Available online at www.sciencedirect.com
SCIENCE DIRECT
Journal of Asian Earth Sciences 26 (2006) 294–303
Journal of Asian Earth Sciences
www.elsevier.com/locate/jaes

An overview of Permian marine stratigraphy and biostratigraphy of Mongolia

I.N. Manankov [a], G.R. Shi [b,*], Shu-zhong Shen [c]

[a] Paleontological Institute, Russian Academy of Sciences, ul. Profsoyusnaya 123, Moscow 117647 Russian Federation
[b] School of Ecology and Environment, Deakin University, Melbourne Campus, 221 Burwood Highway, Melbourne Vic. 3125, Australia
[c] Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, 39 East Beijing Road, Nanjing 210008, People's Republic of China

Received 14 March 2005; accepted 27 November 2005

Abstract

This paper summarizes the spatial distribution, stratigraphical divisions and biostratigraphical zonation schemes of Permian marine deposits in Mongolia. Where appropriate, correlations of the various Permian marine biostratigraphical units with those of adjacent regions are also reviewed and discussed. In general, Permian marine sequences are developed in two separate basins: one in central and northeastern Mongolia where the Permian stratigraphy and marine faunas bear strong similarities with those of the Transbaikal, Verkhoyansk and Kolyma–Omolon regions of southern and eastern Russia; and the other in southeastern Mongolia where the Permian marine faunas and rock sequences are closest to those of northeast China and southern Primorye of Far East Russia.
© 2006 Elsevier Ltd. All rights reserved.

Keywords: Brachiopods; Mixed faunas; Mongolia; Northern transitional zone; Permian

1. Introduction

Permian marine deposits in Mongolia, locally characterized by abundant benthic marine faunas, are distributed in two parallel NE–SW trending belts separated by the South Mongolian microcontinent or terrane: one belt in central and northeastern Mongolia, and the other belt along the southeastern border of Mongolia with China (Fig. 1). The northern belt represents an epicontinental marine basin, formerly known as the 'Khangai-Khentei Geosyncline' (e.g. Durante et al., 1996), and, because it bears striking similarities to Permian deposits and biotas of the Transbaikal region to the north, this belt is also widely regarded as the southern extension of the Permian Mongol–Transbaikalian biogeographical province of the Boreal zoogeographical realm (Manankov, 1999). In contrast, the Permian marine succession and biotas in southeastern Mongolia, or the Southern Mongolian Basin (Manankov, 1999), share many characteristics with those of northeastern China and the southern Primorye region of southeastern Russia, all of which belonged to the Permian Ussurian biogeographical province (Manankov, 1999) of the northern Palaeo-Tethyan region (Fig. 1). In this paper, the stratigraphy, biostratigraphy and faunal successions of the Permian marine successions developed in both belts of Mongolia are summarized and, where appropriate, possible correlations of the various Permian biostratigraphical units with those of adjacent regions are also discussed.

In this paper, the Russian stratigraphical term 'Horizon' is used as a useful regional (as opposed to global) biostratigraphical term, as has been done so in numerous previous stratigraphical works concerning the Upper Palaeozoic stratigraphy of Mongolia (e.g. Manankov, 1998a,b, 1999, 2004; Afanas'eva et al., 2003; Durante et al., 1996). However, we note that this term is not recognized as a formal stratigraphic unit in the international stratigraphic code (Salvador, 1994). In Russia and Mongolia where this term has been used widely as a nationally recognized and recommended formal stratigraphic unit, a 'horizon' refers to a body of sedimentary strata definable principally (but not exclusively) by palaeontological characteristics and clearly traceable within a geographical region, a palaeo-basin, or a palaeobiogeographical province (Zhamoida et al., 1979). In

* Corresponding author. Tel.: +61 3 9251 7619; fax: +61 3 9251 7626.
E-mail address: grshi@deakin.edu.au (G.R. Shi).

1367-9120/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jseaes.2005.11.008

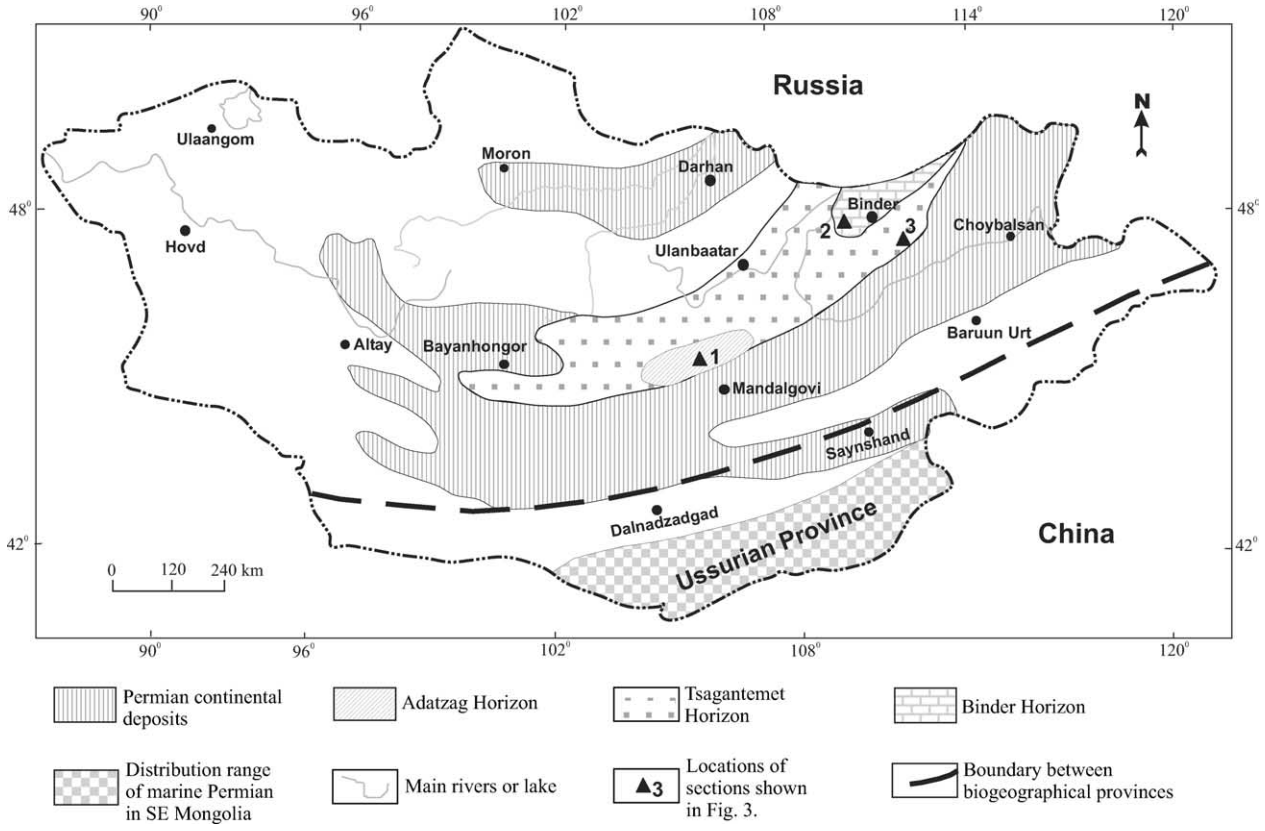

Fig. 1. Overall distribution map of Permian sedimentary rocks in Mongolia. The locations of the three numbered Permian stratigraphic sections are: 1. the Adatzag section; 2. the Binder section (Ikh–Uldsi Mountains); 3. the Tavan–Tolgoy section.

