Molluscan fauna of the “Miocene” Namigata Formation in the Namigata area, Okayama Prefecture, southwest Japan

Abstract

The molluscan fauna of the Namigata Formation, traditionally accepted to be of Miocene age, are reexamined taxonomically, and the geologic age of the formation and its paleogeographic implications are discussed. The formation is subdivided into the main part and two new members (the Senjuin Shell-Sandstone and Ônishi Conglomerate members). The Namigata Formation yielded species of Gastropoda, species of Bivalvia and species of Scaphopoda. The occurrences of Molopophorus watanabei Otuka, Acila (Truncacila) nagaoi Oyama and Mizuno, Chlamys (Nomurachlamys) namigataensis (Ozaki), and Isognomon (Hippochaeta) hataii Noda and Futruichi indicate that the molluscan age should be revised to the late Late Eocene–Early Oligocene. Taking account of the latest elasmobranch data and preliminary strontium isotope ratio, the age of the formation is confirmed to the late Late Eocene. The present and recent results show that the First Seto Inland Sea was actually composed of two sea areas that existed at different times: the Paleogene sea area is estimated to have been an open sea facing south to the Pacific Ocean, whereas that in the Miocene is thought to have been an embayment connected to the northwest to the Sea of Japan. Therefore, the concept of the so-called Miocene First Seto Inland Sea should be reassessed in the Cenozoic geohistory of the Japanese Islands.

Selected molluscan species including Felaniella (Felaniella) namigataensis n. sp. are taxonomically described and/or discussed.

Key words: First Seto Inland Sea, geologic age, Mollusca, Namigata Formation, taxonomy, paleogeography

Introduction

The First Setouchi Series (Kasama and Huzita, 1957; revised by Huzita, 1962) is known to comprise the Lower–Middle Miocene sediments scattered in the Setouchi Geologic Province (Ikebe, 1957) in the central zone of southwest Japan. Recent paleontologic and radiometric studies show that the constituent formations in the coastal areas of the eastern Seto Inland Sea, located in the western part of the province, were not of Miocene age, but were of Eocene–Oligocene age (see Matsubara, 2009 for review). The following marine sediments have been revised as the Eocene–Oligocene: the Tainohata Formation of the Kôbe Group in the west Kôbe area (Ozaki et al., 1996; Matsubara et al., 2010; A in Fig. 1); the Iwaya Formation of the Kôbe Group in the north Awajishima area (Yamamoto et al., 2000b; Yamaguchi et al., 2005; B in Fig. 1); the Maêjima Formation of the Kôbe Group in the Ushimado area (Matsubara et al., 2002b; C in Fig. 1); the Tonoshô Group in the Shôdoshima and Teshima areas (Kurita and Matsubara, 2002; Matsubara, 2002a, c; D, E in Fig. 1, respectively); and the "Bihoku Group” (Tai, 1965) below the Kojima Bay (Kurita et al., 2002; F in Figure 1). In addition, a small outcrop exposure of Upper Eocene–Lower Oligocene marine sediments has been found in the Kurashiki area (Matsubara et al., 2004; Yamaguchi et al., 2008; G in Fig. 1).

The Namigata Formation (Takeyama, 1931) is known as a Miocene fossiliferous formation in the Namigata area, southern Okayama Prefecture, southwest Japan (e.g., Ozaki, 1956b; Itoigawa, 1983; Moriyama et al., 1994a) (Fig. 1). It was also referred to the First Setouchi Series on the basis of its lithology, sedimentary cycle, and molluscan and benthic foraminiferal fossils (e.g., Itoigawa, 1983; Itoigawa and Shibata, 1992; Moriyama et al., 1994a, b; Yano et al., 1995a–c). Based on the benthic foraminiferal assemblages, Yano et al. (1994, 1995a) correlated the Namigata Formation with the Miogypsina kotoi-Operculina complanata assemblage Zone of Nomura (1992), indicating a latest Early–early Middle Miocene age. Yano et al. (1995b, c) also correlated it with Haq et al.’s (1987) third-order cy-
cle TB2.3 (absolute age 16.6–15.5 Ma: Haq et al., 1987) from the sequence chronostratigraphic point of view.

On the other hand, recent reexaminations based on the preliminary strontium isotope ratio and elasmobranch fauna suggest that the Namigata Formation is of Middle–Late Eocene age (Yamamoto et al., 2000a; Tanaka et al., 2006). However, its molluscan fauna has not been fully examined taxonomically, and previous molluscan data include some discrepancies with the latest results because it includes Miocene and younger species (Ozaki, 1956a, b; Itoigawa, 1983). The aim of the present paper is to reexamine the molluscan fauna of the Namigata Formation taxonomically, and discuss its geologic age and implications for the Cenozoic paleogeography of southwest Japan.

Geologic setting

The Namigata Formation has a limited distribution abutting the pre-Cenozoic basement in the mountainous area near the boundary between Ibara City and Yakage Town in the southwestern part of Okayama Prefecture, (Figs. 2, 3). The type locality was designated to be Namigata, Ibara City, Okayama Prefecture (Takeyama, 1931). Its lithology, stratigraphy, paleoenvironment, and sedimentary history were precisely described and discussed by Moriyama et al. (1994a, b) and Yano et al. (1994, 1995a–c).

