Early Carboniferous (Early Visean) Brachiopod Fauna from the Middle Part of the Arisu Formation in the Shimoarisu Area, South Kitakami Belt, Japan

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Early Carboniferous (early Visean) brachiopod fauna from the middle part of the Arisu Formation in the Shimoarisu area, South Kitakami Belt, Japan

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Abstract. In this paper, we describe an early Carboniferous (early Visean) brachiopod fauna from the middle part of the Arisu Formation in the type locality, Shimoarisu, South Kitakami Belt, northeastern Japan. The Shimoarisu fauna consists of 11 species in seven genera: *Ovatia elongata*, *Rhipidomella michelini*, *Schizophoria resupinata*, *Sch. pinguis*, *Sch. woodi*, *Unispirifer striatoconvolutus*, *Unispirifer* sp., *Kitakamithyris hikoroitiensis*, *Syringothyris texta*, *S. platypleura* and *Pseudosyrinx jumonjiensis*. The fauna is assigned to the early Visean. In terms of palaeobiogeography, the Shimoarisu fauna has an affinity with those of the brachiopod province that developed in present-day northwestern–northeastern China in the early Carboniferous. Therefore, South Kitakami, including the Shimoarisu area, was probably located near and to the east of North China in the early Visean.

Key words: Arisu Formation, Brachiopoda, Shimoarisu, South Kitakami Belt, Visean

Introduction

Carboniferous rocks are widely exposed in the South Kitakami Belt, northeastern Japan. The Shimoarisu area in the central part of the belt (i.e., Shimoarisu, Sumita-cho, Kesen-gun, Iwate Prefecture; Figure 1) contains the type locality of the lower Carboniferous Shittakazawa and Arisu formations. The stratigraphy of the lower Carboniferous rocks in the Shimoarisu area has been studied by Minato *et al.* (1953), Takeda (1960), Saito (1966, 1968), Moriai (1972) and Kawamura (1985). However, the age of the Arisu Formation is poorly defined owing to a lack of palaeontological data. Brachiopods are the most common macrofossils in the lower Carboniferous of the South Kitakami Belt, but only five species (*Actinoconchus lamellosa*, *Cleiothyridina royssii*, *Fusella nipponotrigonalis*, *Syringothyris jumonjiensis* and *S. transversa*) have been described from the Arisu Formation of the Shimoarisu area (Minato, 1951, 1952).

The early Carboniferous geography and biogeography of South Kitakami are important in understanding the geotectonic history of the Japanese Islands. Two models have been proposed for the early Carboniferous palaeoposition of South Kitakami: (1) near South China (Ehiro and Kanisawa, 1999; Ehiro, 2001; Isozaki *et al.*, 2011; Okawa *et al.*, 2013); and (2) near North China (Tazawa, 2002, 2006, 2017, 2018b). Brachiopod faunas from several areas, including Shimoarisu, in the South Kitakami Belt, provide useful evidence with which to solve this problem.

In the present study, we describe the brachiopods from the middle part of the Arisu Formation in the Shimoarisu area, and discuss the age and palaeobiogeography of the fauna. The material was collected by Y. Iryu in 1981, in the course of his graduate thesis at the Institute of Geology and Paleontology, Faculty of Science, Tohoku University, under the supervision of J. Tazawa. The brachiopod specimens described herein are now registered and housed in the Tohoku University Museum, Sendai (prefix IGPS, numbers IGPS111710–111735).

Stratigraphy and material

Lower Carboniferous strata are exposed in the Shimoarisu area, forming an anticline with an axis trending N–S to NNW–SSE direction. The strata are divided lithologically into the Shittakazawa, Arisu, Odaira and Onimaru formations in ascending order (Kawamura,

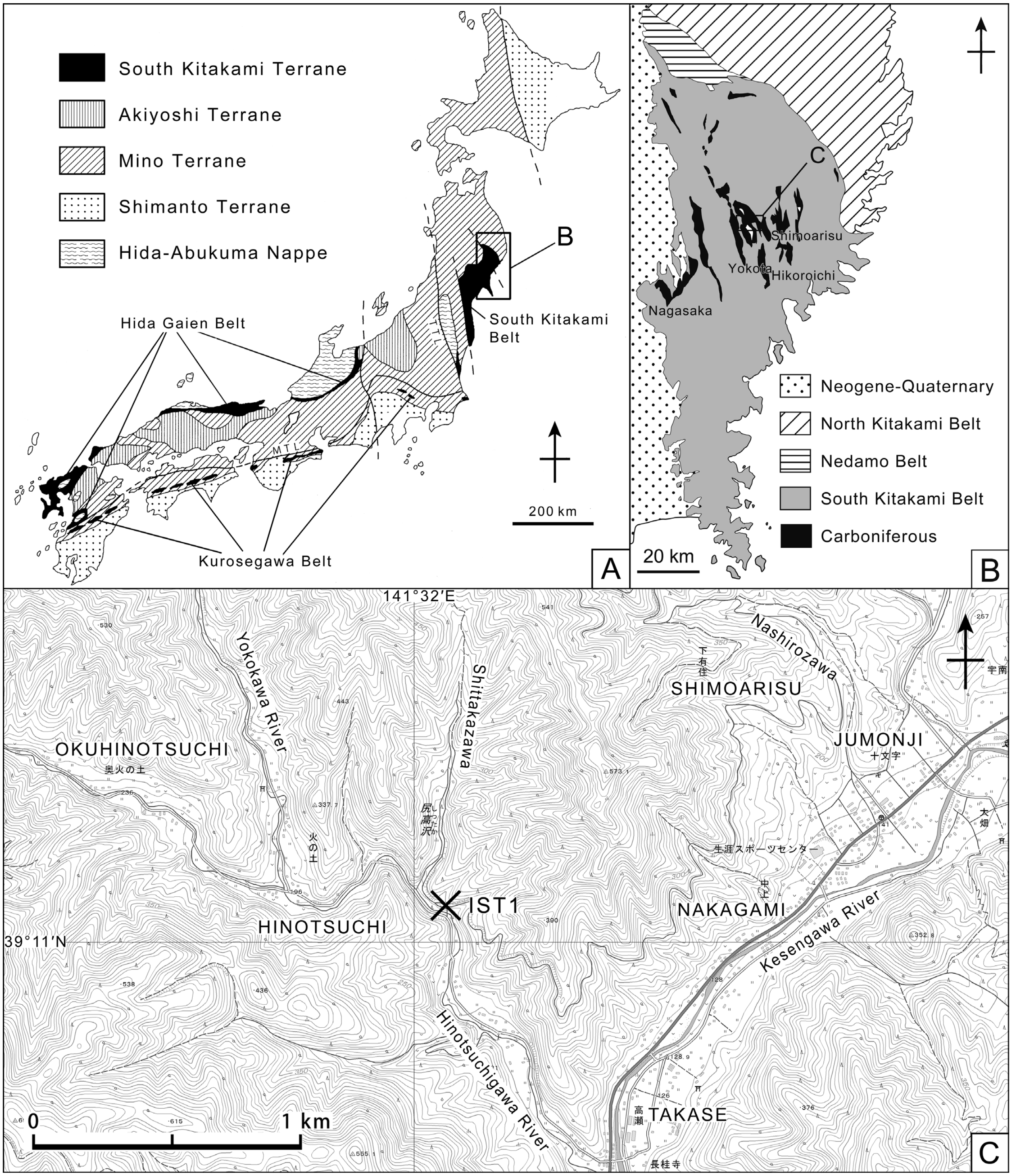

Figure 1. Maps showing the location and geology of the Shimoarisu area, South Kitakami Belt. **A,** geotectonic map of the Japanese Islands, showing the distribution of the South Kitakami Belt (based on Tazawa, 2004); **B,** geotectonic map of the northeastern part of Honshu, Japan, showing the distribution of the Carboniferous rocks in the South Kitakami Belt (based on Kawamura *et al.*, 2013); **C,** map showing the fossil locality IST1 in the Shimoarisu area, South Kitakami Belt (using the electronic topographical map of GSI).