this sense, a 'horizon' may be compared with a 'stage' or 'biozone' in the international stratigraphical code.

2. Central and northeastern Mongolia

The Permian marine succession in central and northeastern Mongolia is exposed along a 900 km long NW–SE trending sublatitudinal belt (Fig. 1). Here, the succession has been divided into three horizons, the Adatzag, Tsagantemet and Binder horizons in ascending order (Table 1; Fig. 2). The Adatzag Horizon is a 200 km long strip distributed in the northern part of central Mongolia (Fig. 1). At its type section near Somon Adatzag (locality 1 in Fig. 1; 46°20′40″N, 105°43′20″E), the horizon is represented by the Delgerkhanskaya Formation (Manankov, 2002), which is a more than 1000 m succession of predominantly fine- to medium-grained terrigenous sedimentary rocks (mudstone, siltstone and sandstone), intercalated with coarse sandstone and conglomerate (Fig. 2). Volcanic and volcaniclastic rocks also occur in this section, but are present mainly in the basal part. Although not common, both plant and marine invertebrate fossils have been found in this section, with marine fossils occurring throughout most of the section, while fragmentary plant remains occasionally appear only in its middle part (e.g. unit 4 of the section) (Fig. 2). Detailed field sampling, backed up by a detailed taxonomic study of the marine fauna of the section showed that the fauna contains seven bivalve species and 10 brachiopod species (Manankov, 2002, 2004; Afanas'eva et al., 2003). Brachiopods taken to characterize the Adatzag Horizon by Manankov (2002, 2004), are dominated by *Jakutoproductus adatsagensis* Manankov and *J. ganelini* Manankov, along with some other species including *Lanipustula baikalensis* Maslennikov, *Anidanthus halinae* Kotlyar, *Costatumulus sidorkini* Manankov, and rare *Mongolochonetes* sp. and *Neospirifer kedonensis* Einor.

The age of the Adatzag Horizon has been considered to be Sakmarian–Early Artinskian by comparing the marine fauna with that of the upper Munugudzhak Horizon in the Kolymo–Omolon Basin and the upper Khorokytian to lower Echian horizons of the Verkhoyansk fold belt in northeast Asia (Table 1) (see Shi, this volume for general geographical and background geological information of northeast Asia). In the latter two regions, associated with the *Jakutoproductus* faunas there is also a distinctive ammonoid fauna consisting mainly of species of *Agathiceras*, *Bulunites* and *Uraloceras*, of principally Sakmarian–Artinskian age (Kutygin, 2006). The Adatzag Horizon is also correlatable with the *Jakutoproductus zabaicalicus–A. halinae* Zone of Transbaikalia (Kotlyar et al., 2002) and possibly also with the Gengenaobao Formation of central Inner Mongolia in northeastern China where a *Jakutoproductus* fauna is also present (Shi et al., 2002; Shen et al., 2006).

The most widely distributed Permian marine sedimentary unit in the northern belt is the Uldzinskoy Formation, which represents a major marine transgression of the Arctic sea into the interior basins of East Asia during the Middle Permian. The

Table 1
Correlation of Permian marine successions within Mongolia and with adjacent regions in East and Northeast Asia

Eastern European scale (NW Russia)				Central & NE Mongolia (Manankov, 2004; this paper)		Southeastern Mongolia (Manankov, 1998b)		Transbaikalia (Kotlyar et al., 2002)		Northeast Asia (Verkhoyansk Fold Belt and Kolyma-Omolon Basin) (Ganelin et al., 2001; Biakov, 1999)			Southern Primorye (Kotlyar et al., 2003)		Tethys scale	Global scale
System	Series	Stage	Horizon	Horizon	Local assemblage zones or beds with fossils	Horizon	Local assemblage zones or beds with fossils	Horizon	Local assemblage zones or beds with fossils	Horizon	Stage	Local assemblage zones or beds with fossils	Horizon	Local assemblage zones or beds with fossils	Stage	Stage
Permian	**Upper**	Tatarian	Vyatkian					Zabaikal.		Kolymian	Khivach	*Stepanoviella pseudocurvata -Intomodesma costata*	Chandalaz	*Lepidolina kumaensis -Metodoliolina lepida*	Midian	Capitanian
												Maitaia tenkensis				
			Severodvinian			Solonker	*Echinauris jisuensis*	Togotuisk	*Cancrinelloides* cf. *curvatus*		Gizhiga	*Cancrinelloides curvatus -Maitaia bella*		*Parafusulina stricta, Timorites, Maitaia bella*		
				Binder	*Cancrinelloides obrutshewi*			Sosucheisk	*Cancrinelloides obrutshewi -Attenuatella olexivi*			*Cancrinelloides obrutshewi -Maitaia bella*				
			Urzhumian	Tsagantemet	*Magadania modotonensis*	Tsagan-Ula	*Alispiriferella lita-Kaninospirifer adressum*		*Magadania bajcurica-M. modotonensis*	Omolon	Yukagirsk	*Magadania bajcurica -Kolymia multiformis*		*Monodiexodina sutschanica -Metodoliolina dutkevichi, Tauroceras*		Wordian
		Kazanian	Upper		*Terrakea korkodonensis*		*Liosotella decimana-Waagenoconcha angustata*	Antinian	*Terrakea* sp., *Olgerdia* sp., *Rhynoleichus lobjaensis*		Olyn	*Terrakea korkodensis -Kolymia plicata*	Vladivostok	*Altudoceras*	Murgab.	
					Terrakea arguta							*Terrakea borealis -Kolymia plicata*			Kubergand.	Roadian
			Lower		*Mongolosia morenkovi*			Alentui			Saryn	*Omolonia snjatkovi-K. inoceramiformis*		*Yakovlevia mammatiformis, Daubichites*		
												Mongolosia russiensis -Aphanaia dilatata				
		Ufim.				Khovsgol	*Kolymaella ogonorensis -Rhynoleichus dsilensis*			Dzhigdala	Khalalin.	*Kolymaella-Bocharella*	Abrek	*Primorewia*	Bolorian	Kungurian (s.l.)
	Lower	Kungurian	Iren				*Megousia aagardi-Paramarginifera nativa*	Kizhiginsk			Koargychan	*Megousia kuliki-Aphanaia andrianovi*				
			Filippov													
			Saranin									*Megousia aagardi -Aphanaia lima*				
		Artinskian	Sargin									*Jakutoproductus burgaliensis -Litophaga gigantea*			Yakhtashian	Artinskian
			Irgin	Adatzag	*Jacutoproductus adatsagensis-J. ganelini*	Totoshan	*?Monodiexodina linearis*	Zhiphoshin	*Jakutoproductus zabaicalicus-Anidanthus halinae*	Munugudzhak	Ogoner	*Jakutoproductus rugosus*	Dunai			
			Burtsev									*Jakutoproductus terekhovi*				
		Sakmarian	Sterlitamakian									*Jakutoproductus insignis*			Sakmarian	Sakmarian
			Tastubian			Agui-Ula	*Sphaeroschwagerina sphaerica gigas*				Orotsh	*Jakutoproductus expositus*				
		Asselian	Shikan				*Pseudoschwagerina uddeni*					*Jakutoproductus mirandus*			Asselian	Asselian
			Cholodnolozk				*Daixina diafana gobiensis*									

