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Molluscan fossils from the Lower Miocene Higashibessho Formation (lower part) in Toyama Prefecture and their paleobiogeographic significance

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Abstract

Thirty molluscan species have been recovered from the upper Lower Miocene Higashibessho Formation around Yamada-Nakanose in Toyama Prefecture. Of these, *Propeamusium fuganjiense* Yamana is the first recorded from this formation and described. Other two interesting species, *Myonera osawanoensis* (Tsuda) and *Liracassis yokoyamai* (Kuroda) are also herein described. The deep-sea fauna of the Higashibessho and uppermost part of Kurosedani Formations share some characteristic species with the Lower to Middle Miocene formations in San-in (Shimane and Tottori Prefectures) and Tokai (Aichi, Gifu and Mie Prefectures) areas. Moreover, the vesicomyid *Pleurophopsis*, the cassid *Liracassis* and the neilonellid *Neilo* (*Multidentata*) migrated southward since the Early Miocene from the west coast of America, Kamchatka and Sakhalin. These data support the extension of a relatively cold-water subsurface current to the Japan Sea side of western Honshu.

Key words: late Early Miocene, Molluscan fauna, Toyama Prefecture, Higashibessho Formation, paleobiogeography

1. Introduction

The upper Lower Miocene Higashibessho Formation (Fujita and Nakagawa, 1948) in Toyama Prefecture mainly consists of mudstone and has been known as a deep-sea deposit conformably overlying the Kurosedani Formation yielding the tropical shallow-water Arcid-Potamid Fauna (Tsuda, 1956). According to Tsuda (1960), only a few fossils are known from the Higashibessho Formation. However, many well-preserved molluscan fossils have been recovered from the lower part of this formation (Amano et al., 2001, 2004). The age of the lower part of the formation was assigned to NPD3A (17.0–16.6 Ma) to NPD3B (16.6–15.9 Ma) by Yanagisawa (1999) based on the diatom fossils. Moreover, the Yamadanaka Tuff just below the Higashibessho Formation was dated to 16.6±0.2 Ma by U-Pb method and to 16.4±1.2 Ma by the FT method (Nakajima et al., 2019). The paleo-depth of the formation was estimated as middle to upper bathyal zone by Hasegawa and Takahashi (1992) based on the benthic Foraminifera. On the other hand, based on molluscan fossils and ostracod fossils, it was estimated as the upper bathyal to lower sublittoral zone by Shimizu et al. (2000), Amano et al. (2004) and Ozawa (2016).

Shimizu et al. (2000) reported 19 species of molluscs including *Aturia* sp. from the lower part of the Higashibessho Formation at four localities (Yamada-

Nakanose, Fuchu-machi-Dojima, Yatsuo-machi-Kashio, Osawano-machi-Iwaki). Of these, the fossil identified as *Saccella confusa* (Hanley) is *Neilo* (*Multidentata*) *multidentata* (Khomenko) from the Oligocene to Miocene of Hokkaido, Sakhalin and Kamchatka (Amano et al., 2000). Later, Amano et al. (2001) described two species of the "oldest" vesicomyids in the Japan Sea side from the Higashibessho Formation at Shimosasahara. Amano et al. (2004) found 87 species of molluscs including one new muricid gastropod, *Pagodula shojii* Amano, Hamuro and Hamuro. However, 32 species from the upper part of this locality were transported from the shallow water to the deep sea. After that, small taxodont *Tindaria* sp. and the vesicomyid *Calyptogena* sp. reported here have been reexamined and proposed as new species, *Tindaria hamuroi* Amano and Haga, 2021 and *Pleurophopsis hamuroi* (Amano and Kiel, 2011).

Thirty species including two hitherto unknown species have been found from the lower part of the Higashibessho Formation at Yamada-Nakanose in Toyama City. We describe these species and discuss their paleobiogeographical significance.

