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Systematic paleontology of two brachiopod specimens (*Karavankina* sp. and *Choristites* sp.) from the Arakigawa Formation in the Hida Gaien belt, central Japan

Keisuke SUZUKI* and Yuta SHIINO**

Abstract

It has been reported that two brachiopod species, namely, productid *Karavankina* sp. and spiriferid *Choristites* sp., occur from felsic tuff beds correlated to the Arakigawa Formation of the Hida Gaien belt, central Japan. Since previous studies have focused primarily on paleobiogeography and only secondarily on description, we reexamined morphological details of these fossils using clear photographic images. For each species, there only exists a ventral valve specimen but morphological features are present to determine the genera. The examined specimen of *Karavankina* sp. is characterized by concentric bands and rugae with numerous regularly arranged spines on the external surface of the ventral valve, while the arrangement of the long spines is altered on the marginal rugae, a trait which appears to be unique to this species. The examined *Choristites* sp. has a pair of dental plates (adminicula) enclosing the adductor and diductor muscle scars on the ventral floor.

Key words: Brachiopoda, Productida, Echinoconchoidea, Spiriferoidea, paleogeography, taxonomy.

Introduction

Biogeographic studies in recent years have established a variety of possibilities in terms of biological adaptation and its relevant geographic, environmental condition (e.g., Dera et al.,

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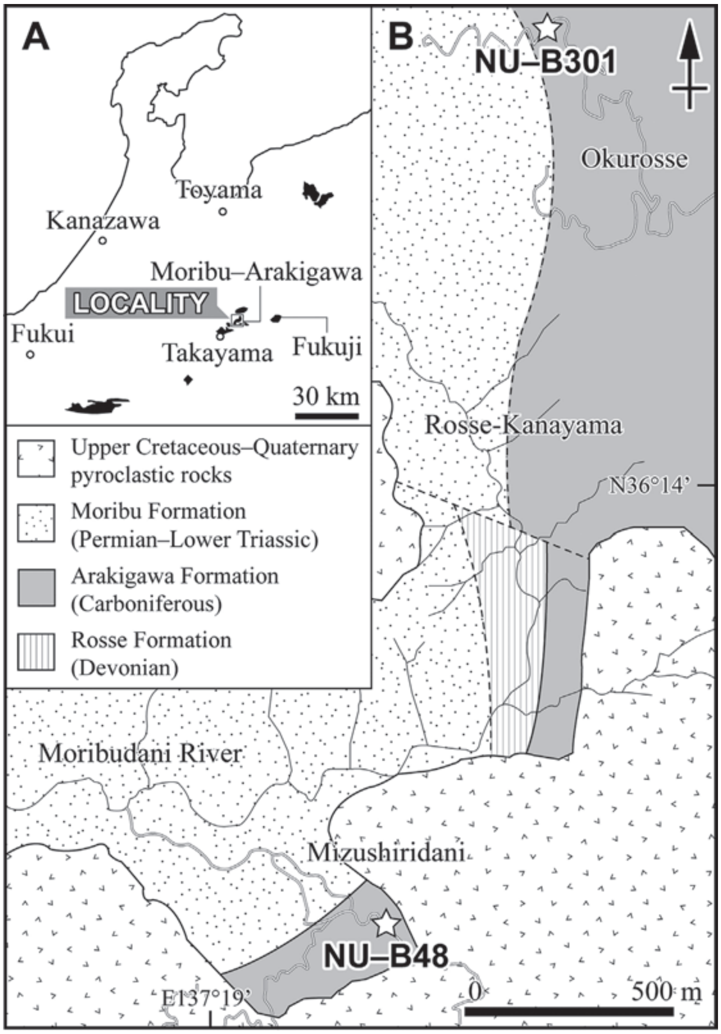

Fig. 1. Geological information of the Hida Gaien belt. A) Map showing the location of the Hida Gaien belt (black areas). B) Simplified geological map of the Moribu–Arakigawa area showing the fossil localities of the described specimens.

2011; Crônier and François, 2014; Wang et al., 2014; Qiao and Shen, 2015). In the case of Paleozoic strata, brachiopod fossils are useful for biogeography because their adaptations depend heavily on the benthic environment (Rudwick, 1970). Hence, the occurrence of brachiopod fossils with certain stratigraphic evidence provides a fundamental framework for paleobiogeography, based on rigorous taxonomic examination.

The Hida Gaien belt, central Japan (Fig. 1A), is one of the enigmatic terranes where Paleozoic strata with shelly fossil taxa are exposed. Of these, the occurrences of Permian brachiopods in the Moribu–Arakigawa area have been historically assigned to the Boreal–Tethyan mixed fauna, the terrane that was geographically close to the continental margin of East Asia including the North China block and the Central Asian Orogenic Belt (CAOB) (Tazawa, 2001, 2018). On the other hand, the Permian fusulinid fauna in the Fukuji area consists of Tethyan elements, suggesting a paleogeographic relationship with the continental margin of the South China block rather than the North China block and the CAOB (Tsukada et al., 1999). Considering the evidence, the Hida Gaien belt is composed of complicated geological records, instead of merely a single terrane, which have developed individually at the continental margins of the North and South China blocks (Wakita et al., 2001; Tsukada, 2003). However, the paleogeography and the relevant geological history of this belt remain problematic, because current attempts to evaluate both hypotheses of the Hida Gaien belt depend solely on the differing fossil taxa, with no integrated discussion of paleogeography.

A clue to reconstruct the geological history of terranes in the Hida Gaien belt arises from comparison of the Carboniferous brachiopods of the Moribu–Arakigawa and Fukuji areas (Tazawa and Hasegawa, 1994; Tazawa et al., 2000; Tazawa, 2010). In the Fukuji area, the spiriferid *Purdonella* occurs from the Carboniferous limestone of the Ichinotani Formation (Tazawa, 2010), which is a cool water element from the Late Carboniferous to Early Permian (e.g., Shi and Waterhouse, 1991). In the Moribu–Arakigawa area, the occurrence of productid *Karavankina* and spiriferid *Choristites* from the Arakigawa Formation has been reported (Tazawa and Hasegawa, 1994; Tazawa et al., 2000). Each species within these two genera has a relatively long stratigraphic range from the Carboniferous to Early Permian, and it has been suggested that they belong to the Boreal and bipolar realms (e.g., Ivanov and Ivanova, 1937; Nelson and Johnson, 1968; Ramovš, 1971). Detailed taxonomic considerations may allow a more definitive conclusion regarding the ongoing paleogeographic problems in the Hida Gaien belt; however, previous studies of *Karavankina* and *Choristites* have reported no morphological information for the specimens (Tazawa and Hasegawa, 1994; Tazawa et al., 2000).

The present study describes two brachiopod species, *Karavankina* sp. and *Choristites* sp., from the Arakigawa Formation of the Hida Gaien belt in the Moribu–Arakigawa area (Fig. 1B), with special reference to the detailed morphology of external and internal features. The specimens of both species have already been reported in previous studies (Tazawa and Hasegawa, 1994; Tazawa et al., 2000) and are housed in the collections of the Department of Geology, Faculty of Science, Niigata University, Japan (NU–B48: *Karavankina* sp.; NU–B301: *Choristites* sp.).

Fossil locality

Two brachiopod specimens, one of *Karavankina* sp. (NU–B48) and one of *Choristites* sp. (NU–B301), were collected from the Arakigawa Formation in the Moribu–Arakigawa area in previous studies (Fig. 1B; Tazawa and Hasegawa, 1994; Tazawa et al., 2000). According to

Tazawa and Hasegawa (1994), *Karavankina* sp. occurs from an outcrop of pale-greenish felsic tuff on the Mizushiridani forest road. Surrounding the outcrop, there are many sandstone boulders, possibly originating from the forest road nearby (Tazawa and Hasegawa, 1994). The boulders contain the fusulinid *Quasifusulina* sp., indicative of the Late Carboniferous to Early Permian (Tazawa and Hasegawa, 1994), though the exact outcrop containing these fossils has not been found. *Choristites* sp. was reported from the matrix portion of pale-greenish tuff breccia on the Okurosse forest road (Tazawa et al., 2000).

Systematic paleontology

Order Productida Sarycheva and Sokolskaya, 1959
Superfamily Echinoconchoidea Stehli, 1954
Family Echinoconchidae Stehli, 1954
Genus *Karavankina* Ramovš, 1966

***Karavankina* sp.**

Figs. 2 and 3

Material: One ventral valve (NU–B48) of external and inner molds. The specimen is 38 mm in length and 44 mm in width.

Description: The ventral valve is transversely subcircular to subquadrate in outline with gently concave profile (Figs. 2, 3). The specimen has a ventral beak and trails but lacks ears of posterior right and left corners. The beak is comparatively narrow, protruding dorsally and anteriorly, up to 2 mm in maximum anterior–to–hinge line (Fig. 3C, D). The exterior ornamentation of the valve is characterized by concentric bands with abundant spines (Fig. 2B–G). Concentric bands around the posterior half of the valve are weak relief with 3.5 mm each in width (Fig. 2D), while those around the anterior half are elevated externally to form sharp, fringe-like reliefs of rugae (Fig. 2F). The width of ruga ranges from approximately 1.5 mm, narrower than the posterior concentric band, down to 1 mm in width. On the concentric bands of the posterior portion, spine bases are vaguely delineated and seem to be conglutinated with the external surface of the valve (Fig. 2E). On the outside of concentric bands where the rugae start to develop, spine bases are distinct with the ends of spines facing anteriorly (Fig. 2G). There are two types of spines on concentric bands and rugae, exhibiting large and small spine bases. The large spines are each approximately 0.5 mm in diameter and arranged singly low on each band, 2 to 3 mm distance from each other (Fig. 2E). On the anterior portion of the valve, the interval between two adjacent large spines decreases down to 0.5 mm at a minimum, with a random arrangement (Fig. 2G). Basements of large spines are positioned at the posteriormost edge of each band or ruga and extend radially along the surface of the ventral valve. The small spines usually occur in up to three

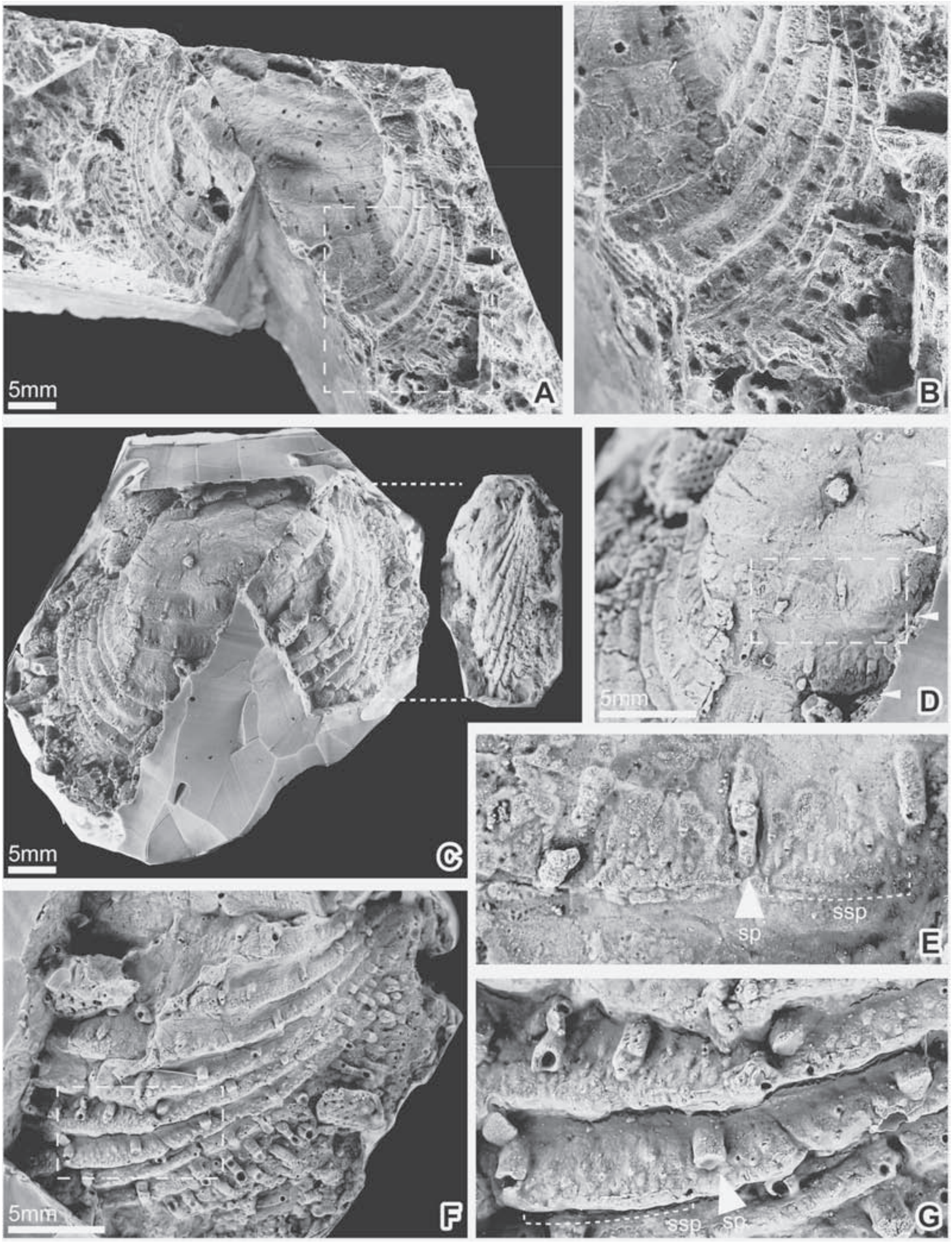

Fig. 2. External morphology of *Karavankina* sp. (NU–B48). A) External mold in ventral view showing outline and ornamentation. B) Concentric bands with abundant spines. Magnified photograph of dashed square in A. C) Silicon rubber cast of external mold in ventral and lateral views. D) Magnified concentric bands around posterior half of C. White arrowheads indicate boundaries of concentric bands. E) Low relief of concentric bands with large and small spine bases. Magnified photograph of dashed square in D. F) Magnified concentric bands (rugae) around shell margin of C. G) Low relief of rugae with large and small spine bases. Magnified photograph of dashed square in F. sp: large spine, ssp: short spine.

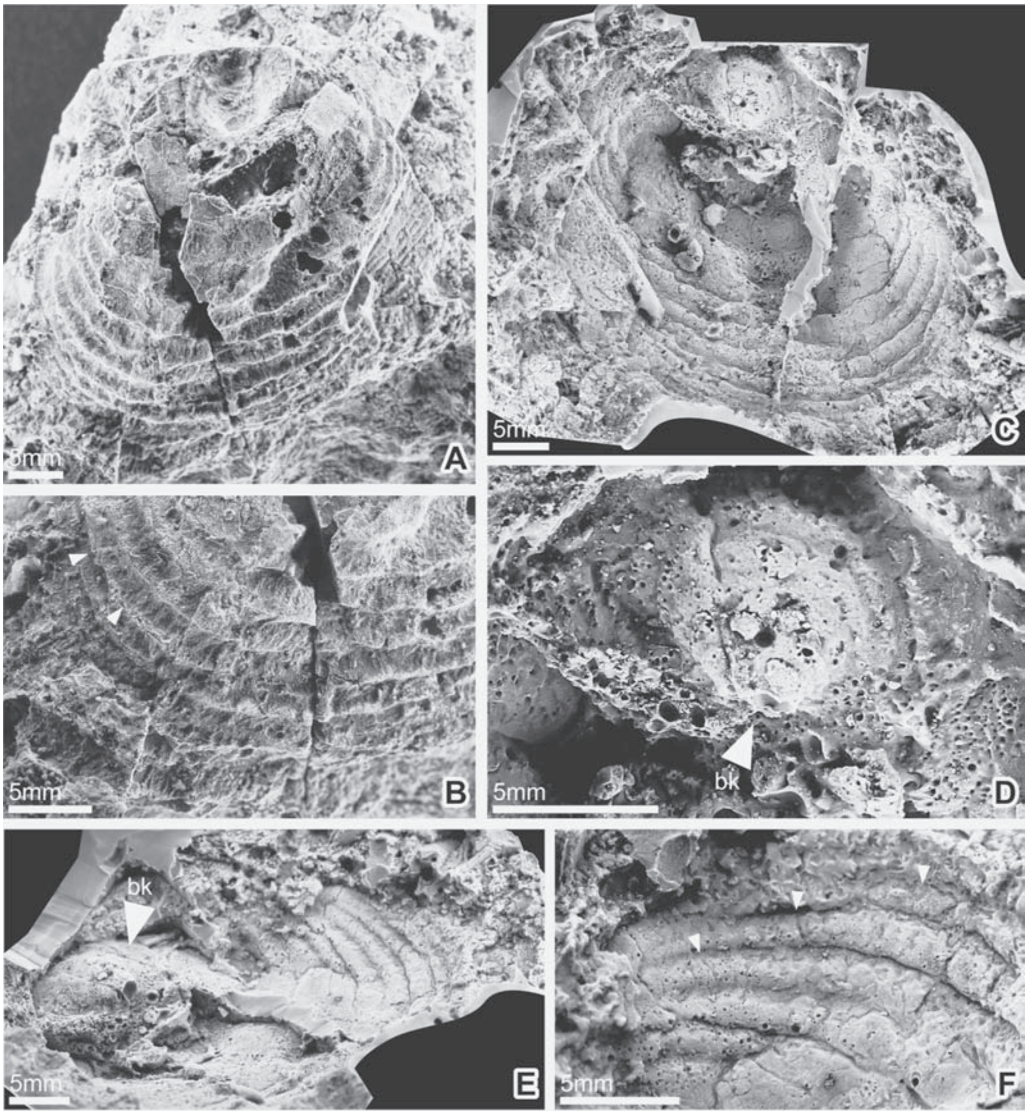

Fig. 3. Internal morphology of *Karavankina* sp. (NU–B48). A) Inner mold in ventral view showing outline. B) Magnified anterior half of A. C) Silicon rubber cast of inner mold in ventral view. D) Magnified beak on posterior part of C. E) Lateral oblique view of C. F) Magnified concentric bands showing saw-tooth relief with unclear furrows around anterior part of C. White arrowheads in B and F indicate furrows extending radially. bk: beak.

rows of quincuncial arrangement between the large spine bases (Fig. 2E, G). Occasionally, the concentric band includes four rows of small spine bases. In the posterior area with the concentric bands, the small spines are 0.4 mm in length and 0.1 to 0.2 mm in width, as if adhering onto the external surface of the ventral valve. The small spines on the anterior rugae exhibit a granular appearance, each spine being 0.2 mm in width (Fig. 2G).