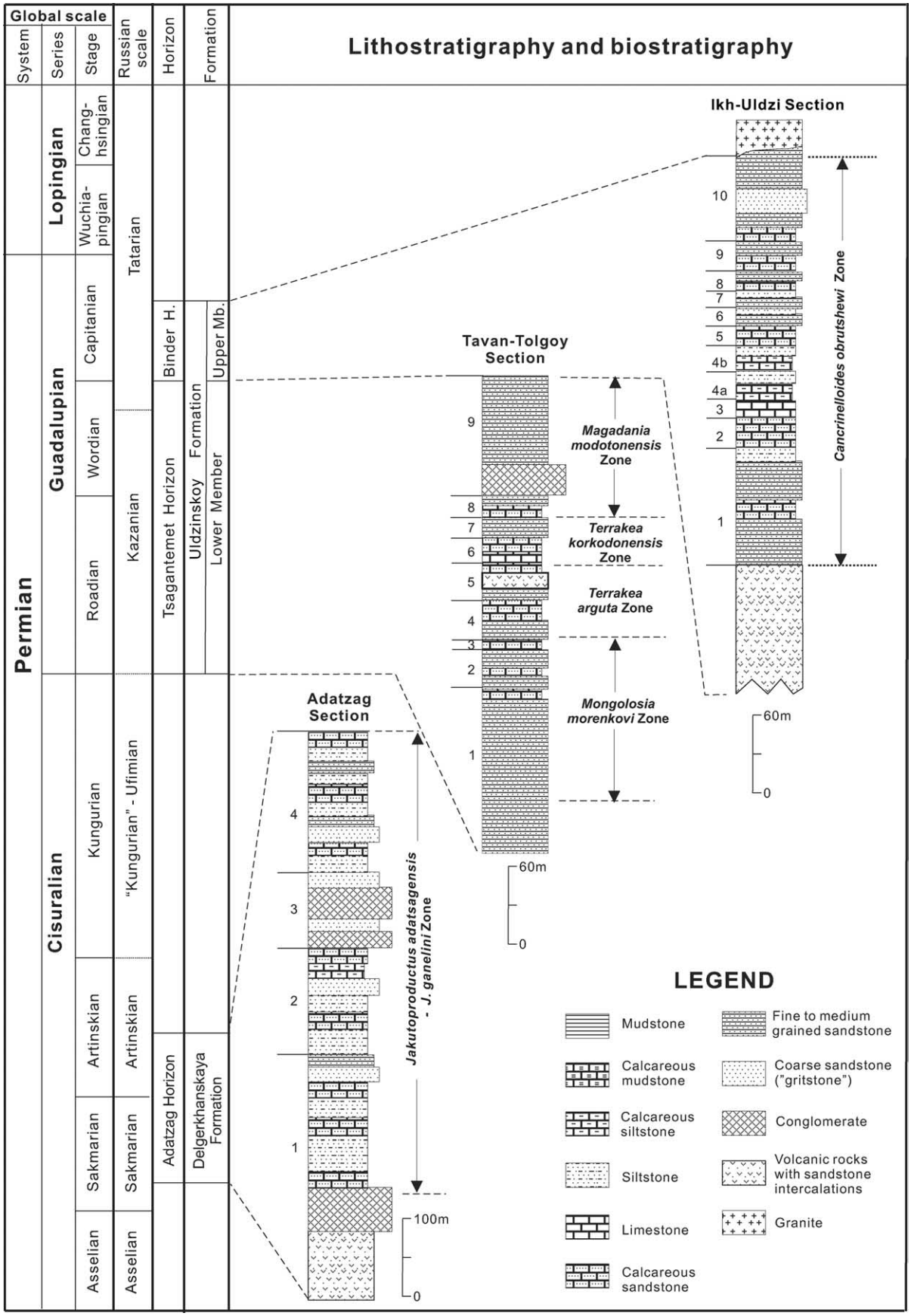

Fig. 2. Stratigraphic columns and lateral correlation of three Permian marine rock successions in central and northeastern Mongolia, redrawn with slight modifications from Manankov (2002). The locations of these sections are shown in Fig. 1 and also given in the text.