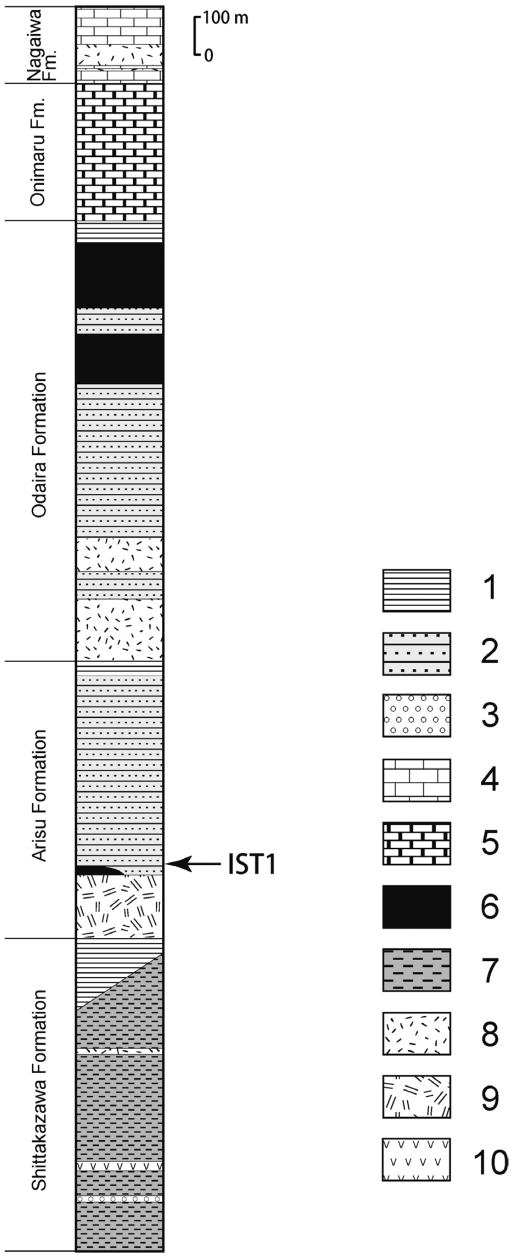

Figure 2. Generalized columnar section of the Carboniferous formations in the Shimoarisu area, showing the fossil horizon IST1. 1, shale; 2, alternating shale and sandstone; 3, conglomerate; 4, limestone of the Nagaiwa Formation; 5, limestone of the Onimaru Formation; 6, limestone of the Arisu and Odaira formations; 7, alternating shale and felsic tuff; 8, andesitic tuff; 9, andesitic lapilli tuff; 10, felsic tuff.

1985). According to the unpublished data by the present author (Iryu), the Arisu Formation is subdivided into the lower part (dark green andesitic lapilli tuff, 40–165 m thick), middle part (alternating shale and sandstone, intercalated with andesitic tuff, 510–520 m thick) and upper part (black shale, 40–50 m thick), with a total thickness of 600–725 m (Figure 2). The brachiopod fossils were collected from the dark grey calcareous shale in the middle part of the Arisu Formation, 25 m above the andesitic lapilli tuff in the lower part at locality IST1 (39°11′06″N, 141°32′06″E; road cutting beside the lower Hinotsuchigawa River, 125 m SE of the junction of the Hinotsuchigawa River and Shittakazawa Valley; Figures 1C, 2). The fossil horizon is equivalent to the D_0 Horizon (Zone) in the Unit III of Minato *et al.* (1953, 1979).

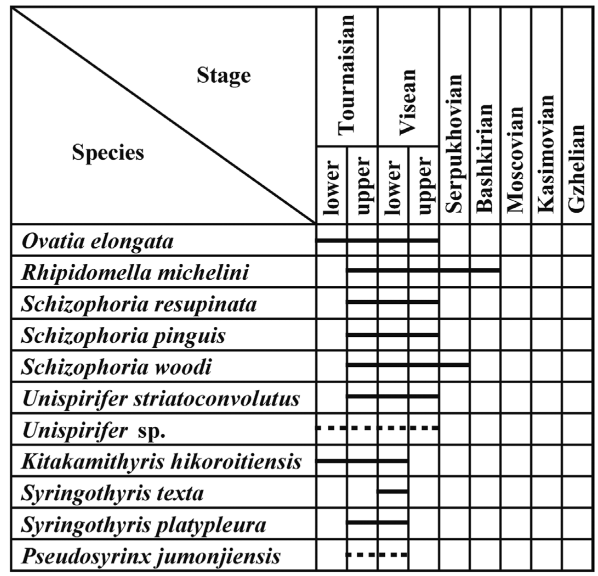

Figure 3. Stratigraphic distribution of brachiopod species of the Shimoarisu fauna. Broken lines show those of the genera.

The Shimoarisu fauna

The brachiopod fauna described herein includes 11 species in seven genera: *Ovatia elongata* Muir-Wood and Cooper, 1960, *Rhipidomella michelini* (Léveillé, 1835), *Schizophoria resupinata* (Martin, 1809), *Sch. pinguis* Demanet, 1934, *Sch. woodi* Bond, 1941, *Unispirifer striatoconvolutus* (Dun and Benson, 1920), *Unispirifer* sp., *Kitakamithyris hikoroitiensis* Minato, 1951, *Syringothyris texta* (Hall, 1857), *S. platypleura* Weller, 1914 and *Pseudosyrinx jumonjiensis* (Minato, 1951). Among the brachiopods, *Schizophoria* and syringothyridids (*Syringothyris* and *Pseudosyrinx*) are abundant in the Shimoarisu fauna. There are no fossils of other taxa in the Shimoarisu fauna, except for some bryozoans and crinoids.

Age

The stratigraphic distributions of the brachiopod species of the Shimoarisu fauna are summarized in Figure 3. Of the brachiopod taxa listed above, *Syringothy-*

Species \ Stage	Japan			USA				N. Russia				UK						
	1. South Kitakami Belt	2. Kanto Mountains	3. Akiyoshi Belt	4. Indiana	5. Missouri	6. Oklahoma	7. Idaho	8. Verkhoyansk Range	9. Taimyr Peninsula	10 . Novaya Zemlya	11. Pechora Basin	12. England	13. Wales	14. Isle of Man	15. Northern Ireland	16. Ireland	17. Poland	18. Belgium
Ovatia elongata	+					+												
Rhipidomella michelini	+								+		+	+	+		+	+	+	+
Schizophoria resupinata	+	+	+				+	+	+	+	+	+	+	+			+	+
Schizophoria pinguis	+											+					+	+
Schizophoria woodi	+											+		+	+		+	+
Unispirifer striatoconvolutus	+																	
Unispirifer sp.	+																	
Kitakamithyris hikoroitiensis	+																	
Syringothyris texta	+			+	+													
Syringothyris platypleura	+				+													
Pseudosyrinx jumonjiensis	+																	

Species \ Stage			W. Russia			C. Russia				NW China					N. China	NE China	SW China		E. Australia
	19. Farnce	20. Spain	21. Moscow Basin	22. Donetz Basin	23. Iran	24. Southern Urals	25. Kuznetsk Basin	26. Kazakhstan	27. Uzbekistan	28. Xinjiang	29. Qinghai	30. Gansu	31. Ningxia	32. Shaanxi	33. Inner Mongolia	34. Liaoning	35. Guizhou	36. Yunnan	37. New South Wales
Ovatia elongata										+	+								
Rhipidomella michelini	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	
Schizophoria resupinata		+	+	+		+	+	+	+	+				+	+		+	+	
Schizophoria pinguis																			
Schizophoria woodi						+													
Unispirifer striatoconvolutus																		+	+
Unispirifer sp.																			
Kitakamithyris hikoroitiensis																			
Syringothyris texta																			
Syringothyris platypleura																			
Pseudosyrinx jumonjiensis																			