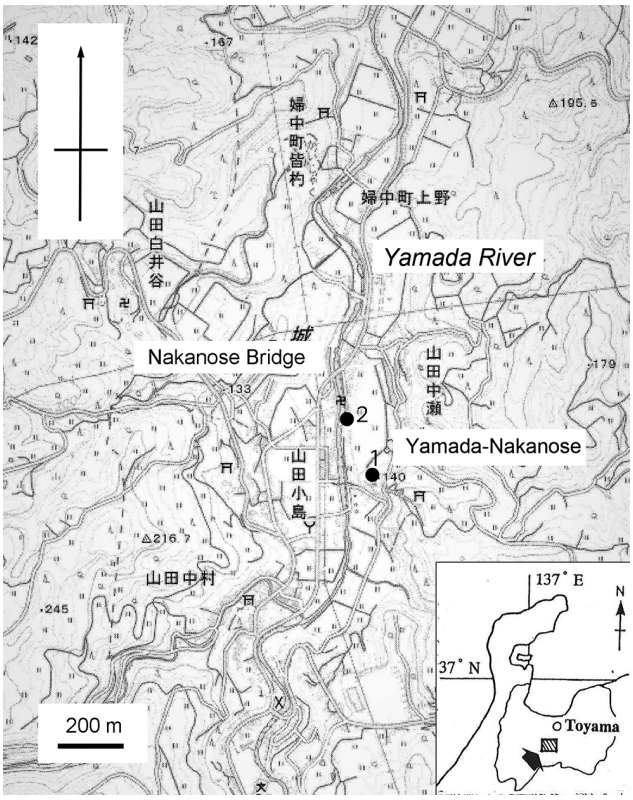

Fig. 1. Locality map of fossils (using the digital topographical map, scale 1:25,000, published by Geospacial Information Authority of Japan).

2. Materials and Methods

Many molluscan fossils were recovered from the large cliff near the steel tower, 200 m south to Yamada-Nakanose, Toyama City (Loc. 1 of Fig. 1; 36°35′38″N, 137°5′6″E) and from the right-side floor of Yamada River at 150 m upstream of Nakanose Bridge (Loc. 2 of Fig. 1; 36°35′44″N, 137°5′2″E). Among them, Loc. 1 corresponds to "Loc. 2" by Shimizu et al. (2000). Many fossils without shells sporadically occurred from the bedded "hard shale" at Loc. 1. On the other hand, some thin shells were recovered from a thin bedding plane of the bedded shale.

As shell material of most specimens is dissolved out, we made silicone rubber cast for identification. For estimating the paleo-depth, we used the maximum depth zone of the same living genera based on the list by Higo et al. (1999). All illustrated specimens are coated with ammonium-chloride and stored at Mizunami Fossil Museum (MFM).

3. Molluscan fossils

Thirty species of molluscs (21 species of bivalves, two scaphopods and seven species of gastropods) were recovered (Table 1). Of these, *Propeamussium fuganjiense* Yamana and *Myonera osawanoensis* (Tsuda) have never been reported from the Higashibessho Formation. *Liracassis yokoyamai* (Kuroda) was once illustrated from the formation as *L. japonica* (Yokoyama) by Amano et al. (2004) but has not been described in detail. Moreover, all species of *Malletia* and *Myonera* are now living in deeper water than the upper bathyal zone.

4. Systematic palaeontology

Class Bivalvia
Family Propeamussiidae Abott, 1954
Genus *Propeamussium* de Gregorio, 1884

***Propeamussium fuganjiense* Yamana, 1997**
(Plate 1, figs.7, 8, 9, 13)

Amussium sp. Yamana, 1972, p. 4–8, pl. 1, figs. 1–6, pl. 2, figs. 1a–6, pl. 3, figs. la–2, pl. 4, figs. 1a–5b.

Parvamussium sp. Itoigawa and Nishikawa, 1976, pl. 33, fig. 4; Yamana, 1977, p. 13–14; Okamoto et al., 1986, pl. 20, figs. 11–14; Yamaoka, 1993, pl. 2, figs. 8a–9; Shimizu et al., 2000, pl., figs. 9–10.

