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Middle Permian (Guadalupian) brachiopods from the Xiujimqinqi area, Inner Mongolia, northeast China, and their palaeobiogeographical and palaeogeographical significance

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Abstract. A small brachiopod fauna is described from the lower part of the Xiujimqinqi Formation of the Xiujimqinqi area in central-east Inner Mongolia, northeast China. The age of this fauna is regarded as Wordian (Middle Guadalupian, Middle Permian) by comparison with a similar brachiopod fauna from the Zhesi area of central Inner Mongolia, and by constraints from fusulinaceans associated with the Zhesi fauna. The Xiujimqinqi fauna is typical of mixed Boreal/Palaeoequatorial Middle Permian brachiopod faunas of East Asia. The mixed nature of these faunas is interpreted to have resulted from the combined effects of a middle palaeolatitudinal position, intensified plate convergence between Sino-Korea and Mongolia, and sea surface current connections with both the Arctic Sea in the north and eastern Palaeo-Tethys to the south. Possible *Kaninospirifer* is reported for the first time from China.

Key words: brachiopods, Middle Permian, northeast China, palaeobiogeography, transitional fauna, Xiujimqinqi

Introduction

Permian marine sedimentary rocks are common in Inner Mongolia and contain abundant and varied marine invertebrate faunas. Generally, these faunas show a consistent palaeobiogeographical pattern, in that those from northern Inner Mongolia appear to be dominated by elements characteristic of the cool- to cold-water Boreal Realm, while faunas in central and southern Inner Mongolia tend to be more characteristic of the warm-water Palaeoequatorial Realm, but at the same time contain some taxa common to, or characteristic of, the Boreal or Gondwanan Realms (Tazawa, 1991; Shi *et al*, 1995; Shi and Zhan, 1996). As such, the Permian marine faunas of central and southern Inner Mongolia typify a transitional biogeographical zone between the Boreal Realm to the north and the Palaeoequatorial Realm to the south, as defined and discussed by Shi *et al.* (1995).

Despite their ubiquity and abundance in the Permian marine sediments in Inner Mongolia and hence great significance for dating and correlation, only a few brachiopod faunas have been systematically described in detail. One of the better studied areas is the Xiujimqinqi area in central-eastern Inner Mongolia (Figure 1), where Permian brachiopods are common throughout the entire Lower and Middle Permian marine volcaniclastic, bioclastic and terrigenous sediments, well over 4,000 m in total thickness (Figure 2). Permian brachiopod faunas from various localities of this area have been studied by Lee *et al.* (1982, 1983, 1985) and Liu and Waterhouse (1985), and have furnished the basic premise for the Permian biostratigraphical zonation schemes of this area (Lee *et al.*, 1982, 1983; Liu and Waterhouse, 1985; BGMNG, 1991).

However, with the exception of Liu and Waterhouse's (1985) work, which described five brachiopod assemblages but did not give specific details on the exact location of

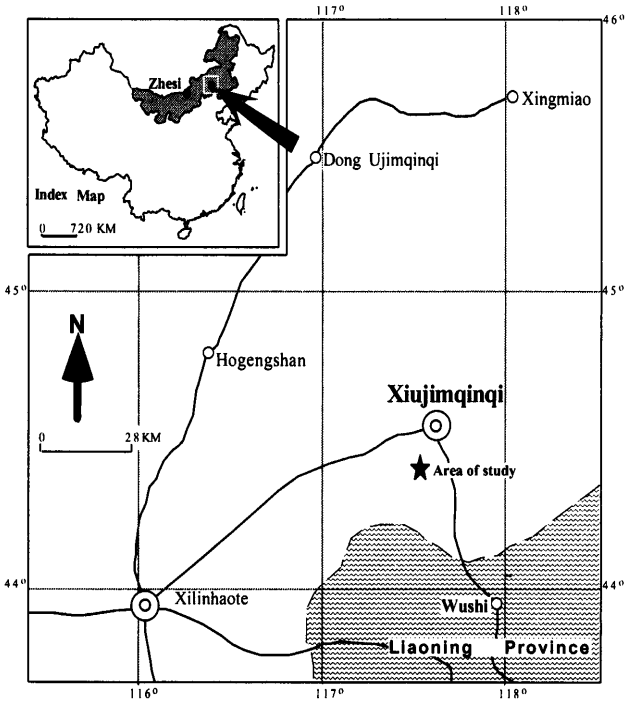


Figure 1. Map showing the study area, as well as the Zhesi area also referred to in the text. The enlarged map shows the detailed location of the area of study (Yuejin Coal Mine) in the Xiujimqinqi area. The shaded area in the index map is the Nei Mongol (Inner Mongolia) Autonomous Region.

their measured sections other than the general Xiujimqinqi area, the other earlier studies (Lee *et al.*, 1982, 1983, 1985) dealt only with certain taxa instead of the entire faunas. These latter investigations demonstrate that there are at least 10 relatively well exposed sections/localities in the general Xiujimqinqi area where Permian marine sequences with abundant brachiopods crop out. Lee *et al.* (1982) provided a detailed list of all the Permian brachiopod species then known to occur in this area, which they used as the basis for the erection of their brachiopod-based stratigraphical assemblages.

The present study is based on a small collection from the Yuejin Coal Mine, about 10 km southwest of Xiujimqinqi Township (Figure 1). This collection was originally made by the officers of the Bureau of Geology and Mineral Resources of Nei Mongol (Inner Mongolia) during the 1950s-1970s and was entrusted to Zhan Li-Pei, Chinese Academy of Geological Sciences (Beijing), for age determination. Zhan Li-Pei subsequently fulfilled this request by providing a list of his identified species and a broad age indication ["Early Permian", which, in terms of Jin's *et al.* (1997) proposed Permian timescale, includes both Early and Middle Permian]. Up to the present, this collection has not yet been systematically described. As will be documented below, this collection provides additional and new records to what is currently known about the Middle Permian brachiopod faunas of the Xiujimqinqi area. Moreover, this collection also affords important material to document *Kaninospirifer* from China for the first time.

Specimens described and illustrated in this paper are housed in the Museum of Victoria, Melbourne, Australia, with registration numbers prefixed with NMVP.

