13th International Symposium on the Ordovician System

ORDOVICIAN OF THE TUNGUS BASIN (Siberian Platform)

Field Excursion Guidebook

A.V. Kanygin, A.V. Dronov, T.V. Gonta, A.V. Timokhin, O.A. Maslova

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FIELD EXCURSION:

22th of July, 2019 – Start of the Excursion from Novosibirsk. Train Novosibirsk-Krasnoyarsk.

23th of July, 2019 – Arrival to Krasnoyarsk, Bus tour of Krasnoyarsk, flight to Bor, helicopter flight to the field camp at Podkamennaya Tunguska River at the mouth of its right tributary Stolbovaya River.

24th of July, 2019 – Middle and Upper Ordovician outcrops of Podkamennaya Tunguska River.

- Stop 1. Outcrop I. Right bank of Podkamennaya Tunguska River between Listvennichnaya and Stolbovaya tributaries.

25th of July, 2019 – Middle and Upper Ordovician outcrops of Stolbovaya River.

- Stop 1. Outcrop II. Left bank of Stolbovaya River 4,5 km upstream from the mouth of Stolbovaya River.

26th of July, 2019 – Middle and Upper Ordovician outcrops of Stolbovaya River.

- Stop 1. Outcrop III. Right bank of Stolbovaya River 9 km upstream from the mouth of Stolbovaya River.
- Stop 2. Outcrop IV. Left bank of Stolbovaya River 12 km upstream from the mouth of Stolbovaya River.

27th of July, 2019 – **The group is divided into two groups.** Middle and Upper Ordovician outcrops upstream of Podkamennaya Tunguska River.

- **The first group.**
- Waterfalls in the Silurian Canyon, 60 km upstream Stolbovaya River.
- **The second group.**
- Stop 1. Outcrop V. Right bank of Podkamennaya Tunguska River 3,5 km upstream of Kuzmovka Village.
- Stop 2. Outcrop VI. Left bank of Podkamennaya Tunguska River 3 km downstream of Kuzmovka village.
- Visit to the Old Believer Village Kochumdek (possibly).

28th of July, 2019 – **The group is divided into two groups.** Middle and Upper Ordovician outcrops upstream of Podkamennaya Tunguska River.

- **The first group.**
- Stop 1. Outcrop V. Right bank of Podkamennaya Tunguska River 3,5 km upstream of Kuzmovka Village.
- Stop 2. Outcrop VI. Left bank of Podkamennaya Tunguska River 3,5 km downstream of Kuzmovka Village.
- Visit to the Old Believer Village Kochumdek (possibly).
- **The second group.**
- Waterfalls in the Silurian Canyon, 60 km upstream Stolbovaya River.

29th of July, 2019 – Middle Ordovician outcrops downstream of Podkamennaya Tunguska.

- Stop 1. Giant *Rusophycus* trace fossils from Baykit Sandstone.
- Stop 2. Baykit Sandstone at the mouth of Gremiachy rivulet.
- Stop 3. Tropical carbonates of Ust'rybnaya Formation (possibly).
- Stop 4. Tour with "Sulomai Pillars".

30th of July, 2019 – Boats trip downstream Podkamennaya Tunguska River from field camp at the mouth of Stolbovaya River to the Bor Village at Yenisei River (200 km). Excursion to the Museum of the Central Siberian State Nature Biosphere Reserve. Flight from Bor to Krasnoyarsk.

CONTENTS

INTRODUCTION

On the territory of Russia there are two separate paleocontinents which are represented by the East European or Russian Platform and by the Siberian Platform (Fig. 1). The two paleocontinents were located far away from each other throughout the Early Paleozoic and this creates an opportunity to test ideas about synchronous eustatic sea-level changes on both of them during the Ordovician. In order to solve this task abundant research and field work on

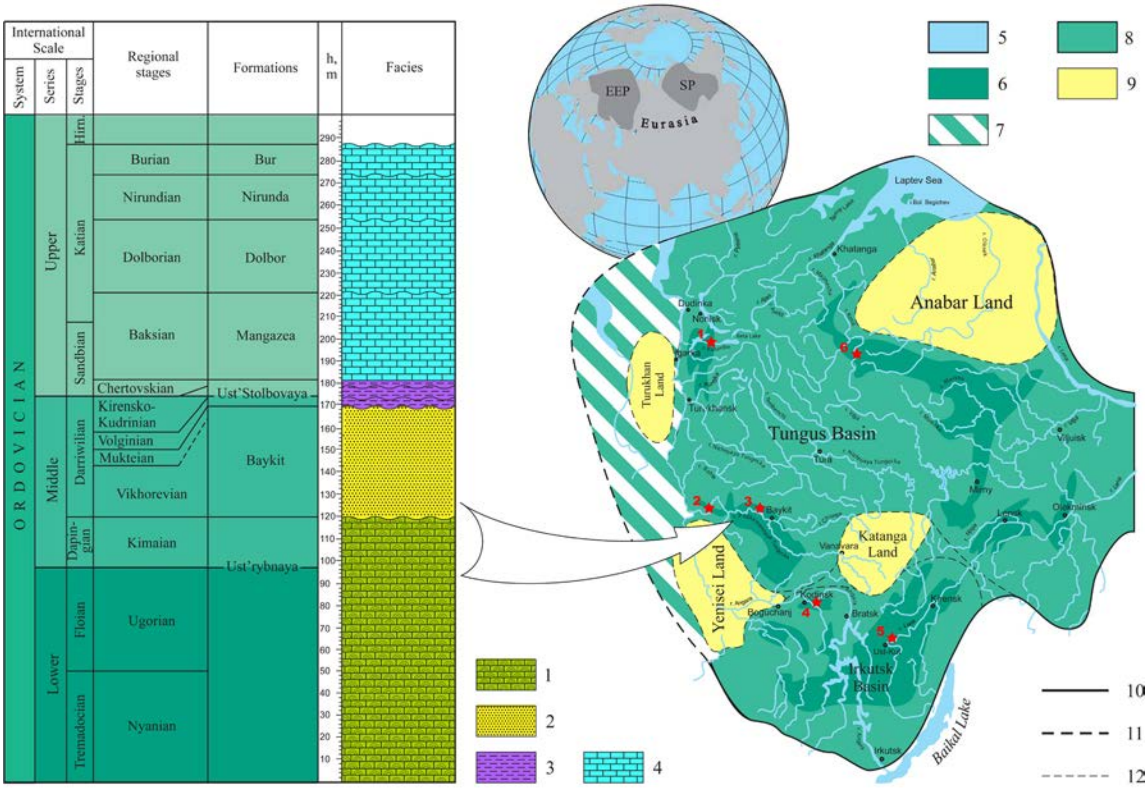


Fig. 1. Distribution of the Ordovician rocks on the Siberian Platform.

Legend: 1. Warm-water carbonates; 2. Quartz sandstone; 3. Variegated (green and red) shale with scattered phosphate pebbles; 4. Cool-water carbonates; 5. Territories covered by waters of seas, lakes and estuaries; 6. Ordovician outcrop areas; 7. Supposed continuation of the Siberian Craton under the Mesozoic cover of the West Siberian basin; 8. Ordovician deposits in the subsurface areas; 9. Land areas without Ordovician deposits; 10. Boundary of the Siberian Craton; 11. Provisional boundaries of the Siberian Craton; 12. Boundaries of the Land areas and sedimentary basins.

EEP – East European (Russian) Platform; SP – Siberian Platform.

Red stars mark position of the main studied Ordovician sections: 1) Kulyumbe River Section; 2) Podkamennaya Tunguska and Stolbovaya River sections; 3) Bolshaya Nirunda River Section; 4) Angara River Section; 5) Lena River Section; 6) Moyero River Section.

the Ordovician rocks of the Siberian Platform have been conducted since 2006 (Dronov et al., 2009; Kanygin et al., 2010a; Kanygin et al., 2010b; Dronov et al., 2011a; Dronov, 2013). One of the surprising results of this work was discovery of widespread cool-water carbonates in the Upper Ordovician of the Tungus basin which seems to be located at the equatorial latitude at that time (Cocks and Torsvik, 2007). The other result was elucidation of the fact that the long-term sedimentological changes in the Ordovician of the Tungus basin on the Siberian Platform reminds us of the contemporaneous evolution of sediments in North American (Laurentia) Platform rather than on the Russian Platform (Baltica) or any other Gondwanan Platform. The discovery of abundant K-bentonite layers in the Upper Ordovician of the Tungus basin only emphasizes this striking similarity (Dronov et al., 2011a).

In order to construct a sequence stratigraphic chart for the Ordovician of the Siberian Platform the key sections of the Tungus and Irkutsk basins have been studied. In the Tungus basin the Kulyumbe River Section in the vicinity of the Turukhan Land, the Moyero River Section in the vicinity of the Anabar Land and the main outcrops in the Podkamennaya Tunguska River valley and its tributaries in the vicinity of the Yenisei Land and the Katanga Land, have been investigated. In the Irkutsk basin the main natural outcrops and quarries near the town of Bratsk, as well as in the Angara River valley, and in the Lena River valley between the towns of Ust'-Kut and Kirensk have been studied (Fig. 1). During the field work particular attention was paid to the recognition, interpretation and correlation of the sequence boundaries. Identification of the systems tracts was not always possible. Amplitudes of regressions and transgressions were estimated based on the depth of erosion of the beds underlying unconformities and on the distribution of relatively deep-water facies.

Precise biostratigraphic correlation of the sequence boundaries between Baltica and Siberia also remains problematic due to the absence of common species in faunal assemblages, but the number of sequences in broader stratigraphic intervals is comparable. This makes it possible to compare a general shape of sea-level curves for the Ordovician of these paleocontinents as well as their long-term lithological evolution and geological history. During the excursion participants will be able to examine Middle and Upper Ordovician succession of the southeastern flank of the Tungus basin.

HISTORICAL BACKGROUND

The first data on the Siberian lower Paleozoic, including the Ordovician, resulted from early geographical expeditions in the middle of the nineteenth century. During the next hundred years the accumulation of information on the lower Paleozoic was slow and irregular, and the data from that period are only of historical interest. Large-scale mapping and drilling projects in the 1950s-1960s stimulated intensive geological and stratigraphic studies in the region and led to a series of monographs on Ordovician stratigraphy and paleontology.

A comprehensive summary of Ordovician paleontology and stratigraphy of the Siberian Platform was published by Nikiforova and Andreeva (1961). It made possible the compilation of the first regional chart for this territory based on the monographic description of brachiopods. It also evaluated the biostratigraphic potential of such benthic groups as tabulate corals, stromatoporoids, crinoids, bryozoans, pelecypods, gastropods, nautiloids, ostracods, trilobites, and some rare exotic fossils. This monograph remains a highly useful synthesis of regional paleontology and biostratigraphy. The most numerous and widely distributed groups were described later. Among these are the bryozoans (Nekhoroshev, 1961), crinoids (Eltysheva, 1960), trilobites (Maksimova, 1962; Rozova, 1968), gastropods (Vostokova, 1962), nautiloids (Balashev, 1962), ostracods (Ivanova, 1959a, 1959b) and graptolites (Obut and Sobolevskaya, 1967; Obut, Sennikov, 1984).). The first conodont studies go back to the mid-1960s (Moskalenko, 1970, 1973; Abaimova, 1975). A summary of the Ordovician stratigraphy and paleontology of the Siberian Platform was published in a book edited by Sokolov and Tesakov (1975).

Since 1972, new integrated studies of the Ordovician of the Siberian Platform were carried out by specialists on paleontology, stratigraphy, and sedimentology from different institutions in Novosibirsk and Saint Petersburg. These studies resulted in a series of monographs and reports (Moskalenko et al., 1978, 1994; Yadrenkina et al., 1978; Kanygin et al., 1980, 1982, 1984a, 1984b, 1988, 1989, 2007; Sennikov, 1996; Tesakov et al., 2003; and others). They contain new data on the stratigraphic distribution of different groups of macro- and microfossils, rare finds of graptolites, and the first information on chitinozoan and acritarch occurrences in the Ordovician of the Siberian Platform. A vast amount of data on Ordovician paleontology, stratigraphy and sedimentology was accumulated from studies of numerous sections that crop out along the rivers and that are known from drill cores.

Since 2006, new studies on the Ordovician sequence stratigraphy (Dronov et al., 2009; Kanygin et al., 2010a,b; Dronov, 2017), trace fossils (Kushlina & Dronov, 2011; Dronov et al., 2016; Dronov & Kushlina, 2018), K-bentonites (Dronov et al., 2011a,b; Huff et al., 2014), isotope stratigraphy (Ainsaar et al., 2015; Pokrovsky et al., 2018) as well as climatic events (Dronov & Zaitsev, 2011; Dronov, 2013) and palaeomagnetism (Pavlov & Gallet, 2005; Shatsillo et al., 2017) were added to traditional biostratigraphy (Kanygin et al., 2007, 2017; Yadrenkina et al., 2010). Provisional correlation of the Siberian regional stages and Global Ordovician stages was published recently (Bergström et al., 2009). However, more extensive and complex multidisciplinary studies are needed for more precise dating and correlation of the regional biostratigraphic and lithological units with global subdivisions.

BASIC REGIONAL DATA

The zoning was based on the typification of sections or the selection of structural-facial zones according to the uniformity of the composing rocks. Each of the zones listed below has its own name, territorial affinity and is characterized by its lithological complex of sediments that meets certain conditions of formation. At present, 14 structural-facial zones are distinguished for the Ordovician deposits on the territory of the Siberian platform (Fig. 2).

