Online ISSN 2435-0931 Print ISSN 0385-0900
DOI: 10.50897/bmfm.52.1_17

Bulletin of the Mizunami Fossil Museum, vol. 52, no. 1, 17–43, 3 pls., 2 figs., 2 tables.

Manuscript accepted on February 18, 2025; online published on April 18, 2025
http://zoobank.org/urn:lsid:zoobank.org:pub:9281B32D-6585-4817-B873-4ACAD8660710

Middle Miocene Climatic Transition in the Japan Sea borderland of Honshu —Middle Miocene molluscan fauna from Unazukimachi-Oritate in Kurobe City, Toyama Prefecture, Japan—

Kazutaka Amano[1], Takuma Haga[1], Tokiyuki Sato[2], Toshikazu Hamuro[3], and Masui Hamuro[3]

1) Department of Geology and Paleontology, National Museum of Nature and Science, 4-1-1 Amakubo, Tsukuba, Ibaraki 305-0005, Japan < amano@juen.ac.jp >
2) Akita Prefectural University, 241-438, Nakano Aza Michibanishi, Shimoshinjo, Akita 010-0195, Japan
3) Toyama Paleontological Research Club, 100 Nishitakagi, Imizu, Toyama 939-0303, Japan

Abstract

Fifty molluscan species have been recovered from boulders in the lower Middle Miocene Sazen Formation at Unazukimachi-Oritate in Kurobe City, Toyama Prefecture. The assemblage includes new species of the trochid *Protorotella* and the plesiotrochid *Trochocerithium*, herein described. Based on the living species of the same genera, it can be estimated that the Oritate assemblage was deposited in water deeper than 50 m. Some characteristic species of Yatsuo-Kadonosawa and Shiobara-Yama faunas are mixed in the assemblage. Moreover, some cold-water species are shared with the Early Miocene Sankebetsu and the Middle Miocene Chikubetsu faunas in Hokkaido which first appeared in the Japan Sea borderland of Honshu. The first appearance of cold-water species corresponded with the Middle Miocene Climatic Transition (MMCT) around oxygen isotope zone Mi 2a.

Key words: cold water, MMCT, *Protorotella*, shallow-water molluscs, *Trochocerithium*

1. Introduction

The Miocene warm period, Miocene Climatic Optimum (MCO; ca. 17 to 14.7 Ma) ended with the subsequent climatic cooling (Middle Miocene Climatic Transition, MMCT; 14.7 to 13.8 Ma) because of declining $p\mathrm{CO}_2$ and Antarctic ice-sheet development (e.g., Methner et al., 2020; Sangiorgi et al., 2021). Such climate change affected the succession of the molluscan fauna in Japan. In central Honshu, the tropical or subtropical Yatsuo-Kadonosawa fauna (Otuka, 1939; Chinzei, 1986a, b) in the MCO was replaced by the temperate Shiobara-Yama fauna around 15 Ma (Chinzei, 1986a). When Ogasawara (1994) recognized the differences of pectinid species around 11 Ma, he subdivided the Shiobara-Yama fauna into the Lower and the Upper. Ogasawara (2002) and Ogasawara et al. (2008) named them as the Older Shiobara-Yama fauna (warm-temperate) and the Younger Shiobara-Yama fauna (mild-temperate) respectively.

In the Middle Miocene (15.98–11.63 Ma), deep-sea deposits prevailed in the Japan Sea side of northern Honshu (e.g., Iijima and Tada, 1990). Few shallow-water fossils which were affected by the climatic change are known from the Japan Sea borderland. One of these faunas was described from the Middle Miocene Tenguyama Formation in the central part of Toyama Prefecture by Ogasawara et al. (1989a). The formation unconformably overlies the Lower to lowest Middle Miocene Higashibessho Formation yielding deep-water molluscan fossils (Amano et al., 2001, 2004, 2022). The age of the tephra at the middle part of Tenguyama Formation was measured as 14.8±0.3 Ma by U-Pb method and 14.8±0.7 Ma by FT method (Nakajima et al., 2019). Among the Tenguyama fossils, the following Early to Middle Miocene warm-water pectinids are dominant: *Kotorapecten kagamianus moniwaensis* (Masuda), *Chlamys meisensis* (Makiyama), *Chlamys arakawai* (Nomura), and *Nanaochlamys notoensis notoensis* (Yokoyama). The fossils also include a venerid *Kaneharaia kannoi* (Masuda), one of the typical elements of the Shiobara-Yama fauna (Iwasaki, 1970; Chinzei, 1986a). However, among 29 species listed up from the Tenguyama Formation by Ogasawara et al. (1989a), only 11 species are identified in the species rank. It is not enough to know the Older Shiobara-Yama fauna in the Japan Sea borderland.

Many molluscan fossils including cold- and shallow-water species were recovered from the lower Middle Miocene deposits from the eastern Toyama Prefecture in the Japan Sea borderland. We describe these molluscan fossils and discuss the relation between the Miocene cooling and the first appearance of shallow- as well as cold-water species from the Japan Sea side of Honshu.

2. Geological setting

The molluscan fossils were recovered from the large boulders (about 1 m in diameter) of pebble-bearing calcareous sandstone dug out by the renovation construction of the Kurobe River in 1998. The locality is the right bank at 600 m downstream from Aimoto Bridge, Unazukimachi-Oritate, Kurobe City, eastern Toyama Prefecture (Fig. 1; 36°51′53″N, 137°32′58″E; Oritate locality hereafter). We call this the Oritate assemblage in the following lines. The Recent alluvial fan deposit consisting of gravels (about 10 m in thickness) distinctly overlies the large boulders which do not consist of the alluvial fan gravels. Judging from the distribution and strike of the formation in the geological map by Takeuchi et al. (2017) and the similar fossil occurrence at Unazukimachi-Akebi recorded by Fujii and Mori (1964), the sandstone yielding fossils at Oritate locality corresponds to the lower Middle Miocene Sazen Formation (Fujii, 1959). This formation is mainly composed of sandy mudston, and rarely of fine-grained sandstone (Takeuchi et al., 2017). From the calcareous concretions in the black siltstone of the Sazen Formation at about 0.7 km northeast of Unazukimachi-Akebi village (Akebi locality hereafter), sea turtle, *Syllomus aegypticus* and the desmostylid *Paleoparadoxia tabatai* occurred (Fujii and Mori, 1961, 1964; Shikama, 1966; Hasegawa et al., 2005). In the same locality, the following molluscan fossils have also been reported; *Aturia minoensis* [= *Aturia cubaensis*], *Portlandia japonica*, *Buccinum* cf. *isaotakii*, *Crassostrea gravitesta* and *Conus* sp. (Fujii and Mori, 1961, 1964). Among these, a brackish-water dweller *Crassostrea gravitesta* having heavy shells cooccurred with the deep-sea species such as *Portlandia japonica* and *Buccinum* cf. *isaotakii. Crassostrea gravitesta* and vertebrate species might have been curried by any gravity flow to the deep water. Such occurrence is similar to the Oritate assemblage including many ostreid fragments with some deep-water species.

The upper part of the Sazen Formation was assigned to the early Middle Miocene, N9 Zone (15.1–14.8 Ma) by planktonic foraminifers (Itoh, 1985) and the Sazen Formation conformably overlies the uppermost Lower Miocene Sasagawa Formation (about 16 Ma by U-Pb method; Nagamoro and Furukawa, 2017). On the other hand, the age of the Tenguyama Formation in Yatsuo area, central Toyama Prefecture was measured as about 14.8 Ma as above mentioned. Thus, at least, the uppermost part of the Sazen Formation can be correlated with the Tenguyama Formation (Nagamori and Watanabe, 2023). From the Oritate locality, three calcareous nannofossil species were picked up from calcareous sandstones by one of the authors, Tokiyuki Sato; *Helicosphaera carteri*, *Sphenolithus heteromorphus* and *Reticulofenestra* sp. Of these, *S. heteromorphus* is an index fossil for NN4 (17.95–14.91) to NN5 (14.91–13.53) by Martini (1971) (Sato et al., 2010). Based on the calcareous nannofossils and planktonic foraminifers from the Sazen Formation and the U-Pb age (about 16 Ma) of the Sasagawa Formation conformably underling Sazen Formation, the age of the deposits at Oritate locality can be assigned to the early Middle Miocene, equal to or older than 15.1–14.8 Ma.

All specimens treated here are stored at the Tohoku University Museum (IGPS), Sendai, Miyagi Prefecture; Department of Geology and Paleontology, National Museum of Nature and Science, Tokyo (NMNS PM), Tsukuba, Ibaraki Prefecture; Hokkaido University Museum (UH), Sapporo, Hokkaido; The University Museum, The University of Tokyo (UMUT CM), Tokyo.

Fig. 1. Map showing the Oritate locality (using the topographical map, scale 1:25,000, published by Geospacial Information Authority of Japan).

3. Molluscan fossils

In total, 26 gastropod, 23 bivalve, and one scaphopod species were identified from the boulders at Oritate locality, of these two gastropods, *Protorotella gigas*, new species. and *Trochocerithium oritatense*, new species. are described as new in this study (Table 1).

Table 1. Molluscan fossils from Oritate locality. *Number of specimens.

Species	N*	registration (NMNS PM)
Protorotella gigas Amano, n. sp.	367	68820–68825
Calliostoma (*Calliotropis*) *simane* Nomura and Hatai	7	68826
Turbinidae gen. et sp. indet.	1	68827
Batillaria sp.	10	68828
Tachyrhynchus ? sp.	2	68829
Trochocerithium oritatense Amano, n. sp.	1	68830
Trochocerithium ? sp.	1	68831
Littorina ? sp.	1	68832
Cryptonatica janthostoma (Deshayes)	1	68833
Glossaulax coticazae (Makiyama)	34	68834
Glossaulax sp.	1	68835
Ranellidae gen. et sp. indet.	1	68836
Telasco ? sp.	5	68837
Reticunassa simizui (Otuka)	2	68838
Reticunassa ? sp.	1	68839
Phos iwakianus (Yokoyama)	2	68840
Siphonalia aff. *spadicea* (Reeve)	2	68841
Babylonia kozaiensis Nomura	2	68842
Mancinella cf. *minoensis* Itoigawa	1	68843
Olivella iwakiensis Nomura and Hatai	31	68844
Megasurcula yokoyamai (Otuka)	2	68845
Comitas sp.	1	68846
Comitas ? sp.	1	68847
Merica ? sp.	1	68848
Odostomia sp.	2	68849
Eocylichna ? sp.	1	68850
Acila (*Acila*) *submirabilis* Makiyama	2	68851
Acila (*Truncacila*) *gottschei* (Böhm)	6	68852
Saccella sp.	6	68853
Anadara arasawaensis Noda	6	68854
Scapharca ninohensis (Otuka)	12	68855
Glycymeris (*Veletuceta*) *cisshuensis* Makiyama	2	68856
Ostreidae gen. et sp. indet.	23	68857
Anomia sp.	1	68858
Cyclocardia siogamensis (Nomura)	20	68859
Lucinoma sp.	1	68860
Diplodonta sp.	2	68861
Vasticardium ? sp.	4	68862
Securella yiizukai (Kanehara)	8	68863
Neogenella cf. *hokkaidoensis* (Nomura)	1	68864
Phacosoma akaisiana (Nomura)	18	68865
Kaneharaia kannoi (Masuda)	2	68866
Sunetta sp.	3	68867
Meretrix ninohensis Hatai	71	68868
Gari ? sp.	2	68869
Spisula (*Pseudocardium*) sp.	8	68870
Spisula (*Mactromeris*) cf. *voyi* Gabb	4	68871
Mya (*Mya*) *cuneiformis* (Böhm)	12	68872
Solidicorbula cf. *nisataiensis* (Otuka)	2	68873
Fissidentalium yokoyamai (Makiyama)	16	68874

Seven species of the assemblage are confined to the Early to early Middle Miocene Yatsuo-Kadonosawa Fauna (Tsuda, 1965; Chinzei, 1981, 1986b; Ogasawara, 1994): *Reticunassa simizui* (Otuka), *Babylonia kozaiensis* Nomura, *Megasurcula yokoyamai* (Otuka), *Scapharca ninohensis* (Otuka), *Cyclocardia siogamensis* (Nomura), *Phacosoma akaisiana* (Nomura) and *Meretrix ninohensis* Hatai. On the other hand, the assemblage also includes characteristic species of the Shiobara-Yama fauna in Honshu: *Anadara arasawaensis* Noda, *Phos iwakianus* (Yokoyama) and *Kaneharaia kannoi* (Masuda). Moreover, *Olivella iwakiensis* Nomura and Hatai has been known from both Yatsuo-Kadonosawa and Shiobara-Yama fauna. *Securella yiizukai* (Nomura) is a characteristic species of the Lower Togeshita fauna in Hokkaido (Amano, 1983, 1986).

4. Systematic paleontology

Class Gastropoda Cuvier, 1795
Family Trochidae Rafinesque, 1815

Genus *Protorotella* Makiyama, 1925

Type species: *Protorotella yuantaniensis* Makiyama, 1925 (original designation), Miocene, Kyoto Prefecture.

