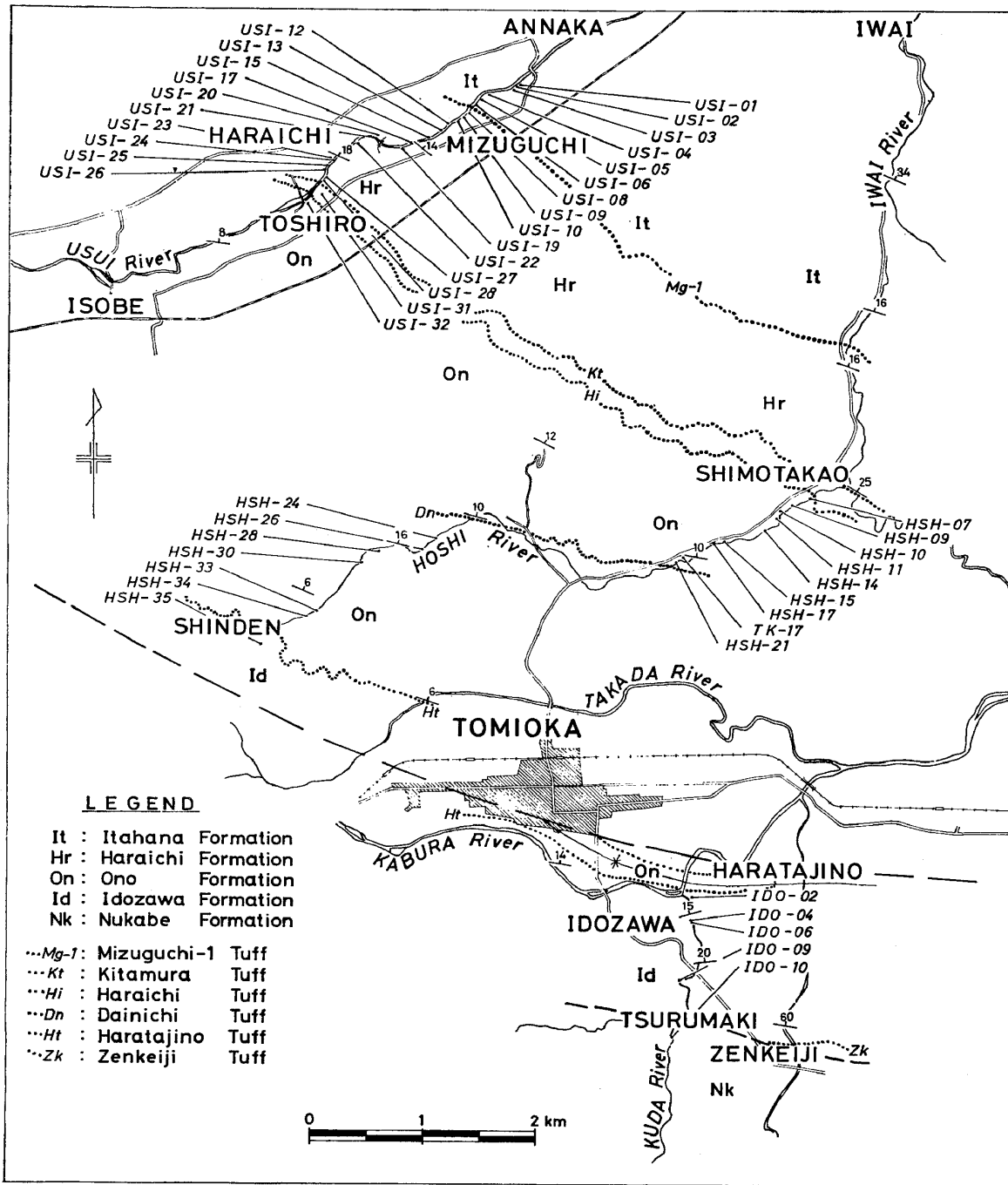


Fig. 10. Geologic map of the Takasaki area showing the sample locations (after Takayanagi *et al.*, 1976).

Relative abundance	Percent
V (Very Rare)	<1 %
R (Rare)	1-2 %
F (Few)	2-4 %
C (Common)	4-16%
A (Abundant)	≥16%

For those samples which are poor in foraminifera (less than 100 specimens), only the presence of foraminifera is indicated by a "+" mark.

Figs. 11, 12, 13 and 14 show the stratigraphic distribution of selected planktonic foraminiferal taxa, which were judged to have biostratigraphic significance in the Boso, Kakegawa, and Takasaki areas.

1) Boso Peninsula

The Boso sequence is the most complete, continuous stratigraphic succession among the areas studied, although there is one horizon of a stratigraphic break. Of the total 134 samples treated here, 125 samples were thoroughly analysed for their planktonic foraminiferal fauna. Throughout the Sakuma and the overlying Toyo-oka Groups, planktonic foraminifera are generally common and are well preserved, except for the Kinone Formation, the middle part of the Amatsu Formation, and the lower part of the Kiyosumi Formation. Fig. 11 shows stratigraphic distribution of the selected planktonic foraminifera within a sequence from the Kinone to the Anno Formations of the peninsula.

In the Kinone and the lower part of the Amatsu Formations, *Globigerinita glutinata* predominates, and such forms as *Globigerina woodi*, *Globigerinoides obliquus*, *G. quadrilobatus* (s. l.), *Globoquadrina dehiscens* (s. l.), *Sphaeroidinellopsis seminulina*, *Globorotalia birnageae*, *G. peripheroronda* and *G. quinifalcata* occur less dominantly. The Kinone Formation yielded *Globigerinoides sicanius* and *Globigerinatella* cf. *insueta*. *Orbulina suturalis* first occurs in the lowermost part of the Amatsu Formation. The lower part of the Amatsu Formation is represented by the first occurrence of *Globorotalia peripheroacuta* which is shortly succeeded by the first occurrence of *Globorotalia* cf. *praefohsi*. At the same level where *G.* cf. *praefohsi* first occurs, *Globorotalia* cf. *miozea conoidea* appears for the first time and *Globorotalia peripheroronda* makes its last occurrence.

Within a sequence from the middle part to the lower half of the upper part of the Amatsu Formation, the abundance of planktonic foraminifera decreases gradually upwards. *Globigerinita glutinata*, *Globigerinoides quadrilobatus* (s. l.), *Globoquadrina dehiscens* (s. l.), *Sphaeroidinellopsis seminulina* are more common species than the rest in this interval. *Globigerina nepenthes* makes its first occurrence in the lower part of the interval. The middle part of the Amatsu Formation is characterized by the concurrence of *Globigerina nepenthes* and *Globorotalia siakensis*. After the last occurrence of *Globorotalia siakensis*, *Globoquadrina dehiscens* (s. l.) predominates but distinctly becomes less abundant upwards. The highest occurrences of *Globoquadrina dehiscens* (s. l.) and *Globorotalia linguaensis* are in the upper part of the Amatsu Formation.

Within a sequence encompassing the upper part of the Amatsu, the Kiyosumi and the Anno Formations, planktonic foraminifera are found commonly again except for the lower part of the Kiyosumi Formation where sandy facies prevails. Throughout the sequence, *Globigerinita glutinata* still dominates, and *Globigerina decoraperta*, *G. falconensis*, *G. pachyderma*, *Globigerinoides obliquus*, *G. quadrilobatus* (s. l.), *Orbulina* spp., *Sphaeroidinellopsis seminulina*, *S. subdehiscens* are the next dominant species. *Globorotalia tumida plesiotumida* first occurs in the upper part of the Amatsu Formation and *Pulleniatina primalis* in the uppermost part. *Globigerina nepenthes* is commonly found in the upper part of the Amatsu Formation and gradually becomes less abundant upwards. *Globigerinoides extremus*, *Globorotalia margaritae*, *G. humerosa* and *G. tumida tumida* first occur in the middle part of the Kiyosumi Formation. *Globigerina nepenthes* has its last occurrence in the lower part of the Anno Formation. *Globorotalia crassaformis* first appears in the middle part of the Anno Formation and co-exists with *Globorotalia margaritae* for a short stratigraphic interval.

Successively, *Sphaeroidinella dehiscens* first occurs in the upper part of the Anno Formation, which commonly contains *Globigerinoides elongatus* and *G. ruber*. *Globorotalia miozea conoidea* makes its last occurrence in the uppermost part of the Anno Formation.

Fossil planktonic foraminifera are generally abundant in the interval corresponding to the Kazusa Group and well preserved except for the lowermost part of the sequence (Kurotaki Formation). Throughout the sequence, *Globorotalia inflata* and *Globigerina pachyderma* predominate, and such forms as *Globigerina bulloides*, *G. falconensis*, *Globigerinoides quadrilobatus* (s. l.), *G. ruber*, *Globoquadrina dutertrei*, *Orbulina suturalis*, *O. universa*, *Pulleniatina obliquiloculata*, *Globorotalia crassaformis*, *G. tosaensis*, and *G. truncatulinoides* are also present less abundantly. *Sphaeroidinella dehiscens* and *Globorotalia tumida tumida* are found commonly in the lower part of the sequence, while *Globigerina quinqueloba* and sinistral coiling forms of *Globigerina pachyderma* in the upper part. In addition, such forms as *Globigerina decoraperta*, *Globigerinoides conglobatus*, *G. obliquus*, *G. tenellus*, *Globorotalia cultrata*, and *G. scitula scitula* are found in some horizons, but they are rare and occur sporadically.

Fig. 12 shows the stratigraphic distribution of the selected planktonic foraminifera and the direction of coiling in the genus *Pulleniatina* in the Kazusa Group. From the basal part of the Kurotaki Formation, *Sphaeroidinella dehiscens*, *Globorotalia crassaformis* and *G. inflata* are distinguished. *Globorotalia tosaensis* occurs in the middle part of the Namihana Formation and continues its presence upwards into the Kakinokidai Formation. *Globorotalia truncatulinoides* makes its first occurrence in the middle part of the Ohara Formation. The highest occurrence of *Sphaeroidinella dehiscens* is in the middle part of the Umegase Formation.

Pulleniatina shows dominantly a sinistral coiling from the uppermost part of the Amatsu Formation to the lower part of the Anno Formation, although it is rare. The coiling change of *Pulleniatina* from sinistral below to dextral above is observed in the middle part of the Anno Formation and is succeeded by additional coiling changes in the higher part of the sequence. Within the sequence equivalent to the Kazusa Group, *Pulleniatina* is still rare at the basal part, but becomes abundant upwards. Dextral coiling specimens of *Pulleniatina* are dominant in the lowermost part of the sequence, but they change abruptly to sinistral-coiling in the middle part of the Namihana Formation. At the horizon of the Kd-38 key-bed, which is in the lower part of the Kiwada Formation, a rapid change of coiling from sinistral to dextral in *Pulleniatina* is observed. Above this level dextral forms occur predominantly for the remainder of its range, although sinistrally coiled forms occur in low and varying frequencies in some horizons.

2) Kakegawa Area

A total of 53 samples, including 35 samples that were initially investigated by the present author (1971) and Kato (1973), are incorporated in the present study. Within the sequence from the Sagara to the lowermost part of the Kakegawa Groups planktonic foraminifera are common, but they are relatively poorly preserved in the lower part of the sequence. Furthermore, no planktonic foraminifera are present in the Sugegaya Formation and near the boundary between the Sagara and Horinouchi Formations owing to the prevalence of conglomeratic and sandy facies. *Globigerina decoraperta*, *G. falconensis*, *G. nepenthes*, *G. pachyderma*, *Globigerinoides quadrilobatus* (s. l.), *G. obliquus*, *Globigerinita glutinata*, *Orbulina universa*, *Sphaeroidinellopsis seminulina* and *S. subdehiscens* are commonly found throughout the sequence. In the main part of the Kakegawa Group, *Globigerina falconensis* and *Globigerinita glutinata* dominate and *Globigerina bulloides*, *G. quinqueloba*,

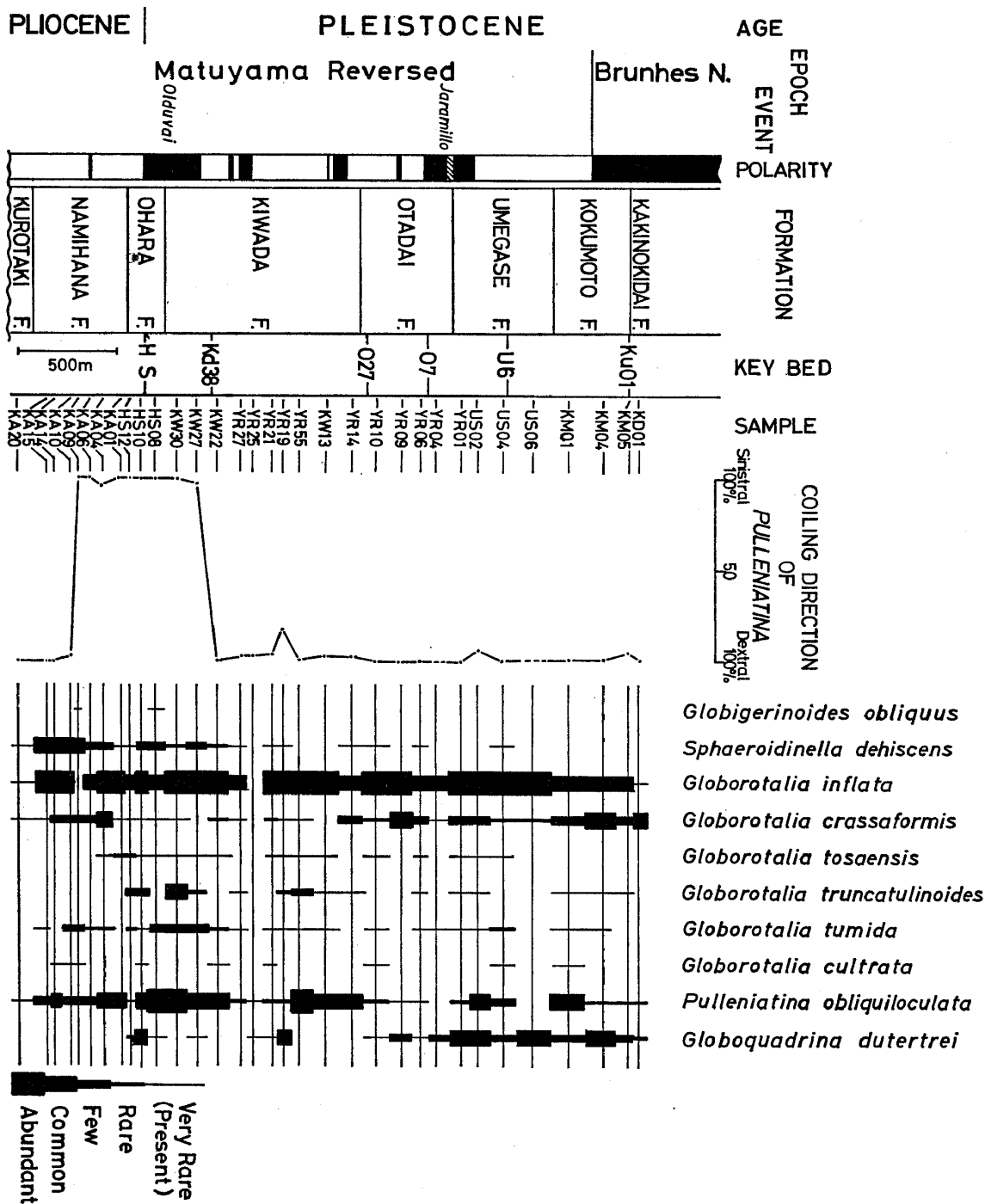


Fig. 12. Stratigraphic distribution of selected planktonic foraminiferal species and coiling direction of the genus *Pulleniatina* in the Kazusa Group of the Boso Peninsula. The magnetic polarity measured in the same stratigraphic unit is shown on the left side column. Age interpretation of the polarity appeared in the figure is explained in the text pages 41-42.

Globorotalia crassaformis and *G. inflata* are present less commonly (vide Table 2 of Kato, 1973).

Fig. 13 shows the stratigraphic position of the samples studied on a composite geologic column and the stratigraphic distribution of selected planktonic foraminiferal taxa in the

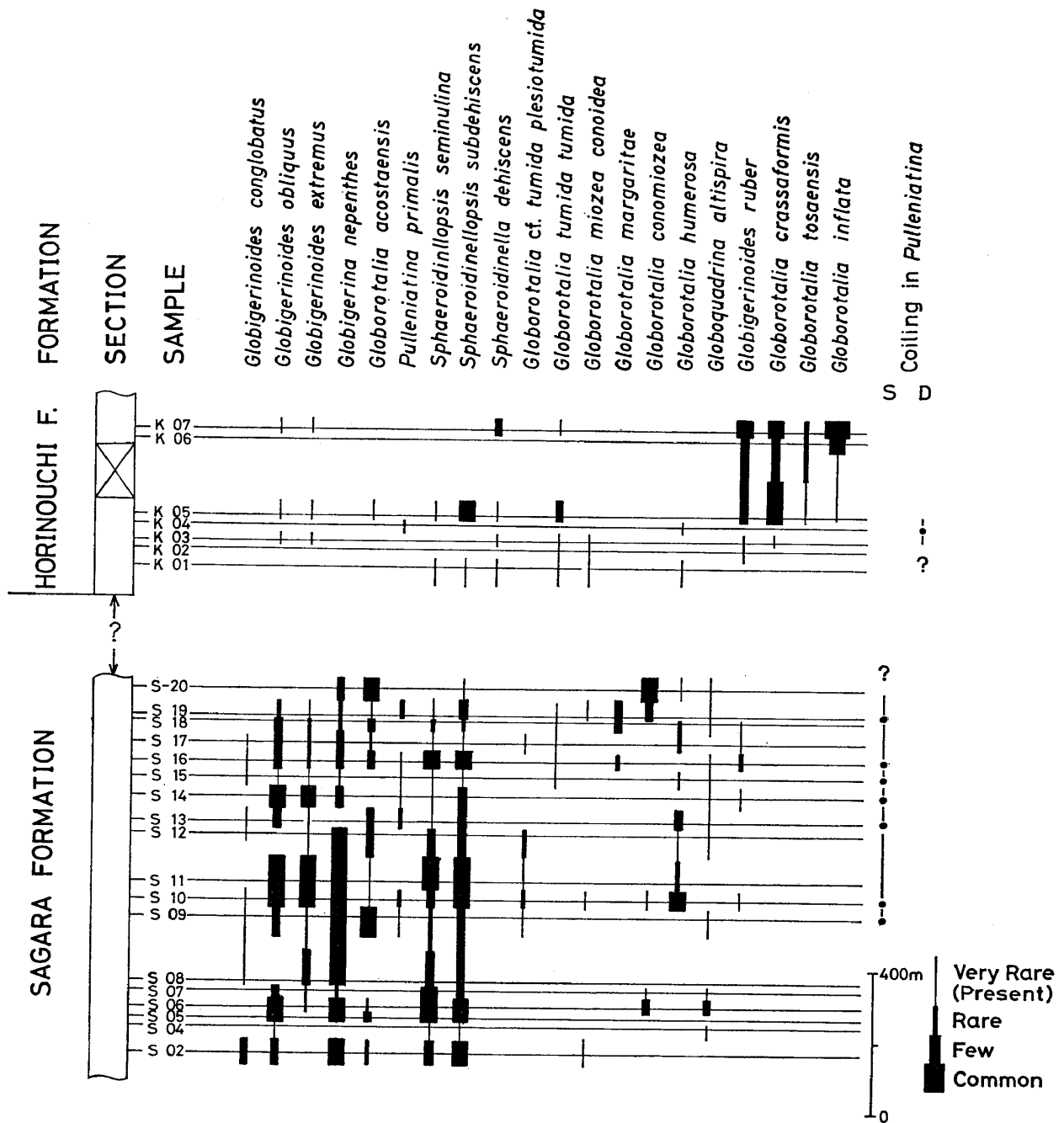


Fig. 13. Stratigraphic distribution of selected planktonic foraminiferal species and coiling direction of the genus *Pulleniatina* in the Sagara and the Horinouchi Formations of the Kakegawa area. Stratigraphic positions of samples used for this study are designated on the right of columns.

Kakegawa area. *Pulleniatina primalis* first appears in the lower part of the Sagara Formation. *Globigerina nepenthes*, *Globorotalia margaritae*, *G. tumida tumida*, and *G. miozea conoidea* are found in some horizons of the Sagara Formation, but former two do not occur in the Horinouchi Formation. *Globorotalia miozea conoidea* last occurs in the lowermost part of the Horinouchi Formation. Successively, *Sphaeroidinellopsis seminulina* and *S. subdehiscens* have their last occurrences in lower part of the Horinouchi Formation where *Globorotalia tosaensis* first appears (Oda, 1971). The first occurrence of *Globorotalia*

truncatulinoides is recognized in the Hijikata Formation by Morozumi (1972) and Kato (1973). *Pulleniatina* is rare in the interval from the Sagara to the lower part of the Horinouchi Formations, but gradually becomes abundant upwards. *Pulleniatina* is predominantly sinistrally coiled in the Sagara Formation but dextrally coiled in the lower part of the Horinouchi Formation. However, the precise level of the coiling shift of *Pulleniatina* from sinistral below to dextral above within the interval from the Sagara to the Horinouchi Formations is uncertain. Successive coiling changes of *Pulleniatina* higher in the section is noted by Kato (1973).

3) Takasaki Area

Planktonic foraminifera from a total of 31 samples, including one sample (Tk-17) initially investigated by Saito (1963), were analyzed. The studied stratigraphic sequence is represented by a composite section. Planktonic foraminiferal species are generally abundant and moderately well-preserved in the lower part of the sequence, whereas, in the upper part of the sequence, planktonic assemblages are much less diversified, and more than half of the specimens are very much compressed and too poorly preserved to be specifically identified. Most recently, the result of a study of three microfossil groups (foraminifera, Radiolaria and calcareous nannofossils) from the same section was published by Takayanagi *et al.* (1976).

In the lower half of the sequence, namely the Idozawa and the lower part of the Ono Formations, *Globigerinita glutinata* predominates, and such forms as *Globigerina falconensis*, *G. praebulloides*, *G. woodi*, *Globigerinoides quadrilobatus* (*s. l.*), *G. subquadratus*, *Globoquadrina dehiscens* (*s. l.*), *G. altispira*, *Sphaeroidinellopsis seminulina*, *Globorotalia birnageae*, *G. peripheroronda*, *G. quinifalcata* occur less abundantly. Within the lower part of the upper sequence, from the upper part of the Ono Formation to the lower part of the Haraichi Formation, *Globigerinita glutinata* still dominates, and *Globigerina praebulloides*, *G. woodi*, *Globigerinoides quadrilobatus* (*s. l.*), *Orbulina* spp., and *Globoquadrina dehiscens* (*s. l.*) occur subordinately. Planktonic foraminifera gradually become less frequent upwards in the sequence from the upper part of the Haraichi to the Itahana Formations, and *Globigerina bulloides* becomes a dominant species.

Fig. 14 shows the position of the samples studied against the geologic column as well as the stratigraphic distribution of selected planktonic foraminiferal species in the Takasaki area. *Globigerinatella insueta*, *Globigerinoides sicamus*, and *Praeorbulina glomerosa* (*s. l.*) are recognized in the Idozawa Formation. *Orbulina* occurs for the first time in the basal part of the Ono Formation and coexists with the aforementioned species in the lower part. *Globorotalia peripheroacuta* is present in the middle part of the Ono Formation. In the upper part of the Ono Formation, *Globorotalia* cf. *miozea conoidea* makes its first appearance and shows predominantly a sinistral coiling. The coiling direction of this species changes from sinistral below to dextral above just below the first occurrence horizon of *Globigerina nepenthes* within the lower part of the Haraichi Formation.

2. PLANKTONIC FORAMINIFERAL EVENTS

To determine a planktonic foraminiferal event, which is useful for stratigraphic correlation, stratigraphic ranges and the evolutionary transition and initial appearance of planktonic taxa were investigated throughout the sequence of the Boso Peninsula, which represents the most complete stratigraphic succession in the present study, and were compared with those from the Kakegawa and Takasaki areas. Previous records on the stratigraphic occurrence of taxa in region outside of the present areas were also taken

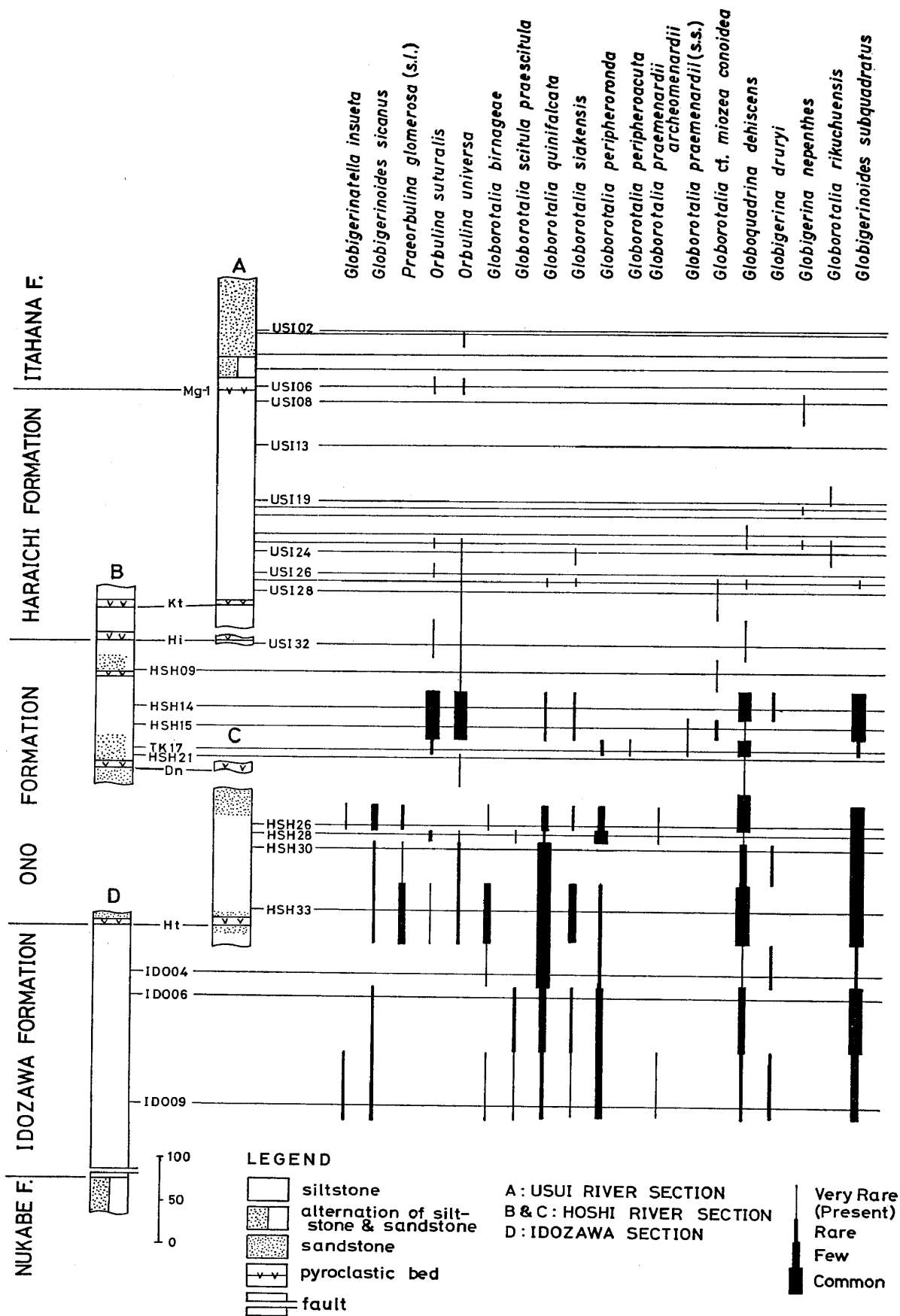


Fig. 14. Stratigraphic distribution of selected planktonic foraminiferal species in the Miocene sequence of the Takasaki area. Stratigraphic positions of samples used for this study are shown on the right of columns. Letter symbols (Mg-1, Kt, Hi, Dn and Ht) in the figure are key beds.

into consideration. Thirteen foraminiferal events were recognized on the basis of the first and last occurrences of species or subspecies which occur relatively continuously (Fig. 15). The levels of 13 foraminiferal events are useful for stratigraphic correlation of the Late Cenozoic sequence in the regions on the western Pacific side of Japan. They may not be applicable elsewhere, although some of these events seem to be important for a time-stratigraphic correlation of widely separated localities. These foraminiferal events are as follows beginning with the oldest:

1) The first appearance of the genus *Orbulina*

Since the evolutionary lineage of *Orbulina* from *Globigerinoides sicanus* through the species of *Praeorbulina* was studied in detail by Blow (1959), its evolutionary appearance has been recognized in the Miocene succession of the warm-water regions by many workers and is now regarded as one of the most reliable datum levels for long-distance stratigraphic correlation. This biostratigraphic event is recognized in the basal part of the Ono Formation in the Takasaki area and in the lowermost part of the Amatsu Formation in the Boso Peninsula. Ikebe *et al.* (1972) designated this event as the *Orbulina* datum based upon published data by previous workers. The first appearance of *Orbulina suturalis* marks the base of Zone N. 9 according to Blow (1969). In the Takasaki area, *Orbulina* coexists with *Globigerinoides sicanus* and *Praeorbulina glomerosa* (*s. l.*) in the lower part of the Ono Formation. Blow (1969) showed a similar overlapping range of these three species within the lower part of his Zone N. 9. Thus, the level of the first appearance of *Orbulina* seems to be quite reliable for long-distance correlation.

2) The first appearance of *Globorotalia peripheroacuta*

The *Globorotalia fohsi* lineage is one of the best demonstrated evolutionary series in the planktonic foraminifera. Blow and Banner (1966) critically reviewed the taxa closely related to *Globorotalia fohsi* and revised their taxonomy. According to them, *Globorotalia peripheroacuta* evolved directly from *Globorotalia peripheroronda*. Blow (1969) defined the base of his Zone N. 10 as the level marked by this phylogenetic event. The first appearance of *Globorotalia peripheroacuta* is recognized in the lower part of the Amatsu Formation in association with *Globorotalia peripheroronda*. In the Takasaki area, *Globorotalia peripheroacuta* is present only in one sample from the middle part of the Ono Formation. Ikebe *et al.* (1972) reported this foraminiferal event as the *Globorotalia fohsi* (*sensu* Bolli) Datum (the base of the *Globorotalia fohsi fohsi* Zone of Saito (1963)) but they did not reexamine the *Globorotalia fohsi* group in the light of Blow and Banner (1966)'s reclassification. According to Ikebe *et al.* (1972), the *Globorotalia fohsi* (*sensu* Bolli) Datum can be recognized in various areas both on the Pacific and Japan Sea sides, and is one of the remarkable events in the Japanese Miocene sequence.

3) The first occurrence of *Globorotalia cf. miozea conoidea*

This foraminiferal event is recognized in the lower part of the Amatsu Formation in the Boso Peninsula and in the upper part of the Ono Formation in the Takasaki area. In both areas, it is situated between the levels of the underlying *Globorotalia peripheroacuta* and the overlying *Globigerina nepenthes* events, so that this event is useful for stratigraphic correlation.

4) The first appearance of *Globigerina nepenthes*

The first appearance of *Globigerina nepenthes*, which evolved from its immediate ancestor, *Globigerina druryi*, is recognized in the middle part of the Amatsu Formation in the Boso Peninsula and in the lower part of the Haraichi Formation in the Takasaki area. Blow (1969) defined the base of his Zone N. 14 as the level marked by this phylogenetic event. A planktonic fauna of the Zone N. 14 has been recorded from the Shimoshiroiwa Formation of the Izu Peninsula by various authors (Saito, 1963; Kitamura *et al.*, 1969). However, the level of this event has not been positioned precisely because the occurrence of planktonic foraminifera is quite limited in that formation owing to the dominance of pyroclastic sediments as pointed out by Ikebe *et al.* (1972).

5) The last occurrence of *Globorotalia siakensis*

The level of the last occurrence of *Globorotalia siakensis* is considered to be a reliable datum level for biostratigraphic correlation within the warm-water provinces. Blow (1969) defined the base of the Zone N. 15 as the level immediately above the extinction level of this species. This event is recognized in the middle part of the Amatsu Formation in the Boso Peninsula, which is characterized by the occurrence of *Globigerina nepenthes*. Most of the forms called "*Globorotalia mayeri*" by Saito (1963) are likely to be referable to *Globorotalia siakensis*, because at that time he adapted the concept of "*Globorotalia mayeri*" of Bolli (1957) and Blow (1959) as pointed out by Ikebe *et al.* (1972). The latter authors designated this foraminiferal event as the *Globorotalia siakensis* (top) Datum which was tentatively placed at the top of the Shimoshiroiwa Formation of the Izu Peninsula, although this datum is difficult to be placed precisely because of the same reason as given for the subjacent foraminiferal event.

