Paleoenvironmental Studies of the Nishiyatsushiro and Shizukawa Groups, South Fossa-Magna Region

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Kazumi Akimoto*

ABSTRACT

The forearc basin-trench system is generally characterized by a paleoenvironmental complex which is reflected in various lines of geological and paleontological evidence. The Fujikawa area in the South Fossa-Magna region belongs to a part of such a complex system along the tectonically active margin of southwest Japan. Analysis of foraminiferal biofacies and lithofacies of the Neogene Nishiyatsushiro and Shizukawa Groups, distributed in the area, reveals complicated patterns of their interaction, which are attributed to the Neogene depositional trends innate to a tectonically complex portion of the Pacific rim.

An emphasis is placed on the estimation of depth ranges of fossil benthic foraminiferal species by assessing both the distribution of modern counterparts and sedimentological properties in a similar active continental margin setting. Such data are used to reconstruct depositional environments of the Neogene sequences.

A quantitative analysis of benthic foraminiferal species in the Neogene sequences reveals four important paleoenvironmental factors influencing the species composition. These factors include such environmental parameters as water depth, dissolved oxygen, and effects of both bottom water currents and coastal water mass. Furthermore, nine types of paleoenvironments are deduced by integrating results of analyses of principal components and sedimentary properties as well as ecological data on modern benthic foraminifera. Each of the nine types of paleoenvironments is represented by a particular biofacies which is named after dominant species as follows : Type a (*Rhabdammina abyssorum* biofacies), Type b (*Melonis sphaeroides-Nodosaria longiscata* biofacies), Type c (*Globobulimina auriculata-Melonis sphaeroides* biofacies), Type d (*Nodosaria longiscata* biofacies), Type e (*Melonis sphaeroides-Stilostomella lepidula* biofacies), Type f (*Stilostomella lepidula* biofacies), Type g (*Globobulimina pupoides-Stilostomella lepidula* biofacies), Type h (*Globobulimina auriculata* biofacies) and Type i (*Ammonia ketienziensis-Ammonia takanabensis* biofacies). Foraminiferal distributions in the NW Pacific off southwest Japan and around Hachijojima Island show that three ancient biofacies (Types a, h, and i) were also distributed under the comparable environments.

The present author developed a dynamic model of sedimentation history which is closely related to the developmental processes of several sedimentary basins in the Fujikawa area. Such sedimentological data as the direction of grain transport and sedimentary structures in fine-grained sedimentary rocks are obtained together with geological and micropaleontological data. Selected biogenous grains in foraminifer-bearing rocks are examined in the laboratory. The distributional pattern of these biogenous grains in the Nishiyatsushiro and Shizukawa Groups resemble that in sediments of the present-day forearc basin. These paleontological and sedimentological data together provide the basis to conclude that the Nishiyatsushiro and Shizukawa Groups were deposited in a forearc basin setting. The Misaka Group, which accumulated contemporaneously with the basal part of the Nishiyatsushiro Group, consists mostly of oceanic materials, and exhibits geological features characteristic of the accretional zone.

The sedimentary basin active during the Neogene is here named the Nishiyatsushiro paleo-forearc basin and the accretional prism which is located beneath the forearc basin the Misaka paleo-trench.

Key words : South Fossa Magna region, Neogene, Foraminiferal biostratigraphy, Environment of sedimentation, Paleo-plate margin

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INTRODUCTION

The Fossa Magna region is located in the middle part of the Honshu Island and lies at the junction of Southwest Japan, Northeast Japan and the Izu-Bonin Arcs. This region is divided into the North (Honma, 1931) and South Fossa-Magne regions (Koike, 1957) on the basis of geological features. The South Fossa-Magna region encompasses eastern Shizuoka Prefecture, Yamanashi Prefecture, Kanagawa Prefecture and the southern part of the Boso Peninsula in Chiba Prefecture. This region is characterized by a thick accumulation of clastic and pyroclastic sediments of Neogene age. These rocks have strongly been folded and faulted to form a west- or north-dipping imbricate structure. The trend of depositional basins and their deformation in this region forms a northward convex arc around the Izu Peninsula (Matsuda, 1979). Opinions diverge with regard to the developmental process of these depositional basins and their deformation (*e.g.* Minato *et al.*, 1965; Matsuda, 1986).

The Fujikawa area, the studied area, is located in the western part of the South Fossa-Magna region in the southern part of Yamanashi Prefecture (Fig. 1). Because of continuous deposition during the Neogene coupled with a rather simple geological structure than that of other areas, numerous studies have been carried out in this region for delineating developmental and sedimentary processes.

A great deal of work has been carried out especially on the Neogene stratigraphy in this area (Otuka, 1955; Matsuda and Mizuno, 1955; Akiyama, 1957; Fujikawa Collaborative Group, 1976; Nishimiya and Ueda, 1976). Otuka (*op. cit.*), Matsuda and Mizuno (*op. cit.*), and

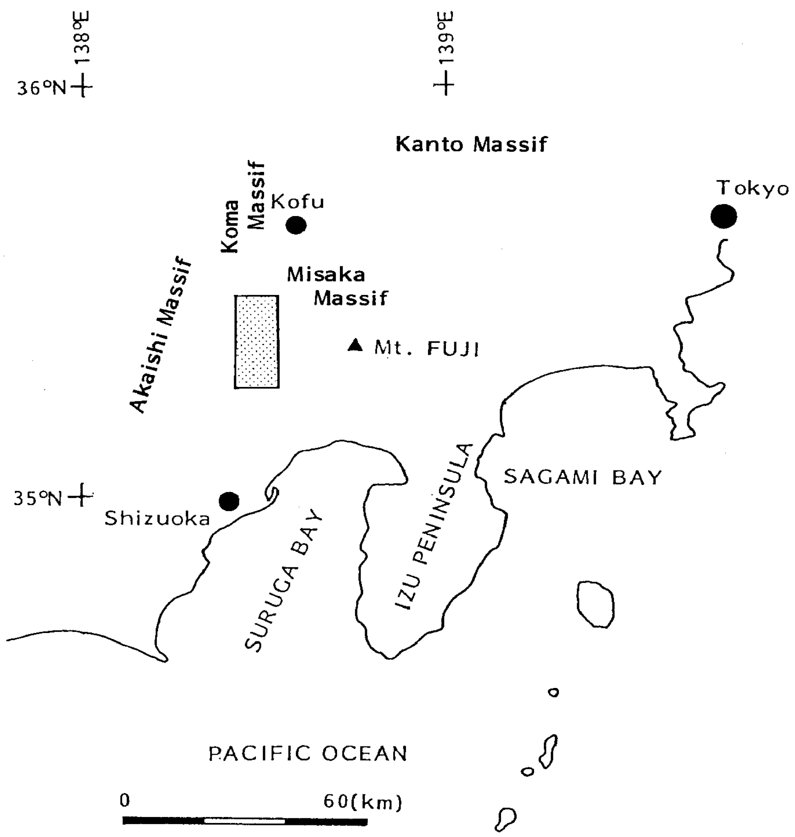

Fig. 1. Index map of the study area.

Akiyama (*op. cit.*) established the lithostratigraphic division of the Neogene strata, which came to be used by subsequent workers. The Nishiyatsushiro and Shizukawa Groups are defined by Matsuda and Mizuno (*op. cit.*), and by Otuka (*op. cit.*), respectively.

In a sedimentological study, Matsuda (1958) reported on paleocurrent directions in the middle part of the Shizukawa Group (Marutaki Conglomerate of the Minobu Formation). Soh (1985) clarified sedimentary environments of this conglomerate and reconstructed a channel system, named the Marutaki Channel, through which these conglomerates were transported. Soh (1986) traced the extent of Marutaki Channel along the southern margin of the Kanto Mountains, and the extended channel system was renamed Nishikatsura Channel. He further regarded it as a paleo-plate boundary between the Philippine Sea and Eurasia Plates. This idea is based on data of grain compositions and paleocurrent directions of the Marutaki Conglomerate and its equivalents as correlated by Konda (1980).

Diverging opinions have been expressed by these workers in regard to developmentary processes of the geology of the Fujikawa area, because of insufficient data available so far toward establishing ages of various strata. For example, there are two different opinions on the age assignment based on planktonic biostratigraphy : One considers the Miocene/Pliocene boundary to be located in the uppermost part of the Shizukawa Group (Nishimiya and Ueda, 1976 ; Oda *et al.*, 1987) ; the other places it in the basal part of the Shizukawa Group (Ujiié and Muraki, 1976 ; Chiji and Konda, 1978).

It is necessary for the reconstruction of developmental and sedimentary processes around the paleo-plate boundary to obtain paleoenvironmental and paleogeographical data. Benthic foraminifera provide a useful tool for paleoenvironmental and paleogeographical reconstruction of the Fujikawa area, during the Neogene, owing to the fact that Neogene deposits in this area are dominated by offshore mudstone and volcanic sedimentary rocks. For example, Konda (1980) established four zones in the Nishiyatsushiro Group, and estimated that the Nishiyatsushiro Group was deposited in the middle bathyal zone. Kano *et al*. (1985) inferred paleobathymetry of the Shizukawa Group based on their recognition of a shallowing upward sequence.

In relation to paleobiogeography in and around the Japanese Islands, it has been suggested on the basis of the distribution of molluscan fossils that the boreal fauna invaded southward during the Middle Miocene, and the boundary between the boreal and temperate faunas was situated near the Kanto region (*e.g.* Chinzei, 1978). In addition, the boreal fauna was discovered in the northern part of the South Fossa-Magna region (Chinzei and Matsushima, 1987). However, Konda (1980) considered on the basis of benthic foraminifera that the Fujikawa area was located in a warm water region. Thus, it is possible to delineate the course of paleobiogeographical change during the Middle Miocene in the South Fossa-Magna region based on changes of faunal distribution.

The basic purposes of this paper are as follows:

1) Accurate geologic age assignment based on planktonic microfossils.

2) Extracting paleoenvironmental factors, by means of Q-mode principal component analysis of benthic foraminiferal faunas in the Fujikawa area.

3) To rationalize those paleoenvironmental factors which are represented by species or species groups by comparing them with the modern counterparts.

4) Conducting sedimentological analysis in order to reinforce the paleoenvironmental data obtained by means of benthic foraminifera. In addition, examining selected sedimentary grains from strata by comparing their distribution in modern ocean.

5) Synthetic reconstruction of paleoenvironments in the Fujikawa area.

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Principal components analysis was processed with a NEAC-ACOS Model 77/700 computer at the Tohoku University Computer Center.

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GEOLOGY

1. LITHOSTRATIGRAPHY

Thick marine Neogene sequences are developed in the South Fossa-Magna region. The Fujikawa area, part of this region in the southern part of Yamanashi Prefecture, was the site of continuous deposition during Middle Miocene to Pliocene times. The Neogene sequence of this area is lithostratigraphically divisible into three groups, the Misaka, Nishiyatsushiro and Shizukawa Groups (Figs. 2 and 3). The Misaka Group crops out in areas around the Misaka Massif, to the east of the Fujikawa area, and is complicatedly faulted. The last two groups are distributed in the Fujikawa area, showing rather broad folding and faulting, and are composed of thick volcanic and terrigenous clastic rocks. The Nishiyatsushiro Group is exposed restrictedly in the Kiri-ishi area.

A basic lithostratigraphic scheme of the Fujikawa area was established by Matsuda and Mizuno (1955), Otuka (1955) and Akiyama (1957). Their lithostratigraphic classification of strata in the Kiri-ishi and Minobu areas are basically followed by subsequent workers. However, a large number of faults developed in this area formed many tectonic blocks and made one basin into fault contact with another basin. As a result, much confusion has arisen over correlations of strata between one tec-

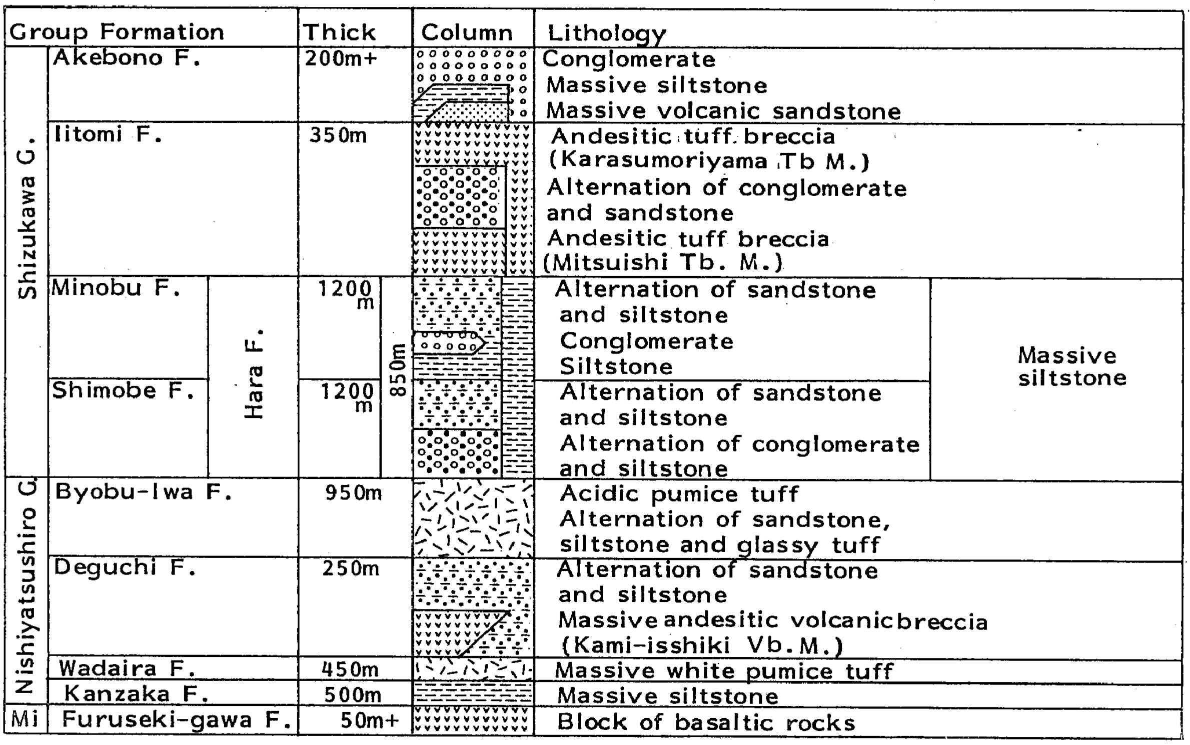

Fig. 2. Schematic stratigraphic section of the Fujikawa area. Mi, Misaka Group.

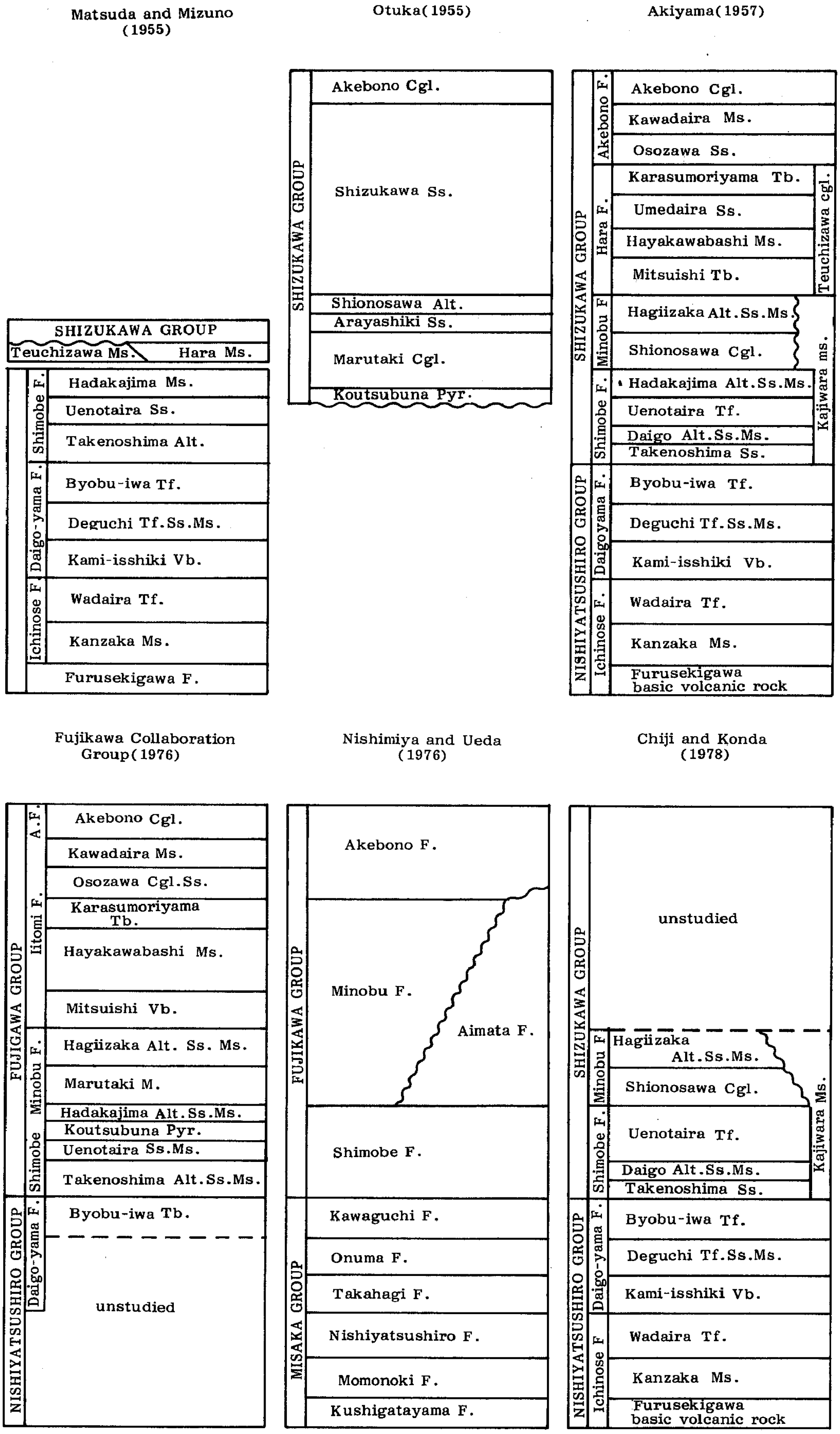

Fig. 3. Comparison of stratigraphic schemes of the Misaka, Nishiyatsushiro and Shizukawa Groups, distributed in the Fujikawa area, proposed by various workers (Matsuda and Mizuno (1955), Otuka (1955), Akiyama (1957), Matsuda (1958), Matsuda (1961), Ujiié and Muraki (1976), Fujikawa Collaborative Group (1976), Nishimiya and Ueda (1976), Chiji and Konda (1978) and Kano *et al.* (1985), and this study).

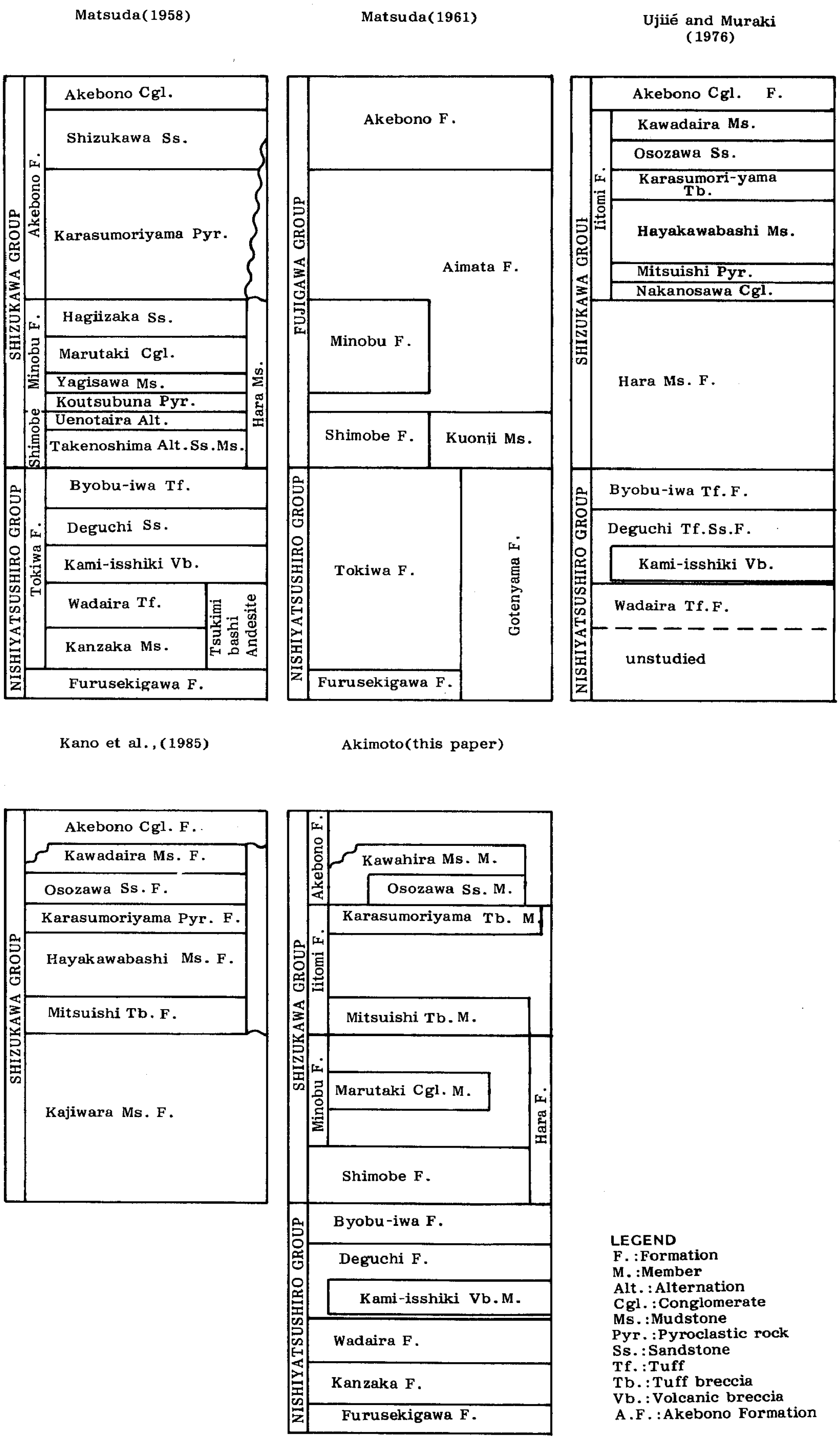

Fig. 3. (continued)

tonic block and another. To resolve such a confusion, the author carried out a detailed geological survey of Neogene sequences in the Fujikawa area (Fig. 4).

a. Misaka Group

The Misaka Group was first defined by Otuka (1939) as a sequence comprising various kinds of volcanic rocks which are exposed in the South-Fossa Magna region. This group, typically developed in the Misaka Massif to the east of the Fujikawa area, consists largely of basaltic rocks and associated fine-grained sedimentary clastics. A narrow geographic distribution of basaltic rocks which are intercalated with siltstone beds has been known as the Furusekigawa Formation of the Nishiyatsushiro Group (*e.g.* Matsuda and Mizuno, 1955). This formation should be included in the Misaka Group because of the similarity in lithofacies between the two.

Furusekigawa Formation

The Furusekigawa Formation was named by Matsuda and Mizuno (1955). Its type locality is chosen at the outcrop along the River Tokiwagawa around Furuseki, Shimobecho, Nishiyatsushiro-gun. This formation consists mainly of pillow lavas and hyaloclastite of tholeiitic basalt. Chemical analyses of the basalt suggest an island arc origin (Shimazu 1984; Shimazu and Ishimaru, 1987). Nishimiya and Ueda (1976) dated by the K-Ar method the basalt of the Furusekigawa Formation to be 34.1 Ma.

Basaltic rocks are intercalated with dark gray or black siltstone beds, which are coeval with the Nakayashiki Mudstone established by Shimazu *et al.* (1976). These siltstones include basalt fragments. Contacts between the basalt and siltstone beds are generally sharp, and reversed fault planes are developed in some outcrops. The uppermost part of the siltstone beds is interbedded with a few silicic tuff layers (about 1 to 2 m thick) and occasionally shows turbidite features. In addition, the basaltic rocks intercalate a red clay layer containing manganese nodules.

Fault blocks bounded in part by a somewhat major fault trend east-west and dip northward. Slate-like cleavages are recognized though weak and rare (FUR06, in Fig. 43). Similar features are reported by Katada and Mizuno (1955) in the Toshiro area.

The total thickness of this formation has not been established. Agglutinated foraminifers and radiolarians occur in a gray or black siltstone of this formation.

b. Nishiyatsushiro Group

The Nishiyatsushiro Group was first proposed by Matsuda and Mizuno (1955) for various Neogene volcanic rocks including the Furusekigawa Formation. This definition has been followed by subsequent researchers (*e.g.* Akiyama, 1957; Matsuda. 1958; Matsuda, 1961; Nishimiya and Ueda, 1976; Chiji and Konda, 1978).

The Furusekigawa Formation is, however, distinct from other formations of the Nishiyatsushiro Group by its inclusion of extremely large volumes of basaltic rocks. Accordingly, this group is here redefined on the basis of its lithology to include only a series of dacitic volcanic and clastic sedimentary rocks represented by such strata as the Kanzaka, Wadaira, Deguchi and Byobu-iwa Formations.

1) Kanzaka Formation

Matsuda and Mizuno (1955) originally defined the Kanzaka Formation as the lower member of the Ichinose Formation, which is dominated by a mudstone facies. The Kanzaka Formation has a rather limited distribution between Kiri-ishi and Tokiwa. Its type locality is a road-cut between Ichinose and Kanzaka, Shimobe-cho, Nishiyatsushiro-gun,

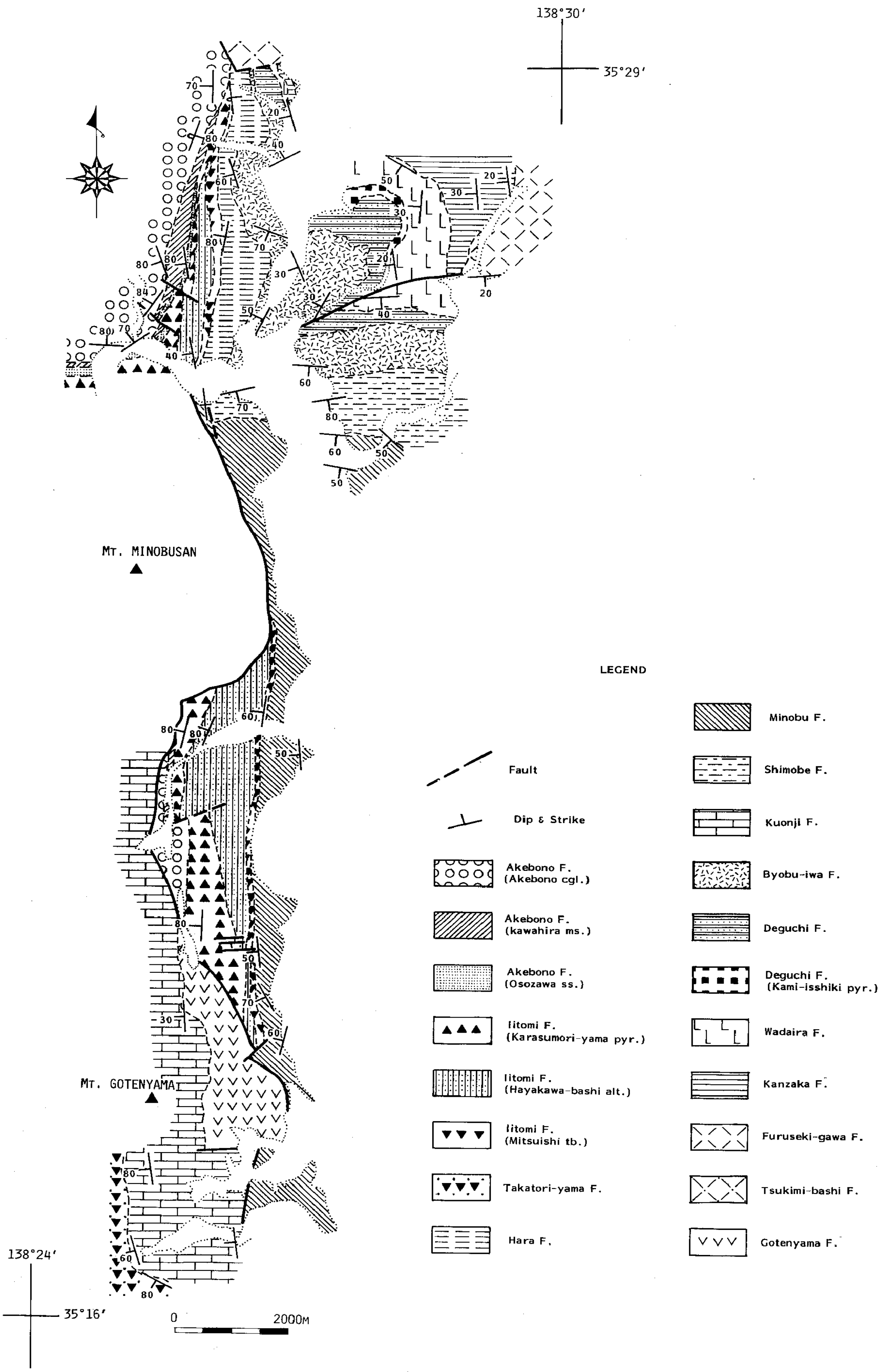

Fig. 4. Geological map of the Nishiyatsushiro and Shizukawa Groups.

Yamanashi Prefecture. The formation consists of a light gray massive sandy siltstone, and contains a thin interbed (20 cm thick) of white silicic glassy tuff in its middle part, and several beds (20 cm thick) of fine-to-medium-grained, massive, black tuffaceous sandstone in its upper part. The source area of this sandstone might have been west of this area as judged from sole marks. The formation also contains interbedded layers of basaltic conglomerate and sandstone in its basal part, wich were derived from the underlying Furusekigawa Formation. The mudstone of this formation grades northward into fine-grained sandstone particularly at Kiri-ishi.

Such deformational structures as slate-like cleavages and faults are not recognized in the siltstone, sandstone or tuff layers.

Maximum thickness of the formation at its type locality amounts to 500 m, and becomes thinner both north- and southward. This formation conformably overlies the Furusekigawa Formation. Such microfossils as planktonic and benthic foraminifers, radiolarians, and echinoid spines are common in this formation, and the occurrence of pteropods was also reported by Shibata *et al.* (1986).

2) Wadaira Formation

The Wadaira Formation was originally proposed by Matsuda and Mizuno (1955) for a series of silicic tuff layers that constitutes the upper part of the Ichinose Formation. It is distributed in areas between Kiri-ishi and Tokiwa. The type locality of this formation is a road cut between Kanzaka and Wadaira, Shimobe-cho. It consists of thick layers of white dacitic tuff interbedded in some parts with several layers (2–10 m thick) of dark greenish gray massive mudstone. These dacitic tuff beds grade from a massive pumice tuff in the lower part into a laminated fine-grained tuff in the upper part. Furthermore, two sets of these tuff beds also show upward grading within respective units. Included pumice blocks are not cellular, and vary in color from dark bluish green, when fresh, to pale yellowish white when weathered. These dacitic tuff layers change their facies into a fine massive white glassy tuff at Kiri-ishi.

The formation attains a maximum thickness of 450 m at the type locality, but becomes thinner northward. The formation conformably overlies the Kanzaka Formation.

Foraminifers and echinoid spines are commonly found in this formation.

3) Deguchi Formation

The Deguchi Formation was originally proposed by Matsuda and Mizuno (1955) as "the Deguchi Tuffaceous Sandstone and Mudstone Member" of the Ichinose Formation. The type locality of this formation is a road cut exposure located to the north of Deguchi, Shimobe-cho. This formation has two separate distributions because of the Tokiwa Anticline. The northern distribution is represented mostly by a medium-to-coarse-grained, greenish black to dark gray, massive, basic volcanic sandstone intercalating a tuffaceous mudstone bed (10 m thick) and the Kami-isshiki Volcanic Breccia Member at the base. The Kami-isshiki Member consists of massive mafic volcanic breccia, whose distinct features are inclusion of numerous phenocrysts of pyroxene and plagioclase (length from 1 to 2 mm), development of amygdale but not vesicular texture, diameter ranges of from 4 to 20 cm, and exhibition of such varied colors as green, reddish brown and black. It shows a slump facies near the Tokiwa Anticline. In the southern distributional area, the Deguchi Formation is composed of a slightly greenish, dark gray to black sandy mudstone, intercalating a bluish gray tuffaceous sandy mudstone but lacking a basaltic sandstone at the base.

Maximum thickness of this formation is 250 m at the type locality, and becomes thinner northward. This formation conformably overlies the Wadaira Formation.

Foraminifers, radiolarians, echinoids and trace fossils occur in the mudstone. Shibata *et al.* (1986) reported the occurrence of pteropods.

4) Byobu-iwa Formation

The Byobu-iwa Formation was originaly defined by Matsuda and Mizuno (1955) as a series of dacitic pumice tuff, tuffaceous sandstone and granule conglomerate. This formation typically crops out at Byobu-iwa, Nakatomi-cho and consists mostly of greenish, thick-bedded, two-pyroxene dacitic pumice tuff. Pumice grains contained are greenish in color, cellular, and mostly 4 mm in diameter. The pumice tuff beds are interbedded with alternating beds of bluish green tuffaceous sandstone and siltstone. They are replaced by a massive, medium-to-coarse-grained tuffaceous sandstone to the north of Imojiya. Flute casts are recognized on the lower surface of sandstone beds and parallel laminations in mudstone beds.

The thickness of this formation is 950 m at maximum, 200 m on the northern flank, and 450 m on the southern flank of the Tokiwa Anticline.

This formation conformably overlies the Deguchi Formation.

Foraminifers, radiolarians and diatoms are common in this formation.

c. Shizukawa Group

The Shizukawa Group was first proposed by Otuka (1955) to include a sequence of andesite and various types of terrigenous sediments containing Pliocene mollusks in the Fujikawa area. It has been adopted by subsequent researchers (*e.g.* Akiyama, 1957; Matsuda, 1958; Ujiié and Muraki, 1976; Chiji and Konda, 1978; and Kano *et al.*, 1985).

1) Hara Formation

The Hara Formation is named after the Hara Mudstone Member defined by Matsuda and Mizuno (1955). These two authors placed this unit stratigraphically between the Daigoyama Formation and the Shizukawa Group, but left its precise position unsettled. The type locality of the Hara Formation lies in a valley to the south of Ogoyama. It is composed of a gray massive mudstone, and the facies becomes coarser to that of very fine silty sandstone at Teuchizawa. This mudstone intercalates thin sandstone beds (1 to 3 cm thick) in the lower part, and white fine-grained glassy tuff (40 cm thick) and pebbly mudstone beds (2 m thick) in the upper part. Furthermore, flame-structure is recognized in the top part of this tuff layer, and ripple marks, bioturbation and flute casts are found in the mudstone and on the lower surface of sandstone beds.

Maximum thickness of this formation is 850 m at the type locality. It becomes thinner both north- and southward, being 120 m in the Teuchizawa area and 400 m in Iitomi area.

This formation conformably overlies the Byobu-iwa Formation.

Foraminifers, radiolarians, echinoids, *Makiyama* sp. and trace fossils are commonly found in this formation. The occurrence of pteropods was also recorded by Shibata *et al.* (1986)

2) Iitomi Formation

The Iitomi Formation was first defined by the Fujikawa Collaborative Group (1976). This formation can be divided into two parts: a sequence of volcanic rocks and alternating beds of conglomerate and sandstone in the lower part; and a volcanic sandstone sequence largely derived from the underlying volcanic rocks and mudstone in the upper part. In addition, this mudstone interfingers with the conglomerate of the Akebono Formation. Accordingly, the Iitomi Formation as used in this study refers to the lower part of the Iitomi Formation as originally defined. The type locality of this formation is an outcrop along the River Yogosawa in the Yogosawa area, Nakatomi-cho, Minamikoma-gun. The formation is composed of a thick-bedded sandstone intercalating conglomerate and siltstone. A layer of black massive tuff breccia (4 to 10 cm in diameter), characterized by a vesicular texture and inclusion of rich plagioclase grains, is recognized in its lower and upper parts. This study defines the Teuchizawa Conglomerate of Akiyama (1957), of which material was derived from the underlying bronzite andesite of the Tsukimibashi Andesite (Matsuda, 1958), as a unit equivlent to the Iitomi Formation. This correlation is based on the fact that a similar conglomerate is found in the Karasumori Tuff Breccia Member. Flute casts are found on the lower surface of some sandstone beds.

The thickness of this formation is 350 m at the type locality, and 1,200 m along the River Hakiigawa.

This formation conformably overlies the Hara Formation.

Foraminifers, radiolarians, diatoms, *Makiyama* sp. and echinoid spines occur commonly from this formation.

3) Akebono Formation

The Akebono Formation was first proposed by Otuka (1955) for the unconsolidated conglomerate bed exposed around the hamlet of Akebono. This study reaffirms the Akebono Formation to include both the Osozawa and Kawadaira Formations, as used by other researchers (*e.g.* Akiyama, 1957). The type locality is situated at Akebono, Nakatomi-cho, Minamikoma-gun. This formation consists mostly of a gray to grayish white conglomerate, accompanied by the molluscan fossil bearing, black, massive coarse volcanic sandstone (Osozawa Sandstone; Akiyama, 1957) and the bluish gray massive sandy mudstone (Kawadaira Mudstone; Akiyama, *op cit.*). The conglomerate comprises boulders and pebbles of black sandstone, slate, shale, granite and andesite, and is interbedded in places with coal and coarse-grained sandstone beds. An imbricated structure is recognized in each conglomerate bed. Based on this structure, Matsuda (1958) inferred that paleocurrents flowed from north to south or northwest to southeast during the deposition.

The thickness of this formation is over 200 m.

It conformably overlies the Iitomi Formation.

Many molluscan fossils occur in the Osozawa Sandstone Member. Otuka (1934, 1955) reported the occurrence of *Cucullaea granulosa* (Jonas) var., *Glycymeris rotunda* (Dunker), *Glycymeris totomiensis* (Makiyama), *Chlamys miurensis* (Yokoyama), *Amussiopecten praesignis* (Yokoyama), *Limopsis tokaiensis* (Yokoyama) and *Pecten iitomiensis* Otuka, *etc.* In addition, Akiyama (1957) reported such forms as *Cucullaea* sp., *Anadara* sp., *Limopsis tokaiensis* (Yokoyama), *Glycymeris* cf. *rotunda* (Dunker), *Glycymeris osozawaensis* Kanno, *Amussiopecten iitomiensis* (Otuka), *Chlamys miurensis* (Yokoyama), *Chlamys nobilis* (Reeve), *Cryptopecten* aff. *vesiculosus* (Dunker), *Patinopecten* sp., *Lima* aff. *konnoi* Otuka and *Venericardia panda* (Yokoyama), *etc.* Kano *et al.* (1985) reported a benthic foraminiferal assemblage characterized by such species as *Elphidium crispum* (Linné), *Cibicides* spp., *Hanzawaia nipponica* Asano, *Melonis sphaeroides* Voloshinova, *Martinottiella communis* (d'Orbigny) and *Cyclammina* sp. from this member. Shibata *et al.* (1986) recognized pteropods from the Kawadaira Mudstone Member. This member also yields radiolarians and diatoms.

4) Shimobe Formation

The name Shimobe Formation was first used by Matsuda and Mizuno (1955) for a series of alternating beds of sandstone and mudstone ("Takenoshima alternation of sandstone and mudstone member"), volcanic sandstone and alternating beds of sandstone and mudstone ("Uenotaira sand-sized volcanic fragments and sandstone mudstone member"), and mudstone ("Hadakajima mudstone member"), in ascending order, all of which are exposed around the hamlet of Shimobe. The type locality is located along the River Fujikawa between Byobu-iwa and Hadakajima, Shimobe-cho, Minamikoma-gun. This formation consists mostly of dark gray to pale greenish gray, alternating beds of sandstone and mudstone, and is interbedded with white laminated pumice tuff beds, granular sandstone and either pale green or violet-colored volcanic sandstone in the upper part. Furthermore, flute casts are recognized on the basal surface of sandstone beds. The lower part of this formation exposed at Takenoshima is composed of alternations of conglomerate and sandstone, accompanied with a sandy siltstone. The conglomerate beds consist of a large number of sandstone pebbles with some chert and green tuff pebbles and are associated with various kinds of sole marks such as flute casts, groove casts and prod casts. The sandstone bed is gray to brown, laminated, and medium- to coarse-grained, contains plant fragments, and is interbedded with coal beds and coarse-grained sandstone beds.

The formation has a maximum thickness of 1,200 m and conformably overlies the Byobu-iwa Formation.

Foraminifers, radiolarians, diatoms, *Makiyama* sp. and pelecypods occur from this formation. Akiyama (1957) reported the occurrence of bryozoan fragments.

5) Minobu Formation

Akiyama (1957) named and defined the Minobu Formation as a series of conglomerate ("Shionosawa conglomerate"), alternating beds of sandstone and mudstone ("Hagiizaka alternation of sandstone and mudstone"), and mudstone ("Kajiwara mudstone"), exposed in the Minobu area. This formation is distributed in areas from Iitomi to Nanbu. Outcrops along a road leading from Hadakajima, Shimobe-cho to Minobu-cho is chosen as the type locality. This formation is subdivided into three parts. The lower part consists of a gray to bluish gray mudstone interbedded with greenish gray thin sandstone and tuff layers, and includes granules. The middle part, the Marutaki Conglomerate of Matsuda (1958), is composed of pebbles of black shale, sandstone, hornfels, silicic igneous rocks and quartz diorite. The upper part is composed of alternations of sandstone and mudstone, interbedded in places with lenticular layers of conglomerate and granular sandstone, pebbly mudstone and slumped beds. Various kinds of sole marks are recognized in the middle and upper parts of this formation.

This formation is 1,200 m thick and conformably overlies the Shimobe Formation.

Foraminifers, radiolarians, diatoms, *Makiyama* sp. and vertebrate bone fragments occur in this formation. Akiyama (1957) reported the occurrence of *Operculina* aff. *ammonoides* (Gronovius).

2. GEOLOGICAL STRUCTURE

The geologic structures of the Fujikawa area have been investigated by Akiyama (1957), Matsuda (1961) and Fujikawa Collaborative Group (1976). They agree with the fundamental feature of the geologic structures. The geologic age when these structures had been formed was not referred to in these papers. The present study focuses especially on the development of the Tokiwa anticline and fault systems of the Misaka Group with an EW trend, and the NS-trending Akebono syncline.

a. Fold system

The Fold systems in this area are classified into two systems based on the direction of fold axes. One system, recognized in the Nishiyatsushiro Group and the Hara Formation, is represented by a northeast-trending anticline and syncline, broadly folded with low to moderate dips (30° to 40°) and plunged westward at a low angle. Geographic spacing of their axes is observed to range from 3 to 4 km, and their axes extend for a distance of about 4 km. This fold system was formed prior to the deposition of the Hara Formation. Exceptionally, the Tokiwa anticline is asymmetrical and slightly overturned southward on its north flank.

The other system is represented by the Akebono syncline named by Matsuda (1958) which folded the Iitomi and Akebono Formations. The geologic map shows that this is an asymmetrical syncline, slightly overturned eastward on its east flank and plunges to the south, and its southern extension is cut by a north-south-trending reverse fault.

b. Fault system

Faults recognized in this area are divided into three systems on the basis of their dimension and directions.

The first maior system includes many reverse faults which cut the siltstone of the Misaka Group in two different directions (EW, 70°N and N50°W, 50°E). These faults are spaced at about 50 cm intervals and their shear zones are about 2 cm wide. This fault system does not extend into the overlying Nishiyatsushiro Group.

The second major system, an east-west trending wrench fault, has cut some folds (*e.g.* Tokiwa Anticline) and extends into the Nishiyatsushiro Group.

The third major system, a north-south reverse fault (Minobu Thrust), intersects the Shizukawa Group and the Akebono Fold (Matsuda, 1958).

In summary, the geological observations lead to the following:

1) Ten formations from the Furusekigawa to Akebono Formations, in upward sequence, are assorted as three groups such as the Misaka, Nishiyatsushiro and Shizukawa Groups.

2) The Misaka group consists mainly of basalt fragments, fine clastic sediments accompanied with red clay.

3) In contrast, the Nishiyatsushiro and Shizukawa Groups are composed entirely of terrigenous material.

4) The Hara, Shimobe and Minobu Formations are situated between the top key tuff layer of the Byobu-iwa Formation and the bottom key tuff layer (the Mitsuishi Tuff Breccia Member) of the Iitomi Formation. Hence, it is clarified that the Shimobe and Minobu Formations are together time-equivalent with the Hara Formation.

5) The Nishiyatsushiro Group attains its maximum thickness around the Kanzaka and Wadaira areas. On the contrary, all the formations belonging to this group are thinner along the Tokiwa Anticline. Thus, this anticline seems to have upwarped during the deposition of the Nishiyatsushiro Group.

6) The Shizukawa Group has its maximum thickness around the Minobu and Ogoyama areas. Some difference in the maximum thickness between these two areas is apparently due to the thickness of the underlying Hara Formation and its equivalents. This group decreases its thickness around the Tokiwa Anticline, but the Iitomi Formation does not do so. This may imply that the anticline had already been developed prior to the deposition of the Iitomi Formation.

7) Two fold systems are recognized

on the basis of direction of fold axes and ages of formation. The E-W-trending fold system was formed prior to the deposition of the Iitomi Formation, and the N-S trending system after the accumulation of the Akebono Formation.

8) Three fault systems are recognized on the basis of direction of fault planes and ages of formation. The E-W fault system became established in two phases. One is the faulting taken place before the deposition of the Kanzaka Formation; the other, at the earliest, after the formation of the Tokiwa Fold. On the contrary, the N-S system was formed after the accumulation of the Akebono Formation.

9) The rock units in the Misaka Group are bounded by a somewhat large-scale reverse fault, with an east-west strike and a northward dip. On the contrary, the Nishiyatsushiro and Shizukawa Groups generally dip westward.

BIOSTRATIGRAPHY

In order to cover the whole Miocene and Pliocene sequence developed in the Fujikawa area, nine sampling routes were selected as shown below. Samples were usually taken at stratigraphic intervals of 0.3 m to 3 m along each section. Since these sections are rather widely spaced, their stratigraphic relationships are determined by tracing marker tephra beds. Several of them are traceable for a long distance and are proven to be excellent key horizons; they are in upward sequence the top of the Wadaira Formation, base of the Byobu-iwa Formation, top of the Byobu-iwa Formation, base of the Mitsuishi Tuff Breccia Member and top of the Karasumoriyama Tuff Breccia Member , and are named Horizons 1, 2, 3, 4 and 5, respectively (Fig. 5, in back pocket; Fig. 6). Samples were collected, in principle, from either just below or above these key beds.

ROUTE	AREA	FORMATION STUDIED
ISH	Kanzaka	Kanzaka F., Wadaira F., Deguchi F.
DEG	Deguchi	Deguchi F.
FUK	Fukamachi	Byobu-iwa F.
OGY	Ogoyanma	Byobu-iwa F., Hara F.
YOG	Yogozawa	Iitomi F., Akebono F.

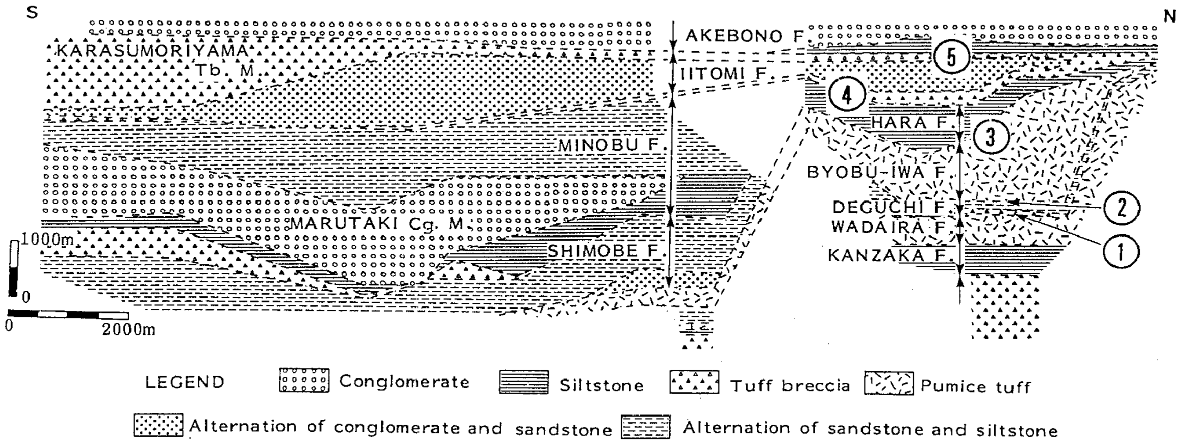

Fig. 6. Stratigraphic section of the Nishiyatsushiro and Shizukawa Groups distributed in the Fujikawa area. Numbers in circles : datum levels defined by characteristic tephra layers.

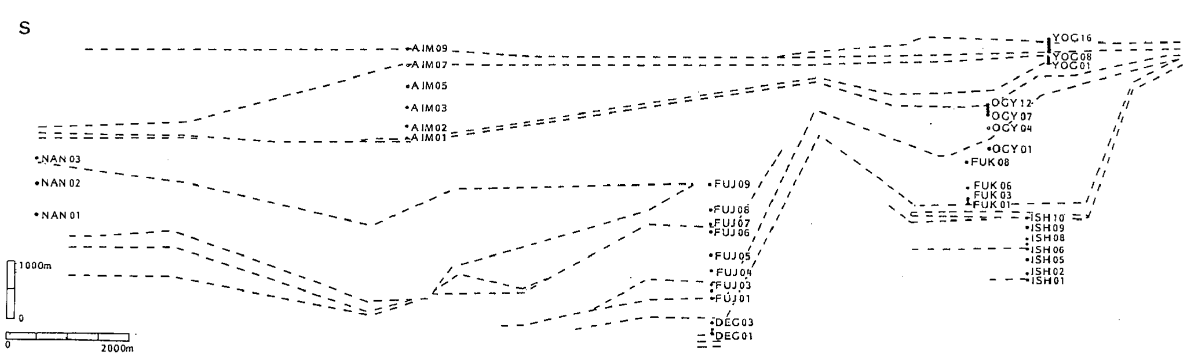

Fig. 7. Stratigraphic and geographic locations of samples used in this study. Abbreviations in Figs. 9, 10, 11, 12 and 13 refer to the following: ISH, Isshiki; DEG, Deguchi; FUK, Fukamachi; OGY, Ogoyama; YOG, Yogosawa; FUJ, Fujikawa; AIM Aimata; NAN, Nanbu.