Protorotella gigas **Amano, new species**

(Pl. 1, Figs. A–G, I)

urn:lsid:zoobank.org:act:D87A5EEC-2F31-4B11-A46D-2436DE759EAA

[New Japanese name: Kurobe-mukashikisago]

Etymology: The present new species is named after the largest size in *Protorotella*.

Type specimens: Holotype, NMNS PM 68820; four paratypes, NMNS PM 68821–68824.

Type Locality: Float boulder, collected from the right bank at 600 m of downstream from Aimoto Bridge, Unazukimachi-Oritate, Kurobe City, Toyama Prefecture; Sazen Formation.

Other Material: 367 specimens were collected from the type locality. Among them, 13 specimens other than the type series (NMNS PM 68825) are rather well-preserved and also measured.

Dimensions: see Table 2.

Table 2. Measurements of *Protorotella gigas* Amano, new species. *Diameter of umbilical callus.

Specimens (NMNS PM)	Type status	D (mm)	H (mm)	UC* (mm)	H/D	UC/D
68820	Holotype	14.3	9.0	8.6	0.63	0.60
68821	Paratype 1	16.4	10.6	7.8	0.65	0.48
68822	Paratype 2	16.3	9.6	9.3	0.59	0.57
68823	Paratype 3	12.1	7.9	8.1	0.65	0.67
68824	Paratype 4	10.4	7.1	5.0	0.68	0.48
68825-1		17.4	10.6	-	0.61	-
68825-2		16.5	10.5	-	0.64	-
68825-3		14.2	10.5	-	0.74	-
68825-4		14.0	9.1	-	0.65	-
68825-5		14.5	8.8	-	0.61	-
68825-6		14.0	9.0	-	0.64	-
68825-7		13.4	8.1	-	0.60	-
68825-8		12.4	6.8	-	0.55	-
68825-9		11.8	7.2	-	0.61	-
68825-10		11.2	6.1	-	0.54	-
68825-11		8.4	5.0	-	0.60	-
68825-12		8.8	4.8	-	0.55	-
68825-13		10.6	6.5	-	0.61	-

Diagnosis: Largest *Protorotella*, attaining 17.4 mm in diameter, smooth surface in adult, but three grooves just above periphery in young shell.

Description: Shell largest in size for *Protorotella*, up to 17.4 mm in diameter, moderately high (Hight/Diameter = 0.54 to 0.68, avg. = 0.62), rather thin. Protoconch one, smooth whorl, 0.7 mm in diameter. Teleoconch whorls three, smooth, with large last whorl and low spire. Surface of whorl smooth except for distinct growth lines in adult, with three grooves just above periphery of young paratype specimen (Pl. 1, Fig. C). Suture deeply depressed. Umbilical callus thick, simple, occupying about half to two-thirds of shell diameter (0.48 to 0.67) for well-preserved type specimens.

Remarks: *Protorotella gigas* new species. resembles *P. yuantaniensis* Makiyama, 1925 (= *Umbonium ishiianum* Yokoyama, 1930) from the Lower Miocene Tsuzuki Group in Kyoto Prefecture, also known from the Lower Miocene Kurosedani Formation in Toyama Prefecture (Oyama, 1955; Kaneko and Goto, 1992, 1997) in having a large shell (max. diameter 10.7 mm) and smooth shell except for growth lines. However, the present new species differs from *P. yuantaniensis* by having larger and rather depressed shell (H/D = 0.60 to 0.79 in *P. yuantaniensis*; Makiyama, 1925, Sugiyama, 1935), a broader umbilical callus (Umbilical callus diameter / Shell diameter = 0.47 to 0.51 in *P. yuantaniensis*; Sugiyama, 1935) and three grooves just above periphery.

Protorotella hayashii Kanno, 1958 from the Lower Miocene Nagura Formation in Chichibu Basin, Saitama Prefecture is also similar to the present new species in having a large shell for the genus (9.7 mm in diameter) and a broad umbilical callus (two-thirds of umbilical callus diameter to shell diameter). However, smaller shell and no groove just above periphery of *P. hayashii* enables us to separate it from *P. gigas* new species.

Stratigraphic and geographic distribution: Known from the Middle Miocene, Sazen Formation in Toyama Prefecture.

Family Plesiotrochidae Houbrick, 1990

Genus *Trochocerithium* Sacco, 1896

Type species: *Trochus turritus* Bellardi and Michelotti, 1840 (original designation), Miocene in Italy.

Remarks: For a long time, most Japanese paleontologists and malacologists have used the genus name, *Orectospira* Dall, 1925 for the deep-sea turreted gastropods (e.g., Urata, 1961, Tsuchida, 1986). Houbrick (1990) synonymized *Orectospira* with *Trochocerithium*. This genus includes the following species: *Trochocerithium turritum* Bellardi and Michelotti, 1840, *T. wadanum* (Yokoyama, 1890), *T. shikoense* (Yokoyama, 1928a), *T. excelsum* (Yokoyama, 1928b), *T. nenokamiense* (Kanno, 1958), *T. takayamai* (Urata, 1961), *T. shimokawarai* (Urata, 1961), *T. mizunoi* Shuto and Ueda, 1967 and *T. ichishiense* (Shibata, 1970). Of these, this is the first time that *T. ichishiense* has been combined with *Trochocerithium*. Most of these species were described from the Eocene to the Pliocene deposits except for one Recent species, *T. shikoense*, living in the deep sea (150–800 m in depth) from Sagami Bay to off Kochi, Pacific side of southwestern Japan (Tsuchida, 1986) and represents one of the “living fossils”.

Trochocerithium oritatense **Amano, new species**

(Pl. 1, Figs. H, N, O)

urn:lsid:zoobank.org:act:2AC61908-BA6C-475C-90E1-5C8679D5F554

[New Japanese name: Oritate-urauzukanimori]

Etymology: The present new species is named after the local name of the fossil locality.

Type specimen: Holotype, NMNS PM 68830; height 23.8 mm+; diameter, 16.1 mm.

Type Locality: Float boulder, collected from the right bank at 600 m of downstream from Aimoto Bridge, Unazukimachi-Oritate, Toyama Prefecture; Sazen Formation.

Description: Shell medium in size for the genus, conical, consisting of more than six whorls; pleural angle about 40 degrees. Surface sculptured by two spiral cords just above and just below deep suture: surface between two cords slightly concave and with very fine spiral striations, opisthogyrate growth lines, and low axial ribs along growth lines, becoming tubercles at crossing point with two keels. Number of tubercles 32 on penultimate whorl. Base flattish, sculptured by fine spirally arched growth lines and without umbilicus. Aperture rhomboidal, with very short and wide siphonal canal.

Remarks: The present new species resembles *Trochocerithium takayamai* (Urata, 1961) from the Eocene Sakasegawa Formation in Nagasaki Prefecture, northern Kyushu in having a similar height (19.3 mm), a similar pleural angle (34–35 degree) and rather weak tubercles. However, the present species has a distinct upper spiral cord just below the upper suture with more numerous tubercles on upper cord on penultimate whorl (27 in *T. takayamai*).

Trochocerithium shimokawarai (Urata, 1961) from the Upper Eocene in the Hobetsu coal mine in Hokkaido is another species similar to the present new species. But *T. shimokawarai* has a larger shell (28 mm in height), no upper spiral cord and less numerous tubercles (22) on the carina of the penultimate whorl.

Trochocerithium nenokamiense (Kanno, 1958) from the Lower Miocene Nenokami Formation in Saitama Prefecture is similar to the present new species by having 32 tubercles on the penultimate whorl. However, *T. nenokamiensis* differs from the present new speies by having more numerous (about 10) whorls, smaller shell (max. height = 18.5 mm), and three nodulous spiral rows.

Stratigraphic and geographic distribution: Known only from the type locality, Middle Miocene, Sazen Formation in Toyama Prefecture.

Family Nassariidae Iredale, 1916

Genus *Phos* Montfort, 1810

Type species: *Murex senticosus* Linnaeus, 1758 (original designation), Recent, Indo-Pacific (type locality was not designated).

***Phos iwakianus* (Yokoyama, 1931)**

(Fig. 2C)

Mitra pristina Yokoyama. Yokoyama, 1926a, p. 130, pl. 16, figs. 1c, 2, 3. [*non Mitra pristina* Yokoyama, 1923]

Nassa iwakiana Yokoyama, 1931, p. 200, pl. 12, figs. 7, 8.

Nassarius iwakianus (Yokoyama). Nomura, 1935a, p. 97, pl. 4, fig. 4; Nomura and Hatai, 1936, p. 140, pl. 17, fig. 16; Nomura and Onisi, 1940, pl. 17, fig. 18.

Phos (*Coraeophos*) *meisensis* Makiyama, 1936, p. 225, pl. 5, figs. 18, 19; Makiyama, 1959, pl. 81, figs. 7, 8.

Coraeophos meisensis ninohensis Chinzei, 1959, p. 114, pl. 9, figs. 18–22.

Phos (*Coraeophos*) *iwakianus* (Yokoyama). Shikama, 1964, pl. 32, fig. 20.

Phos iwakianus (Yokoyama). Iwasaki, 1970, p. 422, pl. 1, figs. 8–10; Ogasawara, 1976, p. 68, pl. 5, figs. 5, 6; Ogasawara, 1982, p. 284, pl. 142, Fig. 1354; Ogasawara et al., 1989b, pl. 3, figs. 4a, b, 5a, b; Shimizu and Fujii, 1991, pl. 1, fig. 3; Amano and Koike, 1993, pl. 2, figs. 1, 3; Nemoto and O'Hara, 2003, pl. 6, figs. 15a, b.

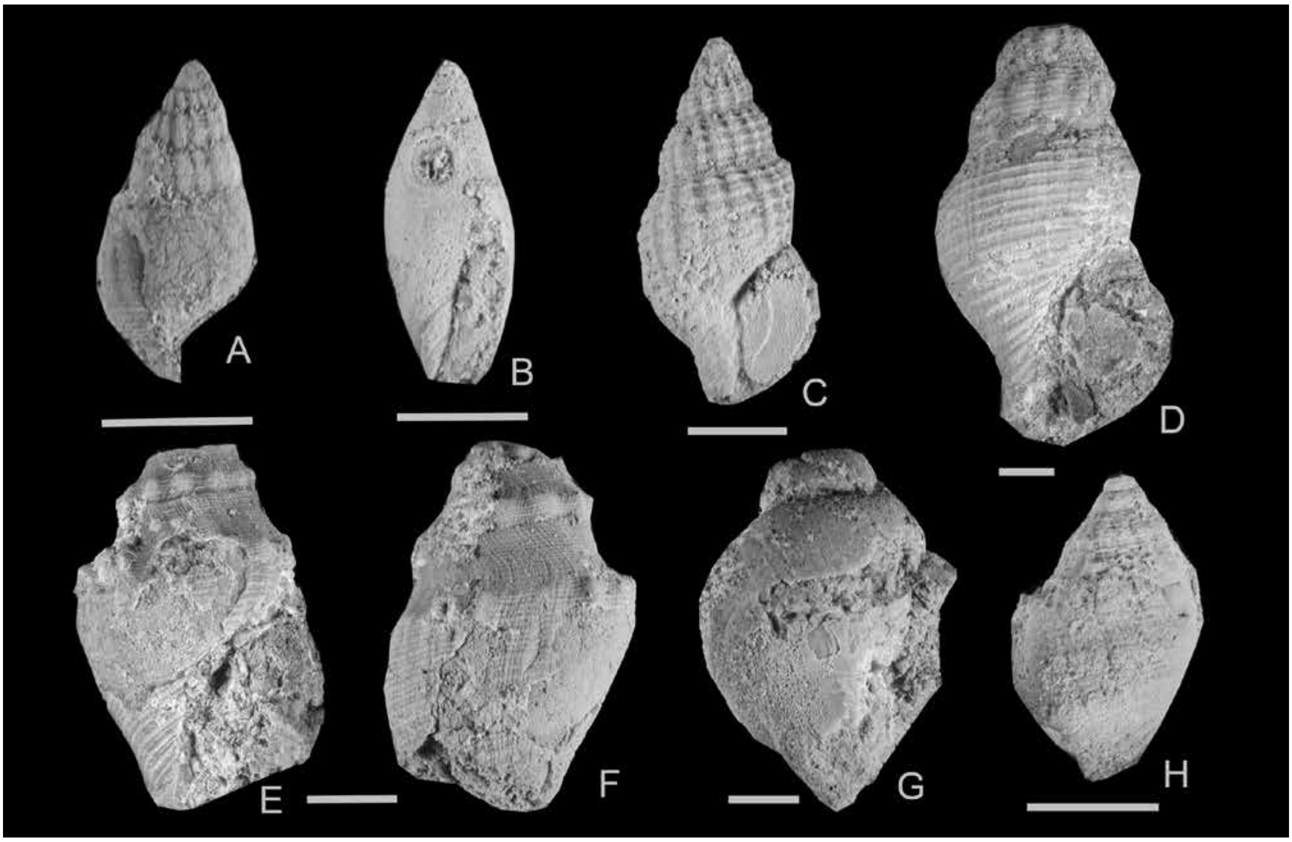

Fig. 2. Some gastropods of the Oritate assemblage. **A, *Reticunassa simizui* (Otuka)**, NMNS PM 68838-1, abapertural view. **B, *Olivella iwakiensis* Nomura and Hatai**, NMNS PM 68844-1, apertural view. **C, *Phos iwakianus* (Yokoyama)**, NMNS PM 68840-1, apertural view. **D, *Siphonalia* aff. *spadicea* (Reeve)**, NMNS PM 68841-1a, apertural view. **E, F, *Megasulcula yokoyamai* (Otuka)**, NMNS PM 68845-1; E, apertural view; F. abapertural view. **G, *Babylonia kozaiensis* Nomura**, NMNS PM 68842-1, apertural view. **H, *Mancinella* cf. *minoensis* Itoigawa**, NMNS PM 68843, abapertural view. All scale bars show 5 mm.

