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Middle Permian brachiopods from the Tumenling Formation in the Wuchang area, southern Heilongjiang, NE China, and their palaeobiogeographical implications

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Abstract

This paper describes nine brachiopod species in eight genera from the Tumenling Formation in the Wuchang area, southern Heilongjiang, northeast China. The Tumenling fauna is constrained to a Wordian–Capitanian (Guadalupian, Middle Permian) age, based on the correlation of the faunas, and previously published data from the same horizons in the same area. This Middle Permian brachiopod fauna is characterized by an admixture of elements of Boreal affinity (*Kochiproductus* sp., *Yakovlevia* sp., *Stenoscisma margaritovi*, *Gypospirifer volatilis*, *Spiriferella keilhavii*, *Spiriferella lita* and *Alispiriferella neimongolensis*), with Palaeoequatorial forms (*Spinomarginifera* sp., *Vediproductus* sp., and *Leptodus nobilis*). The Wuchang fauna, as a whole, is comparable to several contemporaneous faunas described from Inner Mongolia in northern China, Jilin in Northeast China, South Primorye in eastern Russia, and the Hida Gaien Belt of Japan, in terms of its index elements and its Boreal–Palaeoequatorial mixture. During the Middle Permian these areas (or blocks) were referred to the Inner Mongolia–Japan transition zone or the northern transition zone between the Palaeoequatorial and Boreal Realms. The overwhelming majority of the Boreal elements reveal that the Wuchang area was probably situated in the northern subzone of this transitional zone, which belongs to the southern margin of the Bureya Block. These east and northeast Asian blocks acted as migratory stepping stones bridging faunal migration between the Palaeoequatorial and Boreal realms during the Middle Permian.

Keywords: Boreal affinity; Palaeoequatorial affinity; Brachiopod faunas; Middle Permian; Northeast China.

1. Introduction

Several recent studies have revealed that Middle Permian mixed Boreal–Palaeoequatorial marine faunas are distributed along a narrow zone from the Beishan area of northwest China in the west, via Inner Mongolia, Heilongjiang and Jilin of northern and northeast China, the South Primorye region of eastern Russia, eastwards to the Hida Gaien and South Kitakami areas of Japan (Tazawa, 1991, 1998, 2001a; Xu and Yang, 1994; Shi et al., 1995; Shi and Zhan, 1996; Shi et al., 2002). In northeast China, mixed Boreal and Palaeoequatorial elements of brachiopods, corals and fusulinid foraminifers have been mostly reported from the Middle Permian of the central and eastern Jilin Province (Xu and Yang, 1994; Shi and Zhan, 1996). The biogeographical affinity of the southern Heilongjiang Province during the Permian remains obscure, due to the paucity of published palaeontological data, although this region has usually been inferred to be part of the Inner Mongolia–Japan transition zone (Tazawa, 1991) or the Northern transitional zone between the Palaeoequatorial and Boreal realms (Shi et al., 1995). Guo et al. (1992) reported a diverse brachiopod fauna from the Middle Permian Tumenling Formation of the Wuchang area. These taxa, however, appear in the fossil lists. Here, we describe a brachiopod fauna from the Permian succession at the Sanhetuan section of the Wuchang area, southern Heilongjiang Province, northeast China (Fig. 1). The Sanhetuan fauna

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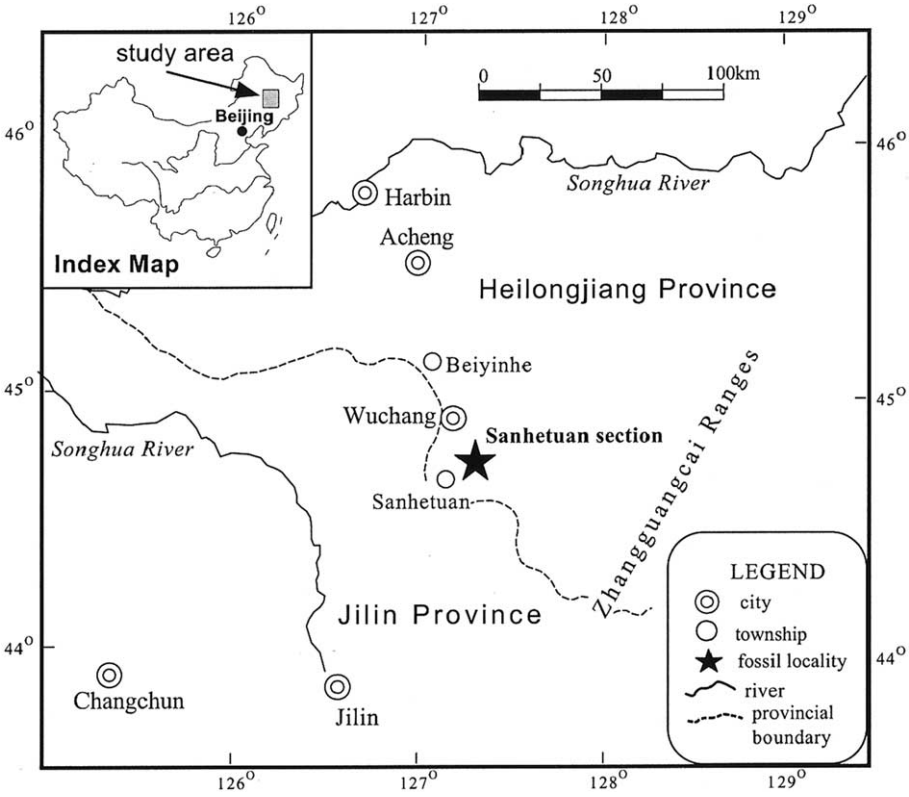

Fig. 1. Geographical map showing the fossil locality and study area.

and previously published information provide the potential to elucidate the Permian biogeographical affinity of the southern Heilongjiang areas based on faunal analysis and correlation.

2. Stratigraphy

Marine Permian successions cropping out in the southern Heilongjiang Province, northeast China are assigned to the Tumenling Formation (Guo et al., 1992). This unit is typically exposed in the Beiyinhe section at Beiyinhe town, 25 km northwest of Wuchang city (Fig. 1). Here, the Tumenling Formation is a succession more than 1044 m thick consisting of alternating sandstone, siltstone and mudstone with interbeds of limestone in the middle and upper part (Fig. 2). This formation is separated from overlying and underlying strata by faults. Thus, the precise thickness of the Tumenling Formation is unknown. However, the middle part of the formation is extremely fossiliferous and characterized by bioclastic limestone and calcareous sandstone (Guo et al., 1992). Regionally, the Tumenling Formation is widely distributed in the Wuchang, Acheng and Tieli areas of the southern Heilongjiang region (Guo et al., 1992; Lee in Jin et al., 2000).