"*Propeamussium*" sp. Shibata and Ina, 1983, p. 39, pl. 2, fig. 9.

Propeamussium fuganjiensis Omori et Inoue (MS). Akagi et al., 1992, pl. 1, fig. 1.

Propeamussium fuganjiensis Omori et Inoue. Yamana, 1997, p. 88, pl. 20, figs. 1a–3, pl. 21, figs. 1–6.

Propeamussium fuganjiensis Yamana, 1997. Kurihara, 2000, p. 11, pl. 4, fig. 22; Kurihara, 2010, p. 36.

Material: 31 specimens.

Measurements: MFM 41021, Length (L)= 60.2 mm, Height (H)= 64.7 mm, Loc. 1; MFM 41023, L= 42.6mm+, H= 49.9 mm+, Loc. 2; MFM 41024, L= 57.5 mm, H= 58.6 mm, Loc. 1.

Remarks: Shells from the Higashibessho Formation are large (maximum L= 60.2 mm), thin, subcircular and flat. They have no byssal notch, oblique anterior and posterior margin of auricles, nine internal ribs only observed near the beak, not attaining the ventral margin, and 13 rude commarginal ribs.

Some authors identified this species as *Parvamussium* sp. (Itoigawa and Nishikawa, 1976; Yamana, 1977; Okamoto et al., 1986; Yamaoka, 1993; Shimizu et al., 2000). However, *Parvamussium* can be separated from *Propeamussium* by having a byssal notch and inner ribs attaining to the ventral margin (Dijkstra, 2013). Our species lacks these characteristics of *Parvamussium* and belongs to *Propeamussium*. Although Akagi et al. (1992) first illustrated this species as *Propeamussium fuganjiensis* Omori et Inoue (MS), they only illustrated the species and did not formally describe it. Yamana (1997) first described and illustrated this species as *Propeamussium fuganjiensis* Omori et Inoue. Therefore, Kurihara (2000) identified Yamana (1997) as the author of this species. We follow his opinion, but as *Propeamussium* is a neutral noun, the species name must be changed as *fuganjiense*.

The Recent species, *Propeamussium watsoni* (E. A. Smith, 1885) is closely similar to *P. fuganjiense* in having a large shell (maximum H= 60 mm; Dijkstra, 1995). However, the Recent species has ten internal ribs and no rude commarginal ribs.

Distribution: Upper Lower Miocene, Morozaki and Shidara Groups in Aichi Prefecture, Higashibessho Formation in Toyama Prefecture; lower Middle Miocene, Haratajino Formation in Gunma Prefecture, Tottori Group (Fuganji Mudstone) in Tottori Prefecture, Bihoku Group in Shimane Prefecture.

Family Cuspidariidae Dall, 1886

Genus *Myonera* Dall and Smith in Dall, 1886

***Myonera osawanoensis* (Tsuda, 1959)**

(Plate 1, figs. 10, 11)

Cuspidaria osawanoensis Tsuda, 1959, p. 73, pl. 2, figs. 2a, b.

Cuspidaria sp. (n. sp.). Shibata in Itoigawa et al., 1974, p. 110, pl. 35, figs. 3, 4.

Cuspidaria (*Tergula*) sp. Itoigawa et al., 1981, pl. 22, fig. 9; Itoigawa et al., 1982, p. 119.

Myonera osawanoensis (Tsuda, 1959). Kurihara, 1999, p. 232, figs. 6-25, 26, 27; Kurihara, 2000, p. 12, pl.4, fig. 15; Kurihara, 2010, p. 77.

Material: Three specimens.

Measurements: MFM 41025, L= 13.2 mm, H=11.2 mm, Loc. 1; MFM 41026, L= 9.6 mm, H= 7.3 mm, Loc. 2.

Remarks: Shells from the Higashibessho Formation are small (maximum L= 13.2 mm), thin, less inflated and ovate. Rostrate area is smooth while the main disc is sculptured by more than six strong commarginal ribs.