Type specimens: Yokoyama (1931) did not assign any type specimens. His illustrated syntypes are UMUT CM 25880 and 25881. However, the latter (UMUT CM 25881) is missing (Ichikawa, 1983). We herein designate the specimen of UMUT CM 25880 which has been illustrated in Yokoyama (1931: pl. 12, fig. 7), Makiyama (1959: pl. 81, fig. 7) and Shikama (1964: pl. 32, fig. 20) as the lectotype.

Type Locality: Hattomaki, Tanagura Town, Fukushima Prefecture; Kubota Formation.

Material: Two specimens recovered from Oritate locality are examined and measured.

Dimensions: NMNS PM68840-1; Height (H), 17.7 mm; Diameter (D), 7.9 mm. NMNS PM 68840-2; H, 13.1 mm+; D, 6.2 mm. *Remarks*: The Oritate locality specimens are safely identified with *Phos iwakianus* (Yokoyama, 1931) because the well-preserved specimen (NMNS PM68840-1) has six whorls including two smooth protoconch whorls, 11 spiral cords on the last whorl, 17 axial ribs on the penultimate whorl and 40 degrees of pleural angle which are within the variation of *Phos iwakianus* shown by Iwasaki (1970).

"*Nassarius*" *nakamurai* Kuroda, 1931 from the Middle Miocene Aoki Formation in Nagano Prefecture is similar to the present species. However, its imperfect shell and numerous axial ribs on the body whorl (27) prevent us from identifying with the present species.

The present species is also similar to *Phos tsukiyoshiensis* Itoigawa, 1960 from the Lower Miocene Akeyo Formation in Gifu Prefecture and the Lower Miocene Kurosedani Formation in Toyama Prefecture. However, *P. tsukiyoshiensis* has a smaller shell (max. height = 10.4 mm), smaller aperture and less numerous, but strong axial ribs (15 on the penultimate whorl).

Phos miyagiensis Masuda and Takegawa, 1965 from the Upper Miocene Fukuda Formation in Miyagi Prefecture (= *P. iwakianus fujinaensis* Ogasawara and Nomura, 1980 from the Upper Miocene Fujina Formation in Shimane Prefecture) is another species similar to *P. iwakianus*. However, *P. miyagiensis* has weaker and more numerous axial ribs (23 to 35) on the last whorl.

Stratigraphic and geographic distribution: Middle Miocene, Sazen Formation in Toyama Prefecture (this study). Late Miocene, Shitazaki Formation in Iwate Prefecture (Chinzei, 1959), Narusawa and Murata formations in Miyagi Prefecture (Nomura, 1935a; Nomura and Onisi, 1940), Kubota Formation in Fukushima Prefecture (Yokoyama, 1931; Nomura and Hatai, 1936; Iwasaki, 1970; Nemoto and O'Hara, 2003), Kanomatazawa Formation in Tochigi Prefecture (Yokoyama, 1926a), Itahana Formation in Gunma Prefecture (Oinomikado, 1938), Ogawa Formation in Nagano Prefecture (Amano and Koike, 1993), Otogawa Formation in Toyama Prefecture (Ogasawara et al., 1989b; Shimizu and Fujii, 1991), Saikawa Formation in Ishikawa Prefecture (Ogasawara, 1976), Lower Banko Sandstone in North Korea (Makiyama, 1936).

Family Olividae Latreille, 1825

Genus *Olivella* Swainson, 1831

Type species: *Oliva* (*Olivella*) *purpurata* Swainson, 1831 (subsequent designation by Dall, 1909), Recent, East Pacific.

Olivella iwakiensis **Nomura and Hatai, 1936**
(Fig. 2B)

Olivella iwakiensis Nomura and Hatai, 1936, p. 135, pl. 16, figs. 3–5; Nomura and Onisi, 1940, p. 185, pl. 18, fig. 4; Masuda and Takegawa, 1965, pl. 2, figs. 23a–24; Itoigawa et al., 1981, pl. 38, figs. 17a, b; Itoigawa et al., 1982, p. 236; Ogasawara et al., 1989b, pl. 3, figs. 3a, b, 7a, b; Kaneko and Goto, 1992, p. 25, pl. 14, figs. 6a, b; Kaneko and Goto, 1997, p. 24, pl. 18, figs. 13a, b, 14a, b; Nemoto and O'Hara, 2003, pl. 6, figs. 18a, b; Nakagawa, 2009, pl. 3, figs. 7a, b.

Olivella sp. Itoigawa et al., 1974, pl. 50, figs. 27, 28 a, b.

Type specimens: Nomura and Hatai (1936) did not assign any specimens to holotype and paratype and two lots of syntypes exist (Reg. nos. 2643 and 4514 of Saito Ho-On Kai Museum, now NMNS PM 21431 and 21381, respectively). Hatai and Nisiyama (1952: 227) stated in their check list of Japanese Tertiary marine Mollusca that the lot "Reg. no. 2643" is holotype. However, the lot comprises at least 71 specimens, and the three figures in the original description (Nomura and Hatai, 1936: pl. 16, figs. 3–5) represent three different specimens. Hatai and Nisiyama (1952)'s work therefore does not uniquely identify a single specimen and cannot be considered as a valid lectotype designation. Thus, we herein designate one of the perfectly preserved syntypes NMNS PM 21431-1 (Nomura and Hatai, 1936, pl. 16, fig. 4) as the lectotype.

Type Locality: Okada, Tanagura Town, Fukushima Prefecture; Kubota Formation.

Material: 31 specimens were collected from Oritate locality (NMNS PM68844). Among them, two specimens are well-preserved and measured.

Dimensions: NMNS PM 68844-1; Height (H), 12.0 mm; Diameter (D), 4.7 mm. NMNS PM 68844-2; H, 9.6 mm; D, 3.6 mm.

Remarks: The Oritate locality specimens can be identified with *Olivella iwakiensis* Nomura and Hatai, 1936 from the Upper Miocene Kubota Formation in Fukushima Prefecture because they have similar shell sizes (max. height of shell, 10.5 mm of the type specimens), similar ratios of diameter to height (0.38 and 0.39 in the Oritate locality specimens; 0.42 to 0.44 in the three type specimens), similar ratio of aperture to shell height (0.52 and 0.58 in the Oritate locality specimens) and two folds on the surface of the inner lip.

Olivella omurai Ogasawara, 1976 was proposed for the specimens from the Upper Miocene Saikawa Formation in Ishikawa Prefecture. Its shell size (12.4 mm in height) and the ratio of diameter to height (0.37 to 0.42) are similar to *O. iwakiensis*. However, *O. omurai* differs from *O. iwakiensis* by having eight to nine folds on the inner lip and fine microscopic axial striations.

Stratigraphic and geographic distribution: Early Miocene, Kurosedani Formation in Toyama Prefecture (Kaneko and Goto, 1992, 1997), Uchiura Group in Fukui Prefecture (Nakagawa, 2009), Akeyo Formation in Gifu Prefecture (Itoigawa et al., 1981, 1982). Early Middle Miocene, Sazen Formation in Toyama Prefecture (this study), Oidawara Formation in Gifu Prefecture (Itoigawa et al., 1981, 1982). Late Miocene, Murata and Fukuda formations in Miyagi Prefecture (Nomura and Onisi, 1940; Masuda and Takegawa, 1965), Kubota Formation in Fukushima Prefecture (Nomura and Hatai, 1936; Nemoto and O'Hara, 2003), Kanomatazawa Formation in Tochigi Prefecture (Nomura and Hatai, 1936), Itahana Formation in Gunma Prefecture (Oinomikado, 1938), Otogawa Formation in Toyama Prefecture (Ogasawara et al., 1989b).

Class Bivalvia Linnaeus, 1758

Family Arcidae Lamarck, 1809

Genus *Anadara* Gray, 1847

Type species: *Arca antiquata* Linnaeus, 1758 (original designation). Recent, West Indies.

***Anadara arasawaensis* Noda, 1966**

(Pl. 2, Fig. I)

Anadara (*Anadara*) *arasawaensis* Noda, 1966, p. 86, pl. 4, figs. 13, 15–17; Noda and Tada, 1968, p. 198, pl. 22, figs. 1–6, 8–10, 14–16, 23; Masuda et al., 1992, p. 32, pl. 2, figs. la–4, pl. 3, figs. la–3b.

Type specimens: Holotype, IGPS no. 90046; Paratype, IGPS no. 90047.

Type Locality: Arasawa, Shizukuishi Town, Iwate Prefecture; Sakamotogawa Formation (= Yamatsuda Formation).

Material: Six specimens were collected from Oritate locality (NMNS PM 68854). Among them, three specimens are rather well-preserved and measured.

Dimensions: NMNS PM 68854-1, Length (L), 51.0 mm, Height (H), 46.2 mm, Number of radial ribs (NR), 30; left valve; NMNS PM 68854-2, L, 49.4 mm, H, 43.0 mm, NR, 31; left valve; NMNS PM 68854-3, L, 43.4 mm, H, 37.9 mm, NR, 31, right valve.

Remarks: The Oritate locality specimens have slightly smaller shells than the type (60.0 mm in length), but a well swollen umbo as in *Anadara arasawaensis* Noda, 1966. The surface is sculptured by 30 to 31 radial ribs which are mostly bipartite but tripartite only in the posterior corner. These ribs are finely granulated at the crossing points of ribs and growth lines. The ligament is wide and crescent shaped with horizontal grooves. These characteristics matches *A. arasawaensis* from the Upper Miocene Sakamotogawa and Yamatsuda formations in Iwate Prefecture. Although Noda (1966) described the species having only bipartite radial ribs, the holotype specimen has some tripartite radial ribs at the posterior corner as in the Oritate locality specimens.

Anadara ogawai Makiyama, 1926 is related to *A. arasawaensis* in having the same size of shell (48 mm in length) and similar number of radial ribs (30 to 31). However, *A. ogawai* differs from *A. arasawaensis* by having a less inflated umbo and wider and flater radial ribs without tripartite ribbing.

Stratigraphic and geographic distribution: Early Middle Miocene, Sazen Formation in Toyama Prefecture (this study). Late Miocene, Sakamotogawa and Yamatsuda formations in Iwate Prefecture (Noda, 1966; Noda and Tada, 1968).

Genus *Scapharca* Gray, 1847

Type species: *Arca inaequivalvis* Bruguière, 1789 (original designation). Recent, Southern India.

***Scapharca ninohensis* (Otuka, 1934)**
(Pl. 2, Figs. D, G, J)

Arca ninohensis Otuka, 1934, p. 609, pl. 47, figs. 21, 22; Nomura and Hatai, 1936, pl. 13, figs. 1, 5.

Anadara ninohensis (Otuka). Mizuno, 1965, p. 331, pl. 2, figs. 2, 2a; Iwasaki, 1970, p. 389, pl. 2, figs. 1–4, pl. 5, fig. 9; Gladenkov et al., 1984, p. 176, pl. 31, figs. 2, 3.

Anadara (*Anadara*) *ninohensis* (Otuka). Noda, 1966, p. 96, pl. 9, figs. 14–18; Gladenkov and Sinelnikova, 1990, p. 42, pl. 20, figs. 4, 6, 10.

Scapharca daitokudoensis (Makiyama). Nakagawa and Takeyama, 1985, pl. 16, fig. 7. [*non Arca* (*Anadara*) *daitokudoensis* Makiyama, 1926]

Anadara (*Scapharca*) *ninohensis* (Otuka). Sasaki, 1990, figs. 14-1–5.

non Arca ninohensis Otuka. Nomura and Hatai, 1936, pl. 13, figs. 2a–b, 3, 4, 6. [= *Anadara* (*Anadara*) *hataii* Noda, 1966]

non Anadara ninohensis (Otuka). Tanaka, 1960, p. 176, pl. 1, figs. 6a–b, 8a–b. [figs. 6a, b = *Anadara kurodai* Tanaka, 1960; figs. 8a, b = *Anadara* (*Anadara*) *tanakai* Noda, 1966]; Iwasaki, 1970, p. 389, pl. 3, figs. 1–5, pl. 7, figs. 1–3. [pl. 3, figs. 1–5 = *Anadara* (*Anadara*) *hataii* Noda, 1966; pl. 7, figs. 1–3 = *Anadara* (*Anadara*) *tanakuraensis* Noda, 1966]

Type specimens: Holotype, UMUT CM, 11863; Paratype, UMUT CM, 11865.