Figure 4. Geographic distribution of brachiopod species of the Shimoarisu fauna.

ris texta is known only from the lower Visean (Weller, 1914; Tazawa, 2006); *Syringothyris platypleura* is known from the upper Tournaisian–lower Visean (Weller, 1914; Minato, 1952); *Kitakamithyris hikoroitiensis* is known from the upper Famennian–lower Visean (Tazawa, 2018a); three species (*Schizophoria resupinata*, *Sch. pinguis* and *Unispirifer striatoconvolutus*) are known from the upper Tournaisian–upper Visean (Campbell, 1957; Pocock, 1968; Shi *et al.*, 2005; Tazawa, 2018b); and *Schizophoria woodi* is known from the upper Tournaisian–Serpukhovian (Demanet, 1934; Lazarev, 1976). *Ovatia elongata* and *Rhipidomella michelini* are long-ranging species, known from the Famennian–upper Visean (Zhang *et al.*, 1983; Zong *et al.*, 2012) and from the upper Tournaisian–Bashkirian (Tazawa, 2018b), respectively. At the generic level, *Unispirifer* ranges from the lower Tournaisian to the upper Visean (Carter, 2006a), and *Pseudosyrinx* ranges from the upper Tournaisian to the lower Visean (Carter, 2006b). In summary, the Shimoarisu fauna is assigned to the early Visean, meaning that the middle part of the Arisu Formation correlates with the lower Visean.

Regarding the age of the Arisu Formation, Minato *et al.* (1953) proposed that the Jumonji Stage (= middle and upper parts of the Arisu Formation) correlates with the upper Tournaisian–lower Visean of Europe and the Osagean of the USA, based on the abundant occurrence of *Syringothyris* in the D_0 Zone. Minato and Kato (1979) later regarded the age of the Arisu Formation as late Tournaisian on the basis of brachiopods (*Syringothyris* spp., *Spirifer kozuboensis* and "*Athyris*" *lamellosa*), a crinoid (*Platycrinus asiaticus*), and a blastoid (*Nymphaeoblastus anossofi*) from the D_0 Zone. Kawamura (1983) considered that the middle part of the Arisu Formation correlated in lithology with the middle part of the Hikoroichi Formation, which was considered to be early Visean in age based on the occurrence of a rugose coral (*Amygdalophyllum etheridgei*). The conclusion of the present study is consistent with that of Kawamura (1983), although the latter study lacked fossil evidence for the age of the middle part (D_0 Zone) of the Arisu Formation.

Palaeobiogeography

The geographic distributions of the brachiopod species of the Shimoarisu fauna are summarized in Figures 4 and 5. Among the 11 species of the fauna, four also occur in the UK (England), Poland and Belgium, and three also occur in central Russia (southern Urals), northwestern China (Xinjiang) and southwestern China (Yunnan). These data suggest that the Shimoarisu fauna has a close affinity with the lower Carboniferous faunas of England, Poland, Belgium, the southern Urals, Xinjiang and Yunnan. It is noteworthy that the syringothyridid genera (*Syringothyris* and *Pseudosyrinx*) are abundant in the Shimoarisu fauna. These genera are antitropical elements distributed in the Boreal and Gondwanan provinces (e.g. Liao, 1995), and characteristic members of the North China Province (Yang, 1980, 1983), the Tianshan–

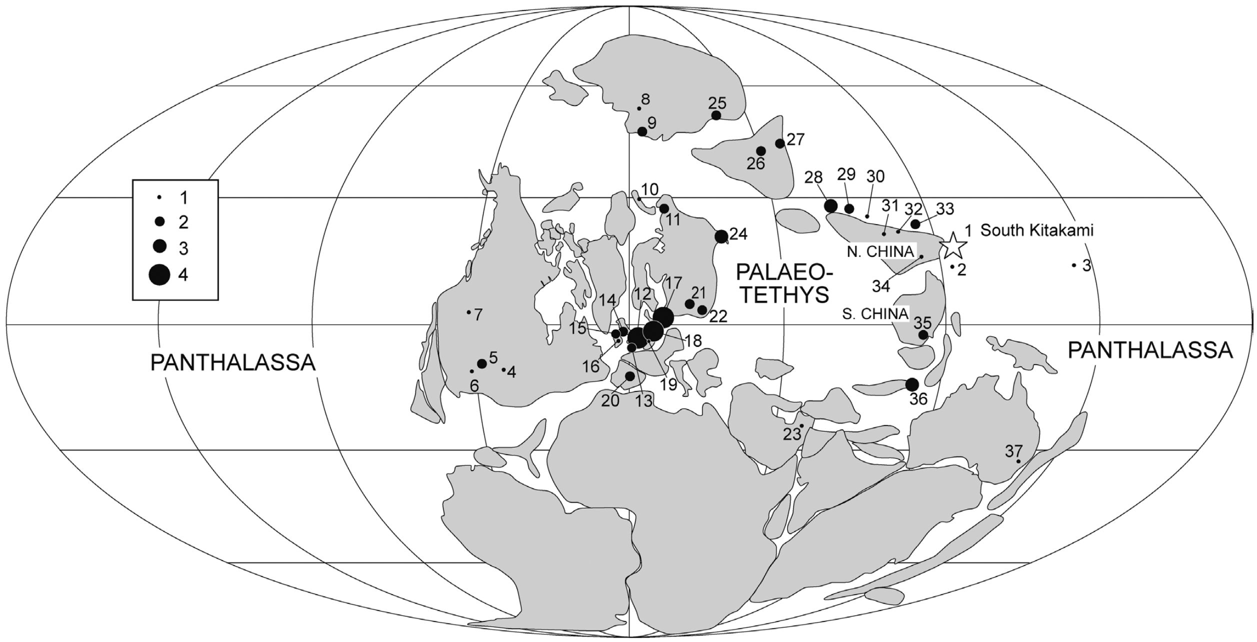

Figure 5. Early Carboniferous (Visean) reconstruction map of the world (adapted from Scotese, 2004), showing the geographic distribution of brachiopod species of the Shimoarisu fauna excluding the one uncertain species (*Unispirifer* sp.). Solid circles indicate numbers of brachiopod species listed in the Shimoarisu fauna. Station numbers are the same as in Figure 4.

Jilin Province (Yang, 1994), and the Tianshan–Hinggan Province (Liao, 1995), all of which occupied the area of present-day northwestern–northeastern China in the early Carboniferous. Therefore, South Kitakami, including the Shimoarisu area, was probably the eastern extension of the brachiopod province of northern China, and located near and to the east of North China in the early Visean. This conclusion is consistent with that of Tazawa (2002, 2006, 2017, 2018b).

Systematic descriptions

Order Productida Sarytcheva and Sokolskaya, 1959
Suborder Productidina Waagen, 1883
Superfamily Linoproductoidea Stehli, 1954
Family Linoproductidae Stehli, 1954
Subfamily Linoproductinae Stehli, 1954
Genus ***Ovatia*** Muir-Wood and Cooper, 1960

Type species.—*Ovatia elongata* Muir-Wood and Cooper, 1960.

Ovatia elongata Muir-Wood and Cooper, 1960

Figure 6H

Ovatia elongata Muir-Wood and Cooper, 1960, p. 312, pl. 114, figs. 1–4, 7, 11, 12; Jin *et al*., 1979, p. 93, pl. 28, figs. 8, 9, 11; Zhang *et al*., 1983, p. 297, pl. 108, fig. 9; Zong *et al*., 2012, p. 423, pl. 1, figs. 41–43.

