Middle Permian (Wordian) brachiopod fauna from Matsukawa, South Kitakami Belt, Japan, Part 2

Jun-ichi TAZAWA* and Hideo ARAKI**

Abstract

In this second manuscript in a series, additional brachiopods, consisting of 9 species in 9 genera, are described from the middle Permian (Wordian) Kamiyasse Formation of Matsukawa, South Kitakami Belt, northeastern Japan. The additional species, including one new species, to the Matsukawa fauna are as follows: *Neochonetes* (*Huangichonetes*) *matsukawensis* Tazawa and Araki, sp. nov., *Kunlunia* sp., *Permundaria asiatica* Nakamura, Kato and Choi, *Petasmaia expansa* Cooper and Grant, *Dicystoconcha lapparenti* Termier and Termier, *Meekella nodosa* Nakamura, *Orthothetina* sp., *Stenoscisma margaritovi* (Tschernyschew) and *Martinia* sp.

Key words: Brachiopoda, Matsukawa, middle Permian, Part 2, South Kitakami Belt.

Introduction

In a recent study (Tazawa and Araki, 2017), we described a brachiopod fauna, consisting of 19 species in 18 genera, from the middle Permian (Wordian) Kamiyasse Formation of Matsukawa, Kesennuma City, Miyagi Prefecture (in the South Kitakami Belt), northeastern Japan (Fig. 1). The present paper is a follow-up report on the middle Perman brachiopods of the Matsukawa fauna. In this paper, we describe brachiopods of 9 species in 9 genera from two localities, Anabuchi (AR4) and Omotematsukawa (KZ9). The locations and stratigraphic horizons of the fossil localities are indicated in Fig. 1 and Fig. 2, respectively. All specimens

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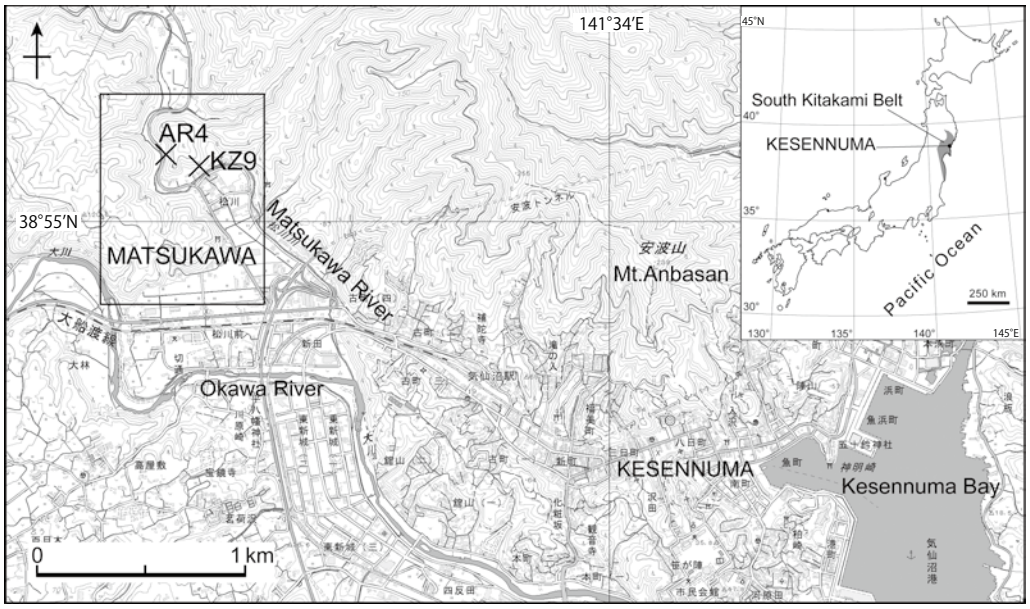

Fig. 1. Map showing the Matsukawa area, South Kitakami Belt and fossil localities AR4 (Anabuchi) and KZ9 (Omotematsukawa) in the area (after Tazawa and Araki, 2017).

were collected by the present author (H. Araki). They are now registered and housed in the Kesennuma Board of Education (tentatively placed in the Old Tsukitate Junior High School) in Kesennuma (prefix KCG, numbers KCG054 to KCG062).

The Matsukawa fauna

In Matsukawa middle Permian (Wordian) brachiopods, consisting of the following 24 species in 23 genera, have been described by Yabe (1900), Hayasaka (1917, 1922, 1925, 1963a, 1963b), Tazawa (1979) and Tazawa and Araki (1984a, 1984b, 1999, 2013, 2017): *Orbiculoidea jangarensis* Ustritsky, *Kitakamichonetes multicapillatus* Afanasjeva and Tazawa, *Capillomesolobus heritschi* Pečar, *Dyoros* (*Dyoros*) sp., *Transennatia gratiosa* (Waagen), *Hexiproductus echidniformis* (Chao), *Urushtenoidea crenulata* (Ding), *Scacchinella gigantea* Schellwien, *Linoproductus hayasakai* Tazawa, *Costatumulus cancriniformis* (Tschernyschew), *Permundaria tenuistriata* Tazawa, *Yakovlevia mammata* (Keyserling), *Y. kaluzinensis* Fredericks, *Productus flemingi* (Sowerby), *Scacchinella gigantea* Schellwien, *Neorichthofenia mabutii* (Tazawa and Araki), *Leptodus nobilis* (Waagen), *Keyserlingina* sp., *Paralyttonia kesennumensis* Tazawa and Araki, *Rhynchonella* (*Uncinulus*) *jabiensis* Waagen, *Martinia* sp., *Alispiriferella lita* (Fredericks), *Licharewia arakii* (Hayasaka) and *Dielasma* sp.

