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Stratigraphy, molluscan fauna and paleoenvironment of the Miocene Katsuta Group in Okayama Prefecture, Southwest Japan

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Abstract

The Miocene Katsuta Group, distributed in the western part of the First Setouchi Geological Province (Kasama and Fujita, 1957), is divided into the Mimasaka, Yoshino and Takakura Formations in ascending order. The relation of the former two is disconformable each other. The Yoshino and Takakura Formations are subdivided into the Makabe Conglomerate and lzumotawa Sandstone Members, and the Nokedai Mudstone and Takeda Sandstone and Mudstone Members, respectively. Both members in each case are conformable while contemporaneously heterotopic locally.

The Mimasaka Formation was deposited in a lacustrine environment under the temperate to warm climatic condition and thus yields the Early Miocene Daijima type flora.

The Yoshino Formation yields the molluscan fauna belonging to the Early Middle Miocene Kurosedani fauna (Tsuda, 1965). It consists of such molluscan assemblages as the *Geloina, Crassostrea gravitesta, Vicarya-Anadara, Turritella, Tellinella-Perna-Vepricardium-Vicaryella, Vepricardium-Euspira, Phacosoma, Saccostrea, Vasticardium-Phacosoma, Globuralia, Chlamys* and *Placopecten*. Each of the assemblages is analyzed on the basis of lithology, the mode of occurrence, mode of life, feeding type and paleoecology. Judging from paleoecology of molluscan assemblages and their spatial and temporal distributions and the distribution of *Operculina complanta japonica*, the Tsuyama Bay had opened to north. As a result, the bay suffered an invasion of warm oceanic water from north. Such an estimation is supported by the analysis of paleocurrent of the Katsuta Group.

The Takakura Formation bears the Korematsu Fauna (Okamoto, 1992) which is composed of the *Limopsis-Fissidentalium*, *Lucinoma-Propeamussium-Delectopecten* and *Vaginella* assemblages that are analyzed by the same procedure in the case of the assemblages of the Yoshino Formation.

The Tsuyama Bay subsided under the sea in inflow of oceanic warm water from north and west by the tectonic movement (probably fault movement) of the basement rocks occurred the near boundary between the Yoshino and Takakura Formations and the transgression.

The paleogeography of Chugoku district is reconstructed for three stages; a lacustrine environment scattered in the area is assumed in the first stage; the second stage is an early stage of the transgression; the third stage is a maximum transgressive phase.

The paleogeographic and paleoclimatic changes of the Japan Arc are discussed in the light with modern geographic and climatic point of view.

Key words: Katsuta Group, stratigraphy, molluscan assemblages, paleoenvironment, Miocene

CONTENTS

I. Introduction

The Miocene Series is sporadically distributed in the Chugoku district which is divided into three as the Saikai, Setouchi and San-in-Hokuriku provinces (Fig. 1). Among them, the second is subdivided into the western and eastern parts near Osaka Bay because of differences of stratigraphy, lithology and molluscan faunas (Itoigawa and Shibata, 1973).

In the western Setouchi Province which is representative of quasicratonic basins (Makiyama, 1954; Itoigawa, 1991), many geological and paleontological studied on the Miocene Series along the southern margin of Chugoku mountainous district have been done (Yokoyama, 1929; Takeyama, 1930; Suyari, 1951; Imamura, 1953; Tai, 1954, 1957; Okamoto and Terachi, 1974; Itoigawa and Nishikawa, 1976; Yoshimoto, 1979; Taguchi et al., 1979, 1981; Taguchi, 1981; Shibata and Itoigawa, 1980; Okamoto et al., 1978, 1986, 1989 a, b, 1991; Okamoto, 1992; Itoigawa and Shibata, 1992; Yamamoto and Nozaki, 1997; Nishimura and Nozaki, 1997 etc.) .

The Tsuyama sedimentary basin is important in the western Setouchi Province because the study of the Miocene Series has been begun in the early stage.

The followings are chronological arrangements of the works.

Yokoyama (1929) : description of molluscan new species.
Takeyama (1930) : geology and paleontology of the Katsuta Group.
Hatai and Nisiyama (1949) : description of molluscan new species.
Suyari (1951) : geological study.
Tai (1954) : benthic foraminiferal study.
Tamura (1957) : geological study.
Kawai (1957) : geological and paleontological studies.
Tai (1957) : benthic foraminiferal study.
Yoshimoto (1979) : studies of planktonic foraminifera, calcareous nannofossil and radioralia.
Shibata and Itoigawa (1980) : paleogeographical study on the basis of molluscan analysis.
Taguchi et al. (1981) : description of new molluscan species.
Taguchi (1981) : reconstruction of species association of brackish molluscs.
Yamana and Yamaga (1982) : report of *Bathynomus* sp.
Taguchi (1983a) : description of new molluscan species.
Taguchi (1983b) : description of new molluscan species.
Taguchi (1984) : paleoenvironmental and paleoclimatic studies on the basis of molluscan analysis.
Ohe et al. (1986) : description of *Scomberomorus* sp. and its paleoenvironment.
Shibata et al. (1989) : study of pteropods.
Taguchi (1990) : description of new molluscan species.

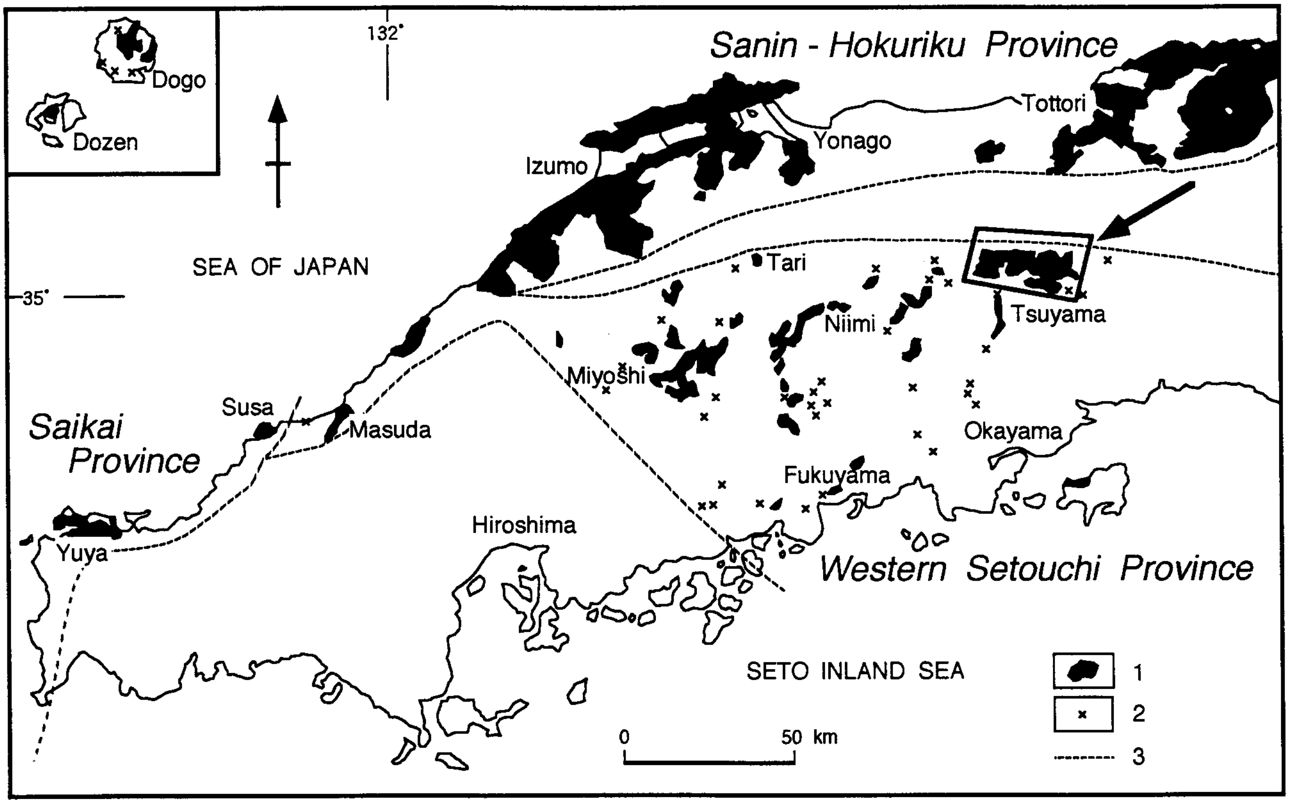

Fig. 1. Distribution of the Miocene sequences in Chugoku district.
1: Miocene strata, 2: Exposures of Miocene strata, 3: Boundary of each province (after Yamauchi and Takayasu, 1987)

(1980)'s revision.

Taguchi (1992) : description of new molluscan species.

Karasawa and Kishimoto (1996) : study of decapod crustacean fauna.

Nishimura and Nozaki (1997) : reconstruction of paleocurrent direction of the Katsuta Group.

Yamamoto and Nozaki (1997) : decision of geological age of the Katsuta Group based on calcareous nannofossils.

In this study, I describe the geology of the Katsuta Group in detail, and discuss the paleoecology and paleoenvironment of it mainly based on the analysis of the molluscan fauna and reconstruct the paleogeography of the Tsuyama basin and the Chugoku district. Finally I will depict the paleogeography of the Japan Arc and its environs with discussion on paleoceanography in relation to the formation of Sea of Japan.

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II. Outline of geology

The Miocene Katsuta Group developed in the northeastern part of Okayama Prefecture is composed of relatively thin clastic sediments accompanied with a little amount of volcanic rocks and unconformably rests on or abuts the basement rocks and contacts with them in fault relation in the northern area.

A. The underlying rocks of the Katsuta Group

The basement rocks of the Katsuta Group are classified into the Sangun metamorphic rocks, non-metamorphic Paleozoic strata the Yakuno Intrusive Rocks, Mesozoic strata and Cretaceous to Paleogene igneous rocks. The Tomata Formation (Kawai, 1957), namely, the Sangun metamorphic rocks, is distributed in the northern area and is mainly pelitic schist accompanied with siliceous and psammitic schists. The Aida Formation (Kawai, 1957) consists of pelitic schist and non-metamorphic strata like as slate, sandstone and conglomerate of which age is the Permian. The Yakuno Intrusive, involved in the Maizuru Group, are composed of metagabbro and metadiabase and so on. Mesozoic strata, the Hirono Formation (Kawai, 1957) designated as the Fukui and Shimoyama Formations by Mitsuno in 1987, is made up mainly of shale and sandstone which yield *Monotis* spp. indicating late Triassic age. The Cretaceous to early Paleogene igneous rocks are composed chiefly of the second rhyolite rocks (Mitsuno, 1987), Nagisen volcanic rocks which are made up of andesite (Mitsuno, 1987), quartz porphyry and granodiorite (Kawai, 1957).

B. The overlying rocks of the Katsuta Group

The alkali basalt, which intruded the Katsuta Group, is sporadically distributed in the Tsuyama sedimentary basin. According to Iwamori (1989) the activity of this volcanism started at 12Ma.

The Nihonbara Formation composed of angular to round gravels with intercalation of sand, is unconformably underlain by the Katsuta Group and is probably an alluvial fan deposit as pointed out by Kawai (1957). Its geological age is perhaps of the late Pleistocene.

C. Nomenclature of the Katsuta Group

The Katsuta Group is stratigraphically divided into the Mimasaka, Yoshino and Takakura Formations in ascending order. The relationship between the former two is discomformable by Ikebe (1957)'s proposal.

The Yoshino Formation and the Takakura Formation are divided into the Makabe Conglomerate and Izumotawa Sandstone Members, and the Nokedai Mudstone and Takeda Sandstone and Mudstone Members, respectively. The Makabe Conglomerate Member is generally conformablly overlain by the Izumotawa Sandstone Member while both members are contemporaneous locally. The relationship between the Nokedai Mudstone Member and the Takeda Sandstone and Mudstone Member is conformable, but both members interfinger partly. Generalized stratigraphy of the Katsuta Group is shown in Table 1. Table 2 shows the correlation of stratigraphic divisions with previous works.

Takeyama (1930) divided this group into the Uetsuki Series below and the Tsuyama Series above. Tamura (1957) gave a new division to the Miocene Series, namely, the Mimasaka Formation and the Katsuta Group in ascending order. The latter of which was subdivided into the Yasuda Sandstone and Shale Formation, Toyokuda Sandstone Formation and Makabe Conglomerate Formation in descending order. He thought that the relationship between the Mimasaka Formation and the Katsuta Group is unconformable. After that, Kawai (1957) named this Miocene Series the Katsuta Group which is divided into three formations, namely, the Uetsuki, Yoshino and Takakura Formations in ascending order, among which the second and the last were subdivided into the Makabe Conglomerate and Izumotawa Sandstone Members and the Takata Sandstone and Oosawa Sandstone and Mudstone Members, respectively. He described that the Uetsuki Formation is conformably overlain by the Yoshino Formation while two formations are unconformable locally. I think that the Mimasaka Formation of Tamura (1957) should be used here because the Uetsuki formation of Kawai (1957) is not typically distributed at Uetsuki.

The Makabe Conglomerate and the Toyokuda Sandstone Formations of Tamura (1957) are roughly comparable with the Yoshino Formation of Kawai (1957). However, the local name of Toyokuda does not appear in quadrant 1:50000 Tsuyama-tobu newly published by Geographical Survey Institute of Japan. Thus the Yoshino Formation is used here. The Yasuda Sandstone and Shale Formation of Tamura (1957) is compared to the Takakura Formation of Kawai (1957) but the name of Yasuda is too small and local. Therefore, the Takakura Formation is

Table 1. Stratigraphy of the Katsuta Group.

Age	Stratigraphy				Maximum thickness	Lithofacies	Fossils
Late Pleistocene	Nihonbara Formation				30 m	Gravel Sand	
Early to Middle Miocene	Katsuta Group	Takakura Formation	Takeda Sandstone and Mudstone Member	Alkaline Basalt	80 m	Mudstone Sandstone Tuff	Fragment of Plants
Early to Middle Miocene	Katsuta Group	Takakura Formation	Nokedai Mudstone Member	Alkaline Basalt	100 m	Mudstone Sandy Mudstone Sandstone Tuff	*Lucinoma acutilineatum* *Propeamssium tateiwai* *Delectopecten peckhami* *Limopsis* sp. *Fissidentalium yokoyamai*
Early to Middle Miocene	Katsuta Group	Yoshino Formation	Izumotawa Sandstone Member	Alkaline Basalt	20 m	Mudstone Sandstone Sandy Mudstone Breccia Conglomerate Tuff	*Geloina* spp. *Vicarya japonica* *Operculina complanata japonica* *Paleoparadoxia tabatai*
Early to Middle Miocene	Katsuta Group	Yoshino Formation	Makabe Conglomerate Member	Alkaline Basalt	40 m	Mudstone Sandstone Conglomerate Tuff	
Early to Middle Miocene	Katsuta Group	Mimasaka Formation		Alkaline Basalt	30 m	Mudstone Sandstone Conglomerate Tuff	*Quercus glauca* *Cinnamomum lanceolatum*
Pre-Neogene	Basement rocks						

Table 2. Correlation table of the Katsuta Group.

Takeyama (1930)	Tamura (1957)		Kawai (1957)			This paper		
Tsuyama Series	Katsuta Group	Yasuda Sandstone Shale Formation	Katsuta Group	Takakura F.	Takata Sandstone Mudstone Member / Ozawa Sandstone Mudstone Member	Katsuta Group	Takakura F.	Takeda Sandstone & Mudstone Member / Nokedai Mudstone Member
Tsuyama Series	Katsuta Group	Toyokuda Sandstone Formation	Katsuta Group	Yoshino F.	Izumotawa Sandstone Member / Makabe Conglomerate Member	Katsuta Group	Yoshino F.	Izumotawa Sandstone Member / Makabe Conglomerate Member
Uetsuki Series	Katsuta Group	Makabe Conglomerate Formation	Katsuta Group	Yoshino F.	Izumotawa Sandstone Member / Makabe Conglomerate Member	Katsuta Group	Yoshino F.	Izumotawa Sandstone Member / Makabe Conglomerate Member
Uetsuki Series	Mimasaka Formation		Uetsuki Formation			Mimasaka Formation		

adopted. Although Kawai (1957) divided the Takakura Formation into the Takata Sandstone and Mudstone and Oosawa Sandstone and Mudstone Members. I herein propose a new stratigraphic division such as the Nokedai Mudstone and Takeda Sandstone and Mudstone Members under the new concept. The relationship between the Mimasaka Formation and the Yoshino Formation is disconformable as can be judged from my field observation (Pls. 1, 2).

III. Stratigraphy of the Katsuta Group

The geological map, geological profiles and geological columnar section of the Katsuta Group are shown in Figs. 2, 3 and 4. The investigated area is divided into the western, central and eastern areas in order to avoid to use complicated local place names, where the type localities of the members and formations are established. In the eastern area, the type localities of the Mimasaka Formation and Yoshino Formation consisting of the Makabe Conglomerate and Izumotawa Sandstone Members are found. In the central area, the type locality of the Takakura Formation including the Nokedai Mudstone Member can be seen. In the western area, the type locality of the Takeda Sandstone and Mudstone Member is established. The general remarks of each formation and member are described in the following lines.

A. Mimasaka Formation (Tamura, 1957)

Type locality: The outcrop of the golf link of Toyokuni, Mimasaka-cho. This locality is redesignated one.

Distribution: This formation exposes only in the eastern area except a very small outcrop in the central area.

Lithofacies: This formation consists of conglomerates, sandstones and mudstones intercalating a tuff and lignitic layers. The conglomerate is chiefly composed of pebbles and cobbles, while boulders are present near the basement rocks and they have sphericity of subround to subangular. Pebbles of rhyolite, porphylite, sandstone and mudstone derived from the Hirono Formation are main components of the conglomerate.

The sandstone is fine to medium-grained in general and looks greenish gray at the fresh outcrops. The mudstone is greenish black except laminated mudstone which displays brownish purple. The white to yellowish white tuff is remarkably altered to illite and kaolinaite (Fig. 5). The lignite is fissile and black .

Fossils: According to Takahashi (1959), this formation yields fossil plants such as *Trachycarpus* sp., *Quercus glauca*, *Cinnamomum lanceolatum*, *C.* sp., *Smilax trinervis*, *Laurus* spp., *Zelkowa ungeri*, *Lindera* sp. and *Pterocarya*? sp. which belong to the Early Miocene Daijima type flora (Yamanoi, personal communication). Unfortunately I could not obtained the well-preserved plants. Any fossil does not find in the formation with the exception of plants.

Thickness: Thickness of the formation varies from 1 m to 40 m.

B. Yoshino Formation (Kawai, 1957)

This formation is divided into the Makabe Conglomerate Member and Izumotawa Sandstone Member, the former of which is conformably overlain the latter, although the both interfinger locally.

1) Makabe Conglomerate Member (Kawai, 1957)

Type locality: A cliff of a small valley at Makabe, Katsuta-cho. This locality is redesignated one.

Distribution: This member is distributed in all over the area except the northern part.

Lithofacies: The member is made up of conglomerates, sandstones, sandy mudstones, mudstones and a tuff layer. The grain size of the conglomerate is mainly pebble to cobble, accompanied with boulder near the basement rocks and its sorting grade varies from well to ill as a whole. The sphericity of them is subround to subangular, but is angular immediately above the basement rocks locally. The grain size decreases upward as a whole. The conglomerate is composed mainly of pebbles of metadiabase, slate, pelitic schist, rhyolite, porphylite, granodiorite, granite, sandstone and mudstone derived from the Mimasaka Formation and so on. The fine- to coarse-grained sandstones show bluish gray in fresh outcrop and their lateral change in lithofacies are remarkable. Cross-laminations are well developed in them. The sandy mudstone and mudstone display dark gray. The tuff shows white to yellowish white.

Fossil: Fossils are not found in the member.

Thickness: The thickness of the member changes from 2 m to 40 m.

2) Izumotawa Sandstone Member (Kawai, 1957)

Type locality: A small cliff at lzumotawa, Sho'oh-cho. This locality is redesignated one.

Distribution: This member occupies all over the area.

Lithofacies: The member is made up of conglomerates, breccias, sandstones, sandy mudstones, mudstones and a tuff bed accompanied with lignite layers and lignitic films.

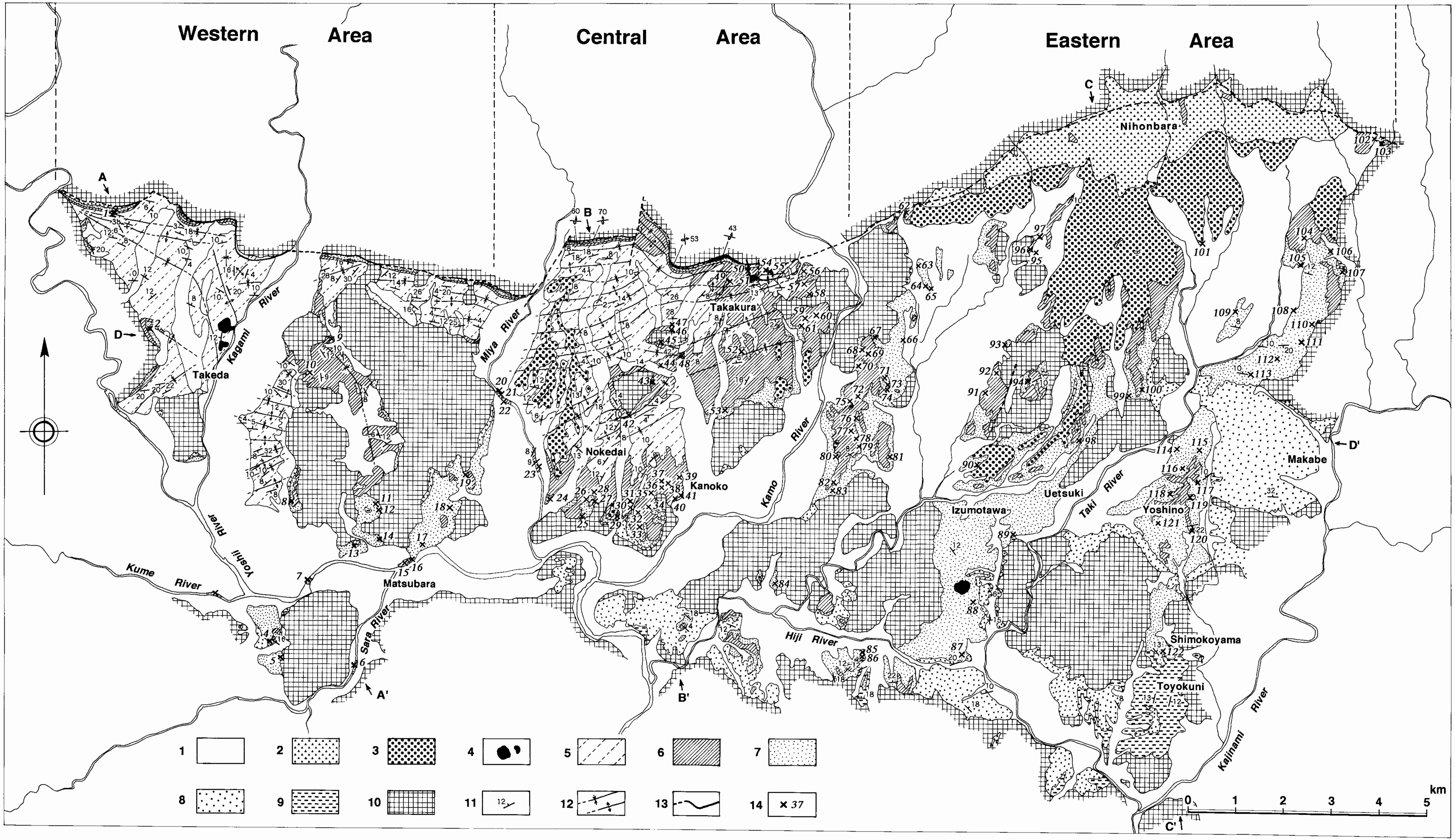

Fig. 2. Geological map. 1: Alluvium, 2-3: Nihonbara Formation, 2: Angular gravel, 3: Round gravel, 4: Basalt, 5: Takeda Sandstone and Mudstone Member, 6: Nokedai Mudstone Member, 7: Izumotawa Sandstone Member, 8: Makabe Conglomerate Member, 9: Mimasaka Formation, 5-6: Takakura Formation, 7-8: Yoshino Formation, 5-9: Katsuta Group), 10: Basement rocks, 11: Strike and dip, 12: Axes of anticline and syncline, 13: Fault, 14: Fossil locality

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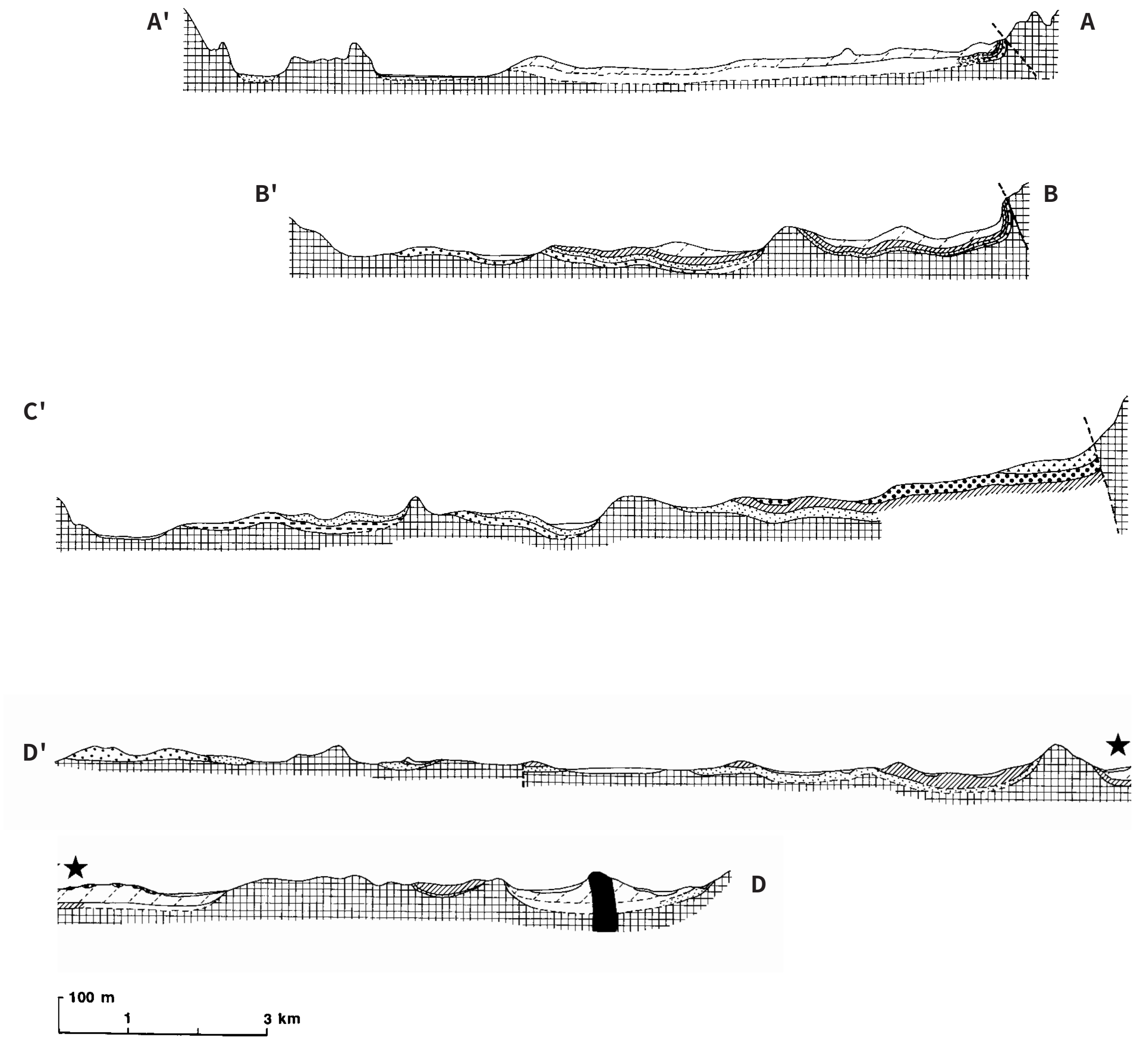


Fig. 3. Geological profiles. Legend is same for geological map.