The inner surface of the ventral valve shows a smooth posterior area where the supposed muscle scars are attached, and its outside area exhibits a saw-tooth relief (Fig. 3).

Because of fossil preservation, there are no internal structures associated with the soft parts. On the outside of the smooth area, the internal surface has saw-tooth relief in a lateral view (Fig. 3C, E, F), which corresponds to the counterpart of the external fringe-like rugae. The bands of saw-tooth relief have unclear furrows extending radially (Fig. 3F). Each furrow is 0.2 mm in width.

Remarks: The described species is characterized by having weak concentric bands posteriorly with faint spines and distinct rugae anteriorly with distinct spines. These morphological features are typical in several echinoconchoid genera. In addition to these characteristics, several types of spine bases on each concentric band or ruga are characteristic of Subfamilies Echinoconchinae and Juresaniinae, the latter differing from the presently described species in having concentric bands at only the anterior area. Within the Subfamily Echinoconchinae, the arrangement pattern of long and small spines as observed in the present species best fits with the diagnosis of Genus *Karavankina*, although it is impossible to identify the detail of the species based only on the ventral valve. The external surface of the present species is similar to that of *Karavankina wagneri* Winkler Prins, 1968. The size of the present species is greater than for other *Karavankina* species.

Age and occurrence: Because *Karavankina* has been reported from the Lower Carboniferous (upper Visean) to Middle Permian (Roadian?) (e.g., Ramovš, 1966, 1969; Winkler Prins, 1968; Lazerew, 1990; Tazawa and Hasegawa, 1994; Sone et al., 2003), the correlation of detailed age requires the other fossil evidence. A hint of the detailed age is the occurrence of *Quasifusulina*, as reported from a sandstone boulder nearby the present fossil locality (Tazawa and Hasegawa, 1994), suggesting the Upper Carboniferous (Kasimovian) to Lower Permian (Sakmarian) (Rosovskaya, 1975). Both evidences of *Karavankina* and *Quasifusulina* in the present area still remain problems of species identifications and stratigraphic horizons, so we avoid determining the detailed age.

Order Spiriferida Waagen, 1883
Superfamily Spiriferoidea King, 1846
Family Choristitidae Waterhouse, 1968
Genus Choristites Fischer de Waldheim, 1825

Choristites sp.

Fig. 4

Material: One ventral specimen (NU–B301) of inner mold. The specimen is 29 mm in length and 35 mm in width.

Description: The ventral valve is rounded pentagonal to subovate in outline, although the actual outline is unclear (Fig. 4A, B). The beak is prominent and strongly incurved dorsally (Fig. 4B). The interarea is lost but assumed to be transverse rectangular to trapezoidal in

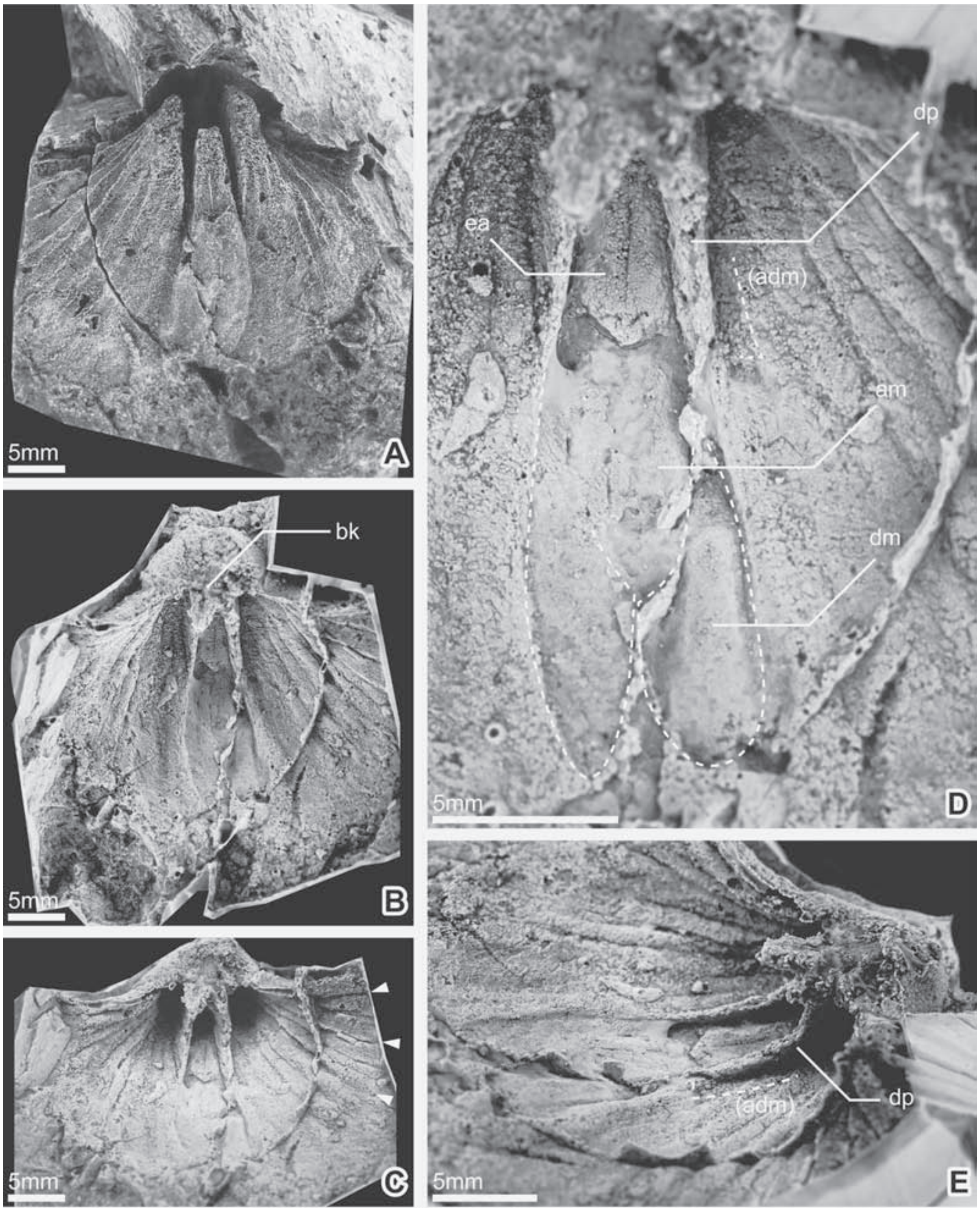

Fig. 4. Internal morphology of *Choristites* sp. (NU–B301). A) Inner mold in ventral view showing outline. B) Silicon rubber cast of inner mold in dorsal view. C) Silicon rubber cast of inner mold in anterodorsal view. White arrowheads indicate furrows extending radially. D) Magnified internal structures in dorsal view around posterior area of B. E) Magnified internal structures in lateral oblique view of B. bk: beak, dp: dental plate (adm: adminicula), am: adductor muscle scar, dm: diductor muscle scar, ea: elevated area.

dorsal view (Fig. 4E). The internal sides of the interarea form a triangular area, which seems to have originally been a triangular delthyrium (Fig. 4E). The interior of the valve shows a pair of dental plates and muscle scars. The posterior side of the dental plates around the teeth and sockets are broken, while the shape of the rubber cast suggests the presence of a pair of dental plates extending from the inner sides of the interarea (Fig. 4B, C). In turn, the dental plates extend toward the ventral floor, and the blade-like dental plates (adminicula) around the floor continue to extend and taper anteriorly (Fig. 4B–E). The adminicula are slightly flared with respect to the ventral floor. The anterior ends of adminicula reach 7 mm anterior to the hinge line. On the ventral floor, two types of muscle scars occur between the adminicula (Fig. 4D). Based on comparative anatomy with extant brachiopods, the posterior scar is an adductor muscle scar, while a pair of anterior scars are diductor muscle scars (Fig. 4D). The adductor scar in the center of the valve is longitudinally elongate and elliptical in shape (Fig. 4D). The pair of diductor scars are positioned anterolaterally to the adductor scars, as a pair of long, tear-shaped smooth impressions (Fig. 4D). Anterior ends of diductor muscle scars are 10 mm distant from ventral adminicula. Both adductor and diductor scars are separated by faint ridges (Fig. 4D). Outside of the adminicula, slit-like furrows extend radially, which may correspond to the counterparts of the external costae (Fig. 4C). The internal surface just posterior to the adductor muscle scars is slightly elevated with respect to the ventral floor (Fig. 4D, E). The anterior margin of the elevated area is triangular, possibly the boundary of muscle scars. The elevated area appears comparatively smooth with a thin and shallow median furrow (Fig. 4D). This furrow never reaches the anterior margin of the elevated area.

Remarks: The described specimen only includes a portion of the internal ventral valve. Species identification requires evidence of both internal and external features of the ventral and dorsal valves. Despite the limited information from the present ventral valve, it is worth noting that the morphology of the dental plates is unique to the Genus *Choristites*. The genus is characterized by having a dorsally incurved ventral beak, as well as long and slender adminicula nearly parallel to each other, both characteristics which agree very well with the present specimen. The internal furrows extending radially at the outside of the adminicula are probably unique to the present *Choristites* sp., although the typical *Choristites* has reticulate or pitted ornamentation instead of the furrows. Similar structures have been reported in other *Choristites* sp. from Austria (Gauri, 1965). Based on the outline and size, Tazawa et al. (2000) pointed out that *Choristites* sp. from the Arakigawa Formation is similar to *C. loczyi* Fredericks, 1926 and *C. teshevi* Ivanov and Ivanova, 1937.

Age and occurrence: Tazawa et al. (2000) suggested that many species of the genus mainly occur from the middle Upper Carboniferous (Moscovian) (Ivanov and Ivanova, 1937; Sarytcheva and Sokolskaja, 1952; Boucot et al., 1965) and regarded the presently discussed specimen as a species of the coeval geologic time. However, *C. loeyensis* has been reported from limestone of the Lower Permian Nam Maholan Formation (Asselian) in Northeast Thailand, which supports the conclusion that *Choristites* has a relatively long stratigraphic range of occurrence from the Carboniferous to Early Permian (Yanagida, 1966; Pérez-Huerta et al., 2007). Apart from the paleontological evidence, Suzuki and Kurihara (2018) reported an Early Permian zircon U–Pb age of ca. 280 Ma (Kungurian) from felsic tuff in Rosse-Kanayama, an outcrop that is stratigraphically close to the present fossil locality. Consequently, the age based on the occurrence of *Choristites* sp. is not necessarily the middle Late Carboniferous. It still remains a possibility that the stratigraphic horizon of the present fossil locality correlates with the Upper Carboniferous to Lower Permian, as well as the case of *Karavankina* mentioned above.

Acknowledgements

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References

Boucot, A. J., Johnson, J. G., Pitrat, C. W. and Staton, R. R., 1965, Spiriferida. *In* Moore, R. C., ed., *Treatise on Invertebrate Paleontology, Part H Brachiopoda*, Geological Society of America, New York and University of Kansas Press, Lawrence, 632–728.

Crônier, C. and François, A., 2014, Distribution patterns of Upper Devonian phacopid trilobites: Paleobiogeographical and paleoenvironmental significance. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **404**, 12–23.

Dera, G., Neige, P., Dommergues, J. L. and Brayard, A., 2011, Ammonite paleobiogeography during the Pliensbachian–Toarcian crisis (Early Jurassic) reflecting paleoclimate, eustasy, and extinctions. *Global and Planet. Change*, **78**, 92–105.

Fischer de Waldheim, G., 1825, *Notice sur la Choristite. Programme d'invitation à la Société Impériale des Naturalistes de Moscou*, 12 p.

Gauri, K. L., 1965, Uralian stratigraphy, trilobites and brachiopods of the western Carnic Alps (Austria). *Jahrb. Geol. Bundesanst.*, **11**, 1–94.

Ivanov, A. P. and Ivanova, E. A., 1937, Fauna brakhiopod srednego i verkhnego karbona Podmoskovnogo basseyna (*Neospirifer*, *Choristites*). *Tr. Paleozool. Inst., Acad. Nauk SSSR*, **6**, 1–213 (in Russian).

King, W., 1846, Remarks on certain genera belonging to the class Palliobranchiata. *Annal. Magaz. Nat. Hist., Ser. 1*, **18**, 26–42.

Lazarev, S. S., 1990, Evolution and system of productids. *Tr. Paleont. Inst.*, **242**, 1–173 (in Russian).

Nelson, S. J. and Johnson, C. E., 1968, Permo–Pennsylvanian brachythyrid and horridonid brachiopods from the Yukon Territory, Canada. *J. Paleontol.*, **42**, 715–746.

Pérez-Huerta, A., Chonglakmani, C. and Chitnarin, A., 2007, Permian brachiopods from new localities in northeast Thailand: Implications for paleobiogeographic analysis. *J. Asian Earth Sci.*, **30**, 504–517.

Qiao, L. and Shen, S. Z., 2015, A global review of the Late Mississippian (Carboniferous) *Gigantoproductus* (Brachiopoda) faunas and their paleogeographical, paleoecological, and paleoclimatic implications. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **420**, 128–137.

Ramovš, A., 1966, Revision des "*Productus elegans*" (Brachiopoda) im ostalpinen Jungpaläozoikum. *Neues Jahrb. Geol. Paläontol. Abh.*, **125**, 118–124.

Ramovš, A., 1969, Karavankininae, nova poddruzina Produktid (Brachiopoda) iz alpskih zgornjekarbonskih in permijskih skladov. *Jeseniski Zbornik Jeklo in Ljudje*, **2**, 251–268.

Ramovš, A., 1971, Connections of the Upper Carboniferous brachiopod faunas from the Carnic Alps and Karavanke Mountains with those of the Cantabrian Mountains (Spain) ROMANO, M.–A new Proetid trílobite from the Lower Westphalían of North–west Spain. *Trabajos de Geología*, **4**, 373–385.

Rosovskaya, S. E., 1975, Composition, phylogeny and system of the Order Fusulinida. *Tr. Paleont. Inst.*, **149**, 1–268 (in Russian).

Rudwick, M. J. S., 1970, *Living and Fossil Brachiopods*. Hutchinson University Library, London, 199 p.

Sarycheva, T. G. and Sokolskaya, A. N., 1952, Opredelitel paleozoyskikh brakhiopod Podmoskovnoy kotloviny. *Tr. Paleont. Inst.*, **38**, 1–307 (in Russian).

Sarycheva, T. G. and Sokolskaya, A. N., 1959, O klassifikatsin lozhnoporistykh brakhiopod [On the classification of pseudopunctate brachiopods]. *Akademiia Nauk SSSR, Doklady (Moscow)*, **125**, 181–184 (in Russian).

Shi, G. R. and Waterhouse, J. B., 1991, Early Permian brachiopods from Perak, west Malaysia. *J. Southeast Asian Earth Sci.*, **6**, 25–39.

Sone, M., Metcalfe, I. and Leman, M. S., 2003, Palaeobiogeographic implications of Middle Permian brachiopods from Johore (Peninsular Malaysia). *Geol. Mag.*, **140**, 523–538.

Stehli, F. G., 1954, Lower Leonardian Brachiopoda of the Sierra Diablo. *Bull. Am. Mus. Nat. Hist.*, **105**, 263–358.

Suzuki, K. and Kurihara, T., 2018, Lithostratigraphy of Lower Permian strata in the Rosse-Kanayama area of the Hida Gaien Belt, central Japan and their depositional age based on zircon U–Pb age. *125th Annu. Meet. Geol. Soc. Japan, Abstr.*, 226 (in Japanese).