formation is distributed in a roughly NE–SW sublatitudinal belt extending across much of central and northeastern Mongolia (Fig. 1). The formation has been divided into two distinctive members (Manankov, 2002). The lower member of the Uldzinskoy Formation is best represented by the Tavan–Tolgoy section located at about 5 km west of the Tavan–Tolgoy Mountain (locality 3 in Fig. 1; 48°39′10″N, 112°41′20″E) where a succession of brachiopod assemblage zones has been recognized (Manankov, 2002) (Fig. 2). In this section, this member is characterized mostly by sandstone, siltstone, with intercalations of limestone and conglomerate. Marine fossils occur throughout the section, although they are most common in calcareous sandstone beds. A total of 15 brachiopod species, four bivalve species and some rare bryozoans and plant fragments have been recognized from the section (Manankov, 2002), among which the brachiopods are of great importance for dating and correlation. The stratigraphic ranges of the 15 brachiopod species at this section are varied, which has enabled Manankov (in Afanas'eva et al., 2003; see also Manankov, 2004) to recognize the Tsagantemet Horizon and to establish a succession of four brachiopod assemblage zones (Fig. 2). The lower three brachiopod zones can be correlated directly with the Antiinsk Horizon of Transbaikalia, the Sarynian and Olyn Subhorizons of the Omolonian Horizon of the Kolyma–Omolon Basin (Ganelin et al., 2001), and the Delendzhian Horizon of the Verkhoyansk fold belt, as many of the key brachiopod species as well as characteristic bivalve and bryozoan species are common to all the correlative horizons. In particular, in both the Verkhoyansk and Kolyma–Omolon regions, strata equivalent to the Tsagantemet Horizon contain some biostratigraphically important ammonoid taxa including *Daubichites*, *Popanoceras* and *Sverdrupites harkeri* (Kutygin, 2006). *Sverdrupites* also occurs in the lower part of the type Kazanian deposits in the Russian Platform (Kotlyar et al., 2004), therefore implying that at least part of the Tsagantemet Horizon may be Kazanian in age (Table 1).

The uppermost part of the Tsagantemet Horizon signals a regressive stage of basin development in northern Mongolia during the Permian and is characterized by beds with *Magadania modotonensis* Kotlyar; it is confined to northeastern Mongolia. The fossil assemblage is defined particularly by the abundant occurrence of brachiopod *M. modotonensis*, allowing the establishment of a brachiopod zone under the same name. Although differing in species composition, this brachiopod zone can be closely compared with the *Magadania bajkurica–M. modotonensis* Zone of Transbaikalia, the *M. bajcurica–Kolymia multiformis* Zone of the Yukagirsk Subhorizon in the upper part of the Omolonian Horizon in the Kolyma–Omolon Basin of northeast Asia, and the Urzhumian Horizon of the Tatarian Stage of the Russian Platform (Kotlyar et al., 2003) (Table 1).

The youngest Permian marine interval in northern Mongolia is represented by the upper member of the Uldzinskoy Formation or the Binder Horizon, which is confined to a small area in the northeast of the country (Fig. 1). At its type section in the Ikh–Uldzi Mountain area near Somon Binder (locality 2 in Fig. 1; 48°35′N, 110°33′E), this member, resting unconformably on the Lower Permian continental deposits of the Gadzanskoy Formation, is marked by a 214 m succession of sandstone, calcareous siltstone and some intercalations of limestone. Marine invertebrate fossils are particularly common in limestone and calcareous siltstone and sandstone beds, and are dominated conspicuously by the brachiopod *Cancrinelloides obrutshewi* Likharev, which may locally account for 90% of the total fossils in a single bed. The high abundance of this species in the upper member of the Uldzinskoy Formation has led to the recognition by Manankov (in Afanas'eva et al., 2003; Manankov, 2004) of the *C. obrutshewi* Zone within the Binder Horizon. Besides the nominal index species, this brachiopod zone also includes *C. licharewi* Kotlyar, *Baitugania duseevi* Grunt, *Neospirifer invisus* Zavodovskiy, *Tumarinia ganelini* (Grigoryeva), *Tumarinia zavodowskyi* (Grigoryeva), etc. This brachiopod assemblage is readily compared to the *C. obrutshewi* Zone of the Dulgalakh Horizon of the Verkhoyansk fold belt, the *C. obrutschewi–Attenuatella olexivi* Zone in the upper part of the Sosusheisk Horizon of Transbaikalia, the *C. obrutschewi–Maitaia bella* Zone in the lower half of the Gizhigan Horizon of the Kolyma–Omolon Basin, as well as the Severodvinian Horizon of the Tatarian in northwest Russia (Table 1). Alignment of this horizon with the Capitanian Stage of the international Permian timescale has also been made possible because of *Timorites*, an index ammonoid genus for the Capitanian that co-occurs with the brachiopod *C. obrutschewi–A. olexivi* Zone in Transbaikalia (Kotlyar et al., 1999, 2003).

3. Southeastern Mongolia

The Permian marine deposits of southeastern Mongolia are distributed approximately within an 800 km long and 150 km wide sublatitudinal belt along the southeastern border with China (Fig. 1). The deposits, locally reaching 5 km in total thickness (Manankov, 1998b), have been affected by structural complications involving folds and faults. Suetenko (in Pavlova et al., 1991) divided the Permian strata into four structural-facies zones (referred to as structure zones hereafter); they are, from south to north: the Solonker structure zone, Dalan-Ula–Lugin-Gol structure zone, Totoshan structure zone and the Khovsgol–Beirim–Obo structure zone (Fig. 3). Despite the structural complications, a stratigraphic framework for the Permian deposits has been established, following detailed field mapping and observation (Pavlova et al., 1991; Manankov, 1998b; 1999). The framework recognizes a succession of five horizons (Manankov, 1998b): the Agui-Ula, Totoshan, Khovsgol, Tasgan-Ula and Solonker, in ascending order (Fig. 4, Table 1). The Agui-Ula Horizon is characterized by sandstone, siltstone and limestone of the lower Angui-Ula Formation in the Dalan-Ula–Lugin-Gol structure zone (Fig. 4). It is also well recognized in the Khovsgol–Beirim–Obo structure zone, where it is represented mainly by volcanic rocks, sandstone and limestone of the lower Bairismobo Formation. The Angui-Ula Horizon contains abundant foraminifers, with rare brachiopods, bryozoans and corals. According to Solov'eva (in Pavlova et al., 1991), three