Type Locality: Shiratori, Ninohe City, Iwate Prefecture.

Material: Twelve specimens were collected from Oritate locality (NMNS PM 68855). Among them, four specimens are relatively well-preserved and measured.

Dimensions: NMNS PM 68855-1, Length (L), 39.6 mm, Height (H), 36.9 mm, Number of radial ribs (NR), 27, left valve; NMNS PM 68855-2, L, 36.0 mm, H, 30.6 mm, NR, 28, left valve; NMNS PM 68855-3, L, 29.8 mm, H, 26.9 mm, NR, 29, left valve; NMNS PM 68855-4, L, 27.2 mm+, NR, 29, right valve.

Remarks: The Oritate locality specimens are almost the same size as the holotype (39 mm in length). The surface is sculptured by 27 to 29 radial ribs which are smooth, squarish, low flat-toped, and separated by narrower interspaces. Some radial ribs have an obsolete medial groove in the middle part of the left valve. No nodes can be observed on the radial ribs even in the left valve. The ligament is asymmetrical triangular with two grooves. Judging from the shell size, shape, and number and condition of radial ribs, the Oritate locality specimens can be identified with *Scapharca ninohensis* (Otuka, 1934) from the lower Middle Miocene Kadonosawa Formation.

Scapharca abdita (Makiyama, 1926) (= *S. makiyamai* Hatai and Nisiyama, 1938) from north Kankyo-do (now North Hamgyong Province), North Korea is the most similar species in having a similar number of radial ribs (24 to 26 for "*S. makiyamai*" and 29 to 32 for *S. abdita*). However, *S. ninohensis* lacks any nodes on the radial ribs which are characteristics of *S. abdita.*

Stratigraphic and geographic distribution: Middle Miocene, Etolon Formation in Kamchatka (Gladenkov et al., 1984; Gladenkov and Sinelnikova, 1990), Kadonosawa Formation in Iwate Prefecture (Otuka, 1934), Sazen Formation in Toyama Prefecture (this study), Shimo Formation of Uchiura Group in Fukui Prefecture (Nakagawa and Takeyama, 1985). Late Miocene Kubota Formation in Fukushima Prefecture (Nomura and Hatai, 1936; Noda, 1966).

Family Veneridae Rafinesque, 1815
Subfamily Venerinae Rafinesque, 1815

Genus *Securella* Parker, 1949

Type species: *Venus securis* Shumard, 1858 (original designation). Pliocene, California.

Remarks: All fossil and Recent species of *Mercenaria* Schumacher, 1817 described in Japan have been allocated to the genus *Securella* because of no rugose nymph and no crossed-lamellar structure in the middle layer of shell (Harte, 1998; Amano, 2000; Matsukuma et al., 2015).

***Securella yiizukai* (Kanehara, 1937)**
(Pl. 2, Figs. K, O, P)

Venus (*Chione*) *securis* Shumard. Nomura, 1935b, p. 35, pl. 4, fig. 3; Slodkewitsch, 1938, p. 162, pl. 87, figs. 3, 4a, b. [*non Venus securis* Shumard, 1858]

Venus (*Chione*) *y-iizukai* Kanehara, 1937, p. 794, p. 25, figs. 1–4.

Mercenaria chitaniana (Yokoyama). Uozumi, 1953, p. 357, pl. 22, fig. 174; Fujie et al., 1964, pl. 7, fig. 4. [*non Chione chitaniana* Yokoyama, 1926b]

Mercenaria y-iizukai (Kanahara). Hayasaka and Uozumi, 1954, p. 168, pl. 22, figs. 3, 4; Kanno and Matsuno, 1960, pl. 5, fig. 5; Tanaka, 1960, p. 139, fig. 13; Mizuno et al., 1969, pl. 27, fig. 2.

Chione (*Securella*) *securis* (Shumard). Ilyina, 1963, p. 103, pl. 44, figs. 1, 1a.

Mercenaria yiizukai (Kanehara). Amano, 1983, p. 51, pl. 2, figs. 10, 11, pl. 4, fig. 10; Amano, 1986, pl. 18, fig. 7; Gladenkov and Sinelnikova, 1990, p. 67, pl. 14, figs. 3a, b, pl. 27, figs. 3a–b, 7; Noda, 1992, p. 87, pl. 3, fig. 9; Ogasawara, 2011, p. 12, figs. 5-18, 5-19.

Chione ensifera chehalisensis Weaver. Gladenkov et al., 1984, p. 223, pl. 50, figs. 7a, b. [*non Chione chehalisensis* Weaver, 1912]

Mercenaria yokoyamai (Makiyama). O'Hara and Nemoto, 1984, p. 55, pl. 1, figs. 14, 15. [*non Venus yokoyamai* Makiyama, 1927]

Type specimens: Neotype, UH Reg. No. 11311 designated by Hayasaka and Uozumi (1954) because the holotype specimen was destroyed during the World War II.

Type Locality: Etaibetsu, Hokuryu Town, Hokkaido.

Material: Eight specimens were collected from Oritate locality (NMNS PM 68863). Among them, three specimens are rather well-preserved and measured.

Dimensions: NMNS PM 68863-1, Length (L), 48.6 mm, Height (H), 49.4 mm, H/L, 1.02, left valve; NMNS PM 68863-2, L, 47.0 mm, H, 46.3 mm, H/L, 0.99, left valve; NMNS PM 68863-3, L, 48.2 mm, H, 44.6 mm, H/L, 0.93, left valve.

Remarks: Although the Oritate locality specimens are average in size for the species (max. length of the type specimens = 72 mm in length), a high shell (H/L = 0.93–1.02 in Oritate locality specimens while H/L = 0.85–0.98 in type specimens) with many distinct commarginal ribs and weak radial threads is as in *Securella yiizukai* (Kanehara, 1937).

Securella chitaniana (Yokoyama, 1926b) is closely related to *S. yiizukai* in having a similar outline and ornamentation of the shell. However, *S. chitaniana* differs from *S. yiizukai* by its larger (more than 80 mm in *S. chitaniana*) and lower shell (H/L = 0.81).

Securella oshuensis (Nomura and Onisi, 1940) from the Miocene Murata Formation resembles the present species, but its lower shell with longer posterior dorsal margin separates this species from *S. yiizukai*.

Stratigraphic and geographic distribution: Middle Miocene, Kakert and Etolon formations in western Kamchatka (Gladenkov et al., 1984), Cape Uandi, Sertunai and Lower Maruyama formations in Sakhalin (Gladenkov et al., 1984), Tachikaraushinai, Chikubetsu, Togeshita and Atsunai formations in Hokkaido (Kanno and Matsuno, 1960; Amano, 1983, 1986; Noda, 1992; Ogasawara, 2011), Uchimura Formation in Nagano Prefecture (Tanaka, 1960), Sazen Formation in Toyama Prefecture (this study).

Subfamily Dosiniinae Deshayes, 1853

Genus *Kaneharaia* Makiyama, 1936

Type species: *Dosinia kaneharai* Yokoyama, 1926a (original designation). Miocene, Tochigi Prefecture.

Remarks: The present extinct genus is characterized by having lamellated commarginal ribs, no escutcheon, a subumbonal pit, a wide triangular pallial sinus and microscopically spherulitic structure in the outer layer of the shell (Amano and Hikida, 1999).

***Kaneharaia kannoi* (Masuda, 1963)**
(Pl. 2, Figs. M, N)

See the detail and acceptable synonym list by Kurihara (2006).

Type specimens: Holotype, IGPS no. 64682.

Type Locality: Kinseido, Kisshu-gun, Kankyo-hokudo, North Korea. Miocene Heiroku Formation.

Material: Two imperfect specimens were collected from Oritate locality (NMNS PM 68866).

Remarks: One right valve of the Oritate locality specimens is fragmentary, but the umbonal part and hinge plate remains. Its subumbonal pit, lamellar commarginal ribs and no distinct groove bounded between the lunule and the main disc show the characteristics of *Kaneharaia* Makiyama, 1936. Moreover, the number of ribs from 10 to 20 mm from the umbo is 13. Judging from these, the Oritate locality specimens can be identified as *Kaneharaia kannoi* (Masuda, 1963) from the Heiroku Formation in North Korea. Recently, Matsubara et al. (2009) synonymized *K. kannoi* with *K. kaneharai* (Yokoyama, 1926a) from the Upper Miocene Kanomatazawa Formation in Tochigi Prefecture based on the presence of fine commarginal ribs in the lectotype of *K. kaneharai*. However, as they did not show the number of ribs of the lectotype, it is uncertain whether these species are synonymous or not.

Stratigraphic and geographic distribution: Early Middle Miocene, Sunakoze and Ainaigawa formations in Aomori Prefecture (Iwai, 1961; Masuda, 1963), Sugota Formation in Akita Prefecture (Masuda, 1963), Taira Member of Kanagase Formation and Moniwa Formation in Miyagi Prefecture (Nomura, 1940; Masuda and Takegawa, 1965), Yanagawa Formation in Fukushima Prefecture (Masuda, 1963), Nagaoka Formation in Tochigi Prefecture (Kurihara, 2006), Saginosu Formation in Saitama Prefecture (Kanno, 1960; Kurihara, 2006), Sazen and Tenguyama formations in Toyama Prefecture (Ogasawara et al., 1989a; this study), Aratani Formation in Fukui Prefecture (Nakagawa, 1998), Heiroku Formation in North Korea (Makiyama, 1936).

Subfamily Meretricinae Gray, 1847

Genus *Meretrix* Lamarck, 1799

Type species: *Venus meretrix* Linnaeus, 1758 (monotypy). Recent, Indian Ocean.

***Meretrix ninohensis* Hatai, 1940**

(Pl. 3, Figs. A, B, D, G, J)

Meretrix meretrix ninohensis Hatai, 1940, p. 128, pl. 1, fig. 1; Sato et al., 2016, p. 36, pl. 15, figs. 19a, b.

Meretrix ninohensis Hatai. Mizuno, 1965, p. 331, pl. 1, figs. 7, 8; Ogasawara, 1973, p. 149, pl. 12, fig. 22.

Meretrix arugai Otuka. Ogasawara and Noda, 1978, p. 35, pl. 3, figs. 17, 20, 22a–b; Ogasawara et al., 1986, pl. 1, fig. 20. [*non Meretrix arugai* Otuka, 1938]

Type specimens: Holotype, IGPS no. 61351.

Type Locality: Nisatai, Niniohe City, Iwate Prefecture. Miocene, Kadonosawa Formation.

Material: 71 disarticulated specimens were collected from Oritate locality (NMNS PM 68868). Among them, four specimens are relatively well-preserved and measured.

Dimensions: NMNS PM 68868-1, Length (L), 61.9 mm+, Height (H), 55.6 mm, right valve; NMNS PM 68868-2, L, 55.0 mm, H, 45.0 mm, H/L, 0.82, left valve; NMNS PM 68868-3, L, 49.3 mm+, H, 43.9 mm, left valve; NMNS PM 68868-4, L, 35.2 mm, H, 29.1 mm, H/L, 0.83, left valve.

Remarks: The Oritate locality specimens have a less swollen umbo, a pointed posterior corner, a blunt ridge running from beak to postero-ventral corner, no lunule, three cardinal teeth and one lateral tooth in both valves, and a shallow and triangular pallial sinus. Judging from the shell outline and hinge, this species can be identified as *Meretrix ninohensis* (Hatai, 1940) from the upper Lower Miocene Kadonosawa Formation (Tate Member; Sato et al., 2016).

Meretrix meretrix Linnaeus, 1758 is the closest species to *M. ninohensis*. However, *M. meretrix* has a larger and higher shell with a more swollen umbo and a more distinct ridge from beak to posteroventral corner.

Mereterix arugai Otuka, 1938 from the upper Lower Miocene Bihoku Group resembles the present species. Ogasawara and Noda (1978) stated that *M. ninohensis* is difficult to separate from *M. arugai*. However, *M. arugai* has a higher shell and a more swollen umbo than the present species. Matsubara (1995) pointed out that "*Meretrix arugai*" by Ogasawara and Noda (1978) and Ogasawara et al. (1986) is synonymous with the present species. Judging from the shell outline and condition of the umbo, Matsubara's opinion is acceptable.

Stratigraphic and geographic distribution: Late Early Miocene, Shimonagasawa Formation in Akita

Prefecture (Mizuno, 1965), Kadonosawa Formation in Iwate Prefecture (Hatai, 1940), Tsukinoki Formation in Miyagi Prefecture (Ogasawara and Noda, 1978). Early Middle Miocene, Nishikurosawa Formation in Akita Prefecture (Ogasawara, 1973), Sazen Formation in Toyama Prefecture (this study).