In this study, 9 species in 9 genera, including one new species, are newly described from Matsukawa. The species described herein are as follows: *Neochonetes* (*Huangichonetes*)

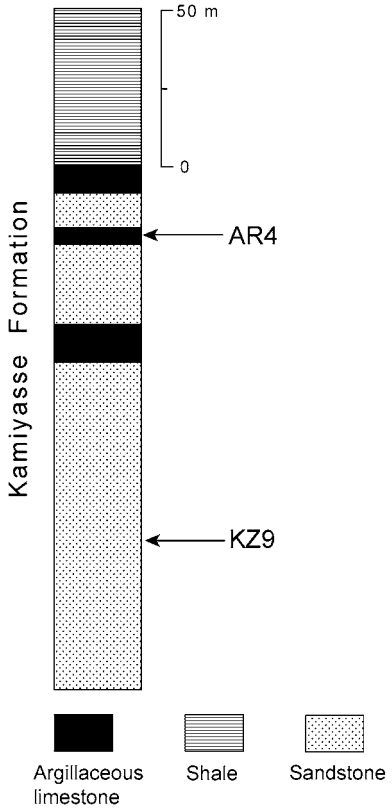

Fig. 2. Generalized columnar section of the lower part of the Kamiyasse Formation in the Matsukawa area, showing the fossil horizons of localities AR4 and KZ9 (after Tazawa and Araki, 2017).

matsukawensis Tazawa and Araki, sp. nov., *Kunlunia* sp., *Permundaria asiatica* Nakamura, Kato and Choi, 1970, *Petasmaia expansa* Cooper and Grant, 1969, *Dicystoconcha lapparenti* Termier and Termier in Termier et al., 1974, *Meekella nodosa* Nakamura, 1972, *Orthothetina* sp., *Stenoscisma margaritovi* (Tschernyschew, 1888) and *Martinia* sp. The total of brachiopods of the Matsukawa fauna, in the present, is 24 species in 23 genera.

On the age of the fauna, *Permundaria asiatica* is restricted to the Wordian; *Petasmaia expansa* is known from the Artinskian–Wordian; two species (*Meekella nodosa* and *Stenoscisma margaritovi*) are known from the Wordian–Wuchiapingian; and *Dicystoconcha lapparenti* is known from the Kungurian–Wuchiapingian (Fig. 3). In summary the Matsukawa fauna is assigned to the Wordian as discussed by Tazawa and Araki (2017). In terms of palaeobiogeography, the Matsukawa fauna is a Tethyan-type dominant Boreal–Tethyan mixed fauna, containing many Tethyan elements, such as *Neochonetes* (*Huangichonetes*), *Permundaria*, *Meekella* and *Orthothetina*, and a few Boreal element, *Kunlunia*. The conclusion is consistent with the previous studies on the middle Permian brachiopod faunas in the South Kitakami Belt (Tazawa et al., 2000; Tazawa and Ibaraki, 2001; Tazawa, 2016; Tazawa and Araki, 2017).

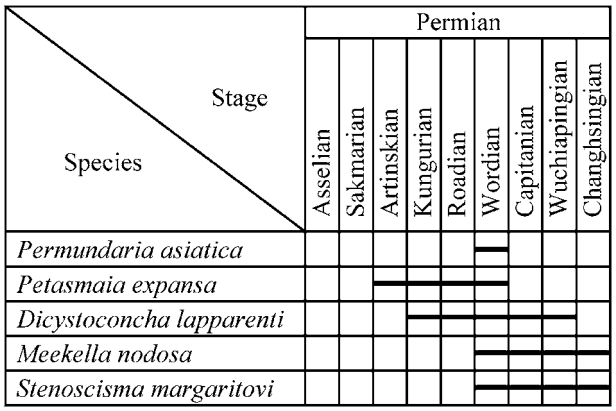

Fig. 3. Stratigraphic distribution of brachiopod species of the Matsukawa fauna, excluding one new species [*Neochonetes* (*Huangichonetes*) *matsukawensis* sp. nov.] and three uncertain species (*Kunlunia* sp., *Orthothetina* sp. and *Martinia* sp.).

Systematic descriptions

Order Productida Sarytcheva and Sokolskaya, 1959

Suborder Chonetidina Muir-Wood, 1995

Superfamily Chonetoidea Bronn, 1862

Family Rugosochonetidae Muir-Wood, 1962

Subfamily Rugosochonetinae Muir-Wood, 1962

Genus *Neochonetes* Muir-Wood, 1962

Subgenus *Huangichonetes* Shen and Archbold, 2002

Type species.—*Chonetes substrophomenoides* Huang, 1932.

Neochonetes (*Huangichonetes*) *matsukawensis* Tazawa and Araki, sp. nov.

Fig. 4.1

Etymology.—Named after the fossil locality, Matsukawa.

Material.—One specimen from locality AR4, external and internal moulds of a ventral valve, KCG061 (holotype).

Diagnosis.—Large, very transverse *Neochonetes* (*Huangichonetes*), with numerous costellae, numbering 56 near anterior margin on ventral valve.

Description.—Shell large in size for genus, transversely trapezoidal in outline; widest at hinge; length 8 mm, width 13 mm in the sole specimen (holotype). Ventral valve strongly convex in lateral profile, most convex at slightly anterior to midlength; umbo small; ears small but prominent; sulcus broad and shallow. External surface of ventral valve

ornamented with numerous costellae, numbering 56 near anterior margin; two or three spine bases preserved on each side of hinge. Ventral interior with a pair of strong teeth and a very short median septum; internal surface of ventral valve radially papillose.

Remarks.—*Neochonetes* (*Huangichonetes*) *matsukawensis* sp. nov. is most similar to the type species, *Neochonetes* (*Hunagichonetes*) *substrophomenoides* (Huang, 1932), redescribed by Shen and Archbold (2002, p. 337, figs. 5E–M), from the Lopingian of Hunan and Guizhou, South China, in shape and external ornament of the ventral valve, but differs from the Chinese species in the larger size and much transverse outline.

Superfamily Productoidea Gray, 1840
Family Dictyoclostidae Stehli, 1954
Subfamily Dictyoclostinae Stehli, 1954
Genus *Kunlunia* Wang in Zhang et al., 1983

Type species.—*Kunlunia aspera* Wang in Zhang et al., 1983.

Kunlunia sp.
Fig. 4.4

Material.—One specimen from locality AR4, external mould of a dorsal valve, KCG059.

Remarks.—This specimen can be assigned to the genus *Kunlunia* in the dictyoclostid shell with large extended ears on the dorsal valve. The Matsukawa species somewhat resembles *Kunlunia grabaui* (Nakamura, 1960), redescribed by Tazawa and Nakamura (2015, p. 162, figs. 5.1–5.3) from the lower part of the Hosoo Formation (Kungurian) of Nakadaira, South Kitakami Belt, in shape and external ornament of the dorsal valve, but differs in the larger size (length 54 mm, width 76 mm in the dorsal valve specimen, KCG059). Specific identification is difficult for the poor material.

Superfamily Linoproductoidea Stehli, 1954
Family Kansuellidae Muir-Wood and Cooper, 1960
Subfamily Auriculispininae Waterhouse in Waterhouse and Briggs, 1986
Genus *Permundaria* Nakamura, Kato and Choi, 1970

Type species.—*Permundaria asiatica* Nakamura, Kato and Choi, 1970.