Material.—Two specimens, external moulds of two dorsal valves, IGPS111725, 111726.

Remarks.—These specimens are referred to *Ovatia elongata* Muir-Wood and Cooper (1960, p. 312, pl. 114, figs. 1–4, 7, 11, 12), from the lower Fayetteville Formation of Oklahoma, in the large, elongate shell (length 43 mm, width 24 mm in the larger dorsal valve specimen, IGPS111725) and external ornament of the dorsal valve consisting of numerous fine costellae and irregular rugae, numbering 12–13 costellae in 5 mm at midlength. *Ovatia ovata* (Hall, 1858), redescribed by Sarytcheva (1937, p. 72, 110, pl. 6, fig. 5) from the upper Visean of the Moscow Basin, western Russia, differs from *O. elongata* in the smaller and less elongate shell and the finer costellae on the dorsal valve. *Ovatia laevicosta* (White, 1860), redescribed by Carter (1999, p. 109, figs. 4I–N) from the St. Joe Formation of Oklahoma, differs from *O. elongata* in having coarser costellae on both ventral and dorsal valves. *Ovatia nascens* Carter (1988, p. 42, figs. 7.32–7.37), from the Glen Park Formation of Illinois, differs from the present species in having finer costellae.

Distribution.—Famennian–upper Visean: northeastern Japan (Shimoarisu in the South Kitakami Belt), USA (Oklahoma) and northwestern China (Xinjiang and

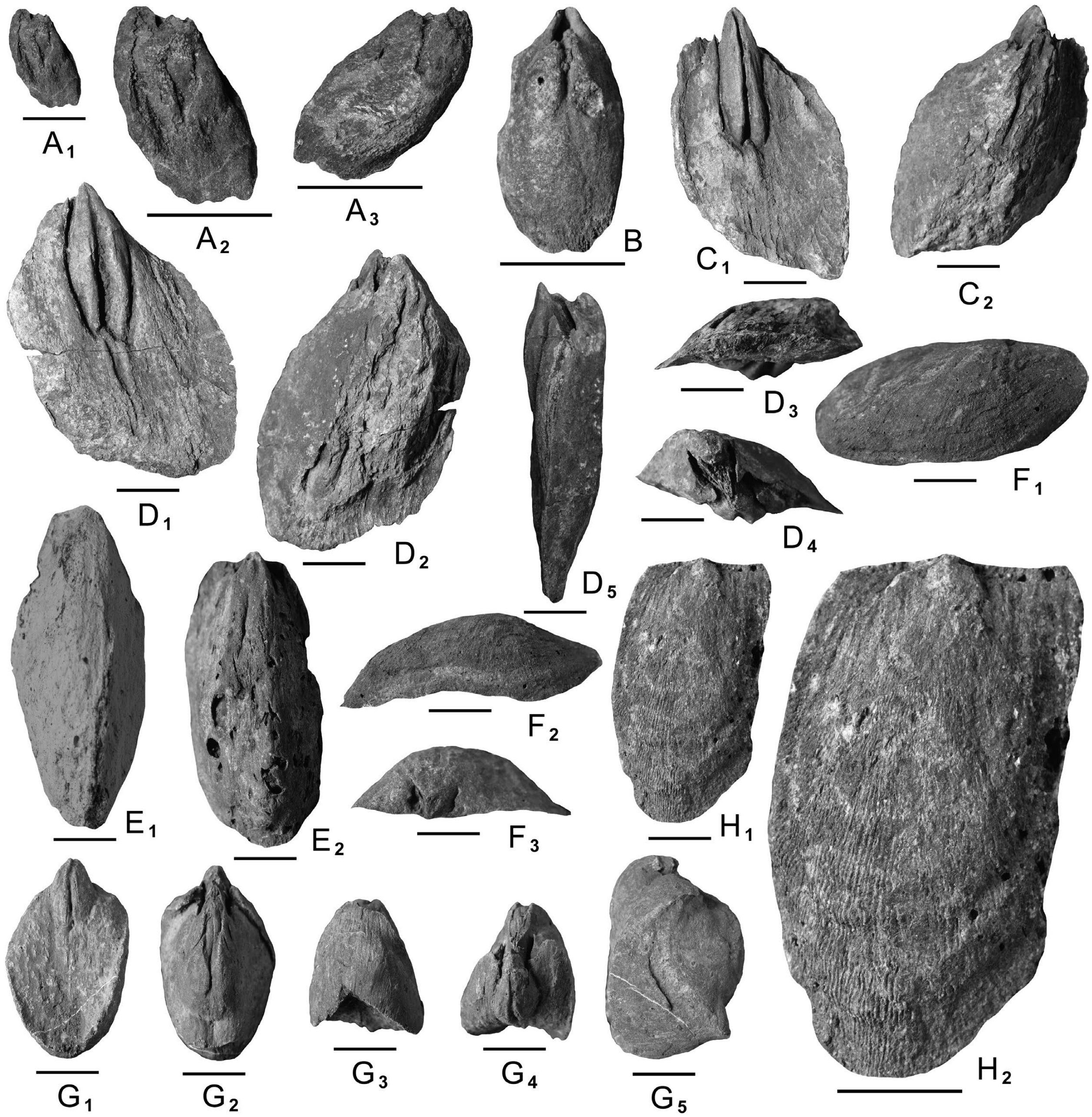

Figure 6. **A, B,** *Rhipidomella michelini* (Léveillé); ventral view (A_1, A_2) and dorsal view (A_3) of internal mould of conjoined shell, IGPS111721; B, internal mould of dorsal valve, IGPS111724; **C, D,** *Schizophoria resupinata* (Martin); ventral view (C_1) and dorsal view (C_2) of internal mould of conjoined shell, IGPS111716; ventral view (D_1), dorsal view (D_2), anterior view (D_3), posterior view (D_4) and lateral view (D_5) of internal mould of conjoined shell, IGPS111715; **E, F,** *Schizophoria pinguis* Demanet; external latex cast (E_1) and internal mould (E_2) of dorsal valve, IGPS111729; ventral view (F_1), anterior view (F_2) and posterior view (F_3) of internal mould of dorsal valve, IGPS111730; **G,** *Schizophoria woodi* Bond, ventral view (G_1), dorsal view (G_2), anterior view (G_3), posterior view (G_4) and lateral view (G_5) of conjoined shell, IGPS111728; **H,** *Ovatia elongata* Muir-Wood and Cooper, external mould (H_1, H_2) of dorsal valve, IGPS111725. Scale bars represent 1 cm.

Qinghai).

Order Orthida Schuchert and Cooper, 1932

Suborder Dalmanellidina Moore, 1952

Superfamily Dalmanelloidea Schuchert, 1913

Family Rhipidomellidae Schuchert, 1913

Subfamily Rhipidomellinae Schuchert, 1913
Genus ***Rhipidomella*** Oehlert, 1890

Type species.—*Terebratula michelini* Léveillé, 1835.