The brachiopod specimens described and illustrated in this paper were collected by Japanese geologists of the Geological Institute of Manchoukuo (GIM) in the 1930 s from the Permian succession cropping out in the Sanhetuan section, about 10 km northeast of Sanhetuan town, Wuchang area, southern Heilongjiang Province (Fig. 1). The Permian sequence exposed at the Sanhetuan section correlates well, bed by bed, with that of the Tumenling Formation in the type section (Guo et al., 1992; Bureau of Geology and Mineral Resources of Heilongjiang Province (BGMRH), 1997). In particular, according to the GIM's original geological records, the strata bearing the brachiopod fauna comprise bioclastic limestone and calcareous sandstone of the middle Tumenling Formation, and equivalent to Units 9–10 of the formation at the Beiyihe section (Fig. 2).

3. The Wuchang fauna and its biogeographical implications

3.1. Age

The described fauna includes nine species in eight genera: *Echinauris* sp., *Kochiproductus* sp., *Vediproductus* sp., *Yakovlevia* sp., *Stenoscisma margaritovi* (Tschernyschew), *Gypospirifer volatilis* Duan and Li, *Spiriferella keilhavii* (von Buch), *Spiriferella lita* (Fredericks) and *Alispiriferella neimongolensis* Wang and Zhang. In

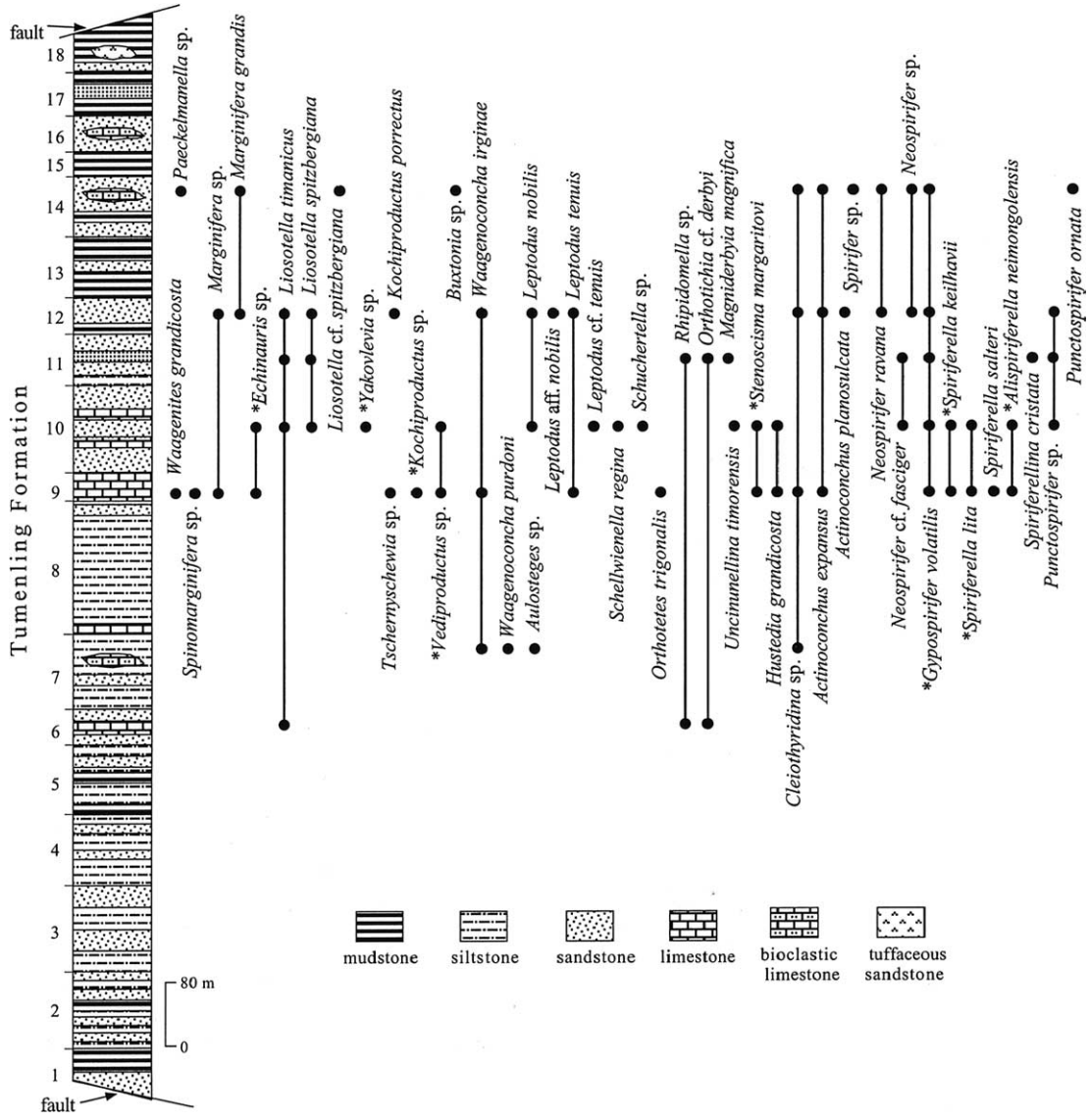

Fig. 2. Columnar section of the Middle Permian Tumenling Formation in the Wuchang area, southern Heilongjiang, northeast China (based on Guo et al., 1992). Brachiopods with asterisk are described here, and others follow Guo et al. (1992) with our revisions (Table 1).

addition, Guo et al. (1992) listed a diverse fauna from the Tumenling Formation of the Wuchang area. Here, by re-examining the Tumenling taxa and the illustrations published elsewhere from northern and northeast China (e.g. Lee and Gu, 1976; Lee et al., 1980; Duan and Li, 1985; Tazawa et al., 2000; Wang and Zhang, 2003) we attempt to make a taxonomic emendation (Table 1).