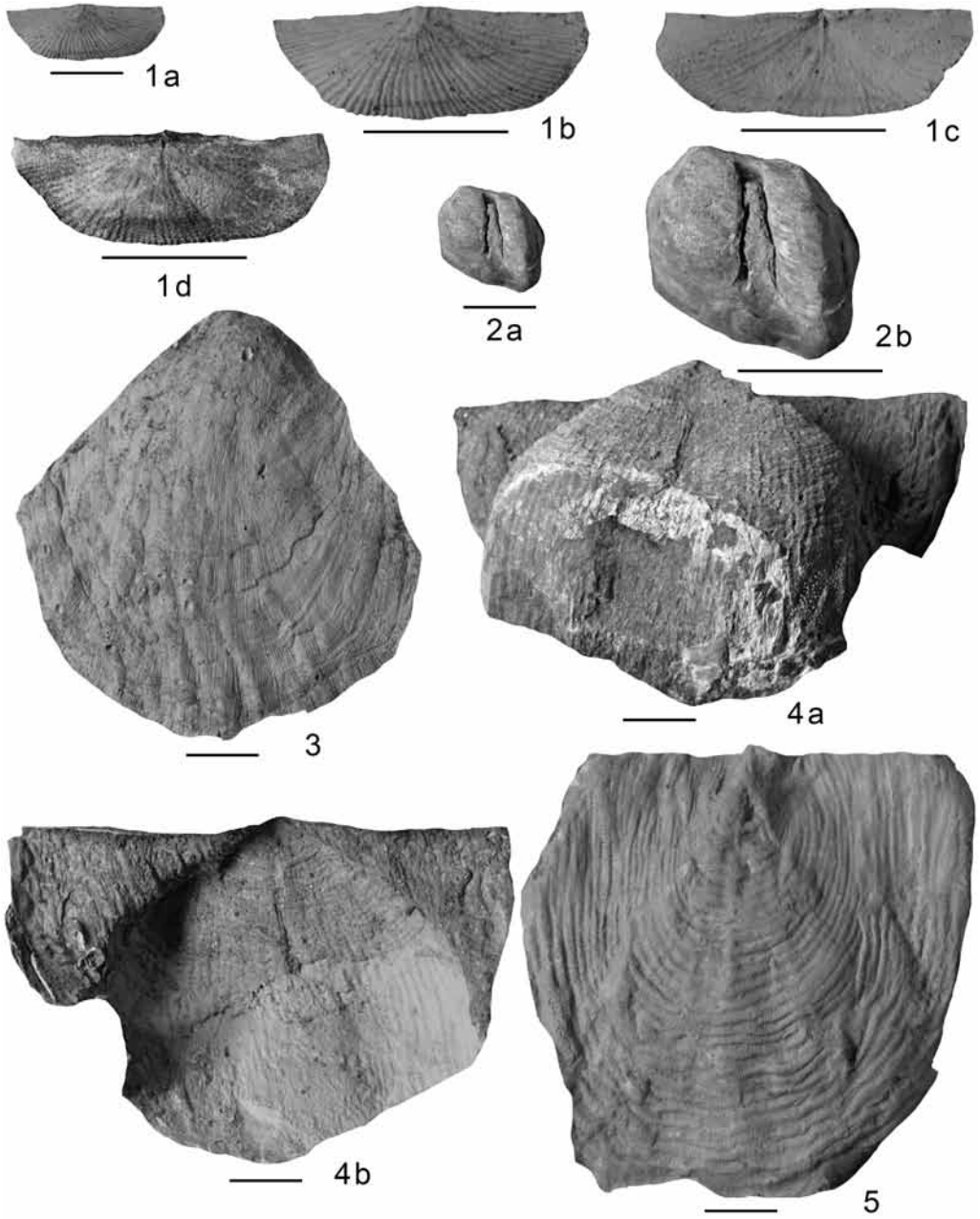

Fig. 4. 1, *Neochonetes* (*Huangichonetes*) *matsukawensis* sp. nov.; 1a–d, external latex cast, internal latex cast and internal mould of ventral valve, KCG061 (holotype). **2,** *Dicystoconcha lapparenti* Termier and Termier; 2a, b, internal mould of ventral valve, KCG058. **3,** *Meekella nodosa* Nakamura, external latex cast of ventral valve, KCG060. **4,** *Kunlunia* sp.; 4a, b, external mould and external latex cast of dorsal valve, KCG059. **5,** *Permundaria asiatica* Nakamura, Kato and Choi, external latex cast of ventral valve, KCG054. Scale bars represent 1 cm.

Permundaria asiatica Nakamura, Kato and Choi, 1970
Fig. 4.5

Striatifera? sp. Hayasaka and Minato, 1956, p. 144, pl. 23, figs. 6, 7.
Permundaria asiatica Nakamura, Kato and Choi, 1970, p. 296, pl. 2, figs. 1, 2; Tazawa, 1974, p. 315, pl. 43, figs. 3, 4; Tazawa, 1976, pl. 2, fig. 7; Minato et al., 1979, pl. 62, figs. 12, 13; Tazawa, 2001, p. 296, figs. 7.17–7.19.

Material.—One specimen from locality AR4, external mould of a ventral valve, KCG054.

Remarks.—This specimen is referred to *Permundaria asiatica* Nakamura, Kato and Choi, 1970, in the large, subquadrate and flattened ventral valve (length more than 65 mm, width more than 64 mm), ornamented with numerous fine costellae (numbering 5 in 2 mm at about midlength) and numerous regular but slightly undulate concentric rugae. As noted by Nakamura et al. (1970, p. 297), *Striatifera*? sp. Hayasaka and Minato, 1956, from the lower part of the Kanokura Series (= Kamiyase Formation) of Imo, South Kitakami Belt, is a synonym of the present species. *Permundaria tenuistriata* Tazawa (1974, p. 317, pl. 43, figs. 1, 2), from the lower Kamiyasse Formation of Kamiyasse, South Kitakami Belt, is distinguished from *P. asiatica* in having finer capillae on both ventral and dorsal valves.

Distribution.—Wordian: northeastern Japan (South Kitakami Belt) and central Japan (Hida Gaien Belt).

Suborder Lyttoniidina Williams, Harper and Grant, 2000
Superfamily Lyttonioidea Waagen, 1883
Family Lyttoniidae Waagen, 1883
Subfamily Lyttoniinae Waagen, 1883
Genus *Petasmaia* Cooper and Grant, 1969

Type species.—*Petasmaia expansa* Cooper and Grant, 1969.

