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Permian spicular chert from the east of Mt. Asahi-dake, Itoigawa City, Niigata Prefecture, Japan

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Abstract

This article documents siliceous spicules with radiolarians from a red-ocher chert sample in the east of Mt. Asahi-dake, Itoigawa City, Niigata Prefecture, Japan. The spicule assemblage is characterized by dominant monaxon, common critriactine and tetractine, and rare anadiaene. One radiolarian species, *Quinqueremis* sp. aff. *Q. robusta* Nazarov and Ormiston, which occurred in the Cisuralian–Guadalupian (lower–middle Permian) as mentioned in previous studies, was also extracted. Permian spicular chert is well-known from the Akiyoshi belt, and the red-ocher chert presumably comes from that belt.

Introduction

Biogenic chert, a sedimentary rock composed of siliceous organisms such as radiolarians and sponges, is one of the significant components of Permian and Jurassic accretionary complexes in the Japanese Islands. The characteristics of the chert in the accretionary complexes have been described and compared (e.g., Imoto, 1983, 1984a, b; Kakuwa, 1991; Imoto and Saijyo, 1993).

Isolated radiolarians and spicules also have been investigated; however, there is a

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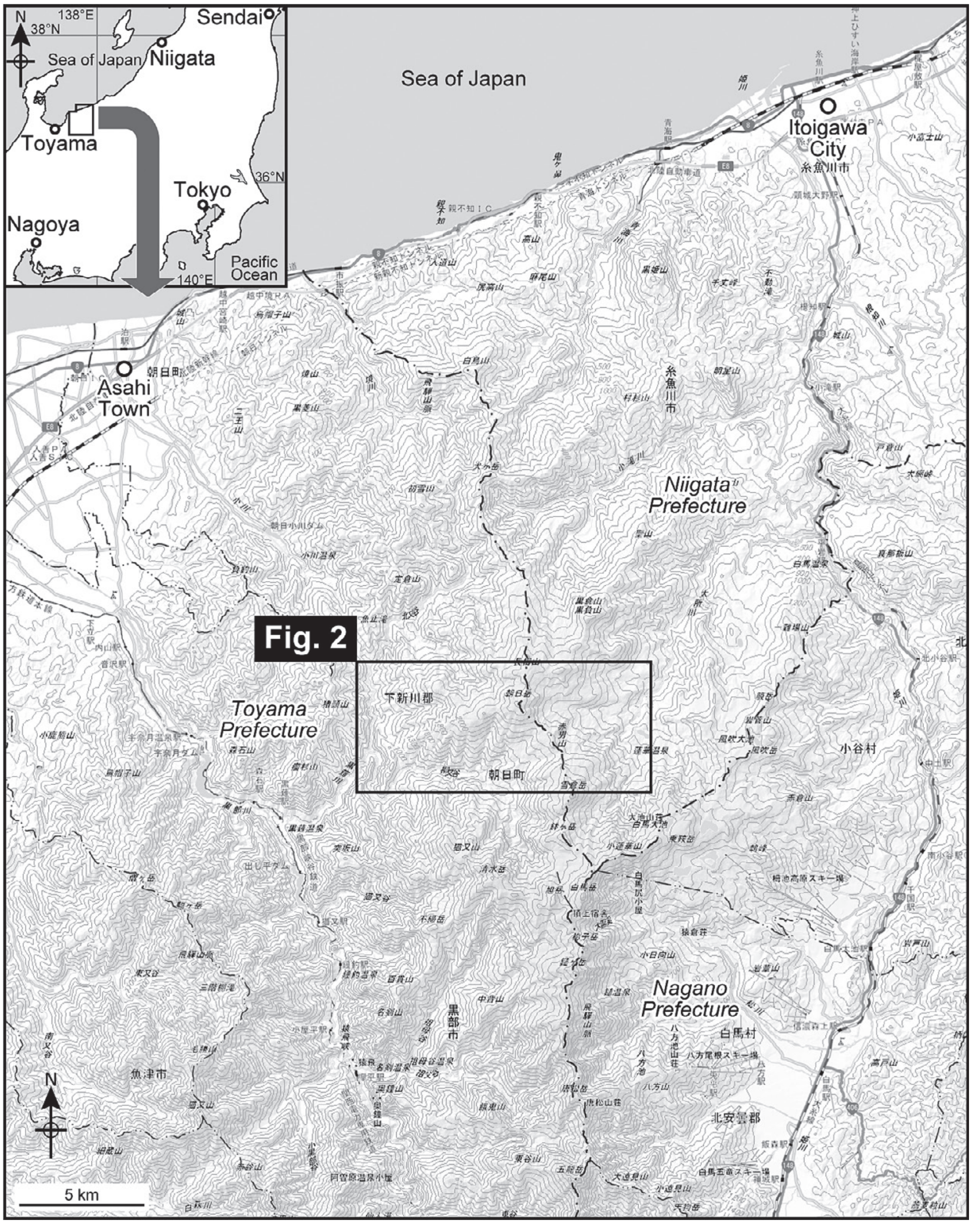

Fig. 1. Index map of sample locality. Modified from a topographic map published by Geospatial Information Authority of Japan (https://maps.gsi.go.jp/).

substantial difference in the accumulation of the research on the isolated fossils. Numerous studies have described isolated radiolarians from the Permian and Jurassic accretionary complexes in the Japanese Islands since around 1980 (e.g., Nakaseko and Nishimura, 1979; Yao, 1979, 1982; Ishiga and Imoto, 1980; Yao et al., 1982; Matsuoka, 1983). On this basis, Permian, Triassic, and Jurassic radiolarian biozonations have been constructed (e.g., Ishiga, 1986, 1990; Matsuoka, 1995; Sugiyama, 1997; Kuwahara et al., 1998; Matsuoka and Ito, 2019). In contrast, studies on spicules from the accretionary complexes are limited; even micrographs and images of isolated spicules have been rarely reported (e.g., Ishiga and Imoto, 1980; Ito and Matsuoka, 2016; Ito, 2021; Ito and Nakamura, 2021).

The collaborative research group (Niigata University, Itoigawa City, and Geological Survey of Japan, AIST) investigated the geology around Mt. Asahi-dake, bordering Niigata and Toyama prefectures, central Japan (Fig. 1) during August 3–6, 2021 (Ito et al., 2021). We discovered a spicular chert east of Mt. Asahi-dake. This article describes isolated siliceous spicules with a few radiolarians from the chert to provide the basic knowledge of spicules.

Geologic outline

Various rocks with a wide age range are exposed from Itoigawa City of Niigata Prefecture to Asahi Town of Toyama Prefecture (e.g., Nakano et al., 2002; Takeuchi et al., 2004, 2017; Nagamori et al., 2010; Ito et al., 2017). Paleozoic rocks belonging to the Renge, Akiyoshi, Maizuru, and Hida-Gaien belts are basement rocks of the area. Mesozoic–Cenozoic deposits cover them, and Mesozoic–Cenozoic volcanic rocks are intruded.

Around Mt. Asahi-dake, serpentinite mélange with metamorphic rock blocks belonging to the Renge belt are distributed (e.g., Ito, 1966; Nakamizu et al., 1989). The isotopic ages of 323 Ma and 311 Ma were determined from muscovite in the metamorphic rock (Shibata and Ito, 1978). The amphibolite of the Renge belt and Permian sedimentary rocks of the Hida-Gaien belt are distributed in the surrounding areas of Mt. Asahi-dake (Nakano et al., 2002; Nagamori et al., 2010; Takeuchi et al., 2017). Devonian–Carboniferous fossils, such as corals, crinoids, and bryozoans, have been reported from limestone around Mt. Asahi-dake (Minato, 1975; Takano and Komatsu, 1984; Ibaraki and Niko, 2012). Mudstone and siliceous tuff to the south and east of Mt. Asahi-dake yielded Permian radiolarians (Takizawa et al., 1995; Takeuchi et al., 2004).

Outcrop distribution based on our fieldwork

Figure 2 shows outcrop distribution mainly along mountain climbing trails based on our fieldwork. Granitic rocks and contact metamorphosed sedimentary rocks are exposed around the Kitamata Dam. Serpentinite is widely distributed in the traverse map and is well exposed around Mt. Asahi-dake and along a southern climbing trail of Mt. Yukikura-dake. Sedimentary rocks also exist in outcropping at several points along the climbing trails in the traverse map.

The sample locality (IT21080602b) in this study was a climbing trail between the Shirakochizawa and Seto rivers (eastern end of Fig. 2). The chert was exposed along the climbing trail. The chert was red-ocher-colored. The outcrops of the chert were small, and

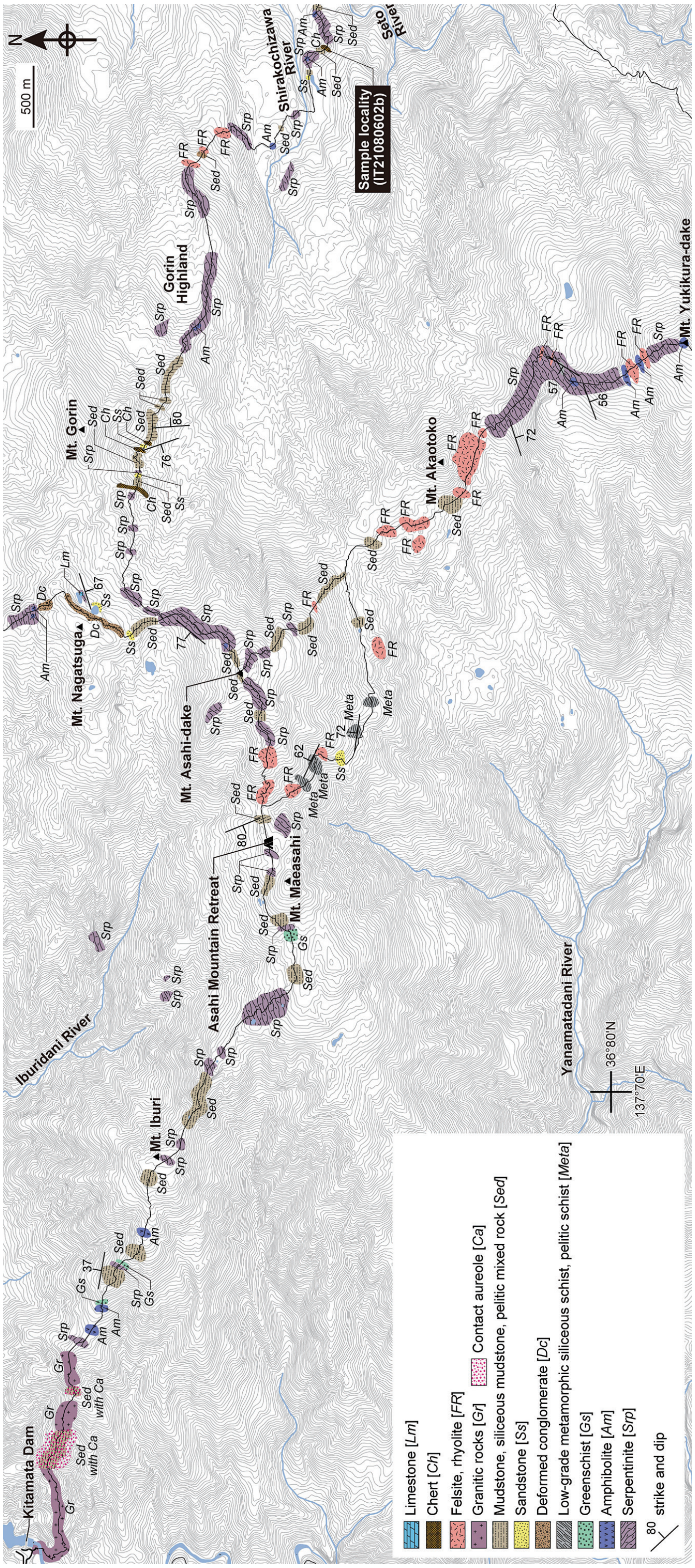

Fig. 2. Travers map around Mt. Asahi-dake based on the authors' fieldwork during August 3–6, 2021.

the chert appeared massive. The chert was exposed in the distributional area of the serpentinite.