Stratigraphy

Over the last 2 decades, there has been a significant increase of lithostratigraphical names applied to the Permian rocks of the Xiujimqinqi area. In the two latest attempts to rationalize the stratigraphical nomenclature for the Permian System for the broad Inner Mongolian province (BGMNM, 1991; Jin *et al.*, 2000), many of the previously used names have been abandoned or treated as synonyms of others. In this study, we follow the stratigraphical framework recommended by BGMNM (1991) for the Xiujimqinqi area, which was also adopted in Jin *et al.* (2000). According to this scheme, the Permian sequence in the Xiujimqinqi area comprises, in ascending order, the Gegenaobao, Xiujimqinqi and Linxi formations (Figure 2). The Gegenaobao Formation is a sequence of acidic to intermediate volcanics, volcaniclastics and a minor amount of carbonate rocks. Both shallow marine and nonmarine fossils occur in this formation, indicating a volcanically active continental marginal marine setting. Among the marine fossils, brachiopods are most common and notably include species of *Jakutoproductus* and *Licharewia* (or *Tumarinia*). The cooccurrence of these two genera in this formation would indicate a relatively broad age range for the formation, from probably Artinskian (Early Permian) to as high as Roadian (early Middle Permian).

The Gegenaobao Formation in the Xiujimqinqi area is conformably overlain by the Xiujimqinqi Formation. The latter is dominated by andesite in the lower part, limestone and mudstone in the middle part, and siltstone in the upper part (Figure 2). Brachiopods occur throughout the formation but are mainly concentrated in several major horizons, each of which appears to form a distinct assemblage (Figure 2). By reference to the lithology and overall species composition, the brachiopod collection described below is considered to have come from the lower portion of the middle part of the formation. Plant fossils have also been reported from the siltstone beds in the upper part (BGMNM, 1991). As will be detailed below, the age of this formation is regarded as Wordian by correlation with faunas elsewhere.

Upwards, the Xiujimqinqi Formation grades to sandstone and conglomerate of the Linxi Formation without distinct disconcordance. The latter contains abundant Late Permian (Lopingian) mixed Cathaysia/Angara type flora

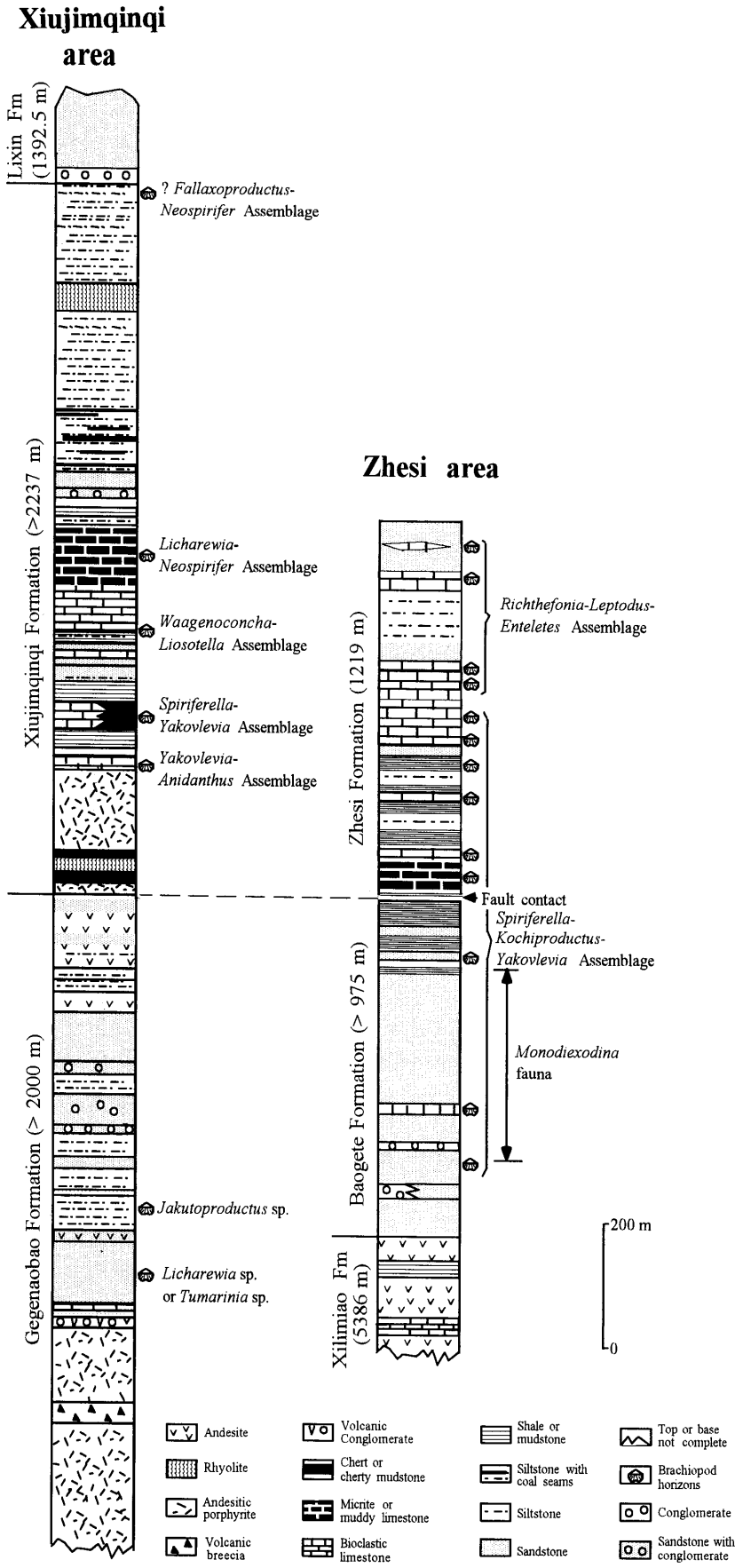


Figure 2. Permian stratigraphical sequences of the Xiujimqinqi and Zhesi areas, Inner Mongolia, northeast China. The stratigraphic columns and biozones are based on data from BGMNM (1991).

(Zhang, 1988).

