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— A stratigraphical-micropaleontological elucidation —

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abstract

Neogene and Quaternary deposits are extensively distributed in the Oshima Peninsula, southwestern Hokkaido. The sedimentary basin of these strata were split into several smaller basins during late Pliocene, and disappeared by Middle Pleistocene. The Kuromatsunai and Setana Formations, the Pliocene and Pleistocene in this region, have recorded paleoenvironmental changes during this period.

In the present study, the author investigated lithostratigraphy of the Kuromatsunai and Setana Formations, their ages assignments based on a K-Ar radiometric analysis and microbiostratigraphic analyses, and the paleoenvironmental changes particularly during the deposition of the upper part of the Setana Formation based on foraminifera, and concluded as follows;

1) The Kuromatsunai Formation was subdivided into three members, the Sumiyoshi Siltstone, Sakkurubetsu Pyroclastic and Okusawa Sandstone, in ascending order in the Imakane-Kamiyakumo area. The Okusawa Sandstone Member, which have been regarded as a member of the Setana Formation, is unconformably overlain by this formation and separated from it.
2) The Kuromatsunai Formation contacts clinounconformably with the Setana Formation in all the areas studied. This fact indicates that tectonic

movements and time-gap between deposition of both formations.

3) The Kuromatsunai Formation was deposited in early Pliocene to early Pleistocene (ca. 5.0 to 1.4Ma), and its paleodepth was middle bathyal zone (over 700m) in maximum.

4) The Setana Stage, the biggest transgressive time in Quaternary of Hokkaido, was subdivided into two substages; the earlier substage began at about 1.2Ma, and this area was under inner sublittoral depth (0 to 45m). This substage is characterized by cold-water molluscs and sirenian mammals lived in such water temperatures as the recent Okhotsk and Bering Seas.

5) The later substage began at about 1.0Ma, and the sea areas were expanded and deepened rapidly. Paleodepth sometimes attained to over 150m. This sea was then shallowed and dried up about 0.6 to 0.4Ma.

6) A detailed faunal analysis was performed on foraminifera and molluscs from the sequence of the upper part of the Setana Formation deposited in 0.95 to 0.85Ma. The sequence consisting of sandstone and four shell concentrations are divided into seven units. In the sequence the author distinguishes the three types of shell concentration, event-concentration, condensed-concentration, and lag-concentration. The author also showed that there are two condensations related to rapid deepening with transgressions.

7) The paleodepths curves based on benthic foraminifera indicate transgressive-regressive cycles between 50 and 100m or more influenced by glacial eustatic sea-level changes. The similarity of paleodepths curves and calcareous nannofossil biostratigraphy suggest that the age of this sequence is assigned to the Oxygen Isotopic Stage 21.

8) The estimated paleodepths on molluscs are usually shallower than those on benthic foraminifera. A detailed stratigraphic study indicates that such a discrepancy is brought from the effect of time-averagings during rapid deepenings of the sea, and a higher resolution by foraminiferal analyses.

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I. Introduction

Neogene to Quaternary deposits distributed along the Japan Sea side in Hokkaido, implying a history of development and changes of the Japan Sea, are one of most important subjects for the study to understand geological and geographical frameworks of the present Japanese Islands. In spite of these facts, it has not been clearly stated that the environmental changes of these areas, near the northern end of the Japan Sea areas, or around the Oshima Peninsula.

The Oshima Peninsula in southwestern Hokkaido is regarded geologically as the northern extension of the "Green Tuff" region of the Inner Zone of the Northeast Japan (e.g. Kato et al. eds., 1991). The peninsula has extensive distributions of the Neogene and Quaternary deposits which unconformably overlie pre-Tertiary sedimentary and igneous rocks. This region has been one of stratigraphical standards of the Neogene in Hokkaido since the study by Nagao and Sasa (1933).

Neogene to Pleistocene marine sediments in this region are generally classified into the following ascending-ordered formations, Kunnui, Yakumo, Kuromatsunai, and Setana (Nagao and Sasa, 1933). These formations are well exposed in middle to northern parts of the peninsula. Such stratigraphy first proposed by Nagao and Sasa (1933) has basically been accepted, but recent biostratigraphical data reveal that the Setana Formation should be of Pleistocene age.

General relationships among these formations are as follows: from the Kunnui to Kuromatsunai Formation they contact conformably each other, but they are clinounconformably overlain by the Setana (e.g. Nagao and Sasa, 1933; Matsui et al., 1955; Hashimoto et al., 1963; Ishida, 1981; Oka and

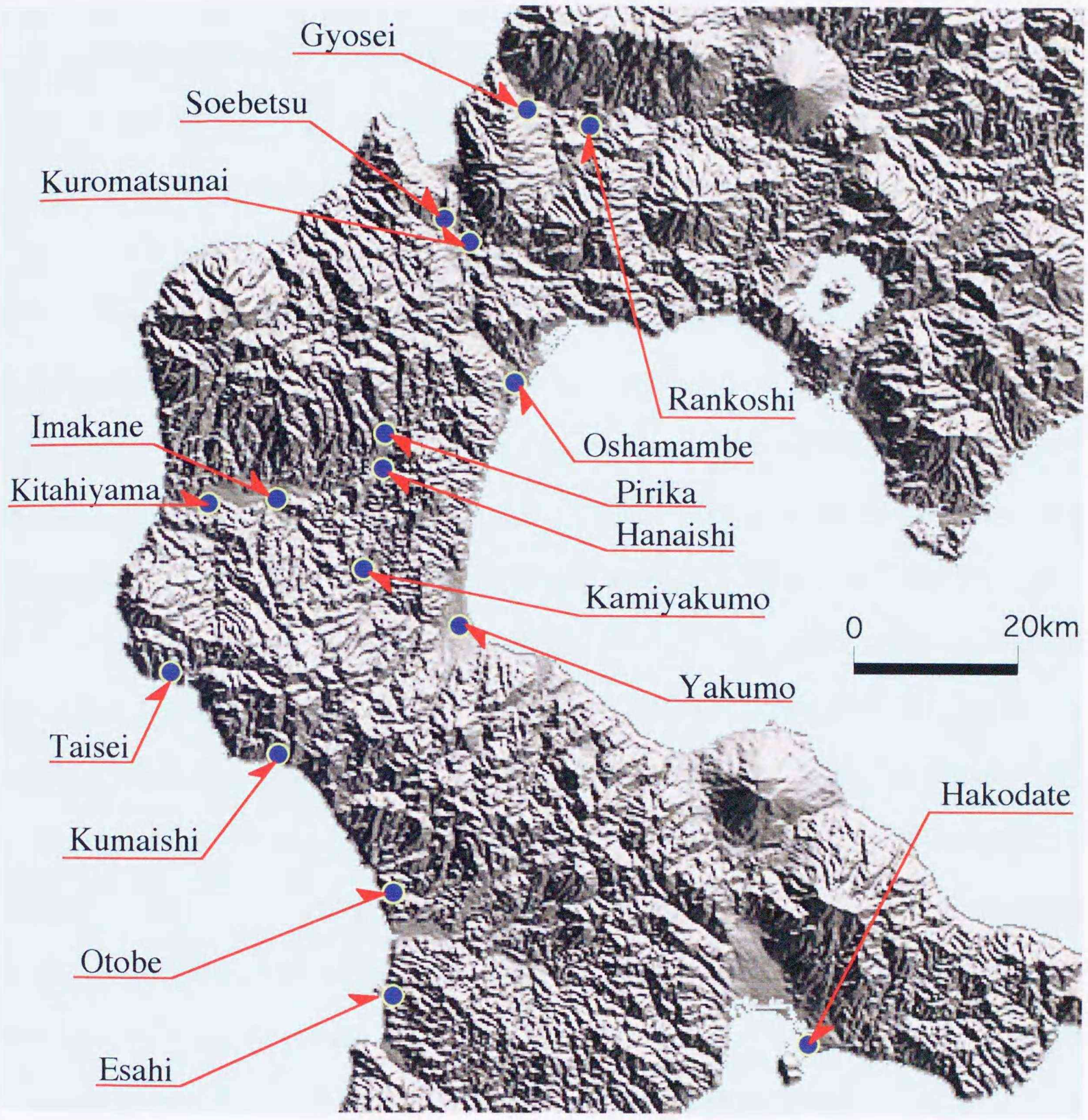


Fig. 1 Geographical names of the studied area

Mitani, 1981; Nojo et al., 1994b).

The Setana Formation has some complexities in a wide variety of sedimentary facies with laterally short-range changes and with no key beds. This formation, therefore, has not been clearly stated its stratigraphical and chronostratigraphical properties yet. Because of such characteristics this formation needs close correlations and estimations of the deposition age by lithostratigraphical and biostratigraphical analyses, in particular, calcareous nannofossils and foraminiferal analyses.

The age of the Setana Formation, 1.2 to 0.8Ma, must be in the time of glacial eustatic sea-level changes. Kitamura and Kondo (1990) stated that the cyclic changes of sedimentary facies and molluscan assemblages within the Omma Formation in central Honshu, being correlated with the Setana Formation, were caused by glacial eustatic sea-level changes. These matters strongly indicate some influences of glacial eustatic sea-level changes also in the Setana Formation. The changes may produce two characteristic facies in deposits; one is the deposition of coarse-grained sediments with fossils of cold-water species in glacial periods, and the other is fine-grained sediments with warm-water species in interglacial periods. However, there have been no reports to date about the changes in the Setana Stage, because no outcrops have been found. The deposits in these time probably include cyclic sets of occurrences of cold- and warm-water mollusca and foraminifera.

In early Pleistocene of Hokkaido occurrences of warm-water species should indicate peaks of warming of the seas, because cold-waters like in the recent Bering Sea may generally have become dominant in that time in northern Japan Sea around Hokkaido (e.g. Suzuki and Akamatsu, 1994). In the northern Japan Sea areas, therefore, it should be emphasized that researches of

warm-water species of multiple taxa, one of the best markers of glacial eustatic sea-level changes, are needed, and such researches will lead us to understand paleoenvironmental changes at that time. Unfortunately, there have been no deposits and also warm-water species ascertained as reflections of glacial eustatic sea-level changes in the Setana Formation.

Studies on the fossils and lithofacies of late Neogene to early Quaternary in southwestern Hokkaido have not clarified in detail paleoenvironmental changes, and this is mainly due to complexities result from similarities of both sedimentary facies and fossils between the Pliocene and Pleistocene in this region.

On the other hand, there are a few reports on microfossils in the Kuromatsunai and Setana Formations. In particular, despite abundant yieldings of foraminifera and calcareous nannofossils from the Setana Formation, there were some reports on foraminifera (Asano, 1936, 1937, 1938; Shirai, 1959, 1960; Masatani and Ohkura, 1980MS; Takahashi et al., 1980MS; Tsuchi and Ibaragi, 1982; Tsubakihara et al., 1989; Nojo et al., 1997a), but not so many reports with chronostratigraphical locations, and we have only a report on calcareous nannofossils by Chitoku (1983). There have also been no reports related to paleoenvironmental changes on the basis of micropaleontological analyses, in spite of its abundant occurrences.

As mentioned above, the Pliocene and Pleistocene deposits are one of important ingredients for studying the processes of topographical and paleoenvironmental changes in these areas. The following problems have remained unsolved about these formations; ambiguity of stratigraphical relationships between these formations, conformable or clinounconformable, unsettled ages of deposition in both formations, and no reports on global sea-

level changes by glacial eustatic movements, some reflections of which probably exist in the Setana Formation. Such insufficiencies of information about these formations result poor understanding on changes of paleotemperature, paleodepth, and configuration of basins since Pliocene. The aims of this study is, therefore, to describe precisely the stratigraphy and the fossils of foraminifera, and to clarify paleoenvironmental changes from early Pliocene to early Pleistocene, and, in particular, the emphasis is on the changes during late Pliocene to early Pleistocene represented by the Kuromatsunai and Setana Formations. Especially the author will focus on the Setana Stage, the biggest transgressive time in Quaternary of Hokkaido with global sea-level changes by glacial eustatic movements. Besides foraminiferal fossils, molluscan fossils are also subsidiarily referenced in this study.

II. A Historical Reviews of Stratigraphical and Foraminiferal Studies

(1) Stratigraphical Studies

Geological studies in southwestern Hokkaido were began in 1862 by two American geologists, R. Pumpelly and W. P. Blake (Kato et al., 1991). They surveyed the Oshima Peninsula in 1862, and made two geological route maps, the first geological route maps in the East Asia (Pumpelly, 1866; Blake, 1874). Neogene deposits in this region were described as the "Toshibets Group" in the first local geological map in Japan (Lyman et al., 1876). Such precursory studies, however, did not give a clear definition and subdivisions about the Neogene in southwestern Hokkaido. About 60 years later, Nagao and Sasa (1933, 1934) made the first brief descriptions of geology in this region. They classified the Neogene in the Oshima Peninsula into the Fukuyama, Yoshioka, Kunnui, Yakumo, Kuromatsunai, and Setana Formations in ascending order. Matsui et al. (1955) further subdivided the Kunnui, Kuromatsunai, and Setana Formations into some members. In these the Setana Formation was subdivided into the lower, middle, and upper parts in the western Imakane area. They also pointed out that the Setana Formation exposed in the eastern Imakane area was composed only of the uppermost middle and upper parts. The type locality of the Setana Formation was first designated at Tanekawa in the Imakane area (Nagao and Sasa, 1933). Hashimoto et al. (1963), however, pointed out by analyzing molluscan fossils that the type section was assigned to the Miocene, and they proposed a new type locality (lectotype) at Hanaishi along the River Shiribeshitoshibetsugawa.

There are a few confusions about the relationship between the

Kuromatsunai and Setana Formations. Many investigators considered that the Kuromatsunai Formation is clinounconformably overlain by the Setana Formation (e.g. Nagao and Sasa, 1933; Matsui et al., 1955; Hashimoto et al., 1963; Ishida, 1981; Oka and Mitani, 1981). On the contrary, Ikeya and Uematsu (1968) recognized that the Setana Formation conformably covers the Kuromatsunai Formation in the Kamiyakumo area, in spite of marked clinounconformity in the northern areas, Pirika to Imakane. From the field surveys in the Kamiyakumo area Chitoku (1983) reluctantly stated with some confusions that the "Setana Formation" should be divided into two; one is that clinounconformably covers the Kuromatsunai Formation, and the other contacts conformably with the Kuromatsunai.

Tsubakihara et al. (1989) redefined the type section of the Kuromatsunai Formation in Kuromatsunai. They assigned the upper part of the formation (the Shubuto Sandstone and Siltstone Member) as the *Neodenticula koizumii* Zone of the diatom biostratigraphic zonation (Koizumi, 1985). They also placed the Garogawa Volcanic Products, which was previously placed above the Kuromatsunai Formation, into the lower part of the same formation.

The author shows a summary of these studies in Fig. 18.

(2) Foraminiferal Studies

Foraminifera in the Oshima Peninsula was first reported by Asano (1936a, b) from the "Setana Group" at two localities, the Rivers Kaigarasawa and Nakanosawa in the Kuromatsunai area. He described 103 species with a subspecies, including six new species. Asano and Nakamura (1937) described four new species from the Japanese fossil and the recent species of the genus *Cassidulina* from Rankoshi, Kuromatsunai, Imakane, and Kitahiyama areas. Asano (1937) also described fossil foraminifera from seven localities in Kuromatsunai, seven in Hanaishi, and five in Setana. Later he described many species including eight new species and three new subspecies (Asano, 1938). Asano (1939) divided the Setana foraminiferal associations into the following three sub-associations, Kuromatsunai, Hanaishi and Setana. He stated that the faunule from Hanaishi and Setana, composed of several characteristic forms of the Families Cassidulinidae, Nonionidae and Polymorphinidae, should be considered to mark a northern limit of the "*Cassidulina* province of the Japan Sea" type, and may be correlated to the Wakimoto and Daishaka associations. On the contrary the faunule from Kuromatsunai is related to both the Japan Sea and Pacific types. He suggested that the "faunule" is comparable to the Anden association in the Oga Peninsula, Northeast Japan or the Naganuma association in the Pacific side.

Shirai (1959) reported the geology and foraminiferal fossils of the Kuromatsunai area, and subdivided the Setana Formation into two parts; one is distributed in the eastern "Kuromatsunai depression" area, and the other is in the western. Based on comparison between assemblages of the Kuromatsunai area and the Oga Peninsula, he suggested that the Setana Formation of the eastern area is younger than that of the western part. Furthermore, he reported

a fossil foraminiferal assemblage from the Kamiiso Formation in Hakodate correlated to the Setana Formation, and pointed out that the assemblage of the lower part is rather similar to lower neritic to upper bathyal faunas in the Recent Oyashio regions (Shirai, 1965).

Masatani and Ohkura (1980MS) reported "No. 3 *Globorotalia inflata* bed" from the lower part of the Tate Formations, "No. 2" from the type locality of the Kuromatsunai Formation, and "No. 1" from the Setana Formation. They stated that the lower part of the Tate Formation correspond to the lower part of the Lower Member of the Tentokuji Formation in northeast Japan, the type locality of the Kuromatsunai Formation to the upper part of the same member, and the Setana Formation to the Sasaoka Formation; the Tate and Kuromatsunai Formations correspond to N. 19 - N. 21 Zone (Blow, 1969), and the Setana Formation to N. 22 - N. 23 Zone (Blow, 1969).

Oda (1981) preliminary studied the planktonic foraminifera from the Kuromatsunai Formation at and near the type locality in Kuromatsunai area, and correlated the formation to the *Globigerina pachyderma* (D) /*Globorotalia orientalis* Zone (Maiya, 1978). Tsuchi and Ibaragi (1982) reported fossil planktonic foraminiferal assemblages from the Setana Formation from Hanaishi and Pirika in Imakane, and correlated the formation at upper Zone N21 to lower N22 of the Blow (1969). Tsubakihara et al. (1989) described some planktonic foraminifera and diatoms from the Kuromatsunai and Setana Formations in the Kuromatsunai area. They indicated that the main part of the Kuromatsunai Formation to the diatom *Neodenticula koizumii* Zone (Koizumi, 1985) , and the lower part of the foraminiferal datum *G. pachyderma* (D) / *Gr. orientalis* Zone (Maiya, 1978). They also assigned the Setana Formation to the upper part of the *G. pachyderma* (D) / *Gr. orientalis* Zone.

III. Stratigraphy of the Pliocene and Pleistocene in Northern and Central Parts of the Oshima Peninsula

(1) The Pre-Pliocene Deposits

In the Oshima Peninsula, the Neogene System is composed of the Fukuyama, Yoshioka, Kunnui, Yakumo, Kuromatsunai, and Setana Formations in ascending order. It is unconformably overlying basement rocks of pre-Tertiary.

Fig. 2 shows distributions of the pre-Tertiary to Quaternary in the Oshima Peninsula.

a) Basement Rocks

The basement rocks of the Tertiary System are composed of slate and sandstone beds with sparsely distributed lenticular limestone, hornfels, quartzite layers, and granitic rocks (Fig. 2). Carboniferous and Jurassic coral fossils were reported from the limestone layers (Hashimoto and Igo, 1962). Cretaceous granitic rocks (126Ma; Kono and Ueda, 1966) intruded into these pre-Tertiary deposits are also sporadically distributed. These formations named the Matsumae, Kamiiso, Tomarigawa Groups, and unnamed Imakane rocks.

Paleogene Matahachizawa Formation was only reported from the Kaminokuni area. This formation is composed of tuff breccia with many angular pebbles derived from the Matsumae Group, and is unconformably overlain by the Fukuyama Formation.

b) Miocene Deposits

Early to Middle Miocene deposits are distributed mainly along the Japan Sea side of the Oshima Peninsula. These formations were named the

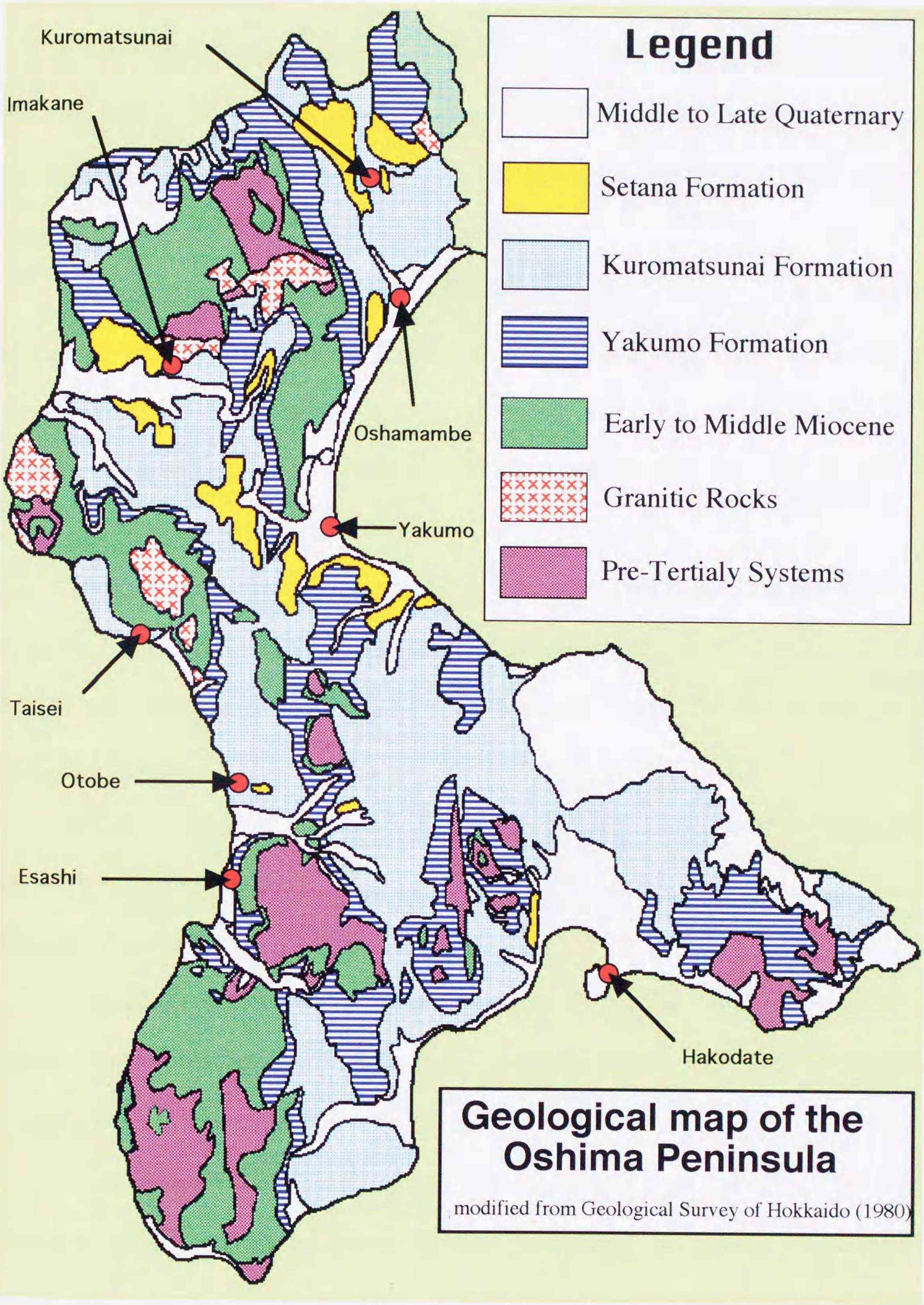


Fig. 2 Geological map of the Oshima Peninsula

Fukuyama, Yoshioka, and Kunnui Formations, in ascending order (Fig. 3).

i) ***The Fukuyama Formation*** Takahashi et al. (1934) described and named this Formation.

Type locality: Matsumae seashore in Matsumae, or Fukuyama in old name. Recently, Hata et al. (1990) have proposed more suitable paratype localities, upper reaches of the River Oibegawa to the Hatakenosawagawa area, or from Matsuura seashore to the River Yoshiokagawa.

Lithofacies: The lower part of this formation is composed of andesite lavas and pyroclastic rocks with a basal conglomerate bed. The lithofacies are more complex in the upper part, including rhyolitic pyroclastic rocks associated with basalt and andesite rocks, rhyolitic welded tuff, and sandstone beds.

Thicknesses are 300m in the lower part and 400m in the upper in Fukushima, and 450m and 400m in Matsumae (Hata et al., 1990), but the formation thickens northward, 500 to 700m in the lower, 500 to 1000m in the middle, and 500 to 1000m in the upper in Kaminokuni (MMAJ, 1981).

Relationship to underlying rocks: This formation unconformably overlies the Paleozoic Matsumae Group, pre-Tertiary granitic rocks, and the Paleogene Matahachizawa Formation.

Correlation: This formation corresponds to the Usubetsu Formation distributed in Kumaishi, the Futoro Formation in Taisei, and the lower part of the Futoro Formation in Setana (e.g. Ganzawa, 1992).

Remarks: Fission track ages have been given as follows; the middle and lower parts of the formation are assigned 23.3Ma, and 24.6Ma, respectively (dacitic tuff; MMAJ, 1981); the upper part of the formation indicate the following ages: 24.2±2.3Ma and 23.1±2.5Ma (rhyolitic tuff;

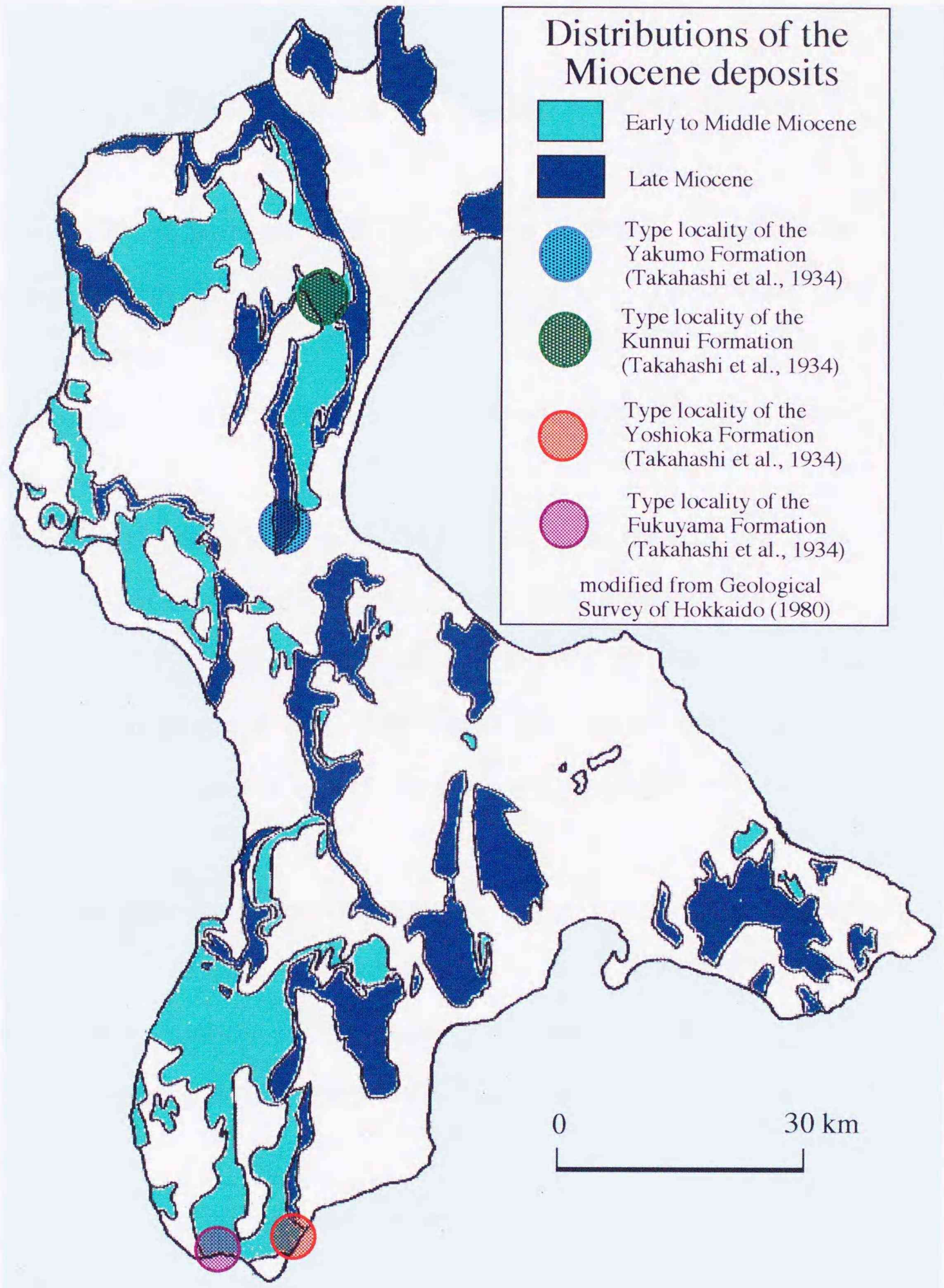


Fig. 3 Distributions of the Miocene deposits

Ganzawa, 1983), 22.3±2.3Ma and 21.7±1.7Ma (dacitic tuff and dacitic green tuff; Koshimizu et al., 1986), and 20.8Ma (rhyolitic tuff; MMAJ, 1981).

ii) ***The Yoshioka Formation*** Takahashi et al. (1934) described and named this formation.

Type locality: Upper reaches of the River Yoshiokagawa in Fukushima.

Lithofacies: Basal parts are composed mainly of pebbly sandstone and tuffaceous sandstone with intercalations of "refractory" claystone, oil-bearing shale, and black mudstone beds.

This Formation is 2 to 170m thick in Fukushima, and 30 to 250m in Matsumae (Hata et al., 1990).

Relationship to underlying rocks: Although there were opinions that the Yoshioka Formation conformably contacts with the underlying Fukuyama Formation (Uozumi et al., 1958; Yoshimura, 1960; Tanai and Suzuki, 1963), Hata et al. (1990) emphasized that this formation clearly contacts with unconformity to the Fukuyama Formation at an outcrop on the River Shirahugawa.

Correlation: This formation corresponds to the Yunotai Formation in Kaminokuni, the Sekinai Formation in the Kumaishi-Taisei area, and the lower part of the Obiragawa Formation in Shimamaki (e.g. Ganzawa, 1992).

iii) ***The Kunnui Formation***; Nagao and Sasa (1933) described and named this formation.

Type locality: Kunnui in Oshamambe.

Lithofacies: The Kunnui Formation is subdivided generally into two parts, lower and upper. The Tatezaki Member, the lower part of the formation in the Fukushima-Shiriuchi area, is composed mainly of sandstone beds. These

sandstone beds in the Kunnui and Setana areas yield many molluscan fossils, such as *Vicarya yokoyamai* and *Vicaryella notoensis*, two of typical components of the Yatsuo-Kadonosawa Fauna (Kanno et al, 1988; Suzuki et al., 1994). The Miyauta Member, the upper part in the Fukushima-Shiriuchi area, is composed mainly of greenish tuff beds and volcanic breccias, which are typical "Green Tuff". Abundant manganese deposits are precipitated at the just below the boundary of the Yakumo Formation in which the mammal *Desmostylus japonicus* has been found (Shikama, 1966).

This formation is 500 to 1400m thick in the Imakane-Kunnui area, and 1500m in the Fukushima-Shiriuchi area (Hata et al., 1990).

Relationship to underlying rocks: The Kunnui Formation clinounconformably covers the pre-Tertiary with thick basal conglomerate beds in the Fukushima-Shiriuchi area (Hata et al., 1990), and also overlies the early Miocene Tsukunai Member of the Futoro Formation in Setana (Suzuki et al., 1994).

Correlation: This formation corresponds to the Hidarimatagawa Formation in Kumaishi, Babagawa Formation in Setana, and the upper part of the Obiragawa Formation in Shimamaki.

Remarks: Three fission track ages were reported; 17.1±1.6Ma of the Tatezaki Member (Yoshimura, 1960) and 14.5±1.4Ma of the Miyauta Member (Yoshimura, 1960), both of which were from andestic tuff by Koshimizu et al. (1986), and 12.5±1.8Ma from greenish tuff of the Miyauta Member by Ganzawa (1992).

iv) ***The Yakumo Formation***; Nagao and Sasa (1933) described and named this formation.

Type locality: Middle reaches of the River Yurappugawa in

Kamiyakumo area.

Lithofacies: This formation is represented by alternations of hard and soft siltstone beds, so-called "hard shale". On the other hand, there is a coarse-grained arcorse sandstone bed, Kaigarabashi Sandstone Member (Hashimoto et al., 1963) in Imakane area. This member is not distributed except that area, and is yielding many fossil molluscs.

This formation is 150 to 1000m or more in thickness, and is widely distributed in the Oshima Peninsula (Fig. 3).

Relationship to underlying rocks: This formation conformably covers the Kunnui Formation in Imakane (Matsui et al., 1955; Oka and Mitani, 1981; Nojo et al., 1994b), but there appears to exist a hiatus or partial unconformity between these two formations in the Fukushima-Shiriuchi area (Masatani and Ohkura, 1980MS).

Correlation: This formation corresponds to the Esashi Formation in the Kaminokuni and Kumaishi-Taisei areas (Sumi et al., 1970), the Kikonai Formation and the Assabu Formation in Tate (Sawamura and Hata, 1981), the Mujinatai Formation in Taisei (Yoshii et al., 1973), the Kogawatoge Formation in Setana (Sagawa and Ueda, 1969), the Orikawa Formation in Shimamaki (DGTCRG, 1984) , and the Yakumo and Futamata Formations in Kuromatsunai (Tsubakihara et al., 1989).

Remarks: There is a few fossil records from this formation except the Kaigarabashi Sandstone Member in the Imakane (Hashimoto et al., 1963). Recently, Suzuki and Nojo (1995, 1996) reported the bivalves *Delectopecten peckhami* and *Conchocele bisecta* from Yakumo and Assabu, respectively. A fossil cetacean was also found in Yakumo (Yakumo town museum, unpublish data). MMAJ (1978) reported the following foraminifera from this formation

in Yakumo; *Cyclammina cancellata, C. japonica, C. orbicularis, Haplophragmoides* spp., *Martinottiella communis, Cribrostomoides* spp., *Spirosigmoilinella compressa, Melonis pompiliodes, M. nicobarense, Epistominella pulchella, E. japonica, Bulimina inflata, Valvulineria sadonica,* and *Globigerina* spp. These assemblages indicate the lower middle bathyal zone (850-950m) based on Hasegawa et al. (1989: Tab. 4).

The grain size and hardness of "hard shale" beds of the Yakumo Formation grade upward into the Kuromatsunai Formation, and the Yakumo Stage ended by about 5Ma (Nojo et al., 1997b). Almost all the areas of the Oshima Peninsula were in bathyal environments in this stage.

(2) The Pliocene and Pleistocene Deposits

a) The Kuromatsunai Formation

This formation was first proposed by Nagao and Sasa (1933) for siltstone and fine-grained sandstone beds overlying the Yakumo Formation in Kuromatsunai and Imakane area. Later, Tsubakihara et al. (1989) redefine the formation in the Kuromatsunai area including its type locality. On the Imakane area, Nojo et al. (1994b) redefined this formation and proposed a paratype locality.

Type locality: Along the River Shubutogawa in Kuromatsunai (Nagao and Sasa, 1933; Tsubakihara et al., 1989). The paratype locality has been designated as the area along the River Shiribeshitoshibetsugawa at Imakane (Nojo et al., 1994b).

Lithofacies: This formation is composed mainly of siltstone, very fine-grained sandstone, intercalated pumice tuff beds, and coarse-grained sandstone only in the upper part (Nojo et al., 1991, 1994b).

This formation is 250 to 780m thick.

Relationships: This formation clinounconformably overlies the Miocene Futamata Formation in Kuromatsunai. In many other areas, on the contrary it contacts conformably with the Yakumo Formation .

Correlation: This formation corresponds to the Tate Formation in the Fukushima to Kumaishi area (e.g. Hata et al., 1990; Sawamura and Hata, 1981), the Makomanai Formation in the Taisei-Setana area (Sagawa and Ueda, 1969), the Honme Formation in Shimamaki (DGTCRG, 1984), and the Mohejigawa Formation in Kamiiso (Mitani et al., 1965).

Remarks: The type section of the Kuromatsunai Formation was redefined by Tsubakihara et al. (1989), because they found out two units

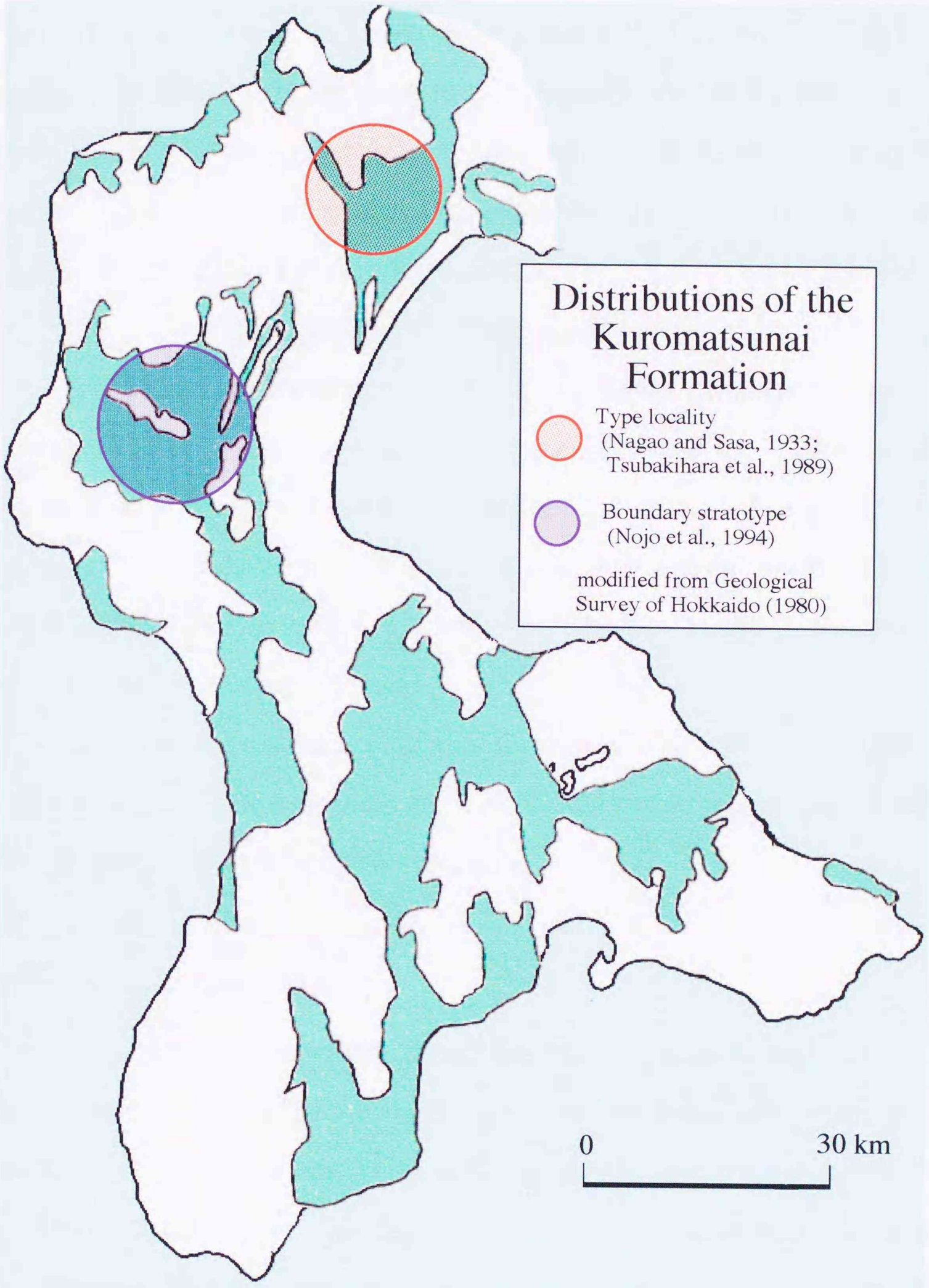


Fig. 4 Distribution of the Kuromatsunai Formation

divided with a clinounconformity in the previous Kuromatsunai Formation. The upper unit is the formation with diatom fossils in the *Neodenticula koizumii* Zone. The lower unit consists of siltstone and volcanics named the Futamata Formation. It is assigned to the *Thalassionema schraderi* Zone of diatom. This is why they redefined the lower part as the Futamata Formation, and subdivided the Kuromatsunai Formation into two members, the lower Garogawa Volcanic Products, the K-Ar dating of which is 4.38±0.44Ma (Kubo et al., 1988), and the upper Shubuto Sandstone and Siltstone Member.

Nojo et al. (1994b) defined the boundary stratotype, and, for convenience, they indicated the boundary between the Yakumo and Kuromatsunai Formation at the lowest tuff bed which runs through both the siltstone and "hard shale" beds. They have also proposed the redefinition and detailed subdivisions to establish a standard lithology of the Kuromatsunai Formation in southwestern Hokkaido.

Because the distribution of this formation is so wide in the Oshima Peninsula that lithologic sequences are variable, the author will discuss in detail about the formation for these areas separately.

Imakane-Kamiyakumo Area

This formation is widely distributed from Pirika to Kitahiyama in the Imakane area, and from the Rivers Yurappugawa to Penkerupeshupegawa in Kamiyakumo area (Fig. 6). It is subdivided into three members at the boundary stratotype in the Imakane area, the Sumiyoshi Siltstone, Sakkurubetsu Pyroclastic, and Okusawa Sandstone Members in ascending order (Fig. 5; Nojo et al., 1994b).

The Sumiyoshi Siltstone Member: This member is the lowermost

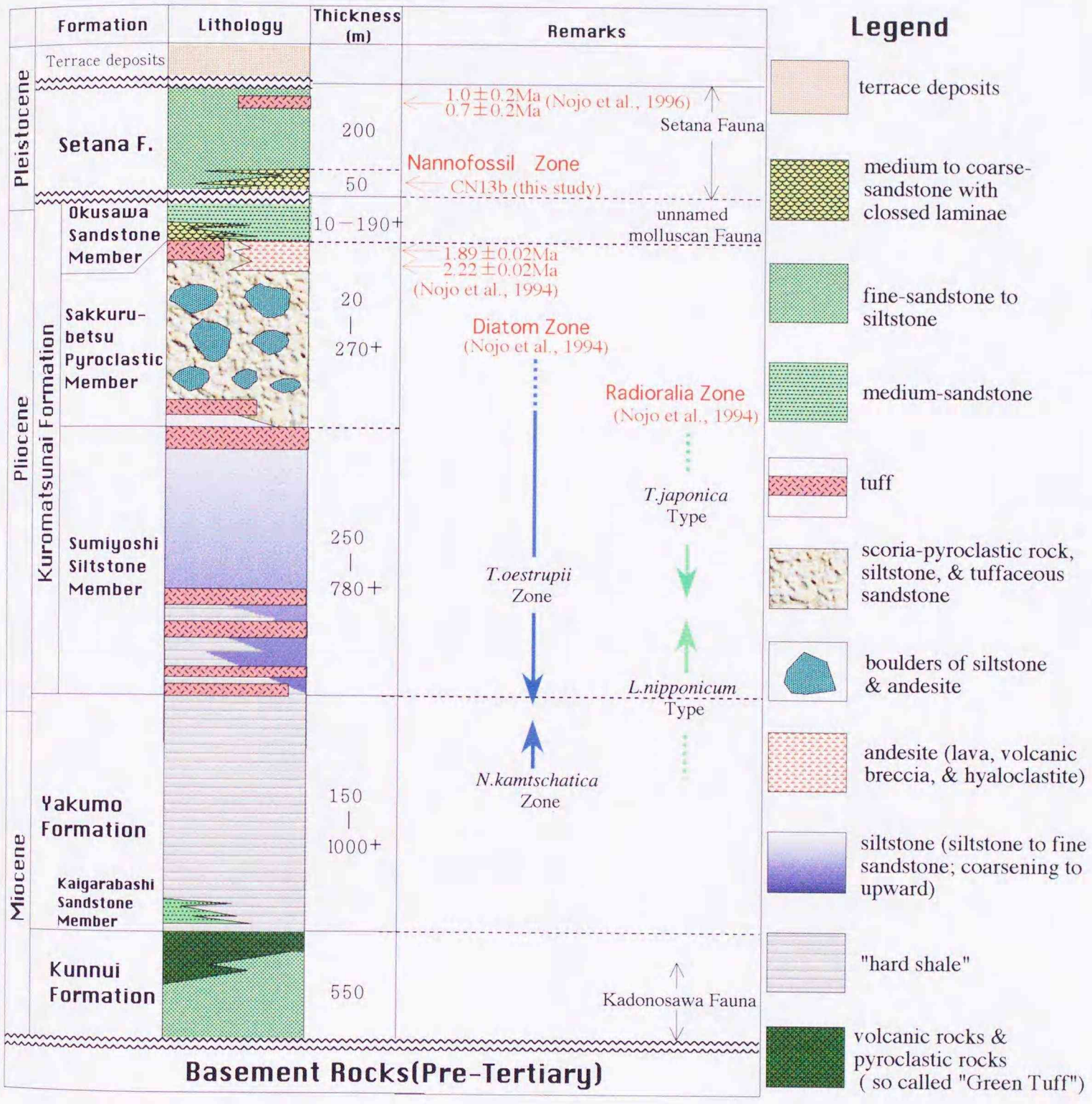


Fig. 5 Schematic geological columnar sections of the Imakane- Kamiyakumo area (modified from Nojo et al., 1994b)

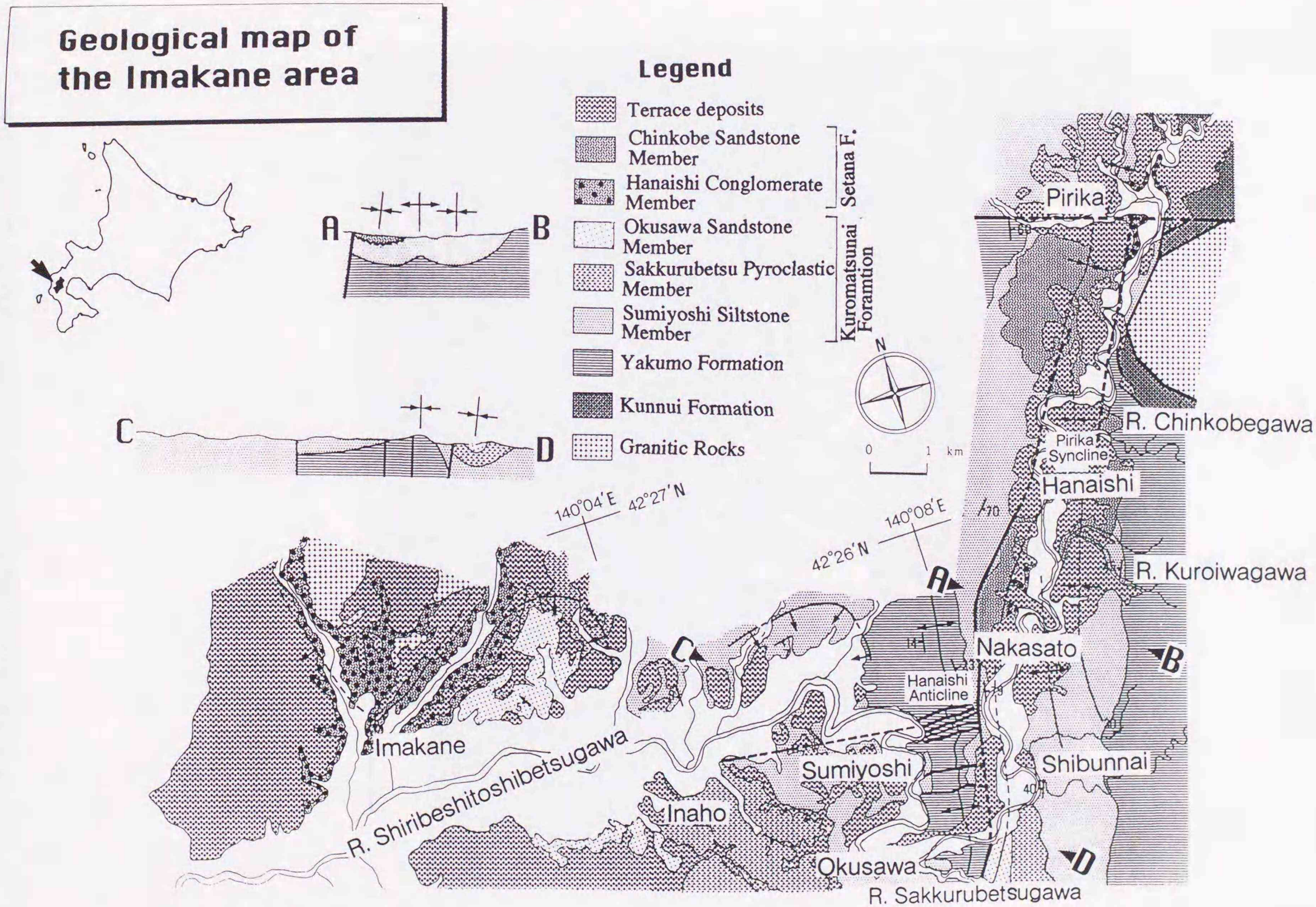


Fig. 6 Geological map of the Imakane area (modified from Nojo et al., 1994b)

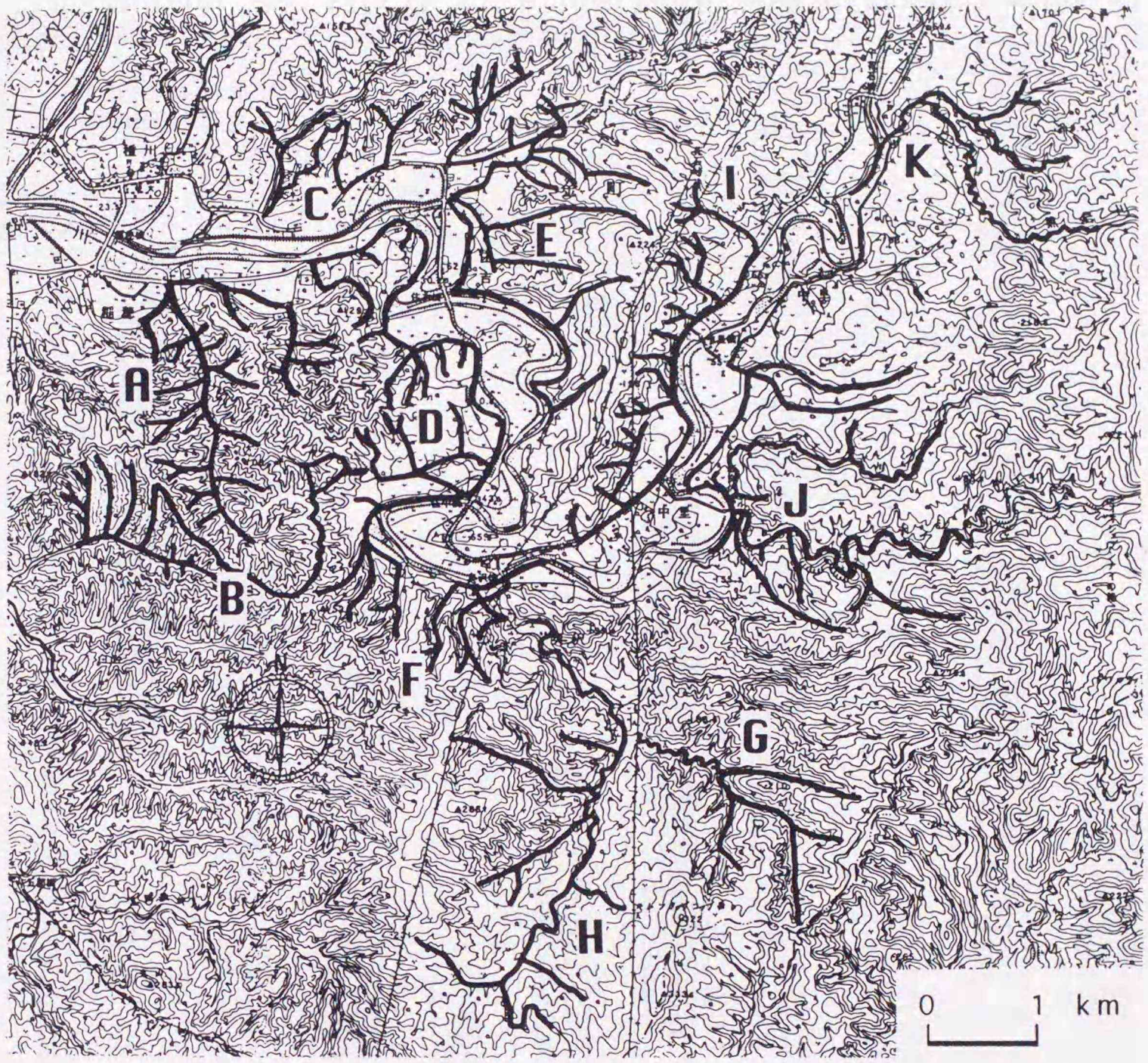


Fig. 7 Index map of the columnar sections (using the topographical map of "Imakane", scale 1:50000 published by Geographical Survey Institue of Japan)

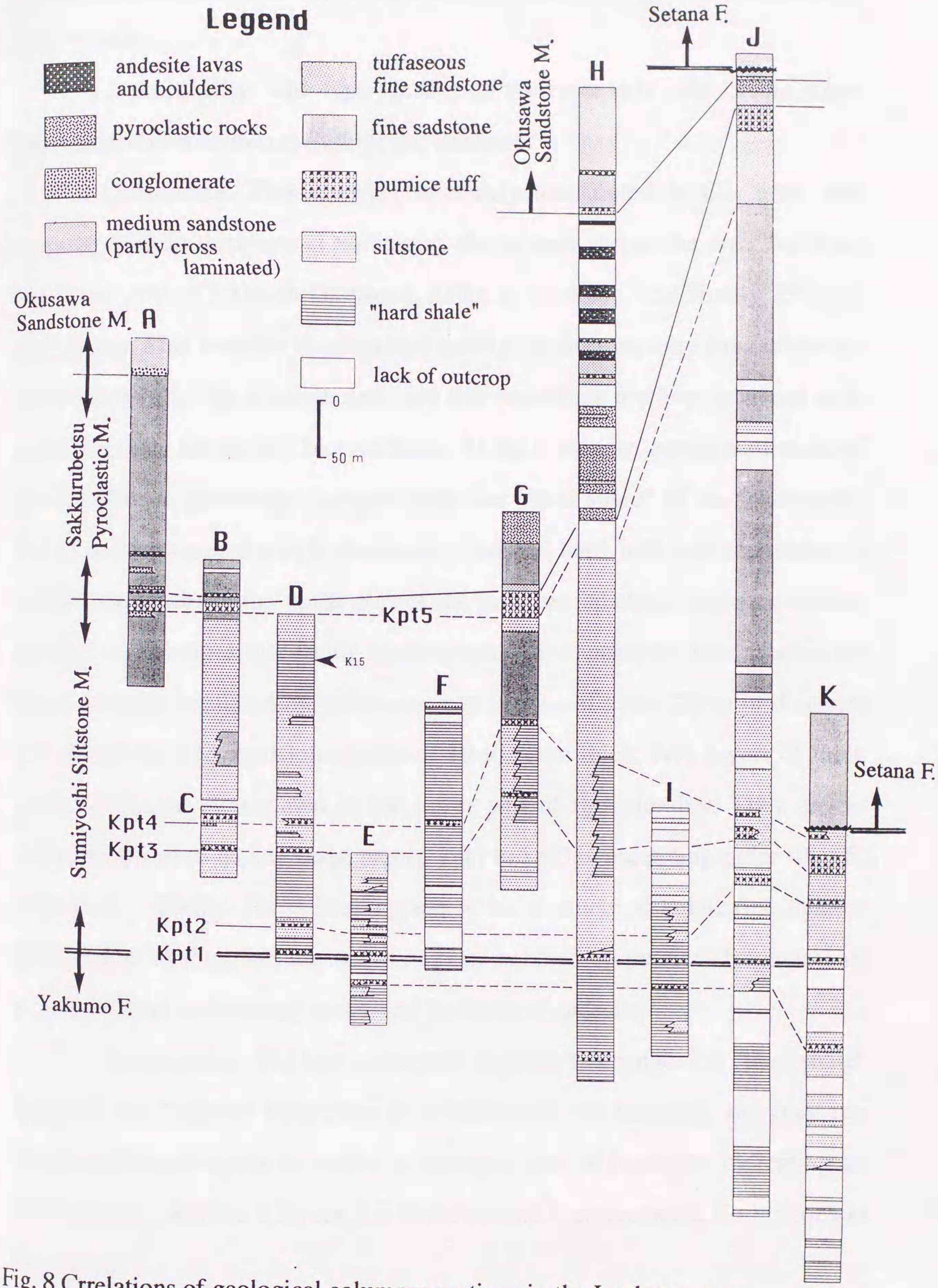


Fig. 8 Crrelations of geological columnar sections in the Imakane area
(modified from Nojo et al., 1994b)

part of the Kuromatsunai Formation in the Imakane-Kamiyakumo area (Nojo et al., 1994b).