Petasmaia expansa Cooper and Grant, 1969
Figs. 5, 6.4

Petasmaia expansa Cooper and Grant, 1969, p. 10, pl. 2, figs. 15–18; Cooper and Grant, 1974, p. 430, pl. 163, figs. 1–8; pl. 164, figs. 1–16; pl. 165, figs. 1–23; pl. 169, figs. 11–16; Tazawa and Ono, 2013, p. 51, figs. 2, 3; Tazawa et al., 2016, p. 374, fig. 7.6.

Material.—One specimen from locality KZ9, internal mould of a ventral valve, KCG055.

Description.—Shell medium in size for genus, transversely wider elliptical in outline, with

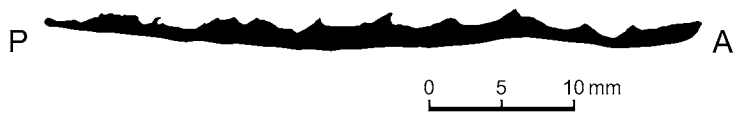

Fig. 5. *Petasmaia expansa* Cooper and Grant, longitudinal section of internal latex cast of ventral valve, KCG055, showing lateral septa, A: anterior, P: posterior.

greatest width at midlength; length about 45 mm, width about 58 mm. Ventral valve almost flat in both lateral and anterior profiles. Interior of ventral valve with numerous regularly and symmetrically arranged thin lateral septa on both sides of a low thin median septum; lateral septa with sharp crests and broad interspaces, being gently convex anteriorly and inclined, dipping posteriorly at low angle to valve surface in lateral profile, numbering 11 pairs of lateral septa.

Remarks.—This specimen is referred to *Petasmaia expansa* Cooper and Grant, 1969, from the Cathedral Mountain Formation (Leonardian) of the Glass Mountains, West Texas, USA, on account of the transversely wider ventral valve and the regularly arranged thin lateral septa, being gently convex anteriorly and inclined posteriorly. The Matsukawa specimen, smaller than the type specimens of West Texas, may be a young individual. *Petasmaia ehiroi* Tazawa and Miyake (2011, p. 8, figs. 3.10, 3.11, 4), from the Toyoma Formation of Maeda, South Kitakami Belt, differs from *P. expansa* in having lateral septa with narrower interspaces.

Distribution.—Artinskian–Wordian: northeastern Japan (Setamai and Kamiyasse–Imo in the South Kitakami Belt), southwestern Japan (Akasaka in the Mino Belt) and western USA (West Texas).

Superfamily Permianelloidea He and Zhu, 1979

Family Permianellidae He and Zhu, 1979

Genus *Dicystoconcha* Termier and Termier in Termier et al., 1974

Type species.—*Dicystoconcha lapparenti* Termier and Termier in Termier et al., 1974.

Dicystoconcha lapparenti Termier and Termier in Termier et al., 1974

Fig. 4.2

Dicystoconcha lapparenti Termier and Termier in Termier et al., 1974, p. 123, pl. 22, figs. 1, 2; text-fig. 22; Wang and Jin, 1991, p. 495, pl. 1, figs. 1–9; pl. 3, figs. 1–7; Shen and Tazawa, 2014, p. 248, figs. 3.1–3.5; Tazawa et al., 2014, p. 383, fig. 2.6; Tazawa, 2015, p. 73, fig. 6.6.

Dipunctella contracta Liang in Wang et al., 1982, p. 229, pl. 102, fig. 3.

Guangjiayanella guangjiayanensis Yang, 1984, p. 212, pl. 31, figs. 11–16; text-fig. 5.9.
Guangdongina xiamaoensis Mou and Liu, 1989, p. 458, pl. 1, figs. 1–9; pl. 2, figs. 1–7; text-fig. 5.
Guangdongina leguminiformis Mou and Liu, 1989, p. 458, pl. 3, figs. 4–8.
Guangdongina perforatus Mou and Liu, 1989, p. 459, pl. 2, fig. 8; pl. 3, figs. 1–3.
Guangdongina sp. Mou and Liu, 1989, p. 459, pl. 2, fig. 9.
Paritisteges latesulcata Liang, 1990, p. 380, pl. 42, figs. 1, 2.
Febulasteges planata Liang, 1990, p. 381, pl. 42, figs. 3, 4.

Material.—One specimen from locality AR4, internal mould of ventral valve, KCG058.

Remarks.—This specimen is referred to *Dicystoconcha lapparenti* Termier and Termier in Termier et al., 1974, from the lower Murgabian of Wardak, central Afganistan, in the small, ovate, strongly convex and bilobate ventral valve (length about 15 mm, width 14 mm). Shen and Tazawa (2014, p. 248) treated the following six forms from the Permian of South China as the junior synonyms of *Dicystoconcha lapparenti*: *Guangjiayanella guangjiayanensis* Yang, 1984, *Guangdongina xiamaoensis* Mou and Liu, 1989, *Guangdongina leguminiformis* Mou and Liu, 1989, *Guangdongina perforatus* Mou and Liu, 1989, *Guangdongina* sp. Mou and Liu, 1989, and *Fabulasteges planata* Liang, 1990. Moreover, *Paritisteges latesulcata* Liang, 1990, from the lower Lengwu Formation of Lengwu, Zhejiang, eastern China, is also considered to be a junior synonym of the present species.

Distribution.—Kungurian–Wuchiapingian: northeastern Japan (Kamiyasse–Imo in the South Kitakami Belt), central Japan (Hitachi), Afganistan, northern China (Inner Mongolia), eastern China (Zhejiang) and central-southern China (Hubei and Guangdong).

Order Orthotetida Waagen, 1884
Suborder Orthotetidina Waagen, 1884
Superfamily Orthotetoidea Waagen, 1884
Family Meekellidae Stehli, 1954
Subfamily Meekellinae Stehli, 1954
Genus *Meekella* White and St. John, 1867

Type species.—*Plicatula striatocostata* Cox, 1857.

Meekella nodosa Nakamura, 1972
Fig. 4.3

Meekella sp. Huang, 1933, p. 31, pl. 4, figs. 8, 9.
Meekella nodosa Nakamura, 1972, p. 388, pl. 6, figs. 3, 4; Minato et al., 1979, pl. 59, fig. 8.