FUJ	Fujikawa	Shimobe F., Minobu F.
NAN	Nanbu	Minobu F.
AIM	Hakiigawa	Iitomi F., Akebono F.
TOG	Togurigawa	Kuonji F.

In the laboratory, 600-odd samples were treated. After dried out in an oven, each rock sample was treated with a saturated sodium sulfate solution and then naphtha for disaggregation (Maiya and Inoue, 1973). The sample was then wet-sieved through a 200-mesh screen and re-dried. Foraminiferal specimens are generally abundant but poorly preserved. Firstly, only those samples which contain better-preserved specimens were examined. Each processed sample was divided by a sample splitter into aliquot parts. In many cases, 200-odd specimens of benthic and planktonic foraminifera larger than 0.125 mm were picked up from an aliquot part under a binocular microscope. Secondly, in consideration of their stratigraphic interval and biohorizons of key species, 54 samples were selected for benthic foraminiferal analysis, and 46 for planktonics. Their sampling localities are shown in Figs. 9 to 13, and their stratigraphic positions in Figs. 5 and 7.

1. PLANKTONIC FORAMINIFERA

Oda, Akimoto and Asai (1987) investigated a planktonic foraminiferal biostratigraphy in five traverses of ISH, DEG, FUK, OGY and YOG routes. Subsequently, the present author attempted to extend his work down to the lowermost part of the Nishiyatsushiro Group, but failed to do so because of a sparse occurrence of planktonic foraminifera.

The planktonic foraminiferal biostratigraphy is summarized in the following lines. Figure 16 shows the stratigraphic distribution of selected taxa within a sequence from the Kanzaka to Akebono Formations in the Fujikawa area.

The lowermost part of the Kanzaka Formation is characterized by the concurrence of *Globorotalia peripheroronda* and *Globorotalia peripheroacuta*. *Globorotalia fohsi praefohsi* and *Globorotalia fohsi fohsi* first appear in the middle part of the Kanzaka Formation (ISH03). Furthermore, the Wadaira Formation is characterized by the first occurrence of *Globorotalia fohsi lobata* (ISH09). The last occurrences of *Globorotalia peripheroacuta* and the *Globorotalia fohsi* group (*Grt. fohsi praefohsi*, *Grt. fohsi fohsi* and *Grt. fohsi lobata*) are recognized in the upper part of the Wadaira Formation. *Globorotalia* cf. *miozea*

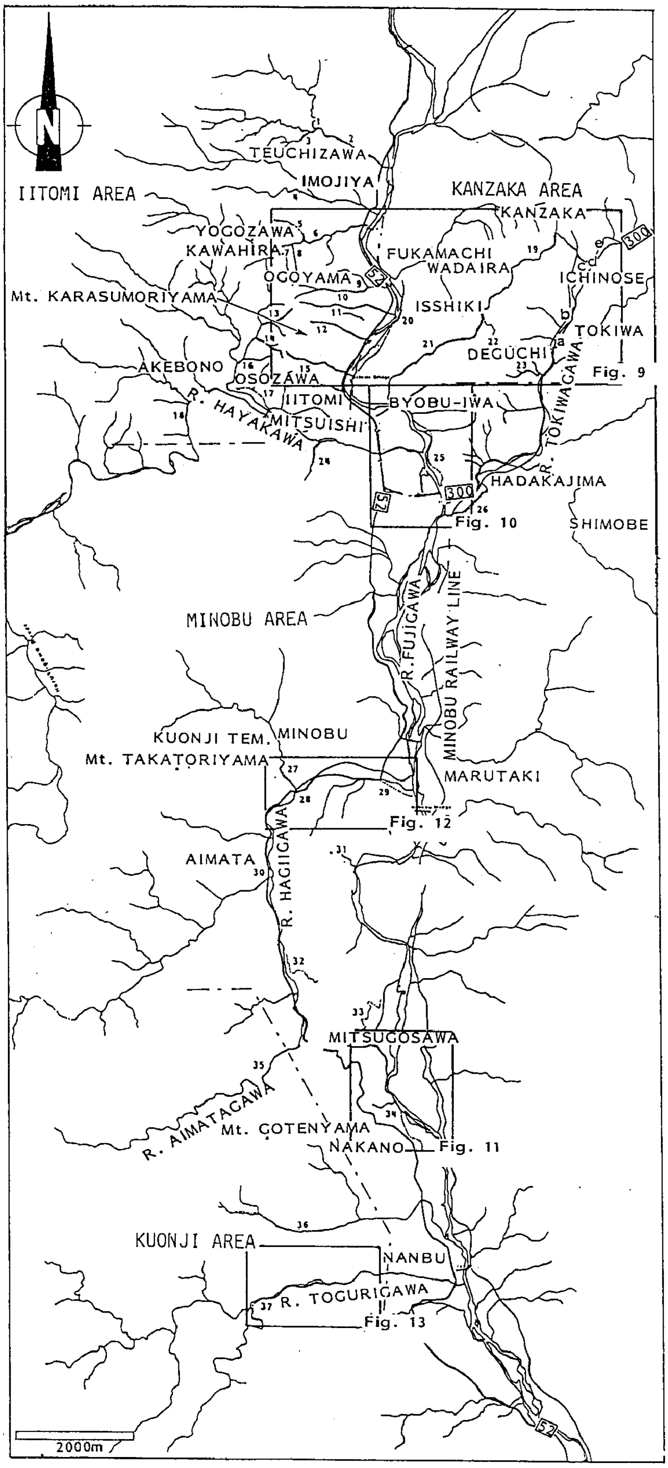

Fig. 8. Index map of sampling routes.

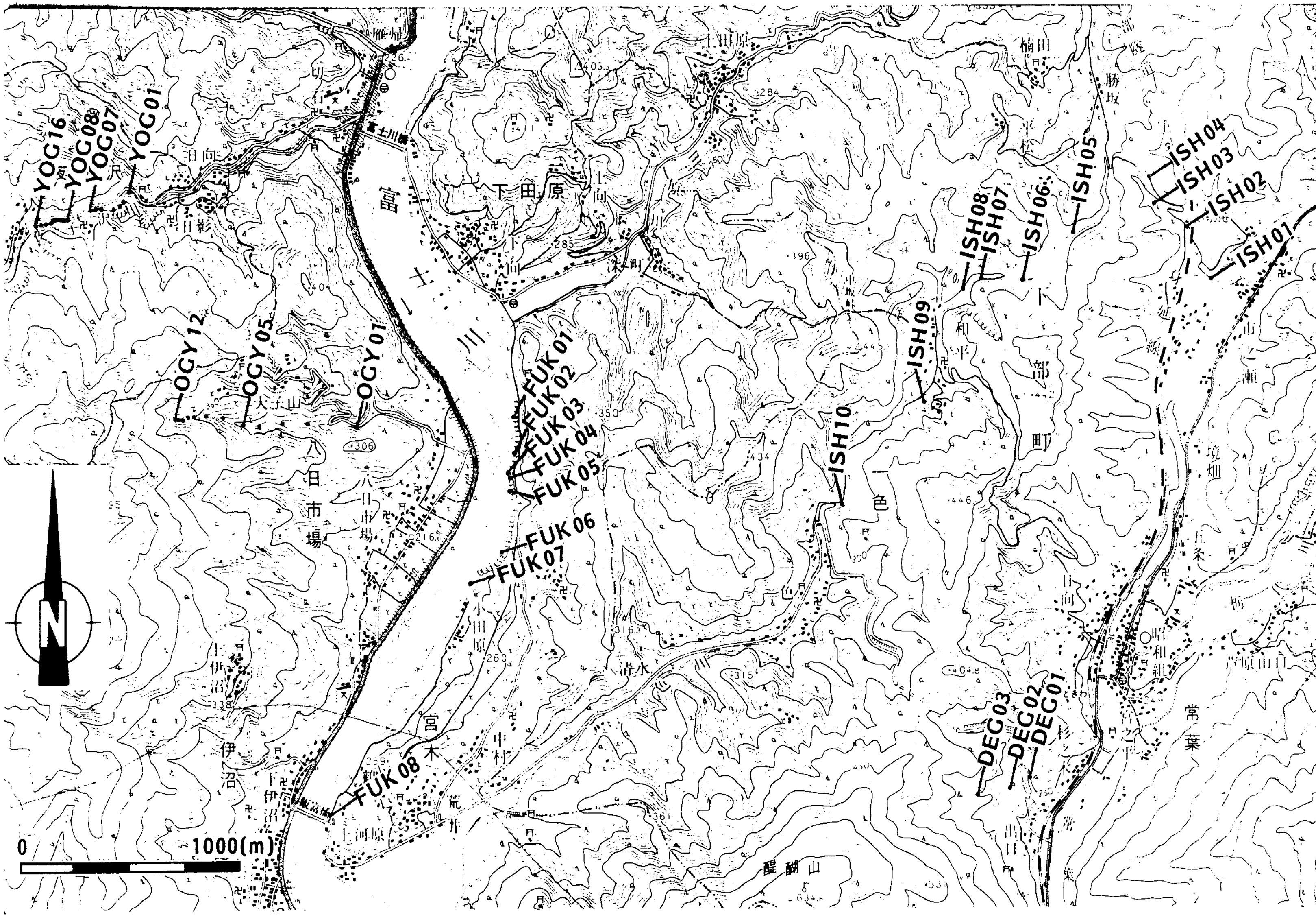

Fig. 9. Sample localities in the Isshiki (ISH), Deguchi (DEG), Fukamachi (FUK), Ogoyama (OYG) and Yogozawa (YOG) routes (Quadrangle "Kiriishi", 1 : 25,000-scale topographic map of Japan, Geographical Survey Institute).

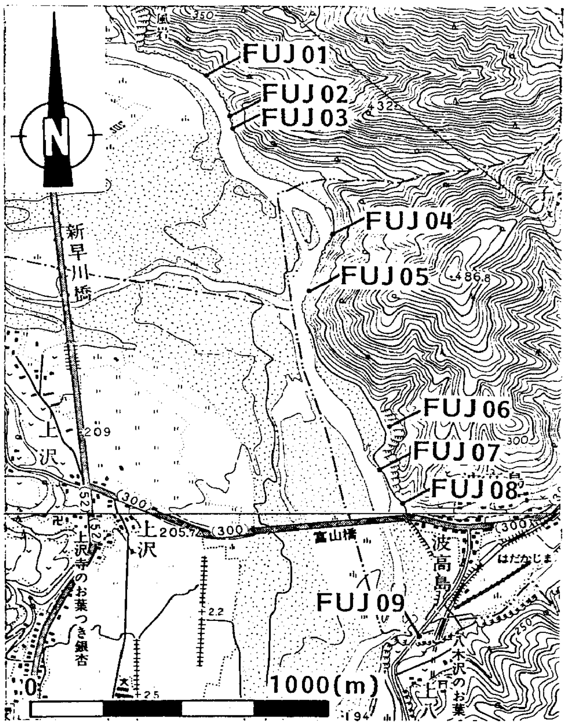

Fig. 10. Sample localities in the Fujikawa route (FUJ) along the River Fujikawa (Quadrangle "Kiriishi", 1 : 25,000-scale topographic map of Japan, Geographical Survey Institute).

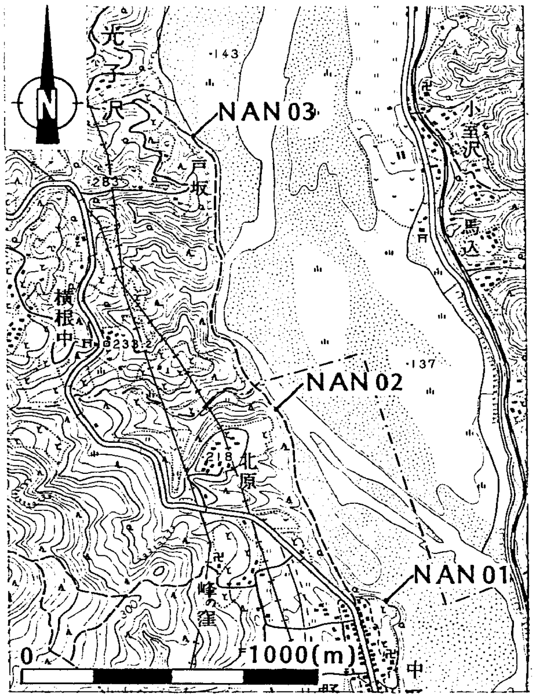

Fig. 11. Sample localities in the Nanbu route (NAN) along the River Fujikawa near Nanbu town (Quadrangle "Nanbu", 1 : 25,000-scale topographic map of Japan, Geographical Survey Institute).

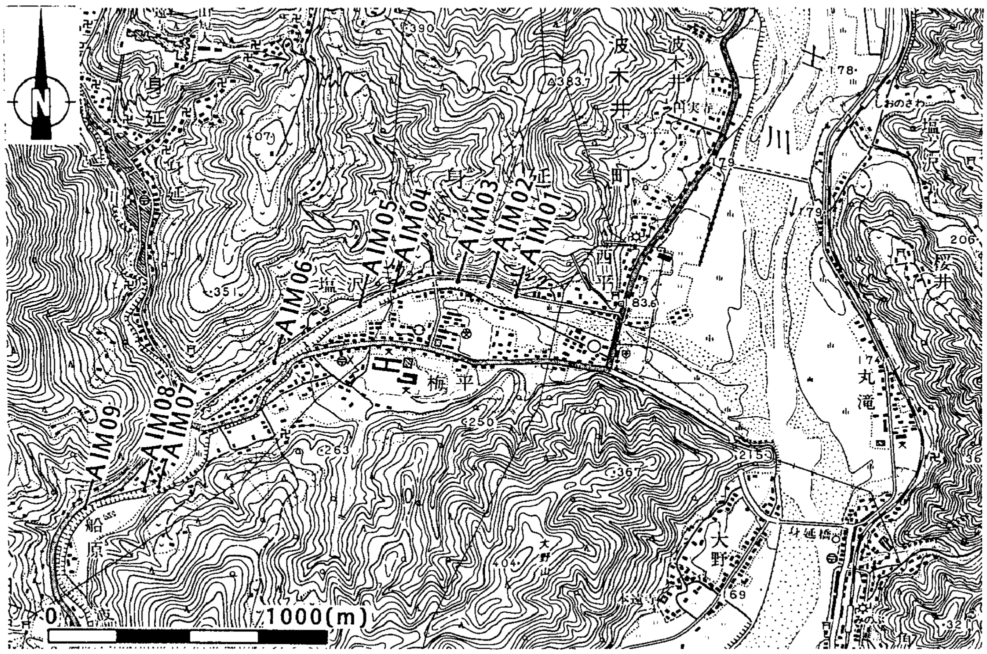

Fig. 12. Sample localities in the Aimata route (AIM) along the River Hakiigawa near Minobu town (Quadrangle "Minobu", 1 : 25,000-scale topographic map of Japan, Geographical Survey Institute).

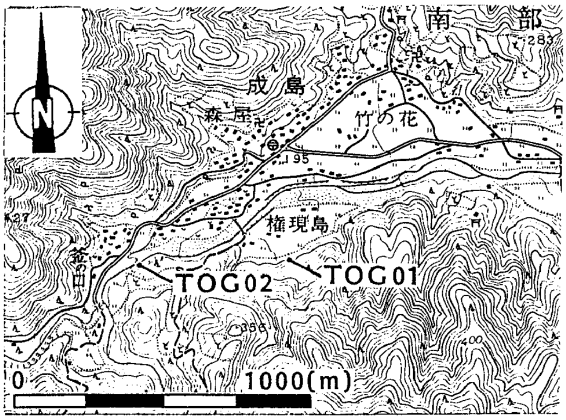

Fig. 13. Sample localities in the Togurigawa route (TOG) along the River Togurigawa to the west of Nanbu town (Quadrangle "Nanbu", 1 : 25,000-scale topographic map of Japan, Geographical Survey Institute).

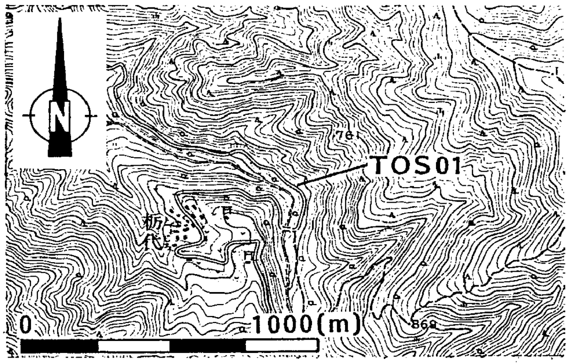

Fig. 15. Sample localities around Toshiro (TOS) (Quadrangle "Shoji", 1 : 25,000-scale topographic map of Japan, Geographical Survey Institute).

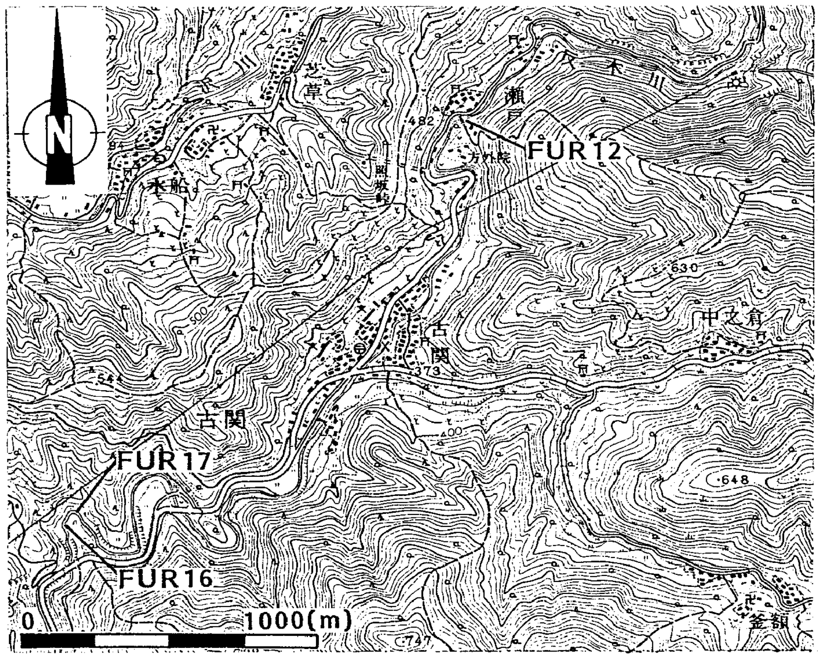

Fig. 14. Sample localities in the Furuseki route (FUR) along the River Tokiwagawa (Quadrangle "Shoji", 1 : 25,000-scale topographic map of Japan, Geographical Survey Institute).

conoidea occurs for the first time below the *Grt. foshi* group datum (ISH02), and ranges up to the middle part of the Hara Formation.

The occurrence of *Globorotalia rikuchuensis* is restricted to the Byobu-iwa Formation. *Globigerina nepenthes* makes its first occurence in the basal part of the Hara Formation (OGY02). The lower to middle part of the Hara Formation is characterized by the concurrence of *Globigerina nepenthes* and *Globorotalia siakensis*. The upper part of the Hara Formation is marked by the last occur-

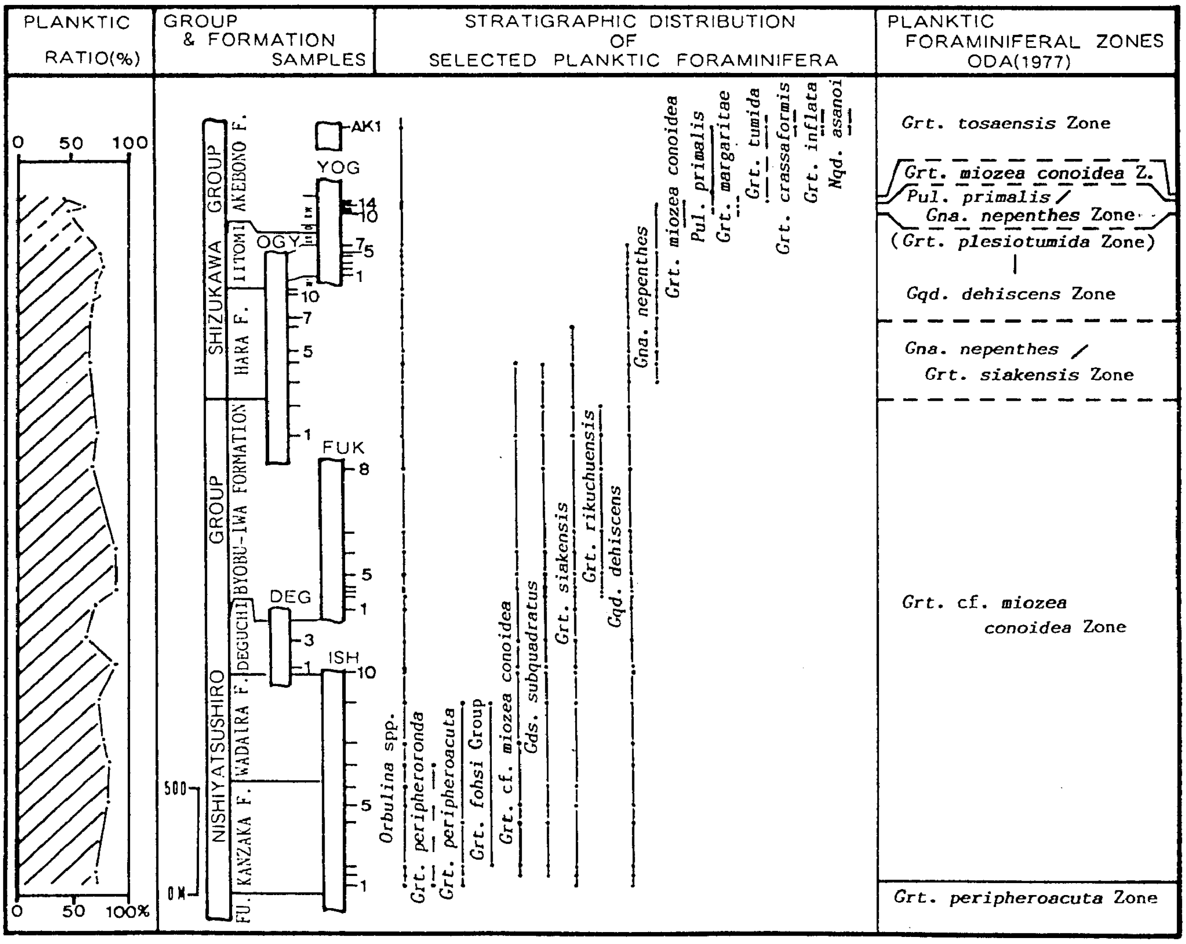

Fig. 16. Stratigraphic ranges of selected planktonic foraminifera and zonation for a composite sequence made of five main sections of the Nishiyatsushiro and Shizukawa Groups (after Oda *et al.*, 1987).

rence of *Globorotalia siakensis*, which ranges from the lowermost part of the Kanzaka to Hara Formation. *Pulleniatina primalis* (sinistrally coiling form) first occurs in the Kawadaira Mudstone Member of the Akebono Formation (YOG12). Furthermore, the Kawadaira Mudstone Member of the Akebono Formation is marked by the last occurrence of *Globigerina nepenthes* at its base (YOG15) and the restricted range of *Globorotalia miozea conoidea* to this member (YOG10 to YOG16). *Globorotalia margaritae* and *Globorotalia tumida* sporadically occur from the middle to upper part of the Kawadaira Mudstone Member. The upper part of the Akebono Formation yields *Neogloboquadrina asanoi*, *Globorotalia inflata*, *Globorotalia crassaformis*, and dextrally coiling specimens of *Pulleniatina*.

Seven foraminiferal datums marked by their first and last occurrences are shown in Figs. 16 and 17 : they are, the first appearance of *Globorotalia* cf. *miozea conoidea*, first appearance of *Globigerina nepenthes*, last occurrence of *Globorotalia siakensis*, last occurrence of *Globoquadrina dehiscens*, first appearance of *Pulleniatina*, last occurrence of *Globigerina nepenthes* and first appearance of *Globorotalia tumida*, in ascending order.

Oda (1977) established a planktonic

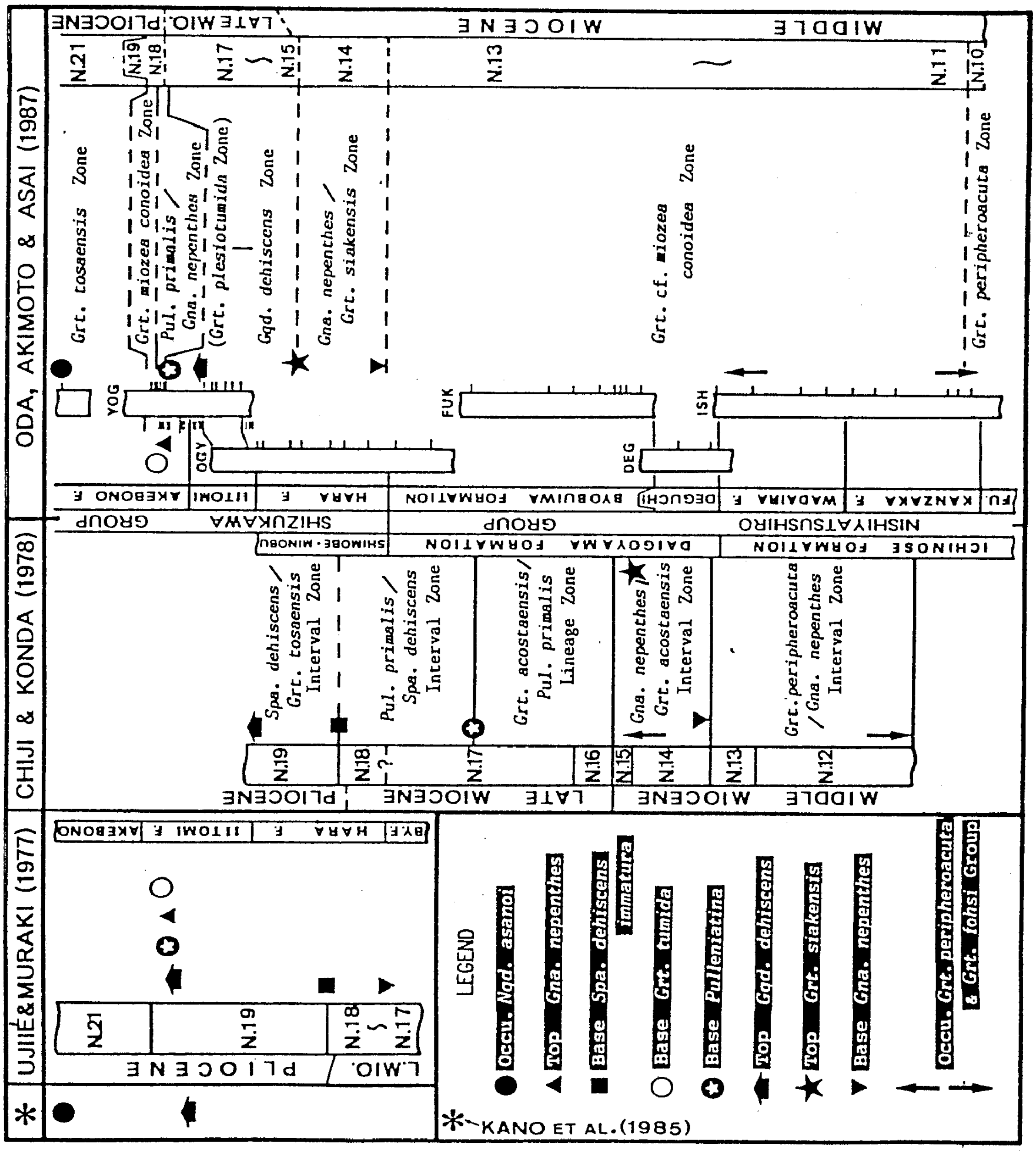

Fig. 17. Comparison of planktonic foraminiferal zones established for the Nishiyatsushiro and Shizukawa Groups distributed in the Fujikawa area, by Ujiié and Muraki (1976), Chiji and Konda (1978), Kano *et al.* (1985), and the present author (after Oda *et al.*, 1987).

foraminiferal zonation of the Upper Cenozoic in Japan. In the studied area, most of his zones are recognized: the *Globorotalia peripheroacuta* Zone, *Globorotalia* cf. *miozea conoidea* Zone, *Globigerina nepenthes/Globorotalia siakensis* Zone, *Globoquadrina dehiscens* Zone, *Pulleniatina/Globigerina nepenthes* Zone, *Globorotalia miozea conoidea* Zone and *Globorotalia tosaensis* Zone. However, the *Globorotalia plesiotumida* Zone was not recognized in this study, because the name-species was not discovered.

2. BENTHIC FORAMINIFERA

A benthic foraminiferal biostratigraphy was prosecuted along the nine routes as mentioned above. Especially, in

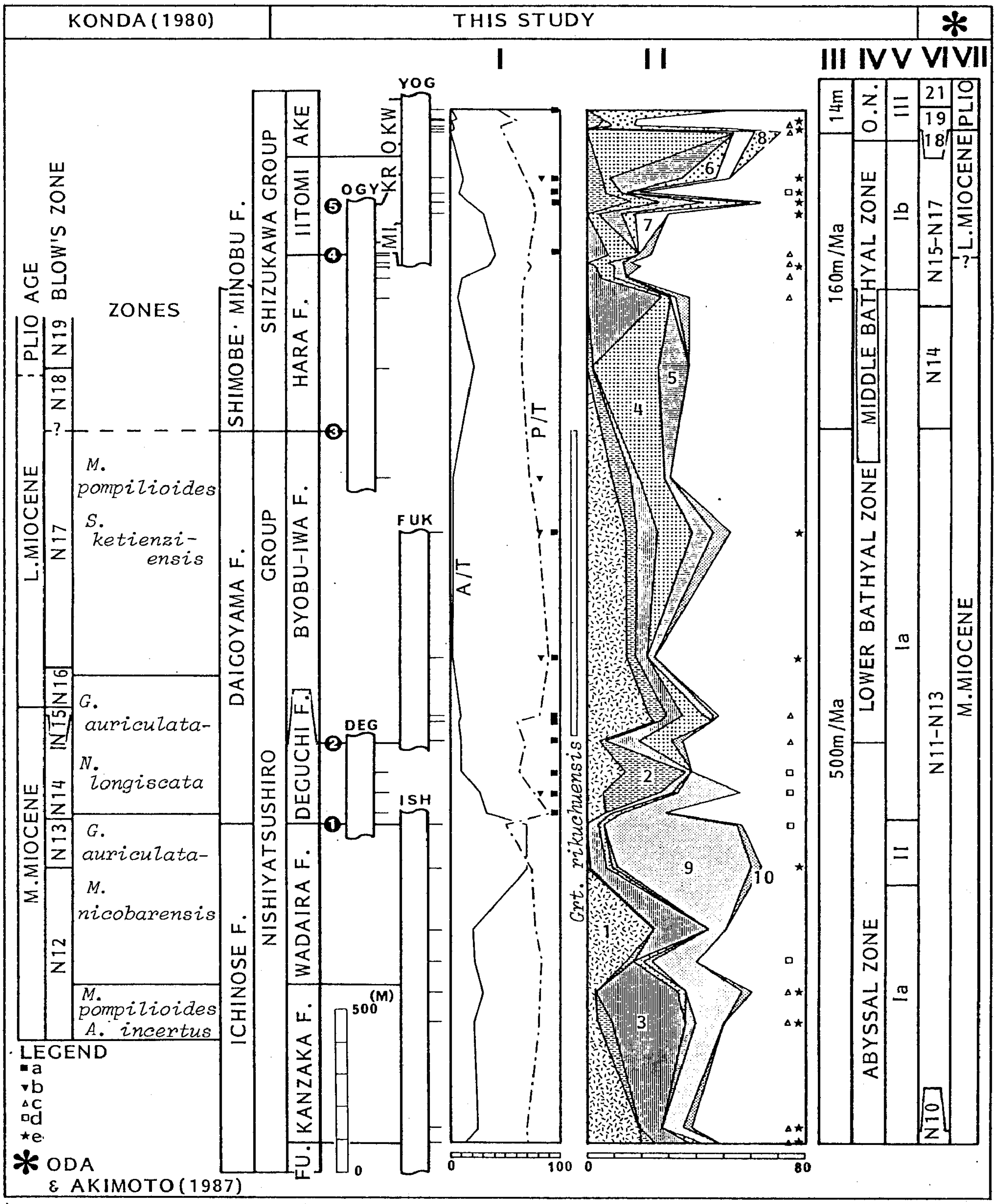

Fig. 18. Comparison of benthic foraminiferal zonation established by Konda (1980) with various data obtained by this study. Vertical fluctuations of foraminiferal statistics (P/T and A/T column I), occurrence of selected benthic foraminifera (column II) in the Nishiyatsushiro and Shizukawa Groups, sedimentation rates (column III) based on radiometric ages, and planktonic foraminiferal and radiolarian datum planes (Tsuchi, 1981, 1983; Kasuya, 1987), paleobathymetric interpretation (column IV), results from cluster analysis (column V) employing selected species shown in Table 4, Blow's zone numbers (column VI) and age determination (column VII) based on Fig. 16.
Symbols: a, radiolarians; b, diatoms; c, bioturbated siltstone; d, massive siltstone; e, framboidal pyrite. 1, *Melonis sphaeroides* Voloshinova; 2, *Globobulimina auriculata* (Bailey); 3, *Nodosaria longiscata* (d'Orbigny); 4, *Stilostomella lepidula* (Schwager); 5, *Uvigerina proboscidea* Schwager; 6, *Elphidium crispum* (Linné); 7, *Cibicidoides mediocris* (Finlay); 8, *Ammonia ketienziensis* (Ishizaki); 9, *Rhabdammina abyssorum* M. Sars; 10, *Trochammina globigeriniformis* (Parker and Jones). 1 to 5 in solid circles denote datum levels defined by characteristic tephra layers.

Akimoto(this paper)			Konda(1980)
Ass	Dominant species	Accompanied species	Assemblage
Ia	*Melomis sphaeroides*	*Globobulimina auriculata* *Nodosaria longiscata* *Stilostomella lepidula* *Rhabdammina abyssorum*	*Melonis pompilioides*- *Ammodiscus incertus* *Globobulimina auriculata*- *Melonis nicobarensis*- *Globobulimina auriculata*- *Nodosaria longiscata* *Melonis pompilioides*- *Stilostomella lepidula*
Ib	*Globobulimina auriculata*	*Nodosaria longiscata* *Stilostomella lepidula* *Uvigerina proboscidea*	
II	*Rhabdammina abyssorum*	*Melonis sphaeroides*	
III	*Ammonia ketienziensis*		

Ass:Assemblage

Fig. 19. Comparison of benthic foraminiferal assemblages of Konda (1980) with those of the present author, defined for the Nishiyatsushiro and Shizukawa Groups.

order to survey vertical changes in the frequency of benthic foraminiferal species in the Neogene sequence, samples were selected from five routes, (ISH, DEG, FUK, OGY and YOG) which are the same as those studied by Oda *et al.* (1987) for a planktonic foraminiferal biostratigraphy.

Figure 18 shows the stratigraphic distribution of selected benthic foraminiferal taxa in the Fujikawa area in a sequence from the Kanzaka to Akebono Formations.

Changes in benthic foraminiferal numbers give no distinct tendency. On the contrary, agglutinated foraminifera/total benthic foraminifera ratios indicate a rapid decrease of calcareous forms between the Deguchi and Byobu-iwa Formations.

Agglutinated forms including *Rhabdammina abyssorum* M. Sars are remarkably rich within the Nishiyatsushiro Group except for the Byobu-iwa Formation. This group is also marked by abundant occurrences of *Melonis sphaeroides* Voloshinova, *Stilostomella lepidula* (Schwager) and *Nodosaria longiscata* d'Orbigny.

Calcareous species are rather rich within the Shizukawa Group. Characteristic species are *M. sphaeroides* in the lower part of the Hara Formation, dominant *N. longiscata* in the middle part of the Hara Formation, concurrence of *Globobulimina auriculata* (Bailey) and *Uvigerina proboscidea* Schwager in the Iitomi Formation, and *Ammonia ketienziensis* (Ishizaki) in the Akebono Formation. *Stilostomella lepidula* (Schwager) first occurs in the upper part of the Deguchi Formation (DEG03), and ranges up to the lowermost part of the Akebono Formation, with its highest frequency occurring in the middle part of the Hara Formation and the Akebono Formation.

AGE AND CORRELATION

1. AGE

There are two different opinions on the assignment of geological ages based on planktonic biostratigraphy: One is that the Miocene/Pliocene boundary is to be located in the basal part of the Akebono

Formation; the other places it within the Hara or Shimobe Formation. Nishimiya and Ueda (1976) compiled the Neogene stratigraphy of Yamanashi Prefecture, with age assignments based on planktonic foraminifera, mollusks and radiometric dating, and placed the Miocene/Pliocene boundary within the Akebono Formation. Oda *et al.* (1987) recognized seven datum planes for an interval between Zones N. 10 and 21, and concluded that the Middle/Late Miocene and Miocene/Pliocene boundaries are situated within the Hara Formation and in the basal part of the Akebono Formation, respectively. Ujiié and Muraki (1976), who studied a planktonic foraminiferal biostratigraphy of the Shizukawa Group in the Fujikawa area, identified a sequence from Zone N. 16 to 21 and put the Miocene/Pliocene boundary in the Hara Formation. Chiji and Konda (1978) also researched on the Nishiyatsushiro Group and the lower part of the Shizukawa Group. They recognized six datum planes for an interval between Zone N. 13 and N. 19, and concluded that the Miocene/Pliocene boundary is within the Shimobe Formation. Kano *et al.* (1985) regarded the main part of the Shizukawa Group to be Pliocene in age based on planktonic foraminifera.

a. Planktonic foraminifera

Neogene formations in the Fujikawa area can be dated by planktonic foraminifera newly discovered in this study (Fig. 17).

Planktonic foraminifera, such as *Orbulina* spp. (*O. universa* plus *O. suturalis*), *Globorotalia peripheroacuta*, *Globorotalia fohsi* group, and *Globorotalia* cf. *miozea conoidea*, were found in the Nishiyatsushiro Group. The lower to middle part of the Hara Formation is characterized by the concurrence of *Globigerina nepenthes* and *Globorotalia siakensis*. According to Blow (1969), the Early/Middle Miocene boundary and the Middle/Late Miocene boundary are defined by the first appearance of *Orbulina suturalis* and the last occurrence of *Globorotalia siakensis*, respectively. Therefore, the Nishiyatsushiro Group and the lower to middle part of the Hara Formation are considered to be of Middle Miocene in age.

The boundary between the Middle and Late Miocene is not exactly determined in the studied section, though it was assumed to lie within the interval from the upper part of Hara Formation to the Iitomi Formation.

The middle to upper part of the Kawadaira Mudstone Member of the Akebono Formation is assigned to the lower Pliocene on account of the occurrence of *Globorotalia margaritae* and *Globorotalia tumida* and the last occurrence of *Globigerina nepenthes*. The occurrence of *Globorotalia crassaformis*, *Globorotalia inflata*, *Neogloboquadrina asanoi* and the right coiling form of *Pulleniatina* characterize the upper part of the Akebono Formation. Oda (1977) established the *Globorotalia tosaensis* Zone which is characterized by the first appearance of the named species and correlated it with Zone N. 21 of Blow (1969). Thus, the upper part of the Akebono Formation is of late Pliocene age.

In addition, the Furusekigawa Formation may be correlative with the lowermost part of the Kanzaka Formation because of the similarity between their assemblages. These assemblages do not include any zonal index species, but their constituent species are essentially in common with those in Blow's Zones N. 8 to 9 of Japan as shown in Table 1.

b. Radiolaria

Table 2 shows the occurrence of radiolarians at the base of the Kanzaka Formation (FUR 16) exposed in the Furuseki area (Fig. 14). After the radio-

Table 1. Occurrence of planktonic foraminifera from the Furuseki (FUR) and Toshiro (TOS) sections. Nishi : Nishiyatsushiro Group ; Furuseki : Furusekigawa Formation.

GROUP	MISAKA		NISHI.
FORMATION	FURUSEKI.		KANZAKA
SAMPLE NO.	TOS 01	FUR 12	FUR 17
SPECIES			
Globigerina praebulloides Blow	+	+	
Gna. woodi Jenkins			+
Globigerinella praesiphonifera (Blow)		+	
Globigerinita glutinata (Egger)		+	
Globigerinoides immaturus LeRoy		+	
Gds. sacculifer (Brady)		+	
Gds. trilobus (Reuss)		+	+
Gds. cf. trilobus (Reuss)	+		
Globoquadrina altispina (Cushman and Jarvis)	+		
Gqd. dehiscens (Chapman, Parr and Collins)		+	+
Globorotalia miozea Finlay		+	
Grt. cf. peripheroronda Blow and Banner			+
Globorotaloides(?) sp.	+		
Sphaeroidinellopsis seminulina (Schwager)		+	
Sps. disjuncta type			+

Table 2. Radiolarians from the Furuseki (FUR) section.

Calocycletta cf. *costata* Riedel
C. *virginis* Moore
Cannartus laticonus Riedel
C. *mammifer* (Haeckel)
Cyrtocapsella cornuta (Haeckel)
C. *japonica* (Nakaseko)
C. *tetrapera* (Haeckel)
Dorcadospyris sp.

FUR 16

larian assemblage data of Riedel and Sanfilippo (1978), the basal part of the Kanzaka Formation may be placed near the Early/Middle Miocene boundary. Thus, it is concluded that the Nishiyatsushiro and Shizukawa Groups were continuously deposited in a time period from the Early/Middle Miocene boundary to the late Pliocene.

The Furusekigawa Formation was formed during the period when the basal part of the Kanzaka Formation accumulated.

2. CORRELATION

The Neogene sequences distributed in southwest Japan and the South Fossa-Magna region are correlated on the basis of plankton biostratigraphic data in order to reconstruct Neogene paleoenvironment and paleoceanography.

Figure 57 shows a summary of correlation of the Neogene sequences distributed in the Kanto region and southwest Japan by means of planktonic foraminiferal zonations established by various studies (Miyazaki region : Suzuki, 1987 ; Kakegawa region : Oda, 1977, Ibaraki, 1986 ; Hamaishidaki region : Ibaraki, 1981 ; Fujikawa region : Akimoto, this paper ; Miura Peninsula : Eto, 1986a, b ; southern Boso Peninsula : Nakao *et al.*, 1986 ; Izu region : Koyama, 1982 ; Shinshu region : Watanabe, 1983, Oda and Akimoto, in press ; Echigoyuzawa region : Akimoto, 1983MS ; Minakami region : Akimoto, 1983MS ; Takasaki region : Takayanagi *et al.*, 1978 ; Hiki (=Iwadono) Hill : Akimoto, 1983MS, Koike *et al.*, 1985). In the area of present study, an interval from the Furusekigawa to Akebono For-

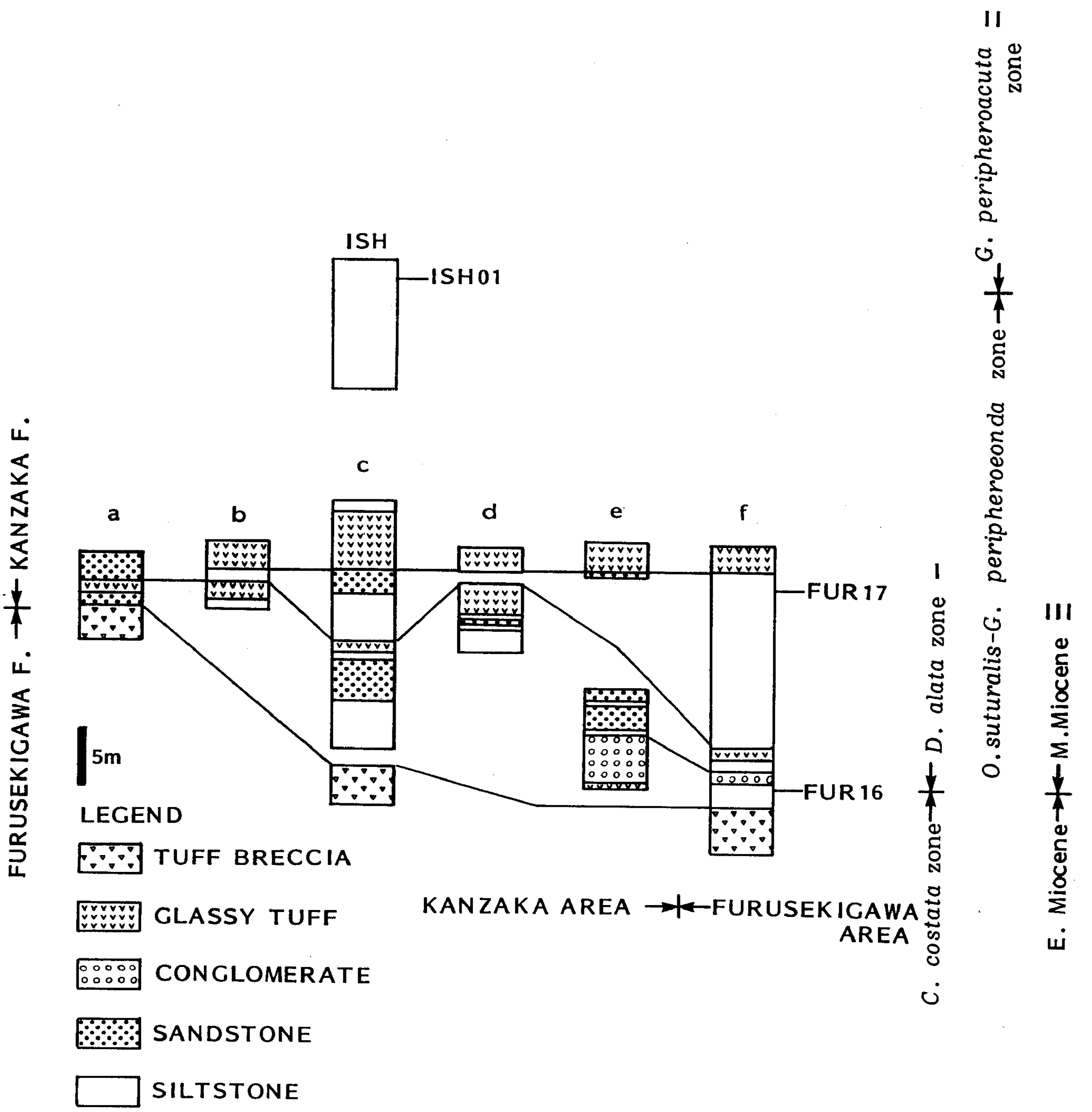

Fig. 20. Columnar sections in the Furuseki section (FUR), showing radiolarian and planktonic foraminiferal zones and applicable radiometric ages.

mations encompasses a zonal succession from the *Orbulina suturalis/Globorotalia peripheroronda* Zone to the *Globorotalia tosaensis* Zone. In this sequence, however, the boundaries between the *Orbulina suturalis/Globorotalia peripheroronda* Zone and the *Globorotalia peripheroacuta* Zone, and between the *Globoquadrina dehiscens* Zone and the *Globorotalia tumida plesiotumida* Zone are indeterminable owing to poorly-preserved faunas.

Oda (1977) attempted a correlation of Neogene sequences distributed in the Takasaki, Kakegawa and Boso areas. Recently, Suzuki (1987) summarized the Miocene-Pliocene stratigraphy of the Miyazaki area, and recorded biohorizons such as the first appearance of *Globorotalia tumida tumida*, last occurrence of

Globigerina nepenthes, change of coiling direction from sinistral to dextral in *Pulleniatina primalis*, and first appearance of *Globorotalia tosaensis*, in ascending order. Eto (1986a, b) determined the age of the Miura Group exposed in the Miura Peninsula by means of datums of planktonic foraminifera and calcareous nannnofossils. Koike *et al.* (1986) investigated the geology of the Iwadono Hill area in northwestern Saitama Prefecture, and discussed geological ages based on planktonic foraminifera. Akimoto (1983MS) traced the datums of *Grt. peripheroacuta* and *Grt.* cf. *miozea conoidea* from Echigoyuzawa in Niigata Prefecture in the north to the Iwadono Hill area in Saitama Prefecture in the south, via the Minakami and Takasaki areas in Gunma Prefecture.

A correlation based on these data is summarized in Fig. 57.