Type locality: The type locality is the river-side cliff of the River Shiribeshitoshibetsugawa at Sumiyoshi, Imakane.

Lithofacies: This member is widely distributed in this area, and exceeds 780m in thickness at Shibunnai, the eastern part of the area, but thins westward, 330 to 390m in Okusawa, 310m in Imakane, and finally 250m in Kitahiyama. This member is composed mainly of siltstone, very fine-sandstone and pumice tuff. The siltstone and very fine sandstone are homogeneous with numerous trace fossils and bioturbations. At the basal part massive siltstone of this member is gradually changed from the "hard shale" of the underlying Yakumo Formation through alternating beds of hard and soft mudstone in upward sequence. In the upper part of the member, siltstone becomes coarser upward, and changes into sandy siltstone and fine-sandstone. These facies are occasionally intercalated by calcareous concretions of about 20cm in diameter and calcareous fine-sandstone layers of 10 to 30cm thick. Five layers of thick pumice tuff, are intercalated in the lower part of this member. They are so characteristic as to be key beds, named kpt1 to kpt5 in ascending order (Fig. 8; Nojo et al., 1994b). These beds appear to be products of submarine pumice flows, because they include many angular pebbles of pumice, fragments of pyroclastic and sedimentary rocks, and boulders of andesite.

Relationship: The lower four tuff beds are intercalated in "hard shale" layers of the Yakumo Formation in southern part of Imakane, but they run into the siltstone layers in central to northern part of Imakane, indicating an interfingering relation between the Yakumo and Kuromatsunai Formations at the contact.

Fossils: There are few mega-fossils from this member except poriferan *Makiyama chitanii*.

This member corresponds to the Hakaimappu Thin-interbed and Meppu Thick-interbed of Nagao and Sasa (1933), the Grayish Mudstone Bed and Black Sandstone-Mudstone Interbed of Matsui et al. (1955), the Shimohakai Pumice Member and Tanekawa Mudstone Member of Hashimoto et al. (1963), the Tanekawa Siltstone Member, Shibunnai Pumice Tuff Member and Shimohakai Pumice Tuff Member of Ikeya and Uematsu (1968), the Makomanai Formation (Sagawa and Ueda, 1969), Sandstone and Siltstone Member of Oka and Mitani (1981), and Facies A of the upper part of the Namarikawa Formation of Chitoku (1984).

ii) ***The Sakkurubetsu Pyroclastic Member***; This member was defined by Nojo et al. (1994b). The type locality is along the River Sakkurubetsugawa. This member are distributed in the upper stream of the River Ocharappegawa. This member is more than 200m thick at Imakane, 270m at Okusawa, and 20m+ at Shibunnai.

This member is composed mainly of pyroclastic medium-sandstone, andestic tuff breccia and volcanic breccia. The most prominent character is the occasional occurrence of the beds huge blocks of siltstone over a thousand cubic meter. Oka and Mitani (1981) called the beds "disturbed facies", which was considered to such submarine volcanic products as, lava flows and pumice flows at the beginning of deposition of the Setana Formation when later stages of the Kuromatsunai Formation still remained in deposition. They included the "disturbed facies" in the Setana Formation. However, around the Shibunnaibashi Bridge, the author found a thick tuff bed (Shibunnai Pumice Tuff: Ikeya and Uematsu, 1968) which continuously contacts with the beds of

andestic tuff-breccia and conglomerate. This tuff bed is clinounconformably covered by cross-laminated medium-sandstone which is continuously distributed from the type locality of the Setana Formation (Nojo et al., 1994b). These indicate that these layers do not belong to the Setana Formation.

There is a tendency of reduced yieldings of *Makiyama chitanii* toward upper parts of the Kuromatsunai Formation, this fossil characterizing the Yakumo and the lower parts of the Kuromatsunai Formations in the Imakane-Kamiyakumo area (Nojo et al., 1994b). Molluscan fossils from this member are as follows; *Limopsis tokaiensis, Cryptonatica janthostomoides, Lunatia* sp., *Turritella* sp., *Neptunea* sp., and *Laqueus* sp. (Nojo et al., 1994b).

Andesite rocks which named the Imakane Volcanic Rocks (Nojo et al., 1994a), are distributed in the southern Imakane to Kamiyakumo area, and showed the K-Ar ages of 2.22±0.2Ma and 1.89±0.2Ma (Nojo et al., 1994a). This member is, therefore, correlated with the Shubuto Sandstone and Siltstone Member (Tsubakihara et al., 1989) of the Kuromatsunai Formation in the type locality. This member is also correlated with the Seiyobetsu Andesite (Ikeya and Uematsu, 1968) in the Kamiyakumo area, the Shiribetsugawa Formation (Yamagishi et al, 1976, 1984) in the Rankoshi, and the Shiriuchi Volcanic Rocks and Idesugawa Formation (Ohtsu and Suzuki, 1995) in Shiriuchi.

iii) ***The Okusawa Sandstone Member***; Nojo et al. (1994b) defined this member. The type locality is around Okusawa, in Imakane, and the member is distributed in Shibunnai, Tashiro, Yatsuka, and Kinbara in Imakane, and Natsuji in Kamiyakumo. The thicknesses of this member are more than 110m in Okusawa, 10m+ in Shibunnai, 200m+ in Yatsuka-Kinbara, and 190m+ in Natsuji.

The member is composed mainly of cross-laminated tuffaceous

middle- to coarse-sandstone. At the boundary with the underlaying member there are some beds of pyroclastic conglomerate, and these beds are overlain by cross-laminated tuffaceous sandstone beds with molluscan fossils such as *Tridonta borealis, Limopsis* sp., *Cryptonatica janthostomoides*, and *Neptunea* sp. There is no poriferan *Makiyama chitanii* from this member.

This member has been identified to the Setana Formation by the previous workers (e.g. Hashimoto et al., 1963; Ikeya and Uematsu, 1968; Ishida, 1981; Oka and Mitani, 1981). On the contrary, the present author regards the relationship between the Okusawa Sandstone Member and Setana Formation as clinounconformity, because such a contact has been found at Kamiyakumo, Shibunnai, and Hatakenosawa (Nojo et al., 1994b). In addition, the opinion of the previous workers seem to be resulted from similarities of the lithofacies and molluscan assemblages of the Okusawa Sandstone Member and the Setana Formation.

Taisei-Otobe Area

The formation which is correlated with the Kuromatsunai Formation in this area is named the Tate Formation and the Ainuma Volcanic Rocks which show complicated relations with the Tate Formation (Hata and Yamaguchi, 1969; Sawamura and Hata, 1981). The Tate Formation is covered by the Nagaiso Andesite.

i) ***The Tate Formation***; The Tate Formation was named by Hata and Yamaguchi (1969), and the type locality is around Tate in Assabu, the southern Oshima Peninsula. This formation is about 500m in thickness, and is widely distributed along the Japan Sea coast from Esashi to Kumaishi. In these areas, alternations of siltstone and sandstone of the Tate Formation are

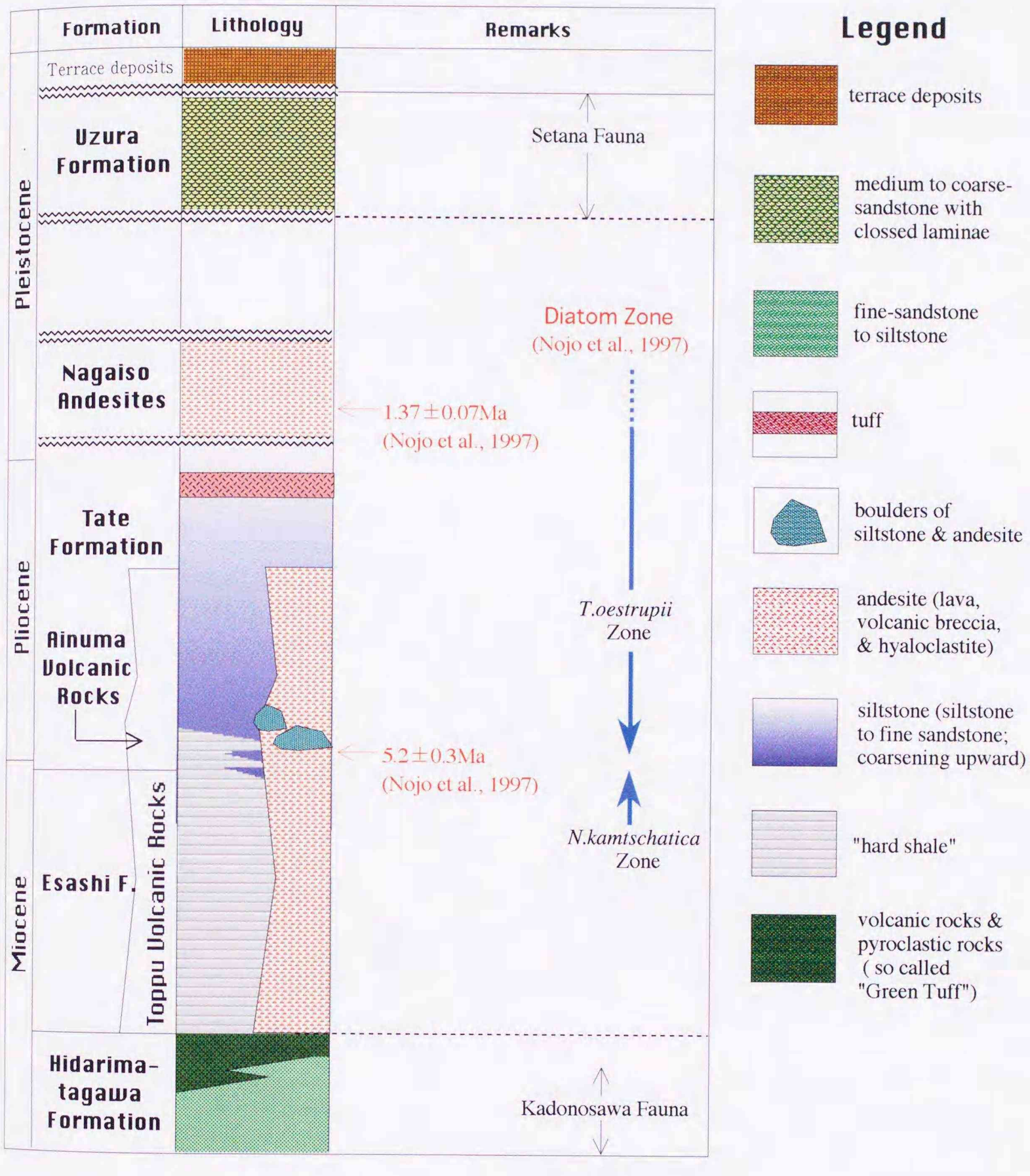


Fig. 9 Schematic geological columnar sections of the Taisei-Otobe area (modified from Nojo et al., 1997c)

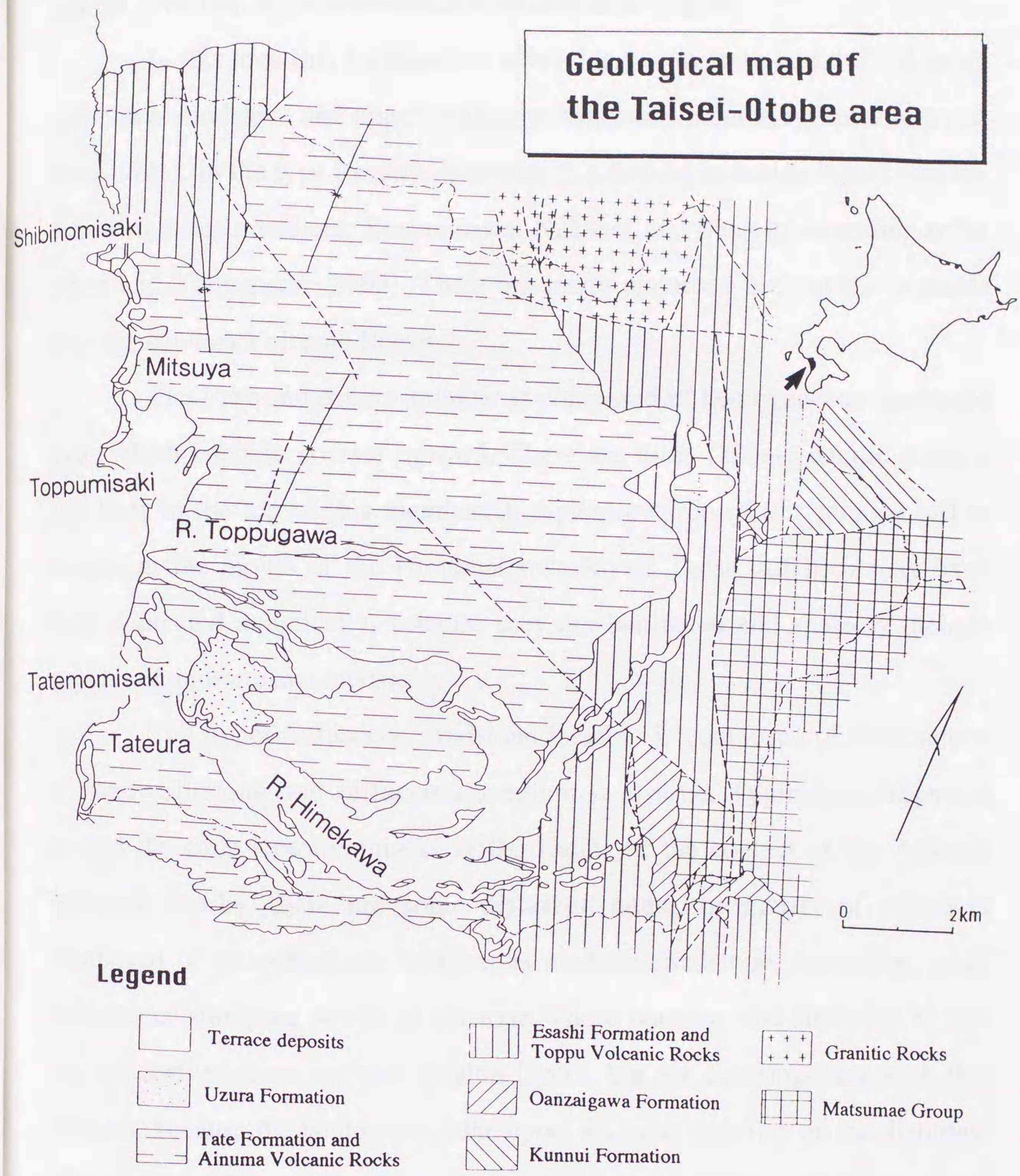


Fig. 10 Geological map of the Taisei-Otobe area

(modified from Nojo et al., 1997c)

gradually changed from "hard shale" facies of the Esashi Formation, without distinct boundary as in Imakane-Kamiyakumo area (Fig. 9).

In this area this formation is subdivided commonly into the following two; lower mudstone and upper tuffaceous sandstone members (Sawamura and Hata, 1981). In the type locality, however, this formation is subdivided into the following three members, Yosumisawa, Nukano, and Suga in ascending order (Hata and Yamaguchi, 1969). There are many disturbed beds at the contacts with the Ainuma Volcanic Rocks.

The lower mudstone member is composed of homogeneous mudstone beds which become coarser upward. There are thick (20m+) dacitic pumice tuff beds in the top of this member. A typical outcrop of this pumice tuff is located at the mouth of the Hiratanaigawa River. These tuff beds may have been deposited aquatically, because they are laminated and sparsely include pebbles of andesite and mudstone.

The upper tuffaceous sandstone member is composed of alternations of sandy siltstone and tuffaceous medium-sandstone. Typical outcrops are around the cape Kotohiramisaki to Gennadai. At the contact of the Ainuma Volcanic Rocks, there are some disturbed beds, the matrix of which is composed of pyroclastic or tuffaceous medium-sandstone, including many boulders or slumping blocks of siltstone. These boulders and slumping blocks are not derived from the underlaying layers, but are contemporary with this member, because the boulders and the upper siltstone beds just on the disturbed parts yield the fossil diatoms of the same biozone, *Neodenticula kamtschatica* Zone (6.6-5.1Ma; Nojo et al., 1997b).

Sawamura and Hata (1981) described many fossil diatoms from the lower member in Kumaishi. They did not give biostratigraphical zonations, but

the author estimated its biozone the *Thalassiosira oestrupii* Zone (5.1-3.7Ma) based on the occurrence of *Thalassionema oestrupi* (sic.) from the table in their paper. Nojo et al. (1997b) have reported that the basal part of the upper tuffaceous sandstone member belongs to the *Neodenticula kamtschatica* Zone (6.6-5.1Ma). The author, therefore, can estimate that the boundary between the *T. oestrupii* (5.1-3.7Ma) and *N. kamtschatica* Zone (6.6-5.1Ma) is situated within the lower member.

Koizumi (1979) and Nojo et al. (1994b) have pointed out that the Suga Member defined as the uppermost member in the Tate Formation belongs to the *N. kamtschatica-N. Koizumii* Zone (3.7-2.5Ma). Masatani and Ohkura (1980MS) reported that the upper tuffaceous sandstone member belongs to the same zone.

These facts indicate that the Tate Formation had been deposited during the time of 5.1 to 2.5Ma, which is correlative with the Sumiyoshi Siltstone to Sakkurubetsu Pyroclastic Members in Imakane.

ii) ***The Ainuma Andesite Rocks***; These rocks were defined by Sawamura and Hata (1981), and the type locality is around the River Ogawa, a side stream of the Ainumanaigawa River. These rocks are widely distributed in Taisei-Otobe area, and the thickness is about 700m (Sawamura and Hata, 1981).

These rocks are composed mainly of pyroxene andestic hyaloclastites and lavas, interlocking with the Tate Formation, and there are many disturbed beds of the Tate Formation at their contact. At the cape Kotohiramisaki, the base of the upper tuffaceous sandstone member covers the disturbed and slumping beds of the Tate Formation which include many boulders of siltstone. Nojo et al. (1997b) obtained 5.2±0.3Ma of K-Ar age for the andesite from the

interlocking horizon with the Tate Formation. This age is harmonious with the age obtained from the microfossils of the Tate Formation.

The horizon of these rocks are correlative with the Sumiyoshi Siltstone Member of the Kuromatsunai Formation which includes many thick tuff layers reflecting active volcanisms same as those in the time of the Ainuma Andesite Rocks.

iii) ***The Nagaiso Andesite***; These andesites were first defined as the Nagaiso Formation by Hata (1967), and were then renamed "Nagaiso Andesite" by Yoshii et al. (1973). The type locality is Nagaiso in Taisei, and these rocks composed of various volcanic facies, such as lavas, hyaloclastites, and volcanic breccias, are distributed along the Japan Sea coast from Taisei to Kumaishi, and their thickness is less than 50m (Sawamura and Hata, 1981).

These rocks unconformably cover the Tate Formation in Kaitorima, but the relationship to the Setana Formation has remained unclear because of no outcrops of the very contact. These rocks have indefinitely been set the horizon under the Setana Formation, but MMAJ (1978) emphasized that the eruption produced these rocks took place at the latest stage of the Tate Stage because of lithological similarities to other andestic rocks in the Kuromatsunai Stage. Besides the K-Ar age of 1.37±0.03Ma from the pyroxene andesite rock from the Nagaiso Andesite (Nojo et al., 1997b), no evidence of active and regional volcanisms in the Setana Stage may also support such a stratigraphical situation of the Nagaiso Andesite (Nojo et al., 1997b).

Kuromatsunai-Rankoshi Area; This area includes the type locality of the formation defined by Nagao and Sasa (1933) , and redefined by Tsubakihara et al. (1989). The Kuromatsunai Formation is subdivided into the following two

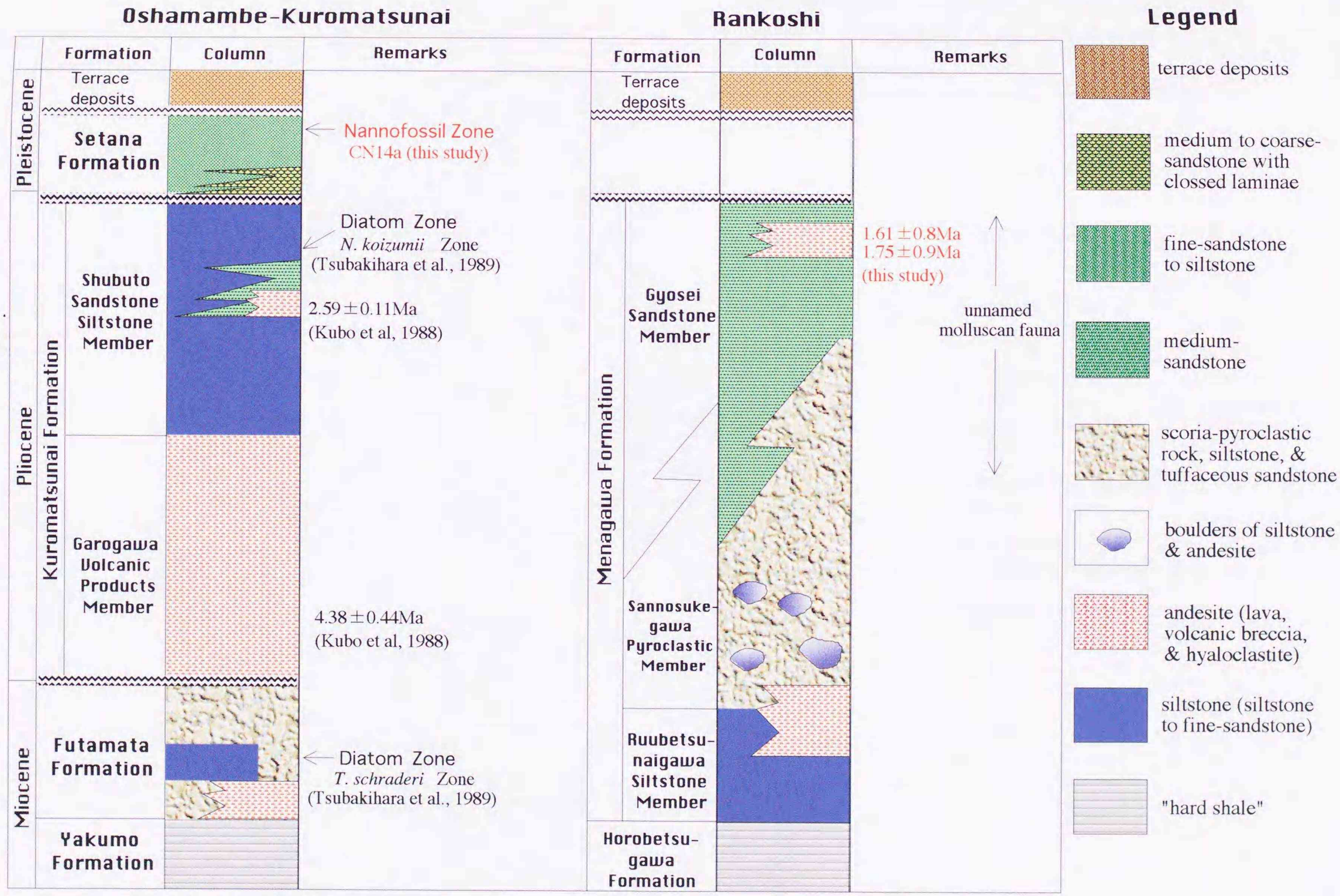


Fig. 11 Schematic geological columnar sections of the Kuromatsunai-Rankoshi area

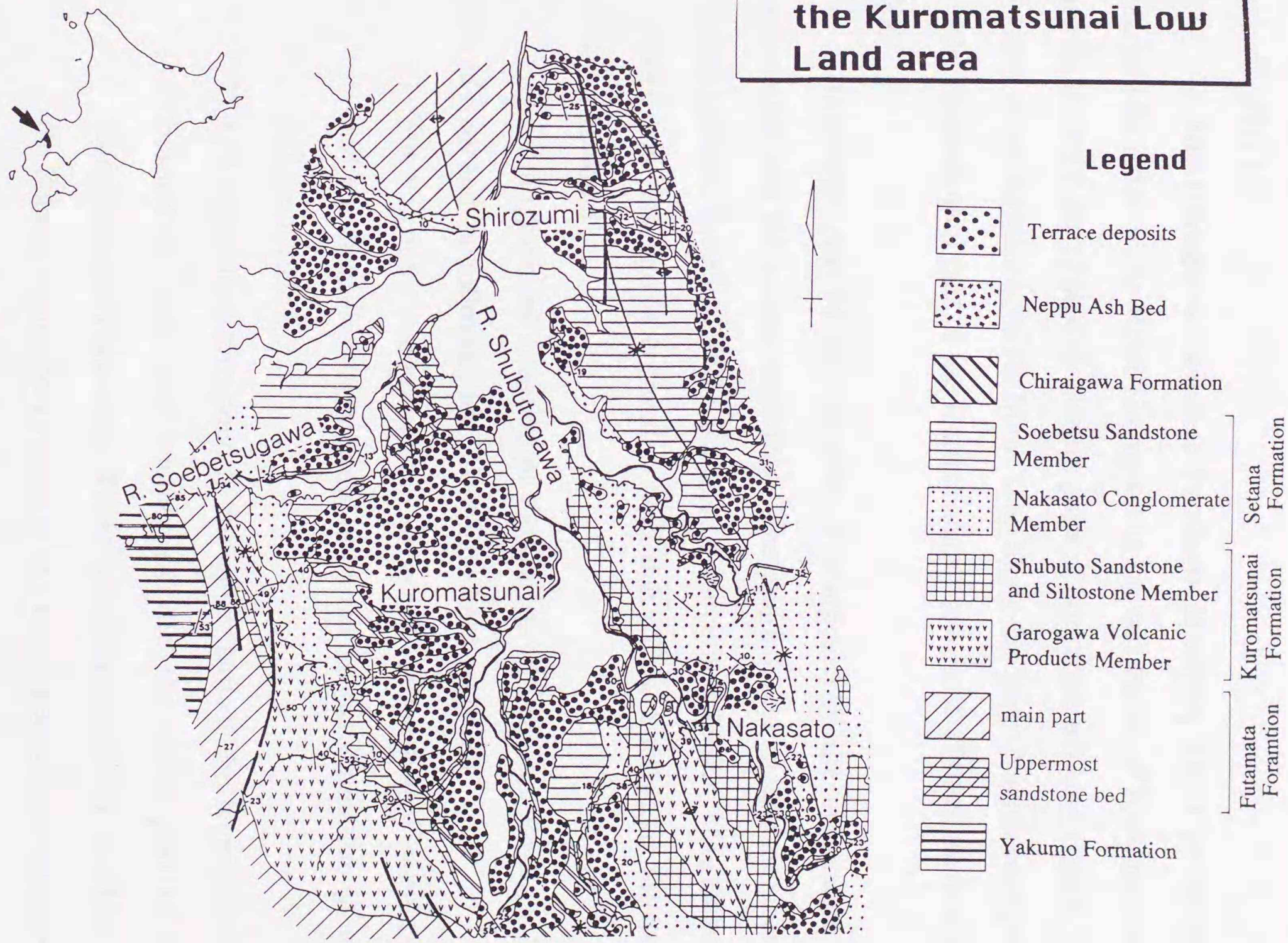


Fig. 12 Geological map of the Kuromatsunai Low Land area
(modified from Tsubakihara et al., 1989)

members, the Garogawa Volcanic Products, and Shubuto Sandstone and Siltstone Members in ascending order (Fig. 11). The Menagawa Formation composed of medium to coarse sandstone beds which can be correlative with the Kuromatsunai Formation are distributed along the River Shiribetsugawa in Rankoshi (Fig. 13).

i) ***The Garogawa Volcanic Products Member***; The type locality is the middle parts of the River Garogawa in the southwest of Kuromatsunai. The volcanics are distributed in western parts of Kuromatsunai and Utasai. The thickness of the formation varies from 700m along the River Nakanosawagawa to 200m in the central part of the Kuromatsunai Low Land (Tsubakihara et al., 1989).

The basal part of this member is composed of the alternation of conglomerate and tuffaceous sandstone. The major facies of the member is pyroxene-andesite breccias. The K-Ar age of which is 4.38±0.44Ma (Kubo et al., 1988), and this age is correlated with that of the Sumiyoshi Siltstone Member in Imakane.

The stratigraphical situation of the Garogawa Volcanic Products has been confused, and the following four ideas have been proposed;

1) The volcanics unconformably cover the Kuromatsunai Formation, and are disconformably overlain by the Setana Formation (Nagao and Sasa, 1933).
2) The volcanics correspond to the upper part of the Kuromatsunai Formation, and conformably overlie the main part of the Kuromatsunai Formation. These are disconformably overlain by the Setana Formation (Yajima et al., 1939; Yajima and Rikukawa, 1939; Sawada, 1962; Suzuki, 1989).

3) The volcanics are contemporaneous with lower parts of the Setana Formation, and are disconformably covers the Kuromatsunai Formation (Shirai, 1959; Ikeya and Hayashi, 1982).

4) The volcanics are conformably overlain by the Shubuto Sandstone and Siltstone Member, the main part of the Kuromatsunai Formation in the type locality of the formation. The Setana Formation does not cover these volcanics, but it clinounconformably overlies the Shubuto Sandstone and Siltstone Member (Tsubakihara et al., 1989).

The author supports the last idea based on the evidences mentioned below;

1) In the upper part of the River Garogawa, the volcanics clearly cover clinounconformably the Miocene Futamata Formation.

2) The type section of the Shubuto Sandstone and Siltstone Member deposited at about 1.9Ma based on biostratigraphy of diatom (see next subsection).

3) The volcanics were active in about 4.4Ma (Kubo et al., 1988).

ii) ***The Shubuto Sandstone and Siltstone Member***; The type locality of this member is located along the River Shubutogawa in southeastern Kuromatsunai (Fig. 12). This member is distributed only in central parts of the Kuromatsunai Low Land, and its thickness is about 350m (Tsubakihara et al., 1989). It conformably overlies the Garogawa Volcanic Products Member in the type locality.

In the type locality, fine-sandstone to medium-sandstone beds are dominant in the lower part of the member. It includes some calcareous layered concretions of about 20cm in diameter, pumice tuff layers of 100 to 200cm

thick, and many cross-laminated sandstone beds of 50 to 150cm thick. Mud contents of this part are less than 50%. Those sandstone beds become finer upward, and are changed into silty facies with many trace fossils in the middle part, showing 50 to 75% of mud contents. In the upper part with no bioturbations, the silty facies is intercalated by at least three "dark layers" of 5 to 100cm in thickness, and mud contents show over 75%.

This member yields many diatoms and radiolarians, but contains few molluscs and foraminifera (Itaki et al., 1997). Tsubakihara et al. (1989) reported some occurrences of diatoms, many *N. koizumii* but no *N. kamtschatica*, belong to the *N. koizumii* Zone, and foraminifera, *Gr. praeinflata and N. asanoi*, belong to lower part of the *N. pachyderma* (D) / *Gr. orientalis* Zone (just below the Olduvai Event; ca. 1.9Ma: Maiya, 1976, 1978); Itaki et al. (1997) also indicated the same planktonic foraminiferal biozone. Itaki et al. (1997) further reported some benthic foraminifera (see Chapter IV) and radiolarians, the latter indicating the *Cycladophora sakaii* Zone (3.2-1.88Ma; Motoyama, 1996) in the north Pacific. The author estimates paleodepth of this member as upper middle bathyal zone (550-950m) of Hasegawa et al. (1989). These facts suggest that this member was deposited at about 1.9Ma, and is correlative with the Sakkurubetsu Pyroclastic Member in Imakane.

iii) ***The Horobetsugawa and Menagawa Formations***; These are tentative names instead of the Shiribetsugawa and Isoya Formations defined by Yamagishi et al. (1976). The type localities were around the River Shiribetsugawa and Isoya coast in Suttsu. According to the definition, the Isoya Formation is composed of "hard shale", siltstone, and hyaloclastite in ascending order, and the Shiribetsugawa Formation is of sandstone and conglomerate

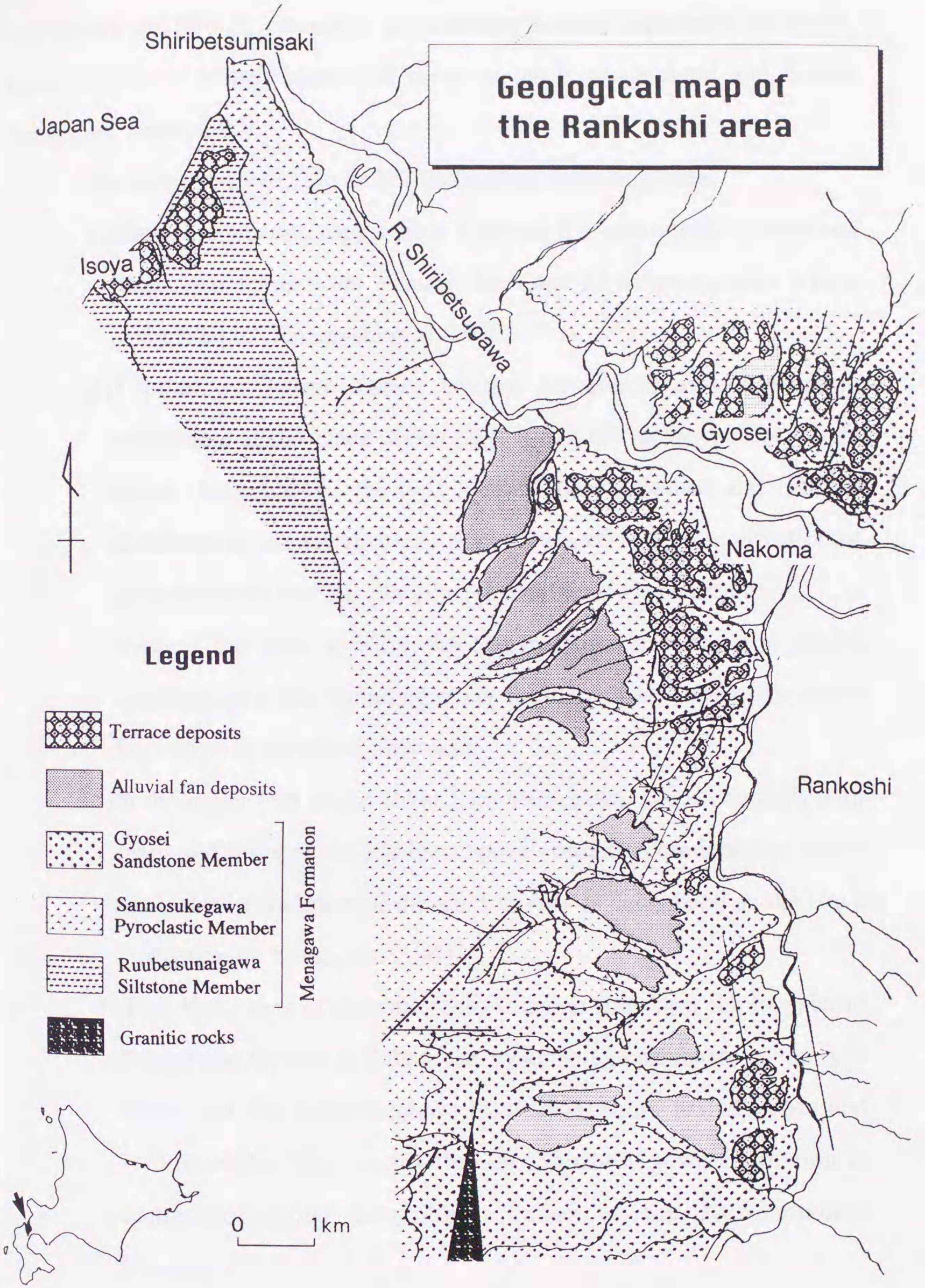


Fig. 13 Geological map of the Rankoshi area

beds partly containing abundant invertebrate fossils especially molluscs. Yamagishi et al. (1984) correlated these to the Kuromatsunai and Setana Formations, respectively.

Recently, however, the author find out the following facts;

1)There are no outcrops which indicate the unconformity between these two formations around the Cape Shiribetsumisaki where designated by Yamagishi et al.(1976).

2)Typical sandstone facies of the Shiribetsugawa Formation observable at the place about 750m south of the Isoyabashi bridge where designated as the type locality have a limited and isolated distribution, namely they can not be pursued along the direction of their strikes so that this place is not suitable as a type locality.

3)Around the type locality the Shiribetsugawa Formation shows slumping structure including many boulders of siltstone of the Isoya Formation in pyroclastic matrices.

4)In the upper part of the River Sannosukegawa, sandstone beds with many molluscs of the Shiribetsugawa Formation conformably cover hyaloclastite and pyroclastic sandstone beds designated as the Isoya Formation by Yamagishi (1984).

5) Two K-Ar ages of andesite rocks sampled from near the Isoyabashi Bridge and Gyosei in Suttsu, the rocks being correlative to the type locality of the Shiribetsugawa Formation, show 1.61±0.08Ma and 1.75±0.09Ma. This means that the Shiribetsugawa Formation is contemporaneous heterotopic facies of the Kuromatsunai Formation.

These facts indicate that the formations need a redefinition along the

course mentioned below;

1) The Isoya Formation of Yamagishi et al. (1976) should be divided into the following two conformable members in tentative names, lower Horobetsugawa and upper Menagawa Formations.
2) The Shiribetsugawa Formation of Yamagishi et al. (1976) should be included within the Menagawa Formation.
3) The Menagawa Formation should be subdivided into the following three members; Ruubetsunaigawa Siltstone, Sannosukegawa Pyroclastic, and Gyosei Sandstone Members in ascending order.
4) These three members are correlative with each member of the Kuromatsunai Formation in Imakane, respectively, and also the Sannosukegawa Pyroclastic and Gyosei Sandstone Members with the Kuromatsunai Formation in the type section. There is, however, a possibility that the Ruubetsunaigawa Siltstone Member may have been deposited during Miocene, because Sagayama (1997) pointed out that the diatom biochronology of the Isoya Formation shows the *N. kamtschatica* Zone (6.60-5.10Ma).

b) The Setana Formation

This formation was first proposed by Nagao and Sasa (1933) for coarse-grained sandstone beds clinounconformably overlying the Kuromatsunai Formation in Kuromatsunai and Imakane-Kamiyakuno area. Later Hashimoto et al. (1963) redefine the formation in the Imakane area including its type locality.

Type locality: The type locality was redefined, from riverside of River Meppugawa to along the River Shiribeshitoshibetsugawa at Hanaishi in Imakane (Hashimoto et al., 1963), because molluscan fossils from the beds located at Tanekawa in Imakane were of Miocene age (Sawada, 1961; Masuda and Sawada, 1961; Kanno, 1962).

Lithofacies: This formation is composed of cross-laminated pebbly coarse-grained sandstone beds and homogeneous fine-grained sandstone to mudstone beds, yielding well-preserved, abundant molluscan fossils belong to the members of the Setana Fauna (Uozumi et al., 1962; Akamatsu, 1987, Suzuki, 1989, Akamatsu and Suzuki, 1990). This formation is averaged about 200m thick, and distributed in Kuromatsunai, Imakane-Kamiyakumo, Otobe, Tate, and Kamiiso (Fig. 14).

Relationship to underlying rocks: This formation is clinounconformably overlying all the underlaying formations (Nojo et al., 1994b).

Correlation: This formation corresponds to the Uzura Formation in the Tate-Otobe area, and the Tomikawa Formation in Kamiiso (Fig. 14).

Because the lithologic sequences are variable between the areas, the author will discuss in detail about the formation for these areas separately.

Imakane-Kamiyakumo Area; This formation was first named by Nagao

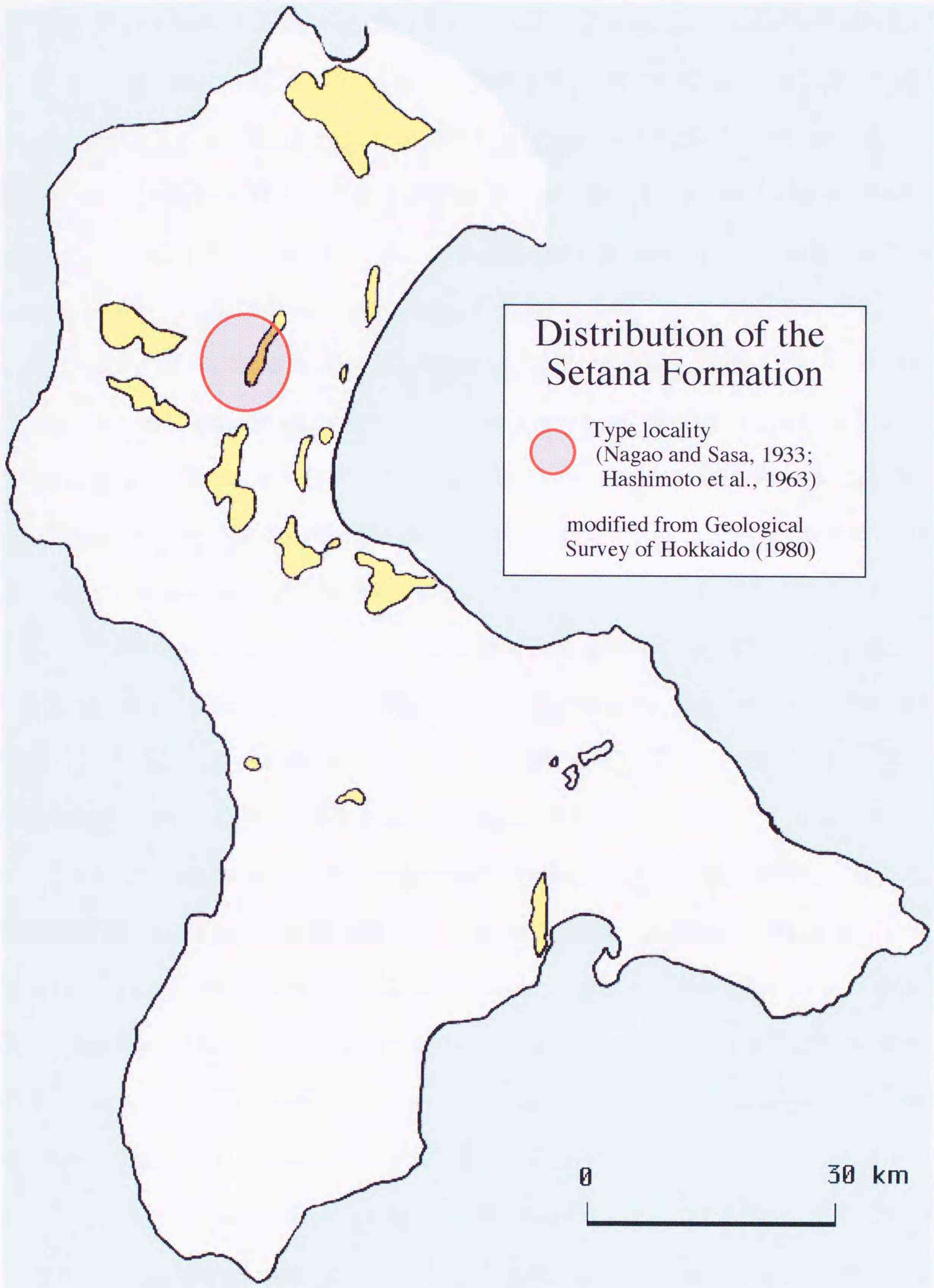


Fig. 14 Distribution of the Setana Formation

and Sasa (1933), and redefined by Hashimoto et al. (1963) in this area. Ikeya and Uematsu (1968) subdivided this formation into four members, Seiyobetsu Andesite, Hanaishi Conglomerate, Chinkobe Sandstone, and Natsuji Conglomerate in ascending order. Recently, Nojo et al. (1994b) separated the Seiyobetsu Andesite from this formation and out into the Sakkurubetsu Pyroclastic Member of the Kuromatsunai Formation based on its stratigraphical position and two K-Ar ages. They also put the Natsuji Conglomerate Member into the Hanaishi Conglomerate Member based on its distribution, stratigraphical position, and properties of molluscan assemblage. As a result, this formation is subdivided into two; the Hanaishi Conglomerate, and Chinkobe Sandstone Members. Both members are partly interfingered each other in lower parts of the formation.

This formation is composed mainly of pebbly medium- to coarse-sandstone beds in the Hanaishi Conglomerate Member, and of siltstone and sandstone beds in the Chinkobe Sandstone Member. The lower part is 50m thick, and the upper 200m thick (Nojo et al., 1994b).

This formation yields numerous well-preserved molluscan fossils. This assemblage has been named the Setana Fauna (Uozumi, 1962), and has been subdivided into three sub-fauna, lower, middle, and upper by Suzuki (1989) based on their components. This fauna has recently been thought to be early to middle Pleistocene by planktonic foraminiferal analyses of the formation (Oda, 1981; Tsuchi and Ibaragi, 1982).

This formation dips gently, less than 10° in most areas, but shows steep angles, perpendicular to occasionally reversal, near the fault on the River Shiribeshitoshibetsugawa in Hanaishi.

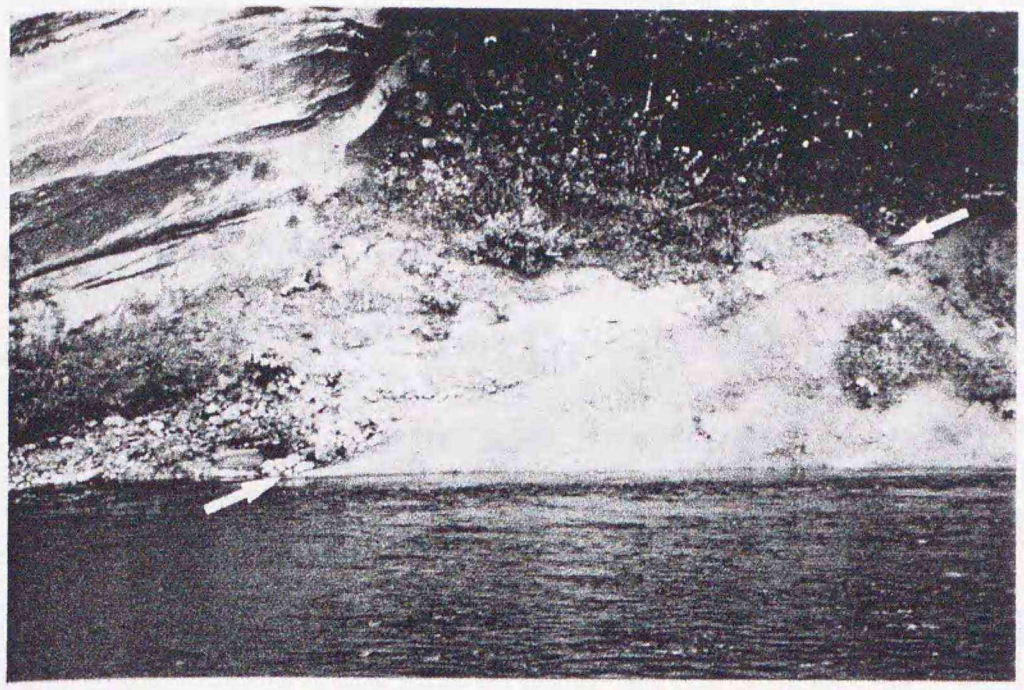
This formation clinounconformably covers the Kunnui Formation in

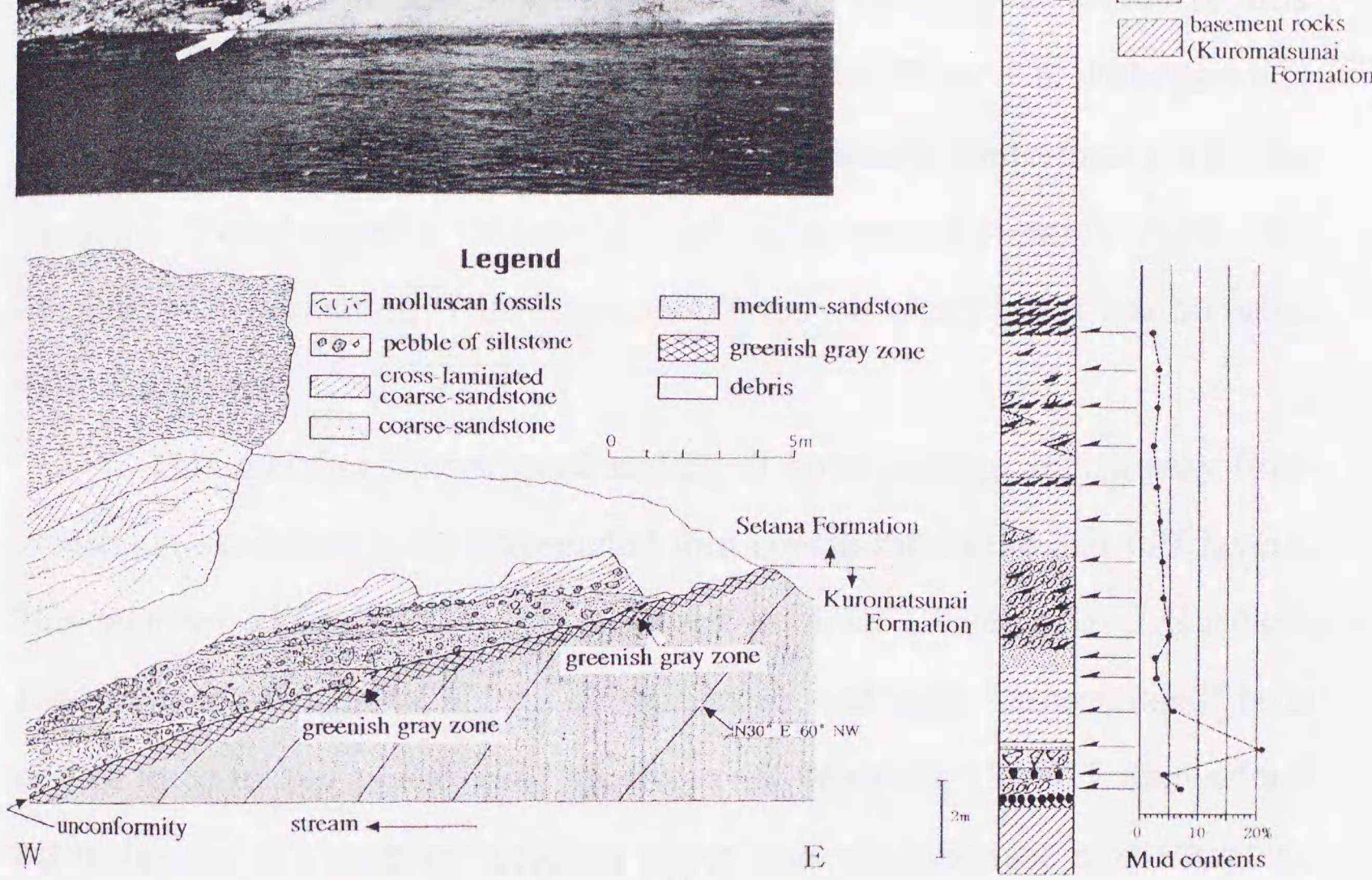
Pirika, the Yakumo Formation in Hanaishi, the Sumiyoshi Siltstone Member of the Kuromatsunai Formation in Nakasato, the Sakkurubetsu Pyroclastic Member in Okusawa, and the Okusawa Sandstone Member in Kamiyakumo.

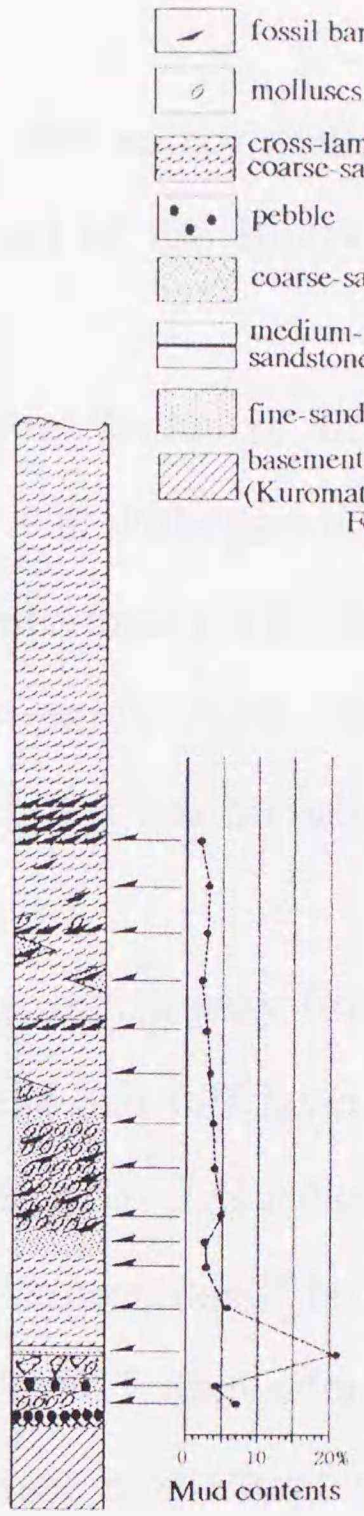
i) ***The Hanaishi Conglomerate Member***; The type locality of this member is riverside along the River Shiribeshitoshibetsugawa at Hanaishi (Fig. 15). This member is confinedly distributed along the River Shiribeshitoshibetsugawa, from Pirika to Kamiyakumo.

The Hanaishi Conglomerate Member is characterized by unconsolidated, crossed-laminated coarse-grained sandstone. The sandstone beds include pebbles of siltstone, pumice, and tuff, most of which appear to be derived from the Kuromatsunai Formation, being with vast numbers of molluscan fossils. This member covers the Sumiyoshi Sandstone Member of the Kuromatsunai Formation with clear clinounconformity at Nakasato. The basal part of this member has many pebbles to boulders with characteristic bore-holes by boring bivalves, which are remarkably observable in the type locality along the River Shiribeshitoshibetsugawa at Nakasato. This basal conglomerate bed is about 2m in thickness. Just below the unconformity, there exists a greenish gray zone formed along the unconformable surface, crossing the primary bedding planes of siltstone of the Kuromatsunai Formation. This zone is probably a weathered crust of the Sumiyoshi Siltstone Member, indicating a considerable time-interval before deposition of the overlying Setana Formation.

The basal conglomerate beds yield vast numbers of invertebrate fossils, such as the molluscs *Chlamys islandicus, Ch. cosibensis*, and *Neptunea eulimata*, the barnacle *Chirona evermanni*, and the coelenterate *Allopora* sp. (Nojo and Matsuda, 1997). These beds are covered by coarse-grained







greenish gray zone

Fig. 15 Type locality of the Hanaishi Conglomerate Member
(lower part of the Setana Formation)

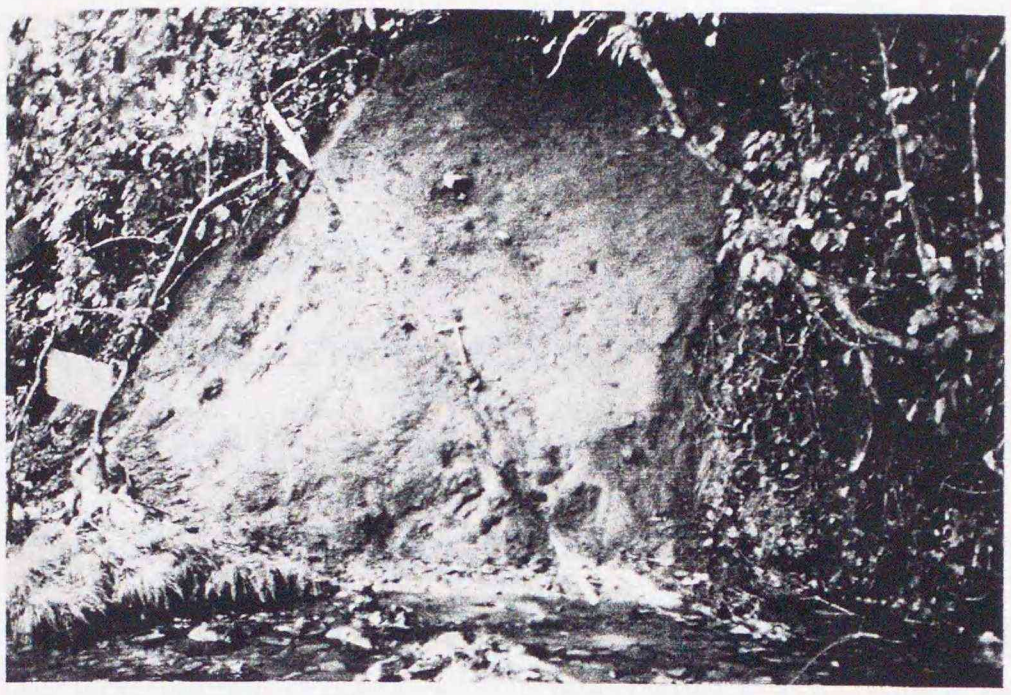
sandstone layers with trough cross-beddings. These layers are 10 to 50m in thickness. These fossils and facies indicate that the Hanaishi Member may have been deposited in shoreface to inner shelf.

