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Late Neogene tropical and subtropical molluscan faunas from the South Fossa-Magna region, central Japan

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Abstract

The latest Miocene to the earliest Pliocene molluscan fauna in the South Fossa-Magna region is named the Zushi Fauna after rich and diverse molluscan fossils from the Zushi Formation. The fauna is characterized by the prolific occurrence of tropical or subtropical species. The Zushi Fauna in the South Fossa-Magna region, contains the following molluscan assemblages: *Turbo* cf. *marmoratus* - *Charonia sauliae* assemblage, *Suchium koyuense* - *Glycymeris osozawaensis* - *Glycydonta marica* assemblage, *Bolma virgata* - *Kelletia brevis* assemblage, *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage, *Glycymeris albolineata* - *Amussiopecten iitomiensis* - *Megacardita panda* assemblage, *Glycymeris rotunda* assemblage, "*Pleurotomaria*" assemblage, *Acesta goliath* assemblage, *Ginebis argenteonitens* - *Acila divaricata* - *Fissidentalium yokoyamai* assemblage. This fauna can be divided stratigrafically into the lower and upper units on the basis of the molluscan assemblages. The lower unit of the fauna from the uppermost Miocene formations contains the *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage, whereas the upper unit of the fauna from the lowermost Pliocene formations contains the *Glycymeris albolineata* - *Amussiopecten iitomiensis* - *Megacardita panda* assemblage. The lower unit of the Zushi Fauna flourished during the Climatic Optimum 3. The upper unit of the fauna contains many common species to the upper Pliocene Kakegawa Fauna. During the late Miocene to the earliest Pliocene, the area south of the Boso Peninsula was under tropical to subtropical marine climates.

The Zushi Fauna generally contains mixed assemblages composed of both shallow-water and deep-water inhabitants. The occurrences of the assemblages reflect the sedimentary environments, that is a narrow continental shelf with a steep slope.

The early Pliocene Shirahama Fauna in the Izu Peninsula yields the *Chlamys satoi* - *Comptopallium tayamai* and *Cryptopecten vesiculosus* - *Lima zushiensis* assemblages. This fauna is comparable with the upper Pliocene Kakegawa Fauna in having some common species. It is remarkable that the Shirahama Fauna contains some tropical species which are absent from the other Neogene faunas in Japan. The Shirahama Fauna was formed in the lower latitude during the Pliocene, when the Izu Terrene was located in the low latitude.

Key words: Late Neogene, South Fossa-Magna region, molluscan fossils, Zushi Fauna, Shirahama Fauna, tropical and subtropical marine climates.

Introduction

Many Neogene deposits are described in the South Fossa-Magna region and yield abundant molluscan fossils (Fig. 1). Representative studies on the Neogene sedimentary rocks and fossils in the South Fossa-Magna region are as follows: the Sagara Group in the Tokai District (Tsuchi, 1961; Ibaraki, 1986), the Akebono Formation of the Shizukawa Group in the Minami-koma area (Otuka, 1934, 1955; Akiyama, 1957a, 1957b; Matsuda, 1958, 1961; Fujikawa collaboration reserch group, 1976; Chiji and Konda, 1978; Tamura *et al.*, 1984), the Shirahama Group in the Izu Peninsula (Nomura and Niino, 1932; Watanabe *et al.*, 1952; Sawamura *et al.*, 1969; Ibaraki, 1976, 1981), the Hayakawa Formation in the Hakone area (Nomura and Niino, 1932; Otuka, 1934), the Furuya Formation in the Nishikatsura area (Fukuta and Shinoki, 1952; Uyeno and Ono, 1982; Kuchino, 1982), the Shimada Formation of the Katsuragawa Group in the Ootsuki area and Uenohara area (Sugita, 1962; Konda, 1980), the Ochiai Formation of the Tanzawa Group in the Northeast Tanzawa mountainland (Mikami, 1955, 1962; Shibata, 1957; Shimazu *et al.*, 1971; Tomida, 1989b), the Nishikoiso Formation in the Shonan Coast

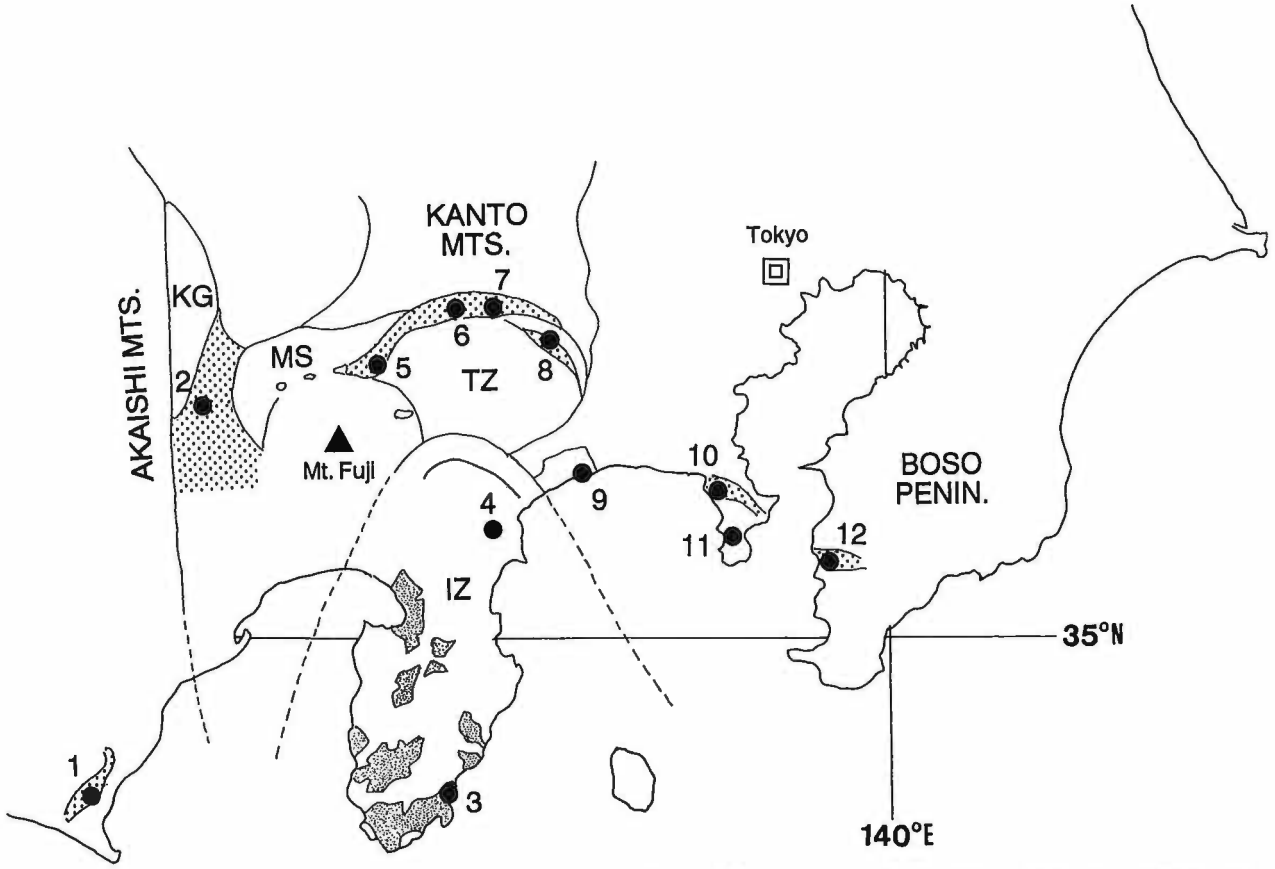


Fig. 1. Map showing the areas of fossil localities in the South Fossa-Magna region. (revised from Chinzei and Matsushima, 1987).

KG: Kushigata-yama Terrane, MS: Misaka Terrane, TZ: Tanzawa Terrane, IZ: Izu Terrane.

●: Areas of molluscan fossil localities.

1. Sagara area (Sg), 2. Osozawa area (Oz), 3. Shirahama area (Sr), 4. Ninotozawa (Nz), 5. Nishikatsura area (Nk), 6. Ootsuki area (Ot), 7. Uenohara area (Uh), 8. Ochiai (Oc), 9. Ooiso (Os), 10. Zushi area (Zs), 11. Hatsuse area (Hs), 12. Nokogiriyama area (Sh).

upper Miocene to lower Pliocene formations

the Pliocene Shirahama Group

(Otuka, 1929, 1931; Ibaraki, 1978), the Zushi Formation (Kanie, 1967; Shikama, 1973), and the Misaki Formation (="Hatsuse" Formation in Okumura and Yamagishi, 1992) of the Miura Group in the Miura Peninsula, and the Senhata Formation of the Miura Group in the Boso Peninsula (Koike, 1949; Ibaraki and Tsuchi, 1980; O'hara and Ito, 1980; Tomida, 1983, 1989a).

The South Fossa-Magna region has been recently well studied from the viewpoint of tectonics, such as the collisions of the Tanzawa and Izu Terranes and paleogeographic reconstruction was made by many geologists (e.g., Niitsuma, 1987). Biostratigraphy and paleobiogeography in the South Fossa-Magna region were discussed in the symposium in the 1987 annual meeting of the Palaeontological Society of Japan on the basis of planktonic microfossils (Okada, 1987; Oda *et al.*, 1987), the molluscan assemblages (Chinzei and Matsushima, 1987), and benthonic foraminifers (Kitazato, 1987).

Concerning fossil molluscan faunas, the spatial and temporal distributions in the South Fossa-Magna region were outlined by Chinzei and Matsushima (1987). Molluscan fossils mainly occur from the following three horizons: the middle Miocene, the upper Miocene to the lower Pliocene, and the upper Pliocene to the lower Pleistocene. Concerning the middle Miocene faunas, *Chlamys* (*Mimachlamys*) *kaneharai* (Yokoyama) was reported from the Chojagoya Formation around the Doshigawa River and the Aikawa Group in the northeast part of the Tanzawa mountainland (Chinzei and Matsushima, 1987). On the upper Pliocene to the lower Pleistocene fauna, various assemblages were reported, such as the *Meretrix lusoria* - *Dosinorbis japonica,* the *Dosinella penicillata* - *Paphia euglypta* and the *Crassostrea gigas*-*Trapezium liratum* assemblages from the Ashigara Group in the southern marginal region of the Tanzawa mountainland (Matsushima, 1982).

Ozawa and Tomida (1992) described the late Miocene and the early Pliocene molluscan assemblages in the South Fossa-Magna region and proposed a new name Zushi Fauna for them. They noted that the Zushi Fauna is composed of tropical and subtropical marine molluscs which flourished under the influence of the paleo-Kuroshio warm current around 7 Ma (Climatic Optimum 3 of Barron and Baldauf, 1990). The fossil molluscs in the South Fossa-Magna region are important to discuss the warm-water faunal succession in Japan. However, fossil molluscs from each locality were not listed and basic data have not been completely reported to make clear detailed characteristics of the molluscan fauna of the South Fossa-Magna region.

In this paper, I report the latest Miocene to earliest Pliocene Zushi Fauna, and discuss paleoenvironments and paleobiogeography. In addition, I also study the early Pliocene Shirahama Fauna in the South Fossa-Magna region and discuss its paleogeographical significance.

Geologic setting

Geological structure of the South Fossa-Magna region is complicated by the subduction of the Philippine Sea Plate and the collisions of the Tanzawa and Izu Terranes. It was difficult to correlate the formations each other, which are deformed and separated by folds and faults. However, microbiostratigraphic studies recently have been made on planktonic foraminifers (Oda *et al.*, 1987) and calcareous nannofossils (Okada, 1987; Kanie et *al.*, 1991), as shown in Table 1.

The geological data of fossil localities is described in each area, as follows. The assemblages noted in this chapter are described in datail later.

1. South Fossa-Magna region excluding Izu Terrene

1) Sagara Area (Sg)

Localities: Sg-1 (Oyori, 13°89′47″E, 34°42′56″N) and Sg-2 (Hirugaya, 138°10′42″E, 34°43′23″N), in Sagara-cho, Haibara-gun, Shizuoka Prefecture.

Age: Early Pliocene.

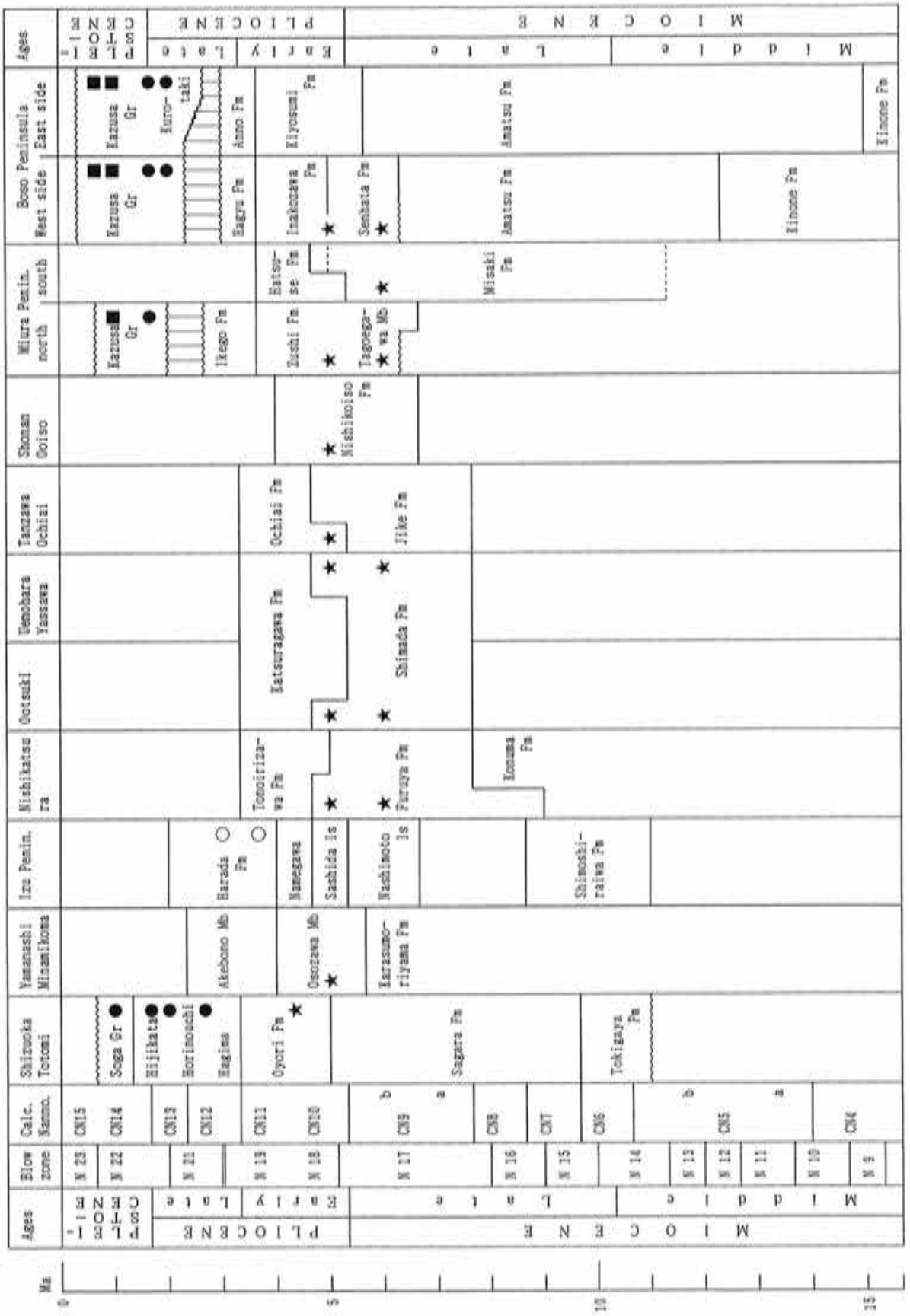
Horizons: The Oyori Formation, the upper part of the Sagara Group.

Lithology: Siltstone.

Chronological data: Sg-1; N18-19 of Blow's planktonic foraminiferal zone (Ibaraki, 1986).

Remarks: The middle Miocene - lower Pliocene

Table 1. Correlation of the Neogene formations in the South Fossa-Magna region.
(Legend: ★=Zushi Fauna, ○=Shirahama Fauna, ●=Kakegawa Fauna, ■=Kuroshio Fauna)



Sagara Group unconformably overlies the lower Miocene Ooigawa Group, and it is unconformably overlain by the Pliocene - Pleistocene Kakegawa Group. The Sagara Group is divided into three formations: the Tokigaya, Sagara, and Oyori Formations, in ascending order (Makiyama, 1941; Tsuchi, 1961). The Oyori Formation conformably overlies the Tokigaya Formation and is composed of a massive siltstone. The planktonic foraminiferal data by Ibaraki (1986), show that the Tokigaya Formation corresponds to the Blow's zone N14 of the late middle Miocene age, and the Oyori Formation corresponds to the N18-19 zone of the early Pliocene age.

Yokoyama (1926) reported some molluscan fossils from the "Sagara bed" in Hirugaya, such as *Lyria hirugayensis* (Yokoyama), *Venus* (*Ventricoloidea*) *foveolata* (Sowerby), *Monia egregia* (Yokoyama), and so on.

Tsuchi (1961) listed 11 species from the upper part of the Sagara Group, containing *Limopsis* cf. *oblonga* (A. Adams), *Glycymeris albolineata nakamurai* (Makiyama), *Glycymeris* cf. *rotunda* Dunker, *Amussiopecten iitomiensis* (Otuka), *Mercenaria chitaniana* (Yokoyama), and *Fissidentalium yokoyamai* (Makiyama), and so on.

Ujihara *et al.* (1990) described pteropod fossils from the Sagara Group which listed the other molluscan fossils obtained from the Oyori Formation of the Sagara Group in Hirugaya: *Carinineilo* sp., *Yoldia* (*Cnesterium*) sp., *Glycymeris* sp., *Delectopecten peckhami* (Gabb), *Polynemamussium* cf. *alaskense* (Pilsbry and Sharp), *Conchocele* sp., and *Fissidentalium* (*Compressidentalium*) *hungerfordi* (Pilsbry and Sharp).

I obtained some molluscan fossils containing *Crenulilimopsis oblonga* (A. Adams) and *Cyrenolimopsis adamsiana* (Yokoyama) from the massive mudstone of the Oyori Formation in Loc. Sg-1 (Oyori) near Hirugaya.

2) Osozawa Area (Oz)

Localities: Oz-1 (Obarajima, 138°25′7″E, 35°27′55″N) in Minobu-cho, Minamikoma-gun, Yamanashi Prefecture, Oz-2 (Osozawa, 138°25′35″E, 35°26′44″N) and Oz-3 (Yogozawa, 138°25′52″E, 35°27′20″N) in Nakatomi-cho, Minamikoma-gun, Yamanashi Prefecture.

Age: Earliest Pliocene.

Horizon: The Osozawa Member of the Akebono Formation, the Shizukawa Group.

Lithology: Gravelly medium- to coarse-grained sandstone, siltstone and coquinoid limestone.

Chronological data: N17-18 of Blow's planktonic foraminiferal zone (Oda *et al.*, 1987).

Remarks: The Akebono Formation, the upper part of the Shizukawa Group, is divided into the following three members: the Osozawa, Kawadaira and Akebono Members, in ascending order (Akiyama, 1957a). The Osozawa Member is composed of gravelly medium- to coarse-grained sandstone and siltstone, and is conformably overlain by the upper Pliocene Akebono Member, which is composed of cobble-sized conglomerate. The planktonic foraminiferal data by Oda *et al.* (1987), show that the Osozawa Member of the Akebono Formation corresponds to N17-18 of Blow's planktonic foraminiferal zone.

The *Turbo* cf. *marmoratus* - *Charonia sauliae* assemblage, the *Glycymeris albolineata* - *Amussiopecten iitomiensis* - *Megacardita panda* assemblage, and the *Bolma virgata* - *Kelletia brevis* assemblage, were recognized from the gravelly medium- to coarse-grained sandstone of the Osozawa Member at Loc. Oz-2. The *Glycymeris rotunda* assemblage occurs from the gravelly medium- to coarse-grained sandstone and also from the siltstone. The *Ginebis argenteonitens* - *Acila divaricata* - *Fissidentalium yokoyamai* assemblage occurs from the siltstone (Locs. Oz-1 and Oz-2).

I obtained the coral reef limestone from Loc. Oz-2 where the coquinoid limestone and the coralline algae frequently occur. This fossil coral is comparable to reef-building coral *Favites* sp. This fact shows that the limestone was formed during tropical or subtropical conditions.

3) Nishikatsura Area (Nk)

Localities: Nk-1 (Tonoirizawa, 138°49′30″E, 35°31′15″N) in Shiraito-cho, Fujiyoshida City, Yamanashi Prefecture, Nk-2 (Mizunoki, 138°49′40″E, 35°31′46″N) in Nishikatsura-cho, Minamitsuru-gun, Yamanashi

Prefecture.

Age: Earliest Pliocene.

Horizon: The Furuya Formation of the Nishikatsura Group.

Lithology: Medium- to coarse-grained sandstone with gravels.

Remarks: The Nishikatsura Group in this area is divided into the Furuya and Katsuragawa Formations, in ascending order (Fukuta and Shinoki, 1952). The Furuya Formation is mainly composed of blackish green sandstone rich in iron sand. The Furuya Formation unconformably overlies the upper Miocene Konuma Formation, and is conformably overlain by the Katsuragawa Formation.

The Furuya Formation yields abundant sea urchin fossils, *Astriclypeus integer* Yoshiwara, and also yields the *Glycymeris albolineata* - *Amussiopecten iitomiensis* - *Megacardita panda* assemblage. Uyeno and Ono (1982) described the fossil shark teeth such as *Carcharodon* sp., *Isurus hastalis* Agassiz and *Hemipristis serra* Agassiz, obtained from Locs. Nk-1 and Nk-2.

4) Ootsuki Area (Ot)

Localities: Ot-1 (River-cliff at Jakotsuzawa, 138°59′10″E, 35°36′56″N) in Saruhashi, Ootsuki City, Yamanashi Prefecture, Ot-2 (River-bed of Katsuragawa, 138°53′46″E, 35°35′45″N) in Hatsukari, Ootsuki City, Yamanashi Prefecture.

Age: Late Miocene to earliest Pliocene.

Horizon: The Shimada Formation of the Katsuragawa Group.

Lithology: Siltstone and gravelly coarse-grained sandstone.

Remarks: In Jakotsuzawa, the Shimada Formation, 20 meters thick, is in fault contact with brecciated tuff, and it is conformably overlain by the Iwadonoyama conglomerate of the Katsuragawa Group (Sugita, 1962).

The molluscan fossils were obtained from the siltstone and gravelly coarse-grained sandstone of the Shimada Formation. The tidal to euneritic muddy-bottom dwellers such as *Cycladicama cumingii* (Hanley), *Leptaxinus oyamai* Habe, and *Crassostrea gigas* (Thunberg) occurs from silt and clay facies. The thin shells of *Cycladicama cumingii* and *Leptaxinus oyamai* are well preserved and often conjoined. This occurrence shows that these molluscs had been little transported from their living site.

From Loc. Ot-2, sandy siltstone which outcrops on the bed of the Sasagogawa River yields abundant shells of *Crassostrea gigas* forming a fossil enclosure. The species is a tidal to euneritic inhabitants on the muddy bottom of the blackish water in the inner bay.

5) Uenohara Area (Uh)

Localities: Uh (River-cliff at Yassawa, 139°5′25″E, 35°37′12″N) in Uenohara-cho, Kitatsuru-gun, Yamanashi Prefecture.

Age: Late Miocene to earliest Pliocene.

Horizon: The Shimada Formation of the Katsuragawa Group.

Lithology: Mudstone and granule- to pebble-sized conglomerate.

Remarks: The Shimada Formation, about 100 meters in thickness, is mainly composed of mudstone, and is in fault contact with the Miocene Misaka Group (Sugita, 1962; Konda, 1980). This formation intercalates more conglomerate beds in its upper part. It is conformably overlain by the Katsuragawa conglomerate.

The massive mudstone yields the *Ginebis argenteonitens* - *Acila divaricata* - *Fissidentalium yokoyamai* assemblage. On the other hand, the conglomerate beds of the upper part yield the *Glycymeris rotunda* assemblage. Shells of *Ginebis argenteonitens* (Lischke) are well preserved, and conjoined valves of *Portlandia lischkei* (Smith) and *Periploma plane* Ozaki are obtained. In contrast, shells of *Glycymeris rotunda* are disarticulated. Concerning on *Turbo* (*Marmarostoma*) cf. *stenogyrus* Fischer, only opercula were obtained.

6) Ochiai Area (Oc)

Locality: Oc (Ochiai, 139°13′40″E, 35°32′46″N) in Kiyokawa-mura, Aiko-gun, Kanagawa Prefecture.

Age: Earliest Pliocene.

Horizon: The Ochiai Formation of the Tanzawa Group.

Lithology: Granule- to cobble-sized conglomerate,

coarse-grained sandstone, limestone, and siltstone.

Chronological data: CN10-11 of calcareous nannoplankton zone by Okada and Bukry (1980) (Okada, 1987).

Remarks: The Ochiai Formation is in contact with the Aikawa Group by the Ochiai Fault. The Ochiai Formation, 300-400 meters in thickness, is mainly composed of granule- to cobble-sized conglomerate intercalating siltstone and sandstone (Mikami, 1962). Shibata (1957) described new species of molluscs such as *Haliotis koikei, Chlorostoma narusei*, and *Astraea omorii*. This formation corresponds to the uppermost part of the Susugaya Subgroup of the Tanzawa Group. The Ochiai Formation overlies the upper Miocene Jike Formation, CN9 in age (Okada, 1987; Mizukami *et al*., 1991).

The conglomerate of the Ochiai Formation which outcrops along the Hayado River (Loc. Oc) yields the following four assemblages: the *Turbo* cf. *marmoratus* assemblage; the *Bolma virgata* - *Kelletia brevis* assemblage; the *Amussiopecten iitomiensis* - *Megacardita panda* assemblage; and the *Glycymeris rotunda* assemblage. In addition to these molluscan assemblages, this conglomerate also frequently yields *Neptunea kuroshio* Oyama, *Acila divaricata* Hinds, *Acesta goliath* (Sowerby), *Keenaea samarangae* (Makiyama), and *Macoma calcarea* (Gmelin).