5. Discussion

Like as above mentioned fossil assembalge at Akebi locality, the present assemblage from Oritate was deposited in deep water. Among the Oritate assemblage, most species of *Acila* now live deeper than 50 m and *Fissidentalium yokoyamai* (Makiyama) now lives in 100 to 400 m depth (Higo et al., 1999). A plesiotrochid *Trochocerithium shikoense* (Yokoyama) is the only relict species of the genus around Japan living in 150–800 m depth (e.g., Hasegawa, 2017). However, Tao and Hu (1992) claimed that *T. shikoensis* from the Pleistocene Sigou Formation in Taiwan might live in shallower water than 50 m, judging from the associated fauna. The surface of shallow-water dwellers found in the Oritate assemblage sometimes tends to be worn or fragmented. In particular, all specimens of the brackish water species, Ostreidae gen. et sp. indet. occurred as fragments. Taking these into account, it is reasonable to assume that Oritate assemblage was deposited in waters deeper than 50 m.

Although the Early Miocene Yatsuo-Kadonosawa fauna includes several mangrove swamp species (Oyama, 1950), the species shared with the Oritate assemblage are warm-temperate elements, represented by *Trochocerithium* and a venerid bivalve *Sunetta*. The Recent *Trochocerithium* has been recorded from the Pacific side of southwestern Japan (Urata, 1961; Tsuchida, 1986). *Sunetta* is now living in southwestern Japan and southward (Higo et al., 1999; Fukuda et al., 2021).

On the other hand, the Oritate assemblage is exceptional in that it yields cold-water elements previously not reported in the Yatsuo-Kadonosawa fauna. *Cryptonatica janthostoma* (Deshayes) [the oldest record in Honshu], *Securella yiizukai* (Kanehara), two species of the genus *Spisula* [*S.* (*Pseudocardium*) sp. and *S.* (*Mactromeris*) cf. *voyi* Gabb], and *Mya* (*Mya*) *cuneiformis* (Böhm) are good examples of cold-water elements. The extant naticid species, *C. janthostoma* first appeared in the Lower Miocene Sankebetsu Formation in northwestern Hokkaido (Majima, 1989). *Securella yiizukai* (Kanehara) has been known from the Middle Miocene formations in Hokkaido (Amano, 1983, 1986, Noda, 1992). The Recent species of *Spisula* now living in the shallow cold-water areas of the northwest Pacific (Higo et al., 1999). On the Miocene species, these subgenera of *Spisula* appeared in the Early Miocene Sankebetsu and the early Middle Miocene Chikubetsu faunas in Hokkaido (Noda, 1992). The oldest record of *M.* (*M.*) *cuneiformis* is from the Lower Miocene formations in Hokkaido, Kamchatka and Alaska (Noda, 1992).

As mentioned above, the age of the Sazen Formation at Oritate locality is assigned to the early Middle Miocene, equal to or older than 15.1–14.8 Ma around oxygen isotope zone Mi 2a (Miller et al., 2017). Around this zone, some climatic cooling event was recognized in the Northeast Atlantic shelf (Sangiorgi et al., 2021). Some cold-water species mentioned above in the molluscan assemblage at Oritate locality reflect such a cooling event in the early Middle Miocene. In the early Middle Miocene, deep-sea deposits are developed in the Japan sea borderland (e.g., Iijima and Tada, 1990), so that there are few data on shallow-water molluscan fossils in this age.

Ogasawara et al. (1989a) described a pectinid-dominated assemblage from the Middle Miocene Tenguyama Formation in Toyama City. Only two species, *Kaneharaia kannoi* (Masuda) and *Mya* (*Mya*) *cuneiformis* (Böhm), are shared with the Oritate assemblage. Among them, only one species, *M.* (*M.*) *cuneiformis*, is a cold-water species. Bito et al. (1980) also listed up a pectinid-dominated assemblage from the lower Middle Miocene Kinjozan Sandstone Member of the Daishoji Formation in Kaga City, Ishikawa. According to them, the member was correlated with upper part of N8 to N9 of Blow (1969) by the planktonic foraminifers. The member yields two cold-water species, *Mya* (*Mya*) *cuneiformis* (Böhm) and *Panomya simotomensis* Otuka. Nakagawa and Yoshizawa (2007) reported many molluscan fossils from the Kasanomisaki Formation in Awara City, Fukui Prefecture. The age of the formation was estimated as 15–14 Ma, based on the planktonic foraminifers from the underlying Daishoji Formation (Bito et al., 1980) and the K-Ar age of the overlying Komegasaki Formation. They listed up *Protorotella depressa* Makiyama, *Phos iwakianus* (Yokoyama), *Securella* cf. *chitaniana* (Yokoyama) and *Pseudocardium* sp. [= *Spisula* (*Pseudocardium*) sp.]. These species are similar to the Oritate assemblage at least in the genus level. Among them, *Spisula* (*Pseudocardium*) sp. is a distinct cold-water element. Consequently, the Oritate assemballage is the oldest certain appearance of cold-water molluscs in the Japan Sea borderland of Honshu. The Oritate assemblage including many derived fossils from shallow water helps us to estimate water temperature of the Japan sea borderland in the early Middle Miocene. In the Pacific side of Northeast Honshu, the pectinid-dominated assemblage has been known in this age (e.g., Kurihara and Yanagisawa, 2002). However, no distinct cold-water species has been found.

6. Acknowledgements

We are very grateful to Geerat J. Vermeij (University of California at Davis) for his critical reading of this manuscript. We thank Tomio Nakagwa (Fukui University) for his critical review and many useeful suggestions. We also thank Kazunori Hasegawa (NMNS) for his information on the differences between *Orectospira* and *Trochocerithium*.

7. References

Amano, K. 1983. Paleontological study of the Miocene Togeshita molluscan fauna in the Rumoi district, Hokkaido. Science Reports of the Institute of Geoscience, University of Tsukuba, Section B 4: 1–72.

Amano, K. 1986. Age and characteristics of the so-called “Atsunai-Togeshita fauna” in Hokkaido. Paleontological Society of Japan, Special Papers (29): 187–198.

Amano, K. 2000. Origin and migration of the boreal type molluscs around Japan. Kaiyo Monthly, Special Volume (20): 18–24. (in Japanese; original title translated)

Amano, K., and Y. Hikida. 1999. Evolutionary history of the Cenozoic bivalve genus *Kaneharaia*. Palentological Research 3: 249–258.
DOI: 10.2517/prpsj.3.249

Amano, K., and K. Koike. 1993. Molluscan fauna from the Miocene Ogawa Formation in the western part of Nagano City, Nagano Prefecture. Bulletin of the Joetsu University of Education 13: 287–300. (in Japanese)

Amano, K., T. Hamuro, and M. Hamuro. 2004. Latest early-earliest middle Miocene deep-sea mollusks in the Japan Sea borderland—the warm-water Higashibessho fauna in Toyama Prefecture. Paleontological Research 8: 29–42.
DOI: 10.2517/prpsj.8.29

Amano, K., T. Hamuro, and M. Hamuro. 2022. Molluscan fossils from the Lower Miocene Higashibessho Formation (lower part) in Toyama Prefecture and their paleobiogeographic significance. Bulletin of the Mizunami Fossil Museum (49): 105–117.
DOI: 10.50897/bmfm.49.0_105

Amano, K., T. Hamuro, M. Hamuro, and S. Fujii. 2001. The oldest vesicomyid bivalves from the Japan Sea Borderland. Venus (Journal of the Malacological Society of Japan) 60: 189–198.
DOI: 10.18941/venus.60.3_189

Bellardi, L., and G. Michelotti. 1840. Saggio orittografico sulla classe dei gasteropoda fossili dei terreni terziarii del Piemonte. Memorie della Reale Accedemia delle Scienze di Torino [1841] [2] 3: 93–174.

Bito, A., T. Hayakawa, Y. Kaseno, K. Ogasawara, and T. Takayama. 1980. The Neogene stratigraphy around Kaga City, Ishikawa Prefecture, Japan. Annals of Science, College of Liberal Arts, Kanazawa University 17: 45–70, pls. 1–3. (in Japanese with English abstract)

Blow, W. H. 1969. Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. Proceedings of the 1st International Conference of the Planktonic Microfossils 1: 199–421.

Bruguière, J. G. 1789–1792. Encyclopédie méthodique ou par ordre de matières. Histoire naturelle des vers, volume 1. Pancoucke. Paris. p. 1–344 (1789); p. 345–757 (1792).

Chinzei, K. 1959. Molluscan fauna of the Pliocene Sannohe Group of Northeast Honshu, Japan. 1. The faunule of the Kubo Formation. Journal of the

Faculty of Science, the University of Tokyo, Section 2 12: 103–132.

Chinzei, K. 1981. The Kadonosawa Fauna. In T. Habe, and M. Omori, eds., Study of Molluscan Paleobiology. Professor Masae Omori Memorial Volume. Editorial committee of Study of Molluscan Paleobiology. Niigata University. Niigata. p. 207–212. (in Japanese with English abstract)

Chinzei, K. 1986a. Faunal succession and geographic distribution of Neogene molluscan faunas in Japan. Palaeontological Society of Japan, Special Volume (29): 17–32.

Chinzei, K. 1986b. Marine biogeography in Japan during early Middle Miocene as viewed from benthic molluscs. Palaeontological Society of Japan, Special Volume (29): 161–171.

Cuvier, G. 1795. Second Mémoire sur l'organisation et les rapports des animaux à sang blanc, dans lequel on traite de la structure des Mollusques et de leur division en ordre, lu à la société d'Histoire Naturelle de Paris, le 11 prairial an troisième [30 May 1795]. Magazin Encyclopédique, ou Journal des Sciences, des Lettres et des Arts, 1795 [1. année] 2: 433–449.

Dall, W. H. 1909. Contributions to the Tertiary paleontology of the Pacific coast. I. The Miocene of Astoria and Coos Bay, Oregon. Department of the Interior United States of Geological Survey, Professional Paper 59: 5–216.

Dall, W. H. 1925. Illustrations of unfigured types of shells in the collections of the United States National Museum. Proceedings of the United States National Museum 66: 1–41.

Deshayes, G. P. 1853. Catalogue of the Conchifera or bivalve shells in the collection of the British Museum. British Museum, London, Part I. Cyprinidae, Veneridae and Glauconomidae. Taylor and Francis. London. 216 p.

Fujie, T., M. Matsui, and S. Uozumi. 1964. 1.2. Study of Ancient Sea —Mollusca—. In Liaison Group of Geological Education of Hokkaido, ed., Fossils from Hokkaido. Editorial Committee of "Fossils from Hokkaido". Sapporo. p. 9–32. (in Japanese)

Fujii, S. 1959. Cenozoic strata in the eastern part of Asahi Town, Toyama Prefecture. Geographical Study of Toyama Prefecture (3): 121–126. (in Japanese; original title translated)

Fujii, S., and G. Mori. 1961. Miocene deposits at Akebi, Toyama Prefecture. Journal of the Geological Society of Japan 67: 401. (in Japanese; original title translated)

Fujii, S., and G. Mori. 1964. Miocene turtles from Akebi, Shimoniikawa-gun, Toyama Prefecture, Japan. Geographical Study of Toyama Prefecture (4): 95–97. (in Japanese with English abstract)

Fukuda, H., S. Ishida, T. Watanabe, S. Yoshimatsu, and T. Haga. 2021. The bivalve genus *Sunetta* Link, 1807 (Heterodonta: Veneridae) of Japan and the neighboring waters — a taxonomic revision with the descriptions of three new species. Molluscan Research 41: 107–171.
DOI: 10.1080/13235818.2021.1937016

Gladenkov, Y. B., V. M. Gladikova, A. N. Kafanov, L. V. Kokova, L. V. Krishtofovich, V. N. Sinelnikova, and S. V. Popov. 1984. Sistematishkaya Chastch' Glava IV. Morskie Mollyuski [Systematic part, Chapter IV. Marine Molluscs]. In V. V. Menner, ed., Atlas fauny neogenobykh otlozheniy Dalinevo Vostoka. Tochilinsky razrez Zapadnoy Kamchatki. [Atlas of Fauna and Flora of the Neogene Sediments of the Far East. Tochilinski Key Section of Western Kamchatka]. Transaction of the Geological Institute, Academy of Sciences of the USSR 385: 152–250. (in Russian)

Gladenkov, Y. B., and V. N. Sinelnikova. 1990. Mollyuski i klimaticheskie optimum miotsena Kamchatki [Miocene Mollusks and Climatic Optimum in Kamchatka]. Transaction of the Geological Institute, Academy of Sciences of the USSR 453: 1–174. (in Russian)

Gray, J. E. 1847. A list of the genera of recent Mollusca, their synonyma and types. Proceedings of the Zoological Society of London (1847) 15: 129–219.

Harte, M. E. 1998. The evolution of *Mercenaria* Schumacher, 1817 (Bivalvia: Veneridae). In P. A. Johnston, and J. W. Haggart, eds., Bivalves: An Eon of Evolution. University of Calgary Press. Calgary. p. 305–315.