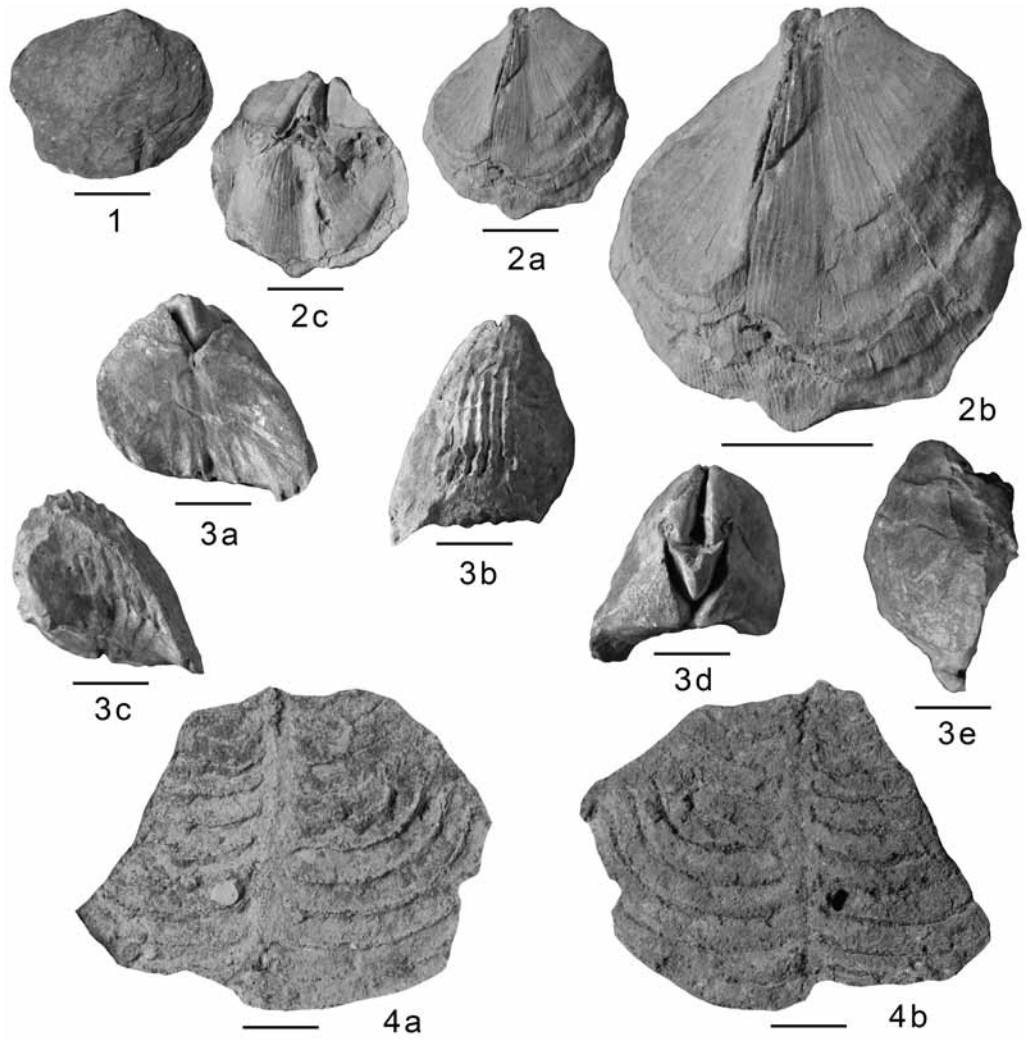

Fig. 6. 1, *Martinia* sp., internal mould of ventral valve, KCG062. **2,** *Orthothetina* sp.; 2a–c, internal latex casts of ventral and dorsal valves, KCG057. **3,** *Stenoscisma margaritovi* (Tschernyschew), 3a–e, ventral, dorsal, anterior, posterior and lateral views of internal mould of conjoined shell, KCG056. **4,** *Petasmaia expansa* Cooper and Grant, 4a, b, internal latex cast and internal mould of ventral valve, KCG055. Scale bars represent 1 cm.

Material.—One specimen from locality KZ9, external mould of a ventral valve, KCG060.

Remarks.—This specimen can be referred to *Meekella nodosa* Nakamura, 1972, from the lower Kanokura Series (= lower Kamiyasse Formation) of Kamiyasse, South Kitakami Belt, by its large size (length 58 mm, width 56 mm) and the characteristic external ornament of the ventral valve, nodose appearance represented by numerous radial costae and costellae crossed by numerous concentric rugae. As noted by Nakamura (1972, p. 389), *Meekella* sp. Huang, 1933, from the Wuchiapingian of Guizhou, southwestern China, is a synonym of the present species. *Meekella irregularis* Schellwien, 1900 (p. 20, pl. 2, figs. 8, 9), from the

Trogkofel Limestone of the Karavanke Mountains, Slovenia, also has nodose ornament on the ventral valve, but the Karavanke species differs from *M. nodosa* in its much elongate outline.

Distribution.—Wordian–Wuchiapingian: northeastern Japan (Kamiyasse and Matsukawa in the South Kitakami Belt) and southwestern China (Guizhou).

Genus *Orthothetina* Schellwien, 1900

Type species.—*Orthothetes persicus* Schuchert in Schuchert and LeVene, 1929.

Orthothetina sp.
Fig. 6.2

Material.—One specimen from locality AR4, internal mould of a conjoined shell, KCG057.

Remarks.—This specimen is safely assigned to the genus *Orthothetina* by its Orthothetid-formed shell and in having a pair of long, thin and subparallel dental plates in the ventral valve. The Matsukawa species resembles the specimens, described by Nakamura (1972, p. 300, pl. 2, figs. 2–5) as *Orthothetina kayseri* (Jäkel) from the lower Kanokura Series (= Kamiyasse Formation) of Imo, South Kitakami Belt, in size and shape of the shell, particularly in having a broad and deep sulcus in the dorsal valve. But accurate comparison is difficult because lacking information on the external ornament of both valves.

Order Rhynchonellida Kuhn, 1949
Superfamily Stenoscismatoidea Oehlert, 1887
Family Stenoscismatidae Oehlert, 1887
Subfamily Stenoscismatinae Oehlert, 1887
Genus *Stenoscisma* Conrad, 1839

Type species.—*Terebratula schlottheimii* von Buch, 1834

Stenoscisma margaritovi (Tschernyschew, 1888)
Fig. 6.3

Camarophoria margaritovi Tschernyschew, 1888, p. 355, figs. 1–3; Fredericks, 1924, p. 48, pl. 1, figs. 32–42; text-fig. 4.