Tomida (1989b) reported a conjoined valve of *Halicardia nipponensis* Okutani from the Ochiai Formation with its paleoecological significance. Moreover, Tomida and Kamiya (1990) reported *Perotrochus* sp. from the Ochiai Formation.

Inhabitants of rocky bottom in shallow waters, such as *Chlorostoma narusei, Turbo* cf. *marmoratus, Dulcerana* cf. *granularis* (Röding), and *Pleuroploca* cf. *trapezium* (Linnaeus), occur in a poorly state of preservation. The shells are defaced and damaged. This fact shows that they have been transported far from rocky shallow shores. On the other hand, *Perotrochus* sp., *Bolma* (*Bolma*) *virgata* (Ozaki), *Neptunea kuroshio, Kelletia brevis* Ozaki, *Keenaea samarangae*, and *Macoma calcarea* were obtained in well preservation, and *Acila divaricata* and *Halicardia nipponensis* were obtained with conjoined valves.

7) Ooiso Area (Os)

Locality: Os (Nishikoiso, 139°17′42″E, 35°17′54″N) in Ooiso-cho, Naka-gun, Kanagawa Prefecture.

Age: Latest Miocene to earliest Pliocene.

Horizon: The Nishikoiso Formation.

Lithology: Pyroclastic granule- to cobble-sized conglomerate, and alternation of tuffaceous conglomerate and siltstone.

Chronological data: N17 of Blow's planktonic foraminiferal zone (Ibaraki, 1978).

Remarks: The Nishikoiso Formation is narrowly distributed on the coast of Ooiso. This formation unconformably overlies the upper Miocene Takatoriyama Formation, and it is unconformably overlain by the Pleistocene Ninomiya Formation.

Otuka (1931) considered that the Nishikoiso Formation is the middle to late Pliocene in age on the basis of the occurrence of the Kakegawa type molluscan fossils and the unconformity between the upper Nishikoiso Formation and the lower Ooiso Formation. Otuka (1932) mentioned that the Nishikoiso Formation is the basal conglomerate of the Ninomiya Group. However, Ijiri and Fujita (1949) regarded that the Nishikoiso Formation as a fossil-enclosure bed intercalated in the Ooiso Formation.

The Nishikoiso Formation yields the *Glycymeris albolineata* - *Amussiopecten iitomiensis* - *Megacardita panda* assemblage. Shells of *Amussiopecten iitomiensis* and *Chlamys miurensis* (Yokoyama) are fragmental, and those of *Glycymeris albolineata* (Lischke), *Megacardita panda* (Yokoyama) and *Mercenaria yokoyamai* (Makiyama) are disarticulated.

8) Zushi Area (Zs)

Localities: Zs-1 (Abuzuri, 139°34′26″E, 35°16′53″N) and Zs-2 (Sakurayama, 139°34′35″E, 35°16′55″N) in Zushi City, Kanagawa Prefecture, and Zs-3 (Kinugasa, 139°39′40″E, 35°15′37″N) in Yokosuka City, Kanagawa Prefecture.

Age: Latest Miocene.

Horizons: Zs-1 and Zs-2: The Tagoegawa Member of the Zushi Formation, the Miura Group. Zs-3: The Shimoyamaguchi Member of the Zushi Formation, the Miura Group.

Lithology: Coarse-grained sandstone (Zs-1, Zs-2

and Zs-3), gravelly sandstone (Zs-3), granule- to pebble-sized conglomerate (Zs-1 and Zs-2), and coquinoid limestone (Zs-1).

Chronological data: CN9b-CN10 of calcareous nannoplankton zone by Okada and Bukry (1980) (Kanie *et al.*, 1991).

Remarks: Shikama (1973) reported a molluscan assemblage from the basal part of the Zushi Formation in the Miura Peninsula. The Tagoegawa Member is a basal conglomerate of the Zushi Formation which unconformably overlies the Miocene Hayama Group. The Zushi Formation is conformably overlain by the Ikego Formation. The Shimoyamaguchi Member corresponds to the lower part of the Zushi Formation, and it is conformably overlain by the Ikego Formation.

I examined the molluscan specimens which had been housed in the Yokohama National University. Field studies and examinations of these specimens led to me to make clear the following facts. The Tagoegawa Member yields the *Turbo* cf. *marmoratus* - *Charonia sauliae* assemblage (Loc. Zs-3), the *Bolma virgata* assemblage (Locs. Zs-1 and Zs-2), the *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage (Locs. Zs-1 and Zs-2), the "*Pleurotomaria*" assemblage (Loc. Zs-1), and the *Acesta goliath* assemblage (Loc. Zs-3), whereas the Shimoyamaguchi Member yields *Suchium koyuense* Shuto (abundant), *Glycymeris* cf. *rotunda*, *Glycymeris osozawaensis* Kanno, and *Glycydonta marica* (Linnaeus) (abundant: at Loc. Zs-3).

The type locality of *Chlamys miurensis* (Yokoyama) is in the Zushi area. The other uppermost Miocene to lower Pliocene fossils of this species were obtained from the Sagara, Osozawa, Ochiai, Nishikoiso, Misaki and Senhata Formations.

The molluscan assemblages in the Zushi Area are the types of the Zushi Fauna proposed by Ozawa and Tomida (1992).

9) Hatsuse Area (Hs)

Localities: Hs-1 (Yato, 139°37′52″E, 35°10′50″N) and Hs-2 (Kanda, 139°38′8″E, 35°10′56″N) in Shimo-Miyada, Hatsuse-cho, Miura City, Kanagawa Prefecture.

Age: Latest Miocene.

Horizon: The Misaki Formation of the Miura Group.

Lithology: Pyroclastic gravelly sandstone and siltstone.

Remarks: The Misaki Formation of the Miura Group overlies the Aburatsubo Formation. It is conformably overlain by the Hatsuse Formation. The Hatsuse Formation is unconformably overlain by the Pleistocene Miyata Formation.

Okumura and Yamagishi (1992) described 19 molluscan species containing a pleurotomariid gastropod from the "Hatsuse" Formation and mentioned that the formation is the late Miocene in age. However, Eto (1986) and Kanie *et al.* (1991) proposed that the Hatsuse Formation is the early Pliocene in age on the basis of the planktonic foraminiferal and calcareous nannoplankton biostratigraphy.

I examined the molluscan specimens which had been housed in the Yokosuka City Museum. These specimens were obtained from Loc. Hs-1. The fossil locality of the specimens is not in the Hatsuse Formation but in the upper part of the Misaki Formation (personal communication from Y. Kanie, Yokosuka City Museum). The provided information shows that the following two assemblages occur from the Misaki Formation: the *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage, containing *Bolma* (*Bolma*) cf. *virgata*, *Mauritia* (*Arabica*) cf. *histrio* (Gmelin), *Chelyconus* cf. *fulmen* (Reeve), *Miyagipecten matsumoriensis* Masuda, *Indocrassatella tenuilirata* (Shuto), *Oxyperas vernardi* (Pilsbry) and *Pitar* (*Pitarina*) sp.; the *Glycymeris rotunda* assemblage.

10) Nokogiriyama Area (Sh)

Localities: Sh-1 (Fudoiwa, 139°49′20″E, 35°9′25″N) in Kanaya-cho, Futtsu City, Chiba Prefecture. Sh-2 (Shiofuki-Tunnel of Myoganesaki, 139°49′35″E, 35°8′58″N), Sh-3 (Nemoto, 139°50′10″E, 35°8′58″N), Sh-4 (West side of Okumotona Quarry, 139°51′0″E, 35°9′8″N), Sh-5 (East side of Okumotona Quarry, 139°51′20″E, 35°9′20″N), and Sh-6 (Towa Sekizai's Quarry, 139°52′0″E, 35°9′26″N) in Kyonan-cho, Awa-gun, Chiba Prefecture.

Age: Latest Miocene.

Horizon: The Senhata Formation of the Toyooka

Subgroup, the Miura Group.

Lithology: Medium- to coarse-grained sandstone, granule- to pebble-sized conglomerate and coquinoid limestone.

Chronological data: N17 of Blow's planktonic foraminiferal zone (Ibaraki and Tsuchi, 1980).

Remarks: The Senhata Formation (Koike, 1949) consists of granule- to pebble-sized conglomerate, and shows a syncline in and around Nokogiriyama. The Senhata Formation unconformably overlies the Miocene Amatsu Formation of the Sakuma Subgroup, the Miura Group. The Senhata Formation is conformably overlain by the lower Pliocene Inakozawa Formation. Tomida (1989a) noted the geology of the fossil localities in the Senhata Formation around Nokogiriyama as follows:

Sh-1: This is a well known locality situated on the northwest flank of the Nokogiriyama syncline. The Senhata Formation outcrops totally 50 meters in thickness. This is the type locality of *Amussiopecten akiyamae* described by Masuda (1962). The pebble-sized conglomerate yields the *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage. Abundant shells of ostreids and barnacles occurs in the lower part of the coarse-grained tuffaceous sandstone of 20 meters thick. This conglomerate is conformably overlain by coquinoid limestone containing many pebble- to cobble-sized gravels composed of chert, shale, sandstone, diorite, diabase, serpentine, and so on. This limestone yields *Amussiopecten akiyamae* and intercalates a coralline algae-bearing bed. A conglomerate intercalated in a coarse-grained sandstone which overlies the limestone, frequently yields fossil shark teeth, and intercalates the mammalian bone-bearing bed reported by Takahashi (1954). This uppermost conglomerate is overlain by the "Gomashio"-like tuff of 1.5 meters thick which is the lower part of the Inakozawa Formation.

Sh-2: The calcarenite, more than 35 meters thick, crops out in this locality. The upper half of the calcarenite is composed of the coquinoid limestone showing the cross-lamination. This calcarenite yields abundant fossils of coralline algae, molluscs, brachiopods, bryozoans, barnacles, and echinoids. The large-sized shells of *Chlamys* are frequently obtained from the upper part which shows a upward-shallowing sequence. The calcarenite underlie the white pumice bed of 3 meters thick. This pumice bed is in fault contact with tuffaceous sandstone of about 10 meters thick. This sandstone underlies the Inakozawa Formation of which the lower part is composed of the coarse-grained sandstone including black scoriae and intercalates accretionary lapilli tuff of 0.1 meters thick and "Gomashio"-like tuff of 2 meters thick.

Sh-3: Coarse-grained sandstone disconformably overlies siltstone of the Amatsu Formation. This is a type locality of a pleurotomariid gastropod, *Entemnotrochus shikamai* Kanie, 1973. This coarse-grained sandstone intercalates some pebble-sized conglomerate beds. The lower part of the sandstone consists of subrounded pebbles of chert and dacite, and yields abundant fossil molluscs and solitary hexacorals which compose the *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage. A deep-water inhabitant, *Acesta goliath*, occasionally occurs from the sandstone. *Oliva oliva* (Linnaeus), *Oxyperas vernardi*, *Solen* cf. *strictus* Gould, and *Glycydonta marica* abundantly occur from the coquinoid limestone in the middle part of the outcrop, and coralline algae abundantly occur from the algal limestone in the upper part of the outcrop, which overlie the conglomerate. These rocks underlie the Inakozawa Formation, of which the lower part is composed of the tuffaceous coarse-grained sandstone of 12 meters thick. The lower part of the Inakozawa Formation intercalates the "Gomashio"-like Ok tuff of 1 meter thick and the accretionary lapilli tuff of 0.1 meters thick.

Sh-4: Medium- to coarse-grained sandstone of 3 meters thick in the lower part of the outcrop intercalates the *Acesta* bed in which autochthonous and allochthonous fossils are mixed. This sandstone graded downward into the mudstone of the Amatsu Formation intercalating the medium-grained sandstone of 15 meters thick. The medium- to coarse-grained sandstone underlies pebble-sized conglomerate composed subrounded gravels, 2.5 meters in thickness. From the conglomerate, the following assemblages are recognized: the *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage; the

Glycymeris rotunda assemblage; and the "*Pleurotomaria*" assemblage containing *Miyagipecten matsumoriensis, Venus* (*Ventricoloidea*) *foveolata*, coralline algae, and echinoids. This pebble-sized conglomerate bed under lies granule-sized conglomerate of 10 meters thick, which yields fossil assemblages similar to those from the lower conglomerate in composition. The granule-sized conglomerate intercalates a white pumice layer of 0.8 meters thick. The granule-sized conglomerate underlies the coarse-grained sandstone of the upper part of the Senhata Formation.

Sh-5: Sandstones of the Senhata Formation crop out in the east of the Okumotona Quarry. In the southern margin of this quarry mudstone of the Amatsu Formation crops out, and it is conformably overlain by a gray pebbly sandstone of the Senhata Formation, about 30 meters in thickness, which yields well preserved shells of *Xenophora tenuis* Fulton and a giant isopod fossil (Tomida, 1989a). The gray pebbly sandstone intercalates the lower tuff of 1.5 meters thick, which contains granules of quartz in its upper part. The gray pebbly sandstone is overlain by a greenish gray sandstone of 20 meters thick. This greenish gray sandstone yields the "*Pleurotomaria*" assemblage and the *Acesta goliath* assemblage. The greenish gray sandstone is overlain by a gray coarse-grained sandstone of 2.5 meters thick, intercalates a pumiceous bed, 0.9 meters in thickness, and a dark-gray clay bed of about 10 centimeters thick in the middle part. The gray coarse-grained sandstone is frequently bioturbated. This gray sandstone is overlain by a greenish gray sandstone of 13 meters thick, which yields solitary hexacorals fossils. The greenish gray sandstone containing hexacorals is overlain by a greenish black tuffaceous sandstone containing granule- to pebble-sized gravels. This black sandstone crops out in Loc. Sh-6 which is about 1 kilometer east to this quarry, and in Loc. Sh-1. The black sandstone abundantly contains light yellowish green and semi-transparent crystals of Andesine, 2-5 millimeters in length (Tomida, 1991). The black sandstone is the base of the Inakozawa Formation and is overlain by the "Gomashio"-like Ok tuff of 2 meters thick.

Three cephalopod species, that is, *Aturia coxi* Miller, *Argonauta itoigawai* Tomida, and *Argonauta* (s. l.) *awaensis* Tomida were obtained from this locality. The former two were obtained from the middle and upper sandstones, but the latter was obtained from the lower, granule-sized conglomerate and the coarse-grained sandstone. The gray pebbly sandstone, the lowermost part of the Senhata Formation, from which *Palaega* sp. occurs (Karasawa *et al.*, 1992), yields more than 10 species of the benthonic and planktonic foraminifera (Tomida, 1989a). They are *Globigerinoides trilobus* (Reuss), *Sphaeroidinellopsis seminulina* (Schwager), *S. subdehiscens* Blow, *Orbulina* sp., *Globorotalia* spp., and so on. This shows that the age of the sandstone is in the Blow's zone N17-18 (latest Miocene to earliest Pliocene).

Sh-6: In the Towa Sekizai's Quarry, mudstone of the Amatsu Formation conformably underlies medium-grained sandstone of the Senhata Formation. The dark gray, medium-grained sandstone, 22 meters in thickness intercalates an *Acesta* shell-bed in its middle part, and this dark gray sandstone is overlain by a light gray tuffaceous fine-grained sandstone, about 20 meters in thickness, which shows ripple marks and bioturbations.

Both sandstones mentioned above are overlain by greenish black, tuffaceous sandstone containing subrounded granules and pebbles, fossil cetacean bones, and fossil shark teeth. This volcanic black sandstone corresponds to be the base of the Inakozawa Formation.

2. Izu Terrene

The Izu Terrene was located in the lower latitude in the Pliocene than today. Localities yielding Pliocene molluscan fossils in Izu Peninsula were shown below.

1) Shirahama Area (Sr)

Localities: Sr-1 (Nagata, 138°58′50″E, 34°42′3″N), Sr-2 (Back of Shirahama Shrine, 138°58′37″E, 34°41′31″N), Sr-3 (Itami, 138°58′43″E, 34°40′48″N) and Sr-4 (Kakisaki, 137°57′53″E, 34°40′20″N), in Shimoda City, Shizuoka Prefecture.

Age: Early Pliocene to early late Pliocene.

Horizons: Sr-1 and Sr-3: the Itami Formation of the Shirahama Group, Sr-2 and Sr-4: the Harada Formation of the Shirahama Group.

Lithology: Sr-1 and Sr-3: tuffaceous breccia sand-

stone. Sr-2 and Sr-4: calcareous sandstone and fine- to medium-grained sandstone.

Chronological data: Sr-2: CN12 of calcareous nannoplankton zone by Okada and Bukry (1980) (Okada, 1987). Sr-2: N19 of Blow's planktonic foraminiferal zone (Ibaraki, 1976, 1981).

Remarks: The Shirahama Group which crops out in the Shirahama Coast, is divided into the Itami and Harada Formations, in ascending order. The Itami Formation is conformably overlain by the Harada Formation (Watanabe *et al.*, 1952). The Itami Formation is composed of tuff and propyrite lava in the lower part and tuffaceous brecciated sandstone in the upper part. The Harada Formation consists of cross-laminated calcareous sandstone and tuffaceous sandstone. These two formations yield abundant fossils of molluscs, echinoids, brachiopods, bryozoans, and calcareous algae. The Itami Formation, which outcrops at Loc. Sr-1, yields the *Chlamys satoi* - *Comptopallium tayamai* assemblage. The Harada Formation, which crops at Loc. Sr-2, yields the *Chlamys satoi* - *Comptopallium tayamai* assemblage and the *Cryptopecten vesiculosus* - *Lima zushiensis* assemblage. The latter assemblage is predominant in its upper part of the outcrop. The assemblage frequently contains pleurotomariids, *Spondylus anacanthus* Mawe, *Neopycnodonte musashiana* (Yokoyama) and *Lucinoma annulatum* (Reeve). In this paper, the Shirahama Group is represented by the formations outcropping in the Shirahama Coast, because the rest of the other localities of the Shirahama Group in the Izu Peninsula yields very poorly-preserved molluscan fossils.

2) Ninotozawa (Nz)

Locality: Nz (Ninotozawa, 139°4′51″E, 35°12′46″N) in Hakone-cho, Ashigarashimo-gun, Kanagawa Prefecture.

Age: Early Pliocene.

Horizon: The Hayakawa Formation.

Lithology: Tuff breccia, granule- to pebble-sized conglomerate and coarse-grained sandstone.

Remarks: The Hayakawa Formation crops out in Ninotozawa, about 300 meters in thickness. The Hayakawa Formation unconformably overlies the Miocene Yugashima Group, and it is conformably overlain by the Sukumogawa andesite (Otuka, 1934).

The Hayakawa Formation mainly consists of tuff breccia and intercalates a pebbly, coarse-grained sandstone rich in cast-fossils of eroded molluscan shells. This bed yields the *Cryptopecten vesiculosus* - *Lima zushiensis* assemblage, and also yields *Chlamys satoi* Yokoyama. The assemblages of the Hayakawa Formation is well comparable with the assemblages of the Shirahama Group.

Molluscan Assemblages

The molluscan assemblages from the South Fossa-Magna region are described in this chapter and shown in Fig. 2 and Appendix 1.

In this paper, terminology on modes of fossil occurrence are as follows.

"Parautochthonous": Shells are randomly distributed in the matrix sediments. Bivalve shells are often conjoined and gastropod shells are well preserved. The species composition is consistent with the sedimentary facies.

"Allochthonous": Shell-concentrated beds or lenses, in which sediments clearly discriminated from matrix sediments around them. Most of the shells are poorly preserved. Bivalve shells are fragmental or disarticulated. The shell surface is abraded. Gastropod shells are poorly preserved. The assemblage contains shells of two or more different habitats.

The terminology of the bathymetric range follows that of Oyama (1952).

1. Zushi Fauna

1) *Turbo* cf. *marmoratus* - *Charonia sauliae* assemblage

Occurrence: Allochthonous....Oz-2, Oc, Zs-3, Sh-3 and Sh-5.

Bathymetric range: Lower tidal to euneritic zone (N_0-N_1).

Bottom sediments: Gravel and rock.

Paleoecological characteristics: Epibenthic creepers are dominant.

Characteristic species: *Turbo* (*Lunatica*) cf. *marmor-*

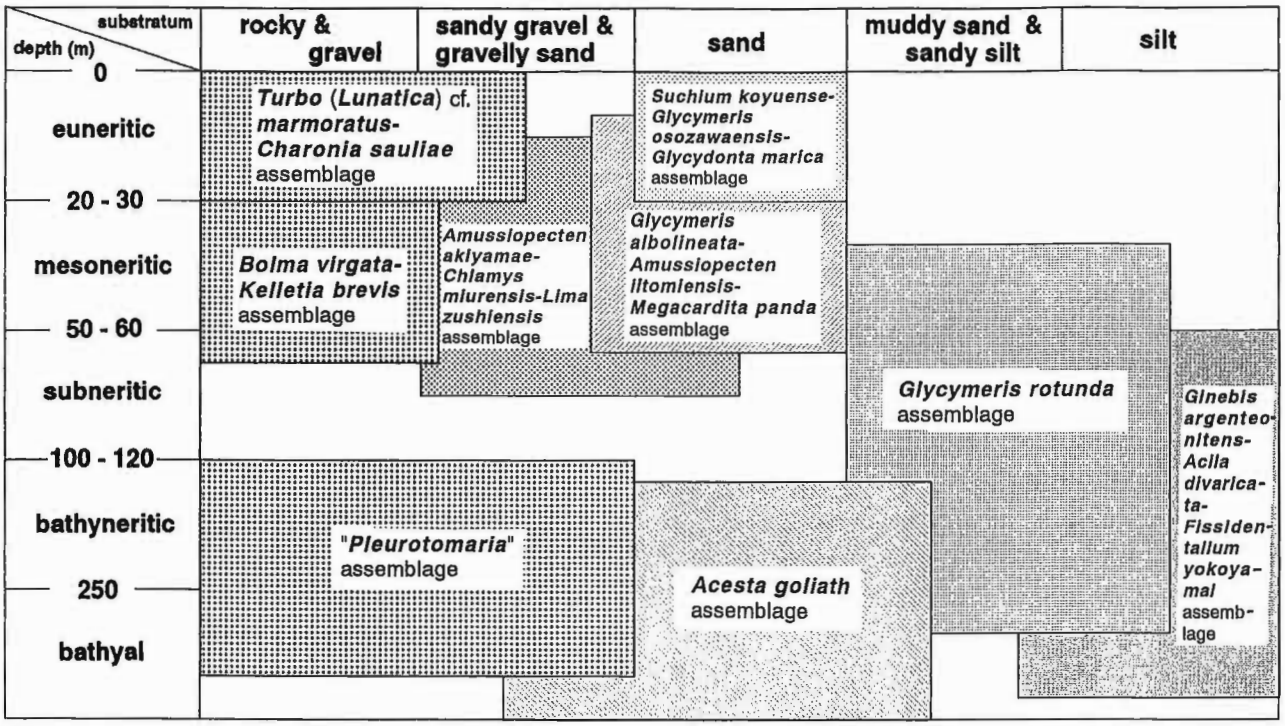


Fig. 2. Molluscan assemblages of the late Miocene to early Pliocene Zushi Fauna in the South Fossa-Magna region.

atus Linnaeus, *Charonia sauliae* (Reeve).

Associated species: *Cellana* cf. *grata* (Gould), *Chlorostoma narusei, Astraea omorii* Shibata, *Astraea* (*Astralium*) cf. *calcar* (Linnaeus), *Turbo* (*Batillus*) sp., *Pleuroploca* cf. *trapezium, Mauritia* (*Arabica*) cf. *histrio, Erosaria* aff. *boivinii* (Kiener), *Dulcerana* cf. *granularis, Pernaviridis* (Linnaeus), *Pinctada fucata* (Gould), *Chlamys* (*Mimachlamys*) cf. *nobilis* (Reeve).

Remarks: This assemblage corresponds to the *Turbo* cf. *marmoratus* assemblage described by Ozawa and Tomida (1992). *Turbo* (*Lunatica*) *marmoratus* Linnaeus on lower tidal to euneritic rocky bottoms of tropic seas from the Yakushima Island to northeastern Australia. *Charonia sauliae* lives on gravelly and rocky bottoms south of the Boso Peninsula to the Philippines. *Pleuroploca trapezium* lives on lower tidal to euneritic rocky bottoms south of the Philippines.

Turbo cf. *marmoratus* bearing assemblage is associated with *Cellana* cf. *grata, Chlorostoma narusei, Astraea omorii, Turbo* (*Batillus*) sp., *Perna viridis, Pinctada fucata* at Loc. Oz-2. In addition, it is associated with *Chlorostoma narusei, Astraea omorii* and *Pleuroploca* cf. *trapezium* at Loc. Oc. They correspond to the *Turbo* cf. *marmoratus* - *Charonia sauliae* assemblage but lacks *C sauliae*. At present, the fossil *C. sauliae* is unknown in the west to the Shonan area.

2) *Suchium koyuense* - *Glycymeris osozawaensis* - *Glycydonta marica* assemblage

Occurrence: Allochthonous....Oz-1, Oz-2, Oc, Os, Zs-3 and Sh-3. Parautochthonous....Nk-1.

Bathymetric range: Tidal to euneritic zone (N_0-N_1).

Bottom sediments: Muddy sand to sand.

Paleoecological characteristics: Epibenthic creepers and shallow endobenthic burrowers.

Dominant species: *Suchium koyuense, Glycymeris osozawaensis, Glycydonta marica.*

Associated species: *Ethalia maxima* (Shuto), *Strombus* (*Canarium*) sp., *Oliva oliva, Olivella fulgurata* (Adams and Reeve), *Chelyconus* cf. *fulmen, Parviconus tuberculosus* (Tomlin), *Anadara* (*Tosarca*) cf. *tosaensis* Noda, *Anadara* (*Scapharca*) *suzukii* (Yokoyama), *Solen gordonis* Yokoyama.