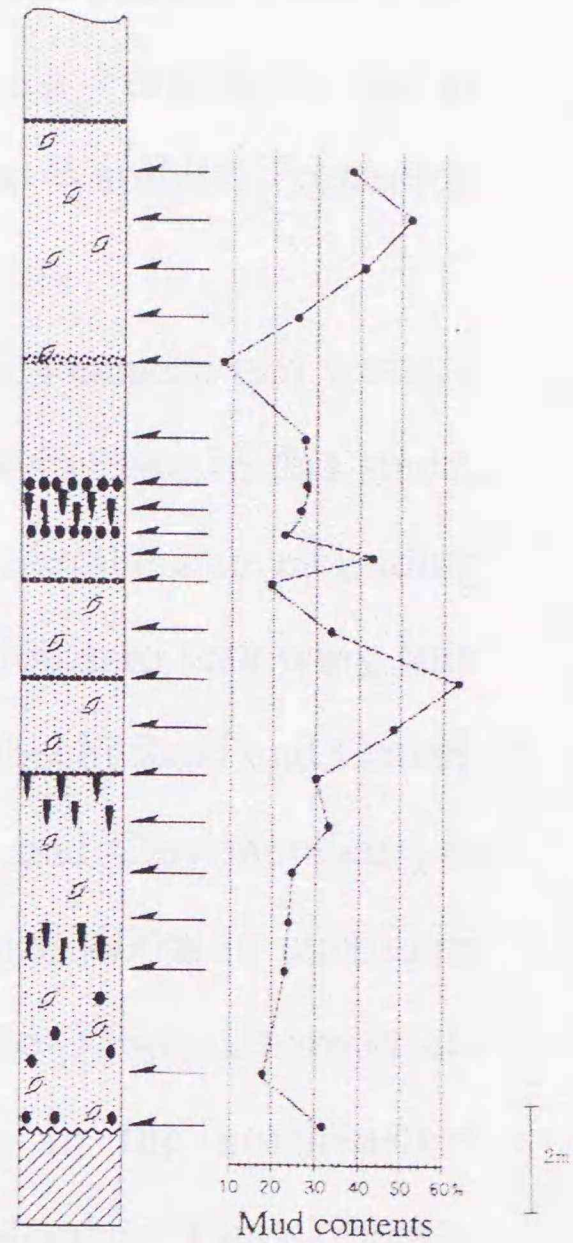
From the outcrops near the Pirikabashi Bridge, the author found many calcareous nannofossils indicative of the middle part of the Bukry's (1973, 1975) CN13b Zone (1.48-1.22Ma).

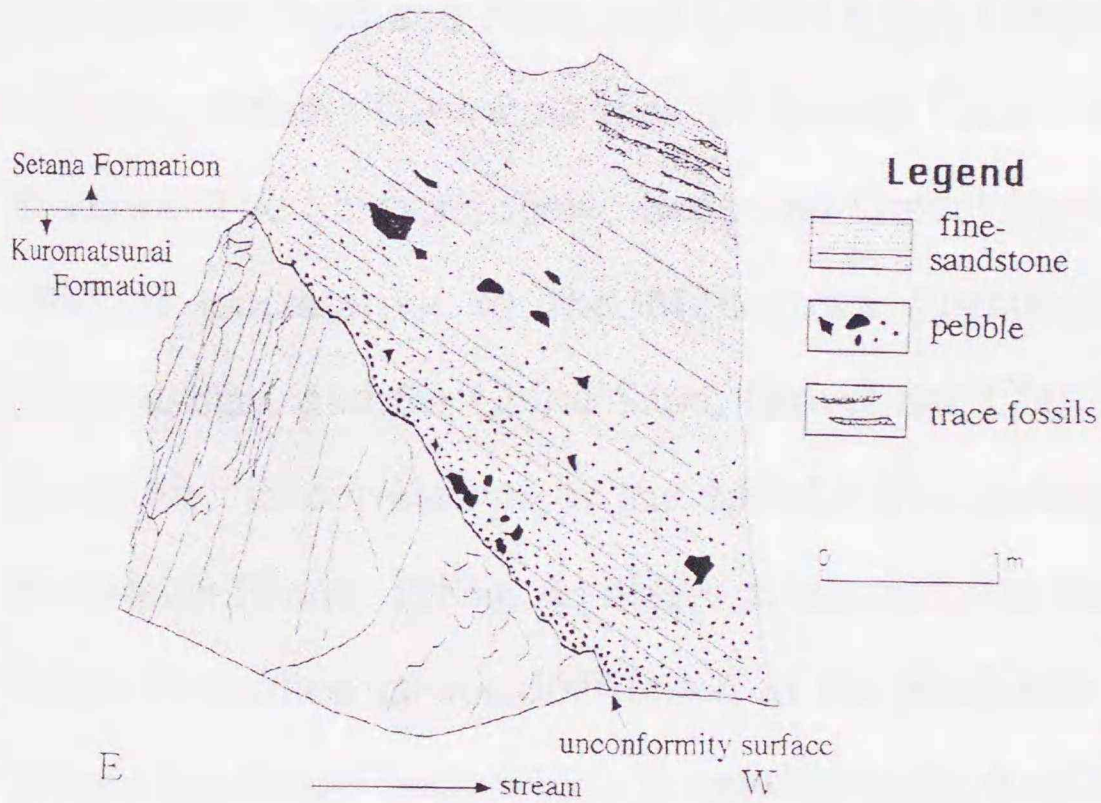
ii) ***The Chinkobe Sandstone Member***; The typical facies of this member is distributed around middle part of the River Chinkobegawa at Hanaishi (Fig. 16). In these areas, this member contacts conformably with the Hanaishi Conglomerate Member, and clinounconformably with the Kuromatsunai Formation. This clinounconformity is clear, but it has no basal conglomerate beds.

This member is composed mainly of homogeneous bluish gray fine- to medium-sandstone with intercalated thin coarse-sandstone and tuff layers. This member yields such many molluscs as *Acila* (*Truncacila*) *nakazimai*, *Limopsis tokaiensis*, and *Chlamys daishakaensis*, and some "concentrated" beds of such trace fossils as *Rosselia*? sp. (Nojo and Matsuda, 1997). Foraminiferal assemblage of this member indicates upper bathyal zone (see next Chapter). These deposits and fossils indicate that this member was deposited in inner shelf to upper bathyal. Nojo et al. (1996) pointed out that this member may be deposited in about 1.0 Ma based on two K-Ar ages of glassy tuff materials of lower part of this member.

This member has wider distributions than those of the Hanaishi Conglomerate Member. The distributions, lithofacies, and stratigraphical situation strongly suggest that the Hanaishi Conglomerate Member may have been deposited at the beginning of transgression in the Setana Stage, and the







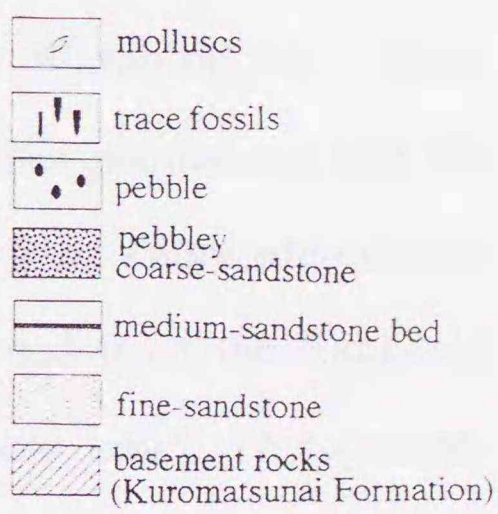


Fig. 16 Type locality of the Chinkobe Sandstone Member
(upper part of the Setana Formation)

Chinkobe Sandstone Member have been deposited during a maximum flooding period in the Setana Stage.

Kuromatsunai-Rankoshi Area; This formation is about 200m in thickness in the Kuromatsunai Low Land (Ikeya and Hayashi, 1982; Suzuki, 1989). The formation clinounconformably covers the Kuromatsunai Formation, and is clinounconformably overlain by the middle Pleistocene Warabitai Formation (Yano et al., 1983).

The lithofacies in this area are different between eastern and western areas of the Low Land, being subdivided into the following two in this study, the Nakasato Conglomerate and Soebetsu Sandstone Members in ascending order. Tsubakihara et al.(1989) subdivided this formation into following four members; the Shirozumigawa Sand and Gravel, Kaigarabuchi Sand and Gravel, Nakanokawa Sand and Mud, and Chirai Sand, Gravel and Clay members, in ascending orders. They state that the Setana Formation is 600m in maximum thickness. The Shirozumigawa Sand and Gravel Member (Tsubakihara et al., 1989) is correlative to the Menagawa Formation in the northeastern Kuromatsunai, and the Chirai Sand, Gravel and Clay Member (Tsubakihara et al., 1989) is correlative to the Middle Pleistocene Warabitai and Chirai Formations (Yano, 1983). As above mentioned, the author pointed out that the Setana Formation is not distributed in the Rankoshi area. There are coarse-grained sandstone beds which is continuously distributed from the Rankoshi area at the northeastern part of the Kuromatsunai Low Land. This coarse-grained sandstone is, therefore, correlative to the Menagawa Formation. In the Kuromatsunai area, Suzuki (1989) subdivided this formation into two parts in eastern area, E1 and E2, and three parts in western area, W1 to W3.

The Nakasato Conglomerate Member is correlative to the Kaigarabuchi Sand and Gravel Member (Tsubakihara et al., 1989), E1 and E2, (Suzuki, 1989). The Soebetsu Sandstone Member is correlative to the Nakanokawa Sand and Mud Member (Tsubakihara et al., 1989) and W1 to W3 (Suzuki, 1989).

i) ***The Nakasato Conglomerate Member***; The author proposes this name in this study, and the type locality of this member is cliff at Nakasato in eastern Kuromatsunai. This member is distributed only in eastern areas of the Low Land, from Nakasato to Toyohoro, and is about 100m thick. This member clinounconformably covers the Kuromatsunai Formation at Nakasato.

This member is composed mainly of pebbly pumiceous medium- to coarse-sandstone beds with conglomerate. The basal parts of this member contain pebbly sandstone showing trough cross-beddings, and yield many fossils such as the molluscs *Glycymeris yessoensis, Acesta goliath, Lima vulgatula, Limopsis tokaiensis, Chlamys daishakaensis, Ch. islandicus, Yabepecten tokunagai* and *Tridonta borealis* (Suzuki, 1989), the barnacle *Chirona evermanni*, and the coelenterate *Allopora* sp.

This member can be correlated with the Hanaishi Conglomerate Member in the Imakane area because of similarities of the lithofacies, stratigraphic position, and properties of molluscan assemblage.

ii) ***The Soebetsu Sandstone Member***; The type locality is cliffs along the middle part of the River Soebetsugawa. This member is widely distributed in western areas of Kuromatsunai, and on the contrary, only around the River Shirozumigawa in eastern areas. This member clinounconformably covers the Futamata Formation at the type locality, and the thickness is about 100m.

The lower part of this member is composed of alternation of sandstone and mudstone. In the type locality the beds dip westward with angles of about 8°, and are underlain by alternations of conglomerate and sandstone which yield many fossil plant fragments but no molluscan and foraminiferal fossils. On the siltstone bed there are four shell concentrating beds in which numerous molluscan fossils such as *Glycymeris yessoensis*, *Crenomytilus grayanus*, *Chlamys cosibensis*, *Clinocardium californiense*, *Mizuhopecten yessoensis* and *Profulvia kurodai* (Suzuki, 1989), and also yield many fossil plant fragments in parts. The alternation clinounconformably overlies the Miocene Futamata Formation at the upper stream of River Soebetsugawa.

The upper part of this member is composed mainly of well-sorted fine-sandstone and alternation of fine-grained sandstone and conglomerate, with intercalated shell beds and lignite beds. Such molluscan fossils are reported as Yoldia *notabilis*, *Musculus niger*, *Empleconia cumingii*, *Pecten albicans*, *Scapharca broughtnii*, *Mizuhopecten tokyoensis*, *Saxdomus purpuratus*, *Doshinia japonica*, and *Mercenaria stimpsoni* by Suzuki (1989).

(3) Ages and Stratigraphical Correlations among The Areas Studied

The Setana Formation yields numerous foraminifera (e.g. Asano, 1936; Shirai, 1959; Tsubakihara et al., 1989; Nojo et al., 1997c). The author brings the planktonic foraminifera assemblages from this member into lower parts of the *N. pachyderma* (S) / *N. incompta* Zone (Maiya, 1978), the base of which is located just below the Jaramillo Event (1.07-0.99Ma; Cande and Kent, 1995; see next Chapter). In the type locality, the Soebetsu Sandstone Member yields many calcareous nannofossils which can be brought into lower parts of the CN14a Zone (1.03-0.83Ma; Bukry, 1973, 1975), especially 0.85-0.95 Ma (see next Chapter).

The author summarizes stratigraphical correlations of these formations which distributed in the Oshima Peninsula in Fig. 17 based on the data mentioned above and on those of Nojo et al. (1994b), and previous studies are correlated with this study in Fig. 18.

Although it has been considered that the Setana Formation may have been started to deposit by late Pliocene, recent studies by the author reveal that the formation began to deposit in early Pleistocene (at about 1.2Ma; see next Chapter).

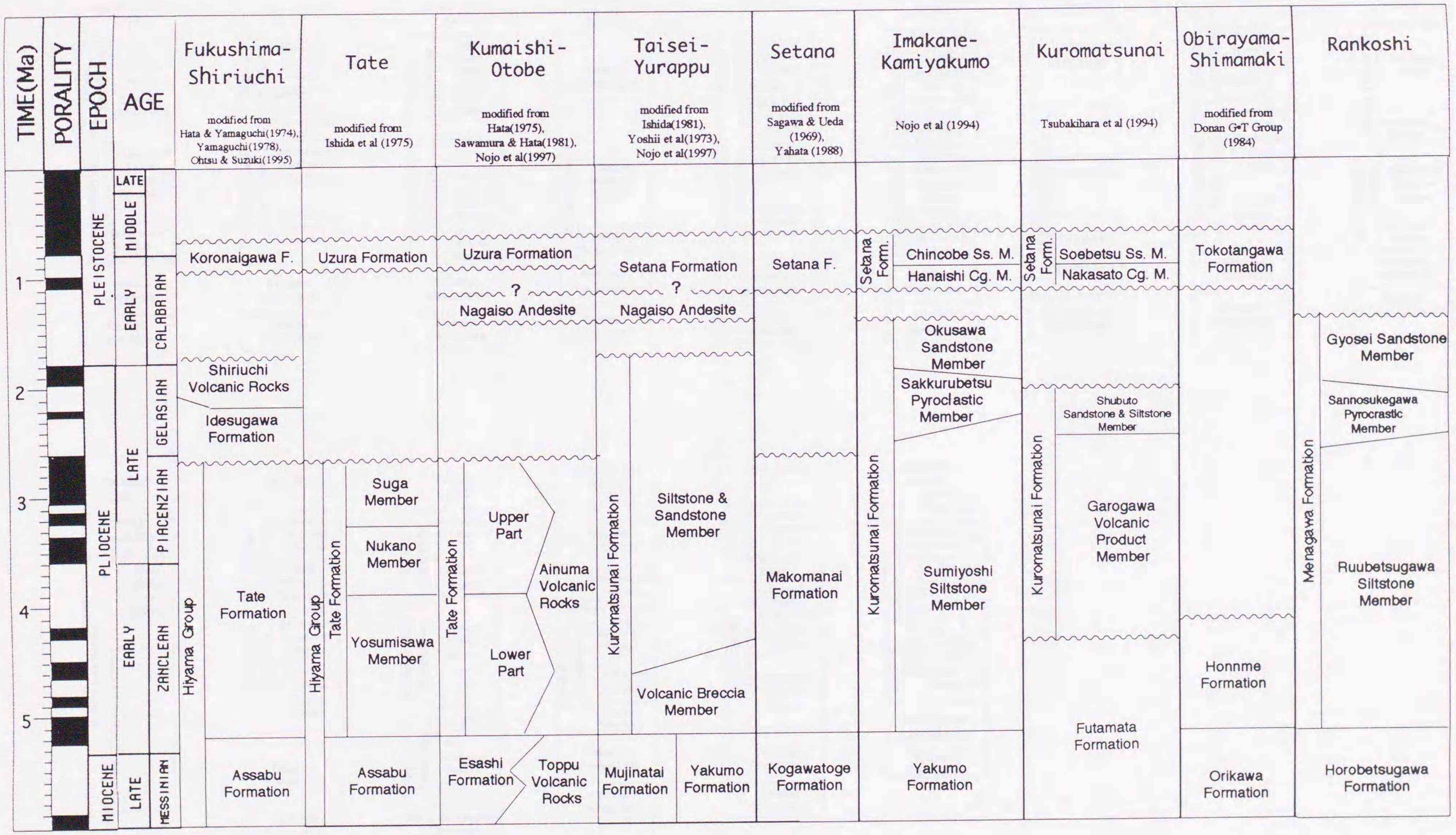


Fig. 17 Geological correrations of the Oshima Peninsula

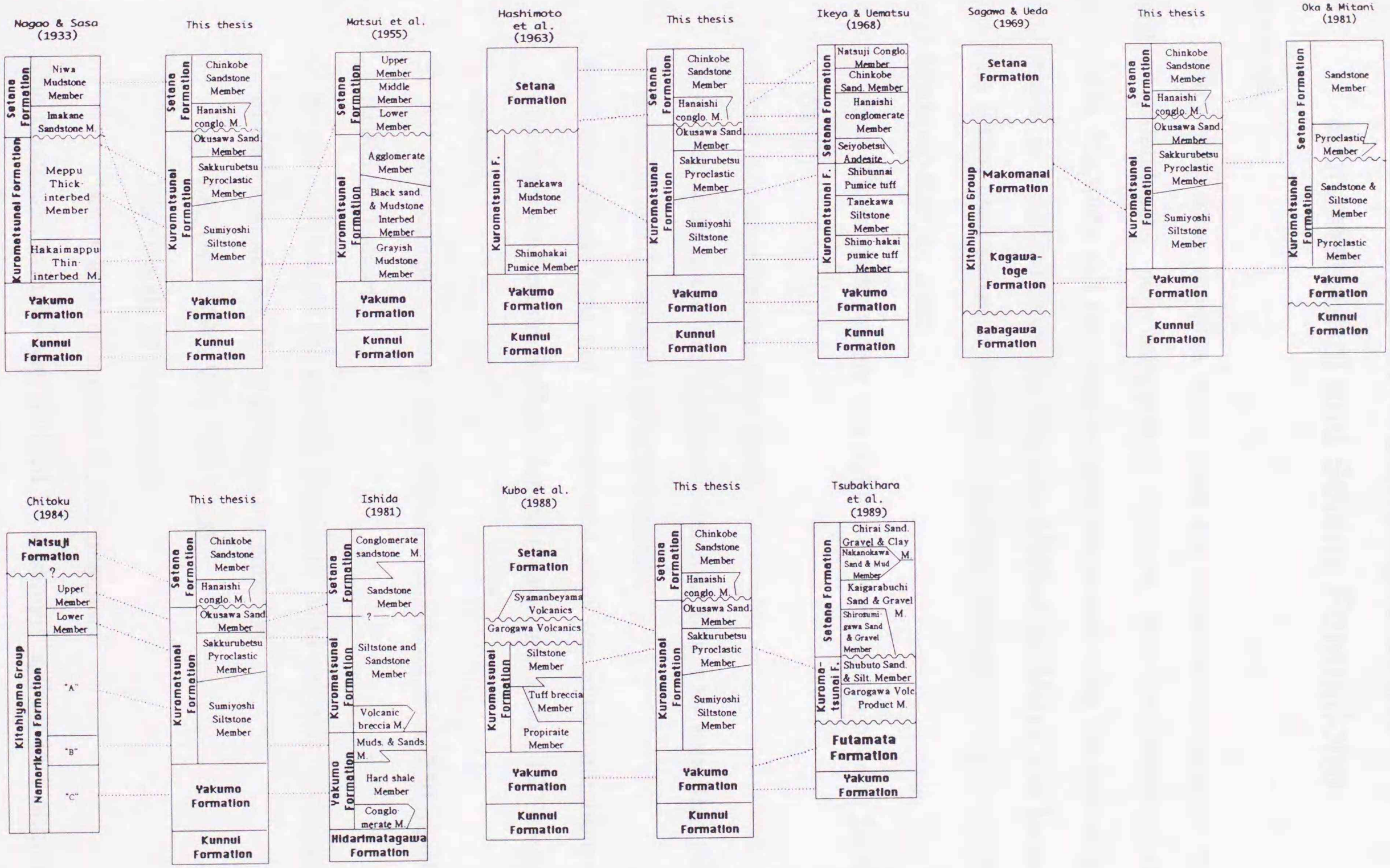


Fig. 18 Correlations of this study with previous works

IV. Foraminiferal Assemblages of the Kuromatsunai and Setana Formations

(1) Methods

Fifty-nine rock samples were used for foraminiferal studies to understand paleodepths, paleotemperature changes, and biochronological estimations in this study. All the samples were macerated using the following method which is modified from the Naphtha Method by Maiya and Inoue (1973). The author used kerosine instead of naphtha, because former is easier to get in Hokkaido than the latter.

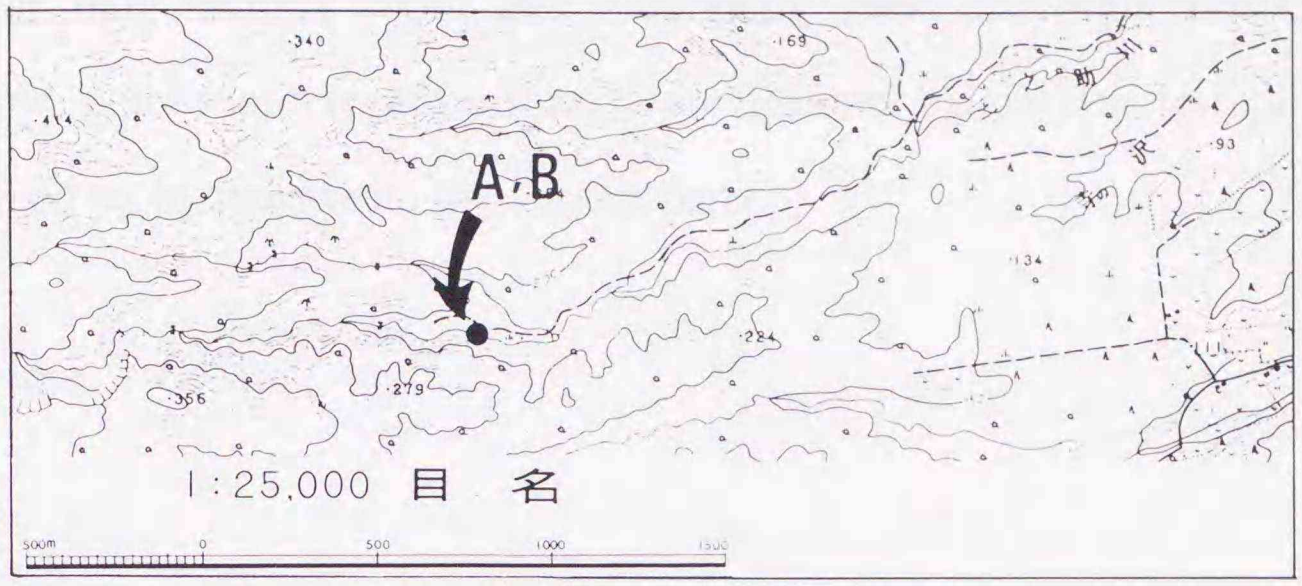
1) Each 80g of rock sample is weight after drying in an oven at 50 to 60 °C.
2) Soak it in kerosine over four hours.
3) Poured with hot water, and boil over four hours to volatilize the kerosine and disintegrate cemented matters.
4) If the sample was not disintegrated after the above-mentioned processes the Sodium Sulfate Method (Maiya and Inoue, 1973) was applied.
5) All the samples were then wet-sieved through a 250 mesh (0.063mm) screen.
6) Re-dry, and weight the residue of sample. Mud contents calculated of each sample (MC%) is as following equation,

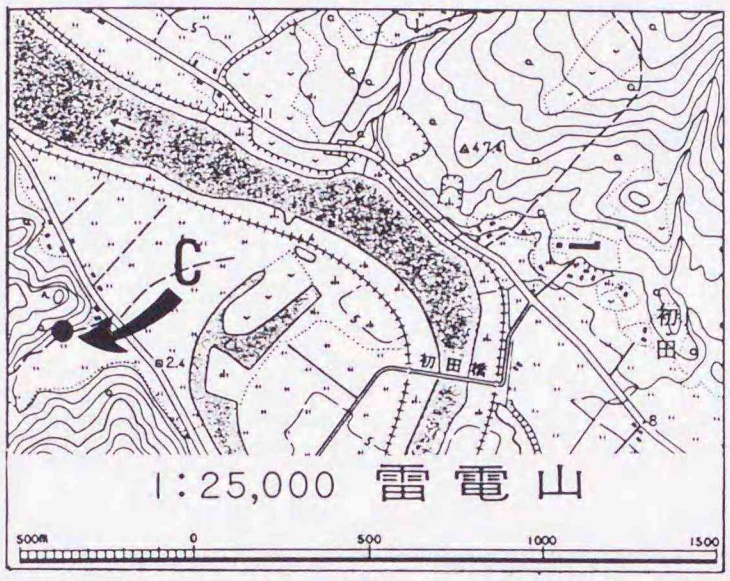
$$MC\ (\%) = (Wa-Wr) / Ws * 100$$

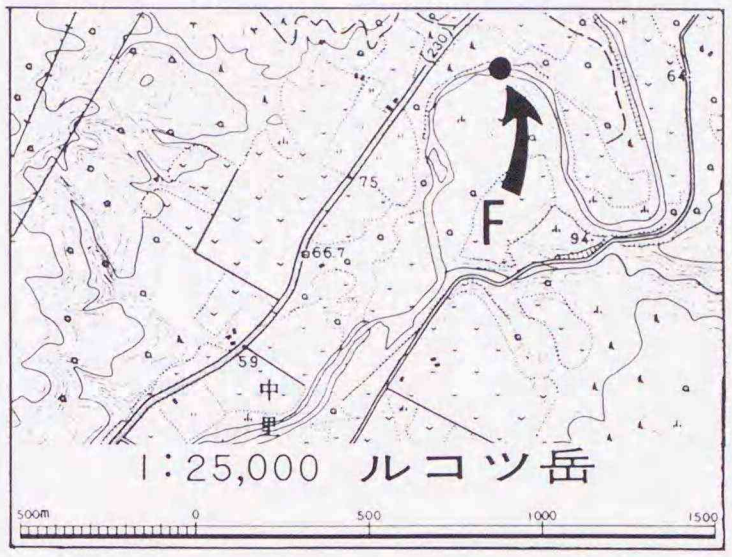
Ws : weight of rock sample

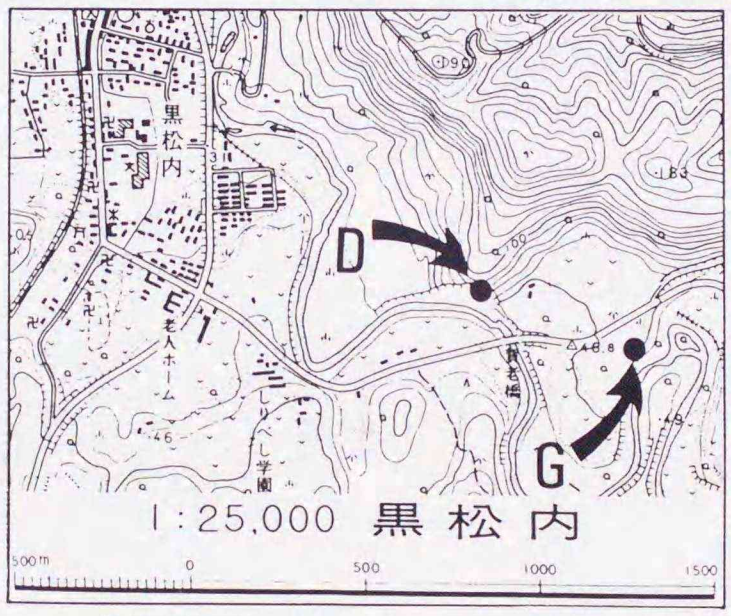
Wr : weight of residue of after treatment

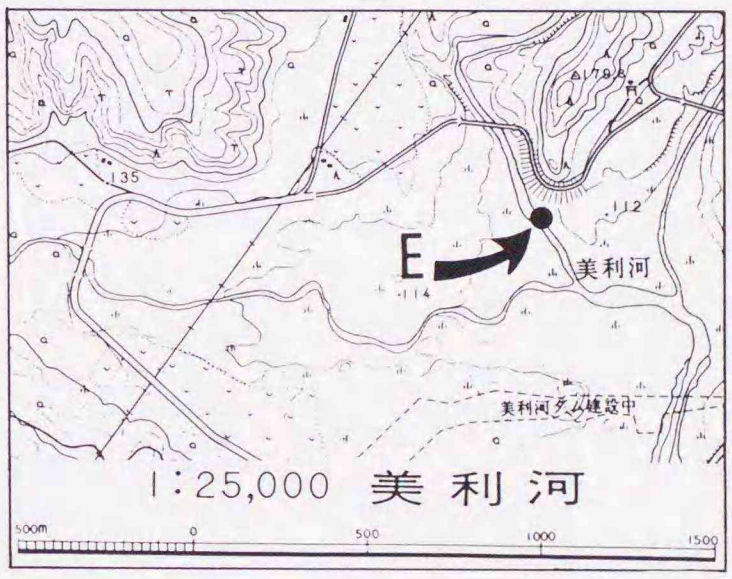
The processed sample was divided by a sample splitter into aliquot











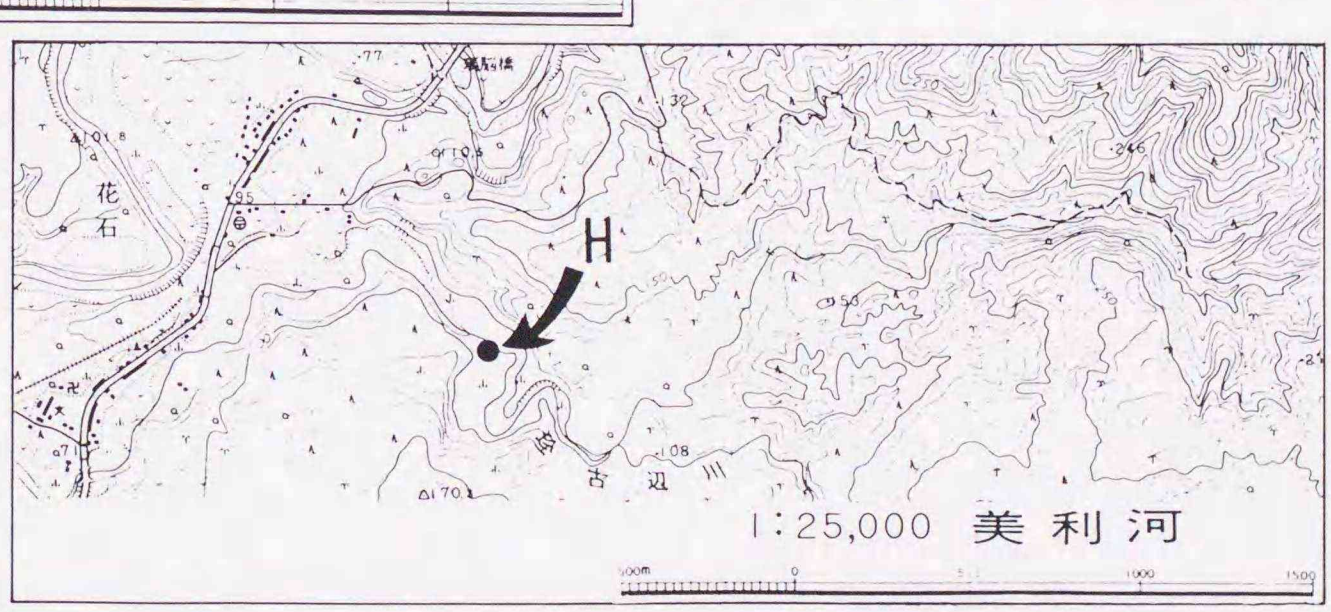


Fig. 19 Sampling locality
(using the topographical map published by Geographical Survey Institue of Japan)

parts which may include about 200 specimens, then, all foraminifera, both benthic and planktonic foraminifera, were floated by carbon tetrachloride and/or picked up by hand from the aliquot parts.

Tab. 1 Planktonic foraminifera of the Kuromatsunai and Setana formations

Sampling horizon	Menagawa Formation	Kuromatsu-nai F.	Lower Setana F.	Lower Setana F.	Lower Setana F.	Upper Setana F.	Upper Setana F.
(<T>; Type locality)	T. Gyosei Sandstone Member	<T>Shubuto Sand. & Silt. M.	Old Pirika Junior School	<T>Hanaishi Conglom-erate M.	<T>Nakasato Conglom-erate M.	<T>Chinkobe Sandstone Member	<T>Soebetsu Sandstone Member
Location number	C	D	E	F	G	H	see Fig. 22
Globigerina bulloides d'Orbigny	222	2	48	32	43	116	843
Globigerina quinqueloba Natland	2	2	17	5		30	143
Globigerinita glutinata (Egger)		9	2	2	1	8	80
Globigerinita uvula (Ehrenberg)		4		1		13	141
Globigerinoides ruber (d'Orbigny)							5
Globorotalia inflata (d'Orbigny)		15	25				1
Grobigerina spp.							11
Neogloboquadrina cf. asanoi (Maiya, Saito, and Sato)	2						
Neogloboquadrina dutertrei (d'Orbigny)	1						
Neogloboquadrina incompta (Cifelli)	10	9	3	21	30	853	2014
Neogloboquadrina pachyderma(D) (Ehrenberg)	4	4	27	10	6	167	152
Neogloboquadrina pachyderma(S) (Ehrenberg)	6	3	15	7	7	246	202
Neogloboquadrina sp.					1		8
Gen. et sp. indet.		1	5			2	
TOTAL COUNTED	247	49	142	78	88	1435	3600
Dext./total N. pachyderma %	40.0	57.1	64.3	58.8	46.2	40.4	42.9
Planktonic Foraminiferal Number(/g)	98.8	9.8	56.8	15.6	70.4	2296.0	790.7
Benthic Foraminiferal Number(/g)	844.8	29.4	124.4	42.4	172.8	841.6	882.3
P/T Ratio(%)	10.5	25.0	31.3	26.9	28.9	73.2	47.3

Tab. 2 Benthic foraminifera of the Kuromatsunai and Setana formations

Sampling horizon (T; Type locality)	Menagawa Foramtion			Kuromatsu-nai F.	Lower Setana F.	Lower Setana F.	Lower Setana F.	Upper Setana F.
	Gyosei Sandstone Member	Gyosei Sandstone Member	T. Gyosei Sandstone Member	T. Shubuto Sand. & Silt. M.	Old Pirika Junior School	T. Hanaishi Conglom-erate M.	T. Nakasato Conglom-erate M.	T. Chinkobe Sandstone Member
Location number	A	B	C	D	E	F	G	H
Alabamina japonica (Asano)				1				
Ammonia beccarii (Linné)						1		
Ammonia ketienziensis (Ishizaki)						1		
Ammonia spp.							1	1
Angulogerina hughesi (Galloway and Wissler)		2	1			1		5
Angulogerina kokozuraensis Asano			1	3				4
Anomalinoides globulosus (Chapman and Parr)			2					
Astacolus hyalacrulus Loeblich and Tappan			1					
Astrononion aomoriense Asano					2			
Astrononion hamadaense Asano					9		3	16
Astrononion spp.	3							
Bolivina decussata Brady				19				18
Bolivina sp. A				1		1	9	60
Bolivina spp.				3				
Buccella frigida (Cushman)				1			5	
Buccella makiyamai (Chiji)			2		2	3	9	
Buccella nipponica (Husezima & Maruhasi)					1			
Buccella tenerrima (Bandy)	7		1					
Buccella spp.		2	3		2			16
Bulimina cf. imamurai Tai				3				
Cibicides lobatulus (Walker & Jacob)	114	13	99	7	115	35	39	
Cibicides refulgens de Montfort	3	50	4	8	13	9	27	
Cibicides subdepressus (Asano)			3	3	3	9		
Cibicides tani Iwasa and Kikuchi	18	7			1	3		24
Cibicides spp.				3		7	3	
Cibicidoides pachydermus (Rzehak)				4				
Cribloelphidium oregonense (Cushman & Grant)						1		
Cycloforia contorta (d'Orbigny)					2			
Cystammina pauciloculata (Brady)				1				
Discopulvimulina bertheloti (d'Orbigny)								3
Discorbinella araucana (d'Orbigny)				10	1			3
Discorbinella spp.	2	1						
Eilohedra spp.	1							
Elphidiella arctica (Parker & Jones)	18	32						
Elphidium bartletti Cushman				3			19	
Elphidium crispum (Linne)	2	8	20		5	3	7	3
Elphidium excavatum forma clavata Cushman					3			
Elphidium frigidum Cushman			12					
Elphidium hanzawai Asano							1	
Elphidium incertum (Williamson)								18
Elphidium janseni (Cushman)	1							
Elphidium macellum (Fichtel and Moll)				1				
Elphidium subarcticum Cushman						14		
Elphidium subincertum Asano							3	
Elphidium translucens Natland								28
Elphidium spp.	15			1	3	1		5
Epistominella pulchella Husezima & Maruhasi	2			1	1	1		54
Epistominella spp.		1	1					
Eponides? sp.				3				
Fissurina cf. annectens (Burrows & Holland)				2				
Fissurina marginata (Walker & Boys)	1	2	1	1	2	1	2	19
Fissurina obscurocostata Galloway & Wisser				1				
Fissurina orbignyana Seguenza	3							
Fissurina semimarginata (Reuss)			2		3			
Fissurina spp.	1		1	2		2		
Gavelinopsis sp.			5					
Glabratella pulvinata (Brady)								1
Glabratella spp.		1						
Glandulina ovula d'Orbigny								

Sampling horizon	Menagawa Foramtion			Kuromatsu-nai F.	Lower Setana F.	Lower Setana F.	Lower Setana F.	Upper Setana F.
(T; Type locality)	Gyosei Sandstone Member	Gyosei Sandstone Member	T. Gyosei Sandstone Member	T. Shubuto Sand. & Silt. M.	Old Pirika Junior School	T. Hanaishi Conglom-erate M.	T. Nakasato Conglom-erate M.	T. Chinkobe Sandstone Member
Location number	A	B	C	D	E	F	G	H
Globocassidulina bisecta Nomura			9	13		5		45
Globocassidulina canalisuturata Eade					4			
Globocassidulina neobrocha								3
Globocassidulina spp.		3	4	7		3	3	10
Guttulina spp.			1					
Hanzawaia nipponica Asano			4				1	
Heterolepa sp.				1				
Islandiella islandica (Nørbang)	7	6						
Islandiella japonica (Asano & Nakamura)		7	2	27	2	35	16	117
Islandiella sublimbata (Asano & Nakamura)	35	45	52	1	88	53	37	56
Islandiella yabei (Asano & Nakamura)	4	20	14			17	2	
Islandiella spp.					1		3	
Karreriella baccata japonica Asano						2		
Karreriella spp.			4					
Lagena apiopleura Loeblich & Tappan	2				1			
Melonis pacificum (Cushman)				1				
Melonis spp.	1							1
Neoconorbina stachi (Asano)					1			
Neoeponides procerus (Brady)							10	
Neoeponides spp.	1		2					
Nonion spp.	1			3	1			3
Nuttaliloides umbonifera				1				
Oolina carteri Albani and Yassini			1					
Oolina melo d'Orbigny					1			
Oolina striatopunctata (Parker & Jones)								2
Oridosalis cf. umbonatus (Reuss)				1				
Patellina corrugata Williamson							1	3
Planoglabratella subopercularis (Asano)	1	1	1		3			5
Polystomellina discorbinoides (Yabe & Hanzawa)					1	1		
Pseudononion japonicam Asano					1			
Pseudononion spp.					2			
Pseudoparrella naraensis Kuwano				1				
Pseudoparrella takayanagii (Iwasa)				2		1	2	
Pullenia apertura Cushman				2				
Pyrgo ezo Asano	1							
Pyrgo fornasinii Chapman & Parr					10			
Quinqueloculina akneriana d'Orbigny	5				8		3	
Quinqueloculina seminulum (Linné)					2			
Quinqueroculina vulgaris d'Orbigny							3	
Quinqueloculina spp.	4		1		5			
Rosalina australis (Parr)		1			1			
Rosalina bradyi (Cushman)			1		1			
Rosalina campanulata (Galloway and Wissler)		1						
Rosalina spp.	1	1	2	1		1		3
Sigmoidella spp.			1					
Sigmoilina sigmoidea compressa Cushman					3			
Sigmomorphina spp.					1			
Sigmomorphina trilocularis (Bagg)			1					
Sphaeroidina japonica Brady				1				
Sphaeroidina spp.			1					
Triloculina rotunda d'Orbigny					1			
Uvigerina juncea Cushman					1		1	
Uvigerina spp.				2				
Valvulineria japonica Asano					1			
Gen. et sp. indet.		4	5	1	3	1	6	12
Total	254	206	264	146	311	209	215	532
Weight (g)	1.2	2.5	0.3	5.0	2.5	5.0	1.2	0.6
Benthic foraminiferal number/g	203.2	82.4	844.8	29.2	124.4	41.8	172.0	851.2

(2) Foraminiferal Assemblages

Twenty-six samples of the Sakkurubetsu Pyroclastic and Okusawa Sandstone Members of the Kuromatsunai Formation and the Setana Formation in the Kuromatsunai-Rankoshi and Imakane areas are yields foraminifera (Tables 1, 2, 8, and 9). A total of 77 benthic species belonging to 40 genera, 10 planktonic species belonging to four genera were identified from the Kuromatsunai Formation in the Kuromatsunai-Rankoshi area, and 155 benthic species belonging to 66 genera and 11 species belonging to five genera were identified from the Setana Formation. Nojo et al. (1997a) also reported 64 benthic species belonging to 32 genera from the Kuromatsunai Formation, and 19 benthic species belonging to 12 genera from the Setana Formation in the Imakane area (Fig.20, Table 3).

a) Paleoenvironmental Trend

Benthic foraminifera have been used as depth-indicators (ex. Nojo et al., 1997a), based on the compilation on their depth distribution around the Japanese Islands by Hasegawa et al. (1989; Table 4). The author estimates paleobathymetric trend during the deposition period of the Kuromatsunai and Setana Formations.

i) The Kuromatsunai Formation

Benthic foraminiferal assemblages of the type sections of the Kuromatsunai Formation in the Kuromatsunai area can be brought into the upper bathyal zone (Hasegawa et al., 1989), and its contemporaneous heterotopic facies, such as the Menagawa Formation in the Rankoshi area and the Sakkurubetsu Pyroclastic Member in the Imakane area, into the middle sublittoral zone (Hasegawa et al., 1989). These facts indicate that there were some different basins in the deposition period, and the Kuromatsunai

Tab. 3 Occurrences of foraminifera in the Imakane area (from Nojo et al., 1997b)

Sample number (Kmv: Sakkurubetsu Pyro. Mem., Kms: Okusawa Sand. Mem, Ss: Setana F.)	Kmv-1	Kmv-2	Kmv-3	Kmv-4	Kmv-5	Kms-1	Ss-1	Ss-2
Planktonic Foraminifea								
Globigerina bulloides d'Orbigny	+	+	+	+		+	+	
Globigerina quinqueloba Natland			+					
Globigerina sp.							+	
Globigerinita glutinata (Egger)				+				
Globigerinita uvula (Ehrenberg)		+					+	
Neogloboquadrina incompta (Cifelli)	+	+	+	+			+	
Neogloboquadrina pachyderma (Ehrenberg) (dextral)	+	+	+	+			+	+
Neogloboquadrina pachyderma (Ehrenberg) (sinistral)	+	+	+	+			+	+
Benthic Formainifera								
Ammonia sp.								+
Angulogerina kokozuraensis Asano			+	+				
Angulogerina sp.		+						
Asterononion hamadaense Asano			+	+				
Bolivina decussata Brady				+				
Bolivina spp.		+	+					
Bolivinita quadrilatera (Schwager)	+							
Buccella frigida (Cushman)			+	+				
Buccella tenerrima (Bandy)		+						
Buccella sp.			+					
Bulimina sp.								+
Cibicides lobatulus (Walker & Jacob)			+					+
Cibicides refulgens Montfort		+						
Cibicides subdepressus (Asano)		+		+				+
Cibicides spp.	+			+				
Cribroelphidium yabei (Asano)			+					+
Cribroelphidium sp.								+
Dyocibicides perforata Cushman & Valentine	+							
Elphidium crispum (Linné)		+						+
Elphidium excavatum forma *clavata* (Cushman)			+	+				
Elphidium jenseni (Cushman)		+						
Elphidium subarcticum Cushman				+				
Elphidium spp.		+						+
Epistominella pulchella Husezima & Maruhasi		+		+				
Epistominella spp.		+						+
Eponides? spp.		+		+				
Fissurina anneciens (Burrows & Holland)			+					
Fissurina baccata Hellon-Allen & Earland	+							
Fissurina marginata (Walker & Boys)	+	+	+	+			+	
Fissurina orbignyana Seguenza				+				

Sample number (Kmv: Sakkurubetsu Pyro. Mem., Kms: Okusawa Sand. Mem, Ss: Setana F.)	Kmv-1	Kmv-2	Kmv-3	Kmv-4	Kmv-5	Kms-1	Ss-1	Ss-2
Benthic Foraminifera								
Fissurina cf. *rizzae* Seguenza				+				
Fissurina cf. *subquadrata* Parr		+						
Fissurina sp.			+					
Glabratella spp.		+					+	
Globocassidulina bisecta Nomura	+	+	+	+				
Globocassidulina jamesoni (McCulloch)				+				
Globocassidulina spp.			+			+		
Guttulina yabei Cushman & Ozawa							+	
Globulina sp.				+				
Guttulina spp.	+	+		+			+	+
Hanzawaia nipponica Asano				+				
Heterolepa praecinctus (Karrer)				+				+
Heterolepa subhaidingerii (Parr)			+					
Islandiella japonica (Asano & Nakamura)	+		+				+	+
Islandiella norcrossi (Cushman)		+						
Islandiella setanaensis (Asano & Nakamura)	+		+				+	+
Islandiella sublimbata (Asano & Nakamura)	+	+	+	+		+	+	+
Islandiella yabei (Asano & Nakamura)		+	+	+			+	+
Islandiella spp.	+	+					+	
Lagena acuticosta (Reuss)	+							
Lagena apiopleura (Loeblich & Tappan)			+					
Lagena striata (d'Orbigny)	+							
Lagena spp.	+			+				
Lenticulina sp.	+							
Melonis pompilioides (Fichtel & Moll)	+							
Melonis uchioi Hasegawa	+							
Nonion sp.		+						
Nonionellina labradorica (Dawson)			+	+				
Oolina striatopunctata (Parker & Jones)				+				
Oridorsalis umbonatus (Reuss)	+							
Planoglabratella subopercularis (Asano)	+							
Polystomellina discorbinoides (Yabe & Hanzawa)		+						
Pseudoparrella takayanagii (Iwasa)			+					
Pullenia apertura Cushman			+					
Pyrgo ezo Asano					+			
Stilostomella sp.	+							
Uvigerina akitaensis Asano				+				
Uvigerina juncea Cushman	+							
Uvigerina schencki Asano			+					
Uvigerina spp.			+					
Shallow Bathymetric Zone (Hasegawa et al., 1989)	upper bathyal	upper bathyal	upper bathyal	up. mid. bathyal	?	?	upper bathyal	upper bathyal

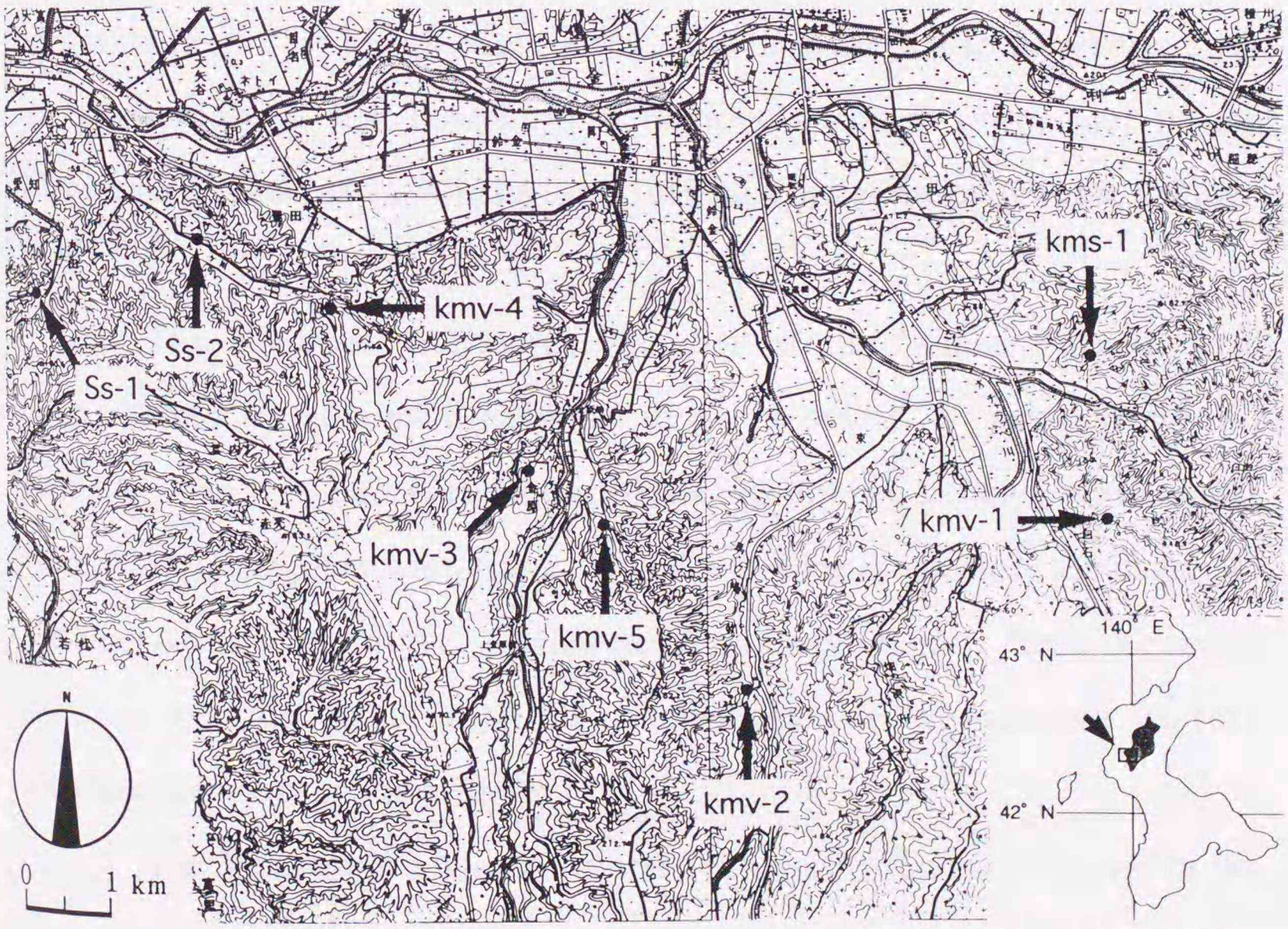


Fig. 20 Sampling locality in the Imakane area (from Nojo et al., 1997b)

Formation in the Kuromatsunai area uniquely remained in bathyal environments when the basins of the Imakane-Kamiyakumo and Rankoshi areas become shallower.

ii) The Setana Formation

Based on the analyses of Table 2, the lower member of the Setana Formation can be brought into the middle sublittoral zone, and the upper into the middle sublittoral to upper bathyal zone (Hasegawa et al., 1989). These facts indicate that the sea at the time of the upper member was more expanded than that of the lower member.

b) **Biochronologic Assignment**

Oda (1981) and Tsubakihara et al. (1989) have been given the same result based on the occurrence of *N. asanoi*. Maiya et al. (1976) pointed out that this species extinct just below the Olduvai Event (1.95-1.77Ma; Cande and Kent, 1995) in the uppermost part of the Funakawa Formation in the Oga Peninsula (Fig. 21a; Maiya et al., 1976). The member is also correlative with the lower part of the Tentokuji Formation in Akita, lower part of the Nishiyama Formation in Niigata, and Junicho Formation in Toyama (Maiya, 1978).

The Soebetsu Sandstone Member of the Setana Formation is characterized by dominant yieldings of *N. incompta*, *N. pachyderma*, *G. bulloides* , and *G. quinqueloba*, with rare occurrence of such warm-water species as *Globigerinoides ruber*. Other warm-water species, for example, *Globigerinoides sacculifer*, *Globorotalia tuncatulinoides*, and *Orbulina universa*, were not found in all the samples examine. *N. incompta* is very abundant species from the member.