6) The first occurrence of *Globorotalia tumida plesiotumida*

Blow (1969) defined the base of his Zone N. 17 at the level of the first evolutionary appearance of *Globorotalia tumida plesiotumida*. The first occurrence of *Globorotalia tumida plesiotumida* is recognized in the upper part of the Amatsu Formation in the Boso Peninsula. But its immediate ancestor, *Globorotalia merotumida*, as described by Banner and Blow (1965b), is not detected in the sequence of the peninsula. The level of this event is older than that of the first appearance of *P. primalis* in the peninsula. *Pulleniatina primalis* first occurs in the middle part of the Zone N. 17 according to Blow (1969). Thus, the level of the initial appearance of *G. tumida plesiotumida* is assumed to be near the base of the Zone N. 17, although further study is needed to confirm this foraminiferal event in Japan.

7) The first appearance of *Pulleniatina primalis*

Recent progresses in the taxonomy of the genus *Pulleniatina* have shed much light on its evolution (Banner and Blow, 1967). According to them, *P. primalis* appears to have directly descended from *Globorotalia acostaensis* within the middle part of the Zone N. 17 of Blow (1969). Its first appearance is recognized in the Boso Peninsula in the uppermost part of the Amatsu Formation just above the key-bed "K" of Kimura (1974). It is also found in the Sagara Formation in the Kakegawa area (Oda, 1971). The level of the first appearance of *P. primalis* is useful for biostratigraphic correlation because *P. primalis* is considered to be phylogenetically the most primitive form of the genus *Pulleniatina* as pointed out by Berggren (1969) and Ikebe *et al.* (1972). The latter authors designated this foraminiferal event as the *Pulleniatina* Datum.

8) The last occurrence of *Globigerina nepenthes*

The level of the last occurrence of *Globigerina nepenthes* is considered to be useful for biostratigraphic correlation by Hays *et al.* (1969) who used this event to define their Datum IV. This event is recognized in the lower part of the Anno Formation in the Boso Peninsula. In the Kakegawa area, *G. nepenthes* occurs only in the Sagara Formation. However, the planktonic faunal record from the upper part of the Sagara to the base of the overlying Horinouchi Formations is not available for the present study. Thus, this foraminiferal event can not be positioned precisely in the Kakegawa area, although it lies presumably in the uppermost part of the Sagara Formation.

9) The last occurrence of *Globorotalia margaritae*

Globorotalia margaritae was originally described from the Miocene of Venezuela. Later, in a new Pliocene zonation proposed by Bolli (1970) on the basis of DSDP cores from the Central Atlantic and Caribbean, the *G. margaritae* Zone, defined as a total-range zone, is considered to be entirely of Pliocene age. The level of the last occurrence of *G. margaritae* has been considered to be a useful biostratigraphic level by Hays *et al.* (1969, their Datum VI), Berggren (1973), Cita (1973) and others. This foraminiferal event is recognized in the middle part of the Anno Formation in the Boso Peninsula. In the Kakegawa area, *G. margaritae* sporadically occurs in the Sagara Formation, but this event is difficult to be placed precisely on the stratigraphic sequence because of the same reason as mentioned for the subjacent foraminiferal event. Further study is needed to improve the stratigraphic position of this foraminiferal event in the Kakegawa area.

10) The last occurrence of *Globorotalia miozea conoidea*

This foraminiferal event is recognized in the uppermost part of the Anno Formation in the Boso Peninsula and in the lower part of the Horinouchi Formation in the Kakegawa area. Oda (1971) recorded the last occurrence of the genus *Sphaeroidinellopsis* in the lower part of the Horinouchi Formation, whereas this foraminiferal event is slightly older than the last occurrence of *Sphaeroidinellopsis* spp. Olsson (1971) showed that *G. miozea conoidea* makes its last appearance in the correlative stratigraphic horizon of a core from the northeastern Pacific where the last occurrence of this taxon lies between the last occurrences of *Globigerina nepenthes* and the genus *Sphaeroidinellopsis*. Thus, this foraminiferal event is considered to be useful for biostratigraphic correlation, at least, in the northern Pacific.

11) The first appearance of *Globorotalia tosaensis*

Blow (1969) defined the base of his Zone N. 21 as the level of the first evolutionary appearance of *G. tosaensis*. The first appearance of *G. tosaensis* was recognized in the lower part of the Horinouchi Formation (Oda, 1971). The present foraminiferal event occurs just above the last occurrence of *Globorotalia miozea conoidea*. Hays *et al.* (1969) noted that the successive evolutionary development of *G. tosaensis* from *Globorotalia crassaformis* is observed in the lower part of the Gauss series, and the typical *G. tosaensis* makes its first appearance just below the Mammoth Event.

12) The last occurrence of the genus *Sphaeroidinellopsis*

According to Hays *et al.* (1969), a core-to-core correlation of the ranges of such solution-

resistant species as *Sphaeroidinellopsis* is very good, as being due to a cortical covering of the test. The level of the genus *Sphaeroidinellopsis* has been considered to be useful biostratigraphic level by Hays *et al.* (*op. cit.*, their Datum V), Berggren (1973), Cita (1973) and others. This foraminiferal event was recognized in the lower part of the Horinouchi Formation slightly above the subjacent foraminiferal event, in the Kakegawa area (Oda, 1971). In the Boso Peninsula, *Sphaeroidinellopsis* spp. occur throughout the Amatsu, Kiyosumi and Anno Formations but do not appear in the Kazusa Group. Therefore, this event is assumed to have occurred within the stratigraphic hiatus between the Anno and Kurotaki Formations.

13) The first appearance of *Globorotalia truncatulinoides*

Since the evolutionary lineage of *Globorotalia truncatulinoides* from its immediate ancestor, *Globorotalia tosaensis*, was first suggested by Takayanagi and Saito (1962), it has been recognized in the late Cenozoic succession by many workers. Berggren *et al.* (1967) compared the phylogeny of *G. truncatulinoides* with the paleomagnetic stratigraphy in a North Atlantic deep-sea core and showed that this evolution occurred within the Olduvai Event of the Matuyama Reversed Epoch. This evolutionary appearance within or near the base of the Olduvai Event was also recognized in the Atlantic (Glass *et al.*, 1967; Phillips *et al.*, 1968) and in the equatorial Pacific (Hays *et al.*, 1969) and has been considered by Hays and Berggren (1971) to be chronostratigraphically reliable for world-wide correlation within the warm-water region. In the present study, *G. truncatulinoides* is placed at the middle part of the Ohara Formation in the Boso sequence. It has been recognized in the Hijikata Formation of the Kakegawa Group in the Kakegawa area (Morozumi, 1972; Kato, 1973).

3. ZONATION

In recent years, a number of biostratigraphical works are published on marine sediments from land sections as well as from the deep-sea. Especially, availability of deep-sea data contributed to a better recognition of evolutionary trends in foraminifera from which judicious selection of index species can be made. Moreover, more precise stratigraphic ranges of these species are delineated in deep-sea areas where sediments are significantly free from local environmental effects. Subsequent examinations of the foraminiferal sequences from many geographically separated sections resulted in the revision of the previously established zonations accompanied by a proposal of new zonation by various authors.

A preliminary zonation by means of planktonic foraminifera in the equatorial region was proposed by Banner and Blow (1965a). Subsequently its utility was discussed in detail by Blow (1969). Blow's (*op. cit.*) zones are considerably standardized for worldwide stratigraphic correlation because his zones were defined mainly on the basis of the first evolutionary appearance of a certain taxon. However, a direct application of his zonation to the sequence of the present study is not possible because of the lack or scarcity of many index species. Late Cenozoic sediments studied may be biostratigraphically subdivided into eleven zones on the basis of planktonic foraminiferal events. These planktonic foraminiferal zones, established by combining biostratigraphic events observed in the present study with some important foraminiferal changes occurring between these events, are as follows beginning with the oldest (Fig. 15).

The *Globigerinoides sicanus*/*Globigerinatella insueta* Zone

The top of this zone is defined by the first appearance of *Orbulina suturalis*, but its base is not defined here because of this zone being the lowest part of the stratigraphic

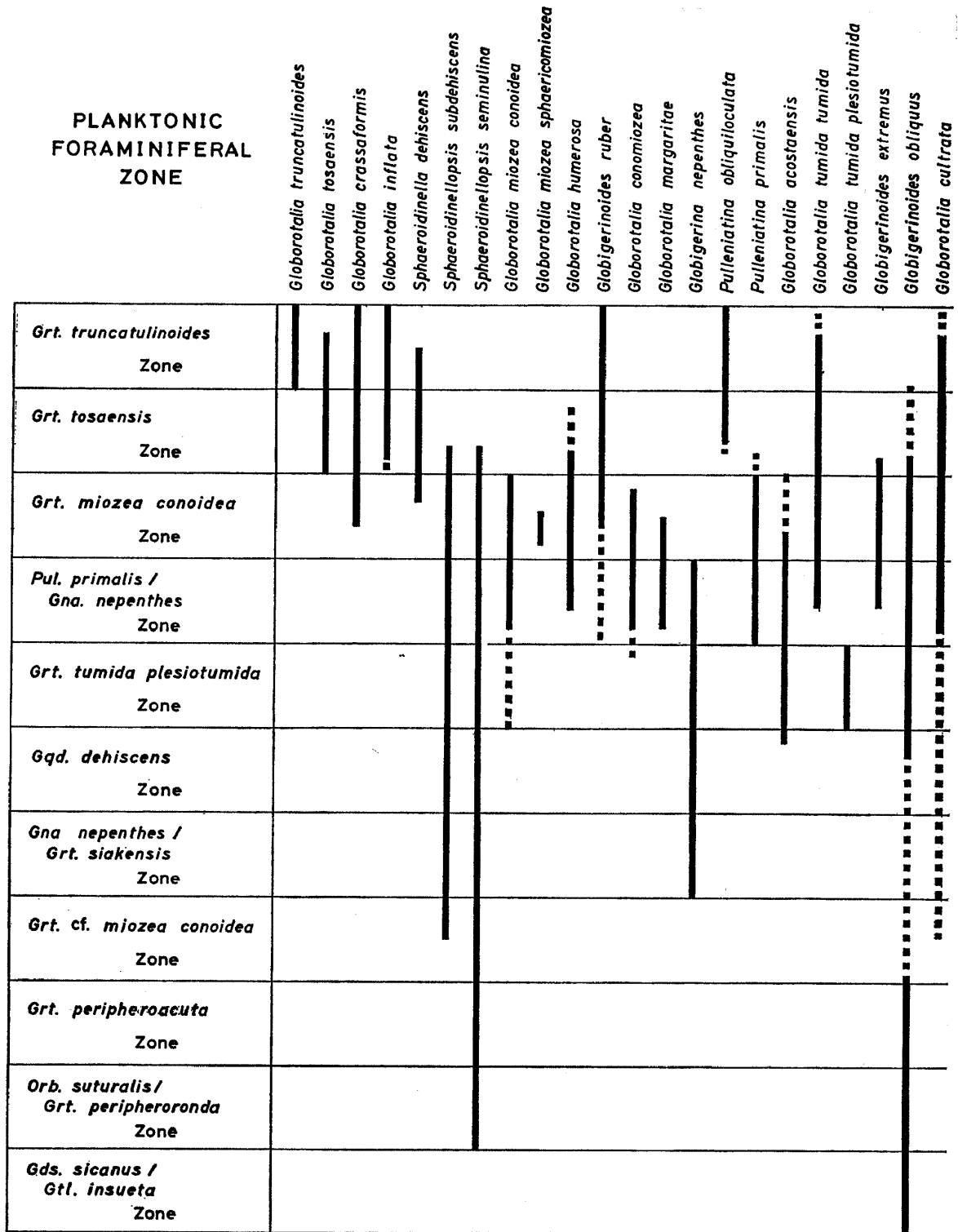
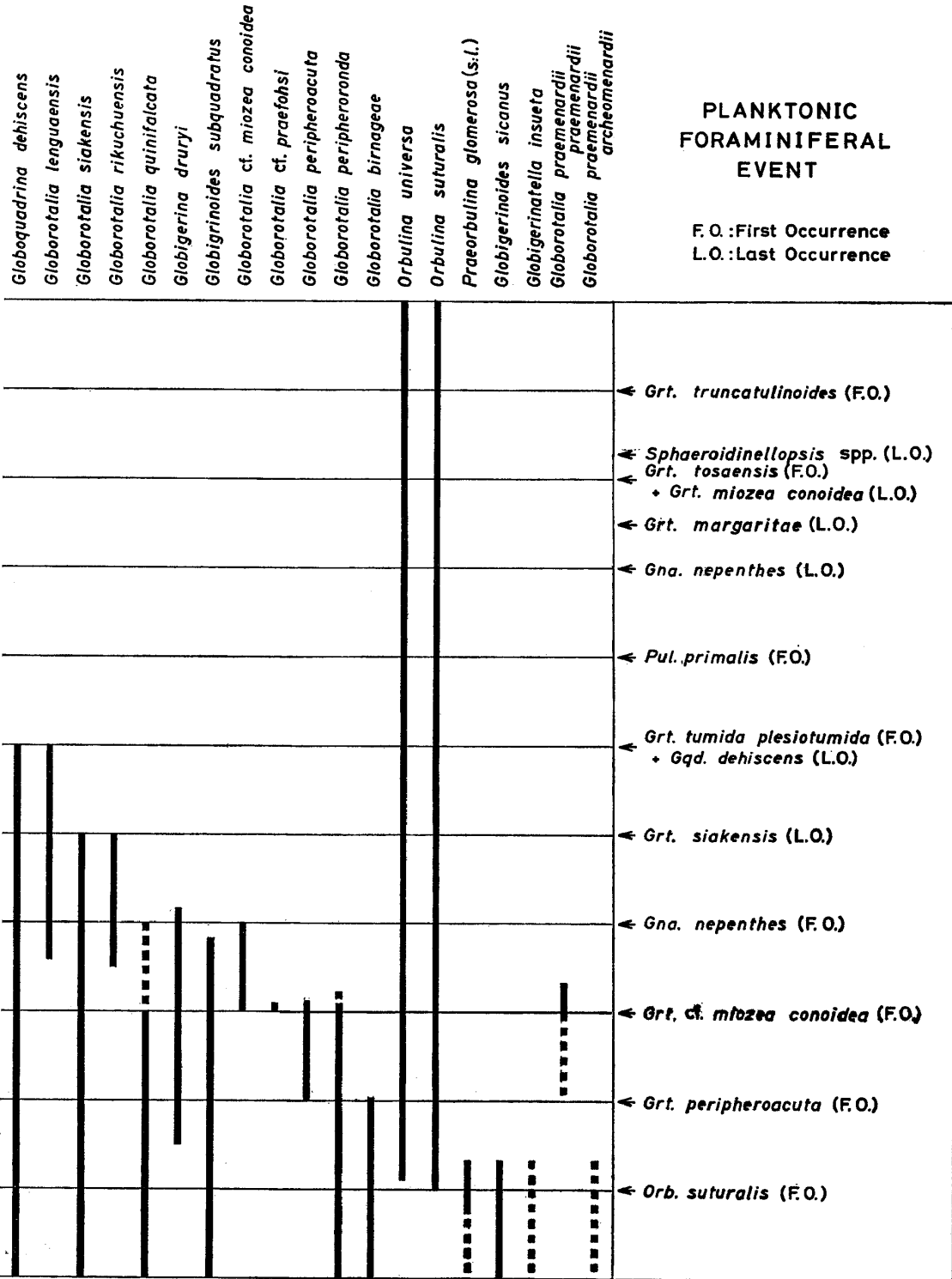


Fig. 15. Biostratigraphic zonation applied to the present study and



the ranges of selected planktonic foraminiferal species.

sequence studied. It is, however, an interval characterized by the joint occurrence of *Globigerinoides sicanus* and *Globigerinatella insueta*.

The zone is represented by only three samples (IDO-09, IDO-06, and IDO-04) collected from the Idozawa Formation exposed along the Kuda River, Takasaki City, Gunma Prefecture. It is also represented by the section along the Kanayama River of the Boso Peninsula, including the Kinone Formation and probably the basal part of the Amatsu Formation.

Globorotalia birnageae, *G. peripheroronda*, *G. praemenardii archeomenardii*, *G. scitula praescitula*, and *Praeorbulina glomerosa* (s. l.) occur within this interval.

This zone is, for the most part, equivalent to the *Globigerinatella insueta*/*Globigerinoides bisphericus* Subzone of Saito (1963). It also corresponds to the Takasaki-I zone proposed by Takayanagi *et al.* (1976) in the Takasaki area.

The *Orbulina suturalis*/*Globorotalia peripheroronda* Zone

This Zone is defined by the first appearance of *Orbulina suturalis* at the base and the first appearance of *Globorotalia peripheroacuta* at the top. This interval is characterized by the presence of *O. suturalis* and the absence of *G. peripheroacuta*.

In the Takasaki area, the base of the zone corresponds to the lower limit of the Ono Formation, but its upper boundary is not clearly recognized because planktonic faunal records are interrupted by sandstone and tuff beds in the middle part of the Ono Formation. Sample Tk-17 from the middle part of the Ono Formation contains, however, the zonal marker, *Globorotalia peripheroacuta*. Therefore, this zone seems to correspond to the lower half of the Ono Formation exposed along the Hoshi River. In the Boso Peninsula, on the other hand, the top of the zone is located in the lower part of the Amatsu Formation, but its lower boundary is indeterminate because of impoverished and ill-preserved planktonic foraminifera.

Globigerinoides sicanus, *Praeorbulina glomerosa* (s. l.), and *Globigerinatella insueta* still persist in this interval in the Takasaki area. *Globorotalia birnageae*, *G. peripheroronda*, and *G. quinifalcata* are also commonly found.

This zone is nearly equivalent to the *Globorotalia fohsi barisanensis* Zone of Saito (1963). It is also correlative with the Takasaki-II zone of Takayanagi *et al.* (1976) in the Takasaki area.

The *Globorotalia peripheroacuta* Zone

This zone is defined by the first appearance of *Globorotalia peripheroacuta* at the base and by the first occurrence of *Globorotalia cf. miozea conoidea* at the top. It is an interval with *G. peripheroacuta* but without *G. cf. miozea conoidea*.

It is represented by only three samples (K51, K49, and K48) collected from the Amatsu Formation exposed along the Kanayama River of the Boso Peninsula. In the Takasaki area, the middle part of the Ono Formation may represent this zone.

Globoquadrina dehiscens, *Globorotalia peripheroronda*, and *G. quinifalcata* commonly occur in this interval. *Globorotalia birnageae* possibly has its last occurrence in the extremely basal part.

The zone is, in general, equivalent to the *Globorotalia fohsi fohsi* Zone of Saito (1963). It is also correlative with the lower part of the Takasaki-III zone of Takayanagi *et al.* (1976) in the Takasaki area.

The *Globorotalia cf. miozea conoidea* Zone

This zone is defined by the first occurrence of *Globorotalia cf. miozea conoidea* at the base and by the first appearance of *Globigerina nepenthes* at the top. It is an interval with *G. cf. miozea conoidea* but without *G. nepenthes*.

The zone is represented by 11 samples (K47, K46, K44-K38, K36, and K35) collected

from the Amatsu Formation exposed along the Kanayama River of the Boso Peninsula. It is also represented by a composite section along the Hoshi and Usui Rivers, corresponding to the upper part of the Ono Formation and the lower part of the Haraichi Formation in the Takasaki area.

Its base is also marked by the first occurrence of *Globorotalia* cf. *praefohsi* in the Boso Peninsula, although extremely rare in abundance. *Globorotalia peripheroacuta* and *G. praemenardii praemenardii*, both of which appear in the underlying zone, still persist in the basal part of the zone and *Globigerinoides subquadratus* in the upper part. Typical form of *Sphaeroidinellopsis subdehiscens*, *Globorotalia cultrata*, *G. linguaensis*, and *G. rikuchensis* first occur in this interval.

This zone is probably equivalent to a part of the *Globorotalia fohsi fohsi* Zone and the *Globorotalia bykovaevae* Zone of Saito (1963). It also corresponds to the upper part of the Takasaki-III zone and the lower part of the Takasaki-IV zone of Takayanagi *et al.* (1976).

The *Globigerina nepenthes*/*Globorotalia siakensis* Zone

This zone is defined by the first appearance of *Globigerina nepenthes* at the base and by the last occurrence of *Globorotalia siakensis* at the top. It is an interval with *G. nepenthes* and *G. siakensis*.

It is represented by six samples (K34, K33, K31–K28) collected from the Amatsu Formation exposed along the Kanayama River in the Boso Peninsula. In the Takasaki area, the middle and upper parts of the Haraichi Formation developed along the Usui River may be included in this zone. The base of the zone is situated in the middle part of the Haraichi Formation, but its upper boundary is not clearly recognized because planktonic foraminifera become rare upward in the sequence from the upper part of the Haraichi to the Itahana Formations.

Globorotalia quinifalcata and *G. rikuchensis* seem to have their last occurrences in this interval.

The present zone is correlative with the *Globorotalia mayeri*/*Globigerina nepenthes* Zone recognized in the Shimoshiroiwa Formation of the Izu Peninsula by Saito (1963). It is also equivalent to a part of the Takasaki-IV zone of Takayanagi *et al.* (1976).

The *Globoquadrina dehiscens* Zone

This zone is defined by the last occurrence of *Globorotalia siakensis* at the base and by the first occurrence of *Globorotalia tumida plesiotumida* at the top. It is an interval with *Globoquadrina dehiscens* but without *G. siakensis* and *G. tumida plesiotumida*.

It is represented by 17 samples (K27–K16, K14–K12, K10, and K09) collected from the Amatsu Formation exposed along the Kanayama River of the Boso Peninsula.

Globigerina nepenthes occurs throughout this interval. *Globoquadrina dehiscens* is commonly found and disappears abruptly at the top. *Globorotalia linguaensis* also disappears at the top. This interval is distinguished by a relatively poor planktonic foraminiferal assemblage characterized by the common occurrence of *G. dehiscens*. *Globorotalia acostaensis* first appears in the upper part of the zone although it is rare.

The zone is equivalent to a part of the *Globorotalia menardii menardii*/*Globigerina nepenthes* Zone of Saito (1963).

The *Globorotalia tumida plesiotumida* Zone

This zone is defined by the first occurrence of *Globorotalia tumida plesiotumida* at the base and by the first appearance of *Pulleniatina primalis* at the top. It is an interval with *G. tumida plesiotumida* but without *P. primalis*.

The zone is represented by seven samples (K09–K02) collected from the Amatsu Formation exposed along the Kanayama River of the Boso Peninsula. In the Kakegawa area, the lower part of the Sagara Formation may comprise this zone.

Globigerina nepenthes, *Sphaeroidinellopsis seminulina*, and *S. subdehiscens* occur commonly within this interval. *Globorotalia miozea conoidea* and *G. conomiozea* show their first occurrences in this zone.

The present zone is equivalent to a part of the *Globorotalia menardii menardii*/*Globigerina nepenthes* Zone of Satio (1963).

The *Pulleniatina primalis*/*Globigerina nepenthes* Zone

This zone is defined by the first appearance of *Pulleniatina primalis* at the base and by the last occurrence of *Globigerina nepenthes* at the top. It is an interval with *P. primalis* and *G. nepenthes*.

The zone is represented by a composite section, including the Kanayama River section (sample K01), the Tashiro River section (samples 42 and 40), the Shikiryatsuzawa section (samples 37, 35, 32-25, and 21), and the Kurotaki-honryu section (samples 18, 17, and 15), and corresponds to the Kiyosumi Formation and the lower part of the Anno Formation of the Boso Peninsula. It is equivalent to the middle and upper parts of the Sagara Formation in the Kakegawa area.

Globigerinoides extremus, *Globorotalia humerosa*, *G. margaritae*, and *G. tumida tumida* seem to appear for the first time in this interval. *Globigerina nepenthes* gradually decreases its abundance upward.

This zone is equivalent to the upper part of the *Globorotalia menardii menardii*/*Globigerina nepenthes* Zone of Saito (1963).

The *Globorotalia miozea conoidea* Zone

This zone is defined by the last occurrence of *Globigerina nepenthes* at the base and by the last occurrence of *Globorotalia miozea conoidea* at the top. It is an interval with *G. miozea conoidea* but without *G. nepenthes*.

The zone is represented by a composite section, including the Kurotaki-honryu section (samples 13-11, and 09), the Sankawadani-higashi section (samples 07, and 05-01), and the Minato River section (samples T06, T03, T05, and T02), and corresponds to the middle and upper parts of the Anno Formation in the Boso Peninsula. It is recognized in the lower part of the Horinouchi Formation in the Kakegawa area.

Globorotalia crassaformis and *Sphaeroidinella dehiscens* seem to make their first occurrences in this interval. *Globorotalia miozea sphericomiozea* occurs for a short stratigraphic interval in the middle part of the Anno Formation in the Boso Peninsula. *Globoquadrina altispira*, *Globorotalia conomiozea*, and *G. margaritae* seem to be of their last occurrences in the interval. *Globigerinoides elongatus* and *G. ruber* are commonly found.

This zone is correlative with a part of the *Sphaeroidinellopsis seminulina* Zone of Saito (1963), because the present zone, the *G. miozea conoidea* Zone, falls within that part of range of *Sphaeroidinellopsis seminulina* following the last occurrence of *Globigerina nepenthes*.

Since the last occurrence of *Globorotalia margaritae* is in the middle part of the zone, the following further subdivision may be possible:

The *Globorotalia margaritae* Subzone

This subzone is defined by the continued occurrence of *Globorotalia margaritae* after the extinction of *Globigerina nepenthes*. It corresponds to the middle part of the Anno Formation of the Boso Peninsula.

The *Globorotalia crassaformis* Subzone

This subzone is distinguished by the concurrent ranges of *Globorotalia crassaformis* and *Globorotalia miozea conoidea* after the disappearance of *Globorotalia margaritae*. It is referable to the upper part of the Anno Formation of the Boso Peninsula.

The *Globorotalia tosaensis* Zone

This zone is defined by the last occurrence of *Globorotalia miozea conoidea* at the

base and by the first appearance of *Globorotalia truncatulinoides* at the top. It is an interval without both *G. miozea conoidea* and *G. truncatulinoides*. *Globorotalia tosaensis* is a significant constituent of the zone.

The present zone is developed in the Minato River section (sample T01) and also in a composite section near the northern part of Katsuura City and Onjuku Town, Boso Peninsula (samples KA20, KA15, KA14, KA10, KA09, KA06, KA04 and KA01). It represents an interval from uppermost part of the Anno Formation, through the Kurotaki and the Namihana, to the lower part of the Ohara Formation in the Boso Peninsula. It is also recognized in the main part of the Horinouchi Formation in the Kakegawa area. The first appearance of *Globorotalia tosaensis* is observed within the lower part of the Horinouchi Formation (Oda, 1971), which represents the basal part of this zone in the Kakegawa area.

Globorotalia inflata and *Pulleniatina obliquiloculata* make their first appearances within this interval. *Globigerinoides extremus*, *Sphaeroidinellopsis seminulina*, and *S. subdehiscens* seem to disappear in the interval.

The lower part of the zone is correlative with uppermost part of the *Sphaeroidinellopsis seminulina* Zone of Satio (1963).

The *Globorotalia truncatulinoides* Zone

This zone is marked at the base by the first appearance of *Globorotalia truncatulinoides*. Its top is not herein defined, because the zone is the youngest biostratigraphic unit recognized in the present study. It is characterized by a partial range of *G. truncatulinoides*.

The zone is represented by a total of 25 samples (HS12-KD01) collected from the middle and upper parts of the Ohara, Kiwada, Otadai, Umegase, Kokumoto, and Kakinokidai Formations in the Boso Peninsula. It is also recognized in the Hijikata Formation in the Kakegawa area.

Globigerina pachyderma and *Globorotalia inflata* are commonly found in this interval. *Globigerinoides obliquus* seems to become extinct in the basal part. *Globigerinoides tenellus* first occurs near the lower limit.

4. COMPARISON OF THE BOSO SEQUENCE WITH THE KAKEGAWA AND CHOSHI SEQUENCES BY MEANS OF THE COILING DIRECTION CHANGES IN THE GENUS *PULLENIATINA*

Many workers have paid attention to the coiling pattern of certain planktonic foraminifera because of their importance in regional and inter-regional correlation. The cause for the coiling ratio changes in *Pulleniatina* is not clearly understood at present, but this change has been considered to be an important indicator for stratigraphic correlation (Bandy, 1963; Bolli, 1964; Huang, 1967; Takayama, 1967, 1973; Matoba, 1967; Hays *et al.*, 1969, and others). Within the geologic sequence of the Boso Peninsula, there are three distinct horizons defined by the coiling direction shift in the genus *Pulleniatina*.

Pulleniatina shows dominantly a sinistral coiling from the uppermost part of the Amatsu Formation to the lower part of the Anno Formation. The first coiling change in *Pulleniatina* (primarily of *P. primalis*) from sinistral below to dextral above is recognized within the middle part of the Anno Formation (Fig. 11). The initial coiling direction change in *Pulleniatina* occurs shortly after the last occurrence of *Globigerina nepenthes* in the Boso Peninsula. Accordingly, the first coiling shift from sinistral to dextral is demonstrated to occur in the *Globorotalia miozea conoidea* Zone of the present zonal scheme (Fig. 17), and

is followed by an additional coiling change higher in the stratigraphic sequence. Fig. 12 shows that there are two more distinct horizons of the coiling direction shift in *Pulleniatina*; the lower shift from dextral to sinistral and the higher one from sinistral to dextral occurring in the lower part of the Kazusa Group in the Boso Peninsula. Takayama (1967) observed an abrupt sinistral to dextral coiling direction change on *Pulleniatina obliquiloculata* in the lowermost part of the Kurotaki Formation, exposed along the Obitsu River flowing parallel to the Yoro River, about 10 km to the west, in the Boso Peninsula (Fig. 21). However, Takayama (1967) did not detect the lower coiling shift recognized in the present sequence in his Obitsu River section. This is probably due to the fact that the lower part of the Kazusa Group in which the lower coiling shift was observed in the eastern area of the peninsula thins out along the Yoro River and in the western area of the river as shown in Fig. 21.

In the Kakegawa area, the dominantly sinistrally coiled specimens of *Pulleniatina primalis* are found in the Sagara Formation whereas the dextrally coiled ones in the lower part of the Horinouchi Formation, although they are very rare (Fig. 13). This sequence thus encompasses the first coiling change in *Pulleniatina* although the precise horizon of the shift could not be detected due to poor state of preservation and/or the absence of the species near the formational boundary.

Fig. 16 shows the changes in the coiling direction of *Pulleniatina* together with the stratigraphic distribution of *Globorotalia tosaensis* and *G. truncatulinoides* in the Boso, Kakegawa, and Choshi sections. A similar pattern of coiling changes in *Pulleniatina* as recognized in the Boso section is recorded in the stratigraphic sequence of the Choshi and Kakegawa areas by Matoba (1967) and Kato (1973). A coiling shift from dextral to sinistral occurs in the middle part of the Namihana Formation of the Boso Peninsula, in the middle part of the Horinouchi Formation of the Kakegawa area, and in the basal part of the Kasuga Formation (Niitsuma, 1970) of the Choshi area. The next younger coiling shift from sinistral to dextral is observed in the basal part of the Kiwada Formation of the Boso Peninsula, in the Hijikata Formation of the Kakegawa area, and in the basal part of the Obama Formation of the Choshi area. *Globorotalia truncatulinoides* makes its first appearance within the interval marked by the sinistrally coiled *Pulleniatina* in the Boso section, and a similar occurrence is observed in the Choshi and the Kakegawa areas. Thus, a shift in the coiling direction from dextral to sinistral occurs in the *Globorotalia tosaensis* Zone and another from sinistral to dextral in the lower part of the *Globorotalia truncatulinoides* Zone. Therefore, the coiling changes in *Pulleniatina* as discussed above are considered to be useful for stratigraphic correlation of Late Cenozoic strata, at least, along the western Pacific coastal region. Furthermore, the initial coiling change in *Pulleniatina* which shortly follows the last occurrence of *Globigerina nepenthes* has been recorded in the stratigraphic sequence of the Philippine by Bandy (1963), in the southern Taiwan by Huang (1967), and in the equatorial Pacific by Hays *et al.* (1969). On the basis of a similar faunal succession occurring in the wide geographic regions as mentioned above as well as in the areas of the present study, the first coiling change in *Pulleniatina* (primarily of *P. primalis*) is considered to be a useful indicator for long-distance correlation as suggested by Hays *et al.* (1969).