Moriyama et al. (1994a) subdivided the Namigata Formation into five members (the lowest, lower, middle, upper, and uppermost members) based on their lithology and stratigraphic relationship. However, the nomenclature for these lithostratigraphic units does not follow the International Stratigraphic Guide (Salvador ed., 1994). I herein propose the following subdivision:

1. Main part

The main part of the Namigata Formation is dominated by massive very fine- to fine-grained sandstone attains to 100 m in maximum thickness (Moriyama et al., 1994a). The basal part may be composed of boulder conglomerate more than 10 m in thickness (B in Fig. 3). The sandstone is strongly bioturbated, and sporadically to commonly includes shells of balanids, brachiopods such as Coptothyris sp. and Terebratalia sp., and bivalve mollusks referred to the Acula-Mactra assemblage of Itoigawa (1983). It intercalates thick bioclastic conglomerate and limestone beds (= the Senjuin Shell-Sandstone Member; see below) and is separated into the two portions (Fig. 3).

2. Senjuin Shell-Sandstone Member (new name)

Definition.—Shell-sandstone and limestone beds in the middle part of the Namigata Formation. This member corresponds to the “middle member” of Moriyama et al. (1994a).

Type locality.—An outcrop exposure at a landscape garden in the precincts of the Senjuin Temple, Ibara.
City (A in Figs. 2, 3). The outcrop was figured by Akagi (1927: pl. 2).

Distribution.—The member is distributed at the type locality and the area between the northeast of Itami, Ibara City and the north of Ōnishi, Yakage Town via the north of Namigata (Fig. 2).

Lithology and thickness.—This member is represented by “Namigata-iwa” (meaning wavy rocks in Japanese), which is composed of shell-sandstone and impure limestone. The bioclasts are originated from molluscs, brachiopods, bryozoans, foraminifers, and calcareous algae (Yano et al., 1995a). Bedding planes are generally weak due to the strong bioturbation. At the type locality, the basal part of the member is composed of an about 3 m-thick, pebble to cobble conglomerate bed consisting of subangular gravels. It is conformably covered by shell-sandstone and limestone more than 5 m in thickness (A in Fig. 3). Although the thickness of the member is generally 10 to 15 m (Moriyama et al., 1994a), it decreases to about 2 m in the northeast of Ōnishi, Yakage Town (F in Fig. 3).

Stratigraphic relations.—It is intercalated in the middle part of the main part. It also abuts on the basement.

3. The Ōnishi Conglomerate Member (new name)

Definition.—Thick cobble to boulder conglomerate beds occupying the uppermost part of the Namigata Formation. This member corresponds to the “uppermost member” of Moriyama et al. (1994a).

Type locality.—An exposure at the upper portion of an abandoned sandpit in the northwest of Ōnishi, Yakage Town (E in Figs. 2, 3).

Distribution.—The member has small distributions on mountains higher than an altitude of about 300 m between the north of Nanayashiki and the type locality, and higher than an altitude of about 320 m in the west and northwest of Senjuin Temple (Fig. 2).

Lithology and thickness.—This member is characterized by massive cobble to boulder conglomerate, which is generally weathered. Its lithofacies is closely similar to that of the Kibi Group (Suzuki et al., 2003) composed...
of fluvial “mountain gravels” (Suzuki et al., 2009). However, Yano et al. (1994) and Moriyama et al. (1994a) included it in the Namigata Formation because a marine bivalve “Cardium” sp. was discovered from this member (Yano et al., 1994). The thickness is evaluated to be more than 10 m, although its upper limit is not observed.

Stratigraphic relations.—It disconformably overlies the main part of the Namigata Formation, and abuts on the basement.

Material and method

Molluscan material has been collected from three localities in the lower portion of the main part, two localities in the Senjuin Shell-Sandstone Member, and three localities in the upper portion of the main part (Figs. 2, 3). Among these, the material from two localities (NON-01 and NON-02) is that collected by Mr. Satoshi Morinobu of the Kasaoka City Horseshoe Crab Museum. The molluscan specimens from the main part were poorly preserved except for those in Loc. NON-01, and they occurred as molds in brittle sandstone. To examine the precise shell characteristics, a silicon vinyl dental impression material (Provil Novo® Putty Fast Set, Heraeus-Kluzer Co., Ltd.) was used during sampling in the field and preparation in the laboratory.

Results and discussion

1. Geologic age of the Namigata Formation

Thirteen species of Gastropoda, 16 species of Bivalvia, and one species of Scaphopoda were discriminated from the Namigata Formation (Table 1, Figs. 4–7). The following species are biostratigraphically important: Isognomon (Hippochaeta) hataii Noda and Furuichi, Acila (Truncacila) nagaai Oyama and Mizuno, Chlamys (Nomurachlamys?) namigataensis (Ozaki), and Molo- pophorus watanabei Otuka. I. (H.) hataii was described from the Eocene Teshima Formation of the Tonoshô Group on Teshima Island, northern Kagawa Prefecture, southwest Japan (Noda and Furuichi, 1972; Noda, 1982). Subsequently, it was also reported from the Eocene Shikai Formation on Shôdoshima Island and from the Middle Eocene–Oligocene Maéjima Formation (Noda, 1982; Matsubara, 2002b). A. (T.) nagaai was considered to be one of the index species of the Maze Stage (Mizuno, 1962) of uppermost Eocene–lowest Oli-