Correlation and age

The present collection comprises 10 species, of which several are species indeterminate and two genera and species indeterminate. At first glance, the assemblage cannot be readily correlated with any of the five assemblages originally established by Lee *et al.* (1982, 1983, 1985) and elaborated by BGMNM (1991) (see Figure 2) because of the lack of key zonal species in our collection; neither can it be matched with certainty with any of the five Early and Middle Permian brachiopod assemblages recognized by Liu and Waterhouse (1985). The closest assemblage among the established schemes is the *Spiriferella-Yakovlevia* assemblage of Lee *et al.* (1982), which occurs in the lower portion of the middle part of the Xiujimqinqi Formation (Figure 2). This assemblage was originally recognized based on the brachiopod fauna from a limestone quarry about 7 km northwest of the present Yuejin Coal Mine (Lee *et al.*, 1982), and is characterized by abundant occurrence of *Spiriferella* and *Yakovlevia*, the former being represented by two species and the latter by four (Lee *et al.*, 1982). Other characteristic species of this assemblage include *Liosotella septentrionalis* (Tschernyshew), *Marginifera gobiensis* Chao, *Paramarginifera zhesiensis* Lee and Gu, *Waagenoconcha permocarbonica* Ustritskiy, *W. xiuqiensis* Lee, Gu and Li, *Strophalosia paradoxa* Fredericks, *S. pulchra* Lee, Gu and Li, *Linoproductus cora* (d'Orbigny), *Leptodus* sp., *Neospirifer xiujumqinqiensis* Lee, Gu and Li, *N. ravana* (Diener), *N. moosakhailensis* (Davidson), and *Paeckelmanella laevis* Lee and Gu. Although lacking many of these species, the present collection nevertheless contains relatively abundant *Spiriferella* and neospiriferids (*Neospirifer* and *Kaninospirifer*), hence suggesting a significant degree of correlation. On the other hand, we note that some other factors, for example, insufficient sampling in the present collection and/or localized specialization of biofacies, may have also contributed to the apparent difference in species composition between the present collection and the *Spiriferella-Yakovlevia* assemblage.

The age of the above *Spiriferella-Yakovlevia* assemblage has been considered to be either late Early Permian (Lee *et al.*, 1982) or middle Early Permian (BGMNM, 1991) in the traditional twofold Permian chronostratigraphical timescale of China (e.g., Zhan and Li, 1984). A more specific age determination for the *Spiriferella-Yakovlevia* assemblage is possible by correlation with the classic Permian brachiopod faunas of the Zhesi area in central Mongolia (see index map in Figure 1 for location), where brachiopods are associated with fusulinaceans. Here, the Permian is divided into three formations: the Xilimiao Formation, Baogete Formation and Zhesi Formation, in ascending order (BGMNM, 1991) (Figure 2). The brachiopod-bearing horizons that are comparable with those of the Xiujimqinqi area lie in the Baogete and Zhesi formations. Permian brachiopods are very rich in this area and have been the subject of two major monographical studies (Grabau, 1931; Duan and Li, 1985). According to them, the Permian brachiopods in this section can be divided into two broad assemblages: the *Spiriferella-Kochiproductus-Yakovlevia* assemblage (or SKY assemblage, as called by Duan and Li, 1985), followed by the *Richthofenia-Leptodus-Enteletes* assemblage (or RLE assemblage). Of these, the SKY assemblage is well correlated with the *Spiriferella-Yakovlevia* assemblage of the Xiujimqinqi area as both assemblages contain abundant Boreal-type genera such as *Neospirifer*, *Spiriferella* and *Yakovlevia*, and are similarly characterized by an admixture of Boreal and Palaeoequatorial taxa. The RLE assemblage of the Zhesi area, on the other hand, is dominated by Palaeoequatorial or Cathaysian-type genera and bears no significant similarities with any of the Xiujimqinqi assemblages.

The age of the SKY assemblage of the Zhesi section is well constrained by the associated fusulinaceans of the *Monodiexodina sutchanica* Zone in its lower part, and the fusulinaceans of the *Codonofusiella* Zone and corals of the *Waggenophyllum-Wentzella* Zone that directly and conformably overly the SKY assemblage and are associated with the brachiopods of the RLE assemblage (Duan and Li, 1985; BGMNM, 1991) (Figure 2). The *Monodiexodina sutchanica* Zone is generally regarded as of early Midian or Wordian age (Kotlyar *et al.*, 1999; Shi and Tazawa, 2001), and the *Codonofusiella* and *Waagenophyllum-Wentzella* zones of Capitanian age (Jin *et al.*, 1997). Thus, the SKY assemblage can be safely assigned to the Wordian in age. This implies that the *Spiriferella-Yakovlevia* assemblage, and hence, by correlation, the present collection from the Yuejin Coal Mine under discussion, is also Wordian in age.

Palaeobiogeographical and palaeogeographical implications

In spite of its small species composition, the present collection demonstrates aspects of a mixed Boreal/Cathaysian palaeobiogeographical fauna. The cool-water Boreal aspect of the fauna is represented by two characteristic northern Eurasian genera: *Anemonaria* and *Kaninospirifer*. *Anemonaria* is primarily restricted to the Arctic region (Arctic Russia, Spitsbergen, Greenland, and Arctic Canada) (Sarytcheva, 1977), although some occurrences from Australia (Briggs, 1998) and middle-latitudinal regions are also known, such as Japan (Tazawa and Niigata Pre-Tertiary Research Group, 1999; Tazawa, 2001) and the Russian Far East (Likharev and Kotlyar, 1978). The only exception to this essentially high-to middle-palaeolatitu-