Of the described taxa and the Tumenling fauna, almost all species have also been reported from the Zhesi Formation in the Zhesi area, Inner Mongolia, northern China (Grabau, 1931; Lee and Gu, 1976; Duan and Li, 1985; Wang and Zhang, 2003). In particular, several species (i.e. *Gypospirifer volatilis*, *Alispiriferella neimongolensis*) are confined to the Zhesi and Wuchang faunas. The Wuchang brachiopod fauna bears an extremely high resemblance to the Zhesi fauna, these faunas are therefore contemporaneous. In addition, *Waagenites grandicosta* has been described from the Capitanian to Wuchiapingian (Middle–Late Permian) of the Salt Range, Pakistan (Waagen, 1884; Chen et al., 2000). Species of *Marginifera* and *Waagenoconcha* are also very abundant in the Capitanian to Wuchiapingian of the Salt Range, Pakistan (Waagen, 1884). Although *Leptodus* species are extremely abundant in the Wuchiapingian (Upper Permian) of South China (Huang, 1932), *Leptodus nobilis* is also exceptionally abundant in the Middle Permian of the Kitakami area, northeast Japan (Tazawa and Ibaraki, 2001) and the Middle Permian *Leptodus* Shales of central Peninsular Malaysia (Campi et al., 2002). *Stenoscisma margaritovi* has also been described from the Middle Permian of Jilin, northeast China (Duan and Li, 1985), South Primorye, eastern Russia (Fredericks, 1924; Licharew and Kotlyar, 1978) and the South Kitakami and Hida Gaien areas of Japan (Tazawa et al., 2000; Tazawa, 2001b). *Spiriferella lita* is also known

Table 1
List of brachiopods from the Beiyinhe section of the Tumenling Formation in the Wuchang area from Guo et al. (1992), with the authors' revisions

Species (Guo et al., 1992)	Unit	Revised species
Chonetes grandicosta	9	*Waagenites grandicosta* (Waagen)
Paeckelmanella sp.	14	
Spinomarginifera sp.	10	
Marginifera sp.	9, 12	
M. grandis	12, 14	
Liosotella timanicus	6, 10, 11, 12	
L. spitzbergiana	10, 11, 12	
L. cf. *spitzbergiana*	14	
Tschernyschewia sp.	9	
Kochiproductus porrectus	12	
Buxtonia sp.	14	
Waagenoconcha irginae	7, 9, 12	
W. purdoni	7	
Aulosteges sp.	7	
Leptodus nobilis	10, 12	
L. aff. *nobilis*	12	
L. tenuis	9, 12	
L. cf. *tenuis*	10	
Schellwienella regina	10	
Schuchertella sp.	10	
Orthotetes trigonalis	9	
Rhipidomella sp.	7, 11	
Orthotichia cf. *derbyi*	7, 11	
Magniderbyia magnifica	11	
Uncinunellina timorensis	10	
Stenoscisma gigantea	9	*Stenoscisma margaritovi*
Hustedia grandicosta	9, 10	
Athyris sp.	7, 9, 11, 12, 14	*Cleiothyridina* sp.
Actinoconchus expansus	9, 12, 14	
A. planosulcata	12	
Spirifer sp.	14	
Neospirifer ravana	12, 14	
N. cf. *fasciger*	10, 11	
N. moosakhailensis	10, 11, 12, 14	*Gypospirifer volatilis*
N. sp.	12, 14	
Spiriferella salteri	9	
S. cristata	11	*Spiriferellina cristata*
Punctospirifer sp.	10, 11, 12	
P. ornata	14	

from the Middle Permian of South Primorye, eastern Russia (Fredericks, 1924) and the South Kitakami and Hida Gaien areas of Japan (Tazawa, 2001b). *Spiriferella keilhavii* has been reported frequently from the Middle Permian of the Arctic region (Yukon Territory, Devon Island, Ellesmere Island, Greenland and Svalbard) and Northeast Asia (Inner Mongolia and Japan) (Tazawa and Ibaraki, 2001, and references therein).

As a result, most elements of the Wuchang fauna suggest a Middle Permian age. Wang et al. (2004) first reported abundant conodonts from the Zhesi Formation of the Zhesi area, Inner Mongolia and constrained the Zhesi fauna to a Wordian to early Capitanian (Middle Permian) age, based on recognition of the conodont *Mesogondolella aserrata* Zone. Consequently, like the Zhesi fauna, the Tumenling Formation and its brachiopod fauna are also likely to be Wordian to early Capitanian in age.

3.2. Faunal correlations and palaeobiogeographical implications

The Wuchang fauna consists of abundant elements with a Boreal affinity: *Liosotella spitzbergiana*, *Kochiproductus porrectus*, *K.* sp., *Yakovlevia* sp., *Gypospirifer volatilis*, *Spiriferella keilhavii*, *Spiriferella lita* and *Alispiriferella neimongolensis*. Other elements: *Waagenites grandicosta*, *Marginifera grandis*, *Waagenoconcha* spp. and *Spiriferella salteri*, which are widespread in the Peri-Gondwanan region and in the transitional zone between the Cathaysian Province of the Palaeoequatorial Realm and the Gondwanan Realm (Shi et al., 1995), also characterize the Wuchang fauna. In addition, the fauna is also distinguished by *Spinomarginifera* sp., *Vediproductus* sp., and *Leptodus nobilis*, characteristic of the Palaeoequatorial Realm during most stages of the Permian (Shi et al., 1995; Shi and Grunt, 2000), although they are also present in the transitional zones between the Palaeoequatorial and Gondawanan Realms and between the Palaeoequatorial and Boreal Realms (Shi et al., 1995; Shi and Grunt, 2000; Campi et al., 2002). Accordingly, the Wuchang fauna is characterized by the admixture of the Boreal and Palaeoequatorial elements, although the overwhelming majority of the fauna consist of Boreal elements.

As discussed above, both Wuchang and Zhesi faunas resemble each other closely, although the latter is much more diverse. These two faunas may therefore have belonged to the same biogeographical province during the Middle Permian. Apart from the Zhesi fauna, the Wuchang fauna is also comparable with several Middle Permian brachiopod faunas from east and northeast Asia, notably the Xiujimqinqi fauna of Inner Mongolia (Liu and Waterhouse, 1985; Shi et al., 2002), the central Jilin fauna of northeast China (Lee et al., 1980; Shi and Zhan, 1996), the South Primorye faunas of eastern Russia (Fredericks, 1924, 1925; Licharew and Kotlyar, 1978) and the Moribu fauna of the Hida Gaien region, central Japan (Tazawa, 2001b). Not only does the Wuchang fauna share many important elements with these faunas, but also all these faunas are characterized by an admixture of Boreal and Palaeoequatorial elements.