Regional stratigraphic scale for the Ordovician of the Siberian Platform (Fig. 2) includes three categories of stratigraphic units: 1) horizons which in stratigraphic range approximately correspond to stages in the International

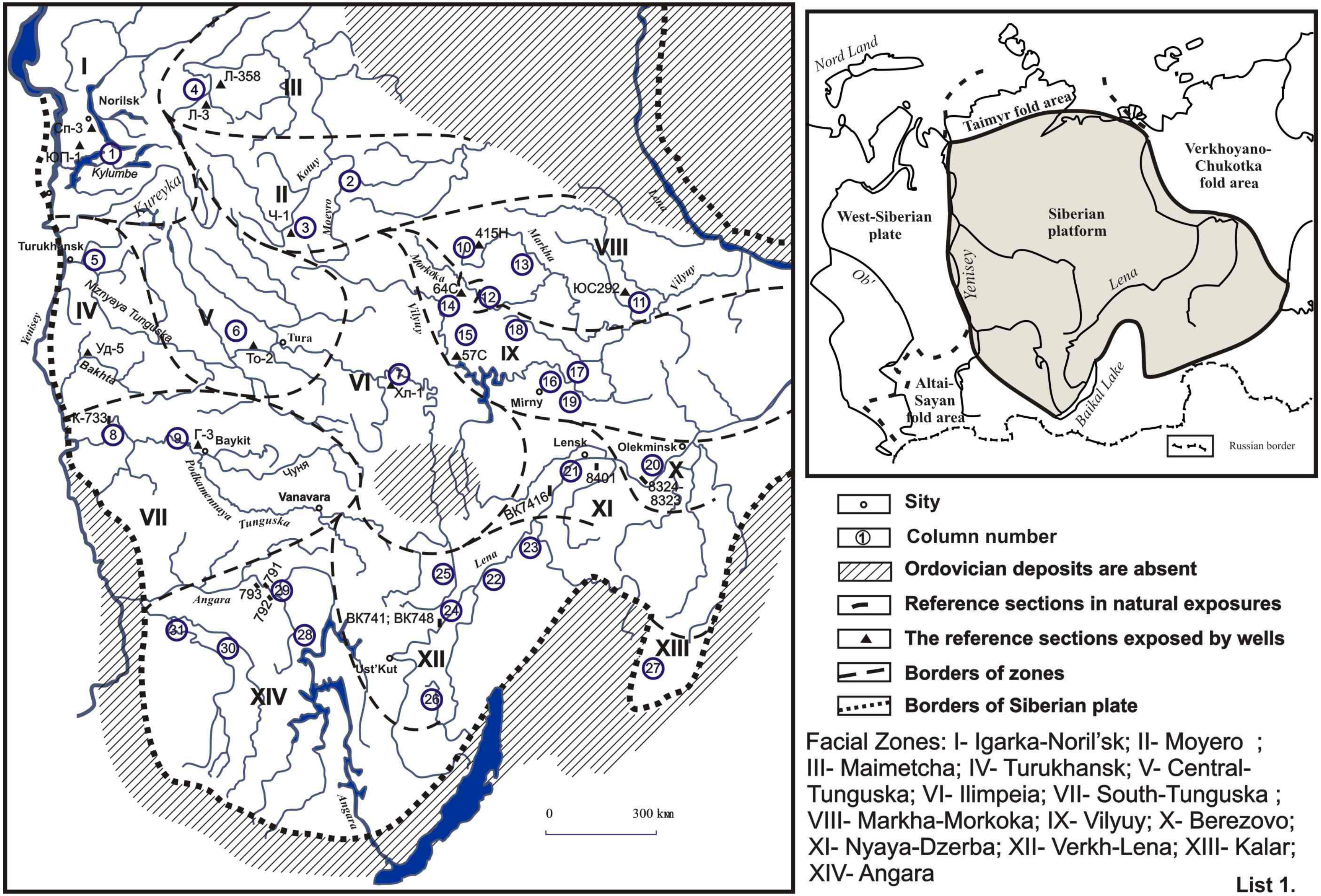


Fig. 2. Regional stratigraphic chart of the Ordovician deposits of the Siberian Platform.
List 1. Scheme of geographic setting of the Ordovician section within facial zones on the Siberian Platform.

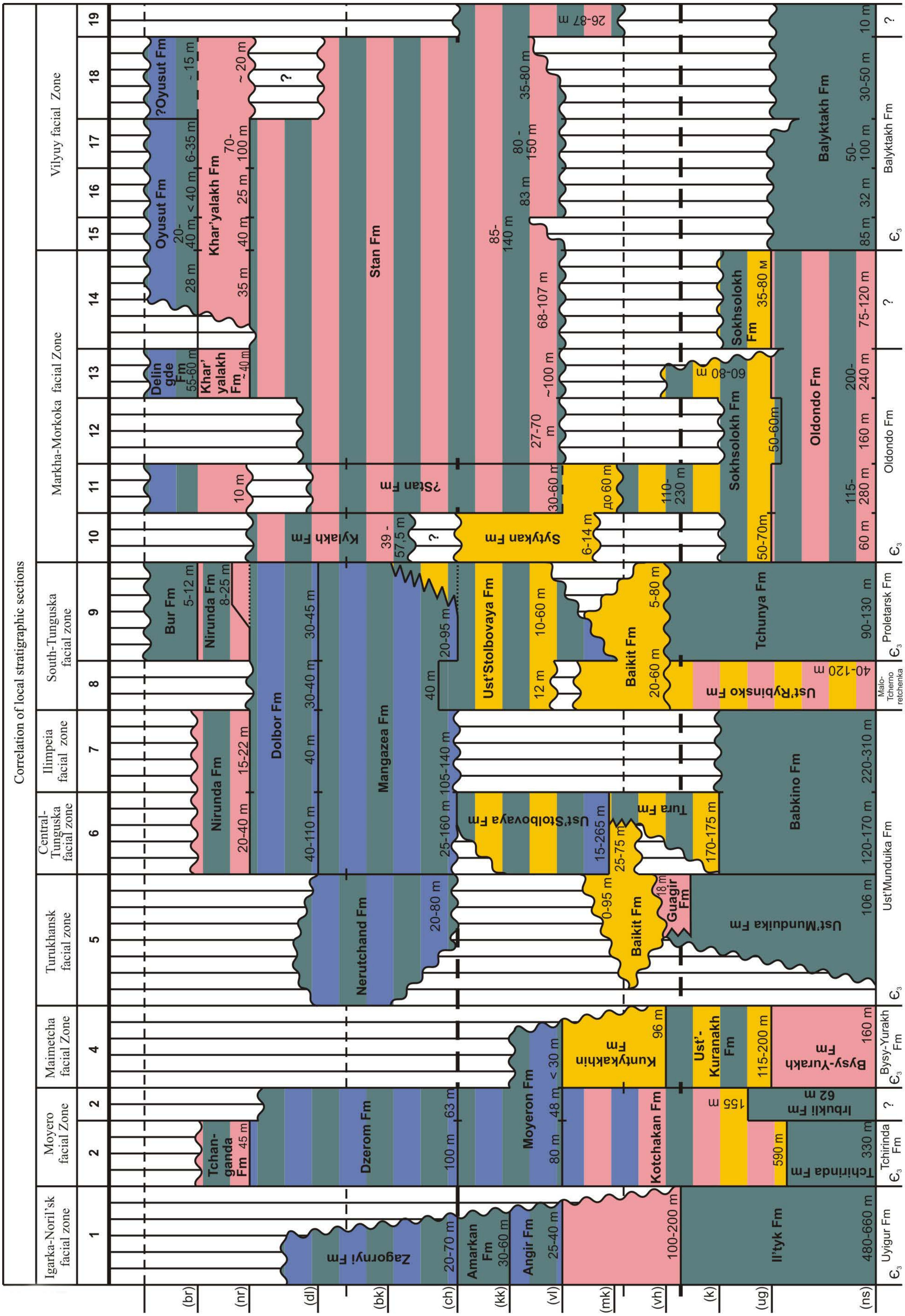
International Stratigraphic scale: System	Series	Stage	AGE (Ma)	Russian Stratigraphic scale: System	Series	Stage
Ordovician	Upper	Hirnantian	445.2	Ordovician	Upper	Ashgillian
		Katian	453.0			Caradoc
		Sandbian	458.4			
	Middle	Darriwilian	467.3		Middle	Llanvirn
		Dapingian	470.0			Arenig
	Lower	Floian	477.7		Lower	
		Tremadocian	485.4			Tremadoc

Horizon	Brachiopods	Trilobites	Ostracods	Conodonts	Graptolite assemlages	Corals	Clams	Gastropods
Burian (br)	Bellimurina sibirica	Bumastus sibiricus		Aphelognathus pyramidalis	Dicellograptus, Glyptograptus, Orthograptus	*Paleofavosites alveolaris* Goldf., *Parasarcinula trabeculata* Sok.et Tes.		
Nirundian (nr)	Evenkorhynchia dichotomians evenkiensis			Acanthodina nobilis	? pacificus			
Dolborian (dl)	Boreadorthis asiatica		Dolborella plana	Ozarkodina dolborica; Acanthocordylodus festus	Glyptograptus siccatus, Oepikograptus bekkeri, Amplexograptus fallax, Glyptograptus euglyphus	*Rhabdotetradium nobile* Sok., *Sibiriolites sibiricum* Sok.		
Baksanian (bk)	Maakina parvuliformis -Leptellina carinata		Parajonesites notabilis	Belodina compressa- Culumbodina mangazeica				
Chertovskian (ch)	Mimella panna	Isalaux stricta	Bodenia aspera	Cahabagnathus sweeti - Phragmodus inflexus				
Kirenskian-Kudrian (kk)	Lenatoechia lenaensis		Quadrilobella recta	Ptiloconus anomalis	Mastigograptus datzenkoi			*Salpingostoma aff. magalostoma* (Eichw.), *Lophospira cf.abnormis* Ulr.et Coop.
Volgian (vl)	Evenkina lenaica - E. anabarensis	Homotellus lenaensis	Soanella maslovi	Phragmodus flexuosus	Orthograptus propinquus	*Billingsaria lepida* Sok., *Lyopora flexibilis Sok. et Tes.*		
Mukteian (mk)	Angarella; Leontiella gloriosa		Cherskiella notanilis - Ventrigyrus intricatus	Cardiodella lyrata - Polyplacoghthus angarense		*Cryptolichenaria miranda* Sok.	*Miagkovia moyeronica* S.Ros.	*Liospira subconcava* Ulr.
Vikhorevian (vh)				Coleodus mirabilis				*Pararaphistoma qualteriatum* (Schl.), *Hormotoma ex.gr. gracilis* Hall.
Kimaian (k)	Nanorthis - Rhyselasma	Biolgina sibirica	Aparhites clivosus	Histiodella angulata				
Ugorian (ug)		Shumardia - Paenebeltella		Scandodus warendensis - Scandodus pseudoquadratus	Rhabdinopora omnutachense			
Nyaian (ns)	Apheorthis melita	Eoapatokephalus - Ijacephalus		Loxodus bransoni - Acodus oneotensis; Cordylodus prolindstromi; Cordylodus casey	Callograptus kravtsovi, Syringotaenia bystrovi			*Tropidodiscus curvilineatus* (Conr.).

Fig. 2. List 2. Correlation of International Stratigraphic scale with the Regional stratigraphic chart. Biostratigraphic zones.

	Paleontological characteristics of regional stratons								
	Typical fauna complexes								
	Monoplakofor	Crustaceans	Problematic	Stenolaemata	Brachiopods	Trilobites	Ostracods	Conodonts	Graptolites
(br)				Rhynidictia morkokensis Nekh., R.altaica Yarosh., Ensipora mirabilis Astr.	Glyptorthis nirundaensis Yadr., G.morkokiana Nikif., Bellimurina sibirica Rozm., Rostricellula burensis Rozm.	Monoracos consimilis Sen., Evenkaspis galeata Kram.	Novoglandites bisulcatus Meln., N.sirotinus Meln., Petalina admiranda Meln.	Aphelognatus pyramidalis (Br., M.et Br.).	Dicellograptus sp., Orthograptus sp., Glyptograptus sp.
(nr)				Homotrypella aperta (Astr.), Ensipora praerecta Astr.	Evenkorhynchia dichotomians evenkiensis Rozm., E. dulkumensis (Rozm.)			Acanthodina nobilis Mosk., A.variabilis Mosk., Scolopodus compositus Mosk.	Paraorthograptus pacificus sibiricus Sen., Glyptograptus sp., Climacograptus sp., Diplograptus sp.
(dl)				Batostoma varians (Yanus), Homotrypella aperta Astr.	Boreadorthis asiatica Nikif., Hesperorthis evenkiensis Nikif., Triplesia dolborica Nikif., Lepidocycloides bajkiticus Nikif., Rostricellula subrostrata Nikif.,	Bumastus sibiricus Z.Max., Stenoporeia avus (Holm.), Carinopyge abscisa Z.Max., Isotelus maximus sibiricus Z.Max. Elasmaspis speciosa Kram.,	Parajoenesites notabilis V.Ivan., Euprimites helenae V.Ivan., Costoprimites textilis V.Ivan., Dolborella bifurcata Meln., D. composita V.Ivan., Planusella bicornis V.Ivan., Aparchitella procera V.Ivan.	Acanthocordylodus festus Mosk., Ozarkodina dolborica (Mosk.).	Glyptograptus siccatus Elles et Wood, Oepikograptus bekkeri (Opik.), Amplexograptus fallax Bulman, Glyptograptus eugliphus (Lapw.)
(bk)				Fimbriapora multifera (Nekh.), F.plebeia (Nekh.), Insignia insignis (Nekh.), Stellipora vesiculosa Modz.	Hesperorthis tricenaria Conr., Maakina parvuliformis Rozm., Leptellina carinata Yadr.	Carinopyge spirifera Bal., Ceraurinus icarus (Bill.) Isotelus maximus sibiricus Z.Max. Monoracos planiusculus Kram.,	Parajonesites notabilis V.Ivan., Costoprimites textilis V.Ivan., C. indiligens V.Ivan., Dolborella composita V.Ivan., D. plana V.Ivan., Euprimites helenae V.Ivan.	Belodina compressa (Br.et M.), B.diminutiva (Br.et M.), Culumbodina mangazeica Mosk.	Oepikograptus bekkeri (Opik)., Glyptograptus siccatus Elles et Wood, Gl. euglyphus (Lapw.), Amplexograptus fallax (Bulman)
(ch)				Nicholsonella petaloides Astr., Virgatella bifoliata Astr., Pachidictya foliata Ulr.	Mimella panna Andr., Atelelasma carinatum (Andr.), Oepikina tojoni Andr., Rostricellula raymondi nana Rozm., Strophomena mangazeica Andr.	Isalaux stricta (Kram.), Monoracos lopatini Schm., Ceratovenkaspis armata Kram. Ceraurinus icarus (Bill.), Isotelus maximus sibiricus Z.Max.	Bodenia aspera V.Ivan., Egorovella captiosa V,Ivan., Coelochilina laccochilinoides V.Ivan.	Cahabagnathus sweeti (Berg.), Phragmodus inflexus Stauf.	
(kk)	Archinacella rotundata Ulr.et Scof.			Stigmatella tungusensis Astr.	Ectenoglossa derupta Yadr., Lenatoechia lenaensis alia Yadr.		Quadrilobella recta V.Ivan., Fidelitella unica V.Ivan., Primitia abundas V.Ivan., P. annae V.Ivan., Schmidtella dorsilobata V.Ivan., Ginella primitiformis V.Ivan.	Ptiloconus anomalis (Mosk.), Bryantodina lenaica Mosk., Microcoelodus tunguskaensis Mosk.	
(vl)				Ceramopora spongiosa Basl., Dianulites petropolitana (Pand.).	Evenkina lenaica (Girar.), E. anabarensis Andr., Atelelasma peregrinum (Andr.), Hesperorthis ignicula (Raym.), Multicostella maaki Andr., Platymena amara (Andr.)	Homotelus lenaensis Z.Max., Calliops armatus Ulr.et Delo, Ceraurinella biformis Z.Max.	Soanella maslovi V.Ivan., Sibiritella costata (V.Ivan.), Egorovella defecta V.Ivan.	Phragmodus flexuosus Mosk.	Orthograptus propinquus (Hadd.).
(mk)	Scenella costata Bjaly		Moyeronia belostozkayae Nikif.et S.Ros.		Leontiella gloriosa Yadr., Angarella mirabilis Yadr.		Cherskiella notabilis Kan., Ventrigurus intricatus Kan.	Cardiodella lyrata Mosk., C.tumida (Br.et M.), Polyplacognathus angarense Mosk.	
(vh)					Angarella bugarictica Yadr., A.mojeronica Yadr.			Coleodus mirabilis Mosk., Neocoleodus dutshtowensis Joung et Cull., Erismodus asymmetricus (Br.et M.).	
(k)	Multifarites lenaense Bjaly	Tolmachovia concentrica Kob.			Nanorthis hamburgensis (Walc.), Rhyselasma mojeroense Yadr., R.akitiense Yadr.	Biolgina sibirica Z.Max.	Primitia distincta Kan., Leperditella insolita Kan.	Glyptoconus quadraplicatus (Br.et M.), Histiodella angulata Mosk., Hirsutodontus mitra (Ab.), Loxodus? asiaticus Ab.	
(ug)	Nyuella incerta S.Ros.				Finkelnburgia convexa Yadr., Angarella? ustini S.Ros.	Nyaya sp.		Scandodus warendensis (Dr. et Jon.), S. pseudoquadratus (Br.et M.), Scolopodus cornutiformis Br.et M., S. ? abberans Mosk.	Rhabdinopora omnutachense Obut et Sob.
(ns)	Kirengella ayaktchica S.Ros.; Pseudoscenella sibirica Bjaly				Apheorthis melita (Hall et Whit.)	Nyaya nyaensis Ros., Eoapatokephalus nyaicus Ros.		Loxodus bransoni Furn., Cordylodus intermedius Furn., C.rotundatus Pand., Acodus oneotensis Furn.; Cordylodus proavus Mul., Hirsutodontus rarus Mil., Oneotodus variabilis Lind., T.nakamurai (Nog.).	Callograptus krawtsovi (Obut et Sob.), Syringotoenia bystrovi Obut

Fig. 2. List 3. Paleontological characteristics of regional stratons.