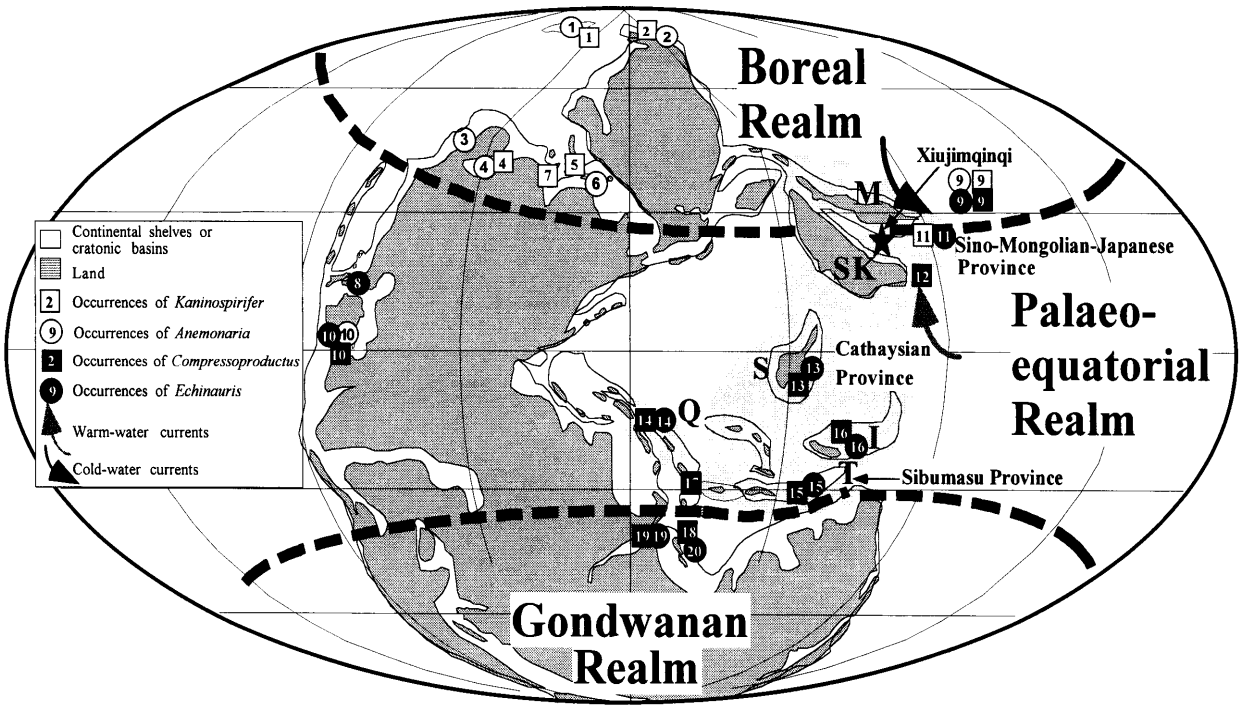


Figure 3. A Permian reconstruction map showing the distribution *of Anemonaria*, *Compressoproductus*, *Echinauris*, and *Kaninospirifer*, and the inferred palaeo-position (indicated by star) of Xiujimqinqi during the Middle Permian (base map from Ziegler *et al.*, 1998). Locations of the occurrences of *Anemonaria*, *Compressoproductus*, *Echinauris*, and *Kaninospirifer* are as follows: **1**, Kolyma Block, Russia; **2**, northern Verkhoyansk, Russia; **3**, Yukon Territory, Canada; **4** Sverdrup Basin, Canada; **5**, Kanin Peninsula, Russia; **6**, Pechora Basin, Russia; **8**, Phosphoria Basin, western USA; **9**, Xiujimqinqi and adjacent areas in northeast China; **10**, Texas, USA and central America; **11**, SW Japan and South Primorye of Far Eastern Russia; **12**, South Kitakami, northeast Japan; **12**, South China **14**, northwest Iran and Armenia; **15**, Shan-Thai (Sibumasu) block; **16**, Indochina; **17**, southeast Pamir, Karakorum and central Afghanistan; **18**, southern Tibet; **19** northwest Nepal, **20**, Salt Range, Pakistan. Explanations of main tectonic blocks: Q, Qiangtang Block; I, Indochina Block; M, Mongolia Block; S, South China Block; SK, Sino-Korea Block; T, Shan-Thai (Sibumasu) Block.

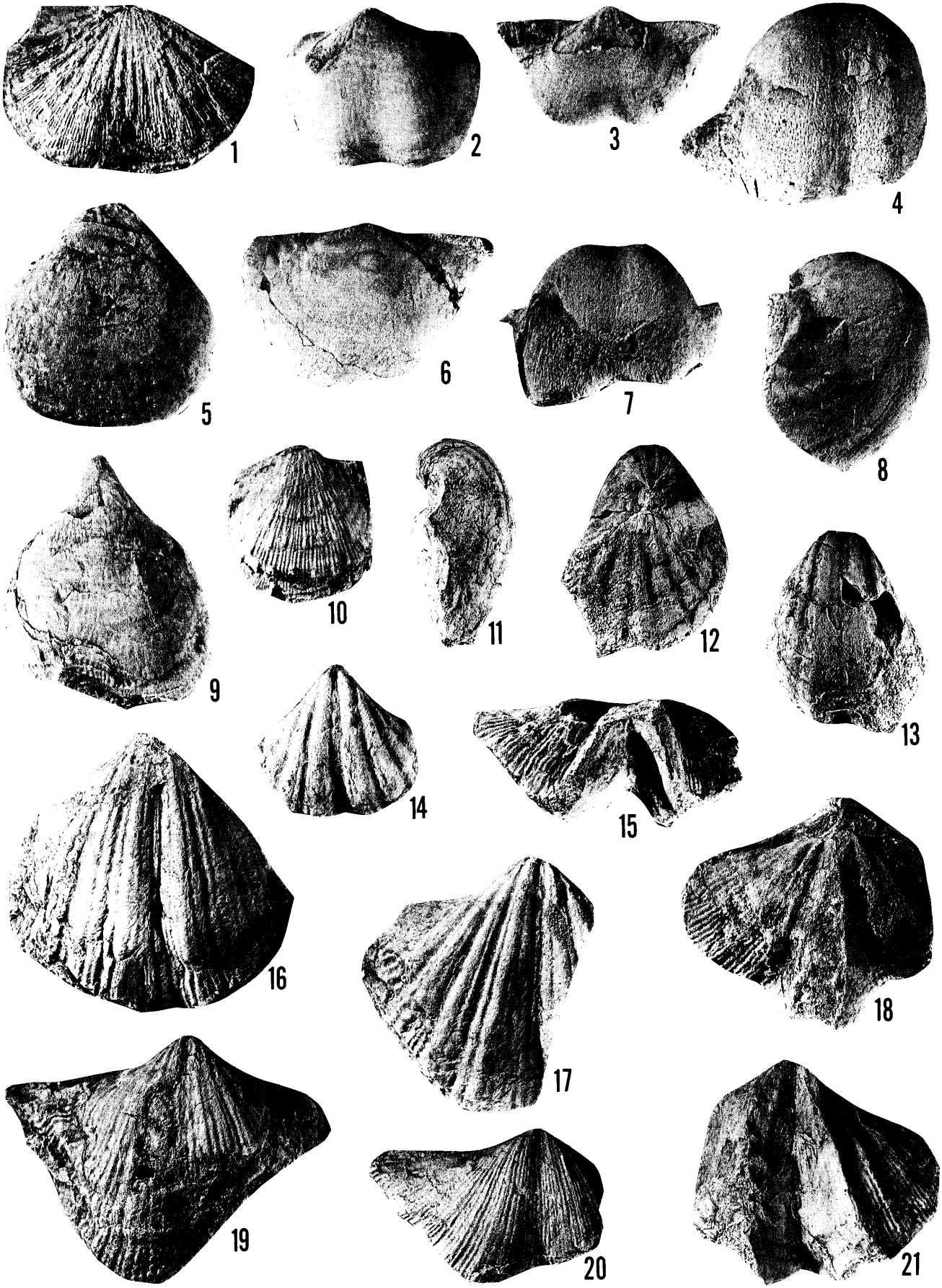
dinal distributional pattern is a record of the genus from Texas, southern U.S.A. (Cooper and Grant, 1969, 1975) and Venezuela (Hoover, 1981). These two "outlying" occurrences may be explained by the possible effect of a California-type cold current that might have intermittently operated off the western coast of northern Pangea during the Permian, bringing cold-water Boreal faunal elements to palaeoequatorial Texas and South America (Shi, 1995; Shi and Tazawa, 2001).