5. CORRELATION OF JAPANESE LATE CENOZOIC STRATA BY MEANS OF PLANKTONIC FORAMINIFERA

Saito (1963) already reported on faunal changes of planktonic foraminifera through Japanese Neogene successions and subdivisions of the Japanese Miocene in terms of the

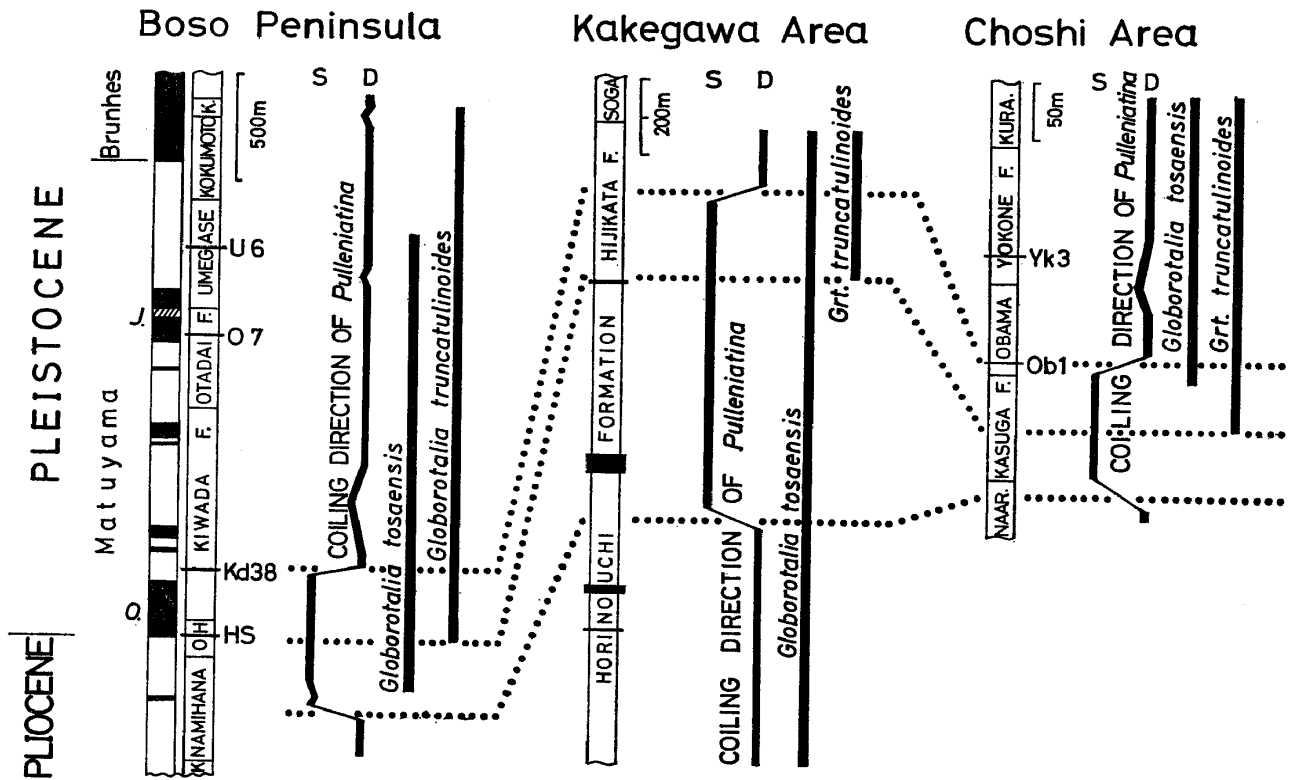
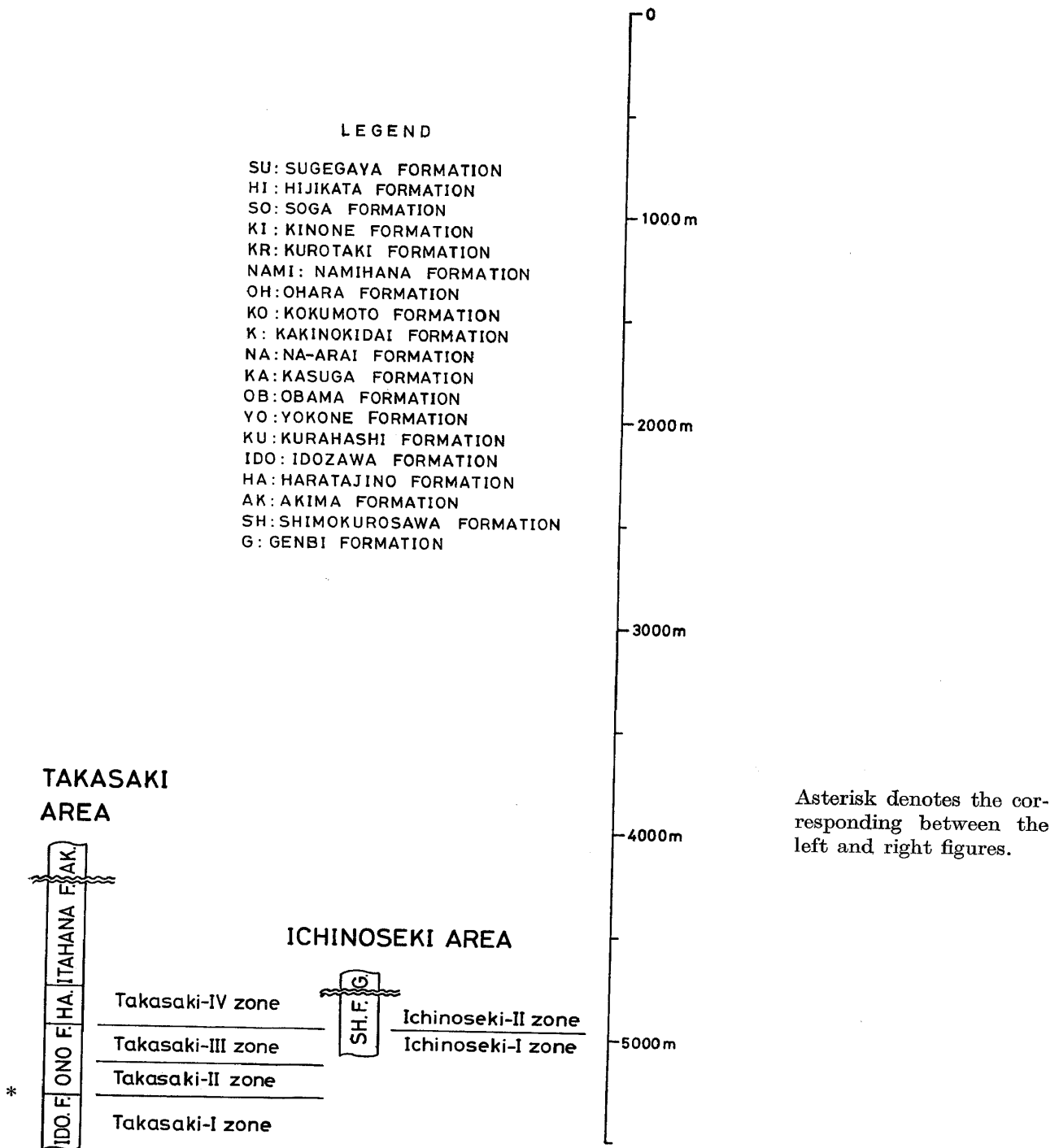


Fig. 16. Correlation of the Boso, Kakegawa and Choshi sections.

eight biostratigraphic zones. Fig. 17 shows a summary of correlation of Japanese Late Cenozoic strata by means of the eleven biostratigraphic subdivisions established in the present study and the stratigraphically important coiling changes in the genus *Pulleniatina*. In the Boso Peninsula, an interval from the Kinone to the Anno Formations encompasses a succession from the *Globigerinoides sicanus*/*Globigerinatella insueta* Zone to the basal part of the *Globorotalia tosaensis* Zone. In this section, the zonal boundary between the *G. sicanus*/*G. insueta* Zone and the *Orbulina suturalis*/*Globorotalia peripheroronda* Zone was not clearly defined owing to poorly preserved planktonic foraminifera there. The superjacent Kazusa Group, underlain by the Anno Formation with an unconformity, comprises a part of the *G. tosaensis* Zone to the *Globorotalia truncatulinoides* Zone. In the Takasaki section in which an interval from the Idozawa to the Haraichi Formations was recovered, recognized a sequence from the *G. sicanus*/*G. insueta* Zone to the *Globigerina nepenthes*/*Globorotalia siakensis* Zone. The zonal boundary between the *O. suturalis*/*G. peripheroronda* Zone and the *Globorotalia peripheroacuta* Zone was not clearly recognized in this section owing to the prevalence of sandstone and tuff beds in the middle part of the Ono Formation. The simultaneous disappearance of *Globigerinoides sicanus*, *Globigerinatella insueta*, and *Praeorbulina glomerosa* (*s. l.*) just below the sandstone and tuff facies and the occurrence of *Globorotalia peripheroacuta* within the middle part of the Ono Formation are interpreted to be an indication of a hiatus between the lower and middle parts of the Ono Formation as suggested by Takayanagi *et al.* (1976), although further study is needed. The Kinone Formation in the Boso Peninsula is correlated with a part of the Idozawa Formation in the Takasaki area, and the lower and middle parts of the Amatsu Formation with the Ono and the Haraichi Formations. In the Kakegawa area, the interval from the Sagara to the Hijikata Formations probably encompasses a sequence from the *Globorotalia*



foraminiferal zones and the coiling direction of the genus *Pulleniatina*.

a part of the Anno Formations in the Boso Peninsula. The main part of the Kakegawa Group is correlative with a lower part of the Kazusa Group in the Boso Peninsula.

Fig. 18 shows a correlation of the present zonal scheme with zones of Saito (1963). Saito (*op. cit.*) made these important suggestions: that tropical and subtropical planktonic faunas prevailed during the Early to early Middle Miocene throughout the Japanese

BEGGGREN (1972, 1973)			PRESENT PAPER	SAITO (1963)
AGE	MEDITERRANEAN STAGES	BLOW (1969)		
PLEISTOCENE	YOUNGER STAGES	N.22	<i>Globorotalia truncatulinoides</i> Zone	
	CALABRIAN			
PLIOCENE	PIACENZIAN	N.21	<i>Globorotalia tosaensis</i> Zone	<i>Sphaeroidinellopsis seminulina</i> Zone
	TABIANIAN	N.20	<i>Globorotalia miozea conoidea</i> Zone	
	ZANCLEAN	N.19 N.18 -?--	<i>Pulleniatina primalis</i> / <i>Globigerina nepenthes</i> Zone	<i>Globorotalia menardii menardii</i> / <i>Globigerina nepenthes</i> Zone
LATE MIOCENE	MESSINIAN	N.17 -?--	<i>Globorotalia tumida plesiotumida</i> Zone	
	TORTONIAN	N.16	<i>Globoquadrina dehiscens</i> Zone	
MIDDLE MIOCENE	SERRAVALLIAN	N.15		
		N.14	<i>Globigerina nepenthes</i> / <i>Globorotalia siakensis</i> Zone	
		N.13 N.12 N.11	<i>Globorotalia cf. miozea conoidea</i> Zone	<i>Globorotalia bykova</i> Zone ?
	LANGHIAN	N.10	<i>Globorotalia peripheroacuta</i> Zone	<i>Globorotalia fohsi fohsi</i> Zone
		N.9	<i>Orbulina suturalis</i> / <i>Globorotalia peripheroronda</i> Zone	<i>Globorotalia fohsi barisanensis</i> Zone
E.MIOCENE	BURDIGALIAN	N.8	<i>Globigerinoides sicanus</i> / <i>Globigerinatella insueta</i> Zone	<i>Globigerinatella insueta</i> Zone <i>Globigerinatella insueta</i> / <i>Globigerinoides bisphericus</i> Subzone
		N.7	?	<i>Globigerinatella insueta</i> / <i>Globigerinoides trilobus</i> Subzone

Fig. 18. Comparison of biostratigraphic zonations of the previous authors and the present study. Correlation of the stratotypes in Italy with Blow's zones as well as the time-scale assigned to the zonal scheme is after Berggren (1972, 1973).

Islands; then warm-water biofacies were abruptly replaced by a boreal fauna having characteristics of temperate to cool-water assemblages in the northern Japan at about the time corresponding to a level immediately above the *Globorotalia fohsi fohsi* Zone, while the fauna in the southern Japan became impoverished. Subsequent studies on planktonic foraminifera confirmed a prevalence of cool-water biofacies in the Late Neogene deposits of the coastal regions of the Japan Sea (Takayanagi and Oba, 1966; Shinbo and Maiya, 1971).

In the present study, marine facies assignable to the interval from the *Globigerinoides sicanus*/*Globigerinatella insueta* Zone to a part of the *Globorotalia peripheroacuta* Zone recognized both in the Boso Peninsula and the Takasaki area, have been observed to have an extensive distribution throughout almost all the sedimentary basins in Japan as pointed out by Saito (1963). The sequence from the top of the *G. peripheroacuta* Zone to the *Globoquadrina dehiscens* Zone is represented by a relatively poor planktonic foraminiferal fauna in contrast to the underlying or overlying biostratigraphic units as recognized in the present study. The strata assignable to these zones are absent in the Kakegawa area, being represented by a stratigraphic break between the Mikasa and the overlying Sagara Groups. In the Takasaki area, the sequence extending from a part of the Ono Formation to the Haraichi Formation, which is, as an interval, assignable to the *Globorotalia* cf. *miozea conoidea* and the *Globigerina nepenthes*/*Globorotalia siakensis* Zones (? and/or a part of the *Globoquadrina dehiscens* Zone), becomes gradually replaced upwards by the coarse-grained sediments (the Itahana Formation) and finally it was unconformably overlain by pyroclastic rocks devoid of planktonic foraminifera (the Akima Formation). Similarly, the Shimokurosawa Formation of the Ichinoseki area in northeast Japan, the unit correlated by Takayanagi *et al.* (1976) with a part of the Ono and the Haraichi Formations in the Takasaki area, becomes also replaced upwards by various kinds of coarse-grained sediments and pyroclastic rocks, and is unconformably overlain by the Genbi Formation consisting of dacitic tuff. Similar trend is also recognized in the Neogene sequence of the Boso Peninsula; namely, the upper half of the lower and the middle parts of the Amatsu Formation, an interval referable to the *G. nepenthes*/*G. siakensis* Zone and the *G. dehiscens* Zone, become gradually dominated by scoria, pumice and tuffaceous sandstone beds upwards and are overlain by the Kiyosumi and the Anno Formations. In the western part of the Boso Peninsula, the Amatsu, Senhata, Inakozawa, and Hagi Formation, in order of decreasing age, are developed in the Nokogiriyama-Byakko section and an unconformable relationship is clear between the Amatsu and Senhata Formations (Mitsunashi and Yazaki, 1958). In the upper part of the Amatsu Formation along the Kanayama River, the concurrent disappearance of *Globoquadrina dehiscens* and *Globorotalia linguaensis* was recognized immediately below the boundary between the *G. dehiscens* and *G. tumida plesiotumida* Zones and the abrupt first occurrence of *Globorotalia tumida plesiotumida* immediately above the zonal boundary. Therefore, the unconformable relationship between the Amatsu and Senhata Formations in the western part is assumed to correspond to the zonal boundary between the *G. dehiscens* and *G. tumida plesiotumida* Zones in the eastern part, although further litho- and biostratigraphic investigations are needed. Thus, the upper part of the Amatsu Formation in the eastern part, referable to the *G. tumida plesiotumida* Zone and a part of the *P. primalis*/*G. nepenthes* Zone, is probably correlative with the Senhata Formation and a part of the Inakozawa Formation in the western part. The Kiyosumi and Anno Formations developed in the eastern part grade into lapilli tuff with association of layers of sandstone and siltstone westwards. Consequently, it may be concluded that the sea began to retreat towards the Pacific Ocean and/or towards the Japan Sea borderlands sometime during the *G. dehiscens* Zone time and an extensive acidic volcanic activity followed during the period probably corresponding to the interval from

the *P. primalis*/*G. nepenthes* Zone to the *G. miozea conoidea* Zone of the present zonal scheme. Furthermore, immediately above the *G. miozea conoidea* Zone, a stratigraphic break between the Anno and the overlying Kurotaki Formations is recognized in the Boso Peninsula. At a horizon approximately correlative with the *G. miozea conoidea* Zone, the basal and/or marginal conglomerate members of the Kakegawa Group deposited in the Kakegawa area. Thus, a new phase of transgression occurred sometime after and/or during the *G. miozea conoidea* Zone time. The sediments deposited are fine-grained marine clastics in the central part of the basin, and rather coarse-grained clastics in the marginal part, frequently exceeding 2000 m in thickness.

OVERSEA CORRELATION AND AGE ASSIGNMENT

1. CORRELATION OF THE PRESENT ZONES WITH THOSE OF BLOW (1969)

Of the thirteen planktonic foraminiferal events recognized in the present study, five were used by Blow (1969) to define his zonal boundaries; they are the *Orbulina*, *Globorotalia peripheroacuta*, *Globigerina nepenthes*, *Globorotalia siakensis*, and *Globorotalia truncatulinoidea* datum planes. In the correlation chart (Fig. 18), they are indicated by solid lines. Dotted lines indicate those correlation levels which are probable but not as certain as the five mentioned above.

The base of the *Globigerinoides sicanus*/*Globigerinatella insueta* Zone is not defined in the present study, but existences of *Globigerinoides sicanus* and *Globorotalia praemenardii archeomenardii* are recorded from the lowermost part of the reference section. According to Blow (1969), the former species appears for the first time at the base of his Zone N. 8; the latter in the middle part of the same zone. Consequently, the *G. sicanus*/*G. insueta* Zone is referred to the upper half of Zone N. 8. The *Orbulina suturalis*/*Globorotalia peripheroronda* Zone is identical with the Zone N. 9 defined by the same criteria. The last occurrence of such species as *Globigerinatella insueta* and *Globigerinoides sicanus* and the common occurrence of *Globorotalia peripheroronda* within this zone may also confirm this correlation. The *Globorotalia peripheroacuta* Zone is probably equivalent to the Zone N. 10 of Blow (1969) because *Globorotalia* cf. *praefohsi* is found in the basal part of the overlying zone. The *Globorotalia* cf. *miozea conoidea* Zone is considered to represent a stratigraphic interval probably equivalent to the Zones N. 11, N. 12 and N. 13. The first occurrences of *Globorotalia cultrata*, *G. linguaensis* and the typical form of *Sphaeroidinellopsis subdehiscens* within the *G. cf. miozea conoidea* Zone may indicate the correlation of it with the interval from Zone N. 11 to Zone N. 13. The *Globigerina nepenthes*/*Globorotalia siakensis* Zone is characterized by the joint occurrence of these two zonal markers, so that this zone is equivalent to the Zone N. 14. The *Globoquadrina dehiscens* Zone may be correlative with a combined interval of Zone N. 15 and Zone N. 16. The first occurrence of *Globorotalia acostaensis* within the *G. dehiscens* Zone, although very scarce, is an evidence to support this correlation. According to Blow (1969), *Pulleniatina primalis* appears to have directly descended from *G. acostaensis* within the middle part of the Zone N. 17. The *Globorotalia tumida plesiotumida* Zone is probably equivalent to a lower half of the Zone N. 17 because the top of the *G. tumida plesiotumida* Zone is defined by the first appearance of *Pulleniatina primalis*. Blow (*op. cit.*) also noted the last occurrence of *Globigerina nepenthes* near the N. 19/N. 20 zonal boundary. Consequently, if the boundary between the Zone N. 19 and Zone N. 20 is tentatively set at the level of the last occurrence of *G. nepenthes*, the *Pulleniatina primalis*/*Globigerina nepenthes* Zone is correlated with a upper half of the Zone N. 17 through Zone N. 19. The top of the *Globorotalia miozea conoidea* Zone approximately coincides with the level of the first appearance of *Globorotalia tosaensis* which defines the

boundary between the Zone N. 20 and Zone N. 21. Therefore, the *G. miozea conoidea* Zone is correlative with the Zone N. 20. Banner and Blow (1965a) defined the base of their Zone N. 22 by the first appearance of *Globorotalia truncatulinoides* evolved from its immediate ancestor, *G. tosaensis*. The base of the *Globorotalia truncatulinoides* Zone is identical with the base of the Zone N. 22 defined by the same criterion. However, the upper boundary of the Zone N. 22 and its distinction from the overlying Zone N. 23 could not be determined because no zonal diagnostic species occurred in the present sequence.

2. INTERPRETATION OF THE PALEOMAGNETIC POLARITY RECORD OF THE BOSO SEQUENCE BASED UPON THE PLANKTONIC FORAMINIFERAL EVENTS

The paleomagnetic studies were made by measuring detrital remanent magnetization (DRM) of samples from the land-based sequence of marine sediments of the Boso Peninsula by Nakagawa *et al.* (1969) and Niitsuma (1970). Later, re-examination of the stability of remanent magnetization and additional measurements on the sample from the same section by the present study were undertaken and the paleomagnetic polarity sequence was determined by Niitsuma *et al.* (1972) and Kimura (1974). Fig. 19 shows the paleomagnetic polarity sequence of the Boso Peninsula (Niitsuma *et al.*, 1972), covering the interval from the uppermost part of the Sakuma Group to the Shimosa Group except for the uppermost part of the Toyo-oka Group.

The relationships of various faunal and floral datum planes to the geomagnetic polarity time-scale have been demonstrated on the basis of numerous deep-sea cores from the world oceans. In one of the stimulating works published during the last few years, Hays *et al.* (1969) have related the ranges of several species of various microfossil groups with the polarity records of cores from the equatorial Pacific. The stratigraphic ranges of nine planktonic foraminiferal species were given in that study covering the time span from the early Gilbert Epoch to the present. Later, the relationship of some planktonic foraminiferal datum planes to the geomagnetic time-scale as far back as the Magnetic Epoch 19 (Early Miocene) was discussed by Opdyke *et al.* (1974). Of these datum planes, whose relationship to paleomagnetic time-scale was well established, five planktonic foraminiferal species were chosen to interpret the observed reversal sequence of the Boso Peninsula. The relationships of six principal levels of the planktonic foraminiferal events, involving five taxa, with the paleomagnetic time-scale published in the previous reports are as follows in descending order.

(1) The first appearance of *Globorotalia truncatulinoides*, referred to as Datum IV by Hays *et al.* (1969), takes place near the beginning of the Olduvai Event of the Matuyama Reversed Epoch. A combined micropaleontological and magnetostratigraphical investigation on cores from the Atlantic, Pacific, and Indian Oceans (Berggren *et al.*, 1967; Berggren, 1968; Glass *et al.*, 1967; Phillips *et al.*, 1968) all recognized this first appearance to take place within the base of the Olduvai Event.

(2) The level of extinction of representative species of the genus *Sphaeroidinellopsis* was recognized by Hays *et al.* (1969; their Datum V) at the end of the Mammoth Event of the Gauss Normal Epoch.

(3) The level of extinction of *Globorotalia margaritae* has been noted to occur at the boundary between the Gauss Normal and Gilbert Reversed Series (Datum VI of Hays *et al.*, 1969).

(4) The initial coiling direction change in *Pulleniatina* (primarily, *P. primalis*), from sinistral below to dextral above, defined as Datum VII by Hays *et al.* (1969), has been shown to occur just above the "a" (Cochiti) Event of the Gilbert Reversed Epoch.

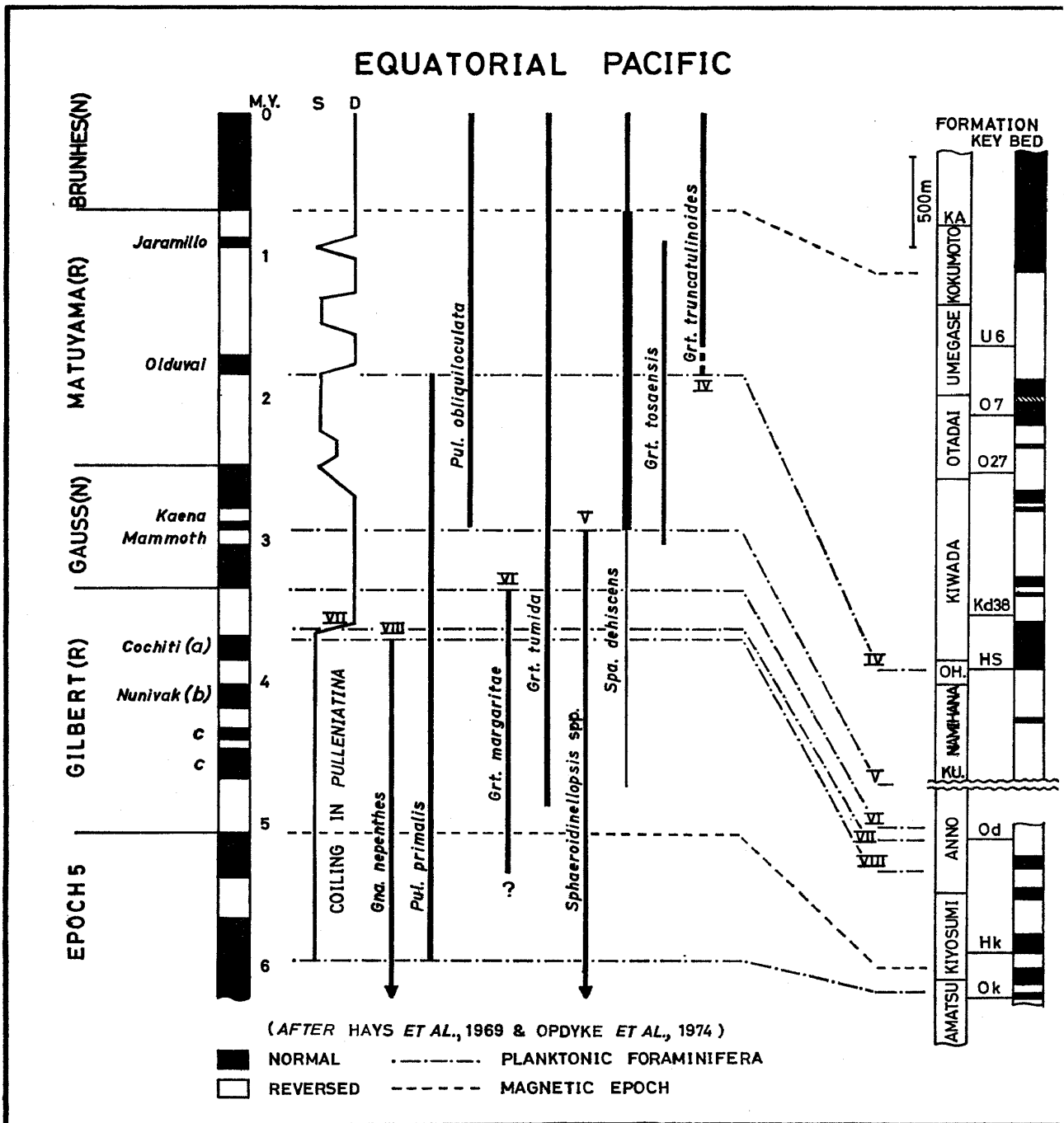
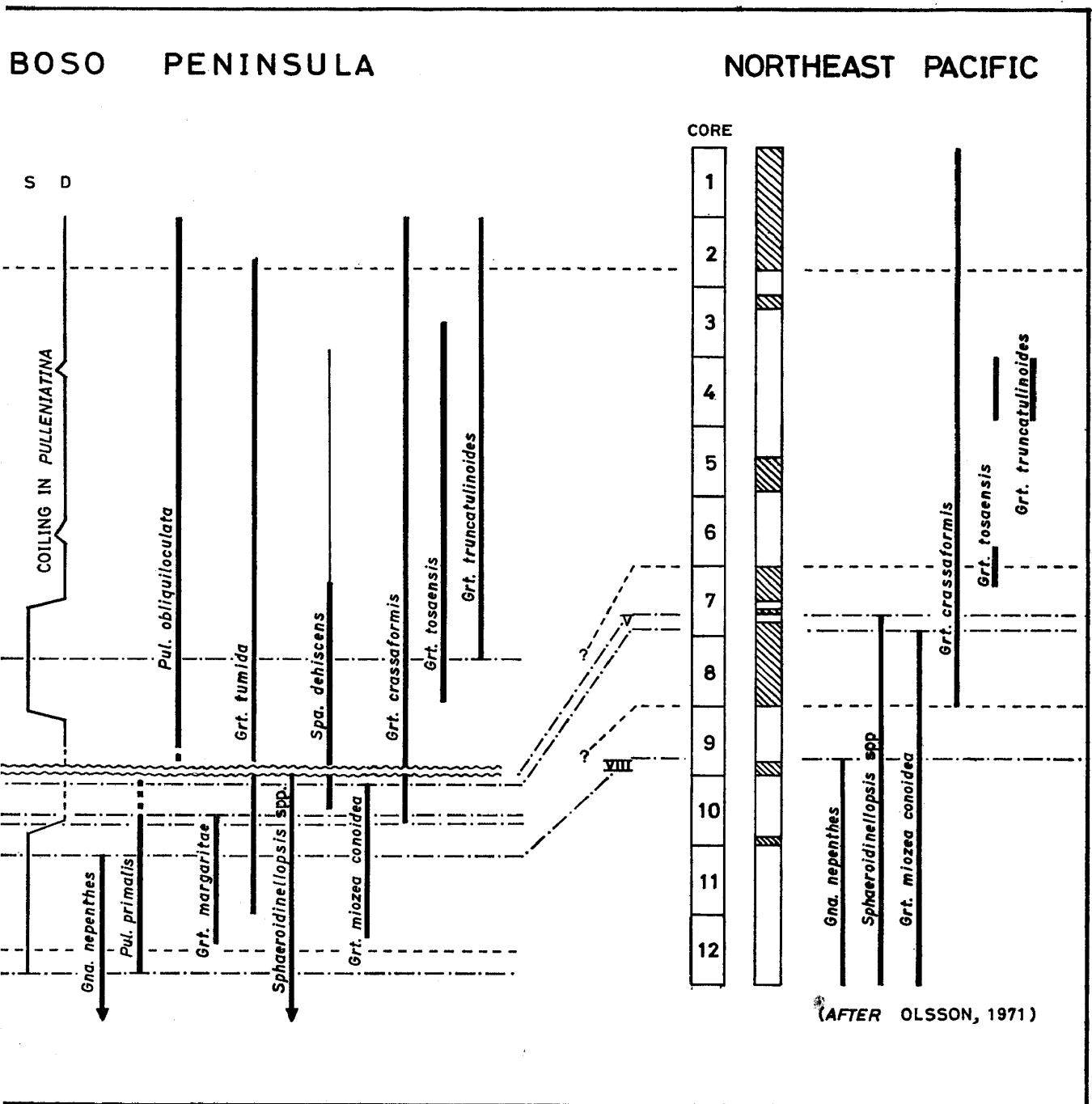


Fig. 19. Comparison of planktonic foraminiferal biostratigraphy and magnetostratigraphy

(5) The level of extinction of *Globobulimina nepenthes* has been noted by Hays *et al.* (1969) to correspond to the top of the "a" Event of the Gilbert Reversed Epoch (their Datum VII).

(6) The first appearance of *Pulleniatina primalis* has been reported by Opdyke *et al.* (1974) and Saito *et al.* (1975) to occur during the early phase of the Magnetic Epoch 5.

The paleomagnetic polarity records of the Kazusa Group and of the subjacent sequence (the uppermost part of the Sakuma Group and the Toyo-oka Group) which is



of the Boso Peninsula with those established in deep-sea cores.

unconformably overlain by the Kazusa Group of the Boso Peninsula are mainly interpreted from the micropaleontological evidence mentioned above (Fig. 19).

Takayama (1973) proposed eight calcareous nannofossil zones for the youngest Cenozoic sequence in Japan and reported that the top of the *Pseudoemiliana lacunosa* Zone defined by the last occurrence of the zonal marker lies at the upper part of the Kurahashi Formation in the Choshi area (Fig. 17). The top of the *P. lacunosa* Zone lies within an interval of the normal polarity (from the middle part of the Kokumoto Formation to the Shimosa

Group) in the Boso Peninsula, although precise position of the last occurrence of *Pseudomiliania lacunosa* (Kamptner) was not detected (Takayama, 1973). Gartner (1973) reported that *P. lacunosa* has its last occurrence within the middle part of the Brunhes Normal Epoch. Furthermore, Molino *et al.* (1976) noted that the Brunhes is trisected by two coccolith datum levels, the extinction of *P. lacunosa* and the first appearance of *Emiliania huxleyi*. According to them, the extinction of *P. lacunosa* occurs in isotopic stage 12 of Shackleton and Opdyke (1973). Thus, the normal polarity interval corresponding to the middle part of the Kokumoto Formation to the Shimosa Group is considered to belong to the lower and probably middle parts of the Brunhes Normal Epoch. This interpretation of the normal polarity interval is the same as that of Nakagawa *et al.* (1969). The normal polarity interval (the middle part of the Ohara Formation to the basal part of the Kiwada Formation) is interpreted to be equivalent to the Olduvai Event (in sense of Foster and Opdyke, 1970) of the Matuyama Reversed Epoch, because *Globorotalia truncatulinoides* makes its first appearance near the basal part of this interval. Consequently, the short normal event (the upper part of the Otadai Formation to the basal part of the Umegase Formation) is interpreted to be equivalent to the Jaramillo Event of the Matuyama Reversed Epoch. Studies of planktonic foraminifera of the same section enabled the writer to identify the Olduvai Event, and this led to a re-interpretation of the polarity records. The new interpretation shows that the Kazusa Group of the present sections ranges from the early part of the Matuyama Reversed Epoch to the early and probably middle parts of the Brunhes Normal Epoch.