Remarks: This assemblage corresponds to the *Suchium koyuense* - *Glycymeris* cf. *cisshuensis* assemblage described by Ozawa and Tomida (1992). *S. koyuense* was originally described by Shuto (1956)

from the Lower Miyazaki Group. *S. koyuense* was also reported from the uppermost Miocene to the lowermost Pliocene formations in the South Fossa-Magna region, such as the Furuya, Ochiai, Nishikoiso, and Zushi Formations (Shikama, 1973). These formations are correlated with the Lower Miyazaki Group. This species is an inhabitant of the sandy bottom in the euneritic zone. Concerning the phylogeny of the late Miocene species, *Protorotella hyugaense* Shuto, *Ethalia maxima*, and *Suchium koyuense*, Ozawa (1983) proposed that these were derived from *Protorotella* and *Suchium* species in the early Middle Miocene Kadonosawa Fauna, and evolved after remaining in the warm sea from southwest Japan to the Ryukyu Islands.

Glycymeris osozawaensis was abundant in some localities in the Osozawa Member of the Akebono Formation at Loc. Os-2, the Nishikatsura Formation at Loc. Nk-1, and the Ochiai Formation at Loc. Oc.

Glycydonta marica was abundant in some localities in the gravelly sandstone of the Shimoyamaguchi Member of the Zushi Formation (Shikama, 1973), at Loc. Zs-3, and the intercalated calcareous sandstone of the Senhata Formation at Loc. Sh-3.

3) *Bolma virgata* - *Kelletia brevis* assemblage

Localities: Allochthonous....Oz-1, Oz-2, Nk-1, Oc, Os, Zs-1, Sh-4 and Sh-5. Parautochthonous....Oc and Sh-3.

Bathymetric range: Euneritic to subneritic zone (N_1-N_3).

Bottom sediments: Gravel and rock.

Paleoecological characteristics: Epibenthic creepers are dominant.

Characteristic species: *Bolma* (*Bolma*) *virgata*, *Kelletia brevis*.

Associated species: *Bolma* (*Oobolma*) *takitai* (Ozaki), *Ceratostoma fournieri* (Crosse), *Arca boucardi* Jousseaume.

Remarks: The shells of *Bolma virgata* and *Kelletia brevis* are completely preserved from the Ochiai Formation in Loc. Oc (this report) and the Na-arai Formation in Tokawa-cho of Choshi City (Ozaki, 1954), and they are accompanied by fossils of deep-sea dwellers such as pleurotomariids. This suggests that *B. virgata* and *K. brevis* had been lived in a deeper gravelly bottom than *B. modesta* and *K. lischkei* which lives in the lower tidal to mesoneritic zones. *K. lischkei* occurs from the near shore facies of the upper Pliocene Kakegawa Group. If *K. brevis* is a direct ancestor of *K. lischkei*, *Kelletia* in Japan changed its habit from deeper gravelly and rocky bottom to near shore rocky bottom during the early Pliocene. The *Bolma virgata* - *Kelletia brevis* assemblage is characteristic in the Zushi Fauna.

4) *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage

Occurrence: Allochthonous....Zs-1, Sh-1, Sh-2, Sh-3, Sh-4 and Sh-5.

Bathymetric range: Euneritic to meseoneritic, or to subneritic zone (N_1-N_2, or -N_3).

Bottom sediments: Gravelly sand and gravel.

Paleoecological characteristics: Epibenthic swimmers and sessils are dominant.

Dominant species: *Amussiopecten akiyamae, Chlamys miurensis, Lima zushiensis* Yokoyama.

Associated species: *Tonna* cf. *luteostoma* (Küster), *Hemifusus tuba* (Gmelin), *Glycymeris osozawaensis, Miyagipecten matsumoriensis, Indocrassatella tenuilirata, Paphia exilis* Shuto.

Remarks: This assemblage corresponds to the *Chlamys miurensis* - *Lima zushiensis* assemblage described by Ozawa and Tomida (1992), and it corresponds to some assemblages described as the *Amussiopecten akiyamae* assemblage by Tomida (1989a).

The *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage in Locs. Hs-1, Sh-3 and Sh-4 contains *Miyagipecten matsumoriensis*. This assemblage is composed of gravelly sand-bottom dwellers.

5) *Glycymeris albolineata* - *Amussiopecten iitomiensis* - *Megacardita panda* assemblage

Occurrence: Allochthonous....Sg, Oz-1, Oz-2, Nk-1, Oc and Os.

Bathymetric range: Euneritic to mesoneritic zone (N_1-N_2).

Bottom sediments: Sand and gravelly sand.

Paleoecological characteristics: Epibenthic creepers and swimmers, and endobenthic shallow-burrowers.

Dominant species: *Glycymeris albolineata, Amus-*

Paleoecological characteristics: Epibenthic creepers and endobenthic shallow-burrowers.

Dominant species: *Ginebis argenteonitens, Acila divaricata, Fissidentalium yokoyamai.*

Associated species: *Lischkeia* cf. *alwinae* (Lischke), *Ginebis crumpii* (Pilsbry), *Portlandia lischkei, Megayoldia tsuruensis* Sugita, *Periploma plane, Fissidentalium vernedei* (Sowerby).

Remarks: This assemblage is associated with *Xenophora chinensis, Neptunea kuroshio,* and *Glycymeris rotunda* at Loc. Oz-2. Well preserved shells of *Ginebis argenteonitens* and *Fissidentalium yokoyamai* occur frequently from Loc. Uh. These are associated by conjoined valves of *Acila divaricata, Portlandia lischkei* (abundant), *Megayoldia tsuruensis,* and *Periploma plane.* The *Ginebis argenteonitens* and *Ginebis crumpii* live now on the muddy and sandy bottoms in the depth of 100-400 meters. *G. argenteonitens* is distributed from the Tsugaru Bay to Kyushu. This assemblage is comparable with the *Bathybembix* community described by Hickman (1984) as one of the Cenozoic deep-water molluscan communities.

2. Shirahama Fauna

1) *Chlamys satoi - Comptopallium tayamai* assemblage

Occurrence: Allochthonous....Sr-1, Sr-3 and Nz.

Bathymetric range: Euneritic to mesoneritic zone (N_1-N_2).

Bottom sediments: Sand and gravelly sand.

Paleoecological characteristics: Epibenthic swimmers and sessils are dominant.

Dominant species: *Chlamys* (*Mimachlamys*) *satoi, Comptopallium tayamai* (Nomura and Niino).

Associated species: *Patinopecten planicostulatus* (Nomura and Niino), *Amussiopecten praesignis, Decatopecten izuensis* (Nomura and Niino), *Chlamys shirahamaensis* (Nomura and Niino), *Spondylus barbatus cruentus* Lischke, *Ostrea circumpicta* Pilsbry, *Dendostrea folium* (Linnaeus), *Dendostrea crenulifera* (Sowerby), *Lioconcha* (*Sulcilioconcha*) cf. *philippinarum* (Hanley).

Remarks: This assemblage is associated with *Chlamys shirahamaensis, Decatopecten izuensis, Spondylus barbatus cruentus, Lima zushiensis Ostrea circumpicta, Dendostrea crenulifera, Lioconcha* (*Sulcilioconcha*) cf. *philippinarum,* and so on. This assemblage is characterized by abundant occurrence of tropical species. *Comptopallium* species lives on gravelly sandy bottom in the tidal to euneritic zones in tropical seas. *L.* (*S.*) *philippinarum* lives in the south of the Okinawa Island. These facts support that the Shirahama Fauna is distributed in warmer water areas than those of the Kakegawa Fauna. This is due to that the Izu Terrane was located in the lower latitudes during the Pliocene than today (Niitsuma, 1987; Hirooka, 1988).

2) *Cryptopecten vesiculosus - Lima zushiensis* assemblage

Occurrence: Allochthonous....Sr-2, Sr-4 and Nz.

Bathymetric range: Mesoneritic to bathyneritic or bathyal zone (N_2-N_4 or -B).

Bottom sediments: Sand and gravel.

Paleoecological characteristics: Epibenthic swimmers and sessils are dominant.

Dominant species: *Cryptopecten vesiculosus* (Dunker), *Lima zushiensis.*

Associated species: Pleurotomariid species, *Glycymeris rotunda, Spondylus anacanthus, Neopycnodonte musashiana, Lucinoma annulatum, Fissidentalium yokoyamai.*

Remarks: The upper part of the Harada Formation (Loc. Sr-2) yields abundant shells of *Cryptopecten vesiculosus* with *Comptopallium tayamai, Decatopecten izuensis*, and *Lima zushiensis*, which have smaller-sized shells than those from the lower part of formation. This variation in this assemblage type may depend on the bathymetrical depth of the habitats. The former assemblage including large *Chlamys* lived in the mesoneritic zone, whereas the latter assemblage domimated by *C. vesiculosus* lived in the bathyneritic zone. Recent *C. vesiculosus* assemblage occurs on the gravelly bottom in the bathyneritic to upper bathyal zones in the Pacific off central Japan. Living *C. vesiculosus* is accompanied by *Mikadotrochus beyrichii* (Hilgendorf) and *Xenophora japonica* Kuroda and Habe. The assemblage dominated by *C. vesiculosus* also occurs from sandstone of the uppermost part of the Shirahama Formation (Loc. Sh-2) and from tuff

breccia of the Hayakawa Formation (Loc. Nz). The fossil assemblages from the localities include pleurotomariid gastropods.

Paleoenvironment

Distributions of the molluscan assemblages are plotted on the paleogeographic map after Niitsuma (1987) and Hirooka (1988) (Fig. 4).

1. Zushi Fauna (latest Miocene to earliest Pliocene)

1) Sagara Area

The upper part of the Sagara Group yields *Glycymeris rotunda, Glycymeris albolineata, Crenulilimopsis oblonga, Amussiopecten iitomiensis, Spondylus anacanthus, Mercenaria yokoyamai*, and *Fissidentalium yokoyamai*, and so on (Tsuchi, 1961). These are a mixture of upper neritic and lower neritic dwellers in a sandy or gravelly sandy bottom in pelagic sea. The Oyori Formation yields *Carinineilo* sp., *Yoldia* sp., *Glycymeris* sp., *Delectopecten peckhami, Polynemamussium* sp., *Conchocele* sp., and *Fissidentalium hungerfordi* (Ujihara *et al.*, 1990). The siltstone of the Oyori Formation yields the muddy bottom inhabitants, such as *Crenulilimopsis oblonga* and *Cyrenolimopsis adamsiana* (this study). These are inhabitants of subneritic to bathyal muddy bottom.

The mudstone of the Sagara Group is considered to have been deposited as a fan delta in the subneritic to bathyneritic basin where the shallow-water inhabitants were transported to the living site of the deep-water inhabitants.

2) Osozawa Area

Many species living in the lower tidal to euneritic rocky bottom, such as *Turbo* cf. *marmoratus, Astraea omorii, Chlorostoma narusei, Cellana* cf. *grata, Arca boucardi, Perna viridis, Pinctada fucata*, were obtained in allochthonous occurrences from gravelly coarse-grained sandstone. Therefore, rocky shore had been distributed along the coast of this area. The euneritic to mesoneritic, gravelly to sandy bottom inhabitants of the *Glycymeris albolineata - Amussiopecten iitomiensis - Megacardita panda* assemblage, were abundantly

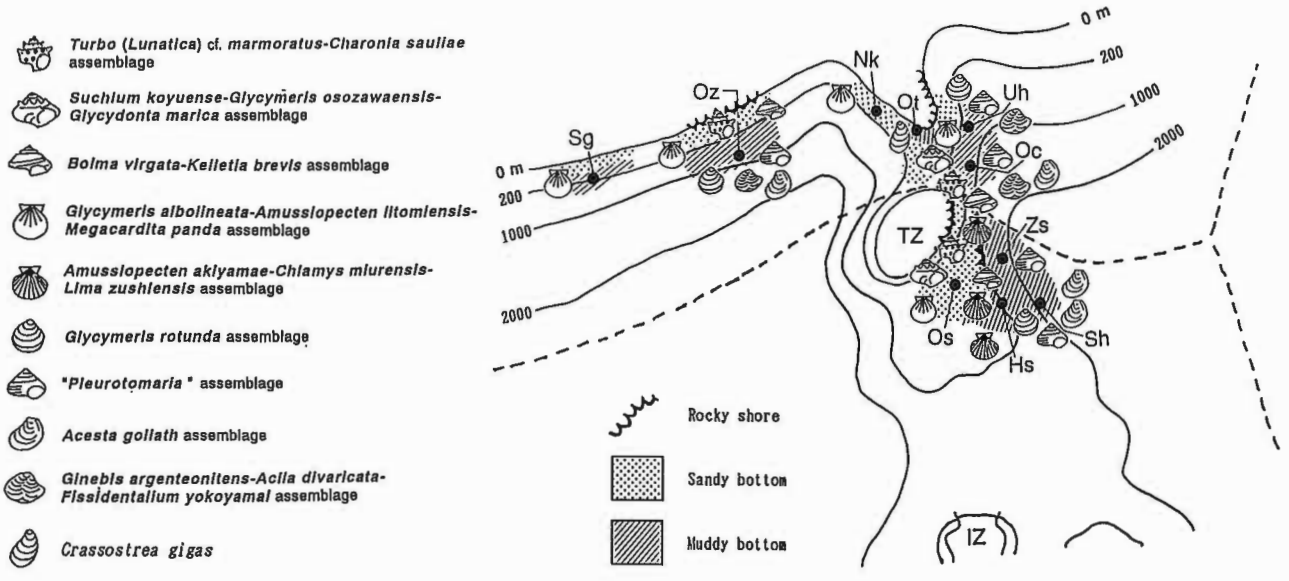


Fig. 4. Map showing the distribution of the late Miocene to early Pliocene molluscan assemblages in the South Fossa-Magna region. (addition to Niitsuma, 1987 and Hirooka, 1988)
TZ: Tanzawa Terrane, IZ: Izu Terrane. ●: Areas of fossil localities. Sg: Sagara area, Oz: Osozawa area, Nk: Nishikatsura area, Ot: Ootsuki area, Uh: Uenohara area, Oc: Ochiai, Os: Ooiso, Zs: Zushi area, Hs: Hatsuse area, Sh: Nokogiriyama area.

obtained in an allochthonous occurrence also from the gravelly coarse-grained sandstone; therefore, the sandy or gravelly sandy bottom had been distributed along the upper sublittoral zone of the continental shelf, where the pelagic warm water flowed. In addition to this, a siltstone yields the *Ginebis argenteonitens - Acila divaricata - Fissidentalium yokoyamai* assemblage in a parautochthonous occurrence. This assemblage is associated by *Xenophora chinensis, Neptunea kuroshio, Glycymeris rotunda, Keenaea samarangae, Pholadomya pacifica, Cuspidaria nobilis,* and so on. Accordingly, it seems that the shallow-sea dwellers were transported to the living site of the bathyal inhabitants. The facts mentioned above suggest that there was a steep slope.

3) Nishikatsura Area

The Furuya Formation yields neritic molluscs such as the *Suchium koyuense - Glycymeris osozawaensis - Glycydonta marica* assemblage in a parautochthonous occurrence, and the *Glycymeris albolineata - Amussiopecten iitomiensis - Megacardita panda* assemblage in an allochthonous occurrence. This area may correspond to the neritic gravelly- to sandy-bottom of the uplift zone in front of the Tanzawa Terrane.

4) Ootsuki Area

The mudstone of the Shimada Formation in Locs. Ot-1 and Ot-2 intercalates *Crassostrea* beds. *Cycladicama cumingii* and *Leptaxinus oyamai* were obtained from the gravelly siltstone in an parautochthonous occurrences, at Loc. Ot-2. These facts suggest that the mudstone in this area was deposited in the upper neritic, muddy-bottom of the inner bay.

Suekane and Kadota (1986) reported an occurrence of coral-bearing limestone lens containing *Porites* sp., *Favia* sp., *Hydnopora* sp., and *Acanthastrea* sp. from the conglomerate of the Nishikatsura Group in the Mt. Rinpozan area. These facts suggest that the deposition of the limestone lens is related to a collision of the Tanzawa Terrane, which drifts northward (Niitsuma, 1987; Hirooka, 1988).

5) Uenohara Area

The mudstone of the Shimada Formation in Loc. Uh contains a few gravel-lenses intercalated in the upper part, and it is conformably overlain by the Katsuragawa conglomerate. The mudstone yields the *Ginebis argenteonitens - Acila divaricata - Fissidentalium yokoyamai* assemblage containing abundant shells of *Portlandia lischkei* and *Periploma plane* in parautochthonous occurrences. The intercalated gravel-lenses yield the *Glycymeris rotunda* assemblage containing a tidal rocky shoreinhabitant, *Turbo* cf. *stenogyrus*. These facts suggest that the shallow-water inhabitants were transported down to the deep-water living site of the bathyneritic to bathyal inhabitants. The deposition of gravel-lenses may be related to a collision of the Tanzawa Terrane, which drifts northward (Niitsuma, 1987; Hirooka, 1988).

6) Ochiai Area

The conglomerate beds of the Ochiai Formation yield *Turbo* cf. *marmoratus* and *Turbo* (*Batillus*) sp., and the fossil assemblage consists of lower tidal to euneritic, rocky-bottom inhabitants. The shells are defaced and damaged. This conglomerate beds also yield the *Glycymeris albolineata - Amussiopecten iitomiensis - Megacardita panda* assemblage in an allochthonous occurrence.

In a mudstone around the conglomerate, the shells of deep-water inhabitants were found in parautochthonous occurrences. For example, an occurrence of conjoined valves of *Halicardia nipponensis* were reported by Tomida (1989b). The species lives in a fine sandy or muddy bottom in the depth of 400-1500 meters off the Sanriku region to Sagami Bay. The shells of the shallow-water inhabitants in the conglomerate were transported to the living site of the deep-sea bottom, more than 400 meters.

7) Ooiso Area

The Nishikoiso Formation is composed of scoriae-rich, gravelly, coarse-grained sandstone. The Nishikoiso Formation yields *Glycymeris albolineata - Amussiopecten iitomiensis - Megacardita panda* assemblage, containing shells of many sandy-bottom inhabitants, but few shells of rocky bottom inhabitants, except for specimens of *Kelletia brevis* and *Tutufa* (*Tutufa*) cf. *bufo* (Röding). The shells of the shallow-

water inhabitants were transported to the bathyneritic and upper bathyal zones where *Neptunea kuroshio* and *Glycymeris rotunda* lived.

This area is characterized by fewer occurrence of rocky-bottom inhabitants compared with other areas such as, Oz-1, Oz-2, Oc, Zs-1, Sh-1, Sh-3 and Sh-4. This suggests that the sedimentary environment was a gravelly to sandy bottom, in the euneritic to mesoneritic zones under a warm water offshore condition.

8) Zushi Area

The conglomerate of the Tagoegawa Member of the Zushi Formation yields the *Turbo* cf. *marmoratus* - *Charonia sauliae* assemblage containing many shells of lower tidal to euneritic rocky-bottom inhabitants in allochthonous occurrences. Abundant shells of the tidal to euneritic, sandy-bottom inhabitants, such as *Suchium koyuense* and *Glycydonta marica*, were also obtained from gravelly sandstone of the Shimoyamaguchi Member. On the other hand, the conglomerate of the Tagoegawa Member yields the euneritic to mesoneritic gravelly sandy-bottom inhabitants, such as *Amussiopecten akiyamae*, and gravelly- and rocky-bottom inhabitants, such as *Chlamys miurensis* and *Lima zushiensis*.

The "*Pleurotomaria*" assemblage containing many species of subneritic to bathyal inhabitants, was also obtained from the conglomerate of the Tagoegawa Member. Therefore the conglomerate of the Tagoegawa Member was deposited in the bathyal zone with transported shells of the tidal to the euneritic, rocky- and sandy-bottom dwellers.

9) Hatsuse Area

The *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage occurs from pyroclastic, gravelly sandstone and siltstone in an allochthonous occurrence. This assemblage is composed of inhabitants of the euneritic to mesoneritic, gravelly-sandy bottom, and tidal, rocky-bottom, such as *Ostrea circumpicta*. The gravelly sandstone and siltstone also yield the *Glycymeris rotunda* assemblage, which lived in the subneritic to upper bathyal zones. In addition, pleurotomariid fossils were obtained from the Misaki Formation. The shells of the shallow-water inhabitants were transported to the bathyal slope.

10) Nokogiriyama Area

According to Tomida (1989a), the mixed occurrence of the shallow-water and deep-water assemblages, is observed in the Senhata Formation, as follows: The euneritic rocky-bottom inhabitants (e.g., *Pretostrea imbricata* (Lamarck) and barnacles) and the mesoneritic, sandy-bottom dwellers (e.g., *Amussiopecten akiyamae*) were transported to the mesoneritic to subneritic, sandy-bottom (Locs. Sh-1 and Sh-2). The tidal and euneritic inhabitants were transported with gravels to the subneritic to bathyneritic sandy-bottom (Loc. Sh-3). The shells of mesoneritic to subneritic inhabitants (e.g., *Amussiopecten akiyamae* and *Chlamys miurensis*) were mixed with deep-sea dwellers such as *Acesta goliath* and pleurotomariid gastropods (Loc. Sh-4). The tidal to euneritic, muddy and sandy inhabitants (e.g., *Ostrea circumpicta* and *Pretostrea imbricata*) were obtained in an allochthonous occurrence from the intercalated, coquinoid limestone bed at Loc. Sh-3. The *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage was obtained from Locs. Sh-1, Sh-2, Sh-3 and Sh-4, in an allochthonous occurrence. This assemblage contains tidal rocky bottom inhabitants, ostreids and barnacles. The "*Pleurotomaria*" and *Acesta goliath* assemblages composed of deep-water inhabitants, were obtained from Locs. Sh-3, Sh-4, Sh-5 and Sh-6.

In the west part of the Nokogiriyama area (Locs. Sh-1, Sh-2 and Sh-3), the Senhata Formation deposited in a neritic zone. From the localities, the shallow-water assemblages, such as the *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* and *Glycymeris rotunda* assemblages and ostreids, occur both in parautochthonous and allochthonous occurrences. On the other hand, in Locs. Sh-5 and Sh-6 (the eastern half of the Nokogiriyama area), the Senhata Formation yields the parautochthonous, hemibathyal to bathyal assemblages and the neritic allochthonous assemblages.

Therefore the bathymetric depth is shallower in the west than in the east of this area. In addition, the cross-lamination at Loc. Sh-6 shows that the gravels

were supplied from the west. The Senhata Formation is the marginal conglomerate caused by a collision of the Tanzawa Terrane, which drifts northward (Niitsuma, 1987; Hirooka, 1988). The mixed occurrence of the shallow- and deep-water inhabitants, may reflect rapid burrial process of the bathyal sea.

2. Shirahama Fauna (early Pliocene)

1) Shirahama Area

The upper part of the Itami Formation yields the *Chlamys satoi* - *Comptopallium tayamai* assemblage including many inhabitants of the euneritic to mesoneritic, sandy to gravelly sandy bottom. The limestone and calcareous sandstone of the Harada Formation, containing abundant fossils of reef-building calcareous algae, were deposited in the Shirahama area during the early Pliocene. The upper part of the Harada Formation yields the *Chlamys satoi* - *Comptopallium tayamai* assemblage and the *Cryptopecten vesiculosus* - *Lima zushiensis* assemblage. Both assemblages contain many inhabitants of sandy to gravelly bottoms in the subneritic to bathyneritic zones. The temporal change of the molluscan assemblage in the Shirahama Group indicates deepening upward sequence (the mesoneritic gravelly-sandy bottom to the bathyneritic sandy and gravelly-sandy bottom).

Nomura and Niino (1932) reported new species, such as *Pleurotomaria yabei, Pecten planicostulatus, Pecten izuensis, Pecten tayamai, Pecten shirahamaensis*, and so on from "Shirahama beds". Tsuchi (1965) listed 11 molluscan species obtained from the "Shirahama" Group near Matsuzaki-cho, Nishiizu-gun. They are *Portlandia* cf. *lischkei, Glycymeris rotunda, Keenaea* cf. *samarangae, Venus foveolata, Paphia* cf. *schnelliana*, and so on. Sawamura *et al.* (1969) revealed the geology of the Shimoda District and listed molluscan fossils of the Shirahama Group. Koyama (1982) reported the molluscan fossils such as *Acila divaricata, Yoldia similis, Portlandia lischkei, Macoma calcarea* from tuffaceous mudstone of the Lower Hiekawa Group, which corresponds to the Shirahama Group, in Nakaizu-cho, Tagata-gun. These molluscs may have lived in bathymetrically deeper bottom than those of the Harada Formation in the Shirahama Coast, which yield abundant calcareous algae forming the shallow-water algal reef.

2) Ninotozawa Area

The *Cryptopecten vesiculosus* - *Lima zushiensis* assemblage occurs from tuff breccia and tuffaceous, granule-sized conglomerate in an allochthonous occurrence. They contain *Pseudotrivia* cf. *eos, Conus* sp., *Chlamys satoi, Spondylus* anacanthus and *Liocon-cha* (*Sulcilioconcha*) cf. *philippinarum,* as associated species.

Otuka (1934) listed 10 species of molluscan fossils from the Hayakawa Formation. They are *Pleurotomaria* sp., *Chlorostoma* sp., *Chlamys satoi, Cryptopecten vesiculosus, Lima zushiensis, Paphia* sp., *Clementia vatheleti* Mabille, and so on. These assemblages contain both inhabitants of euneritic to mesoneritic zone and subneritic to bathyneritic zone.