Camarophoria humbletonensis Howse: Hayasaka, 1922, p. 62, pl. 8, figs. 10–12; pl. 10, fig. 9; Hayasaka, 1966, p. 1226, text-figs. 6–8.

Stenoscisma humbletonensis (Howse): Tazawa, 1976, pl. 2, figs. 9, 10; Minato et al., 1979, pl. 66, figs. 6–8.

Stenoscisma gigantea (Diener): Lee and Gu, 1976, p. 272, pl. 176, fig. 3; pl. 177, fig. 18; Lee et al., 1980, p. 395, pl. 173, figs. 6, 8.

Stenoscisma margaritovi (Tschernyschew): Licharew and Kotlyar, 1978, pl. 17, fig. 7; Koczyrkevicz, 1979, p. 50, pl. 11, figs. 5, 6; Duan and Li, 1985, p. 120, pl. 43, figs. 5–8; Tazawa and Matsumoto, 1998, p. 9, pl. 2, figs. 1–5; Tazawa et al., 2000, p. 10, pl. 1, figs. 7–11; Tazawa, 2001, p. 298, figs. 8.1–8.4; Tazawa, 2002, fig. 10.5; Wang and Zhang, 2003, p. 130, pl. 33, figs. 6, 7, 12–16; pl. 50, fig. 19; Tazawa and Chen, 2006, p. 333, figs. 5.7, 5.8.

Stenoscisma gigantea elongatum Lee and Su in Lee et al., 1980, p. 395, pl. 173, figs. 1, 2.

Stenoscisma purdoni (Davidson): Lee et al., 1980, p. 395, pl. 173, figs. 4, 5, 7.

Material.—One specimen from locality AR4, internal mould of a conjoined shell, KCG056.

Remarks.—This specimen is poorly preserved, but can be referred to *Stenoscisma margaritovi* (Tschernyschew, 1888), from the middle Permian of Vladivostok, eastern Russia, on account of the large, slightly elongate shell with strong and relatively large number of costae on both ventral sulcus and dorsal fold (numbering 5 on the dorsal fold).

Distribution.—Wordian–Wuchiapingian: northeastern Japan (Kamiyasse, Matsukawa, Ogatsu and Takakurayama in the South Kitakami Belt), central Japan (Moribu and Oguradani in the Hida Gaien Belt); northern China (Inner Mongolia), northeastern China (Heilongjiang and Jilin) and eastern Russia (South Primorye).

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. 6.1

Material.—One specimen from locality AR4, internal mould of a ventral valve, KCG062.

Remarks.—This specimen is safely assigned to the genus *Martinia* by its medium (length 23 mm, width 29 mm), subcircular and gently convex ventral valve, with several radial vascular markings. But specific identification is difficult owing to ill preservation of the present material.

Acknowledgements

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References

Bronn, H. G., 1862, *Die Klassen und Ordnungen der Weichthiere (Malacozoa), Bd. 3*, C. F. Winter'sche Verlagshandlung, Leipzig und Heidelberg, 518 p.

Buch, L., von, 1834, Über Terebrateln, mit einem Versuch sie zu classificiren und zu beschreiben. *Phys. Abhandl. König. Akad., Wissenshaft., 1833*, 1–124.

Conrad, T. A., 1839, Descriptions of new species of organic remains. *Second Ann. Rep. Palaeont. Dept., New York State Geol. Surv.*, 57–66.

Cooper, G. A. and Grant, R. E., 1969, New Permian brachiopods from West Texas. *Smithson. Contr. Paleobiol.*, no. 15, 233–794.

Cooper, G. A. and Grant, R. E., 1974, Permian brachiopods of West Texas, 2. *Smithson. Contr. Paleobiol.*, no. 15, 233–794.

Cox, E. T., 1857, A description of some of the most characteristic shells of the principal coal seams in the western basin of Kentucky. *Geol. Surv. Kentucky Rep.*, **3**, 557–576.

Duan, C.-H. and Li, W.-G., 1985, Descriptions of fossils: Brachiopoda. *In* Ding, Y.-J., Xia, G.-Y., Duan, C.-H., Li, W.-G., Liu. X.-L. and Liang, Z.-F., Study on the early Permian stratigraphy and fauna in Zhesi district, Nei Mongol Zizhiqu (Inner Mongolia). *Bull. Tianjin Inst. Geol. Min. Res.*, no. 10, 99–145 and 199–214 (in Chinese).

Fredericks, G., 1924, Upper Paleozoic of the Ussuriland. *Mater. Geol. Polezn. Iskopaem. Dalnego Vostoka*, no. 28, 1–52 (in Russian).

Gray, J. E., 1840, *Synopsis of the Contents of the British Museum, 42nd edition*. Brit. Mus., London, 370 p.

Hayasaka, I., 1917, On the brachiopod genus *Lyttonia* with several Japanese and Chinese examples. *Jour. Geol. Soc. Tokyo*, **24**, 43–53.

Hayasaka, I., 1922, Some Permian brachiopods from the Kitakami Mountains. *Japan. Jour. Geol. Geogr.*, **1**, 51–70.

Hayasaka, I., 1925, On some brachiopods from the *Lyttonia* horizon of the Kitakami Mountains. *Japan. Jour. Geol. Geogr.*, **4**, 89–103.

Hayasaka, I., 1963a, Some Permian fossils from southern Kitakami, 2. Two brachiopod species. *Proc. Japan Acad.*, **39**, 479–483.

Hayasaka, I., 1963b, Some Permian fossils of southern Kitakami, 4. Brachiopod superfamily Orthotetacea Williams. *Proc. Japan Acad.*, **39**, 753–757.

Hayasaka, I., 1966, Some Permian fossils from southern Kitakami, 6. Three brachiopods. *Proc. Japan Acad.*, **42**, 1223–1228.

Hayasaka, I. and Minato, M., 1956, Some brachiopods from the lower Kanokura Series of the Kitakami Mountains, Japan. *Trans. Proc. Palaeont. Soc. Japan, N. S.*, no. 21, 141–147.

He, X. and Zhu, M., 1979, A new form of brachiopods and its systematical classification. *Jour. China Inst. Min. Tech.*, no. 4, 131–140 (in Chinese).

Huang, T. K., 1932, Late Permian Brachiopoda of southwestern China. *Palaeont. Sinica, Ser. B*, **9**, fasc. 1, 1–139.