Rhipidomella michelini (Léveillé, 1835)

Figure 6A, B

Terebratula michelini Léveillé, 1835, p. 39, pl. 2, figs. 14–17.
Orthis michelini (Léveillé). Davidson, 1861, p. 132, pl. 30, figs. 6–12.
Dalmanella michelini (Léveillé). Frech, 1900, p. 201, pl. 16, fig. 15.
Rhipidomella michelini (Léveillé). Tolmatchoff, 1924, p. 212, 569, pl. 13, fig. 4; Rotai, 1931, p. 44, pl. 1, fig. 3; Demanet, 1934, p. 37, pl. 2, figs. 1–9; Sarytcheva in Sarytcheva and Sokolskaya, 1952, p. 26, pl. 1, fig. 7: Litvinovich, 1962, p. 177, pl. 1, fig. 1; Zang in Yang *et al*., 1962, p. 19, pl. 1, figs. 1–7; Ustritsky and Tschernjak, 1963, p. 68, pl. 1, figs. 11, 12; Yang, 1964, p. 58, pl. 1, fig. 1; Brunton, 1968, p. 17, pl. 3, figs. 1–25, text-fig. 5; Litvinovich *et al*., 1969, p. 127, pl. 1, figs. 9, 10; Bublichenko, 1971, p. 29, pl. 2, figs. 9–12; Alexandrow and Solomina, 1973, p. 87, pl. 21, fig. 1; Kalashnikov, 1974, p. 21, pl. 3, figs. 7–9; Volgin and Kushnar, 1975, p. 21, pl. 1, figs. 1, 2; Lee and Gu, 1976, p. 231, pl. 131, figs. 1–6; Martinez Chacon, 1979, p. 63, pl. 3, figs. 12–15; pl. 4, figs. 1–15, text-figs. 6, 7; Lee *et al*., 1980, p. 330, pl. 145, fig. 4; Ding and Qi, 1983, p. 250, pl. 88, fig. 13; Zakowa, 1989, p. 115, pl. 3, fig. 5; pl. 7, fig. 7; Harper and Jeffrey, 1996, fig. 3a. Legrand-Blain in Legrand-Blain *et al*., 1996, p. 180, pl. 28, figs. 21, 22. Jiang, 1997, pl. 1, fig. 3; Bassett and Bryant, 2006, p. 502, pl. 1, figs. 1–4; pl. 6, figs. 11–17; Sun and Baliński, 2008, p. 519, fig. 26; Tazawa, 2018b, p. 52, figs. 26A–C, 30G.
Rhipidomella sp. Tazawa and Katayama, 1979, p. 170, pl. 11, figs. 1–7; Mori and Tazawa, 1980, text-figs. 3.4–3.6; Tazawa, 1984, p. 305, pl. 61, figs. 5–7.

Material.—Four specimens: (1) internal moulds of two conjoined shells, IGPS111721, 111722; (2) internal mould of a ventral valve, IGPS111723; and (3) internal mould of a dorsal valve, IGPS111724.

Remarks.—These specimens can be referred to *Rhipidomella michelini* (Léveillé, 1835), redescribed by Brunton (1968, p. 17, pl. 3, figs. 1–25, text-fig. 5) from the Visean of Fermanagh, northern Ireland, in size and outline of the shell, particularly, in having short hinge and the widest part at slightly anterior to midlength. *Rhipidomella altaica* Tolmatchoff (1924, p. 213, 569, pl. 13, figs. 5–7, 9, 10), from the Tournaisian of the Kuznetsk Basin, central Russia, differs from *R. michelini* in having longer hinge and the widest part at midlength of the shell.

Distribution.—Upper Tournaisian–lower Bashkirian: northeastern Japan (Hikoroichi, Shimoarisu and Yokota in the South Kitakami Belt), northern Russia (Taimyr Peninsula and Pechora Basin), UK (England, Wales and northern Ireland), Ireland, Poland, Belgium, France (French Pyrenees), Spain (Cantabrian Mountains), western Russia (Moscow Basin and Donetz Basin), Iran, central Russia (southern Urals and Kuznetsk Basin), Kazakhstan, Uzbekistan, northwestern China (Xinjiang, Qinghai, Gansu and Ningxia), northern China (Inner Mongolia), northeastern China (Liaoning) and southwestern China (Guizhou and Yunnan).

Superfamily Enteletoidea Waagen, 1884
Family Schizophoriidae Schuchert and LeVene, 1929
Genus ***Schizophoria*** King, 1850

Type species.—*Conchyliolithus (Anomites) resupinatus* Martin, 1809.

Schizophoria resupinata (Martin, 1809)

Figure 6C, D

Conchiliolithus (Anomites) resupinatus Martin, 1809, pl. 49, figs. 13, 14.
Orthis resupinata (Martin). Davidson, 1861, p. 130, pl. 29, figs. 1–4; pl. 30, figs. 1–5.
Schizophoria resupinata (Martin). Yanishevsky, 1918, p. 19, pl. 1, figs. 4, 12; pl. 4, fig. 2; pl. 6, fig. 16; Demanet, 1934, p. 45, pl. 3, figs. 1–5, text-fig. 9; Miloradovich, 1935, p. 6, pl. 1, figs. 11, 12; Bond, 1941, p. 289, pl. 21, figs. A–C, text-figs. 33, 34; Minato, 1952, p. 150, pl. 5, fig. 3; pl. 6, fig. 4; Sarytcheva in Sarytcheva and Sokolskaya, 1952, p. 29, pl. 2, fig. 12; Parkinson, 1954, p. 368, text-figs. 1, 2; Litvinovich, 1962, p. 178, pl. 1, fig. 2; Beznossova in Sarytcheva *et al*., 1963, p. 77, pl. 3, figs. 5–8, text-fig. 24; Ustritsky and Tschernjak, 1963, p. 69, pl. 1, figs. 13–16; Yang, 1964, p. 59, pl. 1, figs. 2, 3; Abramov, 1965, p. 35, pl. 2, fig. 3; Brunton, 1968, pl. 2, figs. 1–6; Pocock, 1968, p. 80, pl. 18, fig. 7, text-figs. 13–15; Beznossova *et al*. in Sarytcheva, 1968, p. 53, pl. 1, figs. 11–13; Lazarev, 1969, pl. 10, figs. 1–5, text-figs. 1, 2; Litvinovich *et al*., 1969, p. 129, pl. 2, fig. 1; Abramov, 1970, p. 107, pl. 1, figs. 5–7; Aisenverg and Poletaev, 1971, pl. 60, fig. 1; Nalivkin and Fotieva, 1973, p. 20, pl. 1, figs. 6–8; Yanagida, 1973, p. 101, pl. 16, figs. 3–9; Kalashnikov, 1974, p. 22, pl. 3, figs. 1–3; Garanj *et al*., 1975, p. 155, pl. 62, fig. 2; Volgin and Kushnar, 1975, p. 23, pl. 1, figs. 3–5; Litvinovich *et al*., 1975, p. 52, pl. 16, fig. 7; Lazarev, 1976, pl. 2, figs. 3, 4; pl. 3, figs. 1–5, text-fig. 58, table 11; Lee and Gu, 1976, p. 229, pl. 131, figs. 7, 9–11; Martinez Chacon, 1979, p. 54, pl. 2, figs. 1–15; pl. 3, figs. 1–10, text-figs. 3–5; Minato *et al*., 1979, pl. 22, figs. 1, 2; Tazawa and Katayama, 1979, p. 169, pl. 11, figs. 8–14; Kalashnikov, 1980, p. 24, pl. 2, figs. 2, 3; Mori and Tazawa, 1980, text-fig. 3.3; Tazawa, 1981, p. 67, pl. 5, figs. 3–5; Ding and Qi, 1983, p. 245, pl. 88, fig. 7; Zhang *et al*., 1983, p. 265, pl. 107, figs. 1–3; Tazawa, 1984, p. 304, pl. 61, fig. 9; Abramov and Grigorjeva, 1986, p. 74, pl. 1, figs. 15–18; Yanai *et al*., 1988, pl. 1, figs. 9, 10; Zakowa, 1989, p. 103, pl. 1, figs. 1–5; pl. 2, figs. 1–5; pl. 3, figs. 1–4, text-figs. 2–10, table 2; Jiang, 1997, pl. 1, figs. 1, 2; Bassett and Bryant, 2006, p. 504, pl. 6, figs. 1–10; pl. 7, figs. 1–16, text-figs. 5–7; Butts, 2007, p. 55, figs. 5.3–5.10; Ibaraki *et al*., 2014, p. 73, figs. 4.1, 4.2; Tazawa, 2018b, p. 54, figs 18A, B, 26G, H, 31A–E.
Schizophoria aff. *resupinata* (Martin). Yanagida, 1962, p. 122, pl. 21, figs. 4–13; text-fig. 22; Hase and Yokoyama, 1975, pl. 16, figs. 6, 7.
Schizophoria (*Schizophoria*) *resupinata* (Martin). Sun and Baliński, 2008, p. 521, figs. 27F–L.