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<th>Table 1. Mollusca from the Namigata Formation. R: rare; F: few; C: common; A: abundant; +: present.</th>
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<tr>
<td><strong>Species name / Locality</strong></td>
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<tr>
<td>Gastropoda</td>
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<td>Cellana? sp. indet.</td>
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<td>Lottia? sp. indet.</td>
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<td>Margaritaria? sp. indet.</td>
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<td>Sinum sp. aff. S. zonale (Quoy and Gaimard)</td>
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<td>Truertella (Kotakaella) sp. aff. T. (K.) infrirata Nago</td>
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<td>Hipponius? sp. indet.</td>
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<td>Epitonidae, gen. et sp. indet.</td>
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<td>Molopophorus watanabei Otuka</td>
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<td>Mollusca? sp. indet.</td>
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<td>Exilia sp. indet.</td>
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<td>Ficus sp. indet.</td>
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<td>Turbonilla? sp. indet.</td>
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<td>Bivalvia</td>
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<td>Acila (Truncacila) nagaai Oyama and Mizuno</td>
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<td>Saccella sp. indet. A</td>
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<td>Glycemeris? sp.</td>
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<tr>
<td>Isognomon (Hippochaeta) hataii Noda and Furuichi</td>
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<td>Aceta (Plicaceta) takeyamai (Ozaki)</td>
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<td>Modiolus sp. indet.</td>
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<td>Septifer sp. indet.</td>
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<td>Chlamys (Nomurachlamys?) namigataensis (Ozaki)</td>
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<td>Crassostrea sp. indet.</td>
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<td>Cyclocardia sp. indet.</td>
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<td>Fasciolaria (Fasciolaria) namigataensis n. sp.</td>
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<td>Caltellus sp. indet.</td>
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<td>Glauconome sp. indet.</td>
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<td>Liocoma sp. indet.</td>
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<td>Macromeris sp. indet.</td>
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<td>SCAPHOPODA</td>
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<td>Dentaliidae, gen. et sp. indet.</td>
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and Okada, 1984; Okada, 1992). However, its upper limit reaches to the Nishisonogi Stage of Oligocene age (Fuse and Kotaka, 1986; Tomita and Ishibashi, 1990). \(M. \text{watanabei}\) occurs in the Iwaki and Asagai formations of the Shiramizu Group, and is known as one of the representative elements of the Asagai Fauna (Makijama, 1934). As summarized by Matsubara et al. (2010), the geologic age of the Shiramizu Group is Late Eocene–Early Oligocene on the basis of planktonic microfossils and a mammal \(Entelodon\ cf.\ orientalis\) Dashzeveg from the upper part of the Iwaki Formation (Tomida, 1986; Yanagisawa and Suzuki, 1987; Kurita, 2004). \(M. \text{watanabei}\) was also recorded from the upper Lower–Lower Upper Oligocene Ashiya Group in the Chikuhô Coalfield, northern Kyûshû, southwest Japan (Hirayama, 1956; Tomita and Ishibashi, 1990). The planktonic foraminifer and calcareous nannofossil assemblages indicate the geologic age of the Ashiya Group to be the late Early–early Late Oligocene (Saito and Okada, 1984; Okada, 1992). \(Ch.\ (N.?\) \namigataensis\) was originally described from the Namigata Formation, and was subsequently recorded from the Eocene or Oligocene Maëjima Formation on Maëjima Island (Matsubara, 2002b). Matsubara (2002b) also identified \(Chlamys\ ashiyaensis\) (Nagao) and \(Patinopecten\) sp. of Nemoto and O’Hara (2001) from the uppermost Eocene–lower Oligocene Iwaki Formation of the Shiramizu Group to be the present species.

Nishimoto and Itoigawa (1977) pointed out that the Namigata Formation yields the \(Odontaspis-Heterodon-\) tus elasmobranch assemblage including \(Carcharodon\\) angustidens Agassiz. As this assemblage is shared with those in the Ashiya Group in the Chikuhô area in northern Kyûshû, the Iwaki Group in the Kottoi and Yuyawan areas in westernmost Honshû, southwest Japan, Nishimoto and Itoigawa (1977) considered that the geologic age of the Namigata Formation is probably older than that of the major constituent formations of the Miocene First Setouchi Series. The geologic ages of the Ashiya and Hioki groups were believed to be Early Miocene at that time, they were later revised as Oligocene based on planktonic microfossils and radiometric dating (Saito and Okada, 1984; Fuse and Kotaka, 1986; Okada, 1992; Ozaki and Hamasaki, 1991; Ozaki, 1999). Subsequently, Yamamoto et al. (2000a) preliminarily assessed the geologic age of the so-called Miocene First Setouchi Series in the coastal area of the eastern Seto Inland Sea, including the Namigata Formation based on the stronitum isotope. They reported a \(^{87}\text{Sr}/^{86}\text{Sr}\) ratio of ca. 0.7077%, indicating a Late Eocene or older age (e.g., Ito, 1993; Howarth and MacArthur, 1997) for these formations. Tanaka et al. (2006) taxonomically reexamined elasmobranch fauna in the Namigata Formation, and concluded this formation is of Middle–Late Eocene age on the basis of the occurrences of \(Carcharodes\ auriculatus\) (Blainville), \(Physogaleus\ secundus\) (Winkler), and \(Hemipristis\ curvatus\) Dames. These data suggest that the upper limit of the Namigata Formation is confined to the Eocene. In conclusion, the geologic age of the Namigata Formation is late Late Eocene, on the basis of integrated mollusc, elasmobranch and strontium isotope ratio data.

2. Paleogeographic implication

It has been known that the molluscan assemblages in the western part of the Setouchi Geologic Province differ significantly between the west-northwestern area (= Bihoku Belt: Yano et al., 1995b) and the east-southeastern area (= Setouchi Êngan Belt: Yano et al., 1995b). Faunal differences occur not only in terms of the generic and specific compositions but also in terms of paleoenvironmental nature (e.g., Itoigawa, 1969, 1971, 1983; Okamoto, 1974; Itoigawa and Shibata, 1992). The west-northwestern area is represented by the \(Cyclina-Vicarya\) and \(Vasticardium\) assemblages, which represent brackish intertidal sandy bottom and upper sublittoral sandy bottom environments in an embayment, respectively. On the other hand, the east-southeastern area is characterized by the \(Ostrea\) and \(Mactra-Acila\) assemblages, indicating open, rocky or gravelly bottom and sublittoral sandy bottom environments, respectively (Itoigawa, 1983; Itoigawa and Shibata, 1986, 1992; Ueda, 1991).