As a result, the Wuchang area belonged to the same biogeographical province as eastern Inner Mongolia, central Jilin, South Primorye, and the Hida Gaien and South Kitakami areas of Japan. These areas (or blocks) formed the Inner Mongol–Japan transition zone (Tazawa, 1991; see also Fig. 3) or the Northern transitional zone between the Cathaysian Province of the Palaeoequatorial (Shi et al., 1995) Realm and the Boreal Realm during the Middle

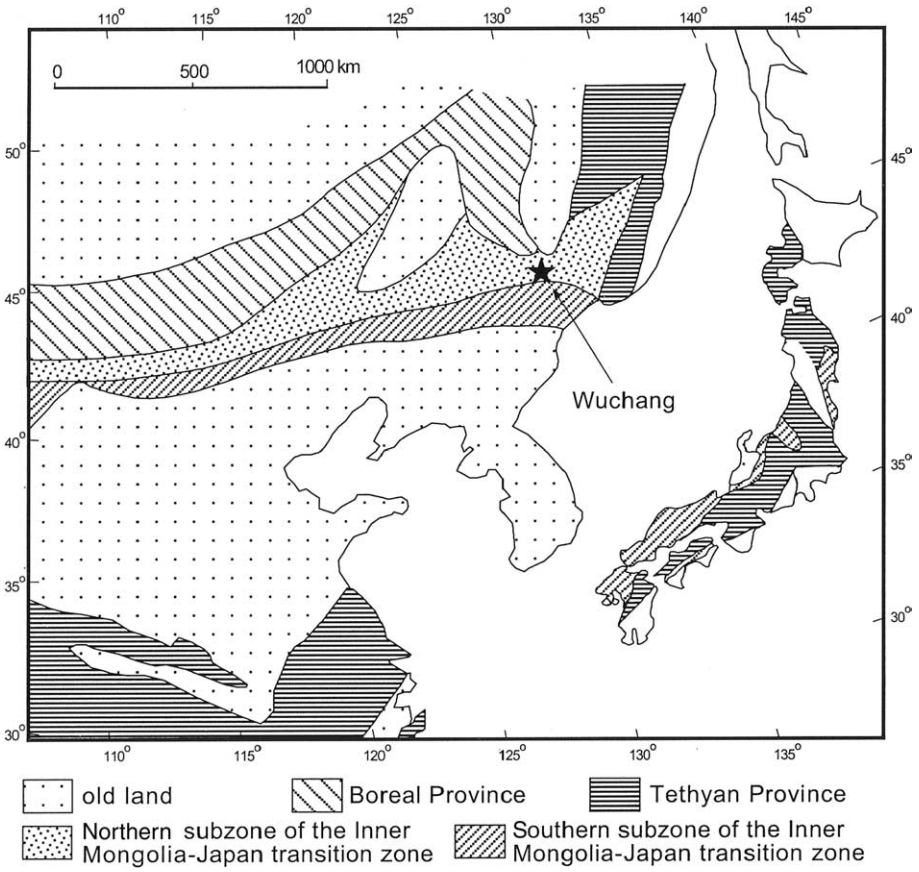

Fig. 3. The Middle Permian brachiopod faunal province in East Asia showing the Wuchang area in the Northern subzone of the Inner Mongolia–Japan transition zone (after Tazawa, 1991).

Permian. The overwhelming majority of Boreal elements indicates that the Wuchang area was biogeographically closer to the Boreal Realm than the Palaeoequatorial Realm during the Middle Permian. As consequence, we support Tazawa's (1991) inference that the southern Heilongjiang region (including Wuchang) was positioned within the Northern subzone of the Inner Mongolia–Japan transition zone, at the southern margin of the Bureya Block (Fig. 4). Like the model of the biogeographical stepping stones (i.e. Indochina, Shan-Thai, Cimmerian blocks) scattered within the southern transitional zone between the Cathaysian Province of the Palaeoequatorial Realm during the Middle

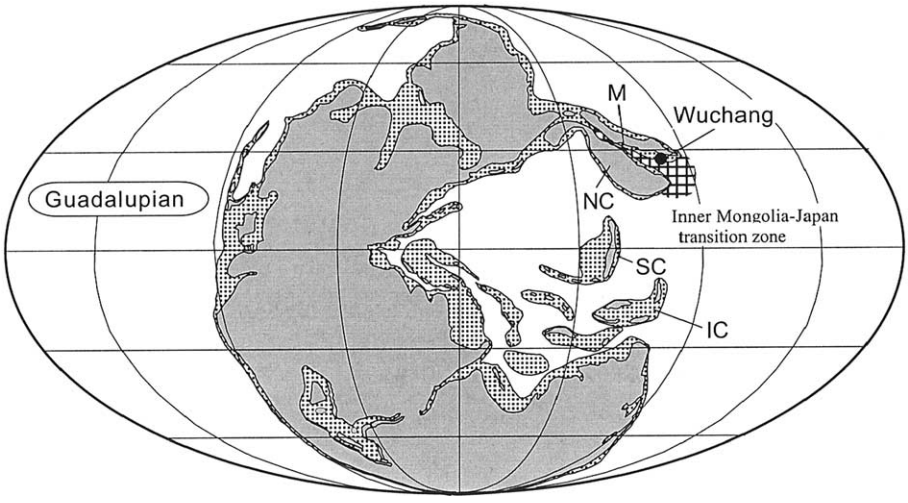

Fig. 4. Middle Permian reconstructed world map, showing the Wuchang area and the Inner Mongolia–Japan transition zone (base map follows Ziegler et al., 1997). SC, South China; IC, Indochina; NC, North China; M, Mongolia.

Permian (Shi et al., 1995; Shi and Chen, 2003), these blocks of the Inner Mongolia–Japan transition zone also acted as stepping stones bridging faunal migration between the Palaeoequatorial and Boreal Realms during the Middle Permian (Fig. 4).

4. Systematic palaeontology

Classification. The classification of the orders Productida, Rhynchonellida and Spiriferida are after Waterhouse (2002), Savage et al. (2002) and Carter et al. (1994), respectively.

Repository. All specimens described are housed in the Department of Geoenvironmental Science, Faculty of Science, Tohoku University, Sendai, Japan and registered as a prefix IGPS followed by a seven digit.

Order Productida Sarytcheva and Sokolskaya, 1959
Suborder Productidina Waagen, 1883
Superfamily Marginiferoidea Stehli, 1954
Family Costispiniferidae Muir-Wood and Cooper, 1960
Subfamily Costispiniferinae Muir-Wood and Cooper, 1960
Genus *Echinauris* Muir-Wood and Cooper, 1960
Echinauris sp.

Fig. 5: 1–3

Material. One incomplete ventral valve (IGPS 94728-01).

Description. Shell large size for genus, 17 mm in length, more than 21 mm in width; transversely subquadrate in outline; Ventral valve strongly and regularly convex in lateral profile; umbo rounded, incurved; ears small, acute, slightly convex and well-demarcated from corpus; median sulcus, commencing anterior to beak, narrow, shallow, indistinct; lateral slopes steep. External surfaces ornamented with numerous fine, rounded spine bases; rugae and costae absent.