Paleobiogeography

The Zushi Fauna is a tropical to subtropical marine water molluscan fauna of late Miocene to early Pliocene (8 Ma to 4.5 Ma) in the central and southwestern Japan. Ozawa and Tomida (1992) noted that the Zushi Fauna flourished under a strong influence of the paleo-Kuroshio warm current at remarkable warming of marine climate around 7 Ma (Climatic Optimum 3 of Barron and Baldauf, 1990). The Zushi Fauna is stratigraphically divided into two units, namely the lower unit in the latest Miocene (7.5 Ma to 6 Ma) and the upper unit in the earliest Pliocene (5.3 Ma to 4.5 Ma), as shown in Tables 1 and 2. The former corresponds to the time of the Climatic Optimum 3. In the late Neogene eustatic curves presented by Malmgren and Berggren (1987), major rises in global sea level are shown at ca. 6.8 Ma, 5.7 Ma, 5-3.8 Ma, 3.5-3 Ma and 2-1.8 Ma. The upper unit corresponds to the time of sea level rise in the earliest Pliocene (around 5 Ma). These remarkable warmings of marine climate are demonstrated by the facts that the calcareous sediments are well developed containing tropical or subtropical elements. For example, the Shimoyamaguchi Member of the Zushi

Table 2. Common and characteristic species in two units of the Zushi Fauna

AGES	SOUTH FOSSA-MAGNA REGION			
			Common species to both units	Characteristic species in each unit
LOWERMOST PLIOCENE	ZUSHI FAUNA	Upper Unit	*Perotrochus africanus* cf. *teramachii* *Ginebis argenteonitens* *Ethalia maxima* *Suchium koyuense* *Astraea tyosiensis* *Bolma* (*Bolma*) *virgata* *Bolma* (*Oobolma*) *takitai* *Turbo* (*Lunatica*) cf. *marmoratus* *Turbo* (*Batillus*) n. sp. *Kelletia brevis* *Acila divaricata* *Glycymeris rotunda* *Glycymeris osozawaensis* *Chlamys miurensis*	*Chlorostoma narusei* *Astraea omorii* *Neptunea kuroshio* *Siphonalia* cf. *declivis* *Makiyamaia subdeclivis* *Hartungia typica* *Anadara* (*Tosarca*) *tosaensis* *Glycymeris albolineata* *Amussiopecten iitomiensis* *Amusium pleuronectes* *Nipponocrassatella* cf. *takanabensis* *Megacardita panda* *Mercenaria yokoyamai*
UPPERMOST MIOCENE		Lower Unit	*Cryptopecten vesiculosus* *Acesta goliath* *Indocrassatella tenuilirata* *Venus* (*Ventricoloidea*) *foveolata* *Callista chinensis* *Paphia exilis* *Fissidentalium yokoyamai*	*Perotrochus aosimai* *Cypraea* (*Zoila*) *itoigawai* *Phalium* (*Mauicassis*) *yokoyamai* *Endemoconus oyamai* *Hartungia* n. sp. *Glycymeris* cf. *cisshuensis* *Amussiopecten akiyamae* *Miyagipecten matsumoriensis* *Chlamys rendoi* *Aturia coxi* *Argonauta* (s. l.) *awaensis*

Formation contains limestone, calcareous mudstone, calcareous sandstone, and calcareous conglomerate, which yield corals, barnacles, bryozoans, algae (Shikama, 1973), and a tropical larger foraminifer, *Amphistegina radiata* (Fichtel and Moll) (see Eto, 1986). The coquinoid limestone, calcareous sandstone, and calcareous conglomerate are also observed in the Osozawa Member of the Akebono Formation (this report), the Nishikoiso Formation (Otuka, 1931), and the Senhata Formation (Tomida, 1989a). The small limestone lens is intecalated in the conglomerate of the Ochiai Formation, the Tanzawa Group, and it yields the larger foraminifers, such as *Amphistegina radiata*, *Cycloclypeus posteidae* Tan, *Nephrolepidina angulosa* (Provale), *Nephrolepidina japonica* (Yabe) (Mikami, 1955; Matsumaru, 1979). The Zushi Fauna, is characterized by the common occurrence of tropical or subtropical molluscs (Appendixes 1 and 2). For example, it frequently yields fossils of cypraeids and conids which are characteristic gastropods in the tropical and subtropical seas. In particular, the Senhata Formation yields many species of the following species: *Cypraea* (*Zoila*) *itoigawai* Tomida, *Mauritia* (*Arabica*) cf. *histrio*, *Nesiocypraea* cf. *midwayensis* Azuma and Kurohara, *Erosaria* aff. *boivinii*, *Cypraea* sp., *Endemoconus oyamai* Tomida, *Endemoconus* cf. *ichinoseana* (Kuroda), *Lithoconus* cf. *litteratus* (Linnaeus), *Chelyconus* cf. *fulmen*, *Parviconus tuberculatus*, and *Conus comatosaeformis* Yokoyama.

The following tropical to subtropical molluscan fossils are important to indicate the paleobiogeography of the Zushi Fauna.

(1) *Turbo* (*Lunatica*) cf. *marmoratus* Linnaeus from the Osozawa Member of the Akebono Forma-

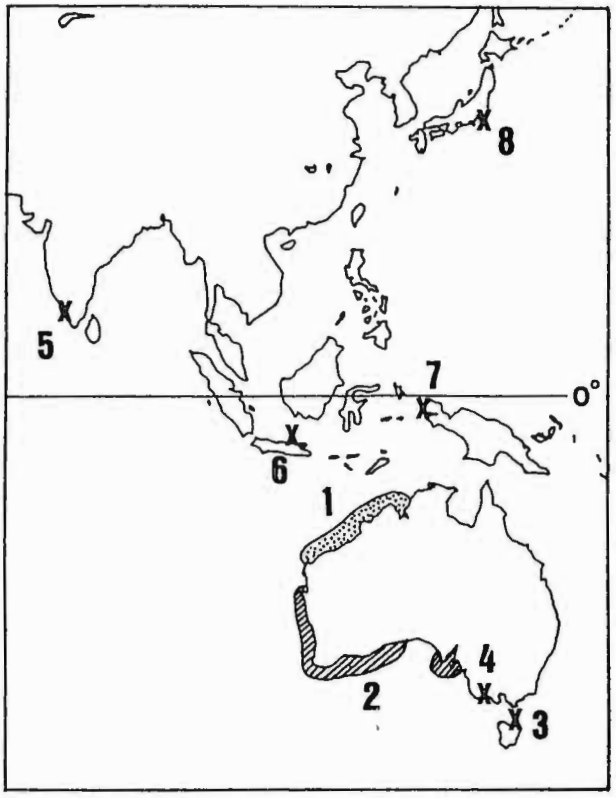


Fig. 5. Geographical distribution of *Zoila*.
(living species: 1-2, fossil species: 3-8)

Appendix- Geographical distribution of *Zoila*.

1-2. living

1. The northern part of western Australia
Cypraea (*Zoila*) *decipiens* E. A. Smith, 1880
Range: North-west Cape to Buccaneer Archipelago.
2. The southern part of western Australia
Cypraea (*Zoila*) *friendi friendi* Gray, 1831
Range: Dorre Is. to the western part of Great Australian Bight.
Cypraea (*Zoila*) *friendi thersites* Gaskoin, 1849
Range: Streak Bay, eastward to Beachport in South Australia.
Cypraea (*Zoila*) *venusta* Sowerby, 1846
Range: Albrolhos Is. to the western part of Great Australian Bight.
Cypraea (*Zoila*) *marginata* Gaskoin, 1848
Range: Dorre Is., western Australia, to Cape Jervis, southern Australia.
Cypraea (*Zoila*) *rosselli* (Cotton, 1948)
Range: Bunbury to Dirk Hartogs Is. of western Australia.

3-8. Fossils

3-4. South Australia (early to middle Miocene)
Cypraea (*Zoila*) *platypyga* McCoy, 1876
Cypraea (*Zoila*) *consobrina* McCoy, 1877
Cypraea (*Zoila*) *toxorhyncha* Tate, 1890
Cypraea (*Zoila*) *simplicior* (Schilder, 1935)
Locality: Portland-Montague, Victoria. (above all)
Cypraea (*Zoila*) *platypyga* McCoy, 1876
Locality: King Is., Flinders, Tasmania.
5. Southern India (late Miocene)
Cypraea (*Zoila*) *schilderi* (Dey, 1962)
Locality: Mangalore-Tuticorin, Malabar.
6. Northern Indonesia (early Pleistocene)
Cypraea (*Zoila*) *gendinganensis* Martin, 1899
Locality: Bawean Is., Nord-Java, Kangeang.
7. New Guinea (Pliocene)
Cypraea (*Zoila*) *caputawisensis* Beets, 1986
Locality: Klagumuk, Volgelkop, West Irian.
8. Japan (latest Miocene)
Cypraea (*Zoila*) *itoigawai* Tomida, 1989
Locality: Okumotona, Kyonan-cho, Awa-gun, Chiba Prefecture.

tion, the Ochiai Formation, and the Zushi Formation.—*Turbo* (*Lunatica*) *marmoratus* lives south of the Yakushima Island (south of 30°N).

(2) *Calliostoma* cf. *formosense* (E. A. Smith) from the Osozawa Member of the Akebono Formation.—*C. formosense* is now distributed from Formosa to the Philippines.

(3) *Cypraea* (*Zoila*) *itoigawai* Tomida from the Senhata Formation, of the Boso Peninsula.—It is an extinct species. The Recent *Cypraea* (*Zoila*) species live on sponges and feed them. *Zoila* lives in the western and southern coasts of Australia. No living species of this subgenus are distributed around Japan. *Zoila* has been reported from the upper Miocene to the Recent in southeastern Australia, and from the upper Miocene to the Pleistocene in India and Indo-Malay archipelago (Schilder, 1941; Wilson and McComb, 1967) (Fig. 5). Beets (1986) mentioned that the distribution of the Recent species of this subgenus is confined to southern Australian waters as relicts. The fossil of *Zoila* from Japan indicates that this subgenus was distributed in the adjacent seas of Japan during the latest Miocene.

(4) *Tutufa* (*Tutufa*) cf. *bufo* (Röding) from the Nishikoiso Formation in Ooiso of the Shonan Coast.—*T.* (*T.*) *bufo* lives in south of the Boso Peninsula to the tropical Indo-Pacific Ocean.

(5) *Haustellum* cf. *haustellum* (Linnaeus) from the Furuya Formation.—*H. haustellum* is now distributed from the Kii Peninsula to the tropical Indo-Pacific Ocean.

(6) *Pleuroploca* cf. *trapezium* (Linnaeus) from the

Ochiai Formation.—*P. trapezium* is now distributed from the Kii Peninsula to the tropical Indo-Pacific Ocean.

(7) *Perna viridis* (Linnaeus) from the Osozawa Member of the Akebono Formation.—The shell size is as large as Recent adult specimens. The species is now distributed in south of the Philippines, and is a tropical element of the Indo-Pacific Ocean.

(8) *Amussiopecten*.—They were commonly ob tained from each formation in the South Fossa-Magna region, and were especially abundant in the Akebono Formation (*A. iitomiensis*) and the Senhata Formation (*A. akiyamae*). Masuda (1971) proposed that *Amussiopecten* appeared in Europe and the Mediterranean region during Oligocene and Miocene, and then imigrated into the Indian Ocean during Miocene, and into southern East Asia (Formosa and Japan) in the late Pliocene. This genus is a tropical-subtropical element, which expanded widely in the early to middle Miocene.

(9) *Amusium pleuronectes* (Linnaeus) from the Osozawa Member of the Akebono Formation.—This species lives in south of the Okinawa Island, and is a tropical element of the Indo-Pacific Ocean.

(10) *Fragum loochoanum* Kira from the Osozawa Member of the Akebono Formation.—This species is now distributed from the Okinawa Island to Formosa.

(11) *Meiocardia tetragona* (Adams and Reeve) from the Osozawa Member of the Akebono Formation.—This species is now distributed from the Boso Peninsula to the tropical Western Pacific Ocean.

(12) *Dysmea occidens* (Gmelin) from the Senhata Formation.—This species is now distributed from the Okinawa Island to the tropical Western Pacific Ocean.

(13) *Pitar* (*Pitarina*) *dohrni* (Römer) from the Senhata Formation.—This species lives in the tropical Indo-Pacific Ocean.

The late Miocene to the early Pliocene fauna in the South Fossa-Magna region is also characterized by common occurrences of planktonic mollusca indicating tropical to subtropical marine climate.

(14) *Hartungia typica* Bronn frequently from the Osozawa Member of the Akebono Formation.—*Hartungia* sp. obtained from the Tamari Formation (Tomida and Itoigawa, 1982, 1984), is also identified

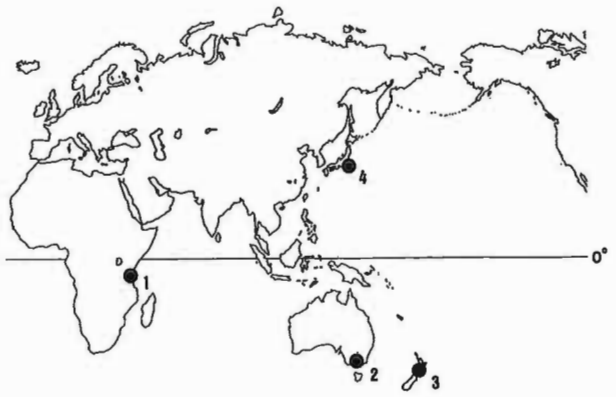


Fig. 6. Map showing the localities of *Aturia coxi* Miller. 1. Pemba, Zanzibar (Miocene), 2. Beumaris, Melbourne (uppermost Miocene) 3. Mohakatino, North Taranaki (middle Miocene), 4. Okumotona, south of Nokogiriyama, Boso Peninsula (uppermost Miocene).

with this species in this study. This species is an extinct species reported mainly from the lower to middle Pliocene in eastern Atlantic, the lower Pliocene in Australia, and the lower Pliocene in New Zealand (Ludbrook, 1978; Beu and Maxwell, 1990). *Hartungia* is a planktonic gastropod referred to the family Janthinidae which lives in sea-surface floating by "a bubble raft". *Hartungia* were obtained from various sedimentary facies in well preservation. These were drifted with a warm ocean current, the Proto-Kuroshio, like Recent janthinid gastropods. It is noteworthy that the planktonic *H. typica* occurs from the lower Pliocene in Japan as well as known from the lower Pliocene in Australia and New Zealand.

(15) A nautilid species (*Aturia coxi* Miller, 1947), two argonautid species (*Argonauta itoigawai* Tomida and *Argonauta* (s.l.) *awaensis* Tomida) from the Senhata Formation, as well as a janthinid species (Hartungia sp.) (Tomida, 1983, 1989a; Tomida and Itoigawa, 1986).—These planktonic gastropods were distributed in tropical to subtropical seas. These fossil occurrences show that the seas around the Boso Peninsula were under tropical to subtropical marine-climates in the latest Miocene of the accumu lating of the Senhata Formation. In particular, a well-preserved juvenile specimen of *Aturia coxi* was accompanied by many adult specimens of *A. coxi* in the Senhata Formation (Tomida, 1992). This suggests that *A. coxi* may have lived in the adjacent sea of the Boso

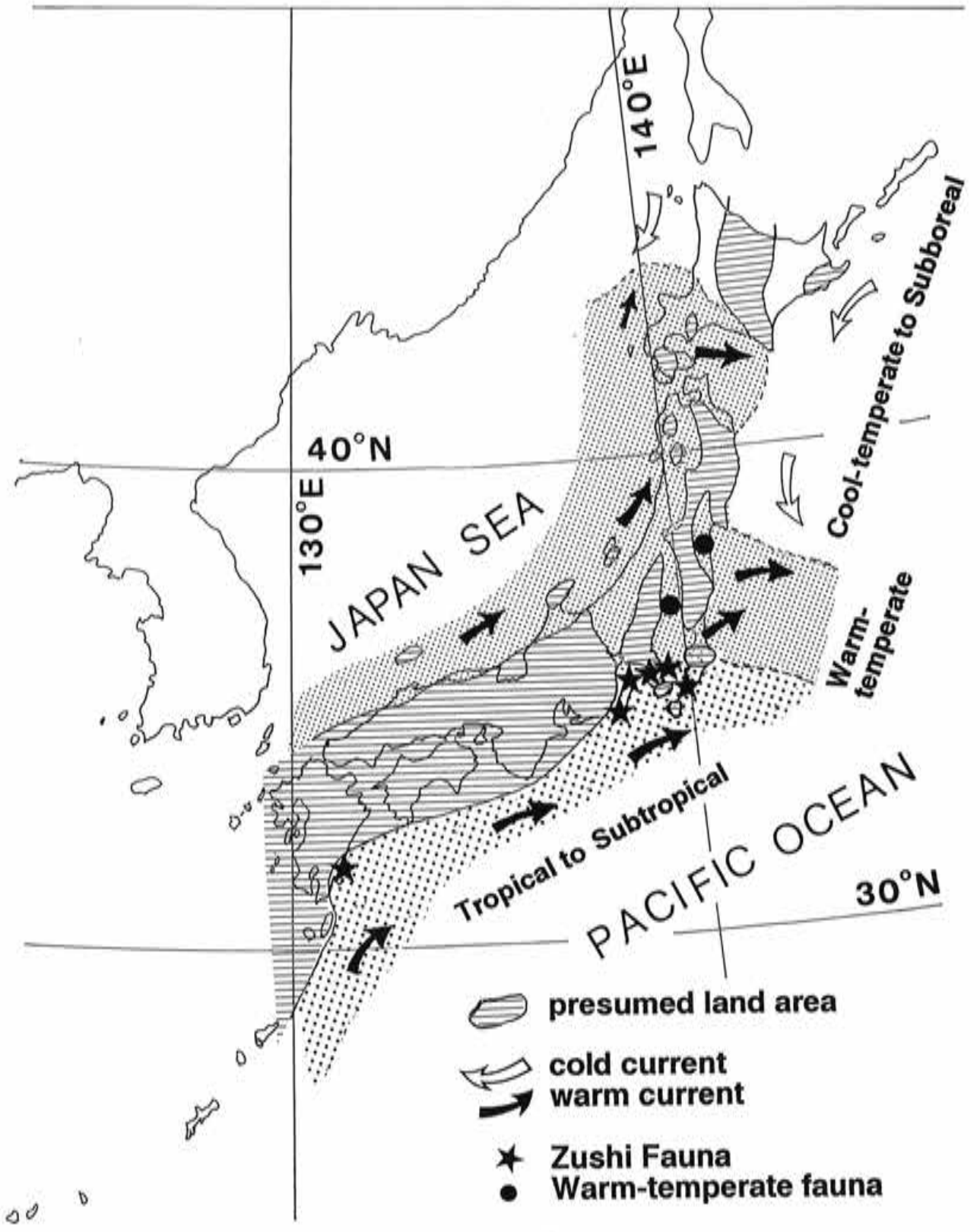


Fig. 7. Distribution of the late Miocene warm-water molluscan faunas, and presumed paleogeography and water current system in N17 (cited from Ozawa and Tomida, 1992).

Peninsula, during the latest Miocene. *A. coxi* has been reported from the Miocene Pemba Formation in Tanzania (Cox, 1927), the uppermost Miocene Cheltenhamian Stage Black Rock Sandstone in Australia, and the middle Miocene Clifdenian basal Mohakatino Formation in New Zealand (Beu, 1973), as shown in Fig. 6. The Senhata Formation is correlated with the Cheltenhamian Stage of Australia.

As mentioned above, the marine climate in the South Fossa-Magna region was tropical-subtropical condition. On the other hand, the northeast Honshu was under the temperate condition because of the lacks of tropical-subtropical species. The middle part of the Kanomatazawa Formation of the Shioya Group (Akutsu, 1964), and the Fukuda Formation (Masuda and Takegawa, 1965) in northeast Japan yields warm-water molluscs such as *Suchium miyagiense* Nomura and Oishi, *Siphonalia* sp., *Glycymeris* cf. *cisshuensis Makiyama*, and so on. *Suchium miyagiense* is related to *Suchium suchiense* (Yokoyama). This assemblage is considered to be a forerunner of the Kakegawa Fauna, and is important to consider the origin of the Kakegawa Fauna (Ozawa, 1983). The age of the Kanomatazawa Formation corresponds to the Climatic Optimum 3 (=Blow's zone N16-17) because Saito (1963) reported the planktonic foraminiferal assemblage of the *Globorotalia menardii* / *Globigerina nepenthes* Zone. During the late Miocene to the earliest Pliocene, south of the north Kanto and Sendai, was under the temperate marine climate, where warm and cold currents met (Fig. 7).

Next, I discuss the significance of the fauna reported in this study from the viewpoint of the temporal change of the marine fauna in Japan.

The Zushi Fauna contains few common species to the early middle Miocene tropical and subtropical Kadonosawa Fauna (Chinzei, 1983; Itoigawa, 1988) during the Climatic Optimum 1 of Barron and Baldauf (1990), as shown in Appendix 3.

The several Miocene molluscs survived from the early and middle Miocene, such as *Phalium* (*Mauicassis*) *yokoyamai* Nomura and Hatai, *Glycymeris* cf. *cisshuensis*, *Amussiopecten akiyamae*, *Miyagipecten matsumoriensis*, and *Aturia coxi*, became extinct at the end of the Miocene (Table 2 and Appendix 3). Beu (1973) pointed out that the terminal Miocene bioevent in the Pacific is well documented by the extinction of *Aturia*.

Many common species between the Zushi Fauna and the late Pliocene Kakegawa Fauna, are as follows: *Ginebis argenteonitens*, *Bufonariella ranelloides*, *Semicassis bisulcata*, *Siphonalia* cf. *declivis*, *Hindsia magnifica*, *Makiyamaia subdeclivis*, *Acila divaricata*, *Cucullaea labiata granulosa*, *Tosarca tosaensis*, *Scapharca suzukii*, *Glycymeris rotunda*, *Glycymeris albolineata*, *Crenulilimopsis oblonga*, *Cryptopecten vesiculosus*, *Nipponocrassatella* cf. *takanabensis*, *Megacardita panda*, *Lucinoma annulatum*, *Callista chinensis*, *Mercenaria yokoyamai*, *Clementia papyracea*, *Venus foveolata*, and so on. On the other hand, as shown in Appendix 1, the upper Miocene to the lowermost Pliocene formations in the South Fossa-Magna region, contain *Suchium koyuense*, *Ethalia maxima*, *Canarium* sp., *Amussiopecten iitomiensis*, *Amusium pleuronectes*, *Chlamys miurensis*, *Mimachlamys* cf. *nobilis*, *Indocrassatella tenuilirata*, *Paphia exilis exilis*, *Paphia exilis takaokaensis*, *Pitarina dohrni*, *Pitarina semeliformis*, and so on., which commonly occur from the upper Miocene Lower Miyazaki Group (Shuto, 1955, 1956, 1960, 1961) but are absent in the late Pliocene Kakegawa Fauna. This fact suggests that the Zushi Fauna is correlated with the molluscan fauna in the Lower Miyazaki Group.

There are differences in the composition of the molluscan assemblages between the Zushi Fauna and the Kakegawa Fauna. For example, the *Glycymeris albolineata* - *Amussiopecten iitomiensis* -*Megacardita panda* assemblage of the Zushi Fauna corresponds to the *Glycymeris albolineata* - *Amussiopecten praesignis* - *Megacardita panda* assemblage of the late Pliocene Kakegawa Fauna. *Amussiopecten iitomiensis* in the Zushi Fauna is replaced by *A. praesignis* in the Kakegawa Fauna. *Amussiopecten iitomiensis* and *Megacardita panda* do not co-occur in the Lower Miyazaki Group. On the other hand, they co-occur in the lowermost Pliocene formations in the South Fossa-Magna region. In the Miyazaki district, *Megacardita panda* occurs accompanied by *Amussiopecten praesignis* in the upper Pliocene Takanabe Formation, of the Upper Miyazaki Group, and this co

-occurrence also is present in the late Pliocene Kakegawa Fauna.

Tomida (1989b) mentioned that *Siphonalia* obtained from the Ochiai Formation, resembles the type specimen of *S. declivis* (Yokoyama, 1926, p. 337, pl. 38, fig. 20), and also resembles the Honohashi form of *S. declivis* or *S. declivis* var. *signum/declivis* from the Dainichi Formation of the Kakegawa Group, described by Makiyama (1941). *Siphonalia* cf. *declivis* also occurs from the lowermost Pliocene Osozawa Member.

The Zushi Fauna in the South Fossa-Magna region is mainly composed of tropical and subtropical elements. It contains some characteristic species which consist in both units of the Zushi Fauna, such as *Ethalia maxima, Suchium koyuense, Astraea tyosiensis, Bolma virgata, Kelletia brevis, Glycymeris osozawaensis, Chlamys miurensis, Indocrassatella tenuilirata, Paphia exilis,* and so on (Table 3).

The Zushi Fauna contains the elements of the Pliocene Kakegawa Fauna as already mentioned, and also many living species which survive from the early and middle Miocene, the upper Miocene (lower unit), and the lowermost Pliocene (upper unit), as shown in Table 2 and Appendixes 1 and 3.

The Shirahama Fauna contains some characteristic species of the late Pliocene Kakegawa Fauna, such as *Amussiopecten praesignis* and *Chlamys* (*Mimachlamys*) *satoi*, but lacks other characteristic species such as *Glycymeris albolineata* and *Megacardita panda*. The Shirahama Fauna is characterized by *Chlamys shirahamaensis, Comptopallium tayamai,* and *Decatopecten izuensis*, which are absent in the Kakegawa and the other Neogene faunas in Japan. The Shirahama Fauna was formed in the lower latitude during the Pliocene, when the Izu Terrene was located in the low latitude (Niitsuma, 1987; Hirooka, 1988).

Conclusion

1) The Zushi Fauna is a tropical to subtropical marine watermolluscan fauna of late Miocene to early Pliocene (8 Ma to 4.5 Ma) in the central and southwestern Japan. It was established and flourished under a strong influence of the paleo-Kuroshio warm current at the time of a remarkable warming of marine climate around 7 Ma (Climatic Optimum 3 of Barron and Baldauf, 1990). The Zushi Fauna in the South Fossa-Magna region is stratigraphically divided into two molluscan faunal units. The lower unit corresponds to the time of a remarkable warming of marine climate (Climatic Optimum 3 of Barron and Baldauf, 1990). During the late Miocene to the earliest Pliocene, the area in the south of the Boso Peninsula was under tropical to subtropical marine climates.

2) The Zushi Fauna, yields the following nine molluscan assemblages: *Turbo* cf. *marmoratus* - *Charonia sauliae* assemblage, *Suchium koyuense* - *Glycymeris osozawaensis* - *Glycydonta marica* assemblage, *Bolma virgata* - *Kelletia brevis* assemblage, *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage, *Glycymeris albolineata* - *Amussiopecten iitomiensis* - *Megacardita panda* assemblage, *Glycymeris rotunda* assemblage, "*Pleurotomaria*" assemblage, *Acesta goliath* assemblage, *Ginebis argenteonitens* - *Acila divaricata* - *Fissidentalium yokoyamai* assemblage.