Three major opinions have been proposed to explain the differences. The first was proposed by Itoigawa and Shibata (1992), who considered that the difference is due to the restricted inflow of open sea waters into the southeastern part of the First Seto Inland Sea from the Pacific Ocean, and that two sea areas were connected through Early–Middle Miocene time. The second is advocated by Ueda (1991) and Takayasu et al. (1992), who thought that the difference is due to a geographic barrier formed by tectonic movement in the Early–Middle Miocene. The third is a compromise between Itoigawa and Shibata’s (1992) and Takayasu et al.’s (1992) opinions. Yano et al. (1995a–c) considered that the First Seto Inland Sea was divided initially into two sea areas by the geographic barrier, and two areas were connected by the subsequent transgression. These three opinions are based on the premise that all constituent formations of the First Setouchi Series are of Early–Middle Miocene age.

On the other hand, as a result of reexamination of the
molluscan fauna from the Maéjima Formation, Matsubara (2002b) considered that the difference can be attributed to differences in the geologic age of the First Setouchi Series between the two areas. The result from the Namigata Formation supports my previous view (Matsubara, 2002b), and shows that the so-called Miocene First Seto Inland Sea was a combination of two geochronologically distinct sea areas. One is of late Early–early Middle Miocene age in the Bihoku Belt, and the other is of late Middle Eocene–Early Oligocene age in the Setouchi Éngan Belt. As suggested by Yano et al. (1995c), the Paleogene sea area in the Setouchi Éngan Belt was an open sea facing south to the Pacific Ocean. On the other hand, the Miocene sea area in the Bihoku Belt was a bay facing northwest to the Sea of Japan (Itoigawa and Shibata, 1992; Takayasu et al., 1992; Yano et al., 1995c). Therefore, the concept of the “First Seto Inland Sea” should be reassessed in the Cenozoic geohistory of the Japanese Islands. As Eocene–Oligocene marine sediments in the coastal area of the eastern Seto Inland Sea are sporadic and their precise geologic age has not fully been dated, further biostratigraphic and geochronologic studies are necessary to reconstruct the precise paleogeography of the Paleogene sea area and its temporal change.

Systematic description of selected species

Abbreviations.—GSJ: Geological Survey of Japan, AIST; IGPS: Tohoku University Museum (formerly housed at Institute of Geology and Paleontology, Tohoku University); MNHAH: Museum of Nature and Human Activities, Hyogo; NMNS: National Museum of Nature and Science.

Class Gastropoda
Genus Molopophorus Gabb, 1869
Type species.—*Bullia* (Molopophorus) striata Gabb, 1869 by original designation.

Discussion.—The taxonomical status of the genus *Molopophorus* Gabb, 1869 is controversial (e.g., Nuttall and Cooper, 1973; Cernohorsky, 1984; Allmon, 1990; Squires, 1997; Haasl, 2000), because the type species *Bullia* (Molopophorus) *striata* Gabb, 1869 was described based on a few, minute, incomplete specimens from the Upper Eocene Tejon Formation of California, U.S.A. Cernohorsky (1984) and Haasl (2000) treat *Molopophorus* Gabb, 1869 as a nomen dubium. Nuttall and Cooper (1973) thought it to be invalid, because they assumed that *B. (M.) striata* is a juvenile of *Brachysphingus sinuatus* Gabb, 1869, the type species of *Brachysphingus* Gabb, 1869. Allmon (1990) followed Nuttall and Cooper’s (1973) view. However, Squires (1997) did not concur with their opinion because *B. (M.) striata* differs significantly from *Brachysphingus* spp. being much smaller and having a subsutural band. I agree with Squire’s (1997) view because the early whorl sculpture of *B. (M.) striata* seems to be different from that of *B. sinuatus*.

Nuttall and Cooper (1973) also believed that *Molopophorus striata* [sic] of Dickerson (1915: pl. 8, fig. 7) from the Tejon Formation of California is not conspecific with Gabb’s (1869) species, and regarded it as an indeterminate species in the genus *Colwellia* Nuttall and Cooper, 1973. However, I consider that the type species of *Colwellia, Cominella flexuosa* Edwards in Lowry, 1866, is not congeneric with the North Pacific species because it has shouldered whorls, a finer, less granulated subsutural band, and dentitions on the inner side of the outer lip. In my opinion, Dickerson’s (1915) figured specimen is correctly identified, and the obsolete axial ribs in the lectotype and an additional specimen figured by Nuttall and Cooper (1973: pl. 8, figs. 1a–b, 2) are due to abrasion of the shell surface. Therefore, I herein treat the genus *Molopophorus* Gabb, 1869 as a valid genus in the family Nassariidae.

*Molopophorus watanabei* Otuka, 1937

(Figs. 4.4–4.6)


*Molopophorus watanabei* Otuka, 1937, p. 170–171, pl. 16, figs. 5–7; Hirayama, 1955, p. 119, pl. 4, figs. 21, 22; Oyama et al., 1960, p. 74, pl. 14, figs. 4a–c; Kamada, 1962, p. 170–171; Shikama, 1964, p. 108, pl. 31, fig. 25; Tomita and Ishibashi, 1990, pl. 15, fig. 10.

*Molopopholus* [sic] *watanabei* Otuka. Kamada, 1962, pl. 20, fig. 8; Kamada, 1972, pl. Pg-6, fig. 19; Nemoto and O’Hara, 1979, pl. 2, figs. 16a–b; Nemoto and O’Hara, 2001, pl. 5, fig. 16; Nemoto and O’Hara, 2007, pl. 2, fig. 9.