The Nakasato Conglomerate and Soebetsu Sandstone Members of the

Tab. 4 Index species for Shallow bathymetric zonation (Hasegawa et al., 1989)

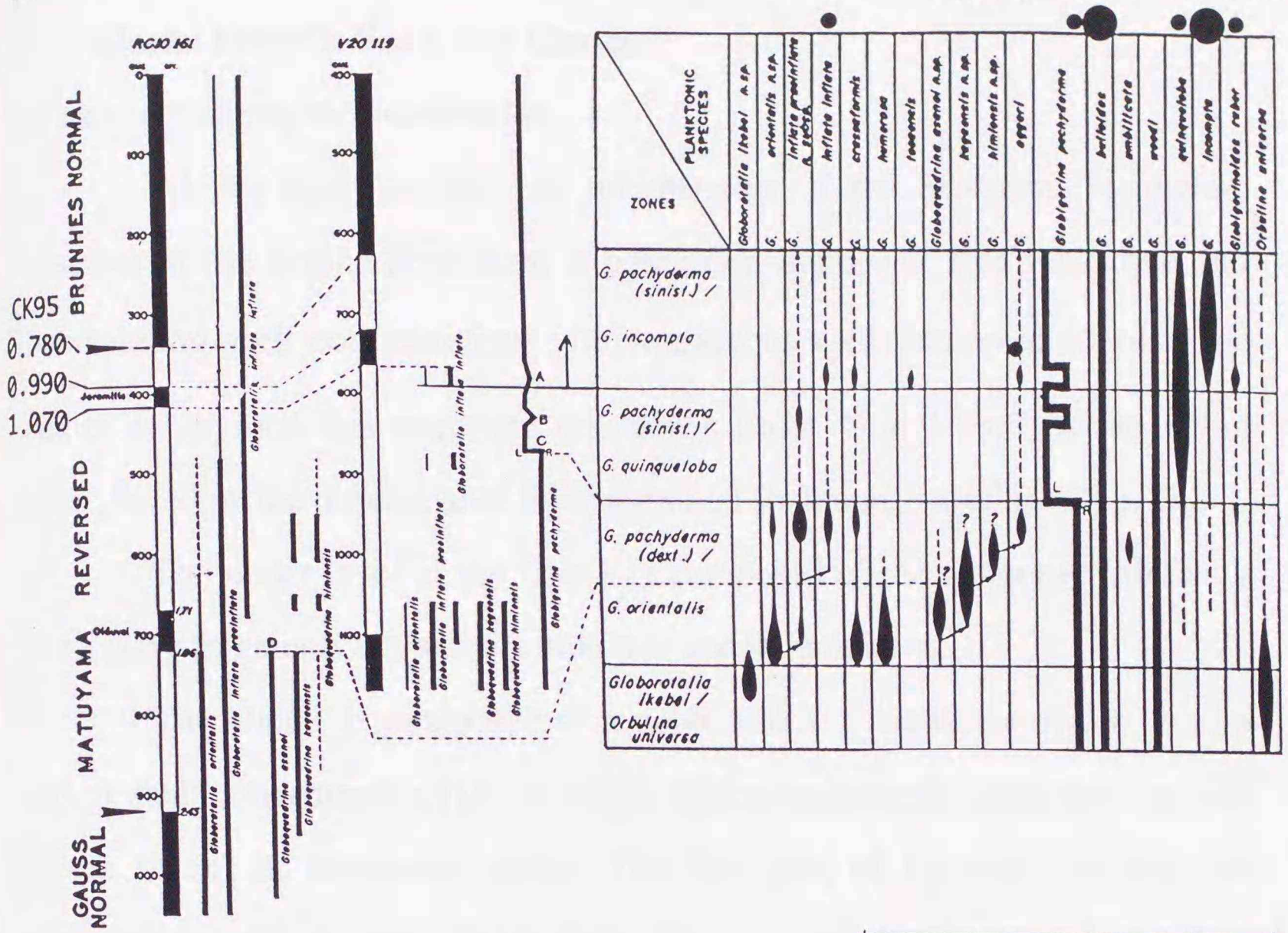
EARLY, MIDDLE MIOCENE	LATE MIDDLE MIOCENE -EARLY PLIOCENE	LATE PLIOCENE -EARLY PLEISTOCENE
	Inner sublittoral Zone	
Ammonia tochigiensis	*Buccella* spp.	*Ammonia beccarii*
Amphistegina spp.	*Cibicides lobatulus*	*Ammonia japonica*
Buccella frigida	*Cibicides refulgens*	*Bolivina robusta*
Buccella tanaii	*Elphidium jenseni*	*Buccella makiyamai*
Cibicides lobatulus	*Glabratella* spp.	*Buccella tenerrima*
Cibicides refulgens	*Hanzawaia nipponica*	*Buccella frigida*
Discorbis spp.	*Rosalina* spp.	*Buliminella elegantissima*
Glabratella spp.		*Cibicides lobatulus*
Hanzawaia tagaensis		*Discorbis* spp.
Miogypsina kotoi		*Elphidium advena*
Neoconorbina spp.		*Elphidium crispum*
Nonion kidoharaensis		*Elphidium excavatum*
Nonionella miocenica		*Elphidium kusiroense*
Operculina complanata japonica		*Elphidium subarcticum*
Pseudononion japonicum		*Gavelinopsis praegeri*
Pseudoparrella takayanagii		*Glabratella* spp.
Quinqueloculina spp.		*Hanzawaia nipponica*
Rosalina spp.		*Nonion manpukuziensis*
Sigmomorphina notoensis		*Pseudononion japonicum*
		Pseudoparrella spp.
		Pseudorotalia gaimardii
		Quinqueloculina spp.
		Rosalina spp.
	Middle sublittoral Zone	
Alabamina japonica		*Bulimina marginata*
Ammonia hatatatensis		*Cibicides refulgens*
Amphicoryna fukushimaensis		*Elphidium bartletti*
Astrononion stelligerum		*Eilohedra nipponica*
Bolivina robusta		*Heterolepa subhaidingeri*
Brizalina marginata		*Paracassidulina nipponensis*
Cibicidoides spp.		*Spiroplectammina higuchii*
Guttulina spp.		
Heterolepa spp.		
	Outer Sublittoral Zone	
Ammonia cf. *takanabensis*	*Cassidulina carinata*	*Ammonia takanabensis*
Amphicoryna pauciloculata	*Globocassidulina oriangulata*	*Cassidulina norvangi*
Cibicides aknerianus	*Heterolepa* spp.	*Globocassidulina bisecta*
Dentalina spp.		*Rectobolivina raphanus*
Elphidium sendaiense		
Fursenkoina spp.		
Gaudryina spp.		
Glandulina laevigata		
Globocassidulina oriangulata		
Gyroidinoides nipponicus		
Hoeglundina elegans		
Nonionellina sp.		
Valvulineria spp.		
	Upper Bathyal Zone	
Angulogerina kokozuraensis	*Alabamina japonica*	*Angulogerina kokozuraensis*
Baggina notoensis	*Angulogerina kokozuraensis*	*Bolivina decussata*
Bolivina dilatata	*Cibicides aknerianus*	*Cibicides aknerianus*
Bulimina striata	*Islandiella norcrossi*	*Dyocibicides* spp.
Epistominella pulchella	*Melonis pompilioides*	*Fissurina* spp.
Lenticulina spp.	*Uvigerina akitaensis*	*Globocassidulina depressa*
Marginulina spp.	*Uvigerina segundoensis*	*Islandiella japonica*
Martinottiella communis		*Islandiella norcrossi*
Nonionella spp.		*Islandiella yabei*
Sigmoilopsis schlumbergeri		*Melonis parkerae*
Stainforthia ishikiensis		*Melonis pompilioides*
		Pullenia apertura
	Upper Middle Bathyal Zone	
Cassidulina carinata	*Discammina* sp.	*Epistominella pulchella*
Globobulimina spp.	*Globobulimina* spp.	*Nonionellina labradorica*
Gyroidina orbicularis	*Valvulineria sadonica*	*Uvigerina akitaensis*
Siphotextularia spp.		
Stilostomella spp.		
Valvulineria spp.		
	Lower Middle Bathyal Zone	
Bathysiphon spp.	*Bathysiphon* spp.	
Cibicides wuellerstorfi	*Cyclammina* spp.	
Cibicidoides malloryi	*Haplophragmoides* spp.	
Cyclammina spp.	*Martinottiella communis*	
Haplophragmoides spp.	*Spirosigmoilinella compressa*	
Nodosaria longiscata		
Oridorsalis spp.		
Parrelloides spp.		
Pleurostomella spp.		
Pullenia bulloides		
Sphaeroidina spp.		
Spirosigmoilinella compressa		
Uvigerina proboscidea		

Setana Formation were assigned to the upper part of the *N. pachyderma* (D) / *G. orientalis* Zone by Oda (1981) and Tsubakihara et al. (1989). The assemblages, however, are characterized by abundant occurrences of *N. pachyderma* (S), *N. incompta* with *G. quinqueloba, G. ruber, and G. bulloides*, and and is assignable to the *N. pachyderma* (S) / *N. incompta* Zone of Maiya (1978). Maiya et al. (1976) put the lower boundary of this zone to just below the Jaramillo Event (1.07-0.99Ma; Cande and Kent, 1995).

Sandstone bed of the Hanaishi Conglomerate Member, lower part of the Setana Formation, yields such calcareous nannofossils as *Coccolithus pelagicus, Gephirocapsa* spp. (small), *G. caribbeanica* (M), *G. oceanica* (diag. L), *Reticulofenestra minutula, R. perplexa,* and *G. caribbeanica* (L). This assemblage can be correlated to the middle part of the CN13b Zone (Bukry, 1973, 1975), and the bed is located between two biohorizons, Last appearance datum (LAD) and First appearance datum (FAD) of Large *Gephirocapsa.* These two horizons are estimated to 1.20 and 1.44Ma, respectively, middle Early Pleistocene based on the Takayama et al. (1995) which adopted the calibration of Cande and Kent (1992; Fig. 21b).

Sandstone bed of the Soebetsu Sandstone Member, upper part of the Setana Formation, yields such calcareous nannofossils as *Coccolithus pelagicus, Gephyrocapsa oceanica* (vert. L; = *G. parallela* of Takayama et al., 1995), *Reticulofenestra asanoi, R. minutula,* and *Syracosphaera* spp. This assemblage can be correlated to the lower part of the CN14a Zone (Bukry, 1973, 1975), and the bed is, therefore, located between two biohorizons, LAD of *R. asanoi* and FAD of *Gephyrocapsa parallela.* These two horizons are estimated to 0.85 and 0.95Ma, respectively, latest Early Pleistocene based on Takayama et al. (1995; Fig. 21b).

a.



b.

	CK92	CK95
Brunhes	0.780	0.780
Jaramillo (T)	0.984	0.990
Jaramillo (B)	1.049	1.070
Cobb Mtn (T)	1.201	1.201
Cobb Mtn (B)	1.212	1.211

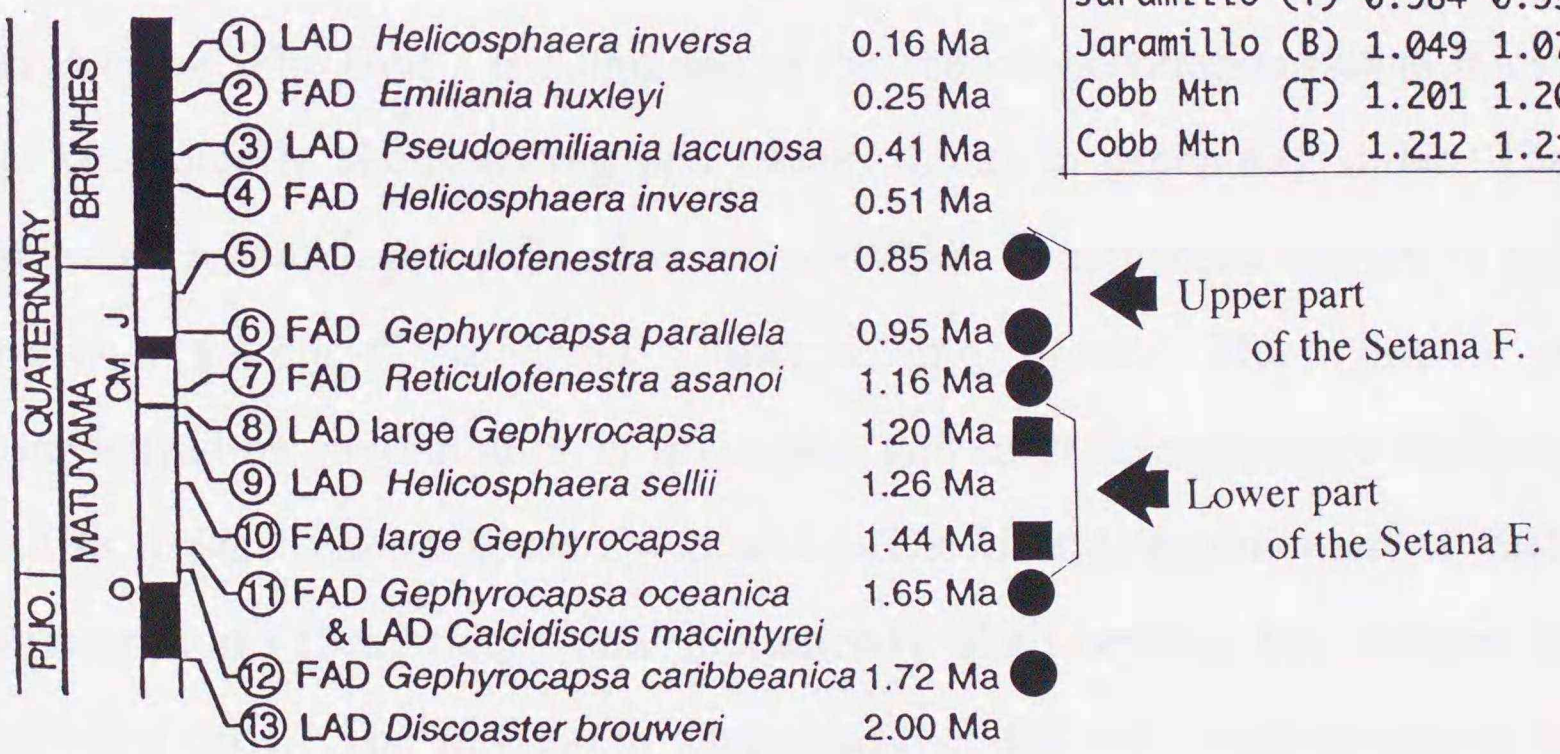


Fig. 21 Biostratigraphy of the Setana Foramtion

a. Planktonic foraminiferal zonation in Japan Sea calibrated by using Cande and Kent (1995) (modified from Maiya et al., 1976)

b. Calcareous nannofossil datum planes and magnetostratigraphy calibrated by using Cande and Kent (1992)(modified from Takayama et al., 1995)

(FAD: first appearance datum, LAD: last appearance datum,
J: Jaramillo Event. CM: Cobb Mountain Event, O: Olduvai Event)

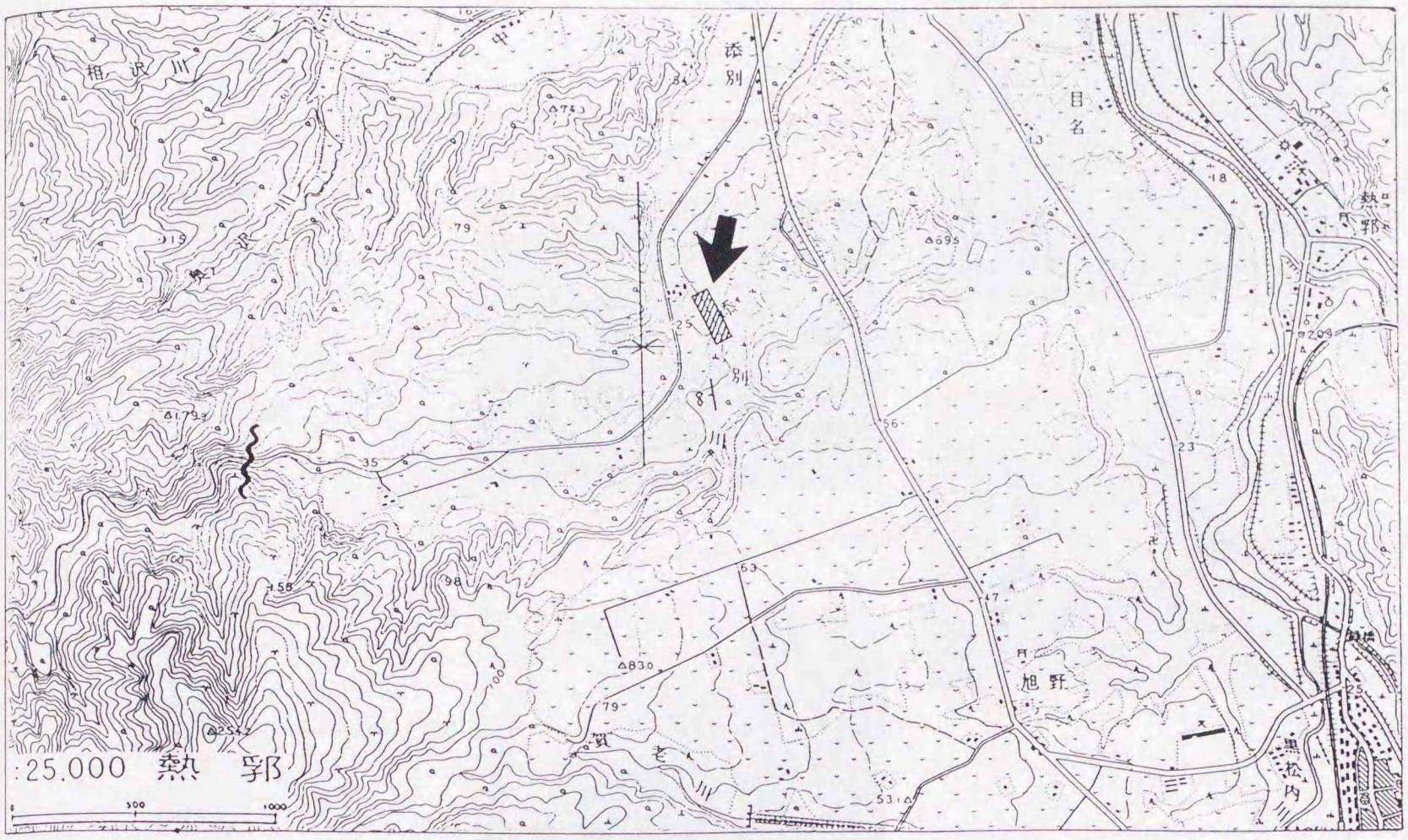
(3) Depositional Sequences of The Setana Formation Related to Glacial Eustatic Sea-Level Changes

a) Lithostratigraphic Subdivision

At the type locality, the middle part of the Soebetsu Sandstone Member of the Setana Formation is composed mainly of fine-sandstone and intercalating shell concentrations with numerous well preserved fossils. The author subdivided this sequence into seven units, Unit 1 to 7 in ascending order, based on the difference of lithofacies and shell concentrations (Fig. 23).

The under layer of the Unit 1 is composed of the siltstone with many fossil plant fragments but without molluscs nor foraminifera.

The Unit 1 is composed of a pebbly coarse-sandstone at the base, a bed of shell concentration (15 cm thick), and a sporadically shell-bearing bed (80cm thick) in ascending order. The last part of the unit yielded the nannofossils indicating the CN14a Zone. The molluscan assemblage of the shell concentration is composed mainly of the bivalvian genera *Cyclocardia*, *Monia*, and *Poterius*. The Unit 2 is composed of the shell concentration (30cm thick) and sporadically shell-bearing bed (90cm thick) in ascending order. The molluscan assemblage of the shell concentration is composed mainly of the bivalvian genera *Cyclocardia*, *Chlamys*, and *Monia*. The Unit 3 is characterized by concentration of bryozoans, and sporadic occurrence molluscs such as *Acila*, *Lucinoma*, and *Cyclocardia*. The Unit 4 is composed of shell concentration (15cm thick) and sporadically shell-bearing bed (85cm) in ascending order. The molluscan assemblage of the shell concentrations is composed mainly of the bivalvian genera *Lucinoma*, *Cyclocardia*, and *Mizuhopecten*. The Unit 5 is composed of a silty-sandstone bed with sporadically shell-bearing bed. The molluscan assemblage is composed mainly



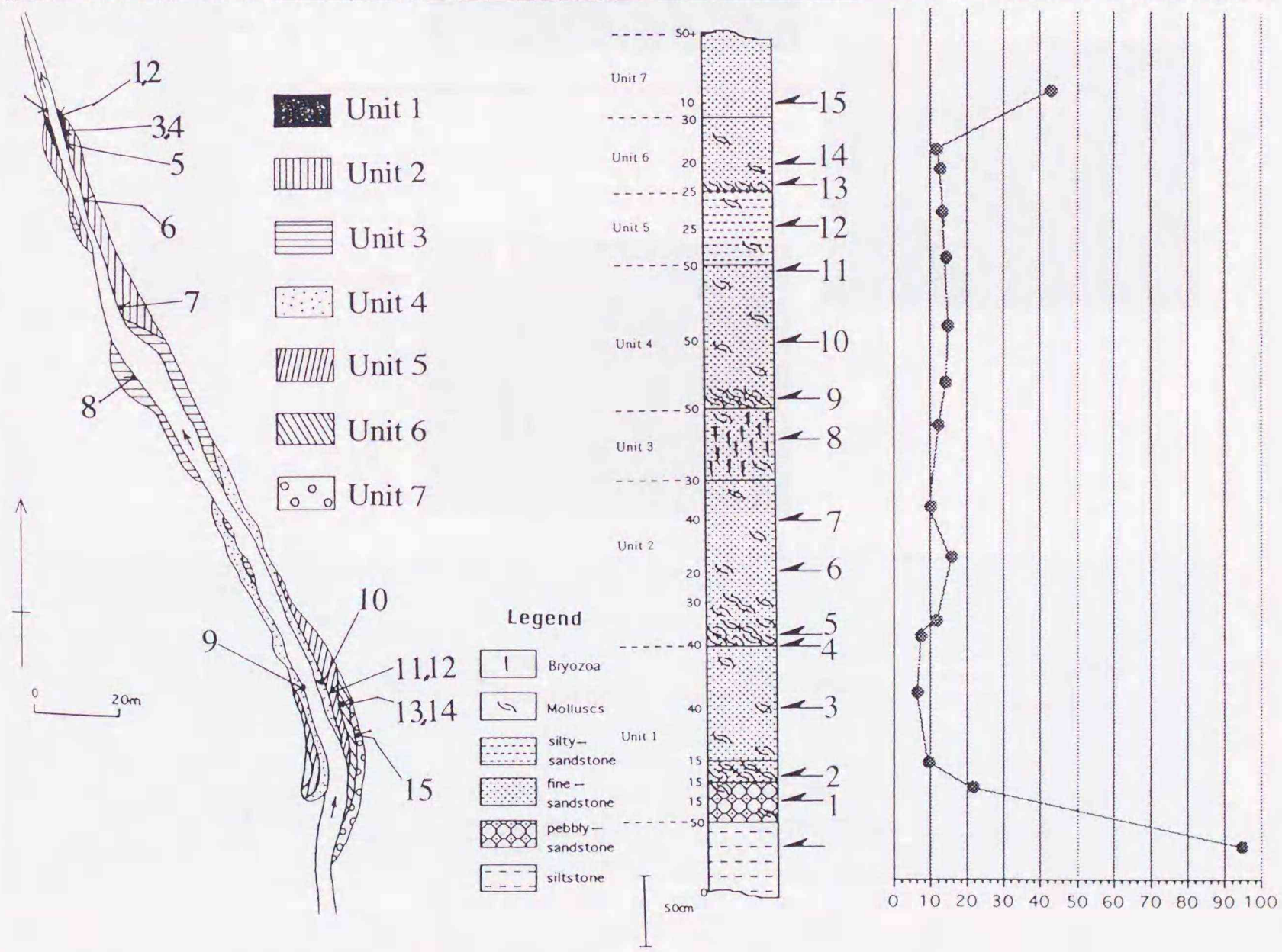


Fig. 22 Sampling locality and columnar section in the Soebetsu section
(type locality of the Soebetsu Sandstone Member)

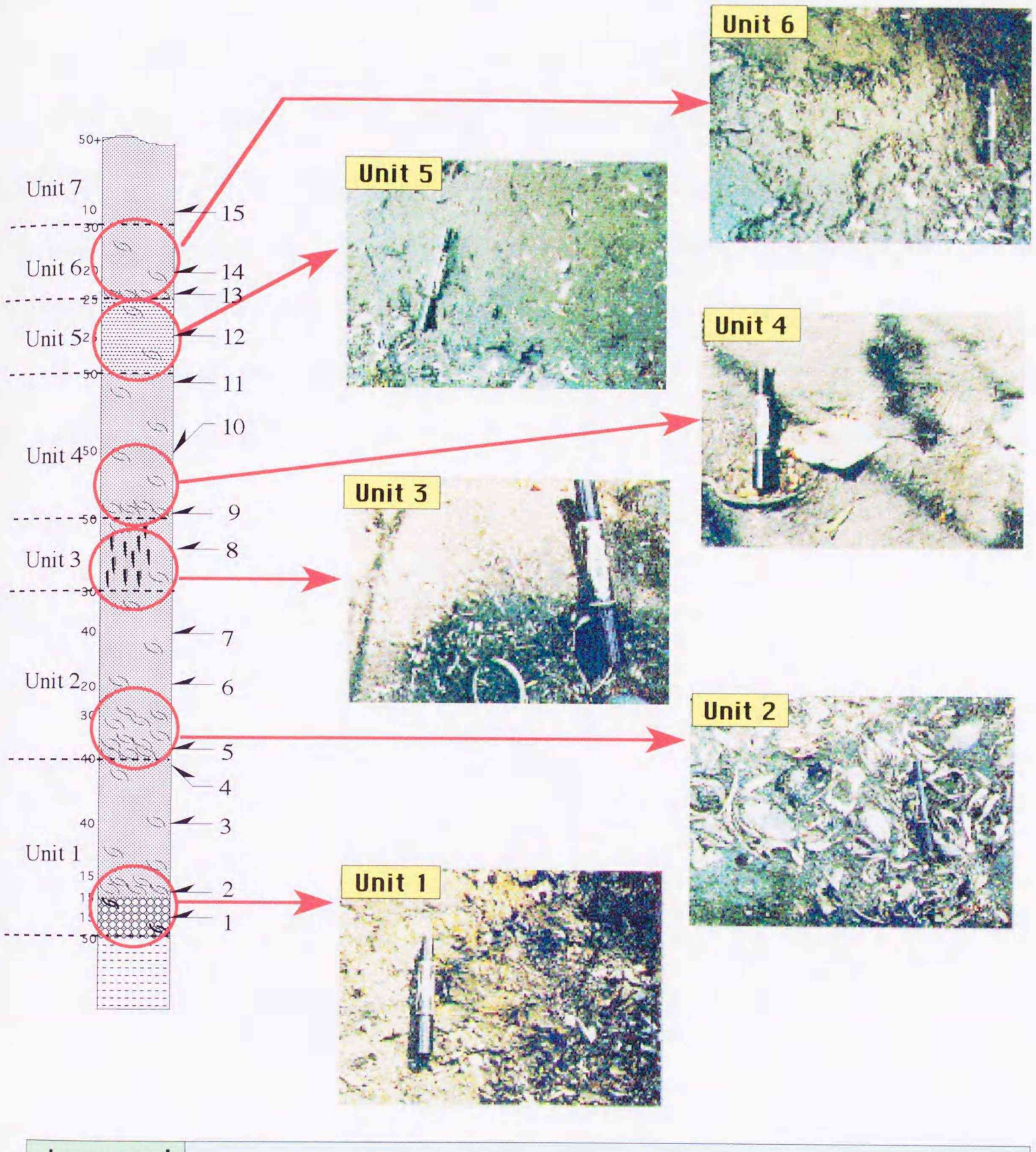


Fig. 23 The Units of the Soebetsu secton

of the bivalvian *Cyclocardia, Mizuhopecten, Glycymeris*, and *Mya*. The Unit 6 is composed of the shell concentration and sporadically shell-bearing bed in ascending order. The molluscan assemblage of this unit is composed mainly of the bivalvian genera *Mizuhopecten, Cyclocardia,* and *Chlamys*, and is characterized by a thin layer containing the bivalve *Mizuhopecten yessoensis*. The Unit 7 yields some fossil plant fragments and such a few molluscan fossils as *Ezocallista, Clinocardium*, and *Mizuhopecten*.

The mud contents of these units are less than 25% throughout the units except the Unit 7.

b) **Molluscan Assemblages**

Molluscan fossils in each unit are listed in Tables 5 and 6. All these assemblages were defined the Upper Setana Fauna by Suzuki (1989), and are characterized by dominant occurrences of "cold-water species". The term "cold-water species" in this study means the molluscs live northward of 35°N in the present Pacific Ocean, and "warm-water species" southward of 35°N in the present Pacific Ocean. "Eury-thermal species" means the molluscs live in both areas. Based on these criteria, molluscan assemblages of each unit can be summarized as following characteristics (Fig. 24).

1) Warm-water species such as *Saccela sematensis* occurs from the Unit 5, and *Rhinoclavis kochi* from the Units 3, 4, and 6, especially from middle to upper part of the Unit 4.
2) All the units yield "eury-thermal species" such as *Lucinoma annulata, Dosinia japonica*, and *Saxidomaus purpuratus*, especially from the Units 2, 4, and 6.
3) All the shell concentrated parts in the Units 1, 2, and 6 show a high ratio of epifaunal species.
4) Sporadically shell-bearing beds of the Units 1 and 2 yield more numbers of epifaunal species than the shell concentrated parts below these units.

Shell concentrations are controlled by two factors, shell input and sedimentation rate. Kidwell (1991) divided shell concentrations into four types based on lithostratigraphy and inferred accumulation history as following types (Fig. 25):

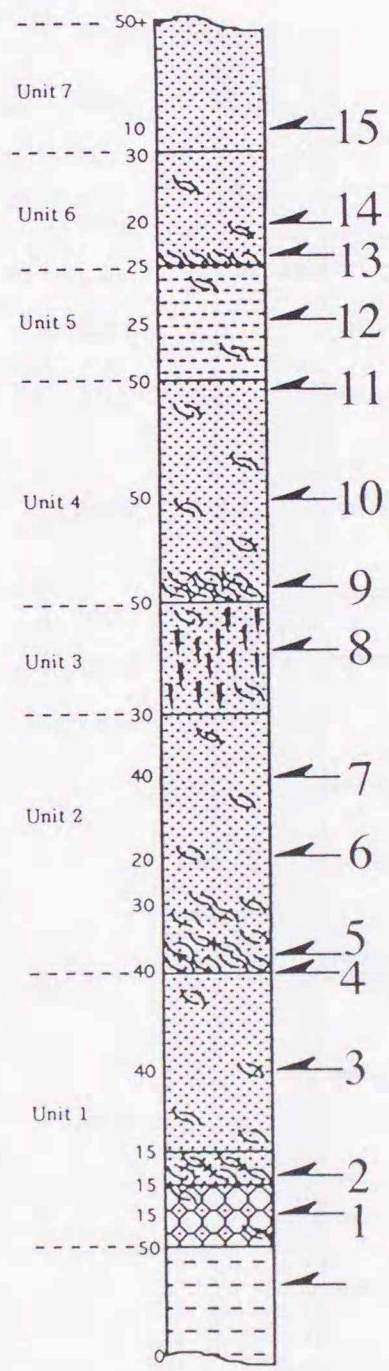
1) *Event-concentrations*, these are resulted from ecologically brief episodes of shell concentration, and have the scale of single laminae

Tab. 5 Bivalvia in the Soebetsu section

Sampling number	2	3	5	6	8	9	10	12	13	14	15
Ennucula tenuis (Montagu) ○								1			
Acila (Truncacila) insignis (Gould) ○			10		24	2	1				
Saccella sematensis (Suzuki and Isizaki) ●							1	2			
Yoldia (Cnesteerium) johanni Dall ○			2	1							
Y. (C.) notabilis Yokoyama ○								4	1		
Arca boucardi Jousseaume ◎		4	5	47							
Porterius dalli (Smith) ◎	10	12	1								
Glycymeris yessoensis (Sowery) ○			2		2	16		21	7		
Crenomytilus grayanus (Dunker) ○		3	5	19	2					1	
Modiolus difficilis Kuroda and Habe ○			6	2			1				
Musculus niger (Gray) ○								2			
Chlamys daishakaensis Masuda and Sawada *	7	14	13	16		1	5	11	9	4	2
Swiftpecten swiftii (Bernardi) ○	3	3	5	4	1	2	2	9	4	2	2
Mizuhopecten yessoensis (Jay) ○	5	4	2		8	22	24	29	22	9	3
Monia macroschisma Deshayes ○	11	33	11	30	1	1					
Lucinoma annulata (Reeve) ◎			2		13	39	4	3			
Tridonta filatovae Habe ○								4			
Cyclocardia crassidens (Broderip and Sowerby)	2		3			2	5				1
C. crebricostata (Krause) ○			1		1	12		496	16	1	1
C. isaotakii Tiba ○	15	8	54	8	11	25	31	4	3		
Miodontiucus nakamurai (Yokoyama) ○								7	3	1	3
Clinocardium ciliatum (Fabricius) ○					5			1			
C. californiense (Dashayes) ◎						8	6	2	2	1	3
Profulvia kurodai (Sawada) *	6	3	2	2		2	1				
Serripes groenlandicus (Bruguiere) ○								18			
Spisula voyi Dall ○								1			
Ezocallista brevisisphonata (Carpenter) ○		15	8	8	11		5	5	6	1	4
Saxidomus purpuratus (Sowerby) ◎			3	1		1					
Dosinia (Phacosoma) japonica (Reeve) ◎						2					
Liocyma fluctuosa (Gould) ○					1	1		6		3	
Mercenaria stimpsoni (Gould) ○								2			
Protothaca euglypta (Sowerby) ○								1			
Calluthaca adamsi (Reeve) ○			1					5	2	1	
Nuttallia commoda (Yokoyama) ○					1	3		2	2		
Macoma calcarea (Gmelin) ○						1		9			
Siliqua sp.								1			
Mya (Mya) truncata Linne ○					2	3		34			
Panomya arctica(Lamarck) ○						2		1			
Pandora (Heteroclidus) pulchella (Yokoyama) ○	1							15			
Myadora fluctuosa Gould ◎					1	2	2				
Thracia kakumana (Yokoyama) ○					3	1					

Legend

Warm-water species : ●
Cold-water species : ○
Eurythermal species : ◎
Extinct species : *

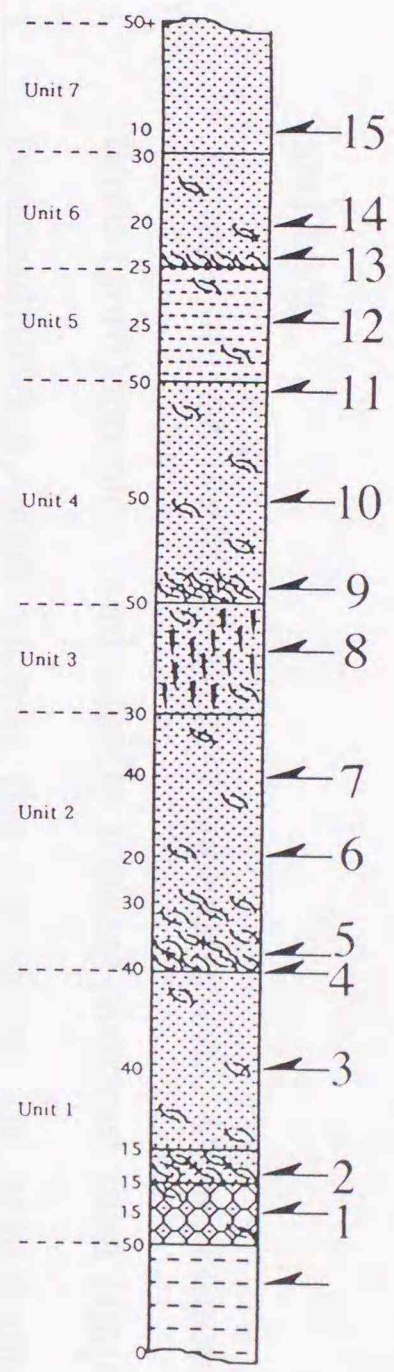


Tab. 6 Gastropoda in the Soebetsu section

Sampling number	2	3	5	6	8	9	10	12	13	14	15
Puncturella nobilis A.Adams ○	1	1		10	1	1		1	1		2
P. major Dall ○			1	1		1					
Acmaea pallida (Gould) ○	1	1	1	2							
Notoacmea concinna (Lischke) ◎			3	6							
Problacmea sybaritica (Dall) ○			1								
Lepeta cf. alba (Dall) ○								1	1		1
L. sp.								1	1		
Homalopoma amussitatum (Gould) ○	1		5	5	2	3	2				
"Margarites" sp.			1	1							
Tristichotrochus multiriratus (Sowerby) ◎						4					
Trucica coreensis Pease ◎	1										
Turritella fortilirata (Sowerby) ○								8	1		
Rhinoclavis kochi (Philippi) ●					1	4	3		1		
Bittium cf. yokoyamai Otuka *			2								
Crepidula grandis Middendorff ○			6	7				8	3		
Amathina nobilis (A.Adams) ○	2	1	6	2		1			1		
Cryptonatica janthostomoides (Kuroda and Habe) ◎			3	1		1	1	17	9	1	
Lunatia pila (Pilsbly) ○			3			2		12	2		
Fusitriton oregonensis (Redfield) ○					1						
Boreoscala greenlandica (Perry) ○						1					
Ocenebra aduncum (Sowerby) ◎			1			1					
Boreotrophon candelabrum (Reeve) ○			1			2		2	1		1
Neptunea arthritica (Bernardi) ○						2	1	1			
N. polycostata Scarlato ○								2			
N. vinosa (Dall) ○								2			
Mohnia? sp.	1							2			
Plicifusus plicatus (A.Adams) ○								17			
Searlesia japonica Yokoyama *								27	3		
Clinopegma sp.								12			
Buccinum sp.								1			
Hinia (Reticumassa) spursa (Gould) ◎							3	47	8		
Rectiplanes sanctioannis (Smith) ○								1			
Suavodrillia declivis (v.Martens) ○						2		1			
Ophiodermella miyatensis (Yokoyama) ○								2		2	
Odostomia sp.								1			

Legend

Warm-water species : ●
Cold-water species : ○
Eurythermal species : ◎
Extinct species : *



and beds.

2) *Composite or multiple-event concentrations,* these concentrations have more complex (and usually longer) histories than simple event-concentrations, and record the accretion or amalgamation of multiple generations and/or event-concentrations. The final, composite concentration is of average or expanded thickness relative to coeval strata. These concentrations range from beds and bedsets to reservoir-scale bioclastic facies.

3) *Hiatal or condensed concentration,* these are resulted from slow net rates of accumulation, i.e. stratigraphical condensation.

4) *Lag-concentrations*, these are thin highly residual concentrations associated with surfaces of significant stratigraphic truncation. Shells are exhumed and concentrated by selective removal of sedimentary matrix, either by erosion or by corrosion.

Shell concentration part of the Unit 1 include many pebbles which are regarded as transgressive lag deposits, and shells are under conditions of an insufficient preservation with fragmentation. These characters indicate that the concentration should be belong the lag-concentration. Shell concentration parts in the Units 2 and 4 yield many well-preserved shells. These concentrations are bioclast-supported and densely packed beds without any sedimentary structure. These beds, therefore, are regarded as either the multiple- or hiatal-concentrations, but can not be decided clearly. Shell concentration part of the Unit 6 are represented by a thin single molluscan layer. Such a sedimentary structure strongly indicates that this bed was made by eventually and episodically hydraulic reworking. This concentration, therefore, belongs event-concentrations.

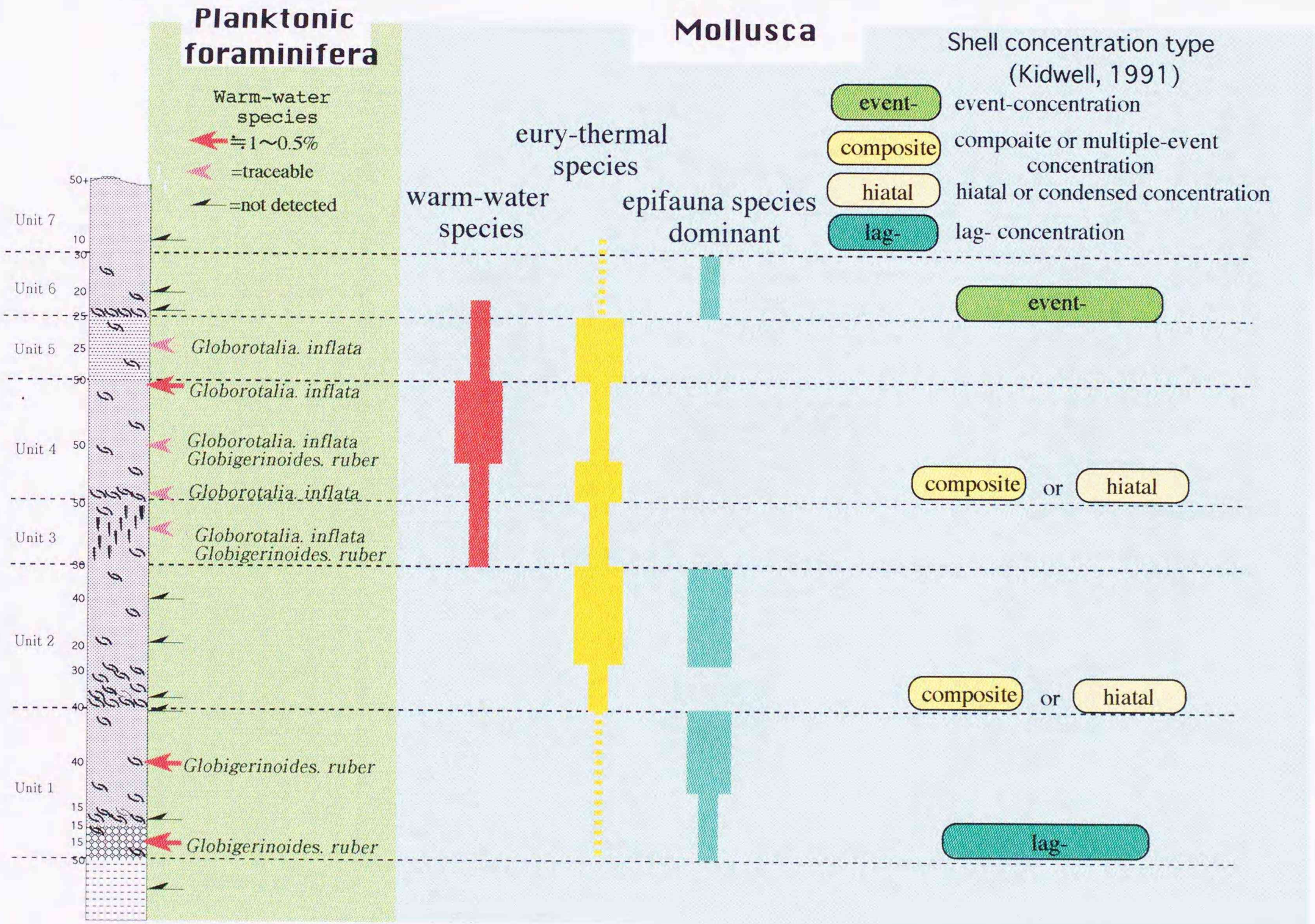


Fig. 24 Characters of Molluscan assemblages and occurrences of planktonic foraminifera in the Soebetsu section

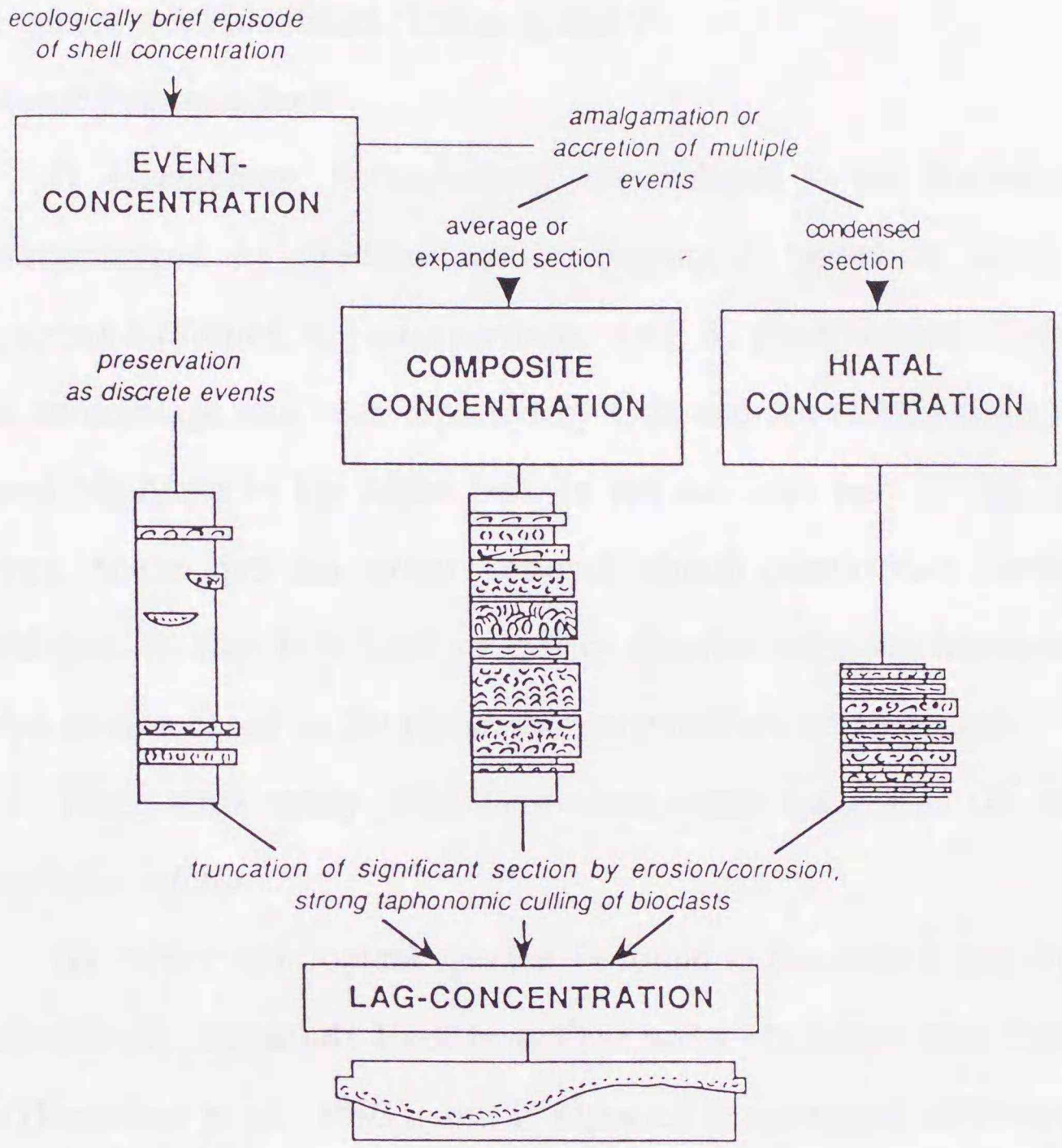


FIGURE 5. Skeletal concentrations reflect a spectrum of accumulation histories and time scales, but can be grouped into four broad categories: these range from simple *event-concentrations* to accretionary, multiple-event accumulations (both *composite concentrations* of "normal" or expanded thickness, and *hiatal concentrations* that are stratigraphically condensed), and highly derived, stratigraphically disjunct *lag-concentrations*. Each category includes biogenic, sedimentological, and mixed-origin coquinas; these may be composed of any proportion of local and exotic shells. Event-concentrations, for example, include predator and scavenger middens, *in situ* clusters created by gregarious behavior of shell-producers, shelly turbidites, and storm-concentrations that have been recolonized or reworked by benthos.

Fig. 25 Four types of Shell concentrations (Kidwell, 1991)

c) **Foraminiferal Assemblages**

Fifteen rock samples were used for foraminiferal studies from the Soebetsu Section to understand vertical changes of its assemblages. A total of 119 benthic species belonging to 57 genera, eight planktonic species belonging to five genera were identified (Tables 8, and 9).

Planktonic Foraminifera

i) ***Assemblage***; Foraminiferal assemblages in the Soebetsu Section are characterized by predominant *N. incompta*, which is associated by *Globigerina bulloides, G. quinqueloba,* and *N. pachyderma* (Table 8). A similar assemblage has been reported by Oda and Xu (1992) from the recent sediment off Akita in the Japan Sea. In the northern part of the Japan Sea, however, there are no other reports about planktonic foraminiferal assemblages, so that it is hard to clarify detailed paleoenvironments of the Soebetsu section based on the planktonic foraminiferal assemblages.

These units rarely yield such warm-water species as *Gs. ruber*, and *Globorotalia inflata.*

Gs. ruber, subtropical species, is found in the units 1 and 4 (Fig. 24). This species predominantly lives in surface water shallower than 50m of 16 to 31°C (Hemleben et al,. 1993), and is reported from waters influenced by the Tsushima Warm-Current in the Japan Sea (e.g. Oda and Xu, 1992). The occurrence of this species, therefore, means that warm-current like the recent Tsushima Warm-Current flew into the Japan Sea.

Gr. inflata has been found from the Units 3, 4, and 5 (Fig. 24). This species lives in the depth of over a hundred meter, and, in particular, the adults occur predominantly below 100m (Bé, 1977). The occurrence of this species, therefore, means that the sea was over 100m in depth during the depositions of

Tab. 7 Basic data of samples of the Soebetsu section

sample number	Unit	Sampl weight	weight <63μm	Benth. counted	Plank. counted	B/T ratio	P/T ratio	Benth. division	Plank. division	Foram. no/g	Mud contents	bent. foram.no	plank. foram.no
1	Unit 1	80.0	62.8	275	389	0.74	0.26	16	4	74.45	0.22	55	19
2	Unit 1	80.0	72.3	319	362	0.47	0.53	128	128	1089.60	0.10	510	579
3	Unit 1	80.0	74.9	177	327	0.35	0.65	256	256	1612.80	0.06	566	1046
4	Unit 2	80.0	74.2	192	260	0.42	0.58	256	256	1446.40	0.07	614	832
5	Unit 2	80.0	70.6	295	240	0.38	0.62	256	512	2480.00	0.12	944	1536
6	Unit 2	80.0	66.8	190	197	0.33	0.67	256	512	1868.80	0.17	608	1261
7	Unit 2	80.0	72.1	208	187	0.69	0.31	256	128	964.80	0.10	666	299
8	Unit 3	80.0	70.2	201	150	0.73	0.27	256	128	883.20	0.12	643	240
9	Unit 4	80.0	68.9	339	385	0.47	0.53	512	512	4633.60	0.14	2170	2464
10	Unit 4	80.0	68.0	473	258	0.65	0.35	256	256	2339.20	0.15	1514	826
11	Unit 4	80.0	68.0	371	255	0.59	0.41	512	512	4006.40	0.15	2374	1632
12	Unit 5	80.0	69.7	203	120	0.63	0.37	128	128	516.80	0.13	325	192
13	Unit 6	80.0	69.3	353	223	0.93	0.07	128	16	609.40	0.13	565	45
14	Unit 6	80.0	70.6	249	247	0.89	0.11	256	32	895.60	0.12	796.8	99
15	Unit 7	80.00	45.70	265	9	0.97	0.03	128	128	438.40	0.43	424	14

Tab. 8 Planktonic foraminifera of the Soebetsu section

Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Globigerina bulloides	115	64	69	80	62	34	43	47	110	52	63	17	30	57
Globigerina quinqueloba	22	14	13	19	12	3	3	12	9	10	4	5	7	10
Grobigerina spp.	5	2	2	1		1								
Globigerinita glutinata	17	5	7	4	6	9			4	17	2	8	1	
Globigerinita uvula	23	15	19	15	8	7	1	8	31	6	2	5		1
Globigerinoides ruber	3		2											
Globorotalia inflata											1			
Neogloboquadrina incompta	170	221	174	108	123	94	85	73	218	158	168	80	171	171
Neogloboquadrina pachyderma(D)	8	13	21	17	13	22	31	4	2	5	6	2	5	3
Neogloboquadrina pachyderma(S)	24	28	18	16	16	27	24	5	9	10	9	2	9	5
Neogloboquadrina sp.	2		2					1	2			1		
Total counted	389	362	327	260	240	197	187	150	385	258	255	120	223	247
Dext./total N. pachyderma %	25.0	31.7	53.8	51.5	44.8	44.9	56.4	44.4	18.2	33.3	40.0	50.0	35.7	37.5
Planktonic Foraminiferal Number(/g)	19.4	579.2	1046.4	832.0	1536.0	1260.8	299.2	240.0	2464.0	825.6	1632.0	192.0	44.6	99.0
Benthic Foraminiferal Number(/g)	55.0	510.4	566.4	614.4	944.0	608.0	665.6	643.2	2169.6	1539.2	2348.8	324.8	566.4	796.8
P/T Ratio(%)	26.1	53.2	64.9	57.5	61.9	67.5	31.0	27.2	53.2	34.9	41.0	37.2	7.3	11.0
Mud contents(%)	22	10	6	7	12	16	10	12	14	15	15	13	13	12

Tab. 9 Benthic foraminifera of the Soebetsu section

Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ammonia spp.	2														
Angulogerina hughesi (Galloway and Wissler)						1									
Anomalinella rostrata (Brady)	1														
Anomalinella spp.		4													
Anomalinoides globulosus (Chapman and Parr)		1				2					4				
Astacolus hyalacrulus Loeblich and Tappan				1											
Astrononion hamadaense Asano									1						
Astrononion spp.	2														
Bolivina decussata Brady				3	5	5		1	4	4	2		3	3	1
Bolivina cf. pseudoplicata Heron-Allen and Earland	1							1	1						
Bolivina spp.		7													
Brizalina alata (Seguenza)								2							
Brizalina spp.	1		5	6	3	2	2			3		1			
Buccella frigida (Cushman)												3	11	1	4
Buccella makiyamai (Chiji)		5	4	11	5	3	13	25	34	27	35	20	23	15	28
Buccella nipponica (Husezima and Maruhasi)				1			3			4	1	1	4	3	
Buccella tanaii Uchio												7			
Buccella tenerrima (Bandy)	1	11	6	5	3	8	14	3	18	62	29	16	47	18	17
Buccella spp.					2			1	3	4		2	6	11	5
Buliminella elegantissima (d'Orbigny)	2	3	1	4	2		2	1	5	5	6	11	21	14	17
Cancris auriculus (Fichtel and Moll)	1														
Cibicides cf. kamadai Asano												2			
Cibicides lobatulus (Walker and Jacob)	18	7		6			10	3	11	14	19				
Cibicides refulgens de Montfort	54	34	12	10	7	4	12	11	15	42	29	6	5	1	
Cibicides subdepressus (Asano)		1		1	4					1					
Cibicides spp.	1	1	2		3	3	1			2			1	2	
Cibicidoides pachydermus (Rzehak)		1				1									
Cornuspira involvens (Reuss)		4													
Cribloelphidium oregoense (Cushman and Grant)												1	1		
Cribroelphidium yabei (Asano)													3	6	1
Cribrolinoides curta (Cushman)						1		1							
Cycloforina contrta (d'Orbigny)		4	10	1		1					2				
Discorbinella araucana (d'Orbigny)	30		1	3	6	1	1	9	8	10	3	1	1		
Discorbinella spp.	1	1													
Elphidium aculeatum (d'Orbigny)	1														
Elphidium advena (Cushman)										1					
Elphidium bartletti Cushman						5				6	2	3	36		
Elphidium crispum (Linné)	4	11	9	7	1	4	4		12	30	25			1	1
Elphidium excavatum (Terquem) forma clavata Cushman	1	1		4	7		2	11	5	4	6	26	49	26	18
Elphidium frigidum Cushman		4	4	2	4										
Elphidium incertum (Wiliamson)															1
Elphidium janseni (Cushman)			2				1	1	2	2	2				
Elphidium orbiculare (Brady)															
Elphidium subarcticum Cushman	20	14	12	22	23	20	37	21	40	43	44	25	79	99	126
Elphidium subgranulosum Asano							1				4	9	21	20	22
Elphidium spp.	3		2		2		1	1		1		6	7	4	3
Epistominella spp.				1							1	2			
Eponides? spp.						1			2					1	
Fissurina annectens (Burrows and Holland)										4	3	2			
Fissurina lacunata (Burrows and Holland)								1							
Fissurina lucida (Williamson)										3					
Fissurina marginata (Montague)	2	7	1	1	6	3	1	1	12	6	5	1	4	1	4
Fissurina obscurocostata Galloway and Wisser								2	1						
Fissurina orbignyana Seguenza										1	1				
Fissurina cf. rizzae Seguenza			1		1						1				
Fissurina cf. subquadrata Parr		2			1										
Fissurina spp.	1	2	1		1	1		1		2	2		1		
Gavelinopsis praegeri (Heron-Allen and Earland)		1					1	1	2						
Gavelinopsis sp.		8													
Glabratella cf. aurantista Seiglie and Bermúdez	1	13	5	5		2	2	6	5	1	1	1	1		
Glabratella mirabilis panamensis Seiglie and Bermúdez				3	5						4				
Glabratella patelliformis (Brady)		4	3	1			4			13					
Glabratella pulvinata (Brady)		2			16	7	4	3	6	7	3	4			
Glabratella sp. A	1	3	2		2					1					
Glabratella sp. B				2	2							1			
Glabratella spp.			1					2		1		1			
Globocassidulina bisecta Nomura				3				1			1				
Globocassidulina spp.	4	14	11	5	13	5			3	2	4	2	3		
Guttulina sp.										1					
Gyroidina spp.												4			
Hanzawaia nipponica Asano	18	4	3	1		1			1	6	5	1			
Haynesina sp.									3		1	1			
Heronallenia sp.							1								
Heterolepa subhaidingerii (Parr)	18		6		3	1	1								
Islandiella helenae Feyling-Hanssen and Buzas										3				1	1
Islandiella japonica (Asano and Nakamura)					3	1						4			
Islandiella norcrossi (Cushman)	2				21	11	6	4	3	5	2	8			
Islandiella sp.			1												
Islandiella sublimbata (Asano and Nakamura)		15	9	11	9	11	9	5			2	3	4		

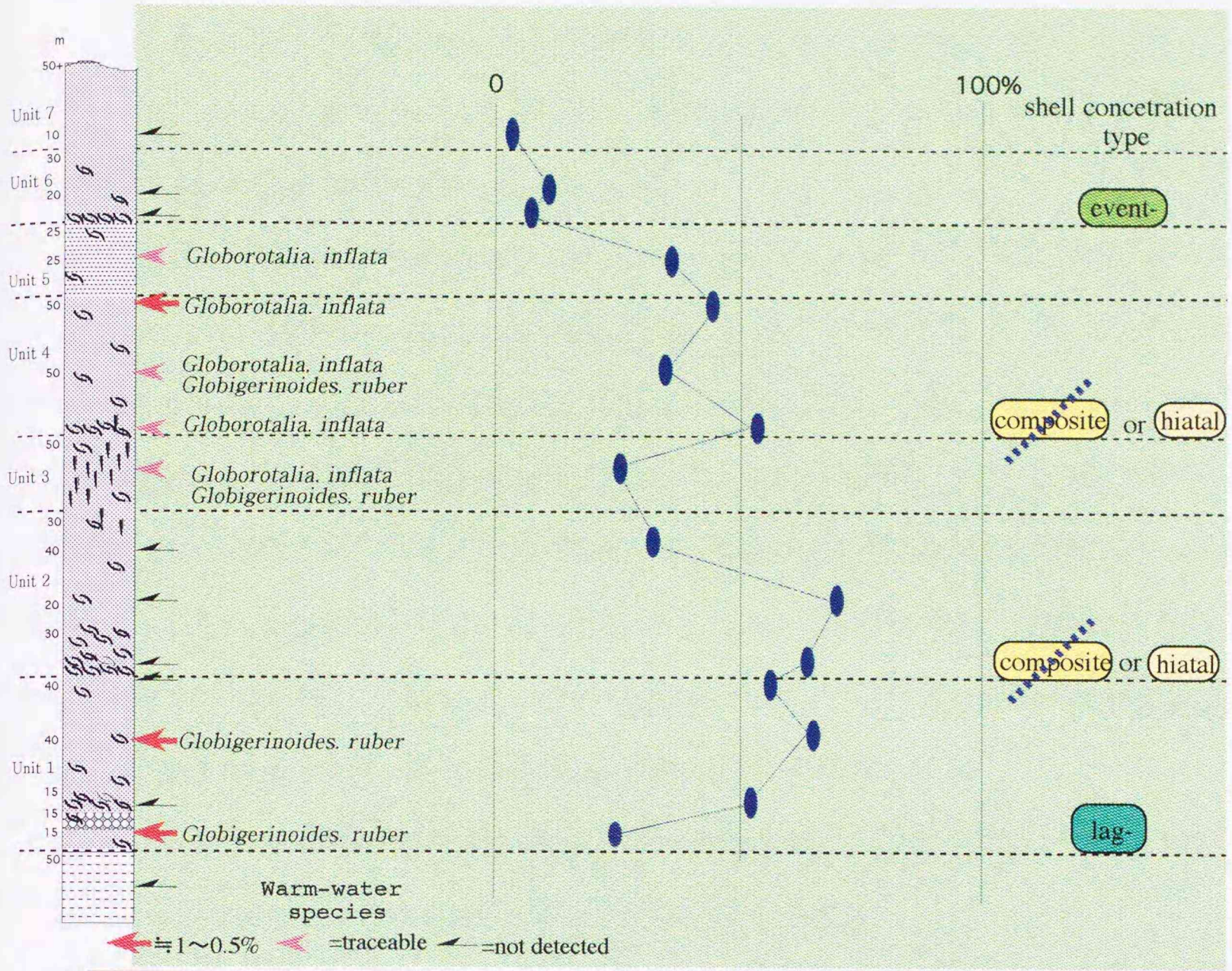
Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Karreriella spp.											1				3
Lagena acuticosta (Reuss)										1	1				
Lagena apiopleura (Loeblich and Tappan)			1	1		1									
Lagena sulcata spicata Cushman and McCulloch				1		2					1				
Lagena sp.															1
Lenticulina nikobarensis (Schwager)											1				
Lenticulina sp.			1												
Melonis pacificum (Cushman)												2			
Melonis uchioi Hasegawa										1					
Miliolinella circularis (Bornemann)					6										
Miliolinella sp.		3	1												
Neoeponides procerus (Brady)	1												2	1	
Nodosarina? sp.								1							
Nonion japonicus Asano									3						
Nonion spp.	1							2		2					
Nonionella stella Cushman and Moyer										2			1		
Nonionoides grateloupi (d'Orbigny)														1	
Oolina costata (Williamson)									1						
Oolina melo d'Orbigny		1			1		1		1		1				
Oolina sp.										1					
Oridosalis umbonatus (Reuss)				1											
Paracassidulina sulcata Belford		3													
Pararotalia nipponica (Asano)		2					1								
Patellina corrugata Williamson			1			3							1		
Patellinella hanzawai Asano	2	2						1	1	2	2				
Pateoris hauerinoides (Rhmbler)		7		11	11	6	8	5	15	18	13				
Planoglabratella australensis (Hellom-Allen and Earland)							1			2	6				
Planoglabratella opercularis (d'Orbigny)		1	5		5	16	1	3	15	3	4				
Planoglabratella subopercularis (Asano)	6		1	5	5	5	8	4	17	15	13	1	2		
Planolgabratella? sp. C												1			
Polystomellina discorbinoides (Yabe and Hanzawa)		2		1	1		2								
Poroeponides cribrorepondus Asano			3												1
Pseudononion japonicum Asano	1						1	1					1		
Pseudononion sp.					1										
Pseudoparrella naraensis Kuwano		13	9	14	37	18	2	7	8	2	4	6	2	5	2
Pseudoparrella takayanagii (Iwasa)	49	3			10	6	19	16	17	36	18	7	5	2	2
Pseudoparrella spp.															4
Pseudopolymorphina sp.											1				
Quinqueloculina agglutinata Cushman							1	1			1				
Quinqueloculina akneriana d'Orbigny		8		6		1	1	1	20		2	1			
Quinqueloculina costata d'Orbigny					1				2						
Quinqueloculina elongata Natland			2	2	8										
Quinqueloculina kuromatunaiensis Asano			1		3								1		
Quinqueloculina sawanensis Asano		3							6	1					
Quinqueloculina seminulum (Linné)		4				6					1				
Quinqueloculina vulgaris d'Orbigny			6		2				6	2					
Quinqueloculina cf. vulgaris d'Orbigny				1											
Quinqueloculina yezoensis Asano					6		3		2	4					
Quinqueloculina sp. C		2	8	7						2	3				
Quinqueloculina sp. F						6			2		9			1	
Quinqueloculina sp. G									4						
Quinqueloculina sp. H										6					
Quinqueloculina spp		10	3	1	17	10	5	9		19	10			1	
Rectobolivina rephanus (Parker and Jones)		1		1											
Rosalina australis (Parr)	4										6				
Rosalina bradyi (Cushman)	7	13	3	7			10	8		14	9	1	1		
Rosalina isabelleana d'Orbigny								6							
Rosalina vilardeboana d'Orbigny	9		1	3	8		4	3	6						
Rosalina spp.	1	28	2			1	1		4	8	1				
Sigmohauerina sp.			1												
Sigmoidella pacifica Cushman and Ozawa														1	
Sigmoilina sp.		1													
Sigmomorphina semitecta terquemiana (Fornasini)		2		1											
Sigmovirgulina sp.	1														
Spirillina limbata Brady				1	1										
Spirillina vivipara Ehrenberg		6	1	2		1		1	2						
Spirillina sp.										1					
Spiroloculina hadai Thalmann									2		1				
Spiroloculina sp.				1											
Spiroplectammina sp. A		4	1												
Spiroprectammina sp.				1											
Spiroplectinella wrightii (Silvestri)		3													
Textularia conica d'Orbingy		1		1											
Textularia spp.		1	4												
Triloculina suttuensis Asano									4						
Triloculina tricarinata d'Orbigny										2					
Triloculina sp. A											2				
Valvulineria hamanakoensis (Ishiwada)												2			
Gen. et sp. indet.	2	6	8	4	13	3	6	13	4	9	11	7	8	10	3
Total counted	277	323	183	201	306	202	222	217	357	494	393	227	381	277	295

these units.

ii) ***Ratio of Planktonic Species to Total Foraminiferal Number (P-T ratio)*****;** The P-T ratio generally indicates oceanic water effects.