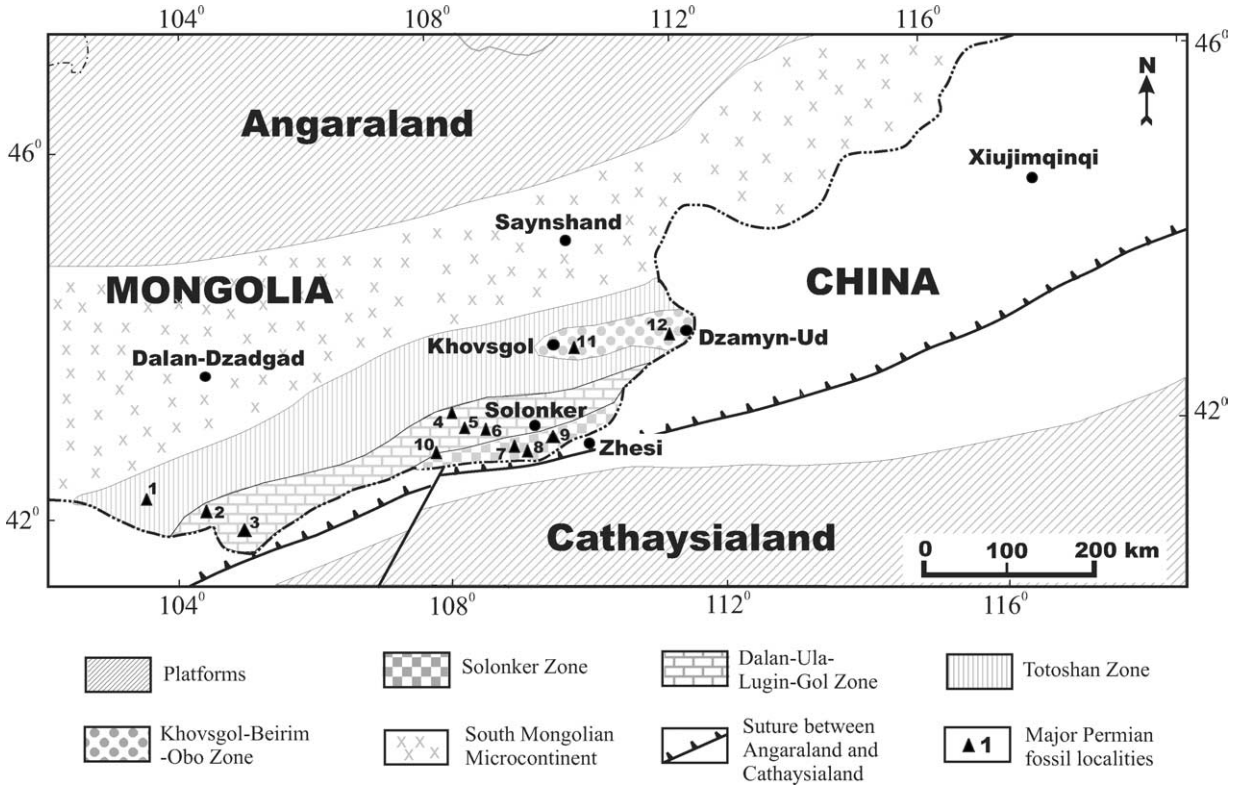

Fig. 3. Distribution of Permian sedimentary rocks in southeastern Mongolia, showing the detailed spatial extent of the four Permian marine structural-facies zones and major marine fossil localities: 1. Ulan-Shivenyi–Khuduk Well; 2. Khuryin-Chibe–Khuduk Well; 3. Mungun–Obo Mountain; 4. Tumen-Ul'dzei-Ula Mountain; 5. Lugin-Gol River; 6. Dzhirem-Ula Mountain; 7. Onts–Obo Mountain; 8. Khoyar–Khuduk Well; 9. Karaerdene-Ula; 10. Agui-Ula; 11. Somon Khovsgol; 12. Beirim–Obo.

foraminiferan zones can be recognized (Table 1), all bearing striking similarities in species composition to those of the Asselian to lower Sakmarian of the South Urals. In the view of Solov'eva (in Pavlova et al., 1991), the diversified foraminifer fauna suggests a subtropical open sea setting for southern Mongolia during this time (see also Manankov, 1998b).

The Totoshan Horizon is distributed mainly in the Khovsgol–Beirim–Obo, Totoshan and Solonker structure zones, where it is represented, respectively, by the middle and upper parts of the Bairismobo Formation, the lower part of the Toluinula Formation and the upper part of the Borinsulkhuduk Formation (Fig. 4). In the Dalan-Ula–Lugin-Gol structure zone, the corresponding unit is known as the upper Angui-Ula Formation (Fig. 4). In general, volcanic rocks and sandstones are most common in this horizon, but locally there are also fossiliferous limestone beds and conglomerates (Fig. 4). The foraminifers from this horizon are dominated by species of the *Monodiexodina linearis* Zone. Solov'eva (in Pavlova et al., 1991) assigned this zone to the Sakmarian to Artinskian. The Totoshan Horizon is supposed to overlie the Agui-Ula Horizon; however, Ueno (2006) after examining the *Monodiexodina* species described by Solov'eva (in Pavlova et al., 1991) considered them all to be referable to *Eoparafusulina* and that the so-called '*M. linearis*' Zone may be part of or laterally equivalent to the Agui-Ula Horizon, therefore also of Asselian–Sakmarian age. If this is accepted, the Totoshan Horizon will automatically become redundant. However, this issue has to await further field investigations and perhaps also a restudy of the '*Monodiexodina*' species from the '*M. linearis*' Zone.

The Kungurian seems to mark a major change in the basin development as well as biogeographical reorganization in southeastern Mongolia. As stated above, the pre-Kungurian Permian rocks are dominated by carbonates with abundant foraminifers including fusulinoideans, and these faunas bear strong affinities to those of the South Urals. However, during the Kungurian there were the first signs of cold-water faunas invading this region. The development of the cold-water Boreal-type Permian biota reached a climax in the Kazanian. Another important feature accompanying the biogeographical reorganization in southeastern Mongolia was the intermingling during these times (Kungurian–Kazanian) of both cold-water Boreal-type and warm-water Palaeo-Tethyan (Cathaysian) brachiopods, bivalves and bryozoans, a feature that apparently characterizes the mid-Permian interval of much of the East Asian region including northeast China, parts of Japan and South Primorye of the Russian Far East (Tazawa, 1991; Shi et al., 1995; Shi, this volume). As a consequence, the Khovsgol Horizon has been defined by predominantly cold-water brachiopod faunas, with two stratigraphically distinctive zones: the *Megousia aagardi–Paramarginifera nativa* Zone and the overlying *Kolymaella ogonorensis–Rhynoleichus dsilensis* Zone. The first zone is typically recognized from a section near Somon Khovsgol in the Khovsgol–Beirim–Obo structure zone (48°35′N, 110°33′E, locality 11 in Fig. 3), where it is represented by the Kharanudunsk Formation (Fig. 4). In