? *‘Nassarius’* sp. Itoigawa, 1983, p. 32. [listed only]

Type material.—UMUT CM13143 (holotype); UMT CM13143–CM13145 (paratypes). All the type material is missing (Ichikawa, 1983).

Material examined.—MNHAH D1-31932 (from Loc. NM01); D1-31936–31938 (from Loc. NM02).

Discussion.—The species from the Namigata Formation can be safely referred to *Molopophorus watanabei* Otuka, 1937, from the lowest Oligocene Asagai Formation in the Jôban area, Fukushima Prefecture, northeast Japan, on the basis of a rather small ovoidal shell with
rounded axial ribs which tend to become obsolete and broader with shell growth, two strong keels on the fasciole, and the lack of a distinct spiral sculpture except for a weakly granulated subsutural band.

Korobkov in Zhidkova et al. (1994) ["1992"] described a new subspecies, *Molopophorus watanabei costulatus*, from the Upper Oligocene Nevelskaya Suite in the Makarov area, South Sakhalin. This subspecies is
easily distinguished from *M. watanabei* by its less developed subsutural band and its body whorl sculptured with feeble axial ribs in greater numbers. It should be treated as a distinct species belonging to the genus *Nassarius* Duméril, 1806, because it seems to lack a few strong keels on the fasciole. *Molopophorus ornatus* Devjatilova in Devjatilova and Volobueva, 1981, from the Eocene Gektinsksyaya Suite in the Panzhina Inlet coastal area, Russia, closely resembles *M. watanabei*. However, it is distinguished from *M. watanabei* by having a smaller shell with more rounded, broader axial ribs. *Molopophorus ovumiformis* Oleinik in Sinelnikova et al., 1991 from the Eocene Snatolskaya Suite is another allied species. However, this species differs from *M. watanabei* in having greater numbers of finer axial ribs on the body whorl. *M. watanabei* is easily distinguished from *Molopophorus denselineatus* (Nagao, 1928), from the Oligocene Aishya Group in the Chikuhô area, northeast Kyûshû, southwest Japan, by having a lower, larger shell with smaller numbers of axial ribs, and lacking a distinct spiral sculpture. As the anterior part of the shell is unknown, its generic position remains uncertain.


Class Bivalvia
Family Nuculidae
Subfamily Nuculinae
Genus *Acila* H. Adams and A. Adams, 1854 *in H. Adams and A. Adams*, 1853–1858
Subgenus *Truncacila* Grant and Gale, 1931 *ex Schenck MS*

**Type species.**—*Nucula castrensis* Hinds, 1843 by original designation.

**Acila (Truncacila) nagaoi** Oyama and Mizuno, 1958
(Figs. 5.6–5.9, 5.12)

*Nucula (Acila) mirabilis* var. *ashiyaensis* Nagao, 1928, pl. 7, figs. 8, 9. [non Nagao, 1928]

*Acila nagaoi* Mizuno (MS). Mizuno, 1956, p. 270, pl. 2, fig. 1. [nomen nudum]

*Acila (Truncacila) gottschei* (Böhm). Ozaki, 1956a, p. 7 [listed only]; Ozaki, 1956b, p. 12. [non Böhm, 1916]

*Acila (Truncacila) nagaoi* Oyama and Mizuno, 1958, p. 595–596, pl. 1, figs. 14, 15; Oyama et al., 1960, p. 101, pl. 21, figs. 1a–b; Kamada, 1980, pl. Pg-19, figs. 1, 2; Tomita and Ishibashi, 1990, pl. 14, figs. 7a–b.

**Acila (Truncacila) sp.** Itoigawa, 1983, p. 32. [listed only]

*Acila (Truncacila) cf. nagaoi* Oyama and Mizuno. Fuse and Kotaka, 1986, pl. 17, figs. 2–4.

*Acila (Truncacila) cf. nagaoi* Oyama and Mizuno. Matsubara, 2002b, p. 134, fig. 5.4.

**Material examined.**—GSJ F5019 (holotype); GSJ F5020 (paratype). MNHAH D1-031943–D1-031946 (from Loc. NM01); D1-031947–D1-031949 (from Loc. NM02); D1-031950–D1-031954 (from Loc. NON03); D1-031955–D1-031963 (from Loc. WON01); D1-031964–D1-031967 (from Loc. WON02).

**Discussion.**—Ozaki (1956a, b) reported *Acila (Truncacila) gottschei* (Böhm, 1916) from the Namigata Formation. The named species was originally described from the “Cretaceous” [= Middle Miocene Sertunayskaya Suite: Kogan, 1939] in Sakhalin. However, the illustration of the lectotype (Böhm, 1916: pl. 29, fig. 6) designated by Schenck (1936) seems to be different from *A. (T.) nagaoi* in having a more rounded shell. According to Kafanov et al. (1999), the type material of *Nucula (Acila) gottschei* Böhm, 1916 is missing today.

The Namigata species closely resembles *Acila (Truncacila) nagaoi* Oyama and Mizuno, 1958 (Fig. 5.8) from the uppermost Eocene–lowest Oligocene Kishima Formation in the Karatsu area, Saga Prefecture, southwest Japan, but has a slightly larger shell and may have a feeble rostral sinus (Fig. 5.9). However, the younger individuals have the same shell outline and lack a rostral sinus. Therefore, I consider the Namigata specimens to fall within the intraspecific variation of *A. (T.) nagaoi*.