Remarks. Cooper and Grant (1975) described 15 species and an uncertain species of *Echinauris* from the Lower and Middle Permian of West Texas, USA. Of these, *E. subquadrata* Cooper and Grant (1975, p. 1016, pl. 340, figs. 1–22) from the Wolfcampian (Gaptank and Neal Ranch Formations) is most allied to our specimen and both possess similar size, slightly transverse outline and an indistinct median sulcus. However, the Texan species cannot include our specimen as it embraces fewer spine bases on the disc and costae on the trail, and its lateral and posterior margins form right angle. Whereas the Sanhetuan specimen bears more numerous spine bases on the disc and acute ears, and lacks trail. *Echinauris opuntia* (Waagen, 1884, p. 707, pl. 79, figs. 1, 2), originally described from the Wargal Limestone of the Salt Range, Pakistan, is also a large species of *Echinauris* and thus approaches the present material, from which Waagen's species is distinguished by its more circular outline and lack of a ventral sulcus. Briefly, the described specimen overall approaches *Echinauris*, but it is distinguished from any known species by its large size, transversely subquadrate outline, wider than long, and lack of halteroid spines on lateral slopes. However, inadequate material prevents the proposal of a new species.

Superfamily Productoidea Gray, 1840
Family Buxtoniidae Muir-Wood and Cooper, 1960
Subfamily Buxtoniinae Muir-Wood and Cooper, 1960

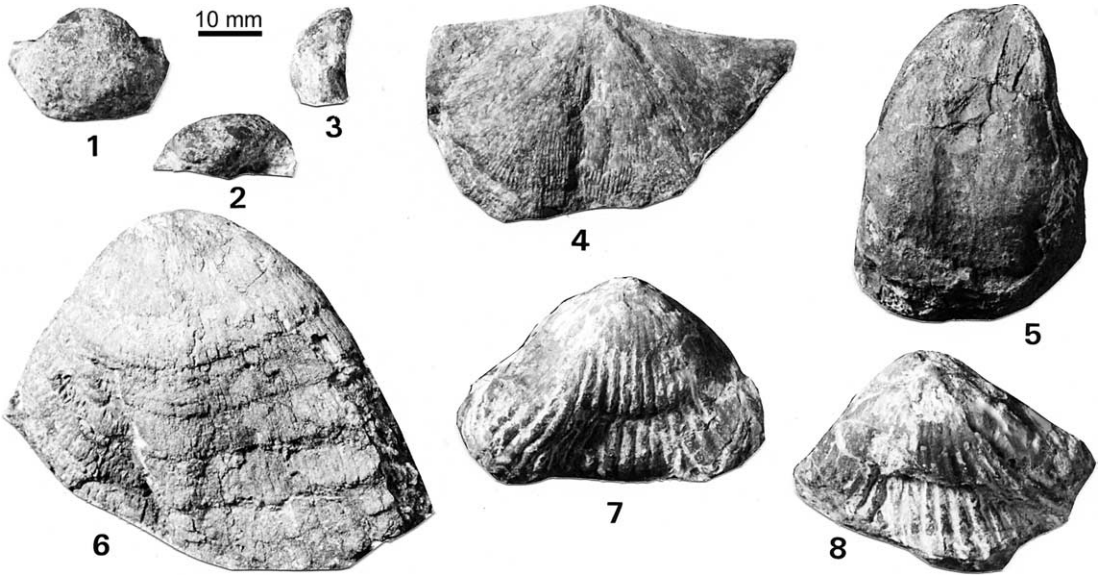

Fig. 5. (1–3) *Echinauris* sp., ventral, posterior and lateral views of a ventral valve (IGPS 94728-01). (4) *Yakovlevia* sp., dorsal view of a dorsal external mould (IGPS 94734-01). (5) *Vediproductus* sp., ventral view of a ventral valve (IGPS 94737-01). (6) *Kochiproductus* sp., ventral view of a ventral valve (IGPS 94733-01). (7, 8) *Stenoscisma margaritovi* (Tschernyschew), ventral and dorsal views of a specimen (IGPS 94728-02). All specimens were collected from the middle Tumenling Formation of the Middle Permian of the Sanhetuan section, Wuchang, southern Helongjiang, northeast China.

Tribe Buxtoniini Muir-Wood and Cooper, 1960
Genus *Kochiproductus* Dunbar, 1955
Kochiproductus sp.

Fig. 5: 6

Material. One incomplete ventral valve (IGPS 94733-01).

Remarks. It is large, elongate shell, approximately 47 mm long, 44 mm wide, and bears a broad, shallow ventral sulcus, which originates anterior to the ventral beak. The external surfaces are ornamented by rows of spine bases that are elongate and obliquely project anteriorly in an acute angle to the shell surface. Rugae are irregular and present on lateral slopes and ears. This specimen resembles superficially *Kochiproductus* sp. described by Tazawa et al. (2001, p. 37, fig. 2A–C) from the Middle Permian of the Dongujimqinqi area of Inner Mongolia, northern China and *Kochiproductus* cf. *porrectus* (Kutorga, 1844) described from the Zhesi Formation of the Zhesi area, Inner Mongolia (Grabau, 1931, p. 295, pl. 30, figs. 10–12; Duan and Li, 1985, p. 109, pl. 36, figs. 1–4; pl. 37, figs. 1, 2). However, the insufficient material does not allow a full comparison with these Inner Mongolian materials and makes species assignment uncertain, although the overall appearance suggests a species of *Kochiproductus*.

Superfamily Echinoconchoidea Stehli, 1954
Family Echinoconchidae Stehli, 1954
Subfamily Juresaniinae Muir-Wood and Cooper, 1960
Tribe Bathymyoniini Lazarev, 1990
Genus *Vediproductus* Sarytcheva in Sarytcheva and Sokolskaya, 1965
Vediproductus sp.

Fig. 5: 5

Material. One broken ventral valve (IGPS 94737-01).

Remarks. The ventral valve observed is 42 mm long and 30 mm wide, and thus its outline is elongately subquadrate. The shell is also strongly convex in lateral profile and bears a broad, shallow ventral median sulcus and steep lateral slopes. Externally, concentric bands characterize the ventral disc and each band bears numerous fine spine bases. These characters fit well with the concept of *Vediproductus*.

Both *Vediproductus vediensis* Sarytcheva (in Ruzhentsev and Sarytcheva, 1965, p. 221, pl. 35, figs. 1–3) from the Roadian (Gnishik Horizon) of the Transcaucasus and *Vediproductus punctatiformis* (Chao, 1927, p. 72, pl. 6, figs. 9–12) from the Kungurian–Roadian of Jiangxi, south China are significantly smaller and much more proportionally transverse, and thus cannot accommodate the Sanhetuan specimen. Like the present specimen, *V. tongluensis* Liang (1990, p. 187, pl. 29, figs. 1–10) from the Capitainian of Zhejiang, south China and the Lower Permian of the Tarim Basin, northwest China (Chen, 2004, p. 21, pl. 3, figs. 14–18) possesses a large size and elongate outline, but the latter is distinguished by its broader umbo, much deeper ventral median sulcus and the coarser spine bases on each band.

In addition, the Sanhetuan valve is also externally comparable in many aspects with *Juresania juresanensis* (Tschernyschew, 1902) described by Fredricks (1925, pl. 4, figs. 118, 119) from the Middle Permian of the Ussuri area, South Primorye, eastern Russia, however, the Sanhetuan specimen's poor preservation does not allow a full comparison with the Primorye material.