FAUNAL ANALYSIS OF BENTHIC FORAMINIFERA

1. STATISTICS

The distribution of foraminifera in modern oceans is fundamentally in harmony with the distribution of water masses and patterns of surface water currents (Akimoto, 1990). In order to reconstruct paleoenvironment, the present author compares statistics of both fossil and modern assemblages. The statistics include such parameters as planktonic foraminiferal numbers, benthic foraminiferal numbers, agglutinated foraminifera/total benthic foraminifera ratios and planktonic foraminifera/total foraminifera ratios.

a. Planktonic foraminiferal number

Planktonic foraminiferal numbers and benthic foraminiferal numbers, respectively, stand for the number of individuals of planktonic and benthic foraminifera contained in one gram of sediments. Planktonic foraminiferal numbers in studied samples are illustrated in Fig. 21. They are small, being less than 50, in most samples from the Nishiyatsushiro Group, but are rather large in the Shizukawa Group except for the lower part of the Shimobe and Akebono Formations. Samples with large numbers are in the middle part of the Byobu-iwa Formation (FUK06) and the Iitomi

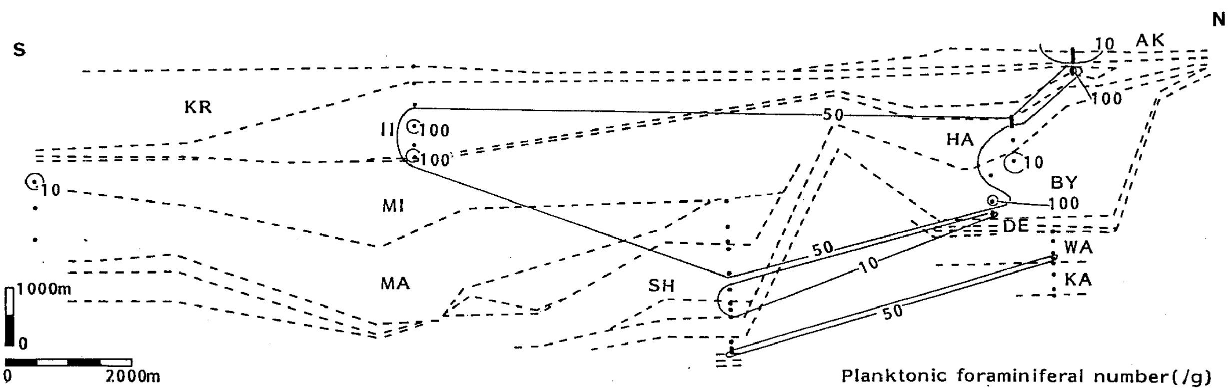

Fig. 21. Schematic cross section showing the distribution of planktonic foraminiferal number. Sample points are shown in Fig. 7. Lines, isopleths of ratio ; broken lines, boundaries of formations. KA, Kanzaka Formation ; WA, Wadaira Formation ; DE, Deguchi Formation ; BY, Byobu-iwa Formation ; HA, Hara Formation, II, Iitomi Formation ; KR, Karasumoriyama Tuff breccia Member ; MI, Minobu Formation ; MA, Marutaki Conglomerate Member ; SH, Shimobe Formation ; AK, Akebone Formation.

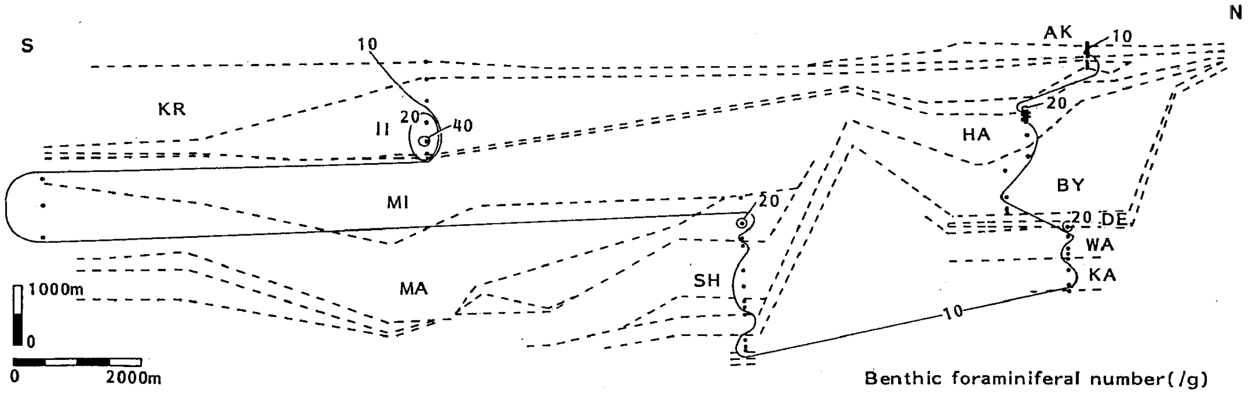

Fig. 22. Schematic cross section showing the distribution of benthic foraminiferal number. Other captions are the same as those in Fig. 21.

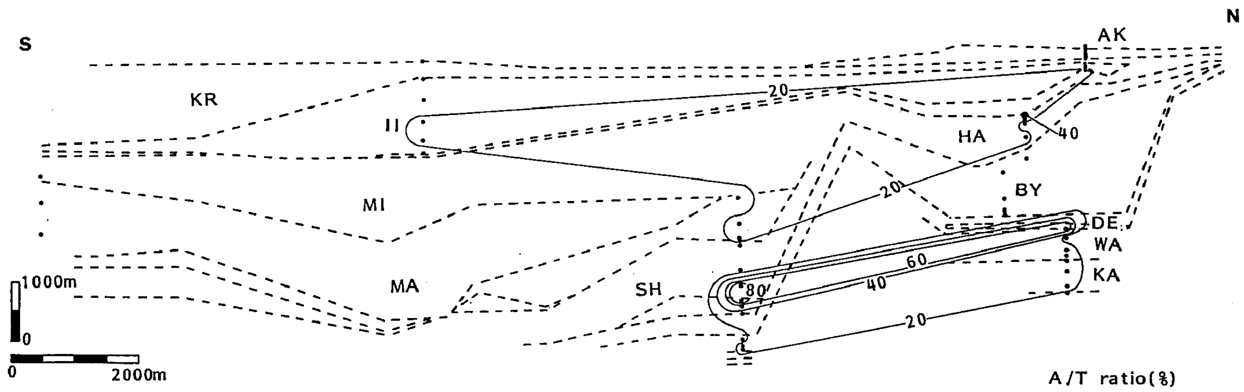

Fig. 23. Schematic cross section showing the distribution of A/T ratio (in %). Other captions are the same as those in Fig. 21.

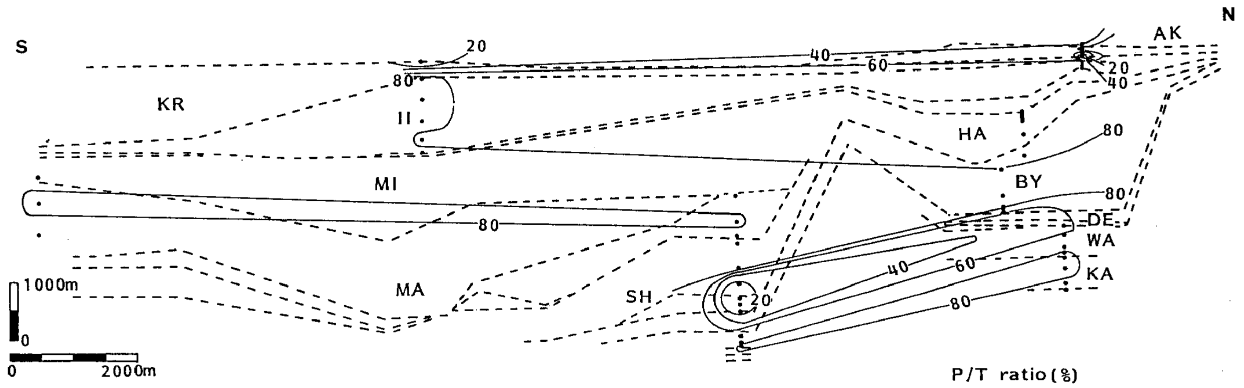

Fig. 24. Schematic cross section showing the distribution of P/T ratio (in %). Other captions are the same as those in Fig. 21.

Formation (AIM01, AIM03, YOG03).

b. Benthic foraminiferal number

Benthic foraminiferal numbers in studied samples are illustrated in Fig. 22. They are small (less than 10) throughout the sections examined. The maximum number is found in the lower part of the Iitomi Formation in AIM route (AIM03).

c. The ratio of agglutinated foraminifera to total benthic foraminifera (A/T ratio)

The frequency distribution of agglutinated foraminifera is shown in Fig. 23. In most samples from the Shizukawa Group, their ratio to total benthic foraminifera (A/T) is less than 20%, but in the lower part of the Shimobe Formation

Table 4. Ninety-three selected species from Table 3 for principal components analysis.

1	Ammodiscoides japonicus Asano and Inomata
2	Ammodiscus sp. A
3	Bathysiphon sp.
4	Alveolophragmuin subglobosa (G.O. Sars)
5	Cyclammina cancellata Brady
6	C. pusilla Brady
7	Alveolophragmium scitulum (Brady)
8	Karreriella bradyi (Cushman)
9	Marsipella elongata Norman
10	Martinottiella communis (d'Orbigny)
11	M. communis (d'Orbigny) var.
12	Psammosphaera fusca Schulze
13	Rhabdammina abyssorum M. Sars
14	Reopohax piliformis Brady
15	Saccammina sphaerica M. Sars
16	Saccorhiza ramosa Brady
17	Silicosigmoilina sp.
18	Siphotextularia concava (Karrer)
19	Trochammina globigeriniformis (Parker and Jones)
20	Ammonia ketienziensis (Ishizaki)
21	A. takanabensis (Ishizaki)
22	Amphicoryna scalaris (Batsch)
23	Anomalinoides glabrata (Cushman)
24	Bolivina robusta Brady
25	Brizalina bradyi (Asano)
26	Bulimina rostrata Brady
27	B. striata d'Orbigny
28	Burseorina pacifica (Cushman)
29	Chilostomella oolina Schwager
30	Cibicides aknerianus (d'Orbigny)
31	C. cicatricosus (Schwager)
32	C. lobatulus (Walker and Jacob)
33	C. praecinctus (Karrer)
34	C. wuellerstofi (Schwager)
35	Heterolepa haidingerii (d'Orbigny)
36	Elphidium crispum (Linne)
37	Fissurina marginata (d'Orbigny)
38	Fursenkoina sp.
39	Globobulimina auriculata (Bailey)
40	G. pacifica Cushman
41	G. perversa (Cushman)
42	G. pupoides (d'Orbigny)
43	Globocassidulina oriangulata (Belford)
44	Gyroidina altiformis (R.E. and K.C. Stewart)
45	G. komatsui Aoki
46	G. orbicularis d'Orbigny
47	G. soldanii d'Orbigny
48	Gyroidinoides nipponicus (Ishizaki)
49	Hanzawaia nipponica Asano
50	Cibicidoides mediocris (Finlay)
51	Hoeglundina elegans (d'Orbigny)
52	Lagena hispida Reuss
53	L. laevis (Montagu)
54	Robulus orbicularis (d'Orbigny)

55 Melonis barleeanus (Williamson)
56 M. sphaeroides Voloshinova
57 M. parkerae (Uchio)
58 M. nicobarensis (Cushman)
59 Nodosaria holoserica (Schwager)
60 N. longiscata (d'Orbigny)
61 N. tosta Schwager
62 Nonionella miocenica Cushman
63 Nonionellina labradorica (Dawson)
64 Oridorsalis umbonatus (Reuss)
65 O. tener (Brady)
66 Orthomorphina spp.
67 Osangularia culter (Parker and Jones)
68 Parrelloides bradyi (Trauth)
69 Frondicularia advena Cushman
70 Plectofrondicularia goharai Kuwano
71 Pleurostomella alternans Schwager
72 Glandulina laevigata (d'Orbigny)
73 Pseudononion japonicum (Asano)
74 Pullenia bulloides (d'Orbigny)
75 P. quinqueloba (Reuss)
76 P. salisburyi R.E. and R.C. Stewart
77 Pyrgo murrhina (Schwager)
78 Quadrimorphina laevigata (Phleger and Parker)
79 Quinqueloqulina akneriana d'Orbigny
80 Rutherfordoides mexicanus (Phleger and Parker)
81 Sigmoilopsis schlumbergeri (Silvestri)
82 Sphaeroidina bulloides d'Orbigny
83 S. compacta Cushman and Todd
84 Stilostomella consobrina (d'Orbigny)
85 S. fistuca (Schwager)
86 S. ketienziensis (Ishizaki)
87 S. lepidula (Schwager)
88 Tosaia hanzawai Takayanagi
89 Trifarina occidentalis (Cushman)
90 Uvigerina hispidocostata Cushman and Todd
91 U. cf. parvula Cushman (=Uvigerina sp.)
92 U. peregrina Cushman
93 U. proboscidea Schwager

it is exceptionally high exceeding 80%. It is generally 20 to 60% in the Nishiyatsushiro Group. Such high ratios may suggest some special conditions in the water masses such as the prevalence of low pH conditions or a deeper water environment below the CCD.

d. The ratio of planktonic foraminifera to total foraminifera (P/T ratio)

The P/T ratios are generally high in sediments of the Fujikawa area, except for the top of the sequence as shown in Fig. 24. The Nishiyatsushiro Group is marked by high P/T ratios, but the Shizukawa Group shows a gradually declining tendency of the P/T ratio toward the Akebono Formation. It is noteworthy that planktonic foraminifers are almost absent in the lower part of the Shimobe Formation in FUJ route. These low P/T ratios may suggest some depositional characteristics under a coastal water or a deep-water environment below the foraminiferal lysocline.

2. PRINCIPAL COMPONENTS ANALYSIS

Principal components analysis was performed in order to detect major factors which controlled the distribution of benthic foraminifera in Neogene sections in the study area. A data matrix for this analysis is composed of 54 samples selected out of a total of 600 rock samples examined and 93 species out of 350 benthic foraminiferal taxa, which are represented by three or more individuals in two or more samples in Table 3 (in back pocket).

The computer program used in this study is a modification of Davis' (1973) one, which has been made by Dr. Kunihiro Ishizaki in order to process efficiently data through an available computer and to facilitate computations of principal components factor loading on the mathematical bases of Kawaguchi (1973). The operation was performed by using a NEAC-ACOS77/700 computer in the Tohoku University Com-

Table 5. Principal component scores of selected benthic foraminiferal taxa for the first five components. (Species number same as in Table 3).

(COLUMNS = EIGENVECTORS, ROWS = OBSERVATION)

	1	2	3	4	5
1	0.6208	-0.7120	0.7621	-0.5451	-0.2178
2	0.4392	-0.1119	0.5270	-0.1035	-0.1760
3	4.8947	7.5336	2.9034	1.4171	2.2745
4	7.3130	-2.8613	1.6775	-0.7262	2.7466
5	2.3084	1.5673	0.7861	1.7287	0.0466
6	1.4916	1.1369	-1.0775	0.2727	0.6134
7	3.2233	-3.7594	2.7778	4.5204	4.9835
8	1.8117	2.4966	0.7152	0.4870	0.8774
9	6.2575	7.2258	5.9545	0.5073	2.1368
10	13.0831	-4.8304	3.8208	0.1614	-0.1273
11	1.7079	1.3413	0.7785	-0.1511	0.2953
12	6.1326	5.9569	1.1854	2.9313	2.2790
13	68.1198	87.2729	51.5470	12.6375	16.5812
14	3.7892	3.3638	2.0371	2.7925	1.0502
15	2.9708	1.5553	1.3384	0.4111	1.1871
16	1.7977	1.7721	1.6450	-0.3893	-0.2057
17	0.7931	-0.4248	0.4258	0.7688	0.4347
18	0.5333	-0.0819	-0.2123	0.0553	0.0122
19	15.3940	-5.5527	15.1822	-8.9068	-1.8740
20	3.7018	-8.3729	6.9055	47.6107	-59.6447
21	0.6539	-1.6037	1.6037	12.0354	-15.0420
22	0.5752	-0.9439	0.5413	1.4764	-0.7268
23	2.0654	0.6249	-2.5294	-0.2096	0.2350
24	0.2040	-0.2402	0.0258	1.0244	-0.6512
25	1.3847	-2.2227	1.1240	0.6755	0.0107
26	13.8855	-8.3370	4.1930	1.3254	-4.8347
27	0.5861	-0.4670	-0.2425	1.0174	-0.0190
28	0.7469	-1.0626	0.5321	1.0373	0.4755
29	3.7468	-1.2287	-4.3803	7.3289	-2.7945
30	5.9732	-9.2460	5.6817	3.2009	4.0145
31	9.0635	-2.2968	4.8019	-1.6114	-2.4523
32	2.9494	1.4799	-2.2624	0.1201	0.4141
33	0.1868	-0.3062	0.1142	1.3240	-1.0434
34	23.4917	-4.4244	4.2145	-7.3483	-1.6875
35	0.1957	-0.3902	0.2711	2.5471	-2.7829
36	4.4594	-7.4817	3.7130	8.2283	7.7634
37	1.6439	-1.0237	-1.3818	0.7740	0.6261
38	1.7453	-1.2039	-0.7642	5.9128	-4.7135
39	31.1077	-6.7061	-8.2671	30.6443	4.0537
40	5.0400	-1.6832	1.0817	4.4396	1.5033

41	5.1613	-3.2757	-2.2381	7.7933	-2.5010
42	5.8478	-1.8574	0.4696	4.4968	1.5680
43	0.7779	-1.1425	0.4493	1.2627	1.0835
44	3.2678	-0.0191	-2.1845	0.4558	0.4905
45	3.4366	1.1376	-0.1758	0.9695	-0.2840
46	6.5745	1.1647	0.0594	-4.8293	-5.8629
47	8.3121	0.2646	-0.1213	0.9422	-2.0476
48	0.6099	-0.1031	-0.9998	0.3682	0.0612
49	1.5458	-2.3119	1.4276	3.7516	-3.2403
50	9.1209	-11.7427	4.1794	14.2575	1.5353
51	1.6551	1.2927	1.2621	1.6651	0.1287
52	0.8424	-0.1352	0.3419	-0.5411	-0.4296
53	2.8588	0.0148	-0.7462	0.5003	0.5660
54	0.2724	-0.5296	0.3205	4.0834	-4.5564
55	10.5996	4.7647	4.6308	0.8470	1.4563
56	59.4309	13.2753	-56.2490	7.0394	12.5077
57	15.5564	-15.1881	11.8288	14.7738	-8.5331
58	2.3687	-0.0410	0.0820	-2.1124	-1.6915
59	2.3699	-0.7311	-1.3387	-0.6899	0.3437
60	59.6625	17.8659	-8.2684	-31.9437	-35.4872
61	3.4636	-1.6956	1.7999	-0.4908	-0.9329
62	1.3213	-1.9307	1.1914	3.5145	-2.9848
63	2.6325	-3.7059	1.6017	8.4245	-3.6994
64	6.2560	-1.4909	0.0354	0.1370	-4.0365
65	14.1440	-14.2634	12.1170	-3.6319	-1.1975
66	2.4945	-0.4346	-1.2592	1.8993	1.3860
67	1.6217	-1.8387	0.9934	-0.2058	0.1844
68	2.8129	1.2132	1.1863	0.9260	0.1298
69	0.6554	-0.2465	-0.4179	0.2356	-0.3793
70	0.8465	-0.3808	0.0067	0.3666	-1.0894
71	2.7443	-0.0678	-1.6526	-0.3204	-0.3828
72	0.9792	-1.2978	0.7666	-0.2288	0.2096
73	0.3509	-0.4045	-0.0451	0.9399	0.1806
74	15.9468	1.3359	1.5756	-1.1331	-1.7855
75	2.3724	-0.4533	-0.5759	-0.3715	-1.1597
76	0.7784	-0.3502	-0.1400	-0.4794	-0.7279
77	14.8663	-6.7927	-4.7414	-3.2729	0.7066
78	1.3114	-0.8551	0.0659	1.6388	-1.1790
79	0.6051	-0.3139	0.1627	-0.3768	-0.7077
80	0.8492	-1.3442	0.5890	3.7440	-3.0862
81	3.4156	-5.6468	3.5461	9.3315	-10.1788
82	6.2063	3.0602	-4.0443	2.2644	-0.4424
83	3.9539	-0.2572	0.5220	-1.3143	-1.0069
84	2.7487	0.4445	-1.9270	-0.2469	-0.2807
85	9.0133	-2.7619	-2.1637	1.5769	0.7871
86	1.1744	-0.1109	-1.6986	0.7516	-0.4840
87	69.0217	-56.1152	21.3201	-20.7539	4.8311
88	13.9831	4.6180	-4.5246	0.2521	-0.3239
89	0.8879	-0.9863	0.2400	0.5766	0.3730
90	6.3269	-6.7824	0.4241	0.8134	2.8249
91	3.5038	1.0762	-2.0812	0.0300	0.1685
92	0.3195	-0.4929	0.2578	0.2356	0.2913
93	27.7293	-28.2807	8.3917	15.3106	30.5949

Table 6. Principal component factor loadings of each sample studied for the first five components.

(COLUMNS = FACTOR, ROWS = OBSERVATION)

	1	2	3	4	5
1	0.7915	0.1349	-0.5251	-0.0421	-0.0030
2	0.5841	0.3276	-0.4486	-0.0108	0.0388
3	0.7133	0.2611	-0.0166	-0.2432	-0.2980
4	0.6485	0.4664	0.1383	-0.2631	-0.2837
5	0.7237	0.3785	-0.1732	0.1381	0.2074
6	0.6730	0.2812	-0.5118	-0.1589	-0.1430
7	0.4799	0.6914	0.4664	0.1032	0.1425
8	0.4803	0.6771	0.4827	0.0972	0.1427
9	0.7024	0.5234	0.1378	0.1264	0.1603
10	0.6395	0.4468	0.1268	0.3214	0.0927
11	0.4933	-0.0190	-0.4429	0.4161	0.0579
12	0.6811	-0.1999	-0.1016	-0.3676	-0.2422
13	0.7180	-0.1160	-0.5781	-0.0227	0.0939
14	0.7565	-0.1135	-0.5575	0.0453	0.1166
15	0.4033	0.0448	-0.5040	0.1976	0.0086
16	0.8086	-0.2874	-0.3176	-0.0757	0.0663
17	0.7214	-0.2854	-0.2572	0.0265	0.0532
18	0.6077	-0.5078	0.3292	-0.1219	0.2134
19	0.4964	0.0157	-0.0314	-0.3833	-0.4897
20	0.5001	-0.3122	0.1563	-0.1773	-0.0203
21	0.4666	-0.2932	0.2602	-0.2292	-0.0047
22	0.4680	-0.4483	0.3439	-0.0802	0.0887
23	0.5038	-0.3323	0.2928	-0.2876	-0.1839
24	0.3217	-0.3180	0.1548	0.1603	0.0849
25	0.3031	-0.3227	0.1137	0.2114	0.2356
26	0.4166	-0.4740	0.1856	0.2594	0.3222
27	0.4163	-0.2644	0.1360	0.3043	0.0846
28	0.2338	-0.3262	0.1312	0.3288	0.4084
29	0.4789	-0.5435	0.2329	-0.1199	-0.0336
30	0.0507	-0.1038	0.0868	0.5256	-0.6202
31	0.2054	-0.2231	0.0811	0.3694	-0.2823
32	0.1708	-0.1616	0.0282	0.6669	-0.5130
33	0.0336	-0.0671	0.0625	0.3847	-0.4763
34	0.0235	-0.0659	0.0578	0.4856	-0.6048
35	0.6575	0.1427	0.0298	-0.0515	-0.0983
36	0.6563	0.6005	0.0318	0.0470	0.1137
37	0.4438	0.6609	0.4798	0.1323	0.1807
38	0.5353	0.6573	0.3601	0.1339	0.2094
39	0.6355	-0.2505	0.1555	0.1076	-0.1098
40	0.4127	-0.1349	0.0203	0.1386	-0.2351
41	0.6824	0.0801	0.1932	-0.0888	-0.0362
42	0.6403	0.3363	0.2142	-0.3351	-0.3345
43	0.6559	-0.2542	0.0801	-0.3456	-0.2898
44	0.4081	-0.2697	-0.0079	0.4557	-0.0256
45	0.5104	-0.5506	0.2196	-0.1013	0.1958

46	0.1756	-0.1455	-0.0156	0.2382	0.0635
47	0.5180	-0.5145	0.2005	-0.2359	0.0196
48	0.3916	-0.2933	-0.0976	0.3299	0.4132
49	0.6191	-0.1101	-0.4840	-0.0161	0.2005
50	0.1709	-0.1669	0.1192	0.2829	-0.0963
51	0.4303	-0.4998	0.3035	0.0620	0.0552
52	0.4315	-0.4337	0.2622	-0.1841	-0.0433
53	0.7548	0.3835	0.0794	0.0579	-0.0928
54	0.2729	0.2121	0.1936	0.2121	0.0505

1, ISH01; 2, ISH02; 3, ISH05; 4, ISH06; 5, ISH07; 6, ISH08; 7, ISH09; 8, ISH10; 9, DEG01; 10, DEG02; 11, DEG03; 12, FUK01; 13, FUK02; 14, FUK03; 15, FUK06; 16, FUK08; 17, OGY01; 18, OGY04; 19, OGY07; 20, OGY08; 21, OGY09; 22, OGY10; 23, OGY11: 24, OGY12; 25, YOG01; 26, YOG03; 27, YOG04; 28, YOG06; 29, YOG08; 30, YOG09; 31, YOG10; 32, YOG12; 33, YOG13; 34, YOG16; 35, FUJ01; 36, FUJ02; 37, FUJ03; 38, FUJ04; 39, FUJ05; 40, FUJ06; 41, FUJ07; 42, FUJ08; 43, FUJ09; 44, NAN01; 45, NAN02; 46, NAN03; 47, AIM01; 48, AIM03; 49, AIM05; 50, AIM06; 51, AIM07; 52, AIM09; 53, TOG01; 54, TOG02.

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The results of analyses (Q-mode technique, variance-covariance matrix) are shown in Tables 5 and 6, and are summarized in Table 7. Table 7 shows that the first five eigenvalues account for about 61.2% of the total variance, which may give a basis for an ordinary discussion of the general distributional pattern of benthic foraminiferal taxa in rock samples from the Nishiyatsushiro and Shizukawa Groups.

The first five principal components were subsequently examined in detail by comparing their scores with pertinent data available.

Table 7. Summary of principal components analysis. Column 1 = Eigenvalues; Column 2 = Percent of trace; Column 3 = Cumulative percent of trace.

	1	2	3
1	15.3615	28.4475	28.4475
2	6.9589	12.8870	41.3345
3	4.1628	7.7089	49.0434
4	3.5154	6.5101	55.5535
5	3.0336	5.6178	61.1714
6	2.6768	4.9571	66.1284
7	2.2719	4.2072	70.3356

a. 1st principal components

The 1st principal component scores of four taxa such as *Rhabdammina abyssorum* (sp. 13), *Melonis sphaeroides* (sp. 56), *Nodosaria longiscata* (sp. 60) and *Stilostomella lepidula* (sp. 87) are extraordinarily high, and mark these four species off from others. They are relatively dominant in each sample. Examination shows a close correlation, as shown in Fig. 25, of the 1st principal component scores with the relative frequency of each benthic foraminiferal taxon.

b. 2nd principal components

Among the species represented by a high positive score of the 2nd principal component, there are *Rhabdammina abyssorum* (sp. 13) and *Melonis barleeanus* (sp. 55). *Ammonia ketienziensis* (sp. 20), *Cibicides aknerianus* (sp. 30), *Cibicidoides mediocris* (sp. 50), *Melonis parkerae* (sp. 57), *Oridorsalis tener* (sp. 65), *Stilostomella lepidula* (sp. 87) and *Uvigerina proboscidea* (sp. 93) all have high negative scores (Fig. 26). Relationships between water depths and the relative frequency of their modern counterparts distributed off southwest Japan

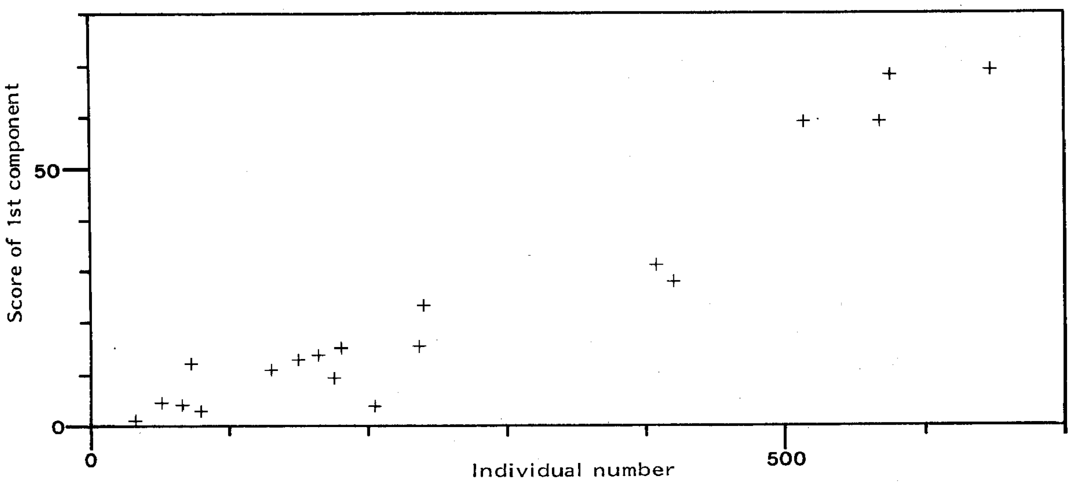


Fig. 25. Relationships between the total individual numbers of the first 19 most abundant benthic foraminiferal species in 54 rock samples and their scores of the first principal component.

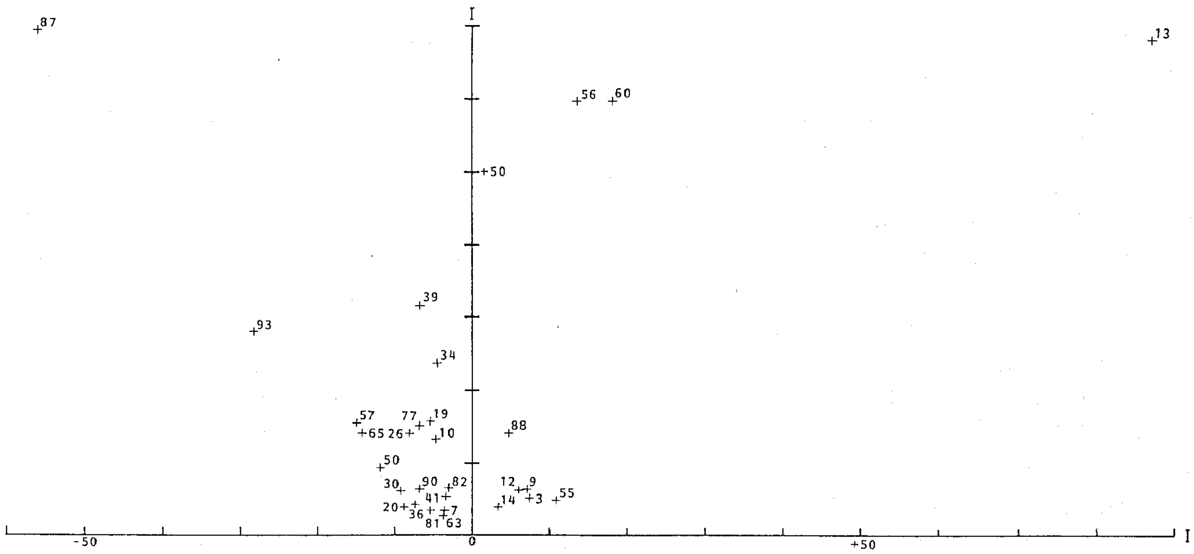


Fig. 26. Scores of the 1st and 2nd principal components for benthic foraminiferal species. 13, *Rhabdammina abyssorum* M. Sars ; 20, *Ammonia ketienziensis* (Ishizaki) ; 30, *Cibicides aknerianus* (d'Orbigny) ; 50, *Cibicidoides mediocris* Finlay ; 55, *Melonis barleeanus* (Williamson) ; 57, *Melonis parkerae* (Uchio) ; 65, *Oridorsalis tener* (Brady) ; 87, *Stilostomella lepidula* (Schwager) ; 93, *Uvigerina proboscidea* Schwager.

are shown in Fig. 33 (in Akimoto, 1990). What is evident in this figure is that sp. 13 (*R. abyssorum*) shows a high frequency below the foraminiferal lysocline, and so do sp. 20 (*Ammonia ketienziensis*), sp. 30 (*Cibicides aknerianus*), sp. 50 (*Cibicidoides mediocris*), sp. 57 (*Melonis parkerae*), sp. 65 (*Oridorsalis tener*) and sp. 93 (*U. proboscidea*) above it.

Figure 27 shows the distribution of the 2nd principal component factor loading. The pattern in this figure is identical with that in Figs. 23 and 24. This coincidence supports the inference of the

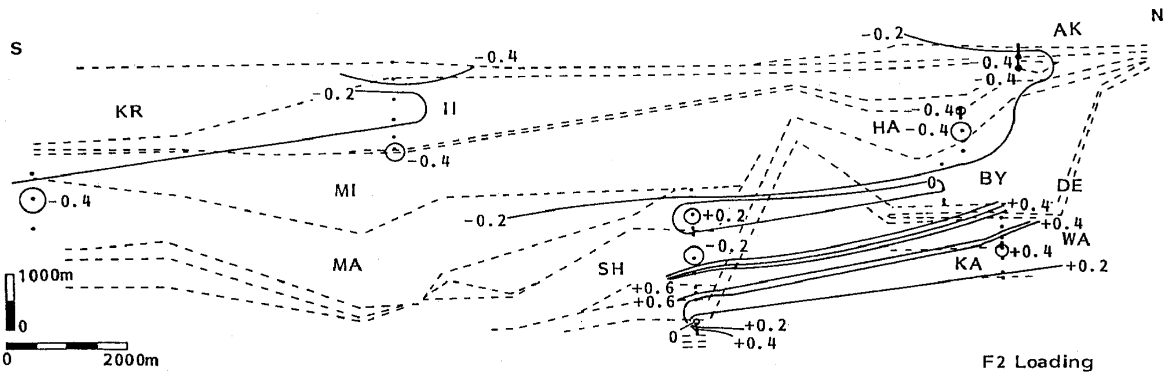


Fig. 27. Schematic cross section showing the distribution of the 2nd principal component factor loadings. Other captions are the same as those in Fig. 21.

2nd principal components.

In summary, Figs. 26 and 27 lead to the following: 1) The 2nd positive principal component indicates the existence of a water mass related to the foraminiferal lysoline, which accords with the distributions of P/T and A/T ratios. 2) The Kanzaka, Wadaira and Deguchi Formations of the Nishiyatsushiro Group and the lower parts of both the Shimobe and Minobu Formations were deposited below the foraminiferal

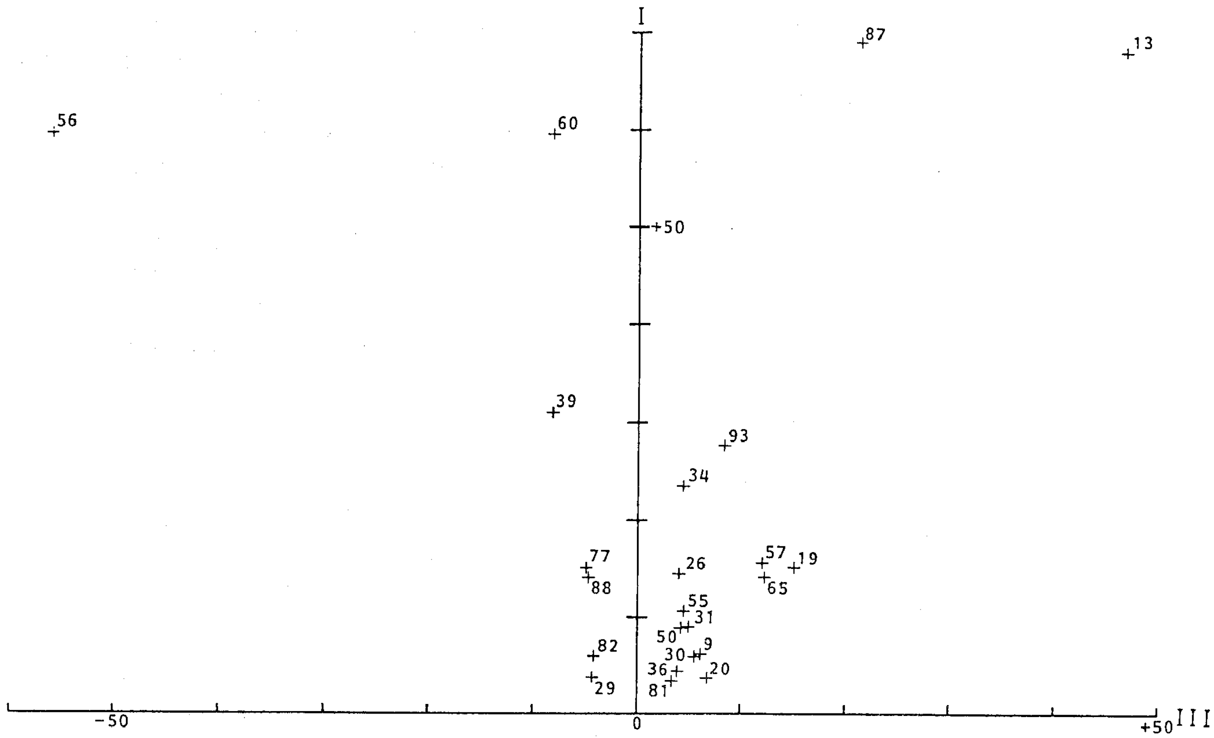


Fig. 28. Scores of the 1st and 3rd principal components for benthic foraminiferal species. 13, *Rhabdammina abyssorum* M. Sars; 19, *Trochammina globigeriniformis* (Parker and Jones); 20, *Ammonia ketienziensis* (Ishizaki); 29, *Chilostomella oolina* Schwager; 56, *Melonis sphaeroides* (Voloshinova); 57, *Melonis parkerae* (Uchio); 65, *Oridorsalis tener* (Brady).

lysocline.

c. 3rd principal components

Figure 28 shows benthic foraminiferal species plots in order of the scores of the 1st and 3rd principal components. The figure indicates that 1) *Rhabdammina abyssorum* (sp. 13), *Trochammina globigeriniformis* (sp. 19), *Ammonia ketienziensis* (sp. 20), *Melonis parkerae* (sp. 57) and *Oridorsalis tener* (sp. 65) have a high positive score, and 2) *Chilostomella oolina* (sp. 29) and *Melonis sphaeroides* (sp. 56) have a high negative score of the 3rd principal components. *Rhabdammina abyssorum* is abundant in a sample from the modern abyssal zone, and *Trochammina globigeriniformis*, *Chilostomella oolina*, *Melonis parkerae* are abundant in the middle bathyal to abyssal zone. *Ammonia ketienziensis* is abundant in a sample from the coastal region, especially off the mouth of the River Tenryugawa (Akimoto, 1990). No data are available on the modern distribution of *Melonis sphaeroides* around the Japanese Islands, but this species is generally considered to be a deep-water species (*e.g.* Hasegawa, 1984).

Thus the 3rd principal components factor loading is not related with water depths or water masses.

A sedimentological examination shows that those species having a high positive score of the third principal component are confined to a sandy silt with less than 70% of mud contents, and *Chilostomella oolina* is abundant in silty sediments with more than 90% mud contents in Recent samples. Figure 42 shows mud contents in examined samples in this study. There is no definite relationship between the 3rd principal components factor loading and mud contents when Fig. 29 is compared with Fig. 40.

Furthermore, the laminated siltstone represented at points DEG03, FUK02, AIM05 and AIM06 is related to high negative values of the 3rd principal components factor loading (Figs. 44, 45). Thus, these negative values may imply the effect of bottom currents. This inference is additionally supported by the existence of fecal pellets in sample OGY09 which has a positive loading.

In summary, Figs. 29, 44 and 45 lead to the following: 1) The 3rd principal components correspond to the movement of water on the bottom surface. 2) The Byobu-iwa Formation and the middle part of the Iitomi Formation, exposed in the Aimata area, were deposited under the influence of bottom currents.

d. 4th principal components

Figure 30 shows benthic foraminiferal species plotted according to the score of the 1st and 4th principal components.

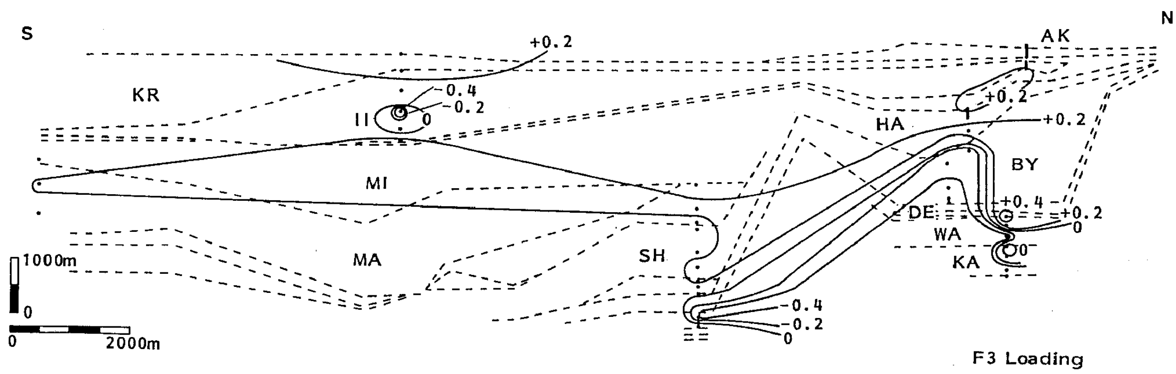


Fig. 29. Schematic cross section showing the distribution of the 3rd principal component factor loadings. Other captions are the same as those in Fig. 21.

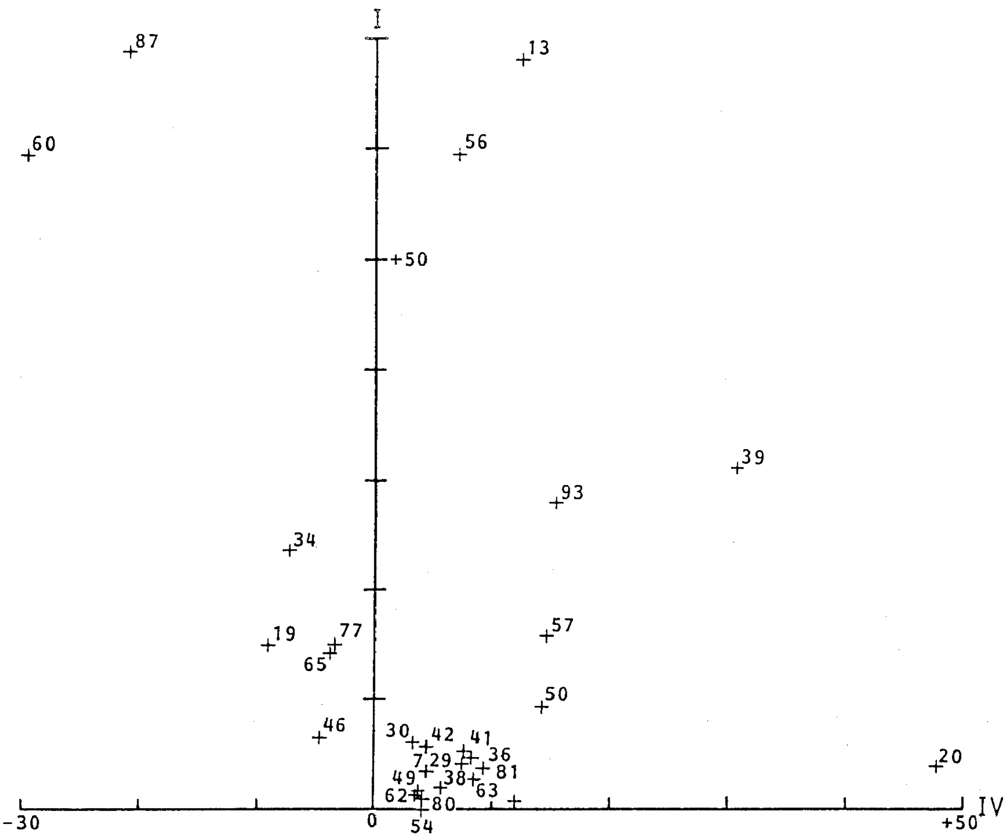


Fig. 30. Scores of the 1st and 4th principal components for benthic foraminiferal species. 19, *Trochammina globigeriniformis* (Parker and Jones); 20, *Ammonia ketienziensis* (Ishizaki); 21, *Ammonia takanabensis* (Ishizaki); 39, *Globobulimina auriculata* (Bailey); 46, *Gyroidina orbicularis* d'Orbigny; 60, *Nodosaria longiscata* (d'Orbigny).

This figure shows that 1) *Ammonia ketienziensis* (sp. 20), *Ammonia takanabensis* (sp. 21) and *Globobulimina auriculata* (sp. 39) have a high positive score of the 4th principal components, and 2) *Rhabdammina abyssorum* (sp. 13), *Gyroidina orbicularis* (sp. 46) and *Nodosaria longiscata* (sp. 60) have a high negative score.

In the modern oceans, *Ammonia ketienziensis* and *Ammonia takanabensis* are abundant in depths ranging from the outer sublittoral to upper bathyal zones, and *Globobulimina auriculata* occurs in the lower bathyal zone (Fig. 33, in Akimoto, 1990). On the other hand, *Rhabdammina abyssorum* prevails mostly below the lower middle bathyal zone. *Gyroidina orbicularis* is widely distributed between the middle sublittoral and abyssal zones. Thus, it is difficult to regard the 4th principal components as a reflection of water depths.

In general, *Globobulimina* lives in a low oxygen condition, but no further data are available for other species in relation to dissolved oxygen conditions.

Sediment characters were analysed in this study in relation to dissolved oxygen (Chapter 7). Anaerobic conditions may be implied by the presence of black siltstone and framboidal pyrite grains as in samples from the Deguchi Formation (DEG03) and those from the Iitomi and Akebono Formations (YOG01 to YOG16) (Figs. 42 and 44). These sites correspond to points of positive higher values of the 4th principal component as

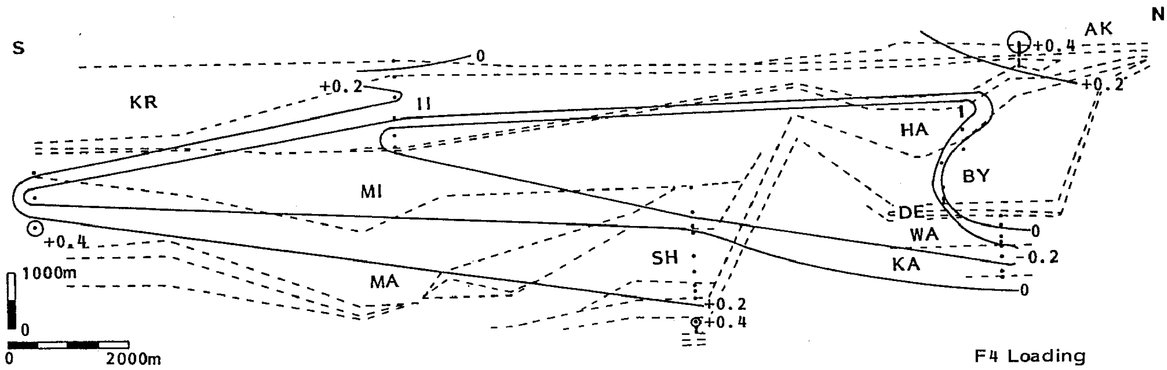


Fig. 31. Schematic cross section showing the distribution of the 4th principal component factor loadings. Other captions are the same as those in Fig. 21.

shown in Fig. 31. The prevalence of anaerobic conditions possibly explain the positive factor loading of the 4th principal components.

e. 5th principal components

Figure 32 shows benthic foraminiferal species plotted with scores of the 1st and 5th principal components. The figure indicates that 1) *Elphidium crispum* (sp. 36) and *Uvigerina proboscidea* (sp. 93) have a high positive score, and 2) *Ammonia ketienziensis* (sp. 20) and *Ammonia takanabensis* (sp. 21) have a high negative score of the 5th principal components.

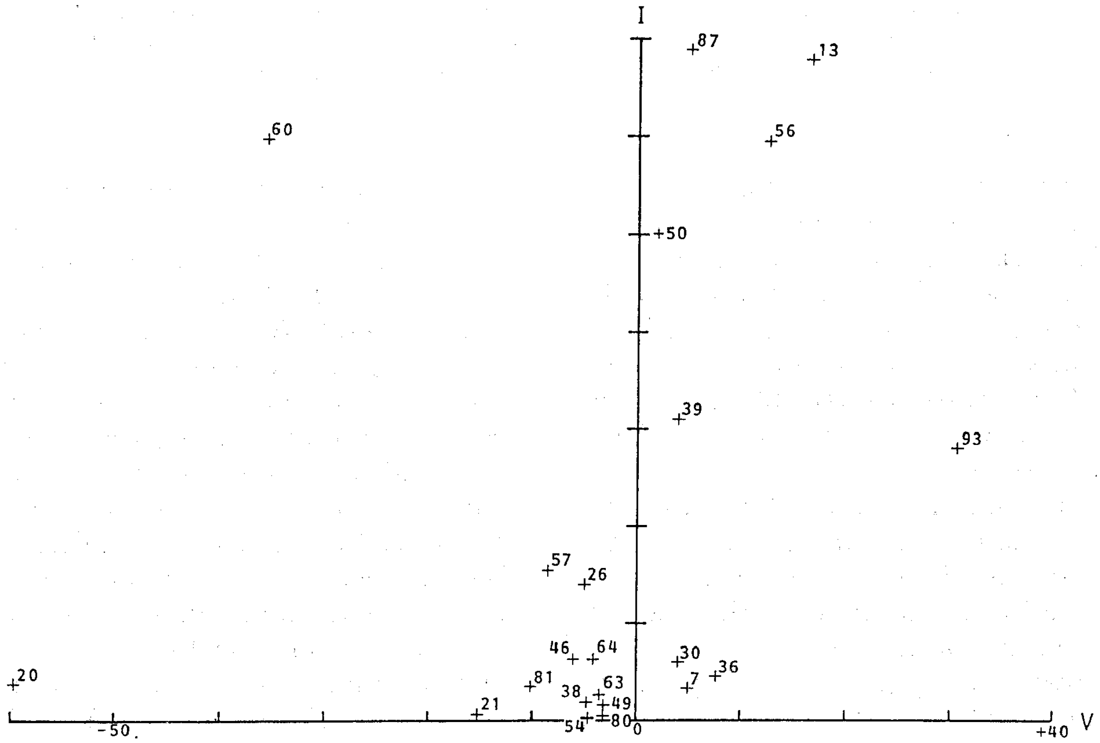


Fig. 32. Scores of the 1st and 5th principal components for benthic foraminiferal species. 20, *Ammonia ketienziensis* (Ishizaki) ; 21, *Ammonia takanabensis* (Ishizaki) ; 93, *Uvigerina proboscidea* Schwager.

