Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Asian Earth Sciences 26 (2006) 225–234
Journal of Asian Earth Sciences
www.elsevier.com/locate/jaes

The Permian biostratigraphy of the Kolyma–Omolon region, Northeast Asia

Victor G. Ganelin [a], Alexander S. Biakov [b,*]

[a] *Geological Institute of the Russian Academy of Sciences, 7 Pyzhevsky, 109027 Moscow, Russian Federation*
[b] *North-East Interdisciplinary Science Research Institute of the Russian Academy of Sciences, Far East Branch, 16 Portovaya, 685000 Magadan, Russian Federation*

Received 16 February 2005; accepted 17 November 2005

Abstract

The main features of the tectonics, Permian paleogeography, biota, structural-facies zonation of the Kolyma–Omolon region are analysed. The characteristics of the Permian regional stratigraphic scale of the Kolyma–Omolon region are described. The Permian deposits of the Kolyma–Omolon region are divided into four regional stratigraphic subdivisions, ranked as superhorizons, which in turn are subdivided into nine horizons. These horizons are further subdivided into 18 provincial zones ('lones' in accordance with Russian stratigraphical nomenclature). Most of the lones distinguished have dual index species, representing the dominant brachiopod and bivalve species. The chosen nominal species of these lones are, as a rule, related to each other phylogenetically, and as such they represent key stages in the evolution of their respective taxonomic groups through the Permian. The resultant biostratigraphic scale is adopted as a regional one for the Kolyma–Omolon, Chukotka, and southeastern part of the Verkhoyan–Okhotsk regions. Almost all the lones distinguished can also be recognized in the Verkhoyansk region, and many of the lones are also traceable outside Northeast Asia.

Keywords: Permian; Northeast Asia; Kolyma–Omolon region; Brachiopods; Bivalves; Foraminifers

1. Introduction

The Kolyma–Omolon region is located to the east of the Verkhoyan–Okhotsk region, occupying the territory of Northeast Asia from the Yana–Indigirka water divide in the west, to the eastern bank of the upper course of the Anadyr' River in the east (Fig. 1). The boundary between the Kolyma–Omolon and Verkhoyansk–Okhotsk regions goes along the upper course of the Yana River; and to the south of the Yana River the boundary coincides with the western boundary of the Magadan region. According to the structural-facial zonation scheme established at the Third Stratigraphic Meeting of Northeastern Russia (Zhamoida, 2003), the Kolyma–Omolon region, as referred to in this paper, comprises the Kolyma–Omolon structural-facial province and also southeastern part of the Verkhoyan–Okhotsk structural-facial province (Fig. 1). The Permian sediments of this region are of considerable thickness, contain abundant fossil remains and have peculiar facies compositions.

2. Tectonic setting

Within the analyzed territory two large massifs (or microcontinents), the Okhotsk and Omolon Massifs, are distinguished. They are surrounded by numerous other tectonic elements, which have been interpreted as folded structures within the framework of these massifs (various anticlinoria, uplifts, folded zones), or as displaced terranes of various origins (cratonic, oceanic, island-arc etc). In this paper, we do not use the term 'Kolyma–Omolon Massif' because, as Merzljakov et al. (1974) and Til'man et al. (1977) noted, such a massif is absent in the Riphean–Phanerozoic history of Northeastern Asia. Parfenov and Kuzmin (2001) suggested that the so-called the Kolyma–Omolon superterrane is a product of the Late Jurassic amalgamation of the Omolon Block and a group of smaller Kolyma terranes. This means that the Kolyma and Omolon blocks were separate tectonic entities during the Late Paleozoic.

2.1. Structural-facial zonation

Within the territory of Northeastern Asia, we distinguish four structural-facial provinces for the Permian deposits: the

* Corresponding author. Tel.: +7 41322 30942; fax: +7 41322 300451.
E-mail address: abiakov@mail.ru (A.S. Biakov).

1367-9120/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jseaes.2005.11.006

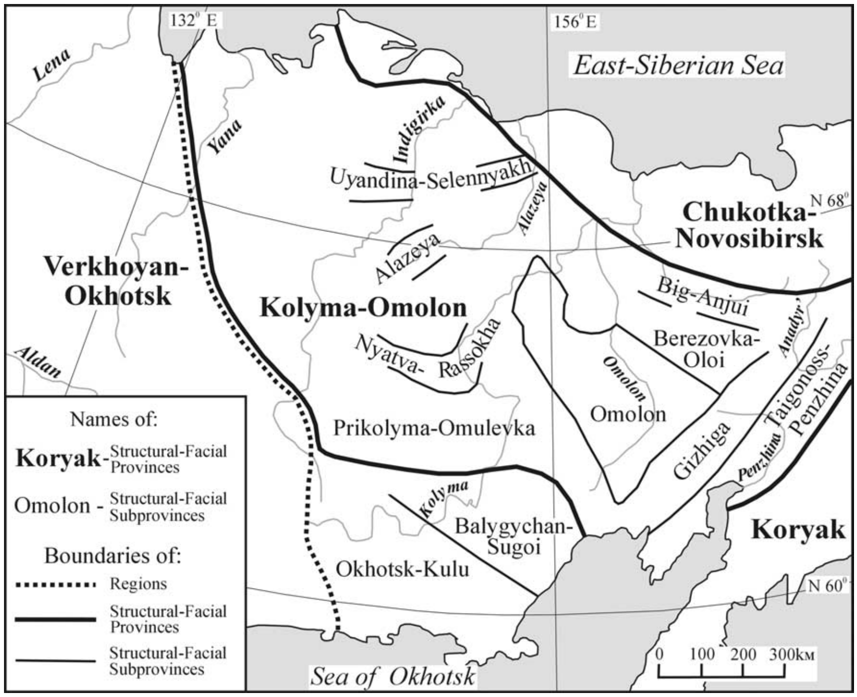


Fig. 1. Structural-facial zonation of the Kolyma–Omolon region for the Permian.

Verkhoyan–Okhotsk, Kolyma–Omolon, Chukotka–Novosibirsk, and Koryak, each in turn has been further subdivided into different subprovinces (Fig. 1). In this paper, we describe only the south-eastern part of the Verkhoyan–Okhotsk structural-facial province, represented by the Okhotsk–Kulu and Balygychan–Sugoi subprovinces; and the Kolyma–Omolon province, consisting of the Prikolyma–Omulevka, Nyatva–Rassokha, Uyandina–Selennyakh, Omolon, Gizhiga, Taigonoss–Penzhina, Berezovka–Oloi, Big–Anjui, and Alazeya subprovinces (Fig. 1).