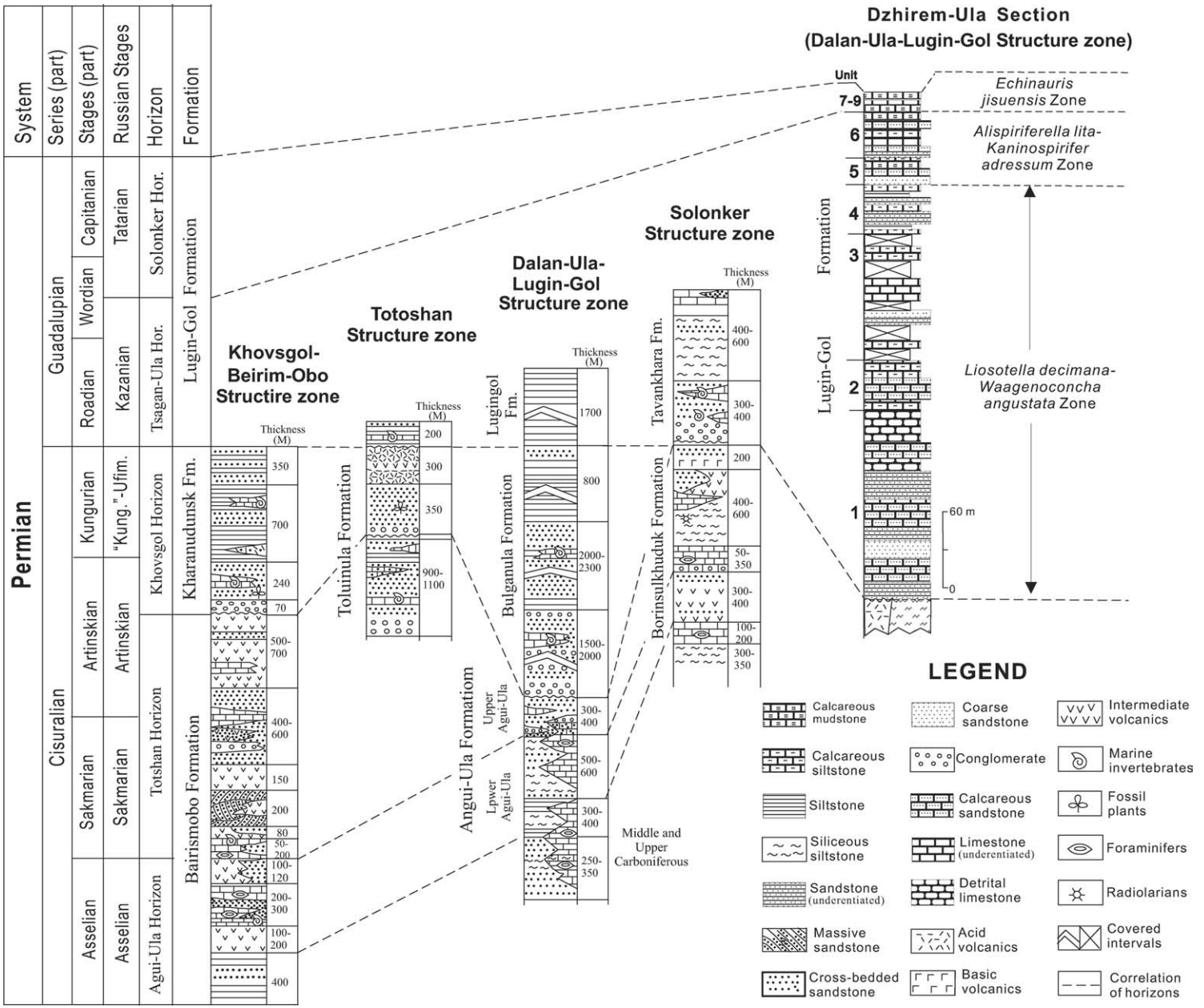

Fig. 4. Representative stratigraphic columns and lateral correlation of Permian marine rock successions in the four structural-facies zones (see Fig. 3 for details) of southeastern Mongolia. The representative stratigraphic columns for the Khovsgol–Beirim–Obo, Totoshan, Dalan-Ula–Lugin-Gol and Solonker zones are synthetic summary logs based on Pavlova et al. (1991, Fig. 3), while the Dzhirem-Ula section is redrawn from Manankov (1999, Fig. 3).

this section, the Khovsgol Horizon is characterized mainly by calcareous sandstone and siltstone, with occasional, thin-bedded calcareous mudstone layers. Marine invertebrate fossils are common throughout the section and are dominated by brachiopods, although some other fossil groups such as bryozoans, bivalves and rare gastropods and ammonoids also occur. Among the brachiopods, *M. aagardi* (Toula) and *P. nativa* Manankov are particularly abundant and common in most of the beds, especially within calcareous mudstone layers, and therefore these two species together constitute the most diagnostic forms for the *M. aagardi–P. nativa* Zone. Besides brachiopods, this zone also includes, an ammonoid *Neouddenites orientalis* (Bogoslovskaya in Pavlova et al., 1991) from the lower part of the section. This ammonoid species is identical to *N.* aff. *caurus* of Andrianov from the Dzhigdala Horizon of the Kolyma–Omolon Basin, northeast Asia, of latest Artinskian to Kungurian age (Table 1); it is also closely comparable to *N. caurus* Nassichuk, Furnish and Glenister from the Lower Permian deposits of northern Yukon Territory in western Canada (Nassichuk, 1995).

According to our recent field work at the Khovsgol section, the *K. ogonorensis–R. dsilensis* Zone of the Khovsgol Horizon has not been clearly recognized; however, it does occur in the Bulganula Formation on the western flank of the Dalan-Ula–Lugin-Gol structure zone (Manankov, 1999). Here, this formation is characterized mainly by intercalated conglomerate, sandstone and siltstone and is conformably overlain by the Lugin-Gol Formation of the Tsagan-Ula Horizon (Fig. 4). Marine fossils of the *K. ogonorensis–R. dsilensis* Zone occur mainly in the upper part of the Bulganula Formation and include, besides brachiopods, bivalves and bryozoans, an ammonoid species from the family Spirolegocerratidae—*Gobioceras elenae* (Pavlova et al., 1991). Bogoslovskaya (in Pavlova et al., 1991) considered the ammonoid species to be the southern analogue of *Epijuresanites*, a typical ammonoid index genus for the Kungurian (Zakharov et al., 1999). Thus, in view of both the brachiopod and ammonoid faunas as well as associated bivalves and bryozoans, the *K. ogonorensis–R. dsilensis* Zone can be correlated with the *K. ogonorensis* Zone of the Tumarian Horizon of the Verkhoyansk fold belt and the same zone in the upper Dzhigdala Horizon of the Kolyma–Omolon Basin in northeastern Asia (Table 1).