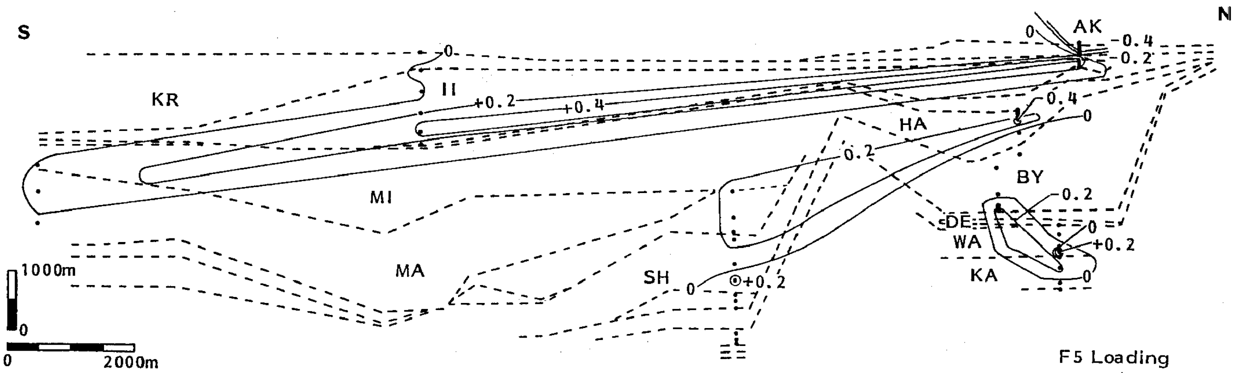


Fig. 33. Schematic cross section showing the distribution of the 5th principal component factor loadings. Other captions are the same as those in Fig. 21.

It is evident from Fig. 32 that *A. ketienziensis* and *A. takanabensis* are highly frequent in samples off the mouth of the River Tenryugawa influenced by coastal waters (Akimoto, 1990), whereas *Uvigerina proboscidea* is frequent in the normal marine, mdidle bathyal zone.

Thus, negative values of the 5th principal components are related to the influence of coastal water.

Figure 33 shows the distribution of the 5th principal components factor loading. The distributional pattern is identical with that of the P/T ratio shown in Fig. 24. This coincidence supports the inference of variance of the 5th principal components.

In summary, the 2nd to 5th principal components delineate independent environmental factors controlling the species distribution, such as water depths, dissolved oxygen, influence by bottom currents and existence of coastal water. Samples are assorted on the basis of the first five principal components, each representing a particular environmental parameter.

All 54 samples examined are clustered into nine sample groups, Types a-i as shown in Table 8, by incorporating three kinds of data, namely principal components, the distribution of modern benthic foraminifera, and sedimentological properties. Paleoenvironments of the Nishiyatsushiro and Shizukawa Groups were inferred by means of these sample groups (Fig. 34).

The relationships between the major biofacies and their corresponding paleoenvironment types are summarized for each sample group as follows:

1) Type a

Biofacies: *Rhabdammina abyssorum* biofacies

Predominant species: *Rhabdammina abyssorum.*

Sample and Formation: ISH09 (Wadaira F.), ISH10, DEG01, (Deguchi F.), and FUJ03, 04 (Shimobe F.)

Sediments: sandy siltstone (tuffaceous light gray sandy siltstone).

Paleoenvironment: Abyssal zone under sluggish bottom currents. This biofacies is estimated to represent depths below the foraminiferal lysocline on the basis of P/T ratio.

Remarks: *Melonis sphaeroides* and *Nodosaria longiscata* are absent or rarely present and *Globobulimina auriculata* accompanies this biofacies. This biofacies more and less resembles the *Globobulimina auriculata-Nodosaria longiscata* Zone of Konda (1980).

2) Type b

Biofacies: *Melonis sphaeroides-Nodosaria longiscata* biofacies.

Predominant species: *Melonis sphaeroides* and *Nodosaria longiscata.*

Table 8. Nine types of paleoenvironments deduced by interpretations of principal components, sedimentological properties, and ecological data on modern benthic foraminifera.

TYPE	COMBINATION OF FACTOR LOADINGS	PALEOENVIRONMENT
a	II+III+	abyssal zone under low velocity bottom current
b	II+III-	abyssal zone under high velocity bottom current
c	II+IV+	abyssal zone under anaerobic condition
d	II+IV-	abyssal zone under aerobic condition
e	II-IV-	lower bathyal zone under high velocity bottom current
f	II-III+IV-	lower bathyal zone under low velocity bottom current and aerobic condition
g	II-III+IV+	lower bathyal zone under low velocity bottom current and anaerobic condition
h	IV+V+	middle bathyal zone under anaerobic condition
i	IV+V-	outer sublittoral zone to upper bathyal zone under anaerobic condition.

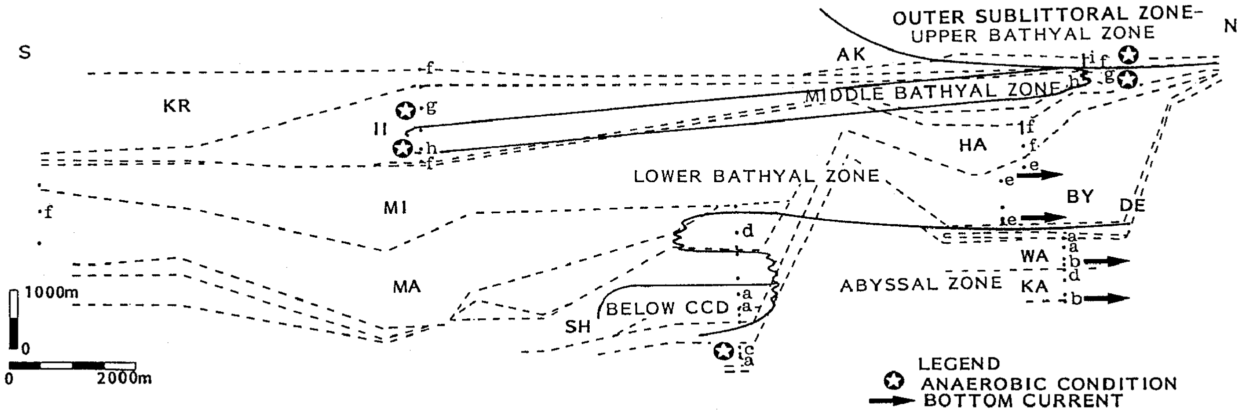


Fig. 34. Schematic cross section showing the stratigraphic distribution of various types of paleoenvironments tabulated in Table 6. Sample points are shown in Fig. 7. Arrows do not indicate true directions of bottom currents. a-i, nine types of paleoenvironments tabulated in Table 6. Other captions are the same as those in Fig. 21.

Accompanying species: *Rhabdammina abyssorum*.
Sample and Formation: ISH01, ISH02 (Kanzaka F.) and ISH07, ISH08 (Wadaira F.).
Sediments: sandy siltstone (thin sandstone interbeds and ripple marks are recognized).
Paleoenvironment: Abyssal zone influenced by high velocity bottom currents.
Remarks: *Rhabdammina abyssorum* is rather rare.

3) Type c
Biofacies: *Rhabdammina abyssorum-Globobulimina auriculata* biofacies.
Predominant species: *Rhabdammina abyssorum* and *Globobulimina auriculata*.
Sample and Formation: DEG02 (Deguchi F.).
Paleoenvironment: Abyssal zone under anaerobic conditions.
Sediments: black sandy siltstone (intercalating thin sandstone layers).
Remarks: *Melonis sphaeroides* and *Nodosaria longiscata* are present but few.

4) Type d
Biofacies: *Nodosaria longiscata-Rhabdammina abyssorum* biofacies.
Predominant species: *Nodosaria longiscata* and *Rhabdammina abyssorum*.
Sample and Formation: ISH05, ISH06 (Kanzaka F.) and FUJ08 (Minobu F.)
Sediments: sandy siltstone (with thin sandstone interbeds).
Paleoenvironment: Abyssal zone under aerobic conditions.
Remarks: *Melonis sphaeroides* and *Globobulimina auriculata* are rare.

5) Type e
Biofacies: *Melonis sphaeroides-Stilostomella lepidula* biofacies.
Predominant species: *Melonis sphaeroides* and *Stilostomella lepidula*.
Subordinate species: *Cibicides wuellerstorfi*, *Globobulimina auriculata* and *Nodosaria longiscata*.
Sample and Formation: FUK02, FUK03, FUK08, OGY01 (Byobu-iwa F.).
Sediments: tuffaceous sandy siltstone.
Paleoenvironment: lower bathyal zone influenced by high velocity bottom currents.
Remarks: This biofacies is characterized by the abundant occurrence of *Melonis sphaeroides* and *Stilostomella lepidula* and the absence of *Rhabdammina abyssorum*.

The *Melonis pompilioides-Stilostomella ketienziensis* Zone established by Konda (1980) in the Byobu-iwa Formation is correlative with this biofacies.

6) Type f
Biofacies: *Stilostomella lepidula* biofacies.
Predominant species: *Stilostomella lepidula*.
Subordinate species: *Trochammina globigeriniformis*, *Oridorsalis umbonatus*, *Oridorsalis tener* and *Uvigerina proboscidea*.
Sample and Formation: OGY04, OGY08, OGY09, OGY10 (Hara F.), AIM01 (Iitomi F.), AIM09 (Akebono F.) and NAN02 (Minobu F.).
Sediments: sandy siltstone (intercalating thin sandstone layers).
Paleoenvironment: lower bathyal zone under aerobic conditions and influenced by sluggish bottom currents.
Remarks: Woodruff (1985) considered that *Stilostomella* spp. are intermediate water inhabitants. In the study area, *Stilostomella lepidula* occurs in abundance in Types e, f, g and h, which are presumed to have deposited at a middle to lower bathyal depth. The subordinate species are distributed in the middle to lower bathyal zone today.

7) Type g
Biofacies: *Globobulimina pupoides-Stilostomella lepidula* biofacies.

Predominant species: *Globobulimina pupoides.*
Subordinate species: *Globobulimina auriculata* and *Stilostomella lepidula.*
Sample and Formation: YOG04, AIM05 (Iitomi F.).
Sediments: black sandy siltstone (with thin sandstone interbeds).
Paleoenvironment: Lower bathyal zone under anaerobic conditions and influenced by sluggish bottom currents.

8) Type h
Biofacies: *Globobulimina auriculata-Uvigerina proboscidea* biofacies.
Predominant species: *Globobulimina auriculata.*
Subodrinate species: *Cibicides aknerianus, Globobulimina pupoides, Uvigerina proboscidea.*
Sample and Formation: YOG01, YOG03, YOG06, AIM02 (Iitomi F.)
Sediments: black sandy siltstone.
Paleoenvironment: Middle bathyal zone under anaerobic conditions.
Remarks: This biofacies resembles the present-day *Globobulimina auriculata* assemblage off Ito, on the east coast of Izu Peninsula.

9) Type i
Biofacies: *Ammonia ketienziensis-Ammonia takanabensis* biofacies.
Predominant species: *Ammonia ketienziensis*
Subordinate species: *Ammonia takanabensis, Cibicides aknerianus, Globobulimina pacifica* and *Sigmoilopsis schlumbergeri*
Sample and Formation: YOG09, YOG10, YOG12, YOG13, YOG16 (Akebono Formation).
Sediments: sandy silt (with thin sandstone interbeds).
Paleoenvironment: Outer sublittoral to upper bathyal zone under anaerobic conditions.
Remarks: This biofacies closely resembles the EN-I biofacies recognized off the mouth of the River Tenryugawa. The P/T ratio in the Type i assemblage is as low as that of the Recent biofacies.

Three biofacies, namely the *R. abyssorum, G. auriculata U. proboscidea* and *A. ketienziensis-A. takanabensis* biofacies, are recognized in modern seas under comparable environments off southwest Japan. The remaining six biofacies are commonly distributed in the Neogene sequence, but are not known in Recent samples. The relationships between these nine biofacies and corresponding paleoenvironmental factors are drawn in Fig. 47.

The conclusions are as follows:

1) Paleobathymetry was becoming shallower as time progresses. For example, the Kanzaka to Deguchi Formations were deposited in the abyssal zone, and the Byobu-iwa and Hara Formations were deposited in the lower bathyal zone. In YOG route, the Iitomi Formation accumulated in the middle bathyal zone, and the Akebono Formation in the outer sublittoral to upper bathyal zone.

2) The same bathymetrical trends are also recognized through the Shizukawa Group exposed in FUJ, NAN and AIM routes. The P/T and A/T ratios suggest that the lower part of the Shimobe Formation was deposited below the CCD, the Minobu Formation and the lower and upper parts of the Iitomi Formation in the lower bathyal zone, and the middle part of the Iitomi Formation in the middle bathyal zone.

3) The above paleobathymetrical reconstructions are also supported by the southward-flowing paleocurrent direction reconstructed between Horizons 3 and 4 (Chapter 7), as well as that in the Akebono Formation reported by Matsuda (1958).

4) Anaerobic conditions occurred intermittently during the depositional time of the Deguchi, Iitomi and Akebono Formations.

5) Furthermore, an assemblage com-

posed mostly of *Globobulimina auriculata*, which is similar to Type h recognized in the Iitomi Formation, is distributed in the present sea off Ito on the Izu Peninsula (Dr. H. Nishi of Yamagata University, personal communication.). This site is located in the middle bathyal zone (*ca.* 1,500 m) where bottom sediments are dark green in color with hydrogen sulfide odor. This fact supports the interpretation of the 4th principal components and Type h sample group.

6) The influence of bottom currents is recognized mostly in the Byobu-iwa Formation which yields *Globorotalia rikuchuensis* in abundance.

3. FAUNAL STRUCTURE

Benthic foraminiferal diversity and equitability are expressed by the Shannon-Wiener information function, somewhat revised by Buzas and Gibson (1969). These two parameters are given in the following formulae:

$$H(s) = -\sum_{i=1}^{S} p_i \ln p_i, \text{ and } E = e^{H(s)}/S,$$

where p_i stands for the proportion of the ith species in a sample, and S the number of species. The latter equation equals the formulation, $H(s) = \ln(S \cdot E)$. By this formula, the relationships between the three parameters, namely diversity, equitability and number of species in a given sample can be directly depicted on a graph.

These three parameters of 54 samples are shown in Fig. 35. Figs. 36–39 show the paleobathymetry reconstructed from the 2nd and 5th principal components.

Figure 36 shows that benthic foraminiferal assemblages in the abyssal zone, indicated by a positive factor loading of the 2nd principal component, possess moderate values of diversity, equitability and the number of species. In addition, assemblages interpreted to have been deposited below the CCD have the lower number of species than the abyssal ones, though these two sets of assemblages have similar values of equitability.

On the contrary, Fig. 37 shows those assemblages in the lower bathyal zone, as expressed by a negative loading of the 2nd prdncipal components. According

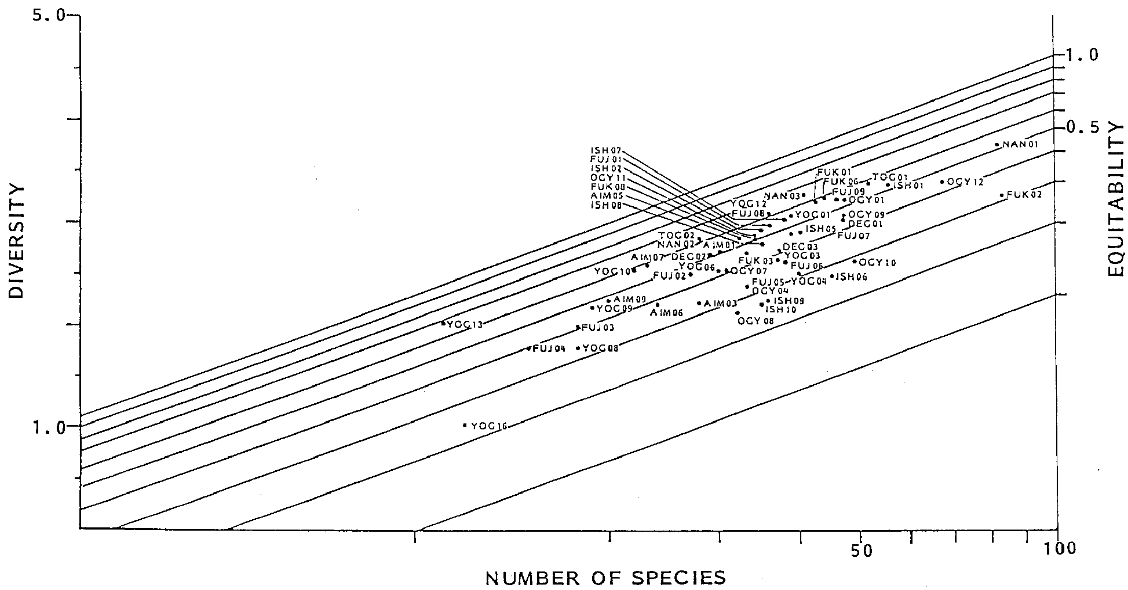


Fig. 35. Diagram showing species diversity, equitability, and number of species of benthic foraminifera in 54 samples from the Nishiyatsushiro and Shizukawa Groups.

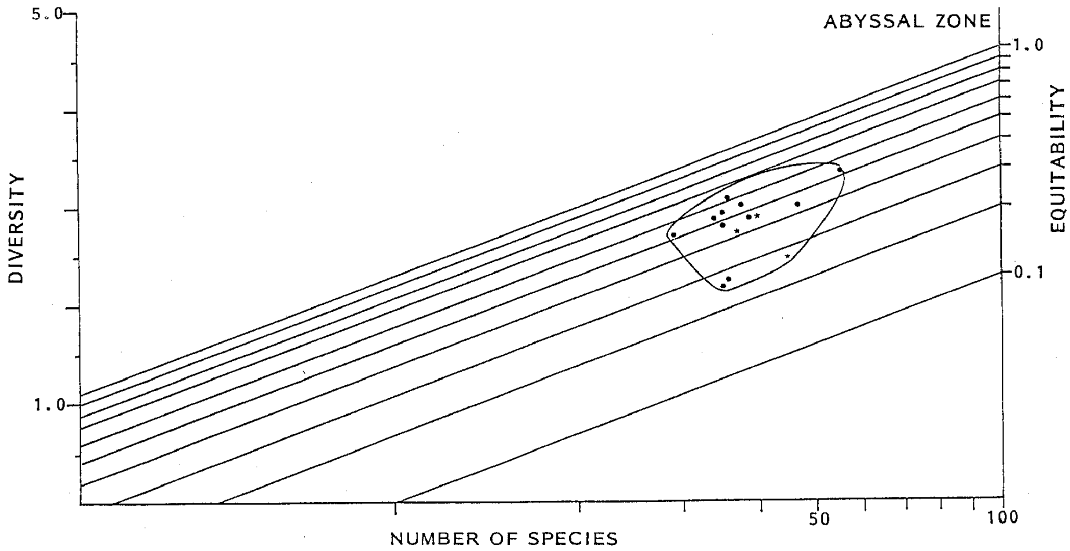


Fig. 36. Diagram showing species diversity, equitability, and number of species for 14 benthic foraminiferal assemblages of abyssal zone discriminated in the Nishiyatsushiro and Shizukawa Groups. Asterisks designate assemblages in anaerobic conditions.

to this figure, the points scatter over a rather wide area, ranging in the number of species from 20 to 80, but can be grouped into two crowds by using the species number of 60. The crowd which includes a larger number of species may represent a mixture of indigenous species and displaced ones from shallow water, as judged from the high frequencies of shallow water species (Table 3).

Those assemblages in the middle bathyal zone, represented by a negative

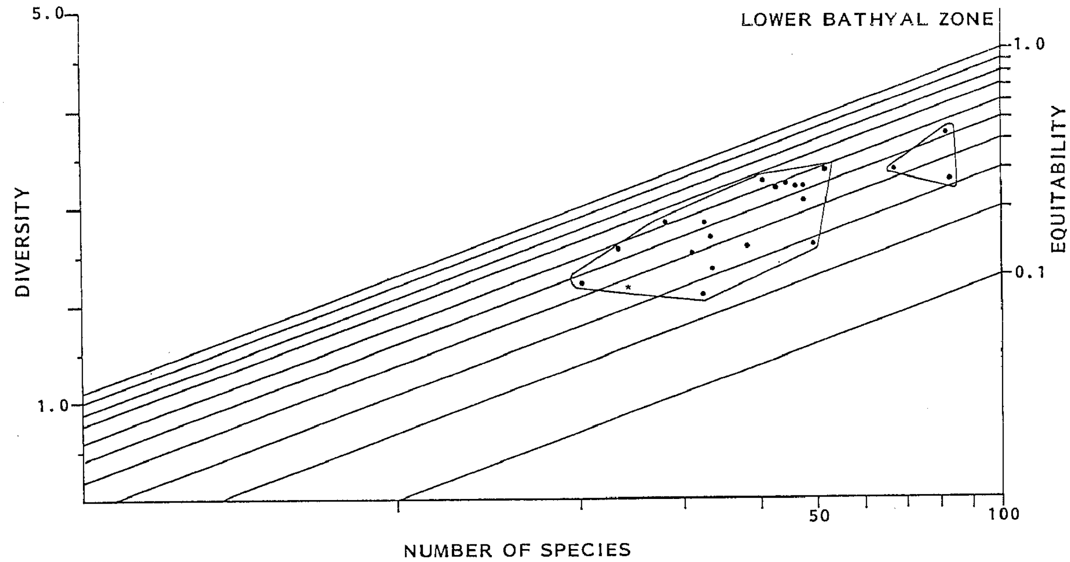


Fig. 37. Diagram showing species diversity, equitability and number of species for 21 benthic foraminiferal assemblages of lower bathyal zone discriminated in the studied area. Asterisks denote assemblages in anaerobic conditions.

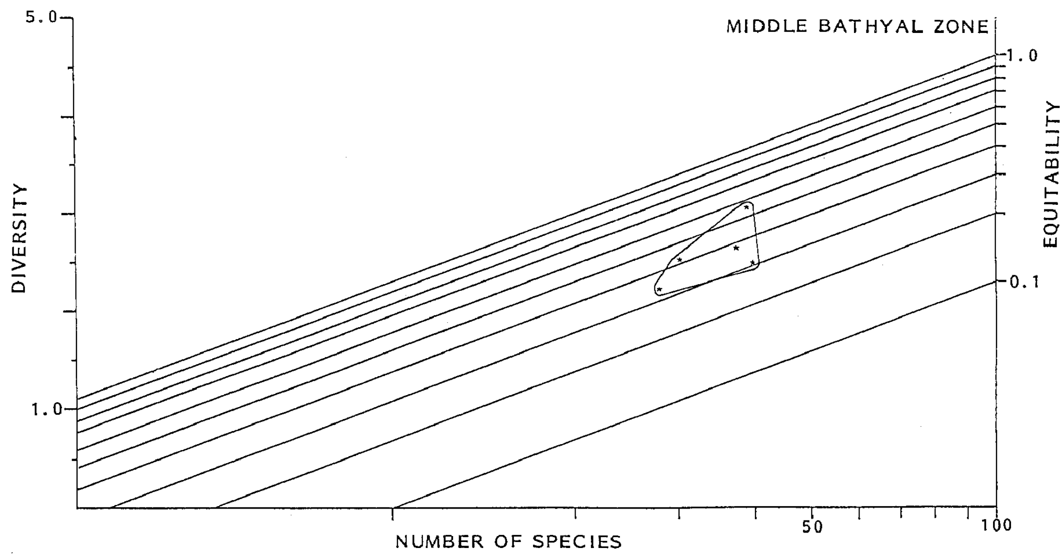


Fig. 38. Diagram showing species diversity, equitability, and number of species for five benthic foraminiferal assemblages of middle bathyal zone discriminated in the Iitomi Formation. Asterisks designate assemblages in anaerobic conditions.

loading of the 5th principal components, appear to be relatively concentrated (Fig. 38).

Those assemblages in the upper bathyal to outer sublittoral zone, marked off by a positive loading of the 5th principal components, consist of a rather small number of species (Fig. 39).

A comparison of assemblage structures between Recent and fossil species in the middle bathyal to abyssal zone shows compatibility of their values. Thus this result provides one supportive evidence of the paleobathymetry estimated on the

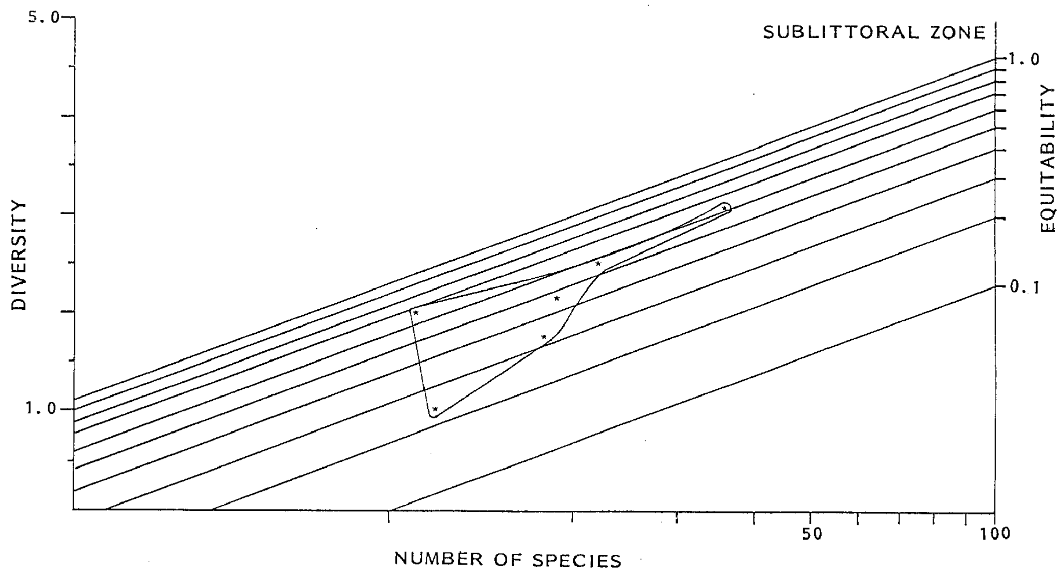


Fig. 39. Diagram showing species diversity, equitability, and number of species for six benthic foraminiferal assemblages discriminated in the Akebone Formation. Asterisks denote assemblages in anaerobic conditions.

basis of the 2nd and 5th principal components.

SEDIMENTOLOGICAL STUDY

In order to delineate the geological setting, developmental processes of sedimentary basins, and nature of paleosubstrates as the habitat of benthic foraminifers, direction of paleocurrents was determined with the aid of sole marks and other sedimentary structures; lithofacies were traced vertically as well as horizontally in the field; and mud contents, kinds of grains present, rock colors and microstructures were examined in the laboratory.

1. ANALYSIS OF FORAMINIFER-BEARING ROCKS

All rock samples used for sedimentological analyses are the same as those subjected to benthic foraminiferal analyses. Polished surfaces of natural rock samples were observed under a binocular microscope. Such analyses yielded four kinds of data sets: mud contents, kinds of grains, rock colors, and microstructures in rock samples.

Mud contents were estimated by determining percentages of dry weight of particles smaller than 0.074 mm in diameter relative to that of a treated rock sample. The mud contents are more than 80% in most samples except for the lower part of the Akebono Formation developed south of the study area (AIM09) (Fig. 40).

Besides picking up fossil foraminifera, the occurrence of selected biogenous grains and minerals of larger than 0.125 mm in diameter were examined under a microscope. These selected grains comprise such organic remains as diatoms, radiolarians, fecal pellets and plant fragments, and framboidal pyrite.

Radiolarian remains amount more than 10^3/g in the Deguchi (DEG01, DEG02, DEG03), Byobu-iwa (FUK01, FUK02, FUK03, FUK06, FUK08), Iitomi (YOG03, YOG04, YOG06), and Shimobe Formations (FUJ01, FUJ06), and occur less abundantly (more than 10^2/g) in the Byobu-iwa (OGY01), Hara (OGY12), Akebono (YOG16), Shimobe (FUJ05) and Minobu Formations (NAN03) (Fig. 41).

Samples such as DEG02 (Deguchi Formation), FUK06, FUK08 and OGY01 (Byobu-iwa Formation), and YOG06 (Iitomi Formation) are marked by a

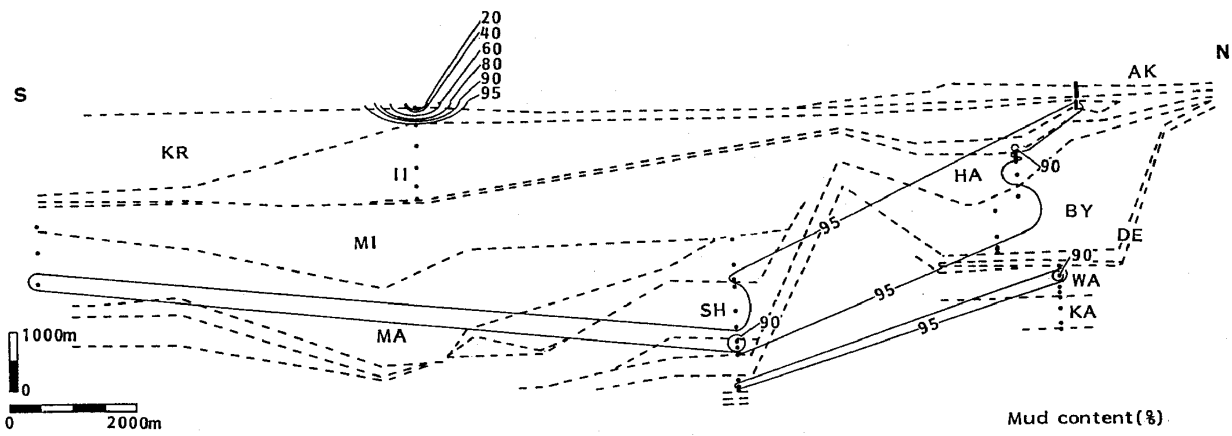


Fig. 40. Schematic cross section showing the distribution of mud contents in the Nishiyatsushiro and Shizukawa Groups (in %). Other captions are the same as those in Fig. 21.

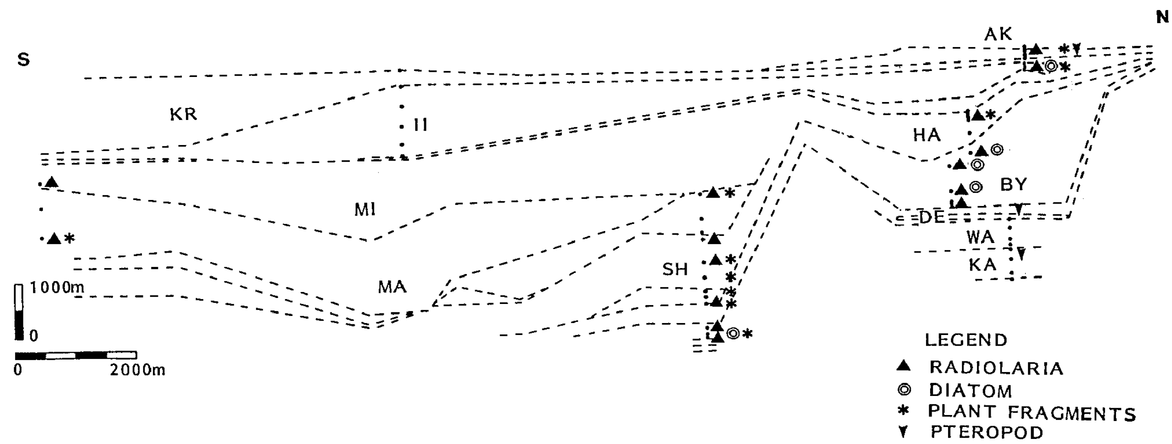


Fig. 41. Schematic cross section showing the distribution of radiolarians, diatoms, plant fragments and pteropods in the Nishiyatsushiro and Shizukawa Groups. Other captions are the same as those in Fig. 21.

rather common occurrence of diatoms amounting more than 10^2/g (Fig. 41).

Plant fragments occur in the Deguchi (DEG02), Hara (OGY08, OGY10, OGY11), Iitomi (YOG01, YOG03, YOG04, YOG06), Akebono (YOG09, YOG12, YOG13), Shimobe (FUJ01 to 05), and Minobu Formations (FUJ09, NAN01) (Fig. 41).

Fecal pellets (Fig. 45) occur only in the Hara Formation (OGY04, OGY07, OGY08 and OGY09).

The distribution of these grains are useful for recognizing paleogeography and sedimentary environment through a comparison with that in Recent sediments. For example, modern distributions show that radiolarians and diatoms are highly frequent in forearc basins (*e.g.* Kumano, Tosa and Shikoku basins) and the Nankai trough. Pellets are recognized in abundance at slope breaks on the continental slope and ocean floor. Plant fragments are distributed on the continental slope off Enshunada, Kumanonada, Tosa Bay and Nankai trough. No plant fragments are found around Tanegashima Island which has an area of 12 km × 55 km. Thus, the occurrence of these kinds of fragments from the strata may imply the existence of a sedimentary basin on the continental slope with a nearby large land area.

The Hara Formation is estimated to

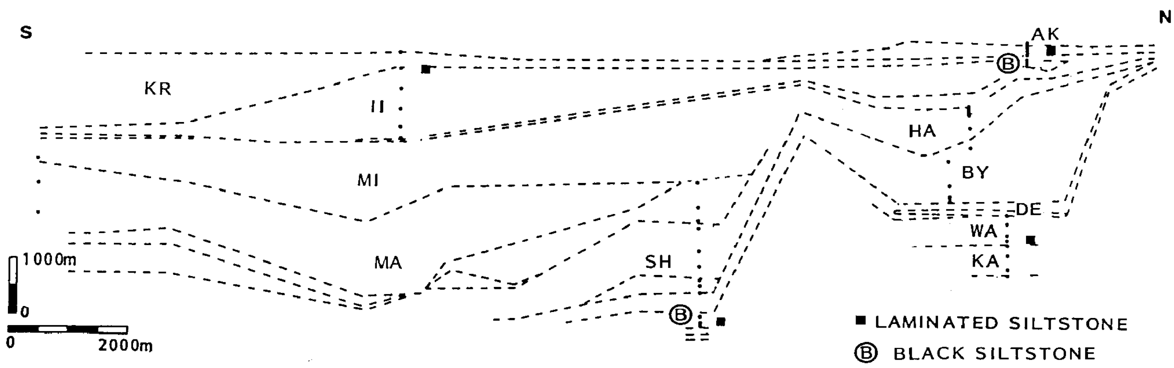


Fig. 42. Schematic cross section showing the distribution of laminated siltstone and black siltstone in the Nishiyatsushiro and Shizukawa Groups. Other captions are the same as those in Fig. 21.

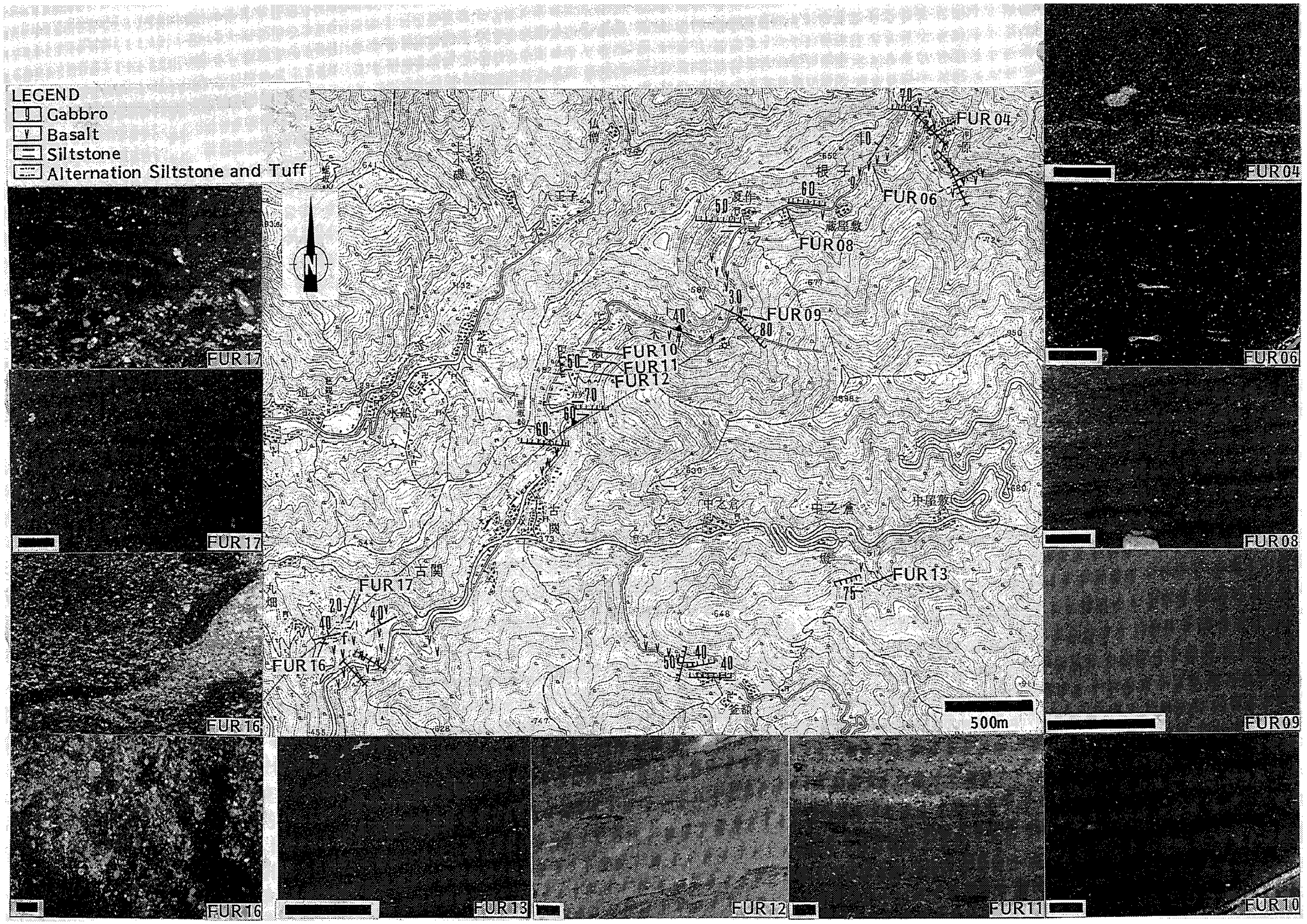


Fig. 43. Sedimentary structures in mudstones in the Misaka Group. Scale bars represent 0.5 mm unless noted otherwise. (Quadrangle "Shoji", 1 : 25,000-scale topographic map of Japan, Geographical Survey Institute).

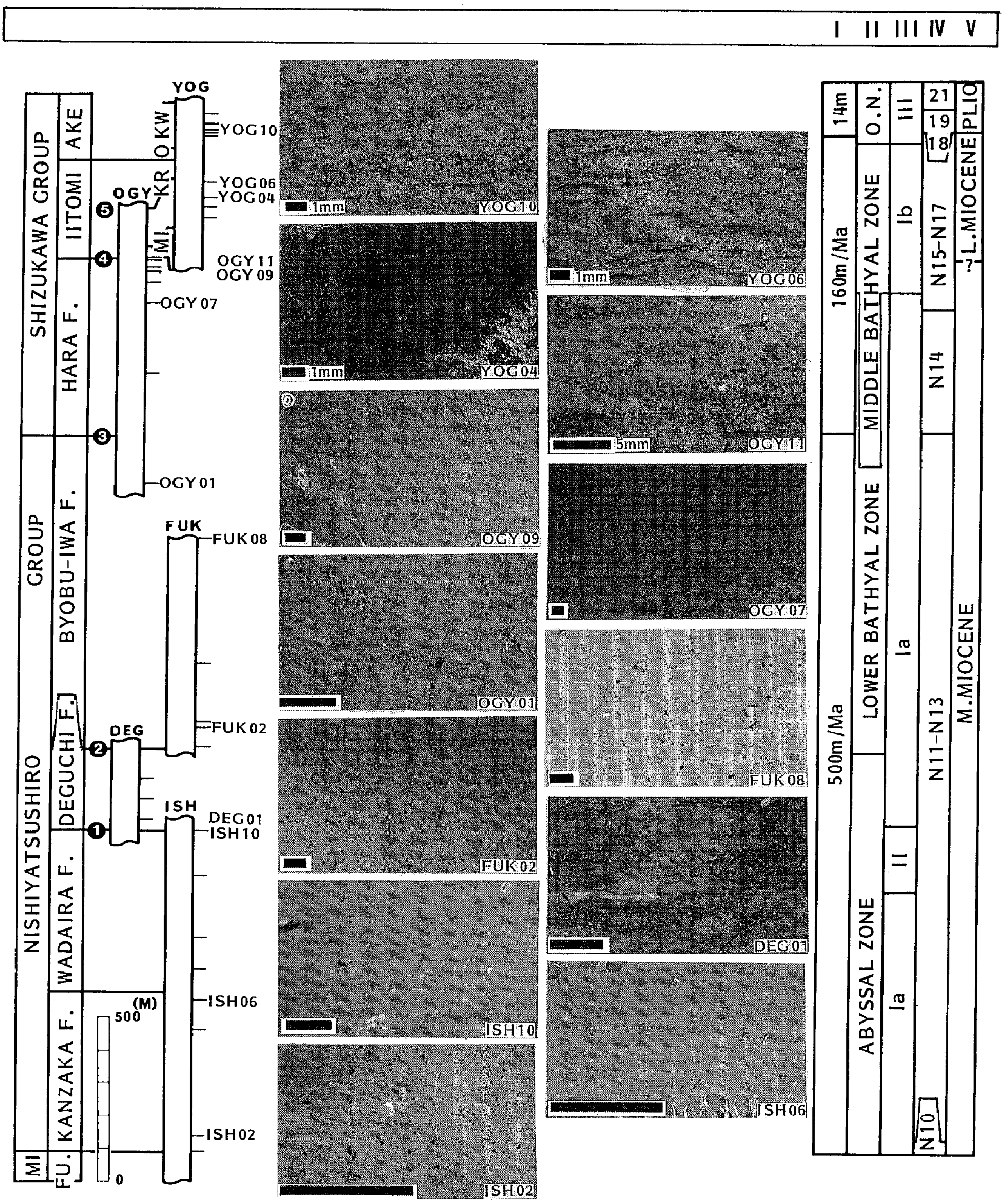


Fig. 44. Sedimentary structures in mudstones in the Nishiyatsushiro and Shizukawa Groups. Scale bars represent 0.5 mm unless noted otherwise. Sedimentation rates (column I) based on radiometric ages, and planktonic foraminiferal and radiolarian datum planes (Tsuchi, 1981, 1983; Kasuya, 1987), paleobathymetric interpretation (column II), results from cluster analysis (column III) employing selected species shown in Table 4, Blow's zone numbers (column IV) and age determination (column V) based on Fig. 16.

Table 9. Occurrence of benthic foraminifera in the Furuseki (FUR) and Toshiro (TOS) sections. Ni: Nishiyatsushiro Group, Furuseki: Furusekigawa Formation, Ka: Kanzaka Formation.

FORMATION	SAMPLE	ROCK COLOR	MICROSTRUCTURE
Furuseki-gawa	FUR02	Greenish black (5GY2/1)	faintly laminated siltstone with foraminifers replaced by calcite
	FUR04	Grayish black(N2)	finely parallel-laminated shale with pyrite grains (pyrite matrix supported)
	FUR06	Grayish black(N2)	faintly laminated siltstone with deformed agglutinated foraminifers
	FUR09	Dusky brown (5YR2/2) :shale Grayish olive green (5GY3/2) :medium-grained sandstone	alternations of shale and medium-grained plagioclase sandstone. The shale is faintly laminated, not deformed, and contains detrital plagioclase grains and ferro-manganese micronodule, and intercalates layers of basaltic grains on a microscopic scale.
	FUR10	Grayish black(N2)	faintly laminated shale with pyrite grains (pyrite matrix supported)
	FUR11	Greenish black (5GY2/1)	thinly parallel laminated sandy shale with pyrite grains
	FUR12	Grayish black(N2)	faintly laminated shale with pyrite grains (pyrite matrix supported)
	FUR13	Greenish black (5GY2/1)	well laminated sandy siltstone

	TOS01	Grayish black(N2)	bioturbated shale with radiolarians replaced by pyrite
Kanzaka	FUR16	Grayish black(N2)	intensely bioturbated sandy shale with pyrite grains
	FUR17	Grayish black(N2)	weakly bioturbated sandy shale with pyrite grains and foraminifers
	ISH02	Grayish olive (10Y4/2)	sandy siltstone containing greenish grains and carbonaceous matter
Wadaira	ISH06	Olive gray (5Y3/2)	faintly laminated tuffaceous mudstone containing carbonaceous matter
Deguchi	ISH10	Olive gray (5Y3/2)	bioturbated sandy siltstone with foraminiferal tests and pumice
	DEG01	Olive gray (5Y3/2)	faintly laminated, but bioturbated in part, siltstone
	DEG03	Brownish black (5YR2/1)	faintly laminated pumice bearing siltstone
Byobu-iwa	FUK02	Moderate olive brown (5Y4/4)	faintly laminated siltstone with pyrite layers
	FUK08	Moderate olive brown (5Y4/4)	faintly laminated tuffaceous siltstone with pyrite grains
	OGY01	Grayish olive (10Y4/4)	faintly laminated tuffaceous sandy siltstone with foraminifer -bearing sand
Hara	OGY07	Olive gray (5Y3/2)	faintly laminated sandy siltstone containing carbonaceous matter

	OGY09	Olive gray (5Y3/2)	faintly bioturbated sandy siltstone containing carbonaceous matter
	OGY11	Greenish olive gray (5GY3/2)	bioturbated sandy siltstone containing greenish grains (chert?) and reddish grains (scoria?)
Iitomi	YOG04	Greenish black (5G2/1)	bioturbated siltstone
	YOG06	Grayish olive green (5GY3/1)	bioturbated silty sandstone containing carbonaceous matter, pyrite grains, and dehydration structure
Akebono	YOG16	Olive gray (5Y4/1)	bioturbated partly laminated tuffaceous silty sandstone containing carbonaceous matter and pyrite grains

have been deposited under sluggish bottom currents judged from the occurrence of pellets. Okamura (1986) reported a relationship between fecal pellets and the velocity of bottom currents, indicating velocities over 4 cm/min. for pellet transport.

The mudstone of the Misaka, Nishiyatsushiro and Shizukawa Groups shows various features in the field. A great variety of sedimentary microstructures is also observed in a small block sample prepared in the laboratory : Such microstructures were observed through a binocular microscope with $\times 25$ magnification, and photographs of examined samples are shown in Figs. 43 and 44. The colors of rock samples are classified into several groups. Rock colors were determined on a polished surface by using a rock-color chart issued by the U. S. Geological Survey (Table 9).

The results are summarized as follows :

a. Lamination which is developed in the Misaka, Nishiyatsushiro and Shizukawa Groups is grouped into three types.

1) Parallel lamination is recognized in samples from the Misaka Group. The lamination is often highlighted by concentrations of plagioclase and basalt fragments. This structure is rarely seen in samples from the Nishiyatsushiro and Shizukawa Groups, which consist of coarser clastic grains.

2) Wave lamination is present only in one sample from the Misaka Group (FUR 13).

3) A faint lamination is seen in several samples from the Nishiyatsushiro and Shizukawa Groups.

b. Bioturbation is abundant in the Nishiyatsushiro and Shizukawa Groups. Sand-filled burrows and irregular sand patches are developed in mudstone of the Nishiyatsushiro and Shizukawa Groups, but none is observable in such a mudstone bed of the Misaka Group.

c. The size and nature of grains contained in the mudstone of the Misaka Group are distinct from those in two other groups.

1) Samples from the Misaka Group consist of grains smaller than those from the Nishiyatsushiro and Shizukawa Groups.

2) Grains of the Misaka Group are made of plagioclase, basalt fragments and black clastic grains.

3) Grains of the Nishiyatsushiro and Shizukawa Groups are quartz, acidic volcanic glass, biotite and plant fragments.

d. Pyrite grains are recognized in most samples from the Nishiyatsushiro and Shizukawa Groups. They are mostly irregular aggregates or are arranged as laminae in the matrix. Such a mode of occurrence may suggest that they were not authigenic but were derived.

e. Sedimentary rock colors

1) The mudstones of the Misaka Group are colored in black except for sample FUR09 which exhibits a reddish hue. This sample also contains ferromanganese micro-nodules, which are abundant on the deep sea floor today. Thus it may be an early Middle Miocene red clay of deep sea origin.

2) The mudstone of the Nishiyatsushiro and Shizukawa Groups is colored in greenish to olive gray, except for samples DEG03 and YOG4, which are black.

f. Dehydration structures are recognized only in the Iitomi Formation (YOG06).

2. LITHOFACIES AND SEDIMENTATION RATES

The Misaka Group consists mainly of basaltic rocks and siltstone. These basaltic rocks are essentially aggregates of fragments of non-vesicular tholeiite basalt (Matsuda, 1958). The basalt was affected by a low-grade metamorphism giving rise to a zeolite to prehnite-pumpellyite facies, which is observable sporadically in the Furuseki area (Shimazu *et al.*, 1976). Some blocks of pillow lava were displaced into siltstone beds.

The siltstone beds are usually less than 4 m thick and are often intercalated with thin layers consisting of coarse-grained basaltic fragments and automorphic plagioclase with carlsbad twin.

On the contrary, the Nishiyatsushiro and Shizukawa Groups are characterized by 1) mostly turbidite sequences, 2) dish structure in sandstone, and 3) absence of such oceanic materials as tholeiite and sediments comparable to pelagic calcareous oozes. Fine-grained rocks of these two groups are all very fine-grained sandstone (Fig. 45). This sandstone sequence frequently intercalates terrigenous, bioturbated sandstone layers composed of silicic tuff, lithic fragments, and quartz grains.

Figure 18 shows sedimentation rates of Neogene sequences calculated by using the planktonic foraminiferal datum planes of Oda *et al.* (1987) and of the present study (Chapter 5). By correlating these datum planes with those of other planktonic groups, magnetic epochs and radiometric ages (Tsuchi and Working Group for Japanese Neogene Bio- and Chronostratigraphy, 1981 ; Tsuchi, 1983 ; Oda, 1986, 1987), radiometric ages of 14.0 Ma, 11.6 Ma, 5.8 Ma and 5.4 Ma are assigned to the first appearance of *Globorotalia fohsi praefohsi*, *Globigerina nepenthes*, *Pulleniatina primalis* and *Globorotalia tumida*, respectively.

