Bathyal molluscan assemblages in the Plio-Pleistocene in the Kakegawa area, Shizuoka Prefecture, central Japan; their relationships with water masses

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静岡県掛川地域より産する鮮新－更新世漸深海帯貝類化石群集と水塊構造

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(要　　旨)

静岡県西部地域に分布する上部中新統－下部鮮新統満水層および上部鮮新統－最下部更新統土方層はいずれも塊状均質なシルト相を示しており，漸深海帯に特有な貝化石群集を産することで知られている．これまでの調査の結果，満水層からは *Akebiconcha kawamurai* 群集，"*Empleconia*" sp. A - *Neilonella coix* 群集が、土方層からは *Nassaria magnifica* 群集，*Limopsis tajimae* 群集，*Neilonella* 群集が認められている．これらの群集はいずれも準自生的な産状を示し，現在日本周辺の漸深海帯に棲息している現生種からそのほとんどが構成されているが，満水層産の二つの群集と土方層産の三つの群集の間に認められる構成種の違いは，それらの群集の生息水深およびそれらに影響を与えていた水塊の違いを示唆している．土方層の三群集は，現在の相模湾の陸棚縁辺部から上部漸深海帯に生息しているものに比較でき，黒潮の影響を受けているものと思われる．満水層の二群集では，土方層で自生的な産状を示していた種が，薄い砂層に取り込まれているなど他生的な産状を示しており，より深い水深に生息しているものと思われる近縁種がそれらにかわって自生的に産出している．また，これらの二群集には北方の水域に分布の中心を持つ数種の貝化石が含まれている．これら冷水性の貝化石は、これまで土方層からは得られていなかったものである．これらのことから，満水層の二群集は，暖かい黒潮系の水塊が支配的な上部漸深海帯よりも深い，冷水塊の影響があった環境に生息していたと考えられる．また，満水層の *Akebiconcha kawamurai* 群集は還元環境を好む種より成り，この水深において貧酸素水塊が断続的に発達していたことが地層中より読み取れる．このように表層部で暖流の影響を受けている一方で，深海において冷水塊の影響を受けた動物群が認められる例は，中新統の師崎層群の貝化石群集や現在の相模湾の中深層水の群集に認められる．今回の結果は，深海域で冷水塊の影響を受ける貝類群集の変遷過程を考察する上で，初期鮮新世当時の基礎資料となるものと思われる．

(Abstract)

Massive silt sediments of the Late Neogene series in the Kakegawa area yield fossil molluscan

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assemblages including many species still living in seas of bathyal depths in Japan. Following five bathyal molluscan assemblages with parautochthonous occurrences are recognized: (1) *Akebiconcha kawamurai* and (2) "*Empleconia*" sp. A - *Neilonella coix* assemblages in the uppermost part of the Tamari Formation, Early Pliocene age; (3) *Nassaria magnifica*, (4) *Limopsis tajimae*, and (5) *Neilonella* assemblages in the Late Pliocene to earliest Pleistocene Hijikata Formation. The differences of species composition between the assemblages of the Hijikata and Tamari Formations suggest the differences of depositional environments and of water masses. Three assemblages of the Hijikata Formation are considered to have lived in upper bathyal depths under the influence of warm paleo-Kuroshio water. On the contrary, two assemblages of the Tamari Formation might have lived in zones deeper than the upper bathyal depths, being influenced by a cold water mass. A cold, deep water mass existed under warm surface water. Moreover, in their habitat depths, hypoxic water masses intermittently developed and caused reducing environments. This water mass condition is similar to that suggested by the Middle Miocene Morozaki fauna and the living fauna in Sagami Bay.

Introduction

Historical changes of the shallow marine molluscan faunas in Japan have been well studied from the Miocene to present by many authors. The outlines are shown by Itoigawa (1986) and Chinzei (1986). On the contrary, on the deep sea faunas, paleontological studies have been made not enough to trace their historical changes, although detailed studies have been made in some areas such as the Early to Middle Miocene Morozaki Group, Chita Peninsula, central Japan. More occurrence data of fossils are required in order to discuss the history of the deep sea fauna.

Some deep-sea facies of the late Neogene series are widely distributed in the Kakegawa area, central Japan. The Late Miocene to Early Pliocene Tamari Formation and the Late Pliocene to earliest Pleistocene Hijikata Formation are composed of grayish massive silt. Makiyama (1963) mentioned that the Tamari Formation commonly yields *Limopsis tajimae*, which still lives in seas around the Japanese Islands at bathyal depths. Moreover, Shibata (1979) reported pelagic molluscs from the Tamari Formation, with associated benthic molluscs. The benthic molluscs are composed of species living in bathyal depths, such as *L. tajimae*, *Neilonella coix*, and *Bathybembix argenteonitens*. These species are commonly found also in the Hijikata Formation. The two formations are likely to have been deposited in bathyal depths. Chinzei (1980) stated that the molluscan fauna of the Hijikata Formation is comparable to the fauna now living in the shelf-edge to upper bathyal depths near the Pacific coast of central Japan. The comparable living fauna in Sagami Bay is under the influence of the warm Kuroshio water (Horikoshi, 1957).