Tazawa, J., 2010, A spiriferid brachiopod species, *Purdonella tschernyschewiformis* (Ozaki, 1931), from the Upper Carboniferous of Fukuji, central Japan. *Sci. Rep., Niigata Univ.* (*Geology*), no. 25, 17–27.

Tazawa, J., 2001, Middle Permian brachiopods from the Moribu area, Hida Gaien Belt, central Japan. *Paleontol. Res.*, **5**, 283–310.

Tazawa, J., 2018, Palaeobiogeographical studies on the Palaeozoic brachiopod of Japan, and their tectonic significance: A review. *J. Geol. Soc. Japan*, **124**, 655–673 (in Japanese with English abstract).

Tazawa, J. and Hasegawa, Y., 1994, Late Carboniferous fusulinid and brachiopod from the upper part of the Arakigawa Formation, Hida Gaien Belt, Central Japan. *Earth Sci.* (*Chikyu Kagaku*), **48**, 493–496 (in Japanese).

Tazawa, J., Hasegawa, Y. and Yoshida, K., 2000, *Schwagerina* (Fusulinacea) and *Choristites* (Brachiopoda) from the Carboniferous Arakigawa Formation in the Hidagaien Belt, central Japan. *Earth Sci.* (*Chikyu Kagaku*), **54**, 196–199 (in Japanese).

Tsukada, K., 2003, Jurassic dextral and Cretaceous sinistral movements along the Hida marginal belt. *Gondwana Res.*, **6**, 687–698.

Tsukada, K., Takahashi, Y. and Ozawa, T., 1999, Stratigraphic relationship between the Mizuyagadani and Sorayama Formations, and age of the Sorayama Formation, in the Hida-gaien Tectonic Zone, Kamitakara Village, Gifu Prefecture, central Japan. *J. Geol. Soc. Japan*, **105**, 496–507 (in Japanese with English abstract).

Waagen, W., 1883, Productus-Limestone fossils. *Palaeont. Indica, Ser. 13*, **1**, 391–546.

Wakita, K., Kojima, S. and Tsukada, K., 2001, Middle Mesozoic accretionary complex of the Mino terrane, and Paleozoic to Mesozoic sedimentary rocks of the Hida marginal belt. *In* Kano, T., ed., *ISRGA Field Guidebook for Major Geologic Units of Southwest Japan*. Field Science Publisher, Osaka, 165–236.

Wang, C., Li, N., Zong, P. and Mao, Y., 2014, Coevolution of brachiopod boreal realm and Pangea. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **412**, 160–168.

Waterhouse, J. B., 1968, The classification and descriptions of Permian Spiriferida (Brachiopoda) from New Zealand. *Palaeontographica, Abt. A*, **129**, 1–94.

Winkler Prins, C. F., 1968, Carboniferous Productidina and Chonetidina of the Cantabrian Mountains (NW Spain): Systematics, stratigraphy and palaeontology. *Leidse Geol. Med.*, **43**, 41–126.

Yanagida, J., 1966, Early Permian brachiopods from north–central Thailand. *In* Kobayashi, T. and Toriyama, R., eds., *Geology and Palaeontology of Southeast Asia, Volume 3*, University of Tokyo Press, Tokyo, 46–97.

Early Carboniferous (late Visean) brachiopods from the Onimaru Formation in the Nagaiwa–Onimaru area, South Kitakami Belt, northeastern Japan

Jun-ichi Tazawa* and Muneo Taira**

Abstract

A brachiopod fauna (the Onimaru fauna), consisting of six species in five genera, is described from the Onimaru Formation in the Nagaiwa–Onimaru area, South Kitakami Belt, northeastern Japan. The age of the fauna is identified as the late Visean. Palaeobiogeographically, the Onimaru fauna has a close affinity with the lower Carboniferous faunas of southwestern Japan (Akiyoshi Belt), northern Russia (northern Urals), England, Kazakhstan and northwestern China (Xinjiang and Qinghai). The South Kitakami region was probably the eastern extension of the North China Province, and located near and to the east of the North China Block in the late Visean.

Key words: Brachiopoda, North China block, Onimaru Formation, South Kitakami Belt, Visean.

Introduction

The Onimaru Formation, which occurs in the eastern and central areas of the South Kitakami Belt, northeastern Japan, consists mainly of the upper Visean dark grey to black limestones with abundant corals such as *Kueichouphyllum*, *Siphonodendron*, and *Dibunophyllum*. The stratigraphy of the Onimaru Formation was studied by Minato (1941), Minato et al. (1953, 1979b), Onuki (1969) and Niikawa (1983a, 1983b). Numerous studies have described fossils from the Onimaru Formation, which include foraminifers (Yabe, 1942;

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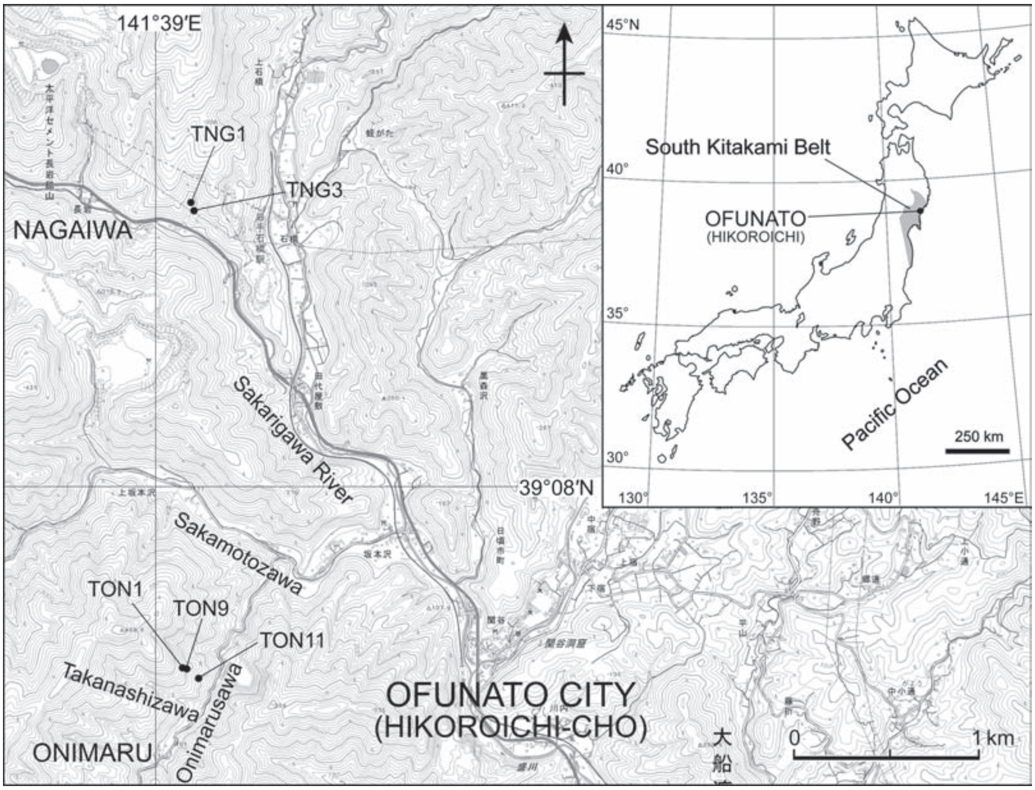


Fig. 1. Map showing the fossil localities TNG1, TNG3, TON1, TON9 and TON11 in the Nagaiwa–Onimaru area, South Kitakami Belt, northeastern Japan (using a digital topographic map of the Geospatial Information Authority of Japan).

Okimura, 1965), corals (Yabe and Hayasaka, 1915; Yabe and Sugiyama, 1939, 1940; Yabe and Minato, 1946; Minato, 1955; Kato, 1959; Minato and Rowett, 1967a, 1967b; Niikawa, 1997), brachiopods (Tazawa and Miyake, 2002), ammonoids (Ehiro and Araki, 1996), trilobites (Araki and Koizumi, 1968; Kobayashi and Hamada, 1978a, 1978b, 1980), and calcareous algae (Endo, 1951, 1952). However, most of brachiopods have not been described, except for one species, *Gigantoproductus* cf. *okensis* Kalashnikov, from the upper part of the Onimaru Formation at Okusakamotozawa in the Nagaiwa–Onimaru area (Tazawa and Miyake, 2002).

In the present study we describe a brachiopod fauna (the Onimaru fauna), comprising six species in five genera from the upper and uppermost parts of the Onimaru Formation of the type locality, the Nagaiwa–Onimaru area (Nagaiwa and Onimaru, Hikoroichi-cho, Ofunato City, Iwate Prefecture), South Kitakami Belt, northeastern Japan (Figs. 1, 2), and discuss the age and the palaeobiogeography of the fauna. The brachiopod specimens described herein are registered and stored in the Ofunato City Museum, Ofunato, Iwate Prefecture, Japan (prefix OCMG, numbers 2044–2050).

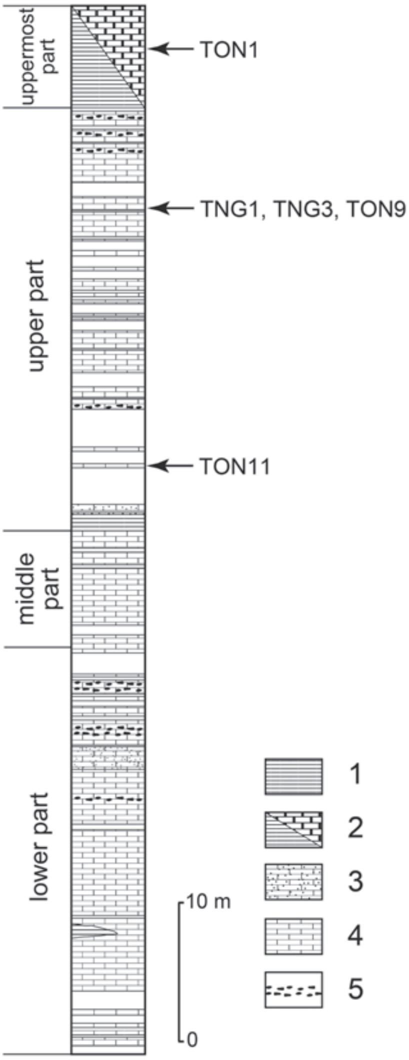


Fig. 2. Generalized columnar section of the Onimaru Formation in the Nagaiwa–Onimaru area, showing the fossil horizons TNG1, TNG3, TON1, TON9 and TON11 (modified and adapted from Niikawa, 1983a). 1, shale; 2, alternating shale and impure limestone; 3, sandy limestone; 4, limestone; 5, chert nodule.

Stratigraphy and material

According to Niikawa (1983a), the Onimaru Formation in the Nagaiwa–Onimaru area has a total thickness of about 73 m, and is divided stratigraphically into four parts; lower (28 m of dark grey limestone with thin layers of shale and sandstone, containing many corals, and characterized by chert nodules in the upper horizon); middle (8 m of dark grey limestone characterized by dense occurrence of the foraminifer *Saccamminopsis*); upper (30 m of dark grey limestone including chert nodules in the lower and upper horizon, and many corals in the upper horizon); and uppermost (7 m of intercalated limestone and shale, with a few coral fossils). The brachiopod fossils were collected by M. Taira from five localities (TNG1, TNG3, TON1, TON9 and TON11) in the Nagaiwa–Onimaru area. The topographic and stratigraphic locations and the fossil contents of the localities are as follows.

TNG1: dark grey limestone (float) at a small tributary between Nagaiwa and Ishibashi (39° 08′ 50″ N, 141° 39′ 08″ E), about the same horizon as TON9, with *Latiproductus edelburgensis*.

TNG3: dark grey limestone (float) at a small tributary between Nagaiwa and Ishibashi (39° 08′ 49″ N, 141° 39′ 09″ E), about the same horizon as TON9, with *Gigantoproductus* sp.

TON1: outcrop of dark grey limestone on the eastern slope of a 459 m hill, 550 m NNE of Onimaru (39° 07′ 28″ N, 141° 39′ 06″ E), 4 m above the base of the uppermost part of the Onimaru Formation, with *Martinia* sp. and *Actinoconchus planosulcatus*.

TON9: outcrop of grey limestone on the eastern slope of a 459 m hill (39° 07′ 28″ N, 141° 39′ 07″ E), 7 m below the top of the upper part of the Onimaru Formation, with *Lamellosathyris qaidamensis*.

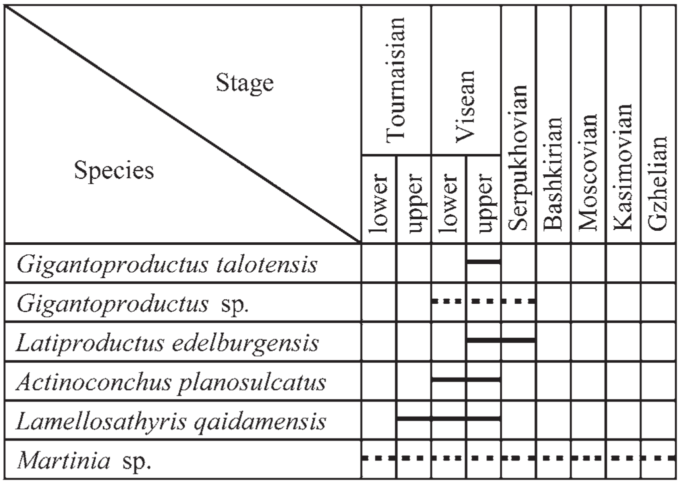
TON11: outcrop of dark grey limestone on the eastern slope of a 459 m hill (39° 07′ 26″ N, 141° 39′ 10″ E), 5 m above the base of the upper part of the Onimaru Formation, with *Gigantoproductus talotensis*.

The Onimaru fauna

The brachiopod fauna described herein includes six species in five genera: *Gigantoproductus talotensis* Kalashnikov, 1974, *Gigantoproductus* sp., *Latiproductus edelburgensis* (Phillips, 1836), *Actinoconchus planosulcatus* (Phillips, 1836), *Lamellosathyris qaidamensis* Chen, Shi and Zhan, 2003 and *Martinia* sp.

Age

The stratigraphic distributions of the brachiopod species are summarized in Fig. 3. Of the brachiopod species listed above, *Gigantoproductus talotensis* is known from the upper Visean (Kalashnikov, 1974; Tazawa and Miyake, 2002), *Latiproductus edelburgensis* from the upper Visean to Serpukhovian (Sarytcheva and Sokolskaya, 1952; Galitskaya, 1977), *Actinoconchus planosulcatus* from the lower and upper Visean (Brunton, 1980; Chen and Archbold, 2000), and *Lamellosathyris qaidamensis* from the upper Tournaisian to upper Visean (Chen et al., 2003). At the generic level, *Gigantoproductus* has a range of the lower Visean–Serpukhovian (Sarytcheva and Sokolskaya, 1952; Brunton et al., 2000; Tazawa, 2018), and *Martinia* is a long-ranging genus known from the lower Tournaisian to Changhsingian (Carter and Gourvennec, 2006). To summarize, the age of the Onimaru fauna is identified as late Visean. This conclusion is consistent with the previous work of Minato (1955), Minato



Species \ Stage	Tournaisian		Visean		Serpukhovian	Bashkirian	Moscovian	Kasimovian	Gzhelian
	lower	upper	lower	upper					
Gigantoproductus talotensis				—					
Gigantoproductus sp.			- - -	- - -	- - -				
Latiproductus edelburgensis				—	—				
Actinoconchus planosulcatus			—	—					
Lamellosathyris qaidamensis		—	—	—					
Martinia sp.	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -

Fig. 3. Stratigraphic distribution of brachiopod species of the Onimaru fauna. Broken line shows range of the genus.

and Kato (1979) and Niikawa (1983b), who considered the age of the Onimaru Formation to be late Visean on the basis of coral fauna.

Palaeobiogeography

The geographic distributions of the brachiopod species of the Onimaru fauna are described in the next chapter, “Systematic descriptions”, and summarized in Fig. 4 and Fig. 5. Of the six species of the fauna, three also occur in northwestern China (Xinjiang), and two in southwestern Japan (Akiyoshi Belt), northern Russia (northern Urals), the UK (England), Kazakhstan and northwestern China (Qinghai). These data suggest that the Onimaru fauna has a close affinity with the lower Carboniferous brachiopod faunas of southwestern Japan (Akiyoshi Belt), the northern Urals, England, Kazakhstan and northwestern China (Xinjiang and Qinghai). This conclusion is consistent with that of Tazawa (2017, 2018), who considered the South Kitakami region to probably be the eastern extension of the North China Province (Yang, 1983), and to have been located near and to the east of the North China Block in the late Visean as can be seen in Tazawa (2018, fig. 15).

