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The Reference Section of the Lower–Upper Permian Boundary Beds in the Verkhoyansk Region and Its Correlation

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Abstract—The following Lower–Upper Permian brachiopod zonation is established in the Baraiy River basin (the western Verkhoyansk region): (1) the *Megousia kuliki* Zone bearing the associated *Neouddenites–Tumaroceras yakutorum* goniatite assemblage, (2) the *Kolymaella ogonerensis* Zone containing the *Baraioceras–Tumaroceras kashirzevi* ammonoid assemblage, (3) the *Mongolosia russiensis* Zone with the *Daubichites–Sverdrupites harkeri* ammonoid assemblage, (4) the *Olgerdia zavodovskyi* Zone, and (5) the *Cancrinelloides obrutshevi* Zone. The boundary between the Kungurian Stage of the Lower Permian and the Ufimian Stage of the Upper Permian is drawn at the base of the *Kolymaella ogonerensis* Zone of the Tumara Horizon. The most distinct biostratigraphic level is the base of the *Mongolosia russiensis* Zone, which corresponds to the lower Roadian boundary. The compatibility analysis of Permian biotic and abiotic events in the western Verkhoyansk region shows that the *Mongolosia russiensis* and *Cancrinelloides obrutshevi* zones correspond to phases of the highest sea level stand, which has determined ranges of the zones. The Baraiy River section can be accepted for the reference one in the Verkhoyansk region. It may also facilitate correlation of the Uralian and North American stage scales.

Key words: *Permian, Tumara Horizon, Delenzha Horizon, Kungurian Stage, Ufimian Stage, goniatites, brachiopods, zone, Verkhoyansk region.*

INTRODUCTION

The Permian rock succession in the Baraiy River basin of the Verkhoyansk region attracts a considerable interest because of many factors. First, it represents a continuous, stratigraphically complete, and well-exposed section of simple geological structure. Second, in the Baraiy structural–lithologic subzone, the Permian sections are predominantly composed of marine facies that yield goniatites, brachiopods, and bivalves. Third, stratotypes and parastratotypes of local and regional stratigraphic units that have been recognized within this basin are unambiguously correlated to the Delenzha and Dulgalakh sections of the Eastern Kuranakh structural–lithologic subzone. The latter are located in the stratotype area of the Permian horizons of the Verkhoyansk region (*Resheniya*..., 1982). Fourth, it should be stressed that the Baraiy River section was examined by many experts on biostratigraphy who study the Upper Paleozoic deposits of the Verkhoyansk region and northeastern Russia (Andrianov, 1966, 1975, 1985; Abramov *et al.*, 1973; Abramov, 1974; Abramov and Grigor'eva, 1988; Solomina, 1988, 1997; Grinenko *et al.*, 1997).

The variety of views on the regional stratigraphic units can be reduced to two. One is viewpoint of Abramov who correlates the Tumara Formation of the western Verkhoyansk region, which is used to distinguish the Tumara Horizon, with the Upper Permian Omolon Horizon, whereas many others consider it as correlative to the Lower Permian Dzhigdala Horizon of Northeastern Russia. Exactly this contradiction made us to take up the pen, because the first, less common view on the Lower–Upper Permian boundary deposits of the Verkhoyansk region (Abramov and Grigor'eva, 1988) was not doubted for ten years and led to miscorrelations of regional bio- and lithostratigraphic units with those of the standard scale. The last point is of great importance for editing geological maps and legends of various kind.

Resolutions of the International Subcommission on Permian Stratigraphy and Second Guadalupian Symposium (Yugan Jin, 1996; Leven *et al.*, 1997), which introduce the Guadalupian Series of the Permian System in practice, necessitate the spare criteria retrieval in order to correlate the Uralian stratotype sections with North American standards. The western Verkhoyansk region is favorable in this aspect, as it is of transitional type and hosts mixed faunas (Budnikov *et al.*, 1994, 1995, 1996). In addition, new data that can substantiate the reliable correlation became recently available from both the Verkhoyansk region (Grinenko *et al.*, 1997) and the North Uralian Province (Bogoslovskaya, 1997) and adjacent areas (Kotlyar *et al.*, 1997). The idea to consider the Tumara goniatite assemblage of the Verkhoyansk region as endemic gradually changes, and index-species of brachiopod zones established in the Verkhoyansk–Kolyma area have been found recently in the North Uralian Province (Ganelin, 1997).

HISTORY OF THE PROBLEM AND FACTUAL DATA

Let us consider the crux of the problem in three aspects corresponding to three classic components of common stratigraphic work. A complex of questions, misinterpretations and different views appears in the course of (1) subdivision of a geological section, (2) subsequent correlation of individual sections (in our case, those of the Verkhoyansk–Okhotsk Province), and (3) dating of the distinguished units, or, what is the same, of their correlation with the stratotype units of the standard scale. The Verkhoyansk terrigenous complex is known to be poor in fossils, and this impedes solution of stratigraphic problems. Accordingly, the main tasks of this work were as follows: (1) to establish the structure and biostratigraphic succession of the Lower–Upper Permian boundary beds in the Baraiy structural–lithologic subzone of the Verkhoyansk region, where one can expect to observe the most complete Permian sections that have been accumulated in close proximity to marine settings; (2) to refine the Permian biostratigraphy in the Baraiy River basin and to better substantiate its correlation with the Permian type sections of the Kolyma–Omolon massif and with successive type zones of the Biarmian paleogeographic province; (3) to define more precisely the possible correspondence between the regional and standard stratigraphic units by means of ranging main biotic and abiotic events.

Those researchers who studied the western Verkhoyansk in various periods elaborated several biostratigraphic schemes based on ammonoids, brachiopods, and bivalves (Andrianov, 1975; Abramov and Grigor'eva, 1988; Solomina, 1997; Kurushin *et al.*, 1996; and others). Each of them suggested their own, though similar correlation schemes of the western Verkhoyansk and other region sections of the Verkhoyansk–Okhotsk Province. As is mentioned, the third task of stratigraphy (dating of deposits) is correlation of successive regional biostratigraphic units with those of the international stratigraphic scale. Goniatites represent the only orthostratigraphic group among other faunas of Verkhoyansk region, which can be most effectively used for such a correlation. After works by Ruzhentsev (1961), Andrianov (1966), and Popov (1970), ammonoids became the main faunal group usable for dating of deposits and for correlating them with Permian marine sections of the globe. The correlation potential of ammonoids was convincingly demonstrated in the fundamental work by Andrianov (1985). Their stratigraphic significance in the Verkhoyansk region is limited however because of sporadic occurrence in Permian deposits, and some benthic faunas, e.g., brachiopods, foraminifers, and bivalves, appeared to be quite important here.

As mentioned above, considerably different viewpoints appear in the course of biostratigraphic correlation of individual regional sections, and subsequently, by their correlation with well-studied sequences of the adjacent Kolyma–Omolon massif. Precisely this is the main goal of this work in addition to the analysis of real biostratigraphic succession. As for the Lower–Upper Permian boundary, it was formerly drawn (*Resheniya...*, 1982) between the Tumara and Delenzha horizons of the Verkhoyansk region, which were correlated respectively with the Dzhigdala and Omolon horizons of the Kolyma–Omolon massif. This view was accepted widely (Ganelin, 1984; Andrianov, 1975, 1985; Klets, 1995; Kotlyar, 1996; Solomina, 1997), but Abramov and Chernyak had different opinions, though apart from the interregional correlation. The Lower–Upper Permian boundary was placed by Abramov (1974) at the base of the Dasaknya Horizon and by Chernyak (1975) at the base of the Dzhigdala Horizon. In other words, they suggested that the Upper Permian begins with the Kungurian Stage. This view gained lesser recognition, though it touched upon problems of interregional correlation, which have no unambiguous solution, as we believe, even in the other approach having a wider support.