There are considerable lateral variations in the Permian sedimentary facies within the Kolyma–Omolon region, as they were controlled by many different factors, most importantly related to the geodynamic nature of the sedimentary basins during the Permian. Preliminarily, we have distinguished two major types of stratigraphic section that characterize the major regional structures (Figs. 2 and 3). The first type, typically represented by the sections of the Omolon Massif, is characterized by marine shallow-water carbonate rocks, usually with limited thickness (up to a few hundred meters). Most of the carbonate facies in this type consist of the so-called 'kolymic' ('atomodesmic') limestones (Tschernyak, 1975; Kashik et al., 1990). The extent of the limestones sharply decreases with distance away from the Omolon Massif, although at the same time the thickness of the rocks increases, as do volcanic rocks of various compositions (Fig. 3). As detailed below, the sections of the Omolon Massif form the basis for the Permian stratigraphical and biostratigraphical scales for Northeastern Asia. The second type of stratigraphic section represents sediments of deep-water origin. They are essentially sandy-clay sediments, often tuffaceous and flysch-like, and usually attain considerable thickness, however fossils are rare. This type of sediment characterizes the larger part of the folded zones surrounding the Omolon Massif (Fig. 3). A comparison of thickness of the Permian sedimentary rocks between the Omolon Massif and the Ayan–Yuryakh Anticlinorium (i.e. the Gizhiga Zone, see Fig. 3) is particularly interesting. The latter reaches more than 7 km in thickness (Biakov and Vedernikov, 1990), more than 20 times thicker than the former.

3. Brief history of study of Permian stratigraphy and biostratigraphy

Zavodovsky (1960) established the first preliminary stratigraphic framework for the region. Later, as a result of works of Ganelin (1977), Tschernyak (1975) and Ustritsky (1975) the earlier scheme was largely substantiated and refined with considerable detail. Ganelin (1984) distinguished provincial zones (lones) based on brachiopod faunas, which were subsequently corroborated by other faunal groups (Kashik et al., 1990). At the same time, independent detailed biostratigraphic scales based on bivalves and small foraminifers were compiled (Biakov, 1990, 2000a; Karavaeva, 1990, 1993). All these works have led to an integrated biostratigraphic scale for the entire Northeastern Asian region which has been adopted by the Third Stratigraphic Meeting on Precambrian, Paleozoic and Mesozoic of Northeast Russia held in December 4–6, 2002 in St Petersburg (Table 1).

4. General features of the Permian biotas

As stated above, marine faunas are particularly rich in the Permian sediments of the Omolon Massif; but they exhibit

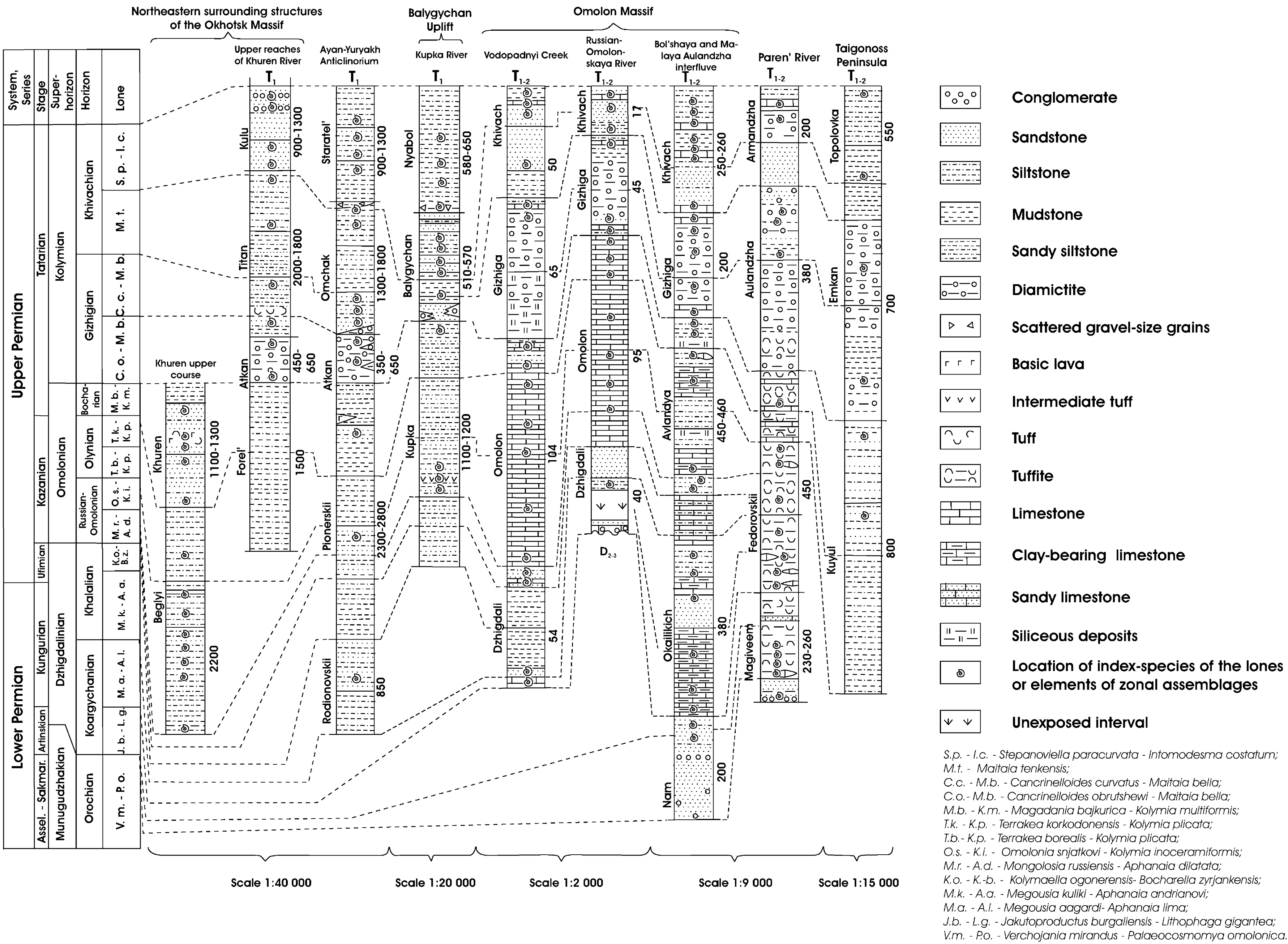


Fig. 2. Correlations of key Permian sections in the Kolyma–Omolon region. The numbers placed on the right side of each stratigraphic column indicate the thickness of each rock unit.