By contrast, the palaeogeographical distribution of *Kaninospirifer* is much more restricted, with occurrences known only from the northern part of the Russian Platform, Arctic Canada, Greenland, and Spitsbergen (Kalashnikov, 1996), Mongolia (Pavlova, 1991), northeast China (this report) and Japan (Tazawa, 2000; see discussion below) (Figure 3).

The warm-water palaeoequatorial aspect of the Xiujimqinqi brachiopod fauna is signaled by *Compressoproductus* and *Echinauris*. These two genera have essentially concordant palaeogeographical distributions, with occurrences restricted to the Tethys and southwest U.S.A. and have never been recorded from either the Gondwanan Realm or the Boreal Realm proper (Figure 3).

In addition to the four genera noted above, the palaeogeographical distribution of *Spiriferella* is also of great interest. Unlike *Anemonaria*, *Kaninospirifer*, *Echinauris* and *Compressoproductus*, which, as noted above, have either restricted high palaeolatitudinal Boreal occurrences or low palaeolatitudinal Tethyan occurrences, the palaeogeographical distribution of *Spiriferella* is typically bipolar and bitemperate (terms as defined in Shi and Grunt, 2000), in that it occurred only in the middle and high palaeolatitudinal regions of both hemispheres (Shi and Grunt, 2000).

The mixed nature of the Xiujimqinqi brachiopod assemblage, as outlined above, is consistent with several other Middle Permian brachiopod faunas reported from northeast China, southeast Mongolia, South Primorye of the Russian Far East, and Japan, as already summarized and discussed by Tazawa (1991), Shi *et al.* (1995) and Shi and Zhan (1996). A refined scenario to interpret the origin of these mixed Middle Permian brachiopod faunas has recently been put forth by Shi and Tazawa (2001). In this interpretation, it is suggested that all the mixed Middle Permian



faunas in eastern Asia (NE China, parts of Japan, Mongolia, and South Primorye of the Russian Far East) are referable to characterize the same single palaeobiogeographical unit, the Sino-Mongolian-Japanese Province (= Inner Mongolia-Japanese Transitional Zone of Tazawa, 1991). This province has a distinct transitional biogeographical nature characterized by intermingling genera typical of both the palaeoequatorial Cathaysian Province in the south and the Boreal Realm to the north. The origin of this biogeographical mixing, apparently limited to the Wordian interval, is thought to have resulted from the interplay of three main factors: (1) a middle palaeolatitudinal position for the Sino-Mongolian-Japanese Province; (2) intensified plate convergence between the Sino-Korea and Mongolia blocks during the Permian; and (3) sea surface current connections with both the warm-water eastern Palaeo-Tethys to the south and the temperate to polar Arctic sea to the north (Figure 3). A middle palaeolatitudinal position for the Sino-Mongolian-Japanese Province, estimated to be 25°–40° N, is suggested by the mixed nature of the faunas which, in analogy to modern latitude-dependent biogeographical zonation patterns (see Yin, 1989), would indicate a mesothermal setting comparable to a middle-latitudinal position or temperate zone. A phase of intensified plate convergence between Sino-Korea and Mongolia through the Permian, especially the Early and Middle Permian is assumed because this would have resulted in the shrinking and progressive shallowing of the Sino-Mongolian seaway that harbored the Sino-Mongolian-Japanese Province. This in turn would have facilitated and enhanced the intermingling of Boreal faunas that originally prevailed on the shelves of the Mongolian block and the eastern Palaeo-Tethyan faunas that dominated the northern shelves of the Sino-Korea block. The inferred sea surface current connections of the Sino-Mongolian-Japanese Province to both the Boreal Realm and the eastern Palaeo-Tethys is important because these currents would have brought their prospective faunal elements to the Sino-Mongolian seaway where they were eventually intermingled. Therefore, in light of these considerations we propose that the Xiujimqinqi area was probably located within the eastern end of the Sino-Mongolian seaway, in an intermediate position between Sino-Korea and Mongolia (Figure 3).

Systematic palaeontology

Order Chonetida Nalivkin, 1979
Suborder Chonetidina Muir-Wood, 1955
Superfamily Chonetoidea Bronn, 1862
Family Rugosochonetidae Muir-Wood, 1962

Rugosochonetidae gen. and sp. indet.

Figure 4.1

Remarks. — An incomplete internal mould of a dorsal valve (NMV P308012) represents a species most likely of Rugosochonetidae in view of its prominent fold, finely papillose inner surface and about 20 coarse costellae each with scores of capillae. The specimen is badly worn, therefore the internal structures are not preserved, rendering even its generic status open.

Order Productida Waagen, 1883
Suborder Productidina Waagen, 1883
Superfamily Productoidea Gray, 1840
Family Productellidae Schuchert in Schuchert and LeVene, 1929
Subfamily Marginiferinae Stehli, 1954
Genus ***Echinauris*** Muir-Wood and Cooper, 1960

Type species. — *Echinauris lateralis* Muir-Wood and Cooper, 1960.