The Seobetsu Section shows high P-T ratio, about 30 to 70%, except the Units 1 at the base, 6, and 7 (Fig. 25). The P-T ratio was reported that it has a peak in the middle shelf of about 140m in depth in the recent Ishikari Bay (Hasegawa et al., 1997). Similar tendencies were reported from off the Shakotan Peninsula (Takata and Hasegawa, 1996), and off the Oshima Peninsula (Hasegawa and Kogame, 1995). These data suggest that the Unit 7 was deposited in the water depth of about 40m, and the Units 1 to 5 were about 80 to 150m in depth.

There are two types of shell concentrations, high and low P-T ratio. Event-concentrations, lag-concentrations, and composite or multiple-event concentrations include conceptually erosion and/or rework. Eroded and/or reworked deposits from shallower area should contain many transported shallower benthos, such as molluscs and benthic foraminifera, therefore, the bed should not show high P-T ratio. Hence shell concentrations of the Units 1, 2, and 4 are hiatal or condensed concentrations.



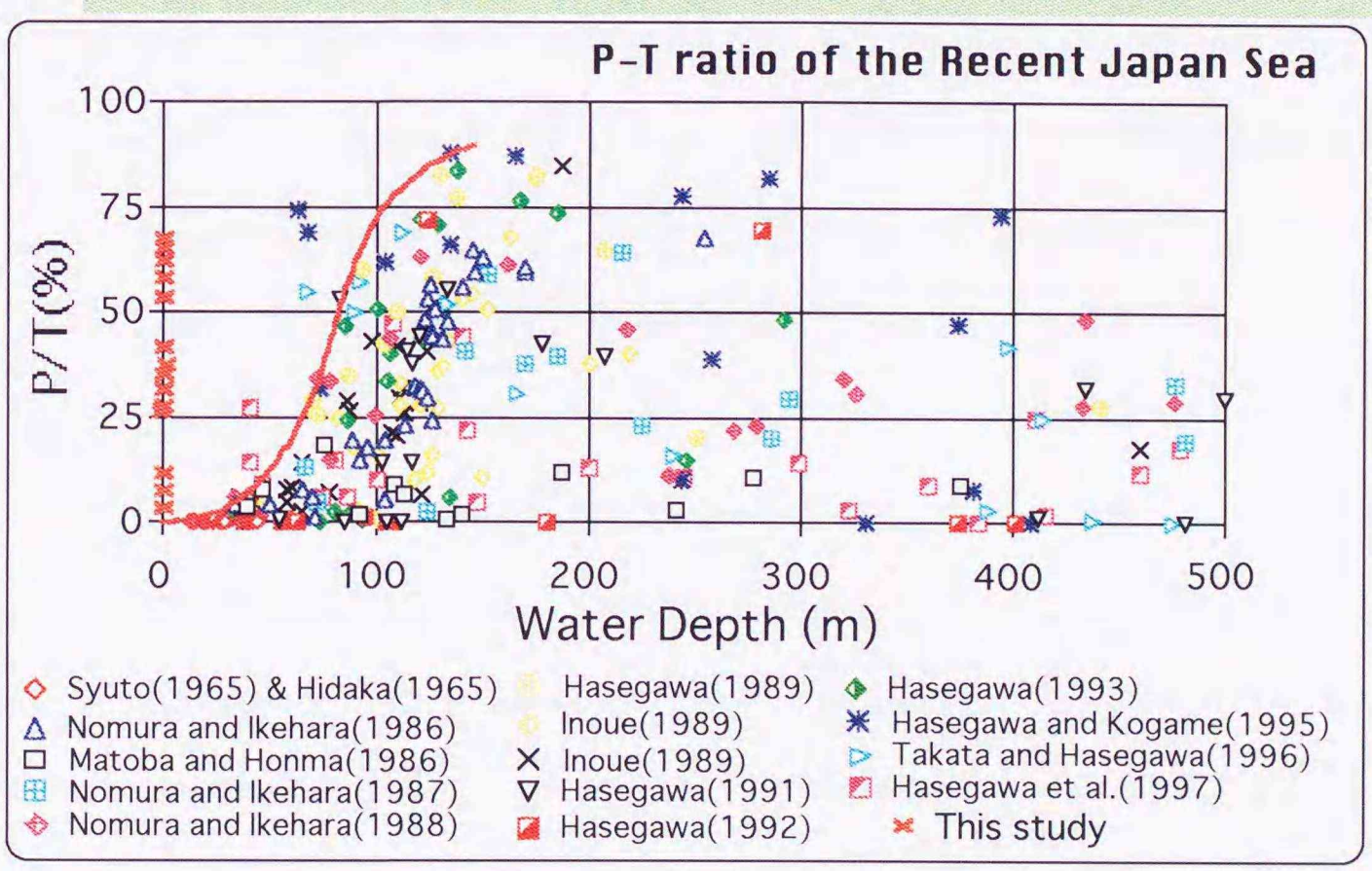


Fig. 26 P-T ratio of the Soebetsu section

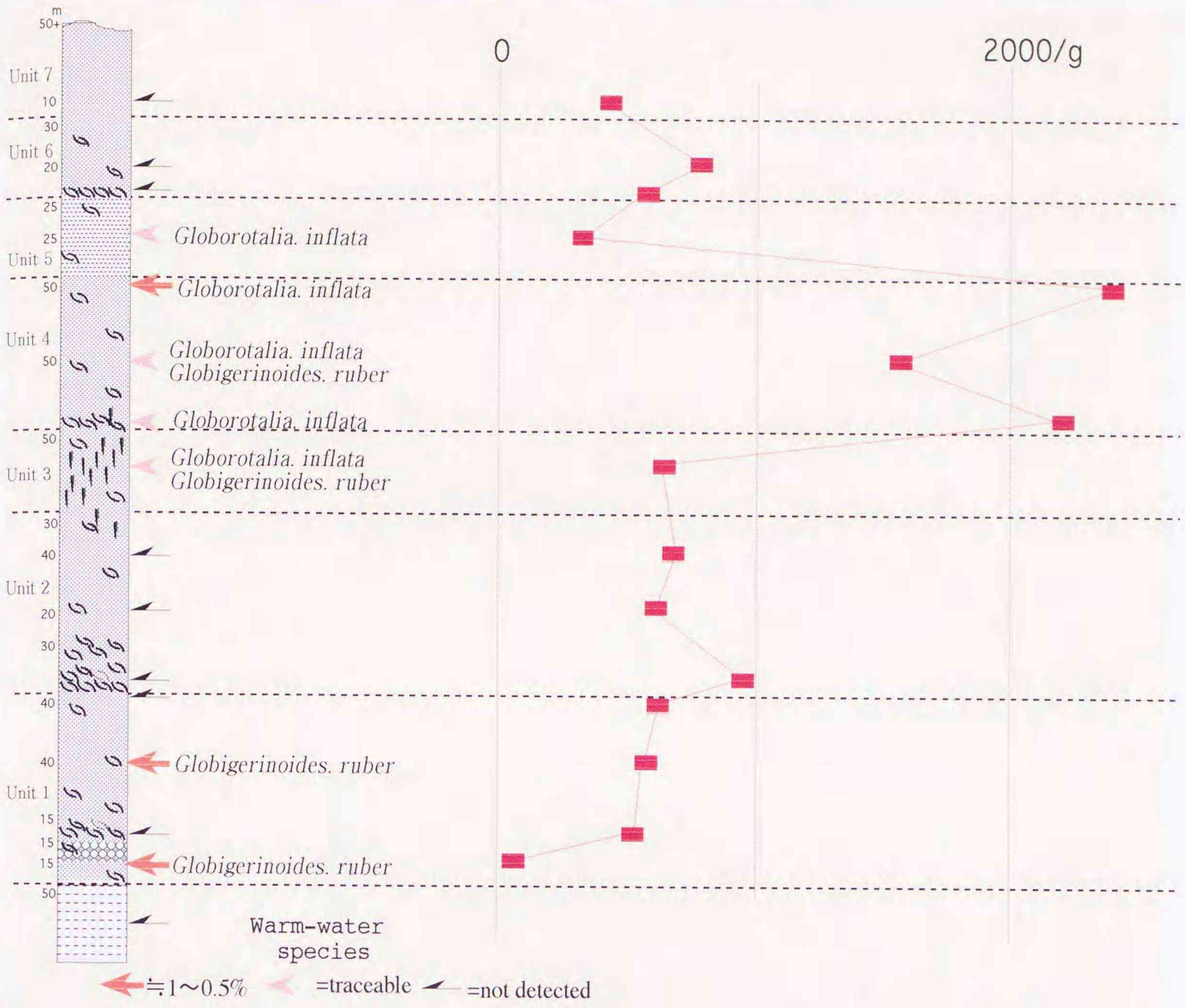
Benthic Foraminifera

i) ***Benthic Foraminiferal Number***; Benthic foraminiferal number (FN) means the total numbers of benthic foraminifera in 1g (dry weight). This parameter usually increases toward off-shore.

In the samples examined the FN is between 55 to 2349, and most samples are over 300 except at the base of the Unit 1 (Fig. 27). In the northern part of the present Japan Sea, the FN attains about 300 around 135m in depth off the Oshima Peninsula (Hasegawa and Kogame, 1995), and in the depth shallower than 100m off Suttsu and Shakotan Peninsula (Takata and Hasegawa, 1996). On the contrary, it is always less than 300 in the Ishikari Bay (Hasegawa et al., 1997). These data and other previous studies are summarized in Fig. 27, and imply that FN is not only related with only depth.

ii) ***Assemblage of Benthic Foraminifera***; The author estimated the changes of paleodepth based on the following method;

1) The R-mode cluster analysis was made to determine species-groups based on relative frequencies of benthic foraminiferal species in every sample. For a similarity index of cluster analysis, Horn's index of overlap (Horn, 1966) is adopted (see Hasegawa (1988) for detailed explanation). As a result of the cluster analysis, the samples were classified 63 clusters (species-groups or individuals) are distinguished at 0.8 of the similarity level (Fig. 28).
2) Habitat of the species-group of each cluster is estimated based on depth distribution of benthic foraminifera in the present Japan Sea by the previous workers (shown in Fig. 28).
3) All the clusters and individuals are adopted with Akimoto and Hasegawa(1989)'s shallow bathymetric zone (SBZ) based on the



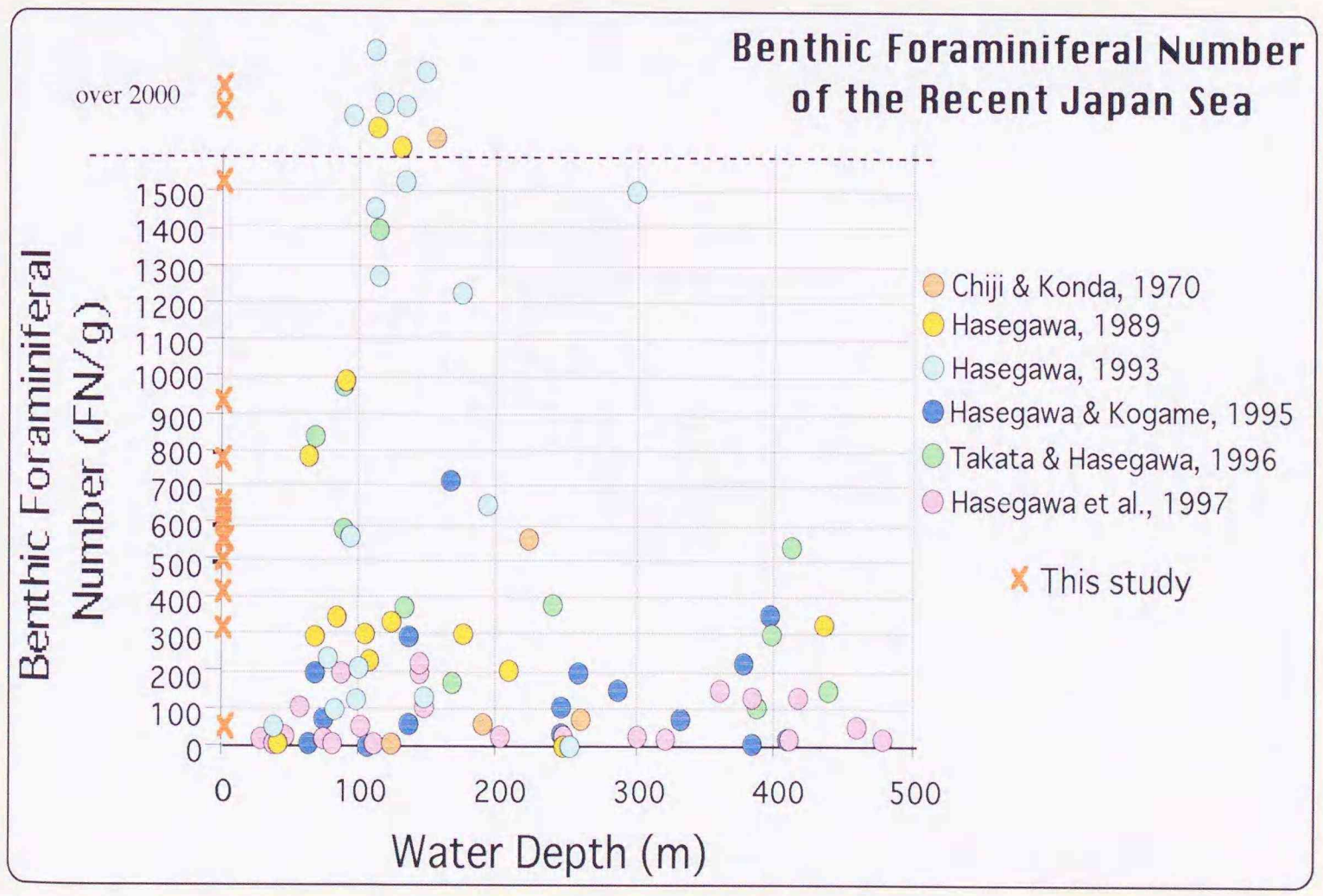
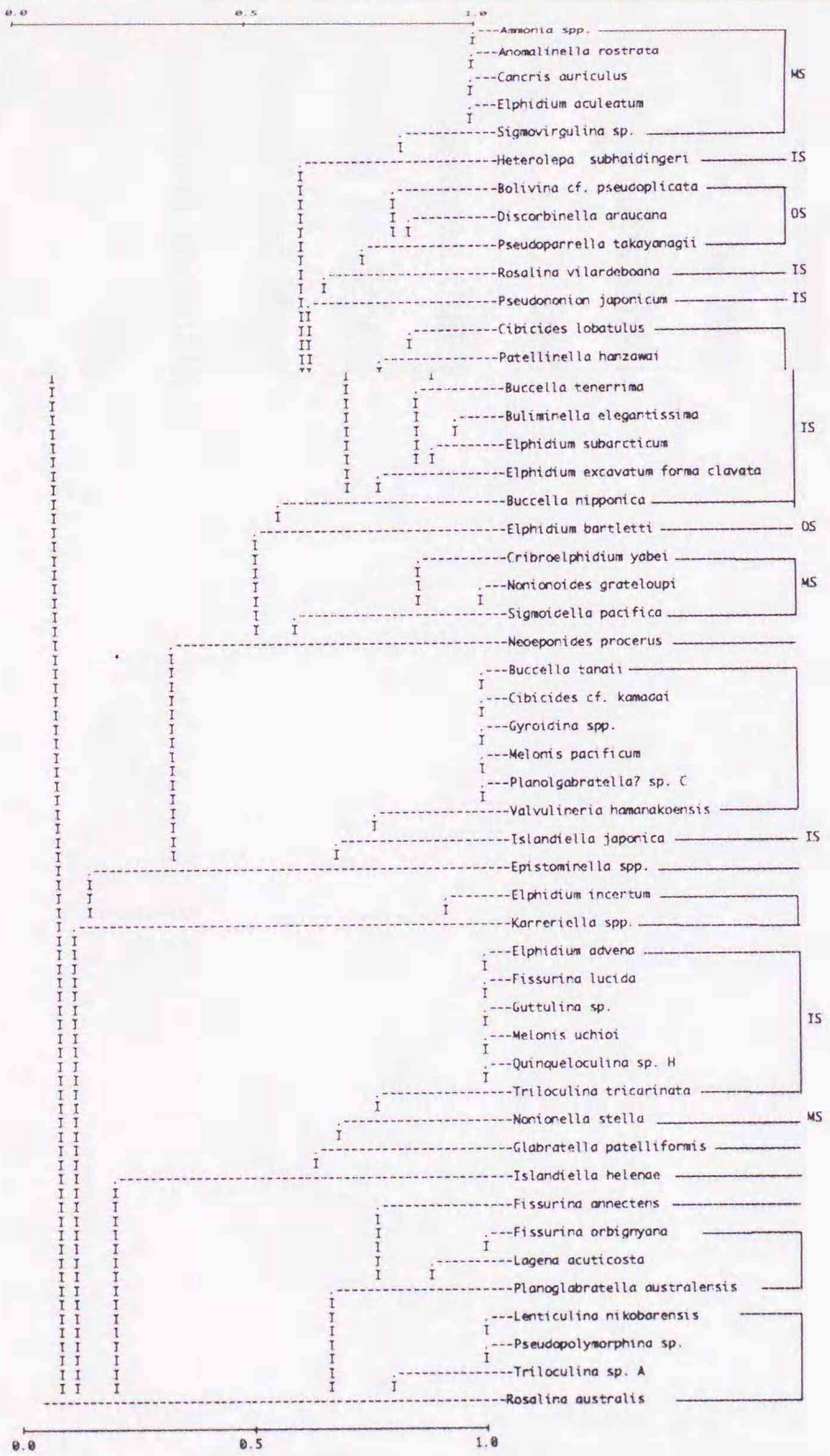


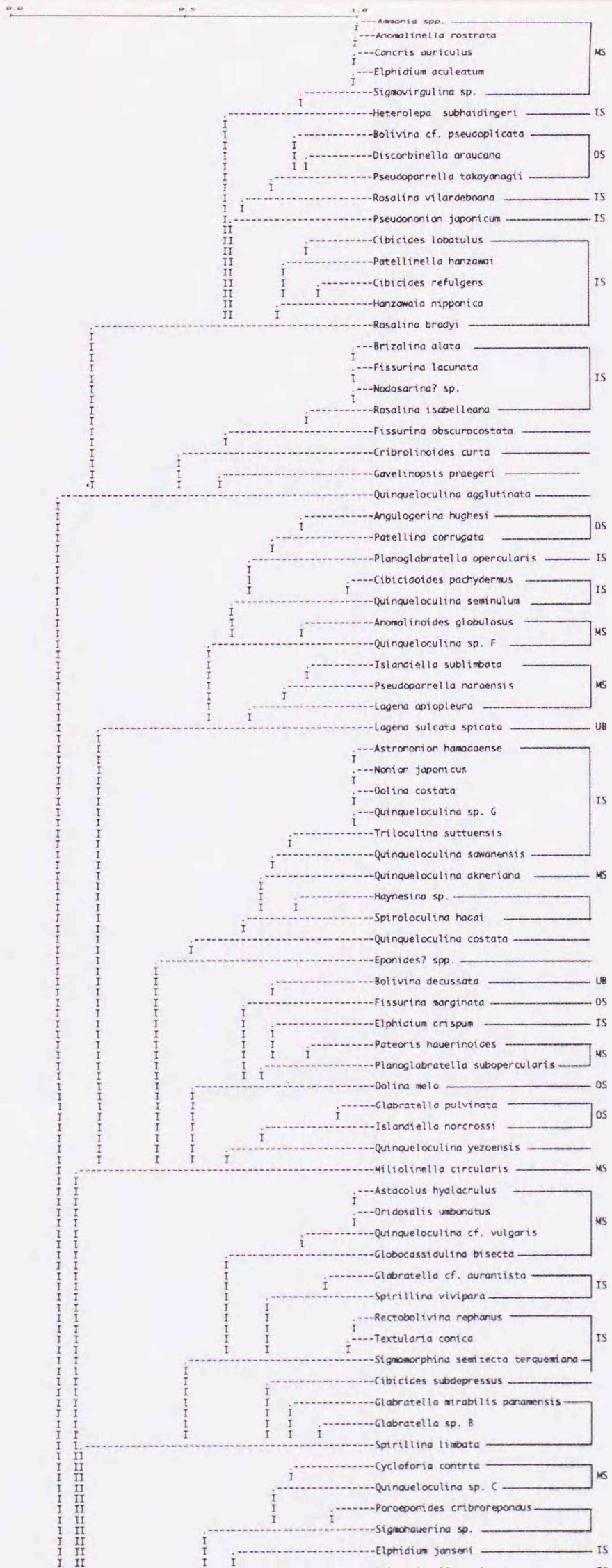
Fig. 27 Benthic foraminiferal number of the Soebetsu section

Fig. 28 I



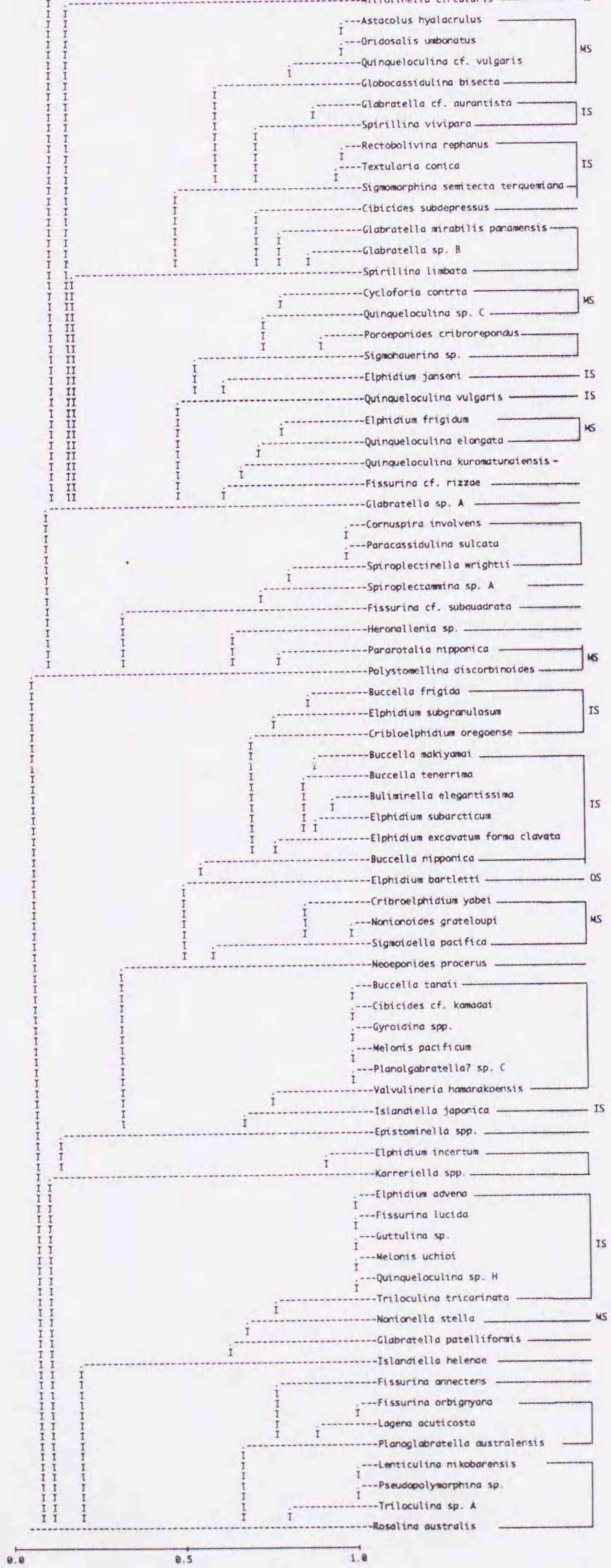
Sample number	depth	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Astrononion hamadaense Asano	1									0						
Brizalina alata (Seguenza)	1												3	11	0	4
Buccella frigida (Cushman)	1		5	4	11	5	3	13	25	34	27	35	20	23	15	28
Buccella makiyamai (Chiji)	1				0			3			4	0	0	4	3	
Buccella nipponica (Husezima and Maruhasi)	1	0	11	6	5	3	8	14	3	18	62	29	16	47	18	17
Buccella tenerrima (Bandy)	1	0	3	0	4	0		0	0	5	5	6	11	21	14	17
Bulimmella elegantissima (d'Orbigny)	1	18	7		6			10	3	11	14	19				
Cibicides lobatulus (Walker and Jacob)	1	54	34	12	10	7	4	12	11	15	42	29	6	5	0	
Cibicides refulgens de Montfort	1		0				0						0	0		
Cibicidoides pachydermus (Rzehak)	1															
Cribloelphidium oregoense (Cushman and Grant)	1										0					
Elphidium advena (Cushman)	1	4	11	9	7	0	4	4		12	30	25			0	0
Elphidium crispum (Linné)	1	0	0		4	7		0	11	5	4	6	26	49	26	18
Elphidium excavatum (Terquem) forma clavata Cushman	1			0				0	0	0	0	0				
Elphidium janseni (Cushman)	1	20	14	12	22	23	20	37	21	40	43	44	25	79	99	126
Elphidium subarcticum Cushman	1							0				4	9	21	20	22
Elphidium subgranulosum Asano	1															
Globocassidulina spp.		4	14	11	5	13	5			3	0	4	0	3		
Gyroidina spp.													4			
Haynesina sp.										3		0	0			
Heronallena sp.								0								
Islandiella helenae Feyling-Hanssen and Buzas											3				0	0
Islandiella sp.				0												
Karreriella spp.												0				3
Lagena acuticosta (Reuss)											0	0				
Lagena sp.																0
Lenticulina nikobarensis (Schwager)												0				
Lenticulina sp.				0												
Melonis pacificum (Cushman)													0			
Miliolinella sp.			3	0												
Neoeponides procerus (Brady)		0													0	0
Nonion spp.		0							0		0					
Oolina sp.											0					
Paracassidulina sulcata Belford			3													
Planoglabratella australensis (Hellom-Allen and Earland)								0			0	6				
Planolgabratella? sp. C													0			
Poroeponides cribroreponduus Asano				3												0
Pseudononion sp.						0										
Pseudoparrella spp.																4
Pseudopolymorphina sp.												0				
Quinqueloculina agglutinata Cushman								0	0			0				
Quinqueloculina costata d'Orbigny						0				0						
Quinqueloculina kuromatunaiensis Asano				0		3									0	
Quinqueloculina yezoensis Asano						6		3		0	4					
Quinqueloculina spp			10	3	0	17	10	5	9		19	10			0	
Rosalina australis (Parr)		4										6				
Rosalina spp.		0	28	0			0	0		4	8	0				
Sigmoilina sp.			0													
Spirillina limbata Brady					0	0										
Spirillina sp.											0					
Spiroloculina hadai Thalmann												0				
Spiroloculina sp.					0											
Spiroplectammina sp. A			4	0												
Spiroprectammina sp.					0											
Spiroplectinella wrighti (Silvestri)			3													
Textularia spp.			0	4												
Triloculina sp. A													0			
Valvulineria hamanakoensis (Ishiwada)														0		
Gen. et sp. indet.		2	6	8	4	13	3	6	13	4	9	11	7	8	10	3
Total Foram. No.		275	319	177	193	296	190	208	201	339	474	371	203	355	249	265
inner sublittoral zone	1	53.8	40.1	40.1	43.5	21.6	32.1	51.4	49.8	55.8	55.5	58.0	59.1	73.2	78.3	87.5
middle sublittoral zone	2	2.2	16.0	22.6	29.5	27.0	24.2	12.0	10.4	17.7	7.0	12.4	4.4	2.0	4.4	0.0
outer sublittoral zone	3	28.7	3.1	0.0	1.6	19.9	18.4	13.9	15.9	13.6	14.8	7.8	10.8	12.7	0.0	1.5
upper bathyal zone	4	0.0	0.0	0.0	1.6	1.7	2.6	0.0	0.0	1.2	0.8	0.0	0.0	0.8	1.2	0.0

Fig. 28 Dendrogram of R-mode cluster analyses and species-groups of the Soebetsu section



Sample number	depth	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Astrononion hamadaense Asano	1										0					
Brizalina alata (Seguenza)	1								0					3	11	0	4
Buccella frigida (Cushman)	1			5	4	11	5	3	13	25	34	27	35	20	23	15	28
Buccella makiyamai (Chiji)	1					0			3			4	0	0	4	3	
Buccella nipponica (Husezima and Maruhasi)	1	0	11	6	5	3	8	14	3	18	62	29	16	47	18	17	
Buccella tenerrima (Bandy)	1	0	3	0	4	0		0	0	5	5	6	11	21	14	17	
Cibicides lobatulus (Walker and Jacob)	1	18	7		6			10	3	11	14	19					
Cibicides refulgens de Montfort	1	54	34	12	10	7	4	12	11	15	42	29	6	5	0		
Cibicidoides pachydermus (Rzehak)	1		0				0										
Cribroelphidium oregoense (Cushman and Grant)	1												0	0			
Elphidium advena (Cushman)	1										0						
Elphidium crispum (Linné)	1	4	11	9	7	0	4	4		12	30	25			0	0	
Elphidium excavatum (Terquem) forma clavata Cushman	1	0	0		4	7		0	11	5	4	6	26	49	26	18	
Elphidium janseni (Cushman)	1			0				0	0	0	0	0					
Elphidium subarcticum Cushman	1	20	14	12	22	23	20	37	21	40	43	44	25	79	99	126	
Elphidium subgranulosum Asano	1							0				4	9	21	20	22	
Fissurina lacunata (Burrows and Holland)	1								0								
Fissurina lucida (Williamson)	1										3						
Glabratella cf. aurantista Seiglie and Bermúdez	1	0	13	5	5		0	0	6	5	0	0	0	0			
Guttulina sp.	1										0						
Hanzawaia nipponica Asano	1	18	4	3	0		0			0	6	5	0				
Heterolepa subhaidingerii (Parr)	1	18		6		3	0	0									
Islandiella japonica (Asano and Nakamura)	1					3	0						4				
Melonis uchioi Hasegawa	1										0						
Nodosarina? sp.	1								0								
Nonion japonicus Asano	1									3							
Oolina costata (Williamson)	1									0							
Patellinella hanzawai Asano	1	0	0						0	0	0	0					
Planoglabratella opercularis (d'Orbigny)	1		0	5		5	16	0	3	15	3	4					
Pseudononion japonicum Asano	1	0						0	0					0			
Quinqueloculina sawanensis Asano	1		3							6	0						
Quinqueloculina seminulum (Linné)	1		4				6						0				
Quinqueloculina vulgaris d'Orbigny	1			6		0				6	0						
Quinqueloculina sp. G	1									4							
Quinqueloculina sp. H	1										6						
Rectobolivina rephanus (Parker and Jones)	1		0		0												
Rosalina bradyi (Cushman)	1	7	13	3	7			10	8		14	9	0	0			
Rosalina isabelleana d'Orbigny	1								6								
Rosalina vilardeboana d'Orbigny	1	9		0	3	8		4	3	6							
Sigmomorphina semitecta terquemiana (Fornasini)	1		0		0												
Spirillina vivipara Ehrenberg	1		6	0	0		0		0	0							
Textularia conica d'Orbigny	1		0		0												
Triloculina suttuensis Asano	1									4							
Triloculina tricarinata d'Orbigny	1										0						
Sigmovirgulina sp.	2	0															
Anomalinella rostrata (Brady)	2	0															
Anomalinoides globulosus (Chapman and Parr)	2		0				0						4				
Astacolus hyalacrulus Loeblich and Tappan	2				0												
Cancris auriculus (Fichtel and Moll)	2	0															
Cribroelphidium yabei (Asano)	2													3	6	0	
Elphidium aculeatum (d'Orbigny)	2	0															
Elphidium frigidum Cushman	2		4	4	0	4											
Globocassidulina bisecta Nomura	2				3				0				0				
Islandiella sublimbata (Asano and Nakamura)	2		15	9	11	9	11	9	5				0	3	4		
Lagena apiopleura (Loeblich and Tappan)	2			0	0		0										
Miliolinella circularis (Bornemann)	2					6											
Nonionella stella Cushman and Moyer	2										0			0			
Nonionoides grateloupi (d'Orbigny)	2														0		
Oridosalis umbonatus (Reuss)	2				0												
Pararotalia nipponica (Asano)	2		0					0									
Pateoris hauerinoides (Rhmbler)	2		7		11	11	6	8	5	15	18	13					
Planoglabratella subopercularis (Asano)	2	6		0	5	5	5	8	4	17	15	13	0	0			
Polystomellina discorbinoides (Yabe and Hanzawa)	2		0		0	0		0									
Pseudoparrella naraensis Kuwano	2		13	9	14	37	18	0	7	8	0	4	6	0	5	0	
Quinqueloculina akneriana d'Orbigny	2		8		6		0	0	0	20		0	0				
Quinqueloculina elongata Natland	2			0	0	8											
Quinqueloculina cf. vulgaris d'Orbigny	2				0												
Quinqueloculina sp. F	2						6			0		9			0		
Sigmoidella pacifica Cushman and Ozawa	2														0		
Cycloforia contrta (d'Orbigny)	2		4	10	0		0					0					
Quinqueloculina sp. C	2		0	8	7						0	3					
Sigmohauerina sp.	2			0													
Angulogerina hughesi (Galloway and Wissler)	3						0										
Bolivina cf. pseudoplicata Heron-Allen and Earland	3	0							0	0							
Discorbinella araucana (d'Orbigny)	3	30		0	3	6	0	0	9	8	10	3	0	0			
Elphidium bartletti Cushman	3						5				6	0	3	36			
Fissurina marginata (Montague)	3	0	7	0	0	6	3	0	0	12	6	5	0	4	0	4	
Glabratella pulvinata (Brady)	3		0			16	7	4	3	6	7	3	4				
Islandiella norcrossi (Cushman)	3	0				21	11	6	4	3	5	0	8				
Oolina melo d'Orbigny	3		0			0		0		0		0					
Patellina corrugata Williamson	3			0			3							0			
Pseudoparrella takayanagii (Iwasa)	3	49	3			10	6	19	16	17	36	18	7	5	0	0	
Bolivina decussata Brady	4				3	5	5		0	4	4	0		3	3	0	
Lagena sulcata spicata Cushman and McCulloch	4				0		0					0					
Ammonia spp.		0															
Anomalinella spp.			4														
Astrononion spp.		0															
Bolivina spp.			7														
Brizalina spp.		0		5	6	3	0	0			3		0				
Buccella tanaii Uchio													7				
Buccella spp.						0			0	3	4		0	6	11	5	
Cibicides cf. kamadai Asano													0				
			0		0	4					0						

Soebetsu section



Quinqueloculina sp. C	2		0	8	7							0	5			
Sigmohauerina sp.	2			0												
Angulogerina hughesi (Galloway and Wissler)	3					0										
Bolivina cf. pseudoplicata Heron-Allen and Earland	3	0						0	0							
Discorbinella araucana (d'Orbigny)	3	30		0	3	6	0	0	9	8	10	3	0	0		
Elphidium bartletti Cushman	3						5				6	0	3	36		
Fissurina marginata (Montague)	3	0	7	0	0	6	3	0	0	12	6	5	0	4	0	4
Glabratella pulvinata (Brady)	3		0			16	7	4	3	6	7	3	4			
Islandiella norcrossi (Cushman)	3	0				21	11	6	4	3	5	0	8			
Oolina melo d'Orbigny	3		0			0		0		0		0				
Patellina corrugata Williamson	3			0			3							0		
Pseudoparrella takayanagii (Iwasa)	3	49	3			10	6	19	16	17	36	18	7	5	0	0
Bolivina decussata Brady	4				3	5	5		0	4	4	0		3	3	0
Lagena sulcata spicata Cushman and McCulloch	4				0		0					0				
Ammonia spp.		0														
Anomalinella spp.			4													
Astronomon spp.		0														
Bolivina spp.			7													
Brizalina spp.		0		5	6	3	0	0				3		0		
Buccella tanaii Uchio														7		
Buccella spp.						0			0	3	4			0	6	11
Cibicides cf. kamadai Asano														0		
Cibicides subdepressus (Asano)			0		0	4					0					
Cibicides spp.		0	0	0		3	3	0			0				0	0
Cornuspira involvens (Reuss)			4													
Cribrolinoides curta (Cushman)							0		0							
Discorbinella spp.		0	0													
Elphidium incertum (Wiliamson)																0
Elphidium orbiculare (Brady)																
Elphidium spp.		3		0		0		0	0		0		6	7	4	3
Epistominella spp.					0							0	0			
Eponides? spp.							0			0					0	
Fissurina annectens (Burrows and Holland)											4	3	0			
Fissurina obscurocostata Galloway and Wisser									0	0						
Fissurina orbignyana Seguenza											0	0				
Fissurina cf. rizzae Seguenza				0		0						0				
Fissurina cf. subquadrata Parr			0			0										
Fissurina spp.		0	0	0		0	0		0		0	0		0		
Gavelinopsis praegeri (Heron-Allen and Earland)			0					0	0	0						
Gavelinopsis sp.			8													
Glabratella mirabilis panamensis Seiglie and Bermúdez					3	5						4				
Glabratella patelliformis (Brady)			4	3	0			4			13					
Glabratella sp. A		0	3	0		0					0					
Glabratella sp. B					0	0							0			
Glabratella spp				0					0		0		0			
Globocassidulina spp.		4	14	11	5	13	5			3	0	4	0	3		
Gyroidina spp.													4			
Haynesina sp.										3		0	0			
Heronallena sp.								0								
Islandiella helenae Feyling-Hanssen and Buzas											3				0	0
Islandiella sp.				0												
Karreriella spp.												0				3
Lagena acuticosta (Reuss)											0	0				
Lagena sp.																0
Lenticulina nikobarensis (Schwager)												0				
Lenticulina sp.				0												
Melonis pacificum (Cushman)													0			
Miliolinella sp.			3	0												
Neoeponides procerus (Brady)		0												0	0	
Nonion spp.		0							0		0					
Oolina sp.											0					
Paracassidulina sulcata Belford			3													
Planoglabratella australensis (Hellom-Allen and Earland)								0			0	6				
Planolgabratella? sp. C													0			
Poroeponides cribrorepondus Asano				3												0
Pseudononion sp.						0										
Pseudoparrella spp.																4
Pseudopolymorphina sp.												0				
Quinqueloculina agglutinata Cushman								0	0			0				
Quinqueloculina costata d'Orbigny						0				0						
Quinqueloculina kuromatunaiensis Asano				0		3								0		
Quinqueloculina yezoensis Asano						6		3		0	4					
Quinqueloculina spp			10	3	0	17	10	5	9		19	10			0	
Rosalina australis (Parr)		4										6				
Rosalina spp.		0	28	0			0	0		4	8	0				
Sigmoilina sp.			0													
Spirillina limbata Brady					0	0										
Spirillina sp.											0					
Spiroloculina hadai Thalmann										0		0				
Spiroloculina sp.					0											
Spiroplectammina sp. A			4	0												
Spiroprectammina sp.					0											
Spiroplectinella wrightii (Silvestri)			3													
Textularia spp.			0	4												
Triloculina sp. A												0				
Valvulineria hamanakoensis (Ishiwada)													0			
Gen. et sp. indet.		2	6	8	4	13	3	6	13	4	9	11	7	8	10	3
Total Foram. No.		275	319	177	193	296	190	208	201	339	474	371	203	355	249	265
inner sublittolar zone	1	53.8	40.1	40.1	43.5	21.6	32.1	51.4	49.8	55.8	55.5	58.0	59.1	73.2	78.3	87.5
middle sublittoral zone	2	2.2	16.0	22.6	29.5	27.0	24.2	12.0	10.4	17.7	7.0	12.4	4.4	2.0	4.4	0.0
outer sublittoral zone	3	28.7	3.1	0.0	1.6	19.9	18.4	13.9	15.9	13.6	14.8	7.8	10.8	12.7	0.0	1.5
upper bathyal zone	4	0.0	0.0	0.0	1.6	1.7	2.6	0.0	0.0	1.2	0.8	0.0	0.0	0.8	1.2	0.0

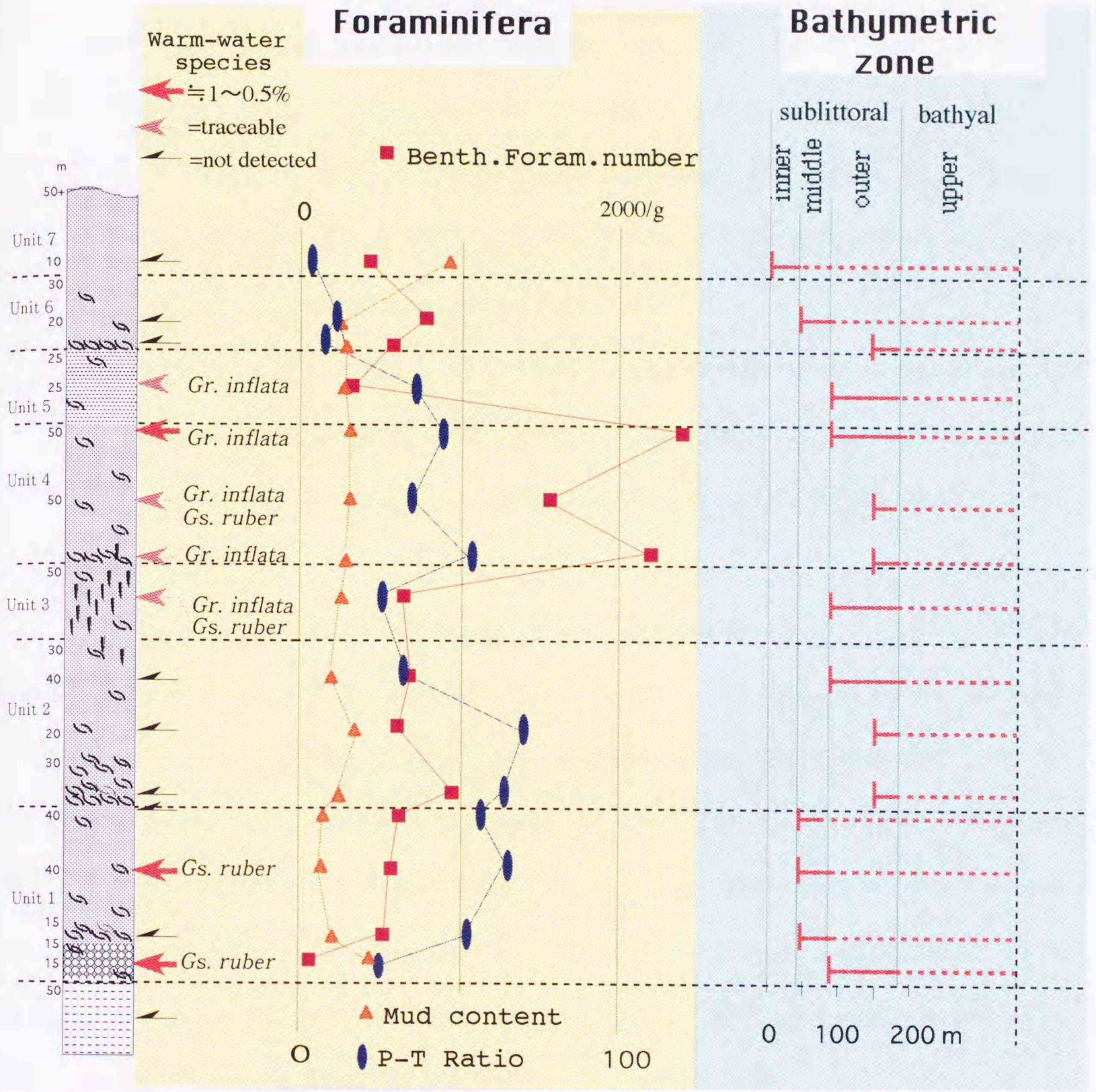
recent living assemblages and/or recent dead ones distributions. Individuals with two or less occurrences were regarded as statistically meaningless or reworked species, and were neglected.

4) The author decided paleodepth as the shallow bathymetric zone based on composition of SBZ group.

5) In the case that there were many zones in one sample, the author used "common" (4.5%-13.5%) or "abundant" (13.5%-) occurrence. Even if minor present (less than 4.5%), however, the author considered that such a upper bathyal species as *Bolivina decussata* is important.

The estimated depth is shown in Fig. 29. The siltstone bed under the Unit 1 may have been deposited in non-marine or brackish environments, such as land, bay, or lagoon, because the bed yields many fossil plant fragments without any molluscs and foraminifera. The Unit 7 also yields many plant fragments with few molluscs and foraminifera.

Shell concentration of the Unit 1 indicates the outer sublittoral zone, and those of the Units 2 and 4 the upper bathyal zone (190-600m), therefore, the data from foraminifera are contradictive on the depth to those from molluscs, the depth of the latter showing intertidal to netric (0-50m). The depth analysis by foraminifera show rapid deepings in the interval between the Units 1 to 2, and 3 to 4. These facts show that the time-averaging, fossil assemblages that accumulate from the [local] live community during the time required to deposit the containing sediment (Walker and Bambach, 1971; in Kidwell and Bosence), may have occurred in the bed, that is, molluscs were deposited in shallower depth before depositions of foraminifera in deeper depth.



Bathymetric zonation

R-mode cluster analysis

Recent foraminiferal distributions (off Noshiro to Ishikari Bay)

Chiji & Konda (1970), Ikeya (1970), Matoba (1976), Matoba & Honma (1986), Akimoto & Hasegawa (1989), Hasegawa (1993), Kogame (1995MS), Hasegawa & Kogame (1995), Hasegawa (1996), Takata & Hasegawa (1996), Hasegawa et al. (1997)

Shallow bathymetric zonation

zone	deeper than..
inner sublittoral	45 m
middle sublittoral	45-90 m
outer sublittoral	90-190 m
upper bathyal	190-600 m

Fig. 29 Bathymetric zonation of the Soebetsu section

iii) ***Paleotemperature Estimation by Benthic Foraminifera***; The author tried to estimated paleotemperature of paleo sea bottom by benthic foraminifera assemblages. The methods are as follows;

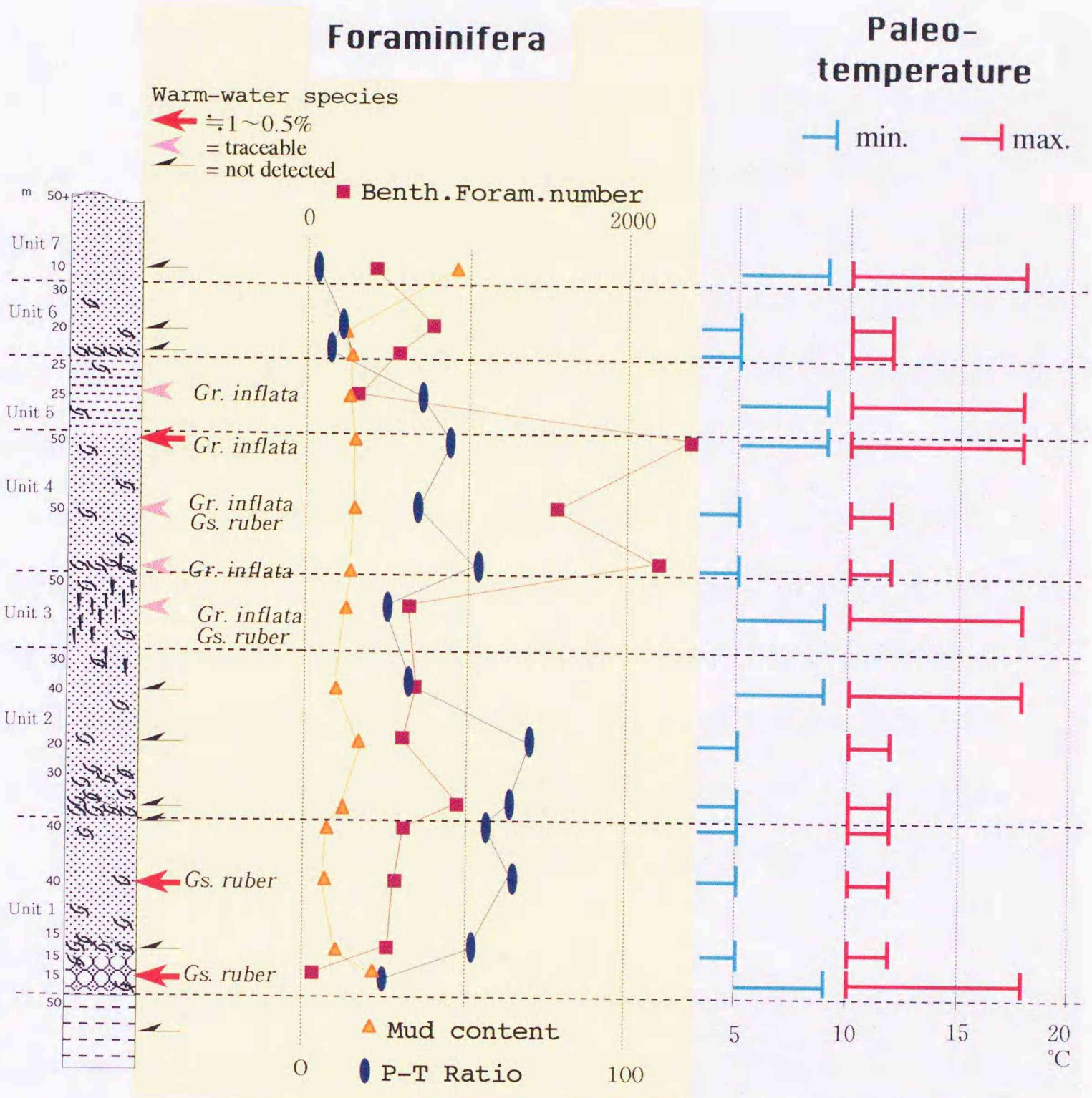
1) A range of paleotemperature for the species-group of each clusters is assumed from the thermal ranges of recent foraminifera along the Japanese Islands (Hasegawa, 1993).
2) Compiling the ranges of clusters, a possible range is estimated for each sample (Fig. 30). These water temperatures are estimated based on foraminiferal assemblages in 100m depth of the recent Japan Sea.

The maximum temperature varies between 18 and 10°C, and the minimum less than 9°C through the section. At the horizons of shell concentration except the Unit 6, the temperatures are relatively low, but relatively high in the shallower bathymetric intervals. Such a reciprocal relation with depth estimation can be explained by thin layers of warm surface waters around Hokkaido. Even if the paleodepth was less than 200m at the highest sea-level period, bottom temperature is relatively cold because the warm waters were restricted in the very surface of the sea.