Correlation of local stratigraphic sections
Igarka-Noril'sk facial zone
Moyero facial Zone
Maimetcha facial Zone
Turukhansk facial zone
Central-Tunguska facial zone
Ilimpeia facial zone
South-Tunguska facial zone
Markha-Morkoka facial Zone
Vilyuy facial Zone
(br)
(nr)
(dl)
(bk)
(ch)
(kk)
(vl)
(mk)
(vh)
(k)
(ug)
(ns)
Zagornyi Fm
Amarkan Fm
Angir Fm
Il'tyk Fm
Uyigur Fm
Tchan-ganda Fm
Dzerom Fm
Moyeron Fm
Kotchakan Fm
Tchirinda Fm
Irbukli Fm
Kuntykakhin Fm
Ust'-Kuranakh Fm
Bysy-Yurakh Fm
Nerutchand Fm
Baikit Fm
Guagir Fm
Ust'Munduika Fm
Nirunda Fm
Dolbor Fm
Mangazea Fm
Ust'Stolbovaya Fm
Tura Fm
Babkino Fm
Bur Fm
Ust'Rybinsko Fm
Malo-Tchernoretchenka Fm
Tchunya Fm
Proletarsk Fm
Kylakh Fm
Sytykan Fm
?Stan Fm
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?Oyusut Fm
Balyktakh Fm

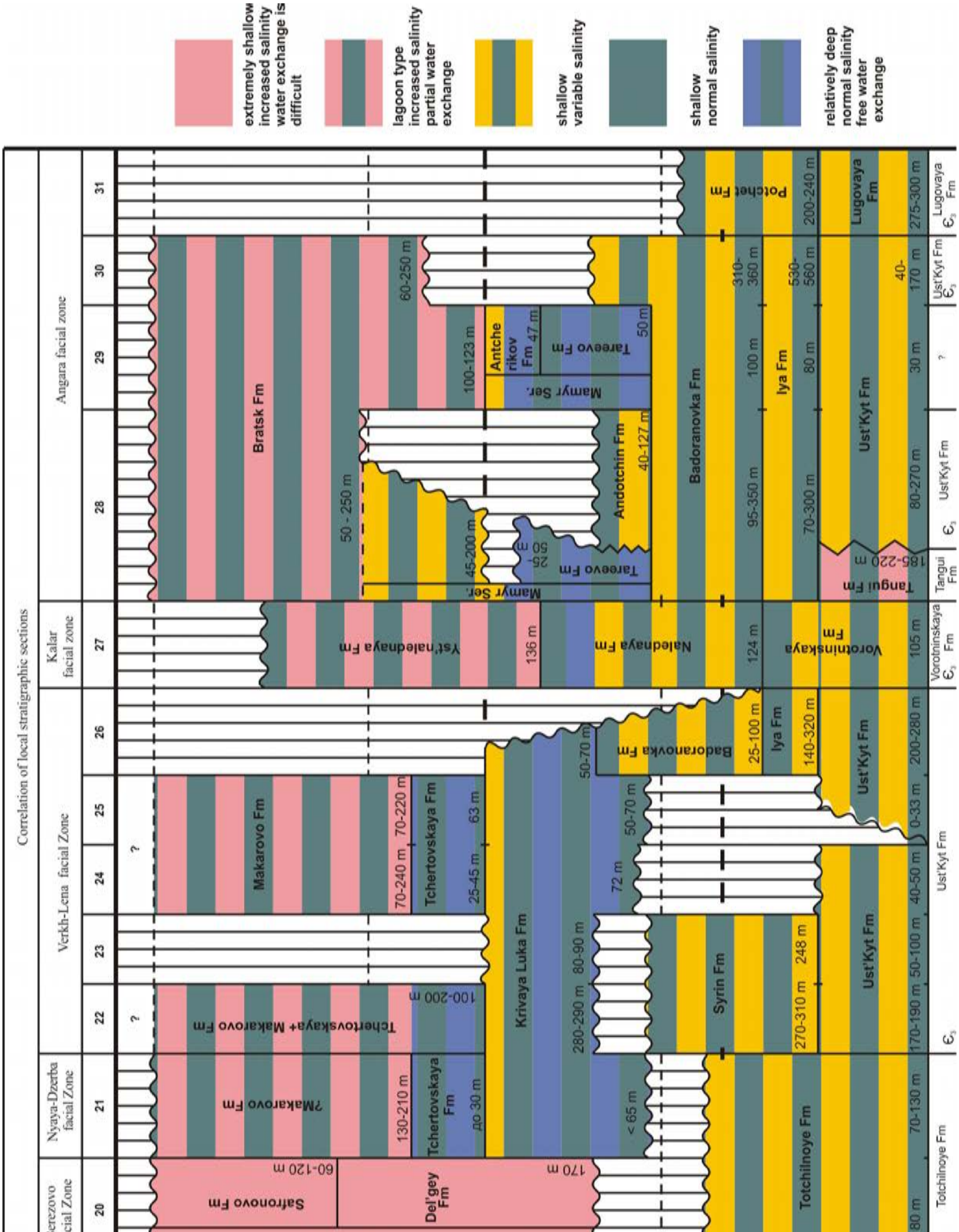

Fig. 2. List 4, 5. Correlation of local stratigraphic sections of different structural-facial zones on the Siberian Platform.

Stratigraphic Scale and may be identified as regional stages; 2) concurrent biostratigraphic zones based on dominant fauna (brachiopods, trilobites, ostracods, conodonts); 3) graptolite beds which appeared to be important datum levels for interregional correlation despite rare occurrence of this group in the sections of the platform. Mentioned groups of fauna are of decisive importance for division and correlation of Ordovician deposits not only on the Siberian Platform but in adjacent regions also, such as Verkhoyano-Chukotka folded area and on Taymyr, which in Ordovician period formed single Kolyma-Siberian biogeographic province (Kanygin et. al., 2017).

Most species and genera of benthic fauna (trilobites, brachiopods, ostracods) are of autochthonous origin, i.e., they are distributed within this province only (with rare exception). Conodont and graptolite assemblages contain more often species and genera of more wide geographic range, particularly in the sections of Verkhoyano-Chukotka folded area. Such cosmopolitan elements of fauna allow several reliable marker levels to be recognized for the intercontinental correlation. Most clear datum level, like in many other regions of the world, corresponds to *Nemagraptus gracilis* Zone that in Siberia coincides with transgression maximum.

In the modern version for the correlation of the Ordovician of the Siberian Platform with the standard units two scales are used: officially adopted International Stratigraphic Scale (ISS) and improved version of British scale, that is used at present in Russia. The relationship between the units of the International, British Stratigraphic Scales and Regional stratigraphic scale of the Siberian Platform is shown in Fig. 2 (Kanygin et al., 2017; Yadrenkina et al., 2010).

Horizon is accepted as the basic regional stratigraphic unit. Ordovician deposits on the Siberian Platform are divided into 12 horizons.

Nyaian Horizon. The stratotype is located in the lower stream of the Kulyumbe River. It is represented by grey, oolitic, stromatolitic, algal limestones, rarely by variegated dolomites and terrigenous rocks. The fauna is represented mainly by brachiopods and trilobites, as well as gastropods, monoplacophors and conodonts.

Ugorian Horizon. The stratotype is located in the lower stream of the Kulyumbe River. It is represented by yellowish-grey clayey and calcareous dolomites with rare interbeds of limestones and marls. Fauna is poor, organic remains are accumulated mainly in upper half of the horizon, where the part of limestones increases. In many places the horizon is arbitrarily established by position in the section. Correlation with Lower Arenigian is also rather conventional.

Kimaian Horizon. The stratotype is also located in the lower stream of the Kulyumbe River. It is represented by series of grey limestones with subordinate interbeds of dolomites and fine-terrigenous varieties. Mass ostracods make their first appearance in upper half. The upper boundary in the stratotype is not clear because of break in exposure, presence of trapp and absence of paleontological remains in overlying rocks. Therefore outcrops in lower part of the Kochakanian Formation in middle stream of the Moyero River is suggested as horizon hypostratotype. They contain fauna assemblage typical of the Kimaian Horizon. Conodonts demonstrate similarity with “D fauna” from North America.

Species *Nanorthis hamburgensis* is encountered in beds with Apheorthis melita in Okhotsk-Omolon zone (Oradovskaya, 1988) and in North America, Goodwin Formation in Nevada State assigned to uppermost strata of Canadian series. The Kimaian Horizon is traceable in most structural-facial zones and aligned with Upper Arenigian.

Vikhorevian Horizon. The stratotype is located in the Angara structural-facial zone in the basin of middle stream of the Angara River, right bank of the Vikhoreva River. It is represented by variegated terrigenous rocks containing peculiar assemblage of organic remains. Horizon boundaries are indistinctly exposed in stratotype area. The section in middle stream of the Moyero River, where these boundaries are clearly seen, is suggested as hypostratotype. The base of the horizon is a clearly marked by conodont succession, defined by the appearance of conodont association known in North America as “Fauna 5”, the age of the latter is determined as Whiterockian. Ostracods *Ventrigyrus intricatus* are of wide occurrence in North-East of Russia in the Elgenchakian Horizon that is considered Llanvirnian.

Mukteian Horizon. The stratotype in middle stream of the Moyero River is represented dominantly by variegated fine-terrigenous rocks rhythmicaly alternating with grey often detrital limestones; small algal bioherms are typical. Boundaries are clearly seen. Despite of certain succession of fauna from preceding horizon many its representatives are characteristic only for this level. Specific fauna assemblage allows the horizon to be well recognized in different parts of the Siberian Platform (Moskalenko, Yadrenkina, 1990). Outline the platform similar conodont assemblage with Cardiodella and Erismoduswas identified from lower part of Middle Ordovician in American Mid-continent, which is assigned to Whiterockian and Chazyan levels. The Mukteian Horizon is aligned with Upper Llanvirnian.

Volgian Horizon. The stratotype is distinguished in the Verkhnelensky structural-facial zone on the Lena River, near Krivaya Luka Village and is well traceable in all facial zones. Rocks are represented by grey and variegated siltstones, mudstones, marls and limestones of lower subformation of the Krivaya Luka Formation; the upper boundary is distinct. The base of the horizon is stressed by clear threshold in development of fauna on the Siberian Platform.

Fauna assemblage of the horizon includes diverse dominantly benthic groups: corals, bryozoans, crinoids are comparatively rare to occur; brachiopods are abundant and widespread; trilobites are more rare; ostracods often form mass accumulations. Conodonts are known from many occurrences; *Phragmodus flexuosus* Mosk. appeared here for the first time becomes dominant species in Volgian conodont assemblage.

Its representatives are known in Middle Ordovician of North America in the composition of “Fauna 6”, that is believed to be Chazyan (Sweet et al., 1971; Sweet, Bergstrom, 1976). A number of ostracod and brachiopod species are known from the Lachugian Horizon of North-Eastern Russia together with graptolites of the *Glyptograptus tereti-usculus* Zone. Thus the Volgian Horizon is assigned to Upper Llanvirnian.

Kirenskian-Kudrian Horizon. The stratotype of lower (Kirensk) part of the horizon is situated near the Krivaya Luka Village; corresponds to the middle part of the Krivaya Luka Formation made up mainly of grey, greenish-grey and brownish-grey siltstones and regular beds with large bun-shaped concretions of limestones and marls associated with the findings of nautiloids and remains of other organisms.

Ostracods and conodonts are the basic groups of fauna. The stratotype of upper (Kudrino) part of the horizon is situated downstream the Lena River, opposite the Kudrino Village; it is represented mainly by variegated and red-colored sandstones of the upper subformation of the Krivaya Luka Formation, by poor lingulids, crustaceans, ostra-cods of the same composition and conodonts. The Kirenskian-Kudrian Horizon is widely represented on the Siberian Platform. Its lower part is well correlated by clear paleontologic characteristics. The upper (Kudrino) part is often defined provisionally (because of poor fauna) by its position in the section. The horizon is conventionally assigned to Upper Llanvirnian.

Chertovskian Horizon. The stratotype is distinguished in the Verkhnelensky structural-facial zone, opposite the Kudrino Village. It is represented at the base by phosphoritic gritstones, overlain by poorly exposed strata of dark-grey mudstones and siltstones and following alternating greenish-grey and brownish-red sandstones, siltstones and grey organic-detrital limestones with greenish or brownish tint. Deposits with Chertovskaya fauna assemblages were recognized in almost all facial zones of the Siberian Platform. The Chertovskian Horizon is one of the most important reference levels. Many elements of its fauna especially brachiopods and ostracods are known in North-East of Russia, where graptolites of *Nemagraptus gracilis* Zone occur together with them. The horizon is aligned with the base of Caradocian, *Nemagraptus gracilis* Zone.

Baksanian Horizon. The stratotype is located in the basin of the Podkamennaya Tunguska River. It is repre-sented by monotonous series of rhythmically alternating green-colored mudstones and grey occasionally lilac-grey organic limestones with abundant and diverse organic remains dominated by bryozoans, crinoids and the representa-tives of mobile benthos.

Thanks to drastic renovation in the composition of all fauna groups, the horizon lower boundary is distinct, while the upper boundary is less distinct. Deposits with rich fauna are developed mainly in western and northern parts of the Siberian Platform. Eastwards they are replaced by red-colored terrigenous rocks with extremely rare organic remains. The Baksanian Horizon is compared with Caradocian (with *foliaceus* and *clingani* zones).

The *Hesperorthis tricenaria, H. australis* and *Glyptorthis pulchra* are known from North America: the former two in deposits of the Wilderness and Trenton stages, the third one in Richmond, Iowa State. The species *Rostricellula transversa* is most developed in lower beds of the Baksanian Horizon and in North America it is described from the lowermost strata of the Wilderness stage, Pooleville Formation in Oklahoma State. Based on the findings of *Oepi-kograptus bekkeri* (Opik), *Glyptograptus siccatus* Elles et Wood, *Glyptograptus euglyphus* (Lapworth), *Amplexograp-tus fallax* Bulman, *Orthograptus* ex gr. *truncatus* (Lapworth), the Baksanian Horizon should be compared with the Caradocian stage (Obut, Sennikov, 1984a).

Dolborian Horizon. Deposits exposed on right bank of the Bol’shaya Nirunda River are considered as strato-type of the Dolborian Horizon. Here within the single section this horizon is exposed in full range, well paleontologi-cally characterized, possessed distinct boundaries. It is represented by grey limestones, marls and siltstones of the Dolbor Formation. The fauna complex is characterized by abundant corals and bryozoans, frequent brachiopods, more rare trilobites, ostracods and conodonts.