In shell size and shape, *Myonera osawanoensis* most closely resembles *M. dautzenbergi* Prashad, 1932 which lives in 500 to 1000 m from Sagami Bay southward to Australia in it shell size and shape. However, the main disc of the latter species has no commarginal ribs.

Distribution: Upper Lower Miocene, Kurosedani Formation (Kashio alternation Member) and Higashibessho Formation in Toyama Prefecture; lower Middle Miocene, Haratajino Formation in Gunma Prefecture, Arakawa Formation in Saitama Prefecture, Oidawara Formation of Mizunami Group in Gifu Prefecture.

Class Gastropoda

Family Cassidae Latreille, 1825

Genus *Liracassis* Moore, 1963

Table 1. List of molluscan fossils from the lower part of Higashibessho Formation around Yamada-Nakanose in Toyama City. Ss*= Shimosasahara, based on the data from the mudstone (L and UM) by Amano et al. (2004). Number in the list shows individuals.

Species	Loc.	1	2	Ss*
Acharax tokunagai (Yokoyama)		19		
Leionucula osawanoensis (Tsuda)		7	4	+
Lamellinucula hokoensis (Kanehara)		1	34	+
Acila (*Acila*) *submirabilis* Makiyama		1		+
Malletia inermis (Yokoyama)		10		+
Neilo (*Multidentata*) *multidentata* (Khomenko)				+
Neilonella tsukigawaensis Kurihara				+
Tindaria hamuroi Amano and Haga				+
Portlandia (*Portlandella*) *lischkei* (Smith)		4	9	+
P. (*Megayoldia*) sp.				+
Bathymodiolus? sp.				+
Solamen fornicatum (Yokoyama)				+
Propeamussium tateiwai Kanehara		16		+
P. fuganjiense Yamana		5	26	
Delectopecten sp.		1		+
Gloripallium izurense Masuda				+
Acesta goliath (Sowerby)				+
Pycnodonte? sp.		2		
Ostrea sp.				+
Pandora sp.				+
Periploma yokoyamai Makiyama				+
P. mitsuganoense Araki				+
Thracia kamayasikiensis Hatai				+
Thracia? sp.			1	
Lyonsiella mitsuganoensis Shibata				+
Vertambitus? sp.		2		
Poromya osawanoensis Tsuda				+
Cardiomya mitsuganoensis (Shibata)		1		+
Myonera osawanoensis (Tsuda)		2	1	
Lucinoma acutilineatum (Conrad)		38		+
L. sp.			22	
Elliptiolucina? sp.		1		
Thyasira sp.		1	5	+
Conchocele cf. *yatsuoensis* Amano, Miyajima, Nakagawa, Hamuro and Hamuro		3		
Vesicomya? sp.		7		
Pliocardia kawadai (Aoki)		1		+
Pleurophopsis hamuroi (Amano and Kiel)				+
Macoma (*Macoma*) sp.				+
Solen sp.				+
Ginebis osawanoensis (Tsuda)				+
Calliostoma (*Calotropis*) *simane* Nomra and Hatai				+
Cryptonatica ichishiana (Shibata)				+
Sinum ineptum (Yokoyama)				+
Semicassis? sp.				+
Liracassis yokoyamai (Kuroda)			1	+
Echinophoria etchuensis (Hatai and Nisiyama)				+
Cassidae gen. et sp. indet.		2		
Cymatiidae gen. et sp. indet.				+
Boreotrophon osawanoensis (Tsuda)				+
Pagodula shojii Amano, Hamuro and Hamuro				+
Muricidae gen. et sp. indet.			1	
Babylonia kokozurana Nomura				+
Buccinidae gen. et sp. indet.				+
Zeuxis kometsubus (Otuka)				+
Neadmete nakayamai Habe				+
Cancellariidae gen. et sp. indet.			1	
Megasurcula yokoyamai (Otuka)				+
M. sp.				+
Cochlespira osawanoensis (Tsuda)				+
Tomopleura osawanoensis Tsuda				+
Comitas sp.				+
Eoscaphander corpulenta (Yokoyama)				+
Cylichna sp.		1		
Bowdenatheca sp.		11		+
Clio itoigawae Shibata		13		
C. sp.				+
Fissidentalium yokoyamai (Makiyama)			2	+
Laevidentalium sp.		3		+

Liracassis yokoyamai (Kuroda, 1933)

(Plate 2, figs.7a, b)

See detail synonym list by Kanno (1973) and Matsubara et al. (2013).