These temperatures indicate that the paleoenvironments bear a close resemble to present off Akita or Nishi-Tsugaru (Fig. 31).

iv) ***Oxygen Isotopic Ratio Both of Benthic and Planktonic Foraminifera***; When creatures made their hard tissue, ^{18}O-^{16}O ratio ($\delta^{18}O$ ratio) of surrounding sea water was inprinted in carbonate biominerals, for example, in calcite and aragonite.

The $\delta^{18}O$ ratios of sea water are fluctuated by salinity and temperature changes. The ratio, further, fluctuated by vital effects among species. The $\delta^{18}O$



Paleotemperature estimation

R-mode cluster analysis

Recent foraminiferal distributions (Hasegawa, 1993)

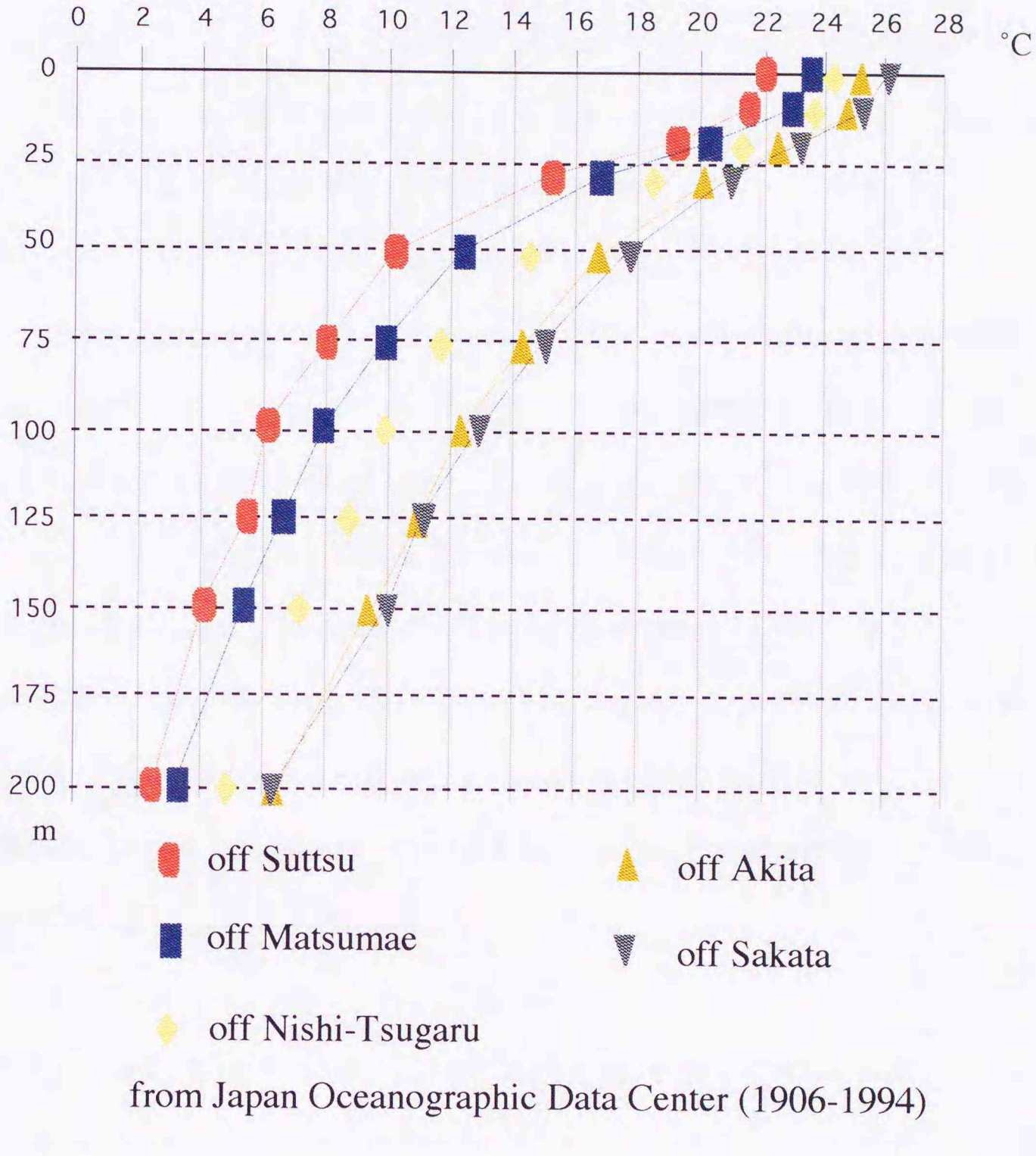
species group
I south of Tsugaru Peninsula, max. temp.>17°C (100m)
II south of Wakkanai area, max. temp.>10°C (100m)
III around Japan except off Shikoku, max. temp.<20°C (100m)
IV north of Okushiri & Okhotsuk Sea, max. temp.>18°C, min. >9°C(100m)
V north of Ishikariwan Bay & Okhotsuk Sea, max. temp.>12°C, min. >5°C(100m)

Fig. 30 Paleotemperature estimation by benthic foraminifera

ratio of fossil foraminifera of glacial ages shows high values than that of interglacial ages, because continental glaciers kept higher contents of ^{16}O than those of ^{18}O. $\delta^{18}O$ data from ocean floors may probably be able to reflect the global climatic changes because of significant distances of ocean floors from land, and they can produce standardized $\delta^{18}O$ curves. If inflows of fresh water of rivers which exhibit low salinities and low $\delta^{18}O$ ratios can be omitted, $\delta^{18}O$ ratio indicates paleotemperature changes. The amplitudes of the $\delta^{18}O$ curves has usually accepted as "$\delta^{18}O$ stages", which indicate warm-cool cycles. In analyses of many core samples from ocean floor, many investigators have correlated these $\delta^{18}O$ stages with magnetostratigraphy, K-Ar ,and/or Ar-Ar datings. These amplitudes are inferred that produced by calculatable astronomical forces so called the "Milankovitch Cycle", and, therefore, $\delta^{18}O$ stages has been calibrated by using astronomical calculations, and become one of standards of time estimation (e.g. Shackleton et al., 1990; Berggren et al., 1995).

$\delta^{18}O$ ratio of foraminifera indicates sea surface conditions from planktonic species, and sea bottom conditions from benthic foraminifera. The author measured $\delta^{18}O$ ratios of both planktonic and benthic foraminifera for estimating surface and bottom conditions.

The $\delta^{18}O$ curves both of benthic and planktonic forms in the Soebetsu section are shown in Fig. 32. The $\delta^{18}O$ ratio of *Elphidium subarcticum* (benthos) varies between 1.8 and 2.2‰, and represent three cycles with small peaks at the upper part of Unit 1 and base of Unit 2, base of Unit 4, and 6 (Fig. 32). The $\delta^{18}O$ ratio of *Neogloboquadrina incompta* (plankton) varies between 0.9 and -0.3‰, and also represent two cycles with small peaks at the Unit 2, Unit 4 to 5 (Fig. 32).



from Japan Oceanographic Data Center (1906-1994)

Fig. 31 Recent water temperature in August of the northern Japan Sea

The upper part of the Unit 1 is assigned to 0.95 to 0.85Ma based on calcareous nannoplankton biostratigraphy, as mentioned above, and planktonic foraminiferal assemblages indicate that this horizon was under relatively warm conditions, moreover, the section includes three weak peaks so that this section can be brought into the $\delta^{18}O$ Stage 21 characterized by containing three peaks (e.g. ODP Site 677 at 1°12'N, 83°44'W; Shackleton et al., 1990; Fig. 33).

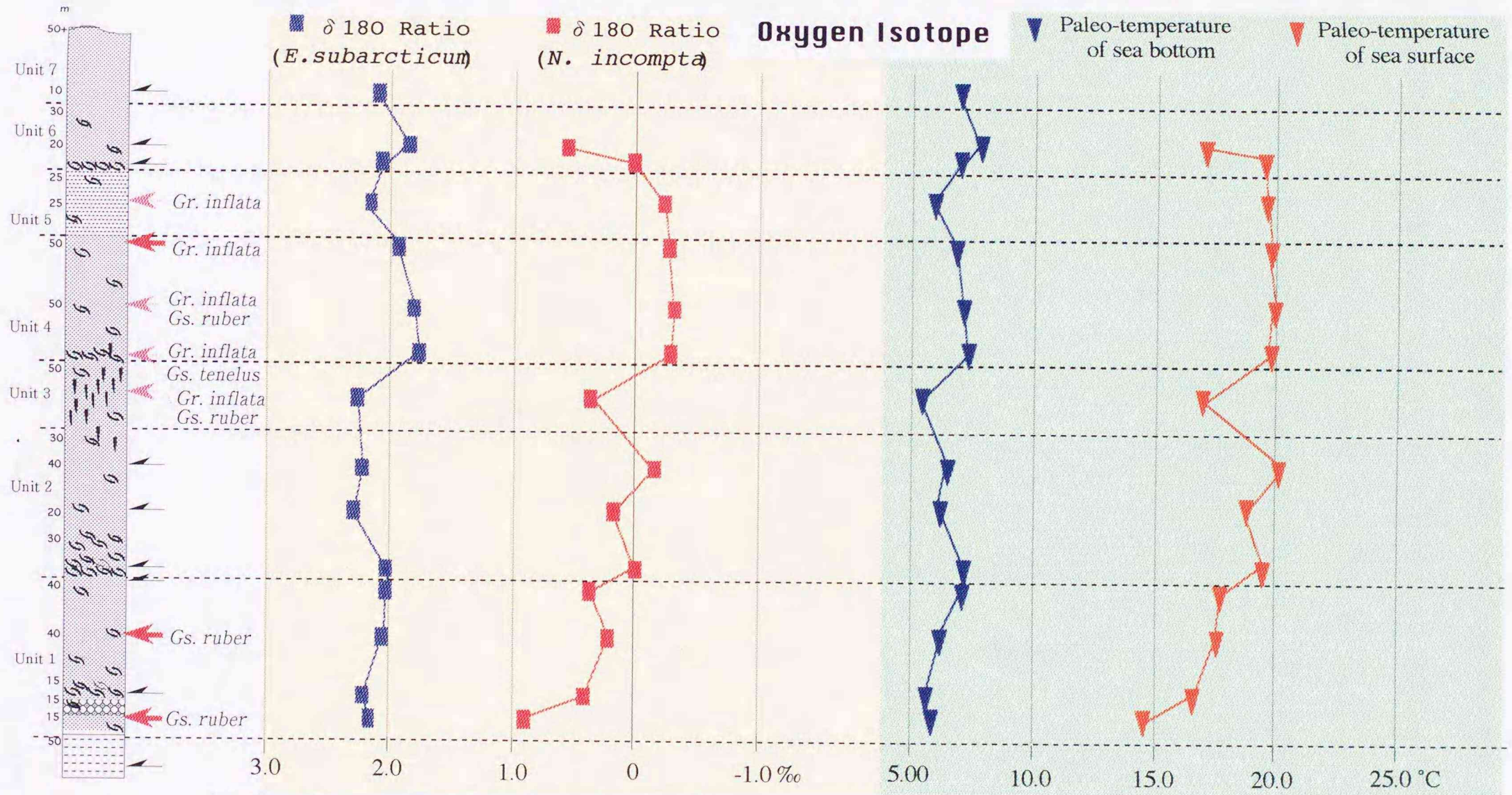
The author calculates paleotemperatures of surface and bottom waters using a equation by Shackleton (1974) as follows;

$$T\ (^{\circ}C) = 16.9 - 4.38(\delta_s - \delta_{sw}) + 0.10(\delta_s - \delta_{sw})^2$$

where, this equation expresses isotopic equilibrium between sea water (sw) and calcite of samples (s). The δ_{sw} is estimated by calculating of ratio between the recent $\delta^{18}O$ amplitude (the average from Last Glacial Maximum (LGM) to Recent) and the Stage 21 based on the $\delta^{18}O$ curve by Shackleton et al. (1990). Because the Stage 21 contains precession peaks, the author calculated δ_{sw}; one is a warm-term (Units 1 except uppermost horizon and 3 to 5; 0.31‰), the other is a weak warm-term (Units 1 upper most to 2, and 6 to 7; 0.58‰). These terms are decided based on occurrences of warm-water species of planktonic foraminifera.

The benthic foraminifera *Elphidium* spp. show a less $\delta^{18}O$ (about -0.9‰) by vital effect than *Uvigerina* spp. (Oba, pers. com), the latter foraminifera being used for measurements of $\delta^{18}O$ in ocean floor, so that the author odds 0.9‰ with the data of benthic foraminifera for calculations.

These data indicate that the units in the Soebetsu Sandstone Member were deposited in interglacial times in $\delta^{18}O$ Stage 21. The author can estimate the water depth at deposition time by comparison between these paleotemperatures and present vertical distribution of water temperatures of



$$T = 16.9 - 4.38(\ \delta s - \delta sw) + 0.10(\ \delta s - \delta sw)^2 \quad \textbf{(Shackleton, 1974)}$$

Fig. 32 $\delta^{18}O$ ratio and water temperature estimation of the Soebetsu section

off Suttu and Matsumae in the northern Japan Sea at August (Fig. 31), because planktonic foraminiferal $\delta^{18}O$ indicates that surface temperatures were about 15 to 20°C. If *N. incompta*, in which no data of its living depth were reported, has been living in 25m±, and on the assumption that the foraminifera make their crusts in summer, the depth in this section may have been changed from about 75-100 to 125-150m (Fig.31). But if *N. incompta* has been living in 50m±, we should used water distribution data off Sakata and Akita. In that case this section may have been changed its depth about 175 to 200m+ (Fig. 31).

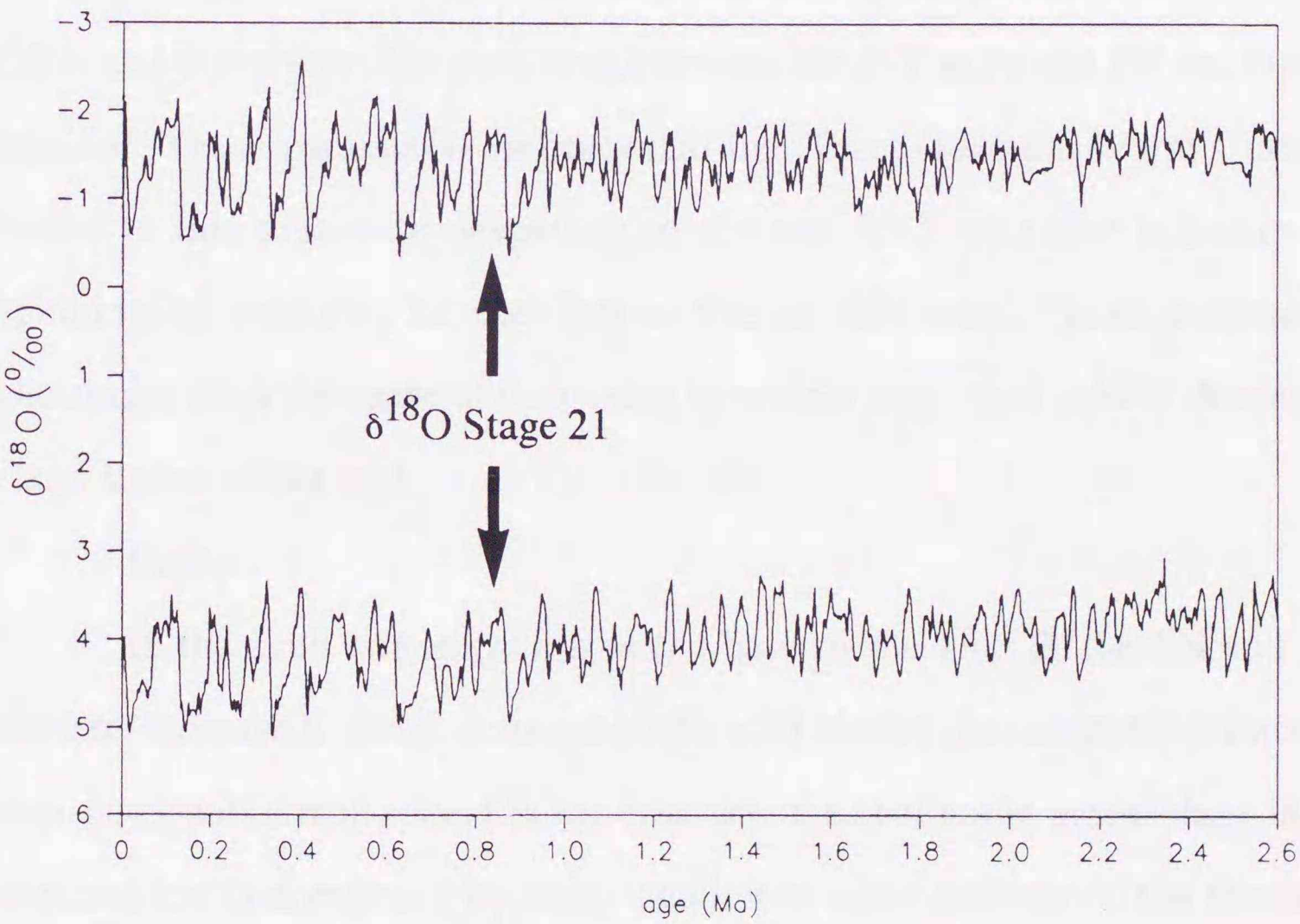


Fig. 33 Planktonic and benthic oxygen isotopic data for ODP677 for past 2.6Ma (modified from Shackleton et al., 1990)

d) **Paleobathymetric and Paleotemperature Changes Related to Glacial Eustatic Sea-Level Changes**; The author describes geological history of the Soebetsu section by using the parameters mentioned above.

"Unit 0"

The "Unit 0" is a siltstone bed under the Unit 1. It yields only plant fragments without mollusca nor foraminifera, suggesting non-marine environment.

Unit 1

This shell concentration of the basal part is regarded as accompanied by many pebbles, and the lag-concentration of Kidwell (1991). It means that a transgression happened at the beginning of the deposition of this unit. *Globigerinoides ruber*, a subtropical planktonic species, occurs in this unit. Within and just above this shell concentration the P-T ratio and FN are rapidly increased. These parameters indicate that the "Paleo-Tsusima Warm Current" reached to this area with deepening of the sea. $\delta^{18}O$ ratio also indicates the beginning of warming of the Setana Sea in this area. These parameters indicating a weak decrease of deepening in middle stage, and rapidly deepening in later stages of this unit.

Unit 2

In the shell concentration at the base of the Unit 2, the FN and P-T ratio are increased. Benthic assemblage also shows the deepening into the lower outer sublittoral zone. On the contrary, the molluscan assemblage in the concentration is composed by many shallower water-indicators. On the other hand, there are dominant yieldings of many fragments of epifaunal and neritic molluscs in the sporadically shell-bearing bed. In this part P-T ratio is still high, and the $\delta^{18}O$ ratio and FN are show the same patterns as those in the

concentration part. These facts indicate that the shell concentration was not derived products, but formed *in situ*. Low ratios of benthic foraminifera also support *in site* deposition of the shell concentration. The author infers that the occurrences of the molluscs in shallower habitats and the foraminifera in deeper habitats indicate this shell concentration the "hiatal or condensed concentration" type of Kidwell (1991), and there are condensed deposits at the shell concentration and occurred the time-averaging in that horizon. These units may have the following depositional history;

1) Condensation and *in situ* shell concentration in middle sublittoral, about 40 to 90m in depth (upper part of the Unit 1).
2) Deeping and formation of bathyal foraminiferal assemblages within the shell concentration in the waters of lower outer sublittoral, about 150-190m (the Unit 2 base).
3) Keeping the lower outer sublittoral zone and rework of fragments of the shallow epifaunal molluscs.
4) Gradual shallowing toward the Unit 3.

Unit 3 to Unit 5

These horizons yield few planktonic foraminifera which lived in water of 100-500m deep. The FN and P-T ratio show high in value. On the other hand, these beds yield some molluscs and foraminifera of warm-water species, and the $\delta^{18}O$ ratio of both benthic and planktonic foraminifera is high in value. These facts indicate that these horizons were under warmer-water conditions with high sea level. From the Unit 3 to the shell concentration at the base of the Unit 4, the FN, P-T ratio, and $\delta^{18}O$ ratio increase, and the bathymetric zone is deepening. Such tendencies are the same as those of the Unit 2. Hence the condensation and time-averaging may occur again.

Depositional history of these units are as follows;

1) Continuously warming and deepening by inflow of the "paleo-Tsushima" current during the Unit 3, and rapidly deepening from the Units 3 to the base of the Unit 4.
2) Condensation and *in situ* shell concentration in upper outer sublittoral zone, about 90m in depth.
3) Deepening and Formation of bathyal foraminiferal assemblages within the shell concentration in the waters lower outer sublittoral zone about 150-190m in depth.
3) Keeping the upper upper bathyal zone, and rework of fragments of the shallow epifaunal molluscs.
4) Gradually shallowing toward the Unit 6.

Units 6 to 7

The shell concentration at the base of the Unit 6 shows clearly depositional structure of a single shell layer. The FN, P-T ratio, and $\delta^{18}O$ ratio show low in value, and benthic foraminiferal assemblage shows middle to inner sublittoral zone. These facts indicate that the shell concentration is "event-concentration" type of Kidwell (1991). It was, therefore, still deeper environment at the base of the Unit 6, and the deposits derived from shallower area were eventually deposited at this horizon. The Unit 7 yields some fossil plant fragments, and few molluscs and foraminifera so that these units represent a process of regression.

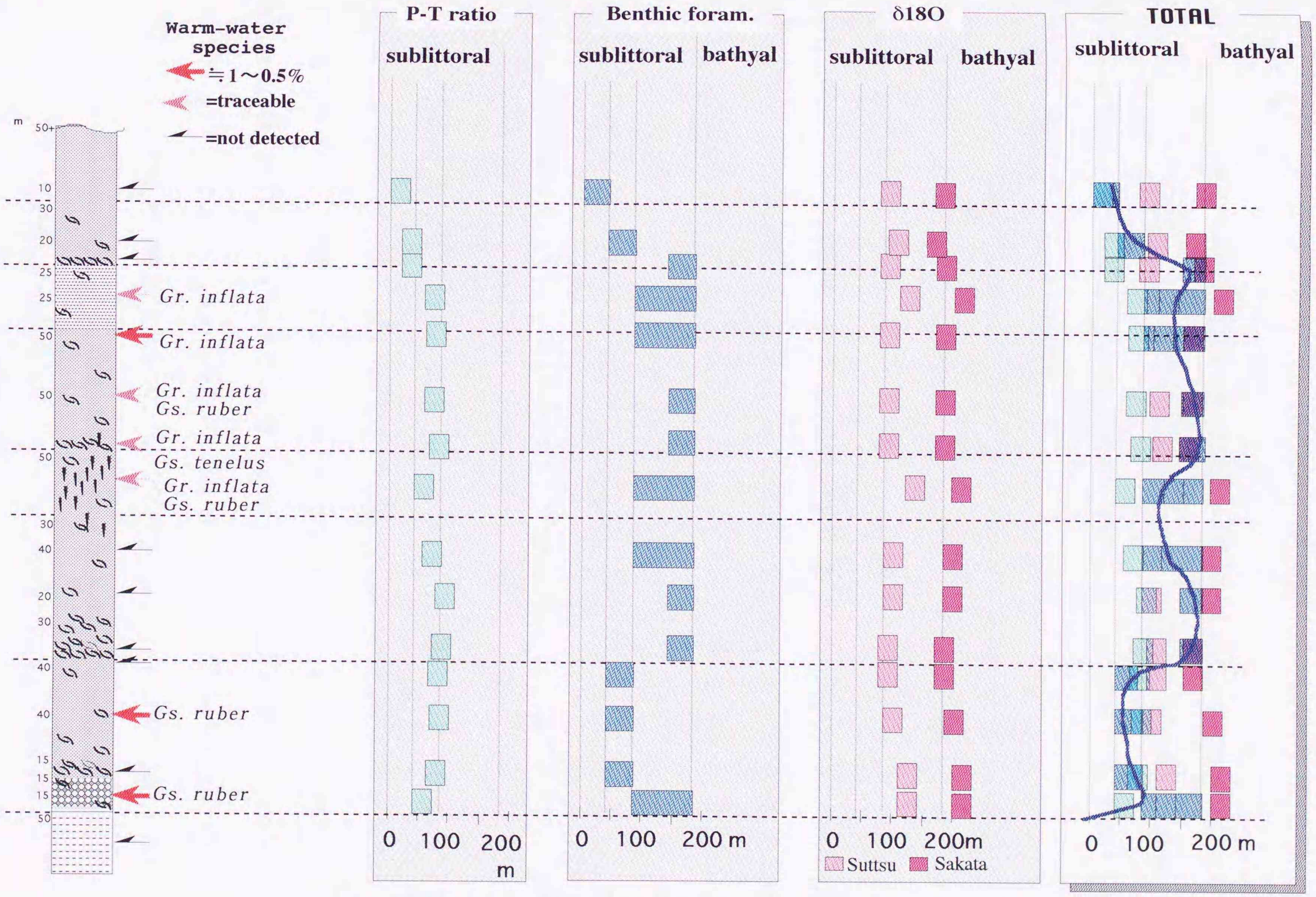


Fig. 34 Paleo-depth estimations based on some parameters

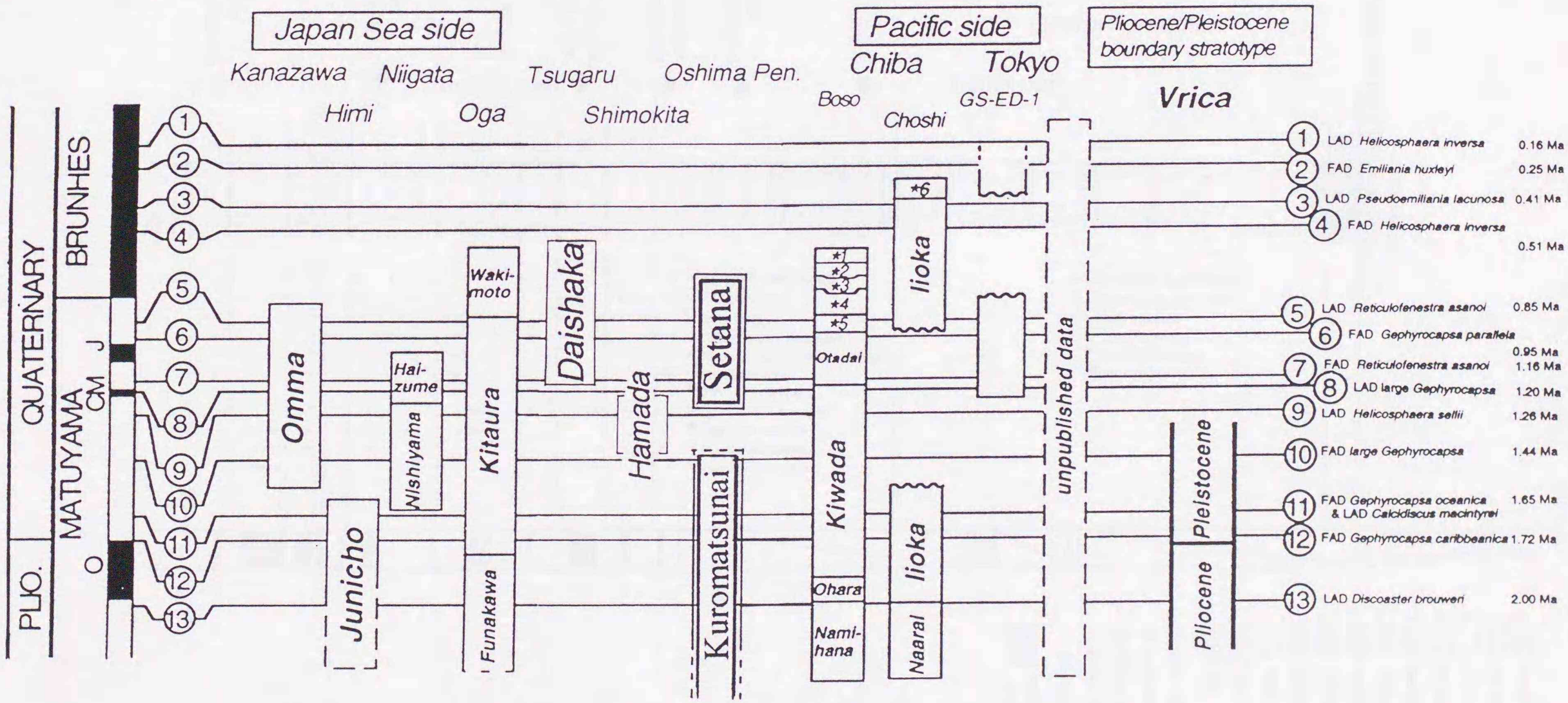
(4) Correlation with Other Deposits of Japan

The Setana Formation is correlated with other Pleistocene deposits of Japan as in Fig. 35.

The author points out here that the facies of the Soebetsu section are deposited by a transgression in the glacial eustatic sea-level changes because the depth-changes are usually synchronized with water temperatures. There were three warmer peaks in the sequence.

A similar glacial eustatic movement has been reported only in the Omma Formation at Kanazawa, central Japan (Kitamura et al., 1994; Kitamura, 1996). Kitamura et al. (1994) represent 11 warm-cold cycles with depth fluctuation based on molluscan assemblages of middle part of the Omma Formation. The depth fluctuations estimated are about 50m±. Estimations of the depth fluctuation of the Soebetsu section are also 50m± based on molluscs, but estimations based on foraminiferal assemblages are 100m±. Such a differences is caused by the condensations, time-averagings, and/or reworkings. There is a possibility of these phenomena in the Omma Formation.

Kitamura et al. (1994) correlated the middle part of the Omma Formation with oxygen isotope record of North Atlantic DSDP Site 607 (Ruddiman et al., 1989) by using paleomagnetic data, calcareous nannofossil biohorizons, paleodepth curve, and water regime inferred from molluscan assemblages. The author correlates the lower member of the Setana Formation with the Cycle 6 of middle part of the Omma Formation, and upper member of the Setana Formation with the upper part I of the Omma Formation, though this part of the Omma Formation have not been reported the relation with glacial eustatic sea-level changes (Fig. 36).



*1. Kasamori F., *2. Chonam F., *3. Kakinokidai F., *4. Kokumoto F., *5. Umegase F., *6. Toyosato F.

Fig. 35 Correlations of Plio-Pleistocene of Japan
by using calcareous nannofossil and foraminifera biohorizones
(modified from Takayama st al., 1995, Sugawara et al., 1997, and Nemoto, 1997)

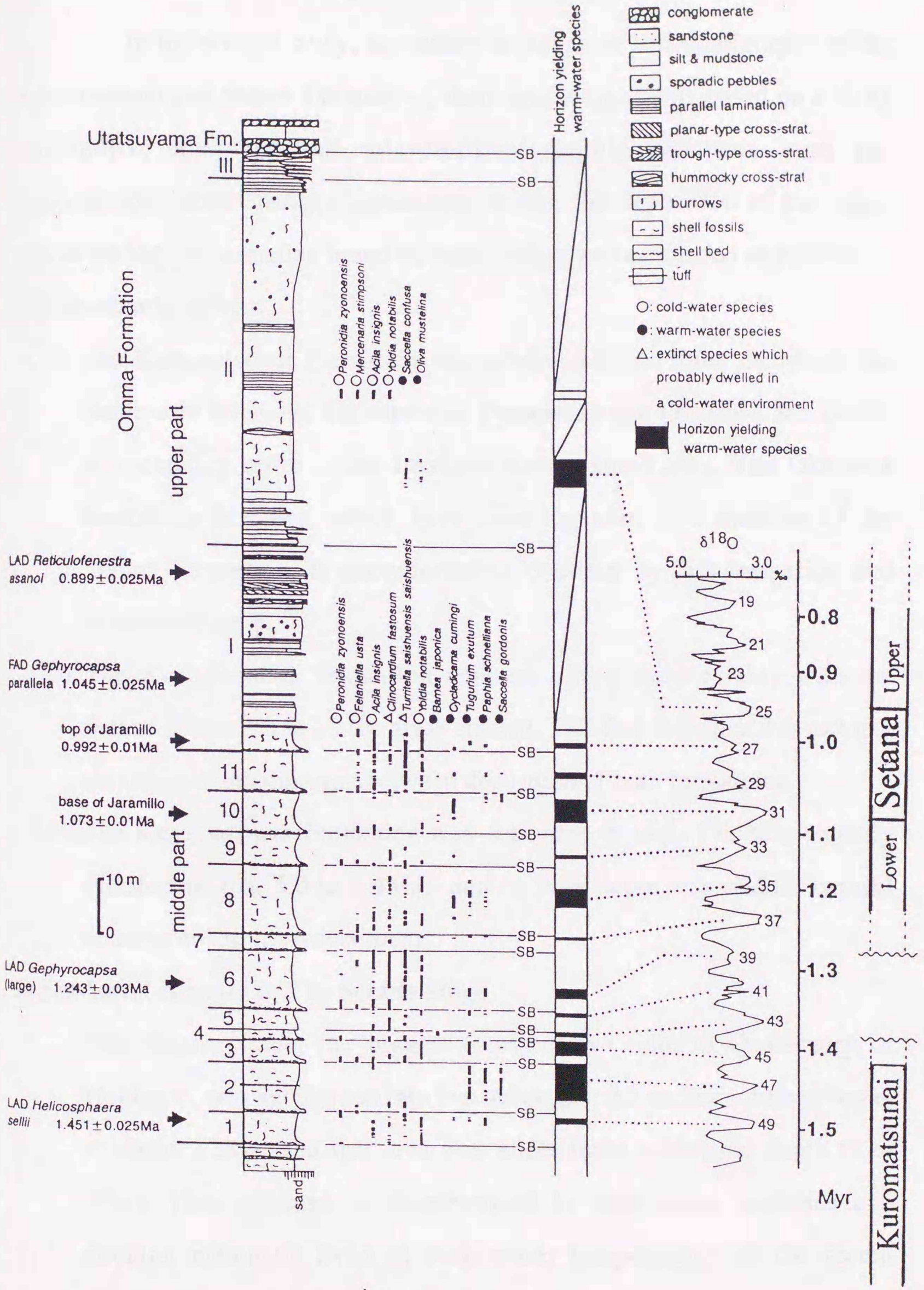


Fig. 36 Correlations of this study with the Omma Formation
(modified from Kitamura, 1996)

V. Conclusions

In the present study, the author investigated lithostratigraphy of the Kuromatsunai and Setana Formations, their ages assignments based on a K-Ar radiometric analysis and microbiostratigraphic analyses, and the paleoenvironmental changes particularly during the deposition of the upper part of the Setana Formation based on foraminifera, and concluded as follows;

1. Lithostratigraphy

1) The Kuromatsunai Formation was subdivided into three members, the Sumiyoshi Siltstone, Sakkurubetsu Pyroclastic and Okusawa Sandstone, in ascending order in the Imakane-Kamiyakumo area. The Okusawa Sandstone Member, which have been regarded as a member of the Setana Formation, is unconformably overlain by this formation and separated from it.

2) The Kuromatsunai Formation contacts clinounconformably with the Setana Formation in all the areas studied. This fact indicates that tectonic movements and time-gap between deposition of both formations.

3) The Kuromatsunai Formation was deposited in early Pliocene to early Pleistocene (ca. 5.0 to 1.4Ma), and its paleodepth was middle bathyal zone (over 700m) in maximum.

2. Sea-Level changes in The Setana Stage

1) The Setana Stage, the biggest transgressive time in Quaternary of Hokkaido, was subdivided into two substages; the earlier substage began at about 1.2Ma, and this area was under inner sublittoral depth (0 to 45m). This substage is characterized by cold-water molluscs and sirenian mammals lived in such water temperatures as the recent Okhotsk and Bering Seas.

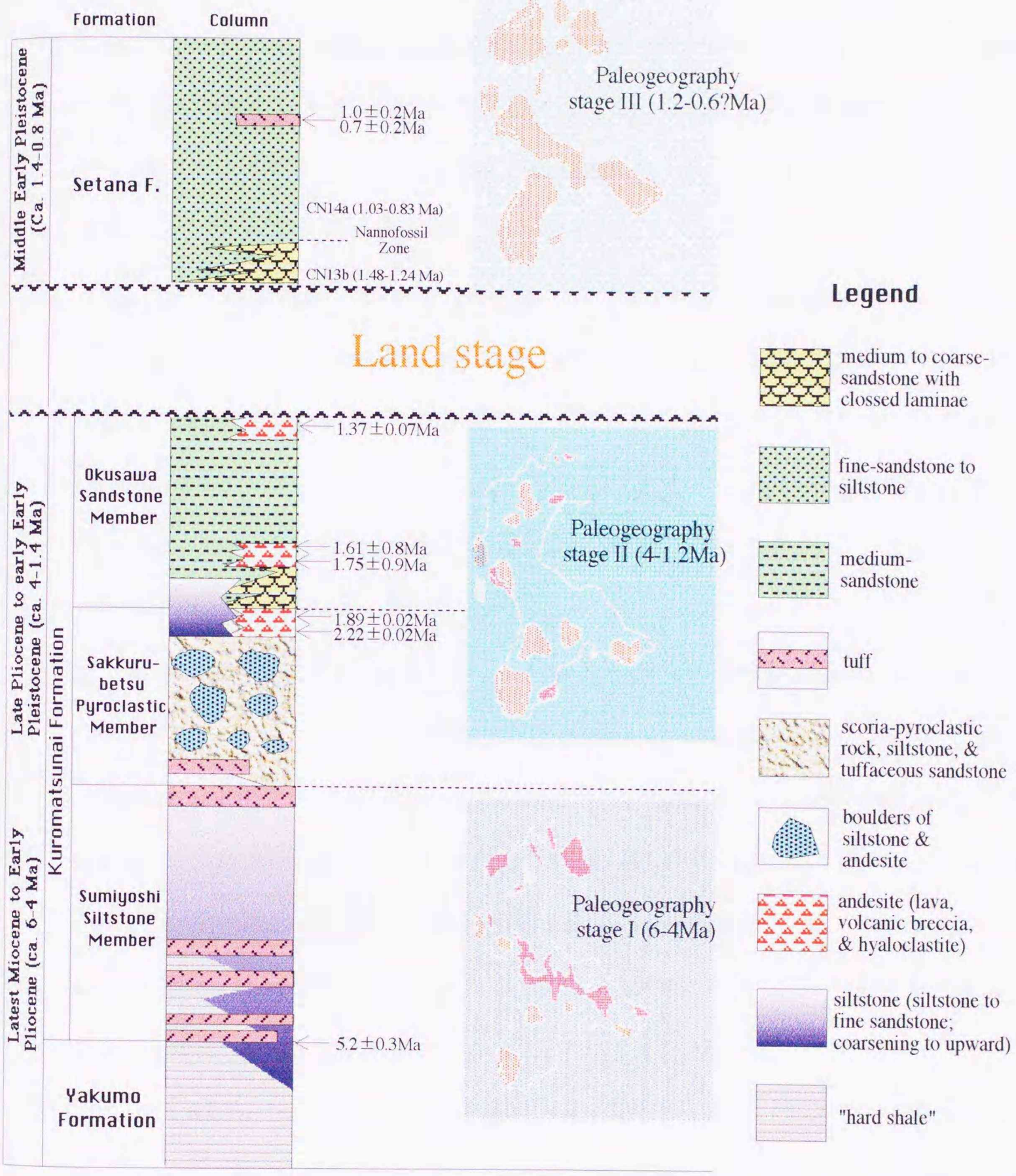


Fig. 37 Paleoenvironmental changes of southwestern Hokkaido

2) The later substage began at about 1.0Ma, and the sea areas were expanded and deepened rapidly. Paleodepth sometimes attained to over 150m. This sea was then shallowed and dried up about 0.6 to 0.4Ma.

3) A detailed faunal analysis was performed on foraminifera and molluscs from the sequence of the upper part of the Setana Formation deposited in 0.95 to 0.85Ma. The sequence consisting of sandstone and four shell concentrations are divided into seven units.

3) The paleodepths curves based on benthic foraminifera indicate transgressive-regressive cycles between 50 and 100m or more influenced by glacial eustatic sea-level changes. The similarity of paleodepths curves and calcareous nannofossil biostratigraphy suggest that the age of this sequence is assigned to the Oxygen Isotopic Stage 21.

3. Environmental Analyzing Method

1) In the second substage of the Setana Stage the author distinguishes the three types of shell concentration, event-concentration, condensed-concentration, and lag-concentration. The author also showed that there are two condensations related to rapid deepening with transgressions. These analytical methods of foraminifera combined with molluscs have capabilities to decide the types of shell concentrations in other areas with successions of cycles like those mentioned above.

2) The estimated paleodepths on molluscs are usually shallower than those on benthic foraminifera. A detailed stratigraphic study indicates that such a discrepancy is brought from the effect of time-averagings during rapid deepenings of the sea, and a higher resolution by foraminiferal analyses.

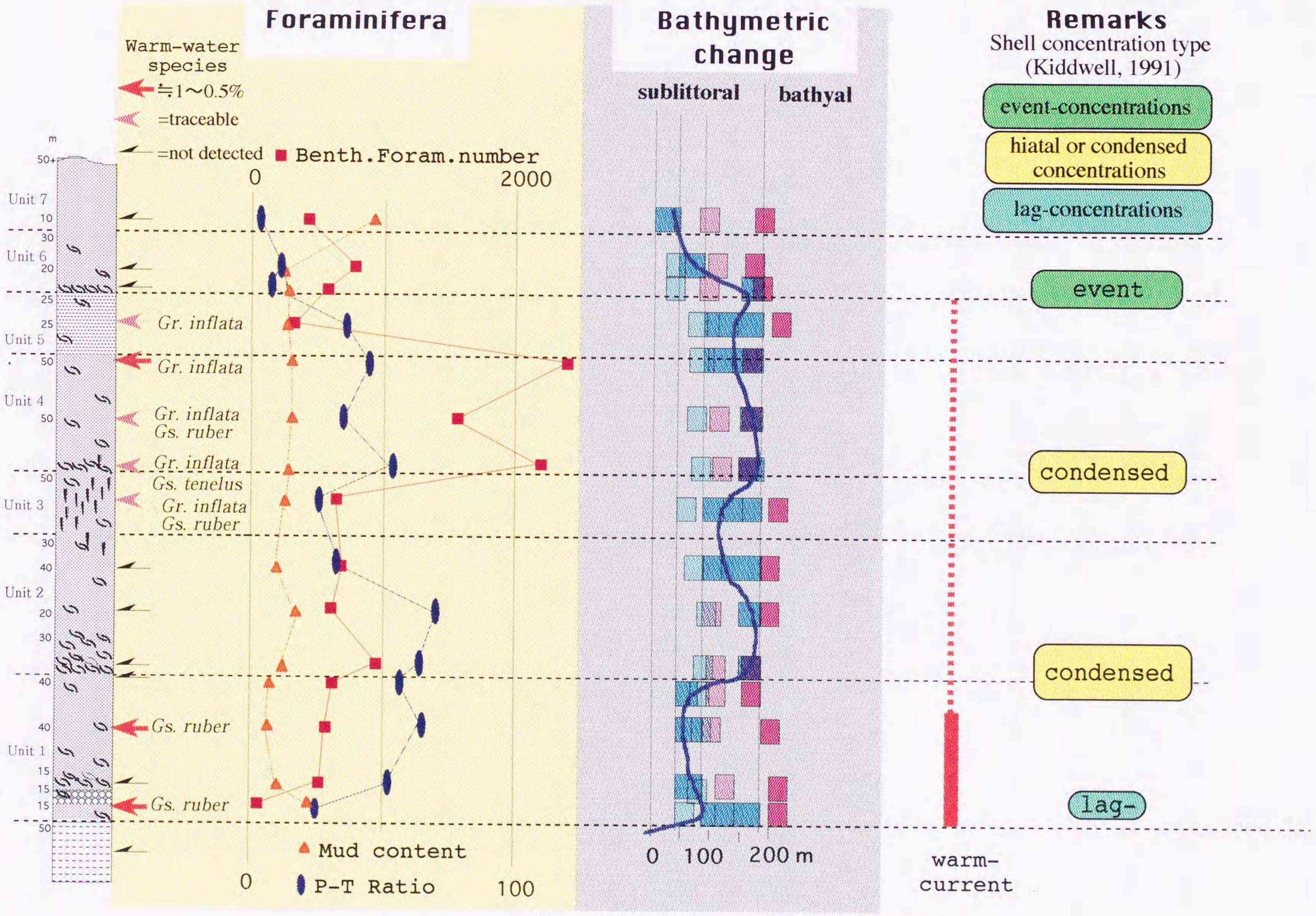


Fig. 38 Occurrences of condensations

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Faunal Reference List

Foraminiferal species from the Kuromatsunai and Setana Formations are alphabetically listed below, under the categories of benthos and planktons. The selected species are illustrated with the photographs taken with a scanning electron microscope in Plates 3 to 14. The original references are given for species. Additional references are selected from those with helpful remarks and illustrations about the species from the areas studied in this thesis. All specimens are catalogued and deposited in the Imakane board of Education.

Benthic Foraminifera

Alabamina japonica (Asano)

Pseudoparrella japonica Asano, 1949, Jour. Paleont., 23 (4), p430, fig. 2, Nos. 2-4.

Ammonia beccarii(Linné)

Nautilus beccarii Linne, 1758, Syst. Nat., se. 10, p. 710.

Ammonia beccarii (Linne), Fizzell and Keen, 1949, Jour. Pal., v. 23, no. 1, p. 106.

Ammonia ketienziensis (Ishizaki)

Steblus ketienziensis Ishizaki, 1948, Acta Geol. Taiwan, 2 (1), 59, pl. 1, figs. 2a-c.

Ammonia ketienjiensis (Ishizaki), Huang, 1964, Micropaleont. v. 10, no. 1, p. 53, pl. 1, figs. 13a-c.

Angulogerina hughesi (Galloway and Wissler)

Uvigerina hughesi Galloway and Wissler, 1927, Jour. Pal., v. 1, p.76, pl. 12, figs. 5a, b.

Angulogerina hughesi (Galloway and Wissler), Asano, 1950, Pacific Sci. v. 4, no. 2, p. 19, figs. 91-93.

Angulogerina kokozuraensis (Asano)

Asano, 1949, Jour. Pal., v. 23 no. 4, p. 428, text-fig. l, nos. 50-53;

1950, Illust. Cat. Japan. Tert. Small. Foram., pt. 2, p. 19, figs- 94-96.

Trifarina kokozuraensis (Asano), Matoba, 1967, Tohoku Univ., Sci. Rep., 2nd ser. (Geol.) , v. 38, no.2, p. 257, pl. 26, fig.3.

Anomalinella rostrata (Brady)

Truncatulina rostrata Brady, 1881, Quart. Jour. Micr. Sci., n. s., v. 21, p. 65.

Anomalinella rostrata Cushman, 1927, Cont. Cushman Labo. Foram. Res., v. 3, p. 93.

Anomalinoides globulosus (Chapman and Parr)

Anomalina grosserugosa Brady, 1884, Challenger Foram., p.675, pl. 94, figs. 4, 5.

Anomalina globulosa Chapman and Parr, 1937, Austr. Antarct. Exp. 1911-14, Sci. Rep., ser. C, 1 (2), p.117.

Astacolus hyalacrulus Loeblich and Tappan

Loeblich and Tappan, 1953, Smithsonian Misc. Coll. v. 121, no. 7, p. 52, pl. 9, figs. 1-4.

Astrononion aomoriense Asano

Asano, 1950, Illust. Cat. Japan. Tert. Small. Foram., pt.1, p. 5, figs. 25, 26.

Astrononion hamadaense Asano

Asano, 1950, Illust. Cat. Japan. Tert. Small. Foram., pt.1, p. 6, figs. 29-31.

Bolivina decussata Brady

Brady, 1881, Quart. Jour. Micr. Sci., n.s., v. 21, p. 28; 1884,Voy.

Challenger, Rep., Zool., v. 9, p. 423, pl. 53, figs. 12-13.

Bolivina pseudoplicata Heron-Allen and Earland

Bolivina pseudo-plicata (sic.) Heron-Allen and Earland, 1930, Jour. Roy. Micr. Soc., v. 50, p. 81, pl. 3, figs. 36-40.

Bolivina sp.A

This form is identified to Bolivina sp. A of Hasegawa (1979), and is similar to *Bolivina decussata* Brady in its outline, but differs from it in less developed, and rounded lobes on the wall surface.

Bolivinita quadrilatera (Schwager)

Textularia quadrilatera Schwager, 1866. Novara Exp. Geol. Theil., 2, p. 253, pl. 7, fig. 10.

Bolivina quadrilatera Asano, 1938, Jour. Geol. Soc. Japan, 45, p. 607, pl. 16, fig. 10.

Brizalina alata (Seguenza)

Vulvulina alata Seguenza, 1862, Atti Accad. Gioenia Sci. Nat., 2 (18), p. 115, pl. 2, figs. 5, 5a.

Bolivina alata Cushman, 1937, Cushman Lab. Foram., Res. Spac. Publ., 9, p. 106, pl.13, figs. 3-11.

Buccella frigida (Cushman)

Pulvinulina frigida Cushman, 1922, Canada Biol. Contr., no. 9 (1921), p. 12.

Buccella frigida (Cushman), Andersen, 1952, Washington Acad. Sci., Jour., v. 42, no. 5, p. 144, figs. 4-6.

Buccella kuromatsunaiensis Shirai, 1960, Jour. Fac. Sci. Hokkaido Univ., Ser. IV, vol. X, 537-543, pl. 2, figs. 2a-c.

Bulimina cf. *imamurai* Tai

cf. Tai, 1959, Hiroshima Univ., Jour. Sci. ser. C, v. 2, no. 4, p. 387, pl. 40, fig. 3.

Buccella makiyamai Chiji

Eponides schreibersii Morishima and Chiji (not of Reuss), 1952, Mem. Coll. Sci., Univ. Kyoto, ser. B, v. 20, no. 2, pl. 2 (XIII), figs. 6a-c.

Buccella makiyamae (sic.) Chiji, 1961, Prof. J. Makiyama, Mem. Vol., Kyoto, p. 234, text-figs. 2a-c, pl. l, figs. 13-14.

Buccella nipponica (Husezima and Maruhasi)

Discorbis nipponica Husezima and Maruhasi, 1944, Jour. Shigenkagaku Kenkyusho (Res. Inst. Nat. Resour., Japan), v. l, no. 3, p. 397, pl. 34. figs. 9a-c.

Buccella tanaii (Uchio)

Eponides tanaii Uchio, 1951, Jour. Geol. Soc. Japan, 57, p. 376, pl. 5, fig. 8.

Buccella tenerrima (Bandy)

Eponides frigidus (Cushman) , Cushman and Todd, 1947, (not *Pulvinulina frigida* Cushman, 1922), Cushman Lab. Foram. Res. Spec. Publ. v. 23, p. 71, pl. 8, fig. 7.

Buccella inusitata Andersen, 1952, Washington Acad. Sci., Jour., v. 42, no. 5, p. 148, figs. 10-11.

Bulimina gibba Fornasini

Fornasini, 1902, Roy. Acad. Sci. Inst. Bologna, Mem, Sci. Nat., ser. 5, v. 9, p.378, pl. 10, figs. 32, 34.

Buliminella elegantissima (d'Orbigny)

Bulimina elegantissima d'Orbigny, 1839, Voy. Amer. Mérid.,

Foraminiféres, v. 5, pt,. 5, p. p. 51, pl. 7, figs. 13, 14.

Buliminella elegantissima (d'Orbigny), Cushman, 1919, U.S. Nat. Mus., Proc., v. 56, p. 606.

Cancris auriculus (Fichtel and Moll)

Nautilus auriculus Fichtel and Moll, 1789, Testacea microscopica, p. 105, pl. 20, figs. a-f; 1803 var. α, p. 108, pl. 20, figs. a-c; var. β, p. 110, pl. 20, figs. d-f.

Cancris auricula (Fichtel and Moll) (sic.), Cushman, 1927, Bull. Scripps Inst. Oceanogr., Tech. Ser., v. 1, no. 10, p. 164, pl. 5. flag. 10.

Chrysalidinella dimorpha (Brady)

Chrysalidina dimorpha Brady, 1881, Quart. Jour. Micr. Sci., n. s., v. 21, p. 24; 1884, Voy. Challenger, Rep., Zool., v. 9, p. 388, pl. 46, figs. 20-21.

Chrysalidinella dimorpha (Brady), Schubert, 1908, Neues Jb. Min. Geol. Pa,1., Beil.-Bd. 25, p. 242.

Cibicides cf. *kamadai* Asano

cf. Asano, 1950, Illust. Cat. Japan. Tert. Small. Foram., pt. 13, p. 17, figs. 33-35.

Cibicides lobatulus (Walker and Jacob)

Nautilus lobatulus Walker and Jacob, 1789, Adams Essays, p. 642, pl. 14, fig. 36.

Cibicides lobatula (Walker and Jacob) (sic.), Cushman, 1931, U.S. Nat. Mus., Bull. 104, pt. 8, p. 118, pl. 21, figs. 3a-c.

Cibicides refulgens de Montfort

de Montfort, 1808, Conch. Syst., v. l, p. 122.

Truncatulina refulgens (Montfort), Brady, 1884, Voy. Challenger,

Rep., Zool., v. 9, p. 659, pl. 92, figs. 7-9.

Cibicides subdepressus (Asano)

Planulina subdepressa Asano (sic.), 1950, Illust. Cat. Japan. Tert. Small. Foram., pt. 13, p. 15, figs. 16-18.

Cibicides tani Iwasa and Kikuchi

Iwasa and Kikuchi, 1954, Paleont. Soc. Japan, Trans. Porc., N. S., no. 16, p. 193, text-figs. 8a-c.

Cibicidoides pachydermaus(Rzehak)

Truncatulina pachyderma Rzehak, 1886,

Cibicides pseudoungeriana Cushman, 1922, U.S. Geol. Surv. Prof. Pap., 129 E, p. 97, pl. 20, fig. 9.

Cibicidoides pachyderma (sic.) , van Morkhoven, 1986, Cenozoic Cosmopolitan Deep-Water Benthic Foraminifera, p. 68-71, pl. 22.

Cornuspira involvens (Reuss)

Operculina involvens Reuss, 1849,

Cornuspira involvens Barker, 1960, SEPM, Spec. Publ., 9, pl. 11, figs. 1-3.

Cribroelphidium ezoense (Asano)

Elphidium ezoense Asano, 1937, Jour. Geol. Soc. japan, 44, p. 787 textfigs 1-2.

Cribroelphidium ezoense (Asano), Asano, 1950, Illust. Cat. Japan. Tert. Small. Foram., pt. 1, p. 11, figs. 62-63.

Cribroelplhidium oregonensis (Cushman and Grant)

Elphidium oregoense Cushman and Grant (sic.), 1927, San Diego Soc. Nat. Hist., Trans., V, no.6, 79, viii, 3.

Cribroelphidium yabei (Asano)

Elphidium yabei Asano, 1938, Geol. Soc. Japan, Jour., v. 45, no. 538, p. 589, pl. 14, figs. 9-10.

Cribroelphidium yabei (Asano), Asano, 1950, Illust, Cat. Japan. Tert. Small. Foram., pt. l, p. 11, figs. 64-65.

Cribrolinoides curta (Cushman)

Quinqueloculina disparilis d'Orbigny var. *curta* Cushman, 1917, U.S. Nat. Mus. Bull. v. 71, no. 6, p.49, pl. 14, fig. 2.

Cribrolinoides curta (Cushman), Cusuman and Leroy, 1939, Contr. Cushman Lab. Foram. Res., v. 15, no. 1, p. 17, pl. 3, figs. 1-11; pl. 4, figs. 1-13.

Cycloforia contrta d'Orbigny

d'Orbigny, 1846, Foram. Foss. Viene, p. 298, pl. 20, figs. 4-6.

Cystammina pauciloculata (Brady)

Trochammina pauciloculata Brady, 1879, Quaterly Jour. Microscopical Science, new ser. 19, p. 58, pl. 5, figs. 13, 14.

Ammpchilostoma pauciloculata (Brady), Eimer and Fickert, 1899, Zeitschrift für Wissenschaftiliche Zoologie 65, p. 692.

Cystammina pauciloculata (Brady), Galloway, 1933, A Manual of Foraminifera. p. 186, pl. 16, fig. 12.

Discorbinella araucana (d'Orbigny)

Rosanila araucana d'Orbigny, 1839,

Discorbinella araucana Jones, 1994, Challenger Foraminifera, p. 93, pl. 86, figs. 10, 11.

Discorbinella bertheloti (d'Orbigny)

Rosalina bertheloti d'Orbigny, 1839, *in* Barker-Webb and Berthelot, Hist. nat. Canaries,v. 2; pt. 2, Zool., p. 135, pl.,1. figs.28-30

Discorbinella bertheloti (d'Orbigny), Loeblich and Tappan, 1964, Treatise on Inbertebrate Pal., Moore R.C., ed., pt. C, Protista, 2, v. 2, p. C575, figs. 453.