Recently Nobuhara and Tanaka (in press) reported two molluscan assemblages in the uppermost part of the Tamari Formation: the *Akebiconcha kawamurai* assemblage and the "*Empleconia*" sp. A - *Neilonella coix* assemblage. From the same localities of the assemblages, I have obtained new material and identified some specimens of cold-water species, such as *Neptunea constricta*. This species has not been reported from the Hijikata

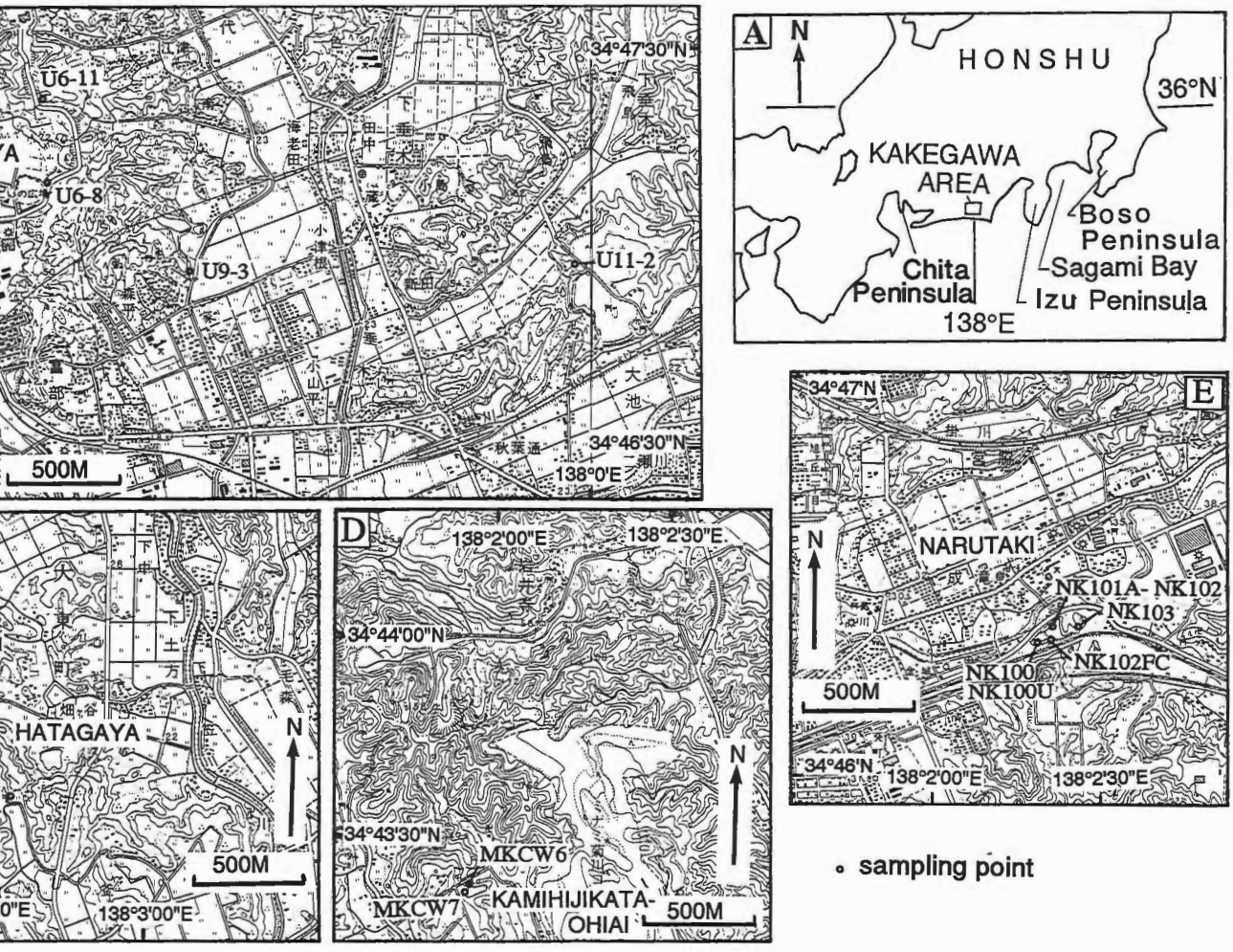


Fig. 1 (A) Index map of the Kakegawa area. (B)-(E) Map showing sampling locations, plotted on 1 : 25000-scale topographic map Quadrangle "Yamanashi" and "Kakegawa" (B), "Shimohirakawa" (C and D), and "Kakegawa" (E).

Formation. In this paper, I point out differences of habitat depths and water masses between these assemblages of the Tamari Formation and those commonly recognized in the Hijikata Formation.

Geological setting and localities

The Kakegawa area is situated in the southwest of Shizuoka Prefecture on the Pacific coast of central Japan (Fig. 1A). It is one of the type areas of Japanese Neogene stratigraphy. The late Neogene series in the Kakegawa area is composed of the Middle Miocene to Early Pliocene Sagara Group and the Plio-Pleistocene Kakegawa Group, in ascending order. They yield abundant marine molluscan fossils, which are known as the Sagara fauna and the Kakegawa fauna, respectively. These two faunas are representatives of the warm water faunas of Southwest Japan during the late Neogene.

The Tamari Formation is a massive silt formation, exposed in the eastern part of Kakegawa City and the northwestern part of Kikugawa-cho as an inlier surrounded mostly by the Horinouchi Formation (the lower to middle part of the Kakegawa Group). The Tamari Formation is about 600m thick (Ibaraki, 1986). The planktonic foraminiferal biostratigraphy of Ibaraki and Tsuchi (1979) indicated that the Tamari Formation is the Late Miocene to Early Pliocene (N.17–N.19).