Material: One specimen.

Measurements: MFM 41034, H= 33.9 mm, Diameter= 25.3 mm.

Remarks: Shell is small for the species (max. H= 53.5 mm by Kanno, 1973). Shell surface is almost weathered out. Nine wide spiral cords with one to three interstitial threads are recognized below the shoulder of the last whorl. Fifteen spinose nodes occur on the shoulder of the last whorl and eighteen weaker nodes are recognized on the cords below the shoulder. These characteristics allow identification of our specimen with *Liracassis yokoyamai* (Kuroda, 1933).

Amano et al. (2004) illustrated *Liracassis japonica* (Yokoyama, 1923) from the Higashibessho Formation at Shimo-sasahara. However, as pointed out by Matsubara et al. (2013), this species name was replaced with *Liracassis yokoyamai* (Kuroda, 1933) which is valid following ICZN Opinion 59.3.

As discussed by Kanno (1973) and Amano (2005), the genus *Liracassis* originated in the late Eocene of western America and migrated to the northwestern Pacific in the Early Miocene.

Distribution: Upper Lower Miocene, Furanui Formation in Hokkaido, Kokozura Formation in Ibaraki Prefecture, Kurosedani and Higashibessho Formations in Toyama Prefecture, Takakura Formation of the Katsuta Group in Okayama Prefecture; upper Lower to lower Middle Miocene, Sugota Formation in Akita Prefecture, Araya Formation in Fukui Prefecture; lower Middle Miocene, Oidawara Formation of Mizunami Group in Gifu Prefecture; Middle Miocene, Bifuka Formation (lower part) in

Hokkaido, Tomezaki Formation in Iwate Prefecture, Yanagawa Formation in Fukushima Prefecture, Daishoji Formation in Ishikawa Prefecture, Fujina Formation in Shimane Prefecture.

5. Discussion

Summarizing the paleobiogeographical significance of the Early Miocene deep-sea fauna in Toyama Prefecture, the following two points are important.

First, the fauna shares some characteristic species with the Lower to Middle Miocene formations in the San-in (Shimane and Tottori Prefectures) and the Tokai (Aichi, Gifu and Mie Prefectures) areas. Yamana (1997) described and illustrated *Nuculana* (*Thestyleda*)? sp. from the lower Middle Miocene Tottori Group (Fuganji Mudstone) in Tottori Prefecture. However, the illustrated species can be identified with *Neilo* (*Multidentata*) *multidentata* (Khomenko) by having similar shell shape and sculpture (*see* Amano et al., 2000). Consequently, the above areas have the following species in common with the above areas; *Neilo* (*Multidentata*) *multidentata*, *Propeamussium tateiwai, P. fuganjiense*, *Gloripallium izurense*, and *Liracassis yokoyamai* (Amano et al., 2000, 2004; the present study). As discussed by Amano et al. (2019a), the chemosymbiotic species arrived soon after the formation of the Japan Sea (ca. 18 Ma). Some deep-sea species without symbionts also invaded into the Japan Sea from the Pacific side.