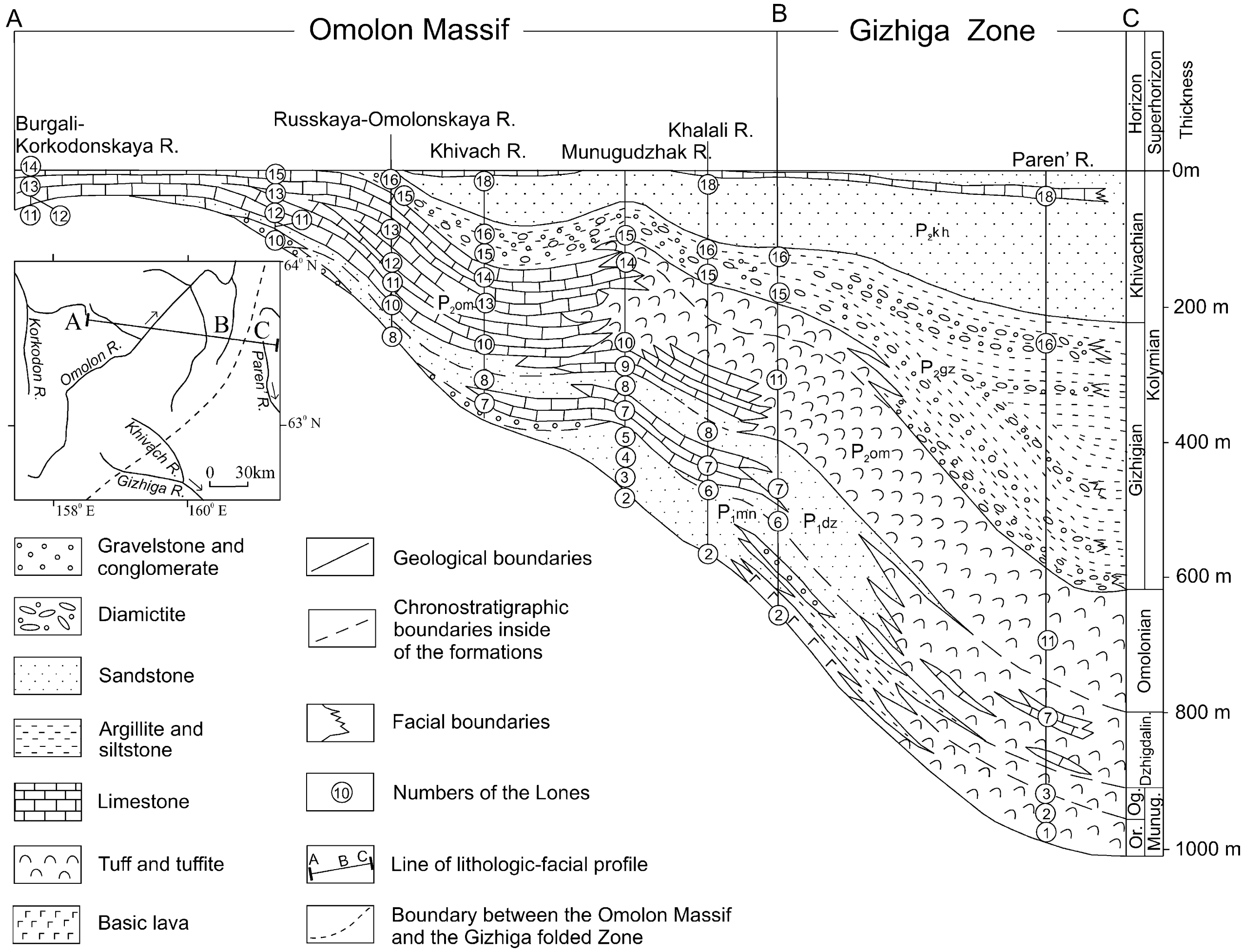


Fig. 3. Schematic lithological–facial profile through the Omolon Massif and the Gizhiga folded Zone. The distances between the sections are not to scale. The numbers of the lones as shown in Table 1.

considerable local variations, both in abundance and composition. Here, three main faunal groups are represented: small foraminifers, brachiopods and bivalves. Other groups, such as conulariids, solitary rugose corals, tabulate corals, bryozoans, gastropods, ammonoids, marine ostracods, crinoids, nautiloids and scaphopods also occur, but are generally less common. Fossil plants are rare. Remains of thermophilic faunas like fusulinids and conodonts are completely absent. In the deep-water, volcanogenic and sandy-clay strata, fossils decrease sharply in both quantity and diversity. Here, only the *Inoceramus*-like and ctenodont bivalves and some gastropods dominated by *Straparolus* occur.

5. General characteristics of the Permian regional stratigraphic scale

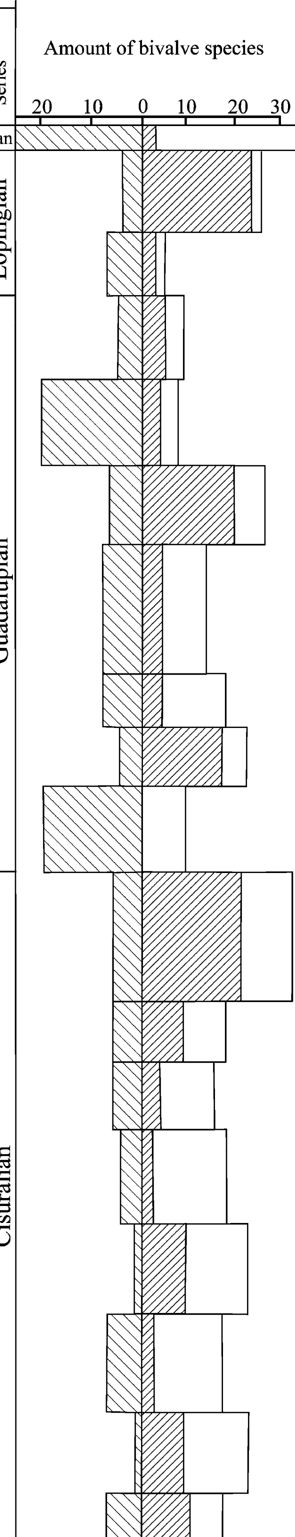
In accordance with the Russian general scale of the Permian System (Zhamoida, 1998), the Permian is divided into two series and seven stages: the Lower series comprising the Asselian, Sakmarian, Artinskian and Kungurian; the Upper series comprising the Ufimian, Kazanian and Tatarian (Table 1). Direct correlation between the Permian stages of the East-European stratigraphic scale, the International Stratigraphic Chart and the sections of the Kolyma–Omolon region is difficult. That is why, according to the Stratigraphic code of Russia (Yarkin and Zhamoida, 1992), a regional stratigraphic scale has been compiled for the region, in which a horizon is the major subdivision of each chronostratigraphic unit. A horizon includes the rocks formed during a defined stage of the geological history of a particular region of the Earth's crust. The rock body so defined reflects the peculiarities of the sedimentation regime and biotic development characteristic for this region. Therefore, a horizon is an equivalent to a stage of the International Stratigraphic Guide (Yarkin and Zhamoida, 1992), but it is applicable only to a particular geographic region.

Horizons may be united into superhorizons, reflecting the largest stages of regional geological and paleobiological development. Similarly, horizons are subdivided into lones (provincial biostratigraphic zones) that reflect localized geological and paleobiological development stages. In this sense, the lones correspond approximately to the assemblage zones of the International Stratigraphic Guide.

The Permian sedimentary succession of the Kolyma–Omolon region is divided into four large sedimentary assemblages known as megacyclites (Ganelin et al., 2003),

Table 1
Permian stratigraphic scale of Northeast Asia and the dynamics of bivalve species diversity through the Permian