The species *G. pulchra* is known in North America, Iowa State (Richmond stage). The Dolborian Horizon con-ventionally by sections in North-East of Russia is aligned with the Upper Caradocian *Pleurograptus linearis* Zone.

Nirundian Horizon. In addition to stratotype section on the right bank of the Bol’shaya Nirunda River (tribu-tary of the Podkamennaya Tunguska River) deposits assigned to the horizon are traceable at the Nizhnyaya Chunku River, in the Gaindinskaya borehole. The horizon in these localities is represented by thin red-colored mudstones of the Nirunda Formation and is poorly paleontologically characterized. In other zones deposits of this level either are absent or not recognizable and are established only by their position in the section. The horizon is provisionally com-pared with the Ashgillian *Dicellograptus complanatus* Zone.

Burian Horizon. This horizon is distinguished at the Bol’shaya Nirunda River and within the basin of the Vilyuy River. In the stratotype it is represented by grey limestones alternating with greenish-grey mudstones and siltstones of the Bur Formation; contains diverse fauna. The range of the Burian Horizon is limited on the plat-form possibly due to washout. Fauna complex of the horizon sharply differs from that of previous horizon. Fauna of the horizon includes corals, bryozoans, nautiloids, brachiopods, trilobites, ostracods, abundant conodonts. The Burian Horizon is aligned with Ashgillian, arbitrarily with the *Dicellograptus anceps* Zone.

OUTLINE OF GEOLOGY AND STRATIGRAPHY

The Siberian paleocontinent, which is represented today in Eurasia by the Siberian Platform, embraced several separate Early Paleozoic sedimentary basins. The Tungus basin represents an extensive intracratonic sedimentary sag basin which occupies the central part of the Siberian Craton (Markov, 1970; Kanygin et al., 2007). The Ordovician of the Tungus basin is subdivided into twelve regional stages based predominantly on trilobites, brachiopods and ostracods. The uppermost (Hirnantian) part of the Ordovician succession on the Siberian Platform is eroded in exposed sections (Kanygin et al., 2007). But that does not exclude the possibility that it exists in the central parts of the Tungus basin and could be reached in future by boreholes. Siberian regional stages allow correlating Ordovician sections in the Tungus basin and all over the Siberian Platform but due to the endemic character of the Siberian fauna precise correlation to the Global chronostratigraphic chart is difficult. Provisional correlation of the Siberian regional stages and Global Ordovician stages was published recently (Bergström et al., 2009).

Actually, for intercontinental biostratigraphic correlation of the Ordovician of Siberian Platform, only four reliable levels exist so far: 1. the base of the Nyaian Regional Stage that correlates to the base of the Ordovician according to recent conodont investigations (Tolmacheva and Abaimova, 2009); 2. the base of the Volginian Regional Stage that correlates to the base of the *Hustedograptus teretiusculus* graptolite Zone; 3. the base of the Chertovskian regional Stage that correlates to the base of the *Nemagraptus gracilis* graptolite Zone and 4. the base of the Silurian. These four stratigraphic levels create three major stratigraphic intervals that can be correlated globally.

The lower boundary of the Ordovician is conventionally placed within the lower part of the *C. linstroemi* Zone in the following succession of species of *Cordylodus* lineage: *C. andresi, C. proavus, C. lindstroemi* and *C. angulatus*. All the representatives of this succession have been found in Siberia. *C. lindstroemi* recently was recovered from sediments of the upper part of the Nyaian regional stage in the Kulyumbe River section on northwestern margin of the Tungus basin (Tolmacheva and Abaimova, 2009). So the base of the Ordovician on the Siberian Platform can be defined at a level no lower than the base of the Nyaian regional stage (Kanygin et al., 2010b).

The base of the Volginian regional stage is the most distinct correlative level within the Middle Ordovician of the Siberian Platform. It corresponds to the base of the Volginian depositional sequence represented on the western margin of the Tungus basin by a prominent transgressive surface (Dronov et al., 2009; Kanygin et al., 2010a). The surface marks the beginning of a transgression that brought significant biotic changes across the Tungus basin. This level is marked by the appearance of numerous new taxa of brachiopods, especially widely used for regional correlation, as well as new taxa of trilobites, crinoids, bryozoans and conodonts. The Volginian and overlying Kirensko-Kudrinian association of brachiopods and ostracods shows close affinities to those of the Lachug regional stage of the Verkhoyano-Chukotka region on the Russian Northeast. Correspondence of this stratigraphic interval with the *Hustedograptus teretiusculus* graptolite Zone of the upper Darriwilian is based on the occurrence of *Hustedograptus* aff. *teretiusculus* (Hisinger) in the shale deposits of the Lachug regional stage in the outcrops along the Kolyma River and its tributaries (Oradovskaya, 1988; Kanygin et al., 2010a).

The base of the Upper Ordovician corresponds with the base of the Chertovskian regional stage and the base of the Mangazea depositional sequence (Dronov et al., 2009; Kanygin et al., 2010a). It coincides with the most distinctive transgression in the Ordovician of Siberia. The lower boundary of the Chertovskian stage is well defined by the appearance of numerous new species of brachiopods and ostracods as well as trilobites and conodonts. In the Verkhoyano-Chukotka region (Kolyma River and its tributaries) this fauna is associated with graptolites of the *Nemagraptus gracilis* Zone. This suggests that the base of the Chertovskian regional stage is close to the Middle/Upper Ordovician boundary.

Precise correlation of the Upper Ordovician Siberian regional stages with the global chronostratigraphic stages is uncertain. But recently found zircon crystals from K-bentonite beds within the upper part of the Baksian regional stage provides a 206Pb/238U age of 450.58±0.27 Ma (Huff et al., 2014). This date confirms the Katian age of the upper part of the Mangazea Formation.

The Ordovician of the Tungus basin consists of two carbonate series of contrasting lithology separated by a unit of quartz sand or quartz sand with siltstones (Fig.1). The most complete section is known from the south-western margin of the Tungus basin (in present day orientation) where the Ordovician is exposed in the natural outcrops along the Podkamennaya Tunguska River and its tributaries and is represented by the following succession of lithostratigraphic units (Fig. 3):

1. The Ust'rybnaya Formation (Nyaian, Ugorian and Kimaian regional stages) is poorly exposed and characterized by contrasting lithology. In the western, most shallow-water part of the basin in the proximity of the Yenisei Land it is represented by coarse grained mainly red colored quartz sandstones intercalated with layers and lenses of conglomerates (quartz gravelstones) and layers of siltstone and limestone. Further to the east it becomes less coarse grained and less siliciclastic with predominantly carbonate sedimentation. Limestones are represented by thick bedded well washed oolitic grainstones with abundant stromatolites, flat-pebbled conglomerates and ripple marks pointing to

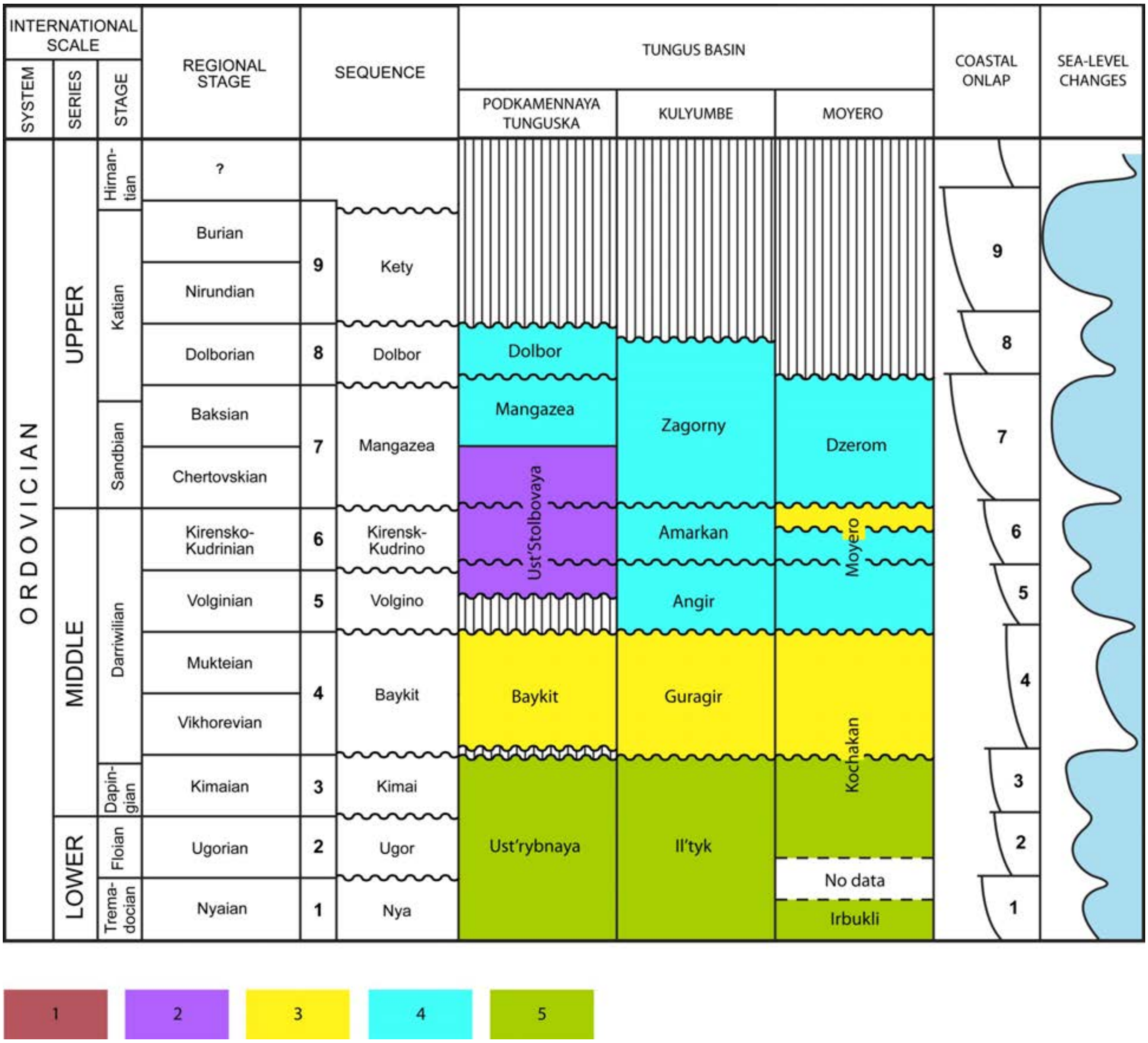

Fig. 3. Stratigraphic chart showing the studied Ordovician successions of the Tungus basin. It also shows depositional sequences, sea-level fluctuations.

Legend: 1. Red siltstones; 2. Variegated siltstones; 3. Quartz sandstones; 4. Cool-water carbonates; 5. Warm-water carbonates.

the shallow-water tropical environment. Dolomitization is widespread. The Ust'rybnaya Formation rests on the Upper Cambrian deposits with a regional unconformity. In the westernmost part of the basin even a low angle angular unconformity is reported (Markov, 1970). The thickness of the formation varies from several meters in the west to 120m in the east. On the north-western margin of the Tungus basin along the Kulyumbe River section this stratigraphic interval is represented by limestones and dolomites of the Il'tyk Formation, about 500 m thick. On the north-eastern margin (Moyero River section) this part of the succession is poorly known. It is represented by the Irbukli Formation (Nyaian regional stage) and the lower part of the Kochakan Formation (Ugorian and Kimaian stages). Both formations consist of oolitic grainstones and dolomites with stromatolites sometimes intercalated with gypsum layers.

2. The Baykit Formation (Vikhorevian and Mukteian regional stages) constitutes a sedimentary body continuing laterally and traceable in the basin of the Podkamennaya Tunguska River at a distance of over 600 km. It is represented by a uniform succession of light-grey and yellowish quartz sandstones 5 to 80 m thick. The sandstones are composed of angular, less commonly well-rounded grains of quartz (up to 80% of the total rock weight) with rare grains of feldspar and tiny fragments of muscovite crystals. The sandstones are often massive or coarse bedded. Several levels display cross-bedded series and sometimes lenses of conglomerate, especially at the base. The inner structure of the Baykit Sandstone is poorly known because of its relatively monotonous composition and poor exposure. The Baykit Sandstone roughly corresponds to the Guragir Formation in the proximity of the Turukhan Land and to the upper part of the Kochakan Formation in the proximity of the Anabar Land (Fig. 2). Both Guragir and the upper part of the

Kochakan formations are represented by intercalations of pure quartz sands and red siltstones, sometimes with abundant pseudomorphic halite crystals. For the upper part of the Kochakan Formation gypsum layers are also typical. The thickness of the siliciclastic units are 200 m for the Guragir Formation and about 60 m for the upper part of the Kochakan Formation.

3. The Ust'stolbovaya Formation corresponds to the Volginian, Kirensko-Kudrian and Chertovskian regional stages. It is represented by a relatively condensed (usually 11–15m) section of red and green argillites with lenses of quartz and phosphate conglomerates at the base and thick (1,5 – 2m) layers of phosphatic conglomerates at the top. The Ust'stolbovaya Formation includes two depositional cycles (sequences) corresponding to the Volginian and Kirensko-Kudrian regional stages, respectively. Deposits of the Chertovskian regional stage are similar to the underlying deposits of the Kirensko-Kudrinian stage and are included into the Ust'stolbovaya Formation, but the sequence boundary coincides with the boundary of Kirensko-Kudrian and Chertovskian stages (Dronov et al., 2009). In the Kulyumbe River section this stratigraphic interval is represented by the Angir Formation (Volginian regional stage, 30m thick) and Amarkan Formation (Kirensko-Kudrinian regional stage, 50m thick) of predominantly grey colored highly bioturbated bioclastic limestone (wackestone). In the Moyero River section it corresponds to the Moyero Formation (about 80 m thick) of predominantly limestone lithology.

4. The Mangazea Formation (Baksian regional stage) is represented by rhythmic intercalations of greenish-grey siltstones and grey micritic (in the lower part) and bioclastic limestones. The bioclasts are mainly represented by fragments of brachiopod shells, trilobite carapaces and bryozoans. Ostracods and crinoids are also numerous. On top of the limestone layers in many cases ripple marks can be observed. Several layers contain glauconite grains. Three K-bentonite layers have been found in the upper part of the Mangazea Formation. They are represented by thin beds (1-2 cm) of soapy light grey or yellowish plastic clays. The beds are different by consistence and color from the enclosing sediments and usually easily identifiable in the outcrops. They were traced over a distance of more than 60 km along the Podkamennaya Tunguska River valley (Dronov et al., 2011b; Huff et al., 2014). The thickness of the Mangazea Formation varies from 40 m in the west to 70 m in the east. In the northern part of the Tungus basin this stratigraphic interval is represented by the Zagorny Formation (about 70 m thick) in the Kulyumbe River section and the Dzherom Formation (about 100 m thick) in the Moyero River section. Both formations share similar lithological characteristics to the Mangazea formation. However bentonite layers are typical only for the south-western margin of the Tungus basin.