Materials and method

The sample was soaked in a hydrofluoric acid (HF) solution (ca. 5%) at room temperature (ca. 20–30 °C) for approximately 24 h. Adequate residues were collected using a sieve (mesh diameter: 54 μm). Some of the sieved residues were enclosed within a prepared slide with a photocrosslinkable mounting medium (GJ-4006, Gluelabo Ltd., Kuwana, Japan). The slide was observed under a transmitted light microscope and imaged. Fossil tests within the dried residues were conducted using binocular microscopy and mounted on a stub. The fossil tests mounted on the stub were coated with gold using a sputter-coater and imaged using a scanning electron microscope (SEM). The HF-etched rock sample was also coated using gold and imaged with SEM in a low-vacuum state.

Fossil occurrence and age assignment

The HF-etched surfaces are shown in Fig. 3. The micrographs of the transmitted microscopy and SEM images of the isolated fossils are shown in Fig. 4.

Spicules, especially monaxon, dominate both the HF-etched surface and residues. Monaxon included the style, strongyloxea, oxea, and strongyle. Anadiaene is present, but it is scarce. Most spicules on the etched surfaces are parallel to the bedding planes of the chert (Fig. 3). A clear preferred orientation was not observed in the bedding planes. As with other spicules, tetractine and critriactine are common in these residues.

The radiolarians *Quinqueremis* sp. aff. *Q. robusta* Nazarov and Ormiston sensu Blome and Reed (1992) were extracted from the residues. *Quinqueremis* sp. aff. *Q. robusta* co-occurred with the Cisuralian–Guadalupian (early–middle Permian) species (Sosson et al., 1984; Blome and Reed, 1992; Basir Jasin and Ali, 1997; Ito and Matsuoka, 2015). Similar specimens possibly identified as *Q. robusta* also occurred in the Cisuralian–Guadalupian (e.g., Wang, 1993a, b, 1995; Nakagawa and Wakita, 2016). Consequently, the sample is likely Cisuralian–Guadalupian in age.

Paleontological note

All specimens shown in this section were extracted from sample IT21080602b. The stub, prepared slide, and HF-etched rock are deposited in the Fossa Magna Museum, Itoigawa City, Niigata Prefecture, Japan. The depository numbers of the HF-etched rock, stub, and prepared slide are FMM06445, FMM06446, and FMM06447, respectively.

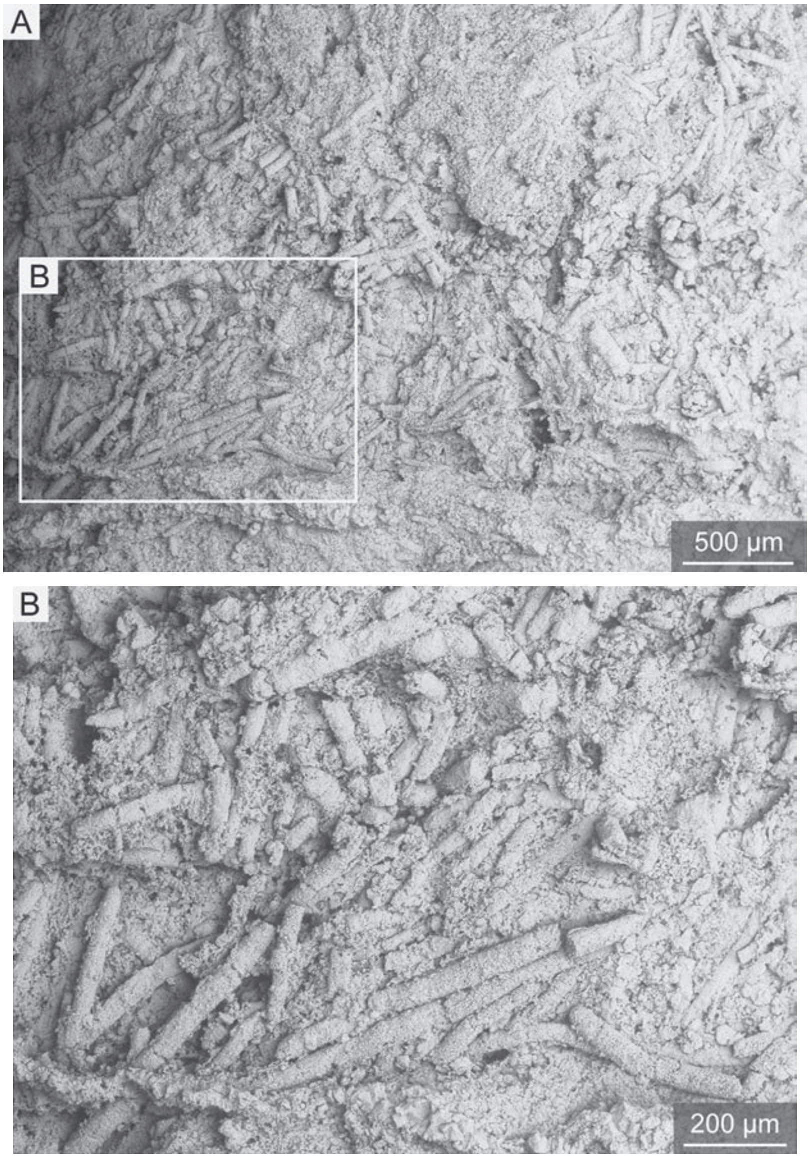

Fig. 3. Etched surface of red-ocher chert (sample IT21080602b). The surface is parallel to the bedding planes. Depository number: FMM06445.

Spicules

Morphological terminology and descriptive classification are preferred to classify isolated spicules from sponges, and Linnaean taxonomy is generally not used. This is because an individual sponge possesses a wide variety of spicule types; different sponge taxa have approximately the same form of spicules (e.g., Boury-Esnault and Rützler, 1997).

Siliceous spicules obtained from Permian siliceous rocks are generally considered to originate from sponges. Previous studies (e.g., Liu et al., 2008; Ito et al., 2016) generally employ the terminology coined by Boury-Esnault and Rützler (1997) for sponge spicules; thus, we used the same terminology in the present study.

Style (monaxon)

Fig. 4.1

Description: This form has a cylindrical spicule of a single axis, with rounded and blunt ends. The shape of the spicule is straight. The blunt end is symmetrical. The surface is generally smooth and has no spine or ornament. The total length is approximately 800 μm, and the maximum thickness (diameter) is approximately 50 μm.

Strongyloxea (monaxon)

Fig. 4.2

Description: This form has a cylindrical spicule of a single axis, with fusiform and blunt ends. The shape of the spicule is slightly flexuous. The blunt end is asymmetrical. The surface is generally smooth and has no spine or ornament. The total length is approximately 800 μm, and the maximum thickness (diameter) is approximately 50 μm.

Oxea (monaxon)

Fig. 4.3

Description: This form has a cylindrical spicule of a single axis with blunt ends. The shape of the spicule is slightly curved. The blunt ends are asymmetrical. The surface is generally smooth and has no spine or ornament. The total length is approximately 700 μm, and the maximum thickness (diameter) is approximately 50 μm.

Strongyle (monaxon)

Figs. 4.4–4.8, 4.12

Description: This form has a cylindrical spicule of a single axis with rounded ends. The shape of the spicule is straight (Figs. 4.6, 4.7), slightly curved (Figs. 4.4, 4.5), or curved (Figs. 4.8, 4.12). The surface is generally smooth and has no spine or ornament. The total length is approximately 200–700 μm, and the maximum thickness (diameter) is approximately 10–50 μm.

Possible monaxon

Figs. 4.9, 4.10

Description: The specimens have a cylindrical spicule of a single axis. The shape of the spicule is flexuous. The end of the spicules was lost, and these specimens might not be derived from monaxons but other forms, such as tetractines. The surface is generally

Fig. 4. Spicules (1–17) and radiolarians (18, 19) from red-ocher chert (sample IT21080602b). (1) Style (monaxon). (2) Strongyloxea (monaxon). (3) Oxea (monaxon). (4–8, 12) Strongyle (monaxon). (9–10) Possible monaxon. (11) Anadiaene. (13, 15) Tetractine. (16, 17) Critriactine. (18, 19) *Quinqueremis* sp. aff. *Q. robusta* Nazarov and Ormiston sensu Blome and Reed (1992). Depository numbers: stub (2, 3, 7–10, 13–17): FMM06446; prepared slide (1, 4–6, 11, 12, 18, 19): FMM06447.

smooth and has no spine or ornament. The minimum length is approximately 800 μm, and the maximum thickness (diameter) is approximately 50 μm.

Anadiaene

Fig. 4.11

Description: This form has a cylindrical spicule of a single axis with two clads curved backward. One end of the spicule (another side of clads) is blunt. The surface is generally smooth and has no spine or ornament. The total length is approximately 300 μm, and the maximum thickness (diameter) is approximately 20 μm.

Critriactine

Fig. 4.16, 4.17

Description: This form has three co-planar spines with a spiral ornament. The end of the spines is hastate. The ornaments are dextrally spiral ribs. The length of each spine is approximately 200 μm, and the maximum thickness (diameter) is approximately 50 μm.

Tetractine

Figs. 4.13, 4.15

Description: This form has four possible co-planar spines. The end of the spine is unclear because it was lost. The spines taper. The surface is generally smooth and has no spine or ornament. The length of each spine is approximately 100–300 μm or more, and the maximum thickness (diameter) is approximately 50 μm.

Radiolarians

The specimens described here are possibly spicules of sponges and not radiolarians. However, the surfaces of sponge spicules are generally smooth or spinous, and grooves on sponge spicules are less commonly present. Instead, grooved arms are the general characteristics of the radiolarian family Ormistonellidae De Wever and Caridroit. Therefore, we regarded the specimens as radiolarians.

Assuming that the specimens are radiolarians, they resemble *Quinqueremis* sp. aff. *Q. robusta* sensu Blome and Reed (1992). The higher taxonomic classification of this species employs the scheme described by Noble et al. (2017).

Order LATENTIFISTULARIA Caridroit, De Wever and Dumitrica, 1999

Family ORMISTONELLIDAE De Wever and Caridroit, 1984

Genus *Quinqueremis* Nazarov and Ormiston, 1983

Type species: *Quinqueremis arundinea* Nazarov and Ormiston, 1983

Quinqueremis sp. aff. *Q. robusta* Nazarov and Ormiston, 1985 sensu Blome and Reed (1992)

Figs. 4.18, 4.19

Quinqueremis sp.: Sosson et al., 1984, pl. I, fig. 6.

Quinqueremis sp. aff. *Q. robusta* Nazarov and Ormiston: Blome and Reed, 1992, figs. 11.17, 11.18, 12.1.

Quinqueremis robusta Nazarov and Ormiston: Basir Jasin and Ali, 1997, pl. 2, fig. 7.
Sponge spicule: Ito and Matsuoka, 2015, fig. 7.21.
?*Quadriremis flata* Wang: Wang, 1993a, pl. IV, figs. 5–9; Wang, 1993b, pl. II, figs. 3, 4. Wang, 1995, pl. II, figs. 3, 6.
?*Ormistonella robusta* De Wever and Caridroit: Nakagawa and Wakita, 2016, pl. 9, figs. 8, 9.
?*Quinqueremis robusta* Nazarov and Ormiston: Wang, 1995, pl. II, fig. 3; Wang et al., 2012, pl. 17, figs. 17, 21.