The Hijikata Formation also consists of massive silt as the Tamari Formation. It is widely distributed in the southern part of the Kakegawa area. It is about 400m thick

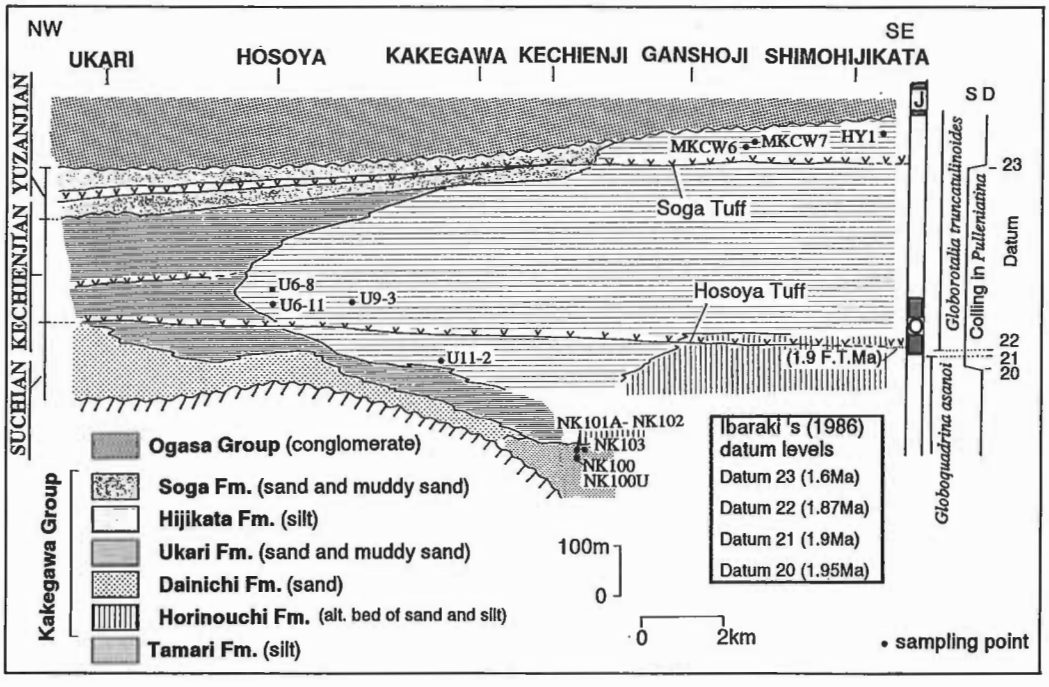


Fig. 2 Schematic cross section of the upper part of the Kakegawa Group and stratigraphic positions of sampling localities.

(Ibaraki, 1986). The Hijikata Formation is an offshore facies of the upper part of the Kakegawa Group. The planktonic foraminiferal biostratigraphy of Ibaraki (1986) indicated that the Hijikata Formation was deposited in the Late Pliocene to earliest Pleistocene (N.21-N.22).

Nobuhara and Tanaka (in press) reported abundant molluscan fossils in the uppermost part of the Tamari Formation at Narutaki in the eastern part of Kakegawa City. Some species of them have not ever been reported from the Tamari and Hijikata Formations. I compare the molluscan assemblages of the localities (NK100-NK103) at Narutaki with those of seven localities of the Hijikata Formation (U6-8, U6-11, U9-3, U11-2, MKCW6, MKCW7, and HY1). The locations are shown in Fig. 1B-E and their stratigraphic positions and ages are shown in Fig. 2. The age of the localities ranges from the Early Pliocene (at NK100-103) to the earliest Pleistocene (at HY1).

Fossil molluscan assemblages in massive silt facies

Bathyal molluscan assemblages in the Kakegawa area were reported by Nobuhara and Tanaka (in press) and Nobuhara (1992MS) with their modes of fossil occurrences. In this paper, among the assemblages, five types are briefly stated on predominant species and association of species, as noted below. Species compositions of the fossil assemblages are shown in Table 1.

With respect to the Tamari Formation, Nobuhara and Tanaka (in press) described two types of fossil molluscan assemblages, i.e. the *Akebiconcha kawamurai* assemblage and the "*Empleconia*" sp. A - *Neilonella coix* assemblage at Narutaki. Nobuhara and Tanaka (in press) also showed that mode of fossil occurrence is distinguished between the two molluscan assemblages. The *Akebiconcha* assemblage occurs in several shell beds, scattered through the massive silt. The silt between shell beds yields sporadic shells of another molluscan fossil assemblage, the "*Empleconia*" sp. A - *Neilonella coix* assemblage. The two assemblages alternate in vertical sequence of massive fine silt with no change of matrix sediment (Fig. 3).

1) *Akebiconcha kawamurai* assemblage (localities: NK101A,B,C, NK102FC, and NK103)

This assemblage is defined with dominant *Akebiconcha kawamurai* Kuroda. *Lucinoma* aff. *acutilineata* (Conrad) and *Conchocele bisecta* (Conrad) are commonly associated. *Solemya johnsoni* Dall frequently occurs. Sublittoral elements, such as *Glycymeris rotunda* (Dunker) occur rarely and have evidently been transported into the shell beds. The constituents of the "*Empleconia*" sp. A - *Neilonella coix* assemblage also occur, mixed into this assemblage.

Large shells are closely spaced and supported by the matrix of fine silt. Most of the shells lie horizontally with their commisure planes parallel to the bedding. Few individuals preserve their life position, although *Lucinoma* and *Conchocele* are known to be deep-burrowers and might be expected not to have been moved from their life position. Most

Table. 1 List of benthic molluscan fossils.