Second, some genera or subgenera originated in the eastern Pacific or northern Pacific (Sakhalin and Kamchatka). The oldest records of the vesicomyid *Pleurophopsis* and the cassid *Liracassis* are known from the late Eocene of the Eastern Pacific (Kanno, 1973; Amano, 2005; Amano and Kiel, 2007; Amano et al., 2019b). The neilonellid *Neilo* (*Multidentata*) appeared in the Oligoene of Sakhalin and Kamchatka (Amano et al., 2000). The deep-sea turbinid gastropod, *Phanerolepida* appeared in the Oligocene of the Eastern Pacific and migrated westward via Kamchatka to Japan during the late Early to early Middle Miocene (Hickman, 1972; Amano, 2000, 2005). During the Miocene Climatic Optimum, the subtropical fauna expanded to southwestern Hokkaido via a warm-water current (e.g., Chinzei, 1986). However, Chinzei (1981) estimated the subsurface relatively cold-water current ("Oyashio senryu") during the late Early Miocene to earliest Middle Miocene in the Pacific side of northern Honshu to Tokai area of central Honshu, based on the distribution of the *Acilana tokunagai* assemblage which is also distributed from Kamchatka to Sakhalin. Our data supports his estimation and the extension of this subsurface current to the Japan Sea side of western Honshu.

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Molluscan fossils from the Lower Miocene Higashibessho Formation (lower part) in Toyama Prefecture and their paleobiogeographic significance

Kazutaka Amano, Toshikazu Hamuro, and Masui Hamuro

Explanation of Plates 1–2

Plate 1

Fig. 1. ***Lamellinucula hokoensis*** **(Kanehara)**, MFM 41015, Loc. 1.

Fig. 2. ***Leionucula osawanoensis*** **(Tsuda)**, MFM 41016, Loc. 1.

Fig. 3. ***Malletia inermis*** **(Yokoyama)**, MFM 41017, Loc. 1.

Fig. 4. ***Portlandia*** **(*Portlandella*)** ***lischkei*** **Habe**, MFM 41018, Loc. 1.

Fig. 5. ***Delectopecten*** **sp.**, MFM 41019, Loc. 1.

Fig. 6. ***Propeamussium tateiwai*** **Kanehara**, MFM 41020, Loc. 1.

Figs. 7, 8, 9, 13. ***Propeamussium fuganjiense*** **Yamana**
Fig. 7, MFM 41021, Loc. 1.
Fig. 8, MFM 41022, Loc. 2.
Fig. 9, MFM 41023, Loc. 2.
Fig. 13, MFM 41024, Loc. 1.

Figs. 10, 11. ***Myonera osawanoensis*** **(Tsuda)**
Fig. 10, MFM 41025, Loc. 1.
Fig. 11, MFM 41026, Loc. 2.

Fig. 12. ***Acharax tokunagai*** **(Yokoyama)**, MFM 41027, Loc. 1.

All scale bars show 5 mm. The illustrated specimens in Figs. 7, 8, 10 are silicone rubber casts coated with ammonium chloride.