The correlation between the Permian deposits of the East Kuranakh (the Endybal and Tumara river basins) and Baraiy (the Baraiy River basin) subzones is of extreme significance not only for the Verkhoyansk region but also for entire Northeastern Russia, because stratotypes and parastratotypes of the regional stratigraphic units are located here. This is one of the subjects of the present work. Abramov and Grigor'eva (1988) proposed the modified Permian stratigraphic scheme for the Verkhoyansk region, in which they suggested older ages of the Mugochan and Nyunegi formations than those accepted before (Abramov *et al.*, 1973, Abramov, 1974). Main distinctions of the new Permian stratigraphic scheme (Abramov and Grigor'eva, 1988, p. 87) from that accepted at the Conference on Regional Stratigraphy (*Resheniya...*, 1982) are as follows: (1) the Delenzha Formation of the Tumara River section is considered as an equivalent of the Mol Formation at the level of the Gizhiga Horizon of the Baraiy River section; (2) the Tumara Formation of the Tumara River section is correlated with the united Mugochan and Nyunegi formations. Earlier (Abramov *et al.*, 1973, p. 115), it was stated that "the Mugochan Formation corresponds to the Lower Delenzha Subformation" and

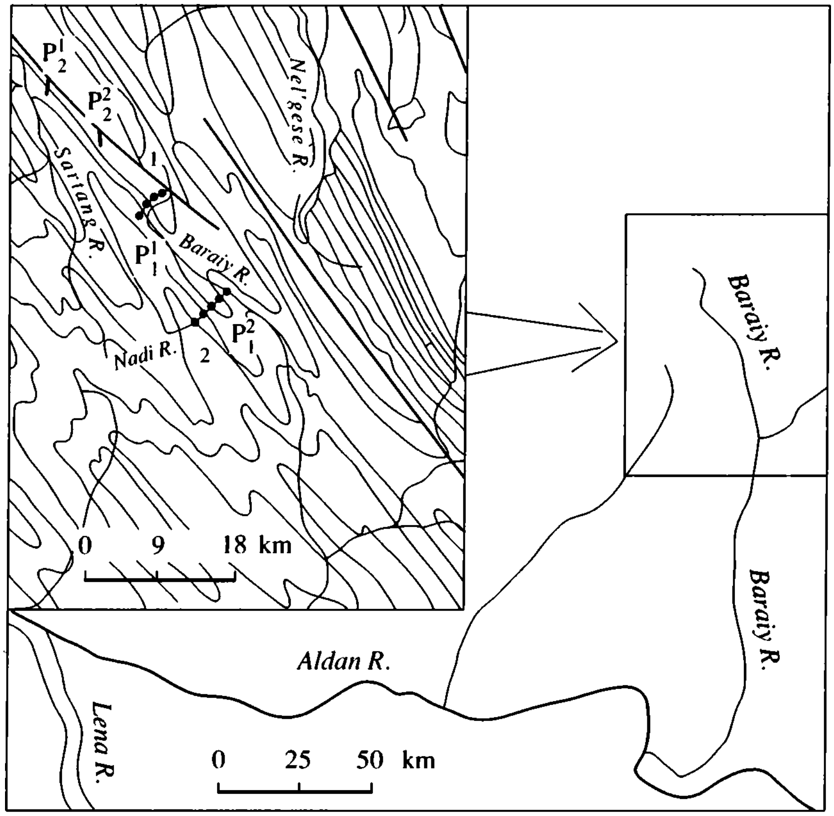


Fig. 1. Geographic position of the Baraiy (1) and Nadi (2) sections.

"the Nyunegi Formation corresponds to the Upper Delenzha Subformation". There is also an intermediate variant of the scheme (Abramov, 1974).

Another Permian biostratigraphic scheme for the Verkhoyansk region was suggested by Solomina (1997) who was one of co-authors of the work published in 1973. She distinguished the Mugochan and Nyunegi horizons on the basis of stratotypes of corresponding formations in the Baraiy River basin but retained the correlation between the Delenzha and Tumara formations of the Delenzha and Tumara river sections as it was in the scheme of 1973.

Our work is based on the results of the large-scale geological mapping and lithological–biostratigraphic investigations in the Baraiy River basin during the field seasons of 1982 and 1992–1994. We studied sections along the Baraiy River and its large tributary Nadi River (Figs. 1 and 2), which include stratotypes or parastratotypes of stratigraphic units mentioned above. We obtained new stratigraphic materials and collected abundant paleontological remains. Following Andrianov (1985) and Solomina (1997), we believe that the western Verkhoyansk area and the Baraiy River sections can be accepted for reference area and section enabling correlation between the northern, western, southern and southeastern parts of the whole Verkhoyansk region and also for remote correlations. We suggest a modified scheme, which is similar to that of Solomina (1997) but includes different regional subdivisions of a higher correlation potential. The succession of horizons corresponds to that suggested by Andrianov (1975), and biostratigraphy is based on distribution of brachiopods and ammonoids. Unlike Solomina (1997), we use traditional names of the regional stratigraphic units (Andrianov, 1975; *Resheniya...*, 1982). Most biostratigraphic zones were originally recognized by Ganelin (1984, 1990), and the *Olgerdia zavodovskyi* Zone was distinguished by Solomina (1989, 1997). The inferred relationships between the Uralian, regional, and local stratigraphic units are summarized in Table 1.

Fossils, except for those especially indicated, were identified by Klets (brachiopods), Kutygin (ammonoids), Sosipatrova (foraminifers, 1983), Boiprav (bivalves), and Gorelova (flora). We used the ammonoid collection of Andrianov, some specimens of which were reclassified by Kutygin.

BIOSTRATIGRAPHY

The Baraiy River section is divided into the Tigechan and Sebinekchan formations of the Lower Permian, and the Mugochan, Nyunegi, Mol, and Amkandzha formations of the Upper Permian. Fig. 2 illustrates correlation between two sections, one exposed at the left side of the Baraiy Canyon and

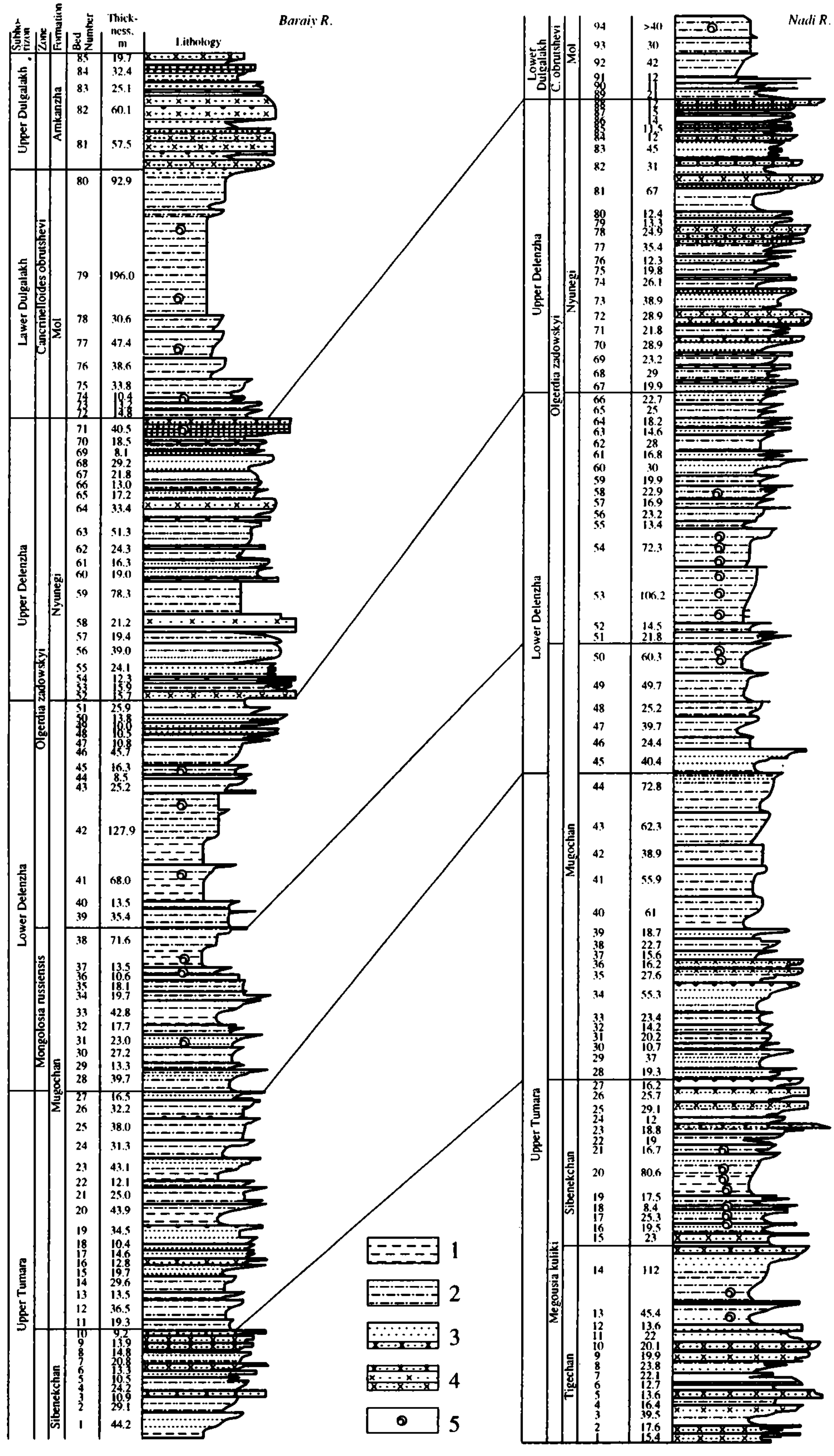


Fig. 2. The correlated Baraiy and Nadi river sections: (1) mudstone; (2) fine- to coarse-grained siltstone; (3) fine- to medium-grained sandstone; (4) coarse-grained sandstone; (5) occurrence levels of fossil discovered by authors.