Species \ Localities / Assemblage types	Hijikata Formation							Tamari Formation									
	U6-11	MKCW6	U6-8	U11-2	MKCW7	U9-3	HY1	NK100	NK100U	NK101A	NK101 A-B	NK101B	NK101C	NK102	NK102FC	NK103	NK107 (float)
	Na	Na	L	L	L	Ne	Ne	I	E	A	E	A	A	E	A	A	I
Bathybembix aeola (Watson)	·	·	·	·	·	·	·	·	·	·	C	·	R	C	R	R	R
B. argenteonitens (Lischke)	·	R	·	·	R	·	·	·	·	·	·	·	R	·	·	·	·
B. argenteonitens cf. *hirasei* (Taki et Otuka)	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·
B. sp.	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·
Phanerolepida cf. *pseudotransenna* Ozaki	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R
Orectospira aff. *excelsa* (Yokoyama)	C	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Euspira plicispira (Kuroda)	·	C	·	·	R	·	F	·	·	·	·	·	·	·	·	·	·
Neptunea constricta (Dall)	·	·	·	·	·	·	·	·	·	·	R	·	R	R	·	·	R
N. kuroshio Oyama	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·
Babylonia elata (Yokoyama) var.	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Siphonalia declivis biconica Makiyama	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. tonohamaensis totomiensis Makiyama	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Nassaria magnifica (Lischke)	VA	VA	A	·	C	·	·	·	·	·	·	·	·	·	·	·	·
Granulifusus kiranus Shuto	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·	·
Baryspira albocallosa (Lischke)	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
B. urashima Kira	A	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·
B. suavis (Yokoyama)	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·
B. sp.	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·
Fulgoraria prevostiana (Crosse)	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
F. mentiens (Fulton)	F	R	R	R	R	·	·	·	·	·	·	·	·	·	·	·	·
F. spp.	F	R	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Marginella (Stazzania) flaccida (Yokoyama)	·	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Makiyamaia coreanica (Adams et Reeve)	C	A	R	R	A	·	F	·	·	·	·	·	·	·	·	·	·
"Rectiplanes" sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R
Gemmula totomiensis (Makiyama)	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Parabathytoma luehdorfi (Lischke)	VA	A	C	·	C	·	R	·	·	·	·	·	·	·	·	·	·
Thatcheria sp.	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	R
Nipponoscaphander cumingii (A. Adams)	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
N. teramachii (Habe)	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·
Fissidentalium yokoyamai Makiyama	·	R	·	·	C	·	A	·	·	·	·	·	R	·	·	·	·
Spadentalina tubiformis (Boissevain)	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·
Entalia quadrangularis Boissevain	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·	·
Solemya (Acharax) johnsoni Dall	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	R	F
Lamellinucula tokyoensis (Yokoyama)	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	R	·
L. sp.	·	C	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·
Acila aff. *divaricata* (Hinds)	R	·	·	·	·	R	F	·	·	·	·	·	·	·	·	·	·
A. sp.	·	·	·	·	·	·	·	·	·	·	R	·	R	R	·	R	R
Ennucula niponica (Smith)	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·
Bathymalletia inaequilateralis Habe	·	·	·	·	·	F	R	·	R	·	·	·	·	R	·	·	R
Carinineilo carinifera (Habe)	·	·	·	·	·	C	R	·	F	·	·	·	·	·	·	·	·
Nellonella coix Habe	·	·	·	·	·	A	VA	·	F	·	C	·	F	R	·	·	C
N. japonioca Okutani	·	·	·	·	·	·	VA	·	·	·	·	·	·	·	·	·	·
N. sp.	·	·	·	·	·	·	VA	·	·	·	·	·	·	·	·	·	·
Nuculana pernula sadoensis (Yokoyama)	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·
N. acinacea Habe	·	·	·	·	·	·	R	·	R	·	·	·	·	R	·	·	·
N. sp.	·	R	·	·	·	·	F	·	·	·	·	·	·	R	·	·	·
Yoldia similis Kuroda et Habe	·	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·
Y. cf. *glauca* Kuroda et Habe	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·	·
Y. sp.	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Scapharca sp.	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Glycymeris albolineata (Lischke)	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
G. rotunda (Dunker)	·	·	·	·	·	·	·	R	·	·	·	·	R	·	·	·	·
Limopsis tajimae Sowerby	VA	F	A	VA	VA	F	·	R	R	·	·	·	R	·	·	·	·
"Empleconia" sp.A	·	·	·	·	·	·	·	·	VA	·	C	·	C	VA	R	R	VA
Crenulilimopsis oblonga (A. Adams)	A	·	·	·	F	·	·	·	·	·	·	·	R	·	·	·	·
Solamen spectabilis (A. Adams)	·	R	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·
Bathyamussium jeffreysi (Smith)	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·
Cryptopecten vesiculosus (Dunker)	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Amussiopecten praesignis (Yokoyama)	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Limatula vladivostokensis Scarlato	·	·	·	·	·	·	·	·	R	·	·	·	·	R	·	·	R
Lucinoma aff. *acutilineata* (Conrad)	·	·	·	·	·	·	·	·	·	R	·	C	VA	·	C	A	A
Conchocele bisecta (Conrad)	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	VA	R
Venericardia panda (Yokoyama)	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·
Indocrassatella oblongata (Yokoyama)	·	·	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·
Crassatellites takanabensis Shuto	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Abra maxima Sowerby	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·	·
A. soyoae Habe	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·
A. spp.	·	·	·	·	·	·	R	·	F	·	·	·	·	·	·	·	·
Akebiconcha kawamurai Kuroda	·	·	·	·	·	·	·	·	R	C	·	C	VA	R	VA	VA	VA
Paphia sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R
Callista chinensis (Holten)	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·