East European Stratigraphic Scale			Permian Stratigraphic Scale of Northeast Asia						International Stratigraphic Chart	
Series	Stage	Horizon	Superhorizon	Horizon	Lones	Number of Lone	Bivalve Zones, Subzones, Beds with bivalves	Foraminifer Zones	Stage	Series
Lower Triassic							*Otoceras*		Induan	
Upper	Tatarian	Vyatkian	Kolymian	Khivachian	*Stepanoviella paracurvata - Intomodesma costatum*	18	*Intomodesma costatum*: *postevenicum*, *evenicum*, *costatum*, *hurenensis*	*Howchinella maxima*	Changhsingian	Lopingian
Upper	Tatarian	Vyatkian	Kolymian	Khivachian	*Maitaia tenkensis*	17	*Maitaia tenkensis*		Wuchiapingian	Lopingian
Upper	Tatarian	Severodvinian	Kolymian	Gizhigian	*Cancrinelloides obrutshewi - Maitaia bella*	16	*Maitaia bella*: Beds with *Glyptoleda borealica*	*Howchinella composita*	Capitanian	Guadalupian
Upper	Tatarian	Severodvinian	Kolymian	Gizhigian	*Cancrinelloides obrutshewi - Maitaia bella*	15	*Maitaia bella*: Beds with *Merismopteria macroptera*	*Howchinella composita*	Capitanian	Guadalupian
Upper	Tatarian	Urzhumian	Omolonian	Bocharian	*Magadania bajkurica - Kolymia multiformis*	14	*Kolymia multiformis*	*Howchinella planilata*	Wordian	Guadalupian
Upper	Kazanian	Upper	Omolonian	Olynian	*Terrakea korkodonensis - Kolymia plicata*	13	*Kolymia plicata*	*Howchinella elongata*	Wordian	Guadalupian
Upper	Kazanian	Upper	Omolonian	Olynian	*Terrakea borealis - Kolymia plicata*	12	*Kolymia plicata*	*Howchinella elongata*	Wordian	Guadalupian
Upper	Kazanian	Lower	Omolonian	Russian-Omolonian	*Omolonia snjatkovi - Kolymia inoceramiformis*	11	*Kolymia inoceramiformis*	*Ichtyolaria ganelinae*	Roadian	Guadalupian
Upper	Kazanian	Lower	Omolonian	Russian-Omolonian	*Mongolosia russiensis - Aphanaia dilatata*	10	*Aphanaia dilatata*	*Ichtyolaria ganelinae*	Roadian	Guadalupian
Upper	Ufimian	Sheshmian, Solikamian	Dzhigdalinian	Khalalian	*Kolymaella - Bocharella*	9			Roadian	Guadalupian
Upper / Lower	Ufimian / Kungurian	Solikamian, Irenian, Filippovian	Dzhigdalinian	Khalalian	*Megousia kuliki - Aphanaia andrianovi*	8	*Aphanaia andrianovi*	*Howchinella prima*	Kungurian s. l.	Cisuralian
Lower	Kungurian	Saranian	Dzhigdalinian	Koargychanian	*Megousia aagardi - Aphanaia lima*	7	*Aphanaia lima*	*Howchinella zavodovskyi*	Kungurian s. l.	Cisuralian
Lower	Artinskian	Sarginian	Dzhigdalinian	Koargychanian	*Jakutoproductus burgaliensis - Lithophaga gigantea*	6	*Lithophaga gigantea*	*Howchinella parva*	Artinskian	Cisuralian
Lower	Artinskian	Irginian, Burtsevian	Munugudzhakian	Ogonerian	*Jakutoproductus rugosus - Palaeocosmomya omolonica*	5	Beds with *Palaeocosmomya omolonica*	*Howchinella parva*	Artinskian	Cisuralian
Lower	Sakmarian	Tastubian	Munugudzhakian	Ogonerian	*Jakutoproductus terekhovi - Cypricardinia eopermica*	4	Beds with *Cypricardinia eopermica*	*Howchinella parva*	Sakmarian	Cisuralian
Lower	Sakmarian	Tastubian	Munugudzhakian	Ogonerian	*Jakutoproductus insignis - Merismopteria permiana*	3	Beds with *Merismopteria permiana*	*Howchinella parva*	Sakmarian	Cisuralian
Lower	Asselian	Shikhanian	Munugudzhakian	Orochian	*Verchojania expositus- Palaeoneilo parenica*	2	*Palaeoneilo parenica*	*Protonodosaria quadrangula*	Asselian	Cisuralian
Lower	Asselian	Kholodnologian	Munugudzhakian	Orochian	*Verchojania mirandus- Palaeoneilo parenica*	1	*Palaeoneilo parenica*	*Protonodosaria quadrangula*	Asselian	Cisuralian



The total number of species (open boxes) and the number of new species (hatched boxes) are shown to the right of the zero mark, and the number of extinct bivalve species are shown to the left.

which bear the rank of regional superhorizons (=subseries): the Munugudzhakian, Dzhigdalinian, Omolonian, and Kolymian Superhorizons, in ascending order (Table 1). Each of these superhorizons is defined by benthic faunal associations indicative of a unique ecological and paleogeographic setting. Based on the development stages of the paleoecological conditions of the benthic associations that correlate with depositional cycles at a lower rank, it has been possible to divide each superhorizon into horizons (=regional stages), each of which in turn can be further subdivided into lones (=provincial zones). As a consequence, we have distinguished nine regional horizons and eighteen lones (Table 1).

It should be pointed that in the new integrated scheme, the Munugudzhakian, Dzhigdalinian and Omolonian Superhorizons have been raised from the rank of horizon as used in previous schemes (e.g. Ganelin, 1984). The fourth superhorizon, the Kolymian, combines the previously distinguished Gizhigian and Khivachian Horizons. In terms of sequence stratigraphy, collectively these four superhorizons would form second-order megasequences (or macrocyclites). Further, the lones (or provincial zones) of the current scale, each defined on the basis of its characteristic paleontological content, also appear to correspond to mesocyclites that have already been recognized in the Omolon Massif (Kashik et al., 1990).

The proposed stratigraphical scale is based on the evolution of benthic fossil communities, especially of widespread groups such as brachiopods, bivalves and foraminifers. The lones distinguished in most cases correspond to well-defined fossil complexes, each of which is characterized by a distinctive paleocommunity type or biofacies that represents a particular depositional setting in the onshore–offshore biofacies gradient (Ganelin et al., 2001). Most of the lones are characterized by two types of index species: one based on brachiopods and the other on bivalves. The chosen nominal zonal index species for each group in the Permian biostratigraphic scale are, as a rule, related to each other phylogenetically, and as such represent the different stages of evolution of the dominant taxa.

The stratigraphic scale under discussion has been adopted as a regional one for the Kolyma–Omolon region, Chukotka and the southeastern part of the Verkhoyan–Okhotsk region (Fig. 1). Almost all the lones distinguished can also be traced in the Verkhoyansk region, and many of them are even traceable outside Northeast Asia (Ganelin, 1984; Biakov, 2000b, 2002). The stratotype sections for almost all the recognized horizons and lones are located within the Omolon Massif.

6. Characteristics of the superhorizons and horizons

The position of the lower boundary of the Permian System in sections of Northeastern Asia has not yet been finally determined. Currently, we could speak about its position at the basement of the *Verchojania mirandus–Palaeoneilo parenica* Lone of the Orochian Horizon. The basis for this proposition is the presence in the lower part of the higher Ogonerian Horizon of Sakmarian goniatites.

6.1. The Munugudzhakian Superhorizon

This superhorizon corresponds to the Asselian to the lower part of the Artinskian and is subdivided into the Orochian and Ogonerian Horizons (Table 1). The most peculiar feature of the paleocommunities characteristic of the Munugudzhakian Superhorizon is the predominance of *Verchojania* and *Jakutoproductus* faunas, together with some bipolarly distributed bivalve genera, including *Pyramus*, *Myophossa*, *Palaeocosmomya*, *Vacunella* and *Merismopteria*.