Systematic descriptions

Order Productida Sarytcheva and Sokolskaya, 1959
Suborder Productidina Waagen, 1883
Superfamily Linoproductoidea Stehli, 1954
Family Linoproductidae Stehli, 1954

Region / Species	Japan		USA				N. Russia	UK			W. Russia		Iran				NW China			NE China	CS China	
	1. South Kitakami Belt	2. Akiyoshi Belt	3. Ohio	4. Indiana	5. Missouri	6. Oklahoma	7. Northern Urals	8. England	9. Poland	10. Algeria	11. Moscow Basin	12. Donetz Basin	13. Elburz Mountains	14. Kazakhstan	15. Uzbekistan	16. Kyrgyzstan	17. Xinjiang	18. Qinghai	19. Gansu	20. Jilin	21. Hubei	22. Hunan
Gigantoproductus talotensis	+						+															
Gigantoproductus sp.	+																					
Latiproductus edelburgensis	+	+					+	+	+	+	+	+		+		+	+	+	+	+	+	+
Actinoconchus planosulcatus	+	+						+							+		+					
Lamellosathyris qaidamensis	+		+	+	+	+							+	+			+	+				
Martinia sp.	+																					

Fig. 4. Geographic distribution of brachiopod species of the Onimaru fauna.

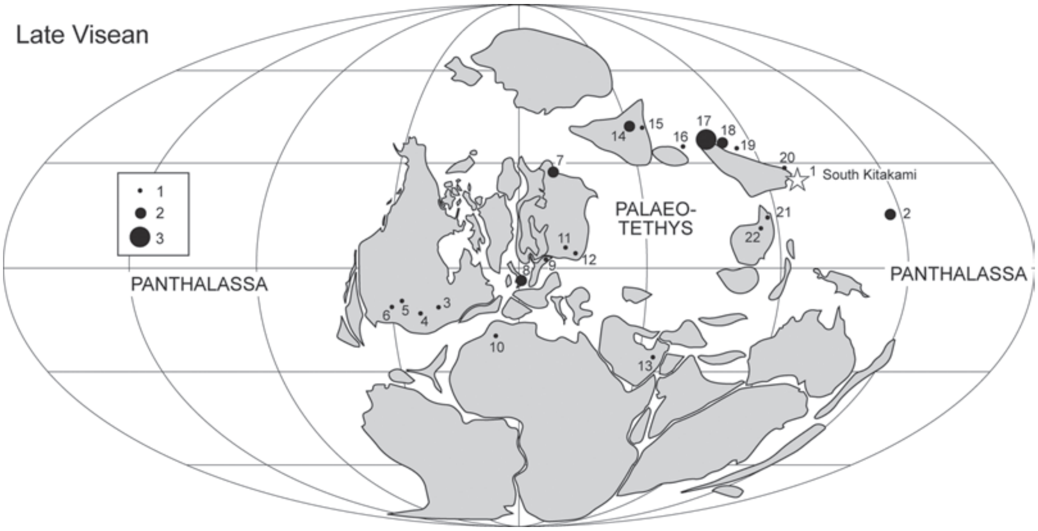


Fig. 5. Late Visean reconstruction map of the world (adapted Qiao and Shen, 2014), showing the geographic distribution of brachiopod species of the Onimaru fauna excluding two uncertain species (*Gigantoproductus* sp. and *Martinia* sp.) Solid circles indicate numbers of brachiopod species listed in the Onimaru fauna. Station numbers are same as in Fig. 4.

Subfamily Gigantoproductinae Muir-Wood and Cooper, 1960

Genus *Gigantoproductus* Prentice, 1950

Type species.—*Productus giganteus* Sowerby, 1822.

Gigantoproductus talotensis Kalashnikov, 1974

Fig. 6A

Gigantoproductus gigantoides talotensis Kalashnikov, 1974, p. 89, pl. 33, figs. 1, 2.

Gigantoproductus cf. *okensis* (Sarytcheva). Tazawa and Miyake, 2002, p. 3, figs. 2, 3.

Material.—One specimen from locality TON11, a ventral valve, OCMG2045.

Description.—Shell medium in size for genus, subquadrate in outline, with greatest width at hinge; length about 80 mm, width about 80 mm. Ventral valve moderately convex in both lateral and anterior profiles, most convex at umbonal region; ears large and triangular in shape, but not clearly demarcated from venter; sulcus absent, trail long. External surface of ventral valve ornamented with numerous, slightly flexuous costae, numbering 11–12 in 10 mm at about midlength. Rugae absent; fluting (by Pattison, 1981, p. 2) obscure, very shallow and irregular; spine bases not preserved.

Remarks.—The single specimen from Onimaru is lacking nearly half of the lateral side of the ventral valve, but not deformed. This specimen can be referred to *Gigantoproductus talotensis* Kalashnikov, 1974, from the upper Visean of the Pechorian Urals (northern Urals), northern Russia, in size, shape and external ornament of the ventral valve, particularly, in having prominent ears. *Gigantoproductus* cf. *okensis* (Sarytcheva, 1928), described by Tazawa and Miyake (2002, p. 3, figs. 2, 3) from the Onimaru Formation of Okusakamotozawa in the Hikoroichi area, South Kitakami Belt, is conspecific with the present species. *Gigantoproductus* cf. *crassiventer* (Prentice, 1949), described by Tazawa and Ibaraki (2009, p. 13, figs. 6.1, 6.2) from the upper part of the lower Hikoroichi Formation (HK2 Unit of Tazawa, 2018; lower Visean) of the Hikoroichi area, South Kitakami Belt, differs from *G. talotensis* in the smaller size and in having stronger fluting on anterior half of the ventral valve.

Distribution.—Upper Visean: northeastern Japan (South Kitakami Belt) and northern Russia (northern Urals).

Gigantoproductus sp.

Fig. 6B

Material.—One specimen from locality TNG3, a ventral valve, OCMG2046.

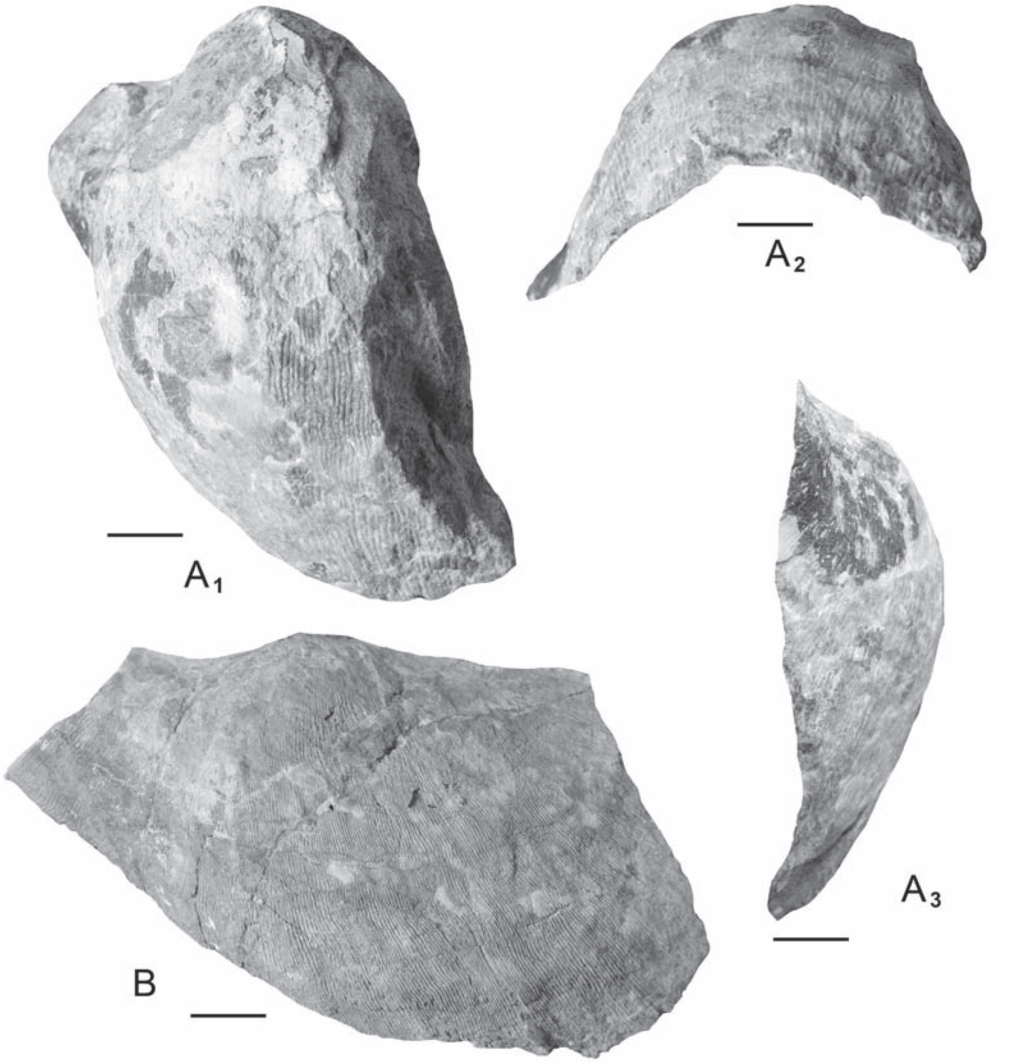


Fig. 6. Brachiopods of the Onimaru fauna (1). **A,** *Gigantoproductus talotensis* Kalashnikov, ventral (A_1), anterior (A_2) and lateral (A_3) views of ventral valve, OCMG2045; **B**, *Gigantoproductus* sp., ventral view of ventral valve, OCMG, 2046. Scale bars are 1 cm.

Remarks.—The single ventral valve specimen from the Nagaiwa–Onimaru area is safely assigned to the genus *Gigantoproductus* by the large, transverse (length about 65 mm, width about 100 mm) and moderately convex ventral valve, and the external ornament consisting of numerous fine costellae (numbering 24–25 in 10 mm at about midlength) and very shallow, irregular fluting on anterior half of the valve. In general shape and external ornamentation of the ventral valve, the Kitakami species resembles *Gigantoproductus maximus* (non M'Coy, 1844), described by Nalivkin and Fotieva (1973, p. 49, pl. 12, figs. 1, 2) from the upper Visean of the western Urals, central Russia. The present species is probably a new species, but the material available is not sufficient for the establishment.

Genus *Latiproductus* Sarytcheva and Legrand-Blain, 1977

Type species.—*Productus latissimus* Sowerby, 1822.

Latiproductus edelburgensis (Phillips, 1836)

Fig. 7

Producta edelburgensis Phillips, 1836, p. 214, pl. 7, fig. 5.

Productus edelburgensis Phillips. Garwood, 1916, pl. 17, fig. 6.

Productus giganteus var. *edelburgensis* Phillips. Davidson, 1861, p. 143, pl. 40, fig. 2; Gröber, 1908, p. 230, pl. 27, figs. 1, 2; Hayasaka, 1924, p. 28, pl. 5, figs. 3–6.

Productus giganteus mut. *edelburgensis* Phillips. Gröber, 1909, p. 372, pl. 1, fig. 11; pl. 2, figs. 3, 4.

Productus (*Gigantoproductus*) *edelburgensis* Phillips. Gladchenko, 1955, p. 19, pl. 10, fig. 1.

Gigantoproductus edelburgensis (Phillips). Sarytcheva in Sarytcheva and Sokolskaya, 1952, p. 131, pl. 35, fig. 180; Prentice, 1956, p. 234, pl. 20, figs. 1, 2; pl. 22, figs. 1, 2; Ding in Yang et al., 1962, p. 71, pl. 27, fig. 4; pl. 28, fig. 1; Litvinovich, 1962, p. 206, pl. 6, figs. 1, 2; pl. 7, fig. 1; Litvinovich in Litvinovich et al., 1969, p. 179, pl. 19, fig. 2; pl. 21, fig. 1. Kalashnikov, 1974, p. 94, pl. 41, fig. 1; Galitskaya, 1977, p. 147, pl. 61, fig. 2; pl. 62, fig. 1; pl. 63, figs. 1, 2; Yang et al., 1977, p. 368, pl. 147, fig. 1; Lee et al., 1980, p. 386, pl. 149, fig. 4; Aisenverg and Poletaev, 1983, pl. 45, fig. 2; Wang, 1984, p. 197, pl. 79, fig. 1; Yang, 1984, p. 225, pl. 36, fig. 1; Yang and Gao, 1996, p. 217, pl. 32, figs. 1, 2; Tan, 1987, p. 122, pl. 17, fig. 7; Gu, 1992, p. 239, pl. 65, fig. 3; Chen and Shi, 2003, p. 155, pl. 7, fig. 16.

Productus-Gigantoproductus-edelburgensis Phillips. Pareyn, 1961, p. 202, pl. 24, figs. 4, 5.

Gigantoproductus cf. *edelburgensis* (Phillips). Legrand-Blain, 1973, p. 103, pl. 2, figs. 1–3, text-fig. 3a.

Gigantoproductus aff. *submaximus* (Bolkhovitinova). Yanagida, 1979, p. 111, fig. 2.

Gigantoproductus aff. *edelburgensis* (Phillips). Yanagida, 1979, p. 112, fig. 3.

Latiproductus? *edelburgensis* (Phillips). Zakowa, 1986, p. 65, pl. 6, fig. 1.

Latiproductus edelburgensis (Phillips). Ibaraki et al., 2014, p. 71, figs. 3.1–3.4.

Material.—One specimen from locality TNG1, a ventral valve, OCMG2044.

Remarks.—This specimen is represented by an abraded ventral valve, but can be referred to *Latiproductus edelburgensis* (Phillips, 1836), redescribed by Sarytcheva in Sarytcheva and Sokolskaya (1952, p. 131, pl. 35, fig. 180) from the Serpukhovian of the

Fig. 7. Brachiopods of the Onimaru fauna (2). *Latiproductus edelburgensis* (Phillips), ventral view of ventral valve, OCMG2044. Scale bar is 1 cm.

Moscow Basin, western Russia, by the large, transverse and moderately convex ventral valve (length more than 67 mm, width about 165 mm), without sulcus, and ornamented by numerous costae numbering 9–10 in 10 mm at about midlength of the valve. The type species, *Latiproductus latissimus* (Sowerby, 1822), redescribed by Sarytcheva and Legrand-Blain (1977, p. 76, pl. 7, figs. 5–7; pl. 8, figs. 1–5) from the Serpukhovian of the Moscow Basin, differs from *L. edelburgensis* in the smaller, more transverse ventral valve, ornamented with finer costae. The shell described by Wu et al. (1974, pl. 4, fig. 11) as *Gigantoproductus edelburgensis* (Phillips) from the Serpukhovian of western Guizhou, southwestern China, is deemed to be *Latiproductus latissimus* (Sowerby).

Distribution.—Upper Visean–Serpukhovian: northeastern Japan (South Kitakami Belt), southwestern Japan (Akiyoshi Belt), northern Russia (northern Urals), UK (England), Poland, Algeria, western Russia (Moscow Basin and Donetz Basin), Kazakhstan, Kyrgyzstan, northwestern China (Xinjiang, Qinghai and Gansu), northeastern China (Jilin) and central-southern China (Hubei and Hunan).

Order Athyridida Boucot, Johnson and Staton, 1964
Suborder Athyrididina Boucot, Johnson and Staton, 1964
Superfamiy Athyridoidea Davidson, 1881
Family Athyrididae Davidson, 1881
Subfamily Athyridinae Davidson, 1881
Genus *Actinoconchus* M'Coy, 1844

Type species.—*Actinoconchus paradoxus* M'Coy, 1844.

Actinoconchus planosulcatus (Phillips, 1836)
Fig. 8A

Spirifer planosulcata Phillips, 1836, p. 220, pl. 10, fig. 15.
Athyris planosulcata (Phillips). Davidson, 1859, p. 80, pl. 16, fig. 2 only.
Athyris (*Actinoconchus*) *planosulcata* (Phillips). Yanishevsky, 1918, p. 108, pl. 4, fig. 12.
Actinoconchus planosulcata (Phillips). Yanagida, 1962, p. 110, pl. 18, figs. 1–5, text-fig. 16.
Actinoconchus planosulcatus (Phillips). Brunton, 1980, p. 224, figs. 13, 14; Chen and Archbold, 2000, p. 191, figs. 5.5, 31, 32.

Material.—A conjoined shell from locality TON1, with external mould of the ventral valve, OCMG2047.

Remarks.—This specimen is referred to *Actinoconchus planosulcatus* (Phillips, 1836), redescribed by Brunton (1980, p. 224, figs. 13, 14) from the upper Visean of Yorkshire, England, in the small, transversely pentagonal shell (length 23 mm, width 30 mm), with shallow median sulci on both ventral and dorsal valves. *Actinoconchus expansus* (Phillips, 1836), redescribed by Brunton (1980, p. 222, fig. 10) from the lower Visean of Yorkshire, England, differs from *A. planosulcatus* in lacking median sulci (sulcus) on the ventral valve. The shell, described by Minato (1952, p. 174, pl. 8, fig. 4; pl. 10, fig. 4) as *Actinoconchus planosulcata* (Phillips) from the Hikoroiti Series (= Choanji Formation, Tazawa and Niikawa, 2018) of Tyoanji (Choanji), South Kitakami Belt, is readily distinguished from the present species by the much larger dimensions.

Distribution.—Lower–upper Visean: northeastern Japan (South Kitakami Belt), southwestern Japan (Akiyoshi Belt), UK (England), Uzbekistan (Fergana) and northwestern China (Xinjiang)

Genus *Lamellosathyris* Jin and Fang, 1983

Type species.—*Spirifer lamellosus* Léveillé, 1835.