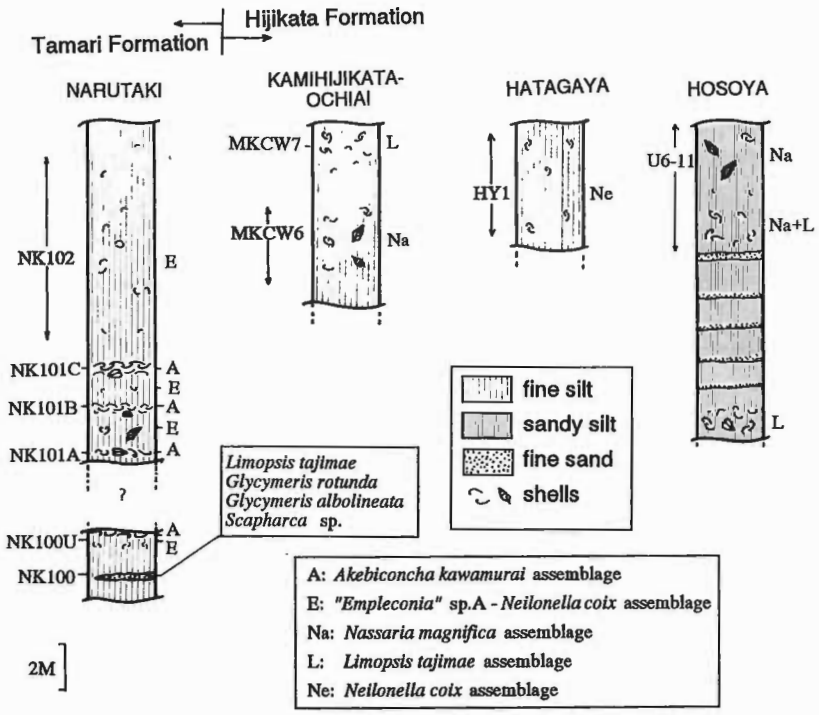


Fig. 3 Columnar sections of representative sampling localities.

of the shells are disarticulated, but I also observed silt blocks containing many articulated shells. Some of them are closed, and others are open but still connected by the ligament. The shells were poorly sorted; the shell length of *Akebiconcha* ranges from ca. 1cm to over 10cm.

The fossil occurrence described above suggests that the shells underwent excavations from their life position and some transportation, but that the transportation was not so far from their original habitat. Therefore, *Akebiconcha kawamurai* formed probably a large-biomass colony with *Lucinoma* aff. *acutilineata*, *Conchocele bisecta*, and *Solemya johnsoni*.

Akebiconcha kawamurai has been reported from about 200–460m deep near the Pacific coast of central Japan. The species composition and the mode of occurrences indicate that this assemblage lived in the bathyal depths. Moreover, except for *A. kawamurai*, this assemblage is very similar to the *Thyasira* Association Group of Matsui (1990) in species composition. According to Matsui (1990), the *Thyasira* Association Group might be restricted to a reducing environment. Many species of genera *Lucinoma*, *Solemya*, *Thyasira* (close to *Conchocele*), and *Calyptogena* (close to *Akebiconcha*) have been confirmed to prefer a reducing environment and possess endosymbiotic sulphide-oxidising bacteria as their nutrition strategy (e.g., Cavanaugh, 1983 ; Felbeck et al., 1981 ; Reid, 1980). Nobuhara and Tanaka (in press) showed that the *A. kawamurai* assemblage is characteristic to a reducing environment in hypoxic bathyal conditions.

2) "*Empleconia*" sp. A - *Neilonella coix* assemblage (localities: NK100U, NK101A-B, NK102)

This assemblage is characterized by dominant "*Empleconia*" sp. A, *Neilonella coix* Habe, and *Bathybembix aeola* (Watson). They are associated with *Acila* sp., *Bathymalletia inaequilateralis* (Habe), and *Neptunea constricta* (Dall). The shells of benthic molluscs sporadically scatter in the massive silt and also form small shell clusters with pteropod shells. The pteropods are warm-water pelagic forms , such as *Clio pyramidata lanceolata* (Lesueur), *C. hataii kakegawaensis* Shibata, *Cavolinia tridentata* (Forskal) var., and *Diacria trispinosa* (Blainville). The mode of occurrence of the benthic molluscs are parautochthonous. Many closed or open but still articulated specimens of bivalves are found. Gastropod shells commonly preserve their protoconchs.

The species composition is comparable to that of the fauna living now in the bathyal zone on the Pacific side of central Japan. Moreover, the constituents of this "*Empleconia*" - *Neilonella* assemblage prefer ordinary oxic bottom environments, whereas the *Akebiconcha* assemblage, noted above, is characteristic of hypoxic bathyal conditions and prefers reducing bottom environments.

With respect to the Hijikata Formation, Nobuhara (1992MS) collected samples from over 30 localities and described some molluscan assemblages. The representatives of them are described below.

3) *Nassaria magnifica* assemblage (localities: U6-11A, and MKCW6)

This assemblage is characterized by abundant occurrences of gastropods such as *Nassaria magnifica* (Lischke), *Parabathytoma luehdorfi* (Lischke), *Makiyamaia coreanica* (Adams et Reeve), *Bathybembix argenteonitens* (Lischke), *Fulgoraria* species, and many minute unidentified gastropods. *Nassaria magnifica* is dominant. Some of the gastropods are living mainly in muddy bottom, 150 to 250 m deep (Chinzei, 1980). Several bivalve species of deep sea facies, such as *Limopsis tajimae* Sowerby, *Yoldia similis* Kuroda et Habe, and *Acila* aff. *divaricata* (Hinds), also are associated with this assemblage. Well preserved shells of gastropods are sporadically disseminated in coarse silt with random orientation. Many gastropod shells have protochonchs preserved. This assemblage is likely to have lived in shelf-edge to uppermost bathyal depths.