The last occurrence of the genus *Sphaeroidinellopsis* is assumed to be within the interval of the stratigraphic break (the Kurotaki Unconformity) between the Anno and Kurotaki Formations, because this taxon is present in the Amatsu, the Kiyosumi and the Anno Formations but absent in the Kazusa Group. *Globorotalia margaritae* has its last occurrence in the upper part of the Anno Formation and the first coiling change of *Pulleniatina* from sinistral below to dextral above is recognized in the middle part of the Anno Formation. This initial coiling shift of *Pulleniatina* continues for a short distance above the last occurrence of *Globigerina nepenthes*. On the basis of the similar faunal succession of these taxa as reported by Hays *et al.* (1969) in the equatorial Pacific, the normal polarity interval in the middle of the Anno Formation is interpreted to be equivalent to the "a" Event of the Gilbert Reversed Epoch. Moreover, the uppermost part of the Anno Formation, although no paleomagnetic polarity has been established, may be correlated with the earlier part of the Gauss Normal Epoch. The first appearance of *Pulleniatina primalis* which occurs within the early part of the Magnetic Epoch 5 in the equatorial Pacific is recognized in the uppermost part of the Amatsu Formation. This fact shows that the interval from the uppermost part of the Amatsu Formation to the lowermost part of the Kiyosumi Formation is equivalent to the Magnetic Epoch 5. Therefore, the boundary between the Epoch 5 and the Gilbert Reversed Epoch is placed in the lower part of the Kiyosumi Formation. Consequently, the stratigraphic interval from the uppermost part of the Amatsu Formation through the Anno Formation is correlated with the Magnetic Epoch 5 to the earlier part of the Gauss Normal Epoch.

As a result of the present interpretation of the polarity records of the Boso sections, the stratigraphic break between the Anno and Kurotaki Formations is considered to cover the middle and late Gauss Normal Epoch and the earliest part of the Matuyama Reversed Epoch. Furthermore, according to Berggren (1973), the initial appearance of *Sphaeroidinella dehiscens* is in the lower part of the Gilbert Reversed Series in the equatorial region. However, the first occurrence of *S. dehiscens* is recognized in the upper part of the Anno Formation between the levels of the last occurrences of *Globorotalia margaritae* and the

genus *Sphaeroidinellopsis* in the Boso Peninsula. Thus, the level of the first occurrence of *S. dehiscens* in the Boso Peninsula may be an indication of either its later than the initial appearance in the equatorial region, or more likely non-preservedness of its initial range in the Boso sequence. According to Hays *et al.* (1969), the increased upward abundance of *S. dehiscens* was observed at the top of the Mammoth Event of the Gauss Normal Epoch, coincidental to the extinction of all species of the genus *Sphaeroidinellopsis* in the equatorial Pacific. And also they noted that level of the increased upward abundance of this species is the same as Bandy's (1963) *Sphaeroidinella dehiscens* datum and is the most easily recognizable foraminiferal datum. Thus, the level of the first occurrence of *S. dehiscens* in the Boso sequence is not the level of its initial appearance of this species, but approximately corresponds to the level of the increased upward abundance of *S. dehiscens* of Hays *et al.* (1969), although the level of the first occurrence of *S. dehiscens* is slightly older than the level of the last occurrence of *Sphaeroidinellopsis* in the Boso sequence. Furthermore, the level of the last occurrence of *Globorotalia miozea conoidea* is observed in the upper part of the Anno Formation following the first occurrence of *Globorotalia crassaformis*, both species thus ranging concurrently for a short stratigraphic interval. The first occurrence of *G. crassaformis* is in the latest part of the Gilbert Epoch (above the top of the "a" Event) and the last occurrence of *G. miozea conoidea* may have taken place within the earlier part of the Gauss Epoch. Olsson (1971) showed a similar overlapping range of these two species at the correlative horizon of a core from the northeastern Pacific, although no magnetic measurements were made on his core. Olsson (1971), however, noted that his correlation with the paleomagnetic scale was done by extrapolating that level on the basis of three paleontological datum planes of *Sphaeroidinellopsis* extinction, *Globigerina nepenthes* extinction, and discoaster extinction and assuming a constant rate of deposition. Thus, two biostratigraphic events, that is, the first occurrence of *G. crassaformis* and the last occurrence of *G. miozea conoidea*, are useful for biostratigraphic correlation, at least, in the North Pacific. In addition, coexistence of *G. crassaformis* and *G. miozea conoidea* within a short stratigraphic interval was reported by Jenkins (1971) in the Opoitian stage in New Zealand. According to Theyer (1972), the Opoitian stage can be correlated with the latest Gilbert and Gauss epochs. This fact in the temperate region may support the present conclusion.

3. AGE ASSIGNMENT

Stages of the Late Cenozoic Erathum distributed in the coastal regions along the Mediterranean Sea have come to be regarded as a standard for international stratigraphic correlation. However, confusion exists concerning the correlation of planktonic succession with the standard geologic time scale because, in many cases, each Late Cenozoic stage is represented by a single section deposited in environments unfavorable for planktonic organism. On the other hand, world-wide correlation of strata has recently been attempted in increasingly finer time increments owing to progress in planktonic microbiostratigraphy and paleomagnetic stratigraphy. Moreover, our expanding knowledge of the total range of fossil taxa allows a more precise correlation of the Italian stratotypes with the sequence of planktonic foraminiferal zones erected in the tropical areas. In the following lines, stratigraphic relations between the planktonic foraminiferal zones and the Early/Middle Miocene, Middle/Late Miocene, Miocene/Pliocene, and Pliocene/Pleistocene boundaries are discussed by referring to recent investigations.

There has been a growing usage of the Langhian, Serravallian, Tortonian, and Messinian as the standard stage for the Middle Miocene and Late Miocene of the Neogene succession. Berggren (1972) proposed a refined Cenozoic radiometric timescale to which

planktonic microfossil zonal scheme can be related. For the planktonic foraminifera, an attempt has been made to adapt Blow's (1969) zonal scheme for the Late Cenozoic. According to Berggren (1972), the Early/Middle Miocene boundary is placed at the base of the Zone N. 9 of Blow (1969) coincident with the first appearance of *Orbulina suturalis* (the *Orbulina* Datum), which occurs in the middle part of the type Langhian (Cita and Blow, 1969), about 16 million years B.P. This data agrees nearly with an age of 14–16 m.y. B.P. assigned by Ikebe *et al.* (1972) on Japanese volcanic rocks bracketing the *Orbulina* Datum in their radiometric dating with K/Ar method. Thus, the *Orbulina* Datum, the most remarkable one of the datum planes in the Neogene, is useful for determining the Early/Middle Miocene boundary as pointed out by Ikebe *et al.* (1972).

The planktonic foraminiferal study of the type section of the Tortonian has been made by Cita *et al.* (1965), Vervloet (1966), and Cita and Blow (1969). According to Cita and Blow (*op. cit.*), *Globorotalia acostaensis* first occurs somewhat above (about 35 meters) the base of the Tortonian. The first appearance of *G. acostaensis* delineates the boundary between the Zone N. 15 and Zone N. 16 of Blow (1969). Accordingly, the base of the Tortonian Stage is no older than the Zone N. 15. The faunal evidence which cites the Middle/Late Miocene boundary at a level near the first appearance of *Globorotalia acostaensis* defining the base of the Zone N. 16 is thus used by many workers. In the present study, the *Globoquadrina dehiscens* Zone of the present zonal scheme is referable to the Zone N. 15 and Zone N. 16 as discussed in the preceding part of the present paper. Therefore, the Middle/Late Miocene boundary is tentatively placed within the *G. dehiscens* Zone.

The Miocene/Pliocene boundary is considered by Mayer-Eymar (1867) to be located between the Messinian and Tabianian. According to Tongiorgi and Tongiorgi (1964), the Trubi marl in Sicily which was referred by Sequenza (1868) as Zanclean is assignable to the Tabianian. The foraminiferal criteria advanced to date for the recognition of the Miocene/Pliocene boundary are the initial appearance of *Sphaeroidinella dehiscens*, which, according to Blow (1969), occurs somewhat above the base of the Trubi marl of Sicily, occurring within his Zone N. 18. However, Parker (1973), who restudied samples from the Trubi, was not able to confirm the presence of *S. dehiscens* in this section, leaving open the question of positive foraminiferal correlation between the Mediterranean and extra-Mediterranean regions. Furthermore, the level of the first occurrence of *S. dehiscens* in the Boso sequence does not represent the initial appearance of this taxon, but is nearly coincident with the level of the increased upward abundance of *S. dehiscens* in the equatorial Pacific by Hays *et al.* (1969) who noted this level to be one of the most easily recognizable foraminiferal datum planes as discussed in the preceding part of the present paper. Thus, the level of the first occurrence of *S. dehiscens* in the Boso sequence is due to its migration from elsewhere rather than the phylogenetic initial appearance of the taxon. Therefore, the first occurrence of this taxon is no assistance for correlation toward recognizing the Miocene/Pliocene boundary. Recently, Berggren (1973) has summarized data regarding the age of the Miocene/Pliocene boundary in Italy which has been indirectly dated at about 5.0 ± 0.1 m.y. B.P. and placed biostratigraphically between the base of the "c" Event of the Gilbert Reversed Epoch and the top of the Magnetic Epoch 5 on the basis of paleomagnetically dated sequences outside the Mediterranean area. Cita and Ryan (1973) and Ryan (1973) placed the boundary in the uppermost part of the Magnetic Epoch 5 on the basis of data derived from paleomagnetically measured deep-sea cores of DSDP (Leg 13) in the Mediterranean near Italy. Ryan (1973) pointed out that this result agrees reasonably well with the data of 5.2 m.y. B.P. assigned by Van Couvering and Miller (1971) in their radiometrical dating for the Late Miocene marine and non-marine type sections in Europe. Thus, the Miocene/Pliocene boundary is placed somewhere between the upper

part of the Magnetic Epoch 5 and the lower part of the Gilbert Reversed Epoch in deep-sea sediments. If this is accepted, the Miocene/Pliocene boundary for the purpose of the present study can be tentatively placed within the lower part of the *Pulleniatina primalis*/*Globigerina nepenthes* Zone of the present zonal scheme near the boundary between the Gilbert Epoch and Epoch 5. The observation of Ericson *et al.* (1963) that *Globigerina nepenthes* ranges up into the Pliocene was recognized by many workers such as Blow (1969), Hays *et al.* (1969) and others. Cita (1973) noted that the first appearance of *Globorotalia margaritae* coincides closely with the Mediterranean Miocene/Pliocene boundary. Therefore, the presence of *G. margaritae* within the *P. primalis*/*G. nepenthes* Zone confirms the present age assignment. Following Cita and Ryan (1973), the Lower/Upper Pliocene boundary is considered to be coincident with the level of the last occurrence of *G. margaritae*.

A number of recent literatures refer the base of the Pleistocene as the base of the Calabrian in the southern Italy. Banner and Blow (1965a) showed that the base of the Calabrian approximates the first evolutionary appearance of *Globorotalia truncatulinoides* from *G. tosaensis*. The first occurrence of *G. truncatulinoides* above the base of the Calabrian in the southern Italy was also recognized by Bayliss (1969), Lamb (1969), Bandy and Wilcoxon (1970), and Lamb and Beard (1972). Berggren *et al.* (1967) compared the phylogeny of *G. truncatulinoides* with the paleomagnetic stratigraphy in a North Atlantic deep-sea core and showed that this evolution occurred within the Olduvai Event of the Matuyama Reversed Epoch. This evolutionary appearance in the lower part of the Olduvai Event was also recognized in the Atlantic (Glass *et al.*, 1967; Phillips *et al.*, 1968), in the Pacific (Hays *et al.*, 1969; Ujiie and Miura, 1971), and in marine sediments from land sections in New Zealand (Kennett *et al.*, 1971). Hays and Berggren (1971) reviewed the status of the Pliocene/Pleistocene boundary in deep-sea sediments and concluded that the boundary defined by Ericson *et al.* (1963) was correlative with the boundary established in the type section and dated it at about 1.8 m.y. B.P. On the other hand, Nakagawa (1971) demonstrated that the base of the Calabrian at le Castella was considerably higher than the horizon of the Gilsa Event of the Matuyama Reversed Epoch of Cox (1969). Saito (1969) recognized the extinction horizon of *Globigerinoides obliquus* in the le Castella section at the Pliocene/Pleistocene boundary. The last occurrence of *G. obliquus* in the Boso and Kakegawa sections occurs near the level of the first appearance of *G. truncatulinoides*. According to Takayama (1970, 1973), discoasters seem to become extinct near the base of the Calabrian at le Castella, and this horizon appears to be equivalent to the Pliocene/Pleistocene boundary recognized in deep-sea cores by Ericson *et al.* (1963). Takayama (1973) pointed out that discoasters become extinct at the level of the highest shift in coiling direction of *Pulleniatina* from sinistral below to dextral above. Thus, the levels of the first appearance of *G. truncatulinoides* and the last occurrence of discoasters nearly coincide, although the former is slightly lower than the latter. It is, thus, approximately compatible with these evidences that the Pliocene/Pleistocene boundary is recognized as occurring near the level of the first appearance of *G. truncatulinoides*. Consequently, the Pliocene/Pleistocene boundary in the present study is drawn at the base of the *G. truncatulinoides* Zone of the present zonal scheme.

DISCUSSION

The age of the Kazusa Group had previously been suggested on the basis of studies of mollusks, foraminifers, mammals, other kinds of fossils, and paleomagnetism. But opinions on the age diverged considerably as will be discussed in the following lines.

Asano *et al.* (1957, 1958), based upon planktonic foraminifera, discussed the Pliocene/Pleistocene boundary in the central part of the Boso Peninsula, and proposed to place the boundary in the middle part of the Umegase Formation where they thought that the first lowering of water temperature occurred. Their view was accepted by Kamei (1962), Takayama (1967), Onishi (1969), Itihara *et al.* (1973) and others. On the contrary, Hatai (1958), from his study on the molluscan fossils, placed the Pliocene/Pleistocene boundary at the contact between the Chonan and the overlying Mandano Formations because the fauna of the Mandano was decidedly of a cold-water type. Similarly, Aoki (1963, 1964), from his study on the benthonic foraminifera, pointed out that the faunal change in the middle part of the Umegase Formation was not so evident as that emphasized by Asano *et al.* (*op. cit.*). Aoki (*op. cit.*) concluded that the Pliocene/Pleistocene boundary could not be higher than the base of the Chonan Formation because the assemblage from this formation was remarkably of cold-water origin. Nakagawa *et al.* (1969), on the basis of their preliminary interpretation of the magnetic polarity records in the sections along the Yoro and Isumi Rivers, stated that the Kazusa Group is correlative with an interval from the Epoch 6 to Brunhes Normal Epoch. According to them, the Pliocene/Pleistocene boundary is in the middle part of the Umegase Formation as suggested by Asano *et al.* (*op. cit.*). With regard to the Miocene/Pliocene boundary, Takayama (1967) claimed that the basal part of the Kurotaki Formation in the Obitsu River section is the basal Pliocene because of the occurrence of *Sphaeroidinella dehiscens* and *Globorotalia truncatulinoides* as well as the abrupt change of coiling direction in *Pulleniatina* from dextral below to sinistral above in the Kurotaki Formation. Niitsuma (1970) stated that the Epochs 5 and 6 of Nakagawa *et al.* (*op. cit.*) fall within the Gilbert Reversed Epoch and therefore the Miocene/Pliocene boundary lies at the base of the Kurotaki Formation. Recently, Takayama (1973) reported on calcareous nannofossils from the sections along the Yoro and Obitsu Rivers and emphasized that the Pliocene/Pleistocene boundary should be placed within the Kurotaki Formation, at the level of Kd-38 key bed, a stratigraphic position much lower than that of the previous authors. In the present study, the Kazusa Group of the present section is considered to range from the early part of the Matuyama Reversed Epoch to the early part of the Brunhes Normal Epoch, that is, from the Late Pliocene to Late Pleistocene. This seems to be in general agreement with the view of Takayama (1973). The Pliocene/Pleistocene boundary in the present sequence, based upon the first evolutionary appearance of *Globorotalia truncatulinoides*, lies at a horizon in the middle part of the Ohara Formation, the level of HS key bed, and falls just below the basal part of the Olduvai Event of the Matuyama Reversed Epoch (Oda, 1975).

Many contributions have been made on the geographical distribution of Recent planktonic foraminifera. According to the studies of Bradshaw (1959), Bé (1959), Parker (1962), and Bé and Tolderlund (1971), the distribution of Recent planktonic foraminifera in the present oceans is mainly related to the surface water temperature. The planktonic foraminiferal assemblages found in the Kazusa Group are closely comparable with those of the Recent ones. *Globigerina pachyderma* is known to be a cold-water species because of that species living typically in the Arctic and Antarctic regions. Ericson (1959) studied the coiling ratios of *G. pachyderma* in the northern part of the Atlantic and reported that the coiling in this species is dominantly sinistral near the Arctic region, whereas it is dominantly dextral in the temperate area. According to Bé (*op. cit.*) and Bradshaw (*op. cit.*), *Globigerina pachyderma*, *G. quinqueloba* and *G. bulloides* belong to the Subarctic fauna. These three species are interpreted to be principal cold-water species, although they also occur in the temperate region.

Referring to numerous studies on the geographical distribution of Recent planktonic

foraminifera, the species listed below are considered to be warm-water and warm/temperate-water species. *Sphaeroidinella dehiscens*, *Pulleniatina obliquiloculata*, *Globorotalia cultrata*, *G. tumida*, *Globigerinoides conglobatus*, and *G. quadrilobatus* (*s. l.*) are warm-water species. *Globigerinoides ruber*, *Globorotalia crassaformis*, *G. truncatulinoides*, *Orbulina suturalis* and *O. universa* are warm/temperate-water species. Of these warm-water species, *P. obliquiloculata* predominates in the present sequence. Bé (1959) reported that *Globorotalia inflata* dominates in the temperate area in the Atlantic Ocean. This species is interpreted to be temperate-water indicator in this paper, although it often ranges into cold Antarctic waters (Bé, 1969). The stratigraphic changes in the faunal composition within the present sequence is shown in Fig. 20. The frequencies of the cold-water species and the warm-water species vary according to different horizons, the relation being an inverse relationship as shown in Fig. 20. The relation seems to be a reflection of the relative vertical changes in paleo-water temperature.

From the upper part of the Ohara Formation to the basal part of the Kiwada Formation a relatively high abundance of warm-water forms and a low frequency of cold-water forms are recognized. In particular, *Globorotalia tumida* and *Sphaeroidinella dehiscens* are found commonly within this interval. It is considered that this horizon represents the warmest phase of the studied sequence.

Within the lower part of the Kiwada Formation (Kd-38 key bed) warm-water forms gradually decrease in abundance, whereas *Globorotalia inflata* increases. The middle part of the Kiwada Formation shows a higher percentage of dextrally coiling *Globigerina pachyderma* associated with *Globigerina quinqueloba* and a decreasing abundance of *G. inflata* and warm-water forms. It is noticeable that the decrease in abundance of the two tropical species, *S. dehiscens* and *G. tumida*, in this horizon seems to continue upward through the studied sequence. This interval is interpreted to indicate a slight lowering of surface water temperatures.

The warmer interval reappears in the upper part of the Kiwada Formation, which is represented by a relatively high proportion of *Pulleniatina obliquiloculata* and a low proportion of *Globigerina pachyderma*.

In the lower part of the Otadai Formation, a relative decrease in abundance of warm-water forms and a gradual increase in abundance of *Globorotalia inflata* and cold-water forms are recognized. Throughout the sequence above this horizon the decrease of warm-water forms seem to continue, and the cold-water forms and *G. inflata* becomes abundant, and sinistrally coiled forms of *Globigerina pachyderma* constantly occur in a varying frequency. These evidences suggest that this interval was influenced by cool-water conditions. Moreover, *Globorotalia cultrata* and *Sphaeroidinella dehiscens* disappear within the middle part of the Umegase Formation.

Aoki (1963) and Takayama (1967) noted that the uppermost part of the Kakinokidai and the overlying Chonan Formations are characterized by the dominant occurrence of sinistral coiling of *Globigerina pachyderma*. It has been considered that this horizon represents the coldest period of the section along the Yoro and Obitsu Rivers (Fig. 21).

The climatic fluctuation based upon the vertical changes of the planktonic foraminiferal assemblages in the present sequence which were dated in terms of the paleomagnetic scale shows a warming trend across the Olduvai Event, the level of the Pliocene/Pleistocene boundary. This is in agreement with the work of Olsson (1971) in the northeastern Pacific. He interpreted the planktonic foraminiferal data to indicate a warming trend across the Pliocene/Pleistocene boundary. Kent *et al.* (1971), from their work on the distribution of ice-rafted material in the paleomagnetically dated cores in the North Pacific, noted that no significant change in abundance of glacial ice-rafted materials cross the Olduvai Event

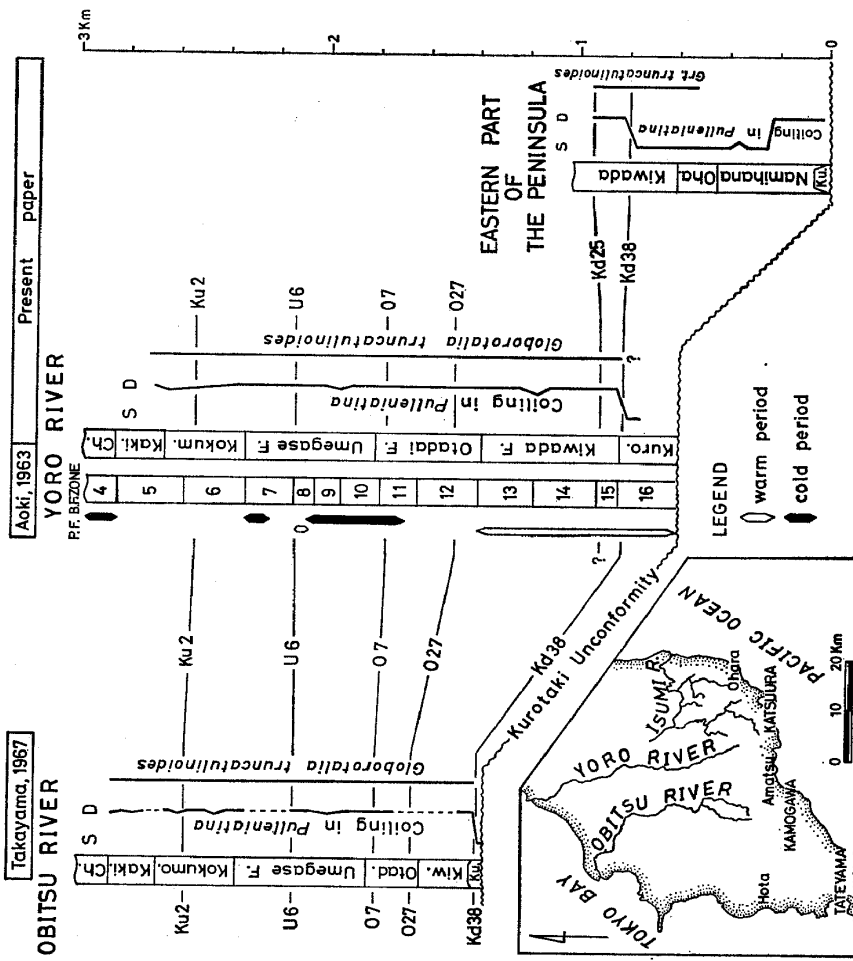


Fig. 21. Columnar sections, coiling direction of the genus *Pulleniatina* and stratigraphic distribution of *Globorotalia truncatulinoides* in the Obitsu River section, Yoro River section and a section in the eastern part of the Boso Peninsula (see the attached index map for the location of these sections). These sections are correlated with one another by means of key beds. The benthonic foraminiferal zones and climatic fluctuations based upon planktonic foraminifera (Aoki, 1963) are also shown for the Yoro River section.

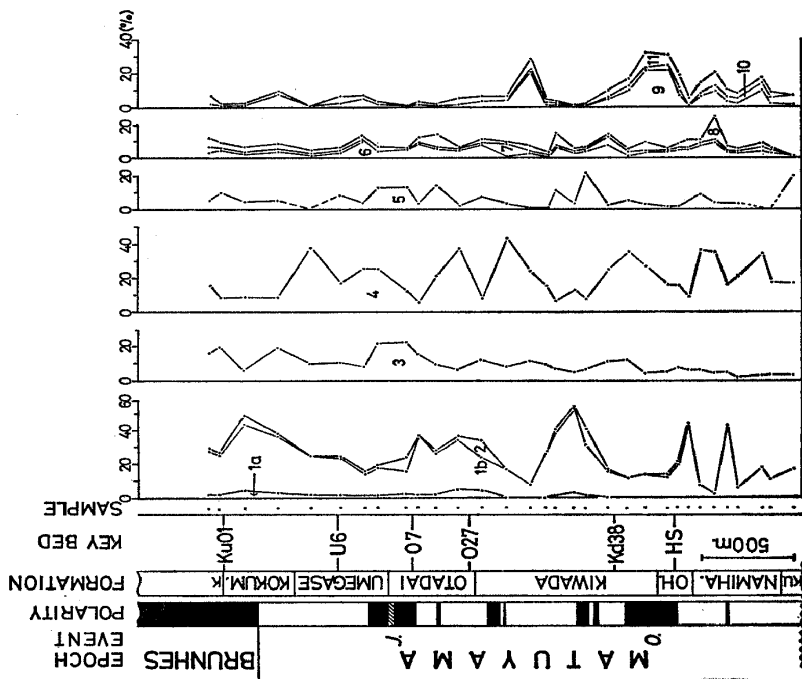


Fig. 20. Relative abundance (%) of planktonic foraminifera in the Kazusa Group of the Boso Peninsula.

- 1a: *Globigerina pachyderma* (sinistral)
- 1b: *Globigerina pachyderma* (dextral)
- 2: *Globigerina quinqueloba*
- 3: *Globigerina bulloides*
- 4: *Globorotalia inflata*
- 5: *Globigerinita glutinata*
- 6: *Globigerinoides ruber*
- 7: *Orbulina* spp.
- 8: *Globorotalia crassaformis*+*Globorotalia truncatulinoides*
- 9: *Pulleniatina obliquiloculata*
- 10: *Sphaeroidinella dehiscens*
- 11: *Globorotalia tumida*+*Globorotalia cultrata*+*Globigerinoides quadrilobatus* Group

of the Matuyama Reversed Epoch. Thus, these aforementioned data in the North Pacific support the conclusion of McIntyre *et al.* (1967) and Hays *et al.* (1969) who interpreted that the coccoliths and diatoms indicate a warming trend across the Pliocene/Pleistocene boundary.

Kent *et al.* (1971) pointed out that a marked increase of ice-rafted material occurred just below the Jaramillo Event, suggesting that it might mark the initiation of mid-latitude glaciation. According to them, a major coiling shift of *Globigerina pachyderma* from dextral below to sinistral above occurs just below the Jaramillo Event. Comparable changes in the coiling direction of *G. pachyderma* were, however, not observed in the correlative horizon in the present section. It may be masked by the presence of warmer surface water temperature around the present area. However, a general cooling trend, denoted by the upward decrease in the abundance of warm-water fauna associated with an increased abundance of cold-water fauna and influx of sinistrally coiling *G. pachyderma* in varying frequency, occurs just below the Jaramillo Event prior to the onset of severe cooling during the early part of the Brunhes Normal Epoch in the present sequence. This is also in agreement with the work of Olsson (1971) who suggested a climatic deterioration caused by the onset of the Pleistocene glacial climate just before the Jaramillo Event.

From the study of the planktonic foraminifers from the Kazusa Group, Asano *et al.* (1957, 1958) pointed out that the first remarkable lowering of water temperature occurred at the level near the U-6 key bed in the middle part of the Umegase Formation. From benthonic and planktonic foraminiferal studies from the Yoro River section, Aoki (1963) subdivided the Kazusa Group into 16 zones as shown in Fig. 21. Based upon changes in the composition of planktonic foraminiferal assemblages as related to water temperature fluctuations, Aoki (*op. cit.*) concluded that deposition under the influence of cold-water took place for the upper part of the Otadai Formation to the lower part of the Umegase Formation (the upper part of zone 11 to the lower half of zone 8), the uppermost part of the Umegase Formation (the upper half of zone 7), and the Chonan Formation (zone 4). And the fauna of zone 4 represents a particularly cold phase among these cold-water horizons. Takayama (1967), from his observation on the planktonic foraminiferal change in the Obitsu River section, considered that the upper part of the Umegase Formation, the lower part of the Kokumoto Formation, and the uppermost part of the Kakinokidai Formation correspond to cold periods and the uppermost part of the Kakinokidai Formation, the top of his studied section, represents the coldest period. Itihara *et al.* (1973) re-interpreted Aoki's result and noted that warm-water facies was prevalent in the horizons below the O-27 key bed of the Otadai Formation, but cold-water environments began to dominate above the key bed. Based upon the climatic fluctuation constructed through the re-interpretation of Onishi's pollen diagram (1969), Itihara *et al.* (*op. cit.*) showed that the climate was generally temperate throughout the lower and middle parts of the Kazusa Group but an indication of increased degree of climatic fluctuation first appeared in the uppermost part of the Otadai Formation. Thus, on the basis of the change in planktonic foraminifera and pollen assemblage it seems certain that the first indication of climatic deterioration was in the Otadai Formation and climatic fluctuation became more evident upwards. This seems to favor the conclusion of the present study and also to be interpreted as showing a cooling near the Jaramillo Event. This feature corresponds well with Selli's (1967) division of the Pleistocene that the upper half represents the glacial era and the lower half, the preglacial Pleistocene. The colder glacial Pleistocene is considered to be equivalent to the Brunhes, perhaps including the uppermost part of the Matuyama Reversed Epoch (near the Jaramillo Event and upwards).

From recent studies of deep-sea cores, evidence for a marked cooling in the Middle

Pleistocene has also been found in the Antarctic by Hays and Opdyke (1967), in the North Atlantic by Berggren *et al.* (1967), and in the equatorial Pacific by Hays *et al.* (1969). These data point out a general climatic deterioration occurring during the Jaramillo Event and continuing up to the Brunhes/Matuyama boundary and therefore are in accordance with the climatic history derived from the present study.

Hays *et al.* (1969) also demonstrated that the upward decrease in abundance of *Sphaeroidinella dehiscens* is recognized at the Brunhes/Matuyama boundary in the equatorial Pacific which may be a further evidence of cooling. This change is not recognized in the present sequence, but the highest occurrence of *S. dehiscens* is observed within that part lying between the Brunhes/Matuyama boundary and Jaramillo Event, and may be evidence of cooling possibly due to the present area being under the influence of much colder surface temperature.

FAUNAL REFERENCE LIST

Planktonic foraminiferal species are alphabetically listed below, but their occurrences and apparent ranges in the present areas are not included because they are given in Tables 1, 2 and 3. Most of the taxa identified are illustrated with the aid of a scanning microscope (JSM-U3) in Plates 1 to 10 of this article. The original references are given for each of the species, and brief remarks are added to some of them. Additional references are selected from those remarks and illustrations which were helpful for the present study. All types are catalogued and deposited in the Institute of Geology and Paleontology, Tohoku University.

Globigerina angustiumbilitata Bolli

Globigerina ciperiensis angustiumbilitata Bolli, 1957b, p. 109, pl. 22, figs. 12a-13c.

Globigerina angustiumbilitata Bolli. Blow, 1959, p. 172, pl. 7, figs. 2a-c; Takayanagi and Saito, 1962, p. 82, pl. 28, figs. 3a-c; Saito and Maiya, 1973, p. 118, pl. 17, figs. 5, 6a, b.

Globigerina apertura CushmanPl. 1, figs. 1a, b.

Globigerina apertura Cushman, 1918, p. 57, pl. 12, figs. 8a-c (*fide* Ellis and Messina, 1940 *et seq.*).

This species is distinguished from *Globigerina bulloides* d'Orbigny by its large and highly arched aperture with a faint rim.

Globigerina bulloides d'OrbignyPl. 1, figs. 2, 3.