Hasegawa, K. 2017. Family Orectospiridae. In T. Okutani, ed., Marine Mollusks in Japan. The Second Edition. Tokai University Press. Hiratsuka. p. 110, 799. (in Japanese and English)

Hasegawa, Y., R. Hirayama, T. Kimura, Y. Takakuwa, H. Nakajima, and Gunma Koseibutsu Kenkyukai.

2005. Skeletal restration of a fossil sea turtle, *Syllomus*, from the Middle Miocene Haratajino Formation, Tomioka Group, Gunma Prefecture, Central Japan. Bulletin of the Gunma Museum of Natural History (9): 29–64. (in Japanese with English abstract)

Hatai, K. 1940. On some fossils from the Ninohe District, Mutu Province, Northeast Honshu, Japan (No. 1). Bulletin of the Biogeographical Society of Japan 10: 119–138.

Hatai, K., and S. Nisiyama. 1938. Remarks on certain fossils from the Borderland of the Japan Sea. Japanese Journal of Geology and Geography 16: 139−145.

Hatai, K., and S. Nisiyama. 1952. Check list of Japanese Tertiary marine Mollusca. Science Reports of the Tohoku University, Second Series, Special Volume (3): 1–464.

Hayasaka, I., and S. Uozumi. 1954. Fossil species of genus *Mercenaria* from the Cenozoic deposits of Hokkaido. Transactions and Proceedings of the Palaeontological Society of Japan, n. ser. (15): 165–172.

Higo, S., P. Callomon, and Y. Goto. 1999. Catalogue and Bibliography of the Marine Shell-bearing Mollusca of Japan. Elle Scientific Publications. Yao. 749 p.

Houbrick, H. 1990. Aspects of the anatomy of *Plesiotrochus* (Plesiotrochidae, fam. N.) and its systematic position in Cerithioidea (Prosobranchia, Caenogasrtopoda). In F. E. Wells, D. I. Walker, H. Kirkman, and R. Lethbridge, eds., The Marine Fauna and Flora of Albany, Volume 1. Western Australian Museum. Perth. p. 237–249.

Ichikawa, T. 1983. Catalogue of the type and illustrated specimens in the Department of Historical Geology and Paleontology of the University Museum, University of Tokyo. Part 2. Cenozoic fossils and Recent specimens. University Museum, University of Tokyo, Material Reports (9): 1–536.

Iijima, A., and R. Tada. 1990. Evolution of Tertiary sedimentary basins of Japan in reference to opening of the Japan Sea. Journal of the Faculty of Science, the University of Tokyo, Section 2 22: 121–171.

Ilyina, A. P. 1963. Mollyuski Neogena Kamchatki [Molluscs of Neogene of Kamchatka]. Trudy VNIGRI (202): 1–242. (in Russian; original title translated)

Iredale, T. 1916. On two editions of Duméril's Zoologie Analytique. Proceedings of the Malacological Society of London 12: 79–84.

Itoh, Y. 1985. Stratigraphy and geochronology of the Neogene in the Tomari area, Toyama Prefecture, Central Japan. News of Osaka Micropaleontologist (13): 1–12. (in Japanese)

Itoigawa, J. 1960. Paleoecological studies of the Miocene Mizunami group, central Japan. Journal of the Earth Sciences, Nagoya University 8: 246–300.

Itoigawa, J., H. Shibata, and H. Nishimoto. 1974. Molluscan fossils of the Mizunami Group. Bulletin of the Mizunami Fossil Museum (1): 43–203. (in Japanese)

Itoigawa, J., H. Shibata, H. Nishimoto, and Y. Okumura. 1981. Miocene fossils from the Mizunami group. 2. Molluscs. Monograph of the Mizunami Fossil Museum (3-A): 1−53. (in Japanese)

Itoigawa, J., H. Shibata, H. Nishimoto, and Y. Okumura. 1982. Miocene fossils from the Mizunami group. 2. Molluscs (Continued). Monograph of the Mizunami Fossil Museum (3-B): 1−330. (in Japanese)

Iwai, T. 1961. The Miocene molluscan fossils from the area southwest of Hirosaki City, Aomori Prefecture, Japan. Transactions and Proceedings of the Palaeontological Society of Japan, n. ser. (41): 1−8.

Iwasaki, Y. 1970. The Shiobara-type molluscan fauna. An ecological analysis of fossil molluscs. Journal of the Faculty of Science, The University of Tokyo, Section 2 17: 351−444.

Kanehara, K. 1937. Neogene shells from the Etaibetsu Oil Field, Hokkaido. Journal of the Geological Society of Japan 44: 791−796.
DOI: 10.5575/geosoc.44.791

Kaneko, K., and M. Goto. 1992. Miocene fossils from Ikuridani, Yatsuo Town, Toyama Prefecture. Special Publication from Toyama Science Museum (5): 1−86. (in Japanese)

Kaneko, K., and M. Goto. 1997. Organisms of Ancient Toyama —Molluscan Fossils from the Kurosedani Formation. Tateyama Museum of Toyama. Tateyama. 79 p. (in Japanese; original title translated)

Kanno, S. 1958. New Tertiary molluscs from the Chichibu basin, Saitama Prefecture. Science Reports of the Tokyo Kyoiku Daigaku, Section C 6 (55): 157−229.

Kanno, S. 1960. Part 2. Paleontology. In J. Arai, and S. Kanno, eds., The Tertiary System of the Chichibu

Basin, Saitama Prefecture, Central Japan. Japan Society for the Promotion of Science. Tokyo. p. 123−396.

Kanno, S., and K. Matsuno. 1960. Molluscan fauna from the "Chikubetsu Formation", Hokkaido, Japan. Journal of the Geological Society of Japan 66: 35−44. DOI: 10.5575/geosoc.66.35

Kurihara, Y. 2006. Redescription of *Kaneharaia kannoi* (Masuda) (Bivalvia: Veneridae) from the Miocene Chichibu Basin, Central Japan. Bulletin of the Saitama Museum of Natural History (23): 35−39. DOI: 10.24715/osmnh.23.0_35

Kurihara, Y., and Y. Yanagisawa. 2002. A pectinid-dominant molluscan assemblage and diatom biochronology of the middle Miocene Shimotezuna Formation of the Taga Group in the Takahagi district, Joban area, northeast Honshu, Japan. Journal of the Geological Society of Japan 108: 421−434. (in Japanese with English abstract) DOI: 10.5575/geosoc.108.421

Kuroda, T. 1931. Fossil Mollusca. In F. Homma, ed., Geology of the Central Part of Shinano, part 4. Kokon Shoin. Tokyo. p. 1−90. (in Japanese)

Lamarck, J. B. M. 1799. Prodrome d'une nouvelle classification des coquilles, comprenant une rédaction appropriée des caractères génériques, et l'établissement d'un grand nombre de genres nouveaux. Mémoires de la Société d'Histoire Naturelle de Paris 1: 63−91.

Lamarck, J. B. de. 1809. Philosophie zoologique, ou exposition. Dentu. Paris. Vol. 1, 422 p., Vol. 2, 473 p.

Latreille, P. A. 1825. Familles naturelles du règne animal: exposées succinctement et dans un ordre analytique, avec l'indication de leurs genres. Bailliére. Paris. 570 p.

Linnaeus, C. 1758. Systema Naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis. Editio decima, reformata, Volume 1. Laurentius Salvius. Holmiae. 824 p.

Majima, R. 1989. Cenozoic fossil Naticidae (Mollusca: Gastropoda) in Japan. Bulletin of American Paleontology 96: 1−159.

Makiyama, J. 1925. The evolution of *Umbonium*. Japanese Journal of Geology and Geography 3: 119−130.

Makiyama, J. 1926. Tertiary fossils from North Kankyo-do, Korea. Memoirs of the College of Science, Kyoto Imperial University, Series B 2: 143−160.

Makiyama, J. 1927. Molluscan fauna of the lower part of the Kakegawa Series in the Province of Totomi, Japan. Memoirs of the College of Science, Kyoto Imperial University, Series B 3: 1−147.

Makiyama, J. 1936. The Meisen Miocene of Korea. Memoirs of the College of Science, Kyoto Imperial University, Series B 11: 193−228.

Makiyama, J. 1959. Tertiary fossils from various localities in Japan. Part 3. Palaeontological Society of Japan, Special Papers (5): 1−4.

Martini, E. 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In A. Farinacci, ed., Proceedings of the 2nd Planktonik Conference, Roma, 1970, vol. 2. Edizioni Tecnoscienza. Roma. p. 739−785.

Masuda, K. 1963. Remarks on some fossil *Dosinia* of Japan. Transactions and Proceedings of the Palaeontological Society of Japan, n. ser. (49): 29−38.

Masuda, K., and H. Takegawa. 1965. Remarks on the Miocene molluscs from the Sennan District, Miyagi Prefecture, Northeast Honshu, Japan. Saito Ho-on Kai Museum Research Bulletin (34): 1−14.

Masuda, K., S. Yoshida, and R. Sato. 1992. Fossil molluscs from Akakurasawa, Tazawako-machi, Akita Prefecture. Annual Report of Akita Prefectural Museum (17): 29−44. (in Japanese with English abstract)

Matsubara, T. 1995. Fossil Mollusca of the Lower Miocene Yotsuyaku Formation in the Ninohe district, Iwate Prefecture, Northeast Japan. Part 2 (1). Bivalvia and Scaphopoda. Transaction and Proceedings of the Palaeontological Society of Japan, n. ser. (180): 321−335.

Matsubara, T., T. Sasaki, and Y. Ito. 2009. Illustrations of Cenozoic molluscan type specimens preserved in the University Museum, the University of Tokyo. Part 4. The genus *Kaneharaia* (Bivalvia: Veneridae). Chiribotan 40: 23−28. (in Japanese)

Matsukuma, A., I. Kong, and R. Takada. 2015. Redescription of newly introduced *Mercenaria mercenaria* (Bivalvia: Veneridae) in Japan, with special reference to generic allocation of native

"*Mercenaria*" *stimpsoni*. Bulletin of the Nishinomiya Shell Museum (9): 1−60. (in Japanese)

Methner, K., M. Campani, J. Fiebig, N. Löffler, O. Kempf, and A. Mulch. 2020. Middle Miocene long-term continental temperature change in and out of pace with marine climate records. Scientific Reports 10: 7989.
DOI: 10.1038/s41598-020-64743-5

Miller, K. G., R. Baluyot, J. D. Wright, R. E. Kopp, and J. B. Browning. 2017. Closing an early Miocene astronomical gap with Southern Ocean $\delta^{18}O$ and $\delta^{13}C$ records: Implications for sea level change. Paleoceanography 32: 600–621.
DOI:10.1002/2016PA003074

Mizuno, A. 1965. Tertiary marine fauna from the environs of Hanawa Basin, North Honshu. Bulletin of the Geological Survey of Japan 16: 329–334. (in Japanese)

Mizuno, A., Y. Sumi, and S. Yamaguchi. 1969. Miocene stratigraphy of the Kushiro Coal Field, eastern Hokkaido, with the special reference to the stratigraphic problem concerning the so-called Chokubetsu Formation. Bulletin of the Geological Survey of Japan 20: 633–649. (in Japanese with English abstract)

Montfort, D. de. 1810. Conchyliologie systématique et classification méthodique des coquilles, Volume 2. Schoell. Paris. 676 p.

Nagamori, H., and M. Watanabe. 2023. Stratigraphic correlation of the Higashibessho, Tenguyama and Otokawa formations in the central to eastern area of Toyama Prefecture, central Japan. Bulletin of the Geological Survey of Japan 74: 119–131. (in Japanese with English abstract)

Nakagawa, T. 1998. Miocene molluscan fauna and paleoenvironment in the Niu Mountains, Fukui Prefecture, central Japan. Science Reports of the Institute of Geoscience, University of Tsukuba, Section B 19: 61–185.

Nakagawa, T. 2009. Miocene tropical sandy and rocky bottom molluscan assemblages of the Shimo Formation, Uchiura Group, Fukui Prefecture, Central Japan. Bulletin of the Mizunami Fossil Museum (35): 127–151. (in Japanese with English abstract)

Nakagawa, T., and K. Takeyama. 1985. Fossil molluscan associations and paleo-environment of the Uchiura Group, Fukui Prefecture, Central Japan. Bulletin of the Mizunami Fossil Museum (12): 27–48. (in Japanese with English abstract)

Nakagawa, T., and Y. Yoshizawa. 2007. Molluscan fossils from the subaqueous volcaniclastic rocks at Bentenmisaki Cape, Awara City, Fukui Prefecture, Japan. Earth Science (Chikyu Kagaku) 61: 405–414. (in Japanese with English abstract)

Nakajima, T., H. Iwano, T. Danhara, T. Yamashita, Y. Yanagisawa, Y. Tanimura, M. Watanabe, T. Sawaki, S. Nakanishi, H. Mitsuishi, O. Yamashina, and S. Imahori. 2019. Revised Cenozoic chronostratigraphy and tectonics in the Yatsuo Area, Toyama Prefecture, central Japan. Journal of the Geological Society of Japan 125(7): 483–516. (in Japanese with English abstract)

Nemoto, N., and S. O'Hara. 2003. Molluscan fossils and sedimentary environments of the Middle Miocene Kubota Formation in Tanagura District. Research Report of Taira Geological Society (24): 3–31. (in Japanese with English abstract)

Noda, H. 1966. The Cenozoic Arcidae of Japan. Science Reports of the Tohoku University, Second Series (Geology) 38: 1–161.