4) *Limopsis tajimae* assemblage (localities: U6-8, U11-2, and MKCW7)

This assemblage is characterized by dominant *Limopsis tajimae* Sowerby. This assemblage occurs at many localities in the Hijikata Formation (Chinzei, 1980 ; Nobuhara, 1992MS) and the occurrences of this dominant species have been reported also from the Tamari Formation (Makiyama, 1963 ; Shibata, 1979). Abundant individuals of *Limopsis tajimae* densely aggregate in massive silt, with random shell orientation. Many articulated shells are found. The assemblage is associated with some gastropods, such as *Makiyamaia coreanica* (Adams et Reeve) and *Fulgoraria mentiens* (Fulton). This assem-

blage is considered to have lived in upper bathyal depths on the basis of the data of living species.

5) *Neilonella* assemblage (localities: U9-3, and HY1)

This assemblage is characterized by dominant nuculoid shells. *Neilonella* species are markedly dominant; *Neilonella coix* (Habe) at U9-3; *N. coix* and *Neilonella japonica* Okutani at HY1. Other nuculoid shells such as *Carinineilo carinifera* (Habe), *Bathymalletia inaequilateralis* Habe, and *Nuculana* spp. are commonly associated forms. The shells sporadically scatter in the massive silt. The shells are well-preserved and many are articulated. The fossil occurrences and the species compositions indicate that the shells were deposited in bathyal depths.

Comparison of species composition and mode of occurrence

As noted above, the fossil occurrences in massive silt facies are generally parautochthonous and the assemblages are likely to have lived on a silt bottom in bathyal depths. Several species are common among some of the assemblages. The following three differences, however, are recognized in species composition and in mode of occurrence between the assemblages of the Tamari Formation and the Hijikata Formation.

Firstly, there is a difference in the mode of occurrence of *Limopsis tajimae* and *Bathybembix argenteonitens*. In the Hijikata Formation, they are commonly found in a parautochthonous occurrence. On the contrary, they occur allochthonously in the Tamari Formation associated with the *Akebiconcha kawamurai* and the "*Empleconia*" sp. A-*Neilonella coix* assemblages.

In the Tamari Formation, a few shells of *Limopsis tajimae* occur in a thin sand layer intercalated in massive silt facies at NK100. The surfaces of the shells are abraded. The massive silt yields another "*Limopsis*" species, "*Empleconia*" sp. A, with most of the shells articulated. These fossil occurrences suggest that the habitat depth of "*Empleconia*" sp. A was deeper than that of *Limopsis tajimae*.

A specimen of *Bathybembix argenteonitens* has been obtained in the silt float of the Tamari Formation at Narutaki, but the specimen is a fragment and its occurrence is rare. On the contrary, *Bathybembix aeola* is subdominantly found in the same massive silt and the shells are well-preserved. The present data on the living depths of two species show that the habitat depth of *B. aeola* is generally deeper than that of *B. argenteonitens*. Okutani et al. (1988) stated that the two species are segregated in bathymetric distribution in the central Tosa Bay. *B. argenteonitens* occurs from 400 to 600m deep, whereas *B. aeola* lives below 600m.

Second, the *Akebiconcha kawamurai* and the "*Empleconia*" sp. A-*Neilonella coix* assemblages contain cold water elements that have never been found from the bathyal assemblages in the Hijikata Formation. The cold elements are *Neptunea constricta* and *Solemya johnsoni*. *Neptunea constricta* lives in Kashima-Nada north up to Hokkaido and Japan Sea, 50-300m deep, at present (Higo, 1973). *Solemya johnsoni* lives off Chosi north

to Bering Sea and off California (Habe, 1977). Moreover, subdominant species of the *Akebiconcha* assemblage, *Lucinoma acutilineata* and *Conchocele bisecta*, are considered to have their main distributions in northern sea areas, although they extend their distributions into sea areas to the south of Chosi (Habe, 1977 ; Okutani and Habe, 1975). The fossils of the species have been reported from many formations in Tohoku, Hokkaido, Sakhalin, and Alaska. Noda (1992) compiled the temporal and spatial distributions of the two species to be the Oligocene to Recent of North America and North Pacific region. The occurrences of these cold elements suggest that the two assemblages in the Tamari Formation are likely to have been under the influence of a cold water mass.

On the contrary, almost all of the composite species of the *Nassaria magnifica*, the *Limopsis tajimae*, and the *Neilonella* assemblages show their geographic distributions restricted on the Pacific side of Southwest and/or central Japan. Their northernmost limit is up to Chosi. For example, instead of *Neptunea constricta* in the Tamari Formation, *N. kuroshio* occurs at HY1. The distribution of living *N. kuroshio* is restricted within Southwest Japan (Higo, 1973).

Finally, the sequential change between oxic and reducing conditions, such as the alternation of the *Akebiconcha kawamurai* and the "*Empleconia*" sp. A - *Neilonella coix* assemblages in the Tamari Formation, have not been found at any other localities of the Hijikata Formation. At the localities of the Hijikata Formation, species preferring an ordinary oxic environment sporadically occur throughout the sequence of the massive silt (Fig. 3). Nobuhara and Tanaka (in press) suggested that the alternation of the reducing and oxic assemblages in the Tamari Formation was related to water mass fluctuation controlling the concentration of dissolved oxygen in bathyal depths. In an open oceanic condition such as the Kakegawa basin, a water mass with minimum dissolved oxygen generally develops in bathyal depths.