Table 1. Correlation scheme for local and regional stratigraphic units

The Cisuralian region, stage	The Verkhoyansk region, subhorizon	The Endybal, Delenzha, and Tumara river basin, subformation	The Baraiy River basin, formation
Kazanian	Upper Delenzha	Upper Delenzha	Nyunegi
	Lower Delenzha	Lower Delenzha	Mugochan
Ufimian			
	Upper Tumara	Upper Tumara	Sebinekchan
Kungurian			Tigechan
	Lower Tumara	Lower Tumara	Talchan

another one near the Nadi River mouth (15 km downstream). Figure 3 shows the composite section, the lower part of which corresponds in lithologic and faunal characteristics to the Tigechan and Sebinekchan formations of the Nadi River section, and the upper one depicts the same characteristics of the Mugochan, Nyunegi, Mol, and Amkandzha formations of the Baraiy River section. Describing the distinguished biostratigraphic units we also used fossil identifications of other researchers.

Tumara Horizon, Upper Tumara Subhorizon

***Megousia kuliki* Zone.**[1] The zone spans the section interval from Bed 1 to Bed 14 (the Tigechan Formation), and further from Bed 15 to Bed 27 (the Sebinekchan Formation). The lower coarser deposits of the Tigechan Formation correspond to thick (5–15 to 20 m and thicker) members of medium- to fine-grained "blocky" sandstones characteristic of the topmost portions of the deltaic "wedges". The upper part of this formation represents a cyclic alternation of silty and sandy interbeds. According to Andrianov *et al.* (1975), this interval of the section corresponds to "flyschoid" stratotype of the rhythmic Tumara Formation and to the Takamkyt Formation of the Baraiy River basin. Siderite concretions in heavily bioturbated and fine-grained interbeds contain brachiopods and bivalves. The Tigechan Formation is about 375 m thick. It yielded brachiopod species *Alispiriferella gydanensis* (Zav.) and *"Neospirifer subfasciger"* Lich. characteristic of the Tumara Horizon (Solomina, 1997; Klets, 1995). The former was found together with the latest *Yakutoproductus* forms in the southeastern Verkhoyansk region (Klets, 1995). In the Kolyma–Omolon massif, the same species is confined to the *Mongolosia russiensis* Zone of the Omolon Horizon (Ganelin, 1990). This evident discrepancy has no explanation so far.

[1] Authors place lower boundaries of zonal units at the base of sedimentary rhythms, but not at the first occurrence levels of zonal assemblages that is not an apt decision. Reviewer A.S. Alekseev.

Andrianov reported on occurrence of *Anidanthus kolymaensis* (Lich.) (=*M. kuliki* (Fred.)), *Saccamina arctica* Gerke, and *Tumaroceras yakutorum* Ruzh. in the lower member of the upper Tumara Subformation (Andrianov, 1966, p. 45) and in the Takamkyt Formation (Andrianov *et al.*, 1975). These species are characteristic of the *M. kuliki* Zone.

The Sebinekchan Formation consists of alternating sandy and silty members in its upper and lower parts. Among them, there are 3- to 15-m-thick members of hard massive fine-grained and well-sorted calcareous sandstones of coastal-marine genesis, and of the deltaic medium- to fine-grained sandstones. These alternate with siltstone members having approximately the same thickness and frequently displaying structures of gravitational sliding. The deposits are heavily bioturbated. The middle part of the formation includes a thick (more than 80 m) member of predominantly silty sediments including interbeds of siderite fossiliferous concretions. Brachiopods are represented here by *Cancrinella janischewskiana* Step., *Megousia kuliki* (Fred.), *Rhynchopora* aff. *variabilis* Stuck., and *Tumarinia barajensis* Sol. Bivalve species are *Nuculana* cf. *undosa* Mur., *Aviculopecten mutabilis* Masl., *Streblopteria pusilla* (Schloth.), *Liebea squamosa* (Sowerby), *Praeundulomya petschorica* Mur. *Atomodesma andrianovi* Mur., *Aviculopecten orientalis* Fred., *Nuculana lunulata* (Demb.), *Vnigripecten* aff. *phosphaticus* (Girty), and *Parallelodon striatus* (Schlotheim).

Brachiopods *Megousia kuliki* (Fred.), *Tumarinia barajensis* Sol. and some bivalves (e.g., *Atomodesma andrianovi* Mur.) unambiguously evidence that their host deposits belong to the Tumara Horizon. Both brachiopods are index-species of the *Megousia kolymaensis* Zone in the schemes of Ganelin (1984, 1990) and Solomina (1997). Following Ganelin (1990), we consider the species *M. kolymaensis* (Lich.) as junior synonym of *M. kuliki* (Fred.). Solomina and Abramov differently dated the Sebinekchan (the upper part of the Sinigichan Formation according to Abramov, 1974) and overlying Mugochan formations. This could be

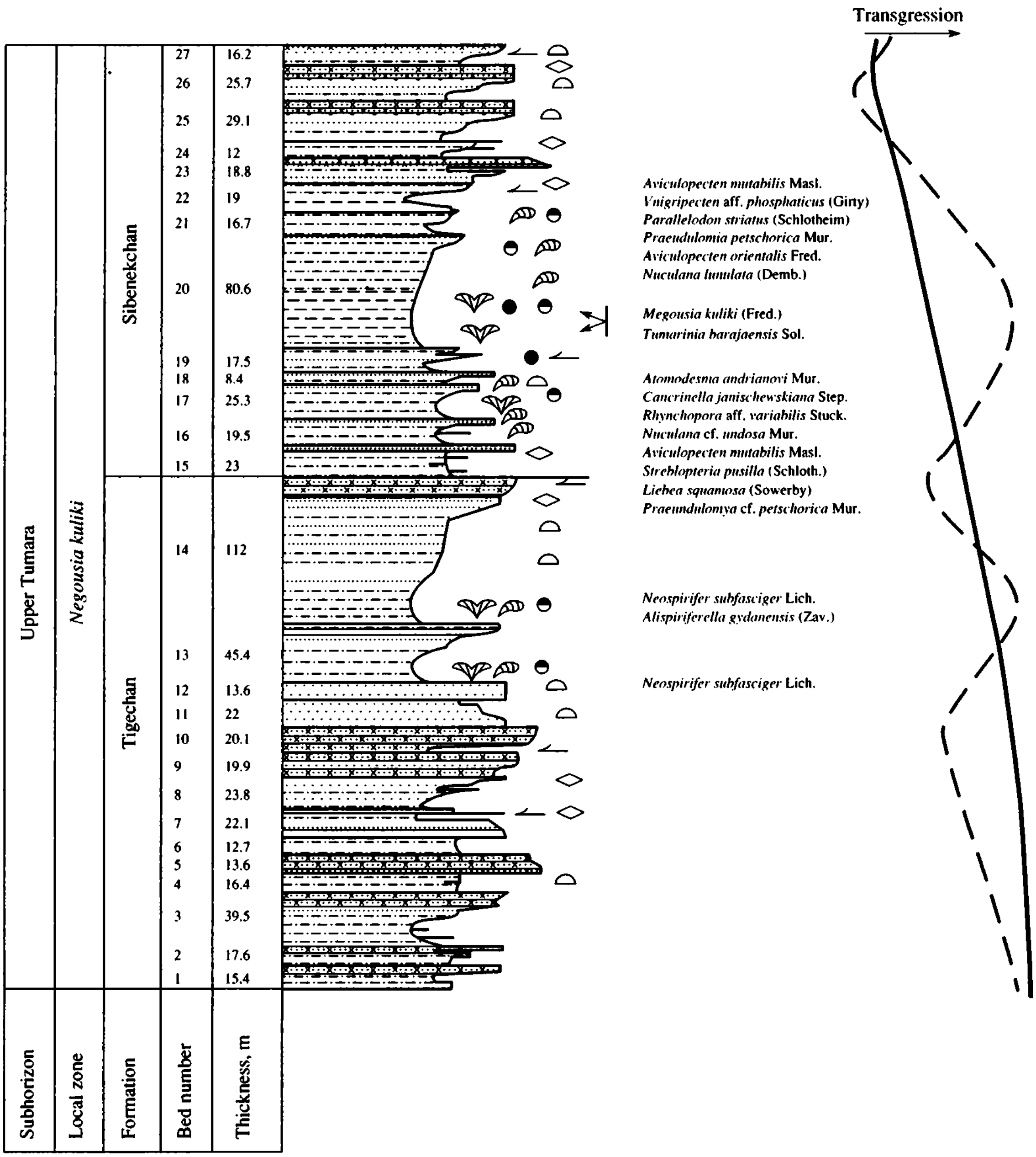


Fig. 3. The composite Baraiy section of the Lower–Upper Permian boundary deposits: (1) mudstone; (2) fine- to coarse-grained siltstone; (3) fine- to medium-grained sandstone; (4) coarse-grained sandstone; (5) ammonoids; (6) brachiopods; (7) bivalves; (8) foraminifers; (9) mud-eaters; (10) plant detritus; (11) floral remains; (12) sideritization; (13) pyritization; (14) oscillation ripple.

caused by find of *T. barajensis* Sol. in the Mugochan and Nyunegi formations (Abramov, 1974; Abramov and Grigor'eva, 1988), because this form was previously considered as index-species of the synonymous zone of the Tumara Horizon (Solomina, 1988). The find could allow Abramov to correlate the Mugochan Formation with the Tumara Formation of the Tumara River basin (the stratotype area of the Tumara Horizon), and this respectively influenced his interregional correlation.