Description: The specimens have four co-planar arms originating from a trapezoidal part. The arms are elongated and three-bladed. Although the arms were broken, the longest one is 200 μm in length, and the width is approximately 50 μm. The arms seem to taper, and each base of the arms is thicker than each confirmable end. The trapezoidal part seems to be unperforated.

Remarks: The specimens are closely similar to *Quinqueremis* sp. aff. *Q. robusta* sensu Blome and Reed (1992). The specimens resemble *Q. robusta* in outline; however, the arms of the species possess small pores in a single row (Nazarov and Ormiston, 1985). In contrast, the arms of *Q.* sp. aff. *Q. robusta* are characterized by deep grooves, similar to the specimens examined in this study.

Furthermore, both *Q. robusta* and *Q.* sp. aff. *Q. robusta* have a trapezoidal part with many small pores and one short vertical spine. The trapezoidal part of our examined specimens seems to be unperforated and to have no spine, although the preservation was poor.

Occurrences: The Cisuralian–Guadalupian (early–middle Permian) from North America (Sosson et al., 1984; Blome and Reed, 1992) and the Cisuralian from Malaysia (Basir Jasin and Ali, 1997) and Southwest Japan (Ito and Matsuoka, 2015).

Implications

Spicule assemblage based on recent sponges

Siliceous spicules from the Phanerozoic are generally considered to originate from sponges. Siliceous sponges are composed of two groups, i.e., demosponges and hexactinellids. The former group generally inhabits shallow seas and the latter deep seas. According to Murchey (2004), rhax, calthrops, desma, and protriaene are isolated from demosponges, whereas hexactine, birotula, and anadiaene from hexactinellids. Monaxon, including the strongyle, is common in both groups.

Our chert sample yielded dominant monaxon, common critriactine and tetractine, and rare anadiaene. Based on the classification of Murchey (2004), its origin was undetermined.

Siliceous spicule assemblages have been reported in some Permian strata (Ishiga and

Imoto, 1980; Kozur and Mostler, 1989; Liu et al., 2008; Ito et al., 2013, 2016). However, the spicules from our examined sample differ from those by having critriactine and lacking oxyaster or polyaxon. Further research in several areas and comparisons are necessary.

Significance of the spicular chert

In this study, we discovered a Permian spicular chert. This type of chert is well-known in the Permian, especially the Permian accretionary complex of the Akiyoshi belt (e.g., Uchiyama et al., 1986; Sano et al., 1987; Sano and Kanmera, 1988; Naka, 1995; Ito and Matsuoka, 2015). The Permian chert in the Akiyoshi belt is generally reddish in the author's observation (Ito and Matsuoka, 2015, 2016) and the previous studies. The present spicular chert presumably belongs to the Akiyoshi belt based on the current knowledge. Although Harayama et al. (1995) showed the distribution of Permian chert in the area, they considered it to belong to the Hida-Gaien belt.

The present results imply the presence of Permian spicular chert of the Akiyoshi belt to the east of Mt. Asahi-dake. An eastern extension of the Akiyoshi belt is distributed in the Itoigawa area, and Permian chert has been reported there (Hasegawa, 1985; Hasegawa et al., 2001; Kawai and Takeuchi, 2001; Kurihara et al., 2020). However, confirmable rock exposures of the Akiyoshi belt are located more than 10 km northeast from the sample locality (Nagamori et al., 2010), and some previous geological maps have shown no distribution of the Akiyoshi belt around Mt. Asahi-dake (e.g., Ito, 1966; Nakano et al., 2002; Takeuchi et al., 2004, 2017; Nagamori et al., 2010). Takizawa et al. (1995) also reported red chert with a possible Permian-type conodont from an area adjacent to our sample locality. Consequently, a certain amount of Permian chert is probably distributed in the area. As mentioned previously, the chert is exposed in the distributional area of the serpentinite; however, the detailed occurrence has not yet been determined. Further fieldwork should be conducted to update the geological map of the area.

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Early Permian (Sakmarian) brachiopod fauna with *Jilinmartinia shansiensis* from Fukuji, Hida Gaien Belt, central Japan

Jun-ichi TAZAWA*, Yousuke IBARAKI** and Yukio MIYAKE***

Abstract

An early Permian brachiopod fauna consisting of nine species in eight genera with *Jilinmartinia shansiensis* is described from the basal part of the Mizuyagadani Formation, Fukuji in the Hida Gaien Belt, central Japan. The brachiopod fauna (Mizuyagadani fauna) is assigned to the Sakmarian. In terms of palaeobiogeography, the fauna is a mixed Boreal–Tethyan fauna, and has affinity with those of northwestern China (Xinjiang and Gansu) and northern China (Shanxi). Thus, the Mizuyagadani fauna probably belonged to the Sino-Mongolian–Japanese Province, and the Hida Gaien region, including Fukuji, was probably located near and to the northeast of the North China Block during the Sakmarian.

Key words: Brachiopoda, Hida Gaien Belt, *Jilinmartinia*, mixed Boreal–Tethyan fauna, Sakmarian.

Introduction

Jilinmartinia shansiensis (Chao, 1929) is type species of the spiriferid brachiopod genus *Jilinmartinia* Lee and Gu, 1980. This species is known to be from the Moscovian–Asselian of northwestern China (Xinjiang and Gansu) and northern China (Shanxi), outside of central Japan (Fukuji in the Hida Gaien Belt). In the present paper, we describe a brachiopod fauna (Mizuyagadani Fauna), with *J. shansiensis*, from the basal part of the Mizuyagadani Formation (named by Igo, 1956), Fukuji, Gifu Prefecture, Hida Gaien Belt, central Japan (Fig. 1),

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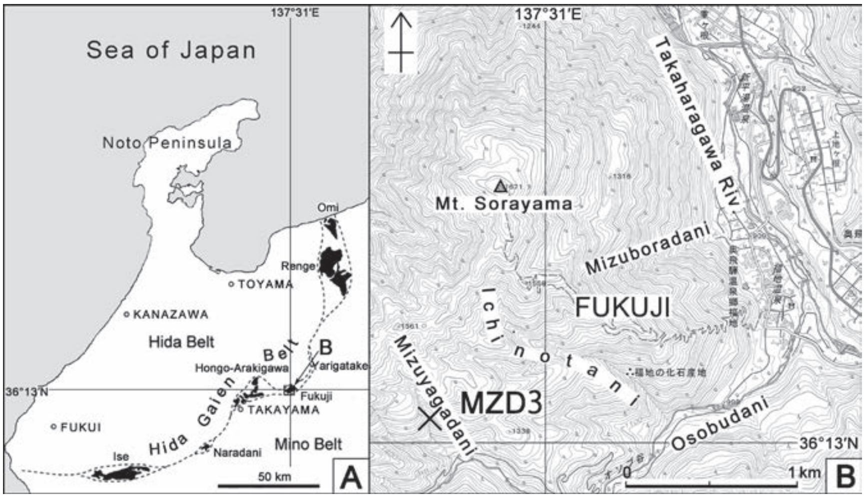

Fig. 1. Maps showing the fossil localiy MZD3 in the Fukuji area, Hida Gaien Belt, central Japan; **A,** Geotectonic map of the north-central part of Honshu, showing the distribution of the Hida Gaien Belt (after Tazawa, 2004); **B,** Topographic map showing the fossil locality MZD3 in the Fukuji area (using the topographical map "Yakedake" 1:25,000 published by the Geospatial Information Authority of Japan).

and discuss the age and palaeobiogeography of the fauna. In a previous study, Kamei (1952) reported the following brachiopods from the same locality of Fukuji: *Marginifera* sp., *Pustula* (*Echinoconchus*) sp., *Spirifer* sp., *Spirifer* (*Spiriferella*) cf. *salteri* Tchernyschew, *Squamulalia asiatica* Chao and *Dielasma* sp. The brachiopod specimens, however, remained undescribed.

In the present study, J. T. initiated the study and was primarily responsible for the taxonomic aspects. Y. I. and Y. M. studied the stratigraphy and collected the brachiopod fossil specimens.

Stratigraphy and material

The stratigraphy of the Mizuyagadani Formation in the Fukuji area has been studied by Kamei (1952), Igo (1956), Niikawa (1980), Niko et al. (1987), Harayama (1990), Tsukada et al. (1999) and Kurihara and Kametaka (2008). According to unpublished data of the present author (Y. I.), the Mizuyagadani Formation is subdivided into the lower part (alternating tuffaceous sandstone and tuffaceous shale, with some lenticular limestone blocks, 68 m thick), middle part (massive sandstone, with a conglomerate bed, 127 m thick) and upper part (alternating sandstone and shale, with some lenticular limestone blocks, 47 m thick), with a total thickness of 242 m (Fig. 2). The Mizuyagadani Formation is in fault contact with the underlying Ichinotani Formation (upper Visean–Uralian; Niikawa, 1980), and is in turn unconformably overlain by the Sorayama Formation (Middle Permian; Tsukada et al., 1999).

The brachiopod specimens were collected from greenish grey tuffaceous, partly

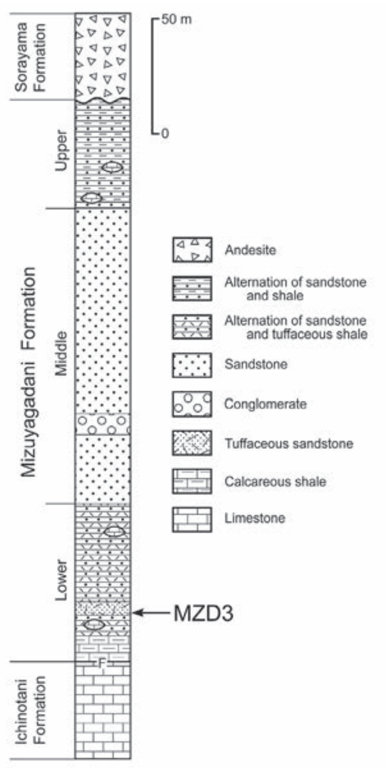

Fig. 2. Generalized columnar section of the Ichinotani, Mizuyagadani and Sorayama formations in the Fukuji area (modified from Niko et al., 1987), showing the fossil horizon of locality MZD3.

calcareous, fine-grained sandstone in alternating tuffaceous sandstone and tuffaceous shale, the basal part (about 20 m above from the base) of the Mizuyagadani Formation at locality MZD3 (36° 13' 5"N, 137° 30'35"E), lower Mizuyagadani Valley. The alternation of tuffaceous sandstone and tuffaceous shale is fossiliferous, and contains various kind of invertebrate fossils such as smaller foraminifers (Okimura et al., 1984), radiolarians (Niko et al., 1987; Kurihara and Kametaka, 2008), rugose corals (Igo, 1959), tabulate corals (Niko, 2001, 2011), brachiopods (Kamei, 1952; this study) and nautiloids (Okimura et al., 1984). The brachiopod specimens described below are registered and housed in the Faculty of Science, Niigata University, Niigata (prefix NU-B, numbers 2333–2362).

The Mizuyagadani fauna

The Mizuyagadani fauna includes nine species in eight genera: *Krotovia pustulata* (Keyserling, 1853), *Incisius incisus* (Schellwien, 1900), *Kutorginella* sp., *Vediproductus punctatiformis* (Chao, 1927), *Linoproductus* sp., *Acosarina dunbari* Cooper and Grant, 1976, *Acosarina* sp., *Jilinmartinia shansiensis* (Chao, 1929) and *Brachythyrina rectangula* (Kutorga, 1844). Among the species, *Brachythyrina rectangul*a is abundant, *Kutorginella* sp. and *Jilinmartinia shansiensis* are common, and the other species are rare.