Echinauris sp.

Figure 4.5

Remarks. — An incomplete ventral valve (NMV P308016) is referable to *Echinauris*. The ventral valve is more than 25 mm long, 29 mm wide, and more than 20 mm thick, has a moderately convex profile and is ornamented with numerous fine spine bases, but appears to have no evident internal ridge. This specimen is much larger than *E. jisuensis* (Chao, 1927; also described and figured by Duan and Li, 1985, p. 112, pl. 35, figs. 7–13) from the Zhesi Formation in the Zhesi area of Inner Mongolia.

← **Figure 4.** **1**. Rugosochonetidae gen. et sp. indet. Internal mold of a dorsal valve, NMV P308012, ×2.5. **2–4, 6–8**. *Anemonaria sublaevis* (King, 1931). **2**. Ventral view of a ventral valve, NMV P308020, ×2; **3, 7**. Posterior and anterior views of a ventral valve, NMV P308017, ×2; **4, 8**. Ventral and lateral views of a ventral valve, NMV P308018, ×2; **6**. Posterior view of a ventral valve, NMV P308019, ×2. **5**. *Echinauris* sp., ventral view of a ventral valve, NMV P308016, ×1.3. **9**. *Compressoproductus corniformis* (Chao, 1927), ventral view of a ventral valve, NMV P308026, ×1.6. **10**. *Cancrinella? cancrini* (de Verneuil, 1845), ventral view of a ventral valve, NMV P308024, ×2. **11–14**. *Spiriferella persaranae* (Grabau, 1931). **11–13**. Lateral, dorsal, and ventral views of a conjoined shell, NMV P308029; **14**. Ventral view of a ventral valve, NMV P308030, ×1.5. **15, 18, 21**. *Neospirifer* sp. Anterior, dorsal, and ventral views of a conjoined shell, NMV P308036. **16–17**. *Spiriferella keilhavii* (von Buch, 1846). **16**. Ventral view of a ventral valve, NMV P308033; **17**. Ventral view of a ventral valve, NMV P308034. **19**. Neospiriferinae gen. and sp. indet. Ventral view of a ventral valve, NMV P308037. **20**. *Kaninospirifer* sp. Ventral view of a ventral valve, NMV P308035. All figures are natural size unless otherwise indicated.

Subfamily Paucispiniferinae Muir-Wood and Cooper, 1960
Genus ***Anemonaria*** Cooper and Grant, 1969

Type species.—*Marginifera sublaevis* King, 1931.

Anemonaria sublaevis (King, 1931)

Figure 4.2–4.4, 4.6–4.8

Marginifera sublaevis King, 1931, p. 89, pl. 23, figs. 15a–c, ?16a, b, 19 (non figs. 13, 14).

Anemonaria inflata Cooper and Grant, 1969, p. 8, pl. 5, figs. 28, 29.

Anemonaria sublaevis (King). Cooper and Grant, 1975, p. 1103, pl. 408, figs. 1–26.

Material.—Three conjoined shells (NMV P308017–308019) and a nearly complete ventral valve (NMV P308020).

Description.—Shell of medium size, subrectangular outline, strongly concavo-convex in profile; widest at hinge; anterior margin slightly emarginated medially; ears alate and acute, triangular in shape, well demarcated from visceral region. Ventral valve strongly but unevenly convex, strongly geniculated; umbonal region swollen; umbonal slopes sharply inclined; sulcus shallow and broad, originating from anterior to umbo, becoming prominent on trail. Dorsal valve deeply concave; fold broad and round on trail. Surface of both valves largely smooth; occasionally with some inconspicuous costae near margin; halteroid spines in row overhanging usually smooth ears; spines rare on body and trail.

Remarks.—King (1931) first named this species, but the type was selected by Cooper and Grant (1975). This species is characterized by subrectangular outline, broad and shallow sulcus, and small triangular ears. This species differs from *A. pseudohorrida* (Wiman, 1914, p. 74, pl. 17, figs. 1–11) from the Kungurian to Guadalupian Kapp Starostin Formation of Spitsbergen and *A. auriculata* Shi and Waterhouse (1996, p. 68, pl. 6, figs. 10–28; text-figs. 22–24) from the Artinskian Jungle Creek Formation in the Yukon Territory of Canada by its deeper and broader sulcus. *A. pinegensis* (Likharev, 1931, p. 26, pl. 3, figs. 24, 25; Sarytcheva, 1977, p. 123, pl. 18, figs. 5–14) from the Kungurian strata in Kanin Peninsula, northwestern Russia, could be conspecific with the present species in terms of its outline, and shallow and broad sulcus, but appears to have more subquadrate ears.

Superfamily Linoproductoidea Stehli, 1954
Family Linoproductidae Stehli, 1954
Subfamily Linoproductidae Stehli, 1954
Genus ***Cancrinella*** Fredericks, 1928

Type species.—*Productus cancrini* de Verneuil, 1845.

Cancrinella*? *cancrini (de Verneuil, 1845)

Figure 4.10

Productus cancrini de Verneuil, 1845, p. 273, pl. 16, figs. 8a–c; pl. 18, fig. 7; Likharev, 1931, p. 319, pl. 1, figs. 11–13; Miloradovich, 1935, p. 131, pl. 5, figs. 4, 5.

Cancrinella cancrini (de Verneuil). Sarytcheva and Sokolskaja, 1952, p. 112, pl. 20; Grigorjeva, 1962, p. 50, pl. 11, figs. 1–10; pl. 15, fig. 1; pl. 16, figs. 1, 2; Grigorjeva *et al.*, 1977, p. 129, pl. 19, figs. 1–9, text-figs. 75, 76.

Material.—A complete ventral valve (NMV P308024) and an incomplete external mould of a dorsal valve (NMV P308025).

Description.—Shell small, subquadrate in outline, hinge slightly narrower than greatest width; with broadly rounded anterior and lateral margins; ventral visceral disc strongly convex, somewhat triangular; beak pointed; ears small; cardinal extremities obtuse; umbonal slopes sharply inclined; sulcus absent; surface marked by strong concentric wrinkles and fine costellae; costellae numbering 7 in 2 mm near the anterior margin; spines thin and delicate; spine bases elongated, widely scattered. Dorsal valve deeply concave; strongly geniculated; surface also with distinct wrinkles and fine costellae; spines unknown.