Bathyal molluscan fauna and water mass structure

On the basis of the facts mentioned above, I depict schematic structure of water masses in Early Pliocene, central Japan (Fig. 4).

The allochthonous occurrence of *Limopsis tajimae* and *Bathybembix argenteonitens*, firstly noted, suggests that the life habitats of the *Akebiconcha kawamurai* and the "*Empleconia*" sp. A - *Neilonella coix* assemblages were deeper than those of the *Nassaria magnifica* and the *Limopsis tajimae* assemblages. According to Chinzei (1980), molluscan faunas comparable to the *Nassaria magnifica* and the *Limopsis tajimae* assemblages are now living near the Pacific coast of central Japan, in the shelf- edge to uppermost bathyal zone and in the upper bathyal zone respectively. Horikoshi (1957) suggested that the faunas in these depths in Sagami Bay, central Japan, are under the influence of the warm Kuroshio water.

Therefore, the cold water, which influenced the *Akebiconcha kawamurai* and the "*Empleconia*" sp. A - *Neilonella coix* assemblages, is estimated to have existed below the paleo-Kuroshio warm water in which the shelf-edge to upper bathyal assemblages flouri-

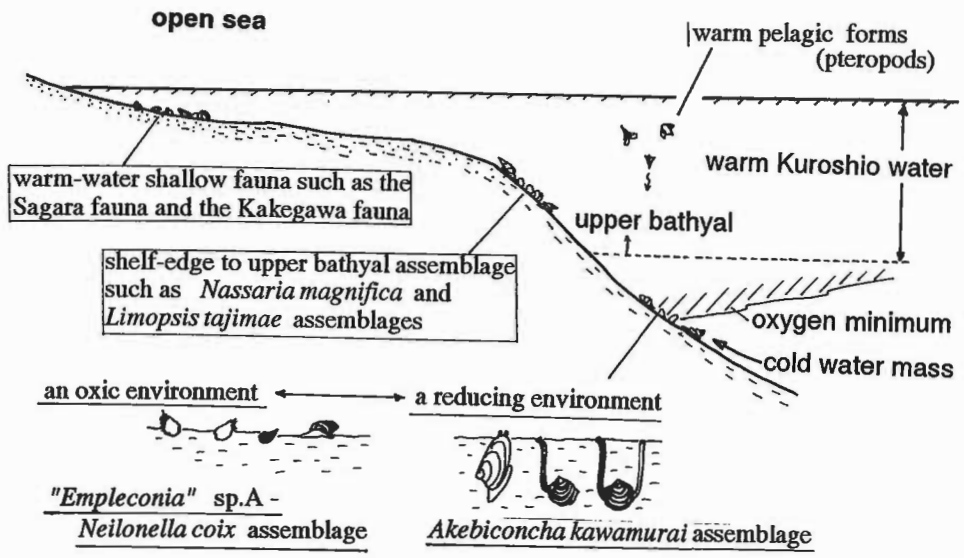


Fig. 4 Schematic cross section of the water mass structure and the distributions of the deep molluscan assemblages in the Kakegawa area, Early Pliocene time.

shed. Shells in the warm water were transported into the assemblages of the Tamari Formation. The occurrence of warm pelagic forms of pteropods in the Tamari Formation supports that the surface water was warm during the depositional period of the Tamari Formation.

Moreover, the oxygen minimum layer intermittently developed near the depths of the cold water mass, as suggested by the occurrence of the reducing, *Akebiconcha kawamurai* assemblage.

The deep assemblages of the Tamari Formation are similar to those of the intermediate water (600-800m) of Sagami Bay in having some cold water elements. Okutani (1968) reported that some species characteristic to the cold Oyashio water, such as *Macoma calcarea* (Gmelin) and *Euspira pallida* (Broderip et Sowerby), occur in the depths of Sagami Bay. Okutani (1968) suggested that their occurrences present some evidence of biological supply from subarctic regions, in spite of recent oceanographers' negative view for the existence of Oyashio Undercurrent.

Therefore, the water mass condition of the Early Pliocene Kakegawa sea was nearly the same as that of Sagami Bay; the shelf and upper bathyal faunas are under the influence of the warm Kuroshio water and the deeper fauna under the influence of cold water mass.

The similar water mass condition was suggested also by the Miocene Morozaki fauna, Chita Peninsula, central Japan. Many authors reported that the Middle Miocene Morozaki Group yields abundant fossils of deep fauna under the influence of cold water mass; marine fish (Ohe, 1990), benthic molluscan assemblages (Shikama and Kase, 1976 ; Shibata, 1977 ; Yamaoka, 1985), and radiolarians (Sugiyama, 1992). In contrast with the cold, deep fauna, in the upper sea layer, warm water pteropods seem to have thrived, as Shibata (1977) suggested. Chinzei (1981) suggested the paleo-Oyashio Cold Undercurrent reached

this sea area in Miocene age, because cold elements of the Chikubetsu fauna, Hokkaido, such as *Portlandia tokunagai*, *Portlandia watasei*, and *Malletia inermis* occurs commonly in the Morozaki Group.

The Pliocene bathyal fauna of cold water mass, reported in this study, presents some basal data for discussion on temporal change of the deep faunas under the influence of cold water mass from the Miocene Morozaki fauna to the living fauna in Sagami Bay.

