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Molluscan fossils from the Kitakanegasawa Formation in Aomori Prefecture, Japan, with remarks on the northern limit of the Tsushima Warm Current during the late Pliocene

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Abstract Forty-three molluscan species have been recovered from the upper Pliocene Kitakanegasawa Formation in Aomori Prefecture, northernmost Honshu, Japan. They include three interesting molluscan species described herein: *Glycymeris* (*Tucetilla*) *pilsbryi* (Yokoyama), *Profulvia kurodai* (Sawada) and *Turritella* (*Neohaustator*) *nipponica nomurai* Kotaka. Among these, the warm-temperate species *G.* (*T.*) *pilsbryi* invaded the Japan Sea as a result of the influx of the Tsushima warm-current during the late Pliocene. The occurrence of the species moves the northern limit of the warm-water current during this age further north to Aomori Prefecture from previous limit at Akita Prefecture.
Key words: Kitakanegasawa Formation, Mollusca, northern limit, Pliocene, warm-water current.

Introduction

During the Pliocene to early Pleistocene, the Omma-Manganji fauna (Otuka, 1939), consisting of many cold-water and extinct endemic species, flourished in the Japan Sea borderland (Ogasawara, 1977, 1986; Masuda and Ogasawara, 1981; Amano, 2001, 2007).

Since around 4 Ma, some warm-water species invaded the Japan Sea as a result of the influx of the warm-water Tsushima Current along with climate warming (Amano *et al.*, 2008). According to Kitamura and Kimoto (2006) and Gallagher *et al.* (2015), a smaller volume of the Tsushima warm-current possibly invaded the Japan Sea during interglacial periods before 1.7 Ma than during interglacial periods after 1.7 Ma.

During the late Pliocene, the Tsushima warm-water current arrived in Akita Prefecture, northern Honshu, as proved by the occurrence of warm-water gastropods such as *Pomaulax omorii* (Shibata), *Mammilla* sp., *Oliva mustelina* Lamarck, *Scalptia kurodai* (Makiyama), *Cyllene satoi* Amano and *Conus* sp. from the upper Pliocene Tentokuji Formation in Akita Prefecture (Ogasawara, 1986; Amano *et al.*, 2000b; Amano, 2019a, b). However, no warm-water species have been found from the Pliocene deposits in Aomori Prefecture, in the northernmost part of Honshu. One warm-temperate species, *Glycymeris* (*Tucetilla*) *pilsbryi* (Yokoyama) and some interesting species were collected from the upper Pliocene Kitakanegasawa Formation in the northwestern part of Aomori Prefecture. In this paper, I describe three rare species including *G.* (*T.*) *pilsbryi* and discuss their paleoenvironmental significance.

Geological setting

The Kitakanegasawa Formation was proposed by Nemoto and Wakabayashi (1995) for the alternating beds of sandstone and siltstone, distributed near Kitakanegasawa at Fukaura Town in Aomori Prefecture, northernmost Honshu. The formation was previously treated as a marginal facies of the Narusawa Formation or the upper part of the Maido Formation (Imanishi, 1949; Iwai, 1960; Iwasa, 1962; Hirayama and Uemura, 1985). The contact of the Kitakanegasawa Formation with the Maido Formation is faulted. Based on the planktonic foraminifers and diatoms, the age of the formation is late Pliocene (Hirayama and Uemura, 1985; Nemoto and Wakabayashi, 1995). Based on cluster analysis of benthic foraminifers, Nemoto and Wakabayashi (1995) estimated that the formation was deposited in the upper bathyal zone.

Materials and Methods

Molluscan fossils have been obtained from three localities (Loc. 1A, 1B, 2 in Fig. 1). Among these localities, Loc. 1A is an outcrop just north of the Route 101 at the entrance of a small stream (40°44′44″N, 140°5′42″N) and Loc. 1B is a small rock, probably derived from Loc. 1A. From these localities, many molluscan fossils have been recovered from siltstone containing granules. These localities are near Loc. N6 from where Iwai (1960, 1965) described fifty-four species of molluscs. Loc. 2 is located 200 m upstream from the small stream (40°44′35″N, 140°5′39″N), from where Nemoto and Wakabayashi (1995) examined the foraminifers. From this locality, many poorly preserved and fragile shells were obtained from shell-bearing medium-grained sandstone (1 m thick) intercalated with alternations of claystone and siltstone.

The data on depth and geographic distribution of Recent species are after Higo *et al.* (1999) and Okutani (2017), and estimated the depth range of each species by using the maximum range in both references. All specimens treated herein are stored at the Department of Geology and Paleontology, National Museum of Nature and Science (NMNS), Tsukuba.

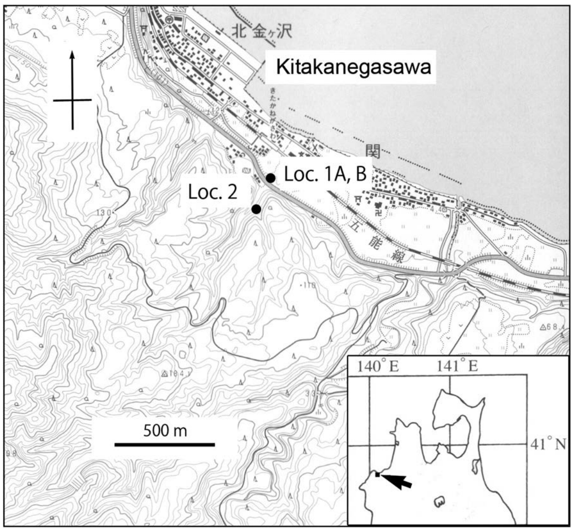

Fig. 1. Locality map of fossils. Base map from "Kitakanegasawa," original map 1 : 25,000; topographical map published by Geospacial Information Authority of Japan.