The boundary between the *Calocycletta costata* Zone and the *Dorcadospyris alata* Zone is coeval with the first appearance datum of *Orbulina* spp. (Oda, *op cit.*), which is estimated to be 14.5 Ma by Tsuchi (1983) based on the K-Ar dating method (Shibata *et al*, 1976).

The first appearance datum of *Globorotalia rikuchuensis* is recognized mid-

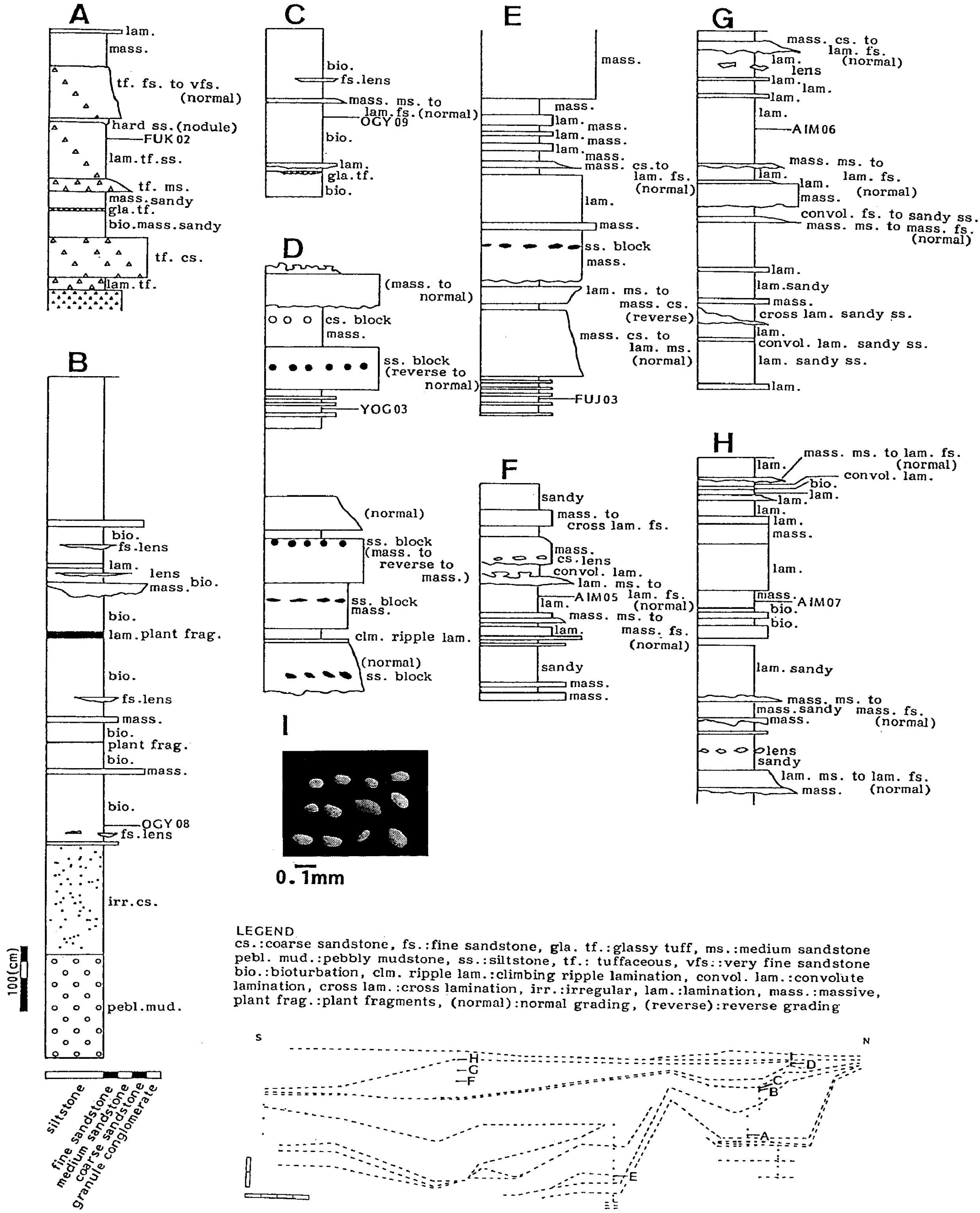


Fig. 45. Measured sections showing sedimentary facies as horizons (locations are given in schematic cross section at the bottom) selected by means of principal components factor loadings. Horizontal scale represents grain size, and vertical scale 100 cm except for I. Fecal pellets (shown in I) occur at point OGY09 of the Hara Formation. Scale bar represents 0.1 mm.

way between the Kitamura tuff and the Baba tuff in the Haraichi Formation in the Takasaki area (Takayanagi *et al*., 1978). Kasuya (1987) reported fission-track ages of these tuff layers to be 13.0 ± 0.7 Ma and 11.4 ± 0.5 Ma, respectively. In the present study, the age of the first appearance of *Globorotalia rikuchuensis* is estimated to be 12.2 Ma, assuming that sedimentation rates are constant between these two tuff layers.

The above-mentioned radiometric ages lead to an estimation of sedimentation rates as shown in Fig. 18. Southward increasing sedimentation rates can be clearly seen in the Shizukawa Group (Fig. 6). The thickness of the Shimobe and Minobu Formations in the south are four times as great as that of the Hara Formation in the north, all of which were formed between Horizons 3 and 4 of the key tuff beds. The same trend is recognized in the Iitomi Formation which is two and half times thicker in the south. The sedimentation rates are thus estimated at 480 m/Ma between Horizons 3 and 4, and 400 m/Ma between 4 and 5 in the south of the studied area.

The Nishiyatsushiro Group is in a sharp contrast to the Shizukawa Group in terms of the sedimentation rate: upward increasing rates are evident in the former, and upward decreasing ones in the latter. Such differences are reflected in the frequency of intercalated sandstone layers.

Sedimentation rates in the Fujikawa area are compared with those in the Recent ocean. Sedimentological studies based on seismic profiles of modern ocean floors show that thick sediments accumulate in the forearc basins. However, it is difficult to carry out a comparative study of sedimentation rates between the present and geologic times, because of the lack of reliable sedimentation rate data in the Recent forearc basins.

According to seismic profiles of the Tosa Basin (Okamura and Joshima, 1986; Okamura *et al*., 1987), sediments called the Tosawan Group, are about 1,500 m thick, and the bottom of the sequence is determined to be Pleistocene in age because of the occurrence of *Globorotalia truncatulinoides*. The radiometric age of the *Grt. truncatulinoides* Datum is estimated at about 1.9 Ma (Saito, 1984). Accordingly, a sedimentation rate may be calculated at 830 m/Ma at least. This value is not only comparable with the estimated rates for the Nishiyatsushiro and Shizukawa Groups, but is also suggestive of a similar geological setting of these groups.

3. PALEOCURRENTS

Three main paleocurrent directions are recognized in the Nishiyatsushiro and Shizukawa Groups on the basis of sole marks as shown in Fig. 46.

The first is an eastward direction recognized in the Kanzaka and Byobu-iwa Formations, and in the upper part of the Iitomi Formation, exposed in the Aimata area. This direction is consistent with that measured mainly on the basis of flute casts accompanying crescent casts on sandstone beds and parting lineation of white tuff beds.

The second is southward as determined from flute casts, and less common groove casts and prod marks. This direction is recognized in the Hara, Shimobe, Minobu Formations, and in the uppermost part of the Iitomi Formation, exposed in the Aimata area.

The last one is westward transport which is recognized by flute casts and prod marks in the Minobu Formation and in the lower part of the Iitomi Formation.

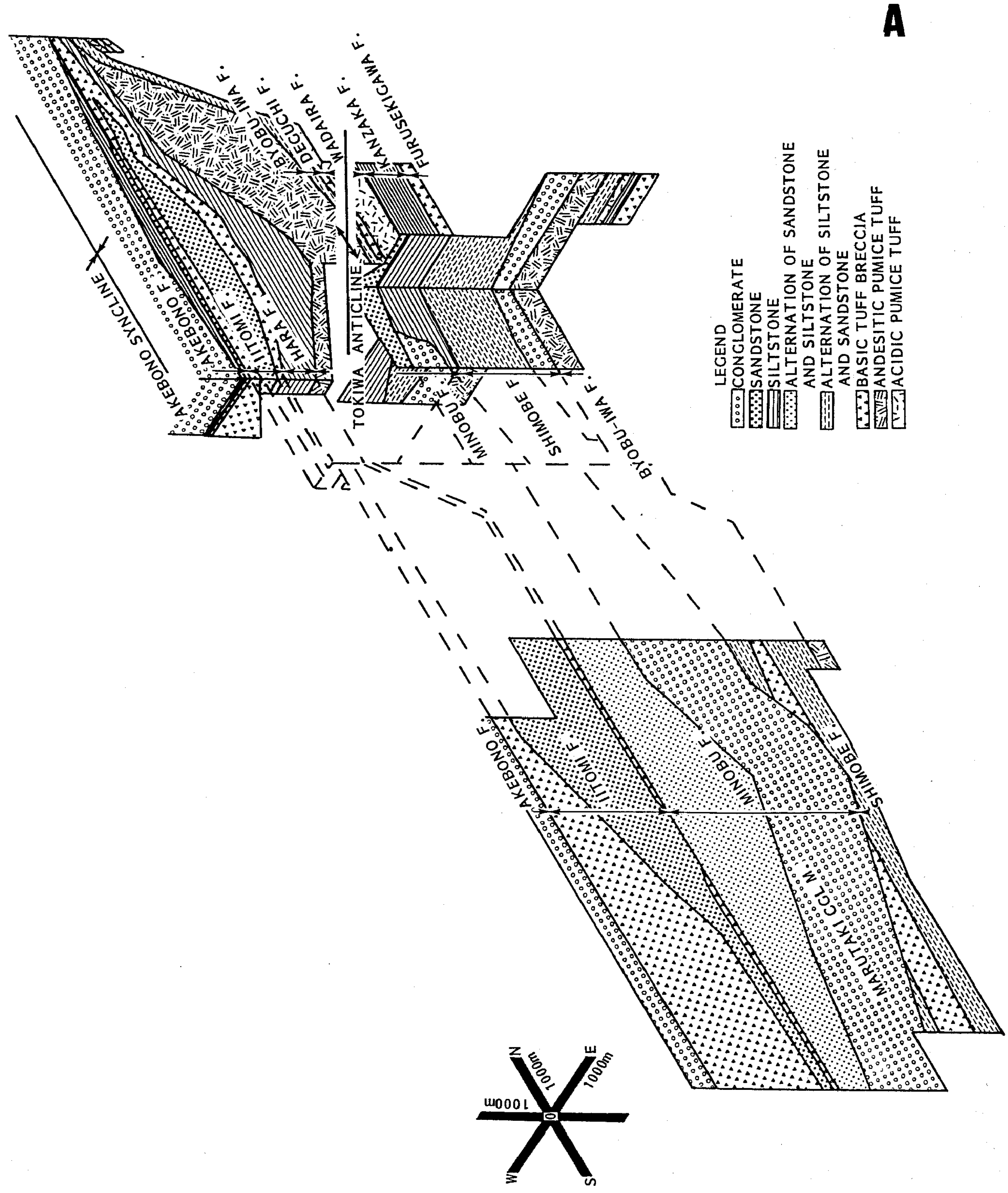


Fig. 46. Panel diagram showing the relationship of each formation composing the Nishiyatsushiro and Shizukawa Groups (A) with paleocurrent directions determined by various sole marks represented in Fig. 5(B).

B

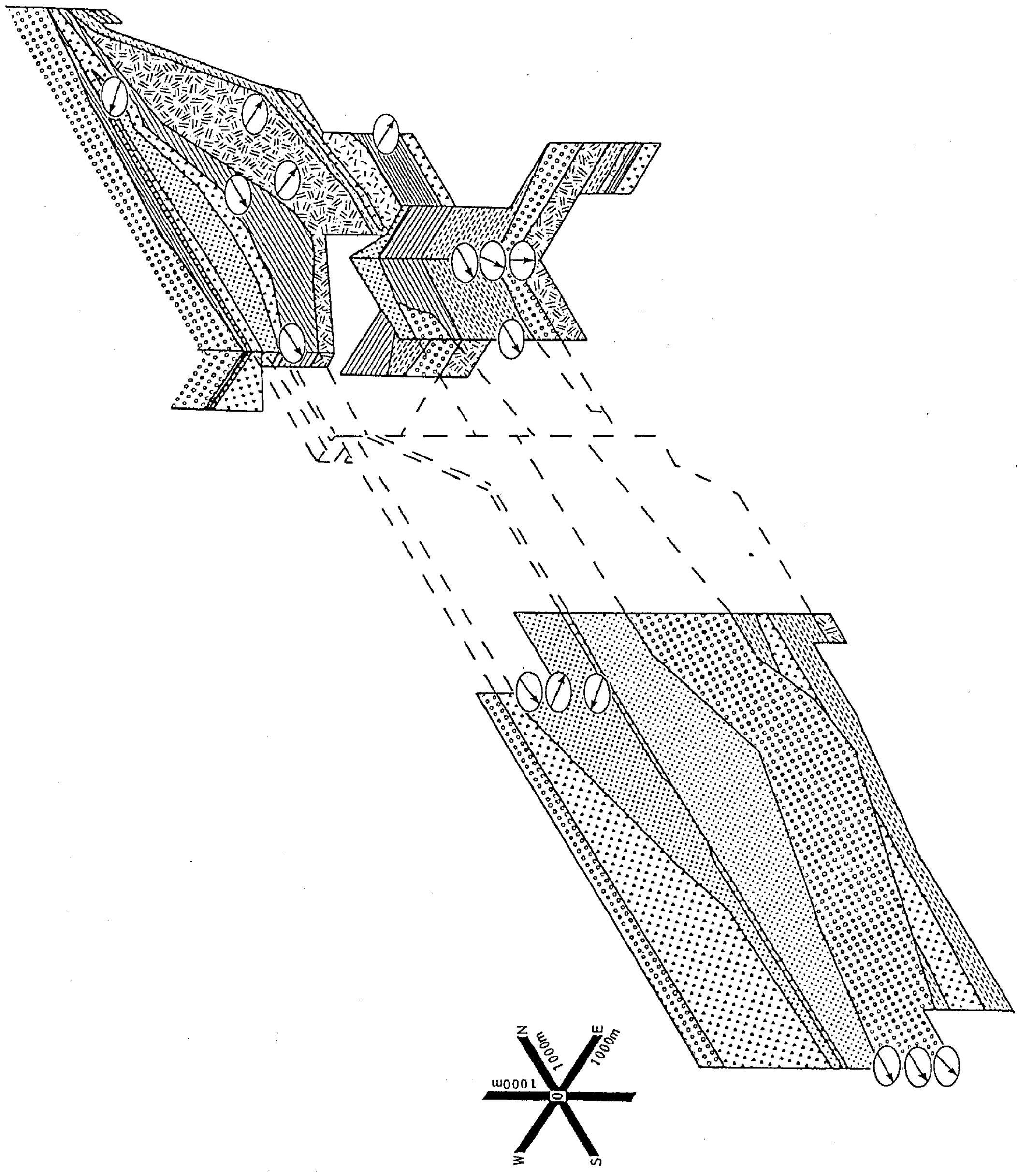


Fig. 46 (continued)

DISCUSSION

1. PALEOBATHYMETRICAL MODELS

Generalized physical, microfaunal, and sedimentological trends across a schematic island arc-trench-ocean floor setting are shown in Fig. 47, incorporating data on major lithologic and microfaunal features which are delineated from the Neogene sequences in the Fujikawa area. A shift in these identified paleoenvironments implies a significant variation of major physical parameters associated with a stratified nature of the water column, and provides basic criteria for understanding the Neogene paleobathymetric and depositional history.

Nine types of paleoenvironments are deduced by interpretating the principal components, sedimentological properties, and ecological data on modern benthic foraminifera. Each paleoenvironmental

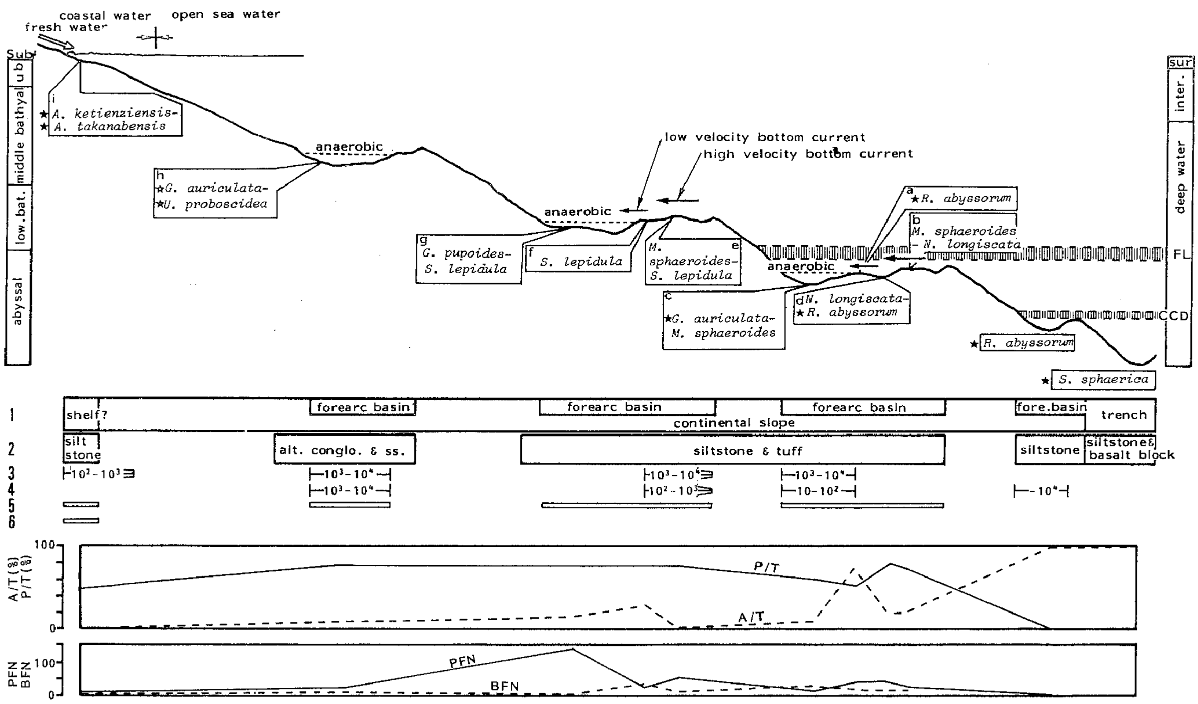


Fig. 47. Significant microfaunal and sedimentologic trends across a schematic littoral to abyssal bathymetric gradient along with associated major physical oceanographic boundaries on the basis of the Recent foraminiferal data off southwest Japan. Foraminiferal trends are based on their Neogene distributional pattern and abundances. Abbreviations: sub, sublittoral zone; ub, upper bathyal zone; low. bat, lower bathyal zone; sur, surface water; inter, intermediate water, FL, foraminiferal lysocline; alt, alternation; conglo, conglomerate; ss, sandstone. A. ketienziensis, *Ammonia ketienziensis*; A. takanabensis, *Ammonia takanabensis*; G. auriculata, *Globobulimina auriculata*; G. pupoides, *Globobulimina pupoides*; M. sphaeroides, *Melonis sphaeroides*; N. longiscata, *Nodosaria longiscata*; R. abyssorum, *Rhabdammina abyssorum*; S. sphaerica, *Saccammina sphaerica*; S. lepidula, *Stilostomella lepidula*; U. proboscidea, *Uvigerina proboscidea*. Numerals: 1, paleotopography; 2, lithofacies; 3, abundance of radiolarians (individuals/g); 4, abundance of diatoms (individuals/g); 5, plants fragments; 6. pteropods. PFN and BFN represent planktonic foraminiferal number and benthic foraminiferal number, respectively.

type is associated with a particular benthic foraminiferal biofacies. Among these, three biofacies, *Rhabdammina abyssorum* biofacies, *Globobulimina auriculata-Uvigerina proboscidea* biofacies, and *Ammonia ketienziensis-Ammonia takanabensis* biofacies, are also recognized today in areas under similar environmental conditions.

However, the remaining six biofacies have not been discovered in the present-day Pacific off southwest Japan. Therefore, it is necessary to assess paleoenvironmental factors which controlled the distribution of fossil species.

Firstly, *Stilostomella lepidula* is characterized by a negative high score of the 2nd principal component. This principal component is related to the foraminiferal lysocline and thus should reflect environment of the lower bathyal zone. Woodruff (1985) also reported that some *Stilostomella* species belong to the "intermediate water assemblage". The distribution of this species was not affected by dissolved oxygen in waters or bottom water currents.

Secondly, *Melonis sphaeroides* has a negative high score of the 3rd principal component. This principal component indicates the influence of bottom water currents, as recognized by sedimentary structures. This species was distributed in an area under rather swift bottom water currents. *Rhabdammina abyssorum*, *Melonis parkerae*, *Trochammina globigeriniformis* and *Oridorsalis tener* occur in samples marked by a positive factor loading of the 3rd principal component. Thus these species were distributed in an area under rather sluggish bottom water currents.

Thirdly, *Nodosaria longiscata* is marked by a negative high score of the 4th principal component, which correlates with the dissolved oxygen. This species may have prevailed in aerobic conditions, and samples which have high positive factor loadings of this component may have been deposited under anaerobic conditions. On the contrary, *Globobulimina auriculata*, *Ammonia ketienziensis* and *Ammonia takanabensis* occur in samples with high positive factor loadings of the 4th principal component. In modern seas off California, Ingle (1980) suggested that *Globobulimina pacifica* may tolerate low-oxygen conditions, and other authors mentioned that *Globobulimina* frequently occurs in water with oxygen content of <0.2 ml/l. In addition, Mullineaux and Lohmann (1981) reported the occurrence of *Globobulimina affinis* in sapropels and suggested that *Globobulimina* is tolerant of low-oxygen conditions. These reports support the author's estimation of paleoenvironments.

The depth distribution of *Melonis sphaeroides* and *Nodosaria longiscata* is not related to any particular paleoenvironment as deduced from the principal component analysis. However, these two species occur in associatien with species which are distributed today in the lower bathyal to abyssal zone, and thus may indicate such an environment. In addition, Morkhoven *et al.* (1986) reported the occurrence of *M. sphaeroides* in the lower bathyal zone.

The above discussion leads to the following relationships between the fossil benthic foraminiferal species and paleoenvironments.

1) Deep water species (abyssal zone):
   Melonis sphaeroides
   Nodosaria longiscata
   Rhabdammina abyssorum
2) Deep water species (lower bathyal zone):
   Melonis sphaeroides
   Nodosaria longiscata
   Stilostomella lepidula
3) Deep water species (middle bathyal zone):
   Uvigerina proboscidea

4) Coastal water species (sublittoral to upper bathyal zone):
Ammonia ketienziensis
Ammonia takanabensis

The paleobathymetrical estimation for each of the above-mentioned species is also supported by faunal structures.

5) Offshore water species:
Uvigerina proboscidea
6) Anaerobic species:
Globobulimina auriculata
7) Aerobic species:
Nodosaria longiscata
8) High velocity bottom water current species:
Melonis sphaeroides
9) Low velocity bottom water current species:
Melonis parkerae
Oridorsalis tener
Rhabdammina abyssorum
Trochammina globigeriniformis

The relationship between these nine types of paleoenvironments and their correlative biofacies are shown in Fig. 47. This figure shows that differences between the ancient and modern biofacies are recognized in the lower bathyal zone.

Konda (1980) established four benthic foraminiferal zones which are used to estimate paleobathymetry of the Nishiyatsushiro Group. He concluded that this group was deposited in the middle bathyal zone with no indication of appreciable changes of environment throughout the sequence. Stratigraphical changes in species frequencies in the four zones are not shown in his figure (Konda, 1980, Fig. 11). These four zones are largely characterized by *Melonis pompilioides, Ammodiscus incertus, Globobulimina auriculata, Melonis nicobarensis, Nodosaria longiscata*, and *Stilostomella ketienziensis*. On the contrary, the present author noticed that the Nishiyatsushiro Group is distinguished by abundant occurrences of *Rhabdammina abyssorum* and *Melonis sphaeroides*. To the present author's knowledge of Recent benthic foraminifera, the former is distributed in the abyssal zone today (Akimoto, 1990), and the latter in the lower bathyal zone (Morkhoven *et al.*, 1986). Thus, the Kanzaka, Wadaira and Deguchi Formations of this group are estimated to have deposited in the abyssal zone and the Byobu-iwa Formation in the lower bathyal zone. *Melonis pompilioides* and *Ammodiscus incertus*, which were used by Konda (*op cit.*) for his zonation, have been discovered in the lower bathyal zone (Morkhoven *et al.*, *op cit.*). Such a divergence of opinion in the estimation of paleobathymetry of the Nishiyatsushiro Group may be a reflection of currently increasing data on foraminiferal depth distributions which are in turn useful for paleobathymetric interpretation.

Kano *et al.* (1985) constructed paleogeography of the Shizukawa Group in the Nakatomi area by means of benthic foraminifera. They mentioned that this group represents a shallowing upward sequence which accumulated in a submarine trough in the middle to upper bathyal zone. The present author also estimates that the Hara Formation was deposited in the lower bathyal zone, the Iitomi Formation in the middle bathyal zone and the Akebono Formation in the upper bathyal to outer sublittoral zone.

2. GEOHISTORY AND RECONSTRUCTION OF TECTONIC SETTING OF THE SOUTH FOSSA-MAGNA REGION

a. Paleobathymetry, sedimentary environments and processes of basin development

The developmental process of various sedimentary basins in the Fujikawa area is reconstructed by means of geology, benthic foraminiferal paleontology and sedimentology.

The studied area is situated in the active continental margin along the

Pacific rim. In the active margin, thick sediments may accumlate in a forearc basin. For example, Mitchell and Reading (1986) referred to the thickness of forearc basin filling sediments. According to them, the thickness of sediments in the Recent forearc basin is 8 km in Western Trough of Burma, about 4 km off Sumatra, up to 5 km off NE Japan, and up to 10 km off Ecuador-Peru-Chile.

Furthermore, characteristics of the forearc basin filling sediment are generalized as follows: 1) "Sediments are derived from three sources: the outer arc, the magmatic arc and, in some cases, longitudinally from the adjacent continent. Clastic sedimentation predominates, with turbidites and other mass-flow deposits commonly passing up into deltaic and fluvial sediments." : 2) "The sediments include a high proportion of volcanically-derived ash and montmoril-

Table 10. Occurrence of benthic foraminifera in the Furuseki (FUR) and Toshiro (TOS) sections. Ni: Nishiyatsushiro Group, Furuseki: Furusekigawa Formation, Ka: Kanzaka Formation.

GROUP	MISAKA		NI.
FORMATION	FURUSEKI		KA.
SAMPLE NO.	TOS 01	FUR 12	FUR 17
SPECIES			
AGGLUTINATED FORAMINIFERA			
Alveolophragmium scitulum (Brady)	4	2	1
Ammodiscus sp.	1	1	1
Cribrostomoides subgrobosa (S. O. Sars)			11
Cyclammina cancellata Brady	13		1
C. orbicularis Brady		1	2
C. pusilla Brady			2
Haplophragmoides sp.		1	
Karreriella apicularis (Cushman)			1
Martinottiella communis (d'Orbigny)	9		5
Rhabdammina abyssorum M. Sars		5	107
R. abyssorum M. Sars forma A			5
Reophax pilulifer Brady	2		7
Saccammina sphaerica (M. Sars)	18		
Trochammina globigeriniformis (Parker and Jones)	19	5	17
Miscellaneous agglutinated foraminifera	28	8	9
CALCAREOUS FORAMINIFERA			
Bulimina rostrata Brady	1		
Cibicides wuellerstorfi (Schwager)			1
Globobulimina auriculata (Bailey)			1
G. pupoides (d'Orbigny)	1		
Gyroidina sp.			1
Melonis sphaeroides Volshinova		3	
Nodosaria longiscata (d'Orbigny)			3
N. tosta Schwager			1
Oridorsalis tener (Brady)			2
Pleurostomella alternans Schwager			6
Pullenia bulloides (d'Orbigny)			2
Sphaeroidina compacta Cushman and Todd			1
Stilostomella fistuca (Schwager)			3
S. lepidula (Schwager)			3
Tosaia hanzawai Takayanagi			1
Miscellaneous calcareous foraminifera	2	1	14
Total number of agglutinated foraminifera	90	21	168
Total number of calcareous foraminifera	4	4	39
Total number of benthic foraminifera	94	25	207
Agglutinated foraminifera /total benthic foraminifera (%)	96	84	81

lonitic clays, and turbidites which grade up into shallow water sediments." (Mitchell and Reading, 1986, p. 499).

Similar features in the thickness and lithology are recognized in the Nishiyatsushiro and Shizukawa Groups. In fact, these Neogene sediments, which amount to at least 4 km in thickness (maximum sedimentation rate 500 m/Ma), are predominated by clastic sediments with turbidites and other mass-flow deposits, include a high proportion of volcanically-derived ash, and represent a shallowing upward sequence; that is, below the CCD during deposition of the Kanzaka Formation (Middle Miocene), and the outer sublittional zone of the Akebono Formation (Pliocene). Therefore, the two groups represent a series of ancient forearc basin-filling sediments.

The Misaka Group consists of voluminous tholeiitic basalt accompanied by red clay and black siltstone interbeds. A K-Ar age of the tholeiite basalt is determined to be 34.1 Ma (Nishimiya and Ueda, 1976). On the contrary, the intercalated siltstone bed is biochronologically estimated to be *ca.* 15 Ma in this study. Such a discrepancy will be reconciled by assuming that this tholeiitic basalt is allochthonous blocks. The black siltstone intercalates thin layers consisting of coarse-grained basaltic fragments. These basaltic fragments are coincident with the allochthonous basalt blocks. The Misaka Group might therefore be deposited where the tholeiite basalt accumulated as blocks within the black siltstone. In addition, benthic foraminiferal data suggest that the siltstone was deposited below the CCD (Table 10).

Recently, an association of such allochthonous basalt blocks with terrigeneous mud have been detected in the Nankai Trough and the Japan Trench (Kaiko Project Phase II, 1987). A comparative study of the distribution of such associations in Recent and the geologic past suggests that the Misaka Group was deposited in a trench.

The ancient trench and forearc basin are named herein the Misaka paleotrench and the Nishiyatsushiro paleoforearc basin, respectively (Fig. 48).

The Nishiyatsushiro paleo-forearc basin was formed in a time period around the Early/Middle Miocene boundary (Fig. 19) in the Furuseki and Ichinose areas, where terrigenous clastic sediments were brought in from the Akaishi Massif continuously up to the time of deposition of the Akebono Formation. The Nishiyatsushiro and Shizukawa Groups were deposited in this basin until the Pliocene. The paleodepth of the

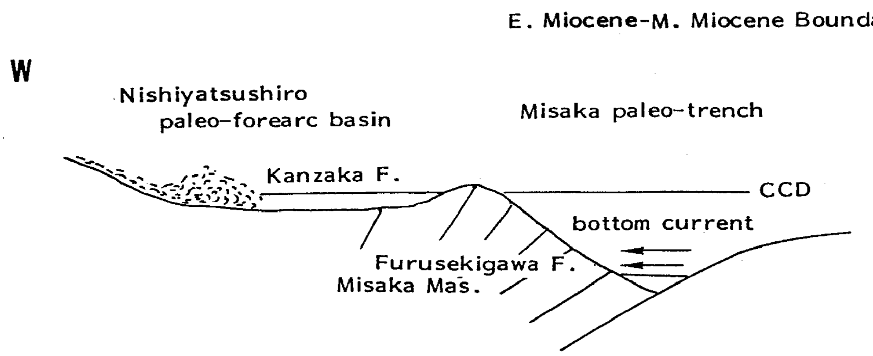


Fig. 48. A schematic paleoenvironment during deposition of both the Furusekigawa Formation and the basal part of Kanzaka Formation. Arrows do not indicate true directions of bottom water currents.

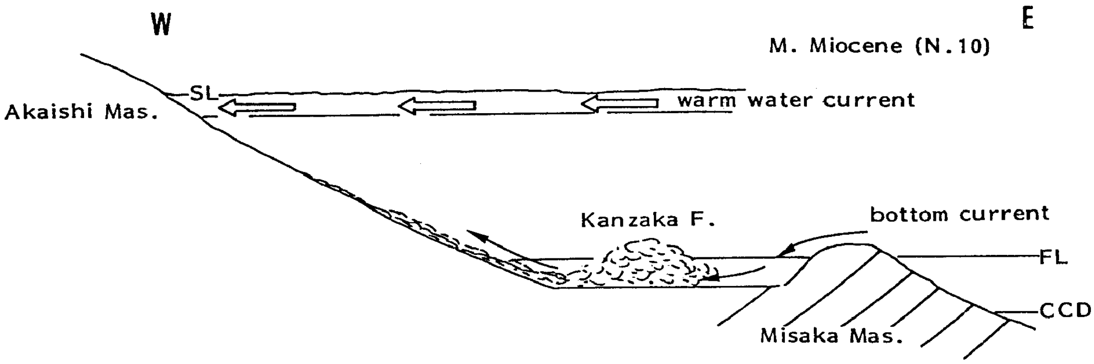


Fig. 49. A schematic paleoenvironment during deposition of the lower part of the Kanzaka Formation. Open thick arrows indicate surface water currents and closed narrow ones show bottom water currents. The latter arrows do not indicate true directions. SL and Mas., sea level and Massif, respectively.

sedimentary basin became shallower with the advancement of time. Paleoenvironments under which each formation was deposited can be interpreted as follows:

Kanzaka Formation (N. 9–11) (Figs. 49, 50):

The Kanzaka Formation might have deposited at a depth between the foraminiferal lysocline (FL) and CCD. The lower part of this formation was additionaly under the influence of bottom currents. Volcanic activity, which is remarkably recorded in the Nishiyatsushiro Group, began during the deposition of the upper part of this formation.

Wadaira Formation (ca. N. 12) (Fig. 51):

This formation accumulated in the abyssal zone below the foraminiferal lysocline, under the influence of bottom currents. Although a typical turbidite facies is absent, influx of terrigenous materials, recognized in earlier times, is continuously detected. This formation is rich in silicic tuff indicating intense volcanic activity. Fiske and Matsuda (1964) reconstructed the process of this volcanic activity and located its vent area. The vents shown in Figs. 51 and 52 are drawn after them.

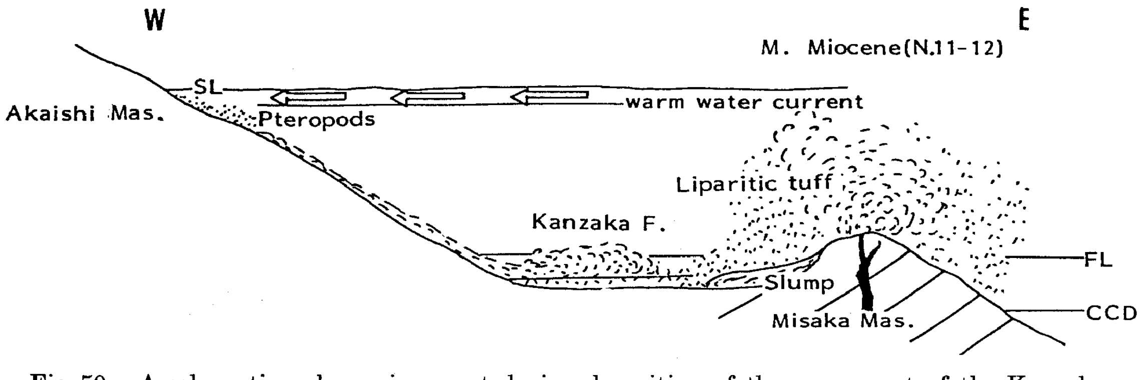


Fig. 50. A schematic paleoenvironment during deposition of the upper part of the Kanzaka Formation. Open thick arrows indicate surface water currents. SL and FL, sea level and foraminiferal lysocline.

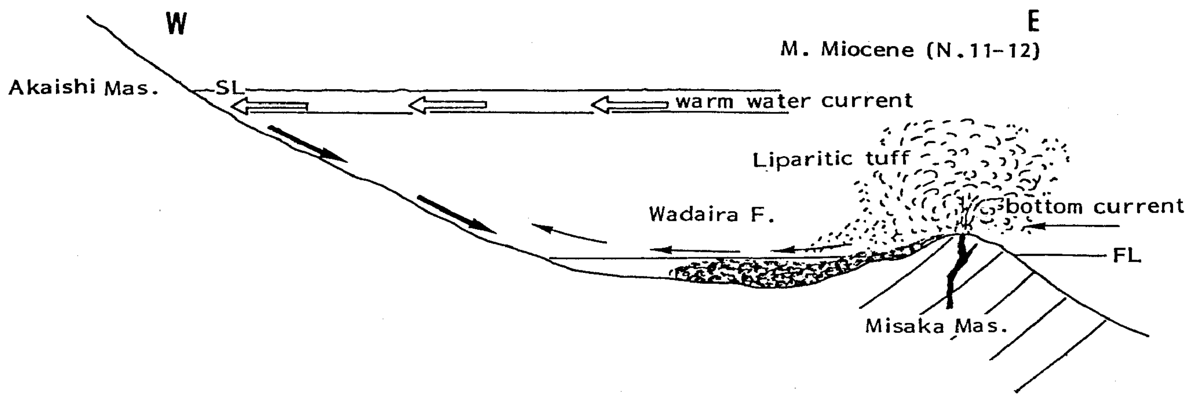


Fig. 51. A schematic paleoenvironment during deposition of the Wadaira Formation. Open thick arrows, closed thick arrows and closed narrow arrows indicate surface water currents, supply of terrigenous materials, and bottom water currents, respectively. The last ones do not indicate true directions. SL and FL, sea level and foraminiferal lysocline.

Byobu-iwa Formation (*ca.* N. 13) (Fig. 52):

The sedimentary basin became even shallower than before. The Byobu-iwa Formation was deposited in the lower bathyal zone above the FL. The influence of both bottom currents and volcanic activity is evident in this formation as shown in Fig. 52. The latter event is recognized as intense eruptions of andesitic tuff and represents part of a series of volcanisms occurred during the deposition of the Nishiyatsushiro Group. This volcanism came to an end when the uppermost part of the formation was accumulated. In the Minobu area beyond the Tokiwa anticline, this formation unconformably covers the Misaka Group (Takagi, 1970MS). His geological map and lithological description indicate that sedimentation in that area began at the time when this formation was deposited.

Hara and Shimobe Formations (N. 14) (Fig. 53):

The Hara Formation was deposited in the lower bathyal zone under the influence of intermittent bottom currents. The Tokiwa anticline played a role of providing a southern sill of the sedimentary basin in the Ichinose area.

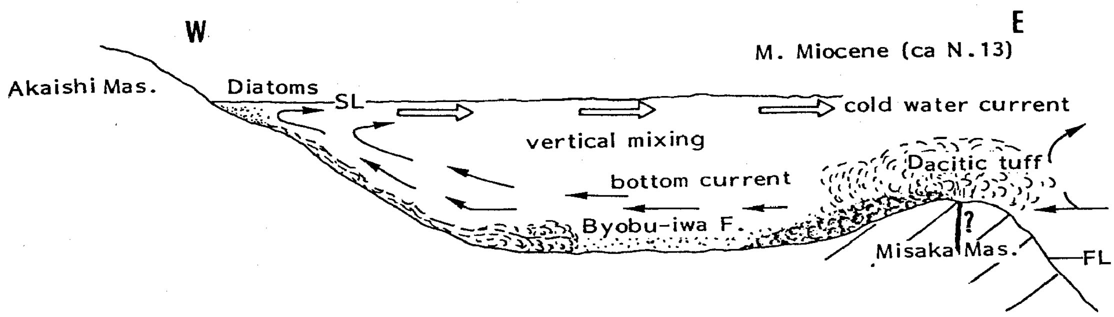


Fig. 52. A schematic paleoenvironment during deposition of the Byobu-iwa Formation. Open thick arrows indicate cold surface water currents and closed narrow ones bottom water currents. The latter arrows do not indicate true directions. SL and FL, sea level and foraminiferal lysocline.

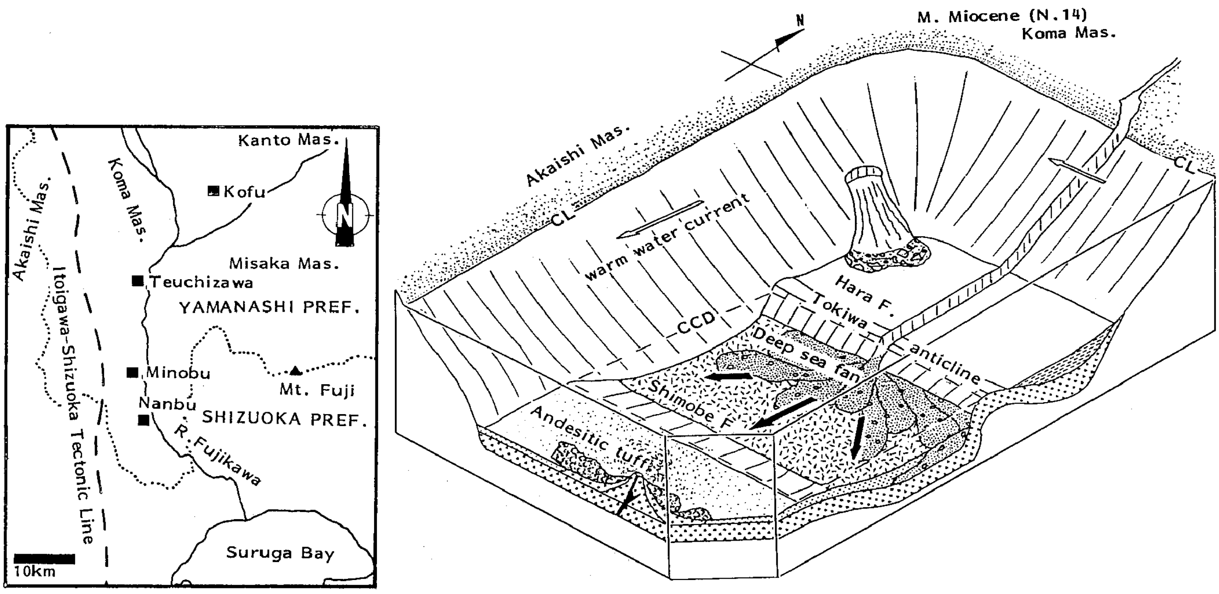


Fig. 53. A schematic paleoenvironment at the time of deposition of the Hara and Shimobe Formations. Open thick arrows indicate warm surface water currents and closed thick ones the supply of terrigenous materials. CL, coast line.

However, terrigenous clastic materials began to flow into the Minobu area through a gap over this sill, giving rise to a pile of sediments known as the Shimobe Formation. Thus, another sedimentary basin developed in the Minobu area, which served as a trap of the Shizukawa Group in this area. The depositional site of the Shimobe Formation changed gradually from depth below the CCD to that of the lower bathyal zone (Fig. 57).

Kinds of pebbles composing the conglomerate and sole marks recognized on sandstone beds indicate that constituents of the conglomerate beds, which are interbedded frequently in the lower part of this formation, were derived from the Koma Massif in the north and that the upper part also included terrigenous material supplied from the north.

Hara and Minobu Formations (*ca*. N. 16–17) (Fig. 54):

The Hara Formation was deposited in the lower bathyal zone under the influence of intermittent bottom currents. Slump structures are recognized in this formation. The Minobu Formation also accumulated in the lower bathyal zone. A remarkable volume of pebbles was brought in at the time of deposition of the middle part of this formation. These pebbles derived from the Kanto Massif form a conglomerate facies called the Marutaki Conglomerate and its characteristic lithofacies and associated sole marks are used to interpret that the facies was accumulated in a channel named the Marutaki Channel by Soh (1985).

The Kuonji Formation named by Matsuda (1961) was deposited in the southwestern part of this basin. It consists mainly of fine terrigenous clastic materials, which began to flow into this basin from the Akaishi Massif. This formation is equivalent to the Hara and Minobu Formations, but its lithofacies and paleocurrent directions are different. On the western side of the Minobu thrust, a depression reaching the lower bathyal zone depth was formed and no easterly paleocurrents prevailed. Thus,

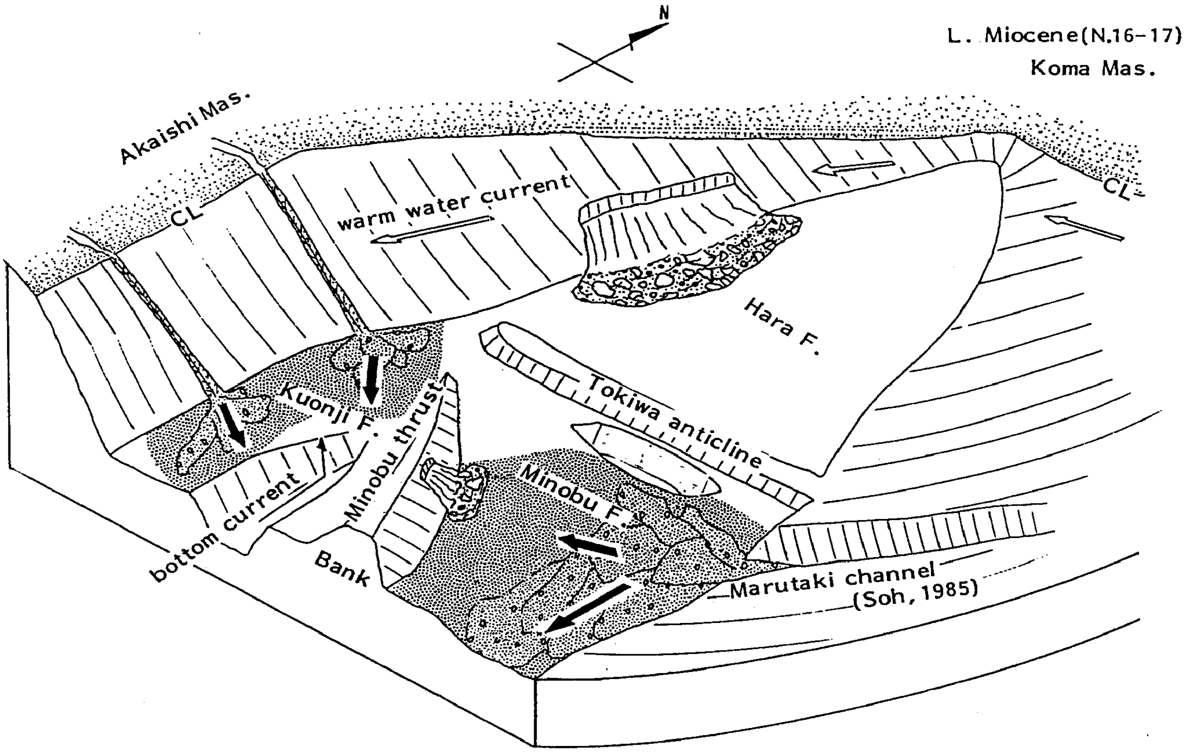


Fig. 54. A schematic paleoenvironment during deposition of the Hara, Kuonji and Minobu Formations, and their equivalents. Open thick arrows, closed thick arrows and closed narrow arrows indicate warm surface water currents, supply of terrigenous materials, and bottom water currents, respectively.

the Minobu thrust may have played a role of serving as a bank in the area south of the sedimentary basin that was formed in the Minobu area.

Iitomi Formation (*ca.* N. 17) (Fig. 55):

The Tokiwa anticline no longer served as a sill between the northern and southern sedimentary basins. The Iitomi Formation was deposited in the middle bathyal zone in the north under the influence of weak bottom currents and in the south in the middle to lower bathyal zone associated with conspicuous bottom currents. This formation includes terrigenous particles supplied from the east and west, as deduced from the direction of sole marks on the sandstone beds. In addition, a remarkable volume of conglomerates occurs in the northern margin of the basin including bronzite andesite pebbles derived from the neighboring uplifted area in the north.

Akebone Formation (N. 18–21) (Fig. 56):

The sedimentary basin became narrower than those of previous time periods. Coastal lines may have been situated along the margin of this basin, delineating the distributional area of this formation. The formation was laid at different water depths in the north and south. In the north, the accumulation was in the outer sublittoral to upper bathyal zone. The Osozawa Sandstone Member is characterized by the accumulation of volcanic sands derived from the underlying andesitic tuff breccia in the marginal uplifted area in the north. The Kawadaira Mudstone Member may represent sediments piled up on the channel wall. Fresh waters began to flow into this basin during the deposition of the Kawa-

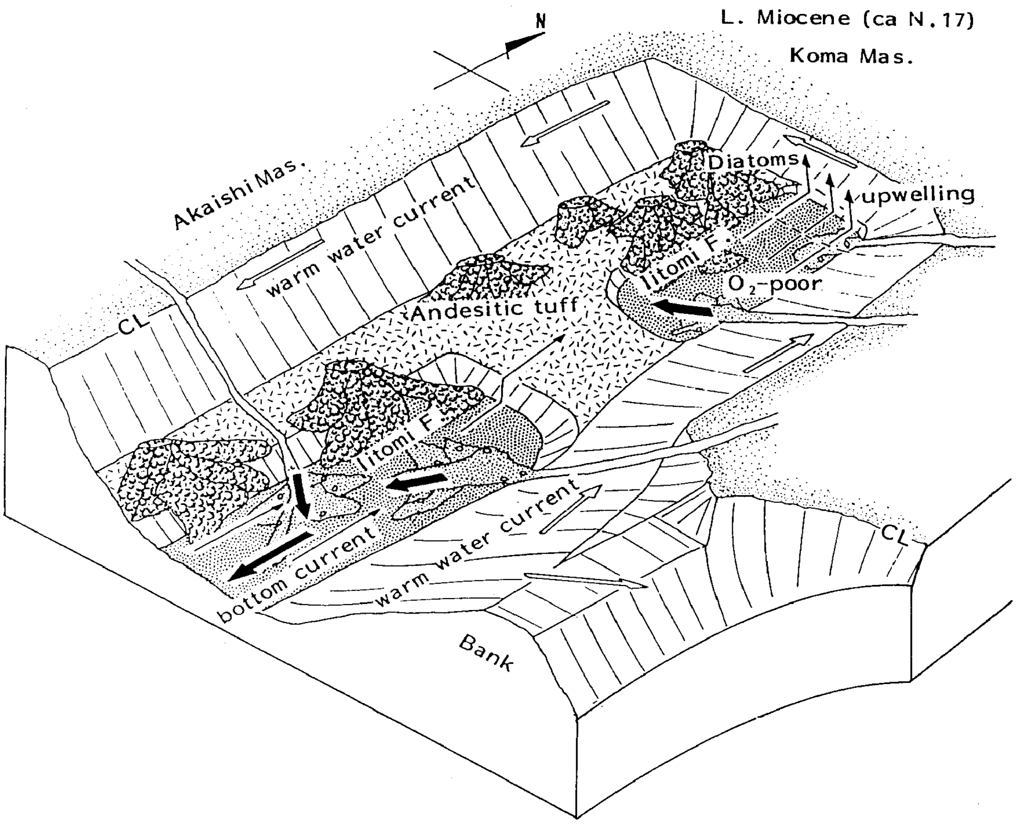


Fig. 55. A schematic sedimentary environment of the Iitomi Formation. Open thick arrows, closed thick arrows and closed narrow arrows indicate warm surface water currents, supply of terrigenous materials, and upwelling, respectively. CL, coast line.

daira Member. In the south, the Akebono Formation accumulated, however, in the lower bathyal zone, without receiving a lateral inflow of sediments from shallower areas. The eastern flank of the Akebono Channel was already uplifted above sea level in the north.

b. Paleogeography, paleoceanography and sea level changes

Three paleoceanographical events are recorded in the Nishiyatsushiro and Shizukawa Groups. These events can be related to widely recognized geohistorical events in the Japanese Island on the basis of correlation as shown in Fig. 57.