Remarks.—The small size, subquadrate outline and very fine costellae of the present specimens are generally identical with the type figured by de Verneuil (1845). However, the unknown dorsal spines renders the generic status of the present material open. Many previously recognized species of *Cancrinella* have been attributed to *Costatumulus* Waterhouse (see Archbold, 1993), which differs from *Cancrinella* in possessing dorsal spines. Therefore, it is also possible that the Xiujimqinqi specimens could belong to *Costatumulus*.

Genus ***Compressoproductus*** Sarytcheva in Sarytcheva, Likharev and Sokolskaja, 1960

Type species.—*Productus compressus* Waagen, 1884.

Compressoproductus corniformis (Chao, 1927)

Figure 4.9

Striatifera compressa var. *corniformis* Chao, 1927, p. 101, pl. 15, figs. 6–9.

Productus (*Striatifera*) var. *corniformis* Chao. Grabau, 1931, p. 291, pl. 29, figs. 6–9.

Compressoproductus compressa var. *corniformis* (Chao). Wang *et al.*, 1964, p. 334, pl. 53, figs. 12, 13.

Remarks. — The occurrence of this species in the Xiujimqinqi collection is shown by a single specimen (NMV P308026). This species has been documented from the Zhesi Formation in Zhesi, Inner Mongolia, by Grabau (1931). The characteristic elongate outline, finely costellate surface and strongly laterally compressed nature of the shell of the present specimen fit very well with the type from the Longtan Formation in Guangxi, South China, as figured by Chao (1927). This species differs from all other species in the genus by the laterally compressed nature of its shell, hence warranting the recognition of Chao's variety as a separate species.

Order Spiriferida Waagen, 1883
Suborder Spiriferidina Waagen, 1883
Superfamily Spiriferoidea King, 1846
Family Spiriferellidae Waterhouse, 1968
Genus ***Spiriferella*** Tschernyschew, 1902

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

Spiriferella persaranae (Grabau, 1931)

Figure 4.11–4.14

Spirifer persaranae Grabau, 1931, p. 156, pl. 19, fig. 4.
Spiriferella persaranae Grabau. Wang *et al.*, 1964, p. 595, pl. 114, figs. 15, 16; Li and Gu, 1976, p. 295, pl. 172, figs. 1–6; Li *et al.*, 1980, p. 418, pl. 178, fig. 5; Duan and Li, 1985, p. 121, pl. 1, figs. 1–11, 17, 18.

Material.—A slightly crushed conjoined shell (NMV P308029) and three incomplete ventral valves (NMV P308030–308032).

Description.—Shell medium in size, elongate in outline, unequally biconvex in profile, hinge narrower than greatest width at slightly anterior to midvalve; ventral beak strongly incurved; interarea very high, strongly concave, delthyrium about one-third of the hinge line; beak ridges angular; ventral sulcus narrow and shallow, commencing from beak, with several inconspicuous costae; boundary costae coarser than other costae; each flank with 4–6 costae; costae commonly bifurcating 1–2 times, producing some small costae beside the main costa; dorsal valve less convex than ventral valve; fold low, with a prominent median groove; each flank with 4–5 costae.

Remarks.—*S. saranae* (de Verneuil, 1845, p. 169, pl. 6, fig. 15a, b) is closest to this species. The original description of *S. saranae* by de Verneuil (1845) from the upper Artinskian of the Ufa River mentioned that this species is characterized by a high interarea, five to six smaller, equally spaced costae in the sulcus and a prominent median groove in the fold. *S. persaranae* differs from *S. saranae* in its more simple costae and less conspicuous and probably fewer and smaller costae in the sulcus. *S. praesaranae* (Stepanov,1948, p. 43, pl. 10, figs. 3–8) is probably synonymous with the present species as indicated by their similar costation, size and outline, but it is from the Upper Carboniferous.

Spiriferella keilhavii (von Buch, 1846)

Figure 4.16, 4.17

Spirifer keilhavii von Buch, 1846, p. 74, pl. 1, figs. 2a, b: Frech, 1901, p. 499, pl. 57c, figs. 1b–c.
Spirifer draschei Toula, 1875, p. 239, pl. 7, figs. 4a–c.
Spirifer parryanus Toula, 1875, p. 232, pl. 7, figs. 8a–d.
Spiriferella keilhavii (von Buch). Tschernyschew, 1902, p. 527, pl. 40, figs. 1–4; Wiman, 1914, p. 36, pl. 2, figs. 25–30, pl. 3, fig. 1; Tschernyschew and Stepanov, 1916, p. 79, pl. 11, figs. 2a–c, 3a–c; Frebold, 1931, p. 28, pl. 5, figs. 7–9; 1937, p. 46, pl. 11, fig. 9; Dunbar, 1955, p. 139, pl. 25, figs. 1–9; pl. 26, figs. 1–11; pl. 27, figs. 1–14; Gobbett, 1964, p. 154, pl. 20, fig. 7; Nelson and Johnson, 1968, p. 736, pl. 96, figs. 7, 8, 12; text-figs. 3e, 8a, 9, 13b; Brabb and Grant, 1971, p. 17, pl. 2, figs. 26–28, 34, 35; Duan and Li, 1985, p. 122, pl. 2, figs. 1, 5, 8.
Spiriferella draschei (Toula). Wiman (partim), 1914, p. 38, pl. 3, fig. 2.
?*Spiriferella keilhavii* (von Buch). Waterhouse and Waddington, 1982, p. 28, pl. 4, fig. 15; pl. 6, figs. 3–14; text-figs. 16e, g–i, 19.

Remarks.—As noted by Likharev and Einor (1939, p. 218) and Dunbar (1955, p. 152), von Buch's original figure of *S. keilhavii* is a drawing constructed from a number of specimens, two of which (a dorsal and a ventral) were later figured by Frech (1901, pl. 57c, figs. 1b–c). Likharev and Einor (1939) selected the dorsal valve of Frech's figured material (Frech, 1901, pl. 57c, fig. 1b) as the 'holotype' (lectotype) of *S. keilhavii* on the ground that the features of the dorsal valve match better with von Buch's original description of the species. Since our material consists only of two ventral valves (NMV P308033, 308034), no comparison can be made with the lectotype of the species, but the observed features of the ventral valves, especially the large and wide valves with a hinge line nearly as wide as the greatest shell width and strongly fasciculated costae, are characteristic of the ventral valve of *S. keilhavii* as figured by Tschernyschew (1902), Dunbar (1955) and Gobbett (1963).