The post-Kungurian Permian marine succession in southeastern Mongolia corresponds to the Lugin-Gol Formation in the Dalan-Ula–Lugin-Gol structure zone and the Tavankhara Formation in the Solonker structure zone. Of these, the Lugin-Gol Formation (Fig. 4) is best known and well studied and, as a result, has been taken as the reference section for the marine Middle Permian (Guadalupian) of southeast Mongolia (Manankov, 1999). This formation, best exposed at the Dzhirem-Ula section (42°40′13.4″N, 108°42′15.3″E, locality 6 in Fig. 3) (Fig. 4), is characterized by alternating sandstone, conglomerate, calcareous siltstone and limestone, with carbonate rocks increasing in proportion up section. Three brachiopod assemblage zones belonging to two horizons have been distinguished from the Lugin-Gol Formation. The Tsagan-Ula Horizon in the lower part comprises two brachiopod zones: the *Liosotella decimana–Waagenoconcha angustata* Zone, followed by the *Alispiriferella lita–Kaninospirifer adressum* Zone (Fig. 4). As a whole, this horizon corresponds to an interval of maximum cold-water faunal invasion in the Permian history of southeastern Mongolia. In this regard, the horizon would be equivalent to the Tsagantemet Horizon of central and northeastern Mongolia, which also records the maximum influx of Boreal-type cold-water species into the Mongol–Transbaikal Province. This maximum faunal invasion has also allowed the possibility of a region-wide correlation for this interval throughout East and northeast Asia. Consequently, not only is it possible to correlate the Tsagan-Ula Horizon with those of Transbaikalia, the Verkhoyansk fold belt and the Kolyma–Omolon Basin, as has been suggested by Manankov (1999), it is also feasible to align the Tsagan-Ula Horizon with certain Permian horizons of East Asia. For example, the Tsagan-Ula Horizon can be closely compared to the upper Vladivostok and lower Chandalaz horizons of South Primorye, the middle part of Osahtian Formation of Priamurie, as well as the Baogete and Zhesi (=Jisu Honguer) formations of Inner Mongolia, northeast China, because they all share a strikingly similar fauna dominated by Boreal-type brachiopod species and genera, intermingled with only limited warm-water Cathaysian taxa. As a result, on the basis of these correlations the age of the Tsagan-Ula Horizon has been determined and assigned to the Kazanian to early Tatarian (early Midian or Wordian) (Kotlyar et al., 1999, 2003; Manankov, 1999). However, despite this broad and region-wide biogeographical similarity and biostratigraphical compatibility, there is a distinct difference between the fauna of the Tsagan-Ula Horizon and those of the correlative horizons in northeast China and South Primorye. In the latter two regions, the equivalent horizons are characterized by conspicuously a fusulinoidean assemblage dominated by *Monodiexodina sutshanica* and associated species, whereas this fauna is absent from the Tsagan-Ula Horizon of southeastern Mongolia. At present, it is not known whether the absence of the *M. sutshanica* Zone in southeastern Mongolia is due to inadequate sampling, or a true reflection of the localized palaeoecological conditions unsuitable for the survival of these fusulinoidean species.

The Solonker Horizon represents the highest Permian marine unit in southeastern Mongolia and is mainly found in the Dalan-Ula–Lugin-Gol structure zone. At its type locality in the Dzhirem-Ula section (Fig. 4), this horizon is represented by a 23 m thick interval of alternating limestone, calcareous mudstone, siltstone and sandstone in the top part of the Luguin-Gol Formation (Manankov, 1999; Fig. 4). The horizon is defined by the brachiopod *Echinauris jisuensis* Zone. Unlike the underlying two brachiopod zones of the Tsagan-Ula Horizon, which are dominated by Boreal-type cold-water elements with only scarce representation of warm-water Cathaysian forms, the *E. jisuensis* Zone is distinguished by Cathaysian brachiopod elements (Manankov, 1999; Afanas'eva et al., 2003). By virtue of the nature of its mixed biogeographical affinities and species composition, the *E. jisuensis* Zone can be closely compared with the *Anidanthus–Squamularia* and *Prorichothofenia ussrica* zones of the Chandalaz Horizon of South Primorye (Kotlyar et al., 2003) and the *Richothofenia*

cornuformis–Enteletes andrewsi–Notothyris nucleolus Assemblage of the Yihewusu Formation in Inner Mongolia, northeast China (Shen et al., 2006), both of Capitanian age (Shi, 2006 for further discussion regional correlation).

4. Discussion and conclusions

The Permian stratigraphy and biostratigraphy outlined above indicates that marine deposition prevailed in two separate basins in Mongolia during the Permian. One of these basins was located in central and northeastern Mongolia. This basin throughout the Permian mostly likely had continual marine connection with the Verkhoyansk Sea (or basin) and the Kolyma–Omolon Basin to the north via Transbaikalia. All these Permian basins share many species and genera, implying readily accessible migration pathways between them. The second Permian marine basin was developed along the southeastern border of Mongolia with China and extends deeply into northeast China; both regions share many depositional and faunal features, despite local differences. This southern basin does not seem to have been connected to the basin in central and northeast Mongolia to the north. This conclusion contrasts with some earlier suggestions (e.g. Bobrov and Kulikov, 1968) that a single marine basin or strait extended from Transbaikalia through northeastern, central and southern Mongolia to northeastern China. In our new interpretation, during the Permian southeastern Mongolia was connected to a large marine basin that included much of northeastern China, the southern part of Primorye in Far East Russia and also parts of Japan (e.g. South Kitakami). The Permian marine fauna of this basin is unique in some respects, among which the most important is the intermingling at some levels of both warm-water Cathaysian and cool- to cold-water Boreal elements (Tazawa, 1991; Shi et al., 1995; Manankov, 1999; Shi, this volume).

In conclusion, the Permian of Mongolia has global significance because it contains two separate basins, which during the Permian were located in different latitudinal settings and, hence different biogeographical provinces. The close geographic proximity of these two palaeogeographically and palaeobiogeographically contrasted basins, coupled with the mixed nature of the Permian marine faunas in southeastern Mongolia and other similarly mixed faunas in East Asia, suggest that Mongolia may serve as an important gateway for correlating the high-latitude Permian marine sequences of northeast Asia (such as the Verkhoyansk and Kolyma–Omolon regions) with those of the lower latitudes including southeastern Russia, Japan and South China.

Acknowledgements

In this paper, I. Manankov is responsible for the description of the Permian stratigraphy and biostratigraphy of Mongolia, while G.R. Shi and S.Z. Shen are primarily responsible for the correlations and related discussions. This study has been supported by the Russian Foundation for Basic Research (project no. 01-05-64470 to I. Manankov), the Australian Research Council (grant LX0348047 to G.R. Shi) and the National Science Foundation of China (grants 40321202, 40328003 to S.Z. Shen and G.R. Shi). A constructive review of an earlier version by Prof. Ian Metcalfe (New England) is much appreciated.

References

Afanas'eva, G.A., Alekseeva, R.E., Grunt, T.A., Lazarev, S.S., Komarov, V.N., Manankov, I.N., Pavlova, E.E., Rozman, Kh.S., Suursuren, Sh., Ushatinskaya, G.T., Erlanger, O.A., 2003. Paleontologiya Mongolii Brakhiopody. Nauka, Moscow, 253 p. (in Russian).