Molluscan fossils

A total of forty-three species were identified from the Kitakanegasawa Formation (Table 1; Figs. 2–4). Among them, thirteen species have already been reported near the Loc. 1A, B by Iwai (1960, 1965). The fauna from the formation includes twelve extinct species and subspecies of the Pliocene to early Pleistocene Omma-Manganji fauna such as *Acila* (*Truncacila*) *nakazimai* Otuka (Fig. 2A), *Glycymeris* (*Glycymeris*) *nipponica* (Yokoyama) (Fig. 2E), *Limopsis tokaiensis* Yokoyama (Fig. 2I, M), *Chlamys* (*Chlamys*) *cosibensis* (Yokoyama) (Fig. 2 L), *Yabepecten tokunagai* (Yokoyama) (Fig. 2N), *Cyclocardia myogadaniensis* (Itoigawa) (Fig. 3D, E), *Profulvia kurodai* (Sawada) (Fig. 3H), *Turritella* (*Neohaustator*) *nipponica nomurai* Kotaka (Fig. 4I), *Tachyrhynchus asatoi* (Oinomikado and Ikebe) (Fig. 4D), *Fusitriton izumozakiensis* Amano (Fig. 4F), *Lirabuccinum japonicum* (Yokoyama) (Fig. 4C) and *Ophiodermella ogurana* (Yokoyama) (Fig. 4H). The first four species have been recorded previously, whereas the remaining seven species and one subspecies have not been recorded from this formation hitherto. Adding to these index species, two rare extant species that merely occur as fossils have been found, *G.* (*T.*) *pilsbryi* (Fig. 2C, F, G) and *Saxidomus purpurata* (Sowerby) (Fig. 3G, I, K; Amano and Nemoto, 2020), both not recorded fossil previously from the Pliocene deposits on the Japan Sea side of Japan.

Systematic paleontology

Class Bivalvia Linnaeus, 1758

Family Glycymerididae Dall, 1908 (1847)

Genus *Glycymeris* da Costa, 1778

Subgenus *Tucetilla* Iredale, 1939

Glycymeris (*Tucetilla*) *pilsbryi* (Yokoyama, 1920)

(Fig. 2C, F, G)

Pectunculus pisbryi Yokoyama, 1920, p. 170, pl. 18, fig. 8; Yokoyama, 1922, p. 190, pl. 16, fig. 8, 9.

Glycymeris (*Tucetilla*) *pilsbryi* (Yokoyama). Habe, 1951, p. 42, fig. 67; Taki and Oyama, 1954, p. 32, pl. 19, fig. 8, pl. 36, figs. 8, 9; Habe, 1961, p. 112, pl. 50, fig. 1; Habe, 1964, p. 165, pl. 50, fig. 1; Ohara, 1968, pl. 2, figs. 4a, b; Ohara, 1972, pl. Q-32, fig. 9; Oyama, 1973, p. 77, pl. 22, figs. 9, 10; Noda, 1980, p. 79; Matsuura, 1985, pl. 38, fig. 26; Matsukuma and Okamoto, 1986, fig. 2H; Tsuchida

Table 1. Molluscan fossils from the Kitakanegasawa Formation. *Characteristic extinct species of the Omma-Manganji fauna; ** Loc. N6 of Iwai (1960, 1965), showing the occurrence with +; ***GD = Geographic distribution: C, cold-water species; CW, temperate species; E, endemic species of the Japan Sea; W, warm-water species. The data on depth and geographic distribution are after Higo *et al.* (1999) and Okutani (2017).