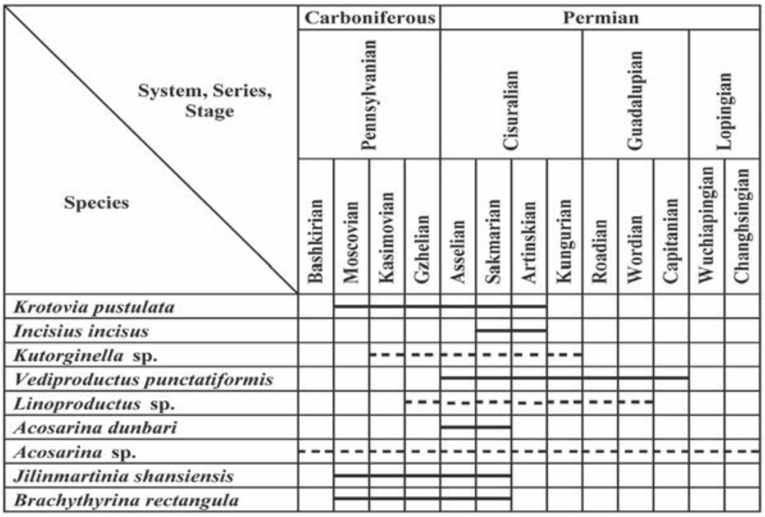

Fig. 3. Stratigraphic distributions of brachiopod species of the MD3 and ICT1 assemblages in the Mizuyagadani fauna. Broken lines show ranges of the genera.

Age

The stratigraphic distributions of the brachiopod species of the Mizuyagadani fauna are described in the section 'Systematic descriptions' and summarized in Fig. 3. Of the brachiopod taxa listed above, *Krotovia pustulata* is known to be from the Moscovian–Artinskian, *Incisius incisus* is known to be from the Sakmarian–Artinskian, *Vediproductus punctatiformis* occurs from the Asselian–Capitanian, *Acosarina dunbari* occurs from the Asselian–Sakmarian, and the other two species (*Jilinmartnia shansiensis* and *Brachythyrina rectangula*) occur from the Moscovian–Sakmarian. At the generic level, *Kutorginella* occurs from the Kasimovian–Kungurian (Brunton et al., 2000), *Linoproductus* from the Gzhelian–Wordian (Brunton et al., 2000), and *Acosarina* from the Bashkirian–Changhsingian (Williams and Harper, 2000). In summary, the Mizuyagadani fauna is identified as the Sakmarian, meaning that the basal part of the Mizuyagadani Formation is correlated with the Sakmarian.

Palaeobiogeography

The geographic distributions of the brachiopod species of the Mizuyagadani fauna are described in the section 'Systematic descriptions'. Palaeobiogeographically, *Krotovia pustulosa* is known to be from the USA, Canada, Russia, Kazakhstan and China; *Incisius incisus* is known to be from Slovenia and southern Thailand; *Vediproductus punctatiformis* is known to be from northeastern Japan (South Kitakami Belt) and both northern and southern China; *Acosarina dunbari* from only the USA (Nebraska); *Jilinmartinia shansiensis* from northwestern and northern China; and *Brachythyrina rectangula* from northern and central Russia, Uzbekistan, northwestern, northeastern and southern China, and southern Thailand. At the generic level, *Krotovia*, *Linoproductus* and *Brachythyrina* are cosmopolitan genera (Muir-Wood and Cooper, 1960; Brunton *et al*., 2000; Carter, 2006); *Kutorginella* is also a cosmopolitan genus, but occurs commonly from the Boreal region (Bamber and Waterhouse, 1971; Kalashnikov, 1980, 1993; Sarytcheva, 1977); and both *Vediproductus* and *Acosarina* are Tethyan or Panthalassan genera inhabit in mostly the equatorial region (Brunton et al., 2000; Harper, 2000). In contrast, *Jilinmartinia* is a Boreal genus, that was recorded in arctic Canada (Carter and Poletaev, 1998), northern Russia (Kalashnikov, 1980) western Russia (Licharew, 1939), central Russia (Tschernyschew, 1902), Uzbekistan (Volgin, 1960), southern Mongolia (Pavlova, 1991) and northwestern–northeastern China (Chao, 1929; Lee and Gu, 1980; Wang and Yang, 1998). It is noteworthy that *Jilinmartinia shansiensis* is known to be from only northwestern China (Xinjiang and Gansu) and northern China (Shanxi), outside of central Japan (Fukuji in the Hida Gaien Belt). In summary, the Mizuyagadani fauna is a mixed Boreal–Tethyan fauna, and possesses affinity with those of northwestern and northern China.

Discussion and conclusion

From what has been discussed above, we can conclude that the age of the basal part of the Mizuyagadani Formation is Sakmarian on the basis of the Mizuyagadani fauna. This conclusion is consistent with that of Igo (1959) based on rugose corals (*Sochkineophyllum japonicum* Igo, *S. pauciseptatum* Igo, *Amandophyllum* sp., *Iranophyllum tunicatum* Igo, *Wentzelella osobudaniensis* Igo and *Lonsdaleiastraea*? sp.) and that of Niko et al. (1987) based on radiolarians [*Pseudoalbaillella lomentaria* Ishiga and Imoto, *P. longicornis* Ishiga and Imoto and *P. sakmarensis* (Kozur)]. On the other hand, Kurihara and Kametaka (2008) considered that the age of the basal part (at ich-07072, Kurihara and Kametaka, 2008) of the Mizuyagadani Formation to be identified as Asselian–Sakmarian on the basis of a radiolarian fauna, including *Pseudoalbaillella u-forma* Holdsworth and Jones, *P. chilensis* Ling and Forsythe, *P. elegans* Ishiga and Imoto, *P. simplex* Ishiga and Imoto, *P. lomentaria* Ishiga and Imoto and *P. sakmarensis* (Kozur).

In terms of palaeobiogeography, the Mizuyagadani fauna is a mixed Boreal–Tethyan fauna. Moreover, the fauna includes *Jilinmartinia shansiensis*, which is known from northwestern China (Xinjiang and Gansu), northern China (Shanxi) and central Japan (Fukuji in the Hida Gaien Belt). Thus, the Mizuyagadani fauna probably belonged to the Sino-Mongolian–Japanese Province (established by Shi and Tazawa, 2001; refigured by Tazawa and Araki, 2017, fig. 5; Fig. 4), which was characterized by a mixture of Boreal and Tethyan brachiopods, and covered a broad area of north to the North China Block in the Permian. This conclusion is consistent with that of Niko (2011), in which a tabulate coral, *Sinkiangopora kanumai* Niko, is described from the basal part of the Mizuyagadani Formation in the same fossil locality. According to Niko (2011), *Sinkiangopora* is known to be from Xizang (Tibet), northwestern China (Xinjiang), northeastern China (Heilongjiang and

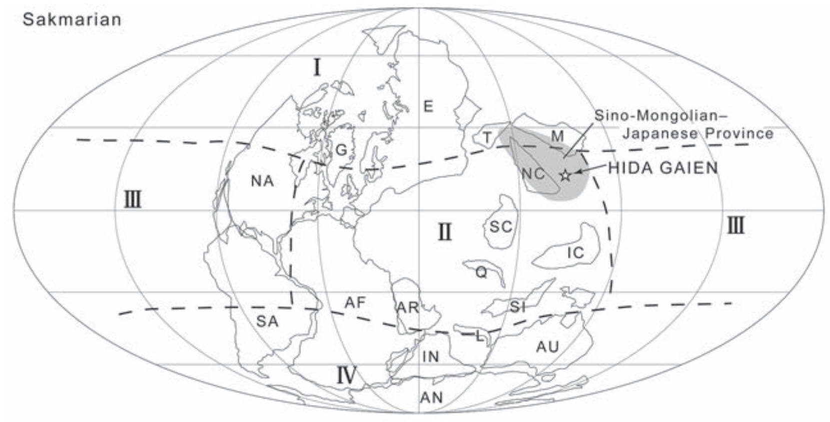

Fig. 4. Early Permian (Sakmarian) reconstruction map of the word, showing palaeoposition of the Hida Gaien area and the Sino-Mongolian–Japanese Province (modified and adapted from Tazawa and Araki, 2017). I, Boreal Realm; II, Tethyan Realm; III, Panthalassan Realm; IV, Gondwanan Realm; AF, Africa; AN, Antarctica; AR, Arabia; AU, Australia; E, Eurasia; G, Greenland; IC, Indochina; IN, India; L, Lhasa; M, Mongolia; NA, North America; NC, North China; Q, Qiangtang; SA, South America; SC, South China; SI, Sibumasu; T, Tarim.

Jilin), central Japan (Omi in the Akiyoshi Belt) and southwestern Japan (Akiyoshi in the Akiyoshi Belt), all located in the anti-tropical region during the Permian.

Systematic descriptions

(by J. Tazawa)

Order Productida Sarytcheva and Sokolskaya, 1959

Suborder Productidina Waagen, 1883

Superfamily Productelloidea Schuchert, 1929

Family Avoniidae Sarytcheva in Sarytcheva et al., 1960

Subfamily Tubersulculinae Waterhouse, 1971

Genus *Krotovia* Fredericks, 1928

Type species.—*Productus spinulosus* Sowerby, 1814.

Krotovia pustulata (Keyserling, 1853)

Fig. 5D

Productus pustulatus Keyserling, 1853, p. 247; Tschernyschew, 1902, p. 271, 617, pl. 30, figs. 1, 2; pl. 53, fig. 6 only.

Krotovia pustulata (Keyserling). Chao, 1928, p. 52, pl. 5, figs. 18–20; Grabau, 1936, p. 150, pl. 14, fig. 4; Cooper, 1957, p. 33, pl. 8A, figs. 1–5; Muir-Wood and Cooper, 1960, pl. 50, figs. 6–9; Mironova, 1967, p. 14, pl. 1, figs. 16, 17; Sarytcheva, 1968, p. 79, pl. 5, fig. 9; Zavodowsky and Stepanov, 1970, p. 81, pl. 12, fig. 4; pl. 26, fig. 10 only; Waterhouse in Bamber and Waterhouse, 1971, pl. 15, fig. 21; pl. 16, fig. 2; Jin and Liao, 1974, p. 280, pl. 147, fig. 8; Lee and Gu, 1976, p. 241, pl. 134, fig. 3; pl. 140, fig. 12; Yang et al., 1977, p. 343, pl. 138, fig. 9; Feng and Jiang, 1978, p. 250, pl. 89, fig. 14; Alexandrov and Einor, 1979, p. 61, pl. 23, fig. 3; Kalashnikov, 1980, p. 41, pl. 8, figs. 6–9; Lee et al., 1980, p. 351, pl. 146, fig. 3; Zhang et al., 1983, p. 290, pl. 109, fig. 8; pl. 126, fig. 7; pl. 127, fig. 12; Kalashnikov, 1986, pl. 111, fig. 1; Shi and Waterhouse, 1996, p. 57, pl. 4, figs. 21–23; Wang and Yang, 1998, p. 68, pl. 3, figs. 14–17; Kuang et al., 1999, pl. 16, fig. 25.

Productus (*Avonia*) *pustulatus* Keyserling. Stepanov, 1948, p. 28, pl. 5, fig. 6.

Krotovia? *pustulata* (Keyserling). Sarytcheva in Sarytcheva and Sokolskaya, 1952, p. 93, pl. 14, fig. 100.

Avonia pustulata (Keyserling). Ustritsky and Tschernjak, 1963, p. 74, pl. 4, figs. 5, 6; Garanj et al., 1975, p. 161, pl. 64, fig. 9.

Material.—Two specimens: (1) external and internal moulds of a ventral valve, NU-B2337; and (2) internal mould of a ventral valve, NU-B2338.