Bobrov, V.A., Kulikov, M.V., 1968. The Mongolian–Transbaikal strait of Permian time. Doklady Akademiya Nauk SSSR 180, 75–77.

Durante, M.V., Lazarev, S.S., Pavlova, E.E., 1996. Mongolia. In: Wagner, R.H., Winkler Prins, C.F., Granados, L.F. (Eds.), The Carboniferous of the World. III (The Former USSR, Mongolia, Middle Eastern Platform & Iran). IUGS Publication No. 33. Instituto Tecnológico GeoMinero de España and National Natuurhistorisch Museum, Madrid, pp. 409–442.

Ganelin, V.G., Biakov, A.S., Karavaeva, N.I., 2001. Some theoretical problems in the stratigraphy and stratigraphic scale of the Permian in northeastern Asia. In: Gladenkov, Yu.B., Kuznetsova, K.I. (Eds.), Toward Detailed Stratigraphic Schemes and Paleogeographic Reconstructions. GEOS, Moskow, pp. 194–208 (in Russian).

Kotlyar, G.V., Zakharov, Yu.D., Popeko, L.I., Tazawa, J., Burago, V.I., 1999. Layers with *Timorites* in East Asia. Geology of Pacific Ocean 14, 361–380.

Kotlyar, G.V., Kurilenko, A.V., Biakov, A.S., Popeko, L.I., 2002. Permian system. In: Oleinikov, A.N. (Ed.), Atlas Faunyi I Flory Paleozoya–Mesozoya Zabaikaliya (Atlas of Faunas and Floras of the Paleozoic–Mesozoic of Zabaikal). Novosibirsk, Nauka, pp. 217–314 (in Russian).

Kotlyar, G.V., Nikitina, A.P., Zhuravlev, A.V., Kossovaya, O.L., 2003. Midian (upper Wordian–Capitanian) mixed faunas of Southeastern Asia. Byulletin Moskovskogo Obschestva Ispytatelei Prirody Otdelenyye Geologii 78 (1), 33–48 (in Russian).

Kotlyar, G.V., Kossovaya, O.L., Shishlov, S.B., Zhuravlev, A.V., Pukhonto, S.K., 2004. Boundary between Permian series in diverse sedimentary facies of northern European Russia: constraints of event stratigraphy. Stratigraphy and Geological Correlation 12, 460–484.

Kutygin, R.V., 2006. Permian ammonoid associations of the Verkhoyansk region. Journal of Asian Earth Sciences 26(3-4), 243–257.

Manankov, I.N., 1998a. Late Permian Productida (Brachiopoda) from Southeastern Mongolia. Paleontological Journal 32, 486–492.

Manankov, I.N., 1998b. The Permian of Southeastern Mongolia. Doklady Earth Sciences 358 (1), 38–40.

Manankov, I.N., 1999. Reference section and upper Permian zonation in Southeastern Mongolia. Stratigrafia i Geologicheskaya Korrelyatsia 7 (1), 56–65 (in Russian).

Manankov, I.N., 2002. New data on biostratgraphy of the Permian of central and eastern Mongolia. Byulletin Moskovskogo Obschestva Ispytatelei Prirody Otdelenyye Geologii 77 (5), 20–27 (in Russian).

Manankov, I.N., 2004. New species of Early Permian brachiopods and biostratigraphy of the Boreal basin of Mongolia. Paleontological Journal 38 (4), 366–372.

Nassichuk, W.W., 1995. Permian ammonoids in the Arctic regions of the world. In: Schoole, P.A., Peryt, T.M., Ulmer-Scholle, D.S. (Eds.), The Permian of Northern Pangea, vol. 1. Paleogeography, Paleoclimates, Stratigraphy. Springer, Berlin, pp. 210–235.

Pavlova, E.E., Manankov, I.N., Morozova, I.P., Solov'eva, M.N., Suetenko, O.D., Bogoslovskaya, M.F., 1991. Permian Invertebrates of Southern Mongolia. Trudy Sovmestnaya Sovetsko-Mongol'skaya Paleontologicheskaya Ekspeditziya (The Joint Soviet–Mongolian Paleontological Expedition Transaction) 40, 1–173 (in Russian).

Salvador, A. (Ed.), 1994. International Stratigraphic Code. A Guide to Stratigraphic Classification, Terminology, and Procedure, second ed. International Union of Geological Sciences and Geological Society of America, Incorporated, Boulder, p. X1X+214.

Shen, S.Z., Zhang, H., Shang, Q.H., Li, W.Z., 2006. Permian stratigraphy and correlation of Northeast China: A review. Journal of Asian Earth Sciences 26 (3-4), 304–326.

Shi, G.R., 2006. The marine Permian of East and NE Asia: an overview of biostratigraphy, palaeobiogeography and palaeogeographical implications. Journal of Asian Earth Sciences 26 (3-4), 175–206.

Shi, G.R., Archbold, N.W., Zhan, L.P., 1995. Distribution and characteristics of mid-Permian (late Artinskian–Ufimian) mixed/transitional marine faunas in the Asian region and their palaeogeographical implications. Palaeogeography, Palaeoclimatology, Palaeoecology 114, 241–271.

Shi, G.R., Shen, S.Z., Tazawa, J., 2002. Middle Permian (Guadalupian) brachiopods from the Xiujimqinqi area, inner Mongolia, northeast China, and their palaeobiogeographical and palaeogeographical significance. Paleontological Research 6 (3), 285–297.

Tazawa, J., 1991. Middle Permian brachiopod biogeography of Japan and adjacent regions in East Asia. In: Ishii, K., Liu, X., Ichikawa, K., Huang, B. (Eds.), Pre-Jurassic Geology of Inner Mongolia, China. Report of the China-Japan Cooperative Research Group, 1987–1989, Osaka, pp. 213–230.

Ueno, K., 2006. The Permian antitropical fuslinoidean genus Monodiexodina: distribution, taxonomy and paleobiogeography. Journal of Asian Earth Sciences 26 (3-4), pp xxx.

Zakharov, Yu.D., Oleinikov, A.V., Kotlyar, G.V., Burago, V.I., Rudenko, V.S., Dorukhovskaya, E.A., 1999. First find of Early Permian goniatite in southern Primorie. Geology of the Pacific Ocean 14, 805–816.

Zhamoida, A.I., Kovalevsky, O.P., Moissejeva, A.I., Yarkin, V.I. (Compilers), 1979. Stratigraphic code of the USSR (Provisional synopsis of rules and recommendations) [English version]. Interdepartmental Stratigraphic Committee of the USSR, Leningrad, 148p.