Species	Loc. 1A	Loc. 1B	Loc. 2	N6**	Depth (m)	GD***	Cat. no. (Fig. no.)
Acila (*Truncacila*) *nakazimai* Otuka*	11	1		+	—	—	NMNS PM 65008 (Fig. 2A)
A. ? sp.			1				
Nuculana sp.	1						
Robaia robai (Kuroda)		1		+	100–1200	E	NMNS PM 65009 (Fig. 2B)
Arca boucardi Joussseaume			4	+	0–50	CW	
Glycymeris (*Glycymeris*) *yessoensis* (Sowerby)	3	3		+	0–40	C	NMNS PM 65004 (Fig. 2D), NMNS PM 65031 (Fig. 2H)
G. (*G.*) *nipponica* (Yokoyama) *	1	2	1	+	—	—	NMNS PM 65026 (Fig. 2E)
G. (*Tucetilla*) *pilsbryi* (Yokoyama)			2		30–600	W	NMNS PM 65027 (Fig. 2C, F), NMNS PM 65028 (Fig. 2G)
Limopsis tokaiensis Yokoyama*		2		+	—	—	NMNS PM 65010 (Fig. 2I), NMNS PM 65032 (Fig. 2M)
L. oblonga A. Adams		7	2		20–200	CW	NMNS PM 65011 (Fig. 2J), NMNS PM 65012 (Fig. 3B)
L. sp.			2				
Anomia sp.	1						
Chlamys (*Chlamys*) *cosibensis* (Yokoyama)*	2	4		+	—	—	NMNS PM 65005 (Fig. 2 L)
Yabepecten tokunagai (Yokoyama)*		2					NMNS PM 65013 (Fig. 2N)
Acesta goliath (Sowerby)		2		+	100–1417	C	NMNS PM 65014 (Fig. 2K)
Astarte hakodatensis Yokoyama		6	1		50–150	C	NMNS PM 65015 (Fig. 3A)
Tridonta borealis Schumacher	3	2		+	10–230	C	NMNS PM 65006 (Fig. 3C), NMNS PM 65033 (Fig. 3F)
T. alaskensis (Dall)	1	1	2	+	7–500	C	NMNS PM 65029 (Fig. 3J)
Megacardita? sp.			1				
Cyclocardia myogadaniensis (Itoigawa)*		4			—	—	NMNS PM 65016 (Fig. 3D), NMNS PM 65017 (Fig. 3E)
Lucinoma? sp.			1				
Conchocele sp.		2					
Clinocardium? sp.			1				
Profulvia kurodai (Sawada)*			1		—	—	NMNS PM 65030 (Fig. 3F)
Ezocallista sp.		2					
E.? sp.	2						
Saxidomus purpurata (Sowerby)		1			0–40	CW	NMNS PM 65018 (Fig. 3G, I, K)
Anisocorbula? sp.		1					
Homalopoma? sp.		1					
Puncturella? sp.		1					
Turritella (*Neohaustator*) *nipponica nomurai* Kotaka*		1		+	(30–100)	(C)	NMNS PM 65019 (Fig. 4I)
Tachyrhynchus asatoi (Oinomikado and Ikebe)*		2			—	—	NMNS PM 65034 (Fig. 4D)
Cryptonatica clausa (Broderip and Sowerby)	4	10			50–3000	C	NMNS PM 65020 (Fig. 4A)
Euspira pila (Pilsbry)		6			0–300	C	NMNS PM 65021 (Fig. 4B)
Naticidae gen. et sp. indet.			1				
Fusitriton izumozakiensis Amano*		1			—	—	NMNS PM 65022 (Fig. 4F)
Lirabuccinum japonicum (Yokoyama)*		1			—	—	NMNS PM 65023 (Fig. 4C)
Buccinum sp.	1						
Ophiodermella ogurana (Yokoyama)*		1			—	—	NMNS PM 65024 (Fig. 4H)
Propebela sp. A		1					
P. sp. B		1					
Antiplanes vinosa (Dall)		4		+	50–500	C	NMNS PM 65025 (Fig. 4G)
A. sanctiioannis (Smith)	1			+	50–1530	C	NMNS PM 65007 (Fig. 4E)

and Kurozumi, 1993, p. 9, pl. 4, fig. 3; Matsukuma, 2000, p. 859, pl. 428, fig. 10; Toba, 2009, p. 69, fig. 16; Matsukuma, 2017, p. 1170, pl. 470, fig. 5.

Tucetilla pilsbryi (Yokoyama). Kuroda *et al.*, 1971, p. 533, pl. 71, figs. 7, 8; Habe, 1977, pl. 8, fig. 8; Ogasawara *et al.*, 1986, pl. 55, figs. 6, 9; Kobayashi, 1986, pl. 1, fig. 5; Okutani *et al.*, 1989, p. 41, fig. 21; Matsuura, 2009, pl. 24, fig. 26; Xu and Zhang, 2008, p. 45, fig. 109.

Glycymeris pilsbryi (Yokoyama). Hayasaka, 1962, pl. 45, figs. 7a, b; Aoki and Baba, 1980, fig. 18-4; Baba, 1990, p. 243, pl. 24, fig. 6.

? *Glycymeris pilsbryi* (Yokoyama). O'Hara and Ito, 1980, pl. 17, fig. 2.

? *Tucetilla pilsbryi* (Yokoyama). Okumura and Ueda, 1998, p. 72, pl. 8, fig. 19.

Glycymeris munda (Sowerby). Matsukuma, 2000, pl. 427, fig. 5.

? *Glycymeris* (*Glycymeris*) *imperialis* Kuroda. Min, 2004, p. 390, fig. 1255.

? *Glycymeris* (*Glycymeris*) *pilsbryi* (Yokoyama). Huber, 2010, p. 151.

Material examined: NMNS PM 65027; NMNS PM 65028.

Remarks: The specimens are rather small for the species (NMNS PM 65028, length = 16.0 mm, height = 14.4 mm; NMNS PM 65027, length = 18.2 mm, height = 16.1 mm). Their posterior margin is subtruncated and pointed at the posterior ventral corner in NMNS PM 65028. The surface is sculp-