Globigerina bulloides d'Orbigny, 1826, p. 277 (no figure given), (*fide* Ellis and Messina, 1940 *et seq.*); Brady, 1884, p. 593, pl. 79, figs. 7a-c; Bolli, Loeblich and Tappan, 1957, p. 31, pl. 4, figs. 1a-c; Banner and Blow, 1960b, p. 3, pl. 1, figs. 1a-c (lectotype), 4a-c; Takayanagi and Saito, 1962, p. 84, pl. 24, figs. 12a-c; Parker, 1962, p. 221, pl. 1, figs. 1-8.

This species is characterized by its fairly large, arched aperture without a lip or rim, and usually having four chambers in the last whorl.

Globigerina decoraperta Takayanagi and SaitoPl. 1, figs. 4, 5, 6.

Globigerina druryi Akers decoraperta Takayanagi and Saito, 1962, p. 85, pl. 28, figs. 10a-c.

This species is characterized by its high-arched aperture with a thickened rim. The aperture is small and subcircular in outline. This species is closely related to *Globigerina druryi* Akers, but differs from the latter in having a larger, high-arched aperture with a thickened rim instead of a low-arched aperture with a thin lip. It also resembles *Globigerina woodi* Jenkins, but it is distinguished from it in having much larger and high-spined test.

Globigerina druryi AkersPl. 1, figs. 10, 11.

Globigerina druryi Akers, 1955, p. 645, pl. 65, figs. 1a-c; Blow, 1969, p. 318, pl. 14, fig. 4.

This species is characterized by having a rather small test, coarsely perforate wall, and a small low-arched aperture with a distinct lip, all of which suggest a close affinity of this species to *Globigerina nepenthes* Todd.

Globigerina falconensis Blow.Pl. 1, figs. 8, 9.

Globigerina falconensis Blow, 1959, p. 177, pl. 9, figs. 40a-c, 41; Takayanagi and Saito, 1962, p.

86, pl. 24, figs. 13a-c; Parker, 1962, p. 224, pl. 1, figs. 14, 16-19; Parker, 1967, p. 150, pl. 19, figs. 11a-c; Blow, 1969, p. 319, pl. 16, fig. 1.

This species is distinguished from allied forms in having a low-arched aperture with a prominent lip.

Globigerina foliata BolliPl. 1, fig. 7.

Globigerina foliata Bolli, 1957a, p. 111, pl. 24, figs. 1a-c; Blow, 1959, p. 177, pl. 10, figs. 42a-c; Takayanagi and Saito, 1962, p. 86, pl. 25, figs. 1a-c.

This species is characterized by its discrete and spherical chambers which increase rapidly in size as added.

Globigerina nepenthes ToddPl. 1, figs. 12, 13, 14a, b.

Globigerina nepenthes Todd, 1957, p. 301, pl. 78, figs. 7a-c; Bolli, 1957a, p. 111, pl. 24, figs. 2a-c; Blow, 1959, p. 178, pl. 8, figs. 44, 45; Saito, 1962, p. 332, pl. 5, figs. 1a-4c, pl. 52, figs. 1-8; Blow, 1969, p. 320, pl. 14, fig. 5; Lamb and Beard, 1972, p. 47, pl. 4, figs. 1-8.

The specific characters of this taxon have been discussed in detail by Saito (1962). This species is characterized by its tightly coiled test with its protruding, thumblike last chamber. It was found in all sections studied. According to Blow (1969), Hays *et al.* (1969), and Parker (1973), it ranges upward through the lower Pliocene. In the present study, this species was last recorded in the Early Pliocene.

Globigerina pachyderma (Ehrenberg)Pl. 2, figs. 1, 2, 3, 4.

Aristerospira pachyderma Ehrenberg, 1861, p. 276, 277, 303 (*fide* Ellis and Messina, 1940 *et seq.*); Ehrenberg, 1873, p. 386, pl. 1, fig. 4 (*fide* Ellis and Messina, 1940 *et seq.*).

Globigerina pachyderma (Ehrenberg). Brady, 1884, p. 600, pl. 114, figs. 19, 20; Bradshaw, 1959, p. 36, pl. 6, figs. 20-23; Bé, 1960, p. 64, text-fig. 1; Bandy, 1970, p. 671, text-fig. 1; Takayanagi and Saito, 1962, p. 89, pl. 29, figs. 4a-c; Parker, 1962, p. 224, pl. 1, figs. 26-35, pl. 2, figs. 1-6.

Globigerina bulloides d'Orbigny var. *borealis* Brady. Banner and Blow, 1960b, p. 4, 5, pl. 3, figs. 4a-c (lectotype).

A multitude of opinion exists as to the taxonomic and stratigraphic position of this species. Forms referred to this species in this article are consistently smaller than its allied forms. They are more compact and usually have an apertural lip and four to four and a half subglobular chambers in the last whorl. Studies on the coiling ratios of *Globigerina pachyderma* have repeatedly demonstrated that their preferred direction of coiling has a significant importance as a paleoclimatic indicator. Dextral forms generally predominate in the studied section, although sinistrally coiled forms occur in some horizons. The sinistrally coiled specimens are usually smaller than the dextrally coiled forms.

Globigerina parabulloides Blow

Globigerina parabulloides Blow, 1959, p. 179, pl. 10, figs. 46a-c; Takayanagi and Saito, 1962, p. 90, pl. 25, figs. 3a-c; Blow, 1969, p. 320, pl. 18, figs. 1, 2 (ideotype).

This species is distinguished from its allied forms such as *Globigerina praebulloides* Blow and *G. bulloides* d'Orbigny, by having a smaller umbilicus, a smaller aperture with distinct but narrow rim or lip, and an elongate equatorial profile, as defined by Blow (1959). These features are also observed on the present specimens.

Globigerina praebulloides praebulloides BlowPl. 1, figs. 15, 16.

Globigerina praebulloides Blow, 1959, p. 180, pl. 8, figs. 47a-c; Jenkins, 1960, p. 352, pl. 2, figs. 1a-c.

Globigerina praebulloides praebulloides Blow. Blow and Banner, 1962, p. 92, pl. IX, figs. O-Q; Blow, 1969, p. 321, pl. 2, figs. 7-9; Saito and Maiya, 1973, p. 117, pl. 17, figs. 1a-c.

This species is the ancestor of *Globigerina bulloides* d'Orbigny and differs from the latter species in having an elongate equatorial profile, chambers which rapidly increase in size as added, and a rather low-arched aperture with a faint lip (Banner and Blow, 1960).

Globigerina praebulloides pseudociperoensis BlowPl. 2, figs. 5, 6.

Globigerina praebulloides pseudociperoensis Blow, 1969, p. 381, pl. 17, figs. 8, 9; Saito and Maiya, 1973, p. 118, pl. 1, figs. 4a-c.

This subspecies is morphologically close to *Globigerina ciperoensis ciperoensis* Bolli, but the former species is distinguished from the latter one by the more rapidly opening and higher spire.

Globigerina quinqueloba NatlandPl. 2, figs. 5, 6.

Globigerina quinqueloba Natland, 1938, p. 149, pl. 6, figs. 7a-c (*fide* Ellis and Messina, 1940 *et*

seq.); Parker, 1962, p. 225, pl. 2, figs. 7-16.

This species has been regarded as a descendant of *Globigerina angustiumbilitata* Bolli by Asano *et al.* (1968). It is distinguished by generally having five chambers in the final whorl, the spinose last chamber having a flaplike lip extending over the umbilicus.

Globigerina woodi JenkinsPl. 2, figs. 7a, b.

Globigerina woodi Jenkins, 1960, p. 325, pl. 2, figs. 2a-c; Takayanagi and Saito, 1962, p. 91, pl. 25, figs. 6a-c; Saito and Maiya, 1973, p. 118, pl. 17, figs. 2a, b, 3.

Globigerina woodi woodi Jenkins. Jenkins, 1971, p. 159, 160, pl. 18, figs. 548-550.

This species is characterized by having a thick and coarsely pitted wall, a high-arched aperture with a distinct rim, and U-shaped sutures. *Globigerina woodi* differs from *Globigerina decorapetra* Takayanagi and Saito in having a larger and low-spired test.

Globigerinatella insueta Cushman and StainforthPl. 3, fig. 13.

Globigerinatella insueta Cushman and Stainforth, 1945, p. 69, pl. 13, figs. 7-9; Brönnimann, 1950, p. 80, pl. 13, figs. 1-12; Bolli, Loeblich and Tappan, 1957, p. 38, pl. 8, figs. 4-7c; Blow, 1959 (part), p. 205, pl. 15, figs. 97, 98 (not fig. 95); Saito, 1963, p. 203, pl. 54, figs. 2, 3; Blow, 1969, p. 330, pl. 26, figs. 1-7.

This species is characterized by its areal pustules or secondary bulla and its areal secondary apertures. The figured specimen (pl. 3, fig. 13) shows the characteristic areal secondary apertures of this species.

Globigerinella aequilateralis (Brady)Pl. 2, figs. 8, 9.

Globigerinella aequilateralis Brady, 1879, p. 285 (*fide* Ellis and Messina, 1940 *et seq.*); Brady, 1884, p. 605, pl. 80, figs. 18-21.

Globigerinella aequilateralis (Brady). Cushman, 1927, p. 87, pl. 19, fig. 7; Bradshaw, 1959, p. 38, pl. 7, figs. 1, 2; Jenkins, 1971, p. 77, pl. 2, figs. 47-49; Saito, Thompson and Breger, 1976, p. 281, pl. 3, figs. 1a-2b, pl. 6, fig. 7, pl. 8, figs. 3, 8.

Hastigerina aequilateralis (Brady). Bolli, Loeblich and Tappan, 1957, p. 29, pl. 3, fig. 4.

Hastigerina (Hastigerina) siphonifera (d'Orbigny). Banner and Blow, 1960a, p. 22, text-figs. 2a-c (lectotype), 3a, b.

Hastigerina siphonifera (d'Orbigny). Takayanagi and Saito, 1962, p. 75, pl. 24, figs. 1a, b.

Globigerinella siphonifera (d'Orbigny). Parker, 1962, p. 228, pl. 2, figs. 22-28; Parker, 1967, p. 152, pl. 22, figs. 5a, b.

Not *Glonigerina siphonifera* d'Orbigny, 1839, p. 83, pl. 4, figs. 15-18 (*fide* Ellis and Messina, 1940 *et seq.*).

The present writer follows Parker's opinion (1962) that the genus *Hastigerina* is distinguished from *Globigerinella* in having a smooth and not spinose wall in the adult stage. D'Orbigny's species has been disinterred by Banner and Blow (1960a) with their designation of a lectotype. Banner and Blow (*op. cit.*) regarded *Globigerinella aequilateralis* as a junior synonym of *Globigerina siphonifera*, but the writer agrees with Todd (1963), Bandy (1964), and Jenkins (1971) that the lectotype of *G. siphonifera* chosen by Banner and Blow (1960a) does not conform to either d'Orbigny's original figure or his description. Saito *et al.* (1976) noted that *Globigerinella aequilateralis* is considered the more acceptable name for specimens of their study because of the uncertainty as to whether the lectotypified specimen was indeed one of the original syntypes of d'Orbigny's *G. siphonifera* and because of marked morphological differences between the original figures of d'Orbigny and lectotype chosen by Banner and Blow (1960a). Saito *et al.* (1976) also noted that the specimen of d'Orbigny resembles more closely those specimens currently classified by many authors as *Globigerina bulloides* d'Orbigny or *G. calida* Parker.

Specimens of *Globigerinella aequilateralis* are rare in the present sequence. They are initially trochoid, becoming planispiral and involute as mentioned previously by Parker (1962), but show often incomplete planispiral coiling of the test. Their test surface is distinctively spinose and differ from the closely related *Globorotalia obesa* Bolli in having an aperture extending over the periphery and in having a planispirally coiled adult test.

Globigerinella glutinata (Egger)Pl. 2, fig. 10.

Globigerinella glutinata Egger, 1893, p. 371, pl. 13, figs. 19-21; Saito, 1963, p. 185, pl. 56, fig. 4.

Globigerinella glutinata (Egger). Parker, 1962, p. 246, pl. 9, figs. 1-16; Parker, 1967, p. 146, pl. 17, figs. 3a-5; Matoba, 1967, p. 258, pl. 30, figs. 6, 7; Saito and Maiya, 1973, p. 121, pl. 19, figs. 1a-c.

- Thin and finely perforate specimens of this species are found with or without having a bulla. It is also found to have a low-arched elongate umbilical aperture with a thin lip in these specimens lacking the bulla.
- Globigerinoides bollii* Blow
Globigerinoides bollii Blow, 1959, p. 189, pl. 10, figs. 65a-c; Takayanagi and Saito, 1962, p. 93, pl. 25, figs. 12a-c.
- Globigerinoides conglobatus* (Brady)Pl. 2, figs. 12, 13.
Globigerina conglobata Brady, 1879, p. 286 (no figure given), (*fide* Ellis and Messina, 1940 *et seq.*); Brady, 1884, p. 603, pl. 80, figs. 1-5, pl. 82, fig. 5; Banner and Blow, 1960b, p. 6, 7, pl. 4, figs. 4a-c (lectotype) [written as *Globigerina conglobata* Brady 1879=*Globigerinoides conglobatus* (Brady) in pl. 4].
Globigerinoides conglobatus (Brady). Takayanagi and Saito, 1962, p. 93, pl. 25, figs. 11a-c; Parker, 1962, p. 229, pl. 3, figs. 1-5; Parker, 1967, p. 154, pl. 20, figs. 3a-4c; Lamb and Beard, 1972, p. 48, pl. 33, figs. 4, 6, 7.
 The species is characterized by having a coarsely pitted test wall and an embracing globe-like test with four chambers in the last whorl. The aperture is rather narrow.
- Globigerinoides elongatus* (d'Orbigny)Pl. 3, figs. 4a, b.
Globigerina elongata d'Orbigny, 1826, p. 277 (*fide* Ellis and Messina, 1940 *et seq.*); Banner and Blow, 1960b, p. 12, pl. 3, figs. 10a-c (lectotype) [written as *Globigerina conglobata* d'Orbigny 1826=*Globigerinoides elongatus* (d'Orbigny) in pl. 3].
Globigerinoides elongatus (d'Orbigny). Takayanagi and Saito, 1962, p. 295, pl. 26, figs. 8a-c; Saito, 1963, p. 194, pl. 56, figs. 11a, b.
 This species is characterized by having very elongate chambers in the last whorl, especially the last formed chamber. It differs from *Globigerinoides ruber* (d'Orbigny) in having the ultimate chamber laterally much compressed to show a sub-triangular outline in umbilical view.
- Globigerinoides extremus* Bolli and BermúdezPl. 3, figs. 5, 6.
Globigerinoides obliquus extremus Bolli and Bermúdez, 1965, p. 159, pl. 1, figs. 10-12; Blow, 1969, p. 324, pl. 21, figs. 2, 3.
Globigerinoides extremus Bolli and Bermúdez. Lamb and Beard, 1972, p. 48, pl. 32, figs. 1-6.
 This species is distinguished from *Globigerinoides obliquus* Bolli by having a more oblique and laterally much compressed last chamber in the final whorl.
- Globigerinoides gomitulus* (Seguenza)
Globigerina gomitulus Seguenza, 1880, p. 308, pl. 17, figs. 16,16a (*fide* Ellis and Messina, 1940 *et seq.*).
- Globigerinoides japonicus* Saito and Maiya
Globigerinoides japonicus Saito and Maiya, 1973, p. 121, pl. 19, figs. 4a-6b.
 This species is distinct because of its single spiral supplementary aperture and a rather high trochospiral test, the features which distinguish it from *Globigerinoides quadrilobatus* (*s. l.*).
- Globigerinoides obliquus* BolliPl. 3, figs. 7, 8, 9.
Globigerinoides obliqua Bolli, 1957a, p. 113, pl. 25, figs. 9a-10c; Blow, 1959, p. 191, pl. 11, figs. 68a, b.
Globigerinoides obliquus Bolli. Takayanagi and Saito, 1962, p. 96, pl. 25, figs. 10a-c; Matoba, 1967, p. 258, pl. 30, figs. 2a,b.
 This species is distinguished from the other species of the genus *Globigerinoides* by having a compressed subquadrate final chamber and a relatively large, arched primary aperture.
- Globigerinoides quadrilobatus immaturus* LeRoyPl. 2, figs. 14, 15.
Globigerinoides sacculiferus (Brady) var. *immatura* LeRoy, 1939, p. 263, pl. 3, figs. 19-21.
Globigerinoides triloba immatura LeRoy. Bolli, 1957a, p. 113, pl. 25, figs. 3a-4c; Blow, 1959, p. 118, pl. 11, figs. 62a, b; Jenkins, 1960, p. 354, pl. 2, figs. 7a-c.
Globigerinoides immaturus LeRoy. Takayanagi and Saito, 1962, p. 95, pl. 27, figs. 2a, b.
 This subspecies is closely related to *Globigerinoides quadrilobatus sacculifer* (Brady), but it differs from the latter by not having an elongate or sacklike terminal chamber. It also differs from *Globigerinoides quadrilobatus trilobus* (Reuss) in having the final chamber which is smaller than the earlier chambers.
- Globigerinoides quadrilobatus sacculifer* (Brady)Pl. 3, figs. 1, 2, 3.
Globigerina sacculifer Brady, 1877, p. 535 (no figure given), (*fide* Ellis and Messina, 1940 *et seq.*);

- Brady, 1884, p. 604, pl. 80, figs. 11-17, pl. 82, fig. 4; Banner and Blow, 1960b, p. 21, pl. 4, figs. 1a-c (lectotype) [written as *Globigerina sacculifer* Brady 1877=*Globigerinoides quadrilobatus* (d'Orbigny) subsp. *sacculifer* (Brady) in pl. 4].
- Globigerinoides triloba sacculifer* (Brady). Bolli, 1957a, p. 113, pl. 25, figs. 5a-6; Blow, 1959, p. 188, pl. 11, figs. 63a, b.
- Globigerinoides sacculifer* (Brady). Takayanagi and Saito, 1962, p. 97, pl. 26, figs. 11a-c; Parker, 1967, p. 156, pl. 21, figs. 1a-2c, 4a-c.
- Globigerinoides quadrilobatus sacculifer* (Brady). Parker, 1962, p. 229, pl. 3, figs. 6-10.
- This subspecies is characterized by having an elongate, well-lobulate final chamber with or sometimes without development of the sacklike form. Specimens with the well-developed sacklike chamber are commonly found in the stratigraphic interval from the *Pulleniatina primalis*/*Globigerina nepenthes* Zone to the *Globorotalia truncatulinoides* Zone of the present author.
- Globigerinoides quadrilobatus trilobus* (Reuss) Pl. 2, fig. 11.
- Globigerina triloba* Reuss, 1850, p. 374, pl. 47, figs. 11a-d (*vide* Ellis and Messina, 1940 *et seq.*).
- Globigerinoides triloba* (Reuss). Blow, 1956, p. 62, text-fig. 1, nos. 1-3.
- Globigerinoides triloba triloba* (Reuss). Bolli, 1957a, p. 112, pl. 25, figs. 2a-c; Blow, 1959, p. 189, pl. 11, figs. 60a, b.
- Globigerinoides trilobus* (Reuss). Takayanagi and Saito, 1962, p. 98, pl. 27, figs. 4a, b; Saito, 1963, p. 199, pl. 54, fig. 15.
- This subspecies is distinct in having an inflated final chamber which embraces much of the earlier chambers. It differs from *Globigerinoides quadrilobatus immaturus* LeRoy in having the final chamber which is larger than all the earlier chambers combined. It also differs from *Praeorbulina glomerosa* (*s. l.*) in the absence of multiple sutural apertures around the lower margin of the last chamber.
- Globigerinoides ruber* (d'Orbigny) Pl. 2, figs. 18, 19.
- Globigerina rubra* d'Orbigny, in Ramon de la Sagra, 1839, p. 82 (plates published separately, vol. 8, pl. 4, figs. 12-14), (*vide* Ellis and Messina, 1940 *et seq.*); Banner and Blow, 1960b, p. 19, pl. 3, figs. 8a, b (lectotype) [written as *Globigerina rubra* d'Orbigny 1839=*Globigerinoides ruber* (d'Orbigny) in pl. 3]; Bolli, Loeblich and Tappan, 1957, p. 32, pl. 4, figs. 2a-c.
- Globigerinoides ruber ruber* (d'Orbigny). Takayanagi and Saito, 1962, p. 96, pl. 26, figs. 9a-c; Saito, 1963, p. 197, pl. 56, figs. 9a, b.
- Globigerinoides ruber* (d'Orbigny). Matoba, 1967, p. 258, pl. 30, figs. 2a, b; Blow, 1969, p. 326, pl. 21, figs. 4, 7.
- This species is distinguished from other species of the genus *Globigerinoides* by its primary aperture which is situated symmetrically above the suture between the penultimate and antepenultimate chambers.
- Globigerinoides sicanus* De Stefani Pl. 3, figs. 10a, b.
- Globigerinoides sicana* De Stefani, 1950, p. 9, pl. 13, figs. 6, 10, 11 (*vide* Blow, 1969).
- Globigerinoides bisphericus* Todd. Blow, 1956, p. 62, text-fig. 1, nos. 4-8, text-fig. 2, nos. 10, 11; Blow, 1959, p. 189, pl. 11, fig. 64; Bolli, 1957a, p. 114, pl. 27, figs. 1a, b.
- Globigerinoides sicanus* De Stefani. Blow, 1969, p. 326, pl. 3, figs. 10, 11 (reproduction of holotype). The writer follows the Blow's (1969) opinion that *Globigerinoides sicanus* is a prior synonym of *Globigerinoides bisphericus* Todd. This species is characterized by having three semicircular apertures on the last chamber. Its test consists largely of the three later chambers, of which the last formed one is nearly equal in size with the penultimate and antepenultimate chambers combined. The specimens referred to this species were found in the Lower to Middle Miocene and have a short stratigraphic distribution.
- Globigerinoides subquadratus* Brönnimann Pl. 3, figs. 11, 12.
- Globigerinoides subquadratus* Brönnimann, in Todd *et al.*, 1954, p. 680, pl. 1, figs. 5, 8a-c; Blow, 1969, p. 327, pl. 21, figs. 5, 6.
- Globigerinoides ruber subquadratus* Brönnimann. Saito, 1963, p. 197, pl. 54, figs. 12a, b.
- Cordey (1967) has already distinguished between *Globigerinoides subquadratus* and *G. ruber* (d'Orbigny) in phylogeny and ontogeny, although they are extremely closely homeomorphic in their adult stages. As noted by Cordey, however, there are differences in the earlier ontogenetic stages of these taxa which allow the recognition of separate morphological entities. In addition, there are differences in the wall texture between these two forms as pointed out by Blow

(1969). Thus, the present writer agrees with Cordey that both *G. subquadratus* and *G. ruber* can be taxonomically differentiated. These two forms are separated in time and their ranges do not overlap.

- Globigerinoides tenellus* ParkerPl. 2, figs. 16, 17.
Globigerinoides tenella Parker, 1958, p. 280, pl. 6, figs. 7-9.
Globigerinoides tenellus Parker. Parker, 1962, p. 232, pl. 4, figs. 11, 12.
 This species was originally described from bottom sediments of the eastern Mediterranean. The present specimens are characteristic in having a small test, with a large and elongate umbilical aperture and depressed sutures, the features which distinguish it from *Globigerinoides ruber* (d'Orbigny).
- Globoquadrina altispira* (Cushman and Jarvis)Pl. 4, figs. 1a-c, 2, 3.
Globigerina altispira Cushman and Jarvis, 1936, p. 5, pl. 1, figs. 13a-14.
Globoquadrina altispira (Cushman and Jarvis). Bolli, Loeblich and Tappan, 1957, p. 32, pl. 5, figs. 5a-c.
Globoquadrina altispira altispira (Cushman and Jarvis). Bolli, 1957a, p. 111, pl. 24, figs. 7a-8b; Blow, 1959, p. 183, pl. 3, figs. 5a-c; Takayanagi and Saito, 1962, p. 92, pl. 25, figs. 7a, b; Saito, 1963, p. 189, pl. 55, figs. 6a-c.
Globoquadrina altispira globosa Bolli, 1957a, p. 111, pl. 24, figs. 9a-10c; Takayanagi and Saito, 1962, p. 92, pl. 25, figs. 8a, b; Saito, 1963, p. 189, pl. 55, figs. 8a-c.
 This species is comparatively rare in Japan and is characterized by its high-spired test and slightly compressed chambers.
- Globoquadrina dehiscens advena* BermúdezPl. 4, figs. 7a, b.
Globoquadrina quadrina var. *advena* Bermúdez, 1949, p. 287, pl. 22, figs. 36-38.
Globoquadrina dehiscens (Chapman, Parr and Collins). Bolli, 1957a, p. 111, pl. 24, figs. 4a-c.
Globoquadrina dehiscens advena Bermúdez. Blow, 1959, p. 182, pl. 8, figs. 50a, b; Jenkins, 1960, p. 355, pl. 3, figs. 4a-c; Blow, 1969, p. 341, pl. 29, fig. 2.
 This subspecies is distinguished from the typical form by having a more tightly coiled test in which the umbilicus is nearly closed and the finely pitted apertural face is concealed. This subspecies is stratigraphically restricted.
- Globoquadrina dehiscens dehiscens* (Chapman, Parr and Collins)Pl. 4, figs. 5, 6.
Globorotalia dehiscens Chapman, Parr and Collins, 1934, p. 569, pl. 11, figs. 36a-c.
Globorotalia quadraria Cushman and Ellisor, 1939, p. 11, pl. 2, figs. 5a-c.
Globoquadrina dehiscens (Chapman, Parr and Collins). Bolli, Loeblich and Tappan, 1957, p. 31, pl. 5, figs. 5a-c; Bolli, 1957a, p. 111, pl. 24, figs. 3a-c (not figs. 4a-c: *Globoquadrina dehiscens advena*); Saito, 1963, p. 191, pl. 55, figs. 9a-c; Lamb and Beard, 1972, p. 49, pl. 9, figs. 6-9.
Globoquadrina dehiscens dehiscens (Chapman, Parr and Collins). Blow, 1959, p. 182, pl. 8, figs. 49a-c; Jenkins, 1960, p. 354, pl. 3, figs. 3a-c; Blow, 1969, p. 341, pl. 29, fig. 1.
 This species is characterized by having a low trochospiral test with a flattened spiral side and strongly convexed umbilical side, a subquadrate equatorial profile, and a rather large and open umbilicus with an asymmetrical tooth. The apertural face is finely punctate and is distinct from the coarsely pitted other parts of the test.
- According to Blow (1969), *Globoquadrina dehiscens* and *G. venezuelana* (Hedberg) became extinct in the lower Pliocene. According to Parker (1967), the former species became extinct somewhat earlier than the latter one, namely *G. dehiscens* at the Miocene/Pliocene boundary or within the Upper Miocene, and *G. venezuelana* in the Upper or Middle Pliocene. In the present study, *G. dehiscens* had a shorter range than *G. venezuelana*, and last occurred in the Upper Miocene.
- Globoquadrina dutertrei* (d'Orbigny)Pl. 4, figs. 10, 11a, b, 12, 13.
Globigerina rotundata d'Orbigny, 1826 (*nomen nudum*), (*fide* Ellis and Messina, 1940 *et seq.*); Fornasini, 1898, p. 208, text-fig. 3 (*fide* Ellis and Messina, 1940 *et seq.*); Banner and Blow, 1960b, p. 11, pl. 2, fig. 2 (lectotype) [written as *Globigerina rotundata* d'Orbigny 1898=*Globigerina dutertrei* d'Orbigny in pl. 2].
Globigerina dutertrei d'Orbigny, 1839, p. 84 (plates published separately, vol. 8, pl. 4, figs. 19-20), (*fide* Ellis and Messina, 1940 *et seq.*); Banner and Blow, 1960b, p. 11, pl. 2, figs. 1a-c (lectotype).
Globoquadrina dutertrei (d'Orbigny). Parker, 1962, p. 242, pl. 7, figs. 1-13, pl. 8, figs. 1-4; Parker, 1967, p. 168, pl. 25, figs. 7a-c; Lamb and Beard, 1972, p. 50, pl. 8, figs. 7-9.

The current concept of this species and its synonymic references have been presented by Parker (1962, 1967). Parker (1962) considered this species to be closely related to *Globoquadrina altispira* (Cushman and Jarvis), but she later reconsidered and now regards it as being closer to *Globorotalia humerosa* Takayanagi and Saito. Lamb and Beard (1972) showed evolutionary stages leading to the development of *Globoquadrina dutertrei*. This species differs from *G. humerosa* by having more numerous chambers, higher spired with respect to coiling, and being larger.

- Globoquadrina larmeyi* AkersPl. 4, figs. 4a, b.
Globoquadrina larmeyi Akers, 1955, p. 661, pl. 65, figs. 4a-c.
 This species is distinguished by having a rather coarsely perforate test wall and subglobular chambers which give the test a subquadrate appearance, and also by a flap-like umbilical tooth of the final chamber.
- Globoquadrina venezuelana* (Hedberg)Pl. 4, figs. 8, 9.
Globigerina venezuelana Hedberg, 1937, p. 681, pl. 92, figs. 7a-c.
Globoquadrina venezuelana (Hedberg). Parker, 1967, p. 171, pl. 26, figs. 4a-10c; Lamb and Beard, 1972, p. 51, pl. 10, figs. 5-7.
 Discussions were given by Parker (1967) regarding the distinction of two closely related forms, *Globoquadrina conglomerate* (Schwager) and *G. venezuelana*. According to Parker (*op. cit.*), *G. venezuelana* is distinguished from its descendant *G. conglomerata* in having a more compact test and a small umbilical opening.
- Globorotalia acostaensis* BlowPl. 5, figs. 2a, b, 3.
Globorotalia acostaensis Blow, 1959, p. 208, pl. 17, figs. 106a-c, 107; Takayanagi and Saito, 1962, p. 75, pl. 24, figs. 2a-c.
Globorotalia (Turborotalia) acostaensis Blow. Banner and Blow, 1967, p. 153, pl. 3, figs. 1a-c (holotype refigured).
 This species is characterized in having usually five chambers in the last whorl, being its equatorial periphery lobulate, and having an arched aperture with a distinct lip. It differs from *Globorotalia continuosa* Blow in having more chambers in the final whorl and usually larger size.
- Globorotalia birnageae* BlowPl. 6, figs. 7a, b.
Globorotalia birnageae Blow, 1959, p. 210, pl. 17, figs. 108a-c; Saito, 1963, p. 174, pl. 56, figs. 3a-c; Saito and Maiya, 1973, p. 118, pl. 18, figs. 1, 2.
Globorotalia (Turborotalia) birnageae Blow. Blow, 1969, p. 346, pl. 34, figs. 7, 8.
 This species is characterized in being consistently smaller in size and having an almost closed umbilicus, and more circular outline, all of which seem to distinguish this species from *Globorotalia peripheroronda* Banner and Blow.
- Globorotalia continuosa* BlowPl. 5, figs. 1a, b.
Globorotalia opima continuosa Blow, 1959, p. 218, pl. 19, figs. 125a-c; Jenkins, 1960, p. 366, pl. 5, figs. 4a-c; Takayanagi and Saito, 1962, p. 80; Saito, 1963, p. 180, pl. 56, figs. 10a, b.
Globorotalia (Turborotalia) continuosa Blow. Blow, 1969, p. 347, pl. 3, figs. 4-6 (holotype refigured).
 This species is characterized by having four subspherical chambers in the last whorl and a distinct lipped aperture, and rather pitted wall surface. It has been regarded as an ancestor of *Globorotalia acostaensis* Blow (Banner and Blow, 1965).
- Globorotalia conomiozea* KennettPl. 8, figs. 4, 5, 6.
Globorotalia conomiozea Kennett, 1966, p. 235, text-figs. 10a-c.
Globorotalia (Globorotalia) crassula conomiozea Kennett. Blow, 1969, p. 361, pl. 41, figs. 5-8.
Globorotalia (Globorotalia) conomiozea Kennett. Jenkins, 1971, p. 85, pl. 5, figs. 123-128.
 This species is characterized by having a sharply conical test with a highly vaulted umbilical side and a well developed thin keel, all of which seem to distinguish it from *Globorotalia crassaformis* (Galloway and Wissler). Kennett (1966) has suggested that *G. crassaformis* developed from *G. conomiozea* in the upper Kapitean-lower Opoitian stages in New Zealand through the reduction of the peripheral keel. On the other hand, Blow (1969) placed this species as a subspecies of *Globorotalia crassula* Cushman and Stewart and suggested that *G. conomiozea* appears to have developed directly from *G. crassaformis* by the acquisition of carinal structures. In the present observation, Blow's hypothesis is untenable because *G. conomiozea* appears considerably earlier than *G. crassaformis*. For instance, *G. conomiozea* occurs in the uppermost Miocene, whereas *G. crassaformis* appears within the Lower Pliocene. The earlier occurrence of *G. conomiozea* than *G.*

crassaformis was also reported in New Zealand by Chapropiere (1973), who suggested that *G. conomiozea* evolved from *Globorotalia miotumida* Jenkins and that the idea of *G. crassaformis* lineage giving rise to *G. conomiozea* is invalid.