Lamellosathyris qaidamensis Chen, Shi and Zhan, 2003
Fig. 8D

Athyris lamellosa (Léveillé). Hall and Clarke, 1895, p. 46, figs. 16–20; Weller, 1914, p. 465, pl. 78, figs. 1–5, 15–20; Zhang et al., 1983, p. 375, pl. 124, figs. 1, 2.
Actinoconchus cf. *lamellosa* (Léveillé). Minato, 1951, p. 380, pl. 1, fig. 6.

Actinoconchus lamellosa (Léveillé). Minato, 1952, p. 173, pl. 11, fig. 6.

Cleiothyridina lamellosa (Léveillé). Yang, 1964, p. 144, pl. 22, figs. 1, 2.

Athyris lamellosus (Léveillé). Litvinovich in Litvinovich et al., 1969, p. 281, pl. 69, fig. 6.

Athyris? *lamellosa* (Léveillé). Gaetani, 1968, p. 708, pl. 51, figs. 1–3, text-fig. 9.

Actinoconchus lamellosus (Léveillé). Minato et al., 1979a, pl. 19, fig. 1.

Lamellosathyris lamellosa (Léveillé). Tazawa, 1989, p. 61, pl. 1, fig. 3; Carter, 1999, p. 121, figs. 13, 14; Bahrammanesh et al., 2011, p. 158, figs. 7aa—gg, 11a—c.

Lamellosathyris qaidamensis Chen, Shi and Zhan, 2003, p. 849, figs. 4, 5.1–5.6, 5.8, 5.9, 5.11, 5.12, 5.16, 5.17, 6; Tazawa, 2018, p. 60, figs. 26M, N, 27A.

Material.—One specimen from locality TON9, a conjoined shell, OCMG2050.

Description.—Shell large in size for genus, transversely subelliptical in outline; cardinal extremities rounded; hinge much shorter than greatest width at midlength; length 43 mm, width 45 mm. Ventral valve moderately convex in lateral profile; sulcus narrow and shallow on anterior portion of valve, with rounded bottom. Dorsal valve more convex than ventral valve, with greatest convexity at posterior to midlength; fold low and narrow on anterior portion of valve. External surface of both valves ornamented with regular, strong concentric lamellae, numbering 2–3 in 10 mm length on dorsal valve; very fine concentric growth lines over valve.

Remarks.—This specimen is represented by an abraded, imperfect conjoined shell, lacking posterior portion of the ventral valve. But it can be referred to *Lamellosathyris qaidamensis* Chen, Shi and Zhan, 2003, from the upper Tournaisian–lower Visean of the Qaidam Basin, Qinghai, northwestern China, on account of the large size, dorsibiconvex profile and strong broad concentric lamellae on the both ventral and dorsal valves. The type species, *Lamellosathyris lamellosa* (Léveillé, 1835), redescribed by Brunton (1980, p. 225, figs. 15–17) from the upper Tournaisian of Tournai, Belgium, differs from *L. qaidamensis* in the smaller size and in having more numerous and narrower concentric lamellae on the both valves. Shells of *Lamellosathyris* species from the lower Carboniferous of the South Kitakami Belt, *Actinoconchus* cf. *lamellosa* (Léveillé, 1835), described by Minato (1951, p. 380, pl. 1, fig. 6) from the Jumonji Stage (= middle part of the Arisu Formation, Tazawa and Iryu, 2019) of the Shimoarisu area and *Actinoconchus lamellosa* (Léveillé, 1835) described by Minato (1952, p. 173, pl. 11, fig. 6) from the Jumonji Stage of the Shimoarisu and Yokota areas, are conspecific with *L. qaidamensis*.

Distribution.—Upper Tournaisian–upper Visean: northeastern Japan (South Kitakami Belt), USA (Ohio, Indiana, Missouri and Oklahoma), Iran (Elburz Mountains), Kazakhstan and northwestern China (Xinjiang and Qinghai).

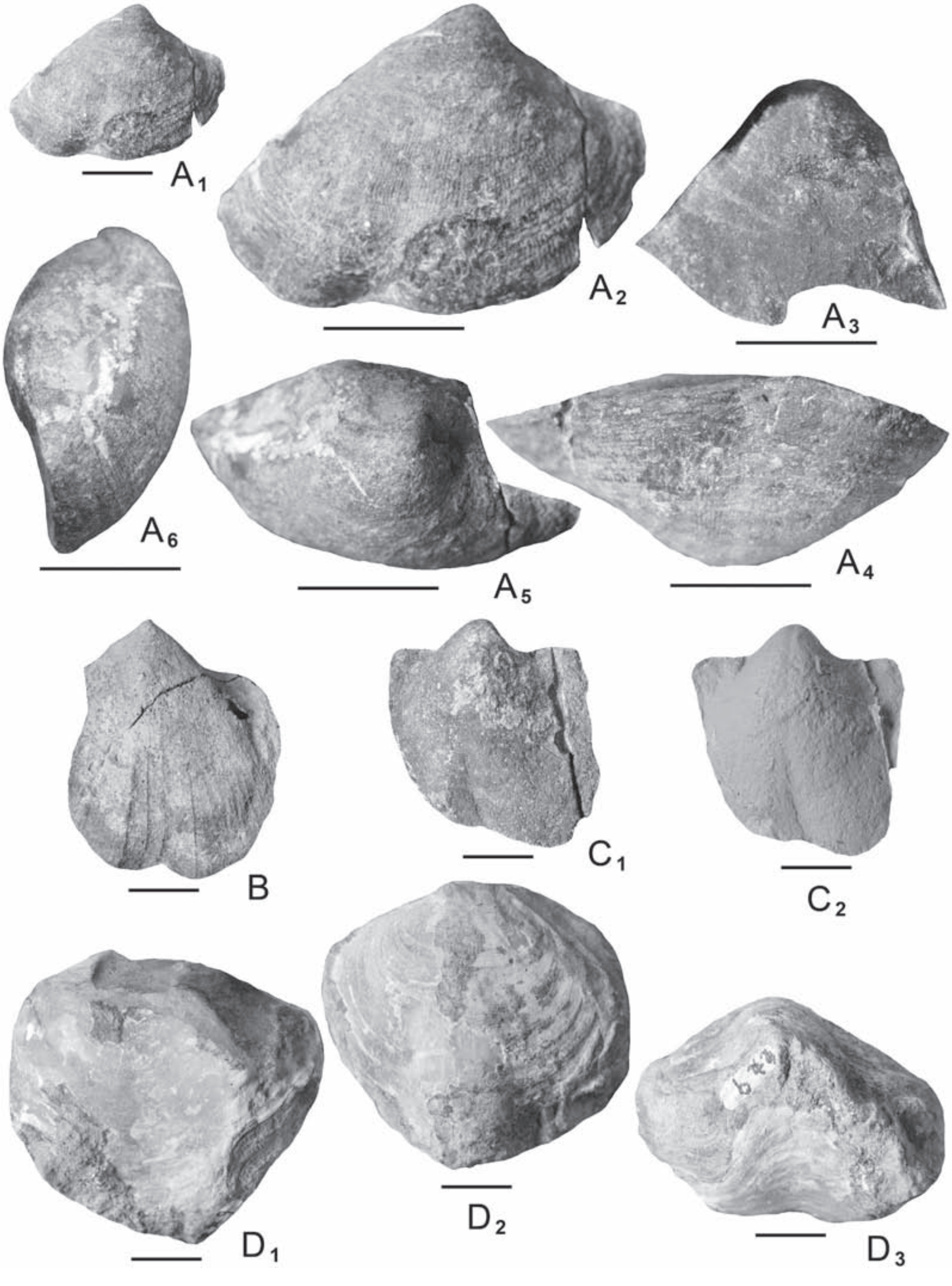


Fig. 8. Brachiopods of the Onimaru fauna (3). **A,** *Actinoconchus planosulcatus* (Phillips), ventral (A_1, A_2), dorsal (A_3), anterior (A_4), posterior (A_5) and lateral (A_6) views of conjoined shell, OCMG2047; **B, C,** *Martinia* sp.; B, internal mould of ventral valve, OCMG2049; C, internal mould (C_1) and external latex cast (C_2) of ventral valve, OCMG2048; **D,** *Lamellosathyris qaidamensis* Chen, Shi and Zhan, ventral (D_1), dorsal (D_2) and anterior (D_3) views of conjoined shell, OCMG2050. Scale bars are 1 cm.

Order Spiriferida Waagen, 1883
Suborder Spiriferidina Waagen, 1883
Superfamily Martinioidea Waagen, 1883
Family Martiniidae Waagen, 1883
Subfamily Martiniinae Waagen, 1883
Genus *Martinia* M'Coy, 1844

Type species.—*Spirifer glaber* Sowerby, 1820.

Martinia sp.
Fig. 8B, C

Material.—Two specimens from locality TON1: (1) external and internal moulds of a ventral valve, OCMG2048; and (2) internal mould of a ventral valve, OCMG2049.

Description.—Shell medium in size for genus, slightly longer pentagonal in outline; cardinal extremities rounded; hinge slightly shorter than greatest width at about midlength; length 39 mm, width about 35 mm in the larger specimen (OCMG2049); length 35 mm, width 32 mm in the smaller specimen (OCMG2048). Ventral valve moderately convex in lateral profile, most convex in umbonal region; ears large; sulcus narrow and shallow on anterior half of valve. External surface of ventral valve almost smooth, with some irregular concentric growth lines. Interior of ventral valve not well preserved except for radial vascular markings.

Remarks.—These specimens can be assigned to the genus *Martinia* by the almost smooth ventral valve and lacking internal structure of the ventral valve except for radial vascular markings. *Martinia pentagonalis* Jin and Hu (1978, p. 121, pl. 4, figs. 25, 26, 29–32), from the Kuhfeng Formation of Anhui, eastern China, somewhat resembles the Onimaru species in pentagonal outline of the ventral valve, but differs in its smaller size. *Martinia karawanica* Volgin (1959, p. 121, pl. 6, figs. 8–10) from the upper Carboniferous of Fergana, Uzbekistan, differs from the Onimaru species in the transverse outline. The type species, *Martinia glabra* (Sowerby, 1820), redescribed by Muir-Wood (1951, p. 111, pl. 3, fig. 2), from the upper Visean of Derbyshire, England, is readily distinguished from the present species in the much larger, transverse shell with smaller ears. The Onimaru species may be a new species, but the material is too poor for the establishment.

Conclusions

In this study, brachiopods of six species in five genera are described from the upper and uppermost parts of the Onimaru Formation in the Nagaiwa–Onimaru area, South Kitakami

Belt, northeastern Japan. The species are as follows: *Gigantoproductus talotensis* Kalashnikov, *Gigantoproductus* sp., *Latiproductus edelburgensis* (Phillips), *Actinoconcus planosulcatus* (Phillips), *Lamellosathyris qaidamensis* Chen, Shi and Zhan and *Martinia* sp. In conclusion, a late Visean age is assigned to the Onimaru fauna. In terms of palaeobiogeography, the Onimaru fauna possesses a close affinity with the lower Carboniferous brachiopod faunas of southwestern Japan (Akiyoshi Belt), the northern Urals, England, Kazakhstan and northwestern China (Xinjiang and Qinghai). The South Kitakami region was probably the eastern extension of the North China Province, and located near and to the east of the North China Block in the late Visean.

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References

Aisenverg, D. E. and Poletaev, V. I., 1983, Brachiopoda. *In* Aisenverg, D. E., Astakhova, T. V., Berchenko, O. I., eds., *Upper Serpukhovian Substage in the Donetz Basin*. Naukova Dumka Publ., Kiev, 73–95 (in Russian).

Araki, H. and Koizumi, H., 1968, Permo-Carboniferous trilobites from the Kitakami Mountainland. *Chigakukenkyu*, **19**, 151–158 (in Japanese).

Bahrammanesh, M., Angiolini, L., Antonelli, A. A., Aghababalou, B. and Gaetani, M., 2011, Tournaisian (Mississippian) brachiopods from the Mobarak Formation, North Iran. *GeoArabia*, **16**, 129–192.

Boucot, A. J., Johnson, J. G. and Staton, R. D., 1964, On some atrypoid, retzioid, and athyridoid Brachiopoda. *Jour. Paleont.*, **38**, 805–822.

Brunton, C. H. C., 1980, Type species of some Upper Palaeozoic athyridide brachiopods. *Bull. Brit. Mus. Nat. Hist.* (*Geol.*), **34**, 219–234.

Brunton, C. H. C., Lazarev, S. S., Grant, R. E. and Jin, Y.-G., 2000, Productidina. *In* Kaesler, R. L., ed., *Treatise on Invertebrate Paleontology, Part H Brachiopoda Revised, Volume 3: Linguliformea, Craniiformea, and Rhynchonelliformea* (*Part*), Geol. Soc. Amer., Boulder and Univ. Kansus, Lawrence, 424–609.

Carter, J. L., 1999, Tournaisian (early Osagean) brachiopods from a bioherm in the St. Joe Formation near Kenwood, Oklahoma. *Ann. Carnegie Mus.*, **68**, 91–149.

Carter, J. L. and Gourvennec, R., 2006, Martinioidea. *In* Kaesler, R. L., ed., *Treatise on Invertebrate Paleontology, Part H Brachiopoda Revised, Volume 5: Rhynchonelliformea* (*Part*), Geol. Soc. Amer., Boulder and Univ. Kansus, Lawrence, 1747–1768.

Chen, Z.-Q. and Archbold, N. W., 2000, Tournaisian–Visean brachiopods from the Gancaohu area of southern Tienshan Mountains, Xinjiang, NW China. *Geobios*, **33**, 183–199.

Chen, Z.-Q. and Shi, G. R., 2003, Early Carboniferous brachiopod faunas and their biogeographical affinities from the western Kunlun Mountains, north-west China. *Palaeontographica, Abt. A*, **268**, 103–187.

Chen, Z.-Q., Shi, G. R. and Zhan, L.-P., 2003, Early Carboniferous athyridid brachiopods from the Qaidam basin, Northwest China. *Jour. Paleont.*, **77**, 844–862.

Davidson, T., 1858–1863, *British Fossil Brachiopoda, Vol. 2. Permian and Carboniferous Species*. Palaeontograph. Soc., London, 280 p.

Davidson, T., 1881, On genera and species of spiral-bearing Brachiopoda, from specimens developed by the Rev. Norman Glass: with notes on the results obtained by Mr. George Maw from extensive washing of the Wenlock and Ludlow shales of Shropshire. *Geol. Mag., N. S.*, **8**, 1–13.

Ehiro, M. and Araki, H., 1996, Early Carboniferous ammonoid *Irinoceras* from the Onimaru Formation in the Southern Kitakami Massif, Northeast Japan. *Jour. Geol. Soc. Japan*, **102**, 755–757.

Endo, R., 1951, Stratigraphical and paleontological studies of the later Paleozoic calcareous algae in Japan 1. Several new species from Sakamotozawa section, Hikoroichi-mura, Kesen-gun, in the Kitakami Mountainous Land. *Trans. Proc. Palaeont. Soc. Japan, N. S.*, no. 4, 121–129.

Endo, R., 1952, Stratigraphical and paleontological studies of the later Paleozoic calcareous algae in Japan 2. Several previously described species from the Sakamotozawa section, Hikoroichi-mura, Kesen-gun, in the Kitakami Mountainous Land. *Trans. Proc. Palaeont. Soc. Japan, N. S.*, no. 5, 139–144.

Gaetani, M., 1968, Lower Carboniferous brachiopods from central Elburz, Iran. *Riv. Ital. Paleont.*, **74**, 665–744.

Galitskaya, A. Ya, 1977, *Early and Middle Carboniferous Productids of Northern Kyrgyzstan*. Ilim, Frunze, 297 p. (in Russian).

Garwood, E. J., 1916, The faunal succession in the Lower Carboniferous rocks of Westmorland and north Lancashire. *Proc. Geol. Assoc.*, **97**, 1–43.

Gladchenko, A. Y., 1955, *Field Atlas of Index Fossils of Brachiopods from the Lower Carboniferous of Northern Kyrgyzstan*. Akad. Nauk Kirgiz., SSR, Frunze, 30 p. (in Russian).

Gröber, P., 1908, Ueber die Faunen des untercarbonischen Transgressionsmeeres des zentralen Tian-Schan, die in der Umgebung des Sart-dschol-Passes gefunden worden sind. *Neu. Jahrb. Miner., Geol. Paläont.*, **26**, 213–248.

Gröber, P., 1909, Carbon und Carbonfossilien des nördlischen und zentralen Tian-Schan. *Abh. König. Akad. Wissenschaft. 2 Klas.*, **24**, 341–384.

Gu, F., 1992, Carboniferous and Permian Brachiopoda. *In* Jilin Institute of Geology and Mineral Resources, ed., *Paleontological Atlas of Jilin*. Jilin Sci. Tec. Publ. House, Changchun, 210–255 (in Chinese).

Hall, J. and Clarke, J. M., 1895, *An Introduction to the Study of the Genera of Palaeozoic Brachiopoda*. Natural History of New York, Palaeontology, Volume 8, Part 2. Charles van Benthuysen and Sons, Albany, 394 p.

Hayasaka, I., 1924, On the fauna of the Anthracolithic limestone of Omi-mura in the western part of Echigo. *Sci. Rep. Tohoku Imp. Univ., Sec. Ser.*, **8**, 3–83.