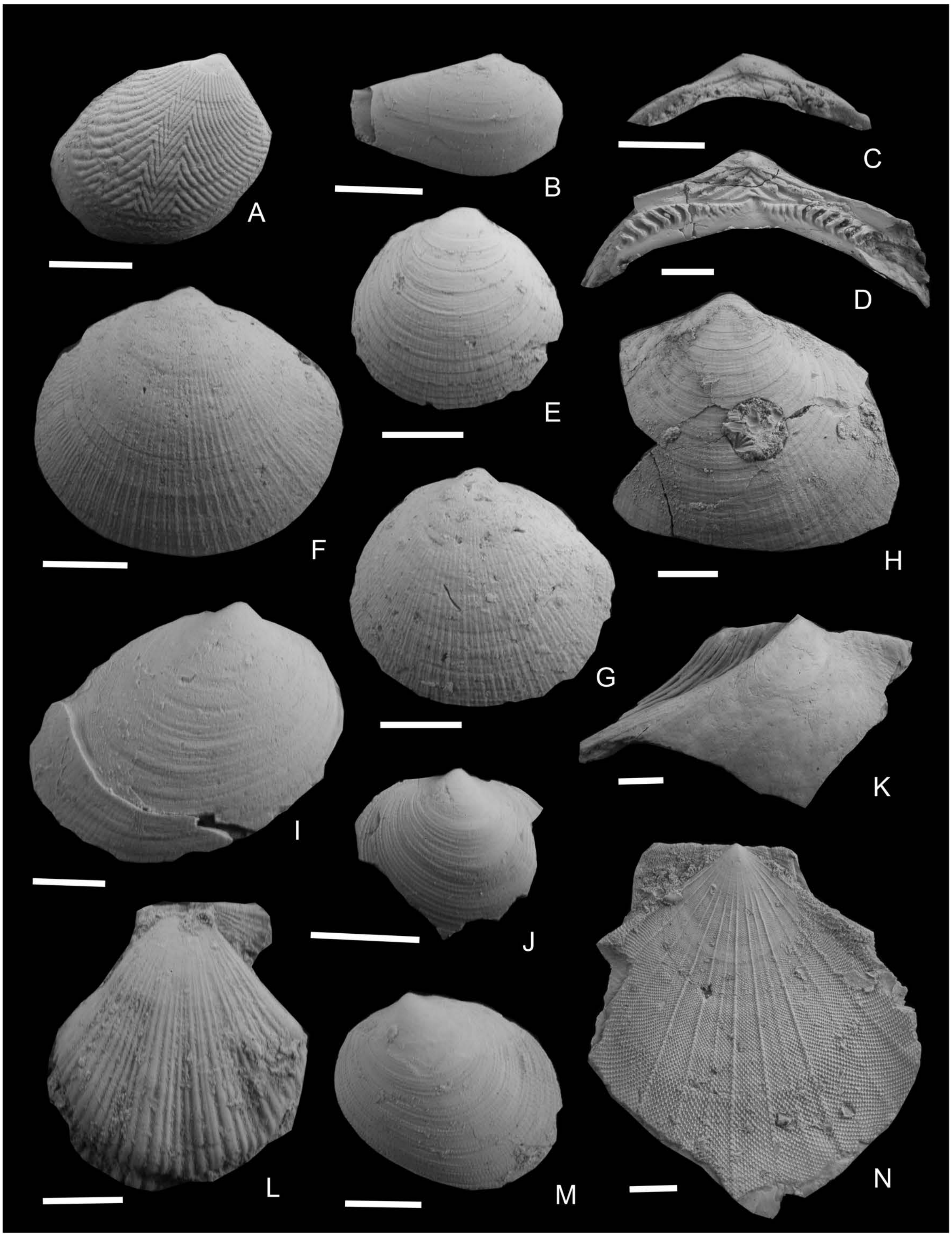

Fig. 2. Bivalve fossils from the Kitakanegasawa Formation (1). **A**, *Acila* (*Truncacila*) *nakazimai* Otuka, NMNS PM 65008, left valve, Loc. 1B. **B**, *Robaia robai* (Kuroda), NMNS PM 65009, left valve, Loc. 1B. **C**, **F**, **G**, *Glycymeris* (*Tucetilla*) *pilsbryi* (Yokoyama); C, F, NMNS PM 65027, Loc. 2; C, hinge of the specimen; F, outer surface of left valve; G, NMNS PM 65028, left valve, Loc. 2. **E**, *Glycymeris* (*Glycymeris*) *nipponica* (Yokoyama), NMNS PM 65026, left valve, Loc. 2. **D**, **H**, *Glycymeris* (*Glycymeris*) *yessoensis* (Sowerby); D, NMNS PM 65004, hinge part of right valve, Loc. 1A; H, NMNS PM 65031, left valve, Loc. 1A. **I**, **M**, *Limopsis tokaiensis* Yokoyama, Loc. 1B; I, NMNS PM 65010, right valve; M, NMNS PM 65032, left valve. **J**, *Limopsis oblonga* A. Adams, NMNS PM 65011, left valve, loc. 1B. **K**, *Acesta goliath* (Sowerby), NMNS PM 65014, right valve, Loc. 1B. **L**, *Chlamys* (*Chlamys*) *cosibensis* (Yokoyama), NMNS PM 65005, right valve, Loc. 1B. **N**, *Yabepecten tokunagai* (Yokoyama), NMNS PM 65013, left valve, Loc. 1B. All scale bars show 5 mm.

tured with 40 to 47 narrow, flat radial ribs with one to three fine riblets in each interspace. Many weak nodes are formed at the crossing point of fine radial ribs and growth lines. Chevron-shaped ligamental grooves can be seen above the hinge plate. In the smaller specimen, 16 small teeth are observed. These characters enable the identification of these specimens as *G.* (*T.*) *pilsbryi*.

O'Hara and Ito (1980) illustrated a specimen as *Glycymeris pilsbryi* (Yokoyama) from the uppermost Miocene to lowermost Pliocene Senhata Formation in Chiba Prefecture. However, the surface sculpture cannot be observed by its ill-preservation. So, it is difficult to exactly identify the specimen as *G.* (*T.*) *pilsbryi*.

Okumura and Ueda (1998) described *Tucetilla pilsbryi* (Yokoyama) from the upper Pliocene Nakatsu Formation in Kanagawa Prefecture. The outline of the shell is similar to this species. However, it is doubtful whether this species can be identified certainly with *G.* (*T.*) *pilsbryi* (Yokoyama) because the specimen seems to have a smooth surface.