1) Middle Miocene

Many attempts have been made on the paleogeographic reconstruction of the Japanese Islands in Early to early Middle Miocene time (Hanzawa, 1950, Ikebe, 1978, Chinzei, 1981, Matsumaru 1981, IGCP National Working Group of Japan, 1981, *etc.*), but rather few dealt with the Middle to late Middle Miocene interval. The connection between the North and South Fossa-Magna regions was discussed by previous workers. Ikebe (1978) illustrated that this connection persisted along the eastern margin of the Itoigawa-Shizuoka Tectonic Line up to Early Pliocene time, while Chinzei (1981) considered it to have existed until the Late Miocene.

The Middle Miocene strata developed in the Fossa-Magna and Kanto regions are summarized diagrammatically in Fig. 58. Oda and Akimoto (in press) discussed the relationship between the seaway

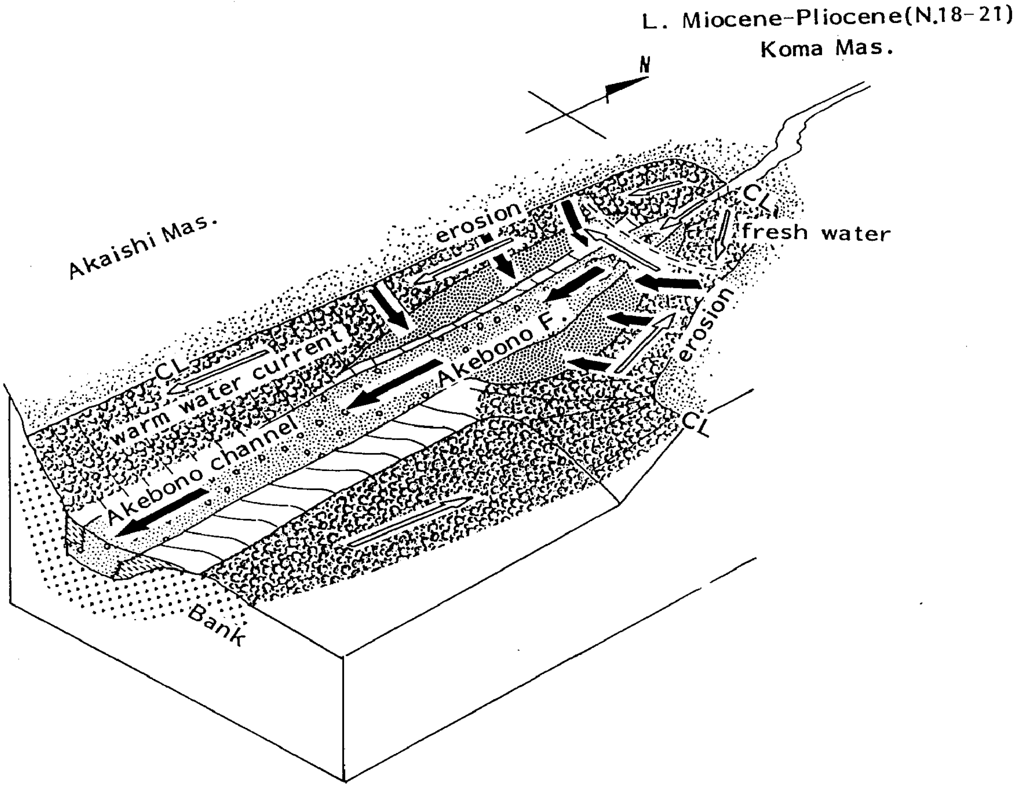
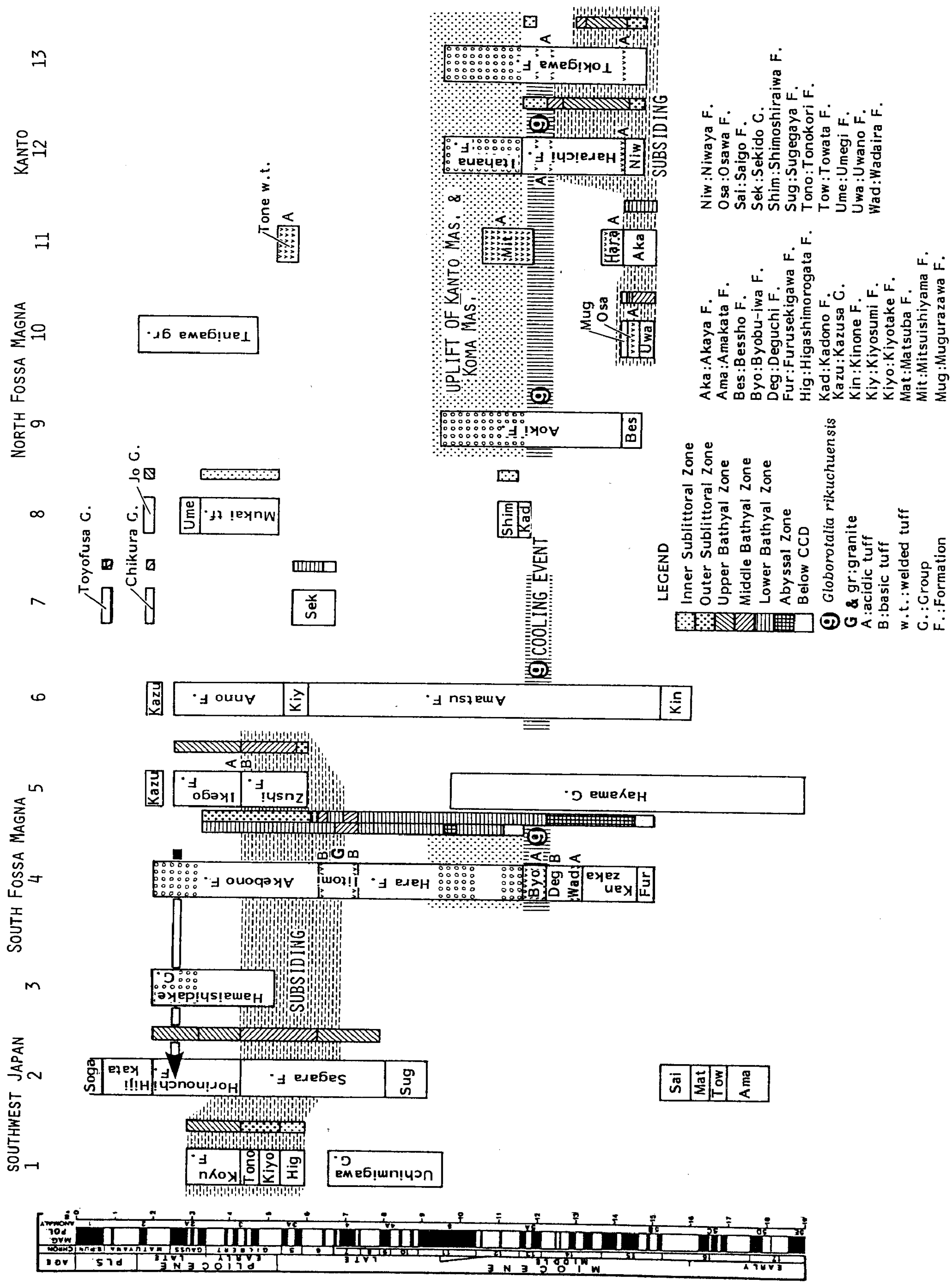


Fig. 56. A schematic sedimentary environment of the Akebono Formation. Open thick arrows and closed thick arrows indicate warm surface water currents and the supply of terrigenous materials, respectively. Broken line shows convergence of coastal water and offshore warm water.

and surface water circulation during the Middle Miocene based on paleobathymetry of several provinces around the South Fossa-Magna region such as the Kanto Massif, the Mineoka uplift and Omaezaki area. The distribution of land and sea during the Middle Miocene is inferred from benthic foraminiferal and sedimentologic data, including especially the supply direction of coarse-grained sediments and characters of the Middle Miocene sediment. Such an attempt is based on the stipulation that the basement rock was in the present-day

Fig. 57. Paleobathymetry, marine environments and subsidence during deposition of Neogene sediments exposed in southwest Japan and the Fossa-Magna region.

1) Miyazaki area (Suzuki, 1986)
2) Kakegawa area (Oda, 1977 ; Ibaraki, 1986 ; Sharma and Takayanagi, 1980, 1983)
3) Hamaishidake area (Ibaraki, 1981)
4) Fujikawa area (Akimoto, this paper)
5) Miura Peninsula (Eto, 1986a, b)
6) Northern Boso Peninsula (Oda, 1977)
7) Southern Boso Peninsula (Nakao *et al.*, 1986)
8) Izu Peninsula (Koyama, 1982)
9) Shinshu area (Suzuki, 1981 ; Watanabe, 1983 ; Oda and Akimoto, in press)
10) Echigoyuzawa (Chihara *et al.*, 1982 ; Akimoto, 1983MS, Ganzawa, 1987)
11) Minakami area (Akimoto, 1983MS, 1983 ; Takahashi, 1987)
12) Takasaki area (Takayanagi *et al.*, 1978 ; Akimoto, 1983MS)
13) Hiki Hill area (Koike *et al.*, 1985 ; Akimoto, 1983MS).


SOUTHWEST JAPAN
SOUTH FOSSA MAGNA
NORTH FOSSA MAGNA
KANTO
COOLING EVENT
UPLIFT OF KANTO MAS. & KOMA MAS.
SUBSIDING
LEGEND
Inner Sublittoral Zone
Outer Sublittoral Zone
Upper Bathyal Zone
Middle Bathyal Zone
Lower Bathyal Zone
Abyssal Zone
Below CCD
Globorotalia rikuchuensis
G & gr:granite
A:acidic tuff
B:basic tuff
w.t.:welded tuff
G.:Group
F.:Formation
Aka:Akaya F.
Ama:Amakata F.
Bes:Bessho F.
Byo:Byobu-iwa F.
Deg:Deguchi F.
Fur:Furusekigawa F.
Hig:Higashimorogata F.
Kad:Kadono F.
Kazu:Kazusa G.
Kin:Kinone F.
Kiy:Kiyosumi F.
Kiyo:Kiyotake F.
Mat:Matsuba F.
Mit:Mitsuishiyama F.
Mug:Mugurazawa F.
Niw:Niwaya F.
Osa:Osawa F.
Sai:Saigo F.
Sek:Sekido G.
Shim:Shimoshiraiwa F.
Sug:Sugegaya F.
Tono:Tonokori F.
Tow:Towata F.
Ume:Umegi F.
Uwa:Uwano F.
Wad:Wadaira F.

situation.

Firstly, in the Kakegawa area, a stratigraphic hiatus between the Saigo and Sagara Groups which spans from the early Middle Miocene to late Middle Miocene (Fig. 57) was recognized by Ujiié and Hariu (1975), Oda (1977) and Ibaraki (1986). In addition, Sharma and Takayanagi (1980, 1982) discussed paleobathymetry of the Late Miocene sequence on the basis of benthic foraminifera, and concluded that the lowermost part of the Sagara Formation was deposited in the upper bathyal zone. Thus, this area was above sea level during the Middle Miocene (Oda and Akimoto, in press). The same situation was recognized at a well site off Omaezaki (Maiya *et al*, 1985). Matsumaru *et al.* (1982) reported that *Miogypsina kotoi* (Hanzawa) occurs in the Moriya Formation in Nagano Prefecture. This area lacks younger Neogene sediments. Thus, the western area of the Itoigawa-Shizuoka Tectonic Line is assumed to have been above sea level throughout nearly the entire Middle Miocene (Fig. 58a).

Secondly, the Takasaki area represents the northeastern sector of the Kanto Massif where thick Neogene marine sediments are developed. These Neogene sediments lie unconformably on pre-Tertiary rocks forming the Kanto Massif. The Nukabe, Idozawa, Haratajino and Sogi Formations in the Takasaki area range from Blow's Zone N. 8 to the lower part of Zone N. 9 (Takayanagi *et al.*, 1978). In the Chichibu Basin situated within the Kanto Massif, there distributed are Neogene sediments which are correlated with those in the Takasaki area. No sediments younger than N. 9 exist in this basin. Therefore, this basin might have uplifted at least by the time of Zone N. 9 (Takahashi and Yukawa, 1986), and this movement was possibly responsible for the development of hiatus recognized between the Sogi and Niwaya Formations in the Takasaki area. This unconformity is traceable from Takasaki to the Iwadono Hill in Saitama Prefecture as shown in Fig. 57. Thus, the Kanto massif uplifted above sea level and remained so for a while since the early Middle Miocene. Thereafter, basin subsidence took place during the interval from the FAD of *Grt.* cf. *miozea conoidea* to the FAD of *Gna. nepenthes* in those basins along the northern to northeastern margin of the Kanto Massif as shown in Fig. 57. A shallowing event is recognized at the FAD of *Gna. nepenthes* (N. 14) in the upper part of the Haraichi Formation (Takayanagi *et al.*, 1984). This formation may have been deposited in the outer bathyal zone as deduced from benthic foraminiferal assemblages (Akimoto, 1983MS). The overlying Itahana Formation, consisting mostly of coarse-grained sediments, indicates a progressively shallowing environment (Omori, 1960; Omori *et al.*, 1976). Kubo and Tsunoda (1973) considered that the Itahana Formation in the Takasaki area accumulated in a delta developed to the northeast. Tsunoda and Goto (1983) also reported that the Yagii Formation exposed along the River Arakawa, a unit correlative with the Itahana Formation, was deposited in a braided channel flowing eastward. The deposition of these two formations took place in the sublittoral zone (Akimoto, 1983MS). In the Itsukaichi basin, the constituents of a conglomerate bed in the Ajiro Formation are largely black sandstones derived from the Paleozoic Chichibu System forming the Kanto Massif located northwest of the Itsukaichi Basin during middle to late Middle Miocene time (Sakai, 1987). On the other hand, such uplifting movement has not been detected by any line of evidence in the area from the western margin of this massif to the Itoigawa-Shizuoka Tectonic Line. Therefore, Oda and Akimoto (in press) reconstruct-

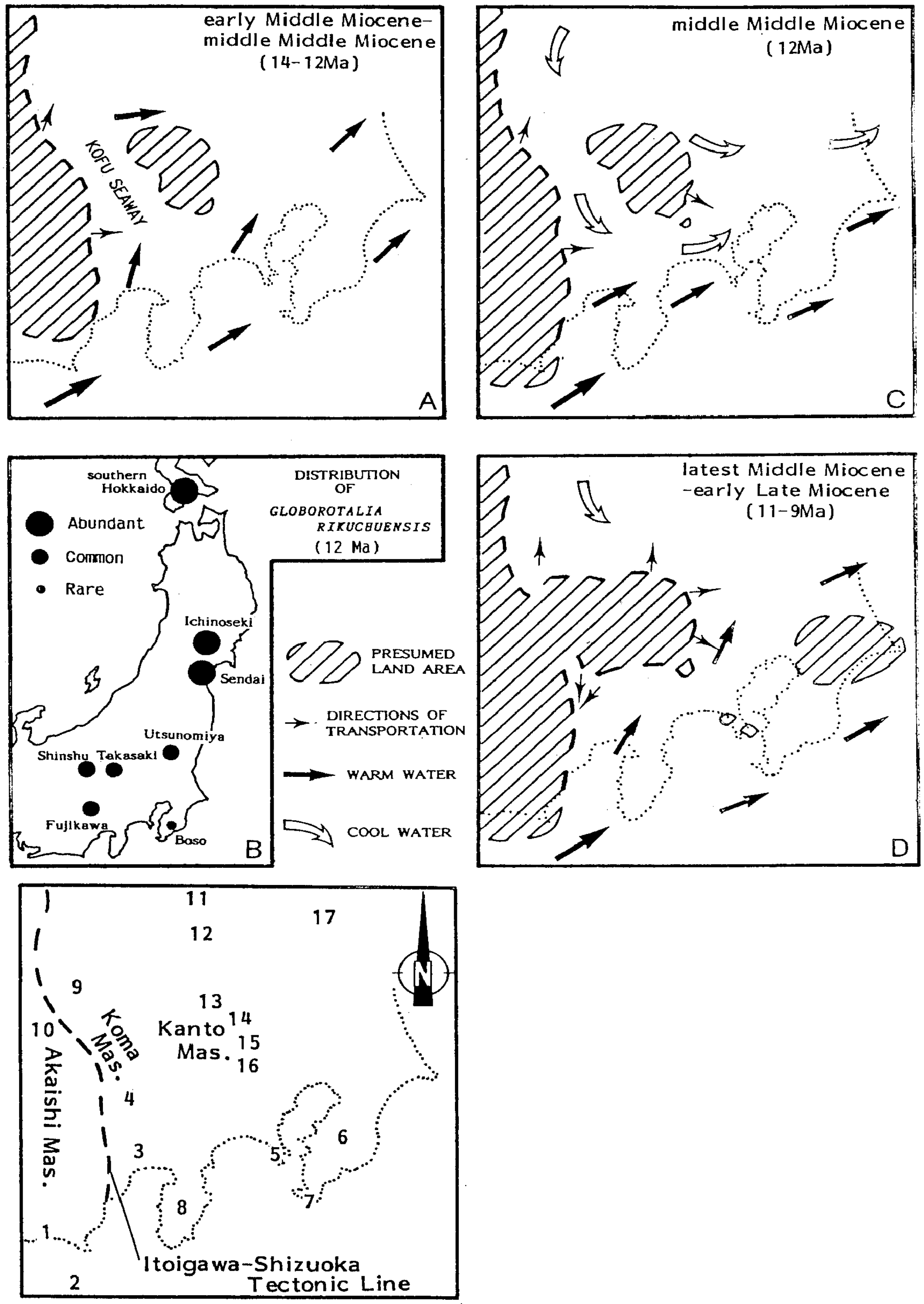


Fig. 58. Paleogeographic map and inferred surface currents during the Middle Miocene of the Fossa-Magna and Kanto regions, central Japan (after Oda and Akimoto, in press). A, Phase I and II; B and C, Phase III; D, Phase IV; Mas., Massif; 1, Kakegawa area; 2, Well site off Omaezaki; 3, Hamaishidake area; 4, Fujikawa area; 5, Miura Peninsula; 6, Northern Boso Peninsula; 7, Southern Boso Peninsula; 8, Izu Peninsula; 9, Shinshu area; 10, Moriya area; 11, Echigoyuzawa area; 12, Minakami area; 13, Takasaki area; 14, Arakawa area; 15, Hiki Hill area 16, Itsukaichi area; 17, Utsunomiya area.

ed a paleogeography by using the direction of sediment transportation based on sole marks and compositions of conglomerate beds in those formations which are distributed in the Shinshu and Fujikawa areas. In the Fujikawa area, the Shimobe Formation, which is correlated with the lower part of the Hara Formation (Chapter 3), is composed largely of conglomerate beds whose constituents were derived from the Koma Massif situated north of the Fujikawa area. The inferred direction of sediment transport from north or northeast to south or southwest during the late Middle Miocene (Figs. 46 and 58d) was quite different from the west-to-east direction during the early to middle Middle Miocene (Figs. 46 and 58a and c). In the Shinshu area of the northern Fossa-Magna region, the upper part of the Aoki Formation, which is probably correlative with a part of the Hara Formation, consists largely of conglomerate beds whose pebbles may have been derived from the southern area as indicated by sole marks and the composition of conglomerate (Suzuki, 1982).

Thirdly, Eto (1986a, b) investigated the geology of the Miura Group in the Miura Peninsula. He also revealed a sedimentary gap in the Miura Group which spans from N. 14 to N. 16. Sedimentation in this area resumed in the outer neritic zone at the Zone N. 17 time (Eto, *op cit.*). Thus, the present author assumes that the Hayama-Mineoka Belt became emergent from the late Middle Miocene to early Late Miocene as shown in Fig. 58d.

A continuous occurrence of marine planktonic microfossils gives an advantage of providing a clue to infer fluctuations and periodic changes in surface water circulations and biogeography. Paleoceanographic conditions in the middle to upper Middle Miocene sequences of northern Honshu have been constructed by using nannofloral compositions (Takayanagi *et al.*, 1984).

The Middle Miocene history of Japan can be subdivided into four phases from a paleoceanographic point of view.

Phase I is the lowest Middle Miocene interval ranging from 16 to 15 Ma, being equivalent to Zone N. 8 and the lower part of Zone N. 9. According to Chinzei (1978), molluscan and other benthic faunas were dominated by tropical and subtropical elements which spread over most of the Japanese Islands except for northern Hokkaido where the cold water fauna occured. The convergence of warm and cold currents was presumably located in central Hokkaido in the earliest Middle Miocene. Phases II, III and IV correspond to episodes of warming, cooling and warming climates, respectively, which were recognized in areas on the Pacific side of northern Japan by Takayanagi *et al.* (1984). They pointed out that the Takasaki area is, on the whole, estimated to have been located near the border between the paleo-Kuroshio and paleo-Oyashio (Chinzei, 1981) during the middle to late Middle Miocene.

Phase II represents the early Middle Miocene interval (about 14–13 Ma). This phase covers from the upper part of the *Globortalia peripheroacuta* Zone to the lower part of the *Globorotalia* cf. *miozea conoidea* Zone, and is equivalent to an interval from Zone N. 10 to N. 12. This was essentially a subsiding period which commenced within Zone N. 10 age, and continued up to the middle Middle Miocene (N. 13) in the northern and northeastern margins of the Kanto Massif (Fig. 57). *Globorotalia miozea* and *Grt.* cf. *miozea conoidea* are recorded from the Kanzaka and Wadaira Formations in the South Fossa-Magna region as well as the Bessho Formation in the North Fossa-Magna region (Watanabe, 1983). It is thus suggested that there was a seaway connection between the Itoigawa-Shizuoka Tectonic Line and the Kanto

Massif in early Middle Miocene time. It is named the Kofu Seaway (Oda and Akimoto, in press). Predominantly warm waters flowed to the north through this seaway in Phases I and II, as shown in Fig. 58a. The convergence between warm and cold currents was located presumably between the Takasaki and Sendai areas because a rapid decline of the warm *Discoaster-Sphenolithus* species groups was observed in between (Fig. 6 in Takayanagi *et al*., 1984).

Phase III is a short interval of the middle Middle Miocene (about 12 Ma) corresponding to the upper part of the *Grt*. cf. *miozea conoidea* Zone, and is characterized by a cooling event as marked by the occurrence of *Globorotalia rikuchuensis* (Fig. 57). This species occurs in high frequencies in northern Japan (Fig. 58b), and has been inferred to be a cool water species because it occurs abundantly in association with the diatom *Denticulopsis praedimorpha* both in northeast Honshu and southern Hokkaido (Oda *et al*., 1987). This species is also common in the northern Kanto and Fossa-Magna regions, and occurs, though rare, even in the Amatsu Formation in the Boso Peninsula. The Byobu-iwa Formation is characterized by the occurrence of *Grt. rikuchuensis* accompanied with abundant diatoms. These features seem to suggest that the surface water cooling caused a vertical mixing. In fact, benthic foraminiferal data also indicate a remarkable influence of bottom currents, as shown by the 3rd positive principal components factor loading. In the Itsukaichi basin, an occurrence of *Grt. rikuchuensis* was reported from the uppermost part of the Ajiro Formation which is correlative with the middle to upper part of the Haraichi Formation, although its abundance is uncertain due to a poor state of preservation (Kurihara, 1980). In addition, an occurrence of pectinoid mollusk *Chlamys kaneharai* was reported from a Middle Miocene sequence in the Tanzawa area which is equivalent to the Byobu-iwa Formation (Chinzei and Matsushima, 1987). These authors pointed out that this species inhabited shallow seas of northeast Japan and Hokkaido in Middle Miocene time, with its southern limit of distribution being at the Tanzawa area. On the basis of distribution pattern and frequency of *Grt. rikuchuensis*, it is assumed that cool surface waters flowed into the South Fossa-Magna region and the Tanzawa area through the Kofu Seaway during the middle Middle Miocene (Fig. 58c). The southward invasion of such cool water species as *Grt. rikuchuensis* and *C. kaneharai* seems to be related to the global cooling event recognized in the middle Middle Miocene (Kennett, 1977, *etc*.). The convergence between warm and cold water currents was presumably located in the southern part of central Honshu around 12 Ma.

Phase IV is the interval from the late Middle Miocene to early Late Miocene (about 11–9 Ma). It is characterized by an uplifting phase. In the late Miocene, warm water species such as *Globorotalia menardii* and *Globigerinoides* groups commonly occur in the middle part of the Amatsu Formation and the Hara Formation. Takayanagi *et al*. (1984) pointed out that a cooling episode between the last appearance datum of *Cyclicargolithus floridanus* and the rapid decrease datum of *Cyrtocapsella tetrapera* was followed by a warm period which commenced around the first appearance datum of *Gna. nepenthes* in northern Honshu, Japan. *Gna. nepenthes* first occurs in the Tanokura Formation in association with such warm water forms as *Sphaeroidinellopsis* and *Globoquadrina* in the Utsunomiya area (Iizuka, 1982MS), which is the northern limit of distribution of *Gna. nepenthes*. The influence of warm-temperate water extended at least to the Utsunomiya area along the Pacific side region in the late Middle Miocene. However, no warm water species has been found in the correlative strata in the northern Fossa-Magna region. No biogeographic connection existed at this time between the southern and northern areas of the Fossa-Magna region. Figure 58d shows that the direction of sediment transport took a radiating pattern from the Kanto and Koma Massifs. Judging from both the direction of sediment transport and the termination of biogeographic connection, it is inferred that the Kanto and Koma Massifs uplifted above sea level and the Kofu Seaway was closed off at about 11–9 Ma. This resulted in a change of circulation pattern of surface water currents in the late Middle Miocene (Fig. 58d).

2) Late Miocene to Early Pliocene

The Iitomi Formation is characterized by the following:

1) It was deposited in the middle bathyal zone in the north, and in the middle to lower bathyal zone in the south.

2) Its foraminiferal assemblages are mainly composed of calcareous species such as *Globobulimina auriculata* and *Uvigerina proboscidea*, in association with rare agglutinated species.

3) Plant fragments, which were brought in from the northern and eastern parts of the study area, and diatoms are present in abundance in the Yogozawa area.

4) Bottom water circulations were sluggish.

5) Volcanic activity was intensive.

Globobulimina is tolerant of low-oxygen conditions as already mentioned in Chapter 6. Ingle (1980) assigned *Globobulimina* and *Uvigerina proboscidea* to a lower middle bathyal biofacies (1,500–2,000 m). Burke (1981) reported some species of *Uvigerina* distributed in the oxygen minimum layer on the Ontong Java Plateau. Miller and Lohmann (1982) studied the environmental distribution of Recent benthic foraminifera on the northeast United States continental slope. In their paper, abundant *Uvigerina peregrina* is attributed to the maximum organic carbon. Consequently, such organic-carbon rich conditions may have reduced oxygen contents of interstitial waters in sediments and of water lying immediately above the sediments.

Uvigerina proboscidea is often abundant today in the middle bathyal zone on the continental slope of southwest Japan, but *Globobulimina* had not been detected in such depths, possibly by reason of a higher dissolved oxygen content of 1 ml/l around Japan (Akimoto, 1990). However, the *Globobulimina-Uvigerina proboscidea* fauna was recently detected in the middle bathyal zone under anaerobic conditions (approximately 1,500 m) off Ito on the Izu Peninsula (Dr. H. Nishi, personal communication). This fact leads to a possibility that a similar assemblage can exist in the middle bathyal zone under anaerobic conditions in the Pacific both off the northeast and southwest coasts of Japan. It also supports the present author's inference on the depositional environment of the Iitomi Formation. However, intensive low-oxygen conditions during the deposition of the Iitomi Formation is not fully explained only by its paleobathymetry; they might have been caused within a semi-isolated basin with restricted bottom water circulation, under a highly fertile, productive surface-water mass, which is associated with increased consumption of dissolved oxygen by an excessive supply of terrigenous and biogenic nutrients.

The existence of upwelling is assumed at the time of deposition of the Iitomi Formation, distributed in the northern part. This formation is characterized by an abundant occurrence of diatoms. As mentioned before, the sedimentary basin of the Iitomi Formation is estimated to have been a shallow, partially enclosed bay open to the north. Thus upwelling might have been caused owing to submarine topography. Actually, such features are also observed today in Suruga Bay, where upwelling of an intermediate water occurs in its inner part (Inoue, 1986). In reality, bottom currents existed in the southern part during deposition of the middle part of the Iitomi Formation, though its direction has not been determined. Furthermore, the circulation of intermediate waters might have intensified due to the surface-water cooling (Kennett, 1982), though no cooling event in the Late Miocene is suggested by planktonic foraminifera. However, stable oxygen isotopic data indicate a surface water cooling in the Pacific Ocean at that time (Woodruff *et al.*, 1981).

The Upper Miocene sedimentary basins distributed in southwest Japan are characterized by a subsiding event which began at the time of the base of Zone N. 17 (Miyazaki region, Suzuki, 1987; Kakegawa region, Sharma and Takayanagi, 1980, 1982; Miura Peninsula, Eto, 1986a, b). However, the magnitude of the basin subsidence and the timing of the subsequent uplift event vary from area to area. For example, the South Fossa-Magna region is estimated to have subsided from the middle bathyal to lower bathyal zones; the Miura Peninsula from the outer sublittoral to middle bathyal zones; the Kakegawa region from the upper bathyal to middle bathyal zones; and the Miyazaki region changed rather less extensively from the inner sublittoral to upper bathyal zones. The above evidence leads to the conclusion that 1) areas that extensively changed paleobathymetry are confined to the Pacific coast around the South Fossa-Magna region, 2) especially, the South Fossa-Magna region itself changed the most, 3) the subsequent uplift began in the South Fossa-Magna, Miura Peninsula, Kakegawa, and Miyazaki regions in order of decreasing age.

This phenomenon is recognized in the basins situated along the margin of the Philippine Sea Plate. Kennett (1982) presents a mechanism to create large transgressions and regressions during times when there can be a change of sea level due to the melting and growth of ice sheets and oscillations in the spreading rate of mid-ocean ridges.

Furthermore, the global sea level change in the Late Miocene has already been documented by various studies (*e.g.* Harland *et al.*, 1982). According to Harland *et al.* (1982), the global sea level in the Late Miocene stood rather high, at most 100 m higher than the present time.

Suzuki (1987) inferred that the subsiding event, which is recognized in the Miyazaki Group, may be attributed to eustatic changes. However, the estimate of sea level change by Harland *et al.* (1982) for the Late Miocene can not account for the subsiding phenomenon occurred in southwest Japan, especially in the South Fossa-Magna region. The greater changes were almost confined to this region. Therefore, this event might have mostly resulted from a tectonic cause, though no data are available at present.

FAUNAL REFERENCE LIST

Benthic foraminiferal species from the Misaka, Nishiyatsushiro and Shizukawa Groups are alphabetically listed below. Some selected species are illustrated with micrographs taken with a scanning electron microscope (Plates 1 to 9). The original references are given for each of the species.

Alabamina tubulifera (Heron-Allen and Earland).
Truncatulina tubulifera Heron-Allen and Earland, 1915, p. 710, pl. 52, figs. 37-40.
Allomorphina pacifica Hofker
Allomorphina pacifica Hofker, 1951, p. 139.
Alveolophragmium scitulum (Brady) ....Pl. 2, figs. 2, 3 ; Pl. 3, fig. 7
Haplophragmium scitulum Brady, 1881, p. 20.
Alveolophragmium scitulum (Brady). Parker, 1954, p. 487.
Alveolophragmium subglobosum (G.O. Sars)....................Pl. 2, fig. 6
Lituola subglobosa G.O. Sars, 1871, p. 253. (*fide* Ellis and Messina, 1940 *et seq.*).
Haplophragmium subglobosum (M. Sars). Brady, 1881, p. 406. (*fide* Brady, 1884).
Alveolophragmium subglobosum (G.O. Sars). Barker, 1960, p. 70, pl. 34, figs. 7, 8, 10 (not 14).
Ammodiscoides japonicus Asano and Inomata
Ammodiscoides japonicus Asano and Inomata. Asano, 1952, p. 3, figs. 9-11.
Ammodiscus cf. *dominicensis* Bermúdez var. *deformis* Bermúdez. ..Pl. 3, fig. 2
cf. *Ammodiscus dominicensis* Bermúdez var. *deformis* Bermúdez, 1949, p. 48, pl. 1, figs. 51, 52.
Ammodiscus pacifica Cushman and Valentine
Ammodiscus pacifica Cushman and Valentine, 1930, p. 7, pl. 1, fig. 1.
Ammonia beccarii (Linné)
Nautilus beccari Linné, 1758, Syst. Nat., ed. 10, p. 710 (*fide* Ellis and Messina, 1940 *et seq.*).
Ammonia beccarii (Linné). Frizzel and Keen, 1949, p. 106.
Ammonia japonica (Hada)
Rotalia japonica Hada, 1931, p. 137, fig. 93.
Ammonia japonica (Hada). Ujiié, 1963, p. 236, pl. 2, figs. 3, 4.
Ammonia ketienziensis (Ishizaki) ....Pl. 8, fig. 1
Streblus ketienziensis Ishizaki, 1948, p. 59, pl. 1, fig. 2.
Ammonia ketienziensis (Ishizaki). Huang, 1964, p. 53, pl. 1, fig. 13.
Ammonia takanabensis (Ishizaki) ....Pl. 8, fig. 2.
Streblus takanabensis Ishizaki, 1948, p. 57, pl. 1, fig. 5.
Ammonia takanabensis (Ishizaki). Huang, 1964, p. 56, pl. 1, fig. 2.
Amphicoryna proxima (Silvestri)
Nodosaria proxima Silvestri, 1872, p. 63, pl. 6, figs. 138-147. (*fide* Ellis and Messina, 1940 *et seq.*).
Amphicoryna proxima (Silvestri). Barker, 1960, p. 134, pl. 64, fig. 15.
Amphicoryna scalaris (Batsch)
Nautilus scalaris Batsch, 1791, pl. 2, fig. 4. (*fide* Ellis and Messina, 1940 *et seq.*).
Amphicoryna scalaris (Batsch). Barker, 1960, p. 134, pl. 63, figs. 28-31.
Amphicoryna scalaris sagamiensis (Asano)
Lagenodosaria scalaris sagamiensis Asano, 1936b, p. 613, pl. 30, figs. 6, 7.
Amphicoryna scalaris sagamiensis (Asano). Matoba, 1967, p. 251, pl. 25, fig. 4.
Amphistegina madagascariensis d'Orbigny
Amphistegina madagascariensis d'Orbigny, 1826, p. 304.
Amphistegina radiata (Fichtel and Moll)
Nautilus radiatus Fichtel and Moll, 1798, p. 58, pl. 8, figs. a-d. (*fide* Ellis and Messina, 1940 *et seq.*).
Amphistegina radiata (Fichtel and Moll). Graham and Militante, 1959, p. 104, pl. 16, figs. 12, 13.
Anomalinoides glabrata (Cushman) ....Pl. 6, fig. 1
Anomalina glabrata Cushman, 1924, p. 39, pl. 12, figs. 5-7.
Anomalinoides glabulosa (Chapman and

Parr)
Anomalina glabulosa Chapman and Parr, 1937, p. 117.
Astrononion stellatum Cushman and Edwards
Astrononion stellatum Cushman and Edwards, 1937, p. 32, pl. 3, figs. 9-11.
Astrononion stelligerum (d'Orbigny)
Nonionina stelligerum d'Orbigny, 1839b, p. 128, pl. 3, fig. 7.
Astrononion stelligerum (d'Orbigny). Cushman and Edwards, 1937, p. 31, pl. 3, fig. 7.
Bolivina pisciformis Galloway and Morrey
Bolivina pisciformis Galloway and Morrey, 1929, p. 36, pl. 5, fig. 10.
Bolivina robusta Brady
Bolivina robusta Brady, 1881, p. 27.
Bolivina seminuda Cushman
Bolivina seminuda Cushman, 1911, p. 34, text-fig. 55.
Bolivinita quadrilatera (Schwager)
Textularis quadrilatera Schwager, 1866, p. 253, pl. 7, fig. 10.
Bolivinita quadrilatera (Schwager). Cushman, 1927a, p. 90.
Brizalina alata (Seguenza)
Vulvulina alata Seguenza, 1862, p. 115, pl. 2, fig. 5.
Brizalina alata (Seguenza). Belford, 1966, p. 24, pl. 1, figs. 1, 2.
Brizalina amygdalaeformis (Brady)
Bolivina amygdalaeformis Brady, 1884, p. 426, pl. 53, figs. 28, 29.
Brizalina bradyi (Asano) . . Pl. 5, fig. 11
Bolivina bradyi Asano, 1938, p. 603, pl. 16, fig. 2.
Brizalina bradyi (Asano). Takayanagi and Hasegawa, 1987, p. 7.
Brizalina hanzawai (Asano)
Bolivina hanzawai Asano, 1936c, p. 330, pl. 37, fig. 9.
Brizalina hanzawai (Asano). Takayanagi and Hasegawa, 1987, p. 7.
Brizalina subangularis ogasaensis (Asano)
Bolivina subangularis ogasaensis Asano, 1936c, p. 142, pl. 18, figs. 17-19.
Brizalina subangularis ogasaensis (Asano). Takayanagi and Hasegawa, 1987, p. 8.
Brizalina subreticulata (Parr)
Bolivina subreticulata Parr, 1932, p. 12, pl. 1, fig. 21.
Brizalina subreticulata (Parr). Belford, 1966, p. 29, pl. 1, figs. 17, 18; text-fig. 3.
Buccella makiyamai Chiji
Buccella makiyamae Chiji, 1961, p. 234, text-fig. 2, pl. 1, figs. 13, 14.
Bulimina cf. *alazanensis* Cushman
. . . . Pl. 5, fig. 9
cf. *Bulimina alazanensis* Cushman, 1927c, p. 161, pl. 25, fig. 4.
Bulimina rostrata Brady
. . . . Pl. 5, fig. 8
Bulimina rostrata Brady, 1884, p. 408, pl. 51, figs. 14, 15.
Bulimina striata d'Orbigny
. . . . Pl. 5, fig. 10
Bulimina striata d'Orbigny, 1826, p. 269, modèles no. 2.
Burseolina pacifica (Cushman)
Cassidulina pacifica Cushman, 1925b, p. 53, pl. 9, figs. 14-16.
Burseolina pacifica (Cushman). Nomura, 1983a, p. 57, text-fig. 48, pl. 5, figs. 1-4; pl. 6, fig. 2; pl. 21, figs. 6-10.
Ceratobulimina pacifica Cushman and Harris
Ceratobulimina pacifica Cushman and Harris, 1927, p. 176, pl. 29, figs. 30-32.
Chilostomella oolina Schwager
. . . . Pl. 8, fig. 7
Chilostomella oolina Schwager, 1878, p. 527, pl. 1, fig 16. (*fide* Ellis and Messina, 1940 *et seq.*).
Cibicides aknerianus (d'Orbigny)
. . . . Pl. 6, figs. 5, 7
Rotalia akneriana d'Orbigny, 1846, p. 156, pl. 8, figs. 13-15.
Cibicides aknerianus (d'Orbigny). Asano, 1951b, p. 17, figs. 30-32.
Cibicides cicatricosus (Schwager)

Anomalina cicatricosa Schwager, 1866, p. 260, pl. 7, fig. 108.
Cibicides cicatricosus (Schwager). LeRoy, 1964, p. 45, pl. 8, figs. 27-29.

Cibicides lobatulus (Walker and Jacob) ....Pl. 6, fig. 8
Nautilus lobatulus Walker and Jacob, 1798, p. 642, pl. 14, fig. 36. (*fide* Ellis and Messina, 1940 *et seq.*).
Cibicides lobatulus (Walker and Jacob). Cushman, 1931, p. 118, pl. 21, fig. 3.

Cibicides praecinctus (Karrer)
Rotalia praecincta Karrer, 1868, p. 158, p. 189, pl. 5, fig. 7. (*fide* Ellis and Messina, 1940 *et seq.*).
Cibicides praecinctus (Karrer). Barker, 1960, p. 196, pl. 95, figs. 1-3.

Cibicides refulgens Montfort
Cibicides refulgens Montfort, 1808, p. 122. (*fide* Ellis and Messina, 1940 *et seq.*).

Cibicides cf. *refulgens* Montfort ....Pl. 6, fig. 9
Cibicides cf. *refulgens* Montfort. Asano, 1951b, p. 18, figs. 42-44.

Cibicides aff. *refulgens* Montfort
This form is similar to Montfort's form but differs from it in its narrowly rounded periphery.

Cibicides wuellerstorfi (Schwager) ....Pl. 6, fig. 11
Anomalina wuellerstorfi Schwager, 1866, p. 258, pl. 7, fig. 105.
Cibicides wuellerstorfi (Schwager). LeRoy, 1941, p. 46, pl. 1, figs. 27-29.

Cibicidoides mediocris (Finlay) ....Pl. 6, figs. 3, 6
Cibicides mediocris Finlay, 1940, p. 464, pl. 67, figs. 198, 199.

Cyclammina cancellata Brady ....Pl. 2, fig. 1; Pl. 3, fig. 3
Cyclammina cancellata Brady, 1879, p. 43.

Cyclammina japonica kaiensis Fukuta and Shinoki ....Pl. 3, fig. 4
Cyclammina japonica Asano *kaiensis* Fukuta and Shinoki, 1952, p. 202, pl. 6, figs. 1-4.

Cyclammina pusilla Brady ....Pl. 3, figs. 5, 6
Cyclammina pusilla Brady, 1881, p. 23.

Dentalina communis d'Orbigny
Dentalina communis d'Orbigny, 1826, p. 254.

Dentalina filiformis (d'Orbigny)
Nodosaria filiformis d'Orbigny, 1826, p. 253.

Discammina compressa (Goës)
Lituolina irregularis Roemer var. *compressa* Goës, 1882, p. 141, pl. 12, figs. 421-423.
Discammina compressa (Goës). Lacroix, 1935, p. 15. (*fide* Loeblich and Tappan, 1964).

Discorbinella convexa (Takayanagi) ....Pl. 8, fig. 4
Planulina convexa Takayanagi, 1953, p. 34, pl. 4, fig. 14.
Discorbinella convexa (Takayanagi). Takayanagi and Hasegawa, 1987, p. 37.

Eggerella bradyi (Cushman)
Verneuilina bradyi Cushman, 1911, p. 54, fig. 87.
Gaudryina bradyi (Cushman). Cushman, 1933a, p. 33, pl. 4, fig. 1.

Eggerella scabra (Williamson)
Bulimina scabra Williamson, 1858, p. 65, pl. 5, figs. 136, 137.
Eggerella scabra (Williamson). Cushman, 1937, p. 50, pl. 5, figs. 10, 11.

Elphidium advena (Cushman)
Polystomella advena Cushman, 1922b, p. 56, pl. 9, figs. 11, 12.
Elphidium advenum (Cushman). Cushman, 1930, p. 25, pl. 10, figs. 1, 2.

Elphidium crispum (Linné) ....Pl. 4, fig. 5
Nautilus crispum Linné, 1758, p. 709. Figured by Plancus, 1739, Conch., pl. 1, figs. 2d-f. (*fide* Ellis and Messina, 1940 *et seq.*).
Elphidium crispum (Linné). Cushman and Grant, 1927, p. 73, pl. 7, fig. 3.

Elphidium subincertum Asano

Elphidium subincertum Asano, 1950a, p. 10, figs. 56, 57.

Elphidium jenseni (Cushman)
Polystomella jenseni Cushman, 1924, p. 49, pl. 16, figs. 4, 6.
Elphidium jenseni (Cushman). Cushman, 1933b, p. 48, pl. 11, figs. 6, 7.

Evolvocassidulina belfordi Nomura
Evolvocassidulina belfordi Nomura, 1983a, p. 79, pl. 2, fig. 6 ; pl. 20, figs. 8-12.

Evolvocassidulina brevis (Aoki)
......................Pl. 4, fig. 13
"*Cassidulina*" *brevis* Aoki, 1968, p. 261, pl. 27, fig. 4.
Evolvocassidulina brevis (Aoki). Nomura, 1983b, p. 49, pl. 4, figs. 4-7 ; pl. 20, fig. 11 ; pl. 21, figs. 1-5.

Fissurina alveolata (Brady)
Lagena alveolata Brady, 1884, p. 487, pl. 60, figs. 30, 32.
Fissurina alveolata (Brady). Parr, 1950, p. 307. (*fide* Barker, 1960).

Fissurina auriculata var. *linearituba* (Cushman)
Lagena auriculata var. *linearituba* Cushman, 1913a, p. 33, pl. 17, fig. 5.
Fissurina auriculata var. *linearituba* (Cushman). Barker, 1960, p. 127, pl. 60, fig. 31.

Fissurina clathrata (Brady)
Lagena clathrata, Brady 1884, p. 485, pl. 60, fig. 4.
Fissurina clathrata (Brady). Parr, 1950, p. 310. (*fide* Barker, 1960).

Fissurina crebra (Matthes)
Lagena crebra Matthes, 1939, p. 72, pl. 5, figs. 66-70.
Fissurina crebra (Matthes). Barker, 1960, p. 122, pl. 59, fig. 6.

Fissurina cucullata Silvestri
Fissurina cuculata Silvestri, 1902, p. 146, text-figs. 23-25.

Fissurina exsculpta (Brady)
Lagena exsculpta Brady, 1884, p. 467, pl. 58, fig. 1 ; pl. 61, fig. 5.
Fissurina exsculpta (Brady). Parr, 1929-1931, p. 308. (*fide* Barker, 1960).

Fissurina formosa (Schwager)
Lagena formosa Schwager, 1866, p. 206, pl. 4, fig. 19.
Fissurina formosa (Schwager). Srinivasan and Sharma, 1980, p. 41, pl. 3, figs. 15, 16.

Fissurina fukamiensis (Asano)
Entosolenia fukamiensis Asano, 1953, p. 11, pl. 1, fig. 29.
Fissurina fukamiensis (Asano). Takayanagi and Hasegawa, 1987, p. 17.

Fissurina marginata (Montagu)
......................Pl. 9, fig. 18
Vermiculum marginatum Motagu, 1803, p. 524. (*fide* Ellis and Messina, 1940 *et seeq.*).
Fissurina marginata (Montagu). Murray, 1971, p. 97, pl. 39, fig. 4-6.

Fissurina orbignyana Seguenza
......................pl. 9, fig. 19
Fissurina orbignyana Seguenza, 1862, p. 66, pl. 2, figs. 24-26.

Frondicularia advena Cushman
Frondicularia advena Cushman, 1923, p. 141, pl. 20, figs. 1, 2.

Glabratella opercularis (d'Orbigny)
Rosalina opercularis d'Orbigny, 1839a, p. 93, pl. 3, figs. 24, 25.
Glabratella opercularis (d'Orbigny). Matoba, 1970, p. 54, pl. 5, fig. 4.

Glabratella subopercularis (Asano)
Discorbis subopercularis Asano, 1951c, p. 3, figs. 14-16.
Glabratella subopercularis (Asano). Matoba, 1970, p. 54, pl. 5, fig. 5.

Glandulina laevigata (d'Orbigny)
......................Pl. 9, fig. 20
Nodosaria (*Glandulina*) *laevigata* d'Orbigny, 1826, p. 252, pl. 10, figs. 1-3.

Globobulimina affinis (d'Orbigny)
......................Pl. 5, fig. 14
Bulimina affinis d'Orbigny, 1839a, p. 105, pl. 2, figs. 25-26.
Globobulimina affinis (d'Orbigny). Parker, 1964, p. 98, fig. 22.

Globobulimina auriculata (Bailey)
......................Pl. 5, fig. 13
Bulimina auriculata Bailey, 1851, p.