Ibaraki, Y., Miyake, Y. and Tazawa, J., 2014, Early Carboniferous (late Visean) brachiopods from the Koyama Limestone of Kamiotake in the Oga area, Okayama Prefecture, southwest Japan. *Earth Sci.* (*Chikyu Kagaku*), **68**, 69–70.

Jin, Y.-G. and Fang, R.-S., 1983, Early Carboniferous brachiopods from Shidian, Yunnan. *Acta Palaeont. Sin.*, **22**, 139–151 (in Chinese).

Jin, Y.-G. and Hu, S.-Z., 1978, Brachiopods of the Kuhfeng Formation in south Anhui and Nanking Hills. *Acta Palaeont. Sin.*, **17**, 101–127 (in Chinese).

Kalashnikov, N. V., 1974, *Early Carboniferous Brachiopods from the Petchorian Urals*. Nauka Leningrad, 166 p. (in Russian).

Kato, M., 1959, On some Carboniferous corals from the Kitakami Mountains. *Trans. Proc. Palaeont. Soc. Japan, N. S.*, no. 33, 33–43.

Kobayashi, T. and Hamada, T., 1978a, Advance reports on the Carboniferous trilobites of Japan, 1. Outline of the trilobite fauna. *Proc. Japan Acad., Ser. B*, **54**, 45–49.

Kobayashi, T. and Hamada, T., 1978b, Advance reports on the Carboniferous trilobites of Japan, 3. One new subgenus and three new species. *Proc. Japan Acad., Ser. B*, **54**, 50–54.

Kobayashi, T. and Hamada, T., 1980, Carboniferous trilobites of Japan in comparison with Asia, Pacific and other faunas. *Palaeont. Soc. Japan, Spec. Pap.*, **23**, 1–152.

Lee, L., Gu, F. and Su, Y., 1980, Carboniferous and Permian Brachiopoda. *In* Shenyang Institute of Geology and Mineral Resources, ed., *Palaeontological Atlas of Northeast China (1) Palaeozoic Volume*. Geol. Publ. House, Beijing, 327–428 (in Chinese).

Legrand-Blain, M., 1973, Les gigantoproductides (brachiopodes) du Sahara Algerien. *Bull. Soc. Hist. Nat. Afr. Nor.*, **64**, 79–157.

Léveillé, C., 1835, Aperçu géologique de quelques localités très riches en coquilles sur les frontières de France et de Belgique. *Mém. Soc. Géol. Fr.*, **2**, 29–40.

Litvinovich, N. V., 1962, *Carboniferous and Permian Deposits of the Western Part of Central Kazakhstan*. Izd. Moskov. Univ., Moskva, 389 p. (in Russian).

Litvinovich, N. V., Aksenova, G. G. and Razina, T. P., 1969, *Stratigraphy and Lithology of the Lower Carboniferous Deposits in the West-Central Kazakhstan*. Nedra, Moskva, 447 p. (in Russian).

M'Coy, F., 1844, *A Synopsis of the Characters of the Carboniferous Limestone of Ireland*, Williams and Norgate, London, 207 p.

Minato, M., 1941, On the Lower Carboniferous deposits at Setamai, Kesen-gori, Iwate Prefecture. *Jour. Geol. Soc. Japan*, **48**, 469–490 (in Japanese).

Minato, M., 1951, On the Lower Carboniferous fossils of the Kitakami Massif, northeast Honsyu, Japan. *Jour. Fac. Sci., Hokkaido Univ., Ser. 4*, **7**, 355–382.

Minato, M., 1952, A further note on the Lower Carboniferous fossils of the Kitakami Mountainland, northeast Japan. *Jour. Fac. Sci., Hokkaido Univ., Ser. 4*, **8**, 136–174.

Minato, M., 1955, Japanese Carboniferous and Permian corals. *Jour. Fac. Sci., Hokkaido Univ., Ser. 4*, **9**, 1–202.

Minato, M., Hashimoto, S., Suyama, K., Takeda, H., Suzuki, Y., Kimura, S., Yamada, K., Kakimi, T., Ichikawa, T. and Suetomi, H., 1953, Biostratigraphie des Karbons im Kitakami-Gebirge, nordöstriches Honshu, Japan. *Jour. Geol. Soc. Japan*, **54**, 385–399 (in Japanese).

Minato, M., Hunahashi, M., Watanabe, J. and Kato, M., 1979a, *Variscan Geohistory of Northern Japan:The Abean Orogeny*. Tokai Univ. Press, Tokyo, 427 p.

Minato, M. and Kato, M., 1979, Chapter 2h4. Upper Visean; Correlation. *In* Minato, M., Hunahashi, M., Watanabe, J. and Kato, M., eds., *Variscan Geohistory of Northern Japan: The Abean Orogeny*. Tokai Univ. Press, Tokyo, 136.

Minato, M., Kato, M., Niikawa, I. and Nakamura, T., 1979b, Chapter 2h2. Upper Visean; Stratigraphy. *In* Minato, M., Hunahashi, M., Watanabe, J. and Kato, M., eds., *Variscan Geohistory of Northern Japan: The Abean Orogeny*. Tokai Univ. Press, Tokyo, 133–134.

Minato, M. and Rowett, C. L., 1967a, A new species of *Yuanophyllum* Yü from the Kitakami Mountains, Japan. *Jour. Fac. Sci., Hokkaido Univ., Ser. 4*, **13**, 333–342.

Minato, M. and Rowett, C. L., 1967b, Discovery of the genus *Aulina* Smith in the Carboniferous of Japan. *Jour. Fac. Sci., Hokkaido Univ., Ser. 4*, **13**, 383–393.

Muir-Wood, H. M., 1951, The Brachiopoda of Martin's "Petrificata Derbiensia". *Ann. Mag. Nat. Hist., Ser. 12*, **4**, 97–124.

Muir-Wood, H. M. and Cooper, G. A., 1960, Morphology, classification and life habits of the Productoidea (Brachiopda). *Geol. Soc. Amer. Mem.*, **81**, 1–447.

Nalivkin, D. V. and Fotieva, N. N., 1973, *Brachiopods from the Boundary of Tournaisian and Visean in the Western Slope of the Urals*. Nauka, Moskva, 118 p. (in Russian).

Niikawa, I., 1983a, Biostratigraphy and correlation of the Onimaru Formation in the southern Kitakami Mountains, Part 1. Geology and biostratigraphy. *Jour. Geol. Soc. Japan*, **89**, 347–357 (in Japanese).

Niikawa, I., 1983b, Biostratigraphy and correlation of the Onimaru Formation in the southern Kitakami Mountains, Part 2. Correlation and conclusion. *Jour. Geol. Soc. Japan*, **89**, 549–557 (in Japanese).

Niikawa, I., 1997, A new tabulophyllid coral from the Dinantian Onimaru Formation, Northeast Japan. *Bol. Roy. Soc. Española, Hist. Nat.* (*Sec. Geol.*), **91**, 85–92.

Okimura, Y., 1965, Endothyroid Foraminifera, *Endothyranopsis* from Japan. *Geol. Rep. Hiroshima Univ.*, **14**, 253–264.

Onuki, Y., 1969, Geology of the Kitakami Massif, Northeast Japan. *Contr. Inst. Geol. Paleont., Tohoku Univ.*, no. 69, 1–239 (in Japanese).

Pareyn, G., 1961, *Les Massifs Carbonifères du Sahara Sud-Oranais, Tome 2 Paléontologie Stratigrahique*. Cent. Nat. Rec. Sie., Paris, 244 p.

Pattison, J., 1981, The stratigraphical distribution of gigantoproductoid brachiopods in the Viséan and Namurian rocks of some areas in northern England. *Rep. Inst. Geol. Sci.*, no. 81/9. 1–30.

Phillips, J., 1836, *Illustrations of the Geology of Yorkshire; or a Description of the Strata and Organic Remains: Accompanied by a Geological Map, Sections and Diagrams and Figures of the Fossils, Part 2. The Mountain Limestone Districts*. John Murray, London, 253 p.

Prentice, J. E., 1949, The *hemispaericus*-like gigantellids of the southern Pennines. *Proc. Yorkshire Geol. Soc.*, **27**, 247–269.

Prentice, J. E., 1950, The genus *Gigantella* Sarytcheva. *Geol. Mag.*, **87**, 436–438.

Prentice, J. E., 1956, *Gigantoproductus edelburgensis* (Phillips) and related species. *Proc. Yorkshire Geol. Soc.*, **30**, 229–258.

Qiao, L. and Shen, S.-Z., 2014, Global paleobiogeography of brachiopods during the Mississippian—Response to the global tectonic reconfiguration, ocean circulation, and climate changes. *Gondwana Res.*, **26**, 1173–1185.

Sarytcheva, T. G., 1928, The Productidae of the group *Productus giganteus* Martin (*Gigantella* gen. nov.) from the Visean of Moscow. *Tr. GNII*, **1**, 1–71 (in Russian).

Sarytcheva, T. G. and Legrand-Blain, M., 1977, Generic composition and evolution of the family Semiplanidae (Brachiopoda). *Paleont. Zhur., 1977*, **2**, 70–82 (in Russian).

Sarytcheva, T. G. and Sokolskaya, A. N., 1952, Description of the Palaeozoic Brachiopoda of the Moscow Basin. *Tr. Paleont. Inst., Akad. Nauk SSSR*, **38**, 1–307 (in Russian).

Sarytcheva, T. G. and Sokolskaya, A. N., 1959, On the classification of pseudopunctate brachiopods. *Dok. Akad. Nauk SSSR*, **125**, 181–184 (in Russian).

Sowerby, J., 1820, *The Mineral Conchology of Great Britain, Vol. 3*. W. Ardling, London, 184 p.

Sowerby, J., 1821–1822, *The Mineral Conchology of Great Britain, Vol. 4*. W. Ardling, London, 114 p.

Stehli, F. G., 1954, Lower Leonardian Brachipoda of the Sierra Diablo. *Bull. Amer. Mus. Nat. Hist.*, **105**, 257–358.

Tan, Z., 1987, Description of important fossils: Brachiopods. *In* Regional Surveying Party, Bureau of Geology and Mineral Resources of Hunan Province, ed., *The Late Devonian and Early Carboniferous Strata and Palaeobiocoenosis of Hunan*. Geol. Publ. House, Beijing, 111–133 (in Chinese).

Tazawa, J., 1989, Chapter 5. Brachiopoda. *In* Ofunato City Museum, ed., *Fossils of Onimaru*. Kawasaki Insatsu, Ichinoseki, 51–65 (in Japanese).

Tazawa, J., 2017, An early Carboniferous (late Visean) brachiopod fauna from Tairagai in the Yokota area, South Kitakami Belt, Japan. *Paleont. Res.*, **21**, 329–346.

Tazawa, J., 2018, Early Carboniferous (Mississippian) brachiopods from the Hikoroichi Formation, South Kitakami Belt, Japan. *Mem. Fukui Prefec. Dinosaur Mus.*, **17**, 27–87.

Tazawa, J. and Ibaraki, Y., 2009, *Linoprotonia* and *Gigantoproductus* (Linoproductoidea, Brachiopoda) from the Lower Carboniferous in the Onimaru Quarry, Hikoroichi, southern Kitakami Mountains, NE Japan. *Sci. Rep. Niigata Univ.* (*Geol.*), no. 24, 7–19.

Tazawa, J. and Iryu, Y., 2019, Early Carboniferous (early Visean) brachiopod fauna from the middle part of the Arisu Formation in the Shimoarisu area, South Kitakami Belt, Japan. *Paleont. Res.*, **23**, 95–109.

Tazawa, J. and Miyake, Y., 2002, *Gigantoproductus* (Brachiopoda) from the Lower Carboniferous (Upper Visean) Onimaru Formation of the southern Kitakami Mountains, NE Japan. *Sci. Rep. Niigata Univ., Ser. E*, no. 17, 1–6.

Tazawa, J. and Niikawa, I., 2018, *Desquamatia* (*Seratrypa*) from the Upper Devonian Choanji Formation in the South Kitakami Belt, Japan, and its stratigraphical significance. *Jour. Geol. Soc. Japan*, **124**, 111–116 (in Japanese).

Volgin, V. I., 1959, New species of Upper Palaeozoic brachiopods (orders Rhynchonellida, Spiriferida and Terebratulida). *Paleont. Zhur., 1959*, no. 4, 115–124 (in Russian).

Waagen, W., 1883, Salt Range fossils, 1. *Productus*-Limestone fossils: Brachiopoda. *Palaeont. Indica, Ser. 13,* **1**, 391–546.

Wang, S., 1984, Phylum Brachiopoda. *In* Regional Geological Surveying Team of Hubei, ed., *The Palaeontological Atlas of Hubei Province*. Hubei Sci. Tech. Press, Wuhan, 128–236 (in Chinese).

Weller, S., 1914, *The Mississippian Brachiopoda of the Mississippi Valley Basin*. Illinois. State Geol. Surv. Monograph 1. Illinois. State Geol. Survey, Urbana, 508 p.

Wu, W., Chang, L. and Ching (Jin), Y., 1974, Carboniferous System of western Guizhou. *Mem. Nanjing Inst. Geol. Palaeont., Acad. Sin.*, no. 6, 72–87 (in Chinese).

Yabe, H., 1942, *Saccaminopsis* Limestone. *Proc. Imp. Acad. Tokyo*, **18**, 682–684.

Yabe, H. and Hayasaka, I., 1915, Palaeozoic corals from Japan, Korea and China. *Jour. Geol. Soc. Tokyo*, **22**, 127–142.

Yabe, H. and Minato, M., 1946, *Amygdalophyllum* from the Lower Carboniferous of the Kitakami Mountainland. *Proc. Japan Acad.*, **22**, 210.

Yabe, H. and Sugiyama,T., 1939, Discovery of *Hexaphyllia* in the Lower Carboniferous of Japan. *Jour. Geol. Soc. Japan*, **46**, 499–502.

Yabe, H. and Sugiyama, T., 1940, Notes on *Heterophyllia* and *Hexaphyllia*. *Jour. Geol. Soc. Japan*, **47**, 81–86.

Yanagida, J., 1962, Carboniferous brachiopods from Akiyoshi, Southwest Japan, Part 1. *Mem. Fac. Sci., Kyushu Univ., Ser. D*, **12**, 87–127.

Yanagida, J., 1979, The large Carboniferous strophomenides from the Akiyoshi Limestone group and their biostratigraphical significance. *Proc. Japan Acad., Ser. B*, **55**, 109–114.

Yang, D., 1984, Systematic description of palaeontology: Brachiopoda. *In* Yichang Institute of Geology and Mineral Resources, ed., *Biostratigraphy of the Yangtze Gorge Area (3) Late Palaeozoic Era*, Geol. Publ. House, Beijing, 203–239, 330–333 and 387–396 (in Chinese).

Yang, D., Ni, S., Chang, M. and Zhao, R., 1977, Phylum Brachiopoda. *In* Geological Institute of Hubei and others, ed., *Palaeontological Atlas of South-Central China, Part 2. Late Palaeozoic Volume*. Geol. Publ. House, Beijing, 303–470 (in Chinese).

Yang, S.-P., 1964, *Lower and Middle Carboniferous Brachiopods from the Northern Slope of Mt. Borochoro, Xinjiang, China, and their Stratiraphical Significance*. Sci. Press, Beijing, 179 p. (in Chinese).

Yang, S.-P., 1983, Palaeozoogeographic provinces of the Lower Carboniferous brachiopods of China. *In* Lu, Y. et al., eds., *Palaeobiogeographic Provinces of China*. Sci. Press, Beijing, 64–73 (in Chinese).

Yang, S. and Gao, J., 1996, Systematic description: Brachiopods. *In* Zeng, X., Zhu, W., He, X., Teng, F. et al., *Permo-Carboniferous Biostratigraphy and Sedimentary Environment of West Qinling*. Geol. Publ. House, Beijing, 211–218 and 271–274 (in Chinese).

Yang, Z., Ting (Ding), P., Yin, H., Zhang, S. and Fang, J., 1962, Carboniferous, Permian and Triassic brachiopod faunas from Chilianshan region. *In* Institute of Geology and Palaeontology, Geological Institute, Academia Sinica and Beijing University of Geology, eds., *Monograph on Geology of the Chilianshan Mountains, Vol. 4, Part 4*, Sci. Press, Beijing, 1–129 (in Chinese).

Yanishevsky, M., 1918, Materials for the study of the Lower Carboniferous fauna of Fergana. *Tr. Geol. Kom., Nov. Zer.*, **162**, 1–145 (in Russian).

Zakowa, H., 1986, Brachiopods of the family Semiplanidae Sarytcheva, 1960 from the upper Visean of Poland. *Biul. Inst. Geol.*, no. 355, 49–70.

Zhang, C., Zhang, F., Zhang, Z. and Wang, Z., 1983, Phylum Brachipoda. *In* Regional Geological Surveying Team of Xinjiang, Institute of Geoscience of Xinjiang, and Geological Surveying Group of Petroleum Bureau of Xinjiang, eds., *Palaeozoic Atlas of Northwest China; Xinjiang Autonomous Region, Part 2. Late Palaeozoic Volume*, Geol. Publ. House, Beijing, 161–286 (in Chinese).