The lower unit of the Zushi Fauna in the uppermost Miocene formations yields the *Amussiopecten akiyamae* - *Chlamys miurensis* - *Lima zushiensis* assemblage. On the other hand, the upper unit in the lowermost Pliocene formations yields the *Glycymeris albolineata* - *Amussiopecten iitomiensis* - *Megacardita panda* assemblage.

This fauna is composed of mixed assemblages composed of shallow-water and deep-water inhabitants. The occurrence of the mixed assemblage reflects that there was a narrow shelf and a steep slope in the sedimentary basin of the South Fossa-Magna region.

3) The Zushi Fauna contains many common species to the upper Pliocene Kakegawa Fauna. Moreover, some species are ancestral forms of the characteristic species of the Kakegawa Fauna, such as *Siphonalia* cf. *declivis, Amussiopecten iitomiensis, Nipponocrassatella* cf. *takanabensis*, and so on. Therefore, the Zushi Fauna is important in the consideration of the origin of the Kakegawa Fauna.

4) The early Pliocene Shirahama Fauna contains some characteristic species of the upper Pliocene Kakegawa Fauna such as *Amussiopecten praesignis*,

Chlamys (*Mimachlamys*) *satoi*, and *Cryptopecten vesiculosus*, but the Shirahama Fauna differs from the Kakegawa Fauna in lacking *Glycymeris albolineata* and *Megacardita panda*. Instead, the Shirahama Fauna contains *Chlamys shirahamaensis*, *Comptopallium tayamai*, *Decatopecten izuensis*, and *Lioconcha* (*Sulcilioconcha*) cf. *philippinarum*, which are absent from the other Pliocene faunas in Japan. The Shirahama Fauna lived in more southern region and was under warmer climate condition than the Kakegawa Fauna.

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Appendix 1. Molluscan fossils of the South Fossa-Magna region.

Species	Localities	(Mz)	Sg	Oz-1	Oz-2	Sr-1	Sr-2	Nz	Nk-1	Nk-2	Ot-1	Ot-2	Uh	Oc
	Blow zone N	1718	19	17-18		19								
	Calc. Nanno					12								10b
	Matrices	MSC	MSC	M, S, L, C		SLC	S, L	C	G-S		M, S, G		M, C	SLC
Entemnotrochus shikamai Kanie														
Perotrochus africanus cf. *teramachii* Kuroda					○									
Perotrochus yabei (Nomura & Niino)							○							
Perotrochus yosiwarai (Ozaki)														
Perotrochus aosimai Ozaki														
Pleurotomaria (s. l.) sp.		○						○					○	○
Haliotis grablosa Nomura & Niino						○	○							
Haliotis (*Nordotis*) *koikei* Shibata														○
Haliotis (*Nordotis*) n. sp.					○									
Cellana cf. *grata* (Gould)					○									
Lischkeia cf. *alwinae* (Lischke)		○		◎	◎				○					
Ginebis crumpii (Pilsbry)					◎								◎	
Ginebis argenteonitens (Lischke)		○		◎	◎								◎	
Calliostoma cf. *formosense* E. A. Smith		(○)			◎									○
Chlorostoma narusei (Shibata)					○									
Microgaza hayamaensis (Shikama)					○									○
Ethalia maxima (Shuto)		○			○									◎
Suchium koyuense Shuto		○							○					
Tectus (*Rochia*) cf. *niloticus* (Linnaeus)					○									
Astraea omorii Shibata					○									◎
Astraea tyosiensis Ozaki				○	○									
Astraea (*Astralium*) cf. *calcar* (Linnaeus)					○									
Bolma (*Bolma*) *virgata* (Ozaki)				○	○				○					○
Bolma (*Bolma*) cf. *girgylla* (Reeve)		○												○
Bolma (*Oobolma*) *takitai* (Ozaki)														
Bolma (*Pseudoastralium*) cf. *henica* (Watson)														○
Turbo (*Lunatica*) cf. *marmoratus* Linnaeus					◎									○
Turbo (*Batillus*) n. sp.		○			◎								○	
Turbo (*Marmarostoma*) cf. *stenogyrus* Fischer														○
Serpulorbis cf. *dentiferus* (Sowerby)														
Serpulorbis sp.				○	○									○
Sabia (*Pilosabia*) *trigona* (Gmelin)					○									
Calyptraea aramakii Shikama				○	○									
Xenophora tenuis Fulton														
Xenophora chinensis (Philippi)		○			◎									
Strombus (*Canarium*) sp.														○
Robertotrivia cf. *eos* (Roberts)								○						
Robertotrivia sagamiensis (Kuroda & Habe)					◎									
Cypraea (*Zoila*) *itoigawai* Tomida														
Hiraseadusta hirasei (Roberts)					○									

Os	Zs-1	Zs-2	Zs-3	Hs-1	Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	(Na)	Geographical Distribution (°N) (Pacific)	Bathymetric range	Bottom sediments	Remarks
17	9b-10				17						17				
M, C	S, L, C		MSLG	MSG	S, L, C			S, C	S		S, C				
	○						○	○						G, R	
								◎	◎			23～35	N_3-B	S, M	
											○				
		○	○					○	○		○				
													N_3-B	M-R	
														R	
														R	
														R	
												25～41	N_0	G, R	
												30～35	N_4-B	M, S	Kakegawa Fauna
											○	30～41	N_3-B	M, S	
			○	○								25～36	N_3-B	M, S	Kakegawa Fauna
												23～25	N_4-B	S	Tropical sp.
		○						○	○	○					
◎			◎												
	○											-20～28	N_0-N_1	R	Tropical sp.
											◎				
	○			○			○	○				0～27	N_0-N_1	R	Tropical sp.
							○				◎				
									○			0～35	N_3-N_4	R	
			○								○				
									○			0～35	N_4-B	M, S	
			○									-20～28	N_1	G, R	Tropical sp.
			○								○				
												28～33	N_0	G, R	
												26～34	N_1-N_3	R	
														R	
												0～35 J38	N_0-N_1	R	
		○													
									○			0～33	N_3-B	M, S, G	
												-25～34	N_2-N_4	M, S	
															Tropical sp.
												32～35	N_2-B	R	
												32～35 J36	N_2-B	S	
								○	○						W. Australia
												-20～33	N_3-N_4	S	

Species	Localities	(Mz)	Sg	Oz-1	Oz-2	Sr-1	Sr-2	Nz	Nk-1	Nk-2	Ot-1	Ot-2	Uh	Oc
	Blow zone N	1718	19	17-18		19								
	Calc. Nanno					12								10b
	Matrices	MSC	MSC	M, S, L, C		SLC	S, L	C	G-S		M, S, G		M, C	SLC
Mauritia (Arabica) cf. *histrio* (Gmelin)														
Nesiocypraea cf. *midwayensis* Azuma & Kurohara														
Erosaria aff. *boivinii* (Kiener)				○	○									
Sinum cf. *javanicum* (Griffith & Pidgeon)														
Uberella cf. *yokoyamai* (Kuroda & Habe)		(○)										○		
Polinices cf. *tumidus* (Swainson)														
Glossaulax sp.		(○)		○	○									
Neverita sp.		○	(○)			○	○		○			○		
Semicassis bisulcata japonica (Reeve)		○												
Semicassis bisulcata pila (Reeve)					○									
Phalium (Mauicassis) yokoyamai Nomura & Hatai		○	(○)											
Morum (Oniscidia) macandrewi (Sowerby)														
Tonna cf. *luteostoma* (Kuster)		○			○									
Ficus filosa (Sowerby)		○												
Fusitriton oregonensis galea Kuroda & Habe												○		○
Charonia sauliae (Reeve)														
Tutufa (Tutufa) cf. *bufo* (Roding)														
Dulcerana cf. *granularis* (Roding)														○
Bursa (Bufonariella) ranelloides (Reeve)														
Haustellum cf. *haustellum* (Linnaeus)									○					
Ceratostoma fournieri (Crosse)														○
Neptunea kuroshio Oyama					◎				○					◎
Buccinum sp.														
Japelion adelphicus (Dall)														
Siphonalia cf. *declivis* Yokoyama		○	○	○	○				○					○
Siphonalia sp.					○									
Kelletia brevis Ozaki					○									◎
Penion sp.														
Hindsia cf. *magnifica* (Lischke)		○			○							○		
Phos varicosus Gould														○
Microfusus asperus (Kuroda)														
Granulifusus cf. *kiranus* Shuto					○									
Pleuroploca cf. *trapezium* (Linnaeus)														○
Hemifusus tuba (Gmelin)		○										○		
Oliva oliva (Linnaeus)		○												
Olivella fulgurata (Adams & Reeve)		○	(○)											
Baryspira okawai (Yokoyama)					○							○		
Lyria cf. *planicostata* (Sowerby)														
Lyria hirugayensis (Yokoyama)			○		○									
Fulgoraria (Nipponomelon) magna Kuroda & Habe														

Os	Zs-1	Zs-2	Zs-3	Hs-1	Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	(Na)	Geographical Distribution (°N) (Pacific)	Bathymetric range	Bottom sediments	Remarks
17	9b-10				17						17				
M, C	S, L, C		MSLG	MSG	S, L, C			S, C	S		S, C				
				○				○				-30～26	N_0-N_1	G, R	Tropical sp.
				○					○			0～26	N_3-B	S, G, R	Tropical sp.
							○	○				20～35	N_0-N_1	R	
							○		○			0～35	N_1-N_2	S	
												33～35	N_3-N_4	S	
								○	○			0～35	N_1	S	
			○						○						
														M, S	
		○										-20～35	N_2-N_4	S	Kakegawa Fauna
									○			-20～35	N_1-N_3	S	
									○						
							○					0～35	N_1-N_4	S, Sh, G	
									○			-30～42	N_1-N_4	M, S	Kakegawa Fauna
									○			-30～33	N_3-N_4	M, S	
												33～35	N_3-N_4	M, S	
			○				○		○			14～36	N_0-N_1	G, R	
○												-20～35	N_0-N_2	G, R	
												-30～35	N_0-N_4	G, R	
									○			0～35	N_2-N_4	S, G, R	Kakegawa Fauna
												-20～34	N_1-N_2	G, R	
												31～35 J38	N_0-N_1	R	
○												31～35	N_4-B	M, S	
			○	○			○	○	○					M, S	
	○		○				○		○			31～35	N_2-N_4	S	
				○			○		◎						Kakegawa Fauna
○	○		○								◎				
								○							Australian gen
									○			31～35	N_2-N_4	S	Kakegawa Fauna
												10～35	N_2-N_4	S	
									○			33～35	N_2-N_4	S	
												25～35	N_2-B	S	
												-20～34	N_0-N_1	R	Tropical sp.
							○	◎	○			0～35	N_1-N_3	M, S	
							◎					-20～34	N_0-N_1	S	Tropical sp.
				○			○					25～35	N_0-N_1	S	Kakegawa Fauna
														S	Kakegawa Fauna
							○		○			10～25	N_1-N_3	S	Tropical sp.
									○			35～42	N_3-B	M	

Species	Localities	(Mz)	Sg	Oz-1	Oz-2	Sr-1	Sr-2	Nz	Nk-1	Nk-2	Ot-1	Ot-2	Uh	Oc
	Blow zone N	1718	19	17-18		19								
	Calc. Nanno					12								10b
	Matrices	MSC	MSC	M, S, L, C		SLC	S, L	C	G-S		M, S, G		M, C	SLC
Fulgoraria (Musashia) sp.		○												○
Fulgoraria (Saotomea) delicata Fulton														
Benthovoluta sp.					○									
Endemoconus oyamai Tomida														
Endemoconus cf. *ichinoseana* (Kuroda)														
Lithoconus cf. *litteratus* (Linnaeus)														
Chelyconus cf. *fulmen* (Reeve)														
Parviconus tuberculatus (Tomlin)														
Conus comatosaeformis Yokoyama		○		○	○									
Thatcheria cf. *mirabilis* Angas		○	○		○									
Riuguhdrillia engonia (Watson)														
Tholitoma nishimotoi Tomida														
Parabathytoma cf. *luedorfi* (Lischke)		○			○									
Makiyamaia subdeclivis (Yokoyama)			○		○									
Elegantiscala sp.														○
Architectonica maxima (Philippi)		○			○									
Hartungia typica Bronn			(○)		◎									
Hartungia n. sp.		○												
Acteon sp.													○	
Acila divaricata Hinds		○	○		○								○	○
Neilonella coix Habe													○	
Carinineilo sp.			○											
Portlandia lischkei (Smith)													◎	
Megayoldia tsuruensis Sugita													○	
Yoldia sp.			○											
Acar congenita Smith														
Arca boucardi Jousseaume					○									
Cucullaea labiata granulosa Jonas		○			○				◎	○				
Anadara (Tosarca) tosaensis Noda					○									
Anadara (Scapharca) suzukii (Yokoyama)				○	○									
Anadara (Scapharca) cf. *shizuokaensis* Noda									○					
Glycymeris rotunda (Dunker)		○	○	◎	◎				○				◎	○
Glycymeris osozawaensis Kanno				◎	◎				○	○				○
Glycymeris cf. *cisshuensis* Makiyama														
Glycymeris albolineata (Lischke)			○		◎				○	○				○
Crenulilimopsis oblonga (A. Adams)			○		○									
Cyrenolimopsis adamsiana (Yokoyama)			○											
Limopsis tokaiensis Yokoyama			○						○					○
Mytilus cf. *coruscus* Gould					○									

Os	Zs-1	Zs-2	Zs-3	Hs-1	Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	(Na)	Geographical Distribution (°N) (Pacific)	Bathymetric range	Bottom sediments	Remarks
17	9b-10				17						17				
M, C	S, L, C		MSLG	MSG	S, L, C			S, C	S		S, C				
								◎	◎			32～35	N_3-B	M, S	
								◎	◎						
							○		○			10～33	N_3-N_4	M, S	Tropical sp.
				○			○		○			-20～33	N_0-N_1	M, S	Tropical sp.
				○								25～35	N_0-N_1	M, S, G	
○				○			○		○		○	33～35	N_2-N_4	S	Kakegawa Fauna
												10～35	N_3-B	M, S	
									◎			-40, 33～35	N_4-B	M, S	
							○		◎						NZ Paleoc. gen.
									○			32～42	N_2-N_4	M, S	Kakegawa Fauna
												25～35	N_3-B	S	Kakegawa Fauna
						○								S-Ane.	
												0～35	N_1-N_2	S-Ane.	Kakegawa Fauna
														Pk	S. Australia
									○					Pk	New Zealand
												32～33	N_1-B	M, S	Kakegawa Fauna
												31～35	N_2-B	S	
													N_3-B	M, S	
												33～34.5	N_3-B	M, S	
							○					10～35	N_2-B	G, R	
												31～42	N_0-N_2	G, R	
												0～35	N_1-N_2	M, S	Kakegawa Fauna
															Kakegawa Fauna
															Kakegawa Fauna
○	○	○	○	○	○	○	◎	◎	○			25～42	N_2-B	M, S	Kakegawa Fauna
			◎		○										
○			○						○			31～35	N_1-N_2	M, S	Kakegawa Fauna
				○								31～41	N_2-B	M, S	Kakegawa Fauna
	○	○	○									31～42	N_0-N_1	R	Kakegawa Fauna

Species	Localities	(Mz)	Sg	Oz-1	Oz-2	Sr-1	Sr-2	Nz	Nk-1	Nk-2	Ot-1	Ot-2	Uh	Oc
	Blow zone N	1718	19	17-18		19								
	Calc. Nanno					12								10b
	Matrices	MSC	MSC	M, S, L, C		SLC	S, L	C	G-S		M, S, G		M, C	SLC
Perna viridis (Linnaeus)					○									
Pteria cf. *loveni* (Dunker)		○												
Pinctada fucata (Gould)					○									
Patinopecten planicostulatus (Nomura & Niino)						○								
Amussiopecten akiyamae Masuda														
Amussiopecten iitomiensis (Otuka)		○	○	○	◎				○					○
Amussiopecten praesignis (Yokoyama)		(○)				○	○	○						
Amusium pleuronectes (Linnaeus)		○			○									
Miyagipecten matsumoriensis Masuda														
Chlamys (*Mimachlamys*) cf. *nobilis* (Reeve)		○			◎				○	○				
Chlamys (*Mimachlamys*) *satoi* Yokoyama		(○)				○	○	○						
Chlamys miurensis (Yokoyama)		○	○	○	○				○	○				○
Chlamys inouei Tomida														
Chlamys rendoi Ozaki														
Chlamys shirahamaensis (Nomura & Niino)						○	○	○						
Cryptopecten vesiculosus (Dunker)		○		○	○		◎	◎						
Delectopecten peckhami Gabb			○										○	
Polynemamussium sp.			○											
Comptopallium tayamai (Nomura & Niino)						○	○	○						
Decatopecten izuensis (Nomura & Niino)						○	◎	○						
Spondylus anacanthus Mawe			○		○	○	○	○						
Spondylus barbatus cruentus Lischke						○								
Neopycnodonte musashiana (Yokoyama)						○	○							
Pretostrea imbricata (Lamarck)														
Dendostrea folium (Linnaeus)						○	○							
Dendostrea crenulifera (Sowerby)							○							
Ostrea circumpicta Pilsbry				○	○	○	○		○				○	○
Crassostrea gigas (Thunberg)									○	○	◎	◎		
Lima zushiensis Yokoyama						○	○	○						
Lima quantoensis Yokoyama													○	
Lima aff. *konnoi* Otuka				○	○									○
Acesta goliath (Sowerby)		○			○									○
Indocrassatella oblongata (Yokoyama)		○											○	
Indocrassatella tenuilirata (Shuto)		○		○	○									
Nipponocrassatella cf. *takanabensis* (Shuto)		(○)			○									
Nipponocrassatella n. sp.					○									
Megacardita panda (Yokoyama)		○	○		◎				◎	○				◎
Megacardita ferruginosa (Adams & Reeve)					○									
Cyclocardia cf. *ferruginea* (Cressin)				○										
Glans hirasei Dall								○						○

Os	Zs-1	Zs-2	Zs-3	Hs-1	Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	(Na)	Geographical Distribution (°N) (Pacific)	Bathymetric range	Bottom sediments	Remarks
17	9b-10				17						17				
M, C	S, L, C		MSLG	MSG	S, L, C			S, C	S		S, C				
								○	○			0～10	N_0-N_1	R	Tropical sp.
								○	○			10～35	N_0-N_2	Yg	
												0～35 J40	N_0-N_1	R	
	○			○	◎	○	◎	◎	○	○					
○															Kakegawa Fauna
				○		○	○	◎	◎						Tropical sp.
												0～35	N_0-N_1	G	
															Kakegawa Fauna
○	◎	○	○	◎	◎	○	◎	○	○		○				
						○	○	○	◎						
				○			○				○				
												30～35	N_3-B	S, G	Kakegawa Fauna
								(○)							
												-10～41	N_3-B	M, S	
															Tropical sp.
															Tropical sp.
				◎			○	◎	◎			0～35	N_2-B	G, R	
											○	26～40 J38	N_0-N_1	R	
						◎				○		25～41 J42	N_1-B	G, R	Kakegawa Fauna
					○	○		○	○			0～35	N_1-N_2	G, R	
												0～34	N_1-N_2	R-Yg	Kakegawa Fauna
												0～35	N_1-N_2	Sh, R	
○	○		○	○	◎	○	◎	○	○			31～41	N_0-N_1	R	Kakegawa Fauna
												20～50	N_0	G, R	
	○	○		○	○	○	○	○	◎		○	30～35	N_2-N_4	S, G, R	
			○									34～35	N_3-B	S, G	
			○				○	◎	◎	○	○	34? 10～42	N_4-B	M, S, G	
			○					○			○	30～35	N_3-B	S, Sh	Kakegawa Fauna
				◎				◎	◎						Kakegawa Fauna
															Kakegawa Fauna
◎							○	○				10～35	N_1-N_2	S, G	
												30～41	N_2-B	S, G	
											○	0～33	N_3-N_4	S, G	

Species	Localities	(Mz)	Sg	Oz-1	Oz-2	Sr-1	Sr-2	Nz	Nk-1	Nk-2	Ot-1	Ot-2	Uh	Oc
	Blow zone N	1718	19	17-18		19								
	Calc. Nanno					12								10b
	Matrices	MSC	MSC	M, S, L, C		SLC	S,.L	C	G-S		M, S, G		M, C	SLC
Meiocardia tetragona (Adams & Reeve)				○										
Cycladicama cumingii (Hanley)												○		
Leptaxinus oyamai Habe												○		
Conchocele bisecta Conrad		○			○									
Lucinoma annulatum (Reeve)		○		○	○	○	○							
Chama fragum Reeve				○	○									
Keenaea samarangae (Makiyama)		○		○	◎									○
Fragum loochoanum Kira					○									
Clinocardium hataii Hayasaka					○									
Clinocardium buellowi (Rolle)												○		
Coelomactra antiquata (Spengler)					○									○
Mactra sp.					○									
Oxyperas bernardi (Pilsbry)					○									
Lutraria maxima Jonas					○				○	○				
Dysmea occidens (Gmelin)														
Tellina (*Tellinella*) cf. *staurella* Lamarck														
Macoma calcarea (Gmelin)				○	○									○
Solecurtus divaricatus Hinds					○									
Solen cf. *strictus* Gould														
Solen gordonis Yokoyama									○					
Calyptogena sp.			(○)		○									
Venus (*Ventricolaria*) cf. *toreuma* Gould				○	○				○	○				○
Venus (*Ventricoloidea*) *foveolata* (Sowerby)		○	○	○	○									
Pitar (*Pitarina*) sp.														
Pitar (*Pitarina*) *dohrni* (Romer)		○												
Pitar (*Pitarina*) *semeliformis* Shuto		○			○									
Sulcilioconcha cf. *philippinarum* (Hanley)						○	○	◎						
Callista chinensis (Holten)		○	○	○	○									
Mercenaria yokoyamai (Makiyama)		○	○		○				○					○
Clementia papyracea (Gray)		○							○	○		○		
Glycydonta marica (Linnaeus)		○												
Dosinia (*Bonartemis*) cf. *histrio* (Gmelin)		○		○	○									○
Dosinia (*Phacosoma*) sp.														
Paphia exilis exilis Shuto		○						○	○					
Paphia exilis takaokaensis Shuto		○			○				○					
Pholadomya pacifica Dall					○									
Periploma plane Ozaki													◎	
Cyathodonta granulosa (Adams & Reeve)														
Thracia sp.					○									
Cuspidaria nobilis (A. Adams)		○		○	○									

Os	Zs-1	Zs-2	Zs-3	Hs-1	Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	(Na)	Geographical Distribution (°N) (Pacific)	Bathymetric range	Bottom sediments	Remarks
17	9b-10				17						17				
M, C	S, L, C		MSLG	MSG	S, L, C			S, C	S		S, C				
											○	0～35	N_2-N_4	S	
												10～40	N_1-N_3	M, S	
												31～35 J38	N_1-N_3	M, S	
												33～60	N_0-B	M	
			◎								○	31～41	N_1-B	M, S	
											○	-20～35	N_0-N_1	R	
			○				○	◎	○			30～35, 41?	N_2-B	M, S	Kakegawa Fauna
				○								26～28	N_0-N_1	S	Tropical sp.
												31～41	N_1-N_3	S	
			○									25～35 J41	N_1-N_2	S	
	○		○	○			○	○				25～35 J41	N_1-N_3	M, S	
									◎			10～35	N_0-N_1	S	
								◎				-20～26	N_1-N_2	S	
									◎			10～34	N_0-N_2	M, S	
												33～60	N_1-B	M, S	
				○			◎					23～35	N_0-N_1	M, S	Kakegawa Fauna
												31～42	N_0	M, S	
			○									31～35	N_0-N_1	M, S	
												0～35	N_0-N_4	S, G	
		○		○				◎	○			30～35	N_2-N_4	M, S	Kakegawa Fauna
			○	○											
								○				0～10	N_1-N_2	M, S	Tropical sp.
												0～28	N_0-N_1	S	Tropical sp.
							○	○				10～40	N_0-N_3	S	Kakegawa Fauna
◎			○												Kakegawa Fauna
												25～41	N_0-B	M, S	Kakegawa Fauna
			◎				○					0～35	N_0-N_1	S	Kakegawa Fauna
		○					○	○				-10～35	N_1	M, S	
				○			○	○							
							○	◎							
												31～42	N_2-N_4	M, S	
												30～35	N_3-B	M, S	
							○					31～35 J38	N_1-N_3	M, S	
				○											
												31～35	N_3-B	M, S	

Species	Localities	(Mz)	Sg	Oz-1	Oz-2	Sr-1	Sr-2	Nz	Nk-1	Nk-2	Ot-1	Ot-2	Uh	Oc
	Blow zone N	1718	19	17-18		19								
	Calc. Nanno					12								10b
	Matrices	MSC	MSC	M, S, L, C		SLC	S, L	C	G-S		M, S, G		M, C	SLC
Halicardia nipponensis Okutani														O
Fissidentalium yokoyamai (Makiyama)		O	O	O	◎	O	O						◎	
Fissidentalium vernedei (Sowerby)		O							O	O			O	O
Fissidentalium hungerfordi (Pilsbry & Sharp)			O											
Dentalium hexagonum Gould									O					
Antalis cf. *weinkauffi* (Dunker)									O					
Aturia coxi Miller														
Argonauta itoigawai Tomida														
Argonauta (s. l.) *awaensis* Tomida														

Areas of molluscan fossil loalities:
Mz···Miyazaki, Sg···Sagara, Oz···Osozawa, Sr···Shirahama, Nz···Ninotozawa, Nk···Nishikatsura, Ot···Ootsuki, Uh···Uenoh
Sh···Nokogiriyama, Na···Na-arai (Mz): Lower Miyazaki Fauna for comparing, after Shuto (1961), (Na): for comparing, a
Planktonic foraminifera data are after Oda (1977, 1987), Ibaraki (1978), and Ibaraki and Tsuchi (1980).
Calcareous nannoplankton data are after Okada (1987) and Kanie *et al.* (1991).
Occurrence: ◎ (dominant), under lined (parautochthonous occurrence).
Matrices: M···Mudstone, S···Sandstone, L···Coquinoid limestone, C···Conglomerate.
Geographical distribution: north latitude in Pacific Coast, and "J" means Japan Sea.
Bathymetric range: N_0···Upper to Lower Tidal zone, N_1···Lower Tidal zone to 20-30m, N_2···20-30m to 50-60m, N_3···50-60m to 100
B···100-120m to 200-250m (after Oyama, 1952b).
Bottom character: M···Mud, S···Sand, Sh···Shelly sand, G···Gravel, R···Rock, Pk···Plankton, Nk···Nekroplankton, Sp.···on Spon
* Data of species comparable with living species are based on geographical and bathymetric data of the living species.
* Remarks indicate that the species occur also in other faunas and areas.