Noda, H., and M. Tada. 1968. Anadarids from the Shizukuishi Basin, Iwate Prefecture, Japan. Transactions and Proceedings of the Palaeontological Society of Japan, n. ser. (69): 193–206.

Noda, Y. 1992. Neogene molluscan faunas from the Haboro Coal-field, Hokkaido, Japan. Science Reports of the Tohoku University, Second Series (Geology) 62: 1–140.

Nomura, S. 1935a. Fossil Mollusca from vicinity of the Narusawa Hot Spring, northeastern part of Kurikoma Volcano, Iwate-ken. Saito Ho-on Kai Museum, Research Bulletin (5): 71–100.

Nomura, S. 1935b. A note on some fossil Mollusca from the Takikawa Beds of the northwestern part of Hokkaido. Science Reports of the Tohoku Imperial University, Second Series 18: 31–39.

Nomura, S. 1940. Molluscan fauna of the Moniwa Shell Beds exposed alon the Natori-Gawa in the vicinity of Sendai, Miyagi Prefecture. Science Reports of the Tohoku Imperial University, Second Series 21: 1–46.

Nomura, S., and K. Hatai. 1936. Fossils from the Tanagura Beds in the vicinity of the Town

Tanagura, Hukusima-ken, Northeast Honshu, Japan. Saito-Ho-on Kai Museum, Research Bulletin (10): 109–155.

Nomura, S., and H. Onisi. 1940. Neogene Mollusca from Sennan District, Miyagi Prefecture, Japan. Japanese Journal of Geology and Geography 17: 181–194.

Ogasawara, K. 1973. Molluscan Fossils from the Nishikurosawa Formation, Oga Peninsula, Akita Prefecture, Japan. Science Reports of the Tohoku University, Second Series, Special Volume (6): 137–155.

Ogasawara, K. 1976. Miocene Mollusca from Ishikawa-Toyama Area, Japan. Science Reports of the Tohoku University, Second Series 46(2): 33–78.

Ogasawara, K. 1982. Neogene molluscan fossils (29). In I. Fujiyama, T. Hamada, and N. Yamagiwa, eds., Gakuseiban, Nihon Koseibutsu Zukan [Encyclopedia of Japanese Fossils for Students]. Hokuryukan. Tokyo. p. 284–285. (in Japanese; original title translated)

Ogasawara, K. 1994. Neogene paleogeography and marine climate of the Japanese Islands based on shallow marine molluscs. Palaeogeography, Palaeoclimatology, Palaeoecology 108: 335–351.
DOI: 10.1016/0031-0182(94)90241-0

Ogasawara, K. 2002. Responses of Japanese Cenozoic molluscs to the Pacific gateway events. Revista Mexicana de Ciencias Geológicas 19(3): 1–8.

Ogasawara, K. 2011. Miocene Mollusca from the Tachikaraushinai Formation, northern Hokkaido, Japan. Earth Evolution Sciences 5: 3–24.

Ogasawara, K., and H. Noda. 1978. Arcid-Potamid fauna (Mollusca) from the Tsukinoki Formation, Sennan District, Miyagi Prefecture, Northeast Japan. Saito Ho-on Kai Museum, Research Bulletin (46): 21–44.

Ogasawara, K., and R. Nomura. 1980. Molluscan fossils from the Fujina Formation, Shimane Prefecture, San-in district, Japan. In H. Igo, and H. Noda, eds., Professor Saburo Kanno Memorial Volume. Memorial Association of Professor Saburo Kanno's Retirement, Institute of Geoscience, the University of Tsukuba. Tsukuba. p. 79–98.

Ogasawara, K., S. Ijima, and Y. Kaseno. 1989a. Miocene molluscs from the Tenguyama Formation, Toyama Prefecture, Hokuriku District, Japan. Science Report of Kanazawa University 34: 67–93.

Ogasawara, K., K. Masuda, and Y. Matoba. 1986. Neogene and Quaternary Molluscs from the Akita Oilfield, Japan. Commemorative Association of Professor Taisuke Takayasu's Retirement and Suppoters' Fundation of Mineral Industry Museum, Mining College, Akita University. Akita. 310 p. (in Japanese)

Ogasawara, K., O. Sasaki, and J. Nemoto. 1989b. The Otokawa fauna of the Hokuriku Neogene and its geohistorical significance. In N. Kashima, M. Komatsu, J. Takahashi, and I. Kawabe, eds., Professor Hidekuni Matsuo Memorial Volume. Matsuo Hidekuni Kyoju taikan kinen jigyo-kai [Professor Hidekuni Matsuo's Retirement Memorial Association], Ehime University. Matsuyama. p. 61–74 (in Japanese with English abstract)

Ogasawara, K., M. Takano, H. Nagato, and T. Nakano. 2008. Cenozoic molluscan faunas and climatic changes in the northern Pacific related to Pacific gateways: review and perspective. Bulletin of the Geological Survey of Japan 59: 355–364.

O'Hara, S., and N. Nemoto. 1984. Molluscan fossil from the type Goyasu Formation of the Joban Coalfield. Journal of the College of Arts and Sciences, Chiba University B-17: 45–61.

Oinomikado, T. 1938. Neogene shells from the vicinity of the City of Takasaki, Gumma-ken, Japan. Journal of the Geological Society of Japan 45: 671–676.
DOI: 10.5575/geosoc.45.671

Otuka, Y. 1934. Tertiary structure of the northwestern end of the Kitakami Mountainland, Iwate Prefecture, Japan. Bulletin of the Earthquake Research Institute, Imperial University of Tokyo 12: 566–638.

Otuka, Y. 1938. Mollusca from the Miocene of Tyugoku, Japan. Journal of the Faculty of Science, Imperial University of Tokyo, Section 2 5(2): 21–45.

Otuka, Y. 1939. Tertiary crustal deformations in Japan (with short remarks on Tertiary paleogeography. In Yabe Kyoju kanreki kinen-kai [Prof. Yabe's 60th Birthday Celebration Party], ed., Jubilee Publication in the Commemoration of Professor H. Yabe, M. I. A. Sixtieth Birthday, vol. 1. Yabe Kyoju Kanreki Kinen-kai. Sendai. p. 481–519.

Oyama, K. 1950. Studies of fossil molluscan biocoenosis, No. 1. Biocoenological studies on the mangrove swamps, with description of new species from Yatsuo Group. Reports, Geological Survey of Japan (132): 1–15.

Oyama, K. 1955. A contribution to the phylogeny of the Umboniinae. Venus (The Japanese Journal of Malacology) 18(3): 169–176. (in Japanese) DOI: 10.18941/venusjjmc.18.3_169

Parker, P. 1949. Fossil and Recent species of the pelecypod genera *Chione* and *Securella* from the Pacific coast. Journal of Paleontology 23: 577–593.

Rafinesque, C. S. 1815. Analyse de la nature, ou tableau du l'univers et des corps organisés. Barravechia. Palerme. 224 p.

Sacco, F. 1896. I molluschi dei terreni terziarii del Piemonte e della Liguria. Parte XIX-XXII. Bollettino dei Musei di Zoologia ed Anatomia comparata della Reale Università di Torino 11: 79–98.

Sangiorgi, F., W. Quaijtaal, T. H. Donders, S. Schouten, and S. Louwye. 2021. Middle Miocene temperature and productivity evolution at a Northeast Atlantic Shelf Site (IODP U1318, Porcupine Basin): global and regional changes. Paleoceanography and Paleoclimatology 36(7). DOI: 10.1029/2020PA004059

Sasaki, O. 1990. Parameters for description of the shell form of the genus *Anadara* (Mollusca; Bivalvia). Transactions and Proceedings of the Palaeontological Society of Japan, n. ser. (158): 513–534.

Sato, S., T. Chiba, T. Yamanaka, J. Nemoto, M. Shimamoto, and T. Matsubara. 2016. A catalogue of name-bearing type specimens of fossil Bivalvia (Mollusca) registered in the Tohoku University Museum. Bulletin of the Tohoku University Museum (15): 9–106.

Sato, T., Y. Kanzaki, T. Okuyama, and S. Chiyonobu. 2010. Calcareous nannofossil biostratigraphy of the Miocene formations distributed in the Hokuriku to northern Japan. Science and Technological Reports of Graduate School of Engineering and Resource Science, Akita University (31): 37–45. (in Japanese with English abstract)

Schumacher, C. F. 1817. Essai d'un nouveau système des habitations des Vers Testacés. Schultz. Copenhagen. 287 p.

Shibata, H. 1970. Molluscan faunas of the first Setouchi Series, Southwest Japan. Part 1, Fauna of Ichishi Group. Journal of the Earth Sciences, Nagoya University 18: 27–84.

Shikama, T. 1964. Index Fossils of Japan. Asakura Shoten. Tokyo. 287 p. (in Japanese)

Shikama, T. 1966. On some Desmostylian teeth in Japan, with stratigraphical remarks on the Keton and Izumi desmostylids. Bulletin of the National Science Museum, Tokyo 9: 119–170.

Shimizu, M., and S. Fujii. 1991. On the molluscan fossils of Otogawa Formation from north-west part of Yatsuo-machi, Toyama Prefecture, central Japan — Study of Otogawa molluscan fossils (part 4) —. Journal of the College of Liberal Arts, Toyama University 24: 21–33. (in Japanese with English abstract)

Shumard, B. F. 1858. Descriptions of new fossils from the Tertiary formations of Oregon and Washington Territories and the Cretaceous of Vancouver's Island, collected by Dr. Jno Evans, U.S. Geologist, under instructions from the Department of the Interior. Transactions of the Academy of Sciences of Saint Louis 1: 120–125.

Shuto, T., and Y. Ueda. 1967. Further notes on new Oligocene gastropods from North Kyushu. Japanese Journal of Geology and Geography 38: 27–42, pl. 2.

Slodkewitsch, W. S. 1938. Tretichnye peletsipody Dal'nego Vostoka [Tertiary Pelecypoda from the Far East]. Part 2. Paleontologiya SSSR [Paleontology of USSR] 10: 1–275. (in English and Russian)

Sugiyama, T. 1935. On the variation of the shells of living and fossil *Umbonium* from Japan, and its evolution. Part 1. Journal of the Geological Society of Japan 42: 404–430. (in Japanese)

Swainson, W. 1831. Zoological illustrations, or original figures and descriptions of new, rare, or interesting animals, selected chiefly from the classes of ornithology, entomology, and conchology, and arranged according to their apparent affinities. Second Series. Volume 2. Baldwin and Cradock. London. pls. 46–85.

Takeuchi, M., R. Furukawa, H. Nagamori, and T. Oikawa. 2017. Geology of Tomari District. Geological Survey of Japan. Tsukuba. 121 p. (in Japanese with English abstract)

Tao, H. J., and C. H. Hu. 1992. Sigou Formation (Pleistocene), Hengchun West Platform, Hengchun Peninsula, Mollusc Fossils (Supplement). Atlas of Molluscan Fossils from Taiwan 3: 1427–1493. (in Chinese; original title translated)

Tanaka, K. 1960. Studies on the molluscan fossils from Central Shinano, Nagano Prefecture, Japan (Part 5) —Molluscan fossils from Uchimura Formation—. Journal of the Faculty of Education, Shinshu University (10): 131–148.

Tsuchida, E. 1986. Taxonomic revision on two species of the genus *Orectospira* (Gastropoda: Prosobranchia). Venus (The Japanese Journal of Malacology) 45: 75–86. (in Japanese with English abstract) DOI: 10.18941/venusjjm.45.2_75

Tsuda, K. 1965. Neogene molluscan assemblages in the inner zone of Northeast Japan —with special reference to middle Miocene assemblages. Fossils (Palaeontological Society of Japan) (10): 20–23. (in Japanese)

Uozumi, S. 1953. Cenozoic fossil commentary 23. Miocene fossils from Hokkaido (Part 1). Shinsei-dai-no-kenkyū (18): 25–27. (in Japanese; original title translated)

Urata, H. 1961. On the Japanese fossil *Orectospira*. Reports on Earth Science, Department of General Education, Kyushu University 7: 11–23.

Weaver, C. E. 1912. A preliminary report on the Tertiary paleontology of western Washington. Washington Geological Survey Bulletin 15: 1–80.

Yokoyama, M. 1890. Versteinerungen aus der japanischen Kreide. Palaeontographica 36: 159–202.

Yokoyama, M. 1923. Tertiray Mollusca from Dainichi in Totomi. Journal of the College of Science, Imperial University of Tokyo 45(2): 1–18.