Material.—Six specimens: (1) internal moulds of two conjoined shells, IGPS111715, 111716; and (2) internal moulds of four ventral valves, IGPS111717–111720.

Remarks.—These specimens are referred to *Schizophoria resupinata* (Martin, 1809), redescribed by Pocock (1968, p. 80, pl. 18, fig. 7, text-figs. 13–15) from the upper Tournaisian–upper Visean of Belgium and Britain, in its medium size (length about 30 mm, width about 56 mm in the largest specimen, SA8), transversely subrectangular outline, respinate shell, and the moderately incised and flabellate ventral muscle field. *Schizophoria connivens* (Phillips, 1836), redescribed by Pocock (1968, p. 64, pl. 18, figs. 1, 2, text-figs. 1–4) from the Tournaisian–Visean of Belgium and Britain, differs from *Sch. resupinata* in its smaller size and in having a deeper sulcus and a more strongly incised, elliptical muscle field in the ventral valve.

Distribution.—Upper Tournaisian–upper Visean: northeastern Japan (Hikoroichi, Shimoarisu and Yokota in the South Kitakami Belt), central Japan (Kanto Mountains), southwestern Japan (Akiyoshi Belt), USA (Idaho), northern Russia (Verkhoyansk Range, Taimyr Peninsula, Novaya Zemlya and Pechora Basin), UK (England, Wales and Isle of Man), Poland, Belgium, Spain, western Russia (Moscow Basin and Donetz Basin), central Russia (southern Urals and Kuznetsk Basin), Kazakhstan, Uzbekistan (Fergana), northwestern China (Xinjiang and Shaanxi), northern China (Inner Mongolia) and southwestern China (Guizhou and Yunnan).

Schizophoria pinguis Demanet, 1934

Figure 6E, F

Schizophoria resupinata var. *pinguis* Demanet, 1934, p. 59, pl. 4, figs. 9–11; Bond, 1941, figs. 33, 34; Pocock, 1968, text-fig. 21.
Schizophoria pinguis Demanet. George and Ponsford, 1938, figs. 8, 9.
Schizophoria resupinata pinguis Demanet. Tazawa and Kurita, 1986, p. 167, figs. 2.2, 2.3.
Schizophoria (*Schizophoria*) *resupinata* forma *pinguis* Demanet. Zakowa, 1989, p. 109, pl. 6, figs. 1–10; pl. 7, figs. 1–4, text-figs. 2–9, table 6.

Material.—Four specimens: (1) external and internal moulds of a dorsal valve, IGPS111729; and (2) internal moulds of three dorsal valves, IGPS111730–111732.

Remarks.—These specimens can be referred to *Schizophoria pinguis* Demanet (1934, p. 59, pl. 4, figs. 9–11) from the upper Visean of Visé, Belgium, in their medium to large size (length 48 mm, width 28 mm in the largest specimen, IGPS111729; length 23 mm, width 46 mm in the best preserved specimen, IGPS111730), highly inflated dorsal valve and weakly uniplicate anterior commissure. *Schizophoria gibbera* (Portlock, 1843), redescribed by Pocock (1968, p. 69, pl. 18, fig. 3, text-figs. 5–7) from the upper Tournaisian–lower Visean of England and Ireland, has also a strongly convex dorsal valve, but differs from *S. pinguis* in having a concentric fold on the dorsal valve. The preceding species, *Schizophoria resupinata* (Martin, 1809), is readily distinguished from the present species in having a gently convex dorsal valve.

Distribution.—Upper Tournaisian–upper Visean: northeastern Japan (Shimoarisu and Okuhinotsuchi in the South Kitakami Belt), UK (England), Poland and Belgium.

Schizophoria woodi Bond, 1941

Figure 6G

Schizophoria resupinata var. *gibbera* (Portlock). Demanet, 1934, p. 55, pl. 4, figs. 1–3 only.
Schizophoria woodi Bond, 1941, p. 299, pl. 22, figs. f, g, text-fig. 37; Pocock, 1968, p. 86, pl. 18, fig. 8, text-figs. 16–19; Lazarev, 1976, pl. 6, fig. 2, text-fig. 64.
Schizophoria (*Paraschizophoria*) *woodi* Bond. Zakowa, 1989, p. 113, pl. 8, figs. 1, 2, table 10.

Material.—One specimen, internal mould of a conjoined shell, IGPS111728.

Remarks.—The single specimen from Shimoarisu is referred to *Schizophoria woodi* Bond (1941, p. 299, pl. 22, figs. F, G, text-fig. 37) from the upper Visean of Craven, Yorkshire, England, based on its small size (length about 33 mm, width about 20 mm) and strongly dorsibiconvex shell, with angular uniplicate anterior commissure. *Schizophoria palliata* Demanet (1934, p. 58, pl. 4, figs. 7, 8), from the upper Tournaisian of Belgium, differs from *Sch. woodi* in having a rounded anterior commissure.

Distribution.—Upper Tournaisian–Serpukhovian: northeastern Japan (Shimoarisu in the South Kitakami Belt), UK (England, Isle of Man and northern Ireland), Poland, Belgium and central Russia (southern Urals).

Order Spiriferida Waagen, 1883
Suborder Spiriferidina Waagen, 1883
Superfamily Spiriferoidea King, 1846
Family Spiriferidae King, 1846
Subfamily Prospirinae Carter, 1974
Genus ***Unispirifer*** Campbell, 1957

Type species.—*Spirifer striatoconvolutus* Dun and Benson, 1920.

Unispirifer striatoconvolutus (Dun and Benson, 1920)

Figure 7A

Spirifera striato-convoluta Dun and Benson, 1920, p. 350, pl. 20, figs. 7, 8.
Unispirifer striatoconvolutus (Dun and Benson). Campbell, 1957, p. 68, pl. 14, figs. 1–9; text-figs. 10–12; Jiang, 1993, p. 216, pl. 1, figs. 1–14, text-figs. 1, 2; Jiang, 1997, pl. 3, figs. 12–14; pl. 4, fig. 13; Tazawa, 2018b, p. 64, fig. 27D–G.