The upper member of the upper Tumara Subformation of the Baraiy River basin yielded *Anidanthus kolymaensis* (Lich.) [=*M. kuliki* (Fred.)], *Tumaroceras yakutorum* Ruzh., *Cancrinella koninkiana* (Keys.), and others. The last indicated species is widespread in the Kungurian deposits of the North Urals and in the *M. kuliki* Zone of the Kolyma–Omolon massif.

***Kolymaella ogonerensis* Zone** characterizes Beds 28–44 (the Mugochan Formation) corresponding to two sedimentological rhythms of the section. It seems expedient to relate this unit with the next stage of the basin evolution. In his monograph on the Upper Paleozoic deposits of the western Verkhoyansk region,

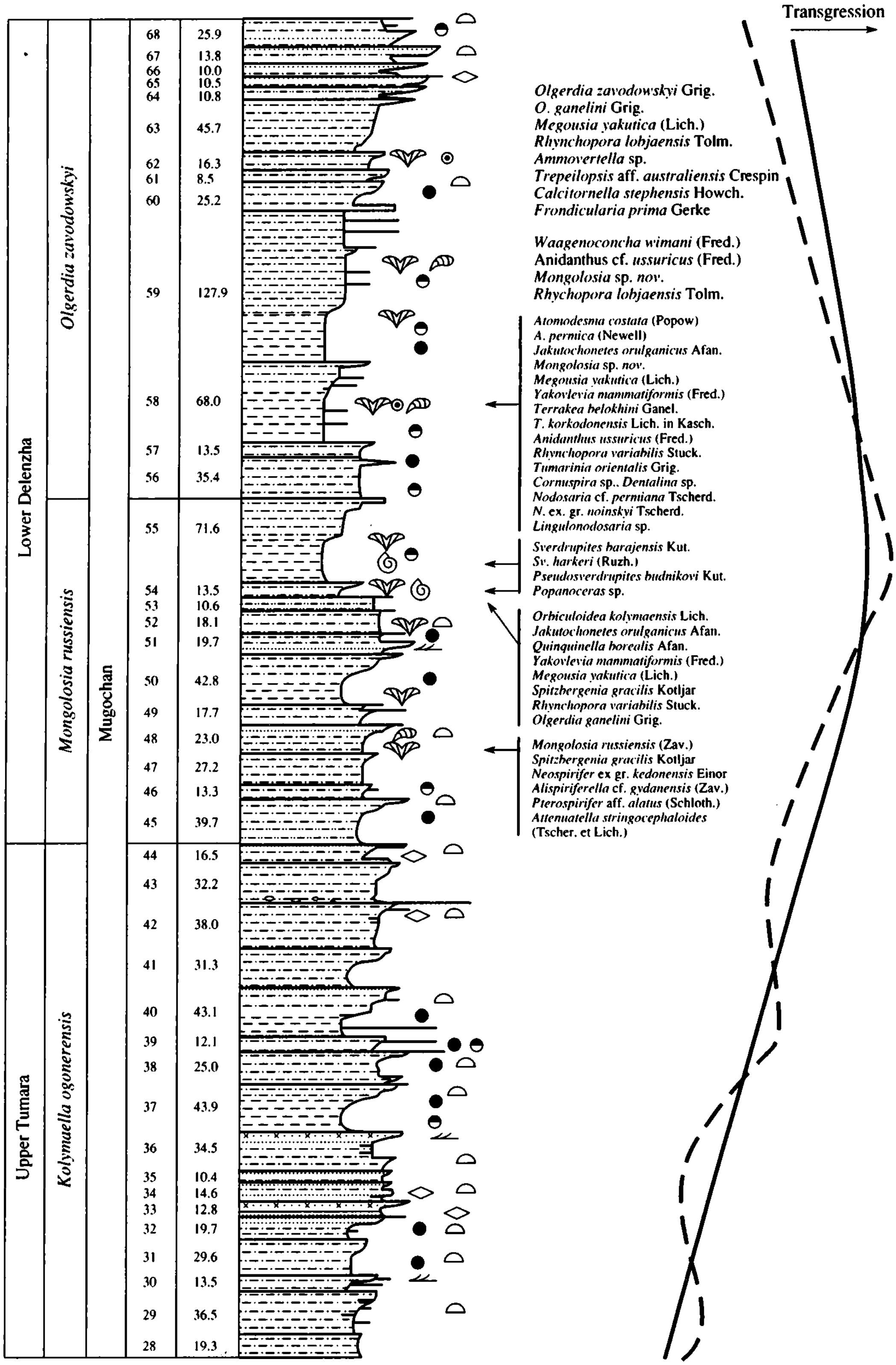
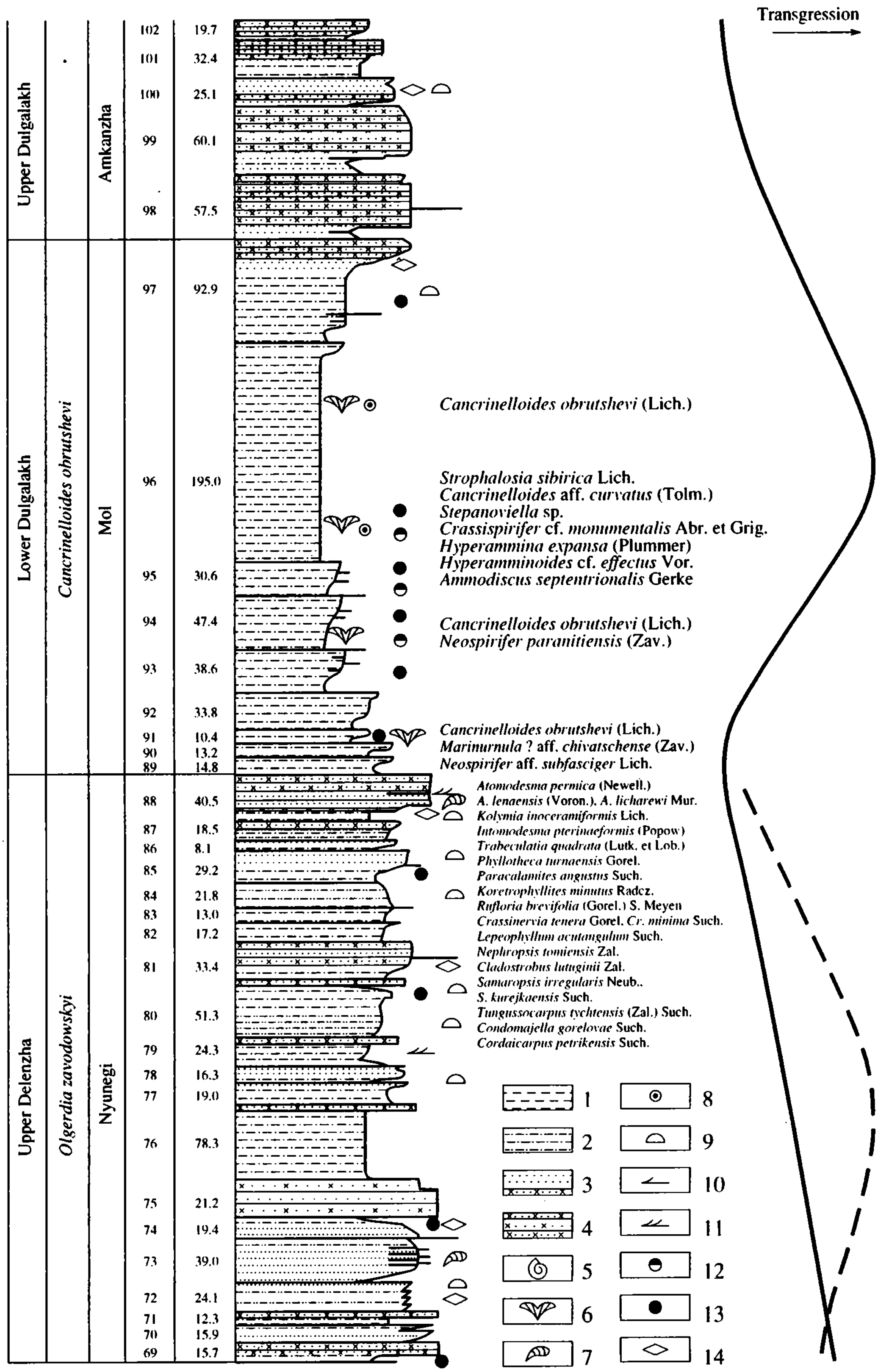