The shell identified by Matsukuma (2000) as *Glycymeris munda* (Sowerby) can be identified with *G.* (*T.*) *pilsbryi* (Yokoyama) because it has a subrounded shell with a pointed postero-ventral corner.

The shell illustrated by Min (2004) as *Glycymeris imperiaris* Kuroda is possibly identified with *G.* (*T.*) *pilsbryi* (Yokoyama) because of its subrounded shell outline and many radial ribs on the surface.

Although Huber (2010) illustrated *Glycymeris* (*Glycymeris*) *pilsbryi* (Yokoyama), his specimen is more elongate than common shell outline of this species and has a wide hinge plate. It is uncertain whether this specimen can be exactly identified with *G.* (*T.*) *pilsbryi*.

Glycymeris (*Tucetilla*) *amamiensis* Kuroda, 1930 is the most similar species to *G.* (*T.*) *pilsbryi* and was synonymized with the latter species by Matsukuma (1986). More recently, Matsukuma (2000, 2017) separated the two species because *G.* (*T.*) *amamiensis* has a more angulated shape and roof-shaped radial ribs.

Stratigraphic distribution: ? Latest Miocene to earliest Pliocene, Senhata Formation in Chiba Prefecture (O'Hara and Ito, 1980) ; Late Pliocene, Kitakanegasawa Formation in Aomori Prefecture (this study) and Ananai Formation in Kochi Prefecture (Kondo *et al.*, 2009); Plio-Pleistocene, Sumagui Formation in the Philippines (Matsukuma, 1986); early Pleistocene, Nakazawa Formation in Akita Prefecture (Ogasawara *et al.*, 1986), Haizume Formation in Niigata (Kobayashi, 1986) and Omma Formation in Toyama Prefecture (Matsuura, 1985, 2009); middle to late Pleistocene, Sanuki, Mandano, Jizodo and Semata Formations in Chiba Prefecture, and Miyata Formation in Kanagawa Prefecture (Baba, 1990); Recent, Tsugaru Strait to Kyushu and southern and northeastern coast of Korean Peninsula on the Japan Sea side, Aomori to Okinawa on the Pacific side of Japan, East China Sea and South China Sea, in 30–600 m depths, in a fine sand and shelly bottom (Higo *et al.*, 1999; Xu and Zhang, 2008; Matsukuma, 2000, 2017).

Family Cardiidae Lamarck, 1809
Subfamily Trachycardiinae Stewart, 1930
Genus *Profulvia* Kafanov, 1976

Remarks: *Profulvia* was established by Kafanov (1976) as an independent genus for the species previously referred to *Papyridea* Swainson, 1840 lived in the North Pacific. After that, Kafanov (1997) ranked *Profulvia* as a subgenus of *Papyridea* because *Profulvia* hardly differs from typical *Papyridea*. Indeed, *Profulvia* may be closely related to *Papyridea*. However, *Profulvia* differs distinctly from *Papyridea* in having no radial ribs extending beyond the edge of the shell near the posterior part of the hinge and no spines on the ribs. Up to this time, it is very difficult to estimate the origin and migration route of *Profulvia*, whose distribution is isolated in the North Pacific area. Based on a molecular phylogeny by Herrera *et al.* (2015), ter Poorten (2019) included the genus *Papyridea* in subfamily Trachycardiinae Stewart, 1930.

Profulvia kurodai (Sawada, 1962)

(Fig. 3H)

Papyridea (*Fulvia*) *nipponica* Yokoyama. Yokoyama, 1926, p. 294, pl. 34, fig. 16.

Papyridea (*Fulvia*) *kurodai* Hatai and Nisiyama. Sawada, 1962, p. 82, pl. 1, figs. 15, 16; Shikama, 1964, pl. 45, figs. 25a, b (reproduced from Yokoyama, 1926).

Papyridea kurodai Hatai and Nisiyama. Kamada, 1962, p.