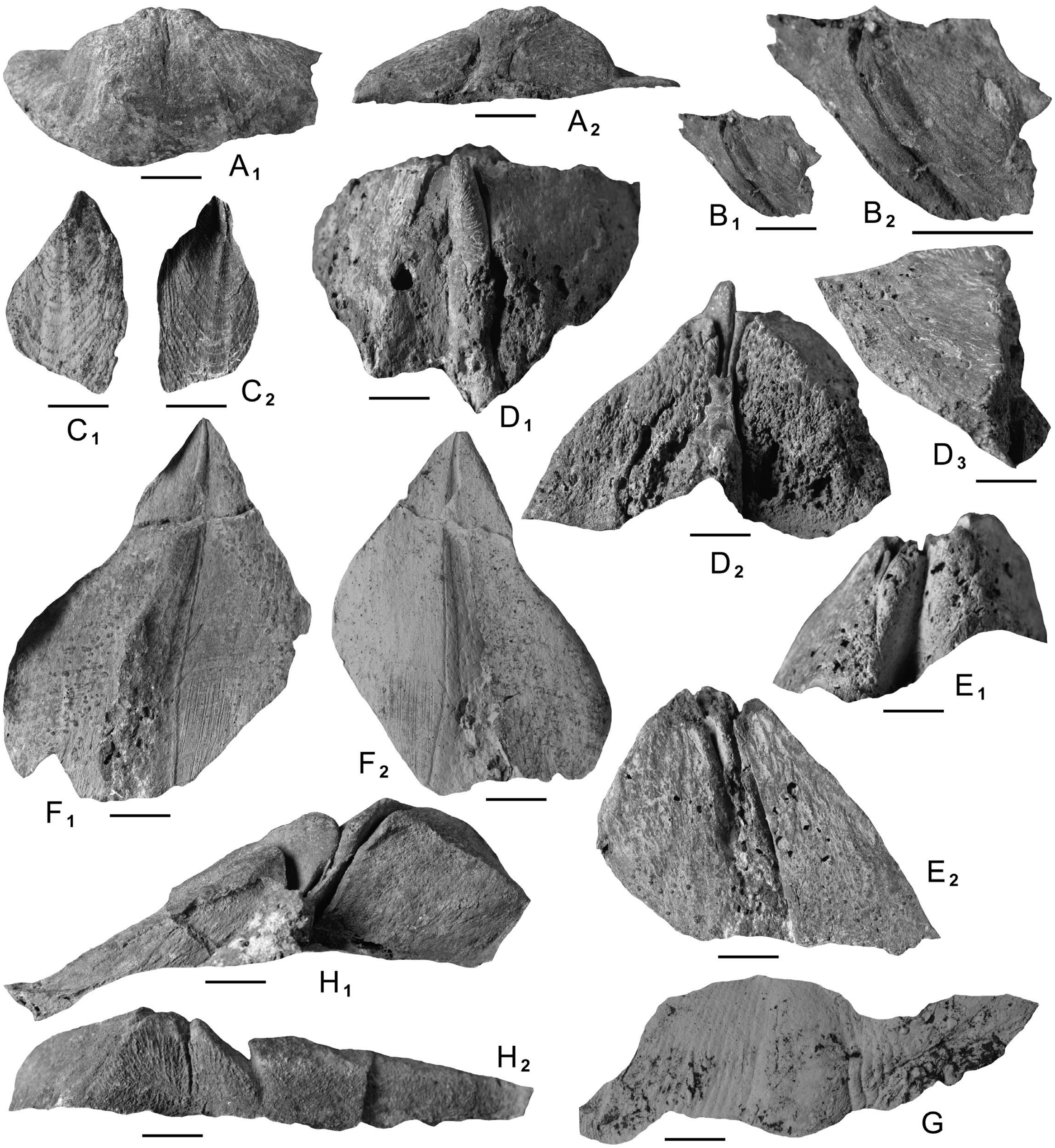

Figure 7. **A,** *Unispirifer striatoconvolutus* (Dun and Benson), ventral view (A_1) and posterior view (A_2) of internal mould of ventral valve, IGPS111733; **B,** *Unispirifer* sp., ventral view (B_1, B_2) of internal mould of ventral valve, IGPS111734; **C,** *Kitakamithyris hikoroitiensis* (Minato), external latex cast (C_1) and external mould (C_2) of ventral valve, IGPS111727; **D, E,** *Syringothyris platypleura* Weller; ventral view (D_1), posterior view (D_2) and lateral view (D_3) of internal mould of dorsal valve, IGPS111711; ventral view (E_1) and posterior view (E_2) of internal mould of ventral valve, IGPS111712; **F, G,** *Pseudosyrinx jumonjiensis* (Minato); external mould (F_1) and external latex cast (F_2) of ventral interarea, IGPS111713; G, external latex cast of dorsal valve, IGPS111714; **H,** *Syringothyris texta* (Hall), posterior view (H_1) and ventral view (H_2) of internal mould of ventral valve, IGPS111710. Scale bars represent 1 cm.

Unispirifer (*Unispirifer*) *striatoconvolutus* (Dun and Benson). Shi *et al*., 2005, p. 55, figs. 12G–K.

Material.—One specimen, internal mould of a ventral valve, IGPS111733.

Remarks.—This specimen is referred to *Unispirifer striatoconvolutus* (Dun and Benson, 1920), redescribed by Campbell (1957, p. 68, pl. 14, figs. 1–9, text-figs. 10–12) from the Merlewood Formation of Babbinboon, New South Wales, eastern Australia, on account of the large, transverse and mucronate ventral valve (length about 26 mm, width about 59 mm), with very shallow sulcus. *Unispirifer fluctuosus* (Glenister, 1955, p. 68, pl. 7, figs. 1–14; pl. 8, fig. 1–8), from the Moogooree Limestone of the North-West Basin, northwestern Australia, differs from *U. striatoconvolutus* in its smaller size and in having more acute cardinal extremities.

Distribution.—Upper Tournaisian–upper Visean: northeastern Japan (Hikoroichi and Shimoarisu in the South Kitakami Belt), southwestern China (Yunnan) and eastern Australia (New South Wales).

Unispirifer sp.

Figure 7B

Material.—Two specimens, internal moulds of two ventral valves, IGPS111734, 111735.

Remarks.—These specimens are safely assigned to the genus *Unispirifer* on the basis of alate cardinal extremities of the ventral valves. The Shimoarisu species resembles *Unispirifer mediocris* (Tolmatchoff, 1924, p. 181, 561, pl. 11, figs. 13, 14), from the Tournaisian of the Kuznetsk Basin, central Russia, in its small size (length 19 mm, width about 25 mm in the larger specimen, IGPS111734) and transverse outline. However, accurate comparison is difficult for the poorly preserved specimens. *Unispirifer kozuboensis* (Minato, 1952, p. 155, pl. 5, fig. 7), from the D$_0$ Zone of the Jumonji Stage (= middle part of the Arisu Formation) of the Yokota area, South Kitakami Belt, differs from the present species in its larger size and more transverse outline.

Suborder Delthyridina Ivanova, 1972
Superfamily Reticularioidea Waagen, 1883
Family Elythidae Fredericks, 1924
Subfamily Elythinae Fredericks, 1924
Genus ***Kitakamithyris*** Minato, 1951

Type species.—*Torynifer* (*Kitakamithyris*) *tyoanjiensis* Minato, 1951.

Kitakamithyris hikoroitiensis (Minato, 1951)

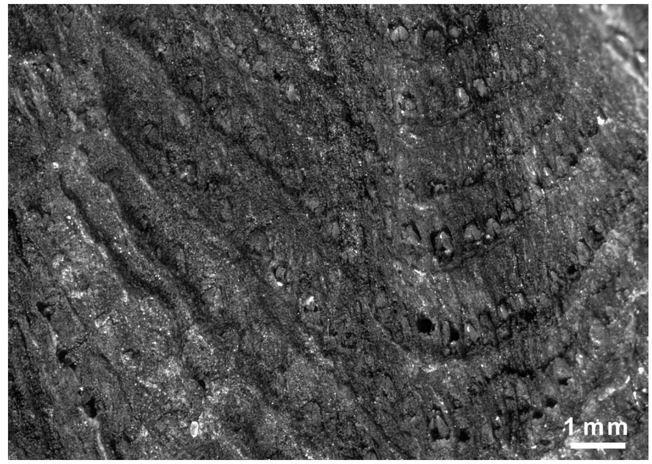

Figure 8. *Kitakamithyris hikoroitiensis* (Minato), enlarged concentric rows of biramous spine bases on external mould of ventral valve, IGPS111727.