12, figs. 25-27.
Globobulimina auriculata (Bailey). Asano, 1958, p. 9, pl. 2, figs. 1-3.
Globobulimina hanzawai Asano
Globobulimina hanzawai Asano, 1958, p. 10, pl. 2, figs. 4-6.
Globobulinrda pacifica Cushman
Globobulimina pacifica Cushman, 1927b. p. 67, pl. 14, fig. 12.
Globobulimina perversa (Cushman)
Bulimina pyrula d'Orbigny var. *perversa* Cushman, 1921, p. 163, text-fig. 2.
Globobulimina perversa (Cushman). Asano, 1950b, p. 5, fig. 21
Globobulimina pupoides (d'Orbigny) ....Pl. 5, figs. 15, 16
Bulimina pupoides d'Orbigny, 1846, p. 185, pl. 11, figs. 11, 12.
Globocassidulina bisecta Nomura
Globocassidulina bisecta Nomura, 1983a, p. 73, pl. 2, figs. 2, 3 ; pl. 2, fig. 3 ; pl. 14, figs. 8-12 ; pl. 15, figs. 1-5
Globocassidulina moluccensis (Germeraad)
Cassidulina moluccensis Germeraad, 1946, p. 72, pl. 2, figs. 29-32. (*fide* Ellis and Messina, 1940 *et seq.*).
Globocassidulina moluccensis (Germeraad). Nomura, 1983b, p. 19, pl. 2, fig. 6, 7 ; pl. 11, fig. 12 ; pl. 12, figs. 1, 2.
Globocassidulina okinawaensis (LeRoy)
Cassidulina okinawaensis LeRoy, 1964, p. F40, pl. 11, figs. 21, 22.
Globocassidulina okinawaensis (LeRoy). Nomura, 1983b, p. 29, pl. 2, fig. 20 ; pl. 18, fig. 2.
Globocassidulina oriangulata Belford
Globocassidulina oriangulata Belford, 1966, p. 148, pl. 25, figs. 1-5, text-figs. 16, nos. 13, 14.
Globocassidulina pseudoquadrata Nomura
Globocassidulina pseudoquadrata Nomura, 1983a, p. 62, pl. 1, fig. 14 ; pl. 12, fig. 5, 6.
Globocassidulina subglobosa (Brady)
Cassidulina subglobosa Brady, 1881, p. 30.
Globocassidulina subglobosa (Brady). Belford, 1966, p. 149, pl. 25, figs. 11-16.
Globulina gibba d'Orbigny
Gobulina gibba d'Orbigny, 1826, p. 267, modèles no. 63.
Glomospira charoides (Parker and Jones)
Trochammina squamata charoides Parker and Jones, 1860, p. 304 (*fide* Eillis and Messina, 1940 *et seq.*).
Glomospira charoides (Parker and Jones). Cushman, 1925b, p. 25, pl. 2, fig. 12.
Glomospira gordialis (Parker and Jones) ....Pl. 4, fig. 4
Ammodiscus gordialis Parker and Jones, 1880, pl. 5, fig. 22. (*fide* Ellis and Messina, 1940 *et seq.*).
Glomospira gordialis (Parker and Jones). Cushman and Javis, 1928, p. 87, pl. 12, figs. 7, 8.
Gyroidina altiformis R.E. and K.C. Stewart ....Pl. 7, fig. 3
Gyroidina soldanii var. *altiformis* R.E. and K.C. Stewart, 1930, p. 67, pl. 9, fig. 2.
Gyroidina komatsui Aoki....Pl. 7, fig. 4
Gyroidina komatsui Aoki, 1964, p. 167, pl. 25, fig. 16.
Gyroidina orbicularis d'Orbigny
Gyroidina orbicularis d'Orbigny, 1826, p. 278, modèles no. 13.
Gyroidina profunda Aoki
Gyroidina profunda Aoki, 1964, p. 167, pl. 25, fig. 17.
Gyroidina soldanii d'Orbigny ....Pl. 7, figs. 5, 6
Gyroidina soldanii d'Orbigny 1826, p. 278, modèles no. 36.
Gyroidinoides nipponicus (Ishizaki)
Gyroidina nipponica Ishizaki, 1944, p. 102, pl. 3, fig. 3. (*fide* Ellis and Messina, 1940 *et seq.*).
Gyroidinoides nipponicus (Ishizaki). Matoba, 1967, p. 255, pl. 29, fig. 13.
Hanzawaia nipponica Asano ....Pl. 6, fig. 4
Hanzawaia nipponica Asano, 1944, p.

99, pl. 4, fig. 1, 2.

Heronallenia lingulata (Burrows and Holland)
Discorbina lingulata Burrows and Holland, 1869, p. 297, pl. 7, fig. 33. (*fide* Ellis and Messina, 1940 *et seq.*).
Heronallenia lingulata (Burrows and Holland). Chapman and Parr, 1931, p. 236, pl. 9, fig. 6.

Heterolepa haidingerii (d'Orbigny)
Rotalia haidingerii d'Orbigny, 1846, p. 154, pl. 8, figs. 7-9.

Hetrolepa subpraecinctus (Asano)
Eponides subpraecinctus Asano, 1951c, p. 12, figs. 88-90.
Heterolepa subpraecinctus (Asano). Takayanagi and Hasegawa, 1978, p. 19.

Hoeglundina elegans (d'Orbigny)
Rotalia (*Turbinulina*) *elegans* d'Orbigny, 1826, p. 276.
Hoeglundina elegans (d'Orbigny). Brotzen, 1948, p. 92.

Hyalinea balthica (Schroeter) ....Pl. 6, fig. 2
Nautilus balthicus Schroeter, 1783, p. 20, pl. 1, fig. 2. (*fide* Ellis and Messina, 1940 *et seq.*).
Hyalinea balthica (Schroeter). Hofker, 1951, p. 508, figs. 364-348.

Islandiella kazusaensis (Asano and Nakamura)
Cassidulina kazusaensis Asano and Nakamura, 1937, p. pl. 14, fig. 2.
Islandiella kazusaensis (Asano and Nakamura). Nomura, 1983b, p. 6, pl. 1, figs. 5 ; pl. 11, figs. 10, 11.

Karreriella apicularis (Cushman)
Gaudryina apicularis Cushman, 1911, p. 69, text-fig. 110.
Karreriella (*Karrerulina*) *apicularis* (Cushman). Barker, 1960, p. 94, pl. 46, figs. 17-19.

Karreriella baccata (Schwager)
Gaudryina baccata Schwager, 1866, p. 200, pl. 4, fig. 12
Karreriella baccata (Schwager). Cushman, 1937a, p. 133, pl. 15, figs. 20-24.

Karreriella bradyi (Cushman)
Gaudryina bradyi Cushman, 1911, p. 67, fig. 107.
Karreriella bradyi (Cushman). Barker, 1960, p. 94, pl. 46, fig. 1-4.

Lagena acuticosta Reuss
Lagena acuticosta Reuss, 1861, p. 305, pl. 1, fig. 4. (*fide* Ellis and Messina, 1940 *et seq.*).

Lagena gracillima (Seguenza)
Amphorina gracillima Seguenza, 1862, p. 51, pl. 1, fig. 37.
Lagena gracillima (Seguenza). Brady, 1884, p. 456, pl. 59, figs. 19-26, (not. 27, 28).

Lagena elongata (Ehrenberg)
Miliola elongata Ehrenberg, 1844, p. 274. (*fide* Ellis and Messina, 1940 *et seq.*).
Lagena elongata (Ehrenberg). Brady, 1884, p. 456, pl. 56, fig. 29

Lagena hispida Reuss
Lagena hispida Reuss, 1858, p. 434. (*fide* Ellis and Messina, 1940 *et seq.*).

Lagena laevis (Montagu) ..Pl. 9, fig. 17
Vermiculum laevis Montagu, 1803, p. 524. (*fide* Ellis and Messina, 1940 *et seq.*).
Lagena laevis (Montagu). Cushman, 1913, p. 5, pl. 1, fig. 3 ; pl. 38, fig. 5.

Lagena parri Loeblich and Tappan
Lagena parri Loeblich and Tappan, 1953, p. 64, pl. 11, figs. 11-13.

Lagena pliocenica Cushman and Gray
Lagena pliocenica Cushman and Gray, 1946, p. 68, pl. 12, figs. 22-25.

Lagena striata (d'Orbigny)
Oolina striata d'Orbigny, 1839b, p. 21, pl. 5, fig. 12.
Lagena striata (d'Orbigny). Asano, 1938c, p. 217, pl. 27, fig. 26 ; pl. 29, fig. 28.

Lagena substriata Williamson
Lagena substriata Williamson, 1848, p. 15, pl. 2, fig. 12. (*fide* Ellis and Messina, 1940 *et seq.*).

Lagena sulcata spicata Cushman and McCulloch
Lagena sulcata var. *spicata* Cushman

and McCulloch, 1950, p. 360, pl. 48, figs. 3-7.

Lenticulina kamakuraensis Asano

Lenticulina kamakuraensis Asano, 1936b, p. 612, pl. 31, fig. 1.

Marginulina glabra d'Orbigny

Marginulina glabra d'Orbigny, 1826, p. 259, modèles no. 55.

Marsipella elongata Norman .... Pl. 3, fig. 10

Marsipella elongata Norman, 1878, p. 281, pl. 16, fig. 7. (*fide* Ellis and Messina, 1940 *et seq.*).

Martinottiella communis (d'Orbigny) .... Pl. 4, fig. 2

Clavulina communis d'Orbigny, 1826, p. 268.

Martinottiella communis (d'Orbigny). Cushman, 1933a, p. 37, pl. 4, figs. 6-8.

Martinottiella communis (d'Orbigny) var. .... Pl. 4, fig. 3

This variety resembles the typical form, but differs from it in having a more coarsely finished surface.

Melonis barleeanus (Williamson) .... Pl. 4, fig. 9

Nonionina barleeana Williamson, 1858, p. 32, pl. 3, figs. 68, 69.

Melonis nicobarensis (Cushman)

Nonion nicobarense Cushman, 1936, p. 67, pl. 12, fig. 9.

Melonis parkerae (Uchio) .... Pl. 4, fig. 7

Nonion parkerae Uchio, 1960, p. 60, pl. 4, figs. 9, 10.

Melonis parkerae (Uchio). Matoba, 1967, p. 256, pl. 29, fig. 15.

Melonis sphaeroides Voloshinova .... Pl. 4, fig. 8

Melonis sphaeroides Voloshinova, 1958, p. 153, pl. 3, figs. 8, 9.

Miliolinella australis (Parr)

Quinqueloculina australis Parr, 1932, p. 7, pl. 1, fig. 8.

Miliolinella(?) *australis* (Parr). Barker, 1960, p. 10, pl. 5, figs. 10, 11.

Miliolinela circularis (Bornemann)

Triloculina circularis Bornemann, 1855, p. 349, pl. 19, fig. 4.

Miliolinella circularis (Bornemann). Asano, 1951a, p. 9, figs. 65-67.

Nodosaria aculeata d'Orbigny

Nodosaria aculeata d'Orbigny, 1846, p. 35, pl. 1, figs. 26, 27.

Nodosaria acuminata Hantken var. *uniforminata* LeRoy

Nodosaria acuminata Hantken var. *uniforminata* LeRey, 1944, p. 80, pl. 1, fig. 21.

Nodosaria holoserica Schwager .... Pl. 9, fig. 9

Nodosaria holoserica Schwager, 1866, p. 2, pl. 5, fig. 9

Nodosaria longiscata d'Orbigny .... Pl. 9, fig. 8

Nodosaria longiscata d'Orbigny, 1846, p. 32, pl. 1, figs. 29. 10, 12.

Nodosaria pupa Karrer

Nodosaria pupa Karrer, 1878, p. 89, pl. 5, fig. 9. (*fide* Ellis and Messina, 1940 *et seq.*).

Nodosaria pyrula d'Orbigny var. *longicostata* Cushman

Nodosaria pyrula d'Orbigny var. *longi-costata* Cushman, 1921, p. 188, pl. 33, figs. 8, 9.

Nodosaria tosta Schwager .. Pl. 9, fig. 5

Nodosaria tosta Schwager, 1866, p. 219, pl. 5, fig. 42.

Nonion depressulus (Walker and Jacob)

Nautilus depressulus Walker and Jacob, 1798, p. 641, pl. 14, fig. 33. (*fide* Ellis and Messina, 1940 *et seq.*).

Nonion depressulus (Walker and Jacob). Barker, 1960, p. 224, pl. 109, figs. 6, 7.

Nonion japonicus Asano .... Pl. 4, fig. 6

Nonion japonicus Asano, 1938a, p. 593, pl. 15, figs. 1, 2

Nonionella miocenica Cushman

Nonionella miocenica Cushman, 1926b. p. 64.

Nonionellina labradorica (Dawson) .... Pl. 4, fig. 12

Nonionina labradorica Dawson, 1860, p. 191, text-fig. 4. (*fide* Ellis and Messina, 1940 *et seq.*).

Nonionellina labradorica (Dawson).

Cushman, 1939a, p. 23, pl. 6, figs. 13-16.

Oolina costata (Williamson)
Entosolenia costata Williamson, 1858, p. 9, pl. 1, fig. 18.
Oolina costata (Williamson). Loeblich and Tappan, 1953, p. 68, pl. 13, figs. 4-6.

Oolina globosa (Montagu)
Vermiculum globosum Montagu, 1803, p. 523. (*fide* Ellis and Messina, 1940 *et seq.*).
Oolina globosa (Montagu). Parr, 1950 p. 302.

Oolina melo d'Orbigny
Oolina melo d'Orbigny, 1839a, p. 20, pl. 5, fig. 9.

Oridorsalis tener (Brady)
.... Pl. 8, figs. 3, 5
Truncatulina tenera Brady, 1884, p. 665, pl. 95, fig. 11
Oridorslis tener (Brady), Pflum and Frerichs, 1976, p. 106, pl. 6, figs 2-4.

Oridorsalis umbonatus (Reuss)
Rotalia umbonata Reuss, 1851, p. 75, pl. 5, fig. 35.
Oridorsalis umbonatus (Reuss). Parker, 1964, p. 626, pl. 99, figs. 4-6.

Osangularia culter (Parker and Jones)
Planorbulina culter Parker and Jones, 1865, p. 421, pl. 19, fig. 1.
Osangularia culter (Parker and Jones). Todd, 1965, p. 25, pl. 15, fig. 1.

Osangularia rugosa (Phleger and Parker)
Pseudoparrella(?) *rugosa* Phleger and Parker, 1951, p. 28, pl. 15, figs. 8, 9.
Osangularia rugosa (Phleger and Parker). Pflum and Frerichs, 1976, p. 122, pl. 7, figs. 2-4.

Paracassidulina miuraensis (Higuchi)
Cassidulina miuraensis Higuchi, 1956, p. 58, text-figs. 58, 59.
Paracassidulina miuraensis (Higuchi). Nomura, 1983a, pl. 5, fig. 3; pl. 25, figs. 4-6; 1983b, p. 70, pl. 6, figs. 7-10.

Paracassidulina neocarinata (Thalmann)
Cassidulina neocarinata Thalmann, 1950, p. 44.
Paracassidulina neocarinata (Thalmann). Nomura, 1983b, p. 63, pl. 5, fig. 11.

Paracassidulina nipponensis (Eade)
Globocassidulina nipponensis Eade, 1967, p. 65, pl. 13, figs. 1, 2, 4.
Paracassidulina nipponensis (Eade). Nomura, 1983a, p. 95, pl. 25, fig. 3; 1983b, pl. 6, figs. 13, 14.

Paracassidulina quasicarinata Nomura
Paracassidulina quasicarinata Nomura, 1983a, p. 100, pl. 2, fig. 19; pl. 25, figs. 9-11.

Parafissurina lateralis Cushman
Parafissurina lateralis Cushman, 1913, p. 9, pl. 1, fig. 1.

Parrelloides bradyi (Trauth)
.... Pl. 6, fig. 10; Pl. 7, fig. 7
Truncatulina bradyi Trauth, 1918, p. 235
Parrelloides bradyi (Trauth). Belford, 1966, p. 100, pl. 11, figs. 10-19.

Pileolina(?) *patelliformis* (Brady)
Discorbina patelliformis Brady, 1884, p. 647, pl. 88, fig. 3; pl. 89, fig. 1.
Pileolina(?) *patelliformis* (Brady). Barker, 1960, p. 184, pl. 88, fig. 3; pl. 89, figs. 1.

Planulina ariminensis d'Orbigny
Planulina ariminensis d'Orbigny, 1826, p. 280, pl. 5, figs. 1-3.

Plectofrondicularia goharai Kuwano
.... Pl. 9, figs. 10, 11, 12
Plectofrondicularia goharai Kuwano, 1950, p. 312, fig. 7.

Plectofrondicularia miocenica Cushman
Plectofrondicularia miocenica Cushman, 1926b. p. 58, pl. 7, figs. 10, 11; pl. 8, figs 11, 12.

Plectofrondicularia totomiensis Makiyama .... Pl. 9, fig. 13
Plectofrondicularia totomiensis Makiyama, 1931, p. 51, pl. 2, fig. 16.

Pleurostomella alternans Schwager
.... Pl. 9, figs. 15, 16
Pleurostomella alternans Schwager, 1866, p. 238, pl. 6, figs. 79, 80

Pleurostomella brevis Schwager
.... Pl. 9, fig. 14

Pleurostomella brevis Schwager, 1866, p. 236, pl. 6, fig. 81.

Psammosphaera fusca Schulze

Psammosphaera fusca Schulze, 1875, p. 113, pl. 2, fig. 8. (*fide* Ellis and Messina, 1940 *et seq.*).

Pseudononion grateloupi (d'Orbigny)

Nonionina grateloupi d'Orbigny, 1826, p. 294.

Pseudononion grateloupi (d'Orbigny). Hasegawa, 1979, p. 152.

Pseudononion japonicum Asano ....Pl. 4, fig. 10

Pseudononion japonicum Asano, 1936a, p. 347, text-figs. a-c.

Pullenia bulloides (d'Orbigny) ....Pl. 8, fig. 9

Nonionina bulloides d'Orbigny, 1846, p. 107, pl. 5, figs. 9, 10.

Pullenia bulloides (d'Orbigny). Parker and Jones, 1862, p. 184. (*fide* Loeblich and Tappan, 1964).

Pullenia quinqueloba (Reuss)

Nonionina quinqueloba Reuss, 1851, p. 71, pl. 5, fig. 31. (*fide* Ellis and Messina, 1940 *et seq.*).

Pullenia quinqueloba (Reuss). Cushman and Todd, 1943, p. 11, pl. 2, fig. 8.

Pullenia salisburyi R.E. and R.C. Stewart

Pullenia salisburyi R.E. and R.C. Stewart, 1930, p. 72, pl. 8, fig. 2.

Pyrgo elongata (d'Orbigny)

Biloculina elongata d'Orbigny, 1826, p. 298.

Pyryo elongata (d'Orbigny). Cushman, 1929, p. 70, pl. 19, figs. 2, 3.

Pyrgo fornasinii Chapman and Parr

Pyrgo fornasinii Chapman and Parr, 1935, p. 5.

Pyrgo murrhina (Schwager)

Biloculina murrhina Schwager, 1866, p. 203, pl. 4, fig. 15.

Pyrgo murrhina (Schwager). Cushman, 1929, p. 71, pl. 19, fig. 6, 7.

Pyrgo vespertilio (Schlumberger)

Biloculina vespertilio Schlumberger, 1891, p. 174, pl. 10, figs. 74-76.

Pyrgo vespertilio (Schlumberger), Thalmann, 1932, p. 295.

Quadrimorphina laevigata (Phleger and Parker)

Valvulineria laevigata Phleger and Parker, 1951, p. 25, pl. 13, figs. 11, 12.

Quadrimorphina laevigata (Phleger and Parker). Belford, 1966, p. 155, pl. 37, figs. 21-25.

Quinqueloculina akneriana d'Orbigny

Quinqueloculina akneriana d'Orbigny, 1846, p. 290, pl. 18, figs. 16-20.

Quinqueloculina contorta d'Orbigny

Quinqueloculina contorta d'Orbigny, 1846, p. 298, pl. 20, figs. 4-6.

Quinqueloculina lamarckiana d'Orbigny

Quinqueloculina lamarckiana d'Orbigny, 1839a, p. 189, pl. 11, figs. 14, 15.

Quinqueloculina polygona d'Orbigny

Quinqueloculina polygona d'Orbigny, 1839a, p. 198, pl. 12, figs. 21-23.

Quinqueloculina totomiensis Asano

Quinqueloculina totomiensis Asano, 1936c, p. 327, pl. 36, fig. 9.

Quinqueloculina vulgaris d'Orbigny ....Pl. 8, fig. 6

Quinqueloculina vulgaris d'Orbigny, 1826, p. 302

Rectobolivina bifrons (Brady)

Sagrina bifrons Brady, 1881, p. 34.

Rectobolivina bifrons (Brady). Cushman, 1927b, p. 204, pl. 23, figs. 13, 14.

Rectobolivina raphanus (Parker and Jones)

Uvigerina (*Sagrina*) *raphanus* Parker and Jones, 1865, p. 364, pl. 18, figs. 16, 17.

Rectobolivina raphanus (Parker and Jones). Loeblich and Tappan, 1964, p. C533, figs. 438 (9-11).

Reophax piliformis Brady ....Pl. 2, fig. 7 ; Pl. 3, fig. 12

Reophax piliformis Brady, 1884, p. 292, pl. 30, figs. 18-20.

Rhabdammina abyssorum M. Sars ....Pl. 2, fig. 8 ; Pl. 3, fig. 9

Rhabdammina abyssorum M. Sars, 1867, p. 248. (*fide* Ellis and Messina, 1940 *et seq.*).

Rhabdammina abyssorum M. Sars forma A .... Pl. 2, fig. 9

This form is similar to the form described by M. Sars, but is distinguished by having a coarser grained surface and a test of larger diameter.

Robulus calcar (Linné)

Nautilus calcar Linné, 1767, p. 1162. (*fide* Ellis and Messina, 1940 *et seq.*).

Robulus calcar (Linné). d'Orbigny, 1846, p. 99, pl. 4, figs. 18–20.

Robulus depressus Asano

Robulus depressus Asano, 1938c, p. 202, pl. 25-fig. 15 ; pl. 26, figs. 10, 27 ; pl. 28, figs. 11.

Robulus lucidus (Cushman)

Cristellaria lucida Cushman, 1923, p. 111, pl. 30, fig. 2.

Robulus lucidus (Cushman). Asano, 1951d, p. 5, figs. 21, 22

Robulus nikobarensis (Schwager)

Cristellaria nikobarensis Schwager, 1866, p. 243, pl. 6, fig. 87.

Robulus nikobarensis (Schwager). Asano, 1938c, p. 204, pl. 28, figs. 5, 6 ; pl. 29, fig. 8.

Robulus orbicularis (d'Orbigny) .... Pl. 9, fig. 21

Robulina orbicularis d'Orbigny, 1826, p. 288, pl. 15, figs. 8, 9.

Robulus pseudorotulatus Asano .... Pl. 9, fig. 22

Robulus pseudorotulatus Asano, 1938, p. 201, pl. 25, figs. 1, 3, 4 ; pl. 26, fig. 28 ; pl. 31, fig. 3, 4.

Robulus surugaensis Asano

Robulus surugaensis Asano, 1936c, p. 328, pl. 37, fig. 4.

Rosalina bradyi (Cushman)

Discorbis globularis var. *bradyi* Cushman, 1915, p. 12, pl. 8, fig. 1.

Rosalina bradyi (Cushman). Matoba, 1970, p. 60, pl. 4, fig. 8.

Rosalina globularis d'Orbigny

Rosalina globularis d'Orbigny, 1826, p. 217. pl. 13, figs. 1–4.

Rutherfordoides mexicanus (Cushman) .... Pl. 4, fig. 11

Virgulina mexicana Cushman, 1922a, p. 120, pl. 23, fig. 8.

Rutherfordoides mexicanus (Cushman). Kohl, 1985, p. 89, pl. 18, fig. 3.

Saccammina sphaerica M. Sars .... Pl. 2, fig. 5

Saccammina sphaerica M. Sars, 1872, p. 250 (*fide* Ellis and Messina, 1940 *et seq.*).

Saccorhiza ramosa Brady

Saccorhiza ramosa Brady, 1879, p. 33, pl. 3, figs. 14, 15.

Sigmoilopsis schlumbergeri (Silvestri) .... Pl. 8, fig. 8

Sigmoilina schlumbergeri Silvestri, 1904, p. 267.

Sigmoilopsis schlumbergeri (Silvestri). Finlay, 1947, p. 270.

Siphotextularia concava (Karrer)

Plecanium concavum Karrer, 1868, p. 129, pl. 1, fig. 3. (*fide* Ellis and Messina, 1940 *et seq.*).

Siphotextularia concava (Karrer). Barker, 1960, p. 86, pl. 42, figs. 13, 14.

Siphotextularia saulcyana (d'Orbigny)

Textularia saulcyana d'Orbigny, 1839a, p. 146, pl. 1, fig. 21, 22.

Textularia (*Siphotextularia*) *saulcyana* d'Orbigny. Asano, 1951a, p. 7, figs. 33, 34.

Sphaeroidina austriaca d'Orbigny

Sphaeroidina austriaca d'Orbigny, 1846, p. 284, pl. 20, figs. 19–21.

Sphaeroidina bulloides d'Orbigny .... Pl. 8, fig. 10

Sphaeroidina bulloides d'Orbigny, 1826, p. 267.

Sphaeroidina compacta Cushman and Todd

Sphaeroidina compacta Cushman and Todd, 1949, p. 19, pl. 4, fig. 14.

Spirosigmoilinella compressa Matsunaga .... Pl. 3, fig. 11

Spirosigmoilinella compressa Matsunaga, 1955, p. 50, text-figs. 1, 2.

Stilostomella consobrina (d'Orbigny)

....................Pl. 9, figs. 6, 7
Dentalina consobrina d'Orbigny, 1846, p. 46, pl. 2, figs. 1-3.
Stilostomella consobrina (d'Orbigny). Barker, 1960, p. 130, pl. 62, figs. 23, 24.

Stilostomella fistuca (Schwager) ....Pl. 9, fig. 4
Nodosaria fistuca Schwager, 1866, p. 216, pl. 5, figs. 36, 37.
Stilostomella fistuca (Schwager). Srinivasan and Sharma, 1980, p. 45, pl. 7, figs. 7-12.

Stilostomella ketienziensis (Ishizaki)
Ellipsondosaria ketienziensis Ishizaki, 1943, p. 684, text-figs. 1, 6, 11.
Stilostomella ketienziensis (Ishizaki). Takayanagi and Hasegawa, 1987, p. 15.

Stilostomella lepidula (Schwager) ....Pl. 9, figs. 1, 2
Nodosaria lepidula Schwager, 1866, p. 210, pl. 5, figs. 27, 28.
Stilostomella lepidula (Schwager). LeRoy, 1964, p. F35.

Tosaia hanzawai Takayanagi ....Pl. 5, fig. 17
Tosaia hanzawai Takayanagi, 1953, p. 30, pl. 4, fig. 7

Trifarina angulosa (Williamson)
Uvigerina angulosa Williamson, 1885, p. 67, pl. 5, fig. 140.
Trifarina angulosa (Williamson). Murray, 1971, p. 123, pl. 51, figs. 1-6.

Trifarina bradyi Cushman
Trifarina bradyi Cushman, 1923, p. 99, pl. 22, figs. 3-9.

Trifarina occidentalis (Cushman) ....Pl. 5, figs. 6, 7
Uvigerina occidentalis Cushman, 1923, p. 169.

Triloculina tricarinata d'Orbigny
Triloculina tricarinata d'Orbigny, 1826, p. 299.

Trochammina globigeriniformis (Parker and Jones)....Pl. 2, fig. 4, Pl. 3, fig. 8
Lituola nautiloidea var. *globigeriniformis* Parker and Jones, 1865, p. 407, pl. 15, figs. 46, 47.
Trochammina globigeriniformis (Parper and Jones). Poag, 1981, p. 85, pl. 13, fig. 1; pl. 14, fig. 1.

Uvigerina hispidocostata Cushman and Todd ....Pl. 5, figs. 3, 4, 5
Uvigerina hispido-costata Cushman and Todd, 1945, p. 51, pl. 7, figs. 27, 31.

Uvigerina peregrina Cushman
Uvigerina peregrina Cushmasn, 1923, p. 166, pl. 42, figs. 7-10.

Uvigerina proboscidea Schwager ....Pl. 5, figs. 1, 2
Uvigerina proboscidea Schwager, 1866, p. 250, pl. 7, fig. 96.

Uvigerina schencki Asano
Uvigerina schencki Asano, 1950b, p. 17, figs. 74, 75.

Uvigerina segundoensis Cushman and Galliher
Uvigerina segundoensis Cushman and Galliher, 1934, p. 26, pl. 4, figs. 11.

DESCRIPTION OF NEW SPECIES

Superfamily Discorbacea Ehrenberg, 1838
Family Discorbidae Ehrenberg, 1838
Genus *Valvulineria* Cushman, 1926
Valvulineria fujikawaensis Akimoto, n. sp.

Pl. 1, fig. 2; Pl. 7, figs. 1, 2.

Description: Test small, ovoid in outline, longer than broad, biconvex, trochospirally coiled, spiral side more convex than umbilical side, periphery rounded, not lobulate; composed of two whorls; chambers somewhat inflated, six in last whorl, increasing gradually in size as added; sutures distinct, not limbate, radial, gently curved, somewhat depressed on spiral side, umbilical side not limbate, radial, nearly straight, more deeply depressed than spiral side; aperture interiomarginal, extraumbilical-umbilical; umbilicus covered with a broad triangle or rhomboidal valvular plate.

Dimension (in mm):

	length	breadth	thickness
Holotype	0.22	0.18	0.10
Paratypes	0.22	0.17	0.12
	0.18	0.14	0.10

Type: Holotype, IGPS coll. cat. no. 100603, from sample ISH01, Kanzaka Formation, near the hamlet of Kanzaka, Shimobe-cho, Nishiyatsushiro-gun, Yamanashi Prefecture.

Remarks: This species is similar to *Valvulineria sadonica* Asano, but differs in having a smaller test, deeply depressed suture on the umbilical side, and being not lobulate in outline. It also differs from *Valvulineria nipponica* Ishizaki in having smaller numbers of chamber, not limbate and raised sutures on the spiral side, and not inflated chambers on the ventral side.

Occurrence: Rare, from the type locality and the lower part of the Shimobe Formation.

Superfamily Buliminacea Jones, 1875
Family Bolivinitidae Cushman, 1927
Genus *Brizalina* Costa, 1856
Brizalina kaiensis Akimoto, n. sp.

Pl. 1, fig. 1; Pl. 5, fig. 12

Description: Test small, elongate, tapering anti-adaperturally, twice and a half as long as broad, oval to compressed in front view; chambers distinct, not inflated, six pairs in biserial arrangement, gradually increase in size; sutures weakly depressed, not limbate, straight arranged obliquely, to form an angle of 30 degrees with the horizontal in the adult; wall smooth, ornamented with 6 to 8 continuous to discontinuous longitudinal costae, except for last chamber, aperture oval, without lip, reaching to basal suture of chamber; toothplate unknown.

Dimension (in mm):

	heigth	breadth	thickness
Holotype	0.18	0.08	0.06
Paratypes	0.17	0.07	0.06
	0.17	0.08	0.06

Type: Holotype, IGPS coll. cat. no. 100602, from sample NAN01, Minobu Formation, near Nanbu, Minobu-cho, Minamikoma-gun, Yamanashi Prefecture.

Remarks: This species is similar to both *Bolivinita subangularis* (Brady) and *Brizalina subangularis ogasaensis* (Asano), but differs from them in having a smaller test, many but weakly developed costae, and less steeply angled sutures with the horizontal. It differs from *Brizalina tongi* (Cushman) in possessing costae which are restricted only to the peripheral portion of the test. It is also distinguished from *Brizalina costata* (d'Orbigny) by having a more broad aperture, fewer numbers of both chambers and costae.

Occurrence: Rare, only from the type locality.

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APPENDIX

Distribution of selected grain components in the Recent marine sediments off southwest Japan and around Hachijojima Island

In order to delineate the geological setting and the nature of substrate which may be responsible for the distribution of kinds of grains in sediment, Recent marine sediments were examined in the laboratory.

Besides picking-up Recent foraminifera, the occurrence of selected biogenous grains of greater than 0.125 mm diameter was examined under a stereomicroscope. These grains consist of such organic remains as pteropods, diatoms, radiolarians, pellets and plant fragments, as well as conspicuous inorganic grains of glauconite. Figures 56-63 show the distribution of these grains.

1. Tanegashima area

Figure 59 shows the distribution of each kind of grains in this area. Diatoms occurred in several points which are restricted to a rather flat topographical

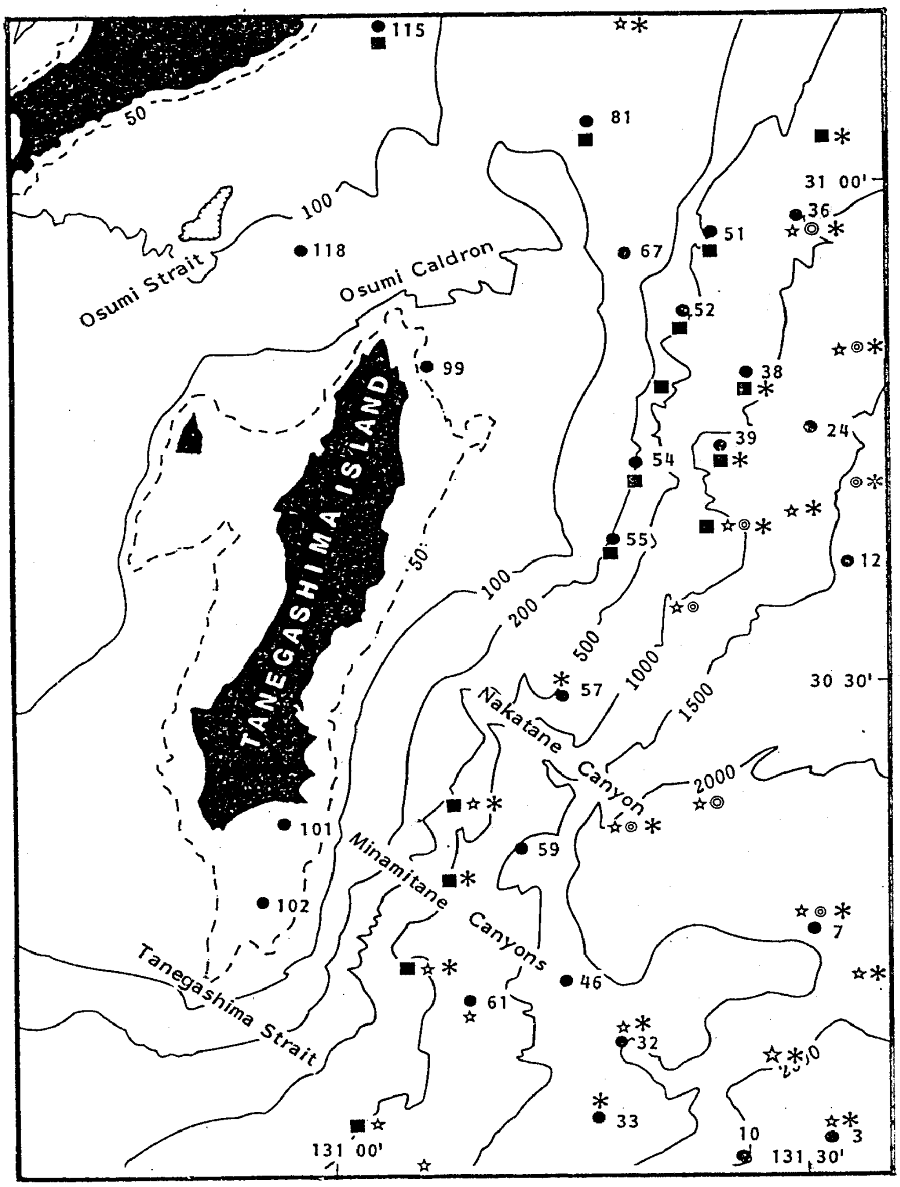


Fig. 59. Distribution of selected kinds of grains off Tanegashima Island. (Legend same as in Figs. 60 and 61).

area with a submarine canyon in water greater than about 800 m (GH84-3-7, 11, 23, 29, 36, 40, 41 and 44). Radiolarians are present at many points below 500 m water depth (GH84-3-1, 3, 7, 9, 11, 23, 25, 29, 32, 36, 40, 41, 44, 61, 63, 74, 76, 78 and 79 ; especially remarkable at 9). The distribution of radiolarian grains resembles that of diatoms. Such a rather flat area below 500 m water depth also has a high frequency occurrence of pellets (GH84-3-1, 3, 7, 9, 11, 23, 25, 32, 33, 35, 36, 38, 39, 40, 44, 57, 74, 75, 76 and 79). Points of 7, 25 and 44 are situated in a small slope break on the continental slope. The distribution of pteropods is restricted to water depth shallower than 1,000 m. Plant fragments and glauconite grains are absent in this area.

2. Kumanonada area

Figure 60 shows the distribution of radiolarians and diatoms in this area, and Fig. 61 that of plant fragments,

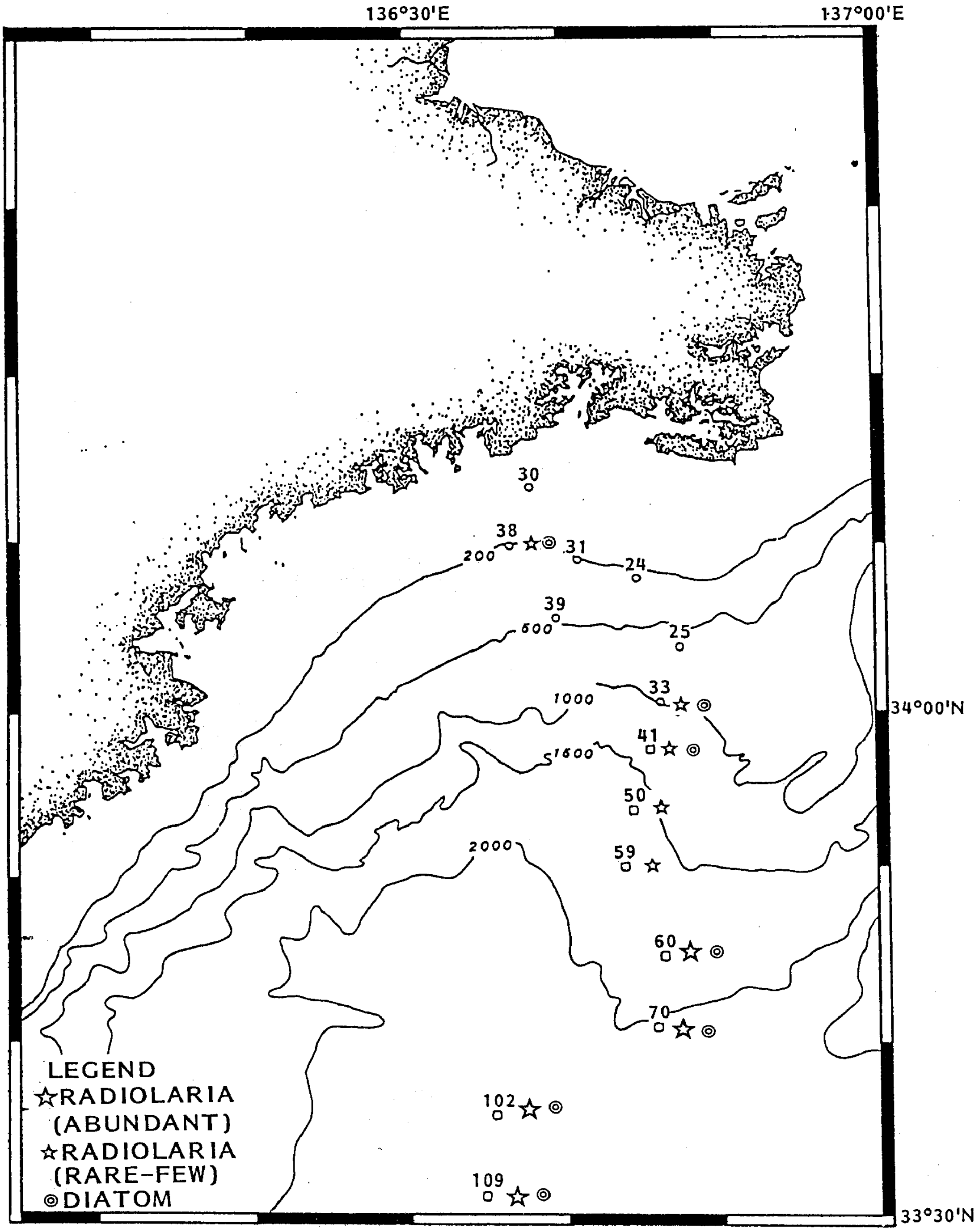


Fig. 60. Distribution of selected kinds of grains in the Kumanonada area.

glauconite and pellets. Diatoms are found at several points but rarely (GH82-2-33, 38, 41, 60, 70, 102 and 109). The abundance of radiolarians is subject to submarine topography: highly frequent occurrences are restricted within the Kumano Basin. Pteropods occurred above about 600 m depth in the upper bathyal zone. Pellets are present at most points (GH82-2-25, 33, 38, 39, 50, 60, 102 and 109). Plant fragments were commonly recognized in this area, and

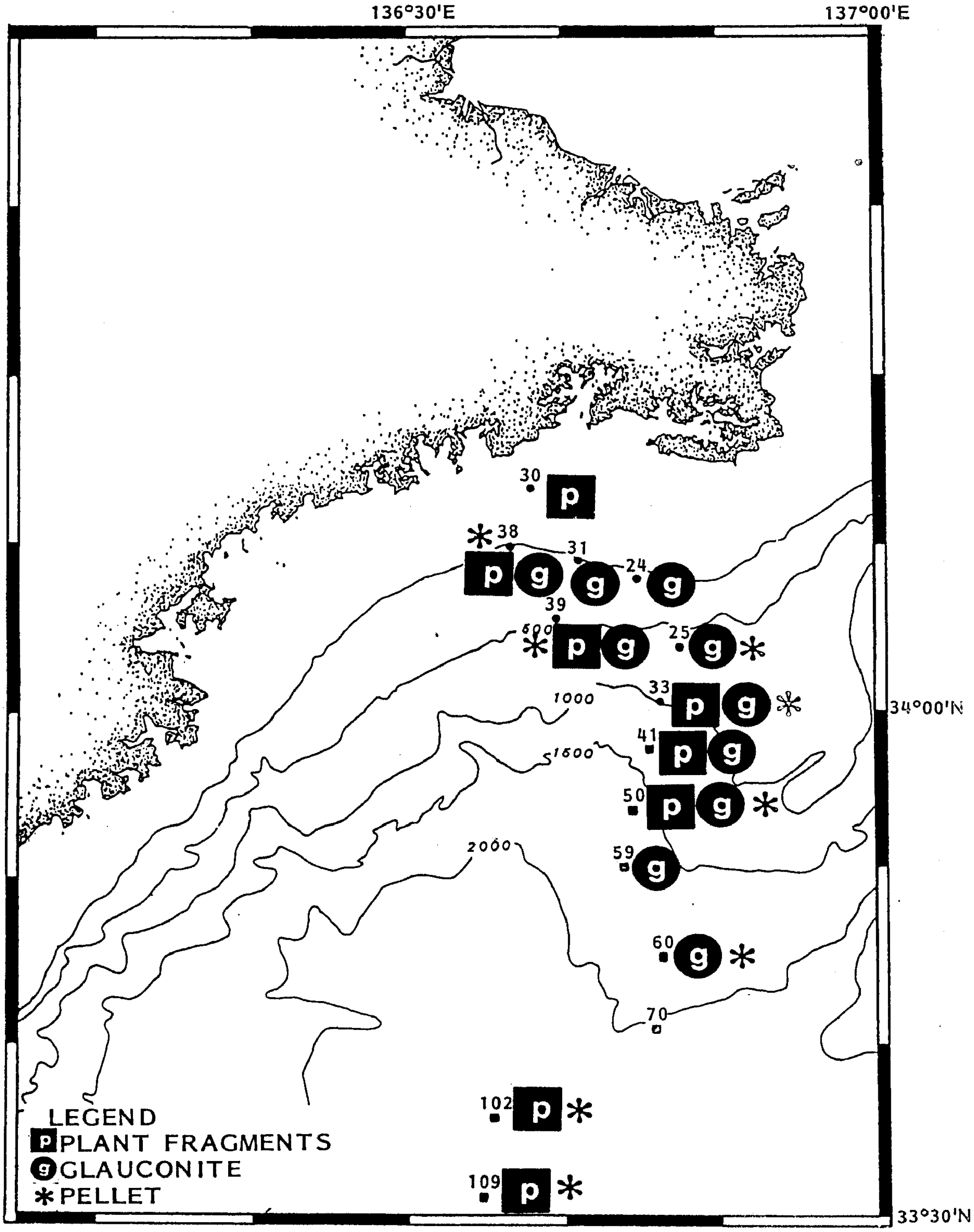


Fig. 61. Distribution of selected kinds of grains in the Kumanonada area.

especially abundant in the Kumano Basin. The occurrence of glauconite grains was restricted to the continental slope area (GH-82-2-24, 25, 31, 33, 38, 39, 41, 47, 50, 59 and 60).

3. Enshunada area

The distribution of selected grains is shown in Fig. 62. Diatoms occurred only in a limited number of samples from a small basin (KT85-6-G7), the Nankai Trough (KT86-11-PP1, PP2, PP7, PP8

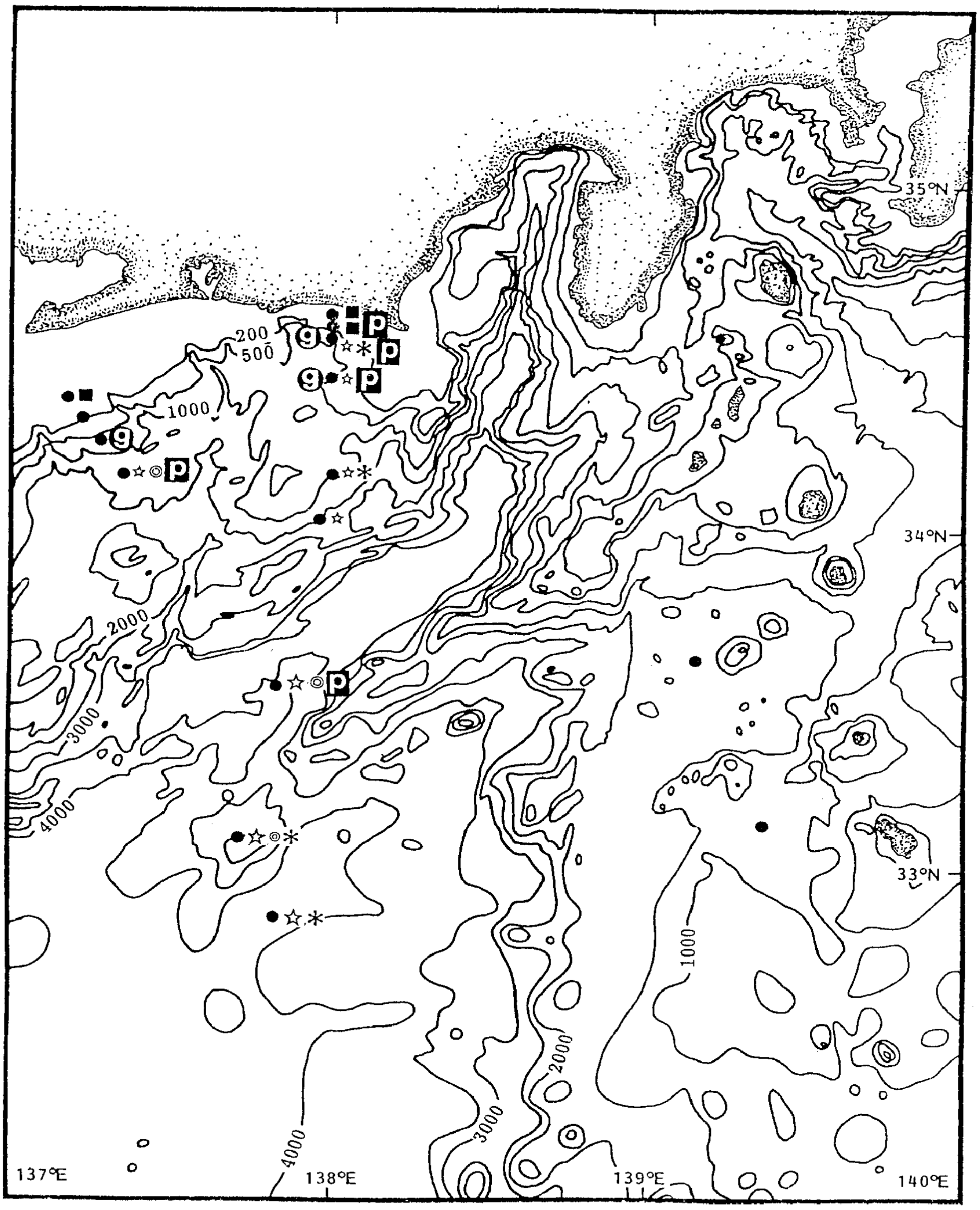


Fig. 62. Distribution of selected kinds of grains in the Enshunada area. (Legend same as in Figs. 60 and 61).

and PP9) and the northern slope of the Zenisu Ridge (KT86-11-PP6). Radiolarians are present in most samples at depths greater than 200 m, but their frequency varies strikingly from sample to sample. Highly frequent occurrences are confined to the Nankai Trough, the Shikoku Basin and the Zenisu Ridge. The latter two areas are also characterized by an abundant occurrence of pellets (only two points on the continental slope off the River Tenryugawa). Samples on the continental slope and in the Nankai Trough contain plant fragments which were not recognized outside this trough. It is worthy of notice that pellets are absent in any of the samples from the Nankai Trough, and plant fragments were not present on the ocean floor. These facts may be very important to

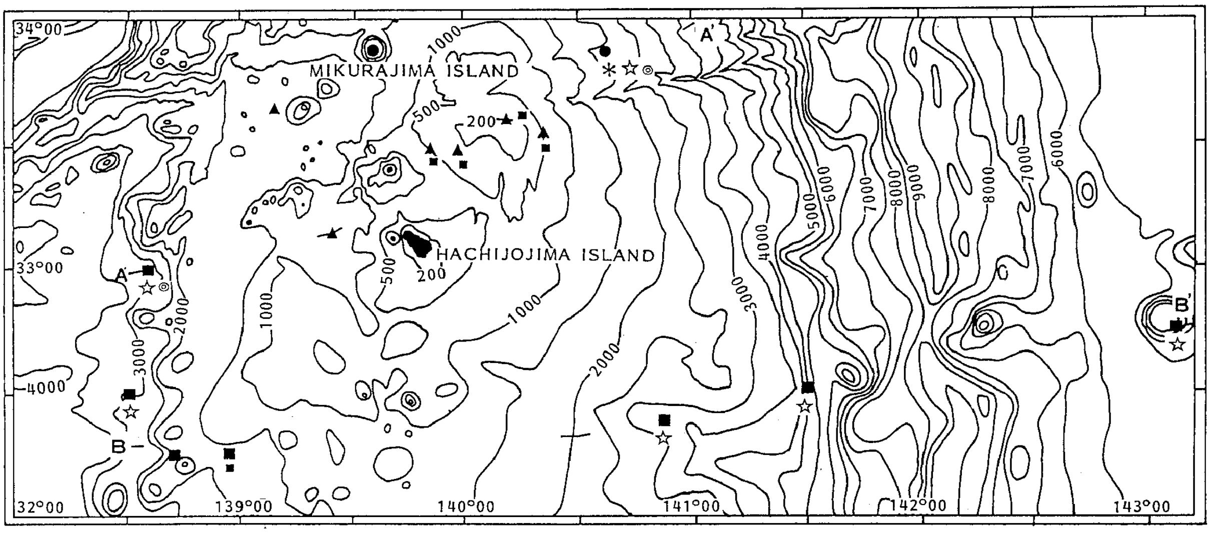


Fig. 63. Distribution of selected kinds of grains around Hachijojima Island. (Legend same as in Figs. 60 and 61).

reconstruct sedimentary environments. Pteropods are present only in three samples at depths shallower than 100 m (KH85-6-G5, 6 and 10).