6.1.1. The Orochian Horizon

This horizon includes two lones: the *V. mirandus–P. parenica* Lone and the *Verchojania expositus–P. parenica* Lone (Ganelin et al., 2003). The base of the horizon is determined by the dominance of the brachiopod genus *Verchojania*, with two dominant species from the same lineage: *V. mirandus* Ganelin and its descendant *V. expositus* Ganelin. As a whole, the horizon is characterized by the last representatives of *Verchojania*, the first lagenids of the assemblage of small *Protonodosaria* (Gerke and Sossipatrova, 1975; Karavaeva, 1990), and a bivalve paleocommunity dominated by *Myophossa* and *Palaeoneilo*.

6.1.2. The Ogonerian Horizon

This horizon consists of three lones: the *Jakutoproductus insignis–Merismopteria permiana* Lone, the *Jakutoproductus terekhovi–Cypricardinia eopermica* Lone, and the *Jakutoproductus rugosus–Palaeocosmomya omolonica* Lone (Table 1). The base of this horizon is defined by the phylogenetic transition in the brachiopod fauna from *Verchojania to Jakutoproductus.* This change is explicitly expressed by abundant occurrences of brachiopod species lacking dorsal spines, at the expense of those brachiopod species that characterize the Upper Carboniferous and lowermost Permian brachiopod faunas. The other important feature that characterizes the base of this horizon is the first appearance of the brachiopods that characterize the Pechora–Ural region of the Russian Platform, notably marked by the genera *Waagenoconcha*, *Striapustula* and *Spiriferella*. The foraminifer *Nodosaria*, the bivalves *Vorkutopecten*, *Vacunella*, *Cypricardinia, Palaeocosmomya* and *Merismopteria* are also characteristic genera. For the first time in this interval, representatives of *Howchinella* occurs. In the lower part of the *J. insignis–M. permiana Lone*, several small goniatites, one of which was determined by M.F. Bogoslovskaya as *Bulunites* sp. were found (Ganelin et al., 2001). According to R.V. Kutygin (personal communication), the ammonoid is close to the most ancient forms of *Uraloceras* (e.g. *Uraloceras* ex gr. *simense* Ruzhencev), implying a Sakmarian age for this lone. In the *J. rugosus–P. omolonica Lone*, ammonoids *Neoshumardites* cf. *triceps* Ruzhencev, *Uraloceras omolonense* Bogoslovskaya and Boiko, and U. kolymense Bogoslovskaya and Boiko have been found (Ganelin, 1984; Bogoslovskaya and Boiko, 2002), pointing to an Early Artinskian age.

6.2. The Dzhigdalinian Superhorizon

This superhorizon corresponds to the upper half of the Artinskian–Ufimian Stages and is divided into the Koargychanian and Khalalian Horizons. The Dzhigdalinian Superhorizon is characterized by numerous representatives of the Pechora–Ural fauna. This fauna is considerably renewed in taxonomic composition and structure in that the *Jakutoproductus* fauna became more diversified and widespread; and the Kolymiidae bivalves occurred for the first time.

6.2.1. The Koargychanian Horizon

This horizon includes two lones: the *Jakutoproductus burgaliensis–Lithophaga gigantea* Lone and the *Megousia aagardi–Aphanaia lima* Lone. Of particular note is the presence of the brachiopod species *Sowerbina borealis* (Haughton) and *Spiriferella vaskovskyi* Zavodowsky in the lower lone of this horizon, as they represent a shallow-water marine setting. Other brachiopods include *Waagenoconcha*, *Bathymionia*, peculiar *Taimyrella flaebelliformis* Licharew and, locally, some relatively rare relict *Jakutoproductus* species. Accompanying bivalves in this shallow-water environment are *L. gigantea* Stuckenberg, *Edmondia nebrascensis* (Geinitz) and other species. In deeper water facies, however, *J. burgaliensis* Ganelin tends to dominate, and is often accompanied by the first appearance of the brachiopod *M. aagardi* (Toula), which becomes more abundant in the succeeding lone.

It is notable that the *M. aagardi–A. lima* Lone of the Koargychanian Horizon completely lacks *Jakutoproductus*. Here, for the first time, the *Inoceramus*-like bivalves, represented by the *Aphanaia* genus, occur. At some places, especially in relatively deep-water facies, they form shell beds and strata of hydrogen sulphate limestones up to 80–100 m thick. Among the brachiopods, the chonetid *Komiella omolonensis* (Licharew) spread across a wide spectrum of facies. Other brachiopods, such as *M. aagardi* (Toula) and *Attenuatella stringocephaloides* (Tschernjak and Licharew), are confined to the most deep-water facies. In relatively shallow-water facies, representatives of the brachiopod genera *Strepthorhynchus*, *Waagenoconcha*, *Costatumulus*, *Kungella*, *Timaniella*, *Tumarinia*, *Neospirifer* and *Spiriferella* are particularly common. Other forms, such as *Uraloproductus* and *Muirwoodia*, also occur but are less common. A coral paleocommunity dominated by *Cladochonus* ex gr. *magnus* Gerth, forming belts of colonial buildups in deep-water facies, is also an interesting feature of the *M. aagardi–A. lima* Lone. Foraminifers are generally less common than brachiopods and bivalves; they are represented mainly by nodosariids, among which *Pseudonodosaria*, *Rectoglandulina* and *Ichtyolaria* first appear.

In view of the stratigraphic superposition relative to strata below and above, the age of the Koargychanian Horizon has been determined to be Late Artinskian to Early Kungurian, approximately equivalent to the Sarginian and Saranian Horizons of the Urals (Table 1). This age assignment is supported by the occurrence of the ammonoid *Paragastriocras jossae* (Verneuil) in the Koargychanian Horizon.

6.2.2. The Khalalian Horizon

This horizon is subdivided into two lones: the *Megousia kuliki–Aphanaia andrianovi* Lone and the *Kolymaella–Bocharella* Lone. The brachiopod *M. kuliki* (Fredericks), which is phylogenetically related to *M. aagardi* (Toula) in the underlying lone, is the most characteristic species of the *M. kuliki–A. andrianovi* Lone. Besides the nominal species, numerous *Striapustula*, large-shelled *Spiriferella consimilis* Abramov and Grigorjeva, single *Rhynchopora*, *Rhynoleichus*, *Tumarinia*, *Tomiopsis* and *Attenuatella* are also characteristic forms of this lone. Bivalves are rather diverse, represented by about 20 genera, among which the family Kolymiidae remains, which are represented by two genera: *Aphanaia* and a yet unnamed new kolymiid genus. The unnamed new kolymiid genus first appears in this lone. The foraminiferal assemblage is represented by an association consisting of seven genera. Ammonoids, represented by *Epijuresanites*, *Daraelites*, *Neouddenites*, *Tumaroceras*, and *Uraloceras* also occur in the lower part of the *M. kuliki–A. andrianovi* Lone, with *Epijuresanites* also occurring in the upper part of this lone.

The *Kolymaella–Bocharella* Lone is sharply different in composition from the *M. kuliki–A. andrianovi* Lone. Two brachiopod species are known (Ganelin and Lazarev, 1999, 2000): *Bocharella zyrjankensis* Ganelin et Lazarev and *Kolymaella ogonerensis* (Zavodowsky). These are related to each other in their phylogenetic features and both derived from *Striapustula*. Bivalves and foraminifers accompanying the brachiopod lone are uncommon.

The age of the Khalalian Horizon has been assigned to the Kungurian–Ufimian, which is approximately equivalent to the Fillippovian–Sheshmian Horizons of the Russian Platform, based on the ammonoids associated with this horizon (Bogoslovskaya, 1984; Andrianov, 1985; Kutygin et al., 2002).