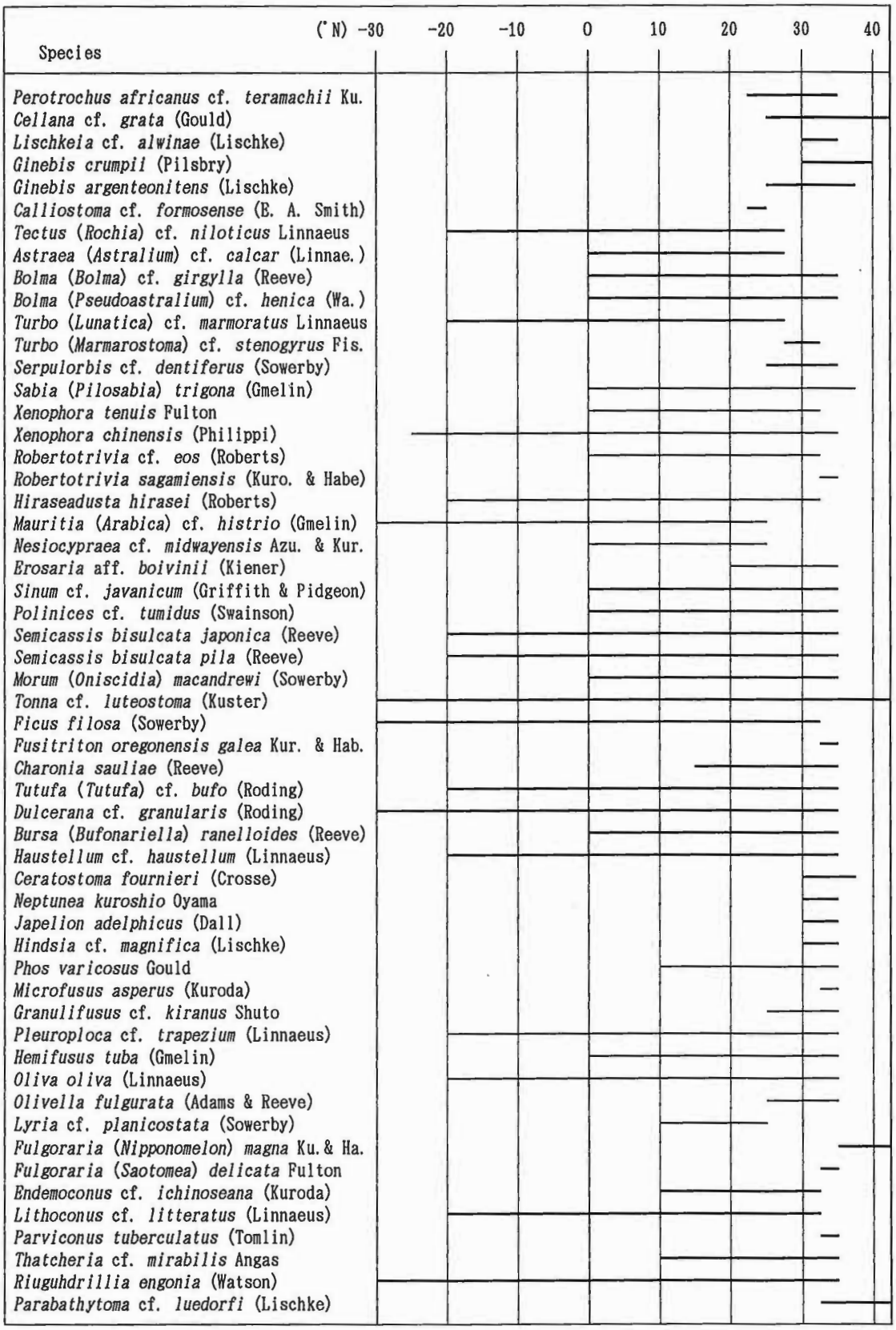
Os	Zs-1	Zs-2	Zs-3	Hs-1	Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	(Na)	Geographical Distribution (°N) (Pacific)	Bathymetric range	Bottom sediments	Remarks
17	9b-10				17						17				
M, C	S, L, C		MSLG	MSG	S, L, C			S, C	S		S, C				
												35～40	B	M, S	
○				○								33～34	N_3-N_4	M, S	Kakegawa fauna
			○								○	31～35	N_1-B	M, S	
												-10～35	N_3-B	S	
												0～42	N_0-N_3	M, S	
												30～41	N_2-B	M, S	
									○					Nk-Pk	Australian sp.
									○	○				Pk	
								○	◎					Pk?	

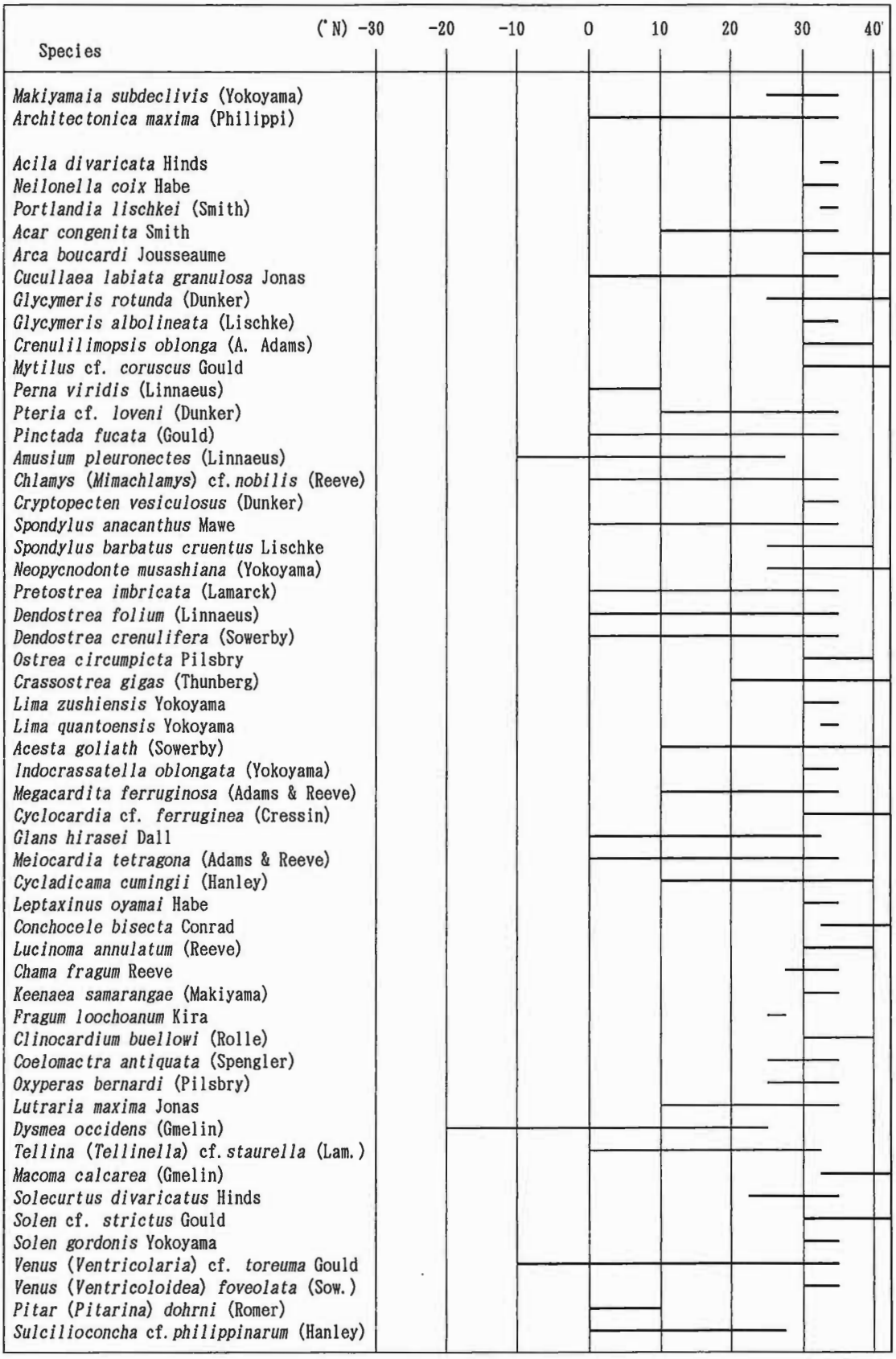
ohara, Os···Ooiso, Zs···Zushi, Hs···Hatsuse,
after Ozaki (1954, 1958), (○): occurred from different horizon}.

00-120m, N_4···100-120m to 200-250m,

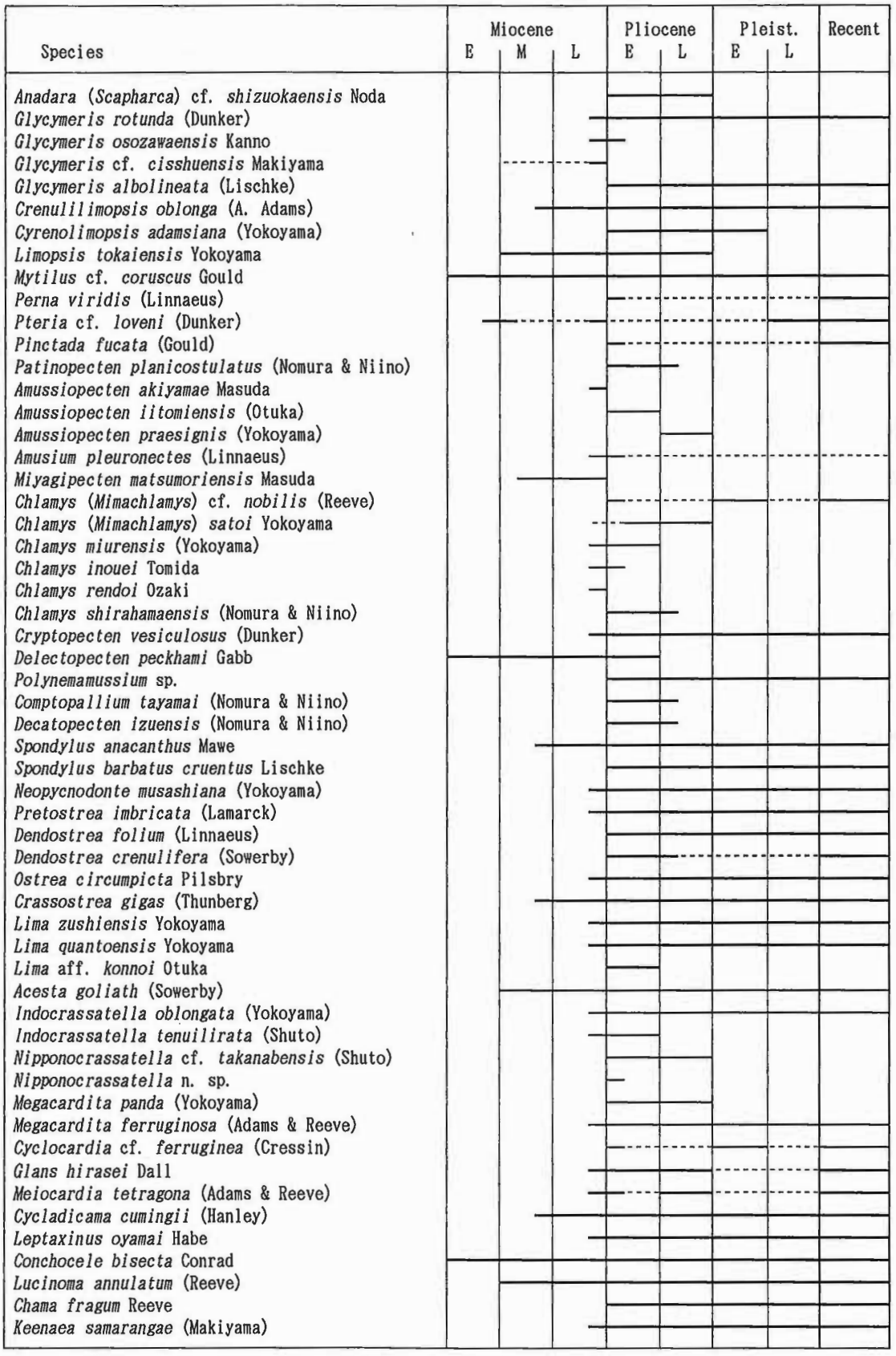
onge, Ane.···on Sea anemone, Yg···adhering to Gorgonaria

Table 4. Geographical distribution of the molluscan species of South Fossa-Magna region.




(°N) -30
-20
-10
0
10
20
30
40
Species
Makiyamaia subdeclivis (Yokoyama)
Architectonica maxima (Philippi)
Acila divaricata Hinds
Neilonella coix Habe
Portlandia lischkei (Smith)
Acar congenita Smith
Arca boucardi Jousseaume
Cucullaea labiata granulosa Jonas
Glycymeris rotunda (Dunker)
Glycymeris albolineata (Lischke)
Crenulilimopsis oblonga (A. Adams)
Mytilus cf. coruscus Gould
Perna viridis (Linnaeus)
Pteria cf. loveni (Dunker)
Pinctada fucata (Gould)
Amusium pleuronectes (Linnaeus)
Chlamys (Mimachlamys) cf. nobilis (Reeve)
Cryptopecten vesiculosus (Dunker)
Spondylus anacanthus Mawe
Spondylus barbatus cruentus Lischke
Neopycnodonte musashiana (Yokoyama)
Pretostrea imbricata (Lamarck)
Dendostrea folium (Linnaeus)
Dendostrea crenulifera (Sowerby)
Ostrea circumpicta Pilsbry
Crassostrea gigas (Thunberg)
Lima zushiensis Yokoyama
Lima quantoensis Yokoyama
Acesta goliath (Sowerby)
Indocrassatella oblongata (Yokoyama)
Megacardita ferruginosa (Adams & Reeve)
Cyclocardia cf. ferruginea (Cressin)
Glans hirasei Dall
Meiocardia tetragona (Adams & Reeve)
Cycladicama cumingii (Hanley)
Leptaxinus oyamai Habe
Conchocele bisecta Conrad
Lucinoma annulatum (Reeve)
Chama fragum Reeve
Keenaea samarangae (Makiyama)
Fragum loochoanum Kira
Clinocardium buellowi (Rolle)
Coelomactra antiquata (Spengler)
Oxyperas bernardi (Pilsbry)
Lutraria maxima Jonas
Dysmea occidens (Gmelin)
Tellina (Tellinella) cf. staurella (Lam.)
Macoma calcarea (Gmelin)
Solecurtus divaricatus Hinds
Solen cf. strictus Gould
Solen gordonis Yokoyama
Venus (Ventricolaria) cf. toreuma Gould
Venus (Ventricoloidea) foveolata (Sow.)
Pitar (Pitarina) dohrni (Romer)
Sulcilioconcha cf. philippinarum (Hanley)

Species	Miocene E	Miocene M	Miocene L	Pliocene E	Pliocene L	Pleist. E	Pleist. L	Recent
Charonia sauliae (Reeve)								
Tutufa (*Tutufa*) cf. *bufo* (Roding)								
Dulcerana cf. *granularis* (Roding)								
Bursa (*Bufonariella*) *ranelloides* (Reeve)								
Haustellum cf. *haustellum* (Linnaeus)								
Ceratostoma fournieri (Crosse)								
Neptunea kuroshio Oyama								
Buccinum sp.								
Japelion adelphicus (Dall)								
Siphonalia cf. *declivis* Yokoyama								
Siphonalia sp.								
Kelletia brevis Ozaki								
Penion sp.								
Hindsia cf. *magnifica* (Lischke)								
Phos varicosus Gould								
Microfusus asperus (Kuroda)								
Granulifusus cf. *kiranus* Shuto								
Pleuroploca cf. *trapezium* (Linnaeus)								
Hemifusus tuba (Gmelin)								
Oliva oliva (Linnaeus)								
Olivella fulgurata (Adams & Reeve)								
Baryspira okawai (Yokoyama)								
Lyria cf. *planicostata* (Sowerby)								
Lyria hirugayensis (Yokoyama)								
Fulgoraria (*Nipponomelon*) *magna* Kuroda & Habe								
Fulgoraria (*Musashia*) sp.								
Fulgoraria (*Saotomea*) *delicata* Fulton								
Benthovoluta sp.								
Endemoconus oyamai Tomida								
Endemoconus cf. *ichinoseana* (Kuroda)								
Lithoconus cf. *litteratus* (Linnaeus)								
Chelyconus cf. *fulmen* (Reeve)								
Parviconus tuberculatus (Tomlin)								
Conus comatosaeformis Yokoyama								
Thatcheria cf. *mirabilis* Angas								
Riuguhdrillia engonia (Watson)								
Tholitoma nishimotoi Tomida								
Parabathytoma cf. *luedorfi* (Lischke)								
Makiyamaia subdeclivis (Yokoyama)								
Elegantiscala sp.								
Architectonica maxima (Philippi)								
Hartungia typica Bronn								
Hartungia n. sp.								
Acteon sp.								
Acila divaricata Hinds								
Neilonella coix Habe								
Carinineilo sp.								
Portlandia lischkei (Smith)								
Megayoldia tsuruensis Sugita								
Yoldia sp.								
Acar congenita Smith								
Arca boucardi Jousseaume								
Cucullaea labiata granulosa Jonas								
Anadara (*Tosarca*) *tosaensis* Noda								
Anadara (*Scapharca*) *suzukii* (Yokoyama)								


Species
Miocene
E
M
L
Pliocene
E
L
Pleist.
E
L
Recent
Anadara (Scapharca) cf. shizuokaensis Noda
Glycymeris rotunda (Dunker)
Glycymeris osozawaensis Kanno
Glycymeris cf. cisshuensis Makiyama
Glycymeris albolineata (Lischke)
Crenulilimopsis oblonga (A. Adams)
Cyrenolimopsis adamsiana (Yokoyama)
Limopsis tokaiensis Yokoyama
Mytilus cf. coruscus Gould
Perna viridis (Linnaeus)
Pteria cf. loveni (Dunker)
Pinctada fucata (Gould)
Patinopecten planicostulatus (Nomura & Niino)
Amussiopecten akiyamae Masuda
Amussiopecten iitomiensis (Otuka)
Amussiopecten praesignis (Yokoyama)
Amusium pleuronectes (Linnaeus)
Miyagipecten matsumoriensis Masuda
Chlamys (Mimachlamys) cf. nobilis (Reeve)
Chlamys (Mimachlamys) satoi Yokoyama
Chlamys miurensis (Yokoyama)
Chlamys inouei Tomida
Chlamys rendoi Ozaki
Chlamys shirahamaensis (Nomura & Niino)
Cryptopecten vesiculosus (Dunker)
Delectopecten peckhami Gabb
Polynemamussium sp.
Comptopallium tayamai (Nomura & Niino)
Decatopecten izuensis (Nomura & Niino)
Spondylus anacanthus Mawe
Spondylus barbatus cruentus Lischke
Neopycnodonte musashiana (Yokoyama)
Pretostrea imbricata (Lamarck)
Dendostrea folium (Linnaeus)
Dendostrea crenulifera (Sowerby)
Ostrea circumpicta Pilsbry
Crassostrea gigas (Thunberg)
Lima zushiensis Yokoyama
Lima quantoensis Yokoyama
Lima aff. konnoi Otuka
Acesta goliath (Sowerby)
Indocrassatella oblongata (Yokoyama)
Indocrassatella tenuilirata (Shuto)
Nipponocrassatella cf. takanabensis (Shuto)
Nipponocrassatella n. sp.
Megacardita panda (Yokoyama)
Megacardita ferruginosa (Adams & Reeve)
Cyclocardia cf. ferruginea (Cressin)
Glans hirasei Dall
Meiocardia tetragona (Adams & Reeve)
Cycladicama cumingii (Hanley)
Leptaxinus oyamai Habe
Conchocele bisecta Conrad
Lucinoma annulatum (Reeve)
Chama fragum Reeve
Keenaea samarangae (Makiyama)

Species	Miocene E	Miocene M	Miocene L	Pliocene E	Pliocene L	Pleist. E	Pleist. L	Recent
Fragum loochoanum Kira								
Clinocardium hataii Hayasaka								
Clinocardium buellowi (Rolle)								
Coelomactra antiquata (Spengler)								
Mactra sp.								
Oxyperas bernardi (Pilsbry)								
Lutraria maxima Jonas								
Macoma calcarea (Gmelin)								
Dysmea occidens (Gmelin)								
Tellina (*Tellinella*) cf. *staurella* (Lamarck)								
Solecurtus divaricatus Hinds								
Solen cf. *strictus* Gould								
Solen gordonis Yokoyama								
Calyptogena sp.								
Venus (*Ventricolaria*) cf. *toreuma* Gould								
Venus (*Ventricoloidea*) *foveolata* (Sowerby)								
Pitar (*Pitarina*) sp.								
Pitar (*Pitarina*) *dohrni* (Romer)								
Pitar (*Pitarina*) *semeliformis* Shuto								
Sulcilioconcha cf. *philippinarum* (Hanley)								
Callista chinensis (Holten)								
Mercenaria yokoyamai (Makiyama)								
Clementia papyracea (Gray)								
Glycydonta marica (Linnaeus)								
Dosinia (*Bonartemis*) *histrio* (Gmelin)								
Dosinia (*Phacosoma*) sp.								
Paphia exilis exilis Shuto								
Paphia exilis takaokaensis Shuto								
Pholadomya pacifica Dall								
Periploma plane Ozaki								
Cyathodonta granulosa (Adams & Reeve)								
Thracia sp.								
Cuspidaria nobilis (A. Adams)								
Halicardia nipponensis Okutani								
Fissidentalium yokoyamai (Makiyama)								
Fissidentalium vernedei (Sowerby)								
Fissidentalium hungerfordi (Pilsbry & Sharp)								
Dentalium hexagonum Gould								
Antalis cf. *weinkauffi* (Dunker)								
Aturia coxi Miller								
Argonauta itoigawai Tomida								
Argonauta (s. l.) *awaensis* Tomida								

Legend: Pleist.=Pleistocene, E=Early, M=Middle, L=Late
------- unknown

Plate

Plate 24

Fig. 1. *Perotrochus africanus* cf. *teramachii* Kuroda
Dorsal view, × 0.7, ESN2608, Senhata Fm. (Sh-4).

Figs. 2a, b. *Haliotis* (*Nordotis*) n. sp.
a: lateral view, b: apical view, × 0.7, Osozawa Mb. (Oz-2).

Fig. 3. *Cellana* cf. *grata* (Gould)
Dorsal view, × 1.0, MFM112123, Osozawa Mb. (Oz-2).

Fig. 4. *Lischkeia* cf. *alwinae* (Lischke)
Apertural view, × 1.3, MFM112124, Osozawa Mb. (Oz-2).

Figs. 5, 6. *Ginebis argenteonitens* (Lischke)
Fig. 5: apertural view, × 1.3, MFM112125, Shimada Fm. (Uh-1).
Fig. 6: dorsal view, × 1.0, YCM-GP859, Misaki Fm. (Hs-1).

Fig. 7 *Calliostoma* cf. *formosense* (E. A. Smith)
Dorsal view, × 1.0, MFM112126, Osozawa Mb. (Oz-2).

Figs. 8, 9 *Chlorostoma narusei* Shibata
Fig. 8: dorsal view, × 1.0, YCM-GP860, Ochiai Fm.
Fig. 9: apical view, × 1.0, MFM112127, Osozawa Mb. (Oz-2).

Fig. 10. *Ethalia maxima* (Shuto)
Apical view, × 1.3, MFM112128, Ochiai Fm.

Figs. 11a, b, 12a, b: *Suchium koyuense* Shuto
Fig. 11a: apical view, b: apertural view, × 1.0, YCM-GP861, Ochiai Fm.
Fig. 12a: apertural view, b: apical view, × 1.0, KPMG-30001, Zushi Fm. (Zs-2).

Fig. 13. *Astraea omorii* Shibata
Apertural view, × 1.0, MFM112129, Ochiai Fm.

MFM: Mizunami Fossil Museum, ESN: Furukawa Museum, Nagoya University, YCM: Yokosuka City Museum, KPMG: Kanagawa Prefectural Museum of Natural History, CGU: Chukyo Gakuin University.