Transgression
Lower Delenzha
Upper Tumara
Olgerdia zavodowskyi
Mongolosia russiensis
Kolymaella ogonerensis
Mugochan
68 25.9
67 13.8
66 10.0
65 10.5
64 10.8
63 45.7
62 16.3
61 8.5
60 25.2
59 127.9
58 68.0
57 13.5
56 35.4
55 71.6
54 13.5
53 10.6
52 18.1
51 19.7
50 42.8
49 17.7
48 23.0
47 27.2
46 13.3
45 39.7
44 16.5
43 32.2
42 38.0
41 31.3
40 43.1
39 12.1
38 25.0
37 43.9
36 34.5
35 10.4
34 14.6
33 12.8
32 19.7
31 29.6
30 13.5
29 36.5
28 19.3
Olgerdia zavodowskyi Grig.
O. ganelini Grig.
Megousia yakutica (Lich.)
Rhynchopora lobjaensis Tolm.
Ammovertella sp.
Trepeilopsis aff. australiensis Crespin
Calcitornella stephensis Howch.
Frondicularia prima Gerke
Waagenoconcha wimani (Fred.)
Anidanthus cf. ussuricus (Fred.)
Mongolosia sp. nov.
Rhychopora lobjaensis Tolm.
Atomodesma costata (Popow)
A. permica (Newell)
Jakutochonetes orulganicus Afan.
Mongolosia sp. nov.
Megousia yakutica (Lich.)
Yakovlevia mammatiformis (Fred.)
Terrakea belokhini Ganel.
T. korkodonensis Lich. in Kasch.
Anidanthus ussuricus (Fred.)
Rhynchopora variabilis Stuck.
Tumarinia orientalis Grig.
Cornuspira sp., Dentalina sp.
Nodosaria cf. permiana Tscherd.
N. ex. gr. noinskyi Tscherd.
Lingulonodosaria sp.
Sverdrupites barajensis Kut.
Sv. harkeri (Ruzh.)
Pseudosverdrupites budnikovi Kut.
Popanoceras sp.
Orbiculoidea kolymaensis Lich.
Jakutochonetes orulganicus Afan.
Quinquinella borealis Afan.
Yakovlevia mammatiformis (Fred.)
Megousia yakutica (Lich.)
Spitzbergenia gracilis Kotljar
Rhynchopora variabilis Stuck.
Olgerdia ganelini Grig.
Mongolosia russiensis (Zav.)
Spitzbergenia gracilis Kotljar
Neospirifer ex gr. kedonensis Einor
Alispiriferella cf. gydanensis (Zav.)
Pterospirifer aff. alatus (Schloth.)
Attenuatella stringocephaloides (Tscher. et Lich.)

Fig. 3. (Contd.)


Transgression
Upper Dulgalakh
Lower Dulgalakh
Upper Delenzha
Cancrinelloides obrutshevi
Olgerdia zavodowskyi
Amkanzha
Mol
Nyunegi
102 19.7
101 32.4
100 25.1
99 60.1
98 57.5
97 92.9
96 195.0
95 30.6
94 47.4
93 38.6
92 33.8
91 10.4
90 13.2
89 14.8
88 40.5
87 18.5
86 8.1
85 29.2
84 21.8
83 13.0
82 17.2
81 33.4
80 51.3
79 24.3
78 16.3
77 19.0
76 78.3
75 21.2
74 19.4
73 39.0
72 24.1
71 12.3
70 15.9
69 15.7
Cancrinelloides obrutshevi (Lich.)
Strophalosia sibirica Lich.
Cancrinelloides aff. curvatus (Tolm.)
Stepanoviella sp.
Crassispirifer cf. monumentalis Abr. et Grig.
Hyperammina expansa (Plummer)
Hyperamminoides cf. effectus Vor.
Ammodiscus septentrionalis Gerke
Cancrinelloides obrutshevi (Lich.)
Neospirifer paranitiensis (Zav.)
Cancrinelloides obrutshevi (Lich.)
Marinurnula ? aff. chivatschense (Zav.)
Neospirifer aff. subfasciger Lich.
Atomodesma permica (Newell.)
A. lenaensis (Voron.), A. licharewi Mur.
Kolymia inoceramiformis Lich.
Intomodesma pterinaeformis (Popow)
Trabeculatia quadrata (Lutk. et Lob.)
Phyllotheca turnaensis Gorel.
Paracalamites angustus Such.
Koretrophyllites minutus Radcz.
Rufloria brevifolia (Gorel.) S. Meyen
Crassinervia tenera Gorel. Cr. minima Such.
Lepeophyllum acutangulum Such.
Nephropsis tomiensis Zal.
Cladostrobus lutuginii Zal.
Samaropsis irregularis Neub..
S. kurejkaensis Such.
Tungussocarpus tychtensis (Zal.) Such.
Condomajella gorelovae Such.
Cordaicarpus petrikensis Such.
1
2
3
4
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12
13
14

Fig. 3. (Contd.)

Andrianov (1966) referred these rhythms (submesocyclites) to the Tumara Formation, contrary to the logic of his own reconstructions. The members correspond to the initial phase of extensive transgression. In the facies zone under consideration, they compose the clayey–silty Mugochan Formation. In the Dulgalakh, Delenzha and Nuora river sections located westward, they are thinner and predominantly sandy. Consequently, the lower rhythm is usually included into the upper Tumara Subformation, and this is compatible with the natural structure of deltaic wedges extending from the Siberian platform. Ignoring this fact, we may come to erroneous stratigraphic reconstructions. Despite the thorough examination, no fauna was found in the described members, the constituent siltstones of which are heavily bioturbated.

Materials of geological mapping and data reported by Andrianov suggest that goniatites *Tumaroceras* aff. *yakutorum* Ruzh. (=*T. kashirzevi* Andr.), and *Tumaroceras* (?) sp. found at the Nadi River locality (Andrianov, 1985, p. 58) occur in the interval of Beds 28–44 (Fig. 3). *Baraioceras stepanovi* Andr. similar to the Kungurian *Paragastrioceras kungurense* (Mirskaya) was found by Andrianov and Shtekh (Andrianov, 1985, p. 58) in the Creek Imtan'ya alluvium (the area of distribution of the Tumara deposits); it may also characterize this interval. Solomina (1997) reported on occurrence of the brachiopod zonal species *ogonerensis* in the same interval of the Baraiy River section, where she recognized the synonymous zone.

Delenzha Horizon

The horizon consists of two subhorizons. The lower Delenzha Subhorizon spans the *Mongolosia russiensis* and *Olgerdia zavodovskyi* zones and corresponds to the upper part of the Mugochan Formation (Beds 45–68, Fig. 3). The formation composed of predominantly silty deposits displaying cyclic structure was accumulated during the early Delenzha stage of an intense transgression. The formation is subdivided into several members. Upper siltstone layers of the members are coarser than in their lower parts and include sandstone interbeds, especially closer to the formation base. These are the so-called submesocyclites readily traceable over the western Verkhoyansk region.

***Mongolosia russiensis* Zone.** The zone corresponds to the interval of Beds 45–55 (Fig. 3) and yields ammonoids *Sverdrupites baraiensis* Kut., *Sv. harkeri* (Ruzh.), *Sv.* aff. *harkeri* (Ruzh.), *Pseudosverdrupites budnikovi* Kut., and *Popanoceras* sp. indet. In association with brachiopods *Orbiculoidea kolymaensis* Lich., *Jakutochonetes orulganicus* Afan., *Quinquinella borealis* Afan., *Mongolosia russiensis* (Zav.), *Yakovlevia mammatiformis* (Fred.), *Megousia yakutica* (Lich.), *Spitzbergenia gracilis* Kotljar, *Rhynchopora variabilis* Stuck, *Olgerdia ganelini* Grig., *Neospirifer* ex gr. *kedonensis* Einor, *Alispiriferella* cf. *gydanensis* (Zav.), *Pterospirifer* aff. *alatus* (Schloth.), and *Attenuatella stringocephaloides* (Tschern. et Lich.). In the lower Delenzha Subformation of the Baraiy River section, Andrianov found *Popanoceras subtumarense* Andr. and *Daubichites* aff. *goochi* (Teichert).

The ammonoids unambiguously indicate the Roadian age of their host deposits (Andrianov, 1985; Kutygin, 1996, 1997). Brachiopods are characteristic in general of the basal Upper Permian deposits in many areas of northeastern Russia. According to Solomina (1997), the Mugochan Horizon contains *Jakutochonetes orulganicus* Afan., *Megousia yakutica* (Lich.), and *Mongolosia russiensis* (Zav.). The Omolon Horizon includes *Megousia yakutica* (Lich.), *Spitzbergenia gracilis* Kotljar, *Mongolosia russiensis* (Zav.), *Attenuatella stringocephaloides* (Tschern. et Lich.), and others (Ganelin, 1990). *Yakovlevia mammatiformis* (Fred.) is a characteristic form of the *Anidanthus aagardi* Zone of the Kolyma–Omolon massif (the Dzhigdala Horizon, Ganelin, 1990) and of the Talata Formation of the Pai-Khoi area (the Kungurian Stage, Kalashnikov, 1993). The same zonal species is also known from the Vladivostok Horizon of the Primor'e (Kotlyar, 1997). The brachiopod assemblage is commonly considered to be of the Ufimian age.