5. The Dolbor Formation roughly corresponds to the Dolbor regional stage (Dronov et al., 2009; Kanygin at al., 2010a). The Dolbor Formation is represented by yellowish-grey fine-grained sandstones and siltstones, sometimes with carbonate cement. In the western section the base of the Formation is a sequence boundary with traces of erosion and a visible change in sedimentation. A series of bioclastic limestones interbedded with greenish-grey siltstones, typical for the Mangazea Formation, is overlain by a series of mainly sandy and siltstone beds with scattered bioclasts and sporadic bioclastic limestone layers. In the eastern sections the Dolbor Formation contains more greenish-grey siltstones with intercalations of thin (0,5 – 2cm) limestone layers. The tabulate corals, stromatoporoids and lenses of cherts are typical for the Dolbor formation in the east. Like the underlying Mangazea Formation it contains numerous K-bentonite beds. The thickness of the Formation is up to 75 m. In the northern part of the Tungus basin, this part of the Ordovician succession is completely removed by erosion.

6. The Nirunda Formation corresponds to the Nirunda regional stage. It is only fragmentarily exposed in natural outcrops along the Bolshaya Nirunda River and is represented mainly by cherry-red and greenish-grey siltstones with greenish-grey thin laminated bioclastic limestone layers at some levels. The macro-fauna is dominated by bryozoans and brachiopods and the thickness of the Formation is about 20 m.

7. The Bur Formation coincides with the Bur regional stage and is represented by the intercalation of greenish-grey siltstones and grey bioclastic limestone beds. An abundance of big (up to 20-30 cm in diameter) tabulate coral colonies is typical for the Bur Formation. Some of the colonies are overturned and obviously affected by storms, while the others are in the natural position. Some of the outcrops (Yuktali River section, the tributary of the Bolshaya Nirunda River) contain K-bentonite layers. The top of the Bur Formation is a regional unconformity and it is directly overlain by Silurian deposits. The thickness of the Formation is about 10–12 m.

During the Cambrian, Ordovician and Silurian times the Siberian Platform, which constitutes the core of the Siberian paleocontinent, was located in the low latitude tropical area (Fig.4) migrating slowly from the southern hemisphere in the Cambrian and Lower Ordovician to the northern hemisphere in the Upper Ordovician and Silurian (Cocks and Torsvik, 2007).

SEQUENCE STRATIGRAPHY

Based mainly on outcrop data, nine depositional sequences bounded by regional unconformities or their correlative conformities have been distinguished in the Ordovician of the Siberian Platform (Dronov et al., 2009; Kanygin

Fig. 4. Palaeogeographical reconstruction for the Late Ordovician showing distribution of cool-water carbonates, position of supposed Taconic-Yenisei Arc and possible cool-water currents and upwelling (based on Cocks and Torsvik, 2007, 2011; Harper et al., 2009; Cherns and Wheeley, 2009, with modifications).

et al., 2010). The sequences correspond to sea level fluctuations of the third order (according to Vail et al., 1977) and have an average duration between 1 and 10 myr. For the purpose of convenience, individual names derived from the names of regional stages, series and formations have been given to them. From the base upwards these are: (1) Nya; (2) Ugor; (3) Kimai; (4) Baykit; (5) Volgino; (6) Kirensk-Kudrino; (7) Mangazea; (8) Dolbor; and (9) Kety sequences (Dronov et al., 2009; Kanygin et al., 2010a), (Fig. 5).

The Nya Sequence

There are no apparent signs of significant erosion near the Cambrian-Ordovician boundary on the Siberian Platform in contrast to the Russian Platform where an erosional unconformity is well displayed (Dronov, 2017). In the Kulyumbe River valley the Upper Cambrian–Lower Ordovician interval is represented by a 50–70 m thick unit of limestone and dolomite with abundant stromatolites, oolitic grainstones, and flat-pebbled conglomerates formed on a tropical shallow-water carbonate platform (Il'tyk Formation). Some transgressive-regressive cycles can be recognized within this unit but no significant gaps have been recorded. The position of the Cambrian-Ordovician boundary on the Siberian Craton has long been a matter of discussion. Based on the first appearance of dendroid graptolites in the Loparian Regional Stage, the boundary has been drawn at the base of the underlying Mansian Regional Stage where distinct lithological changes and traces of erosion occur (Kanygin et al., 1982; 2006). However, recent data on the distribution of conodonts of the *Cordylodus* lineage indicate a considerably higher position for the boundary, approximately near the base of the Nyaian Regional Stage (Tolmacheva & Abaimova, 2009). The Nyaian Regional Stage has always been interpreted as a separate phase in the evolution of biota on the Siberian Platform (Kanygin et al., 2006). Most likely it also represents a separate depositional sequence. Knowledge of the internal structure of this sequence, however, requires further investigation. The Nya Sequence correlates approximately with the Pakerort and the Lower Latorp Sequences of the Russian Platform.

The Ugor Sequence

The Ugor depositional sequence corresponds to the Ugorian Regional Stage. Its lower boundary is best exposed in the Irkutsk basin, where it is represented by a regional unconformity separating the Ust'kut and Iya formations.

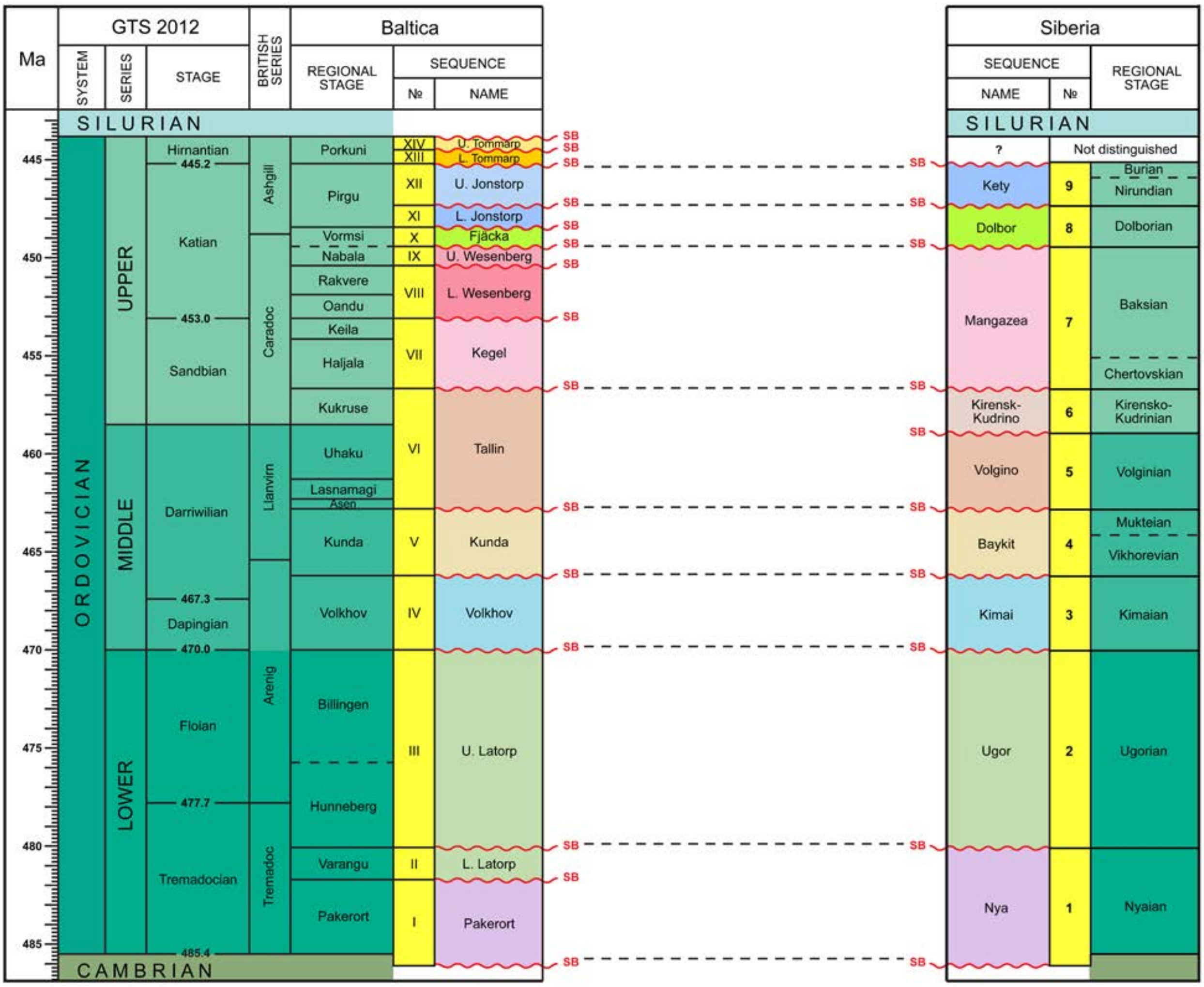

Fig. 5. Comparison the Ordovician sequence stratigraphic charts of Baltica and Siberia.

The surface is well exposed at the Angara River valley, 25 km upstream of the Kodinsk town (Dronov, 2017). It is interpreted as a Type I sequence boundary and marks a shift from predominantly carbonate to siliciclastic sedimentation. The shift was probably caused by a rapid sea level fall, which resulted in subaerial exposure and karstification of a tropical carbonate platform. A subsequent rapid sea level rise was followed by deposition of coarse-grained and cross-bedded quartz sandstone of the Iya Formation.

In the northwestern part of the Tungus basin (the Kulyumbe River Section) the Ugor Sequence has indistinct boundaries. The Ugor Regional Stage deposits correspond to the middle part of the Il'tyk Formation and lithologically they are very similar to the underlying Nyaian Regional Stage and the overlying Kimaian Regional Stage deposits of the same formation. The Ugorian deposits are represented here by yellowish-grey, locally clay-rich dolomites and marls with rare intercalations of grey oolitic grainstones and marls. The Ugor Sequence correlates approximately with the Upper Latorp Sequence of the Russian Platform.

The Kimai Sequence

The Kimai depositional sequence coincides with the Kimai Regional Stage. In the Angara River valley the base of the stage corresponds to the boundary between the Iya and Badaranovo formations. The sequence boundary coincides with a transgressive erosional surface at the base of a 0.6–1,5 m thick unit of glauconite-enriched sandstone with interbeds of bioclastic, glauconitic limestone and pebbly limestone conglomerate. The underlying Iya Formation and overlying Badaranovo Formation are represented by similar pure quartz sandstones with well developed unidirectional cross stratification. The glauconite-rich unit is interpreted as a condensed section representing the upper part of the transgressive systems tracts (Van Wagoner et al., 1988; Loutit et al., 1988; Schutter, 1996). The glauconite-rich deposits were formed during rapid sea level rise, when siliciclastic supply from the adjacent land area ceased and sedimentation rate was very slow. The overlying cross-bedded quartz sandstones of the Badaranovo Formation are considered to be deposits of the subsequent highstand systems tract. In most regions of the Siberian Platform the Kimaian deposits mark a transgressive episode (Kanygin et al., 2006), which was favorable for a wide distribution of relatively uniform benthic and pelagic assemblages. The Kimai Sequence can be correlated to the Volkhov Sequence of the Russian Platform. It should be noted that both sequences exhibit a Type II sequence boundary (Dronov & Holmer, 1999) i.e. with no considerable erosion of underlying beds and no signs of subaerial exposure.

The Baykit Sequence

The Baykit depositional sequence corresponds to the Baykit Formation, which includes deposits of the Vikhorevian and Mukteian regional stages. The best outcrops of the formation are located along the Podkamennaya Tunguska River valley, where monotonous light grey and yellowish quartz sandstones, 5 to 80 m thick, are exposed on both sides of the river. The sandstones are coarsely bedded and frequently massive. At certain levels a well developed cross-stratification occurs and locally, especially at the base, conglomerates are typical (Markov, 1970).

The Baykit Sandstone constitutes a distinctive sedimentary body extending for over 600 km along the Podkamennaya Tunguska River valley. The lower boundary of the sequence is poorly exposed in the natural outcrops. Near the village of Sulomai in the vicinity of the Yenisei Land, however, the Baykit Sandstone overlies different Lower Ordovician strata and even Cambrian units with an angular unconformity (Markov, 1970). The monotonous composition of the sporadically exposed Baykit Sandstone prevents identification of systems tracts. The Baykit Sandstone represents a regressive stage in the evolution of the Tunguska basin. It should also be noted that the underlying Kimai depositional sequence is partly eroded almost over the entire Siberian Platform. The Kimaian deposits were completely removed by erosion in the eastern and northeastern parts of the platform (Kanygin et al., 2006). The unconformity at the base of the Baykit depositional sequence probably reflects one of the most significant forced regressions in the Siberian Platform during the Ordovician. The Baykit Sequence roughly correlates with the Kunda Sequence of the Russian Platform.

The Volgino Sequence

The Volgino depositional sequence coincides with the Volginian Regional Stage, whhose deposits constitute a distinct and characteristic transgressive-regressive cycle traceable over the entire Siberian Platform. An erosional unconformity at the base of the sequence is well pronounced in the Podkamennaya Tunguska River valley where it is marked by conglomerates with pebbles of the underlying Baykit Sandstone (Kazarinov et al., 1969; Markov et al., 1971). An erosional surface at the base of the Volgino depositional sequence is very distinct also in the Kulyumbe River section on the northwestern margin of the Tungus basin and in the Moyero River Section on the northeastern margin of the Tungus basin (Dronov, 2017). The lowermost transgressive part of the Volgino Sequence in the Moyero River section is enriched with iron ooids and iron impregnated bioclasts and pebbles which make the rock look reddish and similar to the iron oolite bed at the base of the Tallinn sequence in the Ordovician basin of Baltoscandia. The Volginian deposits of the Kulyumbe River section belong to the Angir Formation. The upper beds of the Angir Formation show abundant signs of shallowing, including quartz sandstone and multidirectional cross bedding. In the Moyero River Section the top of the sequence is marked by a hardground surface with traces of borings (Dronov, 2017). In the Podkamennaya Tunguska River valley the uppermost Volginian deposits include a thick bed of medium-grained quartz sandstone. The bed may correspond to a highstand systems tract of the Volgino depositional sequence based on its shallow-water depositional environment and stratigraphical position directly below a transgressive surface at the base of the overlying Kirensk-Kudrino depositional sequence. The sequence marks the beginning of one of the most extensive transgressions in the Siberian Platform. The faunal assemblage of the Volginian Stage is easily recognizable and markedly different from the assemblage of underlying strata. The Volginian depositional sequence partly corresponds to the Tallinn sequence in the Ordovician basin of Baltoscandia.

The Kirensk-Kudrino Sequence

The Kirensk-Kudrino depositional sequence coincides with the Kirensko-Kudrinian Regional Stage. Like the underlying Volgino Sequence it forms a full cycle of deposition. In the outcrops along the Podkamennaya Tunguska River the sequence represents a distinct regressive-transgressive-regressive cycle with three components corresponding to lowstand systems tract, transgressive systems tract, and highstand systems tract. The lowstand systems tract is a uniform unit of greenish-grey and bluish-grey siltstones with rare interbeds of quartz sandstone and(or) bioclastic limestone, which directly overlie coarse-grained quartz sandstone of the uppermost Volgino Sequence. The transgressive systems tract is mainly composed of red siltstones with abundant nautiloid shells. It was formed in an open marine environment and represents a deep-water setting, as evident from the abundant cephalopod fauna as well as fine-grained sediments and their red colour. Phosphatization is also associated with these sediments. The highstand systems tract is represented by greenish-grey and bluish-grey siltstones similar to those of the lowstand systems tract but coarser grained in composition. In the section along the Moyero River Section the base of the Kirensk-Kudrino depositional sequence coincides with a prominent hardground surface marked by traces of boring organisms. In the section along the Kulyumbe River valley the sequence is represented by the Amarkan Formation. Similar to the situation observed in the Podkamennaya Tunguska River sections, its lower boundary is a transgressive surface, along which greenish-grey siltstones of the Amarkan Formation overlie nodular limestone and cross-bedded quartz sandstone of the Angir Formation. The middle and upper parts of the Amarkan Formation are composed mostly of red siltstone. In the Irkutsk basin, the boundary between the Volgino and Kirensk-Kudrino sequences is represented by the regional unconformity in the middle of the Mamyr Series (Kanygin et al., 1984a). The lack of natural outcrops and adequate drill-core data prevent the distinction of any systems tracts. The Volgino and Kirensk-Kudrino sequences are correlative with the Tallinn Sequence of the Russian Platform.