6.3. The Omolonian Superhorizon

This superhorizon corresponds to the Kazanian and the lower part of the Tatarian Stages of the Russian Platform, and is divided into three horizons: the Russian–Omolonian, Olynian, and the Bocharian Horizons (Table 1). The dominance of the bivalve family Kolymiidae and the thin-ribbed linoproductid brachiopods is the most important feature of the superhorizon.

6.3.1. The Russian–Omolonian Horizon

This horizon combines two lones: the *Mongolosia russiensis–Aphanaia dilatata* Lone and the *Omolonia snjatkovi–Kolymia inoceramiformis* Lone. The base of the horizon is marked by a very distinctive biostratigraphic boundary defined by a profound change in benthic paleocommunities. The brachiopod genera *Mongolosia* and *Terrakea* are the most characteristic of the lower lone. In general, the genus *Mongolosia* prevails in shallow-water facies, while *Terrakea* tends to dominate deeper water settings, where they form rather thick shell beds. Monospecific shell accumulations of strophalosiids, especially *Strophalosia sphenarctica* Waterhouse, are an essential element of the lone. Representatives of the genera *Alispiriferella*, *Tumarinia* and *Attenuatella* are common, but *Anidanthus*, *Anemonaria* and *Tomiopsis* are rare. Kolymiids, essentially represented by the genus *Aphanaia* (*A. stepanovi* (Muromzeva), *A. dilatata* Biakov), are the most common elements among the bivalves. For the first time, *Kolymia* s. s. occurs in this lone. The *M. russiensis–A. dilatata* Lone also incorporates some thirty foraminiferal species, among which species of *Nodosaria* are most common, followed by *Ichtyolaria* and *Rectoglandulina*. *Dentalina* also first appeared in this lone. The ammonoids *Sverdrupites harkeri* (Ruzhencev) and *Anuites kosinskyi* Andrianov occur throughout this lone, while *Sverdrupites amundseni* (Nassichuk) first appears in the upper part of the lone.

Benthos of the upper lone of the Russian–Omolonian Horizon are poorer than those of the lower lone. Among the brachiopods, two species occur essentially throughout: *Rhynchopora lobjaensis* (Tolmatchew) and *O. snjatkovi* (Zavodowsky). The former persisted through from the lower lone, while the latter occurs for the first time in this lone. Besides the dominant elements, rare specimens of a new species of *Terrakea* are also present in the latter. *A. stringocephaloides* (Tschernjak and Licharew) is probably related to deeper water facies. Bivalves are represented by *K. inoceramiformis* Licharew and related species, while *Aphanaia* remains abundant but less diversified. Rare ammonoids are represented by *S. amundseni* (Nassichuk) in the *O. snjatkovi–K. inoceramiformis* Lone.

The age of the Russian-Omolonian Horizon has been determined by the *Sverdrupites*-dominated ammonoid assemblage characteristic of the Early Kazanian (Roadian).

6.3.2. The Olynian Horizon

This horizon is subdivided into two lones: the *Terrakea borealis–Kolymia plicata* Lone and the *Terrakea korkodonensis–K. plicata* Lone. This horizon is monotonous in taxonomic diversity. *Terrakea* occurs in both lones but with different species. Besides *Terrakea*, *Megousia jakutica* (Licharew) also occurs locally in the lower lone. *R. lobjaensis* (Tolmatchew) is common in this horizon, as it is for the underlying horizons. Other common brachiopod species characteristic of this horizon include *Tumarina orientalis* Grigorjeva and *Neospirifer* ex gr. *neostriatus* Fredericks. Bivalves of the Olynian Horizon are represented mainly by *K. plicata* Biakov and *Heteropecten kolymaensis* (Maslennikow), the last representatives of *Aphanaia*, as well as the first appearance of *Maitaia*. In view of its stratigraphic position relative to the ages of horizons above and below, the Olynian Horizon has been conventionally correlated with the upper half of the Kazanian.

6.3.3. The Bocharian Horizon

This horizon corresponds to the *Magadania bajkurica–Kolymia multiformis* Lone, which has a higher species diversity than the underlying horizon. In this lone, *Terrakea* is replaced by *M. bajkurica* (Ustritsky). In addition, *Strophalosia multituberculata* Ustritsky, *Kungella kolymaensis* (Tolmatchew), *Neospirifer subfasciger* (Licharew), *Olgerdia ganelini* Grigorjeva, *O. zavodowskii* Grigorjeva are also characteristic of this lone. Stratigraphically, *Cancrinelloides* (represented by *C. juregensis* Solomina), a productid genetically related to *Magadania*, first occurs in this horizon. Among the bivalves, *K. multiformis* Biakov and *Maitaia varvarae* Biakov are dominant. In addition, there are also pectinids, vacunellids, *Polidevcia*, and *Cypricardinia*. On the Northeastern periphery of the Okhotsk Massif, the diversity of bivalves increases slightly due to the presence of *Parallelodon*, *Permophorus*, *Solemya*, etc. The foraminifer fauna of the Bocharian Horizon is represented by 25 species, among which *Dentalina* is the most widespread. Besides this genus, *Frondina*, *Gerkeina*, *Pseudonodosaria*, *Lingulonodosaria* and large *Rectoglandulina* ex gr. *borealis* Gerke occur for the first time in this horizon.

The age of the Bocharian Horizon has been determined to be Early Tatarian, as the top of this horizon corresponds to a global extinction event (Biakov and Ganelin, 1998; Kotlyar, 2000) and also to the Kiaman–Illawarra magnetostratigraphic boundary (Kashik et al., 1990).

6.4. The Kolymian Superhorizon

This superhorizon corresponds to the Upper Tatarian, judging from its stratigraphic position and paleomagnetic data (Kashik et al., 1990), as well as from biostratigraphic information (Ganelin et al., 2002). The superhorizon is subdivided into two horizons: the Gizhigian and the Khivachian Horizons (Table 1), which differ from each other significantly in taxonomic composition. The boundary between the Omolonian and Kolymian Superhorizons appears related to a major biotic crisis that is traceable beyond the limits of Northeastern Asia (Biakov and Ganelin, 1998; Kotlyar, 2000; Leven, 2003).

6.4.1. The Gizhigian Horizon

This horizon is subdivided into two lones: the *Cancrinelloides obrutshewi–Maitaia bella* Lone and the *Cancrinelloides curvatus–M. bella* Lone (Table 1). *Cancrinelloides* is the most characteristic brachiopod for the horizon. In the lower lone there are large *C. obrutshewi* (Licharew), accompanied by *C. ochotica* (Zavodowsky). The upper lone has a similar brachiopod composition to the lower lone, but the related species, such as *C. curvatus* (Tolmatchew) and *C. penzhinaensis* (Zavodowsky), are smaller in size, compared to similar forms in the lower lone. *R. lobjaensis* (Tolmatchew) continues to exist in the lower lone, but is absent in the upper lone. Other common brachiopod taxa also include *Strophalosia*, *Neospirifer*, *Penzhinaella*, athyridids and dielasmatids. In most offshore deeper-water facies, *C. obrutshewi* (Licharew) is replaced by *Spitzbergenia alferovi* (Miloradovich).