Asano, 1949, Jour. Pal., v. 23, no. 4, p.428, text-fig. 1, nos. 50-53; 1950, Illust. Cat. Japan. Tert. Small. Foram., pl.2, p. 19, figs. 94-96.

Dyocibicides perforata Cushman and Valentine

Cushman and Valentine, 1930, Contr. Stanford Geol. Dept., v. l, no. l, p. 31, pl. l0, figs. 3a-c.

Elphidiella arctica (Parker and Jones)

Polystomella arctica Parker and Jones, 1864, *in* Brady, Trans. Linn. Soc. London, Zool., v. 24, p. 471, pl. 48, fig. 18.

Elphidium arcticum (Parker and Jones), Cushman, 1930, U. S. Nat. Mus. Bull. 104, pt. 7, p. 27, pl. 11, figs. 1-6.

Elphidiella arctica (Parker and Jones), Cushman, 1939, U. S. Geol. Surv. Prof. Pap. 191, p. 65, pl. 18, figs. 11-14.

Elphidium aculeatum (d'Orbigny)

Polystomella aculeata d'Orbigny (sit.), 1846,

Elphidium aculeatum (d'Orbigny), Thalmann, 1932, Ecologae Geologicae Helvetiae, v. 25, 293-312.

Elphidium advena (Cushman)

Polystomella advena Cushman, 1922, Carnegie Inst. Washington, Publ. 311, p. 56, pl. 9, figsd. 11, 12.

Elphidium advenum (sit.), Cushman, 1930, U.S. Nat. Mus., Bull. 104, pt. 7, p. 25, pl. l0, figs. l, 2.

Elphidium articulatum (d'Orbigny)

Polystomella articulata d'Orbigny, 1839, Amer. Merid.,

Foraminiféres, v. 5, pt. 5, p. 30, pl. 3, figs. 9, l0.

Elphidium excavatum (Terquem), Cushman (not *Polystomella excavata* Terquem, 1875), 1930 (part), U.S. Nat. Mus., Bull. 104, pt. 7, p. 21, pl. 8, figs. 4-7 (not l-3).

Elphidium articulatum (d'Orbigny), Cushrnan, 1930, U.S. Nat. Mus., Bull. 104, pt. 7, p. 26, pl. l0, figs. 6-8.

Elphidium bartletti Cushman

Cushman, 1933, Smithsonian Misc. Coll., v. 89, no. 9., p. 4, pl. 1, figs. 9a, b; Loeblich and Tappan, 1953, Smithsonian Misc. Coll., v. 121, no. 7, p. 96, pl. 18, figs. l0-14.

Elphidium crispum (Linné)

Nautilus crispum Linné, 1758, Syst, Nat., ed. l0, p. 709.

Elphidium crispum (Linné), Cushman and Grant, 1927, San Diego Soc. Nat. Hist. Trans., v. 5, no. 6, p. 73, pl. 7, figs. 8a, b.

Elphidium excavatum (Terquem) forma clavata Cushman

Elphidium incertum (Wlliamson) var. clavatum Cushman, 1930, U. S. Nat. Mus., Bull. 104, pt. 7, p. 20, pl. 7, figs. l0a, b.

Elphidium decipiens (Costa), Hada, 1931, Tohoku Imp. Univ. ScI., Rep., 4th, ser. v. 6, no.3, p. 126, text-figs. 83a, b.

Elphidium hughesi foraminosun Cushman, Asano, 1950, Illust. Cat. Japan. Tert. Small. Fora,., pt. 1, p. 8, text-figs. 46, 47.

Elphidium clavatum Cushman, Loeblich and Tappan, 1953, Smith. Misc. Coll., v. 121, no. 7, p. 98, pl. 19, figs. 8-10. Takayanagi, 1955, Tohoku Univ., Inst., Geol., Pal., Contr., no. 45. p. 42, pl. 1, fig. 25.

Elphidium frigidum Cushman

Cushman, 1933, Smithsonian Misc. Coll., vol. 89, no. 9, p. 5, pl. 1,

fig. 8.

Elphidium incertum (Williamson)

Polystomella umbilicatula var. *incerta* Williamson, 1858, Recent Foraminifera of Great Britain, p. 44, pl. 3, fig. 82a.

Elphidium incertum (Williamson), Macfadyen, 1932, Geol. Mag., vol. 69, no. 821, pl. 35, figs. 6a, b.

Elphidium jenseni (Cushman)

Polystomella macella (Fichtel and Moll) var., Jensen, 1904, Linnean Soc. New South Wales Proc., v. 29, p. 817, pl. 23, fig. 4.

Polystomella jenseni Cushman, 1924, Carnegie Inst. Washington, Publ. 342, p. 49, pl.16, figs. 4 (?), 6.

Elphidium jenseni (Cushman), Cushman, 1933, U.S. Nat. Mus., Bull. 161, pt. 2, p. 48, pl. 11, figs. 6, 7.

Elphidium macellum (Fichtel and Moll)

Elphidium macellum var. tumidocamerale Bogdanowicz, 1932, Oil Geol., Inst., Leningrad, Trans., ser. A, fasc. 22, II, i, 2, text-figs. 9, 10.

Elphidium orbiculare (Brady)

Nonionina orbicularis Brady, 1881, Ann. Mag. Nat. Hist., ser. 5, vol. 8, p. 415, pl. 21, figs. 5a, b; 884, Voy. Challenger Rep., vol. 9 (Zool.), p. 727, pl. 109, figs. 20-21.

Nonion orbiculare (Brady), Cushman, 1930, U.S. Nat. Mus. Bull. 104, pt. 7, p. 12, pl. 5, figs. 1-3.

Elphidium orbiculare (Brady), Loeblich and Tappan, Smithsonian Misc. Coll. Vol. 121, no.7, p102, pl. 19, figs. 1-4.

Elphidium subarcticum Cushman

Cushman, 1944, Cushman Lab. Foram. Res., Spec,. Publ., no. 12, p.

27. pl. 3, figs. 34, 35.

Elphidium nakanokawaense Shirai, 1960, Jour. Fac. Sci. Hokkaido Univ., Ser. IV, vol. X, 537-543, pl. 1, figs. 4a-b, 5a-b.

Elphidium subgranulosum Asano

Asano, 1938, Jour. Geol. Soc. Japan, 45, p. 586, pl. 14, figs. 4a, b.

Elphidium translucens Natland

Natland, 1938, Scripps Inst. Oceanogr. Bull., Tech. ser., v. 4, p. 144, pl. 5, figs. 3, 4.

Epistominella pulchella Husezima and Maruhasi

Husezima and Maruhasi. 1944, Jour. Shigenkagaku Kenkyusho (Res. Inst. Nat. Resour., Japan), v. l, no. 3, p. 398, pl. 34, figs. l0a-c.

Evolvocassidulina cf. *kuwanoi* (Matoba)

Cassidulinoides kuwanoi Matoba, 1967, Tohoku Univ. Sci. Rep., 2nd ser. (Geol), v. 38, no. 2, p. 253, pl. 29, figs. 1a, b.

cf. *Evolvocassidulina kuwanoi* (Matoba) Nomura, 1983, Tohoku Univ. Sci. Rep., 2nd ser. (Geol), v. 54, no. 1, p. 1-93, pl. 4, figs. 1a-c, pl. 20, figs. 4-7.

Fissurina annectens (Burrows and Holland)

Lagena annectens Burrows and Holland, 1895, *in* Jones, Parker and Brady, 1985, Palaeontogr. Soc., London, Part II, p. 203, pt. vii, II.

Fissurina baccata (Hellon-Allen and Earland)

Lagena orbignyana var. *baccata* Hellon-Allen and Earland, 1922, Terra Nova Exped., Zool., VI, no. 2, p. 162, pt. vi, figs. 15, 16.

Fissurina lacunata (Burrows and Holland)

Lagena castrensis Brady (not of Schwager), 1884, Voy. Challenger, Rep. Zool., v. 9, p. 485, pl. 60, figs. 1, 2.

Lagena lacunata Burrows and Holland, 1895, *in* Jones, T.R., Palaeontogr. Soc. London, p. 205, pl. 7, fig. 12.

Fissuriua orbignyana lacunata (Burrows and Holland), Asano, 1938, Tohoku Imp. Univ., Sci. Rep., 2nd ser. (Geol.), v. 19, no. 2, p. 219, pl. 27, figs. 27, 28.

Fissurina lamellata McClloch

McClloch, 1977, Qualitative observations on Recent foraminiferal tests with emphasis on the Eastern Pacific, p. 112, pl. 66, figs. 4,5.

Fissurina lucida (Williamson)

Entosolenia marginata (Montagu) var. *lucida* Williamson, 1848, Ann. Mag. Nat. Hist., ser. 2, v. l, p. 17, pl. 2, fig. 17.

Fissurina lucida (Williamson), Loeblich and Tappan, 1953, Smithsonian Misc. Coll., v. 121, no. 7, p. 76, pl. 14, fig. 4.

Fissurina marginata (Montagu)

Vermiculum marginatum Montagu, 1803, Testacea Britannica, p. 524.

Fissurina marginata (Montagu), Loeblich and Tappan, 1953, Smithsonian Misc. Coll., v. 121, no. 7, p. 77, pl. 14, figs. 6-9.

Fissurina obscurocostata Galloway and Wissler

Galloway and Wissler, 1927, Jour. Pal., v. l, p. 52, pl. 9, fig. l.

Fissurina orbignyana Seguenza

Seguenza, 1862, Foram. monotal. Mioc. Messina, p. 66, pl. 2, figs. 24, 26.

Fissurina cf. *rizzae* Seguenza

cf. Seguenza, 1862, Foram. monotal., Mioc. Messina, p. 72, pl. 2, fig. 50.

Fissurina semimarginata (Reuss)

Lagena sp. (Nos. 64-65) von Schlict, 1870. Die Foraminiferen Septarienthones Pielzpuhl, p. 11, pl. 4, figs. 4-6, l0-12.

Lagena marginata Williamson var. *semimarginata* Reuss, 1870, Sitzb. Akad. Wiss. Wien, v. 62, pt. l, p. 468.

Fissurina cf. subquadrata Parr

cf. Parr, 1954, Roy. Soc. Victria, Proc., n. s., LVI, pt. 2, 203, ix, 5.

Gavelinopsis lobatula (Parr)

Discorbis lobatulus Parr, 1950, Reports B.A.N.Z. Antarctic Research Expedition 1929-1931, Ser. B (zoology, Botany), 5, no. 6,

Gavelinopsis lobatulus Barker, 1960, SEPM Spec. Publ., 9, pl. 88, figs. 1a-c.

Gavelinopsis praegeri (Heron-Allen and Earland)

Discorbina praegeri Heron-Allen and Earland, 1913, Royal Irish Acad., Proc., v. 31, pt. 64, p. 122, pl. l0, figs. 8-l0.

Gavelileopsis praegeri (Heron-Ailen and Earlalld), Hofker, 1951, Siboga Exped., Mon. IV, pt. 3, p. 485. figs. 332-334.

Glabratella cf. *aurantista* Seiglie and Bermúdez

cf. Seiglie and Bermúdez, 1965, Monographia de la familia de foraminíferos Glabratellidae, Geos, 1965, no. 12,

Glabratella mirabiris panamensis Seiglie and Bermúdez

Seiglie and Bermúdez, 1965, Geos, 12, p. 33, pl. 6, a-b, 7, 8.

Glabratella pulvinata (Brady)

Discorbina pulvinata Brady, 1884, Rept. on the Sci. Reslt. of the Voy. of the H. M. S. Challenger during the years 1873-1876, Zoology, v. 9,

Glabratella pulvinata, (Brady), Barker, 1960, SEPM Spec. Publ., 9, pl. 88, figs. 10a, b.

Glabratella sp.A

This species is somewhat resembles G. crassa Hofker but differs from it in having more rounded and inflated chambers, and five to six chambers in final whorl.

Glabratella sp.B

This species is characterized in having planoconvex test with low trochospiral coiling and wiht long spines in its periphery.

Glandulina ovula d'Orbigny

d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 29, pl. 1, figs. 6, 7.

Globocassidulina bisecta Nomura

Nomura, 1983, Tohoku Univ. Sci. Rep., 2nd ser. (Geol), v. 53, no. 1, p. 73-77, pl. 2, figs. 2,3; pl. 14, figs. 8-12; pl. 15, figs. 1-5.

Globocassidulina jamesoni (McCulloch)

Cassidulina (?) *jamesoni* McCulloch, 1977, Quantitative obserbations on Recent foram. tests, with emphasis on the eastern Pacific, p. 390, pl. 164, figs. 15a-c.

Globocassidulina jamesoni (McCulloch), Nomura, 1983, Tohoku Univ. Sci. Rep., 2nd ser. (Geol), v. 54, no. 1, p. 33, 34, pl. 3, figs. 7a-c, 8a, b; pl. 19, figs. 1, 2.

Globocassidulina canalisuturata Eade

Eade,1967, N.Z. Jour. Mar. Freshwater Res., 1. no. 4, p. 440, fig. 3 (5-7), fig. 5 (7, 8).

Guttulina yabei Cushman and Ozawa

Cushman and Ozawa, 1929, Japan ,Jour. Geol. Gcogr., v. 6, nos. 3-4, p. 68, pl. 13, flg. 2, pl, 14, fig. 6.

Hanzawaia nipponica Asano

Asano, 1943, Jour. Geol. Soc. Japan, v. 51, no. 606, p. 98, pl. 4, figs. 1-2.

Heterolepa praecincta (Karrer)

Rotalia praecinctus Karrer, 1868, Sitz. Akad. Wiss. Wien, v. 58, p. 189, pl. 5, fig. 7.

Truncatulina praecincta Cusuman, 1915, U.S. Nat. Mus. Bull., v. 71, no. 5, p. 39, pl. 26, fig. 2.

Eponides praecinctus (Karrer), Asano, 1951, Illust. Cat. Japan Tert. Small Foram., pt. 14, p. 11, figs. 30-32.

Heterolepa subhaidingerii (Parr)

Tappan and Loeblich, 1982, Synopsis and Classification of Living Organisms, pl. 53, fig. 10.

Hoegludina elegans (d'Orbigny)

Rotalia (*Turbinulina*) *elegans* d'Orbigny, 1826, Ann. Sci. Nat., Paris, ser. l, v. 7, p. 276, no. 54.

Hoegludina elegans (d'Orbigny), Brotzen, 1948, Sver. Geol. Undersok., v. 42, no. 2, ser. C, no. 493, p. 92, pl. 17, figs. 7, 8.

Islandiella helenae Feyling-Hanssen and Buzas

Cassidulina teretis Tappan, Loeblich and Tappan (not of Tappan, 1951), 1953, Smithsonian Misc. Coll., v. 121, no. 7, p. 121, pl. 24, figs. 3. 4.

Islandiella helenae Feyling-Hanssen and Buzas, 1976, Jour. Foram. Res., v. 6, no. 2, p. 155, figs. 1-4.

Islandiella islandica (Nørbang)

Cassidulina islandica Nørbang, 1945, Foraminifera. *in* the Zoology of Iceland. v.2, p. 42, text-figs. 7, 8d-f.

Islandiella islandica (Nørbang), Nørbang, 1958, Vidensk. Medd. Dansk Natur-hist. Foren., v. 120, p. 27, 28, pl. 6, figs. 1a, b, 2-5, pl. 7, figs. 6a,b, 7a, b,

Islandiella japonica (Asano and Nakamura)

Cassidulina japonica Asano and Nakamura, 1937, Japan Jour. Geol. Geogr., v. 14, nos. 3-4, p. 144, pl. 13, figs. l, 2.

Islandidlla norcrossi (Cushman)

Cassidulina norcrossi Cnshman, 1933, Smithsonian Misc. Coll., v. 89, no. 9, p. 7, pl. 2, figs. 7a-c.

Islandiella norcrossi (Cushman), Norvang, 1958, Dansk Naturh. Foren. Kobenhavn Vidensk. Meddel., v. 120, p.26.

Islandiella setanaensis (Asano and Nakamura)

Cassidulina setanaensis Asano and Nakamura, 1937, pl. 13, figs. 7a,b

Islandiella setanaensis (Asano and Nakamura) , Nomura, 1983, Tohoku Univ. Sci. Rep., 2nd ser. (Geol), v. 53, no. 1, p. 1-101, pl. 3, fig. 6, pl.4, figs. 3,4, pl. 10, fig. 11, pl. 11, fig. 1-3; 1983, Tohoku Univ. Sci. Rep., 2nd ser. (Geol), v. 54, no. 1, p. 5, pl. 1, figs. 3a-c.

Islandiella sublimbata (Asano and Nakamura)

Cassidulina sublimbata Asano and Nakamura, 1937, Japan Jour. Geol Geogr., v. 14, nos. 3-4, p. 146, pl. 14, figs. 3, 4a, b.

Islandiella sublimbata (Asano and Nakamura), Nomura, 1983, Tohoku Univ. Sci. Rep., 2nd ser. (Geol), v. 53, no. 1, pl. 3, fig. 7, pl. 4, fig. 2, pl. 5, fig. 7, pl. 9, figs. 1-8; 1983, Tohoku Univ. Sci. Rep., 2nd ser. (Ge0l), v. 54, no. 1, p. 9, pl. 1, figs. 6-8.

Islandiella yabei (Asano and Nakamura)

Cassidulina yabei Asano and Nakamura. 1937, Japan. Jour. Geol.

Geogr., v. 14, nos. 3-4, p. 145, pl. 14, figs. 1a, b.

Karreriella baccata (Schwager) *japonica* Asano

Asano, 1938, Japanese Jour. Geol. Geogr., v. 15, nos. 1-2, p. 90, pl. 10, figs. 1a-c.

Lagena acuticosta Reuss

Reuss, 1861, Sitz. Akad. Wiss. Wier., v. 44, no. 1, p. 305, pl. 1, fig. 4.

Lagena apiopleura Loeblich and Tappan

Loeblich and Tappan, 1953, Smithsonian Misc. Coll., v. 121, no. 7, p. 59, pl. l0, figs. 14, 15.

Lagena striata (d'Orbigny)

Oolina striata d'Orbigny, 1839, Voy. Amer. Merid., Foralminiféres, v. 5, pt. 5, p. 21, pl. 5, fig. 12.

Lagena striata (d'Orbigny), Asano, 1938, Tohoku Imp. Univ., Sci. Rep., 2nd ser. (Geol.), v. 19, p. 217, pl. 27, fig. 26; pl. 28, fig. 28.

Lagena sulcata spicata Cushman and McCulloch

Lagena sulcata var. *spicata* Cushman and McCulloch, 1950, Allan Hancock Pacific Exped., v. 6, no. 6, p. 360, pl. 48, figs. 3-7.

Lenticulina nikobarensis (Schwager)

Cristellaria nikobarensis Schwager, 1886, Novara Exp. Geol. Thell., 2, p. 243, pl. 6, fig. 87.

Robulus nikobarensis (Schwager), Asano, 1938, Sci. Rep. Tohoku Univ. ser. 2, 19 (2), p. 204, pl. 28, figs. 5, 6; pl. 29, fig. 8.

Melonis pompilioides (Fichtel and Moll)

Nautilus pompilioides Fichtel and Moll, 1798, Testacea microscopica, p. 31, pl. 2, figs. a-c.

Melonis etruscus Montfort, 1808, Conch. Syst., p. 67.

Melonis uchioi Hasegawa

Hasegawa, 1991, Trans. Proc. Palaeont. Soc. Japan, N.S., no. 164, p. 1003.

Miliolinella circularis (Bornemann)

Triloculina circularis Bornemann, 1855, Zeit. deutsch. Geol. Ces., v. 7, p. 349, pl. 19, fig. 4.

Miliolinella circularis (Bornemann), Asano, 1951, Illust. Cat. Japan. Tert. Small. Foram., pt. 6, p. 9, figs. 65-67.

Melonis pacificum (Cushman)

Nonion umbilicatula var. *pacifica* Cushman, 1924, Carnegie Inst. Wash., v. 342, p. 48, pl. 16, fig. 3.

Nonion pacificum Cushman, 1939, U.S. Geol. Surv., Prof. paper v. 191, p.25, pl. 6, fig. 25.

Neoconorbina stachi (Asano)

Discopulvinulina stachi Asano, 1951, Illust. Cat. Japan Tert. Small. Foram., pt. 14, p. 7, figs. 46-48.

Neoconorbina stachi (Asano), Matoba, 1970, Tohoku Univ., Sci. Rep., 2nd ser. (Geol), v. 42, no. 2, p. 57, pl. 4, flgs. 6a-c.

Neoeponides procerus (Brady)

Pulvinulina procera Brady, 1884, Voy. Challenger, Rep., Zool., v. 9, p. 698, pl. 105, figs. 7a-c.

Neoeponides procerus (Brady), Reiss, 1960. Israel Geol. Surv., Bull. no. 29, p. 17.

Nonion japonicus Asano

Nonion japonicum Asano (sic.) , 1938, Jour. Geol. Soc. Japan, v. 45, no. 593, pl. 15(4), figs. 1, 2.

Nonionellina labradorica (Dawson)

Nonionina labradorica Dawson, 1860, Canad. Nat., v. 5, p. 191, text-fig. 4.

Nonionellina labradorica (Dawson), Voloshinova, 1958, Mikrofauna SSSR, Sbornik 9, VNIGRI, Trudy, no. 115, p. 142.

Nonionella stella Cushman and Moyer

Nonionella miocenica Cushman var. *stella* Cushman and Moyer, 1930, Cushman Lab. Foram. Res., Contr., v. 6, pt. l, p. 56, pl. 7, figs. 17a-c.

Nonionoides grateloupi (d'Orbigny)

Nonionina grateloupi d'Orbigny, 1826, Annales des Sciences Naturelles v. 7, p. 294,

Nonionoides grateloupi (d'Orbigny), Saidova, 1975, Bentosnye Foraminifery Tikhogo Okeana, 3 vol., p. 248.

Nuttallides umbonifera Todd

Nuttallides umboniferus (sic.) Todd, 1965, U.S. Nat. Mus. Bull. 161, pt. 4, p. 29, figs. 1a-c.

Oolina carteri Albani and Yassini

Albania and Yassini, 1989, Aust. J. Mar. Freshw. Res., v. 70, p. 385, fig. 3r-s.

Oolina costata (Williamson)

Entosolenia costata Williamson, 1858, Recent Foraminifera Great Britain, p. 9, pl. 1, fig. 18.

Lagena costata (Williamson), Cushman, 1923, U.S. Nat. Mus. Bull. v. 104, pt.4, p.12, pl.1, fig. 16,, pl. 2, figs. 1, 2 (not pl. 3, fig. 8)

Oolina costata (Williamson), Parker, 1952, Bull. Mus. Comp. Zool., v. 106, no. 9, p. 409, pl: 4, figs. 20,21.

Oolina melo d'Orbigny

d'Orbigny, 1839, Voy. Amer. Merid., Foraminiféres, v. 5, pt. 5, p. 20, pl. 5, fig. 9.

Oolina striatopunctata (Parker and Jones)

Lagena sulcata (Walker and Jacob) var. *striatopunctata* Parker and Jones, 1865, Philos. Trans. Roy. Soc. London, v. 155, p. 350, pl. 13, figs. 25-27.

Entosolenia striatopunctata (Parker and Jones) Dawson, 1870, Can. Nat., n.s., v. 5, p. 178, fig. 11.

Lagena striatopunctata Parker and Jones, Brady, 1878, Ann. Mag. Nat. Hist., ser. 5, v. 1, p. 434, pl. 20, fig. 3.

Oolina striatpunctata (Parker and Jones) Loeblich and Tappan, 1953, Smithsonian Misc. Coll. v. 121, no. 7, p. 74, pl. 12, figs. 2-5.

Oridorsalis umbonatus (Reuss)

Rotalia umbonata Reuss, 1851, Deutsch. geol. Gesell., Zeischr., v. 3, p. 75, pl. 5, figs. 35a-c.

Oridorsalis umbonatus (Ruess), Parker, 1964, Jour. Pal., v. 38, no. 4, p. 626, pl. 99, figs. 4-6.

Paracassidulina sulcata Belford

Belford, 1966, Bur. Min. Resour. Aust. Rep., no. 79, p. 142, 144, pl. 24, figs. 11-14, text-fig. 16, nos. 7, 8.

Pararotalia nipponica (Asano)

Rotalia nipponica Asano, 1936, Jour. Soc. Japan, v. 43, no. 515, p. 614, pl. 30, figs. 2a-c.

Pararotalia nipponica (Asano), Ujiie, 1966, Palaeont. Soc. Japan, Trans. Proc., N.S.m no. 61, p. 192, text-figs. 1-3; pl. 24, figs. 1-7;

pl. 25, figs. 1-5.

Patellina corrugata Williamson

Williamson, 1858, Rec. Foram. Gt. Britain, p. 46, pl. 3, figs. 86-89.

Patellinella hanzawai Asano

Asano, 1936, Jour. Geol. Soc. Japan, v. 43, no. 515, p. 613, pl. 31, figs. 3a-c.

Pateoris hauerinoides (Rhumbler)

Miliolina seminulum (Linne) var. *disciformis* (Macgillivray)

Williamson, 1858 (not *Vermiculum disciforme* Macgillivray, 1843), Recent Foraminifera of Great Britain, p. 86, pl. 7, figs. 188, 189.

Miliola (*Quinqueloculina*) *subrotunda* (Montagu) Parker and Jones, 1865, (not *Vermiculum subrotundum* Montagu, 1803), Philos. Trans. Roy. Soc. London, v. 155, p. 411, pl. 15, figs. 38a, b (erroneously numbered 28a, b on the plate).

? *Massilina secans* (d'Orbigny) Cushman, 1929, U.S. Nat. Mus. Bull. v. 104, pt. 6, p. 37, pl. 7, figd. 3, 4.

Quinqueloculina subrotunda (Montagu) forma *hauerinoides*

Rhumbler, 1936, Foram. der Kieler Bucht, Teil II-Ammodisculinidae bis Textulinidae, v. 1, no. 1, p. 206, 217, 226, text-figs. 167, 208-212.

Quinqueloculina subrotunda (Montagu) F. Parker, 1952, Bull. Mus. Comp. Zool., v. 106, no. 9, p. 406, pl. 4, figs. 4a, b.

Pateoris hauerinoides (Rhumbler) Loeblich and Tappan, 1953, Smithsonian, Misc. Coll. v. 121, no. 7, p. 42, pl. 6, figs. 8-12, text-figs. 1A, B.

Planoglabratella australensis (Hellon-Allen and Earland)

Discorbis australensis Hellon-Allen and Earland, 1932, Discovery

Repts., IV, 416.

Planoglabratella opercularis (d'Orbigny)

Rosalina opercularis d'Orbigny, 1839, Foraminiféres, p. 93, pl. 3, figs. 24, 25.

Discorbis opercularis Cushman, 1915, U.S. Nat. Mus. Bull., vol. 71, no. 5, p. 18, pl. 11, fig. 3.

Planolabratella opercularis (d'Orbigny), Seiglie and Bermúdes, 1965, Geos, 1965, no. 12, 15-65.

Planoglabratella patelliformis (Brady)

Discorbina patelliformis Brady, 1884, Rept. on the Sci. Reslt. of the Voy. of the H. M. S. Challenger during the years 1873-1876, Zoology, v. 9,

Glabratella patelliformis (Brady), Seiglie and Bermúdez, 1965, Monographia de la familia de foraminíferos Glabratellidae, Geos, 1965, no. 12,

Planoglabratella subopercularis (Asano)

Discorbis subopercularis Asano, 1951, Illust. Cat. Japan Tert. Small Foram., pt. 14, p. 3, figs. 17-19.

Glabratella subopercularis (Asano), Matoba, 1970, Tohoku Univ., Sci. Rep., 2nd ser. (Geol.), v. 42, no. l, p. 54, pl. 5, figs. Sa-c.

Planolabratella subopercularis (d'Orbigny), Seiglie and Bermúdes, 1965, Geos, 1965, no. 12, 15-65.

Planoglabratella? sp.C

This species resembles *Planoglabratella subopercularis* (Asano), but differs from it in having less number of chambers in final whorl.

Polystomdlina discorbinoides Yäbe and Hanzawa

Yabe and Hanazawa, 1923, Japan Jour. Geol. Geogr., v. 2, p. 99, text-flgs. a-c.

Poroeponides cribrorepandus Asano

Asano, 1951, Illust. Cat. Japan. Tert. Small. Foram., p. 18, figs. 134, 135.

Pseudononion japonicum Asano

Asano, 1936, Jour. Geol. Soc. Japan, v. 43, no. 512, p. 347, text-figs. a-c.

Pseudoparrella naraensis Kuwano

Kuwano, 1950, Jour. Geol. Soc. Japan, v. 56, no. 657, p. 317, text-figs. 6a-c.

Pseudoparrella takayanagii (Iwasa)

Epistominella takayanagii lwasa, 1955, Jour. Geol. Soc. Japan, v. 61, no. 712, p. 16, text-figs. 4a-c.

Epistominella suttsuensis Shirai, 1960, Jour. Fac. Sci. Hokkaido Univ., Ser. IV, vol X, 537-543, pl. 2,figs. 3a-c.

Pseudopolymorphina suboblonga Cushman and Ozawa

Cushman and Ozawa, 1930, U.S. Nat. Mus., Proc., v. 77, p. 91, pl. 23, figs. 3a-c.

Pullenia apertura Cushman

Pullenia apertura Asano (not of Cushman, 1927), 1951, Illust. Cat. Japan. Tert. Small. Foram., pt. 12, p. l0, figs. 3, 4.

Pyrgo ezo Asano

Asano, 1938, Japanese Jour. Geol. Geogr., v.15, nos. 1-2, p.93, pl. 9, figs. 1-4, 6.

Pyrgo fomasinii Chapman and Parr

Chapman and Parr, 1935, Roy. Soc. W. Australia, Jour., XXI, p. 5.

Quinqueloculiua agglutinata Cuslunan

Cushman, 1917, U.S. Nat. Mus., Bull. 71, pt. 6, p. 43, pl. 9, figs. 2a-c.

Quinqueloculina akneriana d'Orbigny

d'Orbigny, 1846, Foram. Foss. Bas. Vienne, p. 290, pl. 18, figs. 16-21.

Quinqueloculina costata d'Orbigny

d'Orbigny, 1826, Ann. Sci. Nat., v. 7, p. 301. no. 3.

Quinqueloculina elongata Natland

Natland, 1938, Bull. Scripps Inst. Oceanogr. Tech. Ser., v. 4, no.5, p. 141, pl. 4, fig. 5.

Quinqueloculina hasimotoi Asano

Asano, 1938, Japan. Jour. Geol. Geogr., v. 15, no. 1-2, p. 92, pl. 10, figs. 5a-c.

Quinqueloculina kuromatsunaiensis Asano

Asano, 1936, Jour. Geol. Soc. Japan, v. 43, no. 515, p. 621, pl. 32, figs. 4a-d.

Quinqueloculina cf. *lamarckiana* d'Orbigny

cf. d'Orbigny, 1839, Foraminiféres. p. 189, pl. 11, figs. 14, 15.

Quinqueloculina sawanensis Asano

Asano, 1951, Illust. Cat. Japan. Tert. Small. Foram., p. 6, figs. 40-42.

Quinqueloculina seminulum (Linné)

Serpula seminulum Linné, 1758, Syst. Nat., ed. 10, p. 786.

Quinqeloculina seminulum (Linné), d'Orbigny, 1826, Ann. Sci. Nat., Paris, ser. 1, v. 7, . 303, no. 4.

Quinqueloculina vulgaris d'Orbigny

d'Orbigny, 1826, Ann. Sci. Nat., v. 7, p. 302, no. 33.

Quinqueloculina cf. *vulgaris* d'Orbigny

cf. d'Orbigny, 1826, Ann. Sci. Nat., v. 7, p. 302, no. 33.

Quinqueloculina yessoensis Asano

Asano, 1936, Jour. Geol. Soc. Japan. 43, p. 620, pl. 32, figs. 3a-c.

Quinqueloculina sp.B

This species is somewhat similar to *Quinqueloculina elongata* Natland of Asano (1950) in its outline, but is distinguished from it by more inflated chmbers and coarsely perforated wall.

Quinqueloculina sp.C

This species is somewhat similar to *Quinqueloculina contrta* d'Orbigny, but is distinguished by more rounded outline, short size, and apertural view.

Quinqueloculina sp.F

This form is similar to *Quinquelocilina yessoensis* Asano, but is differs from it in having a broadly oval test with more sharply angled periphery in apertural view. This is also similar to *Quinqueloculina kuromatunaiensis* Asano, but is distinguished in having angled periphery of chambers.

Quinqueloculina sp.G

This form is somewhat similar to Quinqueloculina elongata Natland, but is distinguished from it by its triangular appearance in apertural view.

Quinqueloculina sp.H

This form is similar to *Quinqueloculina hasimotoi* Asano, but differs from it in having a test without apertural protrusion.

Rectobolivina raphanuss (Parker and Jones)

Uvigerina (*Sagrina*) *raphana* Parker and Jones, 1865, Roy. Soc.

London Philos. Trans , v. 155, p. 364, pl. 18, figs. 16, 17.

Rectobolivina raphana (sic.) (Parker and Jones), Loeblich and Tappan, 1964, Treatise on Invertebrate Pal., Moore, R.C., ed., pt. C, Protista 2, v. 2, p. C533, figs. 438 (9-11).

Rosalina australis (Parr)

Discorbis australis Parr, 1932, Roy. Soc. Victoria, Proc., XLIV (n.s.) p. 227, pl. xxii, 31.

Rosalina australis (Parr), Jones, 1994, Challenger Foram., pl. 87, figs. 5-7.

Rosalina bradyi (Cushman)

Discorbina globularis Brady (not of d'Orbigny, 1826), 1884, Voy. Challenger, Rep., Zool., v. 9, p. 86, figs. 8a-c.

Discorbina globularis var. *bradyi* Cushman, 1915, U.S. Nat. Mus., Bull. 71, pt. 5, p. 12, pl. 8, figs. 1a-c.

Rosalina bradyi (Cushman), Hornibrook and Vella, 1954, Micropal., v. 8, no. l, p. 26.

Rosalina campanulata

Rosalina globularis d'Orbigny

d'Orbigny, 1926, Ann. Sci. Nat., Paris, ser. l, v. 7, p. 271, no. l, pl. 13, figs. 1-14; Modele no. 69.

Rosalina hofkeri (Asano)

Discopulvinulina hofkeri Asano, 1951, Illust. Cat. Japan. Tert. Small. Foram., pt. 14, p. 5, figs. 30, 31.

Rosalina isabelleana d'Orbigny

d'Obigny, 1839, Foraminiféres. p. 43, pl. 6, figs. 10-12.

Rosalina vilardeboana d'Orbigny

d'Orbigny, 1839, Voy. Amer. Merid., Foraminiféres, v. 5, pt. 5, p. 44, pl. 6, figs. 13-15.

Rosalina cf. *vilardeboana* d'Orbigny

cf. d'Orbigny, 1839, Voy. Amér. Mérid., Foraminiféres, v. 5, pt. 5, p. 44, pl. 6, figs. 13-15.

Sigmoidella margaretae Chushman and Ozawa

Cushman and Ozawa, 1930, U.S. Natl. Mus., Proc., v. 77, art. 6, p. 142, pl. 39, figs. 3a, b.

Sigmoidella pacifica Cushman and Ozawa

Sigmoidella (*Sigmoidina*) *pacifica* Cushman and Ozawa, 1928, Cushman Lab. Foram. Res., Contr., v. 4, p. 19, pl. 2, fig. 13.

Sigmoilina sigmoidea (Brady) *compressa* Cushman

Cushman, 1946, Contr. Cushman Lab. Foram. Res., 22, no. 2, p. 32, pl. 5, figs. 10-12.

Sigmomorphina semitecta terquemiana (Fornasini)

Polymorphina amygdaloides Reuss var. *terquemiana* Fornasini, 1902, Mem. Accad. Inst. Sci. Bologna, ser. 5, no. 9, p. 72, fig. 25.

Sigmomorphina semitecta (Reuss) var. *terquemiana* Cushman and Ozawa, 1930, U.S. Nat. Mus. Proc., v. 77, no. 6, p. 129, pl. 33, figs. 4, 5; pl. 34, figs. 2, 3; ol. 35, fig. 1.

Sigmomorphina trilocularis (Bagg)

Polymorphina trilocularis Bagg, 1912, U. S. Geol. Surv. Bull., 513, p. 75, pl. 20, figs. 15-18.

Sigmomorphina trilocularis (Bagg), Cushman and Ozawa, 1930, U. S. Nat. Mus. Proc., v. 77, no. 6. p. 136, pl. 36, fig. 5.

Sphaeroidina japonica Asano

Asano, 1953, Tohoku Univ., Inst. Geol. Paleont., Short Papers, no. 5, p. 17, pl. 2, figs. 43, 44.

Spirillina limbata Brady

Brady, 1879, Quart. Jour. Microscopic Sci., n.s., vol. 19, p. 64, pl. 8, figs. 26a, b.

Spirillina vivipara Ehrenberg

Ehrenberg, 1843, Phys. Ab. K. Akad. Wiss. Berlin, 1841 (1), p. 323, 422, pl. 3, VII, fig. 41.

Spiroloculina hadai Thalmann

Spiroloculina costata Hada, 1931, Tohoku Univ. Sci. Rep., 4th ser., Biol., v. 6, no. 1, p. 84, text-figs. 37a,b.

Spiroloculina hadai Thalmann, 1933, Jour. Paleont., v. 7, no. 30, p. 354.

Spiroplectammina sp.A

This form somewhat similar to*Textularia candeiana* d'Orbigny, but has a test with planispirally arranged chambers in the early portion.

Spiroplectinella wrightii (Silvestri)

Spiroplecta wrightii Silvestri, 1903, Accad. Pont. Nuovi Lincei, Atti, LVI, p. 59, pl. 1x, figs. 1-6.

Textularia aokii Asano

Asano, 1936, Japan. Jour. Geol. Geogr., v. 13, nos. 3-4, p. 325, pl. 36, figs. 1a, b.

Textularia candeiana d'Orbigny

d'Orbigny, 1839, Foraminiféres, p. 143, pl. 1, figs. 25-27.

Textularia conica d'Orbigny

d'Orbigny, 1839, Foraminiféres, p. 143, pl. 1. figs. 19, 18.

Triloculina rotunda d'Orbigny

d'Orbigny, 1826, Ann. Sci. Nat. v. 7, p. 299, no. 4.

Triloculina suttuensis Asano

Asano, 1936, Jour. Geol. Soc. Japan, v. 43, no. 515, p. 621, pl. 33, figs. 2a-c.

Triloculina tricarinata d'Orbigny

d'Orbigny, 1826, Ann. Sci. Nat., 7, p. 299, no. 7.

Uvigerina akitaenesis Asano

Asano, 1950, Illust. Cat. Japan. Tert. Small. Foram. pt. 2, p. 14 figs 60-62.

Uvigerina juncea Cushman and Todd

Cushman and Todd, 1941, Cushman Lab. Foram. Res., Contr., XVII, p. 78, pl. xx, 4-11.

Uvigerina schencki Asano

Asano, 1950, Illust. Cat. Japan. Tert. Small. Foram. p. 17, figs. 74, 75.

Valvulineria hamanakoensis (Ishiwada)

Anomalina hamanakoensis Ishiwada, 1958, Geol. Surv. Japan Rep., no. 180, p. 18, text-figs. 3a-c; pl. 1, 24-27.

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Plates

Plates

Molluscs (All figures in natural size)

1. *Swiftopecten swiftii* (Bernardi)

2, 4-7, 10. *Cyclocardia crebricostata* (Krause)

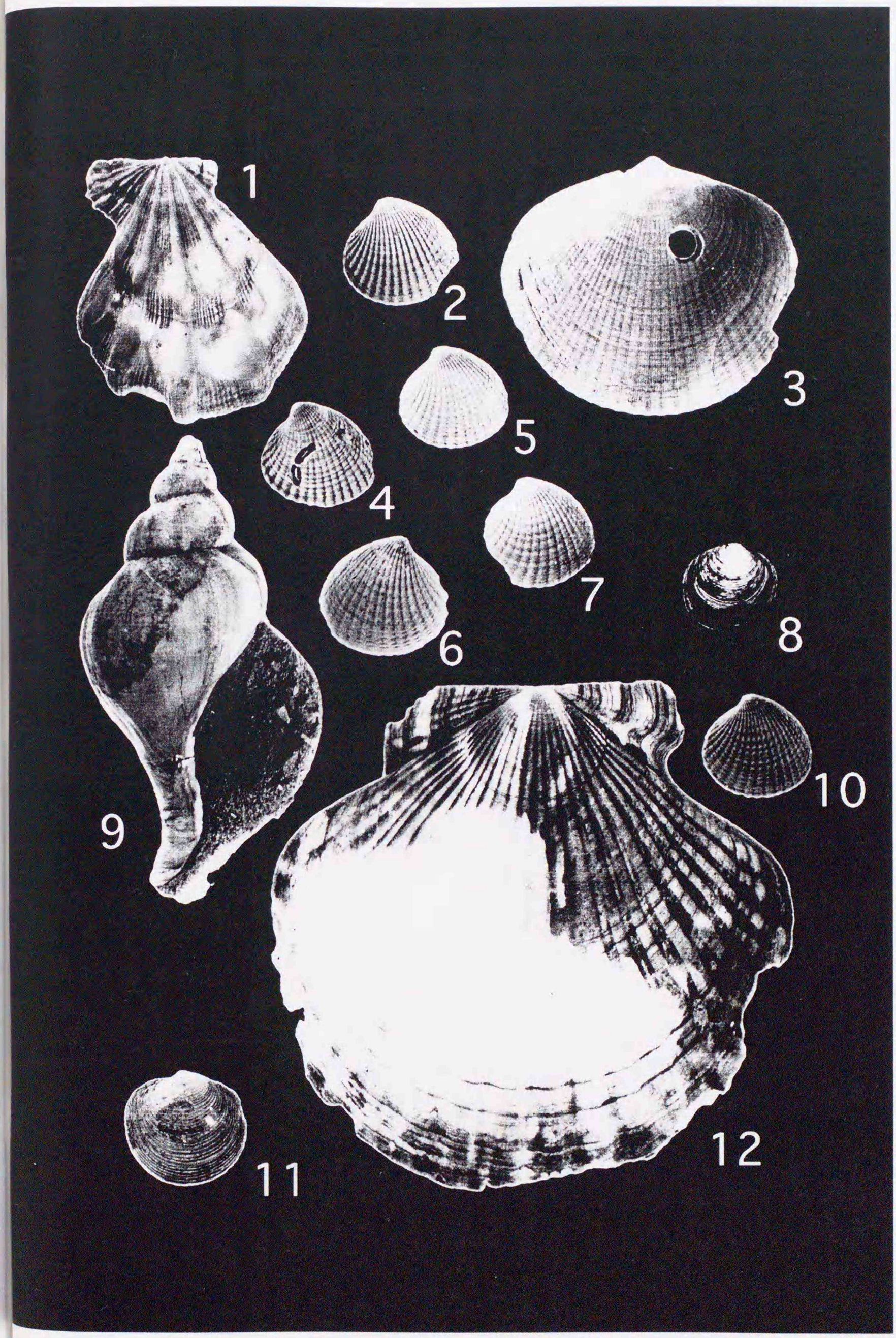
3. *Glycymeris yessoensis* (Sowerby)

8, 11. *Lucinoma annulata* (Reeve)

9. *Neptunea arthritica* (Bernardi)

12. *Mizuhopecten yessoensis* (Jay)

Plate 1



Molluscs (All figures in natural size)

1. *Monia macroschisma* Deshayes

2. *Arca boucardi* Jouseaume

3, 4, 7. *Cyclocardia isaotakii* Tiba

6. *Lepeta* sp.

8. *Amathina nobilis* (A. Adams)

9. *Puncturella nobilis* A. Adams

10. *Boreotrophon candelaburm* (Reeve)

11. *Acmaea pallida* (Gould)

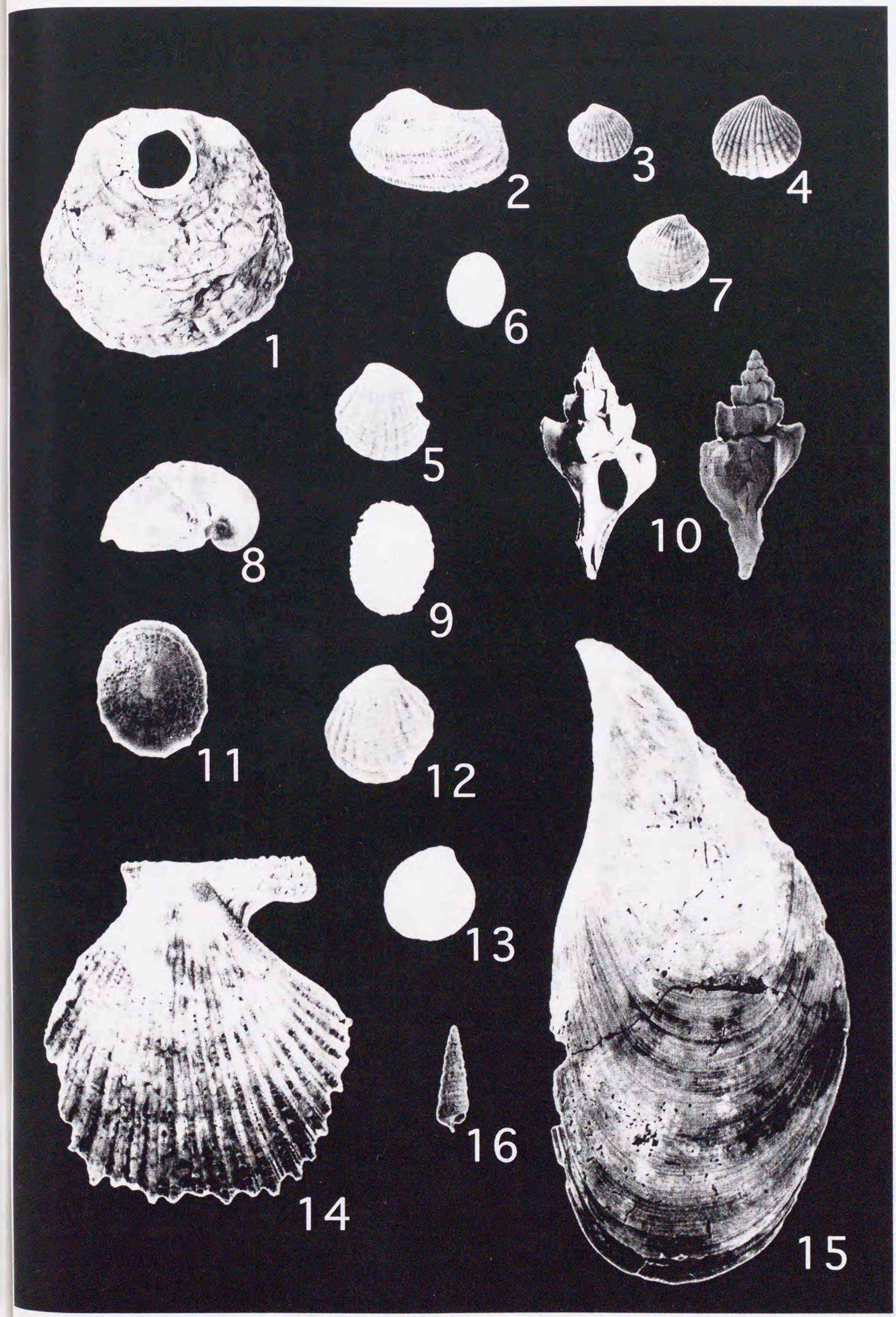
5, 12-13. *Cyclocardia crassidens* (Broderip and Sowerby)

14. *Chlamys daishakaensis* (Masuda and Sawada)

15. *Crenomytilus grayanus* Dunker

16. *Rhinoclavis kochi* (Philippi)

Plate 2



Planktonic Foraminifera

1. *Globigerina bulloides* d'Orbigny

2. *Globigerina quinqueloba* Natland

3. *Globigerinita uvula* (Ehrenberg)

4. *Globigerinita glutinata* (Egger)

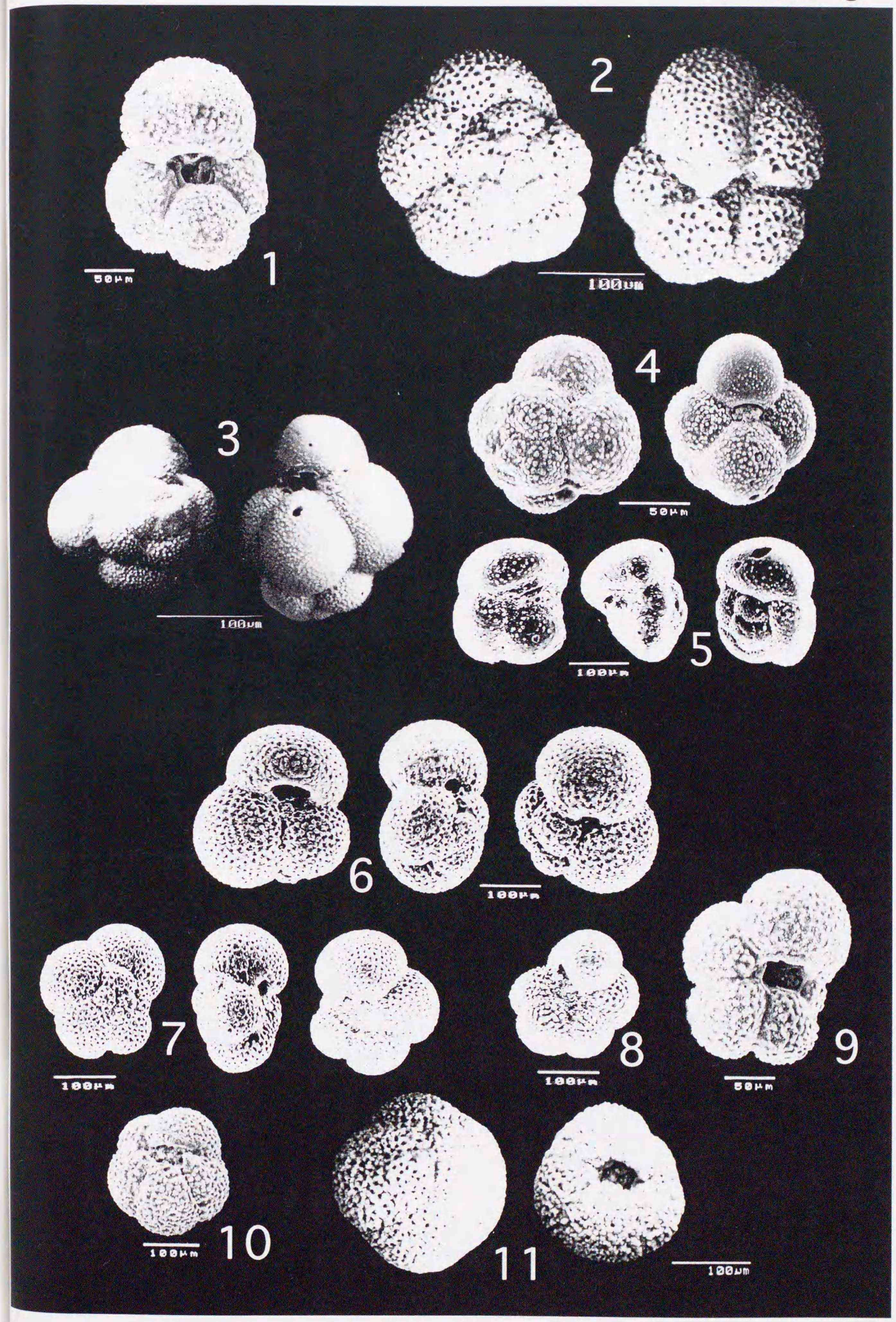
5. *Globorotalia inflata* (d'Orbibny)

6. *Globigerinoides ruber* (d'Orbingy)

7-9. *Neogloboquadrina incompta* (Chifelli)

10-11. *Neogloboquadrina pachyderma* (Ehrenberg)

Plate 3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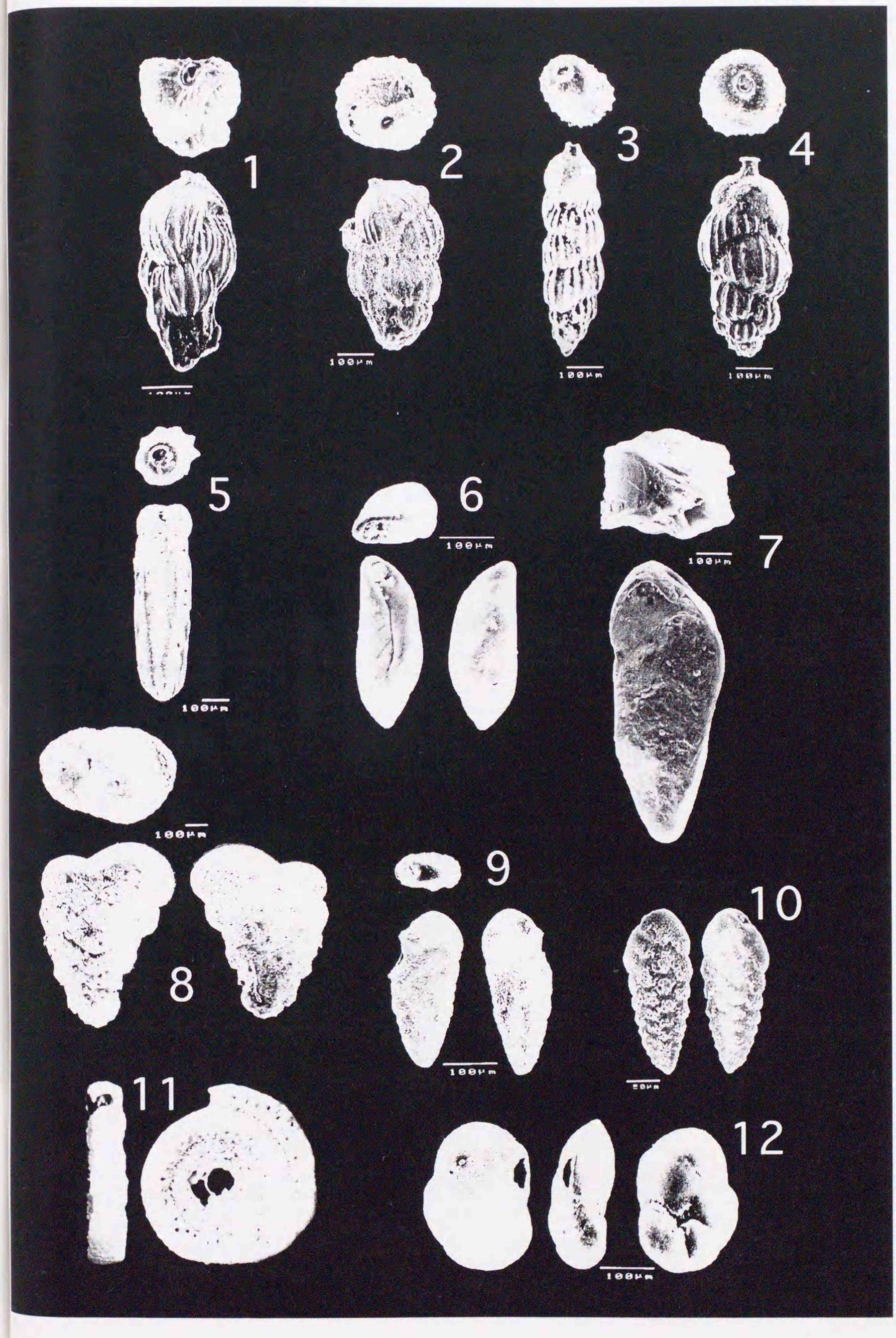
Benthic Foraminifera

1. *Angulogerina kokozuraensis* (Asano)
2. *Uvigerina akitaenesis* Asano
3. *Uvigerina schencki* Asano
4. *Uvigerina juncea* Cushman and Todd
5. *Rectobolivina rephanus* (Parker and Jones)
6. *Buliminella elegantissima* (d'Orbigny)
7. *Bolivinita quadrilatera* (Schwager)
8. *Spiroplectammina* sp. A
9. *Bolivina* sp. A
10. *Bolivina decussata* Brady
11. *Spirillina limbata* Brady
12. *Cancris auriculus* (Fichtel and Moll)

Plate 4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Benthic Foraminifera

1. *Oolina melo* d'Orbigny

2-3. *Lagena apiopleura* Loeblich and Tappan

4. *Oolina costata* (Williamson)

5. *Fissurina lacunata* (Burrows and Holland)

6. *Lagena striata* (d'Orbigny)

7. *Oolina striatopunctata* (Parker & Jones)

8. *Lagena acuticosta* Reuss

9. *Fissurina baccata* (Hellon-Allen & Earland)