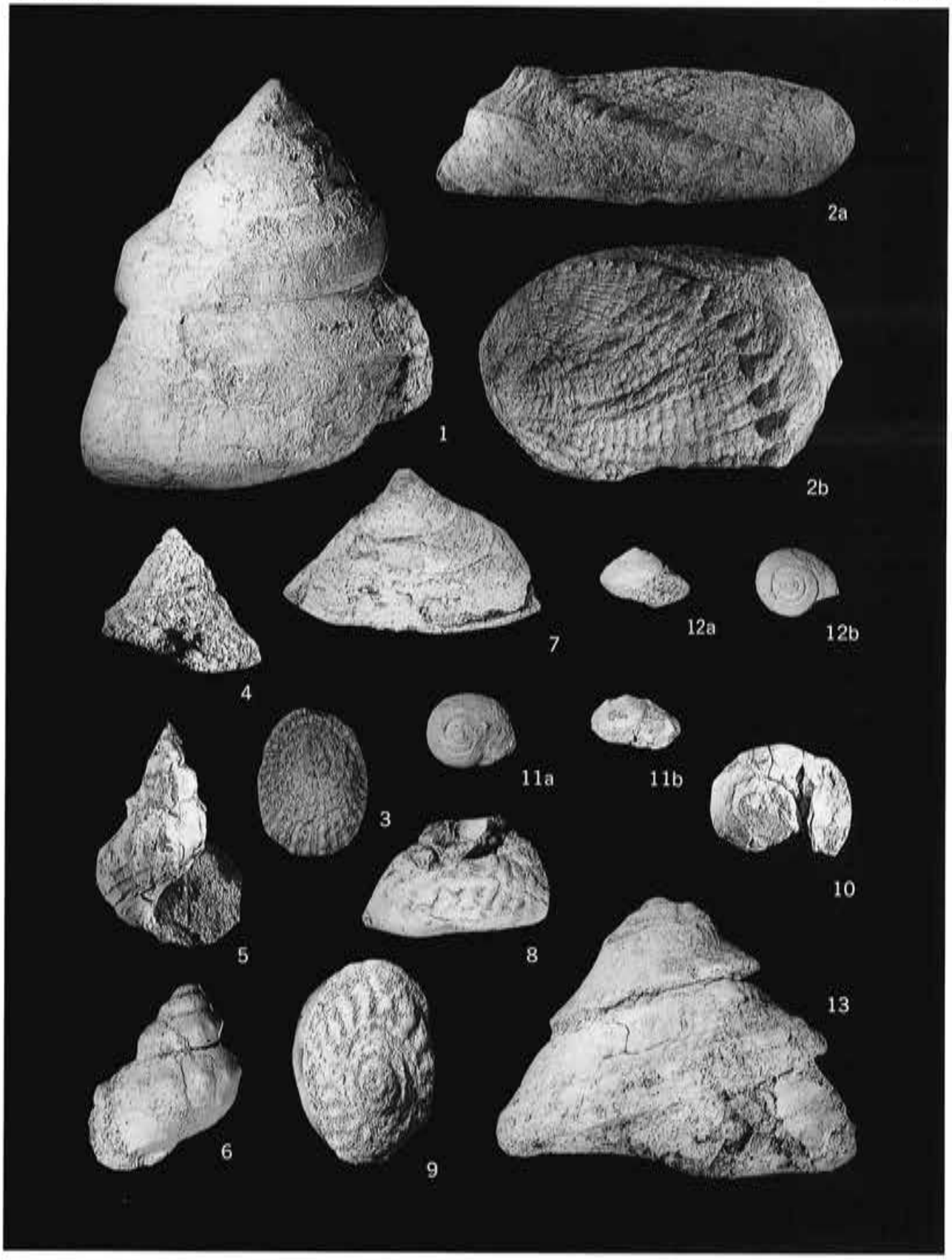

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11a
11b
12a
12b
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Plate 25

Fig. 1. *Astraea tyosiensis* Ozaki

Dorsal view, × 0.8, MFM112130, Osozawa Mb. (Oz-2).

Figs. 2, 3. *Bolma* (*Bolma*) *virgata* (Ozaki)

fig.2: apertural view, × 1.0, YCM-GP862, Senhata Fm. (Sh-3).

fig.3: apertural view, × 1.0, ESN2609, Ochiai Fm.

Fig. 4. *Bolma* (*Oobolma*) *takitai* (Ozaki)

Dorsal view, × 1.0, YCM-GP863, Ochiai Fm.

Figs. 5a, b, 7. *Turbo* (*Lunatica*) cf. *marmoratus* Linnaeus

fig. 5a: apertural view, b: dorsal view (depressed), × 0.5, ESN2569, Osozawa Mb. (Oz-2).

fig. 7: operculum, × 0.8, MFM112131, Ochiai Fm.

Fig. 6. *Turbo* (*Batillus*) n. sp.

Apertural view, × 0.7, YCM-GP864, Ochiai Fm.

Fig. 8. *Turbo* (*Marmarostoma*) cf. *stenogyrus* Fischer

Operculum, × 1.0, MFM112132, Katsuragawa Mb., Shimada Fm. (Uh-1).

Fig. 9. *Astraea* (*Astralium*) cf. *calcar* (Linnaeus)

Apical view, × 1.0, MFM112133, Osozawa Mb. (Oz-2).

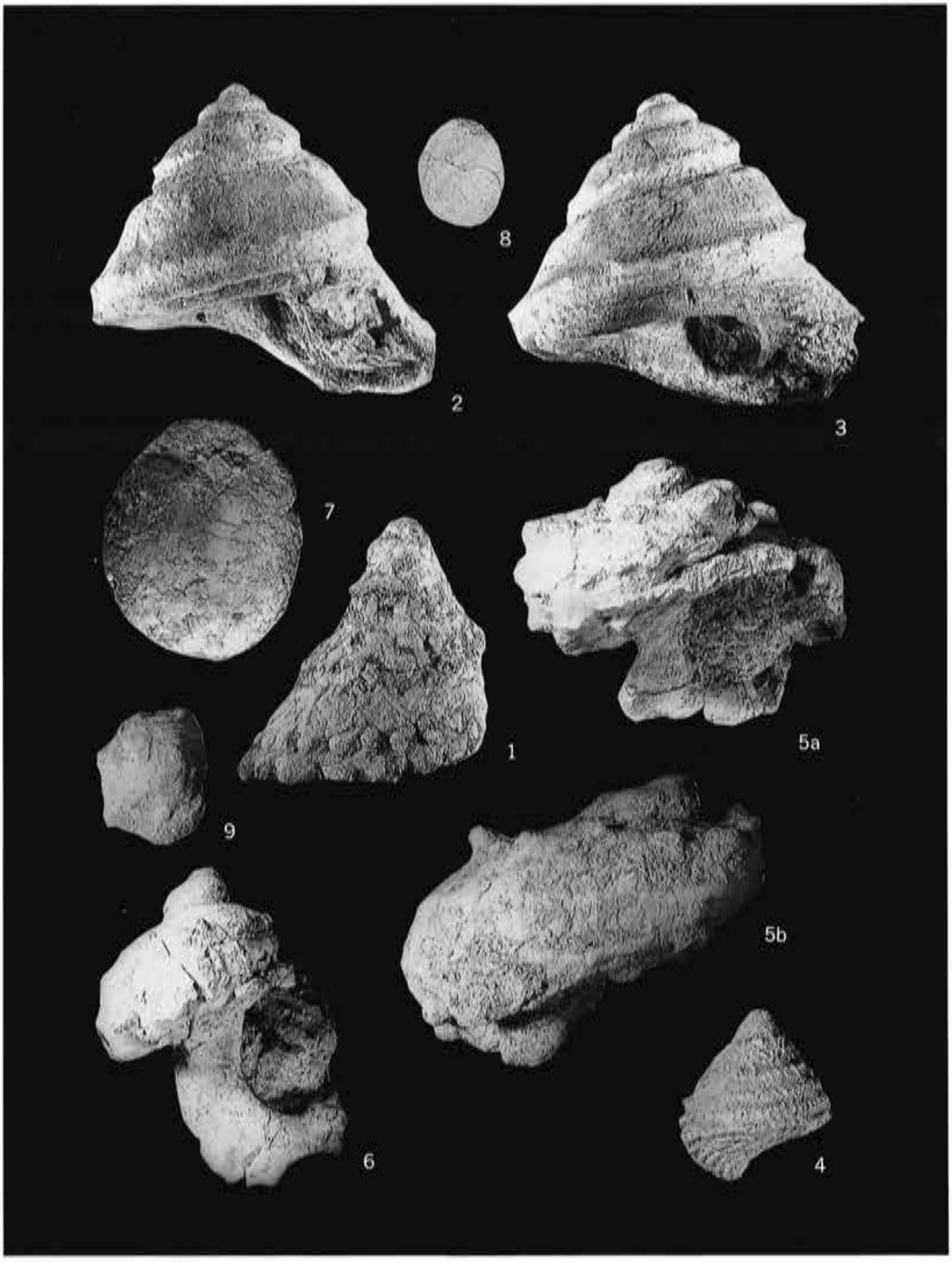

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Plate 26

Fig. 1. *Serpulorbis* cf. *dentiferus* (Sowerby)
Lateral view, × 0.7, MFM112134, Ochiai Fm.
Fig. 2. *Xenophora chinensis* (Philippi)
Apical view, × 1.0, MFM112135, Osozawa Mb. (Oz-2).
Fig. 3. *Strombus* (*Canarium*) sp.
Apertural view, × 1.0, YCM-GP865, Ochiai Fm.
Figs. 4a, b. *Pseudotrivia* cf. *eos* (Roberts)
a: apertural view, b: dorsal view, × 1.0, MFM112136, Hayakawa Fm. (Nz).
Fig. 5. *Hiraseadusta hirasei* (Roberts)
Apertural view, × 0.9, Kamiya's coll., Osozawa Mb. (Oz-2).
Fig. 6. *Nesiocypraea* cf. *midwayensis* Azuma and Kuroda
Apertural view, × 1.0, YCM-GP867, Misaki Fm. (Hs-1).
Fig. 7. *Polinices* cf. *tumidus* (Swainson)
Apertural view, × 1.0, MFM111020, Senhata Fm. (Sh-5).
Fig. 8. *Glossaulax* sp.
Apertural view, × 1.0, MFM111021, Senhata Fm. (Sh-5).
Fig. 9. *Phalium* (*Mauicassis*) *yokoyamai* Nomura and Hatai
Dorsal view, × 1.0, MFM112137, Senhata Fm. (Sh-5).
Fig. 10. *Fusitriton oregonensis galea* Kuroda and Habe
Apertural view, × 1.5, MFM112138, Shimada Fm. (Ot-2).
Fig. 11. *Charonia sauliae* (Reeve)
Dorsal view, × 1.0, MFM111026, Senhata Fm. (Sh-5).
Fig. 12. *Dulcerana* cf. *granularis* (Röding)
Dorsal view, × 1.0, MFM112139, Ochiai Fm.
Fig. 13. *Neptunea kuroshio* Oyama
Apertural view, × 1.0, MFM112140, Ochiai Fm.
Fig. 14. *Haustellum* cf. *haustellum* (Linnaeus)
Apertural view, × 1.4, MFM112141, Nishikatsura Fm. (Nk-1).
Fig. 15. *Ceratostoma fournieri* (Crosse)
Dorsal view, × 1.0, MFM112142, Ochiai Fm.

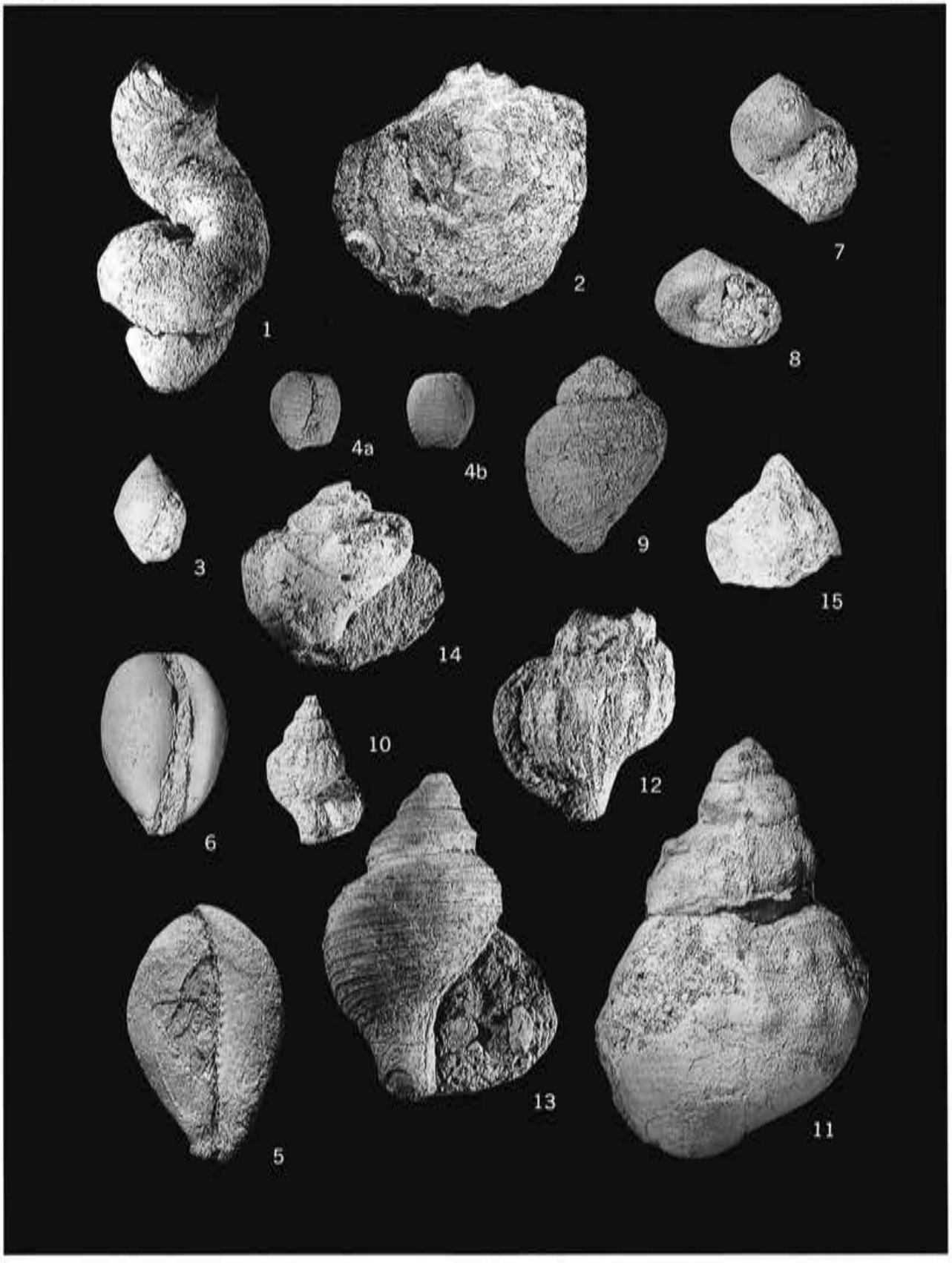

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Plate 27

Figs. 1a, b. *Siphonalia* cf. *declivis* Yokoyama
a: apertural view, b: dorsal view, × 1.3, MFM112143, Ochiai Fm.

Figs. 2, 3. *Kelletia brevis* (Ozaki)
fig. 2: apertural view, × 0.8, ESN2610, Ochiai Fm.
fig. 3: apertural view, × 1.0, MFM112144, Nishikoiso Fm.

Fig. 4. *Phos varicosus* Gould
Dorsal view, × 1.0, MFM112145, Ochiai Fm.

Fig. 5. *Granulifusus* cf. *kiranus* Shuto
Dorsal view, × 1.3, MFM112146, Osozawa Mb. (Oz-2).

Fig. 6. *Pleuroploca* cf. *trapezium* (Linnaeus)
Dorsal view, × 0.8, MFM112114, Ochiai Fm.

Fig. 7. *Hemifusus tuba* (Gmelin)
Apertural view (juvenile), × 1.3, MFM112147, Shimada Fm. (Ot-2).

Fig. 8. *Tutufa* (*Tutufa*) cf. *bufo* (Röding)
Apertural view, × 0.5, MFM112148, Nishikoiso Fm.

Fig. 9. *Siphonalia* sp.
Dorsal view, × 1.0, MFM112149, Osozawa Mb. (Oz-2).

Fig. 10. *Lyria hirugayensis* (Yokoyama)
Dorsal view, × 1.3, MFM112150, Osozawa Mb. (Oz-2).

Fig. 11. *Chelyconus* cf. *fulmen* (Reeve)
Dorsal view, × 1.0, YCM-GP868, Misaki Fm. (Hs-1).

Fig. 12. *Thatcheria* cf. *mirabilis* Angas
Dorsal view, × 1.0, MFM112151, Osozawa Mb. (Oz-2).

Fig. 13. *Parabathytoma* cf. *luedorfi* (Lischke)
Apertural view, × 1.0, MFM112152, Osozawa Mb. (Oz-2).

Fig. 14. *Makiyamaia subdeclivis* (Yokoyama)
Apertural view, × 1.3, MFM112153, Osozawa Mb. (Oz-2).

Fig. 15. *Architectonica maxima* (Philippi)
Apical view, × 1.0, MFM112154, Osozawa Mb. (Oz-2).

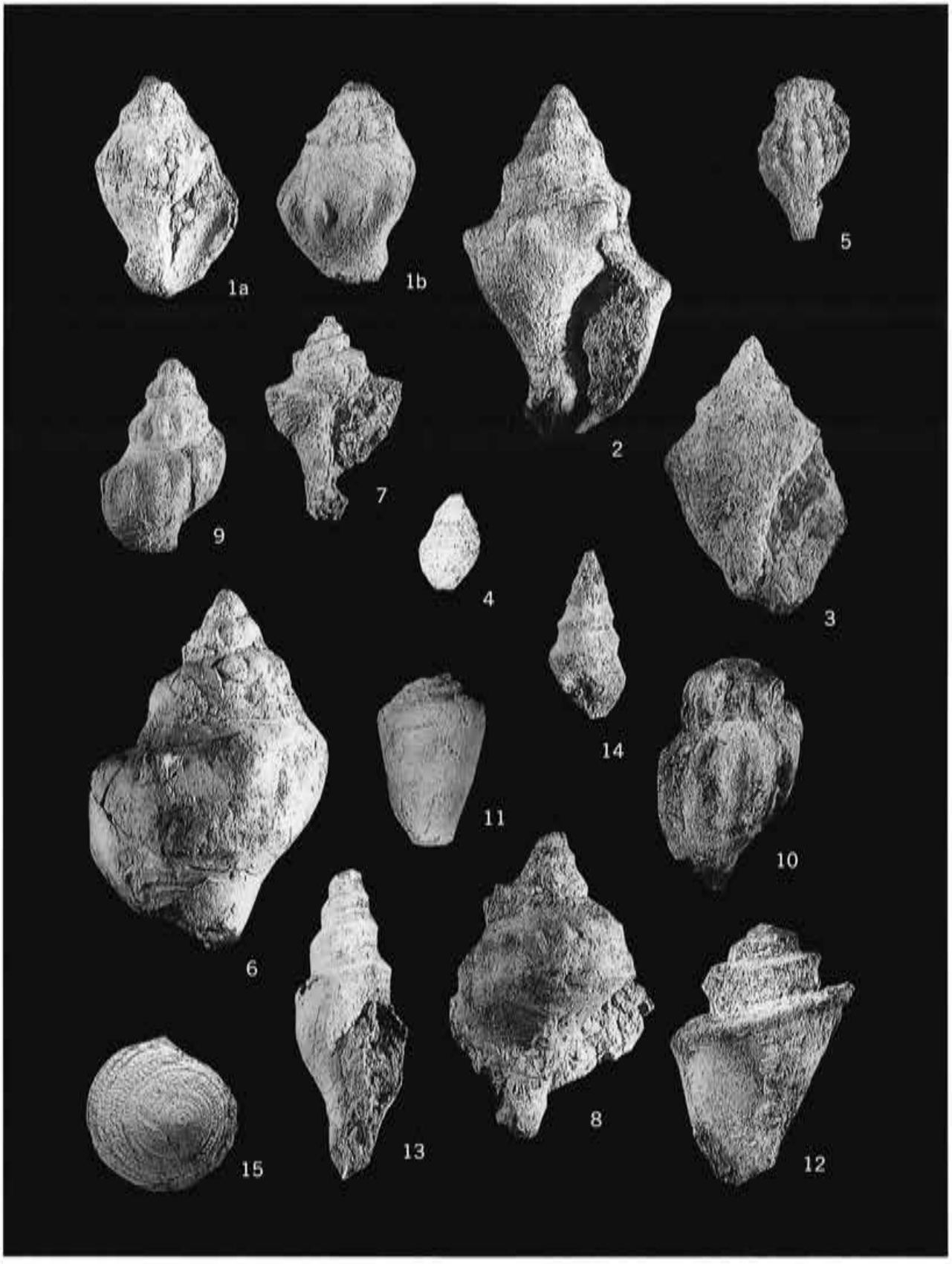

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Plate 28

Fig. 1. *Acila divaricata* Hinds
Right valve, × 1.3, MFM112155, Shimada Fm. (Uh-1).
Fig. 2. *Portlandia lischkei* (Smith)
Right valve, × 1.3, MFM112156, Shimada Fm. (Uh-1).
Fig. 3. *Arca boucardi* Jousseaume
Left valve, × 1.0, MFM112157, Osozawa Mb. (Oz-2).
Fig. 4. *Anadara* (*Tosarca*) *tosaensis* Noda
Right valve, × 0.8, MFM112158, Osozawa Mb. (Oz-2).
Figs. 5a, b, 6a, b. *Glycymeris rotunda* (Dunker)
Fig. 5a: outer view of left valve, b: inner view, × 1.0, MFM112159, Osozawa Mb. (Oz-2).
Fig. 6a: outer view of left valve, b: inner view, × 1.0, MFM112160, Katsuragawa Mb., Shimada Fm. (Uh-1).
Figs. 7a, b, 8. *Glycymeris osozawaensis* Kanno
Fig. 7a: outer view, × 1.0, b: inner view, × 1.2, left valve, MFM112161, Ochiai Fm.
Fig. 8: inner view of left valve, × 1.0, YCM-GP869, Ochiai Fm.
Fig. 9. *Crenulilimopsis oblonga* (A. Adams)
Left valve, × 1.0, MFM112162, Oyori Fm. (Sg-2).
Fig. 10. *Cyrenolimopsis adamsiana* (Yokoyama)
Left valve, × 1.0, MFM112163, Oyori Fm. (Sg-2).
Fig. 11. *Limopsis tokaiensis* Yokoyama
Right valve, × 1.0, YCM-GP870, Ochiai Fm.

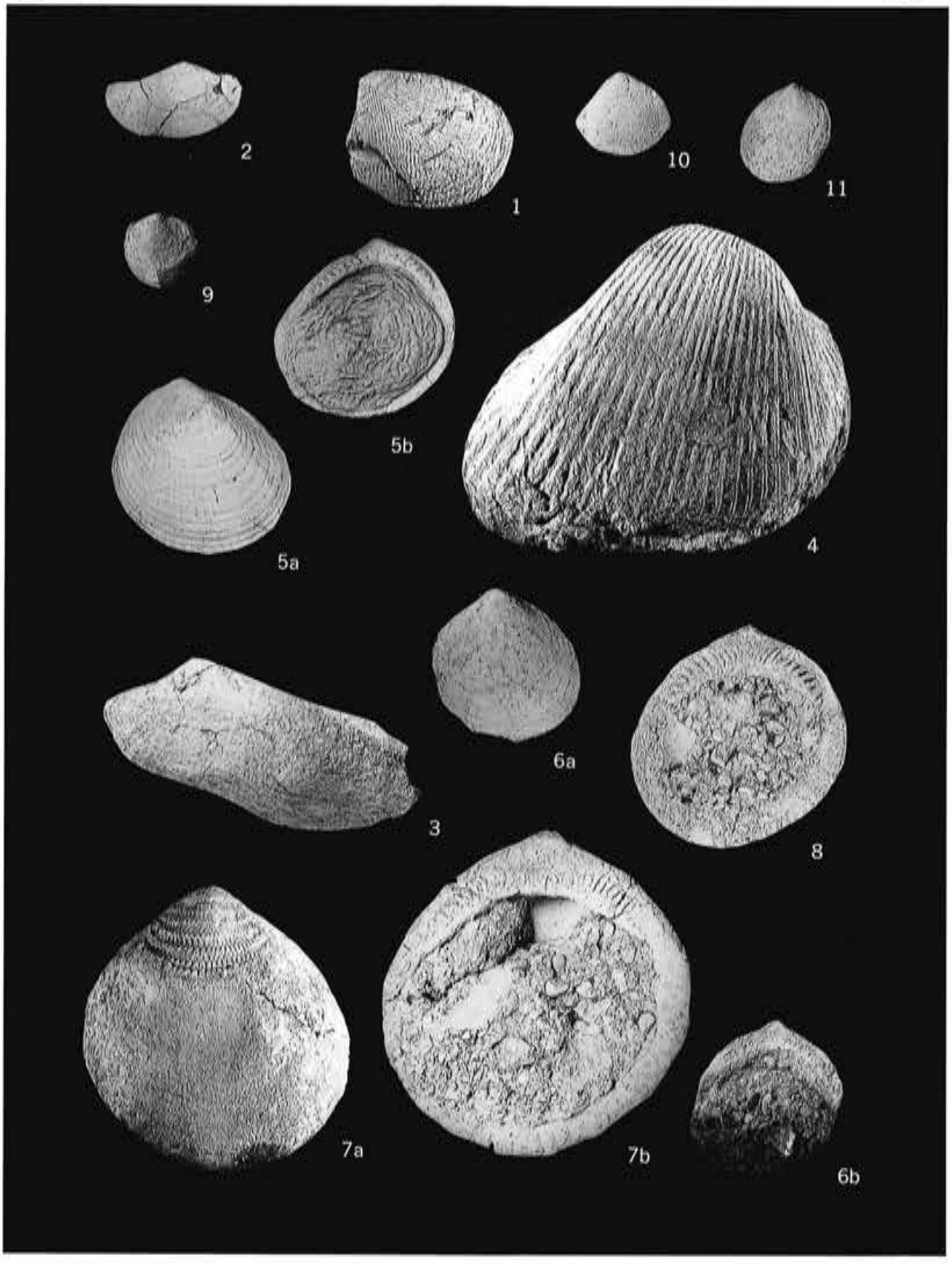

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5b
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5a
6a
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7a
7b
6b

Plate 30

Figs. 1, 2. *Chlamys miurensis* (Yokoyama)
Fig. 1: left valve, × 0.5, KPMG-30003, Zushi Fm. (Zs-1).
Fig. 2: right valve, × 0.5, YCM-GP871, Misaki Fm. (Hs-1).
Fig. 3. *Chlamys* (*Mimachlamys*) cf. *nobilis* (Reeve)
Right valve, × 0.5, MFM112168, Osozawa Mb. (Oz-2).
Fig. 4. *Chlamys* (*Mimachlamys*) *satoi* (Yokoyama)
Left valve, × 1.0, MFM112169, Hayakawa Fm. (Nz).
Fig. 5. *Cryptopecten vesiculosus* (Dunker)
Right valve, × 1.3, MFM112170, Harada Fm. (Sr-2).
Fig. 6. *Comptopallium tayamai* (Nomura and Niino)
Inner view of right valve, × 1.0, MFM112171, Itami Fm. (Sr-1).
Fig. 7. *Decatopecten izuensis* (Nomura and Niino)
Right valve, × 1.2, MFM112172, Harada Fm. (Sr-2).
Fig. 8. *Ostrea crenulifera* Pilsbry
Ventral view of conjoined specimen, × 1.0, MFM112173, Itami Fm. (Sr-1).
Fig. 9. *Crassostrea gigas* (Thunberg)
Inner view of left valve, × 1.0, MFM112174, Shimada Fm. (Ot-2).