***Olgerdia zavodowskyi* Zone** was originally established and described by Solomina (1986, 1997). It corresponds to the interval of Beds 56–68 (the Mugochan Formation) and 69–88 (the Nyunegi Formation) of the section. The corresponding brachiopod assemblage includes *Jakutochonetes orulganicus* Afan., *Mongolosia* sp. nov., *Yakovlevia mammatiformis* (Fred.), *Megousia yakutica* (Lich.), *Waagenoconcha wimani* (Fred.), *Anidanthus* cf. *ussuricus* (Fred.), *Terrakea belochini* Gan., *T. korkodonensis* (Lich.), *Rhynchopora variabilis* Stuck., *Rhynchopora lobjaensis* Tolm., *Tumarinia orientalis* Grig., *Olgerdia zavodovskyi* Grig., and *O. ganelini* Grig. Coexisting foraminifers are represented by *Cornuspira* sp., *Nodosaria* cf. *permiana* Tscherd., *N.* ex gr. *noinskyi* Tscherd., *Dentalina* sp., *Lingulonodosaria* sp., *Ammovertella* sp., *Trepeilopsis* aff. *australiensis* Crespin, *Calcitornella stephensis* Howch., *Frondicularia prima* Gerke, and *Glomospira* ex gr. *gordialis* Par. et Jan.

Brachiopods *Terrakea belochini* Gan., *T. korkodonensis* (Lich.), *Megousia yakutica* (Lich.), and *Tumarinia orientalis* Grig. are characteristic forms of the *Terrakea korkodonensis* Zone of the Kolyma–Omolon massif (Ganelin, 1990). *Olgerdia zavodovskyi* Grig. and *O. ganelini* Grig. characterize upper beds of the Omolon Horizon of that massif (Ganelin, 1990; Abramov and Grigor'eva, 1988) and the Nyunegi Horizon (Solomina, 1997). *Waagenoconcha wimani* (Fred.) is reported from the *Megousia kuliki* Zone (equivalent to the Kungurian deposits) of the Kolyma–Omolon massif (Ganelin, 1990). This species and *Anidanthus ussuricus* (Fred.) are included in the list of fossils from the *Timorites* Beds of the Midian Stage (Kotlyar *et al.*, 1997), which correspond to the *Cancrinelloides curva*-

Table 2. Biostratigraphy of the Lower-Upper Permian boundary deposits in the western and northern Verkhoyansk areas

Uralian scale		Verkhoyansk regional scale			Correlation of sections			Adjacent region	
					Western Verkhoyansk area		Northern Verkhoyansk area	The Kolyma–Omolon massif (Ganelin, 1984, 1990)	
					The Baraiy Zone	The Eastern Kuranakh Zone	The Eastern Kharaulakh Zone		
Stage	Horizon	Horizon	Subhorizon	Zone	The Baraiy R.	The Delenzha and Tumara R.			
Tatarian	Urzhum	Dulgalakh	Lower Dulgalakh	*Cancrinelloides obrutshevi*	Mol Fm.	Lower Dulgalakh Subfm.	Upper Chabardak Subfm.		*Cancrinelloides obrutshevi*
Kazanian		Delenzha	Upper Delenzha	*Olgerdia zavodovskyi*	Nyunegi Fm.	Upper Delenzha Subfm.	Lower Chabardak Subfm.		*Magadania bajkurica*
							Boguchan Fm.		
			Lower Delenzha		Mugochan Fm.	Lower Delenzha Subfm.	Makhchar Fm.		*Ter. korkodonensis-Omolonia snjatkovi*
Ufimian	Sheshma			*Mongolosia russiensis Daubichites-Sverdrupites harkeri*					*Mongolosia russiensis*
	Solikamsk	Tumara	Upper Tumara	*Kolymaella ogonerensis Tumaroceras kashirzevi*		Upper Tumara Subfm.	Meichan Fm.	Dzhigdala Horizon	*Kolymaella ogonerensis*
Kungurian	Iren'			*Megousia kuliki-Neouddenites-Tumaroceras yakutorum*	Sebinekchan Fm.		Khaldzha Fm. (upper part)		*Megousia kuliki*
	Fillipovka				Tigechan Fm.				

tus Beds of boreal regions. According to the general composition of the brachiopod assemblage, the deposits in question can be attributed to stratigraphic analogues of the Ufimian Stage (e.g., to the Lower Delenzha Subhorizon).

The lower boundary of the Nyunegi Formation is drawn at the base of the lowest thick sandstone interbed. The formation is predominantly composed of coastal-marine sandstone members, which are 3 to 20 m thick and reveal ripple marks. The intercalated siltstone interbeds of approximately the same thickness represents elementary cyclites of regressive phases. The deposits are heavily bioturbated and frequently show structures of gravitational sliding. The formation is 532 m thick.

The bivalve assemblage consists of *Atomodesma permica* (Newell.), *A. lenaensis* (Voron.), *A. licharewi* Mur., *Kolymia inoceramiformis* Lich., *Trabeculatia* cf. *quadrata* (Lutk. et Lob.), and *Intomodesma* cf. *pterinaeformis* (Popow). These species characterize the Dzhigdala–Omolon phase of bivalve evolution, whereas *T. quadrata* (Lutk. et Lob.) and *I. pterinaeformis* (Popow) are peculiar of the second half of that phase (Astaf'eva, 1998).

A clay interbed of the upper part of the formation (avandelta facies) yielded floral remains, such as *Phyllotheca turnaensis* Gorel., *Paracalamites angustus* Such., *Koretrophyllites minutus* Radcz., *Rufloria brevifolia* (Gorel.) S. Meyen, *Crassinervia tenera* Gorel., *Cr. minima* Such., *Lepeophyllum acutangulum* Such., *Nephropsis tomiensis* Zal., *Cladostrobus lutuginii* Zal., *Samaropsis irregularis* Neub., and *S. kurejkaensis* Such. According to Gorelova, this flora is typical of the Kuznetsk time in the synonymous coalfield.

We found no brachiopods in the formation. Solomina (see in Abramov *et al.*, 1973) discovered *Cancrinelloides obrutshevi* (Lich.) that was reclassified afterward into *Cancrinelloides juregensis* Sol. (Solomina, 1997) found 100 m below the top of the formation stratotype. *Rhynchopora lobjaensis* Tolm. and abundant *Licharewia* cf. *stuckenbergi* (Netsch.) were encountered at the level of 100 m above the base of the Nyunegi Formation parastratotype (Abramov *et al.*, 1973). In her scheme, Solomina (1997) most likely indicated the last species as *Olgerdia zavodovskyi* (Gan.) and *Strophalosia sibirica* Lich. as *Strophalosia tolli* (Fred.). Abramov and Grigor'eva (1988) detected *Rhynchopora lobjaensis* Tolm. and *Tumarinia barajensis* Sol. in the lowermost beds of the formation. In their opinion, the latter also occurs in the middle part of the underlying Mugochan Formation. We deliberately cite all the brachiopod occurrences in the Mugochan and Nyunegi stratotypes and parastratotypes, as they are reported by Solomina (1997) and also by Abramov and Grigor'eva (1988) despite the essentially different conclusions the authors arrived at. In both works, the Mugochan and Nyunegi formations are attributed to the Omolon Horizon of the Kolyma–Omolon massif, but the suggested correlation of regional horizons in the stratotype area differs substantially, as is noted above.