Yokoyama, M. 1926a. Tertiary Mollusca from Shiobara in Shimotsuké. Journal of the Faculty of Science, Imperial University of Tokyo, Section 2 1: 127–138.

Yokoyama, M. 1926b. Tertiary Mollusca from southern Totomi. Journal of the Faculty of Science, Imperial University of Tokyo, Section 2 1: 313–364.

Yokoyama, M. 1928a. Mollusca from the oil-field of the island of Taiwan. Report, Imperial Geological Survey of Japan (101): 1–112.

Yokoyama, M. 1928b. Shells from Hyuga. Journal of the Faculty of Science, Imperial University of Tokyo, Section 2 2: 331–350.

Yokoyama, M. 1930. Neogene shells from Yamashiro. Journal of the Faculty of Science, Imperial University of Tokyo, Section 2 2: 399–402.

Yokoyama, M. 1931. Tertiary Mollusca from Iwaki. Journal of the Faculty of Science, Imperial University of Tokyo, Section 2 3: 197–203.

Middle Miocene Climatic Transition in the Japan Sea borderland of Honshu —Middle Miocene molluscan fauna from Unazukimachi-Oritate in Kurobe City, Toyama Prefecture, Japan—

Kazutaka Amano, Takuma Haga, Tokiyuki Sato, Toshikazu Hamuro, and Masui Hamuro

Explanation of Plates 1–3

Plate 1

Figs. A–G, I. *Protorotella gigas* Amano, new species.
Figs. A, D, G. holotype, NMNS PM 68820; A, apertural view; D, apical view; G, basal view.
Figs. B, E. paratype 1, NMNS PM 68821; B, apertural view; E, apical view.
Figs. C, F. paratype 4, NMNS PM 68824; C, apertural view; F, apical view.
Fig. I. paratype 3, NMNS PM 68823, basal view.

Figs. H, N, O. *Trochocerithium oritatense* Amano, new species. Holotype, NMNS PM 68830; H, basal view; N, apertural view; O, abapertural view.

Fig. J. *Calliostoma* (*Calliotropis*) *simane* Nomura and Hatai. NMNS PM 68826-1, apertural view.

Figs. K, L. *Cryptonatica janthostoma* (Deshayes). NMNS PM 68833; K, basal view; L, apertural view.

Fig. M. *Glossaulax coticazae* (Makiyama). NMNS PM 68834-1, apertural view.

All scale bars show 5 mm.

Plate 1

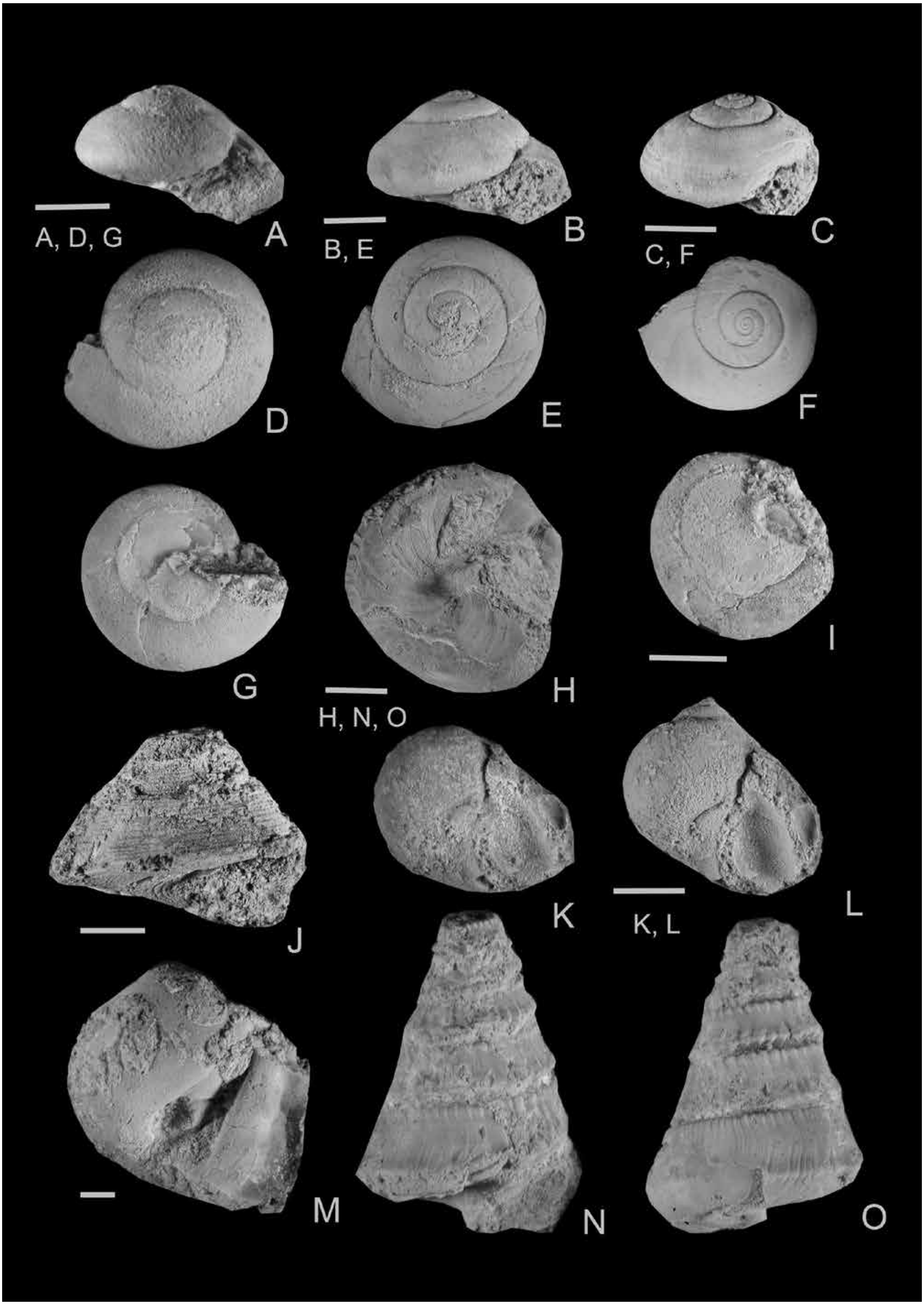

Plate 2

Fig. A. ***Cyclocardia siogamensis*** **(Nomura).** NMNS PM 68859-1, exterior of right valve.

Fig. B. ***Acila*** **(*Acila*)** ***submirabilis*** **Makiyama.** NMNS PM 68851-1, exterior of right valve.

Fig. C. ***Acila*** **(*Truncacila*)** ***gottschei*** **(Böhm).** NMNS PM 68852-1, exterior of right valve.

Figs. D, G, J. ***Scapharca ninohensis*** **(Otuka).**
Figs. D, G. NMNS PM 68855-4; D, dorsal view of right valve; G, exterior of right valve
Fig. J. NMNS PM 68855-3, exterior of left valve.

Fig. E. ***Glycymeris*** **(*Veletuceta*)** ***cisshuensis*** **Makiyama.** NMNS PM 68856-1, exterior of right valve.

Fig. F. ***Saccella*** **sp.** NMNS PM 68853-1, exterior of right valve.

Figs. H, L, Q, R. ***Phacosoma akaisiana*** **(Nomura).**
Fig. H. NMNS PM 68865-1, exterior of left valve.
Figs. L, Q, R. NMNS PM 68865-2; L, hinge of right valve; Q, exterior of right valve; R, NMNS PM 68865-3, interior of right valve.

Fig. I. ***Anadara arasawaensis*** **Noda.** NMNS PM 68854-1, exterior of left valve.

Figs. K, O, P. ***Securella yiizukai*** **(Kanehara).**
Fig. K. NMNS PM 68863-4, hinge of right valve
Figs. O, P. NMNS PM 68863-1; O, dorsal view; P, exterior of left valve.

Figs. M, N. ***Kaneharaia kannoi*** **(Masuda).** NMNS PM 66866-1; M, hinge of right valve; N, exterior of right valve.

All scale bars show 5 mm.

Plate 2

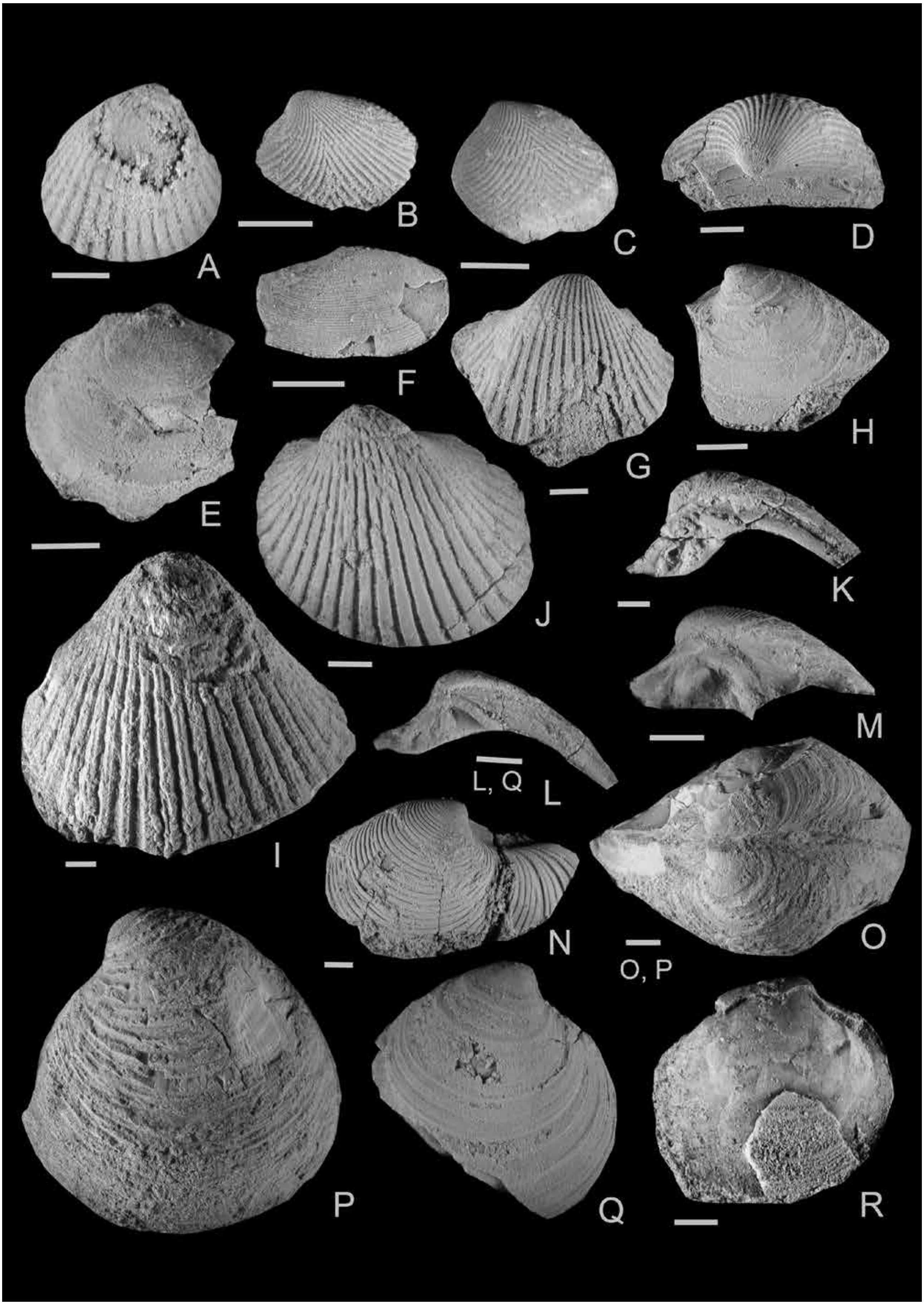

Plate 3

Figs. A, B, D, G, J. *Meretrix ninohensis* Hatai.

Figs. A, G. NMNS PM 68868-3; A, hinge of left valve; G, left valve showing pallial sinus.

Figs. B, J. NMNS PM 68868-1; B, hinge of right valve; J, exterior of right valve.

Fig. D. NMNS PM 68868-4; exterior of left valve.

Figs. C, E, F. *Spisula* (*Pseudocardium*) sp.

Figs. C, E. NMNS PM 68870-1; C, hinge of left valve; E, interior of left valve.

Fig. F. NMNS PM 68870-2, interior of right valve.

Figs. H, I. *Sunetta* sp. NMNS PM 68867-1; H, exterior of left valve; I, interior of left valve.

Fig. K. *Solidicorbula* cf. *nisataiensis* (Otuka). NMNS PM 68873-1, interior of left valve.

Fig. L. *Spisula* (*Mactromeris*) cf. *voyi* Gabb. NMNS PM 68871-1, exterior of left valve.

Fig. M. *Mya* (*Mya*) *cuneiformis* (Böhm). NMNS PM 68872-1, right valve.

Fig. N. *Fissidentalium yokoyamai* (Makiyama). NMNS PM 68874-1, exterior surface.

All scale bars show 5 mm.

Plate 3