Plate 1

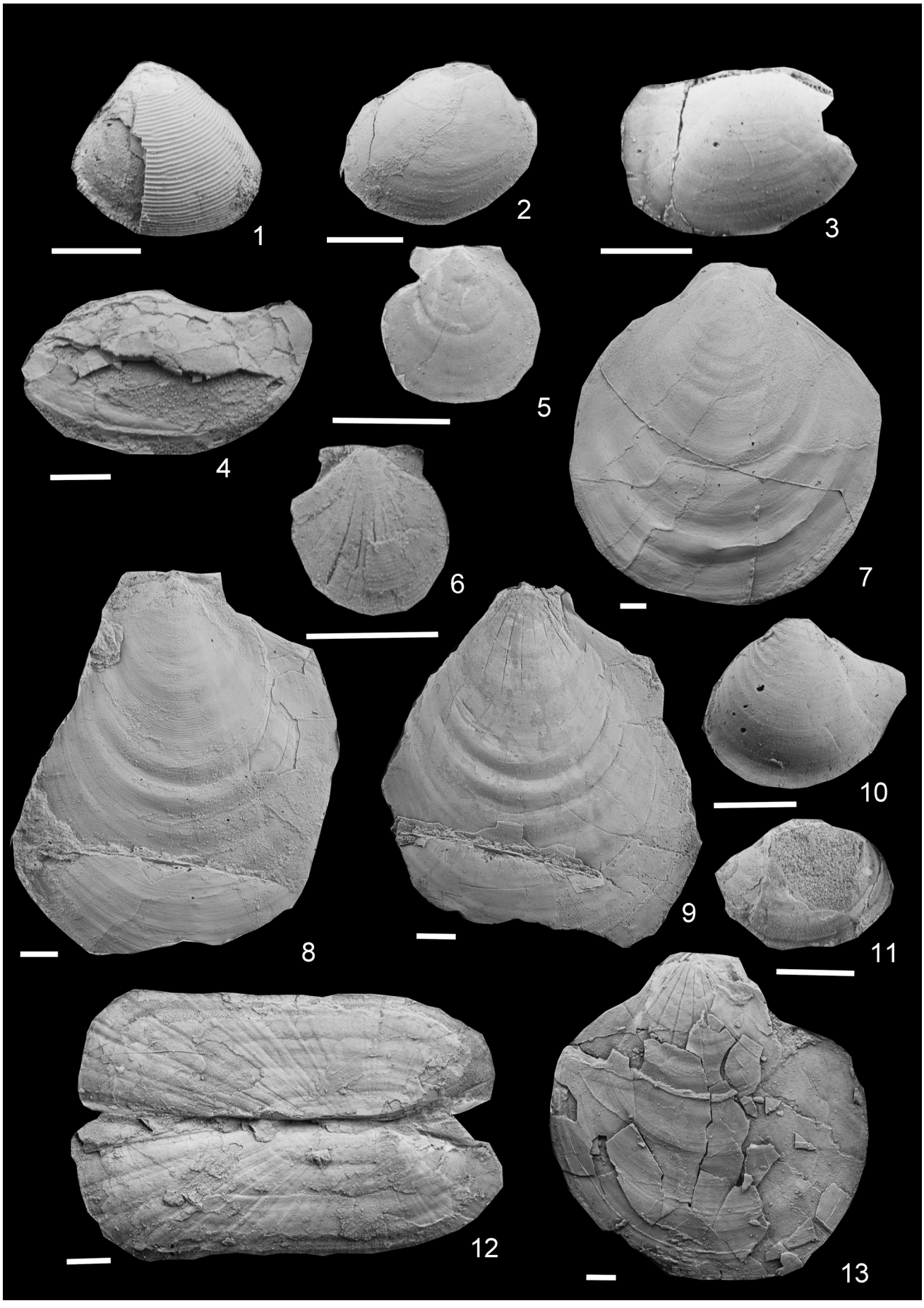

Plate 2

Figs. 1a, b. *Pliocardia kawadai* (Aoki), MFM 41028, Loc. 1.

Figs. 2, 6a, b. *Lucinoma acutilineatum* (Conrad)
Fig. 2, MFM 41029, Loc. 1.
Figs. 6a, b, MFM 41030, Loc. 1.

Figs. 3. *Thyasira* sp., MFM 41031, Loc. 2.

Fig. 4. *Portlandia* (*Portlandella*) *lischkei* (Smith), MFM41032, Loc. 2.

Fig. 5. *Vesicomya*? sp., MFM 41033, Loc. 1.

Figs. 7a, b. *Liracassis yokoyamai* (Kuroda), MFM 41034, Loc. 2.

Fig. 8. *Conchocele* cf. *yatsuoensis* Amano, Miyajima, Nakagawa, Hamuro and Hamuro, MFM 41035, Loc. 1.

Fig. 9. *Clio itoigawae* Shibata, MFM 41036, Loc. 1.

Fig. 10. *Bowdenatheca* sp., MFM 41037, Loc. 1.

Fig. 11. *Fissidentalium yokoyamai* (Makiyama), MFM 41038, Loc. 2.

All scale bars show 5 mm. The illustrated specimens in Figs. 1a, 6a are silicone rubber casts coated with ammonium chloride.

Plate 2