Superfamiy Linoproductoidea Stehli, 1954
Family Yakovleviidae Waterhouse, 1975
Genus *Yakovlevia* Fredricks, 1925
Yakovlevia sp.

Fig. 5: 4

Material. One dorsal external mould (IGPS 94734-01).

Description. Medium size for genus, 34 mm long and 54 mm wide; transversely subrectangular in outline. Dorsal valve almost flat on venter; median fold originating near umbo, broad, low and indistinct. External surfaces finely costellate, about 9–10 costellae per 5 mm at midvalve. Other features not observed.

Remarks. The external features observed are identical with *Yakovlevia elongata* Wang and Zhang (2003), p. 80, pl. 3, figs. 1–12) from the Zhesi Formation of the Zhesi area, Inner Mongolia. However, a full comparison with the Zhesi species will wait until more materials are available to study since many diagnostic characteristics cannot be examined in our specimen. The overall appearance of our shell also recalls *Yakovlevia kaluzinensis* Fredricks (1925, p. 7, pl. 2, figs. 64–66) from the Middle Permian Chandalaz Formation of the Vladivostok area, South Primorye, Russia, but the latter is significantly larger and has a less pronounced dorsal median fold and finer ribbings, and thus can be separated from the Sanhetuan specimen.

Order Rhynchonellida Kuhn, 1949
Superfamily Stenoscismatoidea Oehlert, 1887
Family Stenoscismatidae Oehlert, 1887
Subfamily Stenoscismatinae Oehlert, 1887
Genus *Stenoscisma* Conrad, 1839
Stenoscisma margaritovi (Tschernyschew, 1888)

Fig. 5: 7, 8

1888 *Camarophoria margaritovi* Tschernyschew, p. 355, figs. 1–3.
1922 *Camarophoria humbletonensis* Howse; Hayasaka, p. 62, pl. 9, figs. 10-12; pl. 10, fig. 9.
1924 *Camarophoria margaritovi* Tschernyschew; Fredericks, p. 48, pl. 1, figs. 32–42; text-fig. 4.
1966 *Camarophoria humbletonensis* Howse; Hayasaka, p. 1226, text-figs. 6–8.

1976 *Stenoscisma humbletonensis* (Howse); Tazawa, pl. 2, figs. 9, 10.
1976 *Stenoscisma gigantea* (Diener); Lee and Gu, p. 272, pl. 176, fig. 3; pl. 177, fig. 18.
1978 *Stenoscisma margaritovi* (Tschernyschew); Licharew and Kotlyar, pl. 17, fig. 7a,b.
1979 *Stenoscisma humbletonensis* (Howse); Minato et al., pl. 66, figs. 6–8.
1979 *Stenoscisma margaritovi* (Tschernyschew); Koczyrkevicz, p. 50, pl. 11, figs. 5, 6.
1980 *Stenoscisma gigantea* (Diener); Lee et al., p. 395, pl. 173, figs. 6, 8.
1980 *Stenoscisma gigantea elongatum* Lee and Su in Lee et al., p. 395, pl. 173, figs. 1, 2.
1980 *Stenoscisma purdoni* (Davidson); Lee et al., p. 395, pl. 173, figs. 4, 5, 7.
1985 *Stenoscisma margaritovi* (Tschernyschew); Duan and Li, p. 120, pl. 43, figs. 5–8.
1998 *Stenoscisma margaritovi* (Tschernyschew); Tazawa and Matsumoto, p. 9, pl. 2, figs. 1–5.
2000 *Stenoscisma margaritovi* (Tschernyschew); Tazawa, fig. 3.5.
2000 *Stenoscisma margaritovi* (Tschernyschew); Tazawa et al., p. 10, pl. 1, figs. 7–11.
2001b *Stenoscisma margaritovi* (Tschernyschew); Tazawa, p. 298, figs. 8.1–8.4.
2002 *Stenoscisma margaritovi* (Tschernyschew); Tazawa, fig. 10.5.
2003 *Stenoscisma margaritovi* (Tschernyschew); Wang and Zhang, p. 130, pl. 33, figs. 6, 7, 12–16; pl. 50, fig. 19.

Material. Two conjoined shells (IGPS 94728-02, 94728-03), one ventral valve (IGPS 94728-04) and two dorsal valves (IGPS 94728-05, 94728-06).

Description. Large shells for genus; subtrigonal in outline; greatest width slightly anterior to middle length of shell; length 33 mm, width 42 mm in the best preserved specimen (IGPS 94728-02). Ventral valve gently convex in lateral profile, strongly convex at umbonal region and slightly convex to nearly flattening anteriorly; umbo small and incurved; median sulcus originating anterior to beak, broad and shallow. Dorsal valve moderately convex with gently convex lateral profile; median fold, low, indistinct. External