Globorotalia crassaformis (Galloway and Wissler)Pl. 9, figs. 1a-c, 2, 3a-c.

Globigerina crassaformis Galloway and Wissler, 1927, p. 41, pl. 7, figs. 12a-c.

Globorotalia crassaformis (Galloway and Wissler). Parker, 1962, p. 235, pl. 4, figs. 17, 18, 20, 21; Parker, 1967, p. 176, pl. 30, figs. 1a-3c.

This species has been regarded as an ancestor of *Globorotalia tosaensis* Takayanagi and Saito by previous authors. It has usually four to four and a half chambers in the final whorl, a slightly flattened, somewhat convex, spiral side, and a broadly quadrate outline. Specimens referable to *G. crassaformis* are morphologically variable. The variation occurs largely in the sharpness of the periphery, forms with a rounded periphery being the most common, although the early stage often has an acute periphery.

There are some differences of opinion with respect to the range of *G. crassaformis*. Kennett (1966) preferred to correlate the first appearance of this species with the beginning of the Pliocene. Blow (1969) stated that the lowest occurrence of this species is found in the Upper Miocene. According to Parker (1967), its first occurrence is near the base of the Middle Pliocene. In the present study, this species was first recorded in the Lower Pliocene.

Globorotalia cultrata (d'Orbigny)Pl. 7, figs. 1a, b, 2a, b.

Rotalia (*Rotalie*) *menardii* d'Orbigny, 1826, p. 273 (*nomen nudum*), (*fide* Ellis and Messina, 1940 *et seq.*).

Rotalia limbata d'Orbigny, 1826, pp. 274 (*nomen nudum*), (*fide* Ellis and Messina, 1940 *et seq.*).

Rotalina (*Rotalina*) *cultrata* d'Orbigny, in Ramon de la Sagra, 1839, p. 76 (plate published separately, pl. 5, figs. 7-9), (*fide* Ellis and Messina, 1940 *et seq.*).

Rotalia menardii Parker, Jones and Brady, 1865, p. 20, pl. 3, fig. 81 (*fide* Ellis and Messina, 1940 *et seq.*); Banner and Blow, 1960b, p. 31, pl. 6, figs. 2a-c (lectotype) [written as *Rotalia menardii* Parker, Jones and Brady 1865=*Globorotalia menardii* (Parker, Jones and Brady) ?=*Globorotalia cultrata* (d'Orbigny) in pl. 6].

Rotalia cultrata d'Orbigny. Banner and Blow, 1960b, p. 34, pl. 6, figs. 1a-c (neotype) [written as *Rotalina cultrata* d'Orbigny 1839=*Globorotalia cultrata* (d'Orbigny) in pl. 6].

Globorotalia cultrata (d'Orbigny). Parker, 1967, p. 177, pl. 31, figs. 2a-3c.

Although most of the workers referred this form to *Globorotalia menardii* (d'Orbigny), in the present study it is included in *G. cultrata* based upon the examination of the primary types of both species by Banner and Blow (1960b). Parker (1967) has given a full synonymy for this species.

This species is characterized by its flattened subcircular test and by having five to six chambers in the final whorl and a lobulate periphery with a distinct imperforate carina. It differs from *Globorotalia praemenardii* Cushman and Stainforth by the presence of distinctly limbate and raised sutures, and well-developed carina.

Globorotalia fimbriata (Brady)Pl. 7, figs. 4, 5.

Pulvinulina menardii var. *fimbriata* Brady, 1884, p. 691, pl. 103, figs. 3a, b; Banner and Blow, 1960b, p. 25, pl. 5, figs. 2a, b (lectotype) [written as *Pulvinulina menardii* var. *fimbriata* Brady 1884=*Globorotalia cultrata* (d'Orbigny) subsp. *fimbriata* (Brady) in pl. 5].

Globorotalia fimbriata (Brady). Parker, 1967, p. 178, pl. 31, figs. 4a-c.

Globorotalia (*Globorotalia*) *fimbriata* (Brady). Blow, 1969, p. 362, pl. 42, fig. 6.

This species is characterized by having carinal spines and a vaulted umbilical side with the inflation of the chambers directed towards the umbilicus. The carinal spines seem to be rather restricted only appearing on the earlier chambers.

Globorotalia humerosa Takayanagi and SaitoPl. 5, figs. 4, 5a, b, 6.

Globorotalia acostaensis humerosa Takayanagi and Saito, 1962, p. 78, pl. 28, figs. 1a-2b.

Globoquadrina humerosa (Takayanagi and Saito). Parker, 1967, p. 169, pl. 25, figs. 1a-6; Lamb and Beard, 1972, p. 50, pl. 3, figs. 4-9, pl. 8, figs. 1-6.

This species was first described from the Nobori Formation, Shikoku, Japan. It is characterized by having a nearly flat spiral side, an umbilical-extraumbilical aperture with a lip, and usually six to seven chambers in the last whorl. It has been regarded as a descendant of *Globorotalia acostaensis* Blow. It differs from *G. acostaensis* in having more chambers in the

final whorl and a rather open and deep umbilicus. This form has been regarded as an ancestor of *Globoquadrina dutertrei* (d'Orbigny) (Parker, 1967; Lamb and Beard, 1972).

- Globorotalia inflata* (d'Orbigny)Pl. 10, figs. 1, 2, 3, 4, 5.
Globigerina inflata d'Orbigny, in Barker-Webb and Berthelot, 1839, p. 134, pl. 2, figs. 7-9 (*vide* Ellis and Messina, 1940 *et seq.*); Cushman, 1946, p. 16, pl. 3, figs. 3a-c (Reproduction of holotype, pl. 4, figs. 1-4).
Globorotalia inflata (d'Orbigny). Parker, 1962, p. 236, pl. 5, figs. 6-9; Parker, 1967, p. 179, pl. 29, figs. 1a-c, 3a-c; Matoba, 1967, p. 259, pl. 30, figs. 9a-10c.
Globorotalia (Turborotalia) inflata (d'Orbigny). Banner and Blow, 1967, p. 144, pl. 4, figs. 1a-c (neotype), 11.
 This species is characterized by having a slightly lobulate equatorial periphery, broadly rounded axial periphery, and a uniformly perforate smooth test wall. Two forms may be recognized. One has three and a half to four chambers in the last whorl and slightly depressed intercameral sutures. The second form, being characterized by a more compact test, an almost round equatorial periphery, and three to three and a half embracing chambers in the final whorl, is considered to be variant of *Globorotalia inflata*. Two forms co-occurs through the present sequence.
- Globorotalia languaensis* BolliPl. 5, fig. 11.
Globorotalia languaensis Bolli, 1957a, p. 120, pl. 29, figs. 5a-c; Blow, 1959, p. 213, pl. 17, figs. 115a-c; Saito, 1963, p. 117, pl. 54, figs. 1a-c; Lamb and Beard, 1972, p. 53, pl. 19, figs. 1-3.
Globorotalia (Turborotalia) languaensis Bolli. Blow, 1969, p. 351, pl. 34, figs. 10, 11.
 This species is characterized by having a test with finely perforate smooth wall surface and almost circular equatorial periphery. Some specimens show a faint keel as noted by Blow (1959) and Saito (1963).
- Globorotalia margaritae* Bolli and BermúdezPl. 8, figs. 1, 2a, b.
Globorotalia margaritae Bolli and Bermúdez, 1965, p. 139, pl. 1, figs. 16-18; Parker, 1967, p. 179, pl. 32, figs. 1a-2c; Lamb and Beard, 1972, p. 53, pl. 18, figs. 1-6.
Globorotalia (Globorotalia) margaritae Bolli and Bermúdez. Blow, 1969, p. 363, pl. 44, figs. 1-6, pl. 45, figs. 1-3, 5, 6.
 This species is characterized by having a distinctly spiro-convex test, strongly curved suture on the spiral side, an acute axial periphery with a thin keel, and the pie-shaped final chamber which makes up about one-third of the final whorl.
- Globorotalia miozea conoidea* WaltersPl. 8, figs. 8, 9a, b, 10.
Globorotalia miozea conoidea Walters, 1965, p. 124, figs. 8 (I-M); Olsson, 1971, pl. 2, figs. a-c.
Globorotalia (Globorotalia) miozea conoidea Walters. Jenkins, 1971, p. 92, pl. 6, figs. 141-143.
 This subspecies is characterized by having a very highly vaulted umbilical side and a less, but somewhat convex, spiral side and its ultimate and antepenultimate chambers exhibiting a distinct peripheral keel. It differs from *Globorotalia miozea miozea* Finlay in having a more conically shaped test with a keel on the later chambers of the final whorl and less strongly curved sutures on the spiral side. Walters (1965) noted that *Globorotalia miozea conoidea* gives rise to *Globorotalia miozea sphericomiozea* Walters in the Kapitean stage in New Zealand. This subspecies differs from *G. miozea sphericomiozea* in having a larger test with keeled final chambers.
G. miozea conoidea, according to researchers in New Zealand (Walters, 1965; McInnes, 1965; Jenkins, 1971), is a Miocene marker. Olsson (1971) gives its range from the Miocene to Pliocene. In the present study, this subspecies was last recorded in the Late Pliocene.
- Globorotalia cf. miozea conoidea* WaltersPl. 8, figs. 11a, b, 12, 13.
 This subspecies was found in the Middle Miocene sediments of the Boso Peninsula and the Takasaki area. It differs from *Globorotalia miozea conoidea* Walters usually in having a slightly less convex umbilical side and a rather convex on the spiral side. Saito (1963) has recorded *Globorotalia tumida* (Brady) from the upper part of the *Globorotalia fohsi fohsi* Zone to Recent, but it is likely that the Miocene specimens are referable to *G. cf. miozea conoidea* (Saito, 1963, pl. 53, figs. 8a-c).
- Globorotalia miozea miozea* FinlayPl. 8, figs. 3, 7.
Globorotalia miozea Finlay, 1939, p. 326, pl. 29, figs. 159-161; Hornibrook, 1958, p. 33, pl. 1, figs. 6-10.

- Globorotalia (Globorotalia) miozea miozea* Finlay. Blow, 1969, p. 366, pl. 45, fig. 7; Jenkins, 1971, p. 94, pl. 6, figs. 144-148.
This species has been regarded as descendant of *Globorotalia scitula praescitula* Blow (Jenkins, 1971). It is characterized by having strongly curved sutures on the spiral side and tangentially elongate chambers.
- Globorotalia miozea sphericomiozea* WaltersPl. 8, figs. 14a-c, 15, 16.
Globorotalia miozea sphericomiozea Walters, 1965, p. 126, figs. 8 (N-S).
Globorotalia (Globorotalia) miozea sphericomiozea Walters. Jenkins, 1971, p. 95, pl. 6, figs. 149-151. McInnes (1965) described a transition from a spherical variety of *Globorotalia miozea* Finlay into *Globorotalia inflata* (d'Orbigny) in New Zealand. Walters (1965) named this variety *G. miozea sphericomiozea*. This subspecies is characterized by a compact, round, tightly coiled, and thick-walled test, and having a more strongly vaulted umbilical side which gives a sub-triangular axial periphery.
- Globorotalia multicamerata* Cushman and JarvisPl. 7, figs. 2a, b.
Globorotalia menardii (d'Orbigny) var. *multicamerata* Cushman and Jarvis, 1930, p. 367, pl. 34, figs. 8a-c.
Globorotalia menardii (d'Orbigny) var. *fijiensis* Cushman, 1934, p. 136, pl. 17, figs. 5a-c (*fide* Ellis and Messina, 1940 *et seq.*).
Globorotalia multicamerata Cushman and Jarvis. Parker, 1967, p. 180, pl. 31, figs. 5a-6b.
Globorotalia (Globorotalia) multicamerata Cushman and Jarvis. Blow, 1969, p. 367, pl. 7, figs. 7-9, pl. 42, fig. 7.
This species is somewhat difficult to differentiate from *Globorotalia cultrata* (d'Orbigny), but in has more chambers in the last whorl, narrower chambers relative to their height, and a more circular outline than *G. cultrata*.
- Globorotalia obesa* BolliPl. 5, figs. 7a, b.
Globorotalia obesa Bolli, 1957a, p. 119, pl. 29, figs. 2a-3; Blow, 1959, p. 218, pl. 19, figs. 124a-c; Jenkins, 1960, p. 364, pl. 5, figs. 2a-c; Takayanagi and Saito, 1962, p. 79, pl. 24, figs. 7a-c.
This species is characterized by having a very low trochospiral test with inflated and spherical *Globigerina*-like chambers, and a distinctly lobulate equatorial periphery.
- Globorotalia peripheroacuta* Blow and BannerPl. 6, figs. 4a-c.
Globorotalia fohsi fohsi Cushman and Ellisor. Bolli, 1950, p. 88, pl. 15, figs. 4a-c; Bolli, 1957a, p. 119, pl. 28, figs. 10a-c only; Blow, 1959, p. 212, pl. 17, figs. 112a-c (reproduction of holotype); Saito, 1963, p. 175, pl. 53, figs. 1a-2.
Globorotalia (Turborotalia) fohsi fohsi Cushman and Ellisor. Banner and Blow, 1959, p. 22, pl. 1, figs. 2a-c.
Globorotalia (Turborotalia) peripheroacuta Blow and Banner, 1966, p. 294, pl. 1, figs. 2a-c, pl. 2, figs. 4, 5, 13.
Globorotalia fohsi peripheroacuta Blow and Banner. Olsson, 1972, p. 173, text-fig. 7.
Not *Globorotalia fohsi* Cushman and Ellisor, 1939, p. 12, pl. 2, figs. 6a-c.
This species is distinguished in possessing an acutely compressed periphery in later chambers of the final whorl. The periphery becomes progressively more compressed toward the last-formed chamber, so that the later chambers of the last whorl possess acute peripheral margins which differentiate it from *Globorotalia peripheroronda* Blow and Banner.
- Globorotalia peripheroronda* Blow and BannerPl. 6, figs. 1a, b, 2.
Globorotalia barissanensis (=sic) LeRoy. Stainforth, 1948, p. 120, pl. 26, figs. 24-26.
Globorotalia fohsi barissanensis LeRoy. Bolli, 1957a, p. 119, pl. 28, figs. 8a-c; Saito, 1963, p. 176, pl. 53, figs. 3, 4.
Globorotalia fohsi barissanensis (LeRoy). Blow, 1959, p. 212, pl. 17, figs. 110, 111a-c.
Globorotalia (Turborotalia) peripheroronda Blow and Banner, 1966, p. 294, pl. 1, figs. 1a-c, pl. 2, figs. 1-3.
Globorotalia fohsi peripheroronda Blow and Banner. Olsson, 1972, p. 170, text-figs. 4-6.
Globorotalia peripheroronda Blow and Banner. Saito and Maiya, 1973, p. 119, pl. 1, figs. 7a-8.
Not *Globorotalia barissanensis* LeRoy, 1939, p. 265, pl. 1, figs. 8-10.
This species is characterized by its generally lobate equatorial periphery, a bluntly rounded axial periphery, fairly deeply incised sutures on the spiral side, and a particularly distinct sinuous suture between the last and penultimate chambers on the spiral side. It differs from *Globorotalia*

siakensis (LeRoy) in possessing a more compressed test, circumferentially shorter chambers and smoothly recurved, not straight and oblique, sutures on the spiral side.

Globorotalia cf. *praefohsi* Blow and BannerPl. 6, figs. 3a, b.
Compared with:

Globorotalia (*Globorotalia*) *praefohsi* Blow and Banner, 1966, p. 295, pl. 1, figs. 3a-4c, pl. 2, figs. 6, 7, 10, 11.

The specimens referred to this species are very rare. The periphery of this species is more sharply acute than that of *Globorotalia peripheroacuta* Blow and Banner. This species is principally distinguished from *G. peripheroacuta* by possessing a carina on the later chambers of the adult final whorl. However, the present specimens differ from *Globorotalia praefohsi* in being small in size and not having a distinct imperforate carina. Probably, it is a morphologically and evolutionary primitive form. This form represents the last stage of the *Globorotalia fohsi* lineage. The advanced form was not found in the present study.

Globorotalia praemenardii archeomenardii BolliPl. 6, figs. 9a, b.

Globorotalia archeomenardii Bolli, 1957a, p. 119, pl. 28, figs. 11a-c.

Globorotalia menardii archeomenardii (Bolli) (=sic). Blow, 1959, p. 214, pl. 18, figs. 117a-c.

Globorotalia (*Globorotalia*) *praemenardii archeomenardii* Bolli. Blow, 1969, p. 368, pl. 47, figs. 1-5.

This subspecies is characterized by having a more convex spiral side and in being less lobulate equatorial periphery than those of *Globorotalia praemenardii* Cushman and Stainforth (*s.s.*) and *G. cultrata* (d'Orbigny). This species has been regarded as a descendant of *Globorotalia scitula praescitula* Blow because its chambers, in early forms, are tangentially rather elongate (Blow, 1959).

Globorotalia praemenardii praemenardii Cushman and StainforthPl. 6, figs. 10a, b.

Globorotalia praemenardii Cushman and Stainforth, 1945, p. 70, pl. 13, figs. 14a-c; Stainforth, 1948, p. 121, pl. 26, figs. 34, 35; Bolli, 1957a, p. 120, pl. 29, figs. 4a-c.

Globorotalia menardii praemenardii (Cushman and Stainforth) (=sic). Blow, 1959, p. 214, pl. 18, figs. 116a-c.

Globorotalia (*Globorotalia*) *praemenardii praemenardii* Cushman and Stainforth. Blow, 1969, p. 369, pl. 6, figs. 1-3.

This species differs from *Globorotalia praemenardii archeomenardii* Bolli by having a less convex spiral side and in being more lobulate. It also differs from *Globorotalia cultrata* (d'Orbigny) in having a less pronounced keel and less limbate and raised sutures.

Globorotalia quinifalcata Saito and MaiyaPl. 6, figs. 5a, b, 6.

Globorotalia scitula praescitula Blow. Saito, 1963, p. 181, pl. 53, figs. 6a-c.

Globorotalia quinifalcata Saito and Maiya, 1973, p. 119, pl. 2, figs. 5a-c, 6a-c.

The specimens referred to this species are characterized by its distinctly umbilico-convex test consisting of five, less lobulate chambers in the last whorl. It differs from *Globorotalia peripheroronda* Blow and Banner in having chambers more tangentially elongate, a more strongly vaulted umbilical side, and gently curving sutures on the spiral side. It also differs from *Globorotalia scitula praescitula* Blow by having less lobulate chambers and gently curving sutures on the spiral side, and five, rather than four, chambers in the last whorl.

Globorotalia rikuchuensis Takayanagi and Oda

Globorotalia (*Turborotalia*) *rikuchuensis* Takayanagi and Oda, 1976, in Takayanagi *et al.*, p. 372, pl. 1, figs. 4a-d, 5a-c.

This species is characterized by its biconvex test, slightly lobulate equatorial periphery having no carina or pseudocarina, usually four and a half to five chambers in the last whorl, and tangentially curved sutures on the spiral side. This species resembles *Globorotalia adamantea* Saito, but differs from it in being smaller, having more chambers in the final whorl and a high-arched aperture with a distinct lip. It also differs from *Globorotalia continuosa* Blow by having more chambers in the last whorl and tangentially curved sutures on the spiral side.

Globorotalia scitula praescitula BlowPl. 6, figs. 8a-c.

Globorotalia scitula praescitula Blow, 1959, p. 221, pl. 19, figs. 128a-c.

Globorotalia (*Turborotalia*) *scitula praescitula* Blow. Blow, 1969, p. 356, pl. 4, figs. 21-23 (holotype refigured), pl. 39, fig. 9.

This subspecies is characterized by having four strongly lobulate chambers and tangentially

elongate chambers in the last whorl. It resembles *Globorotalia quinifalcata* Saito and Maiya, but differs from it by having a less vaulted umbilical side, four chambers instead of five in the last whorl, and less lobulate chambers in the final whorl.

- Globorotalia scitula scitula* (Brady)Pl. 9, figs. 12a, b.
Pulvinulina scitula Brady, 1882, p. 716, (no figure given), (*fide* Ellis and Messina, 1940 *et seq.*); Banner and Blow, 1960b, p. 27, pl. 5, figs. 5a-c (lectotype) [written as *Pulvinulina scitula* Brady 1882=*Globorotalia scitula* (Brady) in pl. 5].
Pulvinulina patagonica (d'Orbigny). Brady, 1884, p. 693, pl. 103, figs. 7a-c (not *Rotalia patagonica* d'Orbigny).
Globorotalia scitula (Brady). Bolli, 1957a, p. 120, pl. 29, figs. 11a-12c; Parker, 1962, p. 238, pl. 6, figs. 4-6; Parker, 1967, p. 181, pl. 27, figs. 7a-c.
Globorotalia scitula scitula (Brady). Blow, 1959, p. 219, pl. 19, figs. 126a-c; Takayanagi and Saito, 1962, p. 80, pl. 26, figs. 2a-c.
 The general characters of the present specimens agree with the diagnosis for *Globorotalia scitula scitula* given by Banner and Blow (1960b).
- Globorotalia siakensis* (LeRoy)Pl. 5, figs. 8, 9, 10.
Globigerina siakensis LeRoy, 1939, p. 262, pl. 4, figs. 20-22 (*fide* Ellis and Messina, 1940 *et seq.*).
Globorotalia mayeri Cushman and Ellisor. Bolli, 1957a, p. 118, pl. 28, figs. 4a-c; Blow, 1959, p. 214, pl. 18, figs. 116a-c (not *Globorotalia mayeri* Cushman and Ellisor, 1939).
Globorotalia (*Turborotalia*) *siakensis* LeRoy (= *sic*). Blow, 1969, p. 356, pl. 10, figs. 7-9 (reproduction of holotype)
Globorotalia siakensis LeRoy (= *sic*). Lamb and Beard, 1972, p. 56, pl. 6, figs. 6-9.
 Following the concept of Blow (1969), *Globorotalia siakensis* of the present study would fit the concept of the species that has previously been referred to as *Globorotalia mayeri* Cushman and Ellisor by Bolli (1957a), Blow (1959), and others.
- Globorotalia tosaensis* Takayanagi and SaitoPl. 9, figs. 4, 5, 6, 7.
Globorotalia tosaensis Takayanagi and Saito, 1962, p. 81, pl. 28, figs. 11a-12c; Matoba, 1967, p. 259, pl. 30, figs. 12a, b; Lamb and Beard, 1972, p. 56, pl. 22, figs. 1-7, pl. 23, figs. 1, 2.
Globorotalia (*Turborotalia*) *tosaensis tosaensis* Takayanagi and Saito. Blow, 1969, p. 393, pl. 4, figs. 10-12, pl. 40, figs. 4-7.
Globorotalia (*Turborotalia*) *tosaensis thenaitheca* Blow, 1969, p. 394, pl. 4, figs. 13-17, p. 40, figs. 1-3.
 This species developed from *Globorotalia crassaformis* (Galloway and Wissler) in the Upper Pliocene. It is characterized by having an almost circular equatorial periphery, five chambers in the last whorl, and gently curved sutures on the spiral side, all of which serve to distinguish it from *G. crassaformis*.
- Globorotalia truncatulinoides* (d'Orbigny)Pl. 9, figs. 8, 9, 10a, b, 11.
Rotalia truncatulinoides d'Orbigny, 1839, p. 132, pl. 2, figs. 25-27 (*fide* Ellis and Messina, 1940 *et seq.*).
Globorotalia truncatulinoides (d'Orbigny). Bolli, Loeblich and Tappan, 1957, p. 41, pl. 10, figs. 3a-c; Parker, 1962, p. 239, pl. 6, figs. 7a-c; Parker, 1967, p. 181, pl. 10, figs. 1a-c; Matoba, 1967, p. 260, pl. 30, figs. 13a, b; Lamb and Beard, 1972, p. 56, pl. 24, figs. 1-4, pl. 25, figs. 1-7, pl. 26, figs. 1-3.
Globorotalia (*Globorotalia*) *truncatulinoides pachytheca* Blow, 1969, p. 405, pl. 5, figs. 13-15, pl. 48, figs. 1-5.
Globorotalia truncatulinoides evolved from *Globorotalia tosaensis* Takayanagi and Saito by developing a keeled peripheral margin as suggested by previous authors. This species differs from *G. tosaensis* in having an acute periphery with a distinct keel on all the chambers in the last whorl.
- Globorotalia tumida plesiotumida* Blow and BannerPl. 7, figs. 6a, b, 7a, b.
Globorotalia (*Globorotalia*) *tumida plesiotumida* Blow and Banner, 1965b, p. 1353, figs. 2a-c; Blow, 1969, p. 371, pl. 9, figs. 7-9 (holotype reillustrated), pl. 47, figs. 6-8.
 The differentiation of this subspecies from its descendant, *Globorotalia tumida* (Brady) (*s.s.*), is difficult as pointed out by Parker (1967). In the present study, this subspecies is distinguished from *G. tumida tumida* by having a much smaller and less distinctly biconvex test, a lesser degree of development of coarser granules on the earlier chambers on the umbilical side and a rather thin keel (lesser degree of development of massive carina).

- Globrotalia tumida tumida* (Brady)Pl. 7, figs. 8, 9, 10, 11.
Pulvinulina menardii (d'Orbigny) var. *tumida* Brady, 1877, p. 535 (no figure given), (*fide* Ellis and Messina, 1940 *et seq.*); Banner and Blow, 1960b, p. 26, 27, pl. 5, figs. 1a-c (lectotype) [written as *Pulvinulina menardii* var. *tumida* Brady 1877=*Globrotalia tumida* (Brady) in pl. 5].
Pulvinulina tumida Brady. Brady, 1884, p. 692, pl. 103, figs. 4a-c, 5, 6.
Pulvinulina tumida Brady var. *flexuosa* Koch, 1923, p. 357, text-figs. 9, 10 (*fide* Ellis and Messina, 1940 *et seq.*).
Globrotalia tumida (Brady). Bolli, Loeblich and Tappan, 1957, p. 41, pl. 10, figs. 2a-c; Takayanagi and Saito, 1962, p. 82, pl. 24, figs. 6a-c; Parker, 1962, p. 239, pl. 6, figs. 8-10; Parker, 1967, p. 182, pl. 32, figs. 5a-7; Lamb and Beard, 1972, p. 57, pl. 12, figs. 1-3.
Globrotalia (*Globrotalia*) *tumida tumida* (Brady). Banner and Blow, 1965b, p. 1353, figs. 3a-c; Blow, 1969, p. 371, 372, pl. 9, figs. 7-9 (holotype reillustrated), pl. 49, figs. 1-5.
This species is characterized by its tumid, nearly equally biconvex test having a periphery fringed by a massive carina, and by possessing a prominent apertural lip, extending usually from umbilicus to near the peripheral carina.
Flexuosa forms occur very scarcely in the present section. They are included in *Globrotalia tumida* in this study as suggested by Parker (1967).
- Orbulina bilobata* (d'Orbigny)Pl. 5, fig. 18.
Globigerina bilobata d'Orbigny, 1846, p. 164, pl. 9, figs. 11-14 (*fide* Ellis and Messina, 1940 *et seq.*).
Biorbulina bilobata (d'Orbigny). Blow, 1956, p. 69, text-fig. 2, no. 16; Blow, 1969, p. 334, pl. 23, figs. 5, 6.
Blow (1956), later followed by Bolli (1957b) and others, distinguished *Biorbulina bilobata* from the Miocene *Orbulina universa* d'Orbigny. Jenkins (1960) suggested that *Biorbulina bilobata* is part of the *Orbulina universa* population and is a gerontic growth stage of *O. universa*. This species is very rare and occurs sporadically in the present sequence, and may be merely a bilocular form of *O. universa*.
- Orbulina suturalis* BrönnimannPl. 5, fig. 16.
Orbulina suturalis Brönnimann, 1951, p. 135, text-fig. 2, figs. 1, 2, 5-8, 10, text-fig. 3, figs. 3-8, 11, 13-16, 18, 20-22, text-fig. 4, figs. 2-4, 7-12, 15, 16, 19-22; Blow, 1956, p. 66, text-fig. 2, nos. 5-7; Bolli, 1957a, p. 115, pl. 27, fig. 4; Blow, 1959, p. 200, pl. 13, figs. 82a, b; Takayanagi and Saito, 1962, p. 100, pl. 24, fig. 3.
Blow (1956) stated that *Orbulina suturalis* is distinguished from *Praeorbulina glomerosa* (Blow) (*s. l.*) in lacking the small apertures which are confined in the latter species to the sutures between the last chamber and the initial *Globigerina* stage. Thus, the specimens having apertures outside the sutures are classified as *O. suturalis*. This species is characterized by having a globular, inflated final chambers not entirely enveloping the earlier part of the test, and having apertures present both on the sutures and outside.
- Orbulina universa* d'OrbignyPl. 5, fig. 17.
Orbulina universa d'Orbigny, in Ramon de la Sagra, 1839, p. 2, pl. 1, fig. 1 (*fide* Ellis and Messina, 1940 *et seq.*); Brönnimann, 1951, p. 134, text-fig. 3, fig. 12, text-fig. 4, figs. 1, 13, 14; Blow, 1956, p. 66, text-fig. 2, nos. 8, 9; Bolli, 1957a, p. 115, pl. 27, fig. 5; Blow, 1959, p. 200, pl. 13, fig. 83; Takayanagi and Saito, 1962, p. 100, pl. 27, fig. 1.
This species is distinguished from its immediate ancestor, *Orbulina suturalis* Brönnimann, in not having the *Globigerina*-like juvenile chambers visible on the test surface; also the small apertures are generally scattered over the test surface.
- Praeorbulina glomerosa circularis* (Blow)Pl. 5, fig. 14.
Globigerinoides glomerosa circularis Blow, 1956, p. 65, text-fig. 2, nos. 3, 4.
Porticulasphaera glomerosa circularis (Blow). Bolli, 1957a, p. 115, pl. 27, fig. 2; Blow, 1959, p. 202, pl. 14, figs. 86a, b.
Candorbulina glomerosa (Blow) subsp. *circularis* (Blow). Jenkins, 1960, p. 357, pl. 3, figs. 10a, b.
Praeorbulina glomerosa circularis (Blow). Jenkins, 1971, p. 196, pl. 23, fig. 665.
This subspecies is characterized by having the last chamber embracing the earlier part of the test more than 75 per cent. It is distinguished from *Praeorbulina glomerosa* (Blow) (*s. s.*) in having a circular outline, more numerous apertures, and less deeply incised sutures. It also differs from *Orbulina suturalis* Brönnimann in not having any areal apertures outside the

Globigerina-stage sutures.

Praeorbulina glomerosa curva (Blow)Pl. 5, fig. 12.

Globigerinoides glomerosa curva Blow, 1956, p. 64, text-fig. 3, nos. 9-14.

Porticulasphaera glomerosa curva (Blow). Bolli, 1957a, p. 115, pl. 27, fig. 7; Blow 1959 p. 201, pl. 13, figs. 84a, b.

Candorbulina glomerosa (Blow) subsp. *curva* (Blow). Jenkins, 1960, p. 357, pl. 3, fig. 8.

Globigerinoides glomerosa curvus Blow. Saito, 1963, p. 195, pl. 55, fig. 4.

Praeorbulina glomerosa curva (Blow). Jenkins, 1971, p. 197, pl. 23, figs. 666, 667.

This subspecies is characterized by having the last chamber embracing between 40 and 70 per cent of the earlier test. It is distinguished from *Globigerinoides sicanus* De Stefani in having a more spherical test outline and also more numerous sutural apertures.

Praeorbulina glomerosa glomerosa (Blow).....Pl. 5, fig. 13.

Globigerinoides glomerosa glomerosa Blow, 1956, p. 65, text-fig. 1, nos. 9-14, text-fig. 2, nos. 1, 2.

Porticulasphaera glomerosa glomerosa (Blow). Bolli, 1957a, p. 115, pl. 27, fig. 8; Blow, 1959, p. 202, pl. 14, figs. 85a, b.

Globorotalia (=sic *Candorbulina*) *glomerosa* (Blow) subsp. *glomerosa* (Blow). Jenkins, 1960, p. 357, pl. 3, figs. 9a, b.

Globigerinoides glomerosus glomerosus Blow. Saito, 1963, p. 195, pl. 55, fig. 5.

Praeorbulina glomerosa glomerosa (Blow). Blow, 1969, p. 333, pl. 23, fig. 7; Jenkins, 1971, p. 198, pl. 23, fig. 668.

This species was originally described under the genus *Globigerinoides* by Blow (1956) in his study of the evolutionary lineage to *Orbulina*. In Japanese rocks, Saito (1963) stated that the evolutionary lineage of *Orbulina* from *Globigerinoides bisphericus* Todd via *Globigerinoides glomerosus* can be traced up to the developmental stage of *G. glomerosus* within the upper half of the Saigo Formation in the Kakegawa area. Later, Olsson (1964) erected the genus *Praeorbulina* as a supraspecific taxon for the group of species which are immediately ancestral to *Orbulina*. According to Olsson (*op. cit.*), *Praeorbulina* differs from *Orbulina* in the lack of areal apertures and from *Globigerinoides* by the lack, in the adult stage, of distinct umbilicus and umbilical aperture.