*Acila (Truncacila) nagaoi* closely resembles *Acila (Truncacila) schumardi* (Dall, 1909), the type species of the subgenus *Lacia* Slodkewitsch, 1667. However, *A. (T.) nagaoi* is distinguished from *A. (T.) schumardi* by having a shorter, more inflated shell with coarser external sculpture. As pointed out by Moore (1976), the subgenus *Lacia* Slodkewitsch, 1667 is hardly distinguished from *Truncacila* Grant and Gale, 1931. *Acila (Truncacila) decisa* (Conrad, 1855) from the Eocene Ardath Shale of California, U.S.A., differs from *A. (T.) nagaoi* the shell being smaller and more equilateral. *Acila (Truncacila) oyamadensis* Hirayama, 1955 from the Oligocene Asagai Formation in the Jôban area, northeastern Honshû, Japan, is distinguished from *Acila (Truncacila) nagaoi* by having a smaller, more rounded, higher shell with a less developed escutcheon. *Acila (Truncacila) nagaoi* is distinguished from *Acila (Truncacila) picturata* (Yokoyama, 1890) from the upper Middle–Upper Eocene Poronai Formation in Hokkaidô, northeast Japan, by having a shorter posterior dorso-ventral margin.
Mizuno (1964: p. 55) proposed *Acila (Truncacila) hirayamai* with the following remarks: “*A. hirayamai* is anew named for the Nishisonogian shell which has large angle of bifurcation of ribs”. Although the type material was neither designated nor illustrated, this name is available according to ICZN Art. 13.1.1 because it includes the diagnostic characters. In addition, he noted that *Acila* sp. reported by Hirayama (1956) from the Ashiya Group on Hikoshima (Hirayama, 1956, p. 102, pl. 6, figs. 2–4) is surely referable to this new species.” However, Hirayama’s (1956) illustrated specimens are too poorly preserved to discern its shell characteristics, and are missing today. In addition, I could not find any type material of *A. (T.) hirayamai* in the GSJ collection. Therefore I herein treat this taxon as a non *dubium*. Although *Acila (Acila) ashiyaensis* (Nagao, 1928) from the Oligocene Yamaga Formation of the Ashiya Group has a nearly same shell size to *A. (T.) nagaoi*, it has a distinct rostral sinus even in the younger shell (Fig. 5.13).

**Distribution.**—Maze, Itanoura, Kakinoura formations in Sakito-Matsushima area, Nagasaki Prefecture; Kishima Formation in Karatsu area, Saga Prefecture; Ashiya Group in the Umashima area, Fukuoka Prefecture; Kiwado Formation of Hioki Group in Yuyawan area, Yamaguchi Prefecture; Maéjima Formation in Ushimado area, Okayama Prefecture. Latest Eocene–Late Oligocene.

Family *Pectinidae*

Subfamily *Chlamydinae*

Genus *Chlamys* [Röding], 1798

Subgenus *Nomurachlamys* Kurihara and Matsubara in Kurihara, 2010

**Type species.**—*Pecten kaneharai* Yokoyama, 1926 by original designation.

*Chlamys (Nomurachlamys?)*

namigataensis (Ozaki, 1956a)

(Figs. 6.1–6.4)

*Pecten (Chlamys) namigataensis* Ozaki, 1956a, p. 7–8, pl. 2, fig. 4; Ozaki, 1956b, p. 12.

Non *Chlamys (Mimachlamys) namigataensis* (Ozaki).

Masuda, 1962, p. 188, pl. 21, fig. 1. [= *Chlamys (Nomurachlamys) aff. meisensis* (Makiyama, 1936)]


*Chlamys namigataensis* Ozaki [sic]. Itoigawa, 1983, p. 38. [listed only]

*Chlamys ashiyaensis* (Nagao). Nemoto and O’Hara, 2001, pl. 2, fig. 2. [non Nagao, 1928]

*Patinopecten* sp. Nemoto and O’Hara, 2001, pl. 2, fig. 3.

*Chlamys (Leochlamys) namigataensis* (Ozaki). Matsubara, 2002b, p. 139–140, figs. 5.13, 5.14, 6.12, 6.15.

**Material examined.**—NSMT P1-4379 (holotype); MNHAH D1-031999–D1-032000 (from Loc. NM03; presumable topotypes); D1-032001–D1-032003 (from Loc. NON02); D1-032004 (from Loc. NON03).

**Discussion.**—The present species was originally described from the Namigata Formation and is characterized by its rather large shell with 14–15, highly elevated radial ribs with fine striations with a scaly sculpture on the back, and a large anterior auricle with a deep byssal notch. Matsubara (2002b) thought this species to be a member of the subgenus *Leochlamys* MacNeil, 1967 (type species: *Chlamys (Leochlamys) tugidakensis* MacNeil, 1967) in the genus *Chlamys* [Röding], 1798. However, it is tentatively transferred to the subgenus *Nomurachlamys* Kurihara and Matsubara in Kurihara, 2010 (type species: *Pecten kaneharai* Yokoyama, 1926) on the basis of the shell sculpture consisting of subregular, stout radial ribs with a few fine, scaly ribs on the radial ribs, an interstitial rib and shagreen microsculpture, and a large anterior auricle. A single left valve (Fig. 6.2) has eleven highly elevated radial ribs. The numbers are smaller than the typical specimens, including the holotype. However, it is thought to fall within intraspecific variation, because other shell characters including a large anterior auricle and scaly fine ribs on the radial ribs are identical to *Ch. (N.?*) namigataensis.

**Distribution.**—Namigata Formation (Ozaki, 1956a, b; this study); Maéjima Formation (Matsubara, 2002b); Iwaki Formation (Nemoto and O’Hara, 2001, as “*Chlamys ashiyaensis* Nagao” and “*Patinopecten* sp.”). Late Eocene–Early Oligocene.