Remarks.—The specimens available are referred to *Krotovia pustulata* (Keyserling, 1853), redescribed by Tschernyschew (1902, p. 271, 617, pl. 30, figs. 1, 2; pl. 53, fig. 5) from the Sakmarian of Ufa, southern Urals, in the relatively large, transverse and gently convex ventral valve (length about 24 mm, width about 38 mm in the better preserved specimen, NU-B2337), which is ornamented with numerous large, quincunxially arranged spine bases over the valve. *Krotovia jizodoensis* Tazawa (1980, p. 361, pl. 41, fig. 2), from the upper part of the Karaumedate Formation (upper Visean) of the Nagasaka area, South Kitakami Belt, northeastern Japan, differs from *K. pustulata* in much smaller size. The type species, *Krotovia spinulosa* (Sowerby, 1814), refigured by Muir-Wood and Cooper (1960, pl. 50, figs. 1–5) from the Visean of Cumberland, England, differs from the present species in much smaller size and less transverse outline.

Distribution.—Moscovian–Artinskian: central Japan (Fukuji in the Hida Gaien Belt), USA (Oregon), northern Canada (Yukon Territory), northern Russia (Kolyma Massif, Taimyr Peninsula and northern Urals), western Russia (Moscow Basin), central Russia (southern Urals), Kazakhstan, northwestern China (Xinjiang), northern China (Inner Mongolia), northeastern China (Liaoning), central-southern China (Guangxi) and southwestern China (Guizhou).

Superfamily Marginiferoidea Stehli, 1954

Family Marginiferidae Stehli, 1954

Subfamily Scapharininae Cooper and Grant, 1975

Genus *Incisius* Grant, 1976

Type species.—*Productus incisus* Schellwien, 1900.

Incisius incisus (Schellwien, 1900)
Fig. 5A

Productus incisus Schellwien, 1900, p. 54, pl. 8, figs. 3–5.
Incisius concisus Grant, 1976, p. 105, pl. 23, figs. 1–43; text-figs. 12, 13.

Material.—One specimen, a ventral valve, NU-B2351.

Remarks.—This specimen is referred to *Incisius incisus* (Schellwien, 1900, p. 54, pl. 8, figs. 3–5), from the Trogkofel Formation (Sakmarian) of Slovenia, in the small, slightly elongate and strongly convex ventral valve (length about 6 mm, width about 5 mm), which is narrow, widening anteriorly, having a deep sulcus, and ornamented with a row of large spine bases on each flank. *Incisius concisus* Grant (1976, p. 105, pl. 23, figs. 1–43, text-figs. 12, 13), from the Ratburi Formation of Ko Muk, southern Thailand, is deemed to be a junior synonym of *Incisius incisus*. *Incisus huatangensis* Liao and Meng (1986, p. 77, pl. 2, fig. 1), from the Changhsingian of Hunan, central-southern China, differs from *I. incisus* in much larger size.

Distribution.—Sakmarian–Artinskian: central Japan (Fukuji in the Hida Gaien Belt), Slovenia and southern Thailand (Ko Muk).

Superfamily Productoidea Gray, 1840
Family Productidae Gray, 1840
Subfamily Retariinae Muir-Wood and Cooper, 1960
Genus *Kutorginella* Ivanova, 1951

Type species.—*Kutorginella mosquensis* Ivanova, 1951.

Kutorginella sp.
Fig. 5B

Material.—Four specimens, incomplete four ventral valves, NU-B2347–2350.

Remarks.—These specimens can be assigned to the genus *Kutorginella* on account of the strongly convex ventral valve with faintly reticulate visceral disc and costate long trail, both of which having a broad and moderately deep sulcus. The Fukuji species resembles *Kutorginella yohi* (Chao, 1928, p. 60, pl. 5, figs. 13–17), from the Maping Formation of Guizhou, southwestern China, in size (length about 20 mm, width about 36 mm in the best preserved specimen, NU-B2347), shape and external ornament of the ventral valve, particularly in having relatively coarse costae (9–10 in 10 mm at midlength) on the trail. But accurate comparison is difficult for the poorly preserved specimens.

Superfamily Echinoconchoidea Stehli, 1954
Family Echinoconchidae Stehli, 1954
Subfamily Juresaniinae Muir-Wood and Cooper, 1960
Genus *Vediproductus* Sarytcheva in Sarytcheva and Sokolskaya, 1965

Type species.—*Vediproductus vediensis* Sarytcheva, 1965.

Vediproductus punctatiformis (Chao, 1927)
Fig. 6A

Echinoconchus punctatiformis Chao, 1927, p. 72, pl. 6, figs. 9–12; Yang et al., 1962, p. 52, pl. 20, figs. 1–3; Zhan and Lee, 1962, p. 477, pl. 2, fig. 9.
Bathymyonia punctatiformis (Chao). Feng and Jiang, 1978, p. 256, pl. 90, fig. 10.
Echinoconchus cf. *fasciatus* (Kutorga). Minato et al., 1979, pl. 65, figs. 5–7.
Vediproductus punctatiformis (Chao). Yang et al., 1977, p. 356, pl. 141, fig. 6; Tong, 1978, p. 225, pl. 79, fig. 16; Wang et al., 1982, p. 208, pl. 80, figs. 10, 11; pl. 84, fig. 4; Ding and Qi, 1983, p. 282, pl. 96, fig. 3; Wang, 1984, p. 190, pl. 76, fig. 7; Chang, 1987, p. 759, pl. 2, fig. 4; Liang, 1990, p. 187, pl. 27, fig. 5; Wang, 1995, pl. 1, fig. 20; Wang and Yang, 1998, p. 81, pl. 5, figs. 14–15, 18; Shiino, 2009, p. 255, fig. 4A–H; Tazawa, 2016, p. 19, figs. 7.1–7.5.

Material.—One specimen, a ventral valve, NU-B2336.

Description.—Shell medium in size for genus, elongate oval in outline, hinge slightly shorter than greatest width, which placed at slightly anterior to midlength; length 30 mm, width 23 mm in the sole ventral valve specimen (NU-B2336). Ventral valve strongly and unevenly convex in lateral profile, most convex at umbonal region, slightly convex at venter, roundly geniculated, and followed by a long trail; umbo small, incurved and followed by narrow, strongly convex umbonal slope; ears small; sulcus originating slightly anterior to umbo, narrow and shallow; venter broad, nearly flattened with steep lateral slopes in anterior profile. External surface of ventral valve ornamented with numerous, strong and regular concentric bands (4 in 10 mm at about midlength) with rows of spine bases on each front; spine bases consisting of larger elongate spines and more numerous smaller spines.

Remarks.—This specimen is referred to *Vediproductus punctatiformis* (Chao, 1927, p. 72, pl. 6, figs. 9–12), from the Ksiaokiang Limestone (lower Maokouan) of Jiangxi, eastern China, in the medium-sized, elongate oval and strongly convex ventral valve, ornamented with numerous regular spinose bands. Shen et al. (2002, p. 673) regarded the type species, *Vediproductus vediensis* Sarytcheva (1965, p. 221, pl. 35, figs. 1–3, text-fig. 33), from the Gnishik Horizon of Transcaucasus, as a junior synonym of *V. punctatiformis*. But the former differs from the latter in less convex and transversely wider ventral valve and broader

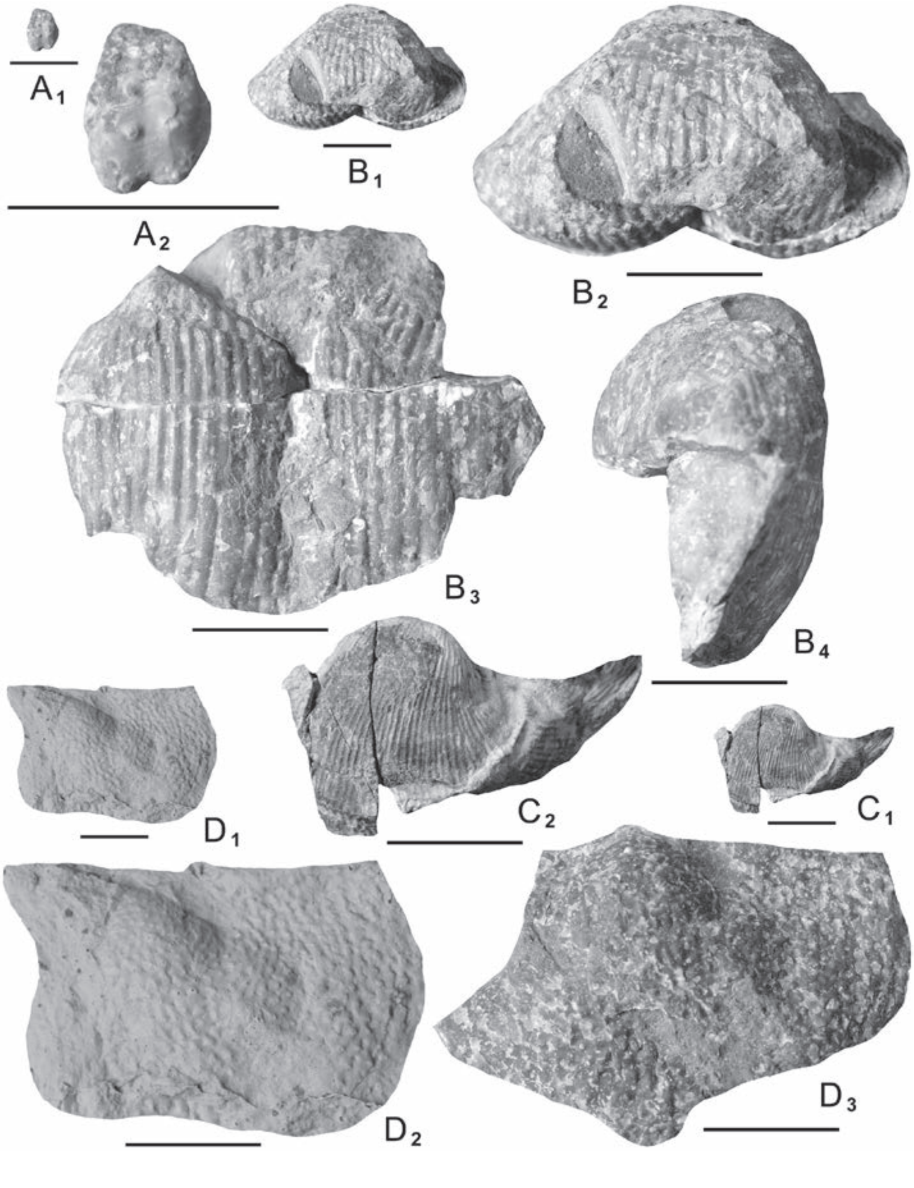

Fig. 5. Brachiopods of the Mizuyagadani fauna (1). **A,** *Incisius incisus* (Schellwien), ventral view (A1, A2) of ventral valve, NU-B2351; **B,** *Kutorginella* sp., ventral (B1, B2), anterior (B3) and lateral (B4) views of ventral valve, NU-B2347; **C,** *Linoproductus* sp., ventral view (C1, C2) of ventral valve, NU-B2352; **D,** *Krotovia pustulata* (Keyserling), external latex cast (D1, D2) and internal mould (D3) of ventral vave, NU-B2337. Scale bars are 1 cm.

concentric bands on the valve. Shells described by Campi et al. (2005, p. 115, pl. 2, figs. B–C, E, H–P. text-figs. 6, 7) as *Vediproductus punctatiformis* (Chao) from the Capitanian–Wuchiapingian of Pahang, Malaysia, are deemed to be *V. vediensis*.

Distribution.—Asselian–Capitanian: northeastern Japan (Kamiyasse–Imo in the South Kitakami Belt), central Japan (Fukuji in the Hida Gaien Belt), northwestern China (Xinjiang, Qinghai and Gansu), eastern China (Anhui, Zhejiang and Jiangxi), central southern China (Hubei) and southwestern China (Guizhou and Sichuan).

Superfamily Linoproductoidea Stehli, 1954
Family Linoproductidae Stehli, 1954
Subfamily Linoproductinae Stehli, 1954
Genus *Linoproductus* Chao, 1927

Type species.—*Productus cora* d'Orbigny, 1842.