This species is characterized by having a strongly embracing and inflated final chamber, covering as much as 75 per cent of earlier chambers, and the multiple slit-like sutural supplementary apertures around the lower margin of the final chamber.

Praeorbulina transitoria (Blow)Pl. 5, fig. 15.

Globigerinoides transitoria Blow, 1956, p. 56, text-fig. 2, nos. 12-15.

Porticulasphaera transitoria (Blow). Bolli, 1957a, p. 115, pl. 27, fig. 3; Blow, 1959, p. 202, pl. 14, figs. 87a, b.

Globigerinoides transitorius Blow. Saito, 1963, p. 198, pl. 56, figs. 7, 8.

This species is extremely rare and occurs only sporadically. Its penultimate chamber embraces the earlier chambers and is nearly equal in size to the final one.

Pulleniatina obliquiloculata (Parker and Jones)Pl. 10, figs. 6, 10.

Pullenia sphaeroides (d'Orbigny) var. *obliquiloculata* Parker and Jones, 1865, p. 365, pl. 19, figs. 4a, b; Banner and Blow, 1960b, p. 25, pl. 7, figs. 4a-c (lectotype) [written as *Pullenia sphaeroides*

var. *obliquiloculata* Parker and Jones 1865=*Pulleniatina obliquiloculata* (Parker and Jones) in pl. 7].

Pulleniatina obliquiloculata (Parker and Jones). Parker, 1962, p. 234, pl. 4, figs. 13-16, 19, 22; Parker, 1967, p. 172, pl. 28, figs. 1a-c; Matoba, 1967, p. 260, pl. 30, fig. 16; Lamb and Beard, 1972, p. 58, pl. 29, figs. 1a-4.

Pulleniatina obliquiloculata obliquiloculata (Parker and Jones). Banner and Blow, 1967, p. 137, pl. 3, figs. 4a-c (lectotype refigured), pl. 4, fig. 9.

Banner and Blow (1967) gave a detailed discussion on this species, emended the species concept, and described its evolutionary development from *Pulleniatina primalis* Banner and Blow. Besides the streptospiral coiling, this species is characterized in having a linear suture and thick, radially perforate later chamber-walls with smooth and brilliant surface.

Beside the species included in the above synonym, Banner and Blow (*op. cit.*) described *Pulleniatina obliquiloculata praecursor* Banner and Blow. This form is not recorded in the present study so that the complete evolutionary transition to *P. obliquiloculata* (*s.s.*) has not been

seen. According to Parker (1967), the distinction between *P. primalis* and *P. obliquiloculata praecursor* is negligible and arbitrary, and the latter form is included with the former because it has no linear suture.

- Pulleniatina primalis* Banner and BlowPl. 10, figs. 7, 8, 9.
Pulleniatina seminvoluta Germeraad. Parker, 1965, p. 151, text-figs. 5a-6c [not ? *Pulleniatina seminvoluta* Germeraad, 1946, pl. 4, figs. 16-18=*Rotalinopsis seminvoluta* (Germeraad), n. comb.].
Pulleniatina primalis Banner and Blow, 1967, p. 142, pl. 1, figs. 3a-8, pl. 3, figs. 2a-c; Parker, 1967, p. 173, pl. 27, figs. 6a-c (not figs. 5a-c); Lamb and Beard, 1972, p. 58, pl. 28, figs. 5, 7-9.
 This species differs from *Pulleniatina obliquiloculata* (Parker and Jones) by having umbilically restricted primary aperture and the absence of distinct linear suture. The phylogenetically earlier specimens are convex on the spiral side and sutures are depressed, but in the phylogenetically younger specimens the spiral sutures are less depressed and the spiral side somewhat flattened as pointed out by Parker (1967).
- Sphaeroidinella dehiscens* (Parker and Jones)Pl. 10, figs. 16, 17.
Sphaeroidina bulloides d'Orbigny var. *dehiscens* Parker and Jones, 1865, p. 394, pl. 19, figs. 5a-c; Banner and Blow, 1960b, p. 35, pl. 7, figs. 3a, b (lectotype) [written as *Sphaeroidina bulloides* d'Orbigny var. *dehiscens* Parker and Jones 1865=*Sphaeroidinella dehiscens* (Parker and Jones) in pl. 7].
Sphaeroidina dehiscens Parker and Jones var. *immatura* Cushman, 1919, p. 40, pl. 14, fig. 2 (*fide* Ellis and Messina, 1940 *et seq.*).
Sphaeroidinella dehiscens (Parker and Jones). Bolli, Loeblich and Tappan, 1957, p. 32, pl. 6, figs. 1-5 (lectotype designated); Takayanagi and Saito, 1962, p. 99, pl. 27, figs. 3a, b; Parker, 1962, p. 234, pl. 3, figs. 1, 2; Parker, 1967, p. 160, pl. 23, figs. 8a-9b; Matoba, 1967, p. 260, pl. 30, figs. 19a-20b.
Sphaeroidinella dehiscens dehiscens (Parker and Jones). Blow, 1969, p. 336, pl. 29, fig. 9.
Sphaeroidinella dehiscens dehiscens forma *immatura* (Cushman). Blow, 1969, p. 336, pl. 29, figs. 6-8.
Sphaeroidinella developed from *Sphaeroidinellopsis* by the addition of a small sutural opening on the dorsal side opposite to the main aperture; later, the small aperture became larger. Thus, this species differs from the species of the genus *Sphaeroidinellopsis* in having supplementary sutural aperture in the adult. *Sphaeroidinella dehiscens immatura* (Cushman) is considered to be an earlier chronospecies in the evolutionary lineage of *S. dehiscens* and is included in this species.
- Sphaeroidinellopsis seminulina* (Schwager)Pl. 10, figs. 11, 12, 13.
Globigerina seminulina Schwager, 1866, p. 256, pl. 7, fig. 112 (*fide* Ellis and Messina, 1940 *et seq.*); Banner and Blow, 1960b, p. 24, pl. 7, figs. 2a, b (neotype) [written as *Globigerina seminulina* Schwager 1866=*Sphaeroidinellopsis seminulina* (Schwager) in pl. 7].
Globigerina kochi Caudri, 1934, p. 144 (*fide* Ellis and Messina, 1940 *et seq.*).
Sphaeroidinella grimsdalei (Keijzer). Bolli, 1957a, p. 114, pl. 26, figs. 8-12c.
Sphaeroidinella seminulina seminulina (Schwager). Blow, 1959, p. 197, pl. 12, figs. 74-79.
Sphaeroidinellopsis seminulina (Schwager). Takayanagi and Saito, 1962, p. 99, pl. 25, figs. 12a-c; Saito, 1963, p. 200, pl. 56, fig. 13; Matoba, 1967, p. 260, pl. 30, figs. 17a-18.
Sphaeroidinella seminulina (Schwager). Parker, 1967, p. 161, pl. 23, figs. 1-5b.
Sphaeroidinellopsis seminulina seminulina (Schwager). Blow, 1969, p. 337, pl. 30, fig. 7.
Sphaeroidinellopsis seminulina kochi (Caudri). Blow, 1969, p. 337, pl. 30, fig. 8.
 Two species, *Sphaeroidinellopsis subdehiscens* (Blow) and *S. seminulina*, seem to be phenotypical variants although they are recognized as a distinct species in the distribution charts of this study. The distinction between them seems to lie in the final chamber, so that *S. seminulina* has four, occasionally five, chambers in the final whorl as opposed to the three-chambered forms which are referred to as *S. subdehiscens*.
- Sphaeroidinellopsis subdehiscens* (Blow)Pl. 10, figs. 14, 15.
Sphaeroidinella dehiscens subdehiscens Blow, 1959, p. 195, pl. 12, figs. 71a-72.
Sphaeroidinellopsis subdehiscens (Blow). Banner and Blow, 1960b, p. 15, text-fig. 5, nos. a-c (reproduction of holotype); Saito, 1963, p. 201, pl. 56, fig. 12.
Sphaeroidinella subdehiscens Blow. Parker, 1967, p. 162, pl. 23, figs. 6a-7c.
Sphaeroidinellopsis subdehiscens subdehiscens (Blow). Blow, 1969, p. 338, pl. 30, figs. 1-3, 6, pl.

31, figs. 1-3, pl. 32, figs. 1-3.

This species was separated by Blow (1959) from *Sphaeroidinella dehiscens* (Parker and Jones) on the basis of the absence of supplementary aperture, less embracing chambers, more visible sutures, generally small test, and more lobulate equatorial periphery. He noted that *Sphaeroidinellopsis subdehiscens* appeared to have developed from *S. seminulina* (Schwager) during the Middle Miocene.

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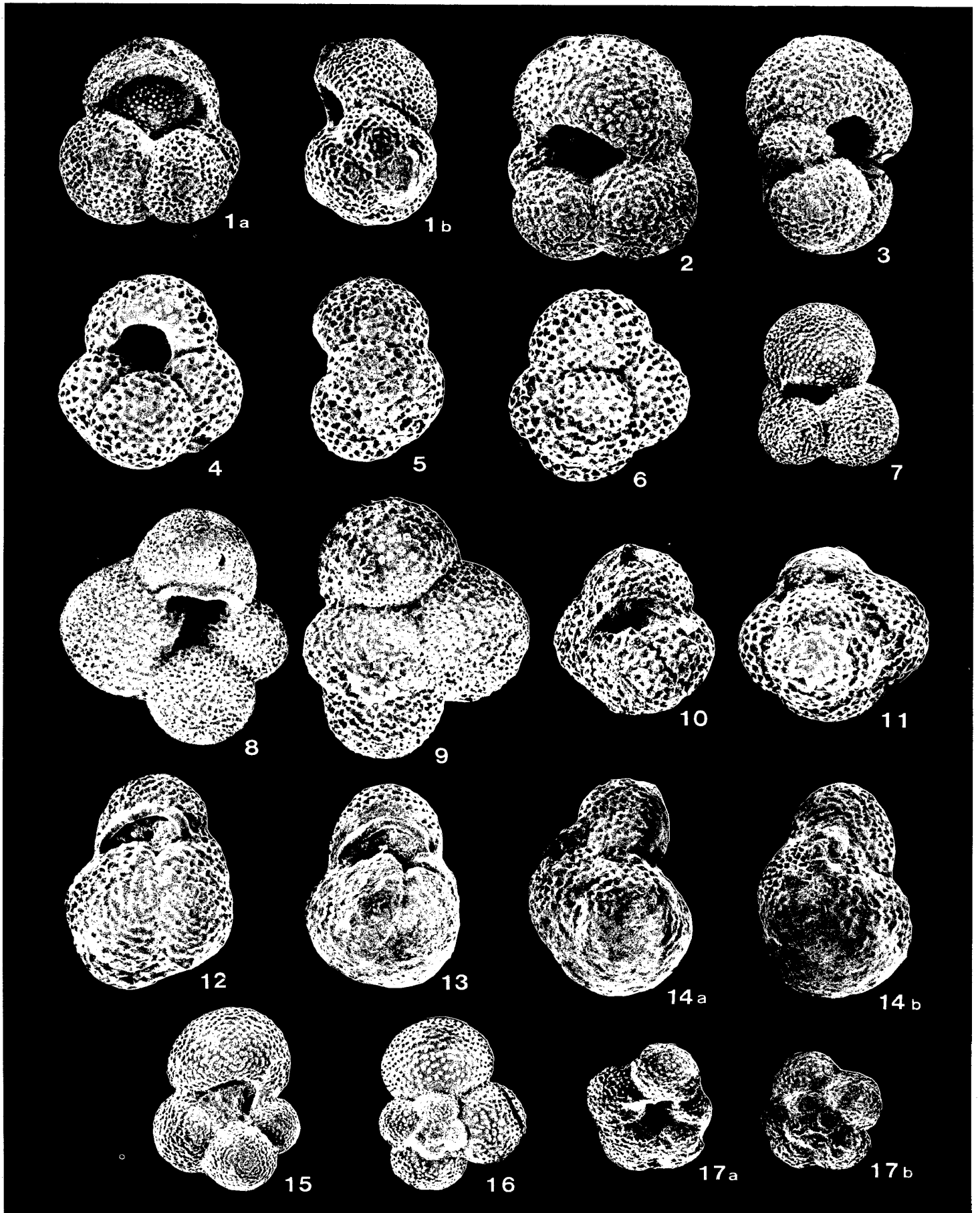
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Explanation of Plates

Plate 1

- Figs. 1a, b. *Globigerina apertura* Cushman
Specimen (IGPS coll. cat. no. 95860) from sample 02, Anno Formation, Boso Peninsula, $\times 100$.
- Figs. 2, 3. *Globigerina bulloides* d'Orbigny
Both specimens (IGPS coll. cat. no. 95861A, B) from sample 02, Anno Formation, Boso Peninsula, $\times 100$.
- Figs. 4-6. *Globigerina decoraperta* Takayanagi and Saito
4-Specimen (IGPS coll. cat. no. 95862A) from sample 11, Anno Formation. 5-specimen (IGPS coll. cat. no. 95862B) from sample 12, Anno Formation. 6-specimen (IGPS coll. cat. no. 95862C) from sample 09, Anno Formation, Boso Peninsula. $\times 150$.
- Fig. 7. *Globigerina foliata* Bolli
Specimen (IGPS coll. cat. no. 95863) from sample 02, Anno Formation, Boso Peninsula, $\times 100$.
- Figs. 8, 9. *Globigerina falconensis* Blow
8- $\times 100$. 9- $\times 150$, both specimens (IGPS coll. cat. no. 95864A, B) from sample YR21, Kiwada Formation, Boso Peninsula.
- Figs. 10, 11. *Globigerina druryi* Akers
Both specimens (IGPS coll. cat. no. 95865A, B) from sample K46, Amatsu Formation, Boso Peninsula, $\times 100$.
- Figs. 12, 13, 14a, b. *Globigerina nepenthes* Todd
All specimens (IGPS coll. cat. no. 95866 A, B, C) from sample 46, Amatsu Formation, Boso Peninsula, $\times 100$.
- Figs. 15, 16. *Globigerina praebulloides praebulloides* Blow
Both specimens (IGPS coll. cat. no. 95867A, B) from sample HSH26, Ono Formation, Takasaki area, $\times 100$.
- Figs. 17a, b. *Globigerina praebulloides pseudociperoensis* Blow
Specimen (IGPS coll. cat. no. 95868) from sample HSH26, Ono Formation, Takasaki area, $\times 100$.



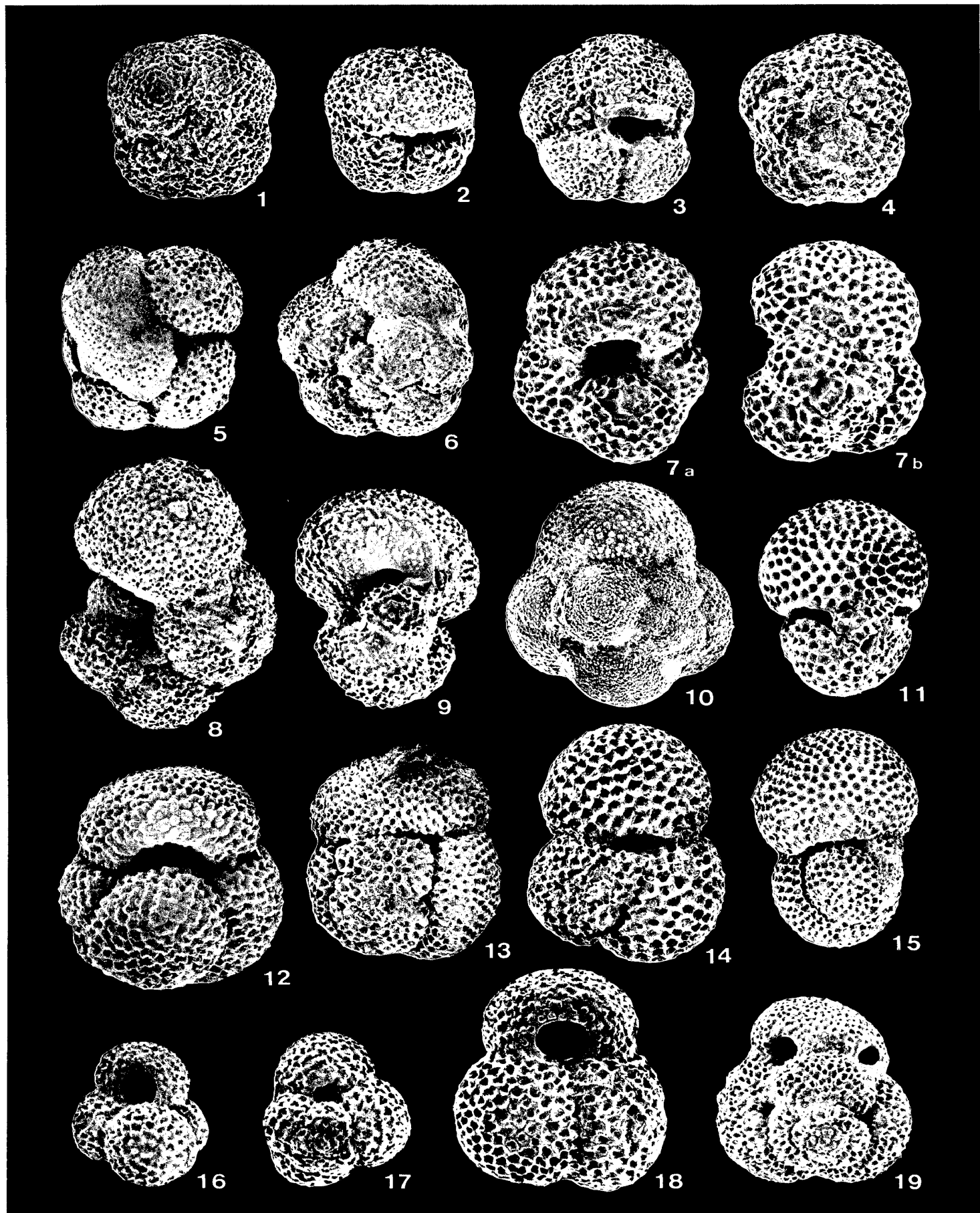
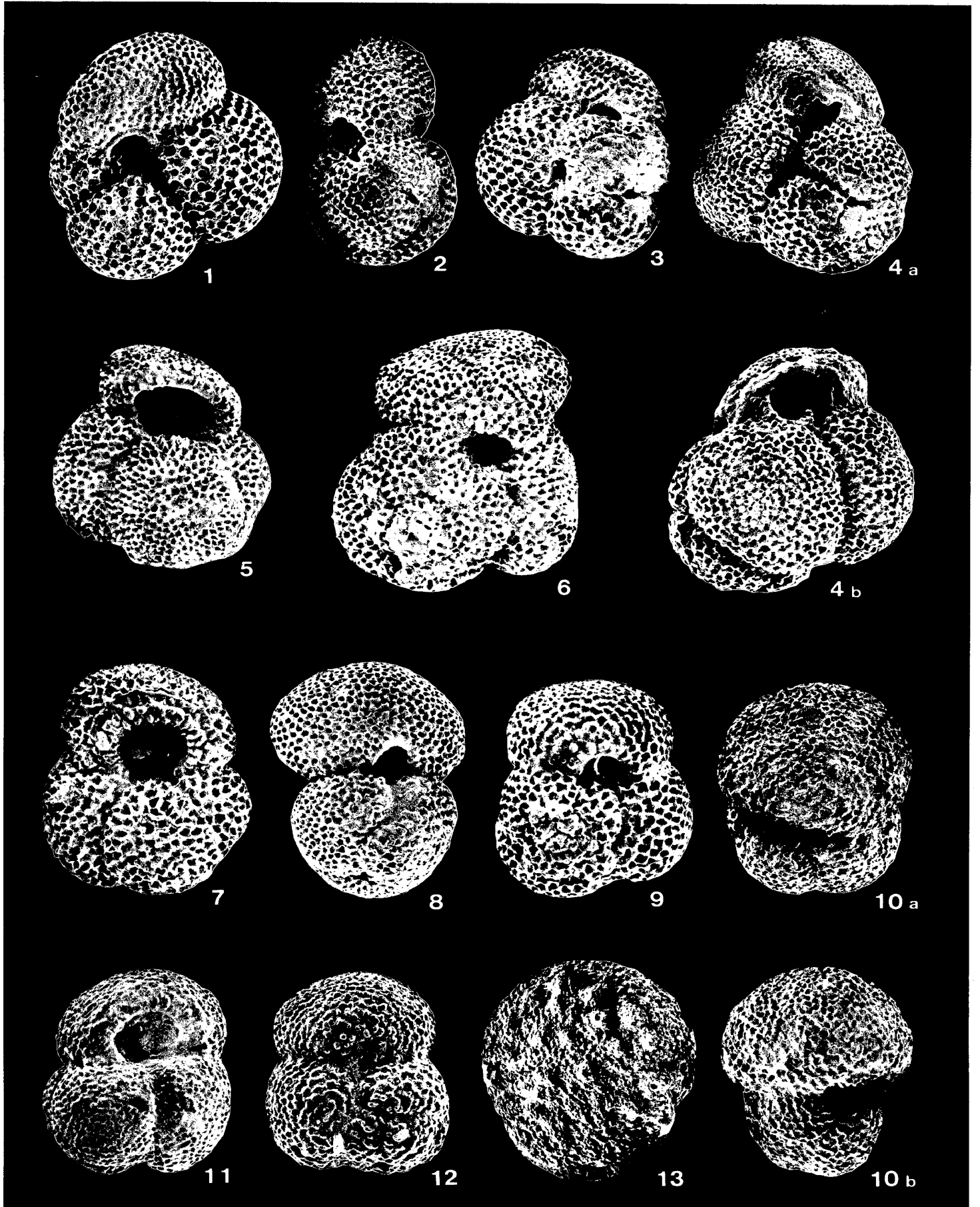


Plate 2

- Figs. 1-4. *Globigerina pachyderma* (Ehrenberg)
1-3- \times 120. 4- \times 150, all specimens (IGPS coll. cat. no. 95869A, B, C, D) from sample KM05, Kakinokidai Formation, Boso Peninsula.
- Figs. 5, 6. *Globigerina quinqueloba* Natland
Both specimens (IGPS coll. cat. no. 95870A, B) from sample YR21, Kiwada Formation, Boso Peninsula, \times 150.
- Figs. 7a, b. *Globigerina woodi* Jenkins
Specimen (IGPS coll. cat. no. 95871) from sample 12, Anno Formation, Boso Peninsula, \times 100.
- Figs. 8, 9. *Globigerinella aequilateralis* (Brady)
8-specimen (IGPS coll. cat. no. 95872A) from sample 15, Anno Formation. 9-specimen (IGPS coll. cat. no. 95872B) from sample 02, Anno Formation, Boso Peninsula, \times 150.
- Fig. 10. *Globigerinita glutinata* (Egger)
Specimen (IGPS coll. cat. no. 95873) from sample YR27, Kiwada Formation, Boso Peninsula, \times 150.
- Fig. 11. *Globigerinoides quadrilobatus trilobus* (Reuss)
Specimen (IGPS coll. cat. no. 95874) from sample KA04, Namihana Formation, Boso Peninsula, \times 100.
- Figs. 12, 13. *Globigerinoides conglobatus* (Brady)
12- specimen (IGPS coll. cat. no. 95875A) from sample 05, Anno Formation, Boso Peninsula, \times 100. 13- specimen (IGPS coll. cat. no. 95875B) from sample KA04, Namihana Formation, Boso Peninsula, \times 75.
- Figs. 14, 15. *Globigerinoides quadrilobatus immaturus* LeRoy
14- \times 75. 15- \times 100, both specimens (IGPS coll. cat. no. 95876A, B) from sample KA04, Namihana Formation, Boso Peninsula.
- Figs. 16, 17. *Globigerinoides tenellus* Parker
16-specimen (IGPS coll. cat. no. 95877A) from sample US04, Umegase Formation. 17-specimen (IGPS coll. cat. no. 95877B) from sample KM05, Kakinokidai Formation, Boso Peninsula, \times 125.
- Figs. 18, 19. *Globigerinoides ruber* (d'Orbigny)
18- \times 125. 19- \times 100, both specimens (IGPS coll. cat. no. 95878A, B) from sample YR21, Kiwada Formation, Boso Peninsula.

Plate 3

- Figs. 1-3. *Globigerinoides quadrilobatus sacculifer* (Brady)
All specimens (IGPS coll. cat. no. 95879A, B, C) from sample KW27, Kiwada Formation, Boso Peninsula, $\times 100$.
- Figs. 4a, b. *Globigerinoides elongatus* (d'Orbigny)
Specimen (IGPS coll. cat. no. 95880) from sample YR21, Kiwada Formation, Boso Peninsula, $\times 100$.
- Figs. 5, 6. *Globigerinoides extremus* Bolli and Bermúdez
5- specimen (IGPS coll. cat. no. 95881A) from sample 05, Anno Formation, Boso Peninsula, $\times 100$.
6- specimen (IGPS coll. cat. no. 95881B) from sample 33, Kiyosumi Formation, Boso Peninsula, $\times 125$.
- Figs. 7-9. *Globigerinoides obliquus* Bolli
7, 9- both specimens (IGPS coll. cat. no. 95882A, C) from sample 05, Anno Formation. 8- specimen (IGPS coll. cat. no. 95882 B) from sample 09, Anno Formation, Boso Peninsula, $\times 125$.
- Figs. 10a, b. *Globigerinoides sicanus* De Stefani
10a- $\times 80$. 10b- $\times 75$, specimen (IGPS coll. cat. no. 95883) from sample HSH26, Ono Formation, Takasaki area.
- Figs. 11, 12. *Globigerinoides subquadratus* Brönnimann
11- specimen (IGPS coll. cat. no. 95884A) from sample HSH30, Ono Formation. 12- specimen (IGPS coll. cat. no. 95884B) from sample HSH33, Ono Formation, Takasaki area, $\times 90$.
- Fig. 13. *Globigerinatella insueta* Cushman and Stainforth
Specimen (IGPS coll. cat. no. 95885) from sample HSH26, Ono Formation, Takasaki area, $\times 100$.



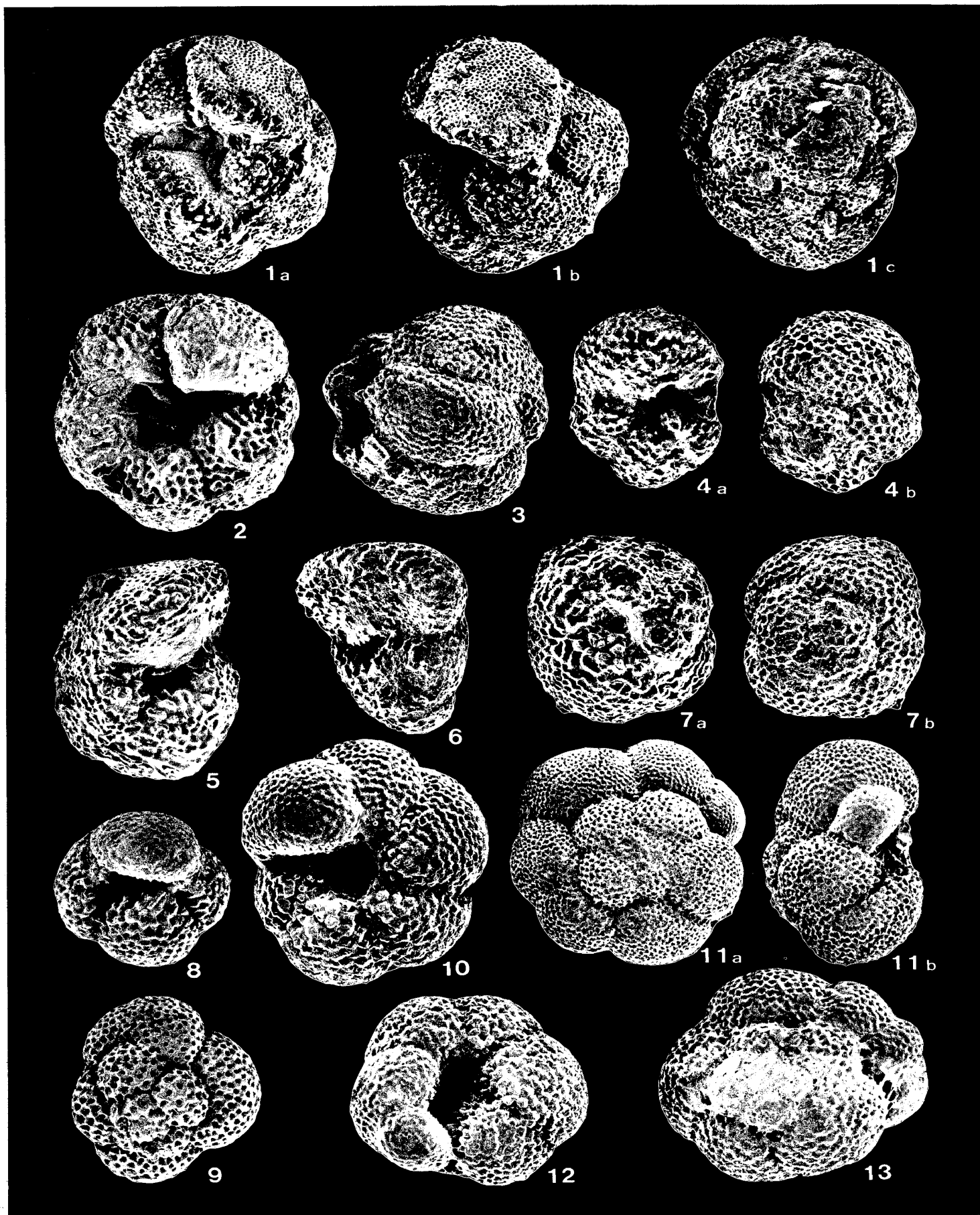


Plate 4

- Figs. 1a-c, 2, 3. *Globoquadrina altispira* (Cushman and Jarvis)
1a-c- $\times 70$. 3- $\times 80$, both specimens (IGPS coll. cat. no. 95886A, C) from sample HSH26, Ono Formation, Takasaki area. 2- specimen (IGPS coll. cat. no. 95886B) from sample SG13, Sagara Formation, Kakegawa area, $\times 100$.
- Figs. 4a, b. *Globoquadrina larmeyi* Akers
Specimen (IGPS coll. cat. no. 95887) from sample HSH26, Ono Formation, Takasaki area, $\times 100$.
- Figs. 5, 6. *Globoquadrina dehiscens dehiscens* (Chapman, Parr and Collins)
Both specimens (IGPS coll. cat. no. 95888A, B) from sample HSH26, Ono Formation, Takasaki area, $\times 100$.
- Figs. 7a, b. *Globoquadrina dehiscens advena* Bermúdez
Specimen (IGPS coll. cat. no. 95889) from sample IDO09, Idozawa Formation, Takasaki area, $\times 100$.
- Figs. 8, 9. *Globoquadrina venezuelana* (Hedberg)
Both specimens (IGPS coll. cat. no. 95890A, B) from sample 21, Anno Formation, Boso Peninsula, $\times 100$.
- Figs. 10, 11a, b, 12, 13. *Globoquadrina dutertrei* (d'Orbigny)
10- specimen (IGPS coll. cat. no. 95891A) from sample HS08, Ohara Formation, Boso Peninsula, $\times 100$. 11a-b-specimen (IGPS coll. cat. no. 95891B) from sample HS10, Ohara Formation, Boso Peninsula, $\times 75$. 12- specimen (IGPS coll. cat. no. 95891C) from sample US04, Umegase Formation, Boso Peninsula, $\times 100$. 13- specimen (IGPS coll. cat. no. 95891D) from sample KM01, Kokumoto Formation, Boso Peninsula, $\times 100$.

Plate 5

Figs. 1a, b. *Globorotalia continuosa* Blow

Specimen (IGPS coll. cat. no. 95892) from sample K35, Amatsu Formation, Boso Peninsula, × 100.

Figs. 2a, b, 3. *Globorotalia acostaensis* Blow

2a-b- specimen (IGPS coll. cat. no. 95893A) from sample 31, Kiyosumi Formation. 3-specimen (IGPS coll. cat. no. 95893B) from sample 37, Kiyosumi Formation, Boso Peninsula, × 100.

Figs. 4, 5a, b, 6. *Globorotalia humerosa* Takayanagi and Saito

4- specimen (IGPS coll. cat. no. 95894A) from sample T03, Anno Formation, Boso Peninsula, × 100. 5a-b- specimen (IGPS coll. cat. no. 95894B) from sample 13, Anno Formation, Boso Peninsula, × 90. 6- specimen (IGPS coll. cat. no. 95894C) from sample 21, Anno Formation, Boso Peninsula, × 90.