Huang, T. K., 1933, Late Permian Brachiopda of southwestern China, Part 2. *Palaeont. Sinica, Ser. B*, **9**, fasc. 2, 1–172.

Koczyrkevicz, B. V., 1979, Permian Stenoscismatacea (Brachiopoda) of South Primorye. *In* Petrashevskaya, V. T., ed., *Invertebrate Fossils from the Far East*. DVNTS AN SSSR, Vladivostok, 50–59 (in Russian).

Kuhn, O., 1949, *Lehrbuch der Palaozoologie*. E. Schweizerbart. Verlagsbuchhandl., Stuttgart, 326 p.

Lee, L. and Gu, F., 1976, Carboniferous and Permian Brachiopoda. *In* Geological Bureau of Nei Mongol and Geological Institute of Northeast China, eds., *Palaeontological Atlas of Northeast China; Nei Mongol, Part 1. Palaeozoic Volume*, Geol. Publ. House, Beijing, 228–306 (in Chinese).

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, Part 1. Palaeozoic Volume*, Geol. Publ. House, Beijing. 327–428 (in Chinese).

Liang, W.-P., 1990, *Lengwu Formation of Permian and its Brachiopod Fauna in Zhejiang Province*. Geol. Mem., Ser. 2, no. 10, Geol, Publ. House, Beijing, 522 p. (in Chinese).

Licharew, B. K. and Kotlyar, G. V., 1978, Permian brachiopods from South Primorye. *In* Popeko, L. I., ed., *Upper Palaeozoic of Northeastern Asia*, DVNTS, Vladivostok., 63–75 (in Russian).

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

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

Mou, C.-J. and Liu, C.-L., 1989, A new type of brachiopods—*Guangdongina* and its ecological environment. *Acta Palaeont. Sinica*, **28**, 455–462 (in Chinese).

Muir-Wood, H. M., 1955, *A History of the Classification of the Phylum Brachiopoda*. Brit. Mus. (Nat. Hist.), London, 124 p.

Muir-Wood, H. M., 1962, *On the Morphology and Classification of the Brachiopod Suborder Chonetoidea*. Brit. Mus. (Nat. Hist.), London, 132 p.

Muir-Wood, H. M. and Cooper, G. A., 1960, *Morphology, Classification and Life Habits of the Productoidea (Brachiopoda)*. Geol. Soc. Amer. Mem., 81, Geol. Soc. Amer., New York, 447 p.

Muir-Wood, H. M., 1995, *A History of the Classification of the Phylum Brachiopoda*. Brit. Mus. (Nat. Hist.), London, 124 p.

Nakamura, K., 1960, *Dictyoclostus* derived from the Middle Permian Kanokura Series and the Lower Permian Sakamotozawa Series of the Kitakami Mountains, Japan. *Jour. Fac. Sci., Hokkaido Univ., Ser. 4*, **10**, 495–511.

Nakamura, K., 1972, Permian Davidsoniacea from the southern Kitakami Mountains, Japan. *Jour. Fac. Sci., Hokkaido Univ., Ser. 4*, **15**, 361–425.

Nakamura, K., Kato, M. and Choi, D. R., 1970, On *Permundaria*, a new genus of the brachiopod family Linoproductidae. *Jour. Fac. Sci., Hokkaido Univ., Ser. 4*, **14**, 293–299.

Oehlert, D. P., 1887, Appendice sur les brachiopodes. *In* Fischer, P., ed., *Manuel de Conchyliologie et de Paléontologie conchyliologique ou Histoire naturelle des Mollusques vivants et fossils, Vol. 4, Part 11*, Lib. F. Savy, Paris, 1189–1334.

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

Schellwien, E., 1900, Die Fauna der Trogkofelschichten in den karnischen Alpen und den Karawanken, 1 Theil: Die Brachiopoden. *Abhandl. K. K. Geol. Reichsanst.*, **16**, 1–122.

Schuchert, C. and LeVene, C. M., 1929, Brachiopoda (generum et genotyporum index et bibliographia). *In* Pompeckj, J. F., ed., *Fossilium Catalogus, Vol. 1. Animalia, Pars 42*. W. Junk, Berlin, 140 p.

Shen, S.-Z. and Archbold, N. W., 2002, Chonetoidea (Brachiopoda) from the Lopingian (Late Permian) of South China. *Alcheringa*, **25**, 327–349.

Shen, S.-Z. and Tazawa, J., 2014, *Pararigbyella* and *Dicystoconcha* (Lyttoniidina, Brachiopoda) from the middle Permian (Wordian) of Japan. *Paleont. Res.*, **18**, 245–249.

Sowerby, J., 1818–1821, *The Mineral Conchology of Great Britain, Vol. 4*. W. Ardling, London, 114 p.

Stehli, F. G., 1954, Lower Leonardian Brachiopoda of the Sierra Diablo. *Bull. Amer. Mus. Nat. Hist.*, **105**, 262–358.

Tazawa, J., 1974, Two species of *Permundaria* from the Kitakami Mountains, northeast Japan. *Trans. Proc. Palaeont. Soc. Japan, N. S.*, no. 94, 313–318.

Tazawa, J., 1976, The Permian of Kesennuma, Kitakami Mountains: A preliminary report. *Earth Sci. (Chikyu Kagaku)*, **30**, 175–185.

Tazawa, J., 1979, Middle Permian brachiopods from Matsukawa, Kesennuma region, southern Kitakami Mountains. *Saito Ho-on Kai Mus. Nat. Hist., Res. Bull.*, no. 47, 23–35.

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

Tazawa, J., 2002, Late Paleozoic brachiopod faunas of the South Kitakami Belt, northeast Japan, and their paleobiogeographic and tectonic implications. *Island Arc*, **11**, 287–301.

Tazawa, J., 2015, Systematics and palaeobiogeography of Permian brachiopods from Pliocence conglomerate of Hitachi, central Japan. *Sci. Rep., Niigata Univ. (Geol.)*, no. 30, 57–88.

Tazawa, J., 2016, Middle Permian (Wordian) mixed Boreal–Tethyan brachiopod fauna from Kamiyasse–Imo, South Kitakami Belt, Japan. *Sci. Rep., Niigata Univ. (Geol.)*, no. 31, 7–43.

Tazawa, J. and Araki, H., 1984a, *Paralyttonia* (Oldhamina, Brachiopoda) from the Permian of Northeast Japan. *Jour. Geol. Soc. Japan*, **90**, 121–123.