Linoproductus sp.
Fig. 5C

Material.—One specimen, an incomplete ventral valve, NU-B2352.

Remarks.—The single incomplete ventral valve specimen from Fukuji can be assigned to the genus *Linoproductus* on account of its medium size (length more than 17 mm, width about 35 mm), subcircular outline with the widest part at hinge, and external ornament consisting of numerous costellae (10–11 in 5 mm at 10 mm anterior to umbo) over the ventral valve. However, specific identification is difficult for the poorly preserved specimen.

Order Orthida Schuchert and Cooper, 1932
Suborder Dalmanellidina Moore, 1952
Superfamily Enteletoidea Waagen, 1884
Family Schizophoriidae Schuchert and LeVene, 1929
Genus *Acosarina* Cooper and Grant, 1969

Type species.—*Acosarina dorsisulcata* Cooper and Grant, 1969.

Acosarina dunbari Cooper and Grant, 1976
Fig. 6B

Acosarina dunbari Cooper and Grant, 1976, p. 2622, pl. 670, figs. 1–8.

Material.—One specimen, external mould of a ventral valve, NU-B2344.

Remarks.—This specimen is referred to *Acosarina dunbari* Cooper and Grant (1976, p. 2622, pl. 670, figs. 1–8), from the Foraker Limestone (lower Wolfcampian) of Nebraska, the USA, in the small and slightly transverse ventral valve (length 8 mm, width 10 mm), which is strongly convex at posterior half but flattened anteriorly, and ornamented with several strong concentric lamellae besides numerous fine costellae (numbering 3 in 1 mm at about midlength of the valve). *Acosarina* cf. *dunbari* Cooper and Grant, described by Tazawa and Oyagi (2019, p. 35, figs. 3G–J) from the upper part of the Ryozensan Formation of Ryozensan, Mino Belt, southwestern Japan, differs from the present species in being slightly larger in size and in having finer costellae on the ventral valve.

Distribution.—Asselian–Sakmarian: central Japan (Fukuji in the Hida Gaien Belt) and USA (Nebraska).

Acosarina sp.

Fig. 6C, D

Material.—Three specimens: (1) a ventral valve, NU-B2359; (2) external mould of a ventral valve, NU-B2345; and (3) internal mould of a ventral valve, NU-B2346.

Remarks.—These specimens can be assigned to the genus *Acosarina* by the small, subcircular and moderately convex ventral valve (length 5 mm, width 6 mm in the largest specimen, NU-B2345), having no sulcus, and ornamented with numerous costellae (3 in 1 mm at midlength). The Fukuji species somewhat resembles *Acosarina rectimarginata* Cooper and Grant (1976, p. 2624, pl. 674, figs. 1–46), from the Neal Ranch Formation (lower Wolfcampian) of the Glass Mountains, Texas, in the small size and rectimarginate anterior commissure, but differs from the Texan species in having coarser costellae on the ventral valve. Specific identification is difficult for the poorly preserved specimens.

Order Spiriferida Waagen, 1883

Suborder Spiriferidina Waagen, 1883

Superfamily Martinioidea Waagen, 1883

Family Martiniidae Waagen, 1883

Subfamily Martiniinae Waagen, 1883

Genus *Jilinmartinia* Lee and Gu, 1980

Type species.—*Brachythyris shansiensis* Chao, 1929.

Jilinmartinia shansiensis (Chao, 1929)

Fig. 7A–C

Brachythyris shansiensis Chao, 1929, p. 55, pl. 9, figs. 1–3.

Martinia shansiensis (Chao). Yang, 1948, p. 207, pl. 2, figs. 19, 20; Zhang et al., 1983, p. 371, pl. 144, fig. 5.

"*Martinia*" *shansiensis* (Chao). Wang et al., 1964, p. 564, pl. 109, fig. 28.

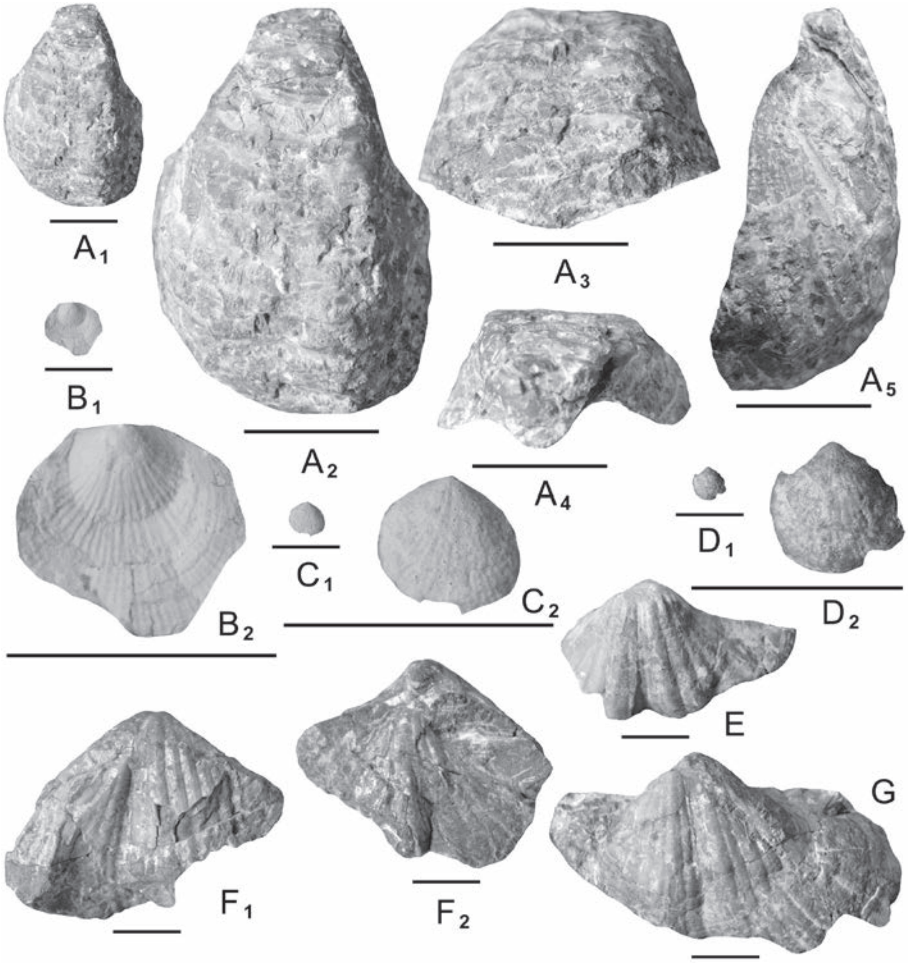

Fig. 6. Brachiopods of the Mizuyagadani fauna (2). **A,** *Vediproductus punctatiformis* (Chao), ventral (A_1, A_2), anterior (A_3), posterior (A_4) and lateral (A_5) views of ventral valve, NU-B2336; **B,** *Acosarina dunbari* Cooper and Grant, external latex cast (B_1, B_2) of ventral valve, NU-B2344; **C, D,** *Acosarina* sp.; external latex cast (C_1, C_2) of ventral valve, NU-B2345; internal mould (D_1, D_2) of ventral valve, NU-B2346; **E–G,** *Brachythyrina rectangula* (Kutorga); E, ventral view of ventral valve, NU-B2341; ventral (F_1) and dorsal (F_2) views of conjoined shell, NU-B2339; G, ventral view of ventral valve, NU-B2340. Scale bars are 1 cm.

Jilinomartinia shansiensis (Chao). Lee and Duan, 1985, p. 258, pl. 79, fig. 6; Wang and Yang, 1998, p. 129, pl. 22, figs. 20–22.

Jilinmartinia shansiensis (Chao). Shen et al., 2017, pl. P28, figs. 16–18.

Material.—Five specimens: (1) external and internal moulds of a ventral valve, NU-B2333; (2) ventral valve, NU-B2353; (3) external mould of a ventral valve, NU-B2334; and (4) internal moulds of two ventral valves, NU-B2335, 2354.

Description.—Shell medium in size for genus, transversely subelliptical in outline; hinge slightly shorter than maximum width at about midlength; cardinal extremities rounded; length

36 mm, width about 57 mm in the largest specimen (NU-B2334). Ventral valve strongly and unevenly convex in lateral profile, most convex at umbonal region; sulcus broad and shallow. External surface of ventral valve nearly smooth, except for faint concentric growth lines over valve. Internal structures of ventral valve not well preserved, except for a large muscle scar.

Remarks.—These specimens are referred to *Jilinmartinia shansiensis* (Chao, 1929), originally described by Chao (1929, p. 55, pl. 9, figs. 1–3) as *Brachythyris shansiensis* Chao, 1929, from the Lichiachuan Formation of Gansu, northwestern China and from the Miaokou Formation of Shanxi, northern China, in the large, transverse ventral valve which is ornamented with faint concentric growth lines. *Jilinmartinia sokolovi* (Tschernyschew, 1902, p. 166, pl. 8, fig. 3; pl. 39, fig. 4), from the Asselian of the Urals, central Russia, differs from *J. shansiensis* by its larger dimensions and in having ventral sulcus with a low median fold.

Distribution.—Moscovian–Sakmarian: central Japan (Fukuji in the Hida Gaien Belt), northwestern China (Xinjiang and Gansu) and northern China (Shanxi).

Superfamily Spiriferoidea King, 1846
Family Choristitidae Waterhouse, 1968
Subfamily Angiospiriferinae Legrand-Blain, 1985
Genus *Brachythyrina* Fredericks, 1929

Type species.—*Spirifer strangwaysi* de Verneuil, 1845.

Brachythyrina rectangula (Kutorga, 1844)
Fig. 6E–G

Spirifer rectangulus Kutorga, 1844, p. 90, pl. 9, fig. 5; Tschernyschew, 1902, p. 158, 545, pl. 8, fig. 1; pl. 41, figs. 1–5; Waterhouse et al., 1981, p. 96, pl. 21, figs. 1–14; pl. 22, figs. 1–8; pl. 23, fig. 1.

Brachythyrina rectangula (Kutorga). Chao, 1929, p. 60, pl. 8, fig. 3; Nelzina, 1965, p. 67, pl. 10, figs. 1, 5; Sergunkova and Zhizhilo, 1975, p. 75, pl. 16, fig. 2; Prokofiev, 1975, p. 101, pl. 21, fig. 1; Yang et al., 1977, p. 439, pl. 175, fig. 1; Lee and Gu, 1980, p. 488, pl. 1, fig. 16; Lee et al., 1980, p. 408, pl. 154, fig. 9; Gu, 1992, p. 248, pl. 79, figs. 21, 23; Wang, 1995, pl. 3, fig. 12; Wang and Yang, 1998, p. 116, pl. 18, figs. 7, 9, 17; Kuang et al., 1999, pl. 18, fig. 7.

Spirifer (*Brachythyrina*) *rectangulus* Kutorga. Grabau, 1936, p. 208, pl. 20, fig. 7.

Material.—Five specimens: (1) internal mould of a conjoined shell, with external mould of the ventral valve, NU-B2339; and (2) external and internal moulds of four ventral valves, NU-B2340–2343.