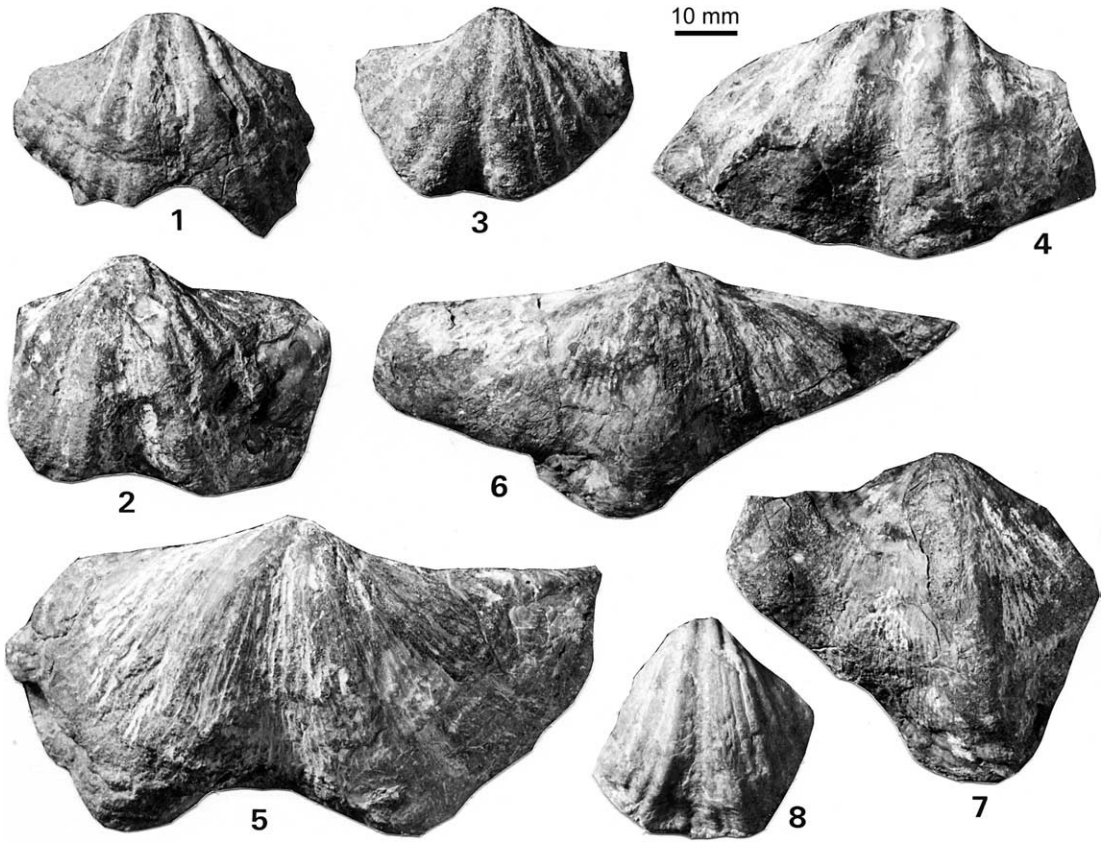

Fig. 6. (1, 2, 8). *Spiriferella keilhavii* (von Buch). (1) Ventral view of a ventral valve (IGPS 94726-05). (2) Ventral view of a ventral valve (IGPS 94726-04). (8) Ventral view of a ventral valve (IGPS 94734-02). (3) *Alispiriferella neimongolensis* Wang and Zhang, ventral view of a ventral valve (IGPS 94726-02). (4) *Spiriferella lita* (Fredericks), ventral view of a ventral valve (IGPS 94726-06). (5–7) *Gypospirifer volatilis* Duan and Li. (5) Ventral view of a ventral valve (IGPS 94736-02). (6) Dorsal view of a dorsal valve (IGPS 94736-03). (7) Dorsal view of a dorsal valve (IGPS 94737-04). All specimens were collected from the middle Tumenling Formation of the Middle Permian of the Sanhetuan section, Wuchang, southern Helongjiang, northeast China.

surfaces strongly costate; costae coarse, rounded, numbering 7 in median sulcus, 8 on median fold, and 6–8 on each lateral flanks. Interiors not observed.

Remarks. The specimens observed agree with Tschernyschew (1888) description and illustrations for the species. The assignment of our materials to this South Primorye species is on account of their large size, shallow ventral median sulcus, low dorsal fold, and relatively great number of costae on both valves. Tazawa et al. (2000, p. 11); Tazawa (2001b, p. 298) have fully described the nominate species and compared materials previously ascribed to *Stenoscisma* from the Middle Permian of Japan, Inner Mongolia and northeast China with the type specimens of the species described from the Middle Permian of the Vladivostok area, South Primorye. As a result, Tazawa et al. (2000) re-assigned the Japanese materials described by Hayasaka (1966); Tazawa (1976); Minato et al. (1979) to the Primorye species. We also agree with Duan and Li (1985) who altered the specimens named *Stenoscisma gigantea* (Diener) by Lee and Gu (1976); Lee et al. (1980), *S. purdoni* (Davidson) by Lee et al. (1980), and *S. purdoni* (Davidson) by Lee et al. (1980), all from the Middle Permian of northern and northeast China, to *S. margaritovi*. Consequently, we herein referred *S. gigantea* listed by Guo et al. (1992) from the Tumenling Formation of the Wuchang area to *S. margaritovi* (Table 1).

Order Spiriferida Waagen, 1883
Suborder Spiriferidina Waagen, 1883
Superfamily Spiriferoidea King, 1846
Family Trigonotretidae Schuchert, 1893
Subfamily Neospiriferinae Waterhouse, 1968
Genus *Gypospirifer* Cooper and Grant, 1976
Gypospirifer volatilis Duan and Li, 1985

Fig. 6: 5–7

1976 *Neospirifer moosakhailensis* (Davidson); Lee and Gu, p. 286, pl. 175, figs. 1–3 only.
1985 *Gypospirifer volatilis* Duan and Li, p. 127, 207, pl. 48, figs. 1, 2; pl. 49, figs. 1, 2.
2000 *Gypospirifer* sp.; Tazawa, figs. 3.12, 3.13.
2001b *Gypospirifer volatilis* Duan and Li; Tazawa, p. 302, figs. 8.23–8.26.
2003 *Gypospirifer marcoui* (Waagen); Wang and Zhang, p. 149, pl. 39, figs. 1–5; pl. 40, figs. 5, 7; pl. 41, fig. 1.

Material. Three conjoined shells (IGPS 94731-01, 94736-01, 94737-01), three ventral valves (IGPS 94736-02, 94737-02, 94737-03) and four dorsal valves (IGPS 94736-03, 94736-04, 94737-04, 94737-05).

Description. Shell large for genus, with the most complete specimen (IGPS 94736-01) 47 mm long and 76 mm wide; outline transversely semielliptical; shell width at hinge; cardinal extremities slightly alate. Ventral valve gently convex in lateral and anterior profiles, most convex at umbonal region; umbo slightly extended and strongly incurved; median sulcus commencing anterior to beak, rather deep, rapidly broadening anteriorly at middle length of shell; sulcus floor U-shaped. Dorsal valve moderately convex in lateral profile; median fold narrow, highly raising on posterior region of shell, broadening anteriorly. External surfaces ornamented by numerous fine costae and concentric rugae; costae with wider intercostals spaces, bifurcate, weakly fasciculate posteriorly, numbering 9–10 in 10 mm at midvalve. Other features not observed.

Remarks. All characters observed agree well with Duan and Li (1985) description for the species. The type species *Gypospirifer nelsoni* Cooper and Grant (1976, p. 2214, pl. 591, figs. 6–9) from the Lower Permian of West Texas clearly differs from the present species in having a larger size, more transverse shell outline with strongly alate extremities.