Plant fossils from the Lower Cretaceous Tetori Group in the Itoigawa area, Niigata Prefecture, central Japan

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Abstract

Sterile fern fronds comparable to *Birisia onychioides* (Vassilevskaja and Kara-Mursa) Samylina [sense Kimura] and assignable to *Cladophlebis* sp. were found from the Lower Cretaceous Tetori Group near Ichiburi in the Itoigawa area, Niigata Prefecture, central Japan. This paper describes these specimens with photographs and line drawings for the first time in Niigata Prefecture. *Birisia* is one of the important elements indicative of the Siberian paleofloristic province. It is common in the Oguchi and Akaiwa floras of Barremian–Aptian age but has not been found in the younger Kitadani (or Tamodani) Flora of Aptian age in the Tetori Group. Lithostratigraphic assignment of the plant fossil-bearing sequence in the study area is discussed.

Key words: *Birisia*, *Cladophlebis*, plant fossil, Mizukamidani Formation, Shiritakayama Formation, Tetori Group, Itoigawa area.

Introduction

The Tetori Group (Oishi, 1933; Yamada and Sano, 2018) consists of Lower Cretaceous terrestrial and shallow marine sediments in the Inner Zone of Southwest Japan. Abundant

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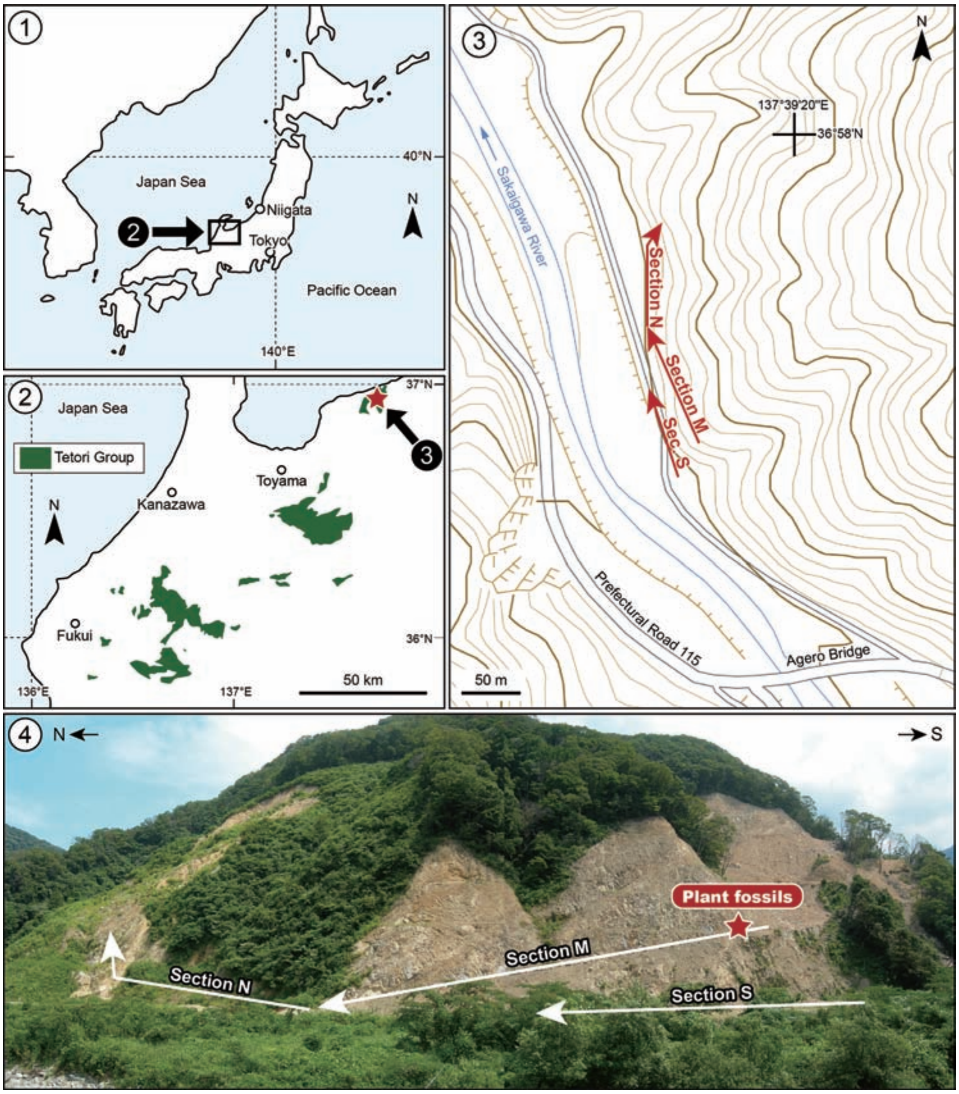

Fig. 1. 1: Locality map of the study area, 2: Distribution of the Tetori Group (modified from Maeda, 1961), 3: The study sections which outcrop along the right bank of the Sakaibgawa River, 4: Panoramic view of the study sections from the left bank of the Sakaigawa River.

non-marine faunas and land plants have been reported from the group in Fukui, Ishikawa, Gifu, and Toyama prefectures (e.g., Maeda, 1961; Fujita, 2003; Yabe et al., 2003; Matsukawa et al., 2006; Sano, 2015; Sano and Yabe, 2017). The Itoigawa area is located at the southwestern end of Niigata Prefecture, central Japan. The Tetori Group in the area occupies the easternmost part of its entire extent (Fig. 1). Fossil records from the Tetori Group in the Itoigawa area are very limited: *Onychiopsis elongata* (Geyler) Yokoyama was the only plant fossil record hitherto reported in the area (Goto, 1983, 1986).

We have investigated the Tetori Group in the Itoigawa area since 2010 to establish the stratigraphy and to accumulate fossil records (Ito et al., 2012, 2014; Sakai et al., 2012, 2013). Our research has been concentrated on the sequence exposed at a quarry (36° 57' 54. 5" N, 137° 39' 14. 9" E) on the right bank of the Sakaigawa River near Ichiburi in the Itoigawa area, Niigata Prefecture (Fig. 1). Sakai et al. (2012) showed detailed geological columnar sections of the Tetori Group and preliminarily reported the occurrence of plant fossils. In this paper, we describe cf. *Birisia onychioides* (Vassilevskaja and Kara-Mursa) Samylina and *Cladophlebis* sp. collected at the quarry. This is the first report on both species from the Tetori Group in Niigata Prefecture. The specimen of cf. *Birisia onychioides* from the quarry was provisionally reported as *Onychiopsis elongata* by Sakai et al. (2013). We discuss stratigraphic correlation of the Tetori Group in the Itoigawa area on the basis of the occurrence of *Birisia* species.

Geological setting and stratigraphic position of plant-bearing beds

The Mesozoic sequences in the Itoigawa area are composed of the Lower Jurassic Kuruma Group and the overlaying Lower Cretaceous Tetori Group. The Tetori Group in the area consists of the Mizukamidani Formation (Kobayashi et al., 1957) and the Shiritakayama Formation (Yoshimura and Adachi, 1976). The stratigraphic relationship between these two formations is not well understood yet. The Mizukamidani Formation was originally considered to be the uppermost part of the Kuruma Group (Kobayashi et al., 1957). It has been included in the Tetori Group since Chihara et al. (1979) revised its lithostratigraphic assignment on the basis of lithologic features. The Shiritakayama Formation was defined by Yoshimura and Adachi (1976) designating its type locality around Mt. Shiritakayama, 6.0 km east of the study section. Kishigami (2000) presented a geological map of the Shiritakayama Formation in the Mt. Shiritakayama area.

The Mizukamidani Formation is well exposed at the quarry (Fig. 1). Sakai et al. (2012) measured three columnar sections, namely S, M, and N from south to north (Fig. 1). Lithostratigraphy of these sections is presented in Fig. 2. The uppermost part of Section S (S-11 to S-13) can be correlated to the lowermost part of Section M (M-01 to M-03), which directly underlies Section N. The strata in the sections approximately strike N80° W and dip 35° N. There are some faults and dikes in the sections. The sections are composed mainly of feldspathic-arenite and conglomerate including chert, sandstone, siliceous mudstone, orthoquartzite, granite, andesite, and mudstone pebbles. Mudstone clasts are included in the conglomerates. Fining-upward cycles are repeated in the sections. Ito et al. (2012, 2014) reported three horizons of radiolarian-bearing chert pebbles in the sections (Fig. 2).

We collected plant fossils from M-02 in Section M (Figs. 2, 3). A fining-upward cycle is observed from M-01 to M-02 in the section. M-02 consists of sandstone-dominated alternating

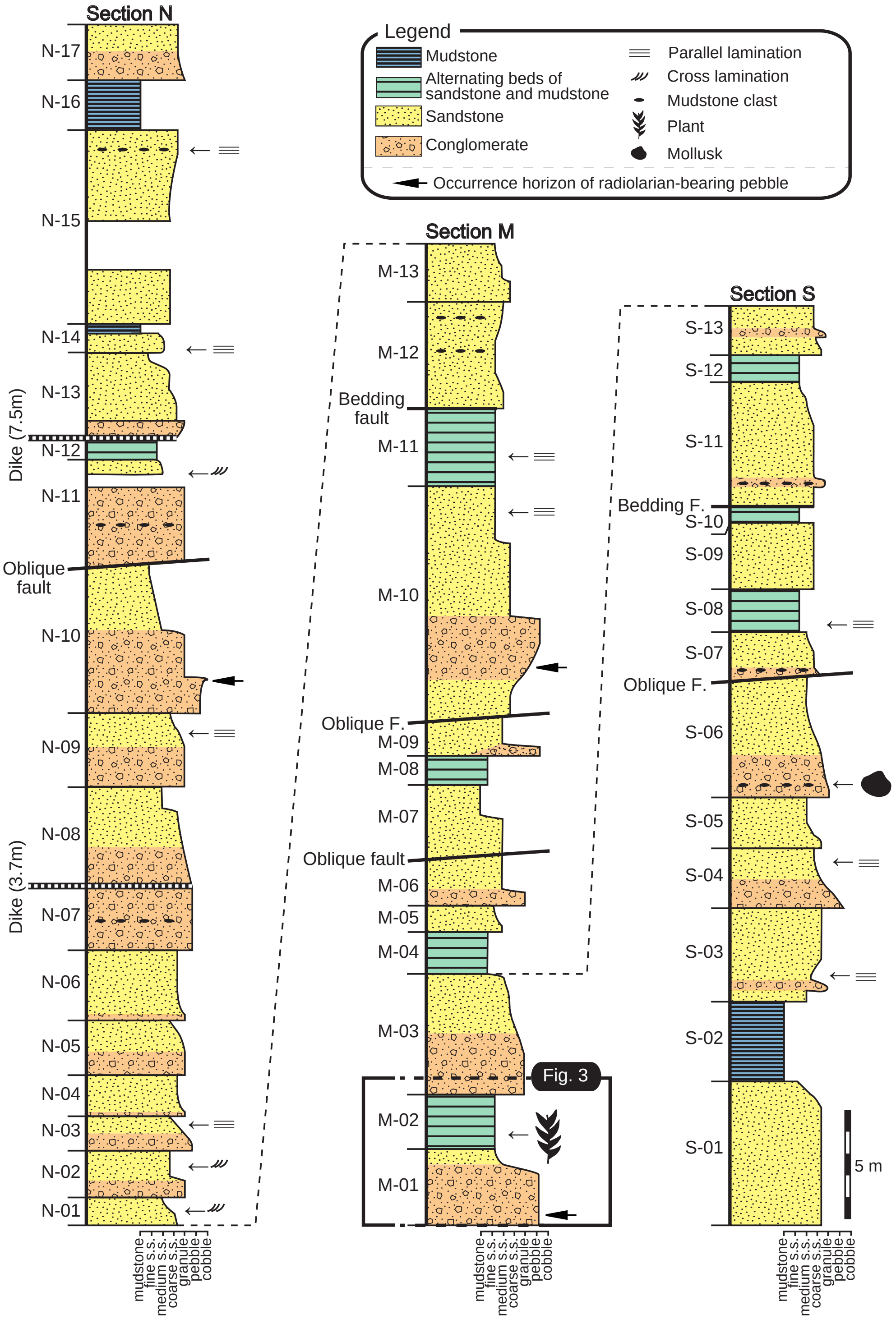

Fig. 2. Columnar sections of the Mizukamidani Formation in the right bank of the Sakaigawa River (modified from Sakai et al., 2012).

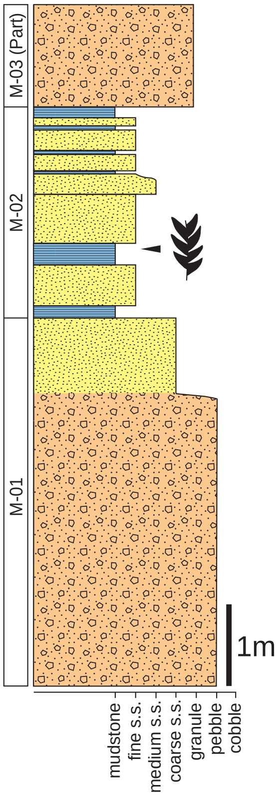

Fig. 3. Detailed columnar section of the lower part of Section M (Fig. 2). Legend is the same as that of Fig. 2.

beds of fine- to medium-grained sandstone and mudstone. The mudstone beds include many small plant fragments and coal. Two plant specimens were taken from a horizon 0.8 m higher than the base of M-02.

Plant fossils

The two plant specimens are fern fronds of cf. *Birisia onychioides* (FMM6179: Figs. 4A–B) and *Cladophlebis* sp. (FMM6180: Figs. 4C–D). They co-occurred in the bed composed mainly of light gray sandy mudstone that changed laterally to light gray well-laminated sandy mudstone. The fern fronds comparable to *B. onychioides* were included in the light gray sandy mudstone bed. *Cladophlebis* sp. was included in the light gray well-laminated sandy mudstone bed. These specimens are stored in the Fossa Magna Museum (FMM), Itoigawa City, Niigata Prefecture.

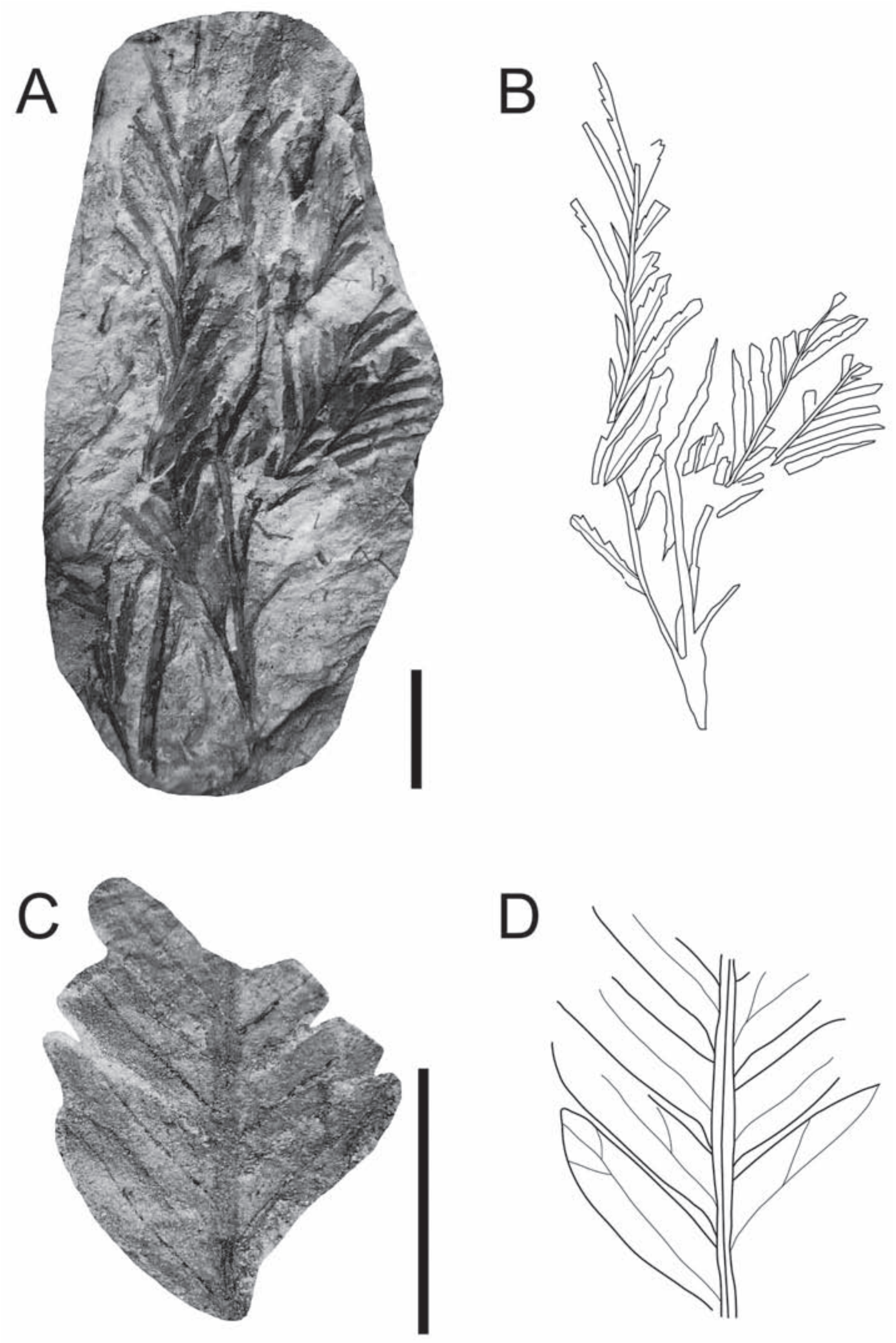

Fig. 4. Plant fossils from the mudstone bed in the Tetori Group distributed in Ichiburi, Itoigawa, Niigata Prefecture. A: Sterile fern fronds comparable to *Birisia onychioides* (Vassilevskaja and Kara-Mursa) Samylina [sense Kimura, 1975] (FMM6179). B: Line drawing of A. C: *Cladophlebis* sp. (FMM6180). D: Line drawing of C. Scale bars are 10 mm.