Family *Limiidae*

Genus *Acista* H. Adams and A. Adams, 1857 in H. Adams and A. Adams, 1853–1858

Subgenus *Plicacerta* Yokose, 1963

**Type species.**—*Lima smithi* Sowerby, 1888 by original designation.

*Acista (Plicacerta) takeyamai* (Ozaki, 1956a)

(Figs. 6.5–6.8)

*Lima smithi* Sowerby. Takeyama, 1933, p. 434. [non Sowerby, 1888]

*Lima takeyamai* Ozaki, 1956a, p. 8, pl. 2, fig. 3; Ozaki, 1956b, p. 11, 12; Masuda and Noda, 1976, p. 85–86.
Lima (Acesta) takeyamai Ozaki. Okamoto and Nakano, 1967, p. 188.

Material examined.—NMNS P1-4380 (holotype); GSJ F15891-1 (= F16689-2) and F15891-2 (K. Okamoto Collection; plaster replicas); MNHAH D1-0031985–D1-031988 (from Loc. NM03; presumable topotypes); D1-031989–D1-031994 (from Loc. NON02); D1-031995–D1-031996 (from Loc. NON03).

Description.—Shell large (shell height to 115 mm), rather thin, higher than long, inequilaterally, posteriorly oblique ovate, weakly inflated; anterior auricle small but thick; posterior auricle rather long, indistinctly defined from disc; anterior dorsal margin long, nearly straight; hinge line straight, moderately long; posterior margin gently curved; ventral margin arcuate; shell surface sculpture of 40–59 strong, rounded or flat topped radial ribs and irregularly strengthened commarginal growth lines; weak scaly sculpture may be present on radial ribs.

Discussion.—Takeyama (1933) identified the present species as Lima smithi Sowerby [= Acesta (Plicacesta) smithi (Sowerby, 1888)] living off Japan at 100–600 m depth, although he pointed out that the specimens from the Namigata Formation have smaller numbers of radial ribs (ca. 40) than those (47–56; Oyama, 1943) of the Recent species. Subsequently, Ozaki (1956a) thought this difference to be sufficient to separate the Namigata species from the Recent one, and proposed a new species, Lima takeyamai. Nakano and Okamoto (1982) treated it as a valid species, and transferred it to the subgenus Plicacesta Vokes, 1963 in the genus Acesta H. Adams and A. Adams, 1854 in H. Adams and A. Adams, 1853–1858.

As a result of reexamination of the type and additional specimens, it became obvious that the number of radial ribs ranges from 40 to 59. This range overlaps those of the Recent Acesta (Plicacesta) smithi. However, A. (P.) takeyamai is distinguished from A. (P.) smithi by having a higher, less inflated shell with a larger posterior auricle, and stronger, flat- or round-topped radial ribs. This species differs from Acesta (Plicacesta) amaxensis (Yokoyama, 1911) from the Middle Eocene Sakasegawa Group in the Amakusa Islands, Kyushu, southwest Japan, in being higher in outline. A. (P.) takeyamai is also separated from Acesta (Plicacesta) watanabei Nakano and Okamoto, 1982 from the Middle Miocene Taisha or Tadaūra Formation in the western Shimane Peninsula, southwest Japan, by its higher, less inflated shell with smaller anterior auricle and larger posterior auricle, and smaller numbers of radial ribs.

Distribution.—Known only from the Namigata Formation. Late Eocene.

Family Carditidae
Subfamily Carditimerinae
Genus Cyclocardia Conrad, 1867
Type species.—Cardita borealis Conrad, 1832, by original designation.

Cyclocardia sp. indet.
(Fig. 7.6)

Cyclocardia siogamensis (Nomura). Itoigawa, 1983, p. 38. [listed only] [non Nomura, 1935]

Material examined.—MNHAH D1-032007 and D1-032008 (both from Loc. WON02).

Discussion.—The species from the Namigata Formation has a small (shell length to 10 mm), circular, moderately inflate shell with 27–31, narrow, roof-topped radial ribs and a small, deeply concave lunule. Cyclocardia siogamensis (Nomura) listed by Itoigawa (1983) is probably the present species. However, C. siogamensis (Nomura, 1935), originally described from the Lower Miocene Ajiri Formation in the Shiogama area, Miyagi Prefecture, northeast Japan, differs from the Namigata species in having a smaller numbers of, more rounded radial ribs (see Sonpirom and Ogasawara, 1997). Cardium? sp. of Yano et al. (1994) from the "uppermost member" [= the Ōnishิ Conglomerate Member in this study] of the Namigata Formation is probably the present species. However, it is represented only by small inner molds derived from a single specimen and precise determination can not be made.

Family Ungulimidæ
Genus Felaniella Dall, 1899
Subgenus Felaniella Dall, 1899
Type species.—Mysia (Felania) ustæ Gould, 1861 by original designation.

Felaniella (Felaniella) namigataensis new species
(Figs. 7.1–7.4, 7.10a–b)

? Cycladiacama takeyamai (Otuka). Itoigawa, 1983, p. 31. [listed only] [non Otuka, 1938]

Diplodonta? sp. Itoigawa, 1983, p. 32. [listed only]

Type material.—MNHAH D1-032009 (holotype; from Loc. NM01); D1-032010 (paratype from Loc. NM01);
D1-032011 and D1-032012 (paratypes from Loc. NM02); D1-032013–D1-032017 (paratypes from Loc. WON02).

Other material examined.—MNHAH D1-032018–D1-032020 (from Loc. WON02; all specimens are silicon vinyl casts lacking original molds).

Type locality.—Loc. NM-01. A small roadside cliff at Namigata, Nogami-chô, Ibara City, Okayama Prefecture (34°37’31”N, 133°31’19”E).

Diagnosis.—Felaniella (Felaniella) with small, circular, nearly equilateral, weakly inflated shell, narrow hinge plate, and small teeth.

Etymology.—Named after Namigata, the type locality.