Remarks.—The specimens from Fukuji are represented by large, transverse ventral valves (length 35 mm, width 53 mm in the largest specimen, NU-B2340), ornamented with

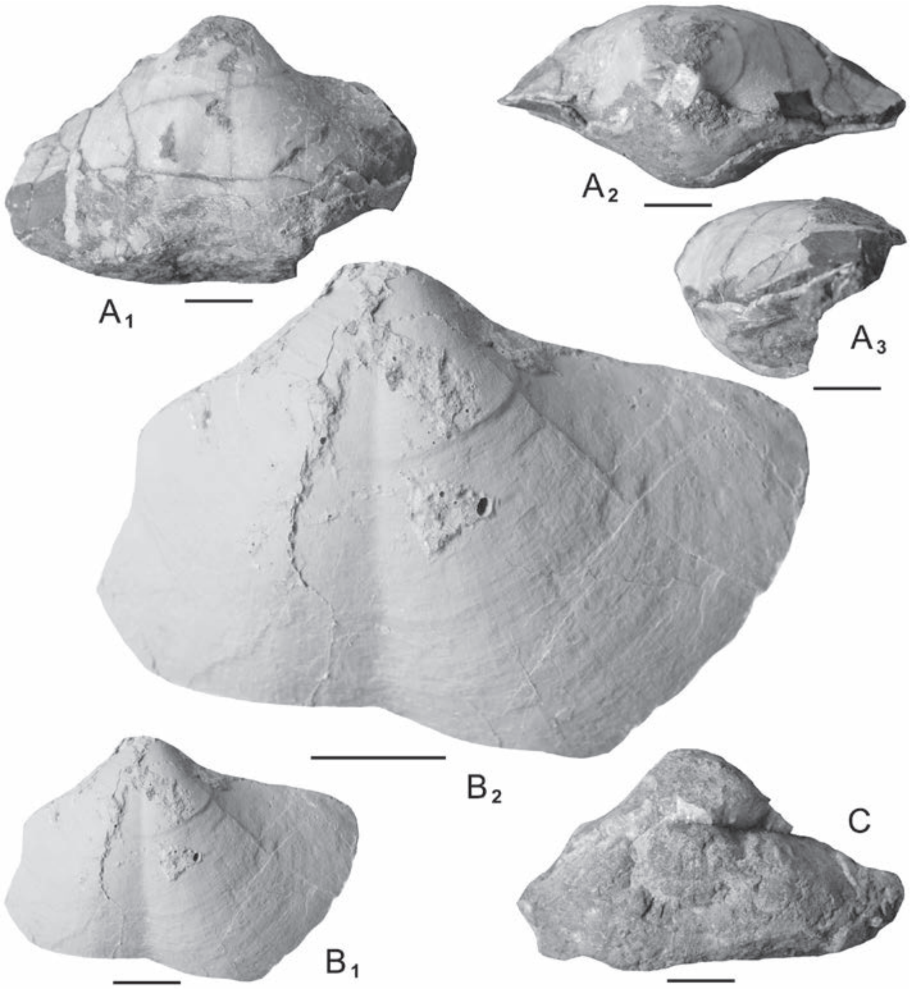

Fig. 7. Brachiopods of the Mizuyagadani fauna (3). **A–C,** ***Jilinmartinia shansiensis*** (Chao); ventral (A_1), posterior (A_2) and lateral (A_3) views of conjoined shell, NU-B2353; external latex cast (B_1, B_2) of ventral valve, NU-B2334; C, internal mould of ventral valve, NU-B2354. Scale bars are 1 cm.

numerous, simple, strong costae and finely and regularly cancellate microornament. These specimens are referred to *Brachythyrina rectangula* (Kutorga, 1844), redescribed by Tschernyschew (1902, p. 158, 545, pl. 8, fig. 1; pl. 41, figs. 1–5), from the Sakmarian of the Urals, on account of size, shape and external ornament of the ventral valve. The type species, *Brachythyrina strangwaysi* (de Verneuil, 1845), redescribed by Sokolskaya (in Sarytcheva and Sokolskaya, 1952, p. 189, pl. 53, fig. 305) from the Moscovian–Gzhelian of the Moscow Basin, differs from *B. rectangula* in the much smaller size. *Brachythyrina* cf. *arctica* Gobbett, 1963, described by Tazawa and Nakamura (2015, p. 172, figs. 9.6, 9.7) from the Hosoo Formation (Kungurian) of Nakadaira, South Kitakami Belt, northeastern Japan, is readily distinguished from the present species by the smaller and less transverse ventral valve.

Distribution.—Moscovian–Sakmarian: central Japan (Fukuji in the Hida Gaien Belt), northern Russia (Onega), central Russia (western and southern Urals), Uzbekistan (Fergana), northwestern China (Xinjiang), northeastern China (Jilin), central-southern China (Guangxi), southwestern China (Guizhou) and southern Thailand (Ko Yao Noi).

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Early Jurassic mollusks from the Kuruma Group around Mt. Kikuishi on the Tsugami Shindō Trail, Itoigawa, Niigata, central Japan

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Abstract

Mt. Kikuishi (1,209 m) is one of the peaks on the Tsugami Shindō Trail. The name was coined in reference to the ammonoids (*Kikuishi*) discovered here by the late Dr. Ken Ono who lead the creation of the trail in the 1960's. The geology on the trail around the Mt. Kikuishi fossil locality has not been studied in detail yet. We carried out geological research and fossil collection on 20 September and 23–24 October in 2021. Careful searching for fossils in the Teradani Formation exposed around the trail made a successful finding of many molluscan fossils including bivalves, gastropods and ammonoids which include *Canavaria* sp. The significance of the occurrence of these molluscan fossils is pointed out.

Keywords: ammonoid, *Canavaria*, Early Jurassic, Kuruma Group, Mt. Kikuishi.

Introduction

The Tsugami Shindō Trail (27 km in total length) runs from the Oyashirazu Cliffs on the coast of the Japan Sea to Fukiage-no-Col, 0.5 km north of Mt. Asahi (2,418 m). Mt. Kikuishi (1,209 m) is one of the peaks on the trail (Fig. 1). The name was coined in reference to the ammonoids (*Kikuishi*) discovered here by the late Dr. Ken Ono who lead the creation of the trail in the 1960's. The ammonoid specimens collected by him are hosted in the Fossa Magna Museum of Itoigawa City (Fig. 2). The year 2021 was the 50^{th} anniversary of the

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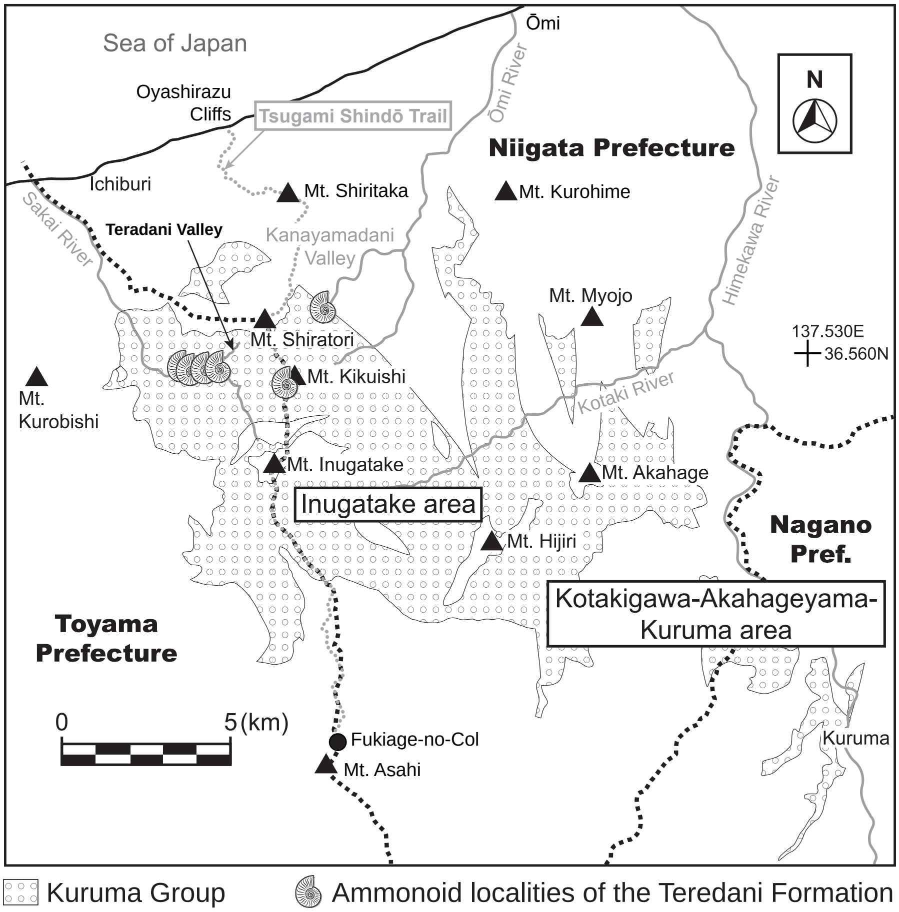

Fig. 1. Index map of the Tsugami Shindō Trail and distribution of the Kuruma Group with ammonoid localities.

opening of the Tsugami Shindō Trail. A commemorative exhibition was held at the museum and the ammonoid specimen (Fig. 2) was presented at the exhibition hall. The ammonoid specimen is believed to come from the Teradani Formation of which the type locality is around the Teradani Valley, 2.5 km west of Mt. Kikuishi (Fig. 1). The Teradani Formation is a shallow marine sequence belonging to the Kuruma Group, a representative of the Lower Jurassic in East Asia.

The year 2021 was another memorable year not only for the trail but also for Jurassic ammonoid and Kuruma Group research. The Pliensbachian ammonoid *Amaltheus orientalis* Nakada, Goto, Meister and Matsuoka was described as a new species from the type locality of the Teradani Formation (Nakada et al., 2021). This new Early Jurassic ammonoid was the first to be recorded in Japan in 50 years since Hirano (1971) described a few new species from the Toyora Group in Yamaguchi Prefecture, southwest Japan. This new ammonoid is the first amaltheid species newly recognized in East Asia. The Kuruma Group is an

Fig. 2. Ammonoid specimen (FMM4868) collected near Mt. Kikuishi by Dr. K. Ono. Scale bar is 1 cm.

important geological entity which includes geochronological and paleobiogeographical significance. The geology around the Mt. Kikuishi fossil locality has not been studied in detail yet. We carried out geological research and fossil collection on 20 September and 23–24 October in 2021 with support of the Tsugami Mountain Organization.

A flash report on our research was presented at the 171st Regular Meeting of the Palaeontological Society of Japan (Matsuoka et al., 2022). This article reports findings from our field research around Mt. Kikuishi and points out the significance of the occurrence of molluscan fossils.

Geological outline of the Kuruma Group

The Kuruma Group comprises Lower Jurassic terrestrial and shallow marine sediments exposed widely in eastern Toyama, western Niigata, and northern Nagano prefectures, central Japan (Fig. 1). The distribution of the group is divided into the Inugatake area in the west and the Kotakigawa-Akahageyama-Kuruma area in the East. The most complete succession is observable in the Inugatake area where the group is subdivided into the Jogodani, Kitamatadani, Negoya, Teradani, Shinatani, Otakidani and Mizukamidani formations in ascending order (Kobayashi et al., 1957) (Fig. 3). Later, the Mizukamidani Formation came to be regarded as a part of the Lower Cretaceous Tetori Group (e.g., Takizawa, 1984; Board of Education of Toyama Prefecture, 2003; Sakai et al., 2012; Takeuchi

Geologic age			Lithostratigraphy of the Kuruma Group	
			Inugatake area	Kotakigawa-Akahageyama-Kuruma area
Jurassic	Early	Toarcian	Otakidani Fm. (ammonoids) latest Toarcian	
		Toarcian	Shinatani Formation	
		184.2 Ma		
		Pliensbachian	Teradani Fm. (ammonoids) L. Pliensbachian	
			Negoya Fm. (ammonoids) E. Pliensbachian	Yoshinazawa Formation
			Kitamatadani Fm. (zircons) 186.3±1.3 Ma 187.0±1.6 Ma	Odokorogawa Formation
		192.9 Ma	Jogodani Fm. (zircons) 187.7±1.2 Ma	Gamaharazawa Fm. (zircons) 189.4±0.9 Ma

Ammonoids Zircons

Fig. 3. Lithostratigraphy of the Kuruma Group with major age assignments by ammonoids and zircon U–Pb dating in previous studies. The numerical ages are based on Gradstein et al. (2021). The ammonoid occurrences are from Sato (1956, 1992) and Nakada et al. (2021); the zircon U–Pb age data are from Takeuchi et al. (2017b).

et al., 2017a). In the Kotakigawa-Akahageyama-Kuruma area, the group is subdivided into the Gamaharazawa, Odokorogawa, and Yoshinazawa formations in ascending order (Shiraishi, 1992; Nagamori et al., 2010; Takeuchi et al., 2015) (Fig. 3).