Figs. 7a, b. *Globorotalia obesa* Bolli

Specimen (IGPS coll. cat. no. 95895) from sample HSH28, Ono Formation, Takasaki area, × 100.

Figs. 8-10. *Globorotalia siakensis* (LeRoy)

8- specimen (IGPS coll. cat. no. 95896A) from sample K32, Amatsu Formation. 9, 10- both specimens (IGPS coll. cat. no. 95896B, C) from sample K35, Amatsu Formation, Boso Peninsula, × 100.

Fig. 11. *Globorotalia linguaensis* Bolli

Specimen (IGPS coll. cat. no. 95897) from sample K24, Amatsu Formation, Boso Peninsula, × 100.

Fig. 12. *Praeorbulina glomerosa curva* (Blow)

Specimen (IGPS coll. cat. no. 95898) from sample HSH33, Ono Formation, Takasaki area, × 100.

Fig. 13. *Praeorbulina glomerosa glomerosa* (Blow)

Specimen (IGPS coll. cat. no. 95899) from sample HSH33, Ono Formation, Takasaki area, × 100.

Fig. 14. *Praeorbulina glomerosa circularis* (Blow)

Specimen (IGPS coll. cat. no. 95900) from sample HSH26, Ono Formation, Takasaki area, × 100.

Fig. 15. *Praeorbulina transitoria* (Blow)

Specimen (IGPS coll. cat. no. 95901) from sample HSH33, Ono Formation, Takasaki area, × 100.

Fig. 16. *Orbulina suturalia* Brönnimann

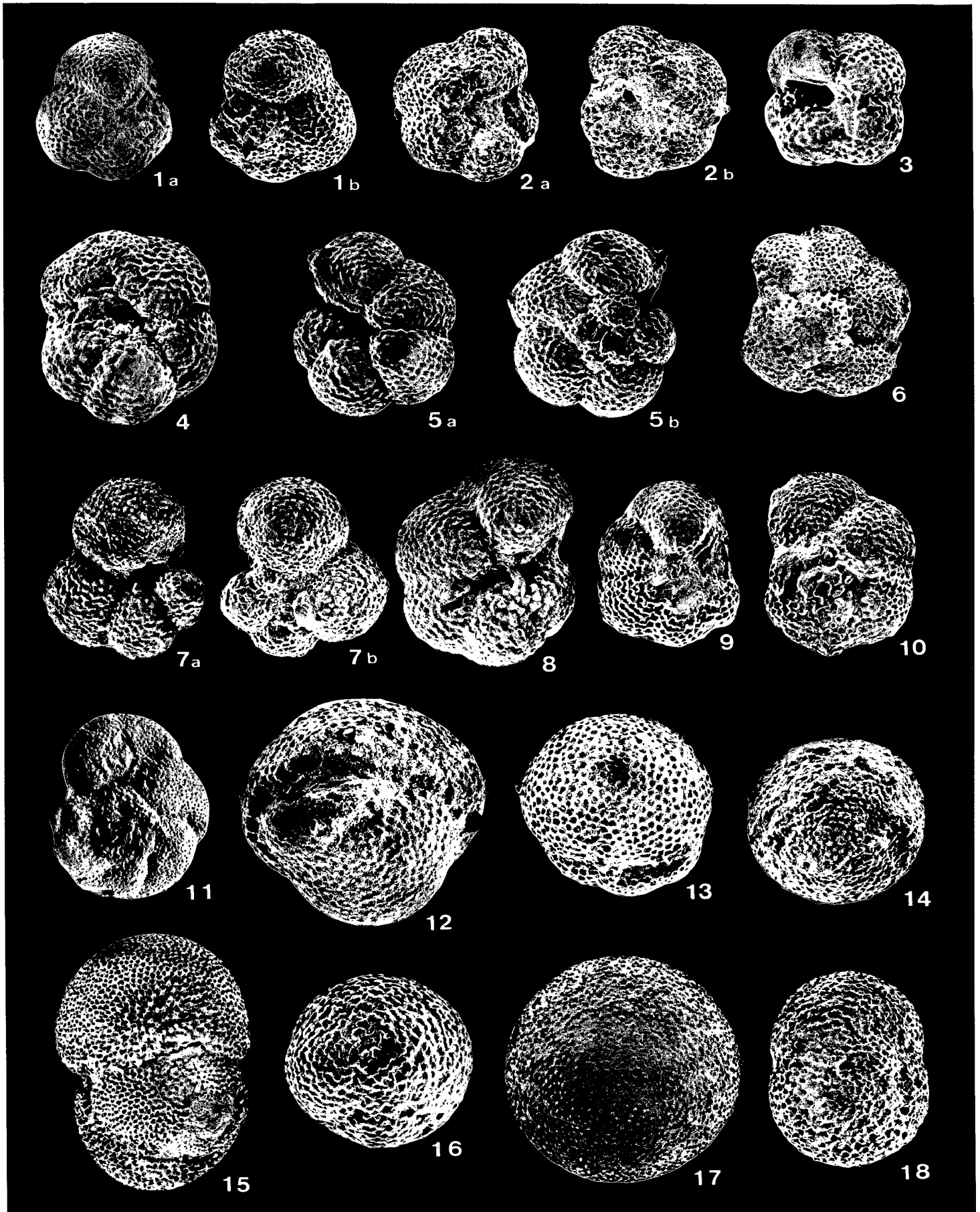
Specimen (IGPS coll. cat. no. 95902) from sample HSH26, Ono Formation, Takasaki area, × 100.

Fig. 17. *Orbulina universa* d'Orbigny

Specimen (IGPS coll. cat. no. 95903) from sample KW27, Kiwada Formation, Boso Peninsula, × 75.

Fig. 18. *Orbulina bilobata* (d'Orbigny)

Specimen (IGPS coll. cat. no. 95904) from sample K47, Amatsu Formation, Boso Peninsula, × 100.



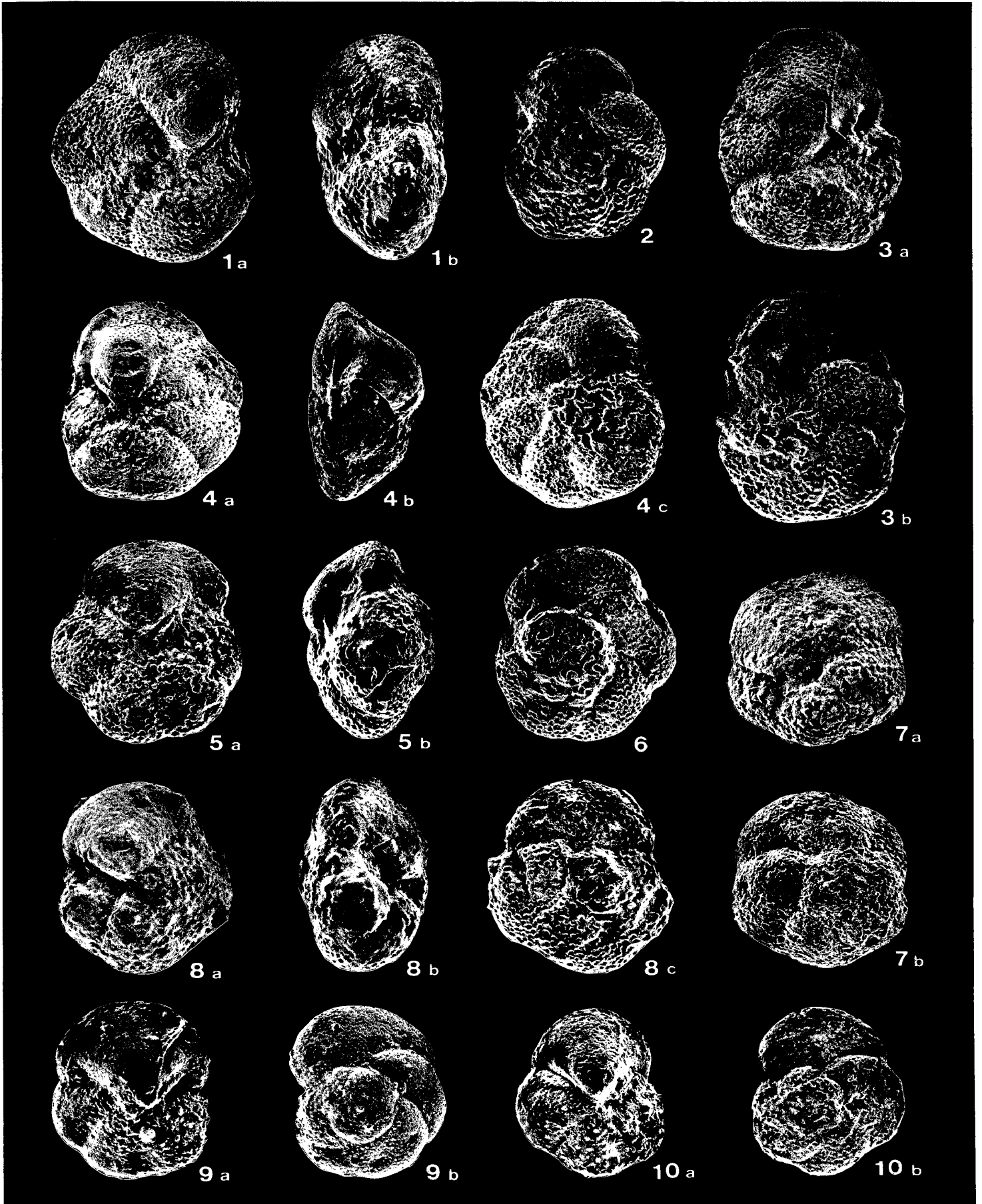
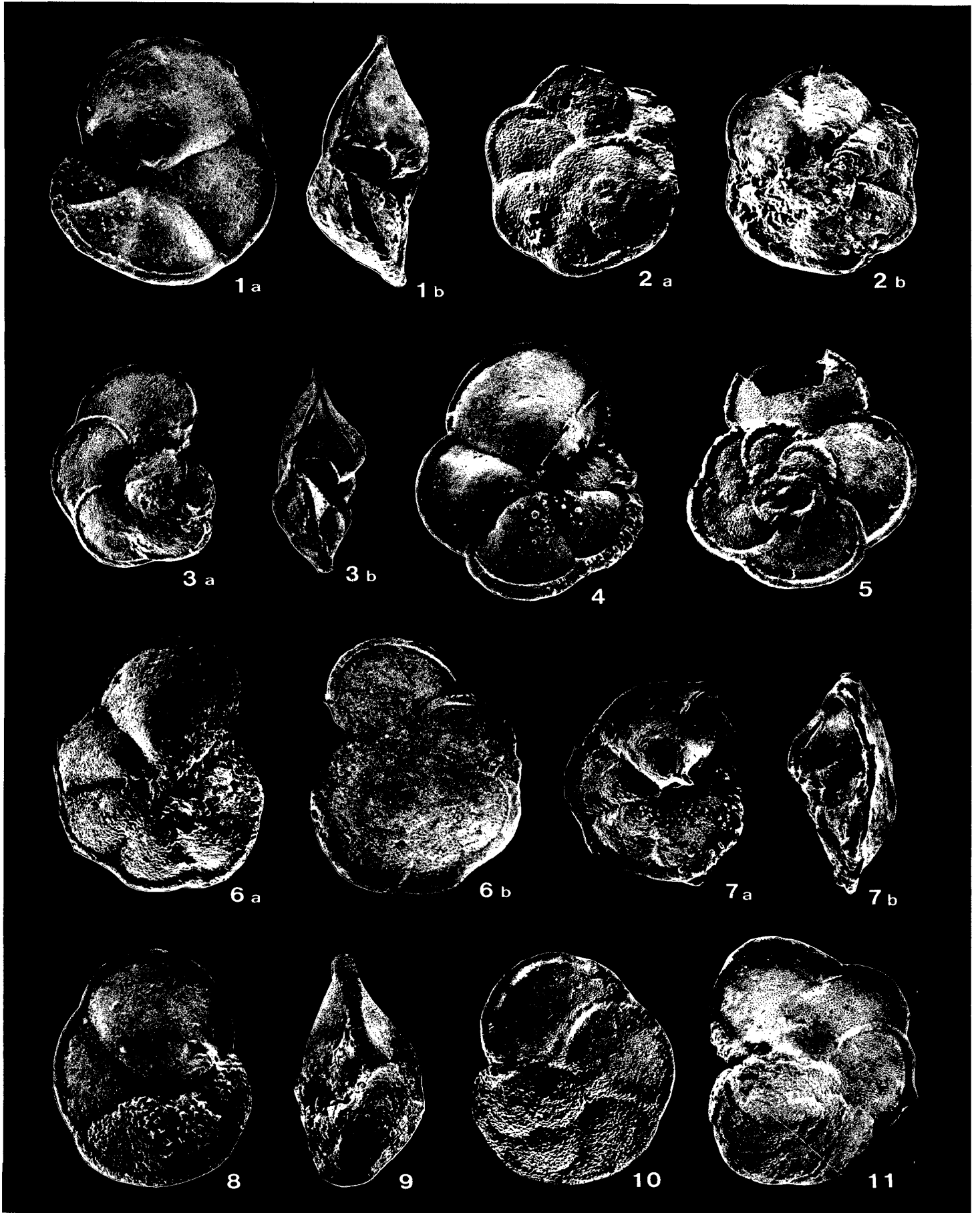


Plate 6

- Figs. 1a, b, 2. *Globorotalia peripheroronda* Blow and Banner
1a-b- specimen (IGPS coll. cat. no. 95905A) from sample K51, Amatsu Formation. 2- specimen (IGPS coll. cat. no. 95905B) from sample K48, Amatsu Formation, Boso Peninsula, $\times 100$.
- Figs. 3a, b. *Globorotalia* cf. *praefohsi* Blow and Banner
Specimen (IGPS coll. cat. no. 95906) from sample K47, Amatsu Formation, Boso Peninsula, $\times 100$.
- Figs. 4a-c. *Globorotalia peripheroacuta* Blow and Banner
Specimen (IGPS coll. cat. no. 95907) from sample K47, Amatsu Formation, Boso Peninsula, $\times 100$.
- Figs. 5a, b, 6. *Globorotalia quinifalcata* Saito and Maiya
Both specimens (IGPS coll. cat. no. 95908 A, B) from sample K47, Amatsu Formation, Boso Peninsula, $\times 150$.
- Figs. 7a, b. *Globorotalia birnageae* Blow
Specimen (IGPS coll. cat. no. 95909) from sample K47, Amatsu Formation, Boso Peninsula, $\times 150$.
- Figs. 8a-c. *Globorotalia scitula praescitula* Blow
Specimen (IGPS coll. cat. no. 95910) from sample IDO09, Idozawa Formation, Takasaki area, $\times 150$.
- Figs. 9a, b. *Globorotalia praemenardii archeomenardii* Bolli
Specimen (IGPS coll. cat. no. 95911) from sample IDO09, Idozawa Formation, Takasaki area, $\times 100$.
- Fig. 10a, b. *Globorotalia praemenardii praemenardii* Cushman and Stainforth
Specimen (IGPS coll. cat. no. 95912) from sample K47, Amatsu Formation, Boso Peninsula, $\times 100$.

Plate 7

- Figs. 1a, b, 3a, b. *Globorotalia cultrata* (d'Orbigny)
1a-b- $\times 100$. 3a-b- $\times 60$, both specimens (IGPS coll. cat. no. 95913A, B) from sample T03, Anno Formation, Boso Peninsula.
- Figs. 2a, b. *Globorotalia multicamerata* Cushman and Jarvis
Specimen (IGPS coll. cat. no. 95914) from sample 30, Kiyosumi Formation, Boso Peninsula, $\times 75$.
- Figs. 4, 5. *Globorotalia fimbriata* (Brady)
Both specimens (IGPS coll. cat. no. 95915A, B) from sample KW30, Kiwada Formation, Boso Peninsula, $\times 75$.
- Figs. 6a, b, 7a, b. *Globorotalia tumida plesiotumida* Blow and Banner
6a-b- specimen (IGPS coll. cat. no. 95916A) from sample K04, Amatsu Formation, Boso Peninsula, $\times 75$. 7a-b- specimen (IGPS coll. cat. no. 95916B) from sample 46, Amatsu Formation, Boso Peninsula, $\times 70$.
- Figs. 8-11. *Globorotalia tumida tumida* (Brady)
8, 9- both specimens (IGPS coll. cat. no. 95917A, B) from sample KW30, Kiwada Formation.
10- specimen (IGPS coll. cat. no. 95917C) from sample KA04, Namihana Formation. 11- specimen (IGPS coll. cat. no. 95917D) from sample 13, Anno Formation, Boso Peninsula, $\times 50$.



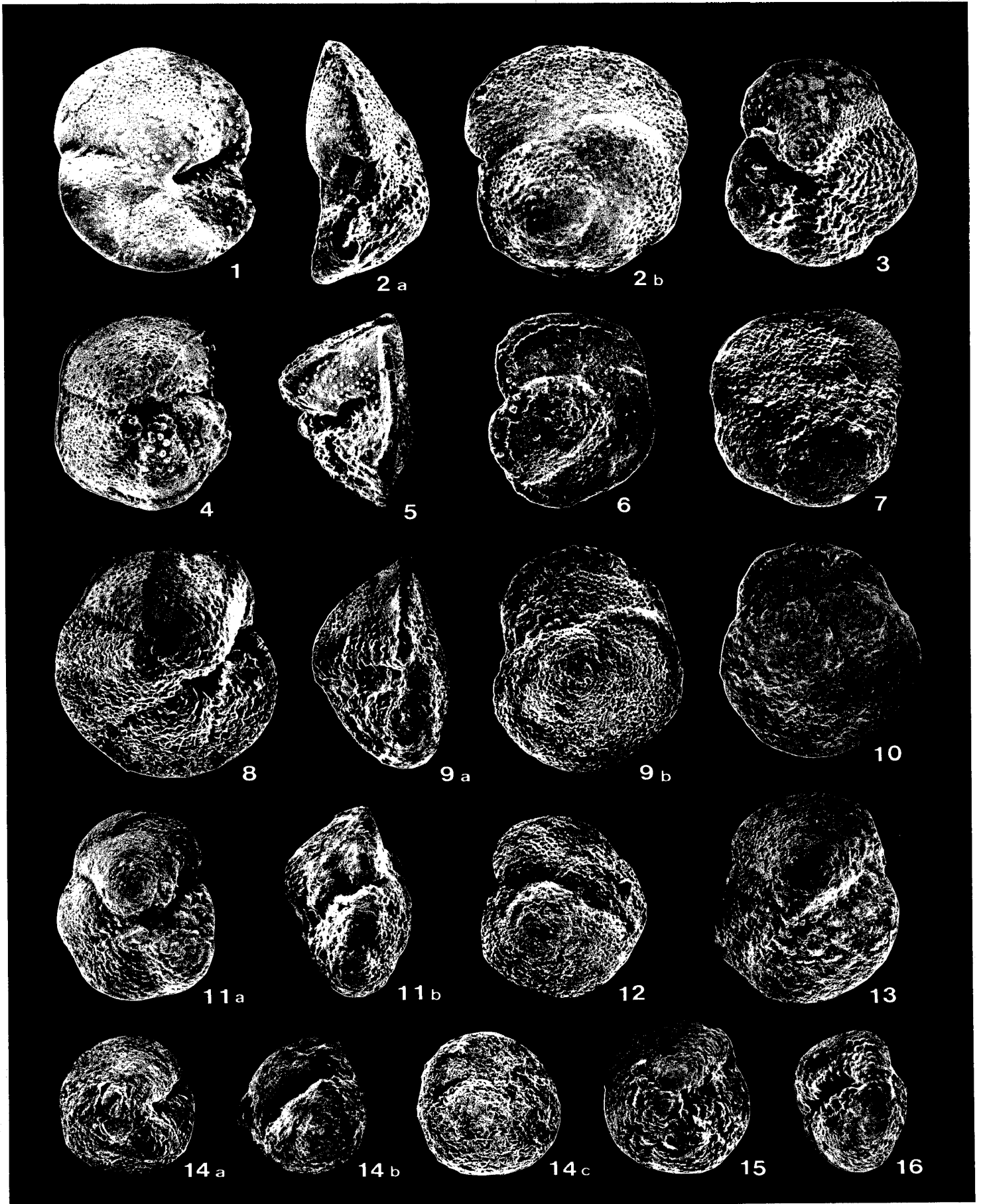


Plate 8

Figs. 1, 2a, b. *Globorotalia margaritae* Bolli and Bermúdez

1- specimen (IGPS coll. cat. no. 95918A) from sample 03, Anno Formation. 2a-b- specimen (IGPS coll. cat. no. 95918B) from sample 15, Anno Formation, Boso Peninsula, $\times 100$.

Figs. 3, 7. *Globorotalia miozea miozea* Finlay

Both specimens (IGPS coll. cat. no. 95919A, B) from sample 46, Amatsu Formation, Boso Peninsula, $\times 50$.

Figs. 4-6. *Globorotalia conomiozea* Kennett

4- specimen (IGPS coll. cat. no. 95920A) from sample 32, Kiyosumi Formation, Boso Peninsula, $\times 70$. 5- specimen (IGPS coll. cat. no. 95920B) from sample 31, Kiyosumi Formation, Boso Peninsula, $\times 80$. 6- specimen (IGPS coll. cat. no. 95920C) from sample 18, Anno Formation, Boso Peninsula, $\times 70$.

Figs. 8, 9a, b, 10. *Globorotalia miozea conoidea* Walters

8- specimen (IGPS coll. cat. no. 95921A) from sample 03, Anno Formation, Boso Peninsula, $\times 100$. 9a-b- specimen (IGPS coll. cat. no. 95921B) from sample 30, Kiyosumi Formation, Boso Peninsula, $\times 80$. 10- specimen (IGPS coll. cat. no. 95921C) from sample 02, Anno Formation, Boso Peninsula, $\times 100$.

Figs. 11a, b, 12, 13. *Globorotalia* cf. *miozea conoidea* Walters

11a-b, 12- $\times 75$. 13- $\times 90$, all specimens (IGPS coll. cat. 95922A, B, C) from sample K47, Amatsu Formation, Boso Peninsula.

Figs. 14a-c, 15, 16. *Globorotalia miozea sphericomiozea* Walters

14a-c- specimen (IGPS coll. cat. no. 95923A) from sample 08, Anno Formation. 15, 16- both specimens (IGPS coll. cat. no. 95923B, C) from sample 02, Anno Formation, Boso Peninsula, $\times 80$.

Plate 9

Figs. 1a-c, 2, 3a-c. *Globorotalia crassaformis* (Galloway and Wissler)

1a-c- specimen (IGPS coll. cat. no. 95924A) from sample KW27, Kiwada Formation. 2- specimen (IGPS coll. cat. no. 95924B) from sample KA04, Namihana Formation. 3a-c- specimen (IGPS coll. cat. no. 95924C) from sample 02, Anno Formation, Boso Peninsula, $\times 100$.

Figs. 4-7. *Globorotalia tosaensis* Takayanagi and Saito

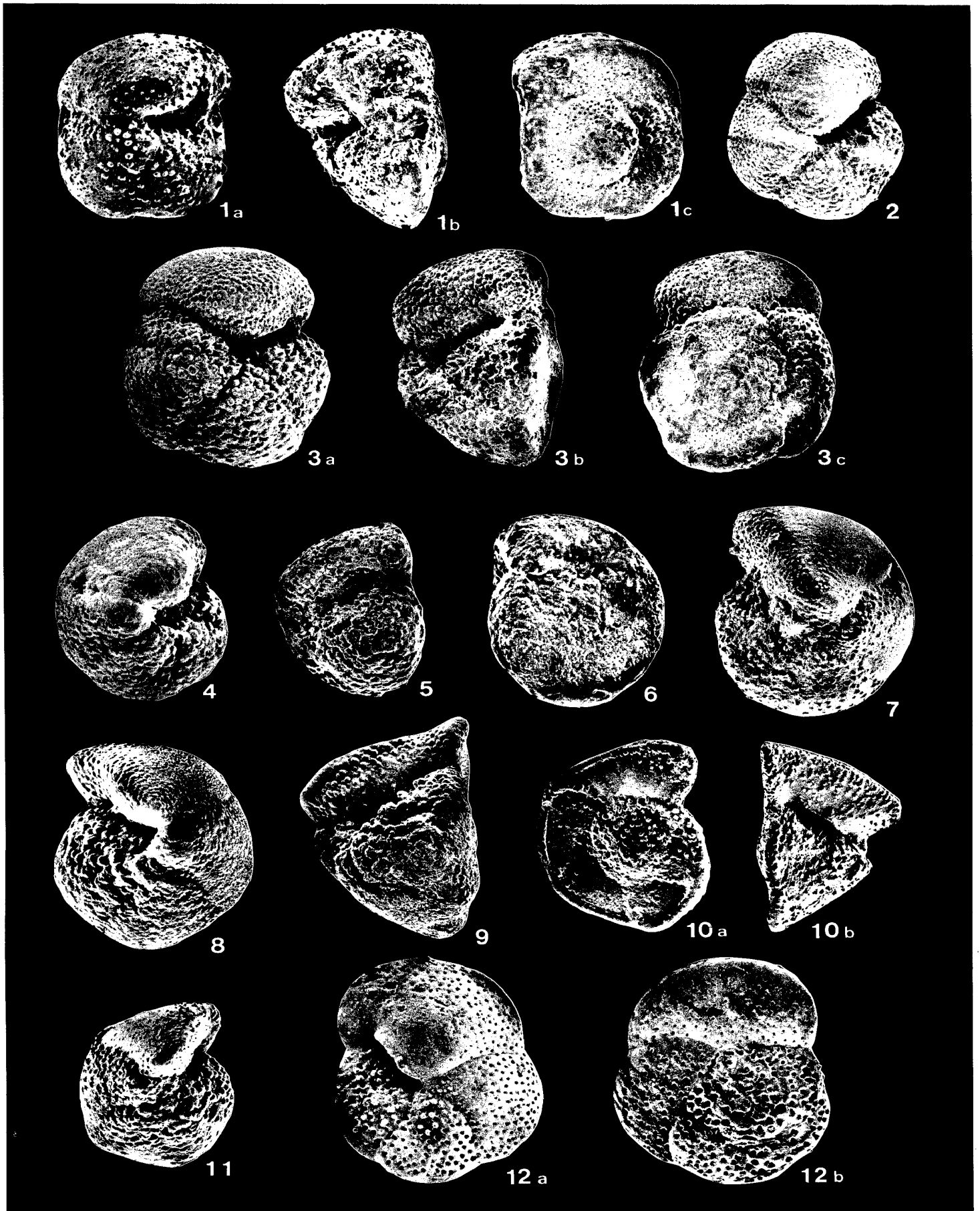
4- specimen (IGPS coll. cat. no. 95925A) from sample KW31, Kiwada Formation. 5, 6- both specimens (IGPS coll. cat. no. 95925B, C) from sample HS12, Ohara Formation. 7- specimen (IGPS coll. cat. no. 95925D) from sample HS10, Ohara Formation, Boso Peninsula, $\times 100$.

Figs. 8, 9, 10a, b, 11. *Globorotalia truncatulinoides* (d'Orbigny)

8, 9- both specimens (IGPS coll. cat. no. 95926A, B) from sample KW30, Kiwada Formation. 10a-b- specimen (IGPS coll. cat. no. 95926C) from sample KM01, Kokumoto Formation. 11- specimen (IGPS coll. cat. no. 95926D) from sample HS10, Ohara Formation, Boso Peninsula, $\times 75$.

Figs. 12a, b. *Globorotalia scitula scitula* (Brady)

Specimen (IGPS coll. cat. no. 95927) from sample KA04, Namihana Formation, Boso Peninsula, $\times 100$.



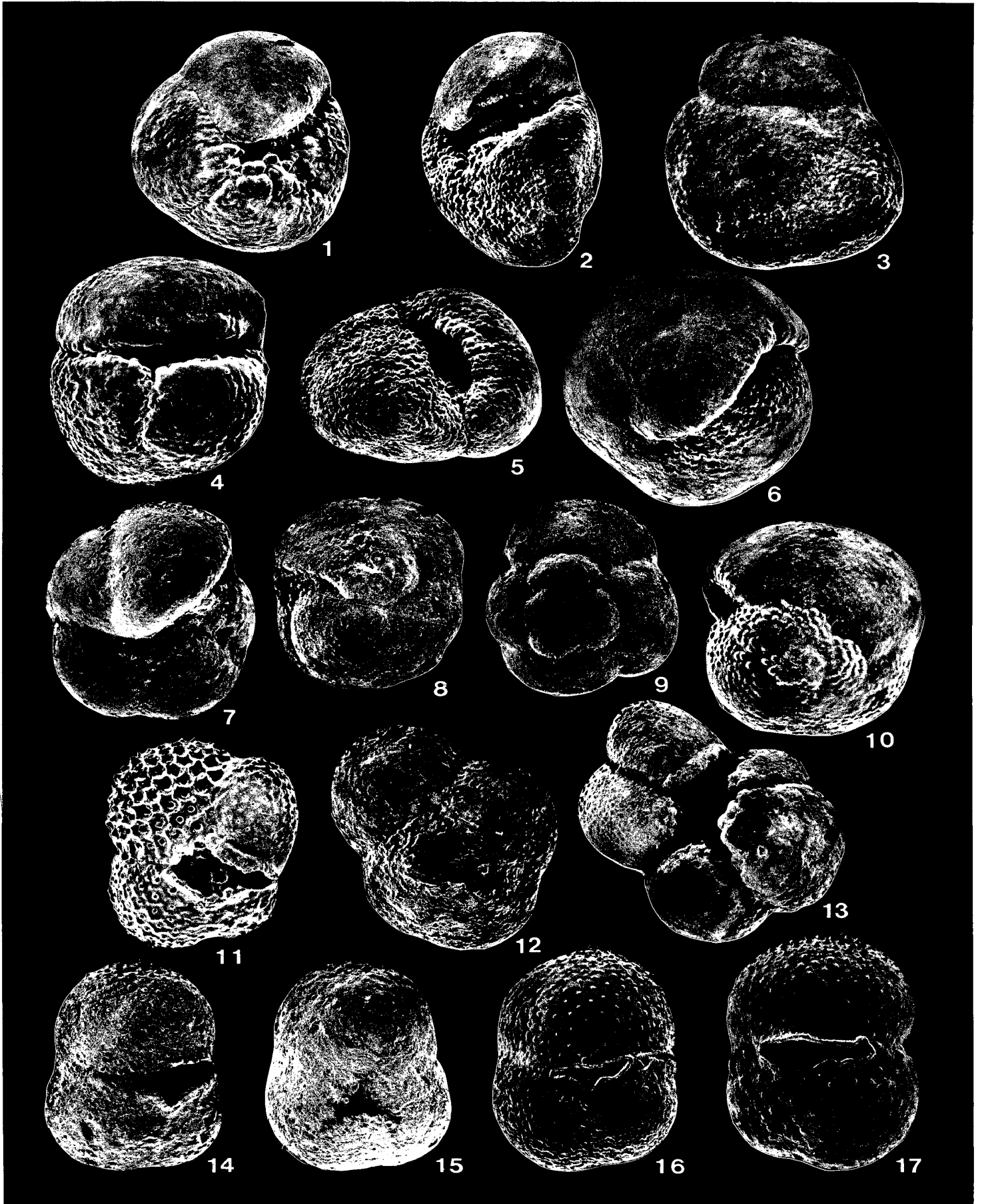


Plate 10

Figs. 1-5. *Globorotalia inflata* (d'Orbigny)

All Specimens (IGPS coll. cat. no. 95928A, B, C, D, E) from sample KW27, Kiwada Formation, Boso Peninsula, $\times 100$.

Figs. 6, 10. *Pulleniatina obliquiloculata* (Parker and Jones)

6- $\times 80$. 10- $\times 75$, both specimens (IGPS coll. cat. no. 95929A, B) from sample KW27, Kiwada Formation, Boso Peninsula.

Figs. 7-9. *Pulleniatina primalis* Banner and Blow

All specimens (IGPS coll. cat. no. 95930 A, B, C) from sample S19, Sagara Formation, Kakegawa area, $\times 100$.

Figs. 11-13. *Sphaeroidinellopsis seminulina* (Schwager)

11- $\times 100$. 12- $\times 75$, both specimens (IGPS coll. cat. no. 95931A, B) from sample 44, Amatsu Formation, Boso Peninsula. 13- specimen (IGPS coll. cat. no. 95931C) from sample K19, Amatsu Formation, Boso Peninsula, $\times 70$.

Figs. 14, 15. *Sphaeroidinellopsis subdehiscens* (Blow)

Both specimens (IGPS coll. cat. no. 95932A, B) from sample 48, Amatsu Formation, Boso Peninsula, $\times 100$.

Figs. 16, 17. *Sphaeroidinella dehiscens* (Parker and Jones)

Both specimens (IGPS coll. cat. no. 95933 A, B) from sample KW27, Kiwada Formation, Boso Peninsula, $\times 75$.