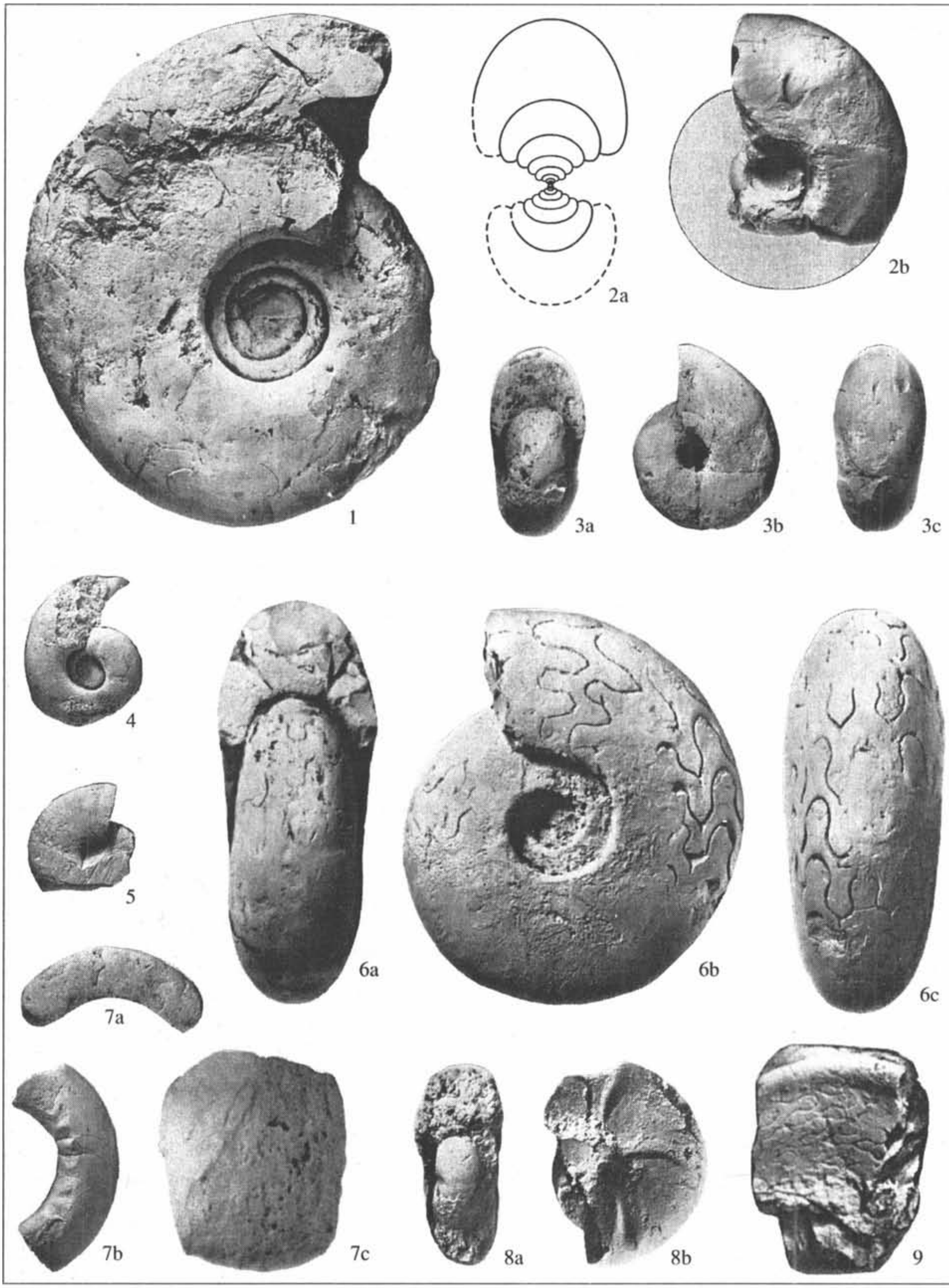
Dulgalakh Horizon, Lower Dulgalakh Subhorizon

***Cancrinelloides obrutshevi* Zone.** corresponds to Beds 89–97 of the section (the Mol Formation). The formation is composed of inequigranular siltstones forming elementary cyclites (rhythms) of regressive type (Fig. 3). Its lower boundary is drawn at the top of the thick interbed of blocky sandstones. The fine-grained siltstones and mudstones in the upper part of the formation contain angular fragments of clayey limestone, the so-called "ryabchiki" (Grinenko *et al.*, 1997). The formation yielded brachiopods *Cancrinelloides obrutshevi* (Lich.), *C.* aff. *curvatus* (Tolm.), *Stepanoviella* sp., *Strophalosia sibirica* Lich., *Marinurnula* ? aff. *chivatschense* (Zav.), *Crassispirifer* cf. *monumentalis* Abr. et Grig., *Neospirifer paranitiensis* (Zav.), and *N.* aff. *subfasciger* Lich. In association with foraminifers *Hyperammina expansa* (Plummer), *Hyperamminoides* cf. *effectus* Vor., and *Ammodiscus septentrionalis* Gerke. These fossils suggest that their host deposits are coeval to the lower half of the Gizhiga Horizon (the *C. obrutshevi* Zone; Ganelin, 1984, 1990). The synonymous zone of the same scope is included in the scheme of Solomina (1997). Genesis of these deposits widespread in northeastern Russia was a subject of long discussion. We support the opinion that the avalanche sedimentation played a significant role in this case (Grinenko *et al.*, 1997). The viewpoint of Kolyasnikov (1997) who argued for influence of seismic sea waves (tsunami) on sedimentation seems interesting as well. We accept the general opinion on the early Tatarian age of the considered zone (Table 2).

EVENTS

The analysis of cyclic sedimentation and changes in fauna composition at the beginning of different sedimentary cycles allow us to distinguish a series of biotic and abiotic events of different correlation value, which took place during the late Early–early Late Permian in the Verkhoyansk region. The biostratigraphic zones correspond to different phases of the transgressive–regressive cycles. The distinguished events are of the short- and long-term types. The former characterize episodes of replacement of one faunal assemblage by another, changeover time of sedimentation regime, and commencement of particular transgressive–regressive cycles. The long-term events correspond to existence periods of zonal assemblages and to phases of the highest sea level stand. We recognize the following succession of the early to later events:

(1) The *Megousia kuliki* phase that coincides with the low-order transgressive–regressive cycle against the background regression of the Late Tumara sea; the phase was long, and its beginning and termination remain obscure.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7c
8a
8b
9

Plate I. Ammonoids.

(1) *Daubichites goochi* (Teichert); specimen no. 55/261, ×0.4; upper reaches of the Baraiy River (the left slope, 1.5–1.8 km upstream the Creek Imtân'ya mouth); the lower part of the Lower Delenzha Subformation; collection of Andrianov, sample 11-1966.

(2, 4) *Pseudosverdrupites budnikovi* Kutygin: (2) holotype no. 16/173, (4) specimen no. 13/173, ×1.2; the upper reaches of the Baraiy River, the Creek Ammonitovyi, 420 m upstream the mouth (right side); Mugochan Formation (Bed 54 in Fig. 3); collection of Budnikov and others, samples 1 and 82(92)-61-1992.

(3, 6) *Sverdrupites harkeri* (Ruzhencev): (3) specimen 5/173; upper reaches of the Baraiy River, the Creek Ammonitovyi, 420 m upstream of the mouth (right side); Mugochan Formation (Bed 54 in Fig. 3); collection of Budnikov and others, sample 1i/82(92)-61-1992, (6) specimen 55/262, ×0.5; upper reaches of the Baraiy River (left slope, 1.5–1.8 km upstream of the Creek Imtan'ya); the lower part of the Lower Delenzha Subformation; collection of Andrianov, sample 11-1966.

(5) *Sverdrupites baraiensis* Kutygin; holotype no. 23/173; upper reaches of the Baraiy River, the Creek Ammonitovyi, about 1 km upstream the mouth (left side); Mugochan Formation (Bed 55 in Fig. 3); collections of Kutygin, sample 5/1-1992.

(7) *Baraioceras stepanovi* Andrianov; holotype no. 55/29, ×0.55; upper reaches of the Baraiy River, the Imtan'ya River (lower course); alluvium in the area of the Tumara Formation, upper subformation; collection of Andrianov and Shtekh, sample 506/11a-1963.

(8) *Popanoceras subtumarense* Andrianov; holotype no. 55/574, ×2.3; upper reaches of the Baraiy River (the Creek Bezymyannyi mouth), the lower part of the Lower Delenzha Subformation; collections of Andrianov and others, sample 506-1972.

(9) *Neouddenites andrianovi* Ruzhencev; specimen no. 55/25; upper reaches of the Baraiy River, the left tributary upstream the Kommunar Settlement; Echa Formation; collection of Andrianov and others, sample 504/1-1963, Early Permian, Artinskian–Kungurian.

(2) The beginning of the Mugochan sea transgression; the event was distinct, though recorded not everywhere because of local peculiarities. The aforementioned problem of transitional beds between the Tumara and Delenzha formations is related.

(3) The *Kolymaella ogonerensis* phase that marks the beginning of the next transgression; the corresponding transgressive–regressive cycle includes three phases: the beginning of transgression, the period of highest sea level stand, and regression phase. The faunal assemblage is closely interrelated with the previous one, but signifies the commencement of a new cycle.

(4) The first occurrence of brachiopods of the *Mongolosia russiensis* Zone and Roadian ammonoid assemblage.

(5) The *Mongolosia russiensis* phase that coincides with the phase of the highest sea level stand; sediments of the phase contain abundant marine fossils (the Roadian ammonoids included) thus being of the highest correlation potential (Kutygin, 1996; Kotlyar, 1997; Nassichuk, 1995).

(6) The *Cancrinelloides obrutshevi* phase; like the previous one, it coincides with the highest sea level stand during the subsequent transgressive-regressive cycle of the highest order.

Plate II. Brachiopods

(1, 2) *Tumarinia barajensis* Sol.: (1) ventral valve, ×1, the Nadi River; Sibenekchan Formation, Bed 20 in Fig. 3 (sample 2i/92-39, 1612 m), (2) ventral valve, view from the area, ×1, the Nadi River; Sibenekchan Formation, Bed 20 in Fig. 3 (Sample 2i/92-39, 1660 m); herein and after: collections of Budnikov and others, 1992–1993.

(3) *Alispiriferella gydanensis* (Zav.); ventral valve, ×1.2, the Nadi River; Tigechan Formation, Bed 14 in Fig. 3 (Sample 2i/92-39, 1312 m).