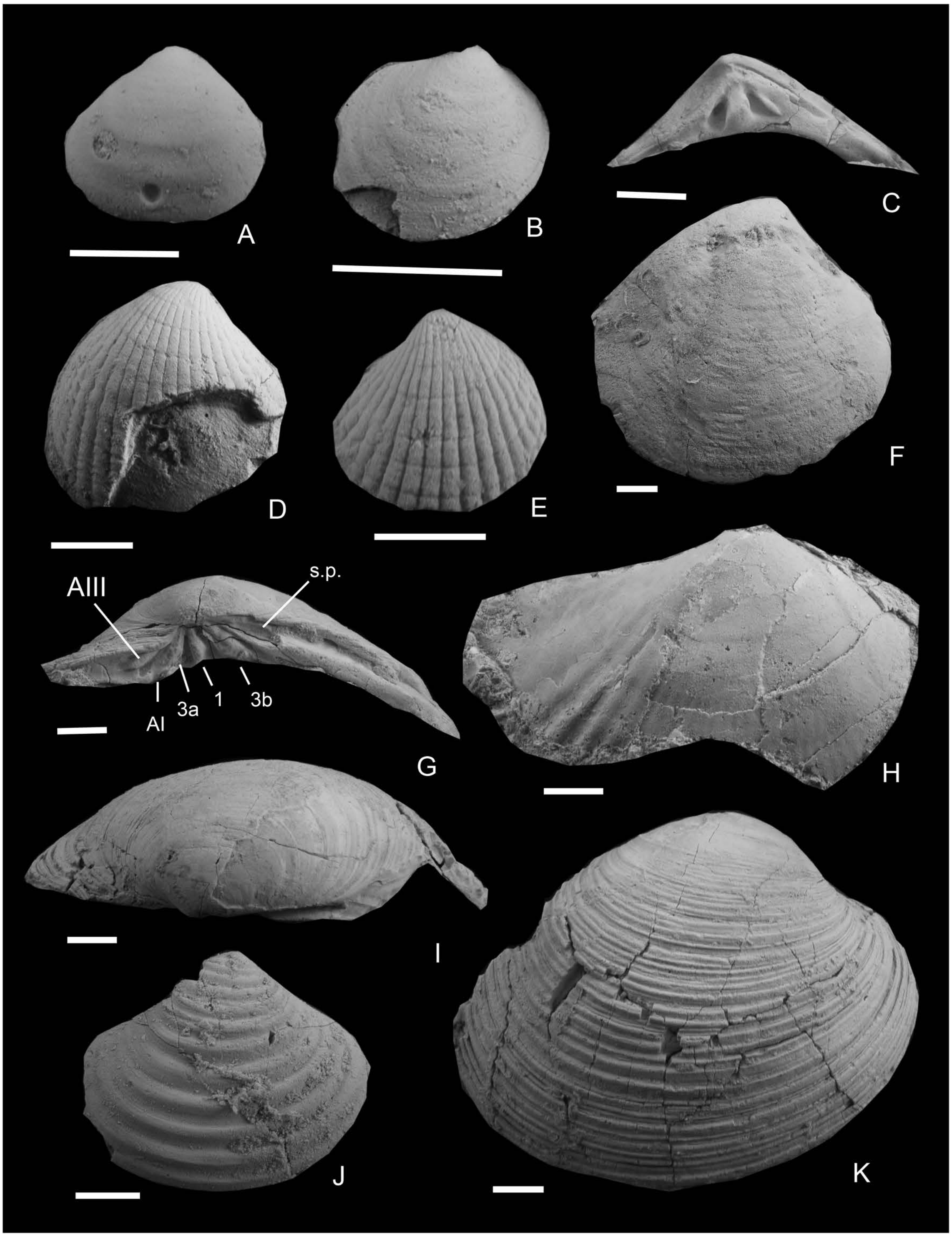

Fig. 3. Bivalve fossils from the Kitakanegasaki Formation (2). **A**, *Astarte hakodatensis* Yokoyama, NMNS PM 65015, left valve, Loc. 1B. **B**, *Limopsis oblonga* A. Adams, NMNS PM 65012, left valve, 1B. **C**, **F**, *Tridonta borealis* Schumacher, Loc. 1A; C, NMNS PM 65006, hinge of right valve; F, NMNS PM 65033, outer surface of right valve. **D**, **E**, *Cyclocardia myogadaniensis* (Itoigawa), Loc. 1B; D, NMNS PM 65016, right valve; E, NMNS PM 65017, left valve. **G**, **I**, **K**, *Saxidomus purpurata* (Sowerby), NMNS PM 65018, Loc. 1B; G, hinge of right valve; I, dorsal view of left valve; K, surface of left valve. **H**, *Profulvia kurodai* (Sawada), NMNS PM 65030, right valve, Loc 2. **J**, *Tridonta alaskensis* (Dall), NMNS PM 65029, left valve, Loc. 1B. Abbreviations: A1, AIII = anterior teeth; 1, 3a, 3b = cardinal teeth; s.p. = subumbonal pit. All scale bars show 5 mm.

109, pl. 11, fig. 9; Itoigawa and Shibata, 1977, pl. 26, fig. 5; Kobayashi, 1986, pl. 16, fig. 4.

Profulvia kurodai (Sawada). Uozumi *et al.*, 1986, pl. 20, fig. 1; Amano and Tanaka, 1992, p. 116, pl. 1, figs. 1–9; Nagamori, 2000, pl. 10, fig. 3; Nagamori, 2014, p. 24, pl. 9, fig. 6; Amano *et al.*, 2008, fig. 4-9;

Papyridea kurodai Sawada. Mizuno and Amano, 1988, p. 82, pl. 16, fig. 15.

Profulvia kurodai (Hatai and Nisiyama). Akamatsu and Suzuki, 1990, pl. 1, fig. 2; Akamatsu and Suzuki, 1992, pl. 2, fig. 1; Amano *et al.*, 2012, fig. 3-8.
Papyridea (*Profulvia*) *kurodai* Sawada. Kafanov, 1997, p. 5, pl. 5, figs. 2a, b (reproduced from Yokoyama, 1926).
Papyridea sp. Miyasaka *et al.*, 1978, pl. 2, figs. 3, 4.
non Cardium (*Papyridea*) *nipponicum* (Yokoyama). Kuroda, 1931, p. 54, pl. 6, figs. 35, 36. [= *Clinocardium* sp.]

Material examined: NMNS PM 65030.

Remarks: One right valve specimen was obtained. The size is small (length = 43.1 mm; height = 23.9 mm; see Amano and Tanaka, 1992) and almost all shell material is weathered away. The inner mold has at least 27 radial ribs, among which the posterior four ribs are stronger than the others. As no shell material of the anterior and posterior parts has been observed, the radial ribs seem to be fewer than the real number of ribs.

Profulvia kurodai is the geochronologically youngest species of the genus *Profulvia*, which flourished in the middle Eocene to middle Miocene in the northwestern Pacific. Except for the occurrence from the upper Pliocene Komahata Formation in eastern Hokkaido, this species is confined to Pliocene to lower Pleistocene strata on the Japan Sea side (Amano and Tanaka, 1992; Kafanov, 2001). During the early to middle Pleistocene, *P. kurodai* was distributed also in southern Hokkaido, while during the Pliocene, the occurrence in the Kitakanegasawa Formation is the northernmost record of *P. kurodai*.