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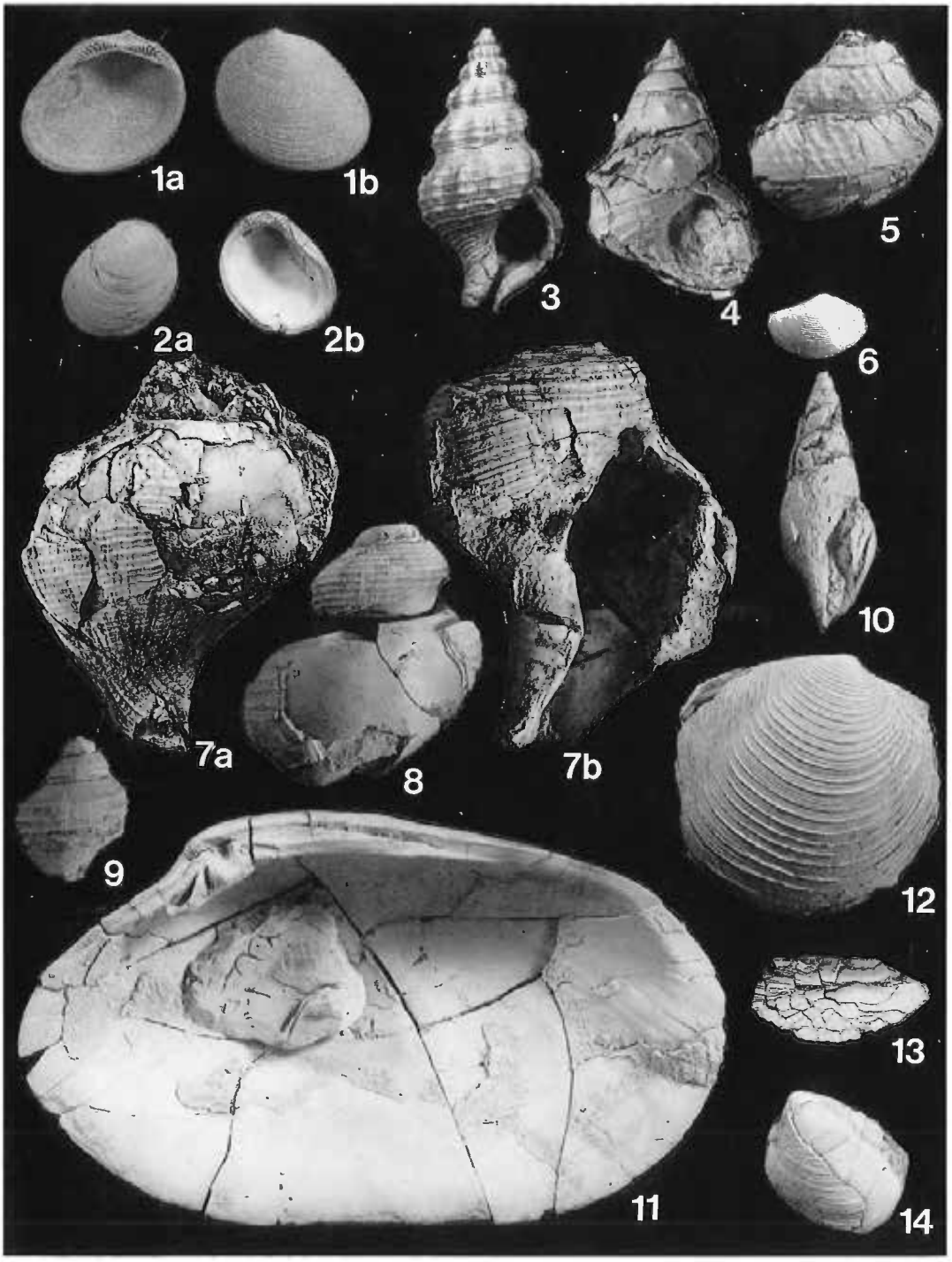
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Plate 68

Characteristic species of the bathyal molluscan assemblages of the Hijikata and the Tamari Formations.

Figs. 1a,b. *Limopsis tajimae* Sowerby, ×1, ESN 50032, about 10m below Loc. U6-11.
Figs. 2a,b. "*Empleconia*" sp. A, ×1, ESN 50001, Loc. NK100U.
Fig. 3. *Nassaria magnifica* (Lischke), ×1.3, ESN 50033, Loc. MKCW6.
Fig. 4. *Bathybembix argenteonitens* (Lischke), ×1, ESN 50038, Loc. MKCW6.
Fig. 5. *Bathybembix aeola* (Watson), ×1, ESN 50002, Loc. NK101A-B.
Fig. 6. *Neilonella coix* Habe, ×2, ESN 50003, Loc. NK100U.
Figs. 7a,b. *Neptunea constricta* (Dall), ×0.8, ESN 50039, Loc. NK102.
Fig. 8. *Neptunea constricta* (Dall), ×1, ESN 50040, Loc. NK10? (float).
Fig. 9. *Neptunea kuroshio* Oyama, ×0.9, ESN 50041, Loc. HY1.
Fig. 10. "*Rectiplanes*" sp., ×0.9, ESN 50042, Loc. NK10? (float).
Fig. 11. *Akebiconcha kawamurai* Kuroda, ×1, ESN 50011, Loc. NK100U.
Fig. 12. *Lucinoma* aff. *acutilineata* (Conrad), ×1, ESN 50005, Loc. NK103.
Fig. 13. *Conchocele bisecta* (Conrad), ×1, ESN 50006, Loc. NK103.
Fig. 14. *Solemya (Acharax) johnsoni* Dall, ×1, ESN 50007, Loc. NK103.


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2a
2b
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7b
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