The Mangazea Sequence

The Mangazea depositional sequence includes the Chertovskian and Baksian regional stages. Its lower boundary coincides with that of the Chertovskian Regional Stage and is represented by a transgressive surface over the entire Siberian Platform. In the Ordovician succession at the Kulyumbe and Lena rivers, this level demonstrates clear signs of erosion and a conglomerate, which can be interpreted as a transgressive lag deposit. In the Moyero River Section, the base of the Mangazea depositional sequence is represented by a transgressive surface separating shallow-water quartz sandstones of the uppermost Moyero Formation and relatively deep-water intercalation of bioclastic limestones and shale of the Dzerom Formation (Dronov, 2017). In the Podkamennaya Tunguska sections the Mangazea Sequence includes the upper part (corresponding to the Chertovskian Stage) of the Ust'-Stolbovaya Formation and the Mangazea Formation. The upper part of the Ust'-Stolbovaya Formation is interpreted as a transgressive systems tract and the Mangazea Formation as a highstand systems tract. The transgressive systems tract consists of two members: (1) greenish-grey siltstones interbedded with fine-grained yellowish-grey sandstones and black shales containing carbonate concretions with Chertovskian fauna and (2) red siltstones with scattered rounded phosphate pebbles 0.5 to 2 cm across and with beds of red conglomerates of phosphate pebbles. Both the black shale and the red phosphate conglomerates are interpreted as relatively deep-water deposits. At the Podkamennaya Tunguska region the highstand systems tract of the Mangazea sequence is a unit of greenish-grey siltstones alternating with bioclastic limestones. The bioclasts are predominantly fragments of brachiopods and trilobites as well as echinoderms, ostracods, and bryozoans. The limestone interbeds sometime show ripple marks on their upper bedding planes. At some levels the bioclastic limestones contain glauconite grains. The intercalations of siltstones and bioclastic limestones of the Mangazea Formation are interpreted as cool-water calcareous tempestites. The Mangazea Sequence correlates with the Kegel and Wesenberg sequences of the Russian Platform.

The Dolbor Sequence

The Dolbor depositional sequence corresponds to the Dolbor Formation and approximately to the Dolborian Regional Stage. The deposits are yellowish-grey, fine-grained sandstone and siltstone, locally with carbonate cement. In the outcrops along the right bank (northern) of the Podkamennaya Tunguska River, between the Stolbovaya and Listvennichnaya rivers, the base of the sequence is rather sharp and easily recognizable (Dronov, 2017). The alternating bioclastic limestones and greenish-grey siltstones of the Mangazea Formation are replaced by predominantly yellowish fine-grained sandstones and siltstones. According to earlier observations based on studies of the outcrops higher upstream along the Podkamennaya Tunguska River, the uppermost beds of the Baksian Regional Stage were eroded and a sequence boundary is indicated by erosional pockets up to 0.4 m deep, filled with fragments of the underlying rocks (Bgatov, 1973). The Dolbor Sequence correlates approximately with the Fjäcka and Lower Jonstorp sequences of the Russian Platform.

The Kety Sequence

The Kety depositional sequence comprises the Nirundinian and Burian regional stages. They were referred to as substages of the Kety Regional Stage in earlier publications (Sokolov and Tesakov, 1975). The sequence is best exposed in the outcrops along the Bolshaya Nirunda and Nizhnyaya Chunku River valleys, the tributaries of Podkamennaya Tunguska. The lower boundary is defined by a sharp change of yellowish-grey and greenish-grey sandstone and siltstone of the Dolbor Formation to the cherry-red mudstone of the Nirunda Formation. By analogy with the cherry-red mudstone facies of the Kirensk-Kudrino Sequence, the Nirundian deposits seem to be related to a transgressive systems tract. The overlying deposits of the Bur Regional Stage are interpreted as the highstand systems tract of the Kety depositional sequence. The Silurian deposits rest unconformably on the deeply eroded Ordovician strata. This does not exclude the presence of younger Ordovician deposits, belonging to the one or two Hirnantian depositional sequences, in the deeper parts of the Tungus basin. The Kety sequence is interpreted to correlate with the Upper Jonstorp Sequence of the Russian Platform.

Comparison with the Russian Platform

The Ordovician successions of the Russian and Siberian platforms show a certain similarity in the number of depositional sequences and the stratigraphic position of their boundaries. The Baltic and Siberian paleocontinents belong to different paleobiogeographic provinces, however and share no common species in the assemblages of trilobites, ostracods and brachiopods. In the Early Ordovician no common genus between the two paleocontinents has been reported. Some similarity of trilobites and brachiopods at the generic level occurred in the Middle Ordovician. Six genera of trilobites and five genera of brachiopods were common for both continents but their stratigraphic distribution was quite different. This fact prevents precise biostratigraphic correlation. To date there has been no direct correlations between the Ordovician successions of the Siberian and Russian platforms.

For intercontinental biostratigraphic correlation of the Ordovician of Siberian Platform, we have so far only four reliable levels: 1. The base of the Nyaian Regional Stage that correlates with the base of the Ordovician based on most recent conodont investigations (Tolmacheva and Abaimova, 2009); 2. The base of the Volginian Regional Stage that correlates with the base of the *Didymograptus bifidus* graptolite Zone; 3. The base of the Chertovskian regional Stage that correlates with the base of the *Nemagraptus gracilis* graptolite Zone, and 4. The base of the Silurian. These four stratigraphic levels constitute three major stratigraphic intervals that can be correlated globally. It is noteworthy that these major stratigraphic intervals include a comparable number of sedimentary sequences in the two different regions. This suggests the synchronous formation of the sequences on both paleocontinents (Fig. 5).

As for the main turnover events in the Ordovician biota and sedimentation patterns, they were different on the Russian and Siberian platforms. The global Hirnantian regression is well displayed on both platforms. The turnover event in the mid-Darriwilian is also very distinct. On the Siberian Platform it is marked by a transgressive surface at the base of the Volgino depositional sequence, which indicates an extended transgression, upwelling, and a significant change in sedimentation. On the Russian Platform it is marked by a transgressive surface at the base of the Aseri Stage, which coincides with an important change in shelly fossils across the basin. The change allowed definition of the regional Tallinn Stage with the lower boundary coinciding with the base of the Aseri Stage (Männil, 1966). Also distinct is the base of the Sandbian Stage (the base of the Caradoc Series of Great Britain). This level probably marks a global eustatic transgression reflected in the basal beds of the *Nemagraptus gracilis* Zone (Fortey, 1984; Barnes et al., 1996; Haq and Schutter, 2008).

By contrast, the important level at the base of the Baykit Sequence of the Siberian Platform, which was related to the sedimentation change, destruction of the carbonate platform and input of enormous siliciclastic masses into the basin, was less pronounced on the Russian Platform. The very distinct unconformity at the Volkhov-Kunda sequence boundary and the important faunal change (Männil, 1966) were not combined with major changes in sedimentation. In general, eustasy seems to have been the main controlling factor for depositional sequence formation on both platforms, but it was combined with regional tectonic effects.

Detecting eustasy

Each of the described depositional sequences represents a transgressive-regressive cycle deposited in response to sea level fluctuations. The base of every sequence is a level of marked facies and biotic changes. But the most prominent changes are associated with the following five stratigraphic levels: (1) the base of the Baykit Sequence; (2) the base of the Volgino Sequence; (3) the base of the Mangazea Sequence; (4) the base of the Kety Sequence; (5) the Ordovician/Silurian boundary. These levels represent remarkable faunal turnovers that can be traced all over the Siberian Craton (Fig. 5).

The base of the Baykit Sequence

One of the most pronounced faunal turnovers is associated with the regional unconformity at the base of the Baykit Sandstone. In the southwestern part of the Siberian Platform (near the Yenisei Land) the Baykit Sandstone rest with a slight angular unconformity on various Ordovician and even Cambrian deposits (Markov, 1970). The input of great volumes of siliciclastic material into the basin points to enlargement of the source area (Bgatov, 1973) and probably to regional tectonic uplift, accompanied by a forced regression. The regression resulted in the final destruction of the tropical carbonate platform that existed on the Siberian paleocontinent throughout the Riphean, Vendian, Cambrian and Early Ordovician. The carbonate platform in the Irkutsk basin disappeared even earlier, during the regression marked by the base of the Ugor Sequence. The Baikit regression is manifest in the northwestern part of the Tungus basin in the vicinity of the Turukhan Land by the quartz sandstones and siltstones of the Guragir Formation. In the eastern part of the basin, near the Anabar Land, it is marked by a considerable hiatus (Kanygin et al., 2007). The underlying Kimaian deposits have been entirely or partly eroded in many areas of the Siberian Platform (Kanygin et al., 2006, 2007). The regression seems to have had a major amplitude (>75 m) according to the semi-quantitative classification of Haq and Schutter (2008). It was one of the largest Ordovician regressions on the Siberian Craton and resulted in significant changes in the development of sedimentation and biotic evolution.

The base of the Volgino Sequence

The transgressive surface at the base of the Volgino depositional sequence marks the beginning of an impressive transgressive event that succeeded the lowstand phase displayed by the deposition of the Baikit Sandstone. The transgression is associated with abrupt changes in faunal assemblages and sedimentation. It is not surprising therefore that the base of the Volginian Regional Stage has been suggested as the boundary between the Lower and the Upper Ordovician series on the Siberian Platform (Sokolov and Tesakov, 1975). These series differ both in lithological composition, facies and thickness of deposits, and in composition and structural organization of biota (Kanygin et al., 2006). Although the transgression that produced the Volgino Sequence was not the largest in amplitude (probably it was in the range of 25-75 m) according to the classification by Haq and Schutter (2008), the transgressive surface at the base of the sequence represents one of the most significant biotic events in the Ordovician of the Siberian Platform.

The base of the Mangazea Sequence

The transgressive surface at the base of the Mangazea Sequence is well pronounced all over the platform. In many places, it is associated with the erosion of underlying deposits and a basal conglomerate. This surface was probably formed during a forced regression and was reworked afterwards into a transgressive surface of erosion. The phosphate pebble conglomerate at the base of the Chertovskian Regional Stage has a widespread distribution and is interpreted as a transgressive lag deposits. It is usually overlain by a relatively deep-water black shale or red bed facies. The transgressions of the Volginian and the Chertovskian stages are the most prominent in the Ordovician of the Siberian Platform (Kanygin et al., 2006). But the amplitude of the Mangazea sea level rise seems to exceed the Volginian one, reaching the amplitude of >75m. The minimal facies differentiation provided distribution of the uniform benthic and pelagic assemblages over the entire Siberian platform.

The base of the Kety Sequence

The cherry-red siltstone of the Nirunda Formation seems to represent a facies analogue of the relatively deep-water marine red bed facies of the Kirensk-Kudrinian and Chertovskian stages. That implies that the sharp Dolbor/Kety sequence boundary is also a transgressive surface that reflects a rapid sea level rise. This sequence boundary has not been adequately studied because this stratigraphic interval has a limited number of natural exposures. The best of them are located in the inner part of the Siberian Platform and are not easily accessible.

The Ordovician-Silurian boundary

The Ordovician-Silurian boundary is marked by a distinct gap generated by a high amplitude forced regression. The sea level fall was of eustatic origin, supposedly connected with continental glaciation of Gondwana. The uppermost beds of the Ordovician (Hirnantian) are absent almost everywhere on the Siberian Platform. The beginning of the Silurian Period was characterized by a new transgression and an essential renovation of marine ecosystems.

ORDOVICIAN KEY SECTIONS OF THE TUNGUS BASIN, SIBERIAN PLATFORM

The bed-by-bed description of Ordovician deposits on the Podkamennaya Tunguska River given below is based on the description of this section published in different monographs (Nikiforova, Andreeva, 1961; Markov 1970; Kanygin et al., 1977; Moskalenko, 1973; Moskalenko et al., 78; Rozman, 1979).

Fossils from the key Ordovician sections on the Podkamennaya Tunguska River have been collected during a number of years by geologists from various institutions. They were carefully studied by many specialists. In this guidebook data obtained by the following workers are presented: brachiopods – O.N. Andreeva, Ch.S. Rozman, A.G. Yadrenkina, O.A.Maslova; trilobites – Z.A. Maximova, N.N. Kramarenko, V.S. Semyonova, A.V. Timokhin; ostracods – A.V. Kanygin, T.V. Gonta, K.M. Melnikova; conodonts – T.A. Moskalenko; graptolites – N.V. Sennikov.

The location of key sections on the Podkamennaya Tunguska River see Fig. 6.

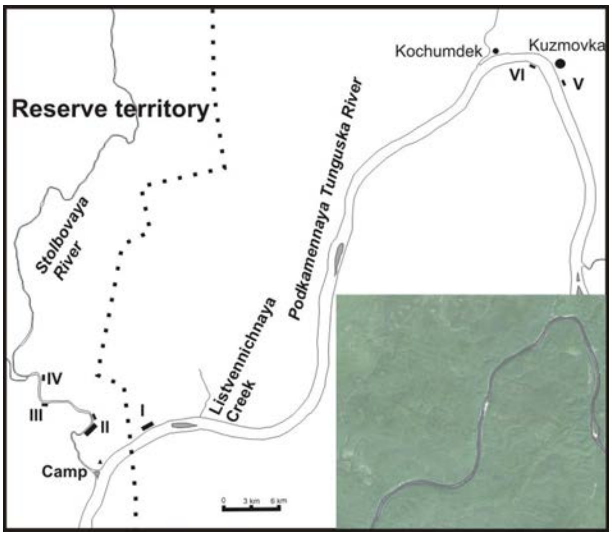

Fig. 6. The location of exposures of the Ordovician rocks on Podkamennaya Tunguska River.