Figures 7C, 8

Torynifer (*Kitakamithyris*) *hikoroitiensis* Minato, 1951, p. 375, pl. 1, fig. 1.

Kitakamithyris hikoroitiensis (Minato). Minato, 1952, p. 171, pl. 7, fig. 3; pl. 8, fig. 6; Minato *et al*., 1979, pl. 16, fig. 1; Tazawa, 2018a, p. 141, figs. 20B, C, 21B, 29A, B.

Kitakamithyris semicircularis Minato, 1952, p. 171, pl. 7, fig. 6; pl. 8, fig. 5; pl. 10, fig. 3; Minato *et al.*, 1979, pl. 15, fig. 1.

Material.—One specimen, external mould of a ventral valve, IGPS111727.

Remarks.—The available material is strongly deformed, but can be referred to *Kitakamithyris hikoroitiensis* (Minato, 1951, p. 375, pl. 1, fig. 1), originally described from the lower part of the Hikoroiti Series (= Choanji Formation of Tazawa and Niikawa, 2018) of Tyoanji (Choanji), South Kitakami Belt, on account of its relatively large and sporadically arranged spine bases (numbering 5–6 in 5 mm at about midlength) on the ventral valve. *Kitakamithyris semicircularis* Minato (1952, p. 171, pl. 7, fig. 6; pl. 8, fig. 5; pl. 10, fig. 3), from the Choanji, Hikoroichi and Arisu formations of the South Kitakami Belt, is deemed a junior synonym of *K. hikoroitiensis*. The type species, *Kitakamithyris tyoanjiensis* (Minato, 1951, p. 374, pl. 1, fig. 3; pl. 4, fig. 7), from the Choanji Formation of Choanji is readily distinguished from *K. hikoroitiensis* by the much smaller and tightly arranged spine bases on the ventral valve.

Distribution.—Upper Devonian (upper Famennian)–lower Visean: northeastern Japan (Choanji, Hikoroichi, Shimoarisu and Yokota in the South Kitakami Belt).

Order Spiriferinida Ivanova, 1972

Suborder Spiriferinidina Ivanova, 1972
Superfamily Syringothyridoidea Fredericks, 1926
Family Syringothyrididae Fredericks, 1926
Subfamily Syringothyridinae Fredericks, 1926
Genus ***Syringothyris*** Winchell, 1863

Type species.—*Syringothyris typa* Winchell, 1863.

Syringothyris texta (Hall, 1857)

Figure 7H

Spirifer textus Hall, 1857, p. 169.
Syringothyris textus (Hall). Weller, 1914, p. 399, pl. 69, figs. 6–9; pl. 70, figs. 1–4; pl. 71, figs. 1, 2.
Syringothyris transversa Minato, 1951, p. 377, pl. 5, fig. 1; Minato, 1952, p. 167, pl. 11, fig. 5 only; Minato *et al*., 1979, pl. 21, fig. 11; Tazawa, 2002, fig. 7.6; Tazawa, 2006, p. 134, figs. 7.1, 7.2.

Material.—One specimen, internal mould of a ventral valve, IGPS111710.

Remarks.—This specimen is referred to *Syringothyris texta* (Hall, 1857), redescribed by Weller (1914, p. 399, pl. 69, figs. 6–9; pl. 70, figs. 1–4; pl. 71, figs. 1, 2) from the Keokuk Limestone of Missouri and the Knobstone Formation of Indiana, in its large, transverse shell and relatively low and slightly concave ventral interarea with a syrinx in the delthyrium. *Syringothyris transversa* Minato (1951, p. 377, pl. 5, fig. 1), from the Jumonji Stage (= middle part of the Arisu Formation) of Shimoarisu and Yokota, South Kitakami Belt, is considered to be a junior synonym of the present species. *Syringothyris altaica* Tolmatchoff (1924, p. 162, 555, pl. 8, figs. 9–11; pl. 9, fig. 1), from the upper Tournaisian of the Kuznetsk Basin, central Russia, differs from *S. texta* in having blunt cardinal extremities. Shells, described by Shi *et al*. (2005, p. 70, figs. 18A, E) as *Syringothyris texta* (Hall) from the Yudong Formation of west Yunnan, differ from *S. texta* in having a much higher and acute triangle-shaped ventral interarea.

Distribution.—Lower Visean: northeastern Japan (Shimoarisu and Yokota in the South Kitakami Belt) and USA (Missouri and Indiana).

Syringothyris platypleura Weller, 1914

Figure 7D, E

Syringothyris platypleurus Weller, 1914, p. 397, pl. 72, figs. 1–4.
Syringothyris sp. Minato, 1952, p. 165, pl. 5, fig. 2; pl. 9, fig. 1.

Material.—Two specimens, internal moulds of two ventral valves, IGPS111711, 111712.

Description.—Shell medium in size for genus, slightly transverse subtriangular in outline with greatest width at hinge; cardinal extremities blunt, acute; length about 45 mm, width about 60 mm in the better preserved specimen (IGPS111711). Ventral valve subpyramidal in shape, with very high, flat interarea, measuring about 50 mm in height and about 60 mm in width, and nearly flat, steep lateral flanks; delthyrium narrowly triangular and having a distinct syrinx. Internally, ventral valve having a large muscle scar in the mid-posterior portion.

Remarks.—These specimens are referred to *Syringothyris platypleura* Weller (1914, p. 397, pl. 72, figs. 1–4), from the Burlington Limestone of the Mississippi Valley, in having a subpyramidal ventral valve with a very high, flat interarea and nearly flat flanks. *Syringothyris* sp. Minato (1952, p. 165, pl. 5, fig. 2; pl. 9, fig. 1) from the Jumonji Stage (= middle part of the Arisu Formation) of the Yokota area, South Kitakami Belt, is deemed a junior synonym of *S. platypleura*. *Syringothyris kitakamiensis* Minato (1952, p. 165, fig. 5), from the Arisu Formation of the Yokota area, South Kitakami Belt, differs from *S. platypleura* in having a high but slightly concave ventral interarea.

Distribution.—Upper Tournaisian–lower Visean: northeastern Japan (Shimoarisu and Yokota in the South Kitakami Belt) and USA (Missouri).

Subfamily Permasyrinxinae Waterhouse, 1986
Genus ***Pseudosyrinx*** Weller, 1914

Type species.—*Pseudosyrinx missouriensis* Weller, 1914.

Pseudosyrinx jumonjiensis (Minato, 1951)

Figure 7F, G

Syringothyris jumonjiensis Minato, 1951, p. 376, pl. 2, fig. 1; Minato *et al.*, 1979, pl. 21, fig. 12.

Material.—Two specimens: (1) external mould of a ventral valve, IGPS111713; and (2) external mould of a dorsal valve, IGPS111714.

Remarks.—These specimens are referred to *Pseudosyrinx jumonjiensis* (Minato, 1951, p. 376, pl. 2, fig. 1), from the middle part of the Arisu Formation of both the Yokota and Shimoarisu areas, South Kitakami Belt, in having a large ventral valve with a high, flat interarea and lacking a syrinx in the delthyrium. The present species most resembles *Pseudosyrinx missouriensis* Weller (1914, p. 406, pl. 65, figs. 5–9; pl. 66, figs. 11–13) from the Burlington Limestone of the Mississippi Valley, in general shape, but the American species is smaller in size. *Pseudosyrinx sampsoni* (Weller, 1909, p. 311, pl. 14, fig. 4), from the Fern Glen Formation of Missouri, is also a large-sized *Pseudosyrinx* species, but differs from *P. jumonjiensis* in having fewer and stronger costae on the dorsal valve.

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Author contributions

JT designed the study and primarily carried out the taxonomic analysis. YI conducted the fieldwork and sampling. Both authors contributed to the writing of the paper.