The grain of conglomerate is round to subround in sphericity, granule to cobble in size and relatively well-sorted. The breccia is composed mainly of angular to subangular pebbles with a small amount of subround pebble sand its maximum diameter measures 2m. Its components are different from place to place, but most of them are derived from the basement rocks nearby. The sandstone shows bluish gray to light gray in flesh outcrop and is medium- to coarse-grained while fine-grained sandstone is rarely observed. The sorting of the sandstone varies from well to ill as a whole. The white to yellowish white tuff is remarkably altered to smectite and chlorite (Fig. 6). The breccia is good key marker which divides the member into the lower and upper parts. The base of breccia shows the bottom of the member.

Fossils: The member yields a large amount of fossils such as molluscs, crabs, elasmobranchs and mammals with pollens and plant leaves.

Thickness: A maximum thickness of the member measures 20 m and it is 2 m in minimum.

C. Takakura Formation (Kawai, 1957)

This formation is divided into the Nokedai Mudstone Member and the Takeda Sandstone and Mudstone Member in ascending order, while both members are contemporaneous locally intercalating the same tuff bed.

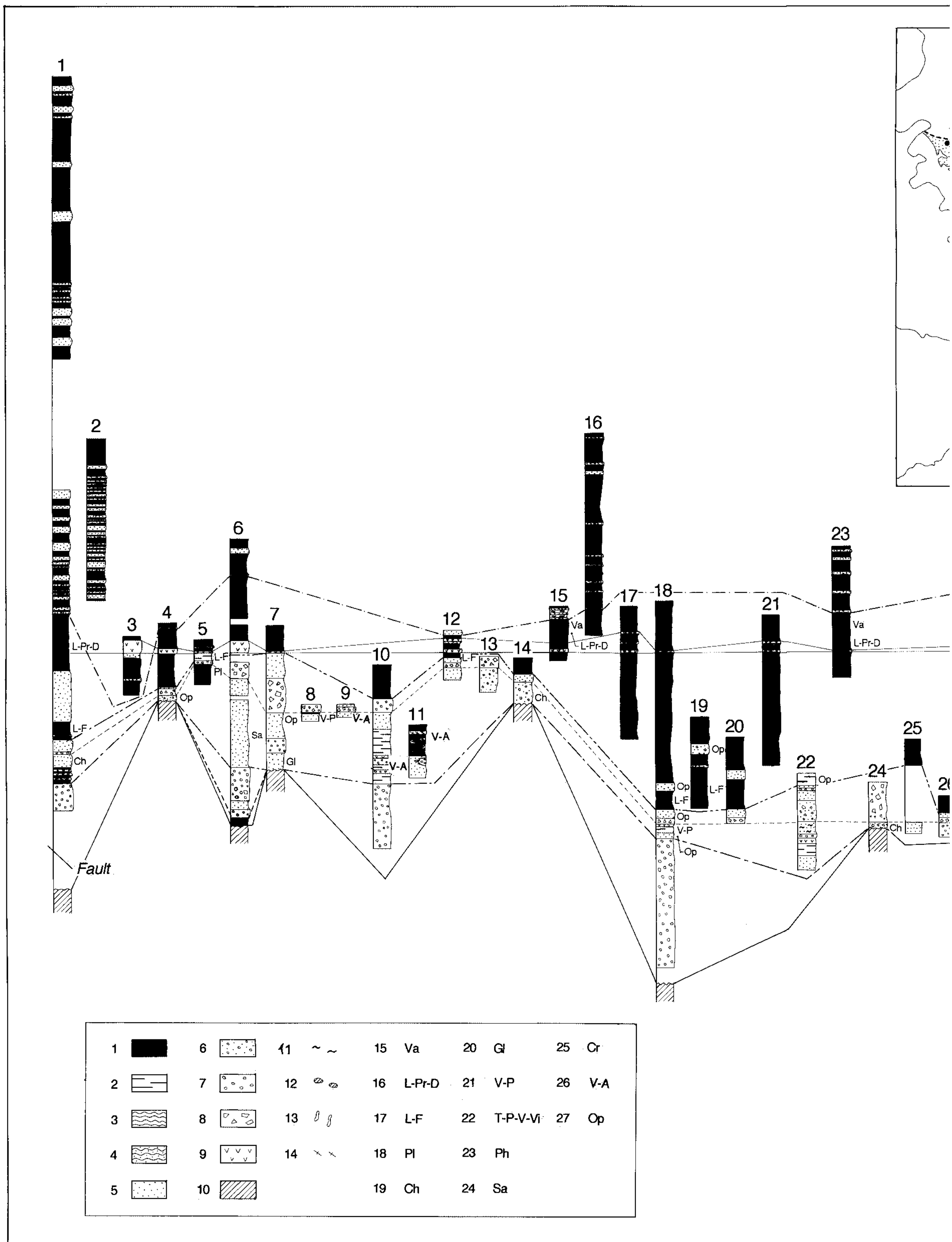
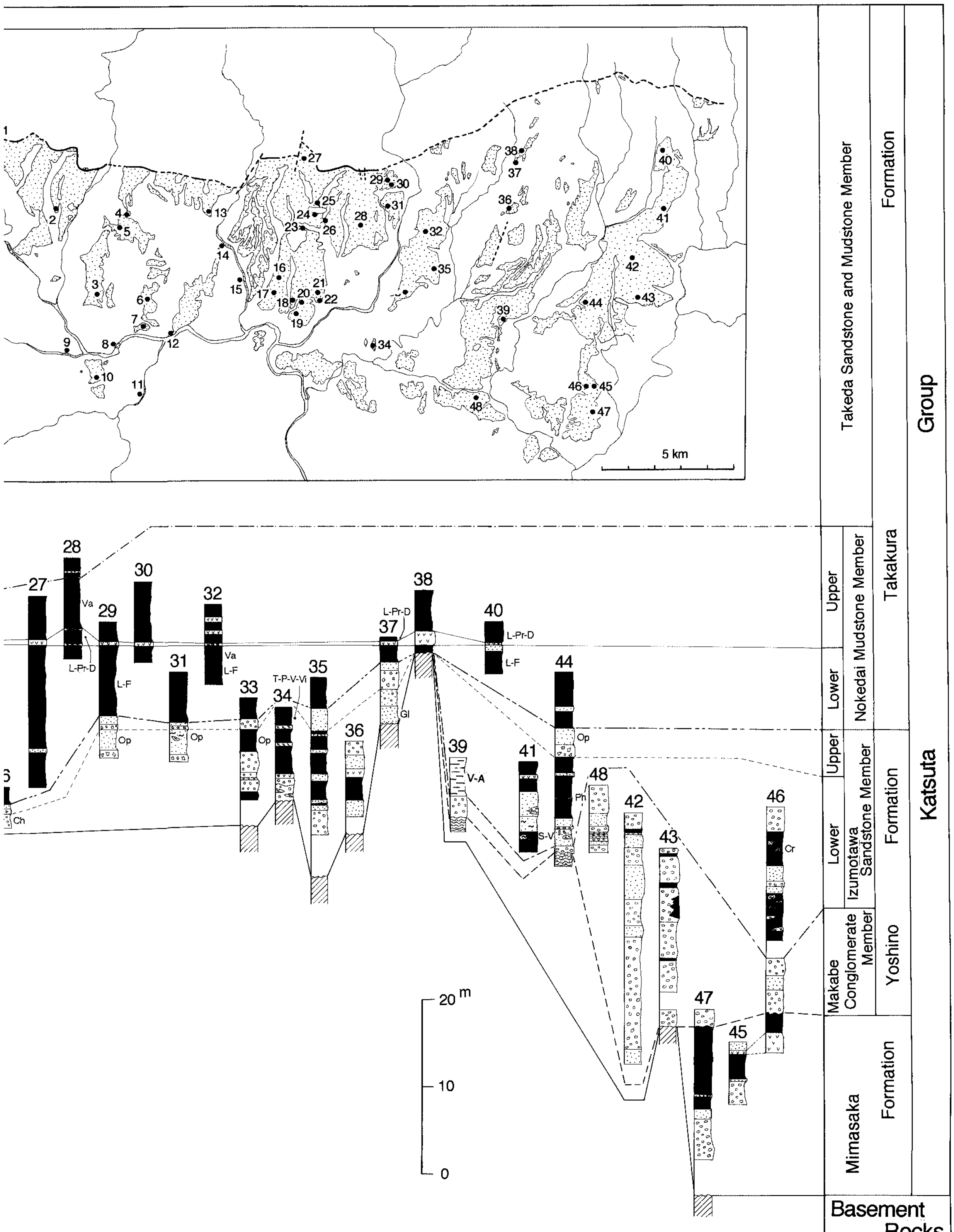


Fig. 4. Geological columns. 1: Mudstone, 2: Sandy mudstone, 3: Laminated mudstone, 4: Laminated sandstone, 5: Sandstone, 6: Pebble-bearing sandstone, 7: Conglomerate, 8: Breccia, 9: Tuff, 10: Basement rocks, 11: Lignite, 12: Nodule, 13: Trace fossils, 14: Coal seam, 15: *Vaginella* assemblage, 16: *Lucinoma-Propeamussium-Delectopecten* assemblage, 17: *Limopsis-Fissidentalium*



assemblage, 18: *Placopecten* assemblage, 19: *Chlamys* assemblage, 20: *Globularia* assemblage, 21. *Vasticardium-Phacosoma* assemblage, 22: *Tellinella-Perna-Vepricardium-Vicaryella* assemblage, 23: *Phacosoma* assemblage, 24: *Saccostrea* assemblage, 25: *Crassostrea gravitesta* assemblage, 26: *Vicarya-Anadara* assemblage, 27: *Operculina complanata japonica*

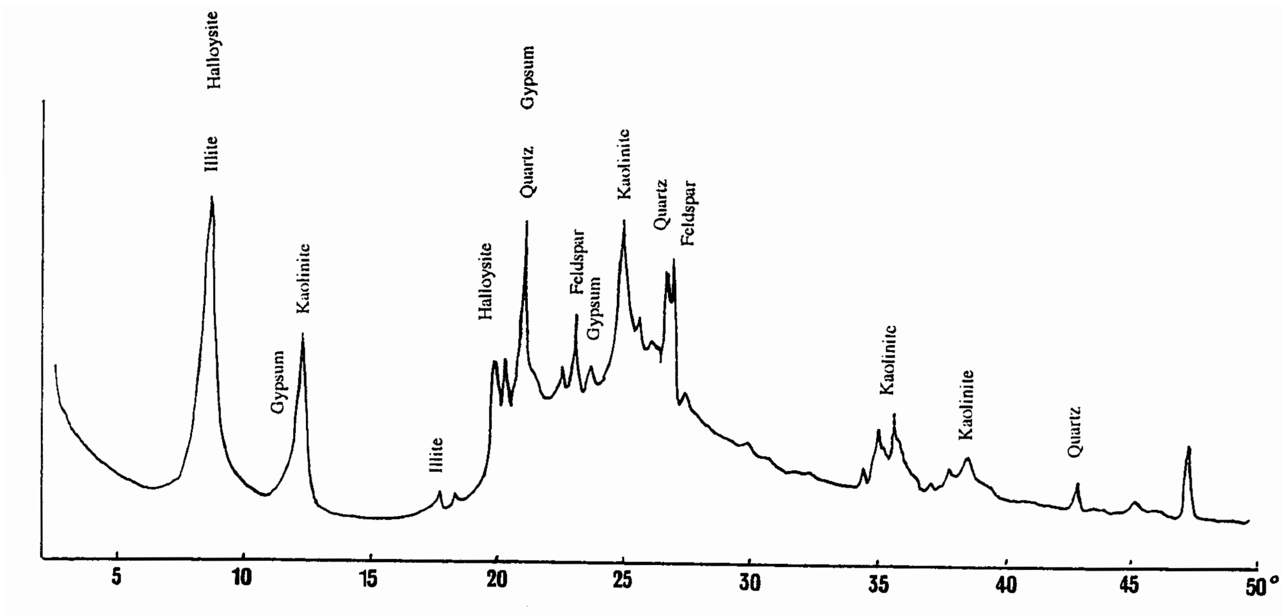


Fig. 5. Diffraction pattern of X ray of the tuff in the Mimasaka Formation.

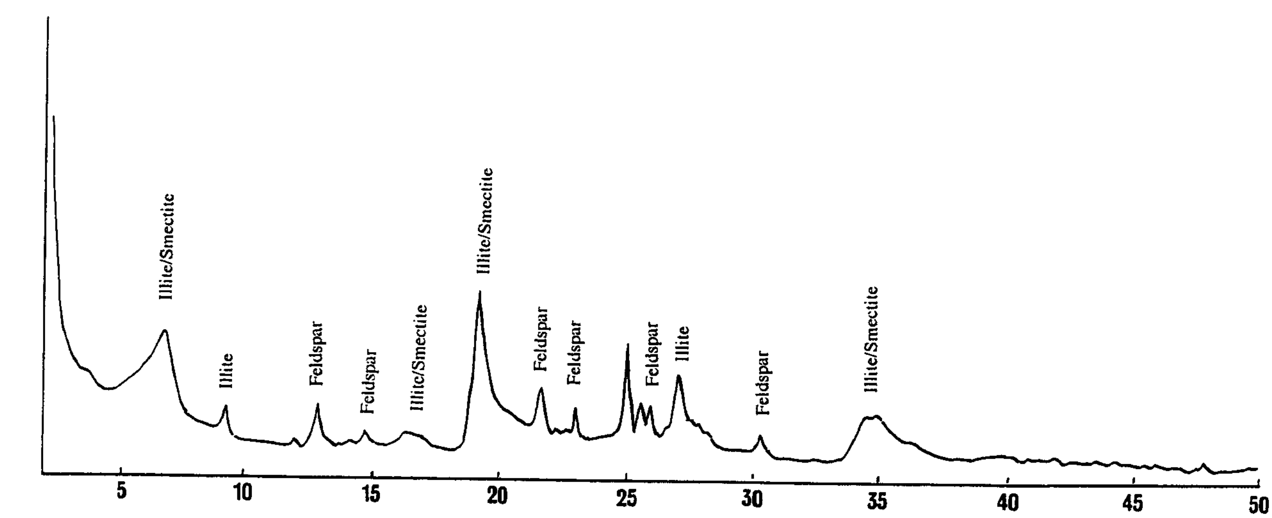


Fig. 6. Diffraction pattern of X ray of the tuff in the Yoshino Formation.

1) Nokedai Mudstone Member (newly proposed name)

Type locality: A road side cutting along Chugoku Express Highway at Nokedai, Tsuyama City. Now the type locality cannot be observed.

Distribution: This member exposes all over the area.

Lithofacies: The member is made up mainly of mudstones, sandy mudstones, sandstones and tuff beds. The mudstone is compact or fissile showing dark gray. The color of the sandy mudstone is as same as that of the mudstone. The sandstone is medium- to coarse-grained with intercalations of granule, displaying yellowish brown in weathered state. The white to bluish gray tuff is altered to smectite (Fig. 7). This tuff, which is locally forked to two or three segments, is a useful key bed of all over the area in the member that is divided into the lower and upper parts at the base of the tuff.

Fossils: A lot of molluscan, foraminiferal and crustacean fossils were obtained from the member.

Thickness: The member is 3 m to 100 m thick.

2) Takeda Sandstone and Mudstone Member (newly

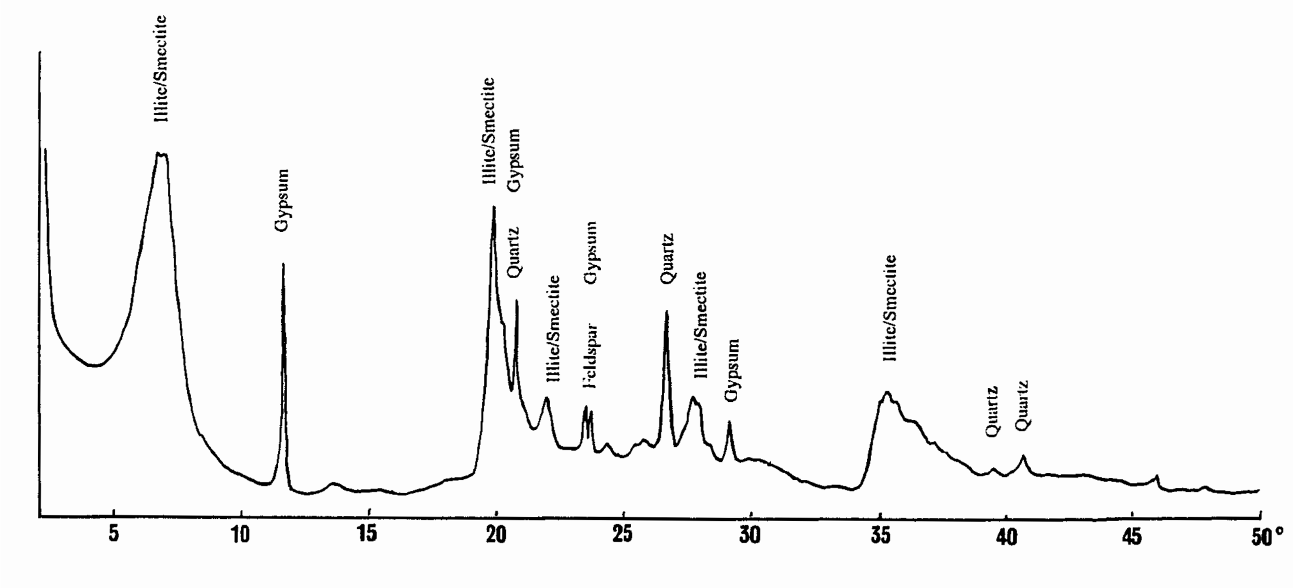


Fig. 7. Diffraction pattern of X ray of the tuff in the Takakura Formation.

proposed name)

Type locality: A relative large cliff at the rear of Kagamino Junior High School in Takeda, Kagamino-cho.

Distribution: The distribution of the member is limited in the western and central areas.

Lithofacies: The member consists of sandstones and mudstones which are intercalated with a thin layer of a tuff. The sandstone is somewhat tuffaceous and is fine-grained indicating light gray in fresh outcrops and yellowish brown in weathered ones. The mudstone exhibits black to dark gray and is compact being broken like shell fragments. The tuff shows yellowish white and is only seen at one locality. The member is made up of flysh type deposits. There is a tendency that normal flysh and sandy flysh, and muddy flysh distribute in the western and central areas, respectively. The groove cast is rarely recognized at the bottom of the sandstone in the western area. On the other hand, within the western area slump beds, which include slump balls and lignitic seams, are well found. In particular, there are some cases that sandy flysh is composed of turbidite sandstone, turbidite dust (turbidite mudstone) and hemipelgic mudstone judging from lithologic characteristics (Tokuhashi, personal communication), although megafossils do not occur in them.

Fossils: In the case of a unit consisting of sandstone and mudstone, it yields a large amount of plant fragments. They occur at the top of sandstone and the base of mudstone in the unit. Other megafossils were not discovered.

Thickness: The member is estimated to be 80 m in maximum thickness.

IV. Geologic structure

The Katsuta Group abuts the basement rocks and especially the Takakura Formation overlaps the Yoshino Formation. The following faults and folds are recognized.

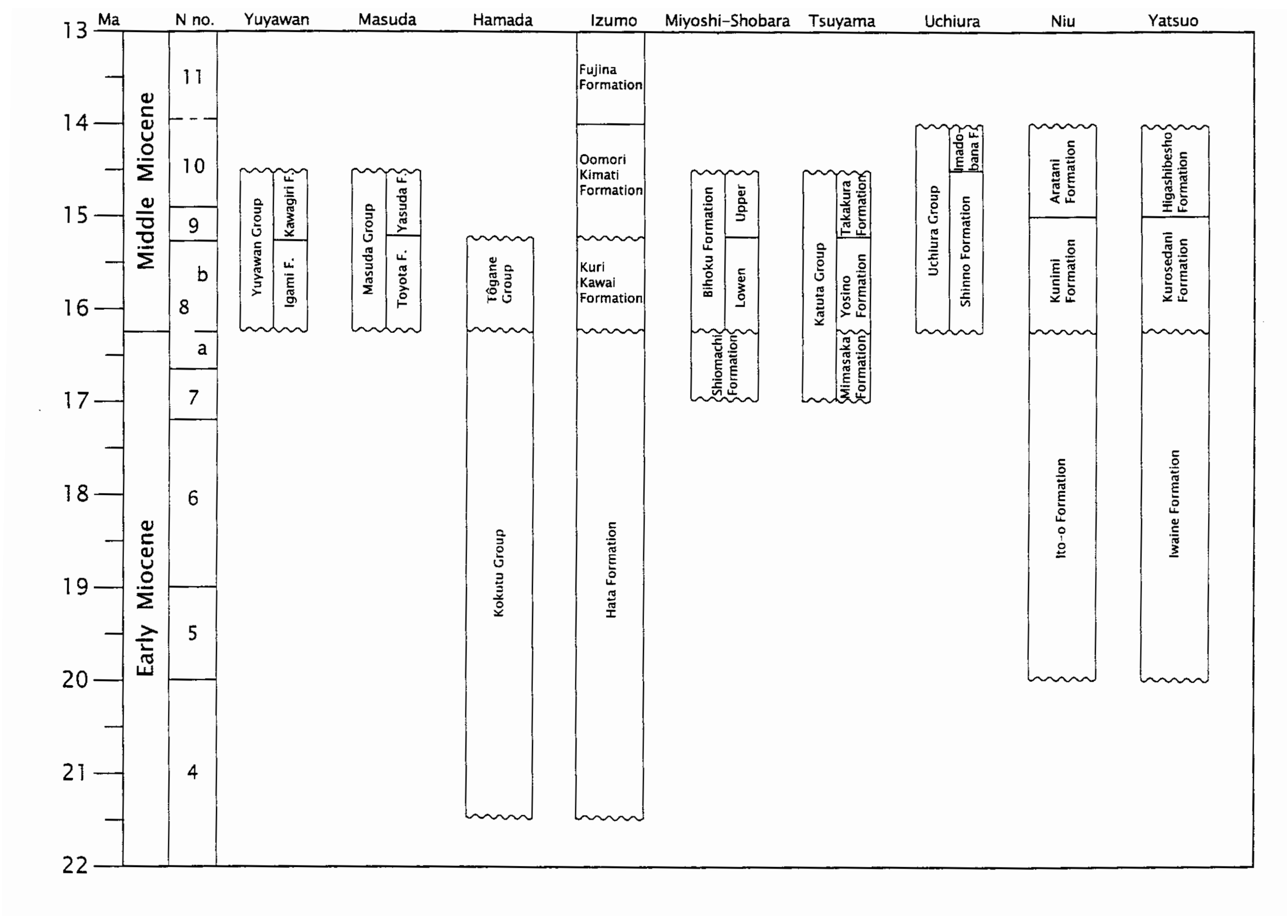
A. Faults

A major fault called the Mimasaka Thrust by Kawai (1957) is extending E-W direction, which is recognized in northern part of the Tsuyama basin. Although Kawai (1957) recognized a very low-angled thrust in the central and eastern areas, I could not find the evidence of such a fault. This fault (The Mimasaka Thrust) bounds the northern limit of the area and is reverse and dips north. For instance, the strikes and dips of the fault at some outcrops indicate N86°W-54°N, N62°W-42°N and N88°W-62°W, respectively (Pl. 2). The Katsuta Group contacts with the southernmost part of the basement rocks by the fault. As mentioned later, this fault seems to have begun its movement at the depositional phase of the Takeda Sandstone and Mudstone Member of the Takakura Formation of the group.

B. Folds

In the eastern area, no fold is obsevable. On the other

Table 3. Correlation table between the Katsuta group and its equivalents.



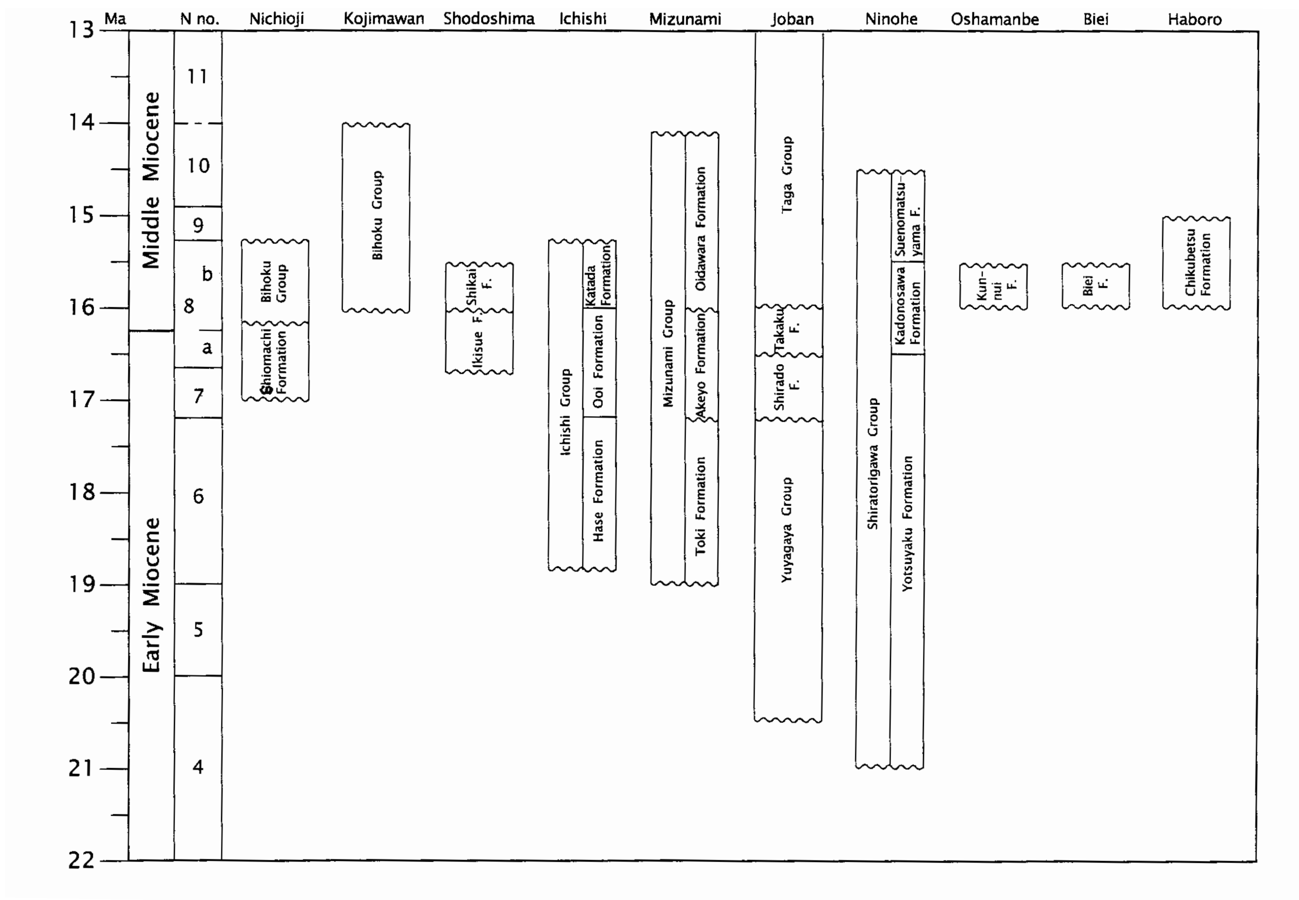
hand, remarkable folds are recognized in the western and central areas. Superimposed upon these structure are many subsidiary synclines and anticline which repeat in the western and central areas. In the central area, the synclines and anticlines with their axes extending EW and ENE-WSW trends are observable all over the area, and indicate gentle dip ranging from 2° to 26°. In the western area, the synclines and anticlines of which axis trends show variable indicating dips from 3° to 76°, make up themselves into a bundle at the northwestern edge of the area. The Katsuta Group frequently overfolds in the northern area where the group contacts with the basement rocks by the fault. Such a complicated geological structure was revealed first by myself.

Yamasaki et al. (1985) first reported and described a large slump bed from the Upper Shale Formation of the Bihoku Group in the Miyoshi sedimentary basin and forecasted existence such slump beds in the beds of equivalents in other areas as Tsuyama. Ueda (1986) also reported it in the Upper Formation of the Bihoku Group in the Shobara sedimentary basin. The slump bed was first discovered by me from the Takakura Formation which is correlative to the Upper Shale Formation of the Bihoku Group. Thus it became clear that the slump beds occupy the same horizon in the three sedimentary basins, namely, the Miyoshi, Shobara and Tsuyama basins. I herein demonstrate that the slump beds occurred owing to tilting of the basement rocks in a large scale. As a result, the action of the Mimasaka and Yamanouchi (Imamura, 1953) thrusts started in this period in the Tsuyama, Miyoshi and Shobara basins, respectively.

In general, it is thought that the overfold was formed in relation to the movement of the Mimasaka thrust. On the other hand, the synclines and anticlines apart from the thrust are disharmonious, probably formed as the gravity glide folds (Yano personal communication).

V. Geological age of the Katsuta Group

The Katsuta Group includes three layers of tuff which



are called the Shimokoyama tuff, the Kanoko tuff and the Matsubara tuff in ascending order, each of which are intercalated in the Mimasaka, Yoshino and Takakura Formations, respectively.

The Shimokoyama tuff has no zircon. Therefore, fission track age can not be measured. However, this tuff is included in the Mimasaka Formation, which yields the Daijima type flora. According to Tanai (1992), this flora occurs concentrated in 16Ma to 18Ma which corresponds to Blow's N7 to N8.

The age of the Kanoko tuff, which occurs in the Yoshino Formation, is determined as 17.9±2.1Ma by the fission track method (Suzuki et al., 1996). Thus, the Yoshino Formation is correlative to Blow's N8 to N10.

The Matsubara tuff, one of constituents of the Takakura Formation, exhibits 16.2±2.1Ma in age by the fission track measurement (Suzuki et al., 1996). Therefore the member is correlative to Blow's N8 to N10.

Recently, Yamamoto and Nozaki (1997) recognized the boundary of NN4/NN5 and CN3/CN4 in the Takakura Formation, which correspond to the boundary of Blow's N8/N9 from the analysis of calcareous nannofossils. Moreover he suggests that the Mitsukaichi tuft in the. Shobara basin, the Matsubara tuff in the Tsuyama basin and the Yamadanaka tuffs in the Yatsuo basin occupy the near horizons.

Correlation of the Katsuta Group and its equivalents

The correlation tables is shown in Table 3. Some parts are based on Takayasu (1992) and Itoigawa and Shibata (1992) and etc.

VI. Faunal list

Faunal list composed of molluscs, foraminifera, crustacea, mammals, fishes, brachiopods, bryozoan and coral are shown in Tables 4 and 5. Among these, molluscs consist of 85 determined and 38 undetermined species from the Yoshino Formation and of 19 determined and 10 undetermined species from the Takakura Formation.

Table 4. Faunal list (Yoshino Formation). L: lower, U: upper; R: rare (~2), F: frequent (3-5), C: common (6-10), A: abundant (11-20), VA: very abundant (21~)

species name / locality	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	17	18	20	25	26	27	29	40	43	48	50	53	61	62	63	64	65	66	74	80	81	83	84	85	88	89	90	94	95	98	99	105	107	108	109	110	111	112	113	114	116	117	118	119	121	122
horizon	L	L	LU	L	L	L	LU	L	L	LU	L	L	L	L	L	L	L	L	L	L	U	LU	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Barbatia sp.																																																							R						
Nipponarca japonica Taguchi																																						C																							
Anadara (Hataiarca) kakehataensis Hatai et Nisiyama																																								C	C											VA									
Scapharca daitokudoensis (Makiyama)																																																R													
S. abdita Makiyama																																						R																							
Striarca elongata Taguchi, Osafune et Obayashi						F																																														VA			VA						
S. uetsukiensis (Hatai et Nisiyama)																																									F											VA									
Porterius sp.																																						R																							
Perna oyamai Taguchi																																						VA																							
Mytilus sp.																									R																																				
Modiolus sp.																																						R																							
M. (Modiolusia) sp.																																																				R									
Isognomon ? sp.																																																				R									
Chlamys cf. nisataiensis Otuka		R																																																											
Ch. sp.	F	F																R							C																																				
Cryptopecten yanagawaensis (Nomura et Zinbo)										F																																																			
Placopecten nomurai Masuda										C																																																			
P. protomollitus (Nomura)										C																																																			
Patinopecten (Mizuhopecten) cf. kimurai (Yokoyama)															R																																														
Anomia sp.																																										R											R								
Ostrea itoigawai Taguchi																																						C																							
Crassostrea gravitesta (Yokoyama)					VA	R				F	F																																						VA			A			F			F			VA
Saccostrea sp.		F									VA																																																		
"Ostrea" sp.								R																	R		R										R																								
Lopha sp.																		R																																											
Saxolucina khataii (Otuka)			R																																													R													
Wallucina okumurai Itoigawa																																																					R					R			
Cycladicama cumingi kukinagaensis (Hayasaka)																																						F																							
Diplodonta ferruginata Makiyama																																																				F									
Eucrassatella ? sp.																																						R																							
Vepricardium (s. s.) okamotoi Taguchi																																						VA				A																			
Vasticardium ogurai (Otuka)							F																																																						
Regozara sp.																																																	R						R						
Mactra sp.																																						R																							
Oxyperas osawanoensis Tsuda										R																																																			
Cardilia toyamaensis Tsuda																																						F																							
Tellinella osafunei Taguchi																																						VA														R									
Fabulina sp.																																																				A									
Leporimetis takaii (Ogasawara et Tanai)																																																				R									
Asaphis sp.																																																				R									
Gari sp.																																						R														R									
Angulus okumurai Taguchi																																						C																							
Hiatula minoensis (Yokoyama)																																																				F	R								
Pharella sp.																																						R																							
Cultellus izumoensis Yokoyama																																																				F									
Trapezium cheonbugensis Yoon				R																																																									
T. modiolaeforme Oyama et Saka																																						R																							
Geloina stachi Oyama																																																				F									
G. yamanei Oyama						R																																																							
Phacosoma nomurai Otuka							R															F																																							
Ph. sohuketoensis (Oyama)																																																												F	
Paphia euglypta ohiroi Masuda																																						F																							
Siratoria siratoriensis (Otuka)																						F																																					R		
Nipponomarcia nakamurai Ikebe			C																																																										

Table 4. (continued)

species name / locality	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	17	18	20	25	26	27	29	40	43	48	50	53	61	62	63	64	65	66	74	80	81	83	84	85	88	89	90	94	95	98	99	105	107	108	109	110	111	112	113	114	116	117	118	119	121	122
horizon	L	L	LU	L	L	L	LU	L	L	LU	L	L	L	L	L	L	L	L	L	L	U	LU	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Liocyma minuta Nomura et Zinbo																																																										R			
Cyclina (Cyclina ?) hwabongriensis Yoon																																																													
et Noda																						R																R																	R						
C. takayamai Oyama		F																																							R																				
Clementia japonica Kamada																																						C			R																				
Solidicorbula succincta (Yokoyama)																																						R			R														R						
Glycymeris sp.							R																																																						
Martesia sp.							R																															R																							
Teredo sp.																																						R																							
Calliostoma (Tristichotrocus)																																																													
myonchonensis Hatai et Kotaka																																						A														R									
C. (T.) sp.																																						R			R			R																	
Cantharidus mizunamiensis Itoigawa																																																													
et Shibata																																						R																							
Chlorostoma sp.																																						R																							
Tectus (Rochia) japonica Horikoshi										R																																																			
Protorotella sp.																																																							R						
Suchium joganjiense Fujii																																									F														R						
Teinostoma yabei Masuda																																									R														F				R		
T. sp.																																																				F									
Homalopoma sp.																																						F																							
Turbo (Marmorostoma) minoensis																						F																					R		C					R											
Itoigawa																						F																														F		A							
T. ozawai Otuka																																											R																		
Lunella kurodai Itoigawa																																																													
L. sp.																																						VA																							
Nerita ishidae Masuda																																																				C									
Neritina sp.																																						R																							
Littorinopsis miodelicatula Oyama																																						R																							
L. sp.																																						R																							
Pygmaeorota rota sp.																																						R														F									
Turritella (Turritella) kiiensis Yokoyama							R																															C																							
T. sp.																																						F																							
Architectonica osawanoensis Tsuda										R																																																			
Tiara sp.		R																																																											
Vicarya japonica Yabe et Hatai		F		F																																R	R	R	R	C	VA					F	R	R	R	F		VA			VA	F	F				
Vicaryella bacula (Yokoyama)																																						R																							
V. ishiiana (Yokoyama)																																						VA																							
V. notoensis Masuda																																						F																							
V. sp.																																						A														A									
Cerithideopsilla tokunariensis Masuda																																																			R	VA									
Cerithidea kanpokuensis Makiyama		R																																																											
C. cf. kanpokuensis Makiyama																																											R																		
Telescopium schenki (Hatai et Nisiysma)																																																				R									
Terebralia itoigawai Taguchi, Osafune																																																													
et Obayashi																																																				A									
T. shibatai Taguchi																																						C																							
Batillaria narusei Taguchi																																						R																							
B. toshioi Masuda																																						R																							
Tateiwaia tateiwai (Makiyama)		F	F	F		F																																VA		F	F							F													
T. yamanarii (Makiyama)		F	F	C		F																																VA														VA			VA						
T. sp.																																						A														VA									
Bittium sp.																																						C																							
Proclava sp.																																						R																							
Calyptraea tubura Otuka																																						R																							
Crepidula nidatoriensis Otuka																																						R																							
C. jimboana Yokoyama										R																																																			

Table 4. (continued)

species name / locality	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	17	18	20	25	26	27	29
horizon	L	L	LU	L	L	L	LU	L	L	LU	L	L	L	L	L	L	L	L	L	L	U	LU
Strombus mimasakaensis Yokoyama																						
Erosaria sp.																						
Globularia (Cernina) nakamurai Otuka															A	F	R					
Sinum yabei Otuka																						
Euspira meisensis (Makiyama)																						
Echinophoria (Shichiheia) sp.																						
Apollon sp.														R								
Rhizophorimurex capuchinus nagiensis Taguchi, Osafune et Obayashi																						
Bedevina sp.																						
Boreotrophon sp.																						
Siphonalia makiyamai Itoigawa																						
S. fujiwarai Itoigawa																						
Searlesia kurodai Makiyama																						
S. kurodai kinseiensis Makiyama																						
Babylonia toyamaensis Tsuda										R												
Pugilina (Semifusus) sazanami (Kanehara)																						
Reticunassa simizui (Otuka)																						
Zeuxis minoensis Itoigawa																						
Nebularia sp.																						
Chrysome sp.																						
Nipponaphera taguchii Oyama, Hirose et Nishimoto																						
Chelyconus sp.																						
Paradrillia sp.																						
Ringicula fragilis Takeyama																						
Operculina complanata japonica Hanzawa						A			C			VA	A						A	A	AV	AR
Crab																						
"Balanus" sp.										R												
Paleoparadoxia tabatai (Tokunaga)										R												
Mysticeti															R							
Shark teeth																						
Scomberomorus sp.																						
Brachiopoda		R																				
Bryozoa										A	A											
Coral										A	A											

species name / locality	40	43	48	50	53	61	62	63	64	65	66	74	80	81	83	84	85	88	89	90	94	95	98	99	105	107	108	109	110	111	112	113	114	116	117	118	119	121	122
horizon	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Strombus mimasakaensis Yokoyama																																	R						
Erosaria sp.																R																							
Globularia (Cernina) nakamurai Otuka																					C																		
Sinum yabei Otuka																R																							
Euspira meisensis (Makiyama)																A																	F				F		
Echinophoria (Shichiheia) sp.																R																							
Apollon sp.																																							
Rhizophorimurex capuchinus nagiensis Taguchi, Osafune et Obayashi																														C									
Bedevina sp.																R																							
Boreotrophon sp.																R																							
Siphonalia makiyamai Itoigawa																R																							
S. fujiwarai Itoigawa																A														F			F						
Searlesia kurodai Makiyama																														F			F						
S. kurodai kinseiensis Makiyama																R														C									
Babylonia toyamaensis Tsuda																																							
Pugilina (Semifusus) sazanami (Kanehara)																A																							
Reticunassa simizui (Otuka)																R																							
Zeuxis minoensis Itoigawa																VA																							
Nebularia sp.																R																							
Chrysome sp.																R																							
Nipponaphera taguchii Oyama, Hirose et Nishimoto																VA																							
Chelyconus sp.																					F																		
Paradrillia sp.																C																	R						
Ringicula fragilis Takeyama																																							
Operculina complanata japonica Hanzawa	VA	VA	VA	VA		VA	VA	VA	VA	A	A		A	A							A																		
Crab																														F									
"Balanus" sp.																R																							
Paleoparadoxia tabatai (Tokunaga)																																							
Mysticeti																																							
Shark teeth											R																												
Scomberomorus sp.																R																							
Brachiopoda																																							
Bryozoa																																							
Coral																																							

Table 5. Faunal list (Takakura Formation). Legend is same for Table 4.

species name / locality	1	1	2	10	15	22	23	28	29	30	31	32	33	34	35	36	37	38	39	41	42	44	47	49	52	54	55	56	56	57	58	59	60	70	71	72	73	75	77	78	79	82	91	92	97	100	101	104	104	119	120
horizon	L	U	L	L	L	L	L	U	L	L	U	L	L	L	L	L	L	U	L	L	L	U	U	L	U	U	U	L	U	U		U	U	U	L	U	L	U	L	L	L	L	L	L	L	L	U	L	U	L	L
Acharax tokunagai (Yokoyama)											R																				U																R				
Acila sp.	R						R									R													R	R						R				R	R							R			R
Lamellinucula sp.							F																		R	R																			R						
"Neilonella" ovata (Takeda)							R									R																																			
Bathymalletia chitensis Shikama et Kase							R																																												
Portlandia watasei (Kanehara)							R		R							R									R	R																									
Megayoldia thraciaeformis Störer																										R																									
Limopsis sp.	R			R	F				R			R			F	A	R											F														F	R	R				A			R
Propeamussium tateiwai Kanehara							A	R			R											F	R		A	F						F	R	R		VA									F				F		
Delectopecten peckhami (Gabb)		R				R	A		A		A			R	C							R		R	VA						F								R						VA			R			
Acesta cf. goliath Sowerby					R																																														
Limatula sp.	R								R		R	F				F																																			
Lucinoma acutilineatum (Conrad)		R					R				F							R				F			VA	F	F				R	R													VA				A		
Placamen sp.																	R														F																				
Periploma mitsuganoense Araki							R									R										R																					R	R	F		
Cuspidaria hirasei Kuroda																											R																								
Cardiomya mitsuganoense Shibata														R					C																		R	R													
Antalis sp.							R																		R																										
Fissidentalium yokoyamai (Makiyama)	R			R																					R			C														C				R					
Orectospira sp.							F																			R																									
Natica sp.			R																						R																							F		R	
Liracassis japonica (Yokoyama)				R	F				R																																										
Obestoma sp.																								R																								R			
Nipponoscaphander sp.																R																																			
Limacina sp.							F									R						VA														R															
Vaginella depressa Daudin							F									F						C														R															
V. sp.							VA										R					VA			A	R										C															
Clio itoigawai (Shibata)							C												R			F																													
C. carinata Audenino							R																																												
Cilo sp.							R																													F															
Cavolinia bisulcata *raritais* Nomura et Zinbo							C													VA	VA																														
Operculina complanata japonica Hanzawa									R	VA			C																						VA		VA														
Bathynomus undecimospinosa (Karasawa, Nobuhara et Matsuoka)																																																R			
Brissopsis makiyamai Morishita																																															F				
Flabellum sp.																																																R			

A. Method of recognition of molluscan assemblages

An assembly of species gathered from one outcrop is recognized as an outcrop assemblage. Gathering some common outcrop assemblages, an assemblage is named (Itoigawa, 1990). Name of characteristic species and genus are selected for the name of the assemblage even if the specimen is imperfect. Special attention is paid to feeding type.

B. The lower part of the Izumotawa Sandstone Member

Geloina assemblage

Locality: 87.

Lithofacies: Fine- to medium-grained sandstone.

Mode of occurrence: The specimens of genus *Geloina* only occur scattered with articulated valves. Therefore, such a mode of occurrence displays autochthonous in origin. The shells are not corroded.

Main component: *Geloina stachi* and *G. yamanei.*

Mode of life: Infauna.

Feeding type: Suspension feeder.

Paleoecology: This assemblage indicates tropical mangrove swamp in tidal fascia which was proved by co-occurrence of pollen of *Bruguiera* sp., one of the main components of mangrove community (Yamanoi et al., 1980).

Crassostrea gravitesta assemblage

Locality: 5 and 122.

Lithofacies: Sandy mudstone.

Mode of occurrence: Only *Crassostrea gravitesta* was discovered in conjoined valves indicating autochthonous origin.

Main component: *Crassostrea gravitesta.*

Mode of life: Sessiling epifauna.

Feeding type: Suspension feeder.

Paleoecology: This assemblage, forming a single colony, lived in tidal fascia of an inner bay.

Vicarya-Anadara assemblage

Locality: 3, 4, 85, 88, 99, 106, 107 and 114.

Lithofacies: Sandy mudstone to mudstone with calcaleous nodules.

Mode of occurrence: A majority of bivalves occurs in state of attached valves except a small amount of them, which is presumed to be autochthonous or semi-autochothonous occurrence. Gastropod shells are suffered a little injury and wear except such genera as *Telescopium*, *Terebralia* and *Rhizophorimurex* of which surface sculpture is nearly perfect in spite of their broken state. These modes of occurrence indicate little movement after death from their original habitat. There are some specimens of *Geloina, Telescopium* and *Vicarya* that are remarkably corroded. Frequently, *Vicarya* co-occurs with articulated valves of Anadara.

Main component: *Anadara* (*Hataiarca*) *kakehataensis, Striarca elongata, S. uetsukiensis, Cultellus izumoensis, Vicarya japonica, Terebralia itoigawai, Tateiwaia tateiwai, Tateiwaia yamanarii* and *Cerithideopsilla tokunariensis.*

Mode of life: Composed of infauna and epifauna such as burrower, crawlirng and adhering types.

Feeding type: Suspension and detritus feeders.

Paleoecology: This assemblage indicates muddy bottom of estuary of mangrove swamp suggested by *Geloina*, *Terebralia*, *Telescopium* and *Rhizophorimurex* in tropical region. Such an estimation is confirmed by occurrence of *Buruguiera*, one of mangrove community (Saito, personal communication).

Saccostrea assemblage

Locality: 11.

Lithofacies: Medium- to coarse-grained sandstone.

Mode of occurrence: The specimens *Saccostrea* and *Crassostrea* were obtained in state of disarticulated valves which are broken. Such an occurrence probably indicates allochthonous.

Main component: *Saccostrea* sp. and *Crassostrea gravitesta.*

Mode of life: Adhering type.

Feeding type: Suspension feeder.

Paleoecology: This assemblage consists of dwellers of rocky or gravelly bottom influenced by oceanic warm water which is inferred from co-occurrence of *Operculina complanata japonica.*

Turritella assemblage

Locality: 98, 112 and 113.

Lithofacies: Medium-grained sandstone and sandy mudstone.

Mode of occurrence: *Turritella* from medium-grained sandstone is nerly perfect in preservation while that species from sandy mudstone is broken or worn. The former occurrence shows autochthonous but the latter one displays allochthonous. The specimens of *Anomia* and *Crassostrea* were obtained as univalves of which surface sculpture is nearly perfect, indicating semi autochthonous.

Main component: *Turritella* (*s.s.*) *kiiensis, Anomia* sp. and *Crassostrea qravitesta*.

Mode of life: Adhering and crawling type.

Feeding type: Suspension and detritus feeders.

Paleoecology: This assemblage probably exhibits sandy, rocky and gravelly bottoms in euneritic fascia.

Tellinella-Perna-Vepricardium-Vicaryella **assemblage**

Locality: 84.

Lithofacies: Mudstone with calcareous muddy nodules.

Mode of occurrence: Bivalve shells occur with conjoined valves except *Ostrea* and *Pharella*, indicating autochthonous. Gastropod shells such as *Terebralia, Tateiwaia* and *Vicaryella* are semi-autochthonous owing to their broken and worn states. The other shells are suffered a little injury and wear. Such a mode of occurrence shows autochthonous in origin.

Main component: *Tellinella osafunei, Perna oyamai, Vepricardium* (*s.s.*) *okamotoi, Angulus okumurai. Ostrea itoigawai, Vicaryella ishiiana, Siphonalia fujiwarai, Euspira meisensis* and *Zuexis minoensi*.

Mode of life: Burrowing, crawling and adhering types.

Feeding type: Suspension and detritus feeders, herbivore and carnivor.

Paleoecology: This assemblage must have lived in/on muddy bottom in tropical euneritic fascia nearby tidal fascia which is inferred from occurrence of *Terebralia, Tateiwaia* and *Vicaryella*. Especially, *Terebralia shibatai* more or less suggests the existence of mangrove swamp environment at the neighboring place of this locality.

Phacosoma **assemblage**

Locality: 118 and 121.

Lithofacies: Medium-grained sandstone.

Mode of occurrence: Only *Phacosoma* occurs with conjoined valves, which indicates little movement after death.

Main component: *Phacosoma suketoensis*.

Mode of life: Burrower.

Feeding type: Suspension feeder.

Paleoecology: This assemblage indicates sandy bottom in euneritic fascia of an inner bay.

Vepricardium-Euspira **assemblage**

Locality: 90.

Lithofacies: Mudstone.

Mode of occurrence: Bivalve shells, which occurs in state of attached valves, exhibit autochthonous origin. Gastropod shells display little damage indicating autochthonous.

Main component: *Vepricardium* (*s.s.*) *okamotoi, Euspira meisensis* and *Zeuxis minoensis*.

Mode of life: Burrowing and crawling types .

Feeding type: Suspension feeder and carnivor.

Paleocology: This assemblage prospered in/on muddy substratum in euneritic fascia in the embayment.

Globularia **assemblage**

Locality: 13, 17 and 95.

Lithotfacies: Medium- to coarse-grained sandstone and granule conglomerate.

Mode of occurrence: Two types of mode of occurrence can be recognized. One is a case that only globularias occur scattered in coarse-grained sandstone (loc. 17) and granule conglomerate (loc. 13). The other is that *Globularia* was obtained from medium-grained sandstone associated with the other kinds of gastropods such as *Cerithidea* and *Chelyconus* (loc. 95). Globularias is suffered deformation but well-preserved. The other gastropod shells are worn and broken. Such modes of occurrence indicate that *Globularia* is autochthonous, and other gastropods are allochthonous.

Main component: *Globularia nakamurai*.

Mode of life: Crawling type.

Feeding type: According to Kase (1990), *Globularia fulcutuata,* living in the Philippines sea, feeds algae. It assumed that fossil *Globularia nakamurai* had same type of feeding as a herbivore.

Paleocology: This assemblage must have lived on sandy and gravelly bottom in tropical euneritic fascia strongly influenced by oceanic water judging from co-occurrence of a lot of specimens of *Operculina complanata japonica*.

Vasticardium-Phacosoma **assemblage**

Locality: 3 and 29.

Lithotfacies: Medium-grained sandstone and sandy mudstone.

Mode of occurrence: Two types of mode of occurrence can be seen. At the locality 3, *Vasticardium* and *Phacosoma* occur as articulated valves which display autochthonous origin. At the locality 29, *Vasticardium*, *Phacosoma, Cyclina* and *Siratoria* were obtained in state of univalve indicating semi-autochthonous occurrence. Gastropod shells of *Turbo* are broken but penultimate whorl is adorned with prickles. They are allochthonous.

Main component: *Vasticardium ogurai, Phacosoma nomurai, Cyclina hwabongriensis, Siratoria siratoriensis* and *Turbo minoensis.*

Mode of life: Burrowing and crawling types.

Feeding type: Suspension and detritus feeders.

Paleoecology: This assemblage probably prospered in/on sandy bottom in euneritic fascia strongly affected by warm oceanic water which is inferred from co-existed many *Operculina complanata japonica.*

Chlamys assemblage

Locality: 1, 2, 20, 45 and 48.

Lithofacies: Medium- to coarse-grained sandstone.

Mode of occurrence: The specimens of genus *Chlamys* were obtained as cast and broken state. *Saccostrea* (loc. 2) and *Mytilus* (loc. 48) were obtained as single valve being broken state. Such modes of occurrence indicate semi-autochthonous or allochthonous.

Main component: *Chlamys* sp., *Saccostrea* sp. and *Mytilus* sp.

Mode of life: Adhering epifauna.

Feeding type: Suspension feeder.

Paleoecology: This assemblage seems to be composed of sandy bottom dweller in mesoneritic fascia strongly influenced by warm oceanic water which is presumed by co-occurrence of abundant *Operculina complanata japonica.*

Placopecten assemblage

Locality: 10.

Lithofacies: Coarse-grained sandstone.

Mode of occurrence: Pectinid shells show state of single valves. The preservation of them, however, very well. Such a mode of occurrence probably exhibit semi-autochthonous.

Main component: *Placopecten nomurai, P. protomollitus* and *Cryptopecten yanagawaensis.*

Mode of life: Planktonic and adhering types.

Feeding type: Suspension feeder.

Paleoecology: This assemblage indicates sandy bottom of mesoneritic fascia affected by warm oceanic water judging from co-occurrence of bryozoans and corals.

As mentioned above, the fossil molluscan assemblages from the main localities of the lower part of the Izumotawa Sandstone Member of the Yoshino Formation were analyzed. However there are many fossil localities (locs. 9, 14, 18, 25, 61, 64, 65, 66, 67, 81, 83, 94, 103, 105, 106, 112, 115, 116, 117, 119 and 120) in which the molluscan assemblages are not identified because of occurrence of a few molluscs and of only *Operculina complanata japonica* at the localities.

C. The upper part of the Izumotawa Sandstone Member

It yields a few molluscs, fragments of echinoids, bryozoans, corals and *Operculina complanata japonica* (locs. 3, 7, 10, 96 and 121). Therefore, it is so difficult discrimination of the molluscan assemblage.

D. Molluscan assemblage from the Takakura Formation

Molluscan assemblage is analyzed by the same procedure in the case of the Yoshino Formation.

Limopsis-Fissidentalium assemblage

Locality : 1, 10, 15, 22, 27, 30, 32, 33, 36, 38, 39, 49, 56, 57, 59, 70, 72, 76, 77, 78, 82 and 104.

Stratigraphic position: The upper part of the Nokedai Mudstone Member.

Lithofacies: Mudstone.

Mode of occurrence: Bivalve shells were obtained as single valves of which sculpture is, nearly perfect in preservation except a few number of valves conjoined. Scaphopod shells indicate perfect preservation. Gastropod shells are deformed and depressed whilst slightly injured and worn. These modes of occurrence exhibit more or less autochthonous and semi-autochthonous.

Main component: *Limopsis* sp., *Fissidentalium yokoyamai, Delectopecten pekhami, Periploma mitsuganoensis, Liracasis japonica, Placamen* sp., *Cardiomya mitsuganoensis., "Neilonella" ovata, Musashia* sp. and *Acesta* cf. *goliath.*

Mode of life: Burrowing. crawling and planktonic types.

Feeding type: Suspension and detritus fedeers and carnivor.

Paleoecology: This assemblage seems to have lived in/on muddy and muddy sand bottom in bathyneritic to hemibathyal fascia strongly influenced by warm oceanic water. This assumption is inferred from co-occurrence of *Vaginella* assemblage consisting of such ptropods as *Clio itoigawai, Vaginella* sp. and *V. depressa.*

Lucinoma-Propeamussium-Delectopecten assemblage

Locality: 1, 23, 28, 34, 35, 38, 44, 47, 52, 56, 57, 60, 97 and 104.

Stratigraphic position: The upper part of the Nokedai Mudstone Member.

Lithofacies: Mudstone.

Mode of occurrence: Occurrence of bivalve shells looks like as single valves but their shell outlines perfectly preserved. Scaphopod shells were obtained being perfect in preservation. Gastropod shells are suffered little injury and wear. These modes of occurrence indicate autochthonos or semi-autochthonous.

Main component: *Lucinoma acutilineatum, Propeamussium tateiwai, Delectopecten peckhami, Megayoldia thraciaeformis, Acharax tokunagai, Lamellinuculla* sp., *Fissidentalium yokoyamai, Orectospira* sp., *Antalis* sp. and *Bathymalletia chitensis.*

Mode of life: Epifauna such as planktonic and crawling types, semi-epifauna and infauna such as deep burrower.

Feeding type: Suspension and detritus feeders.

Paleoecology: This assemblage probably prospered in/on muddy bottom in bathyneritic and hemibathyal fascies. Influence of inflow of warm oceanic water to surface sea layer is assumed co-occurrence of *Vaginella* assemblage composed of such pteropods as *Vaginella* sp., *Carvolinia bisulcata raritatis* and *Limacina* sp.

***Vaginella* assemblage**

Locality: 23, 38, 39, 44, 52, 55, 72 and 104.

Stratigraphic position: The lower and upper parts of the Nokedai Mudstone Member.

Lithofacies: Massive mudstone (locs. 38, 39, 72 and 104 of the lower part) and alternation of siltstone and mudstone (locs. 23, 44, 52 and 55 of the upper part).

Mode of occurrence: All the pteropod specimens are more or less deformed and depressed while their shells are perfectly preserved.

Main component: *Vaginella* sp., *V. depressa, Clio itoigawai, Carvolinia bisulcata raritatis* and *Limacina* sp.

Mode of life: Planktonic type.

Feeding type: Suspension feeder.

Paleoecology: This assemblage displays tropical to subtropical oceanic water condition.

Distribution of representative species

The distribution of the representative species from the Izumotawa Sandstone Member of the Yoshino Formation and the Nokedai Mudstone Member of the Takakura Formation are represented in Figs. 8-22 showing names and their abundance.

VII. Paleoenvironment and paleogeography of the Katsuta Group

Paleoenvironments and paleogeographic conditions of the Katsuta Group are reconstructed below on 5 stages.

A. Mimasaka stage

The paleogeography and paleoclimatic conditions of this stage are shown in Figs. 23 and 27.

The Mimasaka Formation was formed in a lake condition which might be mainly distributed in the eastern area with the exception of a small area of the central area. Marsh environment, which suggested by the lignite beds, had thrived in some places in a lake. As already mentioned, this formation yield the Daijima type flora which prospered around a lake under a warm to temperate paleoclimatic condition.

B. The lower Izumotawa stage

The paleogeography and paleoenvironment of this stage are shown in Figs. 24 and 27. Temporal and spatial distribution of the molluscan assemblages are also shown in same figures.

The inflow of several streams and rivers at the southern and eastern margins of the Tsuyama Bay could be inferred. They are named herein as the Makabe River, paleo-Hiji River, paleo-Sara River and paleo-Kume River which probably inflowed northeastward, westward, northward and eastward respectively. It is thought that mangal flourished in estuary and along the bank of some rivers, which is confirmed by occurrence of mangrove pollens such as *Rhizophora, Bruguiera, Sonneratia* and *Avicennia* (Yamanoi et al., 1980 and Yamanoi, 1984). In such mangrove swamps, the *Geloina* assemblage, which is characterized by in faunal (burrower) suspension feeder, dwelt in sandy bottom of tropical brackish water. As Taguchi (1981) already stated, zonations of mangrove fauna and flora consist of the *Littorinopsis* zone, *Crassostrea-Nerita* zone, *Geloina-Telescopium* zone and the Potamid-arcid zone, associated with the *Bruguiera, Rhizophora*? and cf. *Avicennia* zones except the Potamid-arcid zone (fide in detail Taguchi, 1981) . This schematic model is neccesary to revise more in detail in future because Yamanoi (1984) discovered aforementioned mangrove pollens.

The *Vicarya-Anadara* assemblage is comparabIe with the Potamid-arcid zone. This assemblage, which is

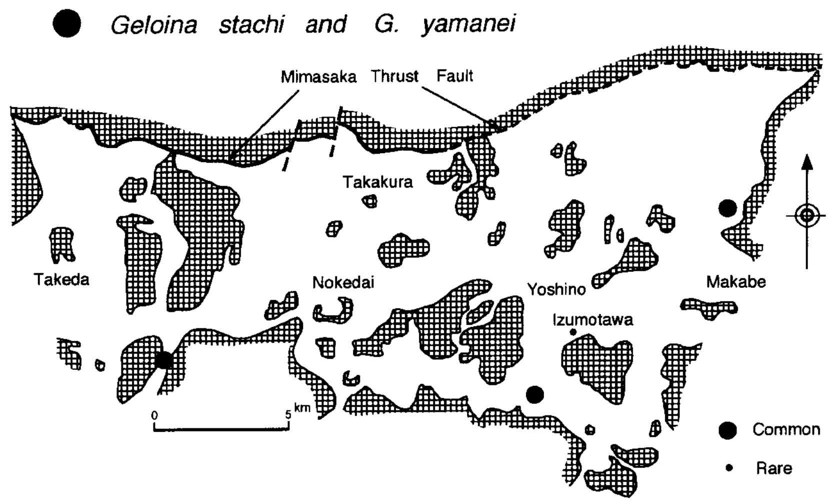


Fig. 8. Distribution of *Geloina stachi* and *G. yamanei*.

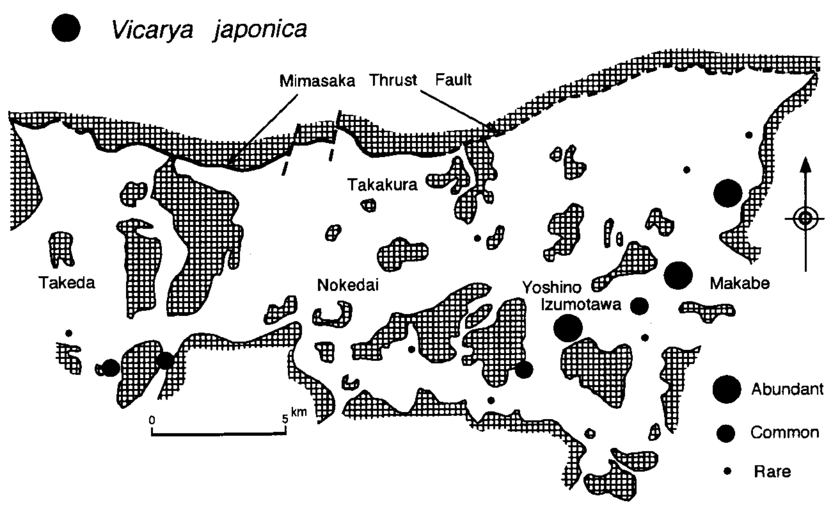


Fig. 9. Distribution of *Vicarya japonica*.

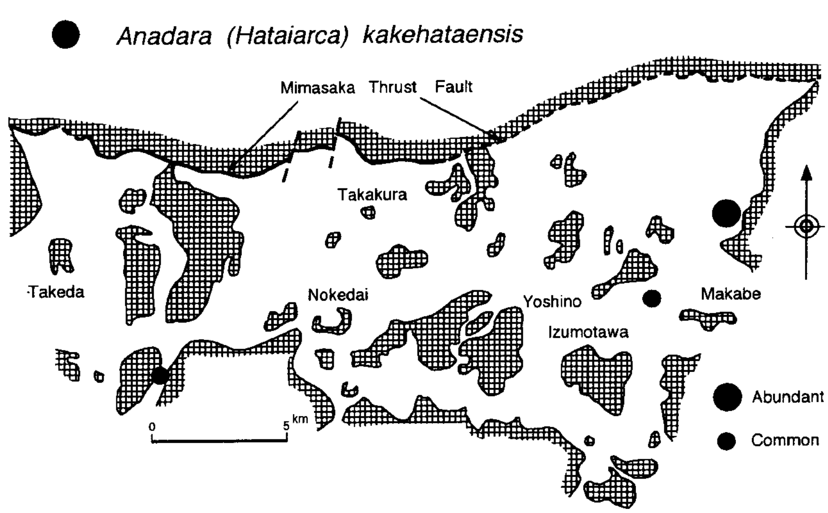


Fig. 10. Distribution of *Anadara* (*Hataiarca*) *kakehataensis*.

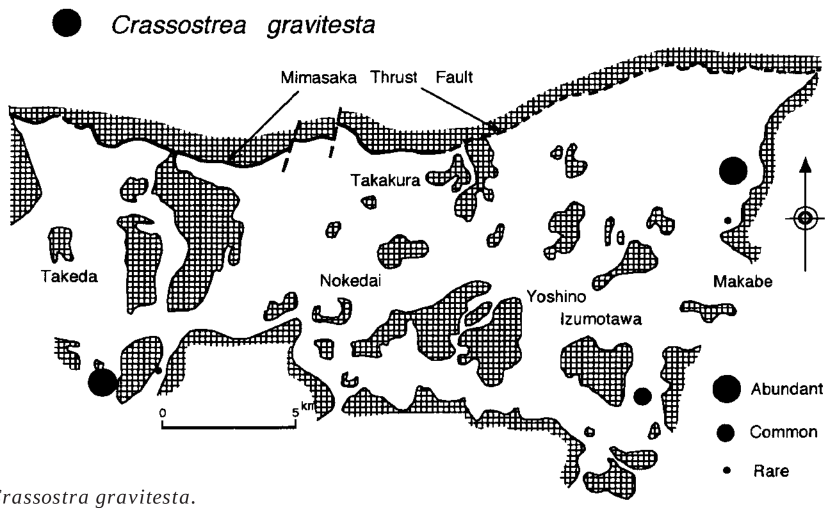


Fig. 11. Distribution of *Crassostra gravitesta*.

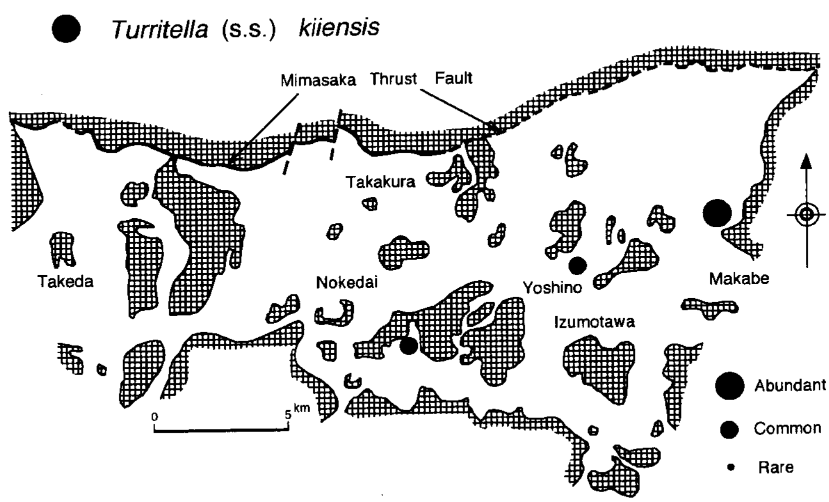


Fig. 12. Distribution of *Turritella* (*s.s.*) *kiiensis*.

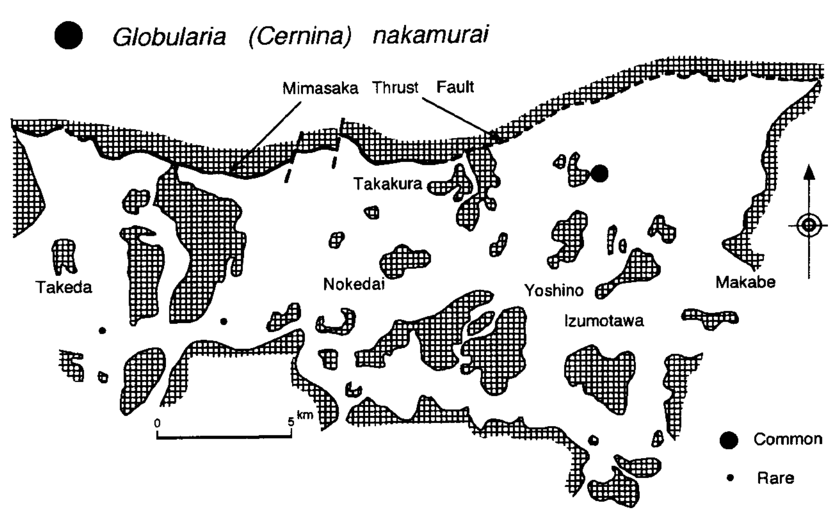


Fig. 13. Dostribution of *Globularia* (*Cernina*) *nakamurai*.

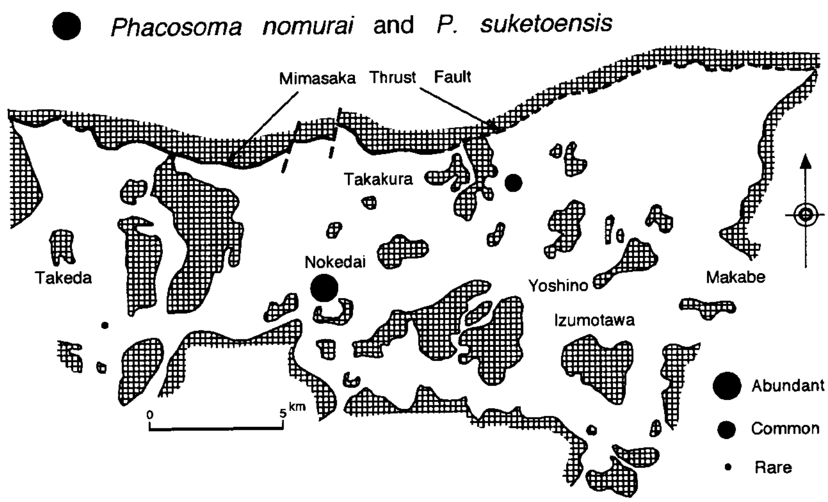


Fig. 14. Distribution of *Phacosoma nomurai* and *Ph. suketoensis*.

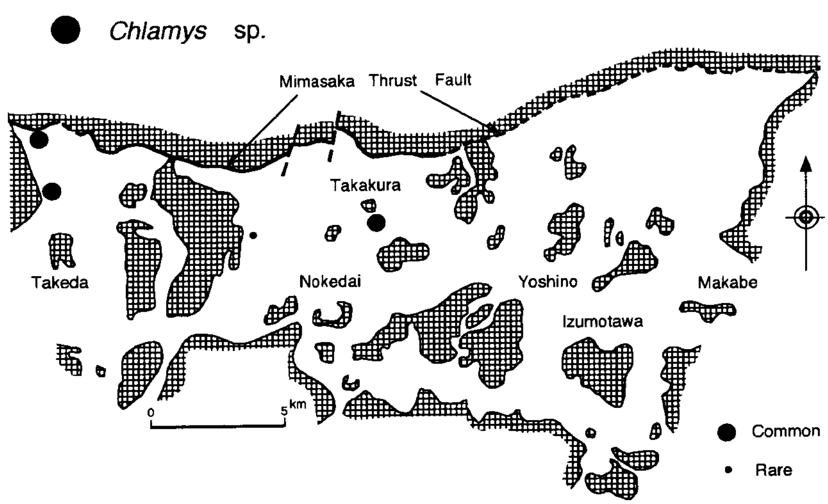


Fig. 15. Distribution of *Chlamys* sp.

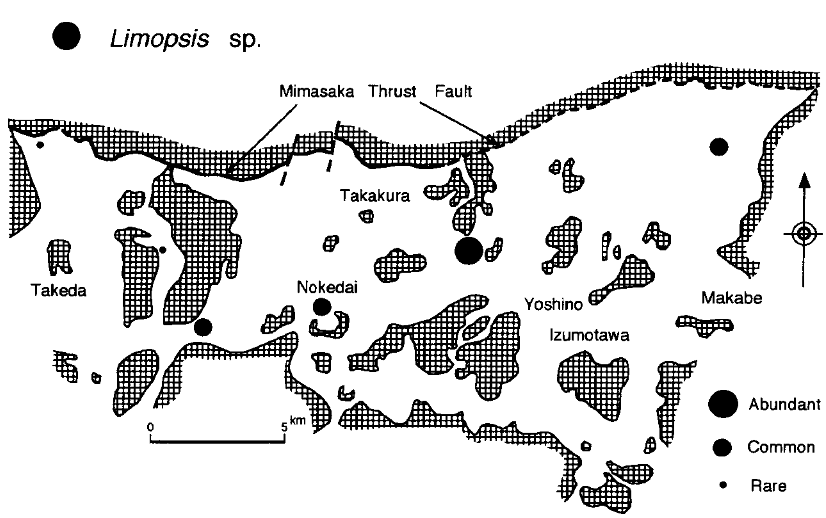


Fig. 16. Distribution of *Limopsis* sp.

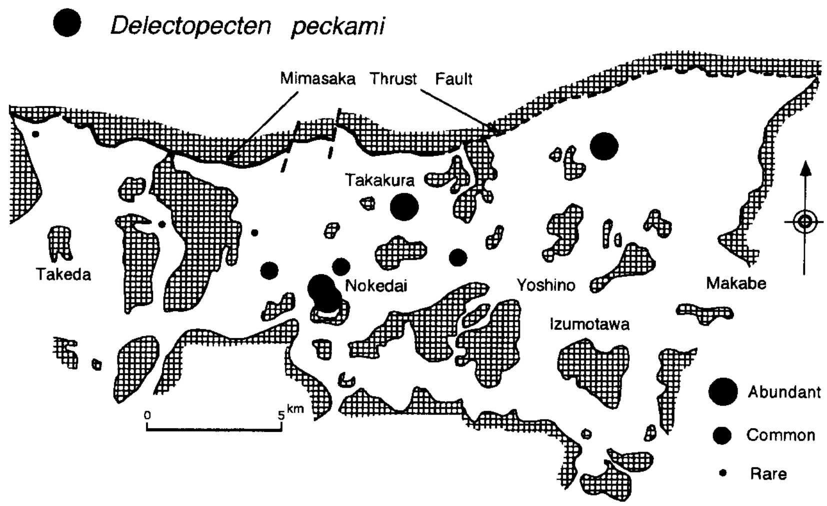


Fig. 17. Distribution of *Delectopecten peckhami*.

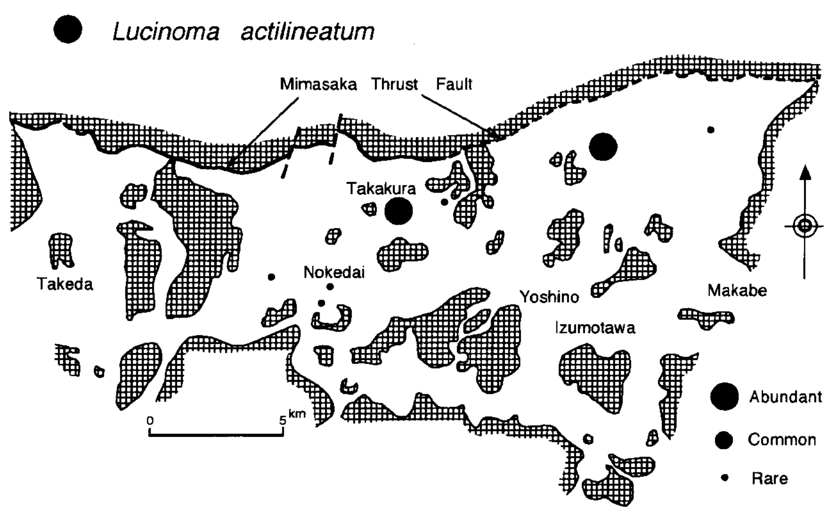


Fig. 18. Distribution of *Lucinoma acutilineatum*.

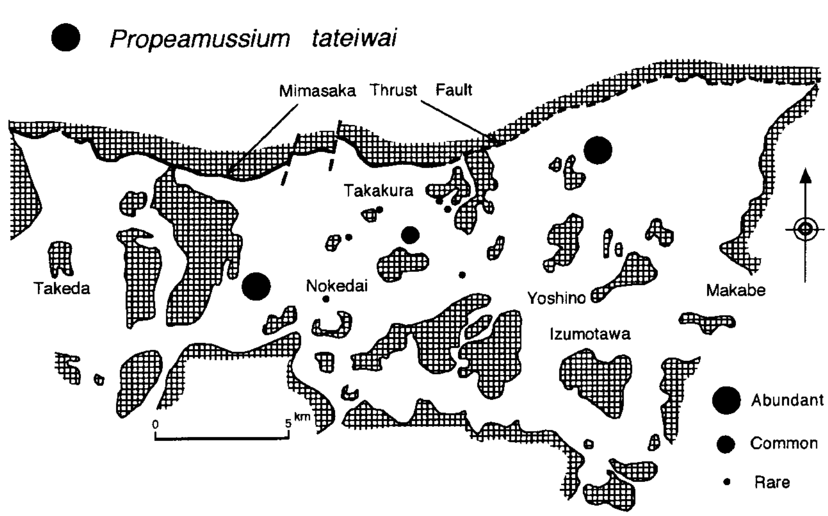


Fig. 19. Distribution of *Propeamussium tateiwai*.

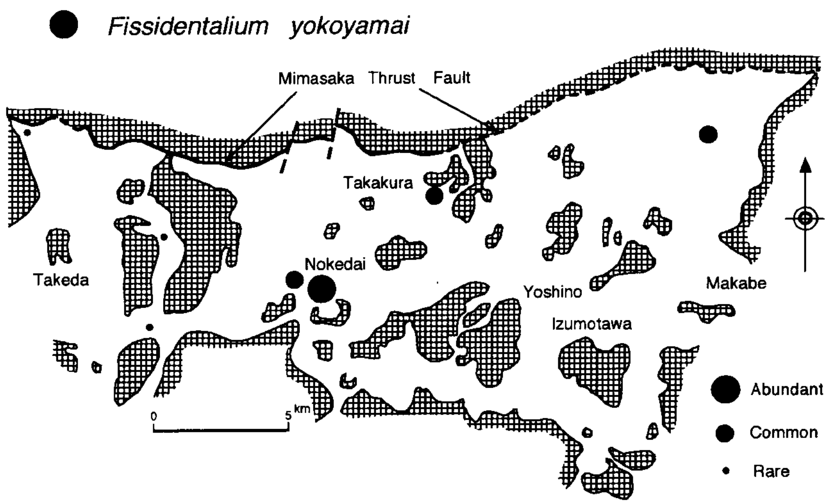


Fig. 20. Distribution of *Fissidentalium yokoyamai*.

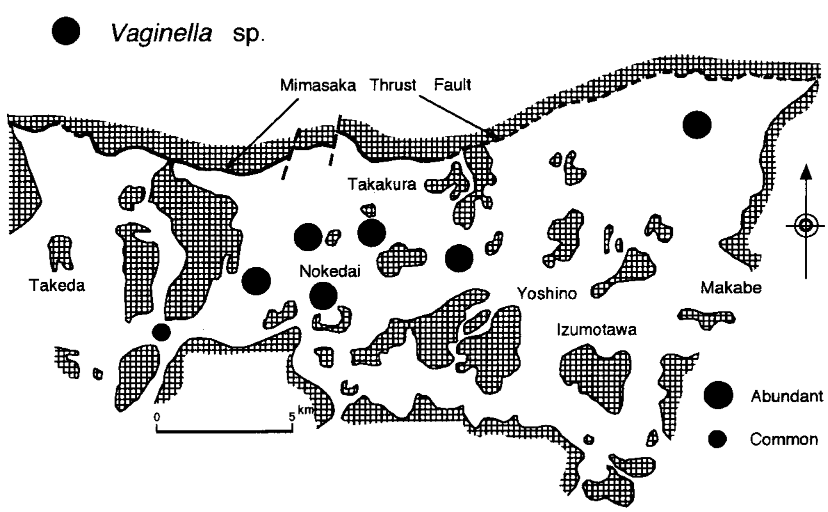


Fig. 21. Distribution of *Vaginella* sp.

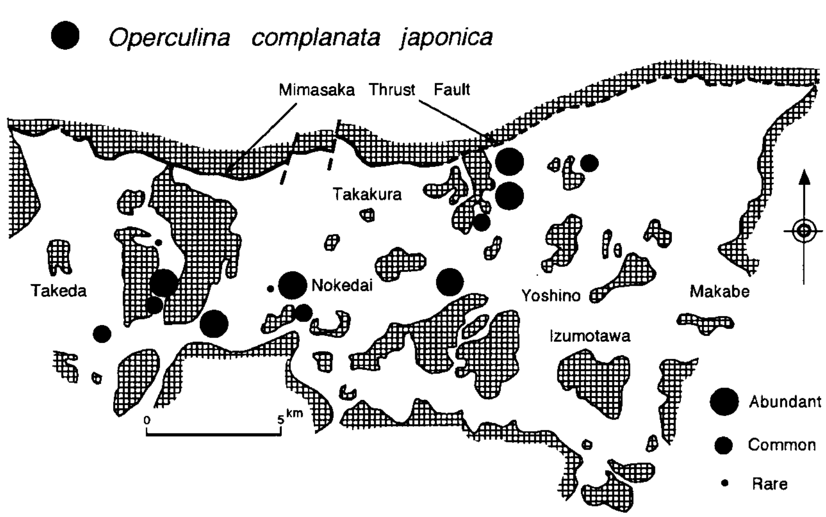


Fig. 22. Distribution of *Operculina complanata japonica*.

composed of burrowing, crawling and attached forms of suspension and detritus feeders (grazer and scavenger) and carnivors, distributed in estuaries of the southern and eastern margins of the Tsuyama Bay associated with typical mangrove swamp elements such as *Geloina*, *Terebralia*, *Telescopium* and *Rhizophorimurex*. The *Crassostrea gravitesta* assemblage occupied the southern margin in the western area and the southeastern margin in the eastern are. It formed probably a single colony, which is characterized by suspension feeder, and lived as epifaunal type (adhering type) in tidal fascia of brackish water. The *Turritella* assemblage only distributed in estuary of the Makabe River in the eastern area had lived in an euneritic fascia being composed of adhering and crawling types of detritus and suspension feeders. The *Phacosoma* assemblage, which is characterized by suspension feeding burrower, only recognized in the eastern area probably lived in an euneritic fascia shallower than 20 m deep being not influenced by oceanic water. The *Tellinella*-*Perna*-*Vepricardium*-*Vicaryella* assemblage, which consists of suspension and detritus feeders (grazer and scavenger) and carnivor, and is made up of infauna (burrower) and epifauna (adhering and crawling types) being dwelt in/on muddy bottom and gravelly and rocky substrata. They presumably flourished in an euneritic fascia about 20 m deep where the assemblage was not so much influenced by oceanic water owing to existence of an island as barrier existed in the southwestern part in the central area. The *Vepricardium*-*Euspira* assemblage, composed of burrowing and crawling suspension feeder and carnivor dwelt in/on muddy bottom of an euneritic fascia about 20 m deep being only occupied the central part in the eastern area. The *Saccostrea* assemblage, consisting of adhering suspension feeder, probably dwelt on gravelly and rocky beach of the southern part of the eastern area influenced by warm oceanic water. The *Vasticardium*-*Phacosoma* assemblage, made up of suspension feeding burrowers and crawling detritus feeders, located at the west part of Matsubara and Nokedai. The assemblage probably prospered in/on muddy and sandy bottoms in an euneritic fascis about 20 m deep influenced by warm oceanic water which is inferred from the co-existing *Operculina complanata japonica*. The *Globularia* assemblage, which distributed in the northern part of the eastern are and around Matsubara, is composed of crawling type species that was feeding algae in an euneritic fascia shallower than 20 m deep of sandy bottom. Its habitat was strongly influenced by warm oceanic water assumed from abundant co-occurrence of *Operculina complanata japonica*. The *Chlamys* assemblage, made up of adhering suspension feeders, distributed in the northern part of Takeda of the western area and the southern part of Takakura of the central area. The assemblage probably flourished in a mesoneritic fascia shallower than 50 m deep inflvenced by warm oceanic water being pressumable from co-occurrence of *Operculina complanata japonica*. The *Placopecten* assemblage, which is characterized by planktonic suspension feeders, only recognized, in the central part of the western area on a sandy substratum in a mesoneritic facia about 50 m deep affected by warm oceanic water. Associated no molluscs, *Operculina complanata japonica* thrived in the northern part of the central and eastern areas, representing inflow of strong and warm oceanic water.

As mentioned above, temporal and spatial distributions, paleoecology and paleoenvironment of the molluscan assemblages reveal that the Tsuyama Bay with several rivers probably opened northward, inlaied many small islands which bore various paleoenvironmental conditions. The bay suffered an invasion of sea (warm oceanic water) mainly from north during the depositional period of the lower part of the Izumotawa Sandstone Member of the Yoshino Formation. Such an estimation is supported by the analysis of the paleocurrent direction of the Katsuta Group (Nishimura and Nozaki, 1997).

C. The upper Izumotawa stage

The paleogeographic map of this stage can not be drawn owing to few occurrence of fossils except abundant occurrence of *Operculina complanata japonica* of this stage. Breccias of debris flow origin are seen indicating the tectonic movement of the basement rocks (probably fault) caused by a rapid deepening of the sedimentary basin as mentioned in the next lines.

D. The lower Nokedai stage

The lower part of the member yields the *Limopsis*-*Fissidentalium* and the *Vaginella* assemblage as already mentioned.

The paleogeography and paleoenvironment are herein reconstructed (Figs. 25 and 27).

The *Limopsis*-*Fissidentalium* assemblage mainly distributed in the central area with exception of two localities in the western and eastern areas seems to have thrived in/on sandy mud and muddy bottom conditions in

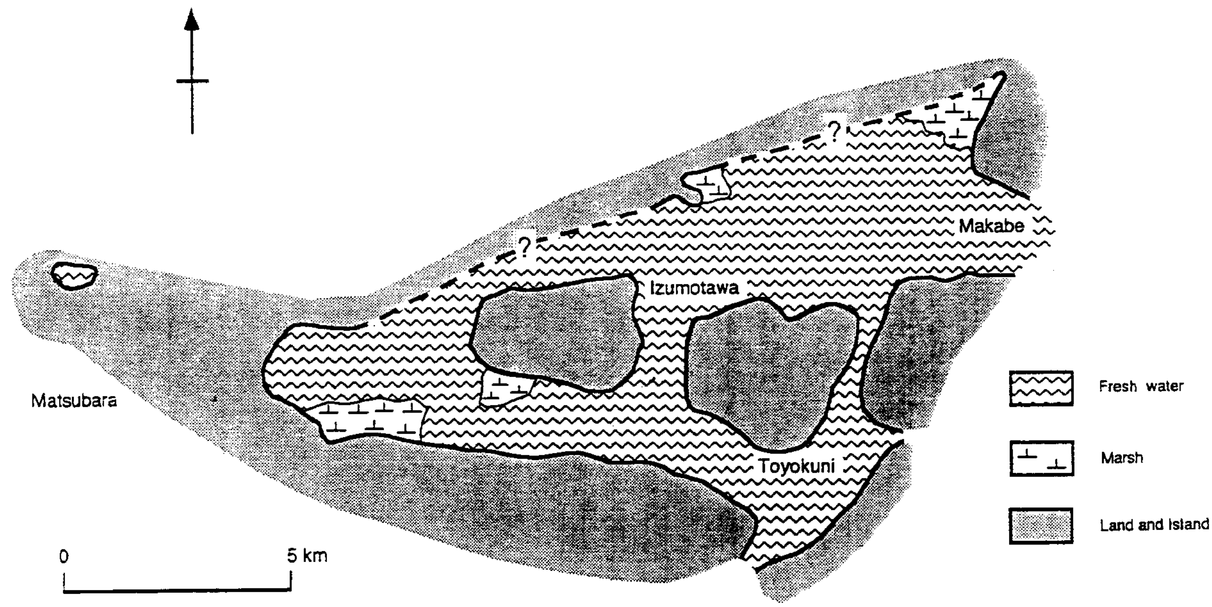


Fig. 23. Paleogeographic map during the depositional period of the Mimasaka Formation.

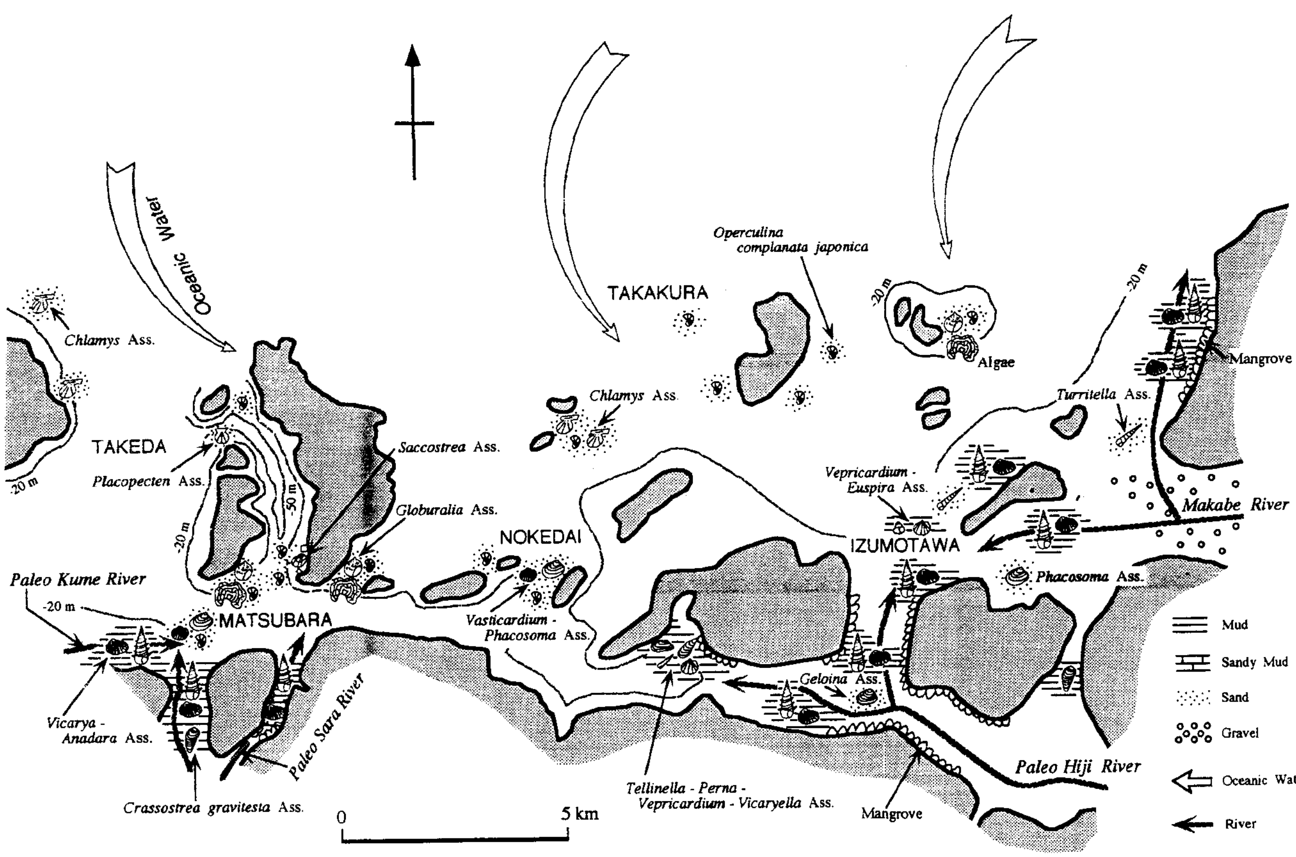


Fig. 24. Paleogeographic map during the depositional period of the lower part of the Izumotawa Sandstone Member of the Yoshino Formation.

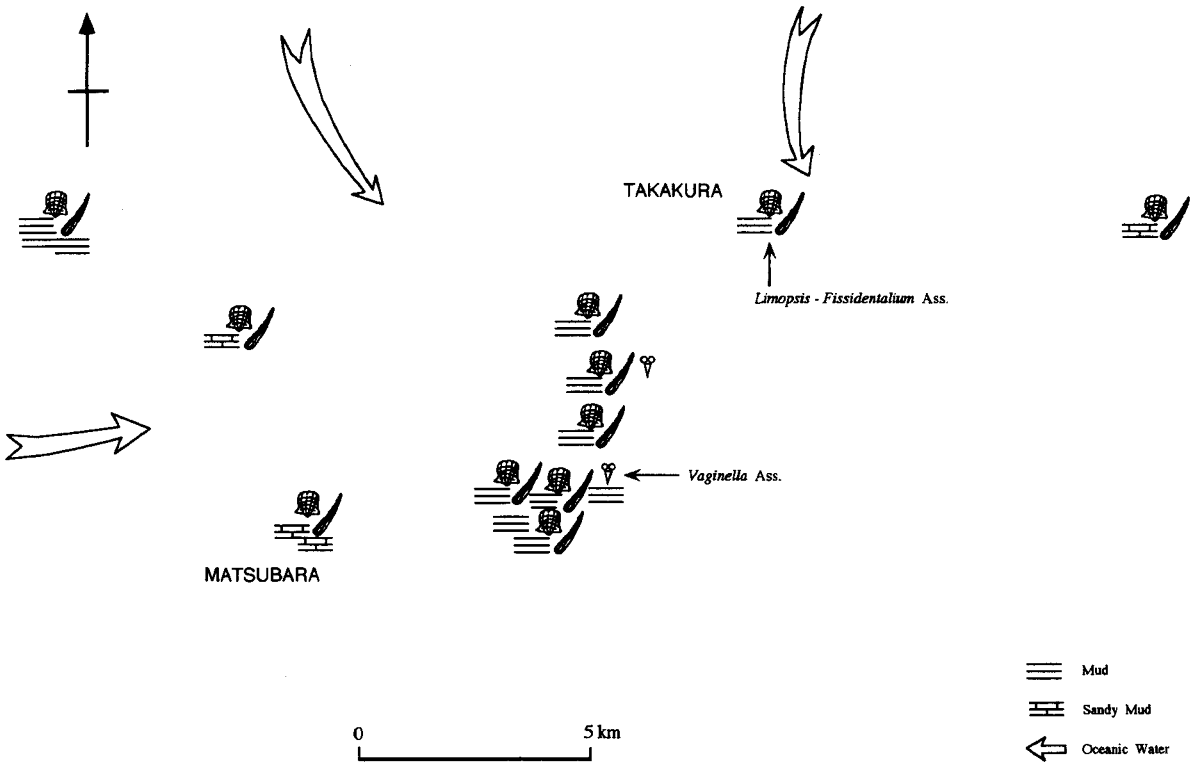


Fig. 25. Paleogeographic map during the depositional period of the lower part of the Nokedai Mudstone Member of of the Takakura Formation.

a bathyneritic to a hemibathyal fascia about 200m deep in depth and indicates cold water mass on the bottom. The *Vaginella* asemblage represents a warm oceanic water mass on the surface sea water layer. The former assemblage consists of epifauna (adhering type) and semi-infauna (shallow burrower), crawling type suspension and detritus feeders with carnivor. The latter one is composed of planktonic suspension feeders.

So far as paleobathymetric depth is concerned, rapid deepning of the sedimentary basin occurred between the *Placopecten* assemblage and the *Limopsis-Fissidentalium* assemblage, representing disparity in depth about 150 m.

E. The upper Nokedai stage

This stratigrapic position is characterized by the *Lucinoma-Propeamussium-Delectopecen* assemblage and the *Vaginella* assemblage which consist of crawling and burrowing detritus and suspension feeders, and planktonic suspension feeders, respectively. The former assemblage presumably inhabited in/on muddy bottom in a hemibathyal fascia probably deeper than 200 m inflowed by surface oceanic water of tropical to subtropical conditions as assumed from co-existing the latter assemblage.

The paleogeographic map, paleoenvironmental conditions and vertical distribution of the assemblages are shown in Fig. 26 and 27, respectively.

VIII. Significance of fauna

The faunas from the lower part of the Izumotawa Sandstone Member, which is the lower Yoshino Formation, are correlative to the Arcid-potamid fauna and the Pectinid fauna of Tsuda (1965) called the Kurosedani fauna. Because such molluscs as *Anadara* (*Hataiarca*) *kakehataensis*, *Striarca uetsukiensis*, *Crassostorea gravitesta*, *Geloina stachi*, *G. yamanei*, *Cultellus izumoensis*, *Cerithidea kanpokuensis* and *Vicarya japonica* are representative elements of the Arcid-potamid fauna and *Scapharca abdita*, *Euspira meisensis*, *Cryptopecten yanagawaensis* and *Operculina complanata japonica* are those of the Pectinid fauna. In the case of the lower part of the Izumotawa, however both faunas occurred in contemporaneous relationship.

Recently, Itoigawa (1988) divided the Kadonosawa fauna (Chinzei, 1986) into the southern Kurosedani fauna

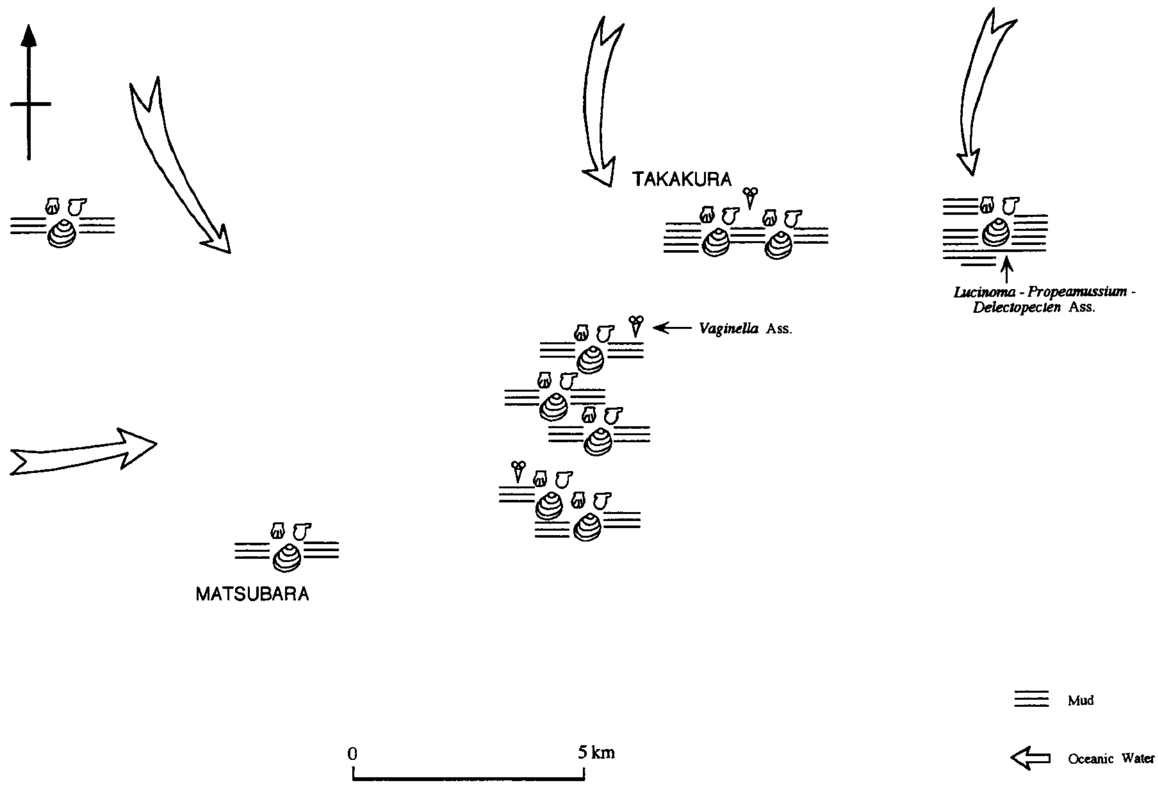


Fig. 26. Paleogeographic map during the depositonal period of the upper part of the Nokedai Mudstone Member of the Takakura Formation.

and the northern Kadonosawa fauna (redesignated) on the ground that the former fauna has tropical elements while the latter one is lacking them. The fauna from the Takakura Formation, which is characterized by *Acharax tokunagai, Megayoldia thraciaeformis, Delectopecten peckhami* and *Lucinoma acutilineatum,* is correlative to the Higashibesho fauna established by Kaseno (1964). Very recently, Shimizu et al. (2000) reported several molluscan species from the Higashibesho Formation, i.e., *Acharax tokunagai, Acila divaricata, Ennucula osawanoensis, Portlandia japonica, Saccella confusa, Delectopecten peckhmai, Gloripallium izurensis, Parvamussium* sp., *Propeamuseum tateiwai, Acesta golioath, Lucinoma annulata, Periploma* sp., *Teredo* sp., *Fissidentalium yokoyamai, Sinum* sp., *Fulgoraria* sp. and *Clio itoigawai.*

As already mentiond, the Takakura Formation is correlative to the Upper Shale Formation of the Bihoku Group in which a lot of specimens of many species were discovered by Okamoto (1992). They consists of about 50 molluscan species, e. g., *Acharax tokunagai, Lamellinuculla* sp., *Portlandia watasei, Limopsis* sp., *Crenulilimopsis* sp., *Nipponolimopsis* sp., *Crenella* sp., *Propeamussium tateiwai, Delectopecten peckhami, Limatula* sp., *Lucinoma* sp., *Cardiomya* cf. *sagamiana, Fissidentalium yokoyamai, Antalis* sp., *Cellana* sp., *Minolia* sp., *Boreotrophon* sp., *Musashia* sp., *Nipponopscaphander* sp., *Limacina* sp., *Vaginella* sp. and *Clio itoigawai* etc.

The diversity of molluscan species from the Korematsu is higher than that of the Higashibessho. Moreover, the species composition of the Korematsu is somewhat different from that of the Higashibessho. Therefore, I newly propose herein the Korematsu fauna of which type locality is Korematsu, Shobara City, Hiroshima Prefecture. This fauna is recognized in the Shimo Formation of the Uchiura Group (Nakagawa and Takeyama, 1985), the Fuganji Member of the Tottori Group (Akagi et al., 1992a, b), the Takakura Formation of the Katsuta Group (this paper), the Upper Shale Formation of the Bihoku Group (Itoigawa and Nishikawa, 1978; Okamoto et al., 1986, 1989; Okamoto, 1992) and the Upper Mudstone Member of the Masuda Group (Tsuru, 1985). Here, I would like to place this fauna between the Kurosedani and Fujina faunas.

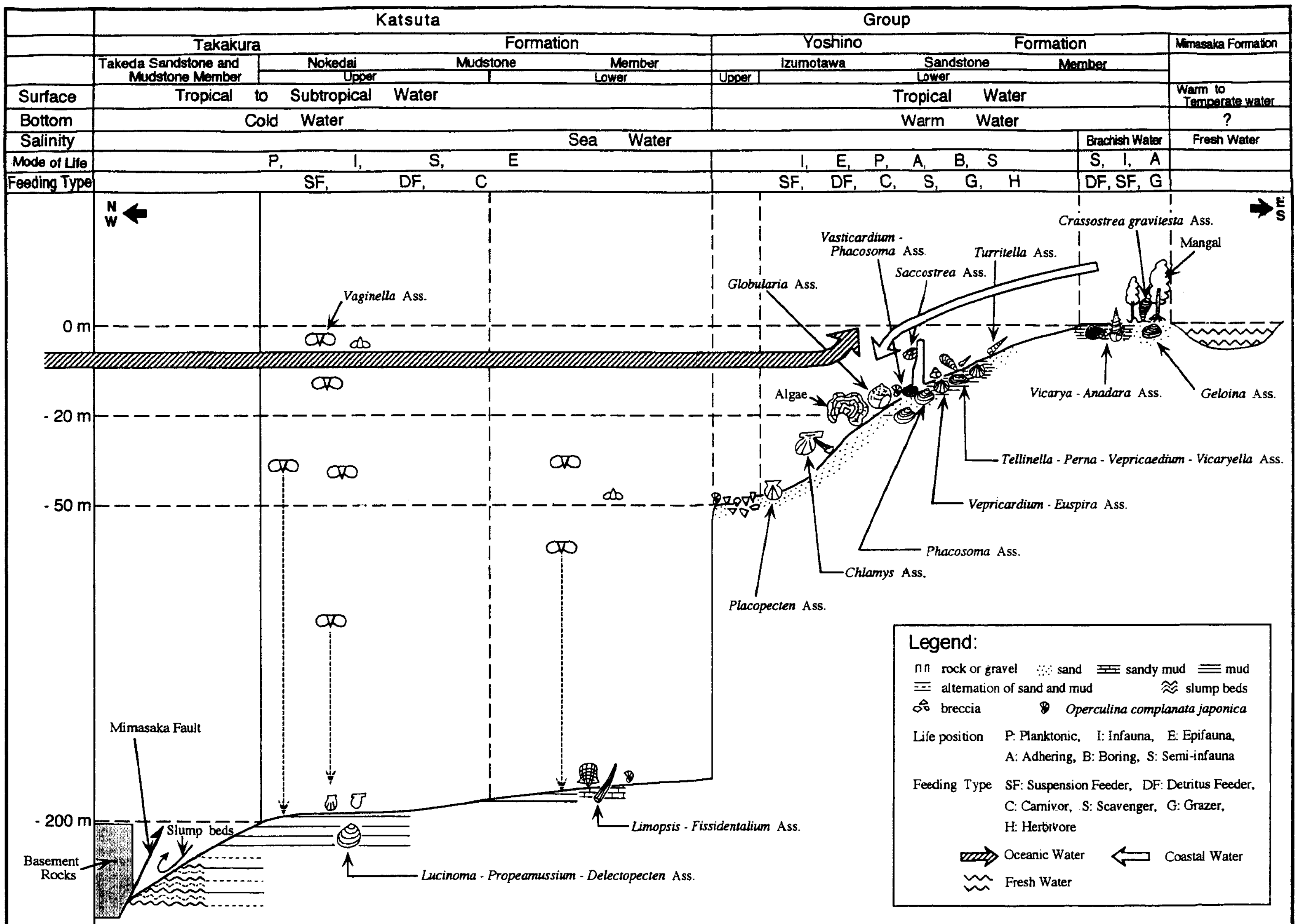


Fig.27. Schematic diagram of the temporal distribution of the molluscan assemblages and their paleoecology, and paleoenvironmental and paleoclimatic conditions during the depositional period of the Katsuta Group.

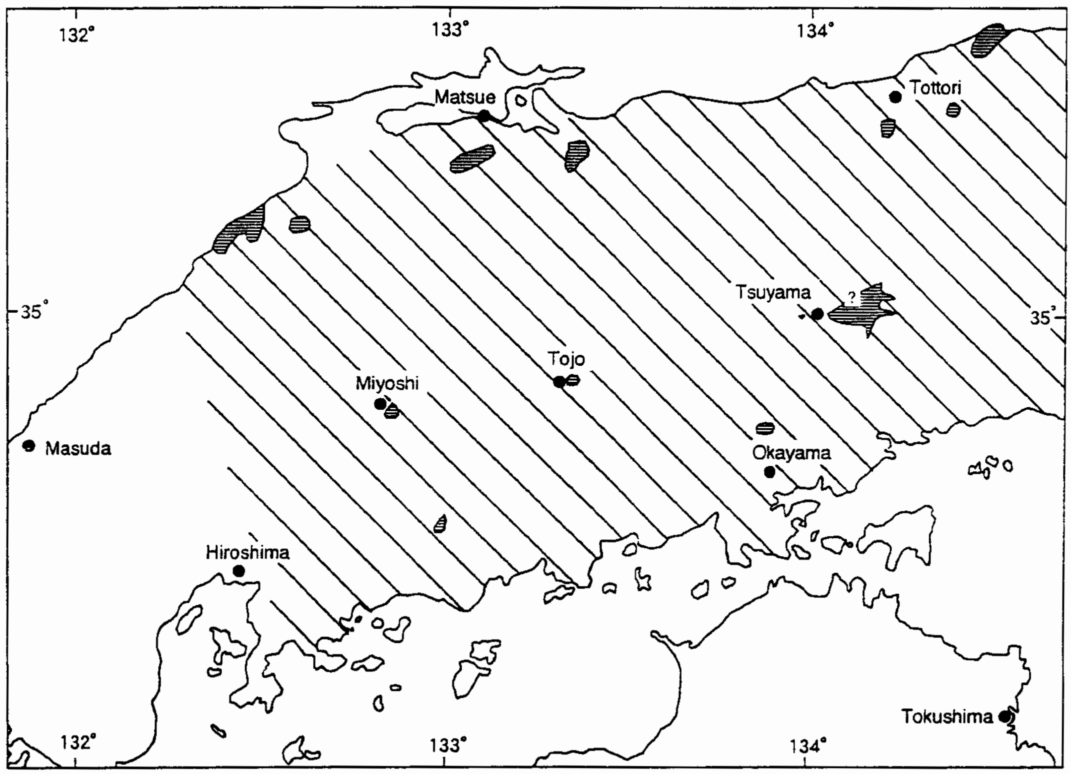


Fig. 28. Paleogeography of Chugoku district in 17Ma.

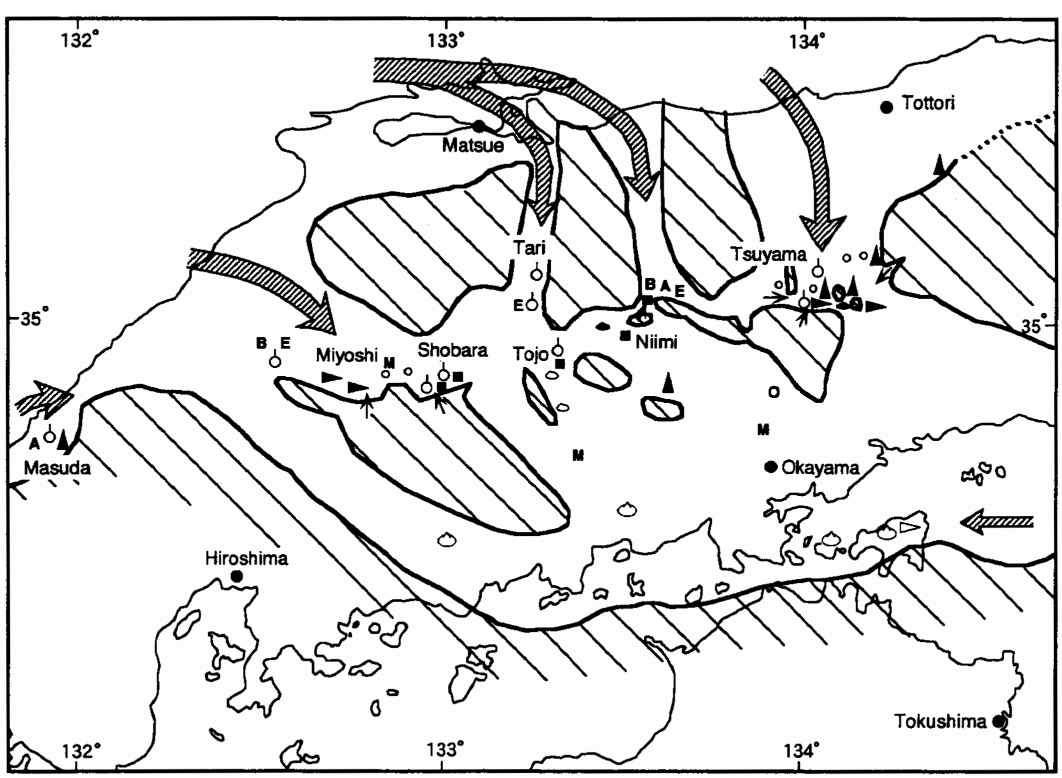


Fig. 29. Paleogeography of Chugoku district in 16Ma.

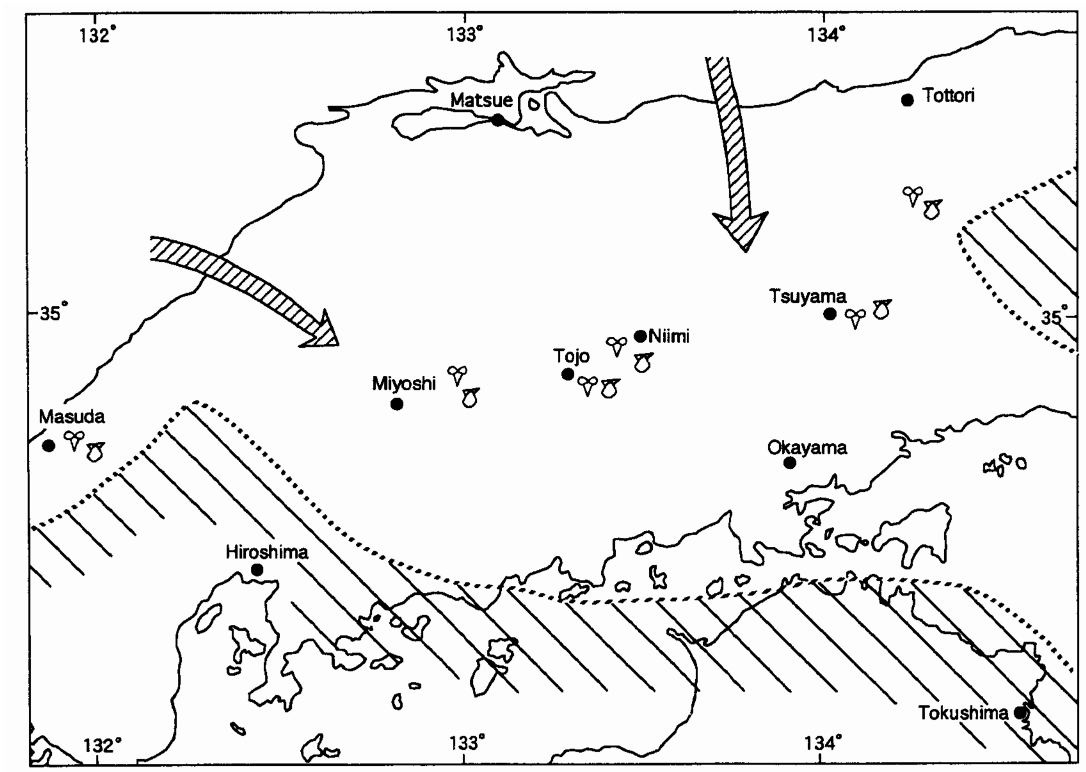


Fig. 30. Paleogeography of Chugoku district in 15Ma.

Legend of Figs. 28-30

Land area
Fresh water area
Sea area
Shore line
Oceanic current
River
Anadara-Vicarya Assemblage
Crassostrea Assemblage
Crassostrea-Tateiwaia Assemblage
Vasticardium-Phacosoma Assemblage
Geloina Assemblage
Batissa Assemblage
Mactra-Acila Assemblage
"Ostrea" Assemblage
Propeamussium-Delectopecten Assemblage
Veginella Assemblage
Operculina
M *Miogypsina*
E Echinoid
B Baranacle
A *Aturia*

IX. Paleogeography of Chugoku district in the Early to Middle Miocene

The paleogecgraphical maps of the Chugoku district in the middle to upper Miocene are shown in Figs. 28, 29 and 30. These three stages are designated as follows:

First stage; this stage is representative of lacustrine environments which were sporadically distributed in the western Setouchi Province and the San'in-Hokuriku Province. The paleogeography of this stage is greatly modified after the figure of Itoigawa and Shibata (1992).

Second stage; this stage exhbits early phase of the transgression. The Tsuyama, Ohsa and Tari areas seem to have connected with the Japan Sea side. The spatial and vertical distributions of molluscan assemblages and *Operculina complanata japonica* in the Tsuyama basin, the occurrence of *Aturia cubaensis* (Tomida, 1992) from the bay head of the Ohsa basin, and spatial distribution of molluscan assemblages from that basin (Taguchi et al., 1979) and of molluscan fossils from the Tari basin (Yamana, 1990), display that these basins opened north. In this point, the paleogeography of this stage is

Generic Name (Specific name) \ Locality	Recent: Southeast Asia	Recent: Formosa	Recent: Okinawa	Recent: Amami	Recent: South Kyushu	Fossil: Bihoku	Fossil: Katsuta	Fossil: Yatsuo	Fossil: Noto	Fossil: Tsuruoka	Fossil: Mizunami	Fossil: Joban
● *Isognomon* (s.s) *(minoensis)*	→	→	→	→	→	×					×	
Katelysia (s.p.)	→	→	→	→	→						×	
Pionoconus (s.p.)	→	→	→	→	→			×				
● *Geloina (stachi, yamanei,* sp.)	→	→	→	→		×	×	×	×	×	×	
Regozara (sp.)	→	→	→	→			×					
● *Terebralia (itoigawai, kakienensis, shibatai,* sp.)	→	→	→	→		×	×	×			×	×
Lyncina (sp.)	→	→	→	→							×	
Labiostrombus (sp.)	→	→	→	→				×				
Cypraecasis (sp.)	→	→	→	→							×	
Phylloda (aff. *foliacea)*	→	→	→					×				
Leporimetis (takaii)	→	→	→				×	×		×		
"Transtrafer" (sp.)	→	→	→					×				
Placuna (sp.)	→	→									×	
Maoricardium (mizunamiensis)	→	→									×	
Vepricardium (s.s) *okamotoi*	→	→					×					
● *Telescopium (schencki)*	→	→					×	×				
Perna (oyamai)	→						×					
Pharella sp.	→						×					
● *Batissa (bihokuensis)*	→					×						
Globularia (nakamurai)	→					×	×	×				
● *Rhizophorimurex (capuchinus nagiensis)*	→						×	×				
Rimella (osawanoenesis)	→					×		×				
Volema (osawanoensis)	→							×				
Number of Genera (Number of Genera of Mangrove Swamp)						6 (3)	10 (4)	12 (4)	1 (1)	2 (1)	8 (2)	1 (1)

Table 6. Comparison of distribution pattern of fossil and living species of subtropical or tropical elements. Solid circle: mangrove element. (modified after Itoigawa and Tsuda, 1984).

discordant with the map presented by Takayasu et al. (1992) and Itoigawa and Shibata (1992). However, the map of this stage resembles with that of Shibata and Itoigawa (1980).

Third stage; this stage shows a maximum transgressive phase. In this stage, the greater part of the Chugoku district was covered by the sea with inflow of warm oceanic water suggested by occurrence of the pteropod fauna. The map of this stage is similar to that of Itoigawa and Shibata (1992) in part.

X. Discussion

Modified after Ogasawara (1994) and Chiji et al. (1990), the paleogeography and paleooceanography of the Japan Arc and its environs in 20-17Ma, 16Ma and 15Ma is presented Figs. 31 to 33, respectively.

Fig. 31 exhibits paleogeography of the Japan Arc before rotation of the arc. Joban area and far south area, Joban area to Kadonosawa area and Kadonosawa area and far north area in this stage were probably correlated with the present sea conditions as Off Choshi and far south area, Off Choshi to Off Sanriku, and Off Sanriku and far north area, respectively. Occurrence of *Terebralia*? sp., toropical species, in the lower part of the Kunugidaira Formation of the Yunagaya Group of the Joban Coal field (Yabe et al., 1995) and the fauna from the Yotsuyaku Formation in the Ninohe district (Matsubara, 1995) being correlative to the Akeyo fauna (Itoigawa, 1987), and the Sankebetu fauna from Hokkaido (Noda, 1992) confirm this assumption.

Fig. 32 displays an initial opening of the Japan Arc. In this stage, the Japan Arc is divided into four marine climetic zones, which are Mizunami-Yatsuo area and far south area, Mizunami-Yatsuo to Tsuruoka-Kadonosawa area, Tsuruoka-Kadonosawa area to south Hokkaido and south Hokkaido and far north area on the basis of Noda (1992), Suzuki and Mukai (1996), Tsuda (1960) and Itoigawa (1960). These zones are correlative with modern

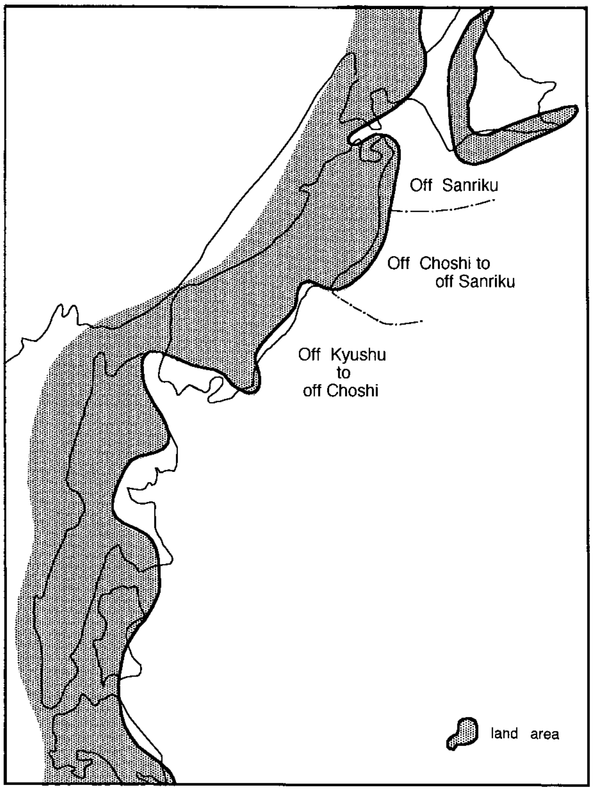


Fig. 31. Paleogeography and paleoclimate of Japan arc in 20-17Ma.

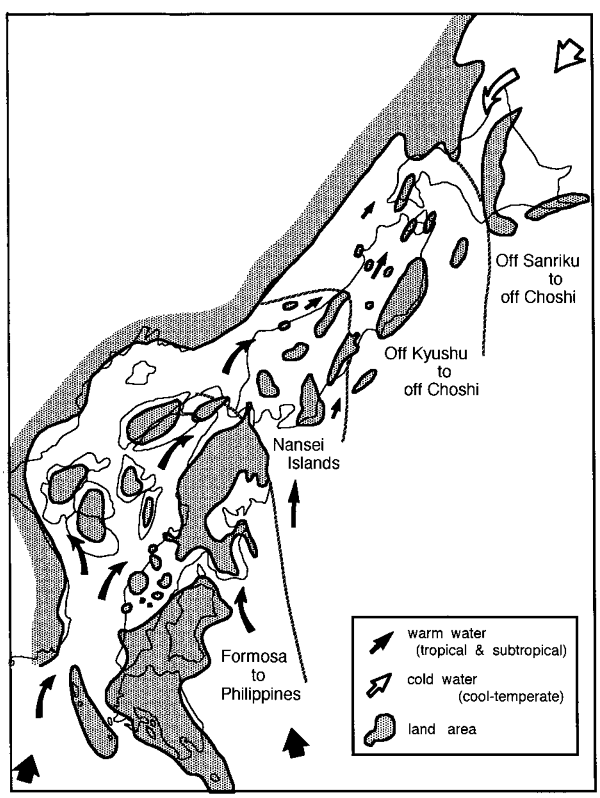


Fig. 32. Paleogeography and paleoclimate of Japan arc in 16Ma.

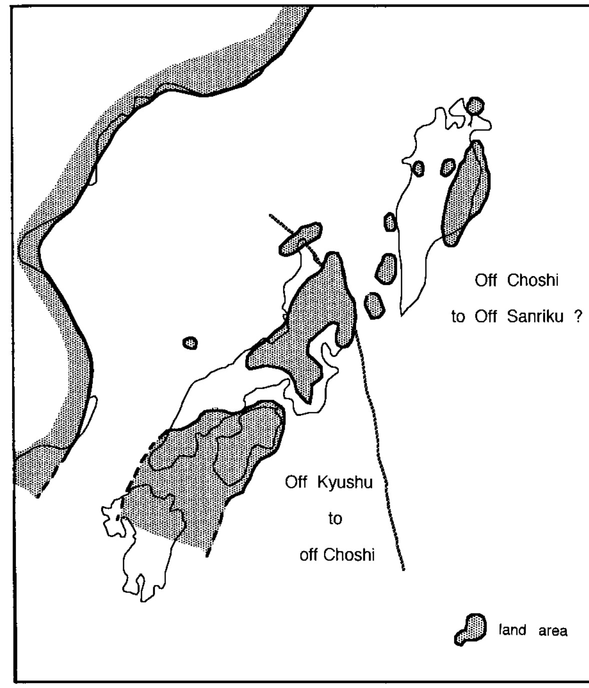


Fig. 33. Paleogeography and paleoclimate of Japan arc in 15Ma.

marine conditions such as Formosa to the Philippines, Nansei Islands, Off Kyushu to Off Choshi and Off Choshi to Off Sanriku, respectively. I divided the tropical to subtropical realm into three marine climates, i. e., Off Kyushu to Off Choshi, Nansei Island and Formosa to the Philippines basin on distribution of tropical to subtropical molluscan genera/species (Table 6). Moerover, the tropical marine climate such as Formosa to the Philippines is assumed from occurrence of a huge soft-shell turtle from the early Middle Miocene Bihoku Group in Niimi City, Okayama Prefecture, western Japan (Hirayama and Taguchi, 1994). The Off Kyushu to Off Choshi climate is inferred from *Vicaryella* bearing molluscan assemblage (Uchimura and Majima, 1992) and Arcid-potamid fauna (Kanno et al., 1988) which is lacking tropical elements. The Off Choshi to Off Sanriku climate is inferred from the Takinoue fauna thet is characterized by occurrene of *Crassostreaea gravitesta, Cultellus izumoensis, Mizuhopecten kobiyamai* and *Cerithideopsilla* cf. *minoensis* (Suzuki and Mukai, 1996). The Off Sanriku and far north climate can be judged from the Chikubetsu faunal elements such as *Anadara ogawai, Cultellus izumoensis, Dosinia* spp. and *Sinum yabei at* the time of the Mid-Neogene Climatic Optimum.

Fig. 33 shows the main opening of the Japan Arc with exception of Hokkaido. The surface marine climate of the Yatsuo-Mizunami areas is probably correlated with modern Off Kyushu to Off Choshi marine climatic condition because the Higashibessho Formation of the Yatsuo Group and the Oidawara Formation of the Mizunami Group yield the pteropod fauna (Shibata, 1980 and 1997, Shimizu et al., 2000). The far north area of two areas is perhaps correlative with modern Off Choshi to Off Sanriku marine climate, although there is no positive fact of molluscan fossils that support the aforementioned marine climate.

XI. Concluding remarks

The concluding remarks are summarized as follows:

1. The Miocee Katsuta Group, distributed in the western part of the Setouchi Province, rests unconformably upon the Pre-Neogene rocks and is unconformably overlain by the Pleistocene Nihonbara Formation. The group is intruded by the late Miocene alkali basalt.
2. The Katsuta Group is divied into three formations, i.e., the Mimasaka, Yoshino and Takakura Formations in ascending order.
3. The Mimasaka Formation is disconformably overlain by the Yoshino Formation which is conformably covered by the Takakura Formation.
4. The Yoshino and Takakura Formations are subdivided into the Makabe Conglomerate and Izumotawa Sandstone Members, and the Nokedai Mudstone and Takeda Sandstone and Mudstone Members, respectively. Both members are contemporaneously heterotopic partly.
5. The main geological structures are characterized by fault and folds. The fault is named the Mimasaka thrust extending E-W direction in the northern part of the investigated area and the folding axis exhibits various directions. The Mimasaka thrust and the folds were probably formed by the tilting of the basement rocks during depositional period of the Takakura Formation.
6. The geological age of the Katsuta Group is Early to Middle Miocene age on the basis of the Daijima type flora from the Mimasaka Formation, and fission-track dating of the Yoshino and Takakura Formations (Suzuki et al., 1996), and analysis of calcareous nannofossil biostratigraphy (Yamamoto, and Nozaki, 1997).
7. The molluscan assemblages are analyzed in consideration of locality, stratigraphic position, lithofacies, mode of occurrence, mode of life, feeding type and their paleoecology. Thus, 12 molluscan assemblages, i. e., the *Geloina, Crassostrea graritesta, Vicarya-Anadara, Turritella, Tellinella-Perna-Vepricardium-Vicaryella, Saccostrea, Phacosoma, Vasticardium-Phacosoma, Vepricardium-Euspira, Globularia, Chlamys* and *Placopecten* from the Yoshino Formation, 3 assemblages, namely, the *Limopsis-Fissidentalium*, *Lucinoma-Propeamussium-Delectopecten* and *Vaginella* from the Takakura Formation are recognized.
8. As a result of analysis of temporal and spatial distributions of molluscan assemblages and spatial distribution of *Operculina complanata japonica,* the Tsuyama Bay had been opened to north during depositional period of the Yoshino Formation. The Tsuyama Bay became to be under sea judging from benthic and planktonic molluscan assemblages at depositional time of the Takakura Formation.
9. The fauna from the Yoshino Formation belong to the Kadonosawa fauna as can be judged from the fact including tropical elements. The fauna from the Takakura Formation is involved in the Korematsu fauna newly proposed.
10. The Miocene paleogeography of Chugoku district is drown for three stages; the first stage exhibits the lacustrine environment sporcadical1y distributed in Chugoku district. The second stages displays the early transgression. The third stage shows the maximum transgressive phase.
11. Three paleogeographic and paleooceanographc maps of the Japan Arc and its environs in connection with rotation were discussed in the light with modern marine climate.

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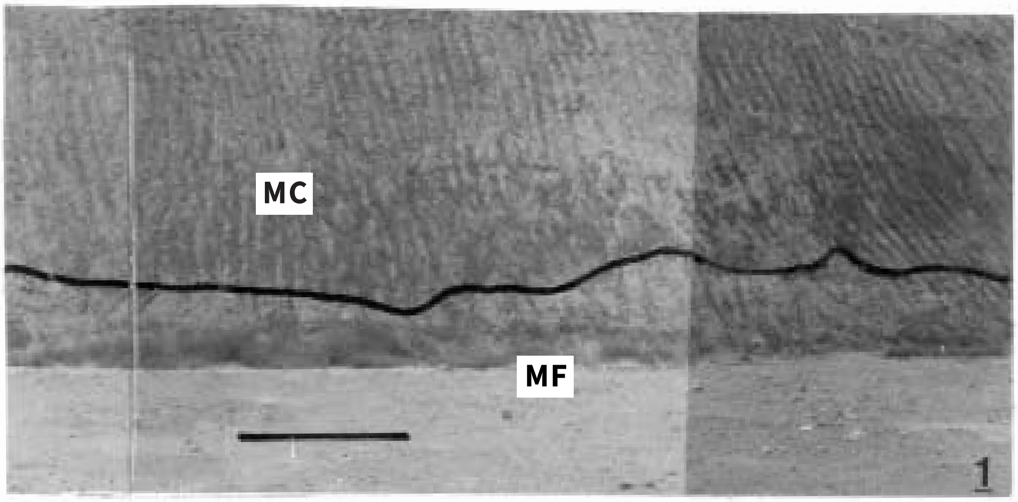
Plate 1

Fig. 1. Disconformity between the Mimasaka Formation and the Makabe Conglomerate Member. Location: Southern part of the eastern area.
Scale bar: 2 m.

Fig. 2. Disconformity between the Mimasaka Formation and the Makabe Conglomerate Member. Location: Izumotawa.
Scale bar: 10 cm.

Fig. 3. Disconformity between the Mimasaka Formation and the Yoshino Formation. Location: Southern part of the eastern area.
Scale bar: 1 m.

MF: Mimasaka Formation, MC: Makabe Conglomerate Member, YF: Yoshino Formation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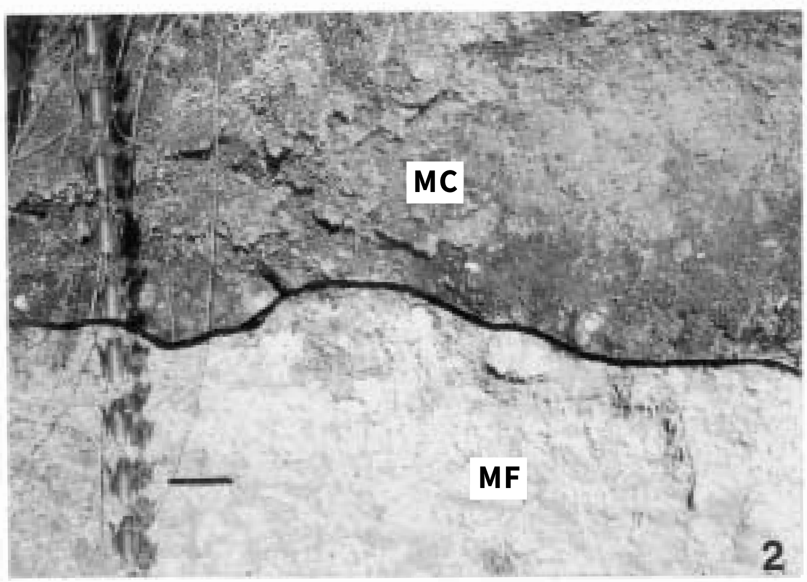
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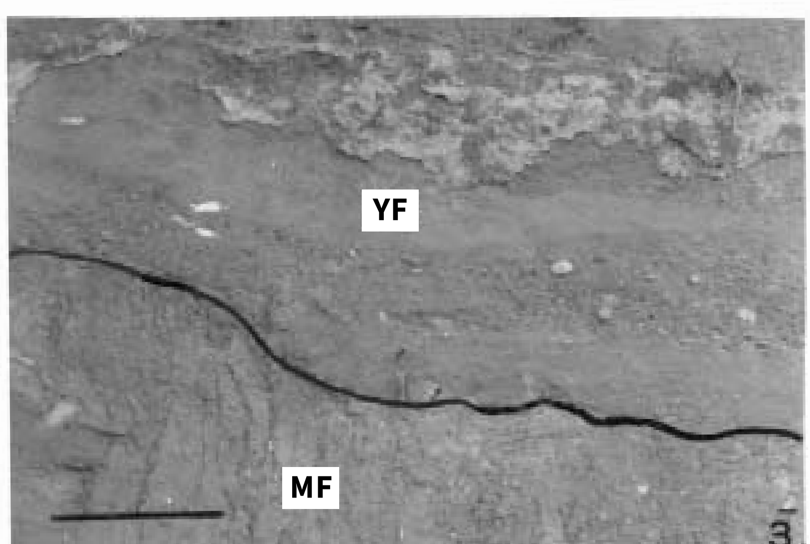
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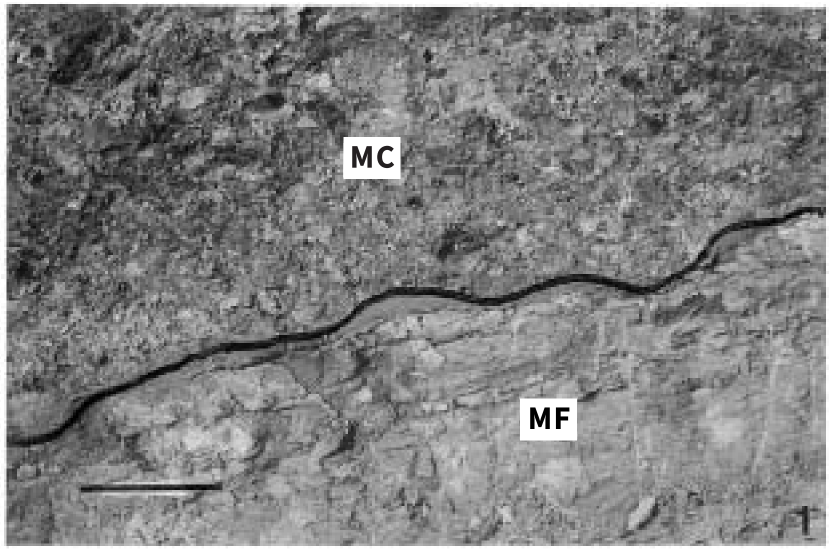
Plate 2

Fig. 1. Disconformity between the Mimasaka Formation and the Makabe Conglomerate Member. Location: Middle part of the western area.
Scale bar: 10 cm.

Fig. 2. Mimasaka thrust. Location: Northern part of the western area.
Scale bar: 3 m.

Fig. 3. Mimasaka thrust. Location: Northern part of the western area.
Scale bar: 1 m.

MF: Mimaska Formation, MC: Makabe Conglomerate Member, BR: Basement rocks, IS: Izumotawa Sandstone Member.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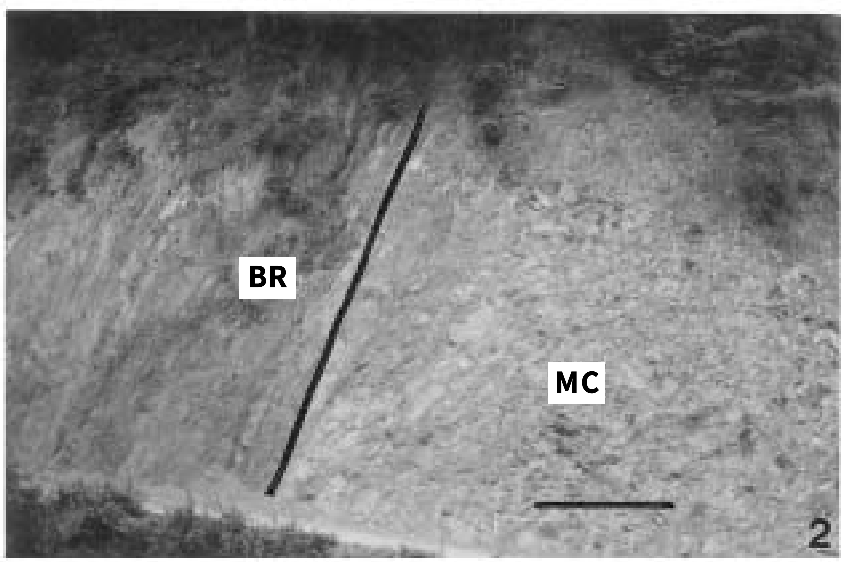
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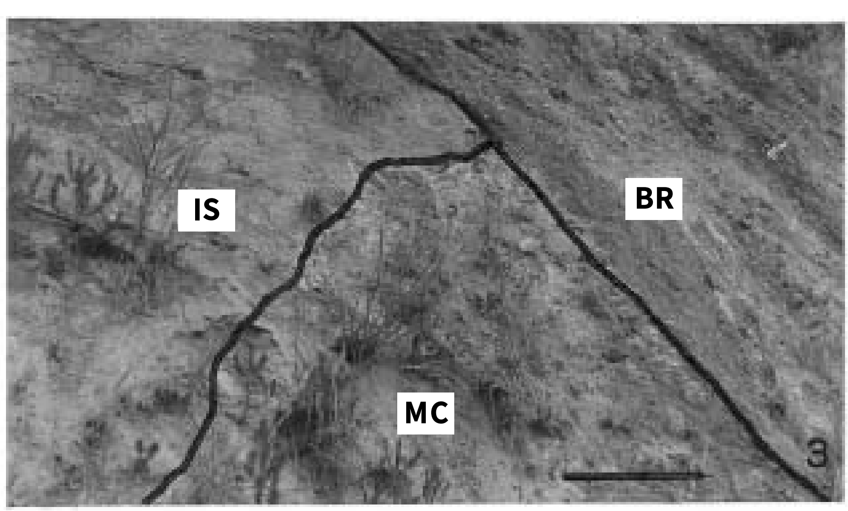
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Plate 3

Fig. 1.	*Archarax tokunagai* (Yokoyama), loc. 31, upper part (U) of the Nokedai Member (NK).
Fig. 2.	*Lamellinucula* sp. loc. 23, U of NK.
Fig. 3.	*Megayoldia thraciaeformis* Störer, loc. 23, U of NK.
Fig. 4.	*Limopsis* sp. loc. 23, U of IZ.
Figs. 5-8.	*Anadara* (*Hataiarca*) *kakehataensis* Hatai et Nisiyama, loc. III, Lower part (L) of the Izumotawa Sandstone Member (IZ).
Fig. 9.	*Scapharca abdita* (Maiyama), loc. 84, L of IZ.
Fig. 10.	*Striarca elongata* Taguchi, loc. 111, L of IZ.
Fig. 11.	*Nipponarca japonica* Taguchi, loc. 84, L of IZ.
Fig. 12.	*Striarca uetsukiensis* Hatai et Nisiyama, loc. 111, L of IZ.
Fig. 13.	*Mytilus* sp. loc. 84, L of IZ.
Figs. 14, 15.	*Modiolus* sp. loc. 84, L of IZ.
Fig. 16.	*Perna oyamai* Taguchi, loc. 84, L of IZ.
Fig. 17.	*Propeamussium tateiwai* Kanehara. loc. 23, U of NK.
Fig. 18.	*Placopecten nomurai* Masuda, loc. 10, U of IZ.
Fig. 19.	*Chlamys* sp. loc. 2, L of IZ.
Fig. 20.	*Limatula* sp. loc. 57, U of NK.

All figures are in natural size.

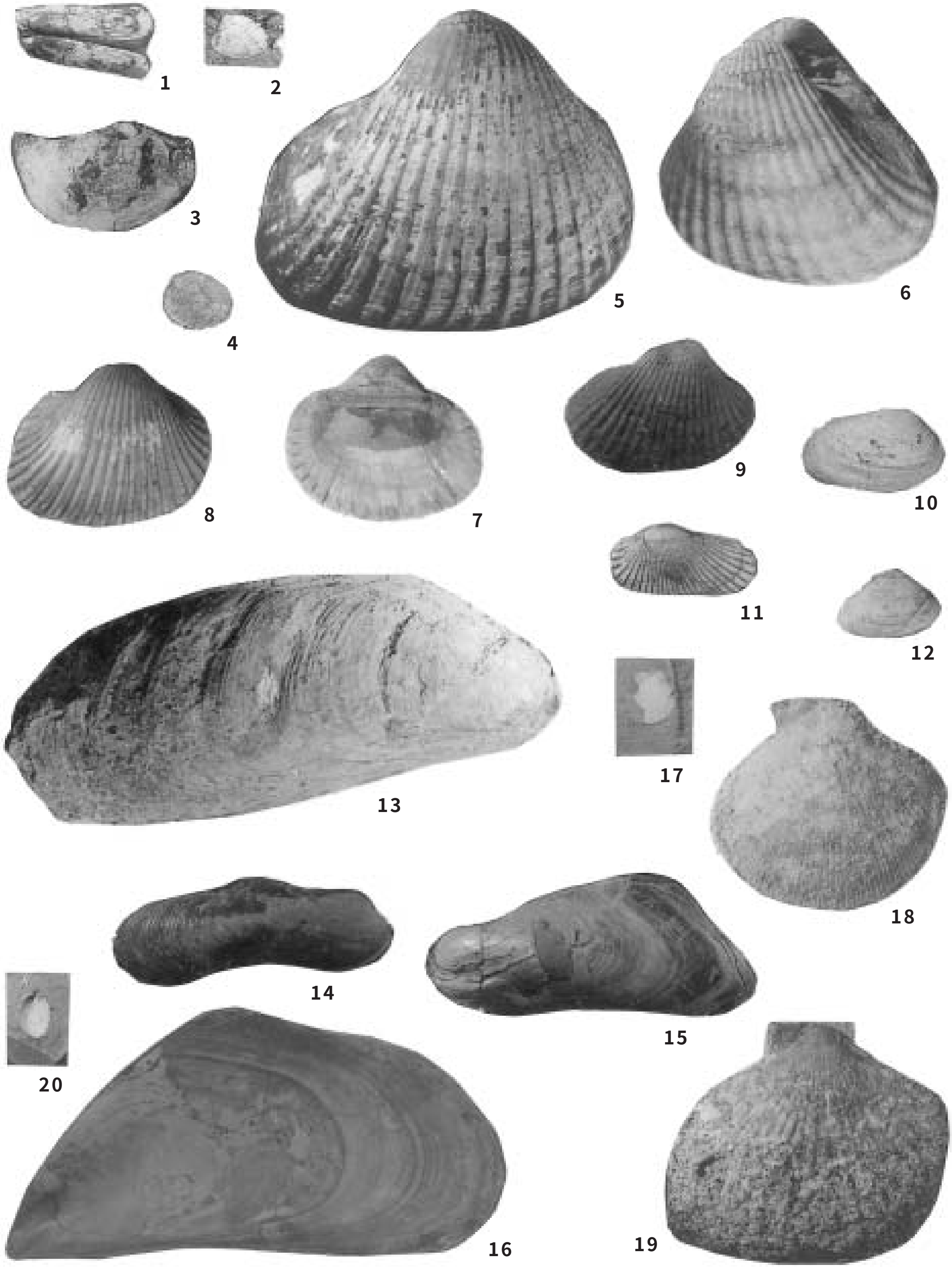
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Plate 4

Fig. 1. *Crassostrea gravitesta* (Yokoyama), loc. 111, lower part (L) of the Izumotawa Sandstone Member (IZ).
Fig. 2. *Saccostrea* sp. loc. 10, L of IZ.
Figs. 3a, 3b, 3c, 4. *Ostrea itoigawai* Taguchi, loc. 84, L of IZ.
Fig. 5. *Lucinoma acutilineatum* (Conrad), loc. 97, upper part (U) of the Nokedai Mudstonr (NK).
Fig. 6. *Vasticardium ogurai* (Otuka), loc. 26 L of IZ.
Figs. 7, 8. *Vepricardium okamotoi* Taguchi, loc. 84, L of IZ.
Fig. 9. *Regozara* sp. loc. 114, L of IZ.
Fig. 10. *Tellinella osafunei* Taguchi, loc. 84, L of IZ.
Fig. 11. *Trapezium cheonbugensis* Yoon, loc. 84 L of IZ.
Fig. 12. *Trapezium modiolaeforme* Oyama et Saka, loc. 84, L of IZ.
Fig. 13. *Leporimetis takaii* Ogasawara et Tanai, loc. 111, L of IZ.
Figs. 14, 15. *Cultellus izumoensis* Yokoyama, loc. 111 L of IZ.
Fig. 16. *Pharella* sp. loc. 84, L of IZ.

All figures are in natural size.

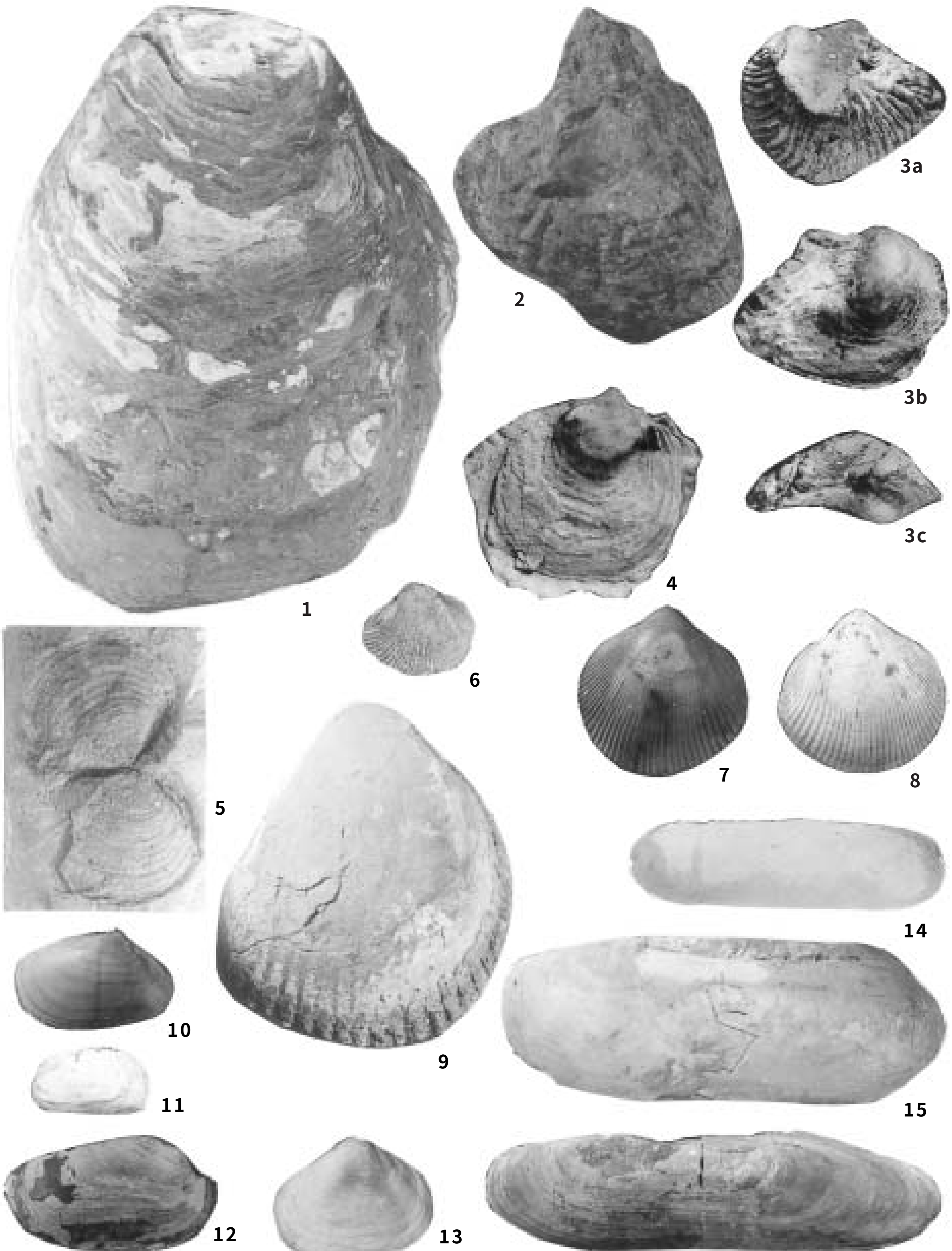
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Plate 5

Fig. 1.	*Angulus okumurai* Taguchi, loc. 84, lower part (L) of the Izumotawa Sandstone Member (IZ). ×2.
Fig. 2.	*Hiatula minoensis* (Yokoyama), loc. 111, L of IZ.
Fig. 3.	*Asaphis* sp. loc. 111, U of IZ.
Fig. 4.	*Geloina yamanei* Oyama, loc. 6 L of IZ.
Fig. 5.	*Geloina stachi* Oyama, loc. 89 L of IZ.
Fig. 6.	*Phacosoma suketoensis* (Otuka), loc. 21, L of IZ.
Fig. 7.	*Solidicorbula succincta* (Yokoyama), loc. 89, L of IZ.
Fig. 8.	*Phacosoma nomurai* (Otuka), loc. 26, L of IZ.
Fig. 9.	*Siratoria siratoriensis* (Otuka), loc. 26, L of IZ.
Fig. 10.	*Clementia japonica* Masuda, loc. 84, L of IZ.
Figs. 11, 12.	*Cyclina hwabongriensis* Yoon et Noda. loc. 114, loc. 116, L of IZ.
Fig. 13.	*Periploma mitsuganoensis* Araki, loc. 23, upper part (U) of the Nokedai Mudstone Member (NK).
Fig. 14.	*Cyclina takayamai* Oyama, loc. 3, L of IZ.
Fig. 15.	*Mactra* sp. loc. 84, L of IZ.

All figures are in natural size unless otherwise stated.

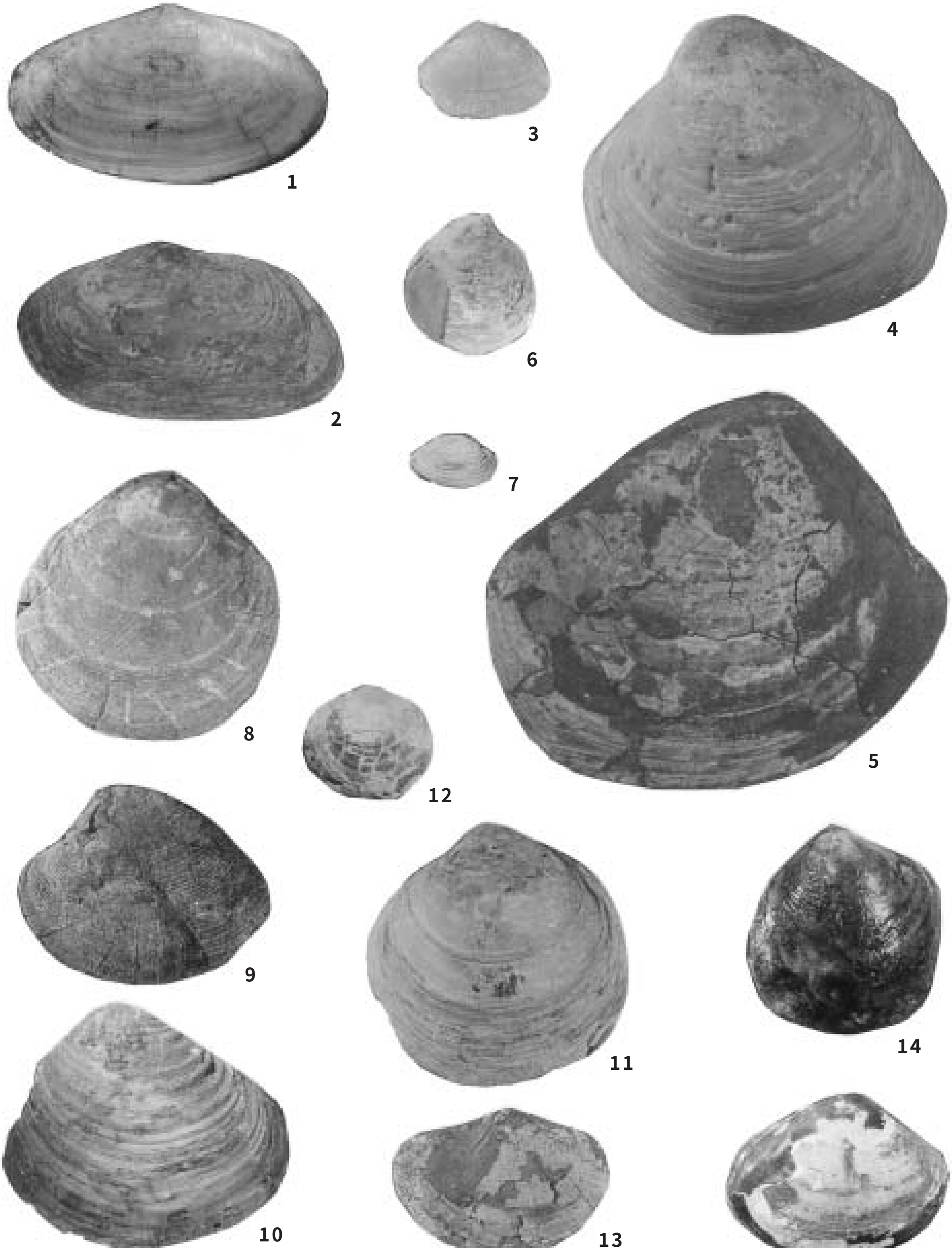
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Plate 6

Fig. 1.	*Fissidentalium yokoyamai* Makiyama, loc. 36, lower part (L) of the Nokedai Mudstone Member (NK).
Fig. 2.	*Antalis* sp. loc. 23, upper part (U) of NK. ×2.
Fig. 3.	*Calliostoma* (*Tristichotrocus*) *myonchonensis* Hatai et Kotaka, loc. 84, lower part (L) of the Izumotawa Sandstone Member (IZ).
Fig. 4.	*Chlorostoma* sp. loc. 84, L of IZ.
Figs. 5, 6.	*Turbo* (*Marmorostoma*) *minoensis* Itoigawa, loc. 94 (Fig. 5), loc. 26 (Fig. 6), L of IZ.
Fig. 7.	*Turbo ozawai* Otuka, loc. 89, L of IZ.
Figs. 8, 9.	*Lunella* sp. loc. 89, L of IZ.
Figs. 10, 11.	*Turritella kiiensis* Yokoyama, loc. 84 (Fig. 10), loc. 112 (Fig. 11) L of IZ.
Fig. 12.	*Nerita ishidae* Masuda, loc. 111, L of IZ.
Figs. 13-15.	*Vicarya japonica* Yabe et Hatai. loc. 111, L of IZ.
Fig. 16.	*Bittium* sp. loc. 111, L of IZ ×2.
Fig. 17.	*Tateiwaia tateiwai* (Makiyama), loc. 111, L of IZ.
Fig. 18.	*Vicaryella ishiiana* (Yokoyama), loc. 84, L of IZ.
Fig. 19.	*Cerithidea* cf. *kampokuensis* Makiyama, loc. 95, L of IZ.
Fig. 20.	*Turritella* sp. loc. 84, L of IZ.
Fig. 21.	*Cerithideopsilla tokunariensis* (Masuda), loc. 111, L of IZ.
Fig. 22.	*Batillaria toshioi* Masuda, loc. 84, L of IZ.

All figures are in natural size unless otherwise stated.

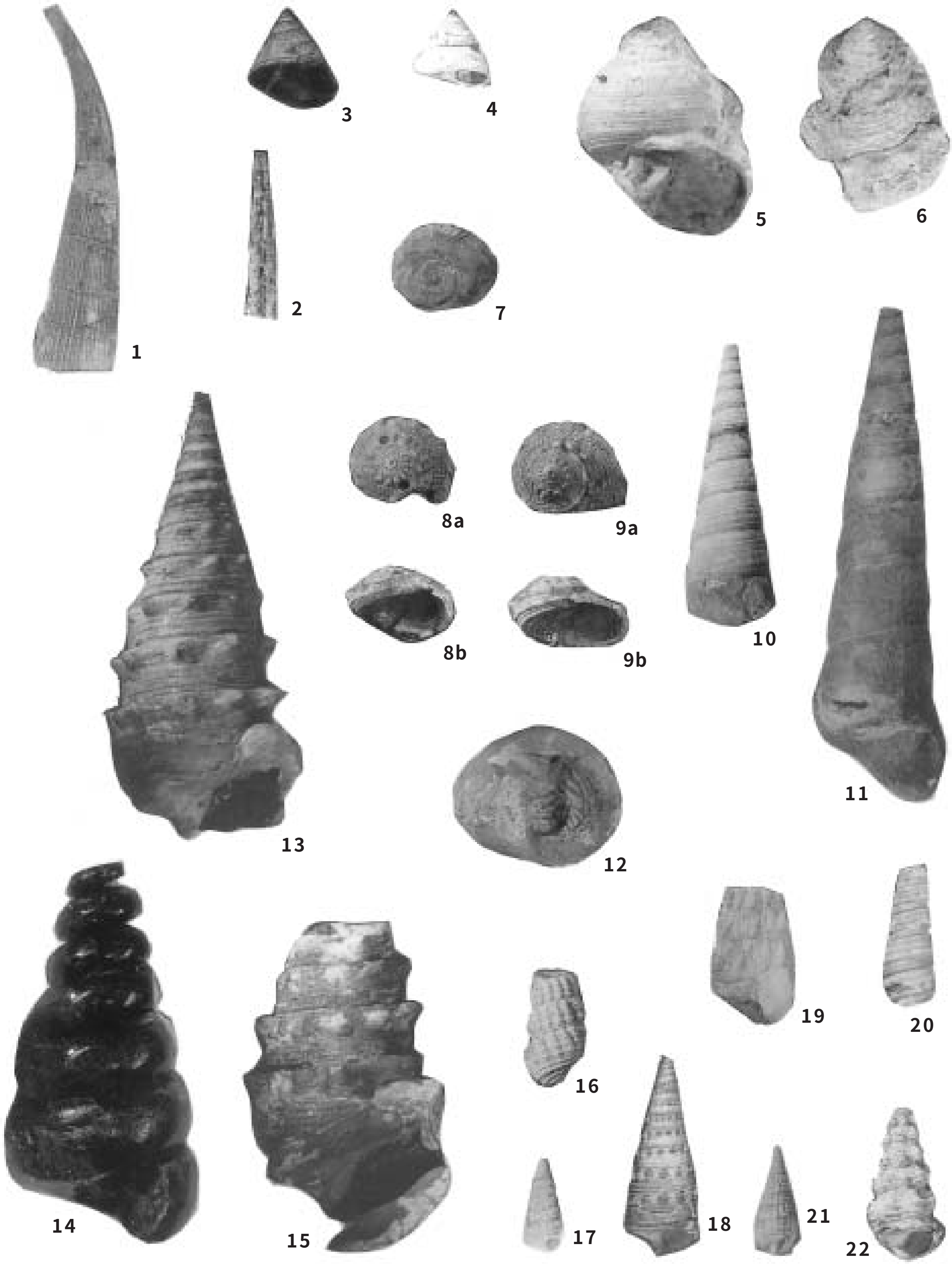

Plate 7

Fig. 1.	*Telescopium* cf. *schencki* (Hatai et Nisiyama), loc. 84, L of IZ.
Figs. 2, 3.	*Terebralia itoigawai* Taguchi, Osafune et Obayashi. loc. 111, L of IZ.
Fig. 4.	*Tateiwaia yamanarii* (Makiyama), loc. 111, L of IZ.
Fig. 5.	*Batillaria narusei* Taguchi, loc. 84, L of IZ. ×2.
Fig. 6.	*Vicaryella* sp. loc. 111, L of IZ.
Fig. 7.	*Terebralia kakiensis* Taguchi, Osafune et Obayashi, loc. 111, L of IZ.
Fig. 8.	*Terebralia shibatai* Taguchi, loc. 84, L of IZ.
Figs. 9a, 9b, 10.	*Globularia* (*Cernina*) *nakamurai* Otuka, loc. 95 (Figs. 9a, b), loc. 17 (Fig. 10) L of IZ.

All figures are in natural size unless otherwise stated.

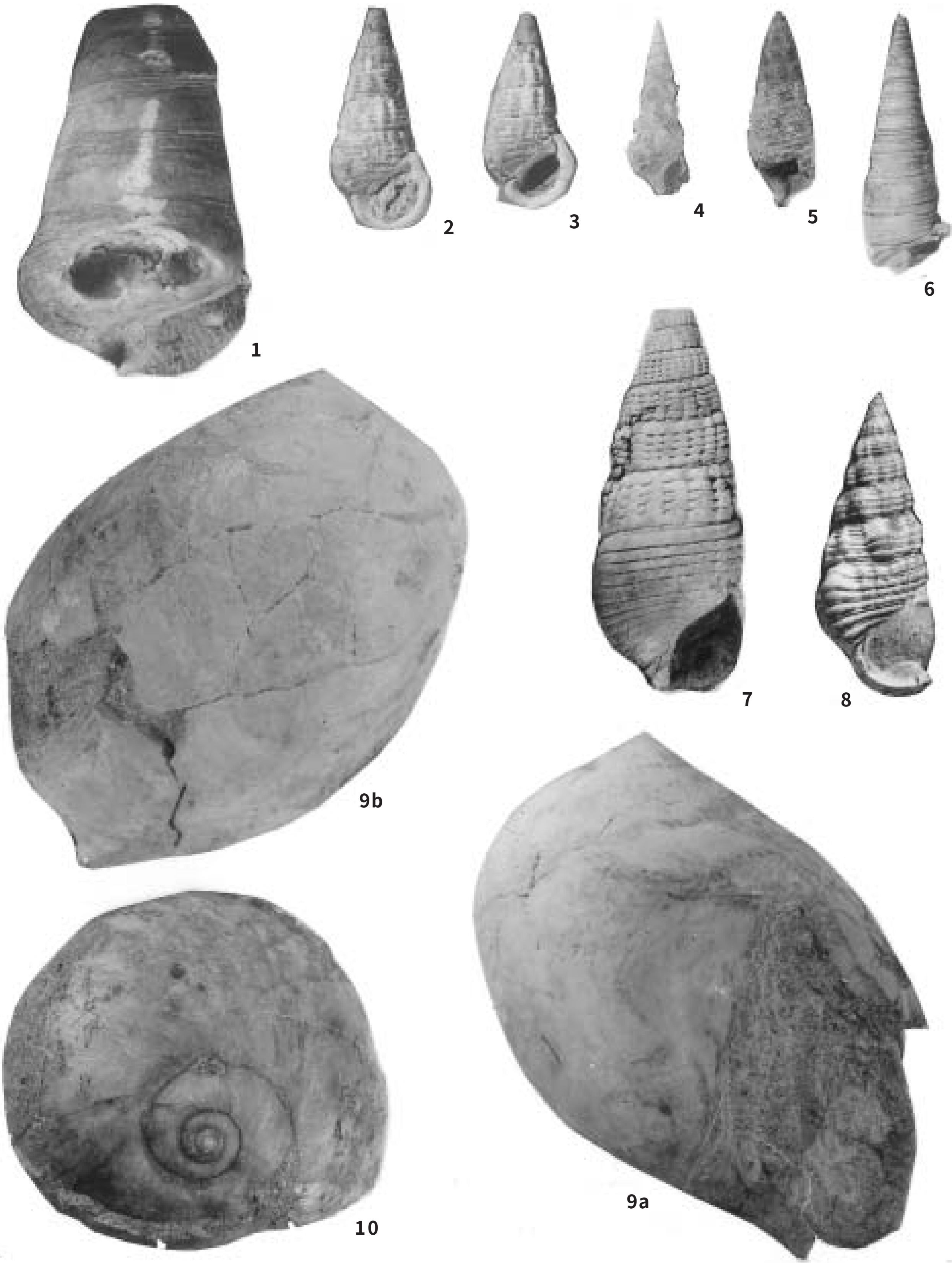
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Plate 8

Fig. 1.	*Crepidula jimboana* Yokoyama, loc. 84, lower part, (L) of the Izumotawa Sandstone Member, (IZ).
Fig. 2.	*Calyptraea tubura* Otuka, loc. 84, L of IZ.
Fig. 3	*Euspira meisensis* (Makiyama), loc. 84, L of IZ.
Fig. 4.	*Echinophoria* (*Sichiheia*) sp. loc. 84, L of IZ.
Fig. 5.	*Rhizophorimurex capuchinus nagiensis* (Taguchi, Osafune et Obayashi), Loc. 111, L of IZ.
Fig. 6.	*Natica* sp. loc. 2, L of IZ.
Figs. 7a, b.	*Siphonalia fujiwarai* Taguchi, loc. 84, L of IZ.
Fig. 8.	*Liracassis japonica* (Yokoyama), loc. 15, lower part (L) of the Nokedai Mudstone Member (NK).
Fig. 9.	*Pygmaeorota* sp. loc. 84. L of IZ.
Figs. 10, 11.	*Pugillina* (*Semifusus*) *sazanami* (Kanehara), loc. 84, L of IZ.
Fig. 12.	*Strombus mimasakaensis* Yokoyama, loc. 114, L of IZ.
Fig. 13.	*Musashia* sp. loc. 104, lower part (L) of the Nokedai Mudstone Member (NK).
Fig. 14.	*Chrysame* sp. loc. 84, L of IZ.
Fig. 15.	*Siphonalia makiyamai* Itoigawa, loc. 84, L of IZ.
Fig. 16.	*Boreotrophon* sp. loc. 84, L of IZ.
Fig. 17.	*Nipponaphera taguchii* Oyama, Hirose et Nishimoto, loc. 84 L of IZ.
Fig. 18.	*Vaginella* sp. loc. 23, upper part (U) of the Nokedai Mudstone Member (NK) ×3.
Fig. 19.	*Clio itoigawai* (Shibata), loc. 38, U of NK. ×3.

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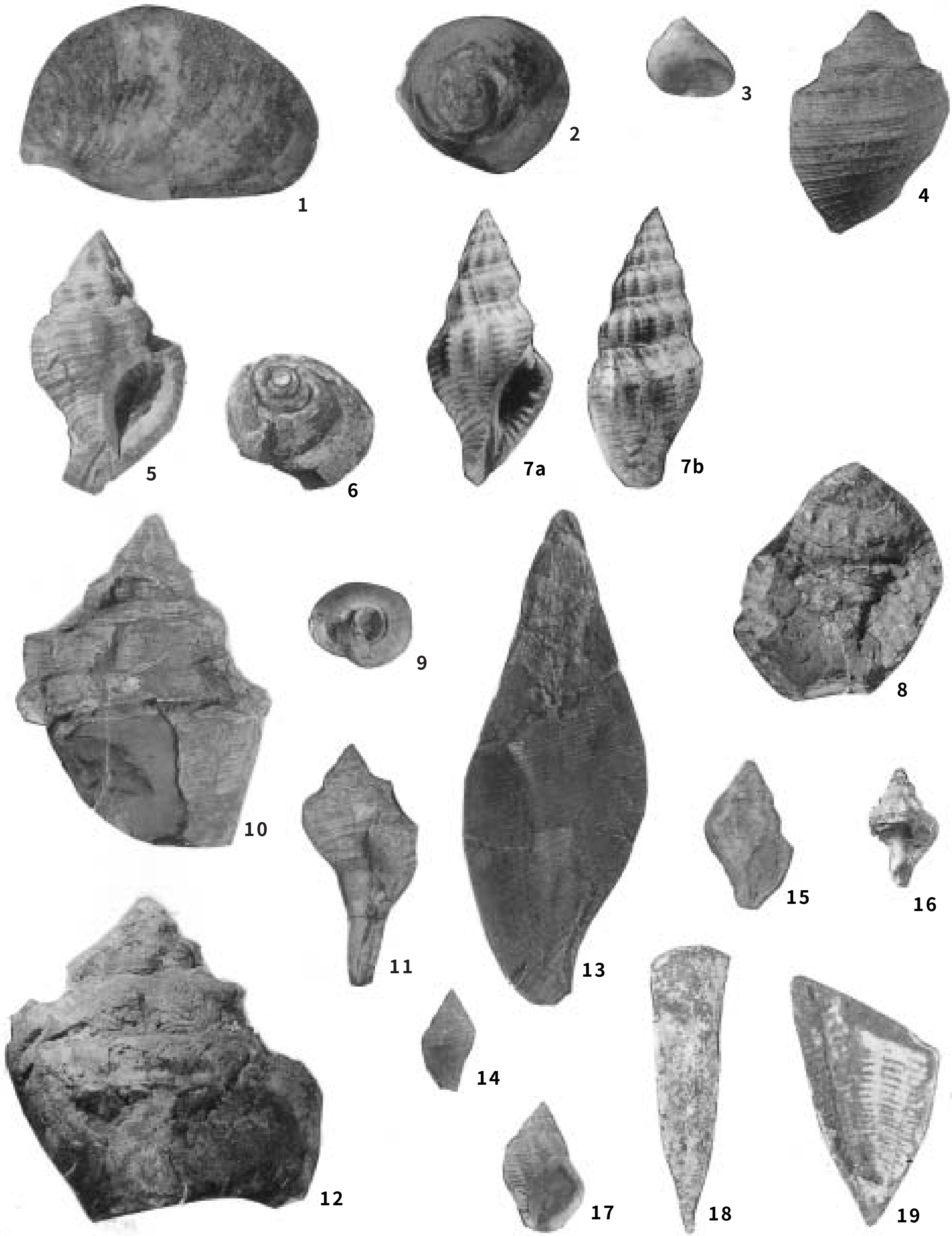
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