Description of geological outcrop

Outcrop –I (Figs 7–16) – the Podkamennaya Tunguska, right bank, between mouths Stolbovay River and Listvennichnaya Creek. In the high steep coast, in a middle part of the naked site:

1. Sandstones, greenish-grey, fine-grained, porous, with the glaukonits. **1,2 m**

2. Sandstones, coarse-grained, weakly cemented, porous. **0,3 m**

3. Conglomerate layer containing a large number of phosphate pebbles. General background is dark grey. Brachiopods have been found in large numbers. **0,3 m**

4. Mudstones, silty, green, thinly-laminated, enclosing flattened concretions of hard grey dense limestone. Minute phosphate pebbles are observed in considerable amount. The brachiopods *Evenkina lenaica* (Girard), ostracods *Quadrilobella arpilobata* V. Ivan., *Leperditella* sp. **1.0 m**

5. Sandstones, dark grey, greenish-grey, poorly sorted. **0,6 m**

6. Siltstones and mudstones, greenish-grey, bluish-grey. **0,3 m**

7. Sandstones, grey, greenish-grey, fine-grained in down, coarse-grained in up. Upwards, these are succeeded gravelit. **0,5 m**

8. Mudstones, silty, green, thinly-laminated, phosphate pebbles, with rare nodules and discontinuous limestone interbeds, The underlying mudstones are interbed with nautiloides *Stolbovoceras borealis* Bal., ostracods *Primitia abundans* V. Ivan., *Fidelitella* sp. **1.0 m**

9. Siltstones are motley, green and lilac, with separate calcareous concretions. **0,2 m**

10. Mudstones, with interbeds green and lilac. A layer of limestone thin dense, minute phosphate pebbles are observed in considerable amount. Rare lingula, nautiloides, ostracods *Aparchitella* sp., *Fidelitella simplex* V. Ivan., *Quadrilobella arpilobata* V. Ivan., *Primitia annae* V. Ivan., *Prybitina levis* V. Ivan., *Schmidtella dorsilobata* V. Ivan. **3,7 m**

11. Mudstones, green. Rare ostracods. **2,5 m**

12. Mudstones, thinly-laminated, dark-green, green. Above sandstones the concluding small phosphate pebbles and brachiopods *Evenkina lenaica* (Girard), *Murinella jakuticaensis* Andr., *Strophomena* sp., ostracods *Bodenia aspera* V. Ivan., *Bolbinella* ex. gr. *cumulata* Kan., *Coelochilina* sp., *Egorovella captiosa* V. Ivan., trilobites *Isalaux stricta* (Kram.). **0,35 m**

13. Mudstones are red and variegated, calcareous, limy, with minute phosphate pebbles. **1,2 m**

14. Mudstones, green, with thin interlayers of organogenic-clastic limestone. The trilobites *Carinopyge*? sp., ostracods. **0,6 m**

15. Limestones, grey, coarse-crystalline, with abundant phosphate pebbles. **0,15-0,2 m**

16. Mudstones, green, with rare phosphate pebbles. **0,25 m**

17. Limestone, clayey, greenish-grey, with phosphate pebbles. **0,15 m**

18. Mudstones, green, with thin laminae limestone rich in various organic remains. Brachiopods *Mimella panna* Andr., *Rostricellula* sp., bryozoans *Pachydictya foliata* Ulr., trilobites *Ceratevenkaspis armata* Kram., *Ceraurinus icarus* (Bull.), *Monorakos magnus* Kram., *Evenkaspis sibirica* (Schm.), ostracods *Aparchitella* sp., *Costopritnites indiligens* V. Ivan., *Euprimites helenae* V. Ivan. **1,7 m**

Scree. Closed interval.

19. Mudstones, green, with brachiopods *Glyptorthis* sp., *Rostricellula* sp., bryozoans, trilobites *Monorakos* cf. *magnus* Kram., ostracods *Aparchitella major* V. Ivan., *A. procera* V. Ivan, *Euprimites helenae* V. Ivan., *Parajonesites notabilis* V. Ivan., *Planusella bicomis* V. Ivan. **1,2 m**

20. Limestones, clayey, greenish-grey, with ostracods *Bodenia aechminiformis* V. Ivan., *Euprimites helenae* V. Ivan. **0,5 m**

21. Mudstones, green, with ostracods *Planusella bicomis* V. Ivan., *Jonesites* sp., bryozoans *Diplotrypa incrustans* Astr., brachiopods *Mimella* sp., *Rostricellula* ex. gr. *subrostrata* Nikif., *Triplesia* sp., trilobites. **0,7 m**

22. Mudstones, green, with thin interlayers of clastic limestone. **0,5 m**

23. Mudstones, green, with interlayers of organogenic-clastic limestone, ostracods *Aparchitella* sp., *Parajonesites notabilis* V. Ivan., *Rostricellula* sp., trilobites *Monorakos magnus* Kram. **0,8 m**

24. Limestones, organogenic-clastic. **0,4 m**

25. Mudstones, grey and greenish-grey, with thin limestone interbeds. The remains of brachiopods *Glyptorthis pulchra* Wang, *Strophomena* sp., *Rostricellula* sp., ostracods *Parajonesites notabilis* V. Ivan., *Aparchitella* sp. **2,5 m**

26. Limestones, grey and greenish-grey, with thin mudstones interbeds, green. The remains of trilobites *Ceraurinus icarus* (Bill.). **1,2 m**

27–28. Mudstones are greenish, with thin and sparse limestone interbeds, which contain brachiopods *Leptellina* sp., *Strophomena* sp., *Evenkaspis* sp., *Sigmobolbina*? sp. **2,6 m**

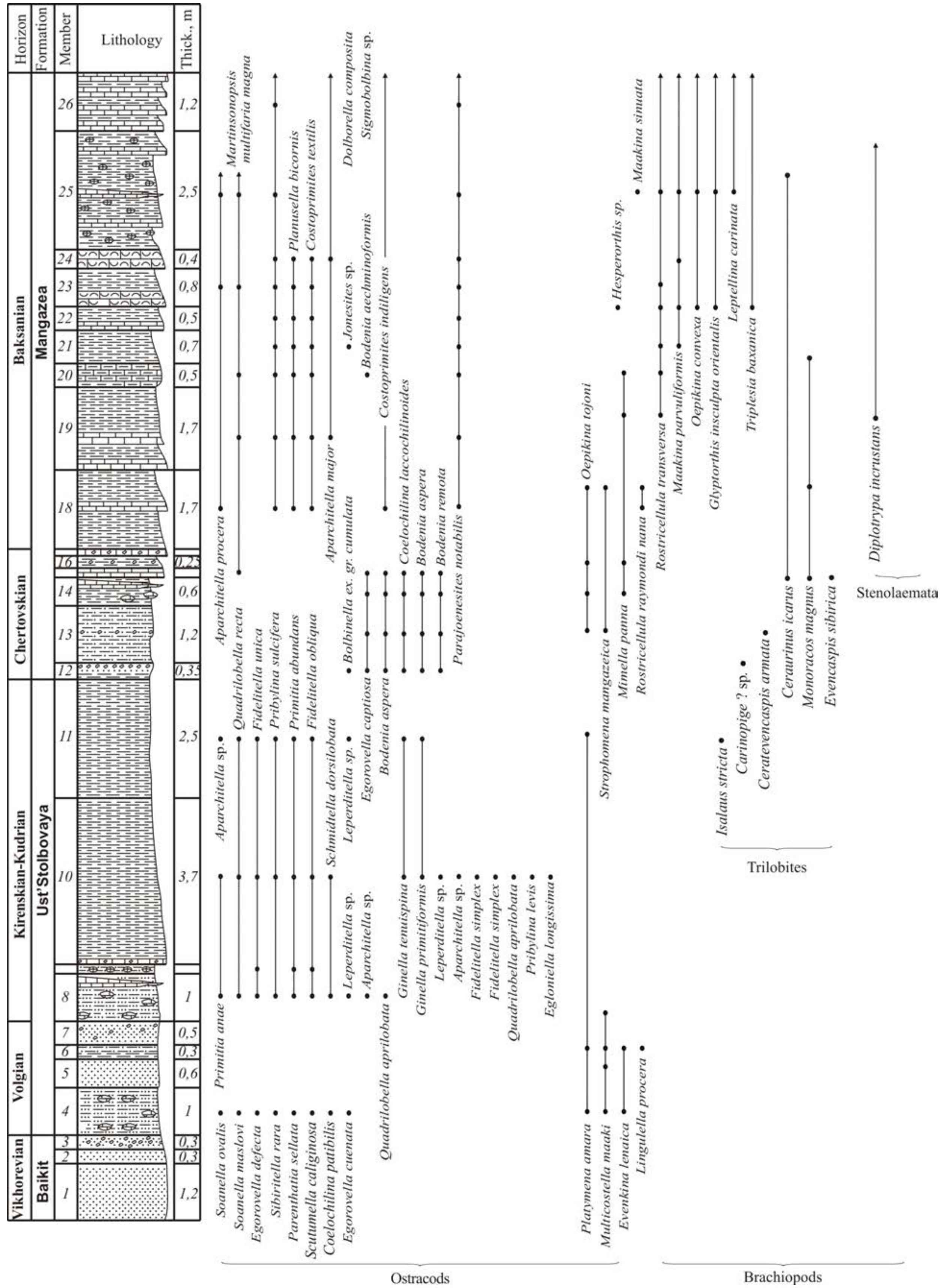

Fig. 7. Lithology and ranges of fossil taxa from the Outcrop-**I** — the Podkamennaya Tunguska River, right bank, between mouths of Stolbovaya River and Listvennichnaya Creek.

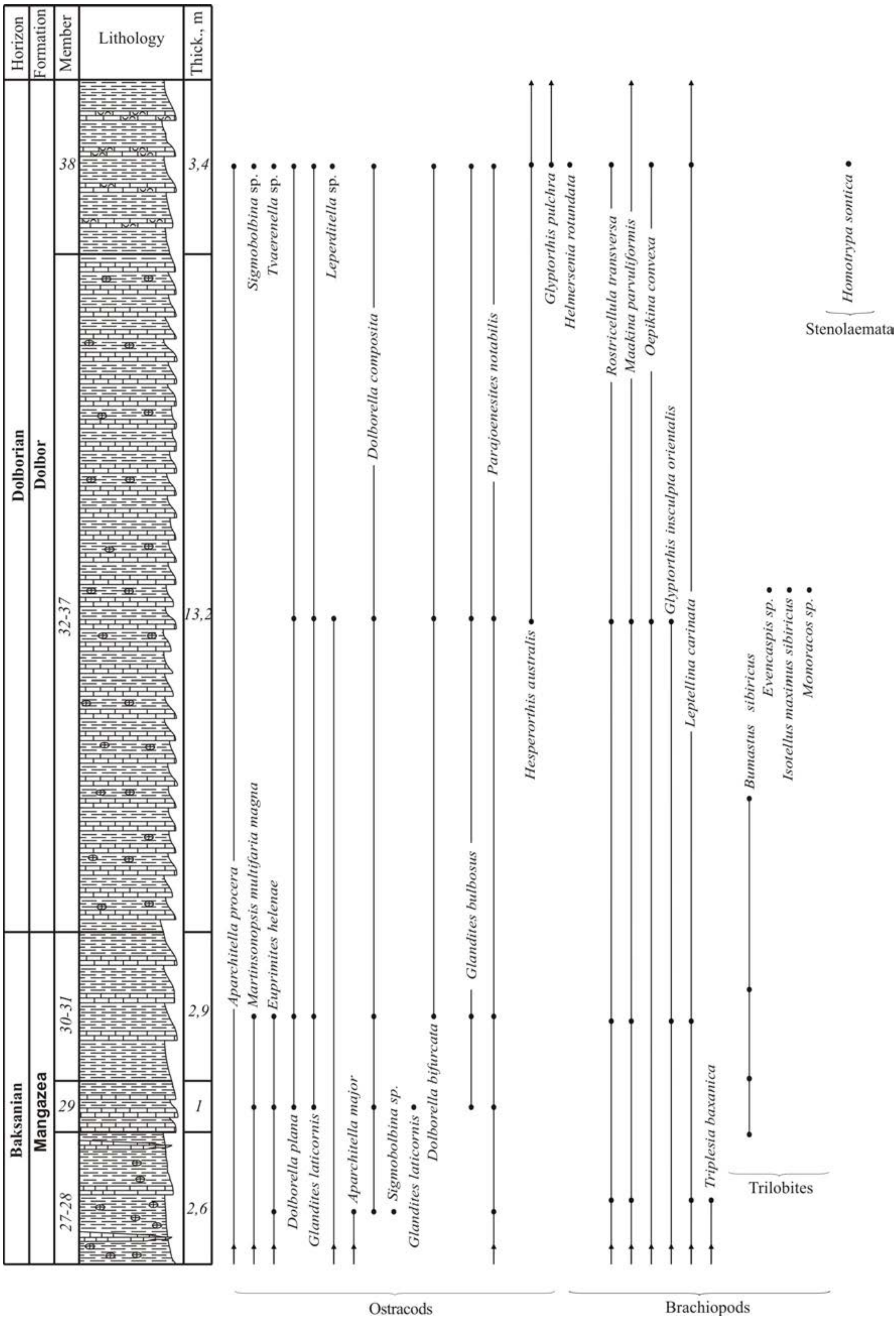

Fig. 7. Continued**.**

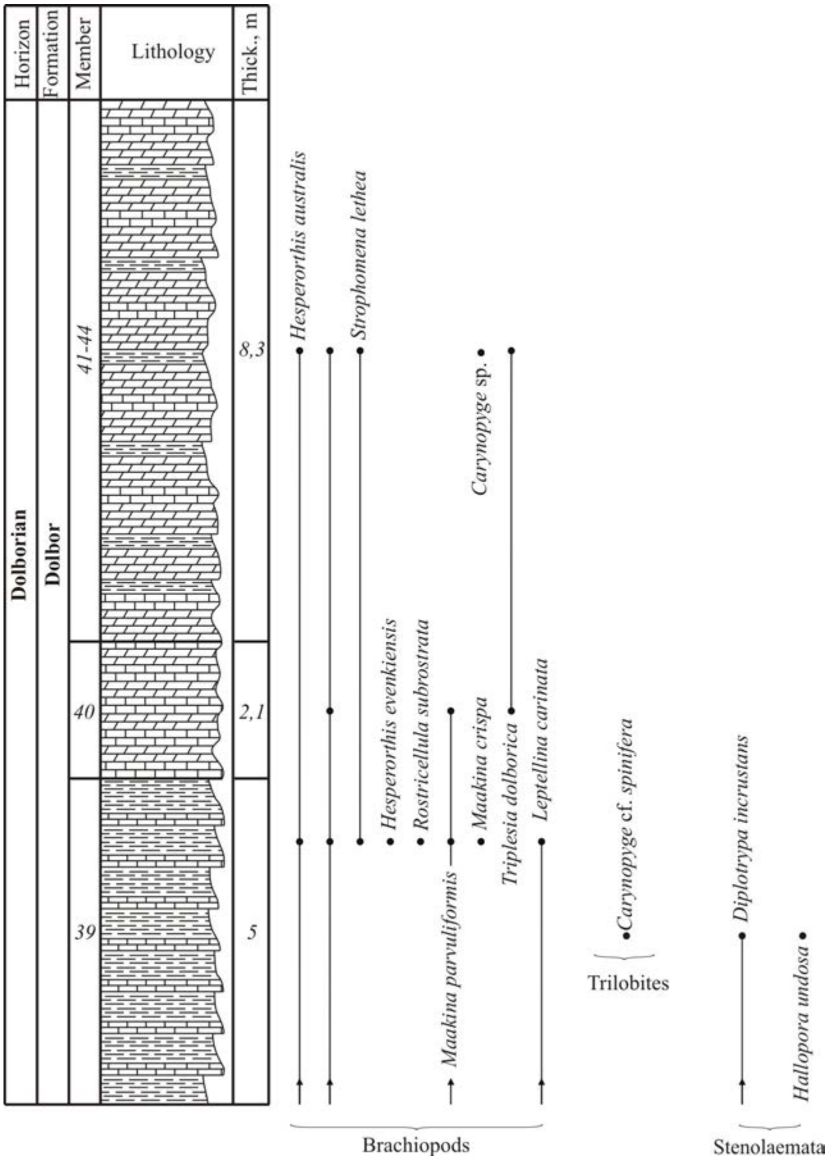
Horizon
Formation
Member
Lithology
Thick., m
Dolborian
Dolbor
41-44
40
39
8,3
2,1
5
Hesperorthis australis
Strophomena lethea
Carynopyge sp.
Hesperorthis evenkiensis
Rostricellula subrostrata
Maakina crispa
Triplesia dolborica
Leptellina carinata
Maakina parvuliformis
Carynopyge cf. spinifera
Diplotrypa incrustans
Hallopora undosa
Trilobites
Brachiopods
Stenolaemata

Fig. 7. The End**.**

Fig. 8. General view on the main outcrop on the right bank of Podkamennaya Tunguska River between Listvennichnaya and Stolbovaya rivers. Middle and Upper Ordovician deposits from Baykit till Dolbor formations with Silurian deposits on the top.