4. Hachijojima area

Figure 63 shows the distribution of each kind of grains in this area. Radiolarians occurred in several points such as GH79-4-D372, D373, D375, D367, GH80-4-RC102 and KT85-6-D1. The latter two points also yielded diatoms. These two kinds of grains are restricted to a rather flat topographical area with a submarine canyon (except for D376) in depth below about 2,000 m. Pellets occurred only at GH80-4-RC102. Plant fragments and glauconite grains are absent in this area. Pteropods are present in high frequency at several points shallower than about 1,500 m water depth (GH79-4-D371, GH80-4-85, 94 and 96).

In summary, these figures (Figs. 59-63) lead to the following conclusions :

1) No plant fragments were found around Tanegashima or Hachijojima Island, or in the Shikoku Basin.

2) The occurrence of plant fragments bears out the existence of a wide land as a source area.

3) Radiolarians and diatoms are restricted to a rather flat topographic area with a submarine canyon below the middle bathyal zone, where they occurred in abundance.

4) Pellets were recognized in abundance at a slope break and on the ocean floor, and were absent within the trench and on a ridge.

5) Pteropods are rarely present in the coastal water region, and their occurence is restricted to depths shallower than 1,000 m. This kind of grains, however, occurred down to 1,500 m water depth in the open sea region influenced by the Kuroshio Current.

6) Glauconite was recognized in the upper part of the continental slope in front of wide hinterlands.

The above-mentioned results indicate that these patterns provide important clues to both the analysis of sedimentary paleoenvironments and the reconstruction of geological settings.

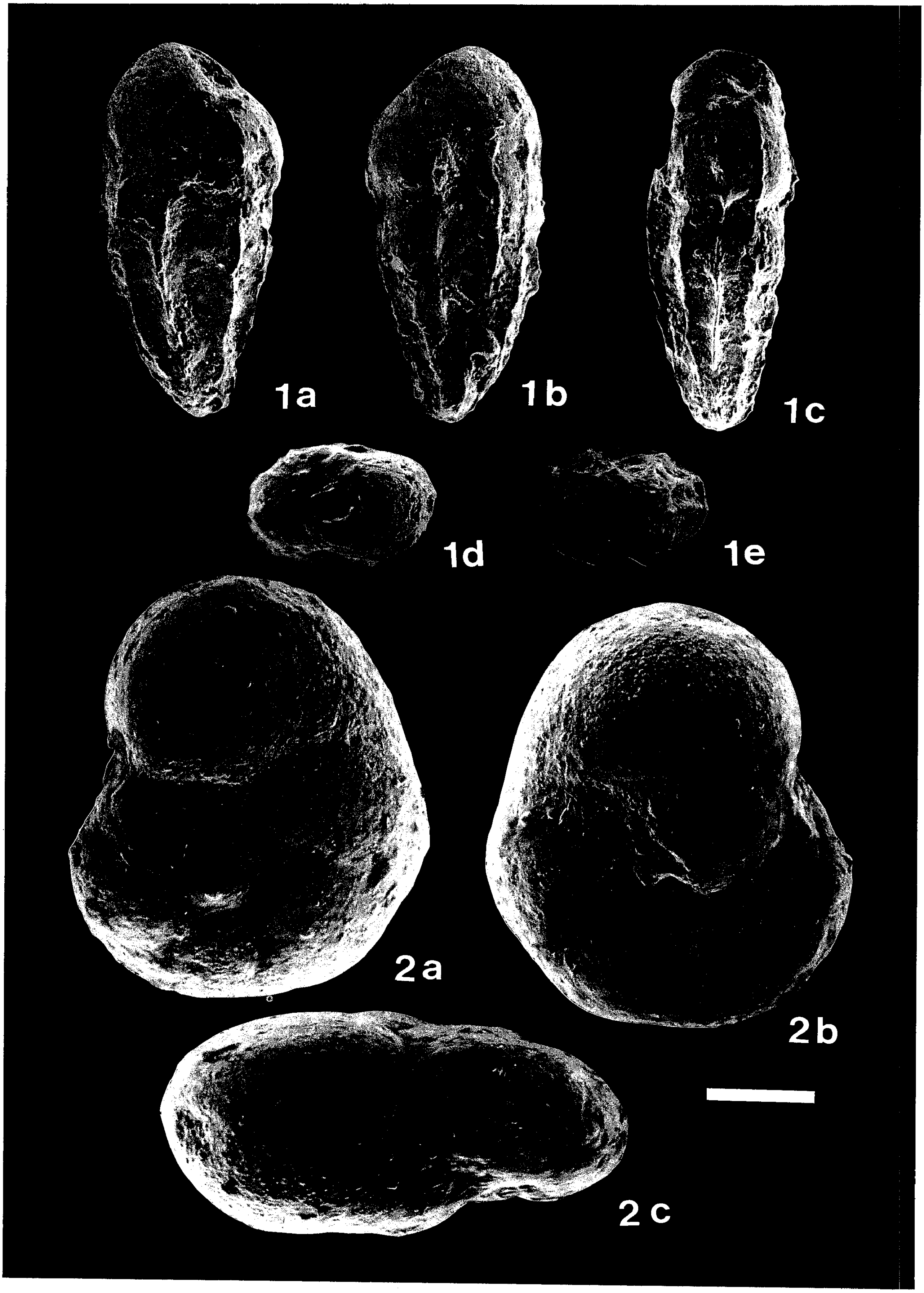
Plates 1–9

Plate 1

Fig. 1. *Brizalina kaiensis* Akimoto, n. sp.
Paratype (IGPS 100601), Sample NAN01, Minobu Formation

Fig. 2. *Valvulineria fujikawaensis* Akimoto, n. sp.
Holotype (IGPS 100603), Sample ISH01, Kanzaka Formation

Scale bar : 0.1 mm.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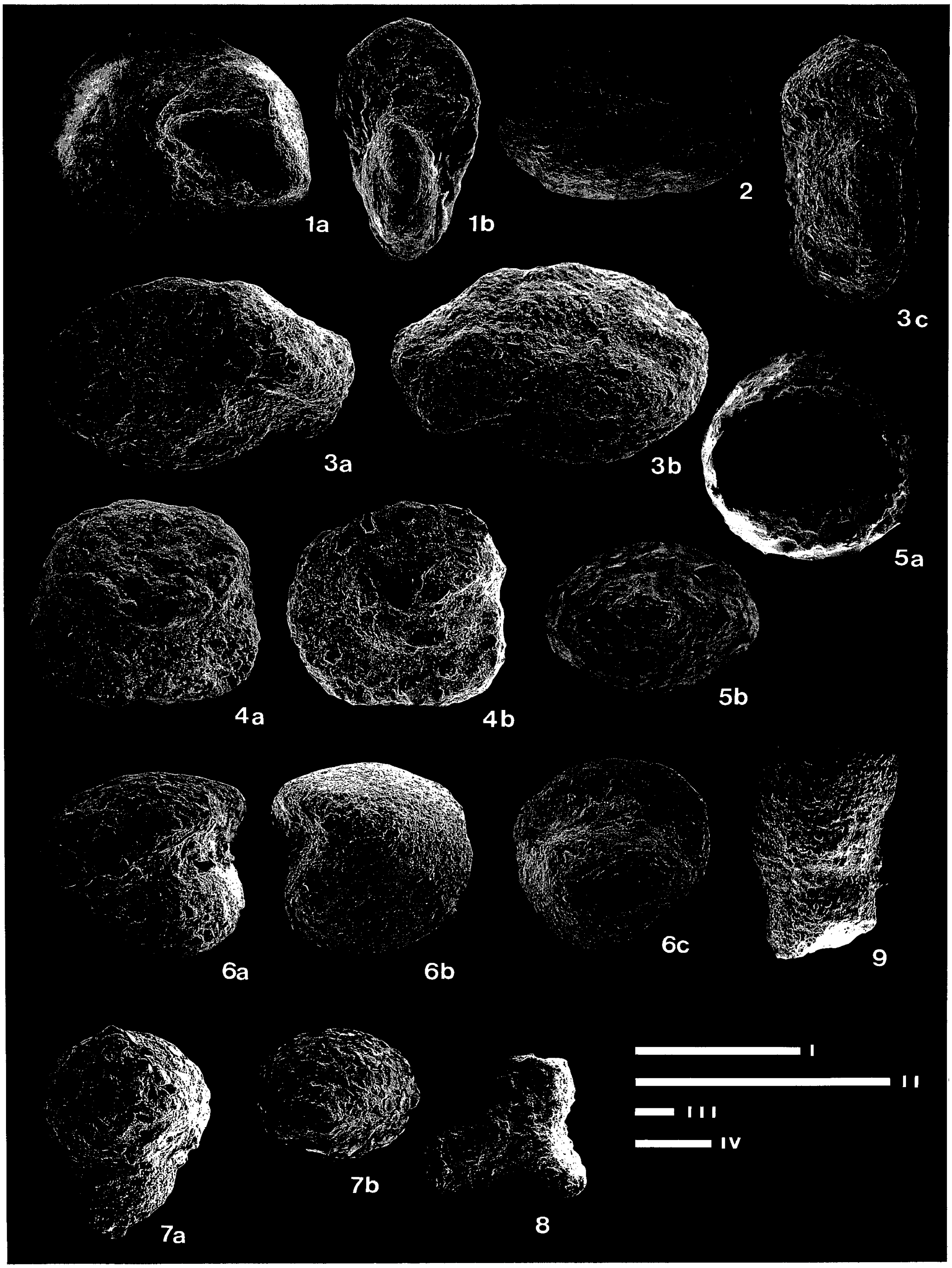
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Plate 2

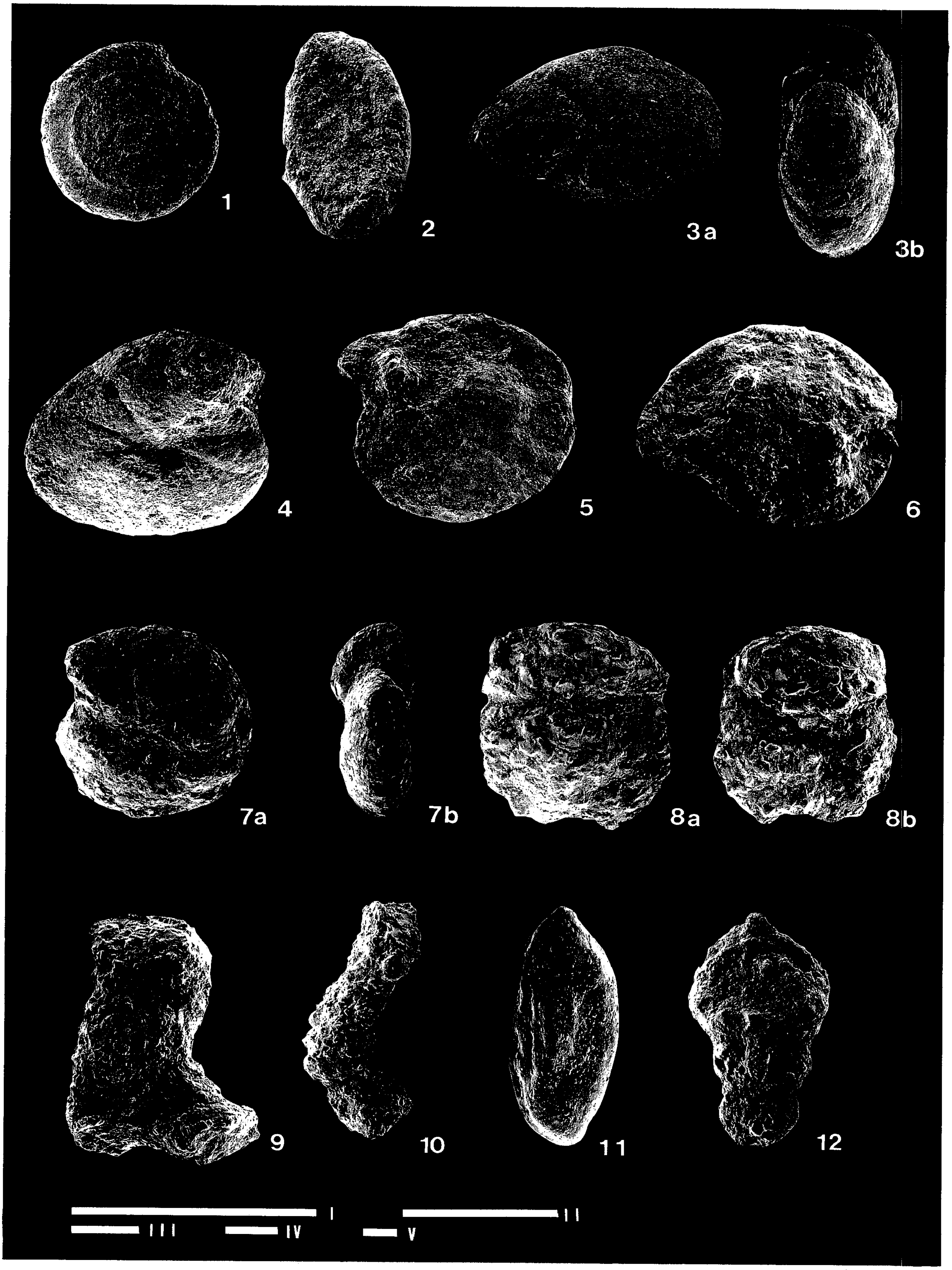
Fig. 1. *Cyclammina cancellata* Brady
IGPS 100604, Sample TOS01 Furusekigawa Formation
Figs. 2, 3. *Alveolophragmium scitulum* (Brady)
2. IGPS 100605, Sample TOS01, Furusekigawa Formation
3. IGPS 100606, Sample FUR12, Furusekigawa Formation
Fig. 4. *Trochammina globigeriniformis* (Parker and Jones)
IGPS 100607, Sample TOS01, Furusekigawa Formation
Fig. 5. *Saccammina sphaerica* M. Sars
IGPS 100608, Sample TOS01, Furusekigawa Formation
Fig. 6. *Alveolophragmium subglobosum* (G.O. Sars)
IGPS 100609, Sample FUR17, Kanzaka Formation
Fig. 7. *Reophax piliformis* Brady
IGPS 100610, Sample FUR17, Kanzaka Formation
Fig. 8. *Rhabdammina abyssorum* M. Sars
IGPS 100611, Sample FUR17, Kanzaka Formation
Fig. 9. *Rhabdammina abyssorum* M. Sars forma A
IGPS 100612, Sample FUR17, Kanzaka Formation

Scale bar I, II : 1 mm ; III, IV : 0.1 mm ; I : 8, 9 ; II : 7 ; III : 2, 3, 5, 6 ; IV : 1, 4.

Plate 3

Fig. 1. *Ammodiscus* sp.
IGPS 100613, Sample ISH01, Kanzaka Formation
Fig. 2. *Ammodiscus* cf. *dominicensis* Bermúdez var. *deformis* Bermúdez
IGPS 100614, Sample ISH03, Kanzaka Formation
Fig. 3. *Cyclammina cancellata* Brady
IGPS 100615, Sample YOG10, Akebono Formation
Fig. 4. *Cyclammina japonica kaiensis* Fukuta and Shinoki
IGPS 100616, Sample OGY04, Hara Formation
Figs. 5, 6. *Cyclammina pusilla* Brady
5. IGPS 100617, Sample ISH01, Kanzaka Formation
6. IGPS 100618, Sample ISH03, Kanzaka Formation
Fig. 7. *Alveolophragmium scitulum* (Brady)
IGPS 100619, Sample YOG03 Iitomi Formation
Fig. 8. *Trochammina globigeriniformis* (Parker and Jones)
IGPS 100620, Sample YOG03, Iitomi Formation
Fig. 9. *Rhabdammina abyssorum* M. Sars
IGPS 100621, Sample ISH05, Wadaira Formation
Fig. 10. *Marsipella elongata* Norman
IGPS 100622, Sample ISH03, Kanzaka Formation
Fig. 11. *Spirosigmoilinella compressa* Matsunaga
IGPS 100623, Sample ISH04, Kanzaka Formation
Fig. 12. *Reophax piliformis* Brady
IGPS 100624, Sample ISH04, Kanzaka Formation

Scale bar I, II : 1 mm ; III, IV, V : 0.1 mm ; I : 2, 7, 8 ; II : 3, 4 ; III : 11 ; IV : 1, 5, 6, 9 ; V : 10, 12.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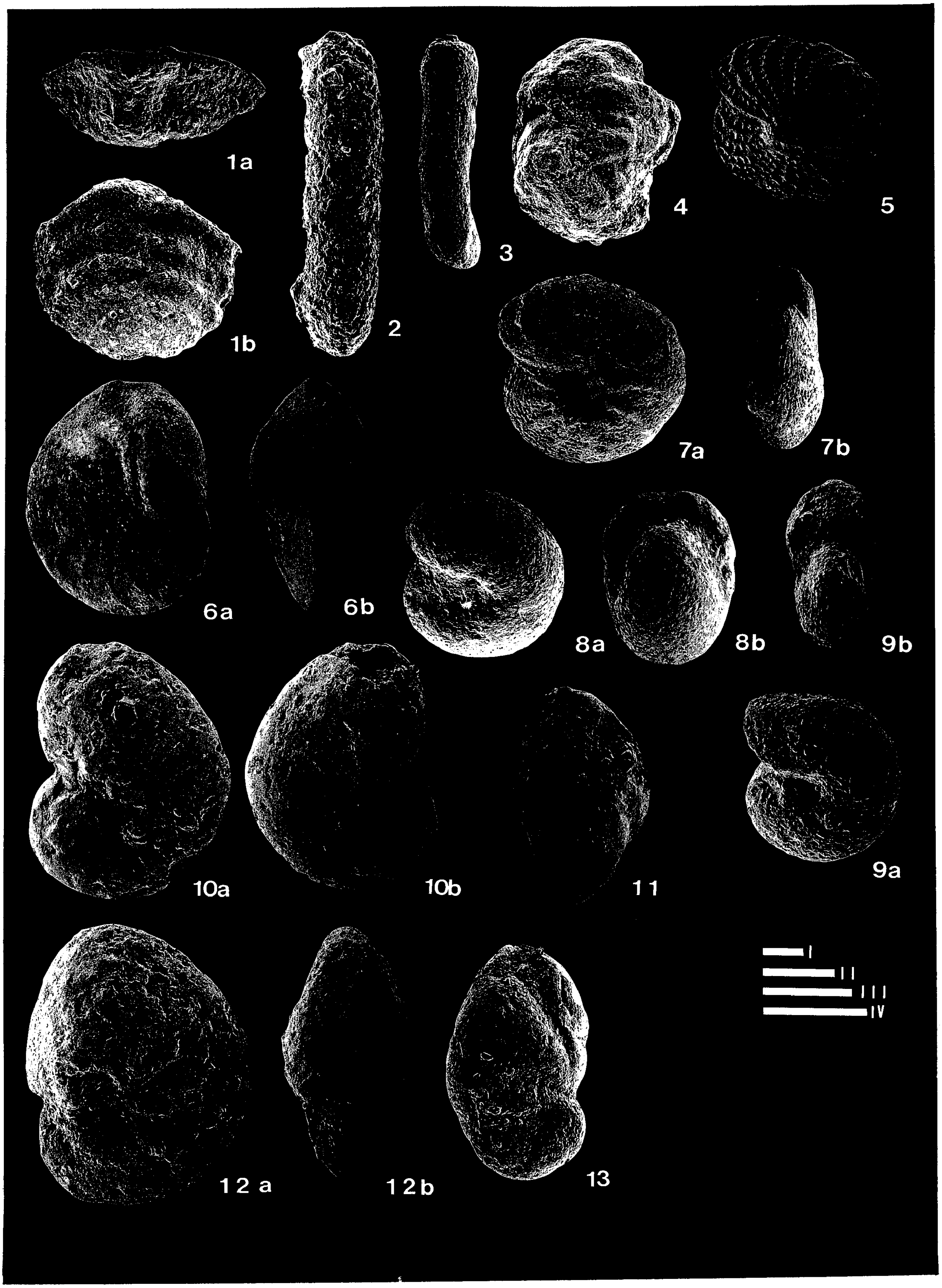
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Plate 4

Fig. 1. *Textularia* sp.
IGPS 100625, Sample YOG03, Iitomi Formation
Fig. 2. *Martinottiella communis* (d'Orbigny)
IGPS 100626, Sample ISH05, Wadaira Formation
Fig. 3. *Martinottiella communis* (d'Orbigny) var.
IGPS 100627, Sample ISH05, Wadaira Formation
Fig. 4. *Glomospira gordialis* (Parker and Jones)
IGPS 100628, Sample ISH01, Kanzaka Formation
Fig. 5. *Elphidium crispum* (Linné)
IGPS 100629, Sample NAN01, Minobu Formation
Fig. 6. *Nonion japonicus* Asano
IGPS 100630, Sample YOG10, Akebono Formation
Fig. 7. *Melonis parkerae* (Uchio)
IGPS 100631, Sample NAN01, Minobu Formation
Fig. 8. *Melonis sphaeroides* Voloshinova
IGPS 100633, Sample ISH01, Kanzaka Formation
Fig. 9. *Melonis barleeanus* (Williamson)
IGPS 100632, Sample OGY04, Hara Formation
Fig. 10. *Pseudononion japonicum* Asano
IGPS 100634, Sample NAN03, Minobu Formation
Fig. 11. *Rutherfordoides mexicanus* (Cushman).
IGPS 100635, Sample YOG10, Akebono Formation
Fig. 12. *Nonionellina labradorica* (Dawson)
IGPS 100637, Sample YOG06, Iitomi Formation
Fig. 13. *Evolvocassidulina brevis* (Aoki)
IGPS 100636, Sample FUJ06, Shimobe Formation

Scale bar : 0.1 mm ; I : 2, 3, 5, 7, 12 ; II : 1, 4, 6, 11 ; III : 8, 9, 13 ; IV : 10.

Plate 5

Figs. 1, 2. *Uvigerina proboscidea* Schwager
  1. IGPS 100638, Sample ISH03, Kanzaka Formation
  2. IGPS 100639, Sample ISH05, Wadaira Formation

Figs. 3, 4, 5. *Uvigerina hispidocostata* Cushman and Todd
  3. IGPS 100640, Sample FUJ06, Shimobe Formation
  4. IGPS 100641, Sample NAN03, Minobu Formation
  5. IGPS 100642, Sample NAN03, Minobu Formation

Figs. 6, 7. *Trifarina occidentalis* (Cushman)
  6. IGPS 100643, Sample ISH03, Kanzaka Formation
  7. IGPS 100644, Sample ISH01, Kanzaka Formation

Fig. 8. *Bulimina* cf. *alazanensis* Cushman
IGPS 100645, Sample OGY02, Hara Formation

Fig. 9. *Bulimina rostrata* Brady
IGPS 100646, Sample YOG06, Akebono Formation

Fig. 10. *Bulimina striata* d'Orbigny
IGPS 100647, Sample OGY02, Hara Formation

Fig. 11. *Brizalina bradyi* (Asano)
IGPS 100648, Sample FUJ06, Shimobe Formation

Fig. 12. *Brizalina kaiensis* Akimoto, n. sp.
Paratype (IGPS 100601), Sample NAN01, Minobu Formation

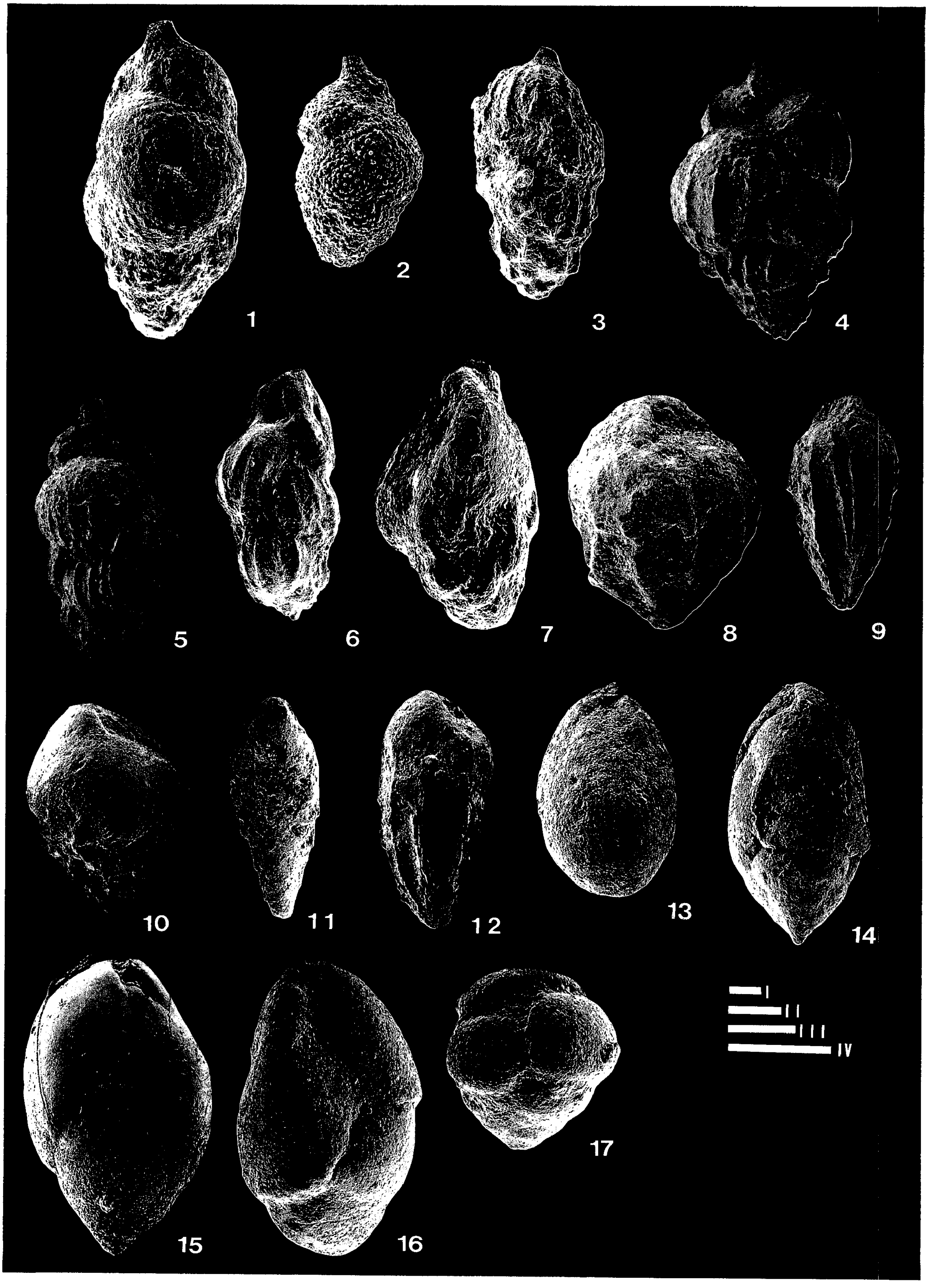
Fig. 13. *Globobulimina auriculata* (Bailey)
IGPS 100649, Sample OGY04, Hara Formation

Fig. 14. *Globobulimina affinis* (d'Orbigny)
IGPS 100650, Sample FUJ06, Shimobe Formation

Figs. 15, 16. *Globobulimina pupoides* (d'Orbigny)
  15. IGPS 100651, Sample ISH05, Wadaira Formation
  16. IGPS 100652, Sample ISH05, Wadaira Formation

Fig. 17. *Tosaia hanzawai* Takayanagi
IGPS 100653, Sample ISH01, Kanzaka Formation

Scale bar: 0.1 mm; I: 13; II: 4, 5, 14, 15, 16; III: 2, 3, 9, 11, 12, 17; IV: 1, 6, 7, 8, 10.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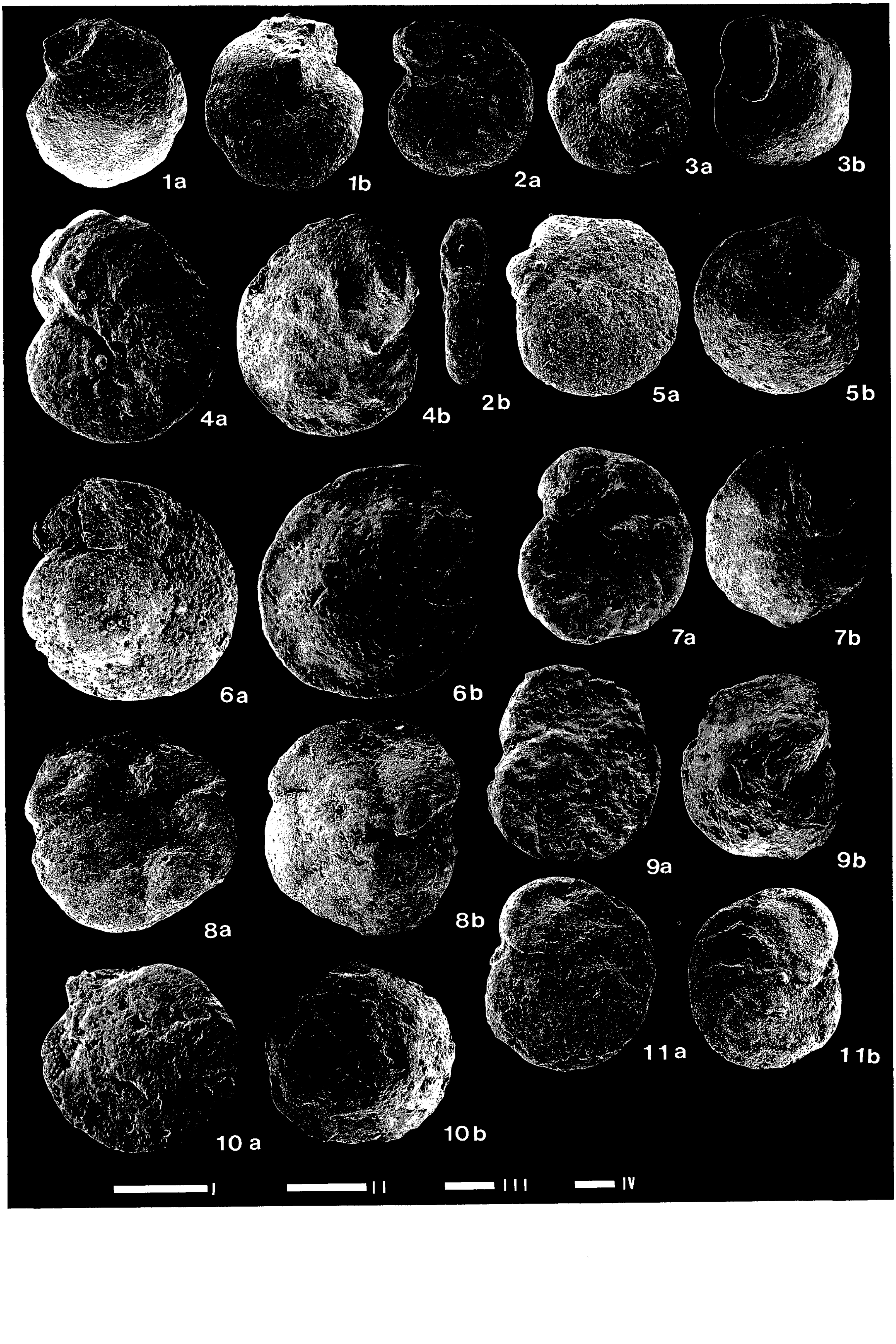
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Plate 6

Fig. 1. *Anomalinoides glabrata* (Cushman)
IGPS 100654, Sample ISH01, Kanzaka Formation
Fig. 2. *Hyalinea balthica* (Schroeter)
IGPS 100655, Sample YOG10, Akebono Formation
Figs. 3, 6. *Cibicidoides mediocris* (Finlay)
3. IGPS 100656, Sample FUJ06, Shimobe Formation
6. IGPS 100659, Sample YOG04, Akebono Formation
Fig. 4. *Hanzawaia nipponica* Asano
IGPS 100657, Sample NAN03, Minobu Formation
Figs. 5, 7. *Cibicides aknerianus* (d'Orbigny)
5. IGPS 100658, Sample FUK02, Byobu-iwa Formation
7. IGPS 100660, Sample NAN03, Minobu Formation
Fig. 8. *Cibicides lobatulus* (Walker and Jacob)
IGPS 100661, Sample FUK02, Byobu-iwa Formation
Fig. 9. *Cibicides* cf. *refulgens* Montfort
IGPS 100662, Sample NAN01, Minobu Formation
Fig. 10. *Parrelloides bradyi* (Trauth)
IGPS 100663, Sample FUJ06, Shimobe Formation
Fig. 11. *Cibicides wuellerstorfi* (Schwager)
IGPS 100664, Sample OGY04, Hara Formation

Scale bar : 0.1 mm ; I : 9 ; II : 2, 5, 10 ; III : 1, 4, 6, 7, 8, 11 ; IV : 3.

Plate 7

Figs. 1, 2. *Valvulineria fujikawaensis* Akimoto, n. sp.
1. Paratype (IGPS 100665), Sample ISH01, Kanzaka Formation
2. Paratype (IGPS 100666), Sample ISH01, Kanzaka Formation

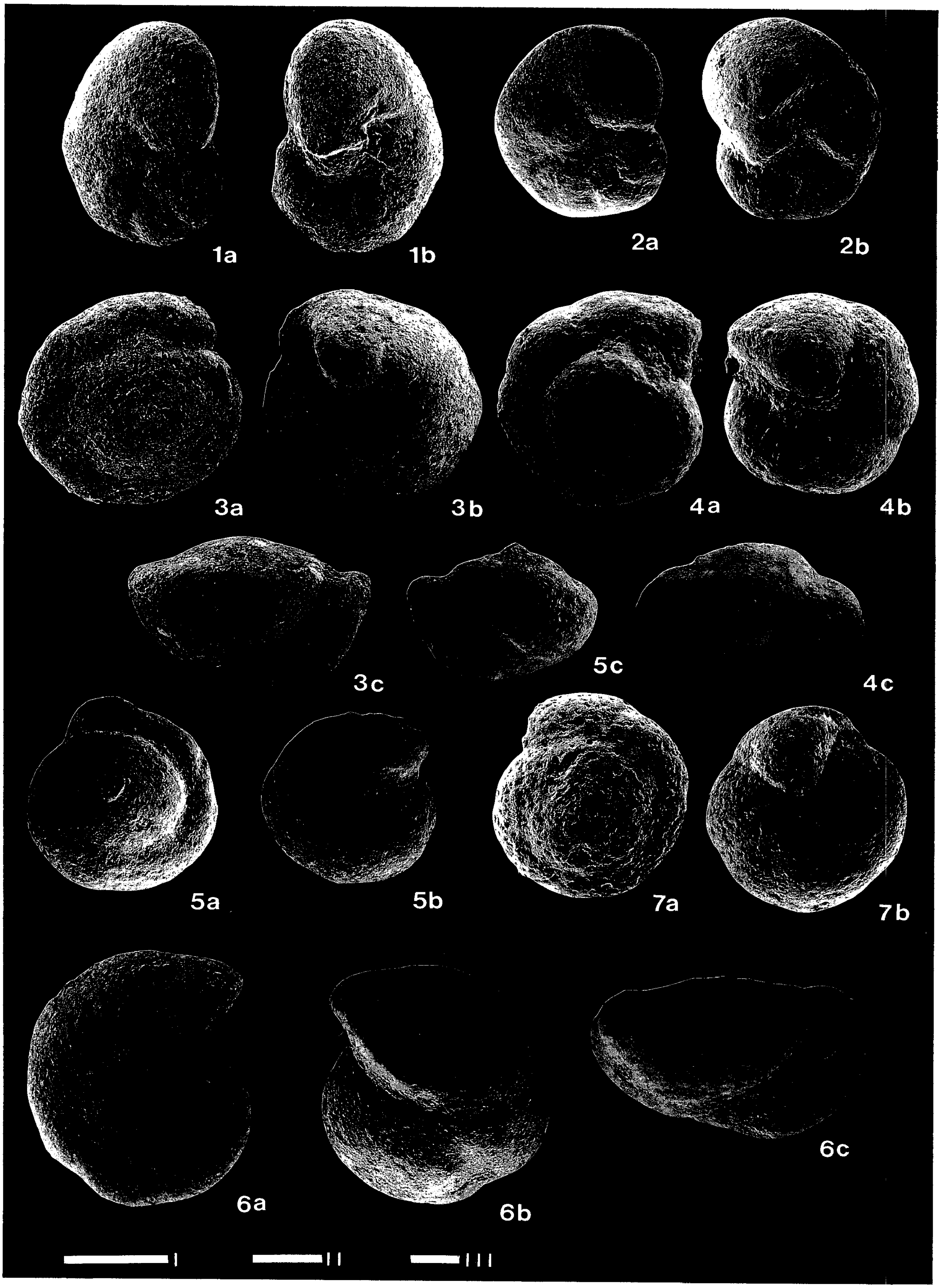
Fig. 3. *Gyroidina altiformis* R.E. and K.C. Stewart
IGPS 100667, Sample FUK06, Byobu-iwa Formation

Fig. 4. *Gyroidina komatsui* Aoki
IGPS 100668, Sample ISH03, Kanzaka Formation

Figs. 5, 6. *Gyroidina soldanii* d'Orbigny
5. IGPS 100669, Sample ISH03, Kanzaka Formation
6. IGPS 100670, Sample FUK03, Byobu-iwa Formation

Fig. 7. *Parrelloides bradyi* (Trauth)
IGPS 100671, Sample FUJ06, Shimobe Formation

Scale bar : 0.1 mm ; I : 4 ; II : 2, 3, 5, 7 ; III : 1, 6.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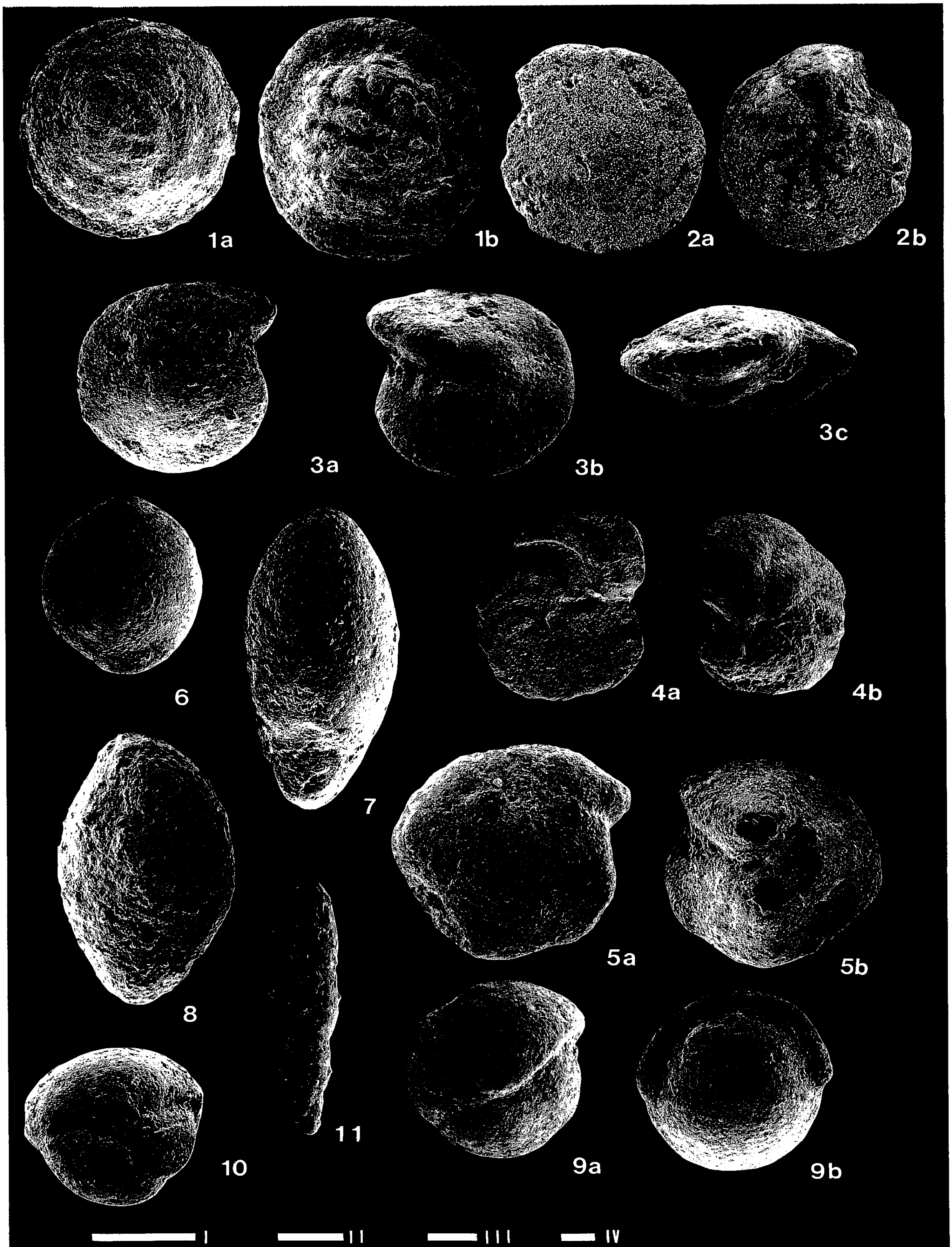
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Plate 8

Fig. 1. *Ammonia ketienziensis* (Ishizaki)
IGPS 100672, Sample YOG15, Akebono Formation
Fig. 2. *Ammonia takanabensis* (Ishizaki)
IGPS 100673, Sample YOG04, Akebono Formation
Figs. 3, 5. *Oridorsalis tener* (Brady)
3. IGPS 100674, Sample FUJ06, Shimobe Formation
5. IGPS 100676, Sample OGY02, Hara Formation
Fig. 4. *Discorbinella convexa* (Takayanagi)
IGPS 100675, Sample NAN01, Minobu Formation
Fig. 6. *Quinqueloculina vulgaris* d'Orbigny
IGPS 100677, Sample ISH05, Wadaira Formation
Fig. 7. *Chilostomella oolina* Schwager
IGPS 100678, Sample YOG12, Akebono Formation
Fig. 8. *Sigmoilopsis schlumbergeri* (Silvestri)
IGPS 100679, Sample ISH05, Wadaira Formation
Fig. 9. *Pullenia bulloides* (d'Orbigny)
IGPS 100680, Sample ISH01, Kanzaka Formation
Fig. 10. *Sphaeroidina bulloides* d'Orbigny
IGPS 100681, Sample FUJ06, Shimobe Formation
Fig. 11. *Fursenkoina* sp.
IGPS 100682, Sample YOG10, Akebono Formation

Scale bar : 0.1 mm ; I : 8 ; II : 3, 4, 7, 9, 10 ; III : 5, 11 ; IV : 1, 2, 6.

Plate 9

Figs. 1, 2. *Stilostomella lepidula* (Schwager)
- 1. IGPS 100683, Sample OGY09, Hara Formation
- 2. IGPS 100684, Sample YOG06, Akebono Formation

Fig. 3. *Stilostomella* sp.
IGPS 100685, Sample OGY04, Hara Formation

Fig. 4. *Stilostomella fistuca* (Schwager)
IGPS 100686, Sample FUK08, Byobu-iwa Formation

Fig. 5. *Nodosaria tosta* Schwager
IGPS 100687, Sample FUJ06, Shimobe Formation

Figs. 6, 7. *Stilostomella consobrina* (d'Orbigny)
- 6. IGPS 100688, Sample ISH01, Kanzaka Formation
- 7. IGPS 100689, Sample ISH03, Kanzaka Formation

Fig. 8. *Nodosaria longiscata* d'Orbigny
IGPS 100690, Sample ISH04, Kanzaka Formation

Fig. 9. *Nodosaria holoserica* Schwager
IGPS 100691, Sample ISH04, Kanzaka Formation

Figs. 10, 11, 12. *Plectofrondicularia goharai* Kuwano
- 10. IGPS 100692, Sample ISH04, Kanzaka Formation
- 11. IGPS 100693, Sample ISH05, Wadaira Formation
- 12. IGPS 100694, Sample OGY02, Hara Formation

Fig. 13. *Plectofrondicularia totomiensis* Makiyama
IGPS 100695, Sample YOG10, Akebono Formation

Fig. 14. *Pleurostomella brevis* Schwager
IGPS 100696, Sample ISH01, Kanzaka Formation

Figs. 15, 16. *Pleurostomella alternans* Schwager
- 15. IGPS 100697, Sample OGY02, Hara Formation
- 16. IGPS 100698, Sample OGY02, Hara Formation

Fig. 17. *Lagena laevis* (Montagu)
IGPS 100699, Sample ISH05, Wadaira Formation

Fig. 18. *Fissurina marginata* (Montagu)
IGPS 100700, Sample FUJ06, Shimobe Formation

Fig. 19. *Fissurina orbignyana* Seguenza
IGPS 100701, Sample ISH01, Kanzaka Formation

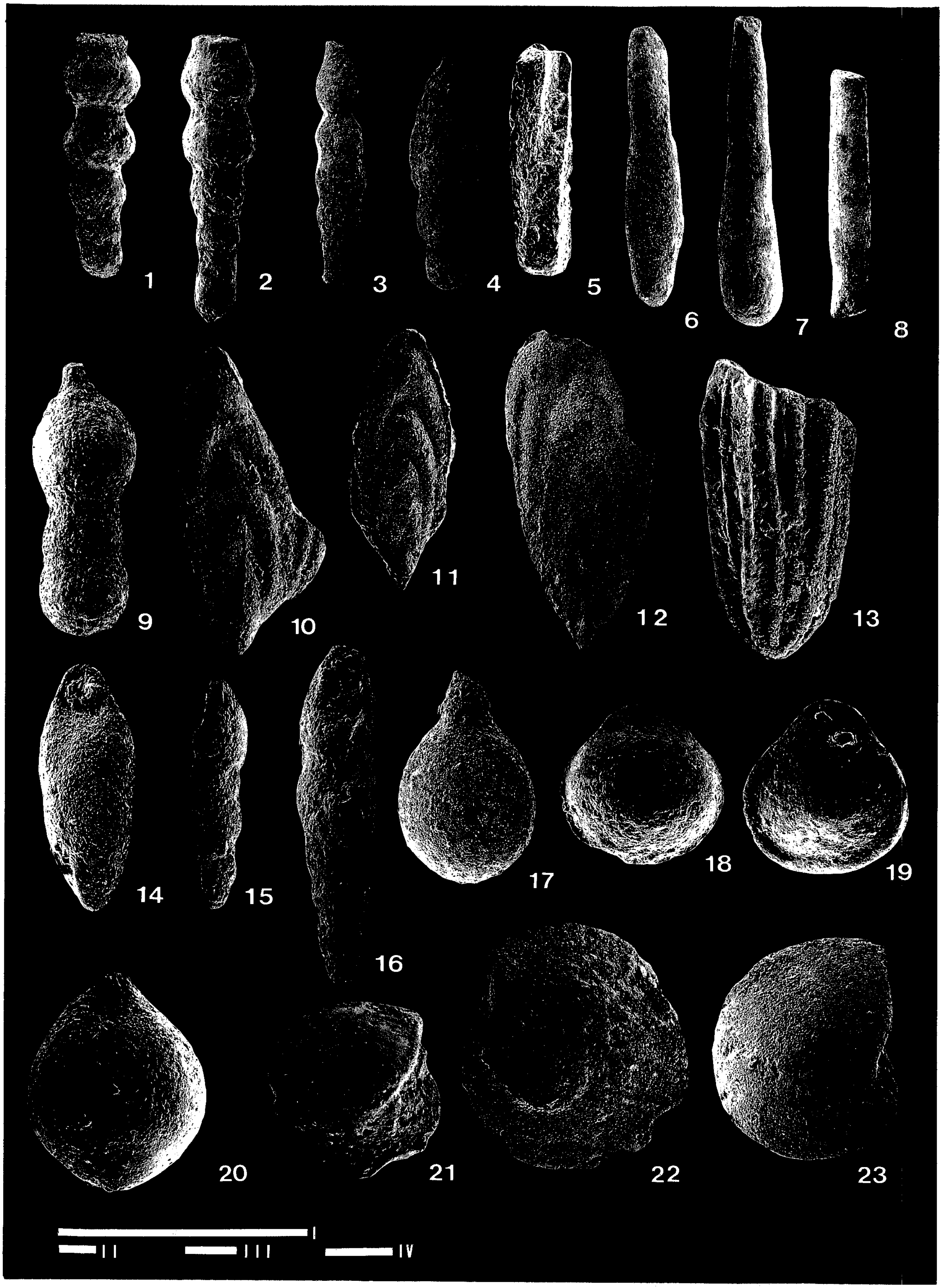
Fig. 20. *Glandulina laevigata* (d'Orbigny)
IGPS 100702, Sample ISH03, Kanzaka Formation

Fig. 21. *Robulus orbicularis* (d'Orbigny)
IGPS 100703, Sample YOG12, Akebono Formation

Fig. 22. *Robulus pseudorotulatus* Asano
IGPS 100704, Sample YOG10, Akebono Formation

Fig. 23. *Robulus* sp.
IGPS 100705, Sample ISH05, Wadaira Formation, ×150.

Scale bar : I : 1 mm ; II, III, IV : 0.1 mm ; I : 8 ; II : 3, 4, 5, 9, 22 ; III : 1, 2, 7, 15, 18, 20, 21, 23 ; IV : 6, 10, 11, 12, 13, 14, 16, 17, 19.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