Tazawa, J. and Araki, H., 1984b, A new species of *Richthofenia* (Brachiopoda) from the Permian of Northeast Japan. *Saito Ho-on Kai Mus. Nat. Hist., Res. Bull.*, no. 25, 1–6.

Tazawa, J. and Araki, H., 1999, *Scacchinella* (Permian Brachiopoda) from the southern Kitakami Mountains, northeast Japan. *Earth Sci. (Chikyu Kagaku)*, **53**, 452–455.

Tazawa, J. and Araki, H., 2013, Four brachiopod species newly described from the Middle Permian of Kesennuma, South Kitakami Belt, northeast Japan. *Sci. Rep., Niigata Univ. (Geol.)*, no. 28, 1–14.

Tazawa, J. and Araki, H., 2017, Middle Permian (Wordian) mixed Boreal–Tethyan brachiopod fauna from Matsukawa, South Kitakami Belt, Japan. *Paleont. Res.*, **21**, 265–287.

Tazawa, J. and Chen, Z.-Q., 2006, Middle Permian brachiopods from the Tumenling Formation in the Wuchang area, southern Heilongjiang, NE China, and their palaeobiogeographical implications. *Jour. Asian Earth Sci.*, **26**, 327–338.

Tazawa, J. and Ibaraki, Y., 2001, Middle Permian brachiopods from Setamai, the type locality of the Kanokura Formation, southern Kitakami Mountains, northeast Japan. *Sci. Rep., Niigata Univ., Ser. E*, no. 16, 1–33.

Tazawa, J., Kikuchi, Y., Nikaido, A., Adachi, S. and Okumura, Y., 2014, Permian brachiopods from boulders in the Pliocence basal conglomerate of Hitachi, central Japan, and their tectonic implications. *Jour. Geol. Soc. Japan*, **120**, 377–391 (in Japanese).

Tazawa, J. and Matsumoto, T., 1998, Middle Permian brachiopods from the Oguradani Formation, Ise district, Hida Gaien Belt, central Japan. *Sci. Rep., Niigata Univ., Ser. E*, no. 13, 1–19.

Tazawa, J. and Miyake, Y., 2011, Late Permian (Changhsingian) brachiopod fauna from Maeda in the Ofunato area, South Kitakami Belt, NE Japan. *Sci. Rep., Niigata Univ. (Geol.)*, no. 26, 1–22.

Tazawa, J. and Nakamura, K., 2015, Early Permian (Kungurian) brachiopods from Nakadaira, South Kitakami Belt, northeastern Japan. *Paleont. Res.*, **19**, 156–177.

Tazawa, J. Okumura, Y., Miyake, Y. and Mizuhara, T., 2016, A Kungurian (early Permian) brachiopod fauna from Ogama, Kuzu area, central Japan, and its palaeobiogeographical affinity with the Wolfcampian–Leonardian (early Permian) brachiopod fauna of West Texas, USA. *Paleont. Res.*, **20**, 367–384.

Tazawa, J. and Ono, T., 2013, Permian lyttoniid brachiopod *Petasmaia* from Akasaka, Mino Belt, central Japan. *Jour. Geol. Soc. Japan*, **119**, 51–55.

Tazawa, J., Takizawa, F. and Kamada, K., 2000, A Middle Permian Boreal–Tethyan mixed brachiopod fauna from Yakejima, southern Kitakami Mountains, NE Japan. *Sci. Rep., Niigata Univ., Ser. E*, no. 15, 1–21.

Termier, G., Termier, H., de Lapparent, A. F. and Marin, P., 1974, *Monographie du Permo–Carbonifère de Wardak (Afghanistan Central)*. Doc. Lab. Geol. Fac. Sci., Lyon, H. S. 2, Lyon, 167 p.

Tschernyschew, Th. N., 1888, Note on the Carboniferous collection from around Vladivostok. *Izv. Geol. Kom.*, **7**, 353–359 (in Rusian).

Waagen, W., 1883–1884, Salt Range fossils, 1. *Productus*-Limestone fossils: Brachiopoda. *Palaeont. Indica, Ser. 13*, **1**, 391–546 (1883) and 547–728 (1884).

Wang, C. and Zhang, S., 2003, *Zhesi Brachiopod Fauna*. Geol. Publ. House, Beijing, 210 p. (in Chinese).

Wang, G., Liu, Q., Jin, Y., Hu, S., Liang, W. and Liao, Z., 1982, Phylum Brachiopoda. *In* Nanjing Institute of Geology and Mineral Resources, ed., *Palaeontological Atlas of East China, Part 2. Late Palaeozoic*

Volume. Geol. Publ. House, Beijing, 186–256 (in Chinese).

Wang, H.-Y. and Jin, Y.-G., 1991, On Permianellids (Brachiopoda). *Acta Palaeont. Sinica*, **30**, 481–501 (in Chinese).

Waterhouse, J. B. and Briggs, D. J. C., 1986, Late Palaeozoic Scyphozoa and Brachiopoda (Inarticulata, Strophomenida, Productida and Rhynchonellida) from the southeast Bowen Basin, Australia. *Palaeontographica, Abt. A*, **193**, 1–76.

White, C. A. and St. John, O., 1867, Descriptions of new Subcarboniferous Coal-Measure fossils, collected upon the geological survey of Iowa, together with a notice of new generic characters involved in two species of Brachiopoda. *Chicago Acad. Sci. Trans.*, **1**, 115–127.

Williams, A., Harper, D. A. T. and Grant, R. E., 2000, Lyttoniidina. *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. Kansas, Lawrence, 619–642.

Yabe, H., 1900, The brachiopod *Lyttonia* from Rikuzen Province. *Jour. Geol. Soc. Tokyo*, **7**, 1–4.

Yang, D., 1984, Systematic descriptions of palaeontology: Brachiopoda. *In* Yichang Inst. Geol. Min. Res., ed., *Biostratigraphy of the Yangtze Area, (3) Late Palaeozoic Era*. Geol. Publ. House, Beijing, 203–239, 330–333 and 387–396 (in Chinese).

Zhang, C., Zhang, F., Zhang, Z. and Wang, Z., 1983, Phylum Brachiopoda. *In* Regional Geological Surveying Team of Xinjiang, Institute of Geoscience of Xinjiang, and Geological Surveying Group of Petroleum Bureau of Xinjiang, eds., *Palaeontological Atlas of Northwest China; Xinjiang Autonomous Region, Part 2. Late Palaeozoic*, Geol. Publ. House, Beijing, 262–386 (in Chinese).