Description.—Shell small (length to 12 mm), circular, weakly inflated; beak small, weakly prosocline, situated rather anteriorly to mid-point of shell length; anterior dorsal margin short, weakly recurved; posterior dorsal margin nearly straight; anterior margin gently arcuate; ventral margin weakly curved, posterior margin subtruncated; shell surface sculpture of very fine, irregular, commarginal growth lines; posterior ridge indistinct; hinge plate narrow, with two cardinal teeth; left valve anterior tooth nearly perpendicular, trigonal, bifid; left valve posterior tooth anteriorly oblique, narrow;

<table>
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<th>MNHAH reg. no.</th>
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<th>Height</th>
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<th>Remarks</th>
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<td>Holotype</td>
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<td>8.6</td>
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<td>Paratype</td>
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<td>9.2</td>
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Fig. 7. Bivalvia from the Namigata Formation (3). All specimens are silicon vinyl cast, unless otherwise stated. 1–4, 10. Felaniella (Felaniella) namigataensis n. sp. 1. MNHAH D1-032014. Internal view of left valve. 2. MNHAH D1-032019. Internal view of right valve. 3. MNHAH D1-032018. Internal view of right valve. 4. MNHAH D1-032013 (Paratype). Right valve. 10. MNHAH D1-032009 (Holotype). Left valve. 10a. Internal view, 10b. External view. All views are ×2.5. 5. Felaniella (Felaniella) confusa (Nagao). IGPS 36358 (Holotype). Left valve, ×2. Shown for comparison. 6. Cyclocardia sp. indet. MNHAH D1-032007. Left valve, ×2.5. 7. Liocyma sp. indet. MNHAH D1-032023. Internal view of left valve. ×2.5. 8. Cultellus sp. indet. MNHAH D1-032021. Internal view of fragmental right valve, ×1.5. 9, 12, 13. Mactromeris sp. indet. 9. MNHAH D1-032026. Cardinal properties of right valve. 12. MNHAH D1-032024. Inner mold of left valve. 13. MNHAH D1-032031. Left valve. All views are ×1.
right valve anterior tooth perpendicular, narrow; right valve posterior tooth anteriorly oblique subtrigonal, bifid; nymph narrow; adductor muscle scars and pallial line indistinct; ventral margin smooth.

Discussion.—Felaniella (Felaniella) namigataensis n. sp. closely resembles Felaniella (Felaniella) confusa (Nagao, 1928) from the Oligocene Yamaga Formation of the Ashiya Group in the Chikuhô Coalfield, Kyûshû, southwest Japan (Fig. 7.4). However, F. (F.) confusa differs from F. (F.) namigataensis n. sp. in having a larger shell (shell length to 20 mm) with a longer posterior dorsal margin, a broader hinge plate and larger cardinal teeth (see Okamoto and Sakai, 1995: pl. 9, figs. 6, 7). Felaniella (Felaniella) usta (Gould, 1861), living in the Northwestern Pacific, is another allied species. However, F. (F.) usta is easily distinguished from F. (F.) namigataensis n. sp. in having a larger, more inflated, more anteriorly oblique shell with stronger cardinal teeth.

Itoigawa (1983) reported two unguilid species, “Cycladica takeyamai (Otuka)” and “Diplodonta?” sp.,” from the Namigata Formation. Among them, C. takeyamai (Otuka, 1938), originally described from the Miocene Bihoku Group in the Shôbara area, Hiroshima Prefecture, southwest Japan, differs from F. (F.) namigataensis n. sp. in having a larger, more inequilateral and more inflated shell with a more concave nymph. The two species reported by Itoigawa (1983) may be conspecific with F. (F.) namigataensis n. sp., although these two species are only listed and its shell characters are not known.

Measurements.—Table 2.

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in Japanese with English abstract
in Russian
in Russian with English abstract
in German
in Latin and German
in French

用語対比
Asagai 浅貝
Ashiya 芦屋
Awaji 淀路
First Seto Inland Sea 第瀬戸内海
First Setouchi Series 第瀬戸内層群
Ibara 井原
Iwaki 石巻
Iwaya 岩屋
Jōban 常盤
Kōbe 神戸
Kojima Bay 児島湾
Kurashiki 倉敷
Maëjima 前島
Maze 関瀬
Namigata 浪形
Nishisonogi 西彼杵
Ōnishi 大西
Senjuin 千手院
Shikai 四海
Shiramizu 白水
Shōdoshima 小豆島
Tainohata 多井畑
Teshima 豊島
Tonoshō 土庄
Ushimado 牛窪
Yakage 矢掛

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岡山県井原地域に分布する“中新統”浪形層の両生類化石群について分類学的、種系学的再検討を行い、本層の地質年代と古地理学的意義について議論した。浪形層は、主層と千手院貝殻礫岩部層（新称）、大西礫岩部層（新称）の2層に区分される。本層から8種の亀足類、13種の二枚貝類および1種の掘足類が得られた。Molopophorus watanabei Otuka, Acila (Truncacila) nagaoi Oyama and Mizuno, Chlamys (Nomurachlamys?) namigataensis (Ozaki) および Isognomon (Hippochaeta) hataii Noda and Furuichi の産出から、本層の両生類化石年代は後期始新世後期～前期新世に改訂される。最新の板礫類化石のデータおよび予察的なストロンチウム同位体比を考慮すると、本層の年代は後期始新世後期に限られる。本研究および最近の研究から、第一瀬戸内海は異なる時代に存在した2つの海域、すなわち、南で太平洋に面した古第三紀の外海と北西部で日本海と接続していた内海の中新世の海域から構成されていたことが示される。したがって日本の新生代地史における「第一瀬戸内海」の概念については再評価される必要がある。Felaniella(Felaniella) namigataensis n. sp. (和名：ナミガタウソシジミ)を含むいくつかの種について、分類学的な記載・議論を行った。