Fig. 9. Baykit and Ust'Stolbovaya formations.

Fig. 10. Baykit Sandstone at the base of the outcrop.

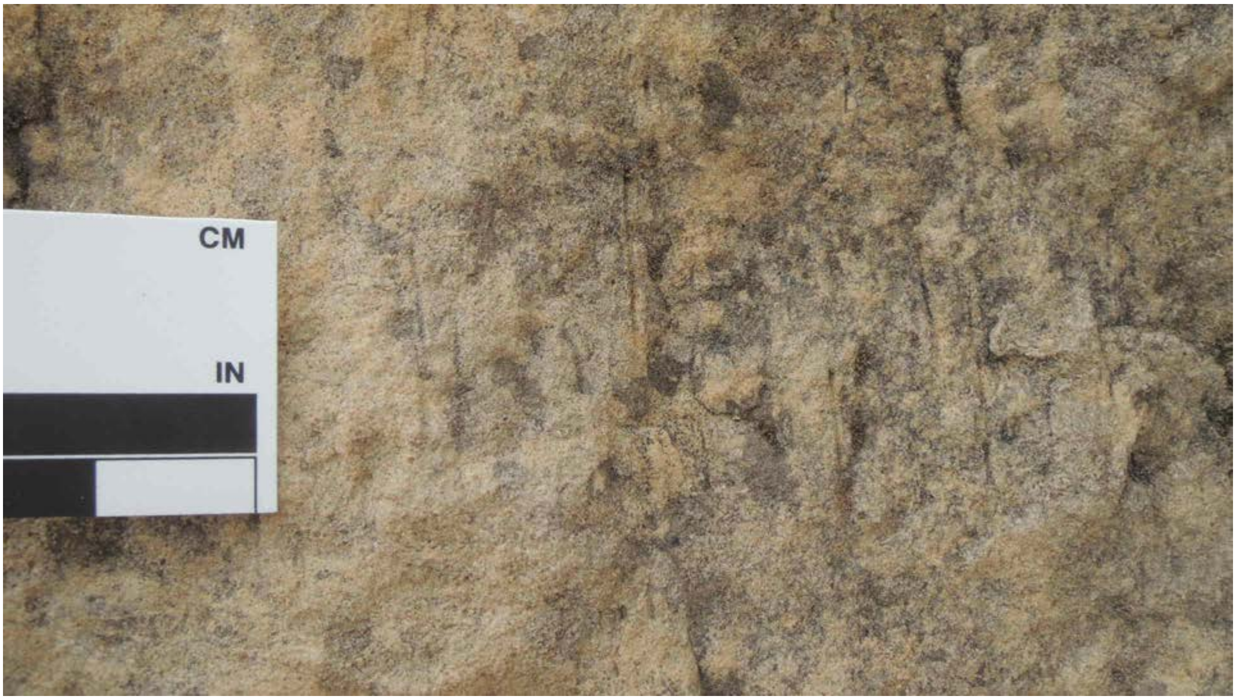

Fig. 11. *Skolithos* trace fossils in the Baykit Sandstone.

Fig. 12. Desiccation cracks at the bedding plane of the Baykit Sandstone.

Fig. 13. Phosphate pudding conglomerate of the Chertovskian Regional Stage.

Fig. 14. Carbonate lenses in the Chertovskian Regional Stage deposits (Ust'Stolbovaya Formation).

Fig. 15. Intercalation of mudstones (alevrolites) and cool-water bioclastic carbonates in the deposits of Mangazea Formation.

Fig. 16. Boundary between Mangazea and Dolbor formations. Unconformity and sequence boundary. Base of the Dolbor depositional sequence.

29. Limestones, light grey, which passes up into light green marls with rare ostracods *Glandites laticornis* V. Ivan., *Parajonesites* aff. *notabilis* V. Ivan. **1.0 m**

30–31. Mudstones, thinly interbedded with organogenic limestones. Ostracods are abundant *Parajonesites notabilis*. **2,9 m**

32–37. Thinly and rhythmically alternating mudstones and organogenic limestone. Numerous organic remains include: brachiopods *Glyptorthis insculpta orientalis* Nikif., *Hesperorthis australis formalis* Nikif., *Leptellina* sp., *Opikina parvula* Cooper, *Rostricellula* ex. gr. *subrostrata* Nikif., *Rostricellula* sp., *Strophomena* ex gr. *lethea* Nikif., *Strophomena* sp., trilobites *Evenkaspis* sp., *Isotellus maximus sibiricus* Z. Max., *Monorakos* sp., ostracods *Costoprimites indiligens* V. Ivan., *Parajonesites notabilis* V. Ivan. **13,2 m**

38. Mudstones, with clayey limestone interbeds. Organic residues in limestones are prolific: bryozoans *Homotrypa sontica* (?) Astr., ostracods *Aparchitella* sp., *Parajonesites* aff. *notabilis* V. Ivan., *Sigmobolbina* sp., *Tvaerenella* sp., *Leperditella* sp. **3,4 m**

39. Mudstones, greenish to dark grey, with thin and sparse limestone interbeds, which contain brachiopods *Glyptorthis* sp., *Hesperorthis evenkiensis* Nikif., *Rostricellula subrostrata* Nikif., *Strophomena lethea* Nikif., bryozoans *Diplotrypa incrustans* Astr., *Hallopora undosa* Astr., trilobites *Carynopyge* cf. *spinifera* Bal. **5.0m**

40. Limestone and marls, yellowish- grey. Gastropods. **2,1 m**

41–44. Marls, non-stratified, greenish-grey, with mudstones green, and limestones, grey interbeds, and rare organic remains of brachiopods and trilobites *Carinopyge* sp. **8,3 m**

Outcrop -II (Figs 17–23) – The Stolbovaya River, left bank, 4-5 kilometers above the river mouth. The steep bank overhanging the water edge exhibits:

1. Sandstones, coarse-grained, weakly cemented, porous, bluish grey. **0.5–0.7 m**

2. Sandstones, calcareous, poorly sorted, often oolite-like, sometimes porous, with phosphorite pebbles. Bedding surfaces of sandstones are uneven. **0.15 m**

3. Mudstones, ash- and dark grey, fine-gravelly and thinly-laminated, containing minute phosphate pebbles. Ostracods have been found in large numbers. A thin, not persistent nautiloids-bearing limestone intercalation containing septarian nodules is observed in the upper part. **0.7 m**

4. Gravelites, grey. **0.15—0.20 m**

5. Siltstones, ash-grey, with numerous minute phosphate pebbles with burrows from mud eaters. Organic residues are rare and indefinable. **0.8 m**

6. Sandstone, fine-grained, greenish-grey. Phosphate pebbles and detritus material are abundant. **0.2 m**

7. Siltstones, sandy, nonuniform, dark grey. In the upper part, there is a thin intercalation of sandstone. **0.5 m**

8. Sandstone, coarse- and medium-grained, calcareous, grey. The bed forms an identifiable bench in the lower part of the outcrop. **0.6 m**

9. Siltstones, nonuniform, often grade into mudstones, greenish and yellowish-grey, with sparse discontinuous interlayers of limestone, locally enriched with irregular-shaped phosphorite pebbles. Ostracods *Primitia abundans* V. Ivan., *Fidelitella simplex* V. Ivan abundant in the middle and upper parts are generally poorly preserved. **2.0 m**

10. The under- and overlying mudstones are motley, greenish- and reddish-grey, purple-red in the middle part. Minute phosphate pebbles are observed in considerable amount. A thin interbed of compact limestone is traced at 0.5 m from the base and is overlain by lenticular calcareous interlayers containing abundant nautiloids. The middle part is extremely rich in the ostracods *Fidelitella simplex* V. Ivan., *Quadrilobella arpilobata* V. Ivan. **1.7 m**

11. Mudstones are red and variegated, mostly green-coloured at the topmost part, with few thin limestone interbeds. In the upper part, limestone nodules appear first as isolated, then passing up into a persistent interlayer. Organic residues are unevenly distributed. ostracods *Fidelitella simplex* V. Ivan., *Quadrilobella arpilobata* V. Ivan. and concentrations of nautiloids are prolific in the lower part. The number of fossil finds tend to reduce up the section to the extent that only rare lingulids have been reported in the uppermost part. **4.4 m**

12. Mudstones, silty, green, thinly-laminated, enclosing flattened concretions of hard grey dense limestone. Ostracods *Fidelitella* sp., *Quadrilobella* sp., *Leperditella* sp. occur sporadically; lingulids are scant. **2.5 m**

13. The thin dense limestone interbed is succeded by mudstones, thinly-laminated, purple-red, passes up into gravelstone, red-coloured, containing abundant quartz pebbles. **1.3 m**

14. Siltstones are motley, greenish-, reddish- and yellowish-grey, calcareous, with minute phosphate pebbles. **0.10–0.1 m**

15. Mudstones, green, fine-rubbly, with sharp discontinuous thin interlayers of organogenic-clastic limestone. The brachiopods *Mimella* cf. *panna* Andr. and the trilobites *Evenkaspis sibirica* (Schm.) have been reported. **2.3 m**

16. Mudstones, green, with aggregates of minute phosphate pebbles and detritus and thin limestone interbeds. Brachiopods, trilobites, ostracods, as well as ramifying bryozoan colonies are common. Brachiopods belong to *Lingula* sp., *Rostricellula* sp., trilobites belong to *Cariaopyge* sp., *Monorakos lopatini* (Schm.), *M. jnagnus* Kram., and ostracods are assigned to *Costoprimites* sp., *Glandites bulbosus* V. **1.3 m**

17. Mudstones, green, with thin laminae of clayey limestones rich in various organic remains. Individual laminae contain numerous minute phosphate pebbles. **1.2 m**

18. Mudstones, green, with persistent pinkish-grey dense limestone interbed at the base. Upwards, these are succeeded by alternating mudstones and limestones. Limestones are represented by clayey and crystalline varieties. Brachiopods *Rostricellula* sp., bryozoans *Fimbriapora gregaria* (Schm.), ostracods *Parajonesites notabilis V. Ivan*., *Glandites bulbosus* V. Ivan., and indefinable species of trilobites have been reported. **3.0 m**

19. A member of thinly alternating mudstones and limestones. Fragments of brachiopods and trilobites are observed. **2.5 m**

20. A layer of limestone, hard, dark grey, succeeded by very dark thinly-laminated mudstones with numerous ostracods *Hallotina*? sp., *Planusella*? sp., passing up into green-coloured mudstone. Nodule-like concretions and thin layers of limestone are traced throughout the bed. **3.0 m**

21. Thinly alternating mudstones and limestones. Calcareous nodules continue to occur. **2.5 m**

22. Alternating mudstones and limestones. **2.6 m**

24. Alternating mudstones and limestones. The encountered abundant and diverse organic remains comprise: brachiopods *Hesperorthis* cf. *tricenaria* (Conrad), *Leptellina* sp., *Rostricellula* sp., trilobites *Carinopyge* sp., ostracods *Eridoconcha* sp., *Bolbina* sp., *Tetradella* sp., *Parajonesites* sp. **7.2 m**

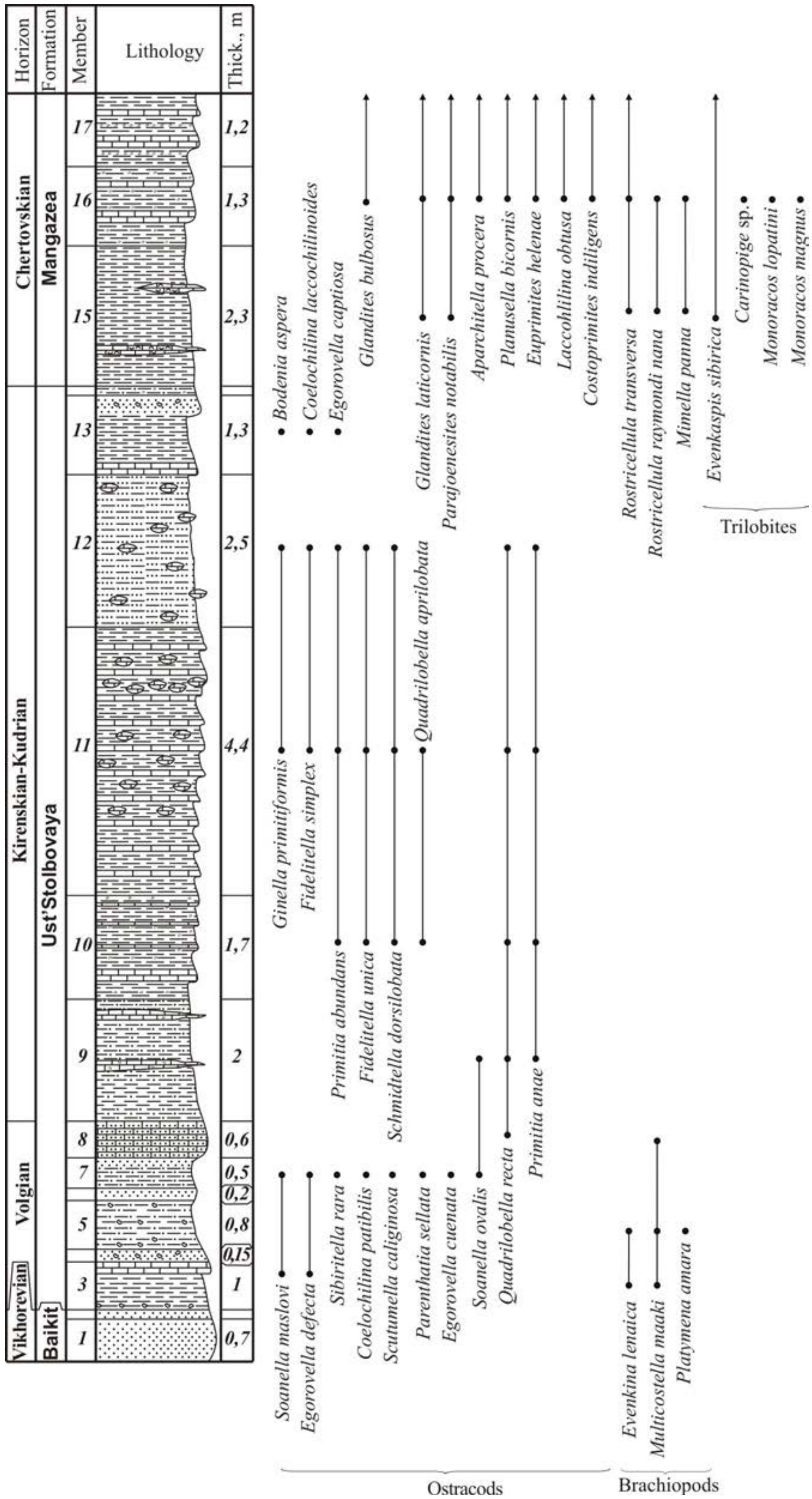

Fig. 17. Litology and ranges of fossil taxa from the **Outcrop-II**– the Stolbovaya River, left bank, 4-5 kilometers above the river mouth.