Stratigraphic distribution: Pliocene, Komahata Formation in Hokkaido (Miyasaka *et al.*, 1978), Kitakanegasawa Formation in Aomori Prefecture (this study), ? Kuwae Formation in Niigata Prefecture (Amano *et al.*, 2000a), Ogikubo Formation in Nagano Prefecture (Itoigawa and Shibata, 1977; Amano and Tanaka, 1992; Nagamori, 2000, 2014), Suginoya Siltstone in Ishikawa Prefecture and Mita Formation in Toyama Prefecture (Amano and Tanaka, 1992; Amano *et al.*, 2008); early Pleistocene, Shimonopporo and Setana Formations in Hokkaido (Akamatsu and Suzuki, 1990, 1992; Sawada, 1962; Amano and Tanaka, 1992), Sawane, Haizume and Kota Formations in Niigata Prefecture (Yokoyama, 1926; Kobayashi, 1986; Mizuno and Amano, 1988); upper part of Zukawa Formation in Toyama Prefecture (Amano *et al.*, 2012); middle Pleistocene, Zaimokuzawa Formation in Hokkaido (Akamatsu, 1984).

Class Gastropoda Cuvier, 1795
Family Turritellidae Lovén, 1847
Genus *Turritella* Lamarck, 1799
Subgenus *Neohaustator* Ida, 1952
Turritella (*Neohaustator*) *nipponica nomurai* Kotaka, 1951

(Fig. 4I)

Turritella nipponica Yokoyama. Kanehara, 1942, pl. 3, figs. 11, 13, 16; Iwai, 1960, pl. 4, figs. 14a, b.; Iwai, 1965, p. 49, pl. 19, figs. 10a, b.
Turritella nomurai Kotaka. Kotaka, 1951, p. 10, pl. 1, figs.1, 6, 7.
Turritella fortilirata tibana Nomura. Ida, 1952, p. 54, pl. 5, fig. 8.
Turritella (*Neohaustator*) *fortilirata habei* Kotaka. Iwai, 1959, p. 46, pl. 1, figs. 8, 9a.
Turritella (*Neohaustator*) *nomurai* Kotaka. Kotaka, 1959, p. 69, pl. 8, figs. 10, 15; Hatai *et al.*, 1961, pl. 4, fig. 15a, b.
Turritella (*Neohaustator*) *nipponica nomurai* Kotaka. Amano, 1994, pl. 4, fig. 5.

Material examined: NMNS PM 65019.

Remarks: One imperfect specimen without protoconch was obtained. The shell is small (height = 21.4 mm +, diameter = 8.3 mm) and consists of eight whorls, which are somewhat straight-sided. According to the notation of spiral cords by Kotaka (1959), the primary spiral cords C and B have nearly the same width. Cord C is located at the periphery, while B is at the middle part of whorl. The primary cord A is weaker than cords B and C and immediately located at secondary cord r. The most strongly sinuous point of the growth line is located between cords B and A. Consequently, the notation of cords is expressed as (.CBa_3r_4).

Although this subspecies is an extinct form, it is closely similar to the extant species *Turritella* (*Neohaustator*) *nipponica nipponica* Yokoyama in its straight-sided whorls and similar pattern of spiral cords (C_1 B_2 a_3 r_4). However, *T.* (*N.*) *nipponica nomurai* has a very narrow interspace between the spiral cords “a” and “r.” Moreover, the most strongly sinuous point of the growth lines is located more adapically in *T.* (*N.*) *nipponica nomurai* than in *T.* (*N.*) *nipponica nipponica*.

Stratigraphic distribution: Pliocene, Kitakanegasawa and Higashimeya Formations in Aomori Prefecture (Iwai, 1960, 1965; this study) and Nitta and