Systematic Paleontology

Filicales
Family Dicksoniaceae
Genus *Birisia* Samylina, 1972
Type species.— *Birisia alata* (Prynada) Samylina, 1972

Cf. *Birisia onychioides* (Vassilevskaja and Kara-Mursa) Samylina [sense Kimura, 1975]

Figs. 4A–B

Cf. *Birisia onychioides* (Vassilevskaja and Kara-Mursa) Samylina, Kimura, 1975, p. 71–74, pl. 5, figs. 6–9; pl. 6, figs. 1–4; figs. 4-2a–d.

Material.— FMM6179.

Description.— A few pinnae probably derived from a single frond were obtained. The specimen is 80 mm long and 36 mm wide. The frond is slender and at least bipinnate. Pinnae are elongate, 40 mm long and 18 mm wide at the widest portion. They are alternately arranged and are attached to the rachis at an angle of 20–30°. Pinnules are lanceolate, 20 mm long and 2 mm wide, pinnatifid and are gradually narrowed toward the apex. They are attached to the rachis at an angle of about 32°. The base of pinnules are constricted exmedially and are typically decurrent admedially. The primary veins are conspicuous and nearly straight, persisting almost to the apex (*Cladophlebis*-type). The secondary veins are indistinct. Fertile part of the pinnule is not preserved.

Remarks.— The genus *Birisia* was proposed by Samylina (1972) for fern frond with sterile pinnules of *Cladophlebidium*-type and fertile pinnules of *Coniopteris*-type. Samylina (1972) described four *Birisia* species from the Cretaceous of Siberia., i.e., *B. aculata* Samylina, *B. alata* (Prynada) Samylina, *B. ochotica* Samylina, and *B. onychioides* (Vassilevskaja and Kara-Mursa) Samylina. Two of these *Birisia* species were recorded in the Tetori Group in central Japan: *B. onychioides* and *B. alata* (Kimura, 1975; Kimura et al., 1978; Yabe et al., 2003). Kimura (1975) discussed variation of sterile fronds of *B. onychioides* in detail and synonymized *Cladophlebis shinshuensis* Tateiwa (Tateiwa, 1929; Oishi, 1940) to this species. Although our specimen (FMM6179) does not yield fertile part, it is inseparable from *B. onychioides* [sense Kimura, 1975] including *C. shinshuensis* in the shape and derivation angle of pinnules, especially decurrent basal side forming wings. Therefore, we followed the treatment by Kimura (1975) and compared our specimen to *B. onychioides.*

This species has been reported from fossil localities of the Tetori Group in Ishikawa, Gifu, and Toyama prefectures (Kimura, 1975; Kimura et al., 1978; Kunimitsu and Nakashima, 1987; Yatsuo Town Board of Education, 1996; Matsuura, 2001). It is common in these localities.

Form-genus *Cladophlebis* Brongniart, 1849

Cladophlebis sp.

Figs. 4C–D

Material.— FMM6180.

Description.— An ultimate part of a sterile fern frond with four pairs of pinna was obtained. The specimen is 12 mm long and 10 mm wide. Pinnules are narrow triangular with acute apex, and 6 mm long and 1.5 mm wide at the widest portion. They are arranged alternately and are attached to the rachis at an angle of 40°. The base of the pinnules are constricted exmedially and are decurrent admedially. The primary veins are conspicuous and nearly straight, persisting almost to the apex (*Cladophlebis*-type). The secondary veins are unclear and not forked. The secondary veins are attached to the primary veins at an angle of 30–35°, reaching the margin.

Remarks.— Although FMM6180 is poorly preserved, it is referable to the form-genus *Cladophlebis* because of its *Cladophlebis*-type nervation. Six species of *Cladophlebis* have been recorded in the Tetori Group, i.e., *Cladophlebis* ex gr. *denticulata* (Brongniart) Fontaine, *C. hamasakai* Kimura and Sekido, *C. hukuiensis* Oishi, *C. laxipinnata* Prynada, *C.* ex gr. *williamsoni* (Brongniart) Brongniart, and *C.* sp. cf. *C. pseudolobifolia* Vachrameev (Kimura et al., 1978; Yabe et al., 2003). Based on pinnule shape and nervation, our specimen (FMM6180) is distinct from any *Cladophlebis* species reported from the Tetori Group. However, the authors refrain from making a species assignment in this study because our specimen is so fragmental and poorly preserved in venation characters.

Discussion

This study reports a plant fossil specimen comparable to *Birisia onychioides* (Vassilevskaja and Kara-Mursa) Samylina [sense Kimura, 1975] from the Tetori Group in the Itoigawa area. The fossil record represents the northeasternmost occurrence of *B. onychioides* or comparable forms in the Tetori Group. Since Kimura (1974, 1975) reported *B. onychioides* for the first time from the Tetori Group in the Kuzuryu area, Fukui Prefecture, this taxon has been reported from the group in the Shiramine area, Ishikawa Prefecture (Kimura et al., 1978; Matsuura, 2001), in the Shokawa area, Gifu Prefecture (Kunimitsu and Nakashima, 1987), and in the Inotani area, Toyama Prefecture (Yatsuo Town of Board of Education, 1996). Recently Sakai et al. (2020) reported the occurrence of *B. onychioides* in the Itsuki Formation in the Itoshiro area, Fukui Prefecture.

Kimura (1975) proposed three stratigraphically discernible floras in the Tetori Group, namely the Oguchi, Akaiwa, and Tomodani floras in ascending order. *Birisia onychioides* is common in the Oguchi and Akaiwa floras but has not been found in younger flora represented by the Tamodani Flora (Kimura, 1975; Kimura et al., 1978) or the Kitadani Flora (Sano, 2015). Yabe et al. (2003) suggested that *B. onychioides* was recorded in the Oguchi and Tomodani floras. The locality, where the Tamodani Flora with *B. onychioides* was reported in Yabe et al. (2003), can be correlated to a certain horizon within the Akaiwa Formation or its equivalent based on our own research. This fits well with the idea that the Oguchi and Akaiwa floras of Barremian–Aptian age is different in floral composition from the younger Kitadani Flora of Aptian age (Sano and Yabe, 2017). In addition, Kimura (1975) pointed out that *B. onychioides* is one of the important elements indicative of the Siberian paleofloristic province in the Early Cretaceous.

The plant fossil-bearing sequence in the quarry was originally assigned to the Mizukamidani Formation. Takeuchi et al. (2015, 2017) designated it as the type section of the Shiritakayama Formation based on their research on Mesozoic deposits around the border between Toyama and Niigata prefectures including the Itoigawa area. Takeuchi et al. (2015) reported the youngest detrital zircon U–Pb age of ca. 110 Ma from sandstones in the Mt. Shiritakayama area, the original type area of the Shiritakayama Formation. On the other hand, the youngest peak age of detrital zircon grains in sandstones around the quarry is 191 Ma (Takeuchi et al., 2015), which is much older than those in the Mt. Shiritakayama area. The resetting of the type section does not seem conclusive because the detrital zircon U–Pb age data are discordant. Moreover, the plant fossil evidence presented herein, possibly indicative of Barremian–Aptian age, is not always supportive for the resetting.

Concluding remarks

This paper gives a description of plant fossils with photographs and line drawings from the Tetori Group in the Itoigawa area. *Birisia* species have a potential not only for regional correlation within the Tetori Basin but also for correlation on a global scale because they have been found widely in Asia (Vakhrameev, 1991). Further collection of plant fossils and floral analysis will give a clue to elucidate the stratigraphy of Mesozoic sequences in the Itoigawa area where fossil evidence is still sparse.

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References

Brongniart, A., 1849, *Tableau des Genres de Végétaux Fossiles Considerés sous le Point de Vue de leur Classification Botanique et de leur Distribution Géologique*, Paris, 127p.

Chihara, K., Komatsu, M., Uemura, T., Hasegawa, Y., Shiraishi, S., Yoshimura, T. and Nakamizu, M., 1979, Geology and tectonics of the Omi-Renge and Joetsu Tectonic Belts (5): Geology and tectonics of the Omi-renge Tectonic Belt. *Sci. Rep. Niigata Univ., Ser. E*, no. 5, 1–60.

Fujita, M., 2003, Geological age and correlation of the vertebrate-bearing horizons in the Tetori Group. *Mem. Fukui Pref. Dinosaur Mus.*, no. 2, 3–14.

Goto, M., 1983, Some bivalves from the Lower Jurassic Kuruma Group of central Japan. *Trans. Proc. Palaeont. Soc. Japan*, no. 130, 79–85.

Goto, M., 1986, Discovery of *Onychiopsis elongata* (Geyler) Yokoyama from the uppermost part of the Lower Jurassic Kuruma Group, Toyama and Niigata Prefectures. *Bull. Toyama Sci. Mus.*, no. 9, 87–88, pl. 1 (in Japanese with English abstract).

Ito, T., Sakai, Y., Ibaraki, Y. and Matsuoka, A., 2014, Middle Jurassic radiolarians from a siliceous mudstone clast within conglomerate of the Tetori Group in the Itoigawa area, Niigata Prefecture, central Japan. *Sci. Rep., Niigata Univ. (Geol.)*, no. 29, 1–11.

Ito, T., Sakai, Y., Ibaraki, Y., Yoshino, K., Ishida, N., Umetsu, T., Nakada, K., Matsumoto, A., Hinohara, T., Matsumoto, K. and Matsuoka, A., 2012, Radiolarian fossils from siliceous rock pebbles within conglomerates in the Mizukamidani Formation of the Tetori Group in the Itoigawa area, Niigata Prefecture, central Japan. *Bull. Itoigawa City Mus.*, no. 3, 13–25 (in Japanese with English abstract).

Kimura, T., 1974, Late Early Cretaceous floras of the Tetori basin. *Chigakukenkyu, Kyoto*, **25**, 159–169 (In Japanese).

Kimura, T., 1975, Middle–Late Early Cretaceous plants newly found from the upper course of the Kuzuryu River Area, Fukui Prefecture, Japan. *Trans. Proc. Palaeont. Soc. Japan*, no. 98, 55–93, pls. 5–8.

Kimura, T., Sekido, S. and Yamazaki, Y., 1978, Plant fossil assemblages from the Oguchi and the Akaiwa Formations of the Itoshiro Subgroup, with special emphasis on the fossils from the Shiramine Village, Ishikawa Prefecture, central Japan. *In* Ishikawa Prefectural Board of Education, *Research report on the silicified wood localities of the Tetori Group along the Tedori River, Ishikawa Prefecture*, 119–271, pls. 57–112 (in Japanese).

Kishigami, M., 2000, Lithology and stratigraphy of the Shiritakayama Formation. *Bull. Omi Nat. Mus.*, no. 2, 11–13 (in Japanese).

Kobayashi, T., Konishi, K., Sato. T., Hayami, I. and Tokuyama, A., 1957, On the Lower Jurassic Kuruma Group. *Jour. Geol. Soc. Japan*, **63**, 182–194 (in Japanese with English abstract).

Kunimitsu M. and Nakashima K., 1987, A note on Tetori type fossil plants from Ogamigo, Shokawa-mura, Ono-gun, Gifu Prefecture. *Bull. Gifu Pref. Mus.,* no. 8, 1–10 (in Japanese).

Maeda, S., 1961, On the geological history of the Mesozoic Tetori Group in Japan. *Jour. Coll. Arts and Sci., Chiba Univ.*, **3**, 369–426 (in Japanese with English abstract).

Matsukawa, M., Ito, M., Nishida, N., Koarai, K., Lockley, M. G. and Nichols, D. J., 2006, The Cretaceous Tetori biota in Japan and its evolutionary significance for terrestrial ecosystems in Asia. *Cretaceous Res.*, **27**, 199–225.

Matsuura, N., 2001, *Research Report of the Fossil Research Group of Hakusan Dinosaur Park Shiramine: Fossils from the Tetori Group in east of Ichinose and from the Asuwa Group in Omichidani, Shiramine*

Village, Ishikawa Prefecture. Shiramine Village Board of Education and Hakusan Kyoryu Park Shiramine (Hakusan Dinosaur Park), 78p. (in Japanese).

Oishi, S., 1933, On the Tetori Series, with special references to its fossil zones. Part 2. *Jour. Geol. Soc. Tokyo*, **40**, 669–699 (in Japanese).

Oishi, S., 1940, The Mesozoic floras of Japan. *Jour. Fac. Sci., Hokkaido Imp. Univ.*, Ser. 4, **5**, nos. 3–4, 123–480, 48 pls.

Sakai, Y., Ito, T., Ibaraki, Y., Yoshino, K., Ishida, N., Umetsu, T., Nakada, K., Matsumoto, A., Hinohara, T., Matsumoto, K. and Matsuoka, A., 2012, Lithology and stratigraphy of the Mizukamidani Formation of the Tetori Group in the right bank of the Sakaigawa River in the Itoigawa area, Niigata Prefecture, central Japan. *Bull. Itoigawa City Mus.*, no. 3, 1–11 (in Japanese with English abstract).

Sakai, Y., Kitagawa, Y., Uehara, K., Takagi, S., Ibaraki, Y. and Matsuoka, A., 2013, Plant and molluscan fossils from the Mizukamidani Formation of the Tetori Group in the right bank of the Sakaigawa River in the Itoigawa area, Niigata Prefecture, Japan -Mesozoic in Itoigawa Part 2-. *120th Ann. Meet. Geol. Soc. Japan, Abstr.*, 293 (in Japanese).

Sakai, Y., Wang, Y. D., and Matsuoka, A., 2020, Early Cretaceous plants from the Itsuki and Nochino formations of the Tetori Group in the Kuzuryu area, central Japan and their paleoclimatic implications. *Cretaceous Res.*, **105**, 104066.

Samylina, V. A., 1972, *Birisia* - novyj rod melovykh paporotnikov Sibiri [*Birisia* - a new genus of Cretaceous ferns of Siberia]. *Botanicheskij Zhurnal*, **57**, 94–101 (in Russian).

Sano, S., 2015, New view of the stratigraphy of the Tetori Group in Central Japan, *Mem. Fukui Pref. Dinosaur Mus.*, no. 14, 25–61.

Sano, S. and Yabe, A., 2017, Fauna and flora of Early Cretaceous Tetori Group in Central Japan: The clues to revealing the evolution of Cretaceous terrestrial ecosystem in East Asia. *Palaeoworld*, **26**, 253–267.

Takeuchi, M., Furukawa, R., Nagamori, H. and Oikawa, T., 2017, *Geology of Tomari District, Quadrangle Series, 1: 50,000*. Geol. Surv. Japan, AIST, 121p. (in Japanese with English abstract).

Takeuchi, M., Ohkawa, M., Kawahara, K., Tomita, S., Yokota, H., Tokiwa, T. and Furukawa, R., 2015, Redefinition of the Cretaceous terrigenous strata in the northeastern Toyama Prefecture based on U–Pb ages of zircon. *Jour. Geol. Soc. Japan*, **121**, 1–17 (in Japanese with English abstract).

Tateiwa, I., 1929, Geological Atlas of Tyosen (Korea), No. 10, Keishu-Eisen-Taikyu and Wakwan Sheets, 1/50000, Geol. Surv. Tyosen (Korea) (in Japanese).

Vakhrameev, V. A., 1991, *Jurassic and Cretaceous Floras and Climates of the Earth*. Cambridge University Press, Cambridge, 318p.

Yabe, A., Terada, K. and Sekido, S., 2003, The Tetori-type flora, revisited: a review. *Mem. Fukui Pref. Dinosaur Mus.*, no. 2, 23–42.

Yamada T. and Sano. S., 2018, Designation of the type section of the Tetori Group and redefinition of the Kuzuryu Group. *Mem. Fukui Pref. Dinosaur Mus.*, no. 17, 89–94.

Yatsuo Town Board of Education, 1996, *Fossils of Kiritani from the Tetori Group of Yatsuo Town, Toyama Prefecture, Central Japan*. Yatsuo Town Board of Education, 32p. (in Japanese).

Yoshimura, T. and Adachi, H., 1976, Futomiyama Group in Niigata Prefecture. *Contributions, Dept. Geol. Mineral. Niigata Univ.*, no. 4, 131–136 (in Japanese with English abstract).

CONTENTS

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