Family Spiriferellidae Waterhouse, 1968
Subfamily Spiriferellinae Waterhouse, 1968
Genus *Spiriferella* Tschernyschew, 1902
Spiriferella keilhavii (von Buch, 1846)

Fig. 6: 1, 2, 8

1846 *Spirifer keilhavii* von Buch, p. 74, fig. 2a,b.
1914 *Spiriferina keilhavii* (von Buch); Wiman, pl. 2, figs. 25–30; pl. 3, fig. 1.
1914 *Spiriferina draschei* (Toula); Wiman, p. 38, fig. 2 only.
1931 *Spiriferella keilhavii* (von Buch); Frebold, p. 28, pl. 5, figs. 7–9.
1931 *Spiriferella keilhavii* (von Buch); Grabau, p. 164, pl. 20, fig. 9a–c; pl. 21, figs. 1–5.
1937 *Spiriferella keilhavii* (von Buch); Frebold, p. 46, pl. 11, fig. 9.
1937 *Spiriferella keilhavii* (von Buch); Stepanov, p. 143, 179; pl. 7, figs. 8–11.
1937 *Spiriferella parryana* (Toula); Frebold,, p. 45, pl. 11, fig. 6.
1955 *Spiriferella keilhavii* (von Buch); Dunbar, p. 139, pl. 25, figs. 1–9; pl. 26, figs. 1–11; pl. 27, figs. 1–14.
1960 *Spiriferella keilhavii* (von Buch); Harker, p. 72, pl. 22, figs. 9–11; pl. 23, figs. 1, 2.
1963 *Spiriferella keilhavii* (von Buch); Gobbett, p. 152, pl. 20, figs. 8–10.
1963 *Spiriferella keilhavii* (von Buch); Yanagida, pl. 9, figs. 4–9; pl. 10, figs. 1–7.
1968 *Spiriferella keilhavii* (von Buch); Nelson and Johnson, p. 736, pl. 96, figs. 7, 8, 12; text-figs. 3e, 8a, 9, 13b.
1971 *Spiriferella* aff. *keilhavii* (von Buch); Bamber and Waterhouse, pl. 20, fig. 7.
1979 *Spiriferella keilhavii* (von Buch); Koizumi, pl. 1, figs. 10, 11 only.
1979 *Spiriferella keilhavii* (von Buch); Minato et al., pl. 67, figs. 1–3.
1980 *Spiriferella keilhavii* (von Buch); Lee et al., p. 418, pl. 178, fig. 8.

1982 *Spiriferella keilhavii* (von Buch); Tazawa and Gunji, p. 70, pl. 4, figs. 4–7.
1982 *Spiriferella keilhavii* (von Buch); Waterhouse and Waddington, p. 28, pl. 6, figs. 3–14; text-figs. 16e,g–i, 19; not pl. 4, fig. 15.
1985 *Spiriferella keilhavii* (von Buch); Lee et al., p. 122, pl. 2, figs. 1a, b, 5, 8.
1999 *Spiriferella keilhavii* (von Buch); Tazawa, p. 5, pl. 1, figs. 2–6.
2001 *Spiriferella keilhavii* (von Buch); Tazawa and Ibaraki, p. 16, pl. 4, figs. 1–10.
2002 *Spiriferella keilhavii* (von Buch); Shi et al., p. 293, figs. 4.16, 4.17.
2002 *Spiriferella keilhavii* (von Buch); Tazawa, figs. 10.4a, 10.4b.

Material. Three broken ventral valves (IGPS 94726-04, 94726-05, 94734-02).

Description. Medium to large size for genus, with the largest specimen (IGPS 94726-03) 33 mm long and 44 mm wide; outline subquadrate, wider than long; shell width at hinge. Ventral valve gently convex in lateral profile, with maximum convexity at umbo; umbo well extended and strongly incurved; interarea narrow, gently concave, with large delthyrium; median sulcus originating at beak, broadening and deepening anteriorly; 2 weak costae on each inner slope of median sulcus. External surfaces strongly costate; costae broad, rounded, and bifurcate anteriorly to form weak fascicles of 2–3 costae near anterior margins; 3–4 fasciculated costae on each lateral flank; fine concentric lirae visible on well preserved shells.

Remarks. This species has been multiply described from the Middle Permian of northeastern Asia. The overall appearance of the Sanhetuan specimens agrees well with the type specimens and other materials previously published from the Middle Permian around the world. In particular, the transverse outline and the well-preserved, weakly fasciculated costae make the present assignment more convincing. *Spiriferella loveni* (Diener, 1903), re-described and re-figured by Waterhouse and Waddington (1982, p. 22, pl. 5, figs. 2–17; pl. 6, figs. 1, 2; text-figs. 16b,d,f, 17, 18) from the Middle Permian of the Canadian Arctic region, is somewhat confused with *S. keilhavii* in shell size and general shape, but it differs from the latter by its less transverse outline and having more robust, broader costae on the ventral valve.

Spiriferella lita (Fredericks, 1924)

Fig. 6: 4

1924 *Spirifer saranae* mut. *lita* Fredericks, p. 36, pl. 1, figs. 16–27; text-figs. 2a,b.
1925 *Spirifer saranae* mut. *lita* Fredericks; Hayasaka, p. 98, pl. 5, fig. 14.
1979 *Spiriferella lita* (Fredericks); Tazawa, p. 28, pl. 4, figs. 12, 13; pl. 5, figs. 1–4, 6.
2000 *Spiriferella lita* (Fredericks); Tazawa, fig. 3.9.
2001b *Spiriferella lita* (Fredericks); Tazawa, p. 302, figs. 8.19–8.22.

Material. Three broken ventral valves (IGPS 94726-03, 94726-06, 94726-07).

Remarks. The materials examined are assignable to the South Primorye species because they bear a large size (the largest specimen IGPS 94726-06 is 43 mm long and 63 mm wide), transverse outline, 4–5 pairs of simple, coarse costae. The commonest species of the Middle Permian of Northeast Asia, *Spiriferella keilhavii* (von Buch), described above, is also a medium to large, transverse species of *Spiriferella*, and thus may be confused with *S. lita*, from which it is differentiated by its costae weakly fasciculate on both valves.

Genus *Alispiriferella* Waterhouse and Waddington, 1982
Alispiriferella neimongolensis Wang and Zhang, 2003

Fig. 6: 3

2003 *Alispiriferella neimongolensis* Wang and Zhang, p. 154, pl. 46, figs. 9–18; pl. 50, figs. 5, 9.

Material. Three broken ventral valves (IGPS 94726-01, 94726-02, 94731-02).

Remarks. The examined ventral valves are large and transverse. The best-preserved specimen (IGPS 94726-02) is 27 mm long and 38 mm wide. They possess a smooth, V-shaped median sulcus and five pairs of broad, unbranching costae on the ventral valve. These features agree well with Wang and Zhang (2003) description for the nominate species, which was originally described from the Zhesi Formation of the Xiujimqinqi and Zhesi areas, Inner Mongolia. The type species *Alispiriferella ordinaria* (Einor in Licharew and Einor, 1939, p. 140, pl. 23, figs. 6, 7; pl. 24, fig. 1a–d) from the Lower Permian of Novaya Zemlya, Russia differs from *A. neimongolensis* by its less transverse shell outline and two prominent costae in the ventral median sulcus. *A. japonica* Tazawa (2001b, p. 303, figs. 8.15–8.18) from the Middle Permian Moribu Formation of the Moribu area, central Japan cannot be confused from the Zhesi species as it is much more transverse.

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