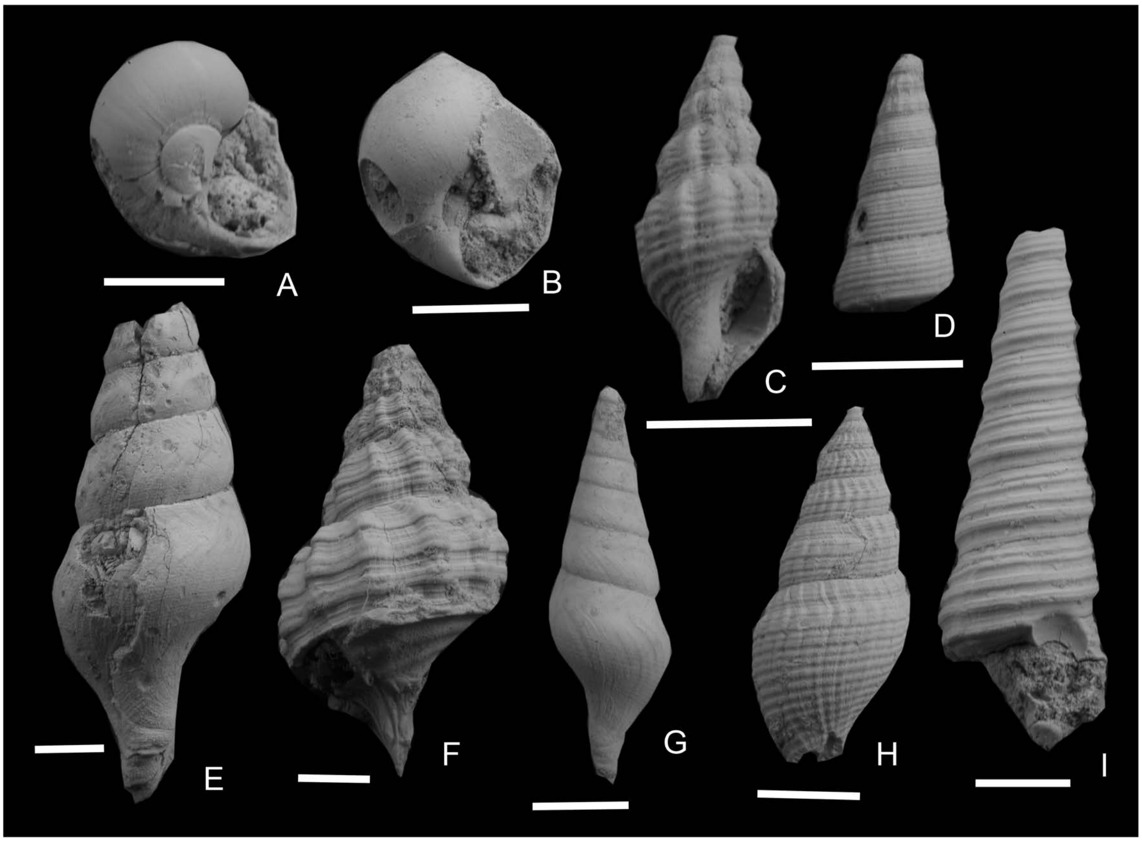

Fig. 4. Gastropod fossils from the Kitakanegasaki Formation. **A**, *Cryptonatica clausa* (Broderip and Sowerby), NMNS PM 65020, apertural view, Loc. 1B. **B**, *Euspila pila* (Pilsbry), NMNS PM 65021, apertural view, Loc. 1B. **C**, *Lirabuccinum japonicum* (Yokoyama), NMNS PM 65023, apertural view, Loc. 1B. **D**, *Tachyrhynchus asatoi* (Oinomikado and Ikebe), NMNS PM 65034, abapertural view, Loc. 1B. **E**, *Antiplanes sanctiioannis* (Smith), NMNS PM 65007, abapertural view, Loc. 1A. **F**, *Fusitriton izumozakiensis* Amano, NMNS PM 65022, abapertural view, Loc. 1B. **G**, *Antiplanes vinosa* (Dall), NMNS PM 65025, abapertural view, Loc. 1B. **H**, *Ophiodermella ogurana* (Yokoyama), NMNS PM 65024, abapertural view, Loc. 1B. **I**, *Turritella* (*Neohaustator*) *nipponica nomurai* Kotaka, NMNS PM 65019, apertural view, Loc. 1B. All scale bars show 5 mm.

Ikenosawagawa Formations in Niigata Prefecture (Noda, 1962; Amano, 1994); early Pleistocene Hamada Formation in Aomori Prefecture (Hatai *et al.*, 1961); middle Pleistocene Shibikawa Formation in Akita Prefecture (Kanehara, 1942; Kotaka, 1951, 1959).

Discussion

The molluscan fossil species reported here include five extant molluscs living in the lower sublittoral to upper bathyal zones (Higo *et al.*, 1999; Okutani, 2017) as shown in Table 1: *Robaia robai* (Kuroda) (Fig. 2B), *Acesta goliath* (Sowerby) (Fig. 2K), *Astarte hakodatensis* Yokoyama (Fig. 3A), *Antiplanes vinosa* (Dall) (Fig. 4G) and *Antiplanes sanctiioannis* (Smith) (Fig. 4E). It is possible that the extinct species *A.* (*T.*) *nakazimai*, *L. tokaiensis* and *Y. tokunagai* might also have inhabited the same depth zone to the above Recent species (*e.g.* Matsui, 1990). These occur in association with three shallow-water species, *Arca boucardi* Jousseaume, *Glycymeris* (*Glycymeris*) *yessoensis* (Sowerby) (Fig. 2D, H) and *S. purpurata*. According to Nemoto and Wakabayashi (1995), the Kitakanegasawa Formation was deposited in the upper bathyal zone, based on species composition of benthic foraminifers. Judging from the lithology and fossils, the formation was deposited in the upper bathyal zone and shallow-water shells were transported into deeper water.

Based on Higo *et al.* (1999) and Okutani (2017), many specimens of the nine Recent cold-water species are recognized: *G.* (*G.*) *yessoensis*, *A. goliath*, *A. hakodatensis*, *Tridonta borealis* Schumacher (Fig. 3C, F), *Tridonta alaskensis* (Dall) (Fig. 3J), *Cryptonatica clausa* (Broderip and Sowerby) (Fig. 4A), *Euspira pila* (Pilsbry) (Fig. 4B), *A. vinosa* and

A. sanctiioannis (Table 1). Although *T.* (*N.*) *nipponica nomurai* is an extinct subspecies, its Recent relative *T.* (*N.*) *nipponica nipponica* is a cold-water dweller. Consequently, *G.* (*T.*) *pilsbryi* is the only warm-temperate species recorded above. The occurrence of this species indicates that in the late Pliocene, the warm-water Tsushima current arrived in Aomori Prefecture, where its influence is recognized further north than in Akita Prefecture, where it was recognized previously (Ogasawara, 1986; Amano *et al.*, 2000b; Amano, 2019a, b). Only one warm-water species was found from the Kitakanegasawa Formation because the formation was deposited in the upper bathyal zone and only a few species were transported into the deposition site by turbidity currents.

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