The bivalve fauna of the lower lone is represented mainly by *Merismopteria macroptera* (Morris), *Cypricardinia*, *Myonia*, *Pachymyonia*, *Maitaia* and *Pyramus*. The genus *Kolymia* s. s. is completely absent in this lone. Bivalves in the upper lone are represented essentially by the shell beds of *Maitaia* (*M. bella* Biakov) and some rare *Myonia*, *Stutchburia* and *Streblopteria*.

As noted above, the base of the Gizhigian Horizon appears to coincide with the Illawarra Reversal, although the lower parts of the horizon do not have good paleomagnetic characteristics (Kashik et al., 1990). This paleomagnetic reversal can be correlated with a similar feature in the lower half of the Upper Tatarian. An additional feature, significant for the age determination of the Gizhigian horizon, is the presence of the ammonoid *Timorites* found together with the index-species *C. obrutshewi* (Licharew) and *M. bella* Biakov in the Transbaikal region, therefore allowing the correlation of the Gizhigian Horizon with the Capitanian (Kotlyar et al., 1997).

6.4.2. The Khivachian Horizon

This horizon is subdivided into two lones: the *Maitaia tenkensis* Lone and the *Stepanoviella paracurvata–Intomodesma costatum* Lone (Table 1). The lower lone is poor in species diversity, consisting of only rare *Stepanoviella* sp., *M. tenkensis* Biakov, *Polidevcia* sp. and *Conocardium* sp. The upper lone, on the contrary, contains a fauna with high species diversity. The fossils in the lower parts of this upper lone are represented mainly by *S. paracurvata* Zavodowsky; upwards strophalosiids, peculiar rhynchonellids, single neospiriferids and large dielasmatids also appear. On the other hand, foraminifers became very abundant in the *S. paracurvata–I. costatum* Lone. Curiously, many species are unusually large in this lone, reaching more than a millimeter in size. The foraminifer fauna includes 50 species in 10 genera and is characterized by the first appearance of several new genera, including *Cornuspira* and *Tristix* (Karavaeva, 1993). The bivalve fauna of the *S. paracurvata–I. costatum* Lone is characterized by a major turnover in taxonomic composition, manifested by the first appearance of five new genera: *Intomodesma*, *Cyrtorostra*, *Streblochondria*, '*Fasciculiconcha*', and *Claraioides*. Like the foraminifers, many of the kolymiids also attained gigantic sizes. Another feature of the bivalve fauna of this lone is the incorporation of some typical Tethyan genera such as *Cyrtorostra*, *Streblochondria*, and *Vnigripecten*.

At its type locality (Vodopadny Creek, Omolon Massif), the Khivachian Horizon contains alternating normal and reversed paleomagnetic polarity zones (Kashik et al., 1990), which makes it possible to correlate this horizon with the Upper Tatarian.

The Permian–Triassic boundary in Northeast Asia is drawn at the top of the *S. paracurvata–I. costatum* Lone, which contains bivalve species that also characterize the Changhsingian of South China. This suggests that the Permian is complete, at least locally, in the Kolyma–Omolon region (Biakov, 2001).

Acknowledgements

These studies have been financially supported by the Russian Foundation for Basic Research, Projects 05-05-64407, 05-05-65027, 05-05-65234, 03-05-96012-Arctic and FEB RAS, Project 06-111-A-08-350. The authors are grateful to Drs Guang R. Shi and Monica Campi for their critical and constructive reviews and editorial help.

References

Andrianov, V.N., 1985. Permskie i nekotorye kamennougol'nye ammonoidei Severo-Vostoka Asii (Permian and some Carboniferous ammonites of Northeast Asia). Nauka, Novosibirsk pp. 1–181 (in Russian).

Biakov, A.S., 1990. Beds with bivalves. In: Kashik, D.S. (Ed.), Opornyi razrez permi Omolonskogo massiva (Permian key section of the Omolon Massif). Nauka, Leningrad, pp. 127–133 (in Russian).

Biakov, A.S., 2000a. Bivalve zonation in Permian deposits of Northeastern Asia. Stratigraphy and Geological Correlation 8 (1), 30–48.

Biakov, A.S., 2000b. Interregional and transregional correlation of Permian deposits of the Boreal Realm based on bivalves. Tikhookeanskaya Geologiya 19 (3), 3–11 (in Russian).

Biakov, A.S., 2001. Complete succession of the Permian in Northeast Asia: paleontological evidence for the presence of Changhsingian analogues. Doklady Akademii Nauk 378 (4), 399–401.

Biakov, A.S., 2002. Permian bivalves from the Transbaikal region. Paleontological Journal 36 (5), 460–468.

Biakov, A.S., Ganelin, V.S., 1998. The early Tatarian (Gizhigian) biotic crisis in Northeast Asia and its possible sources. In: Kruchinina, N.V., Modzalievskaya, T.L. (Eds.), Biostratigrafiya i ekologo-biosfernyie aspekty paleontologii. Tesisy dokladov XLIV sessii Paleontologicheskogo obshestva (Biostratigraphy and environmental-biospherical aspects of paleontology. Abstract paper of XLIV session of the Russian Paleontological Society), St Petersburg, pp. 17–18 (in Russian).

Biakov, A.S., Vedernikov, I.L., 1990. Stratigrafiya permskich otlozhenyi severo-vostochnogo obramlenyia Ochotskogo massiva, central'noi i yugo-vostochnoi chastei Aian–Yuriachskogo antiklinoryia (Stratigraphy of Permian deposits of northeast framework of Okhotsk Massif, central and southeast parts of Ayan–Yuryakh antiklinorium). Severo-Vostochnyi Kompleksnyi Nauchno-issledovatel'skii Insitut Dal'nevostochnogo Otdeleniya Rossiiskoi Akademii nauk, Magadan, pp. 1–69 (in Russian).

Bogoslovskaya, M.F., 1984. Ammonoids. In: Kotljar, G.V., Stepanov, D.L. (Eds.), Osnovnye cherty stratigrafii permskoi sistemy SSSR (Main Features of Stratigraphy of the Permian System in the USSR). Nedra, Leningrad, pp. 248–257 (in Russian).

Bogoslovskaya, M.F., Boiko, M.S., 2002. The evolution and distribution of the Early Permian genus *Uraloceras* (Ammonoidea). Paleontological Journal 36 (6), 598–605.

Ganelin, V.G., 1977. Biostratigraphy of Upper Paleozoic deposits of the Kolyma-Omolon Massif. In: Sarycheva, T.G. (Ed.), Brachiopody verchnego paleozoia Sibiri i Arctici (Brachiopods of the Upper Paleozoic of the Siberia and Arctic). Paleontologicheskii Institut, Moscow, pp. 7–18 (in Russian).

Ganelin, V.G., 1984. Taimyr–Kolyma Subrealm. In: Kotljar, G.V., Stepanov, D.L. (Eds.), Osnovnye cherty stratigrafii permskoi sistemy SSSR (Main Features of Stratigraphy of the Permian System in the USSR). Nedra, Leningrad, pp. 111–142 (in Russian).

Ganelin, V.G., Lazarev, S.S., 1999. Revision of the Permian thin-ribbed linoproductoids, article 1. Linoproductoids of the *'Cancrinella' koninckiana* (Keyserling, 1846) group. Paleontological Journal 33 (3), 243–253.