The Kuruma Group consists chiefly of sandstones, mudstones and conglomerates, and is characterized by alternation of marine and non-marine sediments (Kobayashi et al., 1957; Nagamori et al., 2010; Takeuchi et al., 2017a). The group has yielded a variety of fossil taxa including ammonoids (Sato, 1955, 1956, 1992; Nakada et al., 2021), bivalves (Hayami, 1957a, b, c, d, e, 1958a, b, 1962; Goto, 1983; Ibaraki et al., 2017), belemnites (Iba et al., 2015), brachiopods (Hasegawa and Goto, 1990), crinoids (Goto, 1994), turtles (Sonoda et al., 2015), sea reptiles (Tanimoto and Okura, 1989), dinosaur footprints (Hatakeyama, 1995; The Academic Research Group of Dinosaur Fossil Footprints of Otari Village, 2000) and land plants (Yagi, 1918; Oishi, 1931a, b; Kimura and Tsujii, 1980a, b, 1981, 1982, 1983, 1984; Kimura et al., 1988; Terada, 2013; Terada et al., 2017).

Among the above-mentioned fossils, geochronologically important ones are early Pliensbachian ammonoid (*Eodeoceras*) from the Negoya Formation, late Pliensbachian ammonoids (*Amaltheus, Canavaria*) from the Teradani Formation and latest Toarcian ammonoids (*Grammoceras, Hammatoceras*) from the Otakidani Formation (Sato, 1956, 1992). Recently Nakada et al. (2021) clarified the ammonoid succession in three sections in the upper stream area of the Sakaigawa River including the Teradani Valley, the type locality of the Teradani Formation. Zircon U–Pb ages from 186.3 ± 1.3 Ma to 189.4 ± 0.9 Ma, indicating early Pliensbachian in age (Gradstein et al., 2021), were obtained from sandstone, tuffaceous sandstone and vitric tuff in the Jogodani, Kitamatadani and Gamaharazawa formations (Takeuchi et al., 2017b), which are concordant with the age assignments by ammonoids from the Kuruma Group (Fig. 3).

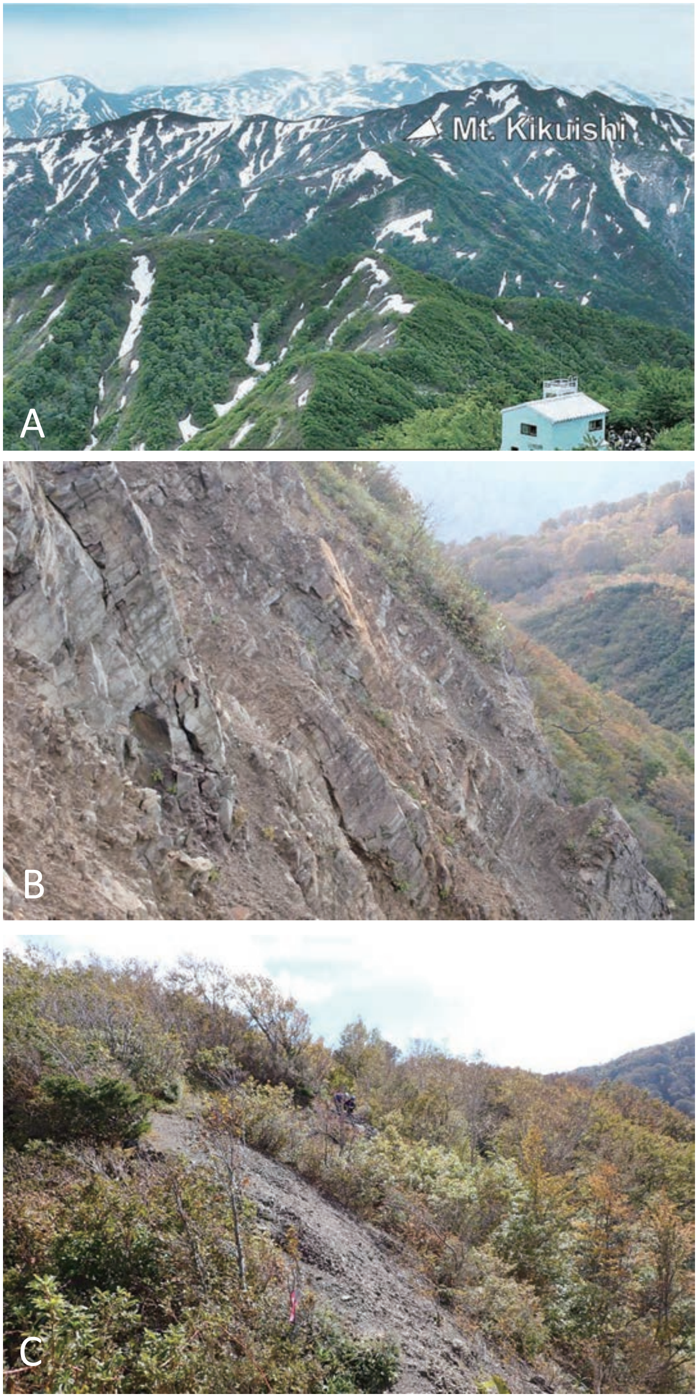

Fig. 4. Landscape and outcrop photographs of the Kuruma Group on the Tsugami Shindō Trail. A: Panoramic view of the Tsugami Shindō Trail from Mt. Shiratori to the south; B: Steep escarpment composed of alternating beds of sandstone and mudstone belonging to the Shinatani Formation of the Kuruma Group, southwest side of Mt. Shimokomagatake; C: Outcrop of the Teradani Formation of the Kuruma Group on the ridgeway of the Tsugami Shindō Trail, north of Mt. Kikuishi.

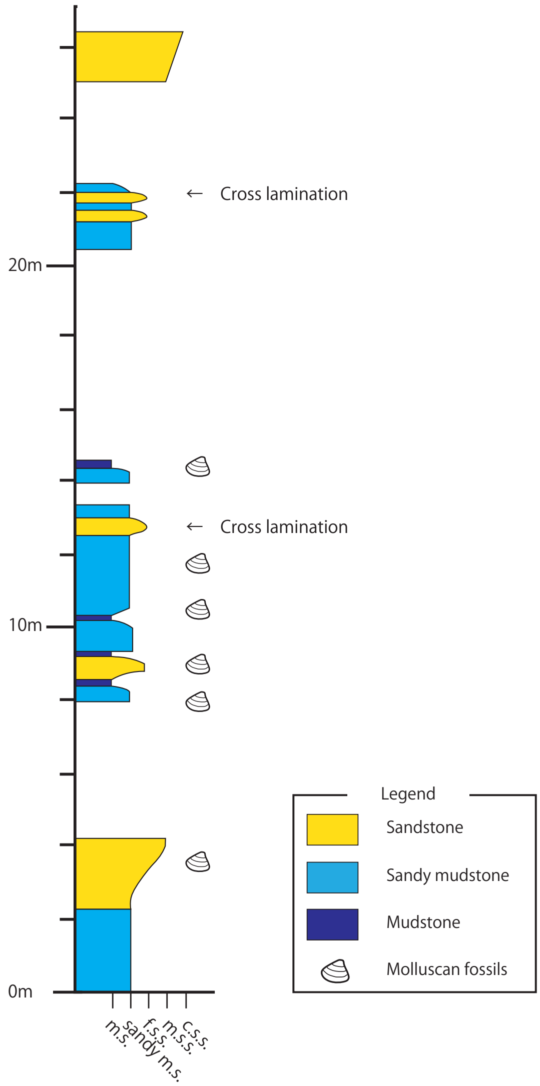

Fig. 5. Columnar section of the Teradani Formation of the Kuruma Group along the ridgeway, including the outcrop shown in Fig. 4-C, north of Mt. Kikuishi.

The Kuruma Group on the Tsugami Shindō Trail and fossil occurrences

The Kuruma Group on the Tsugami Shindō Trail is exposed between Mt. Shiratori and Mt. Inugatake (Fig. 4-A). A steep escarpment (Fig. 4-B) composed of alternating beds of sandstone and mudstone is situated on the southwest side of Mt. Shimokomagatake (1,241 m), located between Mt. Shiratori and Mt. Kikuishi. The alternating beds belong to the Shinatani Formation which conformably overlies the Teradani Formation. The boundary between the Teradani and Shinatani formations is located at a point in the southern slope of

Fig. 6. Molluscan fossils from the Teradani Formation of the Kuruma Group around Mt. Kikuishi on the Tsugami Shindō Trail. A–C: Specimens collected on 20 September in 2021 by S. Tsurumoto (A, B) and S. Ino (C), D–E: Specimens collected on 24 October in 2021 by A. Matsuoka. A: ammonoid, B: bivalve, C: gastropod, D: ammonoids, E: bivalves. Scale bars in A–C are 1 cm.

Mt. Shimokomagatake. Mudstone-dominated beds are sporadically exposed south of the boundary. Better outcrops of the Teradani Formation are exposed on the ridgeway and western slope of the Tsugami Shindō Trail ca. 50 m north of Mt. Kikuishi (Fig. 4-C). A columnar section of the outcrops along the ridgeway is depicted in Fig. 5. Beds in the section are composed mainly of sandy mudstone associated with sandstone and mudstone. Six fossil-bearing horizons are recognized in the stratigraphic section. The majority of fossils found in the outcrops is bivalve.

Fossil findings were performed in the west slope of the ridgeway on 20 September and 24 October in 2021. Careful searching for fossils on floating stones in the slope made a successful finding of many molluscan fossils including bivalves, gastropods and ammonoids (Fig. 6). The most abundant fossils collected are bivalves followed by gastropods. Four specimens of ammonoids have a rather complete shell (Fig. 6-A, D). Some of them are tentatively assigned to *Canavaria* sp., a common genus in the Teradani Formation. The fossil specimens are stored at the Science Museum in the Faculty of Science, Niigata University. They will be registered and hosted at the Fossa Magna Museum after paleontological research.

Concluding remarks

In our 2021 field research we have successfully discovered ammonoid specimens from the Teradani Formation of the Kuruma Group north of Mt. Kikuishi. Some of them can be assigned to *Canavaria* sp. in our preliminary identification. The *Canavaria* assemblage zone is the upper zone among the three successive ammonoid assemblage zones established in the Teradani Formation (Nakada et al., 2021). The exposures that yielded ammonoids obtained in our research can be attributed to the *Canavaria* assemblage zone, corresponding to the latest Pliensbachian. In previous study, some *Amaltheus* ammonoids (*A. stokesi* (Sowerby) and *A. margaritatus* de Montfort) were obtained from Mt. Kikuishi (Sato, 1955; Nakada et al., 2021). Therefore, we expect to discover other zone-diagnostic ammonoid species of the genus *Amaltheus* in future research.

In terms of paleobiogeography, it has been pointed out that the genus *Amaltheus* is a typical Boreal ammonoid while the genus *Canavaria* is a Tethyan one (Sato, 1956, 1992; Kobayashi et al., 1957; Nakada et al., 2021). It is important to elucidate how ammonoid faunas change in a continuous sequence because ammonoids are key taxa to give both geological ages and paleogeographic information. The succession exposed north of Mt. Kikuishi (Fig. 5) has a potential to trace not only ammonoid faunal change but also bivalve and gastropod faunal changes.

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