(4) *Megousia yakutica* (Lich.); cast of the ventral valve, ×1, the Baraiy River; Mugochan Formation, Bed 58 in Fig. 3 (Sample 1i/92-56, 2352 m).

(5, 6) *Megousia kuliki* (Fred.): (5) ventral valve, ×1.25, the Nadi River; Sibenekchan Formation, Bed 20 in Fig. 3 (Sample 2i/92-39, 1612 m); (6) ventral valve, ×1, the Nadi River; Sibenekchan Formation, Bed 20 in Fig. 3 (Sample 2i/92-39, 1612 m).

(7) *Olgerdia zavodovskyi* Grig.: the shell cast, ×1, ventral view (7a) and dorsal view (7b); the Baraiy River; Mugochan Formation, Bed 62 in Fig. 3 (Sample 1i/92-51, 2104 m).

(8) *Mongolosia russiensis* (Zav.); interior of the dorsal valve, ×1; the Baraiy River; Mugochan Formation, Bed 48 in Fig. 3 (Sample 1i/92-70, 2661 m).

(9) *Yakovlevia mammatiformis* (Fred.); cast of the ventral valve, ×1; the Baraiy River; Mugochan Formation, Bed 58 in Fig. 3 (Sample 1i/92-56, 2352 m).

(10, 11) *Terrakea korkodonensis* (Lich. in Kasch.): (10) imprint of the dorsal valve, ×1, (11) imprint of the ventral valve, ×1; the Baraiy River; Mugochan Formation, Bed 58 in Fig. 3 (Sample 1i/92-56, 2352 m).

(12) *Terrakea* cf. *belokhini* Gan.; cast of the ventral valve, ×1; the Baraiy River; Mugochan Formation, Bed 58 in Fig. 3 (Sample 1i/92-56, 2352 m).

(13, 14) *Pterospirifer* aff. *alatus* (Schloth.); casts of the ventral valves, ×1; the Baraiy River, Mugochan Formation, Bed 48 in Fig. 3 (Sample 1i/92-70, 2661 m).

(15) *Spitzbergenia gracilis* Kotljar; shell, ×1; the Baraiy River; Mugochan Formation, Bed 48 in Fig. 3 (Sample 1i/92-70, 2661 m).

(16, 17) *Cancrinelloides obrutshevi* (Lich.): shell cast, view from the ventral valve, ×1.4 (16a) and from the dorsal valve, ×1 (16b); the Baraiy River, Mol Formation, Bed 91 in Fig. 3 (Sample 1i/92-15, 1060 m); (17) ventral valve, ×1; the Baraiy River, Mol Formation, Bed 96 in Fig. 3 (Sample 1i/92-10, 540 m).

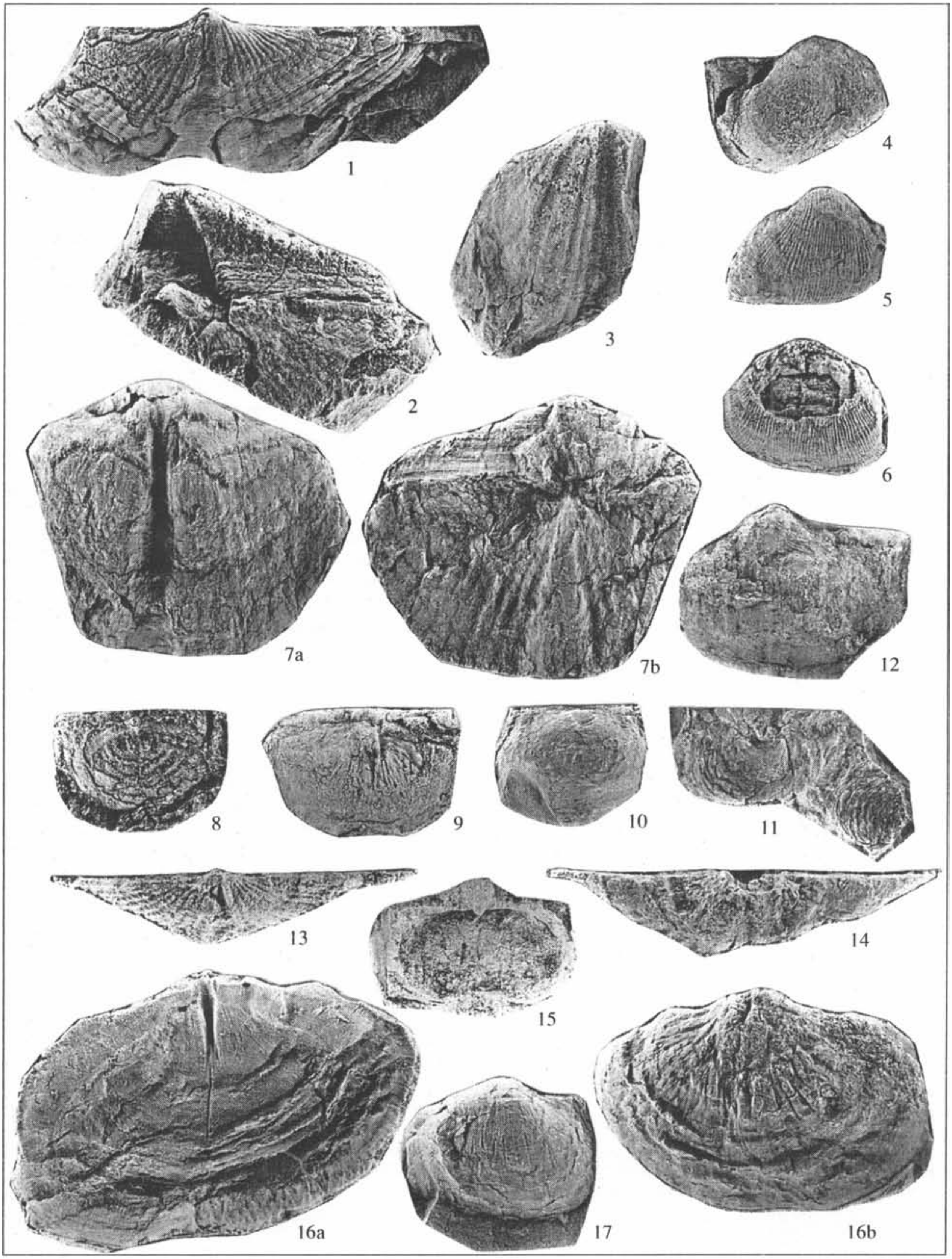
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Table 3. Correlation of stratigraphic subdivisions of the western Verkhoyansk region with those accepted in Russia and suggested by the International Commission on Stratigraphy

Stage	Ubhorizon	Zone	Series
Ufimian	Lower Delenzha	*Mongolosia russiensis*	Guadalupian
		Spitsbergenia ogonerensis	Cisuralian
Kungurian	Upper Tumara	*Megousia kuliki*	

CONCLUSIONS

The analysis of geological records outlining the short- and long-term biotic and abiotic events lead to definite conclusions. The most significant short-time event is marked by appearance of brachiopods of the *M. russiensis* Zone and coeval ammonoid assemblage (point 4 above). The event is correlative with the early Roadian of the North American scale and with the boundary between the Solikamsk and Sheshma horizons of the Uralian scale.

According to resolutions of the Interdepartmental Stratigraphic Committee and Conference on Regional Stratigraphy (*Resheniya...*, 1982), the Lower–Upper Permian boundary is drawn at the base of the Solikamsk Horizon, or inside the Tumara Horizon (point no. 2 above) at the last occurrence level of the *Megousia kuliki* zonal assemblage, or at the base of the *Kolymaella ogonerensis* Zone that yields the *Tumaroceras kashirzevi* Andr. ammonoid assemblage.

Thus, we distinguished the following faunal succession in the Lower–Upper Permian boundary deposits of the Baraiy River section: *Megousia kuliki–Kolymaella ogonerensis–Mongolosia russiensis* (Table 3). The first species is associated with goniatite *Tumaroceras yakutorum* and brachiopods of the *Cancrinella coninkiana* group. The second species coexisted with *Tumaroceras kashirzevi* Andr. and, probably, with *Baraioceras stepanovi*. The third one was found together with the *Sverdrupites harkeri* and *Daubichites* assemblages of Roadian ammonoid. Genera *Tumaroceras* and *Epijuresanites* previously considered as endemic were found recently in Kungurian deposits of the Urals, Pai-Khoi and other regions (Chuvashov, 1997; Bogoslovskaya, 1997; Kotlyar, 1997). These finds suggest that the Lower–Upper Permian boundary should be placed inside the upper Tumara Horizon at the level, where the brachiopod assemblage of the *Megousia kuliki* zone is replaced by that of the *Kolymaella ogonerensis* Zone. However, we should admit that the most significant biotic event is recorded in the western Verkhoyansk region at the base of the brachiopod *Mongolosia russiensis* Zone also bearing goniatites. This level corresponds to the boundary between the Cisuralian and Guadalupian series, or between the Kungurian (the Solikamsk Horizon inclusive) and Roadian stages.

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