Ganelin, V.G., Lazarev, S.S., 2000. Revision of the Permian thin-ribbed linoproductoids. Article 2. The *'Cancrinella' ogonerensis* Zavodowsky Zavodowsky, 1960 group. Paleontological Journal 34 (1), 40–46.

Ganelin, V.G., Biakov, A.S., Karavaeva, N.I., 2001. Some questions of stratigraphical theory and Permian stratigraphic scale of Northeast Asia. In: Gladenkov, Yu.B., Kuznetsova, K.I. (Eds.), Puti detalizatsii stratigraficheskich schem i paleogeograficheskich rekonstruktsii (Toward Detailed Stratigraphic Schemes and Paleogeographic Reconstructions). GEOS, Moscow, pp. 194–209 (in Russian).

Ganelin, V.G., Biakov, A.S., Karavaeva, N.I., 2002. Marine analogues of the Tatarian stage in Northeast Asia. In: Lozovsky, V.R. et al. (Ed.), Tesisy dokladov vserossiiskoi konferentsii "Tatarskyi yarus Evropeiskoi Rossii: problemi stratigrafii i korrelyatssii s morskoi teticheskoi shkabi (The Tatarian Stage in European Russia: the problems of its stratigraphy and correlation with the Tethys Scale). Permskaya Komissiya Mezhvedomstvennogo Stratigraficheskogo Komiteta, Moscow, pp. 23–24 (in Russian).

Ganelin, V.G., Biakov, A.S., Karavaeva, N.I., 2003. Permian stratigraphic scale of Northeast Russia. In: Goncharov, V.I. (Ed.), Geodinamika, magmatizm i metallogeniya kontinental'nych okrain severa Patsifiki (Geodynamics, magmatism and metallogeny of continental margins of northern Pacific), vol. 1. Severo-Vostochnyi Kompleksnyi Nauchno-issledovatel'skii Insitut Dal'nevostochnogo Otdeleniya Rossiiskoi Akademii Nauk, Magadan, pp. 125–131 (in Russian).

Gerke, A.A., Sossipatrova, G.P., 1975. Stratigraphical significance of Late Paleozoic foraminifera of Northeast USSR. In: Ustritsky, V.I. (Ed.), Verchnyi paleozoi Severo-Vostoka SSSR (The Upper Paleozoic of Northeast USSR). Nauka, Leningrad, pp. 26–41 (in Russian).

Karavaeva, N.I., 1990. Beds with foraminifera. In: Kashik, D.S. (Ed.), Opornyi razres permi Omolonskogo massiva (Permian key section of the Omolon Massif). Nauka, Leningrad, pp. 118–127 (in Russian).

Karavaeva, N.I., 1993. Significance of smaller foraminifera in subdivision of Permian deposits in the northeastern USSR. Occasional publications of the Earth Sciences and Resources Institute, University of South Carolina, New Series, N9A-B, pp. 61–62.

Kashik, D.S., Ganelin, V.G., Karavaeva, N.I., Biakov, A.S., et al., 1990. Opornyi razres permi Omolonskogo massiva (Permian key section of the Omolon Massif). Nauka, Leningrad pp. 1–200 (in Russian).

Kotlyar, G.V., 2000. Mid-Tatarian event. In: Koren', T.N. (Ed.), Ispol'zovanie sobytiyno-stratigraficheskich urovnei dlya mezhregional'noi korrelyatsyi Fanerozoya Rossii (Event-Stratigraphic Levels in the Phanerozoic of Russia and their Correlation Potential). Vserossiiskii Geologicheskii Institut, St. Petersburg, pp. 53–55 (in Russian).

Kotlyar, G.V., Zakharov, Yu.D., Popeko, L.I., Tazawa, J., Burago, V.I., 1997. Strata with *Timorites* in the East of Asia. Tikhookeanskaya Geologiya 16 (3), 41–50 (in Russian).

Kutygin, R.V., Budnikov, I.V., Biakov, A.S., Kletz, A.G., 2002. Beds with ammonoids in the Permian of the Verkhoyan. Otechestvennaya Geologiya 5, 66–71 (in Russian).

Leven, E.Ya., 2003. Diversity dynamics of fusulinid genera and main stages of their evolution. Stratigraphy and Geological Correlation 11 (3), 220–230.

Merzljakov, V.M., Terekhov, M.I., Bjalobzesky, S.G., 1974. On the median massifs of the North-East of the USSR. Geotektonika 5, 61–73 (in Russian).

Parfenov, L.M., Kuzmin, M.I. (Eds.), 2001. Tektonika, geodinamika i metallogeniya territorii Respubliki Sakha (Yakutiya) (Tektonics, Geodinamics and Metallogeny of the Sakha Republic (Yakutia). Nauka/Interperiodika, Moscow, pp. 1–572 (in Russian).

Til'man, S.M., Afitsky, A.I., Chekhov, A.D., 1977. Comparative tectonics of the Alazeya and Oloi Zones (the North-East of the USSR) and problem of the Kolyma Massif. Geotektonika 4, 6–17 (in Russian).

Tschernyak, G.E., 1975. The project of the unified stratigraphic chart of the Upper Paleozoic of the Northeast of the USSR. In: Ustritsky, V.I. (Ed.), Verchnii paleozoi Severo-Vostoka SSSR (The Upper Paleozoic of the Northeast of the USSR). Nauka, Leningrad, pp. 5–25 (in Russian).

Ustritsky, V.I., 1975. The history of the Northeast of the USSR in the Upper Paleozoic. In: Ustritsky, V.I. (Ed.), Verchnii paleozoi Severo-Vostoka SSSR (The Upper Paleozoic of the Northeast of the USSR). Nauka, Leningrad, pp. 54–75 (in Russian).

Yarkin, V.I., Zhamoida, A.I., 1992. Regional stratigraphic units. In: Zhamoida, A.I. (Ed.), Stratigraficheskyi kodeks. Vtoroe izdanie, dopolnennoe (Stratigraphic Code. Second Edition, Supplemented). Vserossiiskii Giologicheskii Institut, St. Petersburg, pp. 35–41 (in Russian).

Zavodovsky, V.M., 1960. The new stratigraphic chart of the Permian deposits of the Northeast of the USSR (except the Verkhoyan). Materialy po geologii i poleznym iskopaemym Severo-Vostoka SSSR. Magadanskoye Knizhnoye Izdatel'stvo, Magadan 14, pp. 186–188 (in Russian).

Zhamoida, A.I. (Ed.), 1998. The Order on the Report of the Chairman of Permian Commission of Interdepartmental Stratigraphic Committee G.V. Kotlyar 'Chronostratigraphic standard and the problems of stage division of the Upper Permian' Postanovleniya Mezhvedomstvennogo stratigraficheskogo komiteta i ego postoyannych kommissyi, vol. 30. Vserossiiskii Geologicheskii Institut, St. Petersburg, pp. 28–29 (in Russian).

Zhamoida, A.I. (Ed.), 2003. The Order on Stratigraphic Schemes of the Precambrian, Paleozoic, and Mesozoic of Northeast Russia Postanovleniya Mezhvedomstvennogo stratigraficheskogo komiteta i ego postoyannych kommissyi, vol. 34. Vserossiiskii Geologicheskii Institut, St Petersburg, pp. 6–9 (in Russian).