10. *Fissurina orbignyana* Seguenza

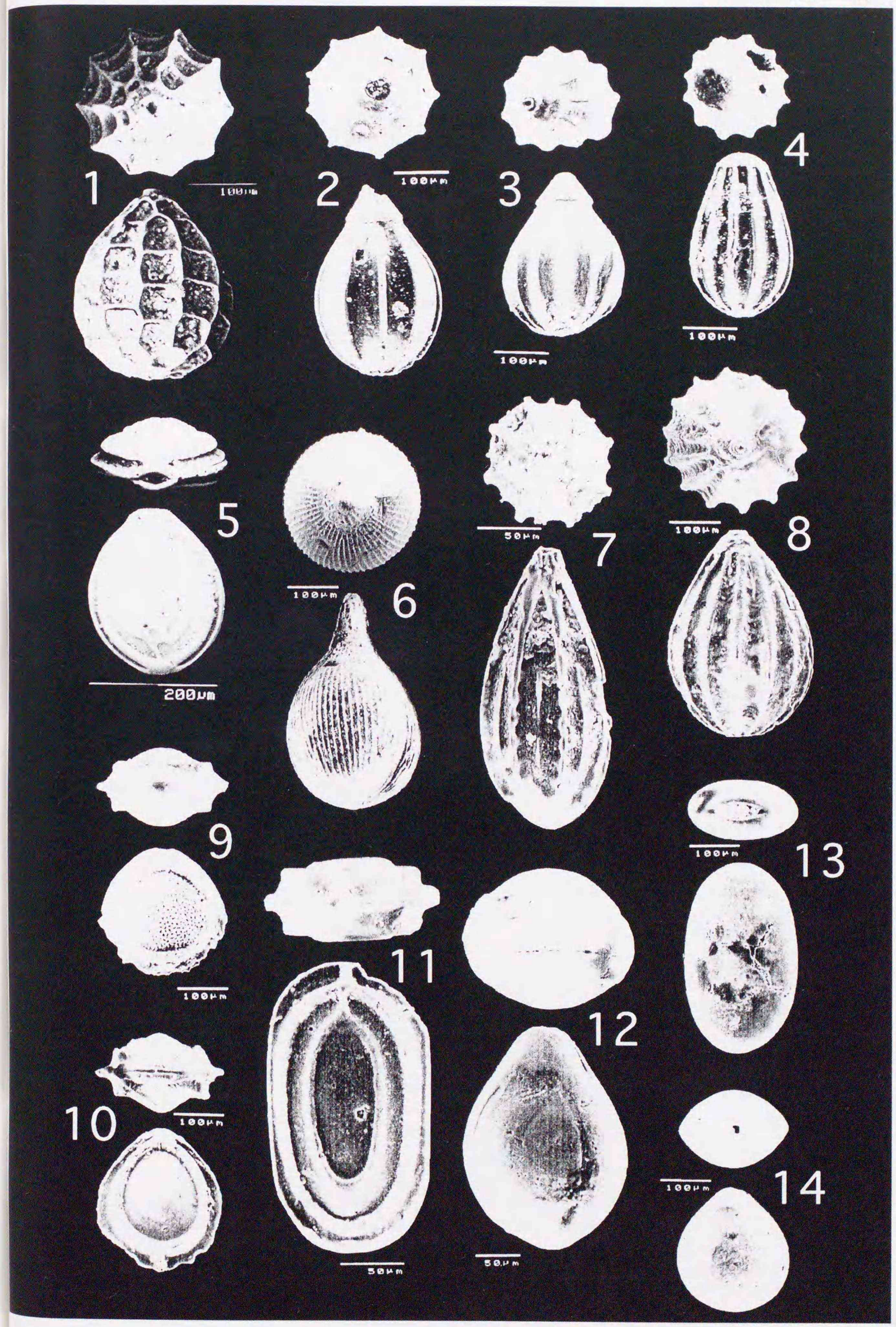
11. *Fissurina* cf. *rizzae* Seguenza

12. *Fissurina annectens* (Burrows & Holland)

13. *Fissurina cf. subquadrata* Parr

14. *Fissurina marginata* (Montagu)

Plate 5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Benthic Foraminifera

1. *Cibicides lobatulus* (Warker and Jacob)

2-3. *Cibicides refulgens* de Montfort

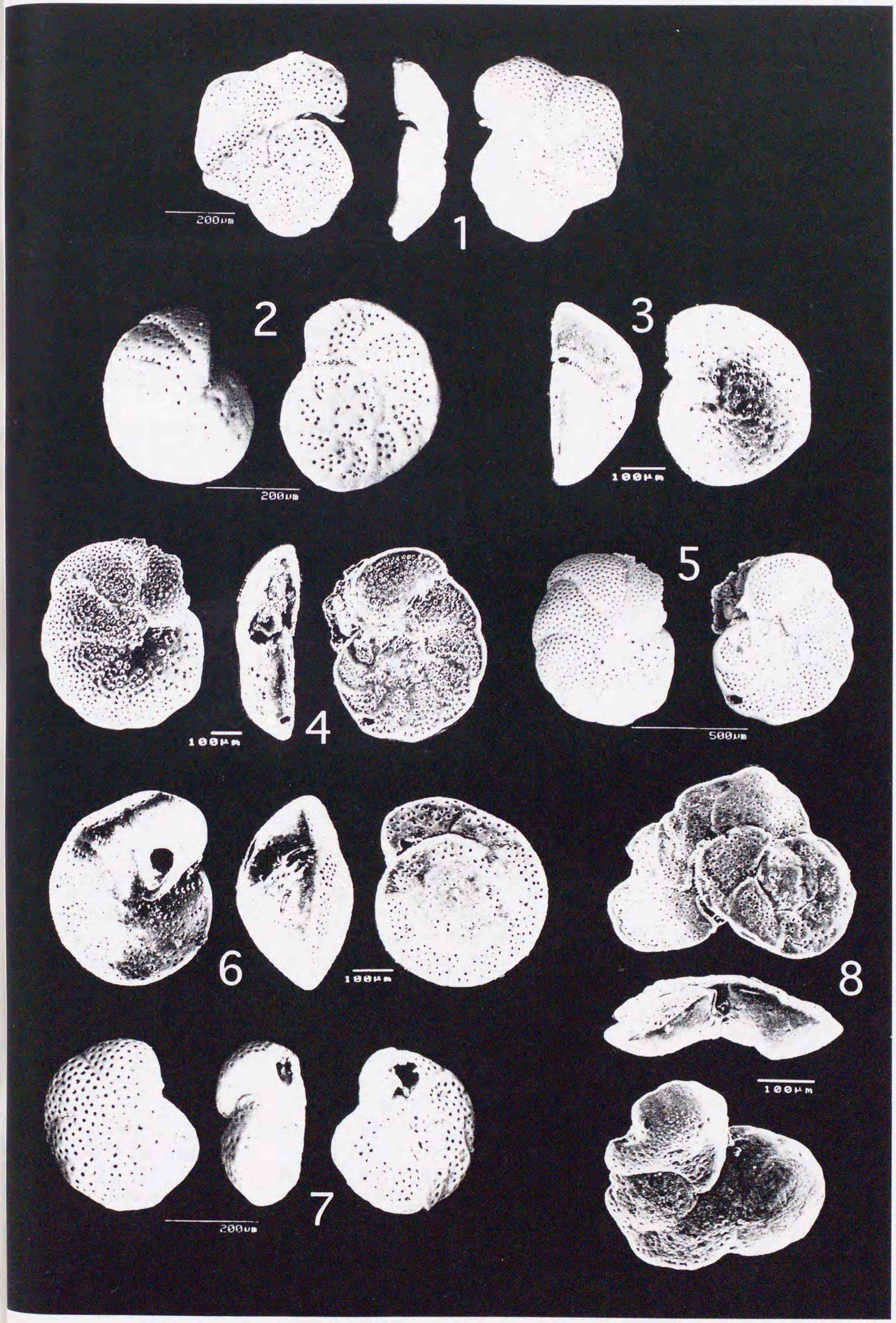
4-5. *Cibicides subdepressus* (Asano)

6. *Heterolepa subhaidingerii* (Parr)

7. *Anomalinoides globulosus* (Cushman and Parr)

8. *Dyocibicides perforata* Cushman and Valentine

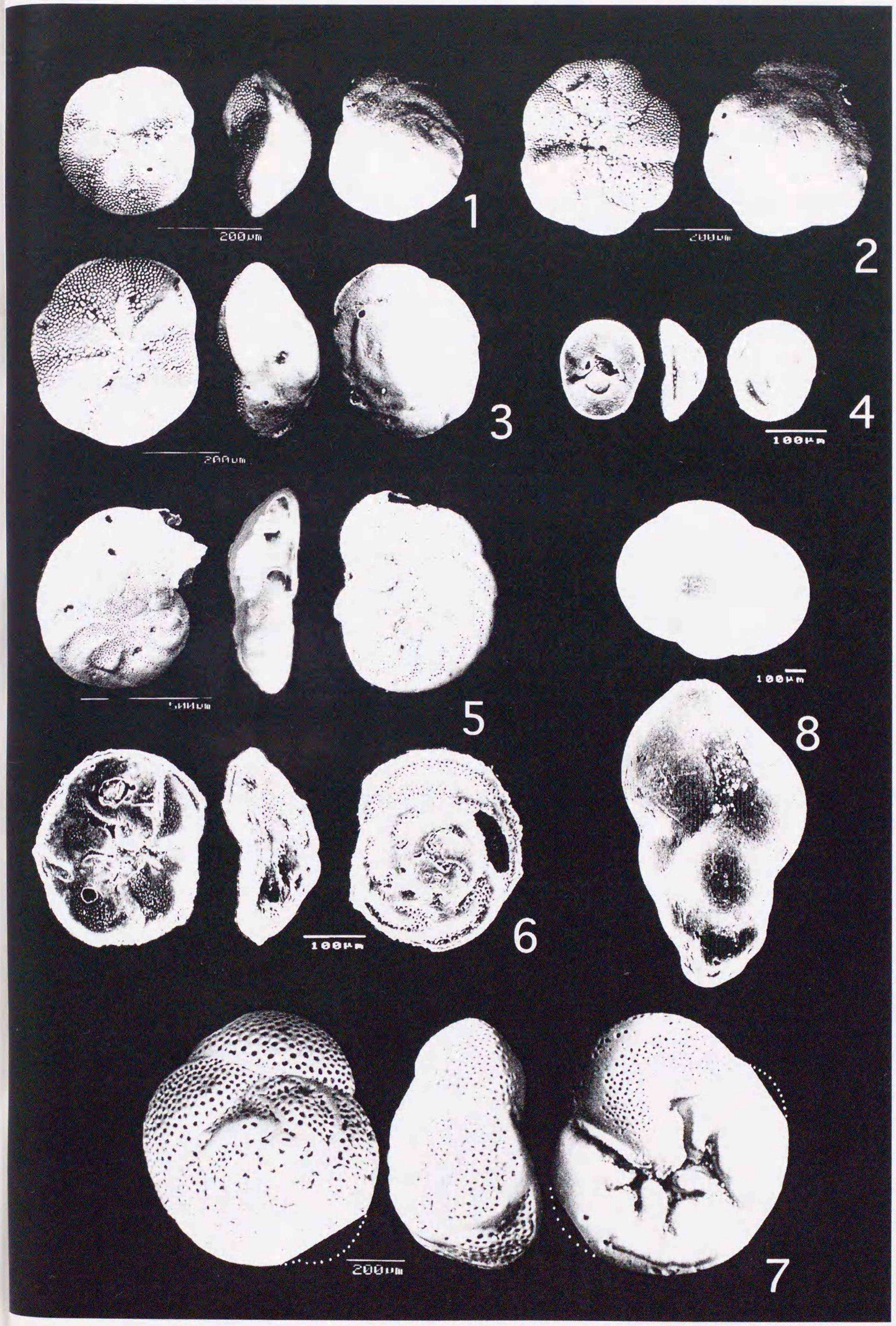
Plate 6



Benthic Foraminifera

1. *Buccella frigida* (Cushman)
2. *Buccella makiyamai* (Chiji)
3. *Buccella tenerrima* (Brady)
4. *Patellinella hanzawai* Asano
5. *Hanzawaia nipponica* Asano
6. *Rosalina australis* (Parr)
7. *Rosalina bradyi* (Cushman)
8. *Guttulina yabei* Cushman and Ozawa

Plate 7



Benthic Foraminifera

1. *Elphidium subgranulosum* Asano

2. *Elphidium frigidum* Cushman

3-5. *Elphidium subarcticum* Cushman

6,7. *Elphidium crispum* (Linné)

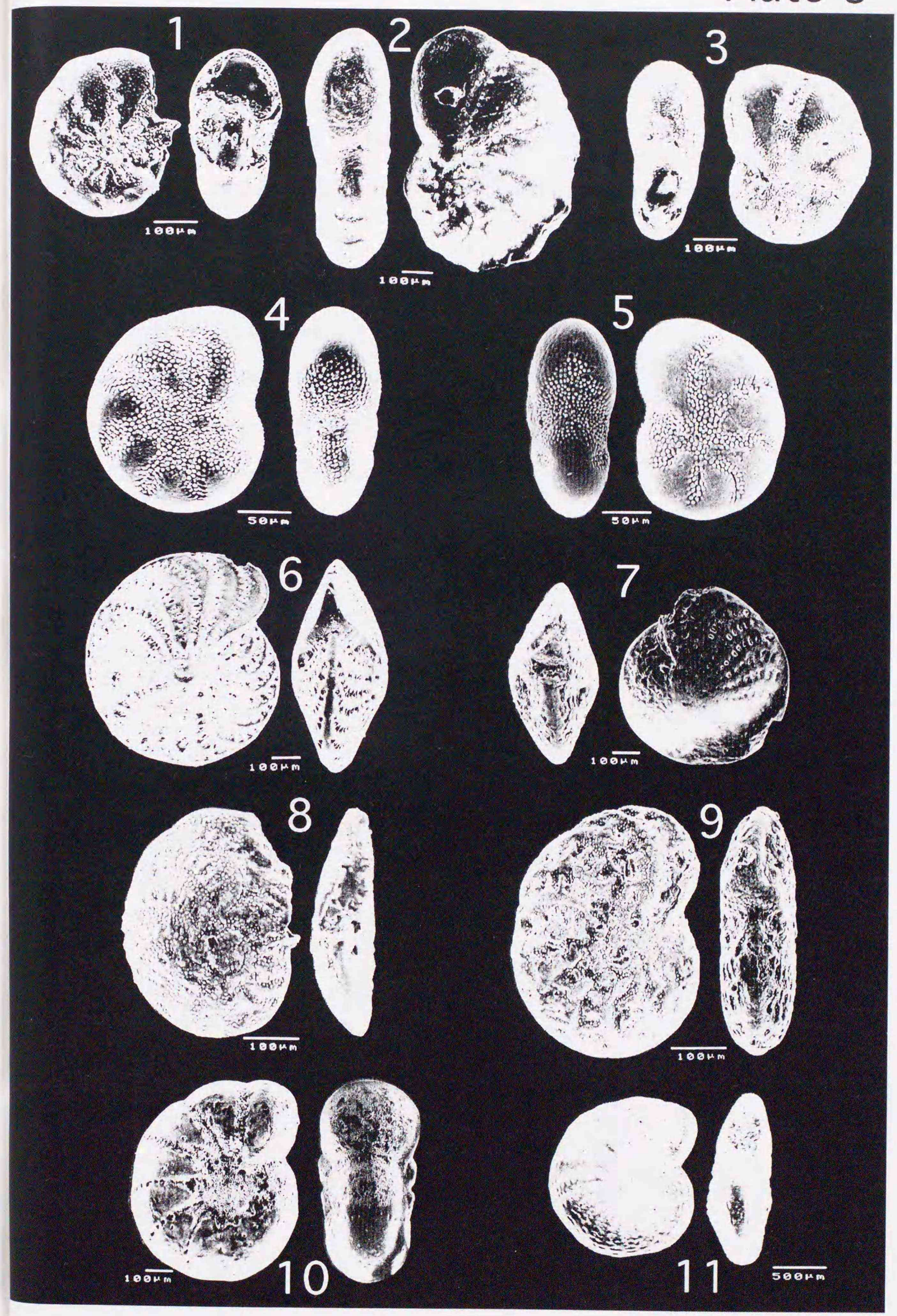
8. *Polystomdlina discorbinoides* Yabe and Hanzawa

9. *Elphidium jenseni* (Cushrnan)

10. *Cribroelphidium yabei* (Asano)

11. *Cribroeplhidium oregonensis* (Cushman and Grant)

Plate 8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Benthic Foraminifera

1,8. *Astrononion hamadaense* Asano

2. *Elphidium excavatum* (Terquem) forma clavata Cushman

3. *Nonion japonicus* Asano

4. *Melonis uchioi* Hasegawa

5. *Pullenia apertura* Cushman

6. *Melonis pompilioides* (Fichtel and Moll)

7. *Lenticulina nicobarebsis* (Schwager)

9. *Nonionellina labradorica* (Dawson)

Plate 9

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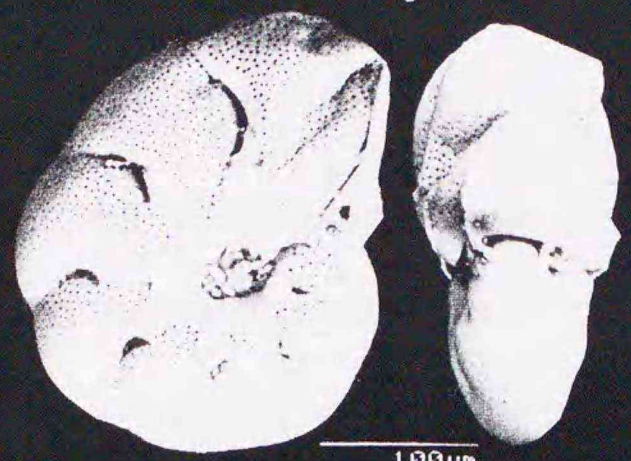

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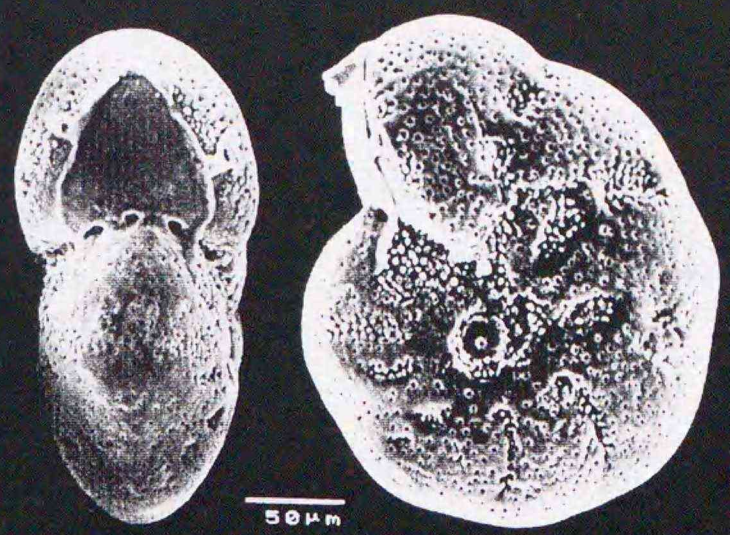

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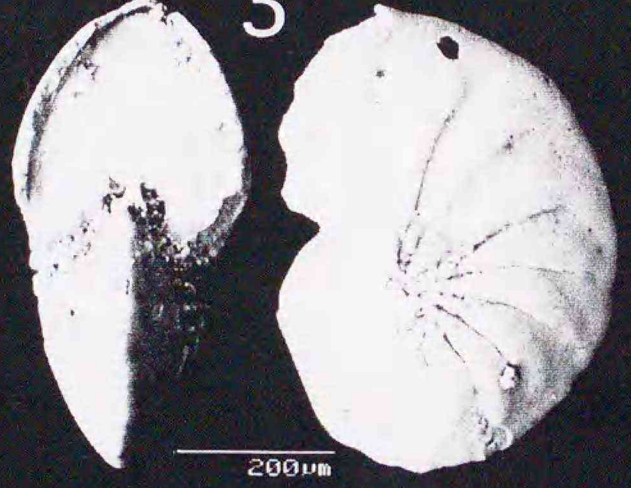

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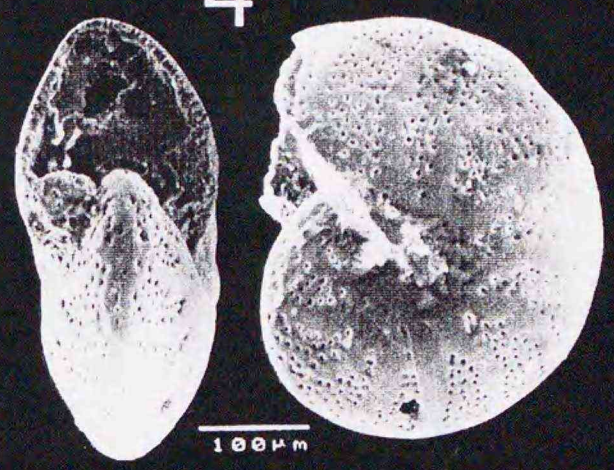

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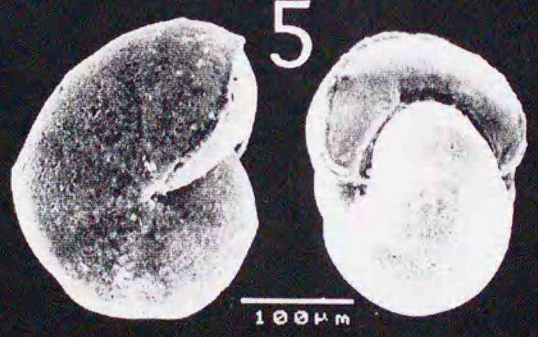

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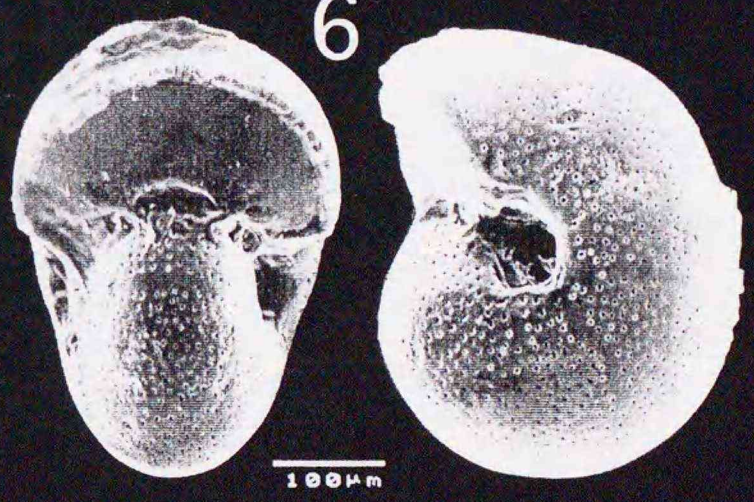

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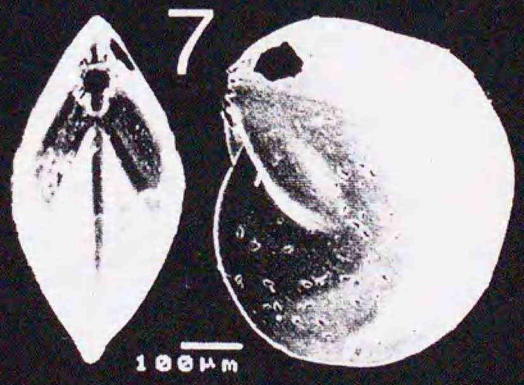

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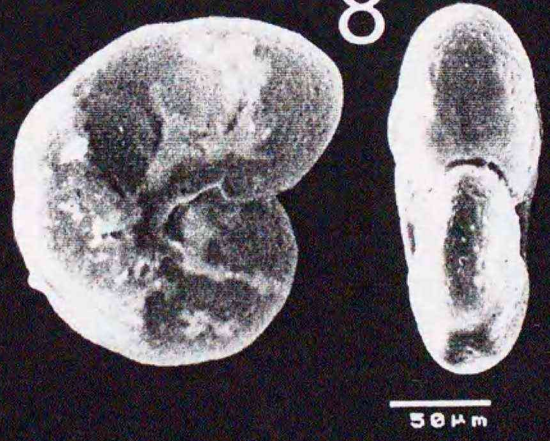

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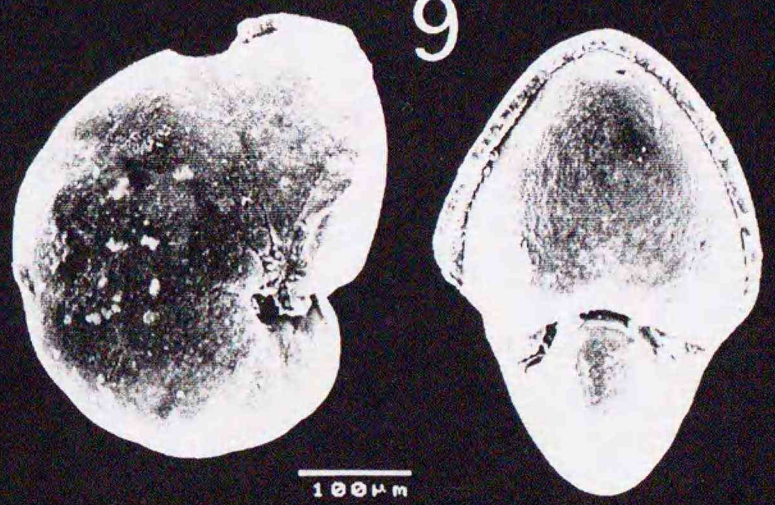


Benthic Foraminifera

1. *Planoglabratella*? sp. C

2. *Planoglabratella australensis* (Hellon-Allen and Earland)

3. *Planoglabratella opercularis* (d'Orbigny)

4.*Planoglabratella subopercularis* (Asano)

5.*Glabratella mirabiris panamensis* Seiglie and Bermúdez

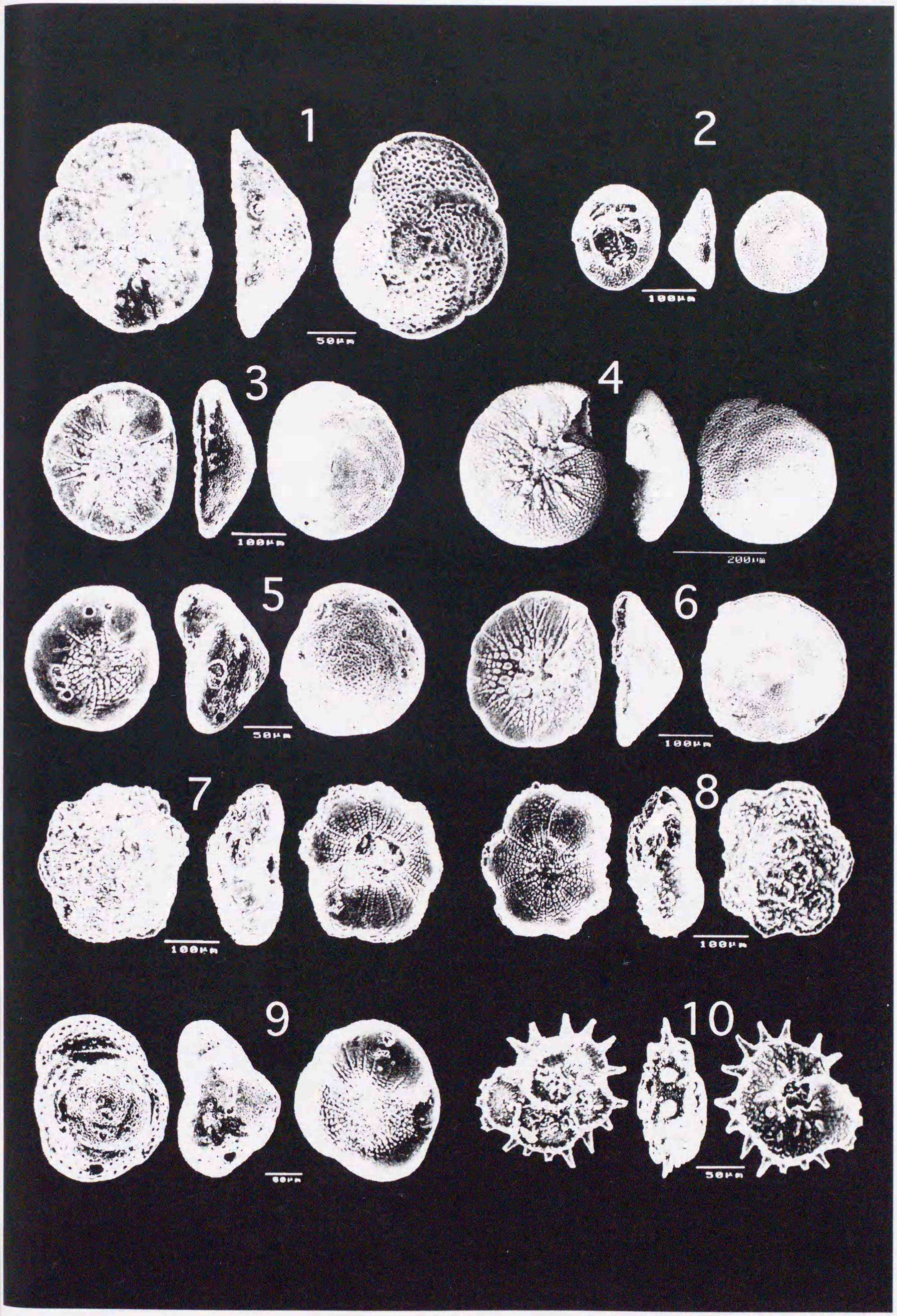
6. *Planoglabratella patelliformis* (Brady)

7-8. *Glabratella* sp. A

9. *Glabratella pulvinata* (Brady)

10. *Glabratella* sp. B

Plate 10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Benthic Foraminifera

1. *Planoglabratella subopercularis* (Asano)
2. *Epistominella pulchella* Husezima and Maruhasi
3. *Ammonia beccarii* (Linné)
4. *Islandidlla norcrossi* (Cushman)
5. *Islandiella japonica* (Asano and Nakamura)
6. *Islandiella yabei* (Asano and Nakamura)
7. *Islandiella helanae* Feyling-Hanssen and Buzas
8. *Islandiella yabei* (Asano and Nakamura)
9. *Pseudoparella takayanagii* (Iwasa)
10. *Pseudoparella naraensis* Kuwano

Plate 11

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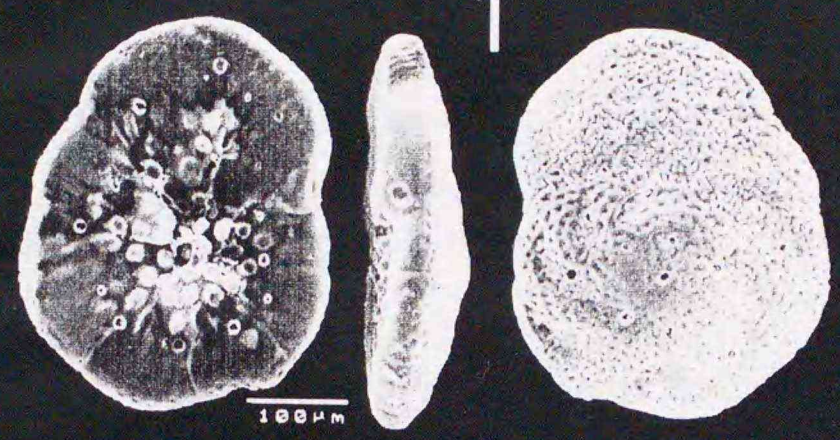

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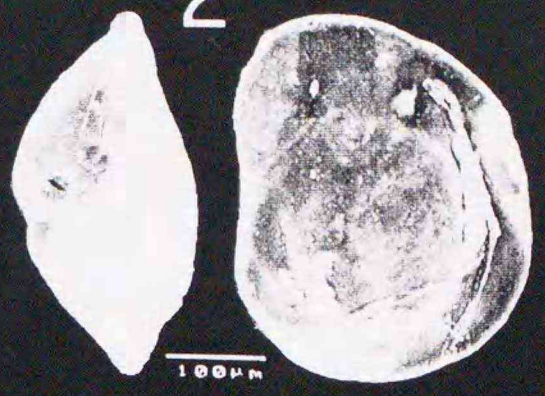

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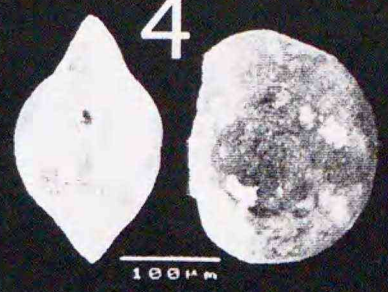

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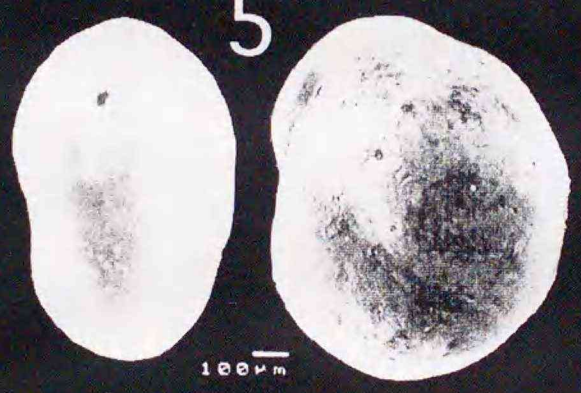

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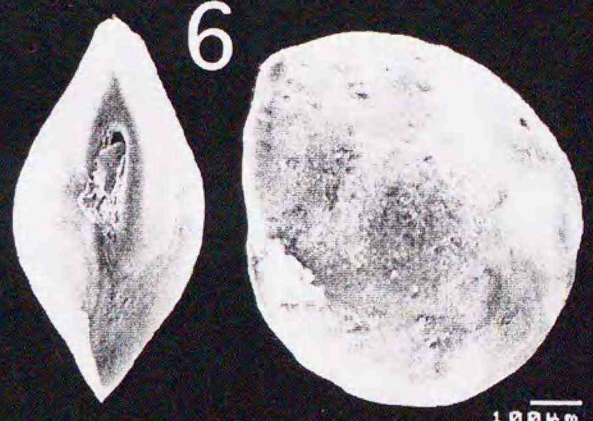

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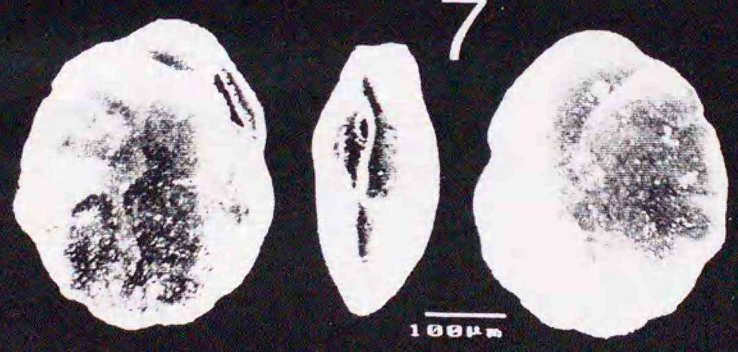

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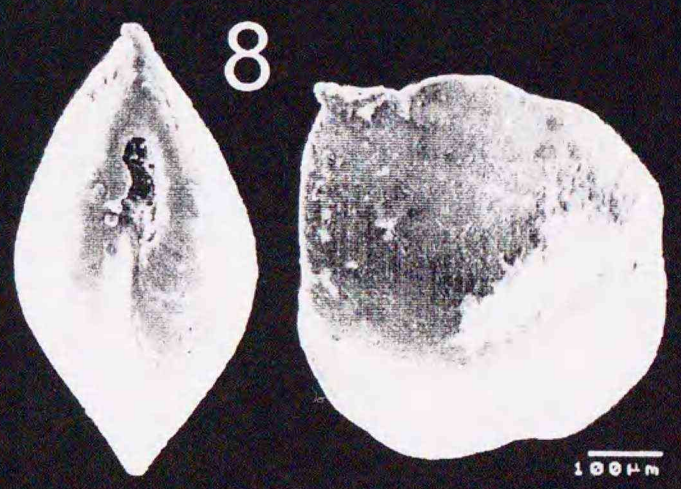

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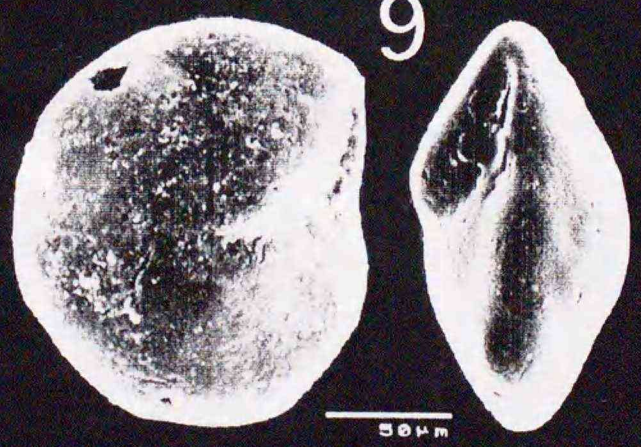

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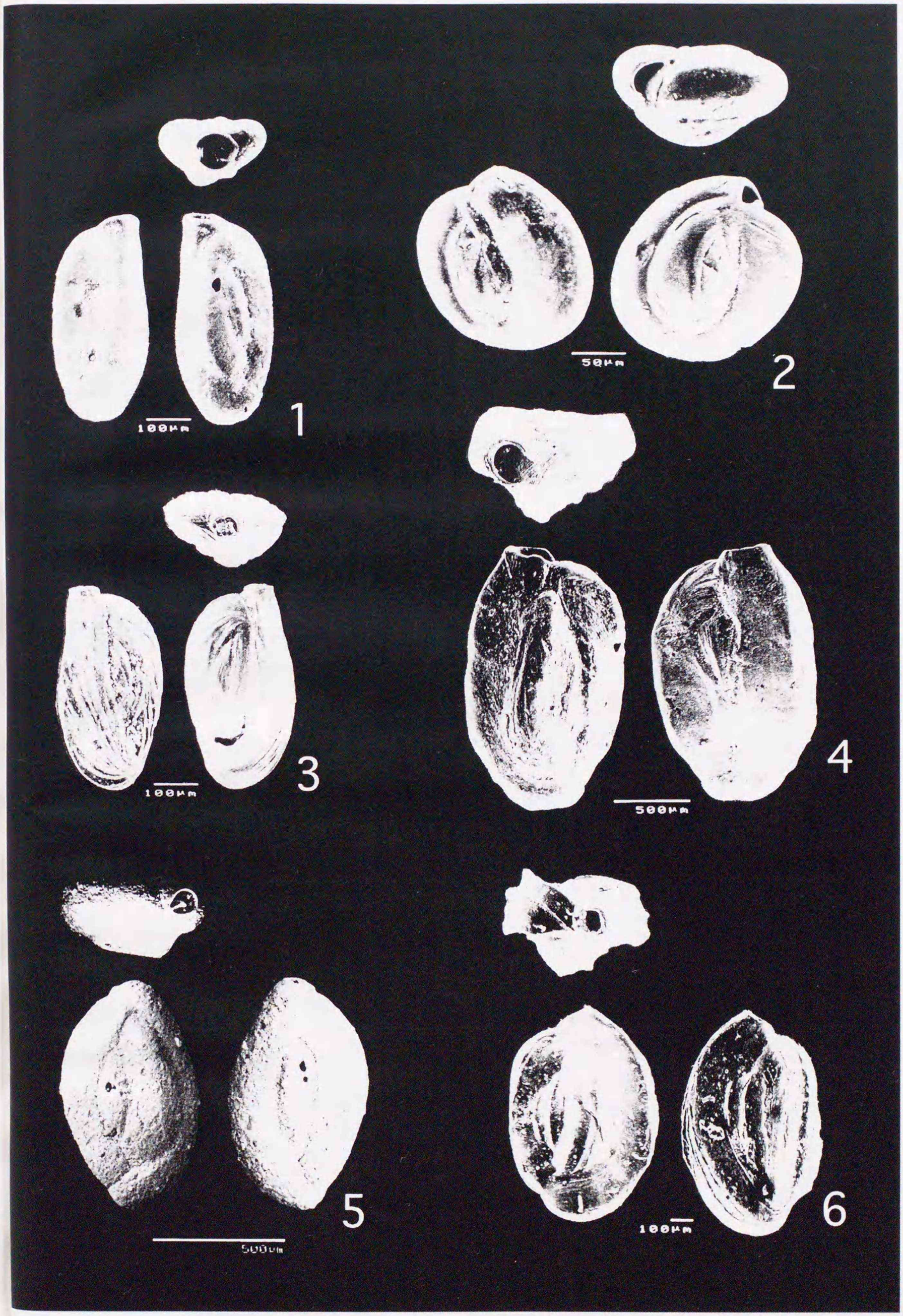
Benthic foraminifera

1. *Quinqueloculina* sp.G
2. *Pateoris hauerinoides* (Rhunbler)
3. *Quinqueloculina costata* d'Orbigny
4. *Quinqueloculina kuromatunaiensis* Asano
5. *Quinqueloculiua agglutinata* Cuslunan
6. *Quinqueloculina* sp.F

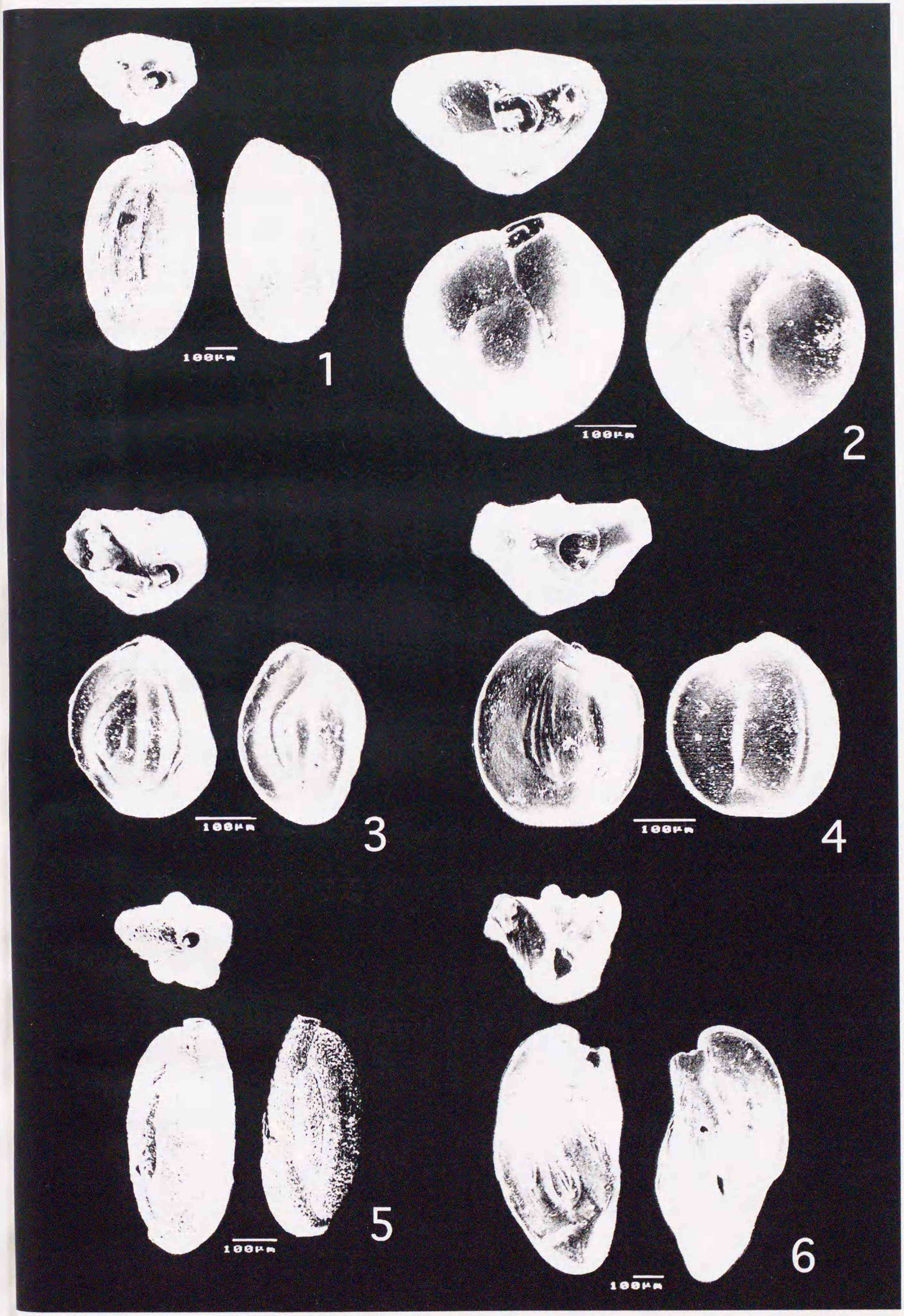
Plate 12



Benthic Foraminifera

1. *Cycloforia contrta* (d'Orbigny)
2. *Quinqueloculina akneriana* d'Orbigny
3. *Quinqueloculina* sp. C
4. *Cribrolinoides* curta (Cushman)
5. *Quinqueloculina* sp. B
6. *Quinqueloculina yessoensis* Asano

Plate 13



Benthic foraminifea

1. *Quinqueloculina akneriana* d'Orbigny

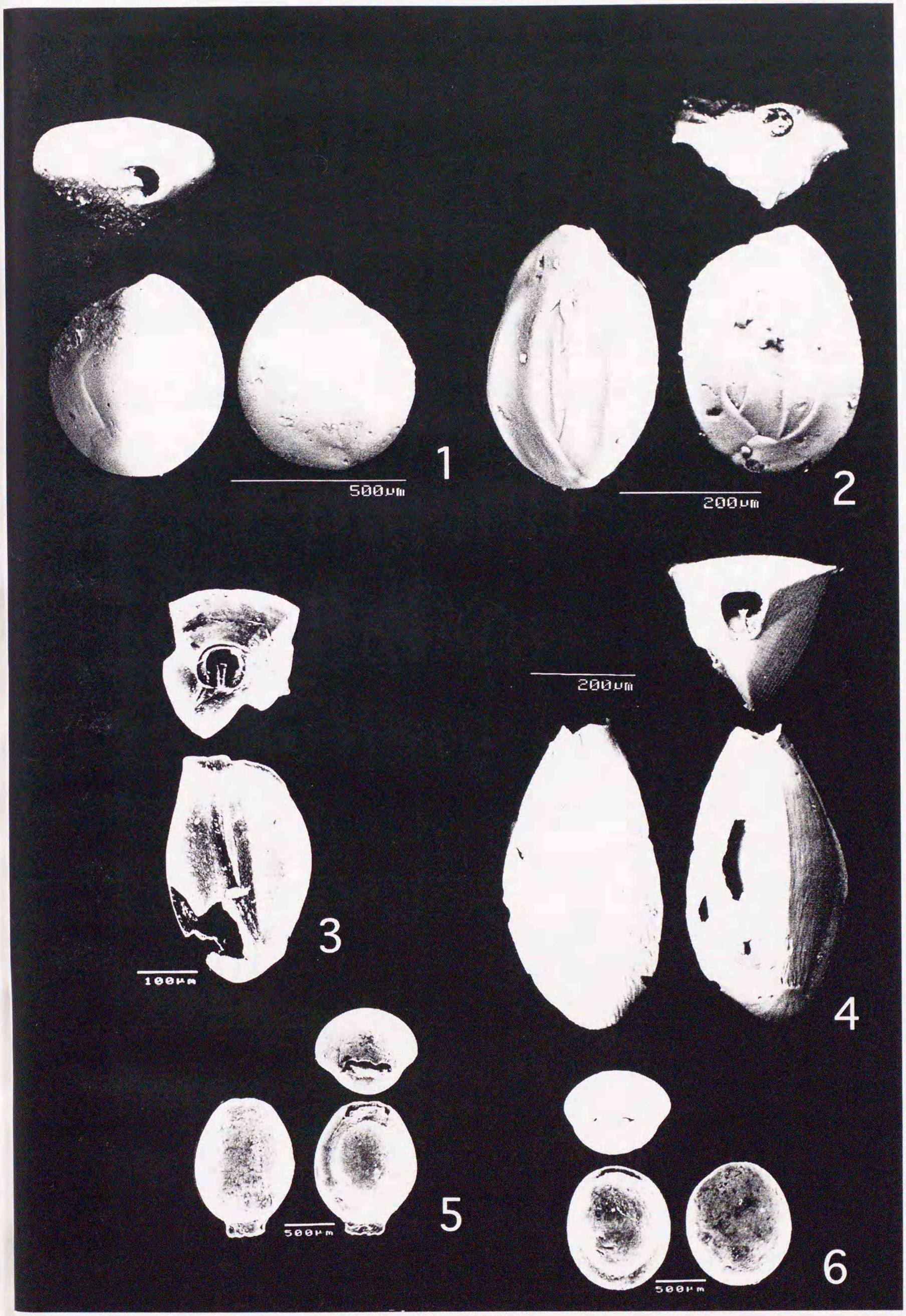
2. *Quinqueloculina sawanensis* Asano

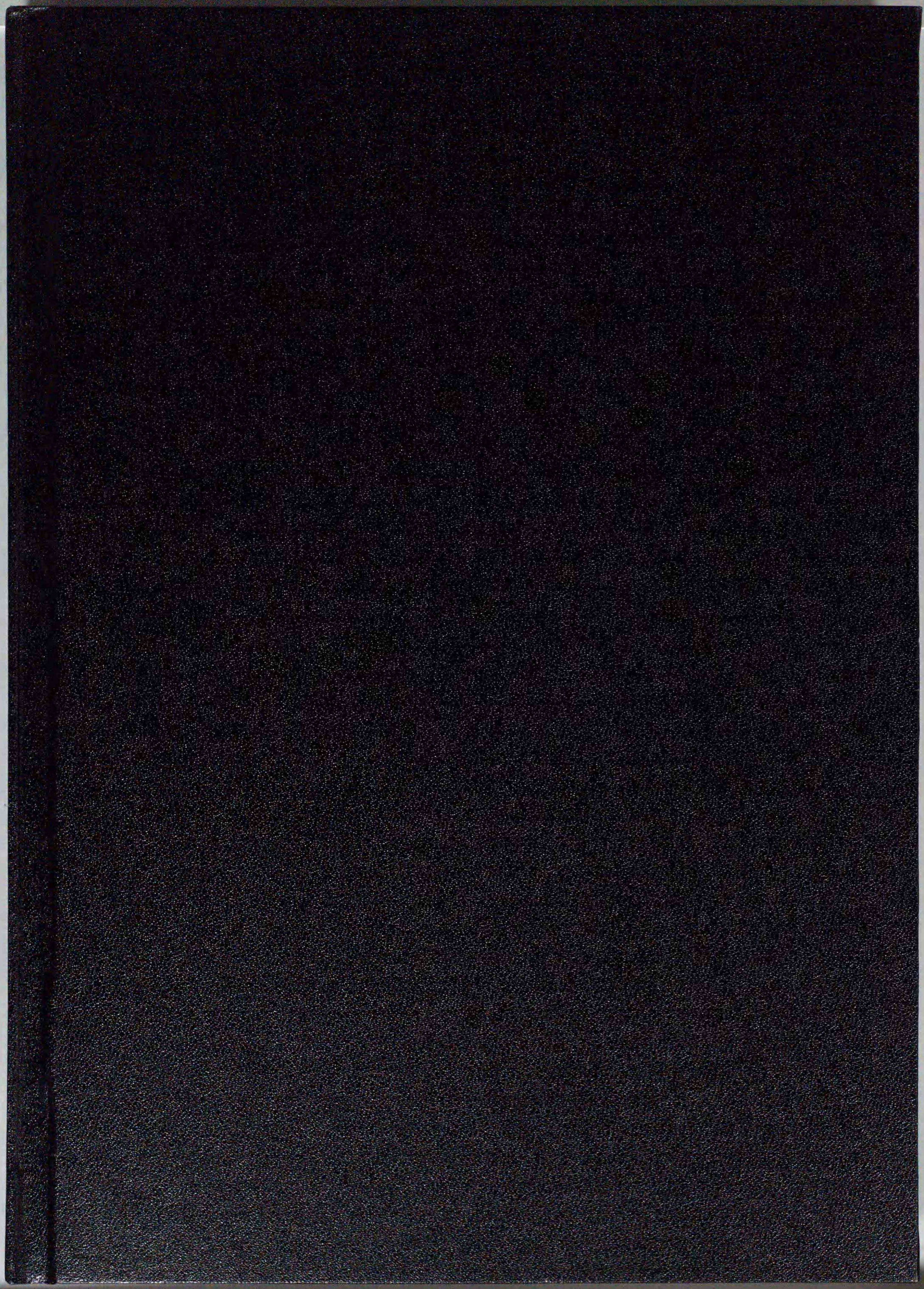
3. *Triloculina suttuensis* Asano

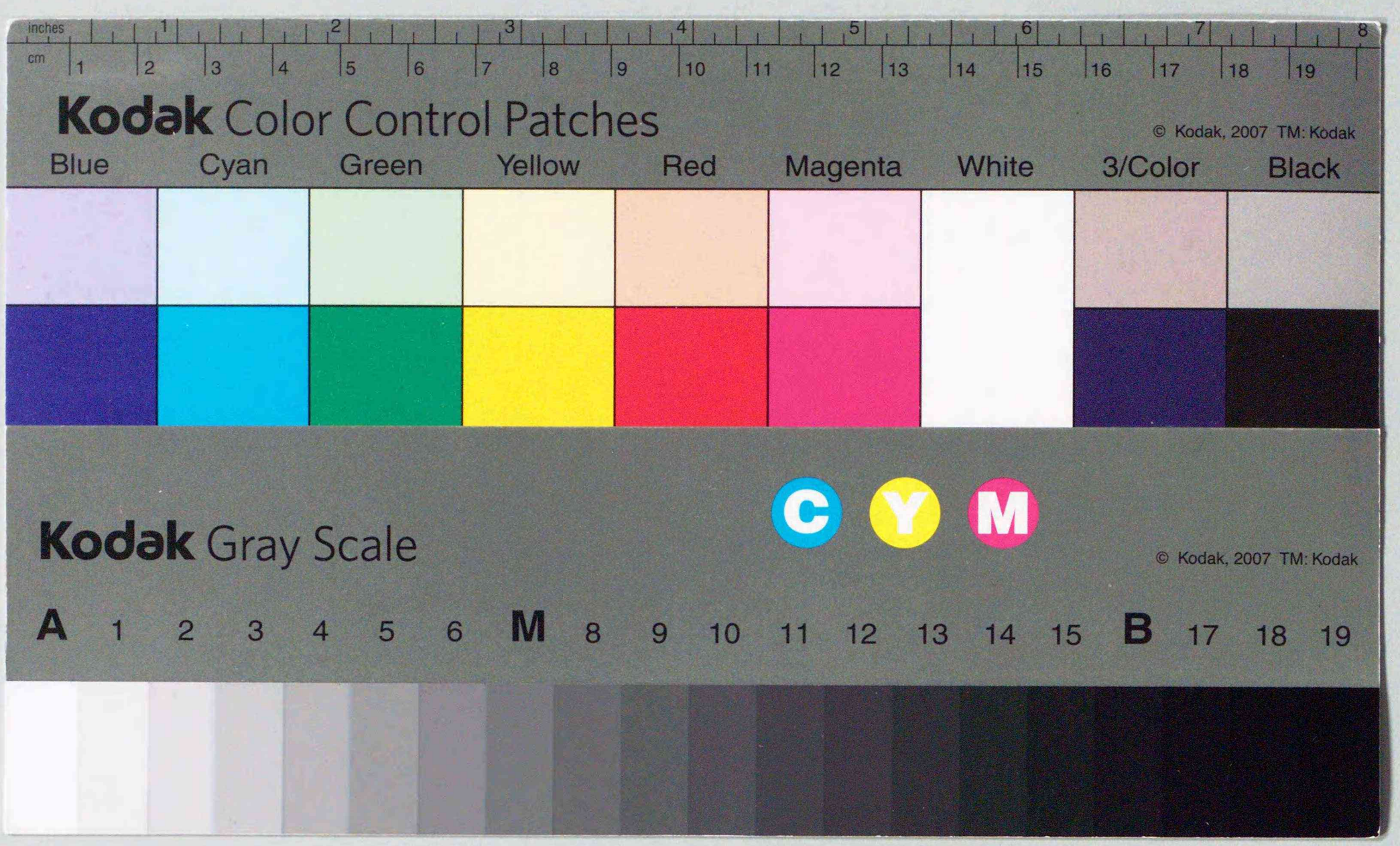
4. *Triloculina tricarinata* d'Orbigny

5-6. *Pyrgo ezo* Asano

Plate 14



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