Spirifer parryanus Toula (1875) from Spitzbergen was erected based on several incomplete specimens, and has been referred to *S. keilhavii* (Dunbar, 1955, p. 145). Specimens figured by Waterhouse and Waddington (1982) from Yukon Territory of Canada have flat, coarse and unbranched costae and a relatively narrower hinge, suggest-

ing that they are probably different from the type material of *S. keilhavii* as described and figured by Dunbar (1955, pl. 27, figs. 8, 9).

Family Spiriferidae King, 1846
Subfamily Kaninospiriferinae Kalashnikov, 1996
Genus ***Kaninospirifer*** Kulikov and Stepanov in Stepanov *et al.*, 1975

Types species.—*Spirifer kaninensis* Likharev, 1943.

Remarks.—When proposing Kaninospiriferinae, Kalashnikov (1996) included two genera in this new subfamily: *Kaninospirifer* and *Imperiospira* Archbold and Thomas, 1994. The former is distinguished from the latter by its transverse outline, ill-defined fasciculation if present at all, and lack of adminicula within the ventral interior. On the other hand, both genera are readily distinguished from members of the Neospiriferinae by fine and equidimensional costae, generally weak fasciculation and absent to weakly developed adminicula.

As already noted, *Kaninospirifer* has very limited stratigraphical and geographical distributions. Kalashnikov (1996) has listed the genus occurring mainly in the Arctic region (Arctic Canada, Greenland, Spitsbergen, Arctic Russia) and East Asia (South Primorye of Far East of Russia, southeast Mongolia, northeast China). Pavlova (1991, p. 130) also listed some previously reported species from Timor and the Salt Range as possible representatives of the genus, but the true identities of these species have not yet been confirmed. On the other hand, *Gypospirifer* sp. from the Middle Permian of the Hida Gaien Belt of central Japan (Tazawa, 2000, figs. 3.12, 3.13) appears referable to *Kaninospirifer* judging by its shape and costation pattern. In all of its confirmed occurrences, *Kaninospirifer* is known to be associated with Kazanian (or Wordian) faunas.

Kaninospirifer sp.

Figure 4.20

Remarks. — An incomplete ventral valve (NMV P308035) in the collection indicates *Kaninospirifer*. The specimen is characterized by a transverse outline, very weak fasciculation that is visible only on the umbo, fine and equidimensional costae numbering about 15 per cm at about 2 cm from the beak, and a broad and well defined sulcus. This specimen appears to be closest to *Kaninospirifer kaninensis* (Likharev, 1943, p. 279, figs. 1–4), type species of the genus, from the Kazanian (Wordian) of the Kanin Peninsula, Russia. The two forms share a transverse outline, weak fasciculations that do not form prominent bundles, fine and even costae, and a well developed sulcus, but further comparison is hampered because of insufficient material in our collection, especially the total lack of knowledge of the interior.

Pavlova (1991) assigned several species from the Middle Permian of Mongolia, South Primorye of Russian Far East, and northeast China to *Kaninospirifer*. Both *K. incertiplicatus* Pavlova (1991, p. 131, pl. 29, figs 5, 6; see also Fredericks, 1925, p. 27, pl. 4, figs. 111, 112) and *K. adpressum* (Liu and Waterhouse, 1985, p. 36, pl. 12, figs. 5–10; see also Pavlova, 1991, p. 132, pl. 29, figs. 7, 8) are larger than the present specimen, less transverse and more subquadrate in outline, and possess variably developed plicae on the shell surfaces.

Gypospirifer sp., from the Middle Permian Moribu Formation of the Hida Gaien Belt of central Japan (Tazawa, 2000, figs. 3.12, 3.13), is likely a representative of *Kaninospirifer*, judging by its transverse outline, relatively fine and even costae and ill-defined fasciculation, but the ventral valve (Tazawa, 2000, fig. 3.12) seems to display slightly coarser costae than the present specimen.

Subfamily Neospiriferinae Waterhouse 1968
Genus ***Neospirifer*** Fredericks 1923

Type species.—*Spirifer fasciger* von Keyserling, 1846.

Neospirifer sp.

Figure 4.15, 4.18, 4.21

Remarks. — An incomplete conjoined shell (NMV P308036) has a deeply V-shaped sulcus in the ventral valve and a highly elevated fold in the dorsal valve. The crests of the plicae that bound the sulcus are sharp. Costae on flanks are fascicostellate and fine, numbering about 10 per cm near the anterior margin. Each fascicle consists of 6–8 costae. This species differs from any known species of *Neospirifer* by its fine costae on both valves and the deep, V-shaped sulcus. *N. fasciger* (von Keyserling, 1846) is somewhat similar to this species in terms of its outline and general fasciculation pattern, but differs by its shallower and U-shaped sulcus and coarser costae.

Neospiriferinae gen. and sp. indet.

Figure 4.19

Remarks. — An incomplete ventral valve (NMV P308037) indicates possibly another species of *Neospirifer* or a related genus. The specimen has a subquadrate outline, weak fasciculation, coarse and somewhat flattened costae which are grouped into bundles of two to four (generally three), and a relatively broad and shallow sulcus. No known species of *Neospirifer* seems to resemble this specimen very closely. On the other hand, *Cratispirifer nuraensis* Archbold and Thomas (1985, p. 280, figs. 8A–F)

from the Sakmarian of Western Australia appears comparable in general terms, especially on account of their coarse, flattened and equidimensional costae that are grouped into bundles of no more than four (usually three), but the latter species is clearly distinguishable by its transverse outline, a proportionally high ventral interarea, and flattened costae. *Spirifer*? sp. from the Kungurian Talatinsk Formation of the Kozhim River section of the Pechora Basin, Russia (Kalashnikov, 1998), shares a similar outline and costation pattern with the present specimen, but it has a deeper sulcus and a more convex umbonal region.

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