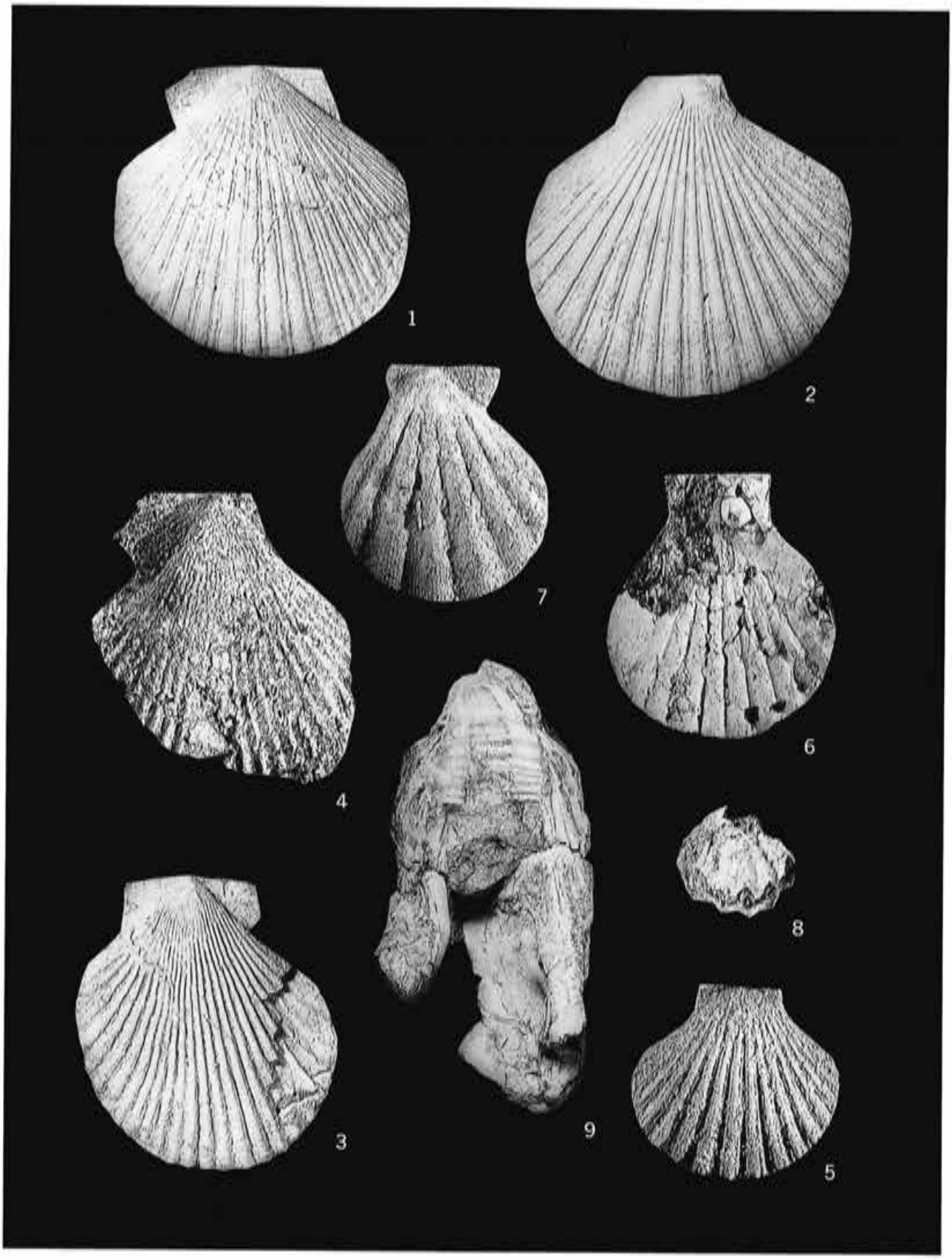

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Plate 31

Fig. 1. *Lima zushiensis* Yokoyama
Right valve of conjoined specimen, × 1.0, MFM111080, Senhata Fm. (Sh-4).
Fig. 2. *Acesta goliath* (Sowerby)
Right valve, × 1.0, KPMG-30004, Zushi Fm. (Zs-2).
Fig. 3. *Nipponocrassatella* cf. *takanabensis* (Shuto)
Left valve of conjoined specimen, × 1.3, MFM112175, Osozawa Mb. (Oz-2).
Figs. 4, 5. *Megacardita panda* (Yokoyama)
Fig.4: right valve, × 1.0, MFM112176, Osozawa Mb. (Oz-2).
Fig.5: left valve, × 1.0, MFM112177, Nishikoiso Fm.
Fig. 6. *Glans hirasei* Dall
Right valve, × 1.0, YCM-GP872, Ochiai Fm.
Fig. 7. *Meiocardia tetragona* (Adams and Reeve)
Left valve (depressed), × 1.0, MFM112178, Osozawa Mb. (Oz-1).
Fig. 8. *Cycladicama cumingii* (Hanley)
Left valve, × 1.0, MFM112179, Shimada Fm. (Ot-2).
Fig. 9. *Conchocele bisecta* Conrad
Left valve of conjoined specimen, × 1.3, MFM112180, Osozawa Mb. (Oz-2).
Fig. 10. *Lucinoma annulatum* (Reeve)
Right valve of conjoined specimen, × 1.0, KPMG-30005, Zushi Fm. (Zs-2).
Fig. 11. *Keenaea samarangae* (Makiyama)
Left valve, × 1.3, MFM112181, Ochiai Fm.
Fig. 12. *Fragum loochoanum* Kira
Left valve, × 1.0, MFM112182, Osozawa Mb. (Oz-1).
Fig. 13. *Coelomactra antiquata* (Spengler)
Right valve, × 0.5, MFM112183, Osozawa Mb. (Oz-2).
Fig. 14. *Oxyperas bernardi* (Pilsbry)
Left valve, × 1.0, YCM-GP873, Misaki Fm. (Hs-1).

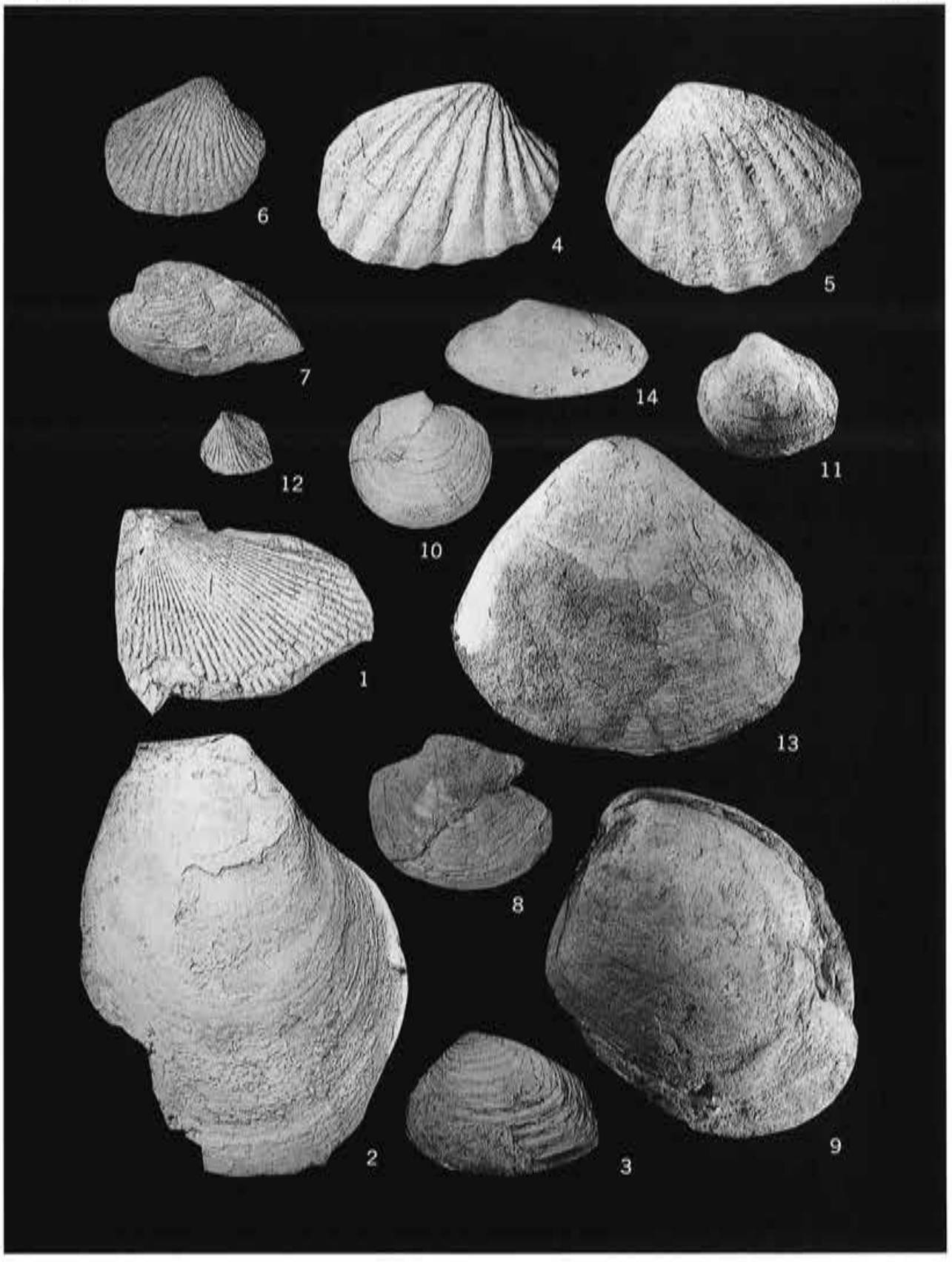

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Plate 32

Fig. 1. *Oxyperas bernardi* (Pilsbry)
Right valve, × 1.0, MFM112184, Osozawa Mb. (Oz-2).
Fig. 2. *Macoma calcarea* (Gmelin)
Left valve, × 1.4, MFM112185, Ochiai Fm.
Fig. 3. *Venus* (*Ventricolaria*) cf. *toreuma* Gould
Left valve, × 1.0, YCM-GP874, Ochiai Fm.
Fig. 4. *Pitar* (*Pitarina*) sp.
Right valve, × 1.0, YCM-GP875, Misaki Fm. (Hs-1).
Fig. 5. *Pitar* (*Pitarina*) *semeliformis* Shuto
Right valve, × 1.0, MFM112186, Osozawa Mb. (Oz-1).
Fig. 6. *Lioconcha* (*Sulcilioconcha*) cf. *philippinarum* (Hanley)
Left valve, × 1.0, MFM112187, Hayakawa Fm. (Nz).
Fig. 7. *Callista chinensis* (Holten)
Right valve, × 1.0, MFM112188, Osozawa Mb. (Oz-2).
Fig. 8. *Mercenaria yokoyamai* (Makiyama)
Right valve, × 0.7, ESN2612, Nishikoiso Fm.
Fig. 9. *Pholadomya pacifica* Dall
Conjoined valve, × 1.5, MFM112189, Osozawa Mb. (Oz-2).
Fig. 10. *Periploma plane* (Ozaki)
Conjoined valve (depressed), × 1.2, MFM112190, Shimada Fm. (Uh-1).
Fig. 11. *Cuspidaria nobilis* (A. Adams)
Right valve, × 1.5, MFM112191, Osozawa Mb. (Oz-2).
Fig. 12. *Fissidentalium yokoyamai* Makiyama
Lateral view (compressed), × 1.3, MFM112192, Osozawa Mb. (Oz-1).
Figs. 13, 14. *Fissidentalium vernedei* (Sowerby)
Fig. 13: lateral view, × 1.2, MFM112193, Katsuragawa Mb., Shimada Fm. (Uh-1).
Fig. 14: lateral view, × 1.2, MFM112194, Ochiai Fm.

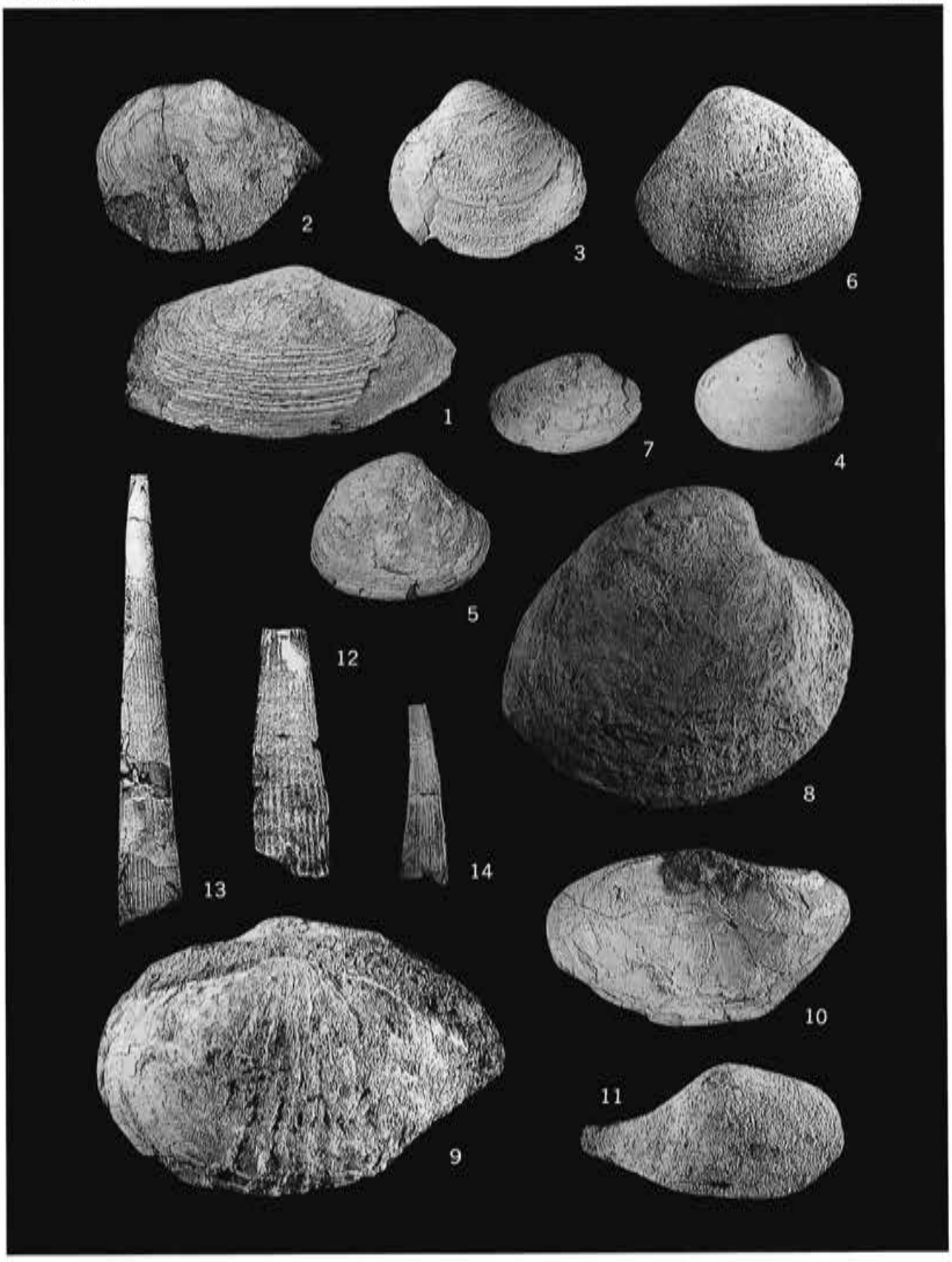

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Plate 33

Fig. 1. *Perotrochus* sp.
Apertural view, × 1.0, Kamiya's coll., Ochiai Fm.

Fig. 2. *Cypraea* (*Zoila*) *itoigawai* Tomida
Lateral view, × 2.0, MFM110105 (Paratype), Senhata Fm. (Sh-5).

Figs. 3a, b, 4. *Hartungia typica* Bronn
Fig. 3a: apertural view, b: dorsal view, c: apical view, × 1.0, MFM112195, Osozawa Mb. (Oz-2).
Fig. 4: dorsal view (compressed), × 1.0, MFM112196, Osozawa Mb. (Oz-2).

Fig. 5. *Miyagipecten matsumoriensis* Masuda
Conjoined valve, × 0.8, MFM111061, Senhata Fm. (Sh-5).

Fig. 6. *Venus* (*Ventricoloidea*) *foveolata* (Sowerby)
Right valve, × 1.2, MFM112197, Osozawa Mb. (Oz-2).

Figs. 7a, b. *Halicardia nipponensis* Okutani
a: left valve of conjoined specimen, b: dorsal view, × 1.2, MFM110103, Ochiai Fm.

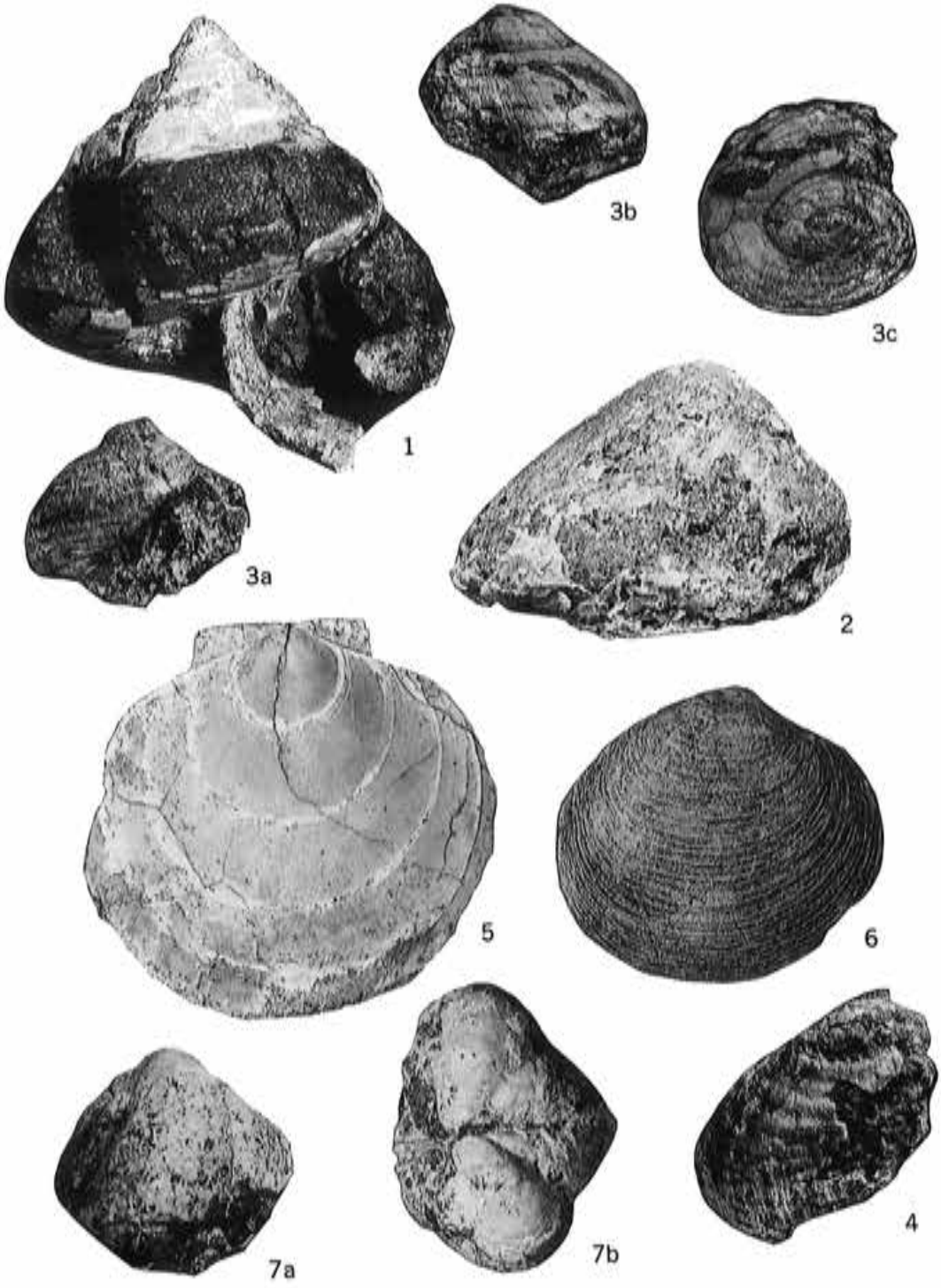

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3a
3b
3c
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7a
7b
4

Plate 34

Figs. 1a, b, 2. *Aturia coxi* (Miller)

Fig. 1a: ventral view, × 0.8, b: lateral view, × 0.7, Inoue's coll., Senhata Fm. (Sh-5).

Fig. 2: lateral view, × 1.0, MFM111108, Senhata Fm. (Sh-5).

Figs. 3a, b, 4a, b. *Argonauta itoigawai* Tomida

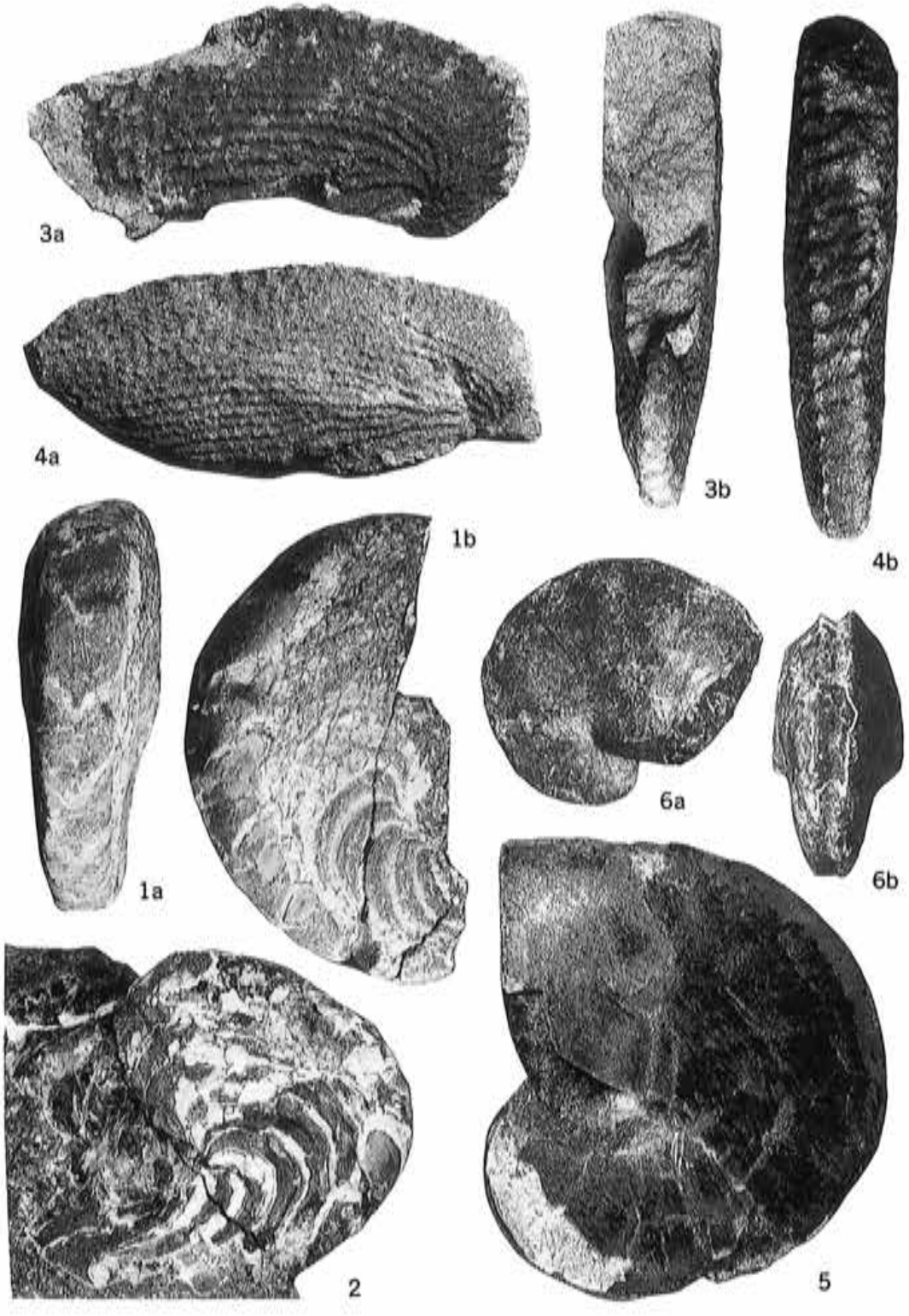
Fig. 3a: lateral view, b: apertural view, holotype, × 0.5, MFM110005, Senhata Fm. (Sh-5).

Fig. 4a: lateral view, b: ventral view, paratype, × 0.5, CGU10001, Senhata Fm. (Sh-5).

Figs. 5, 6a, b. *Argonauta* (s.l.) *awaensis* Tomida

Fig. 5: lateral view (adult), holotype, × 1.0, MFM110006, Senhata Fm. (Sh-5).

Fig. 6a: lateral view (juvenile), b: ventral view, paratype, × 1.3, MFM110007, Senhata Fm. (Sh-5).


3a
4a
3b
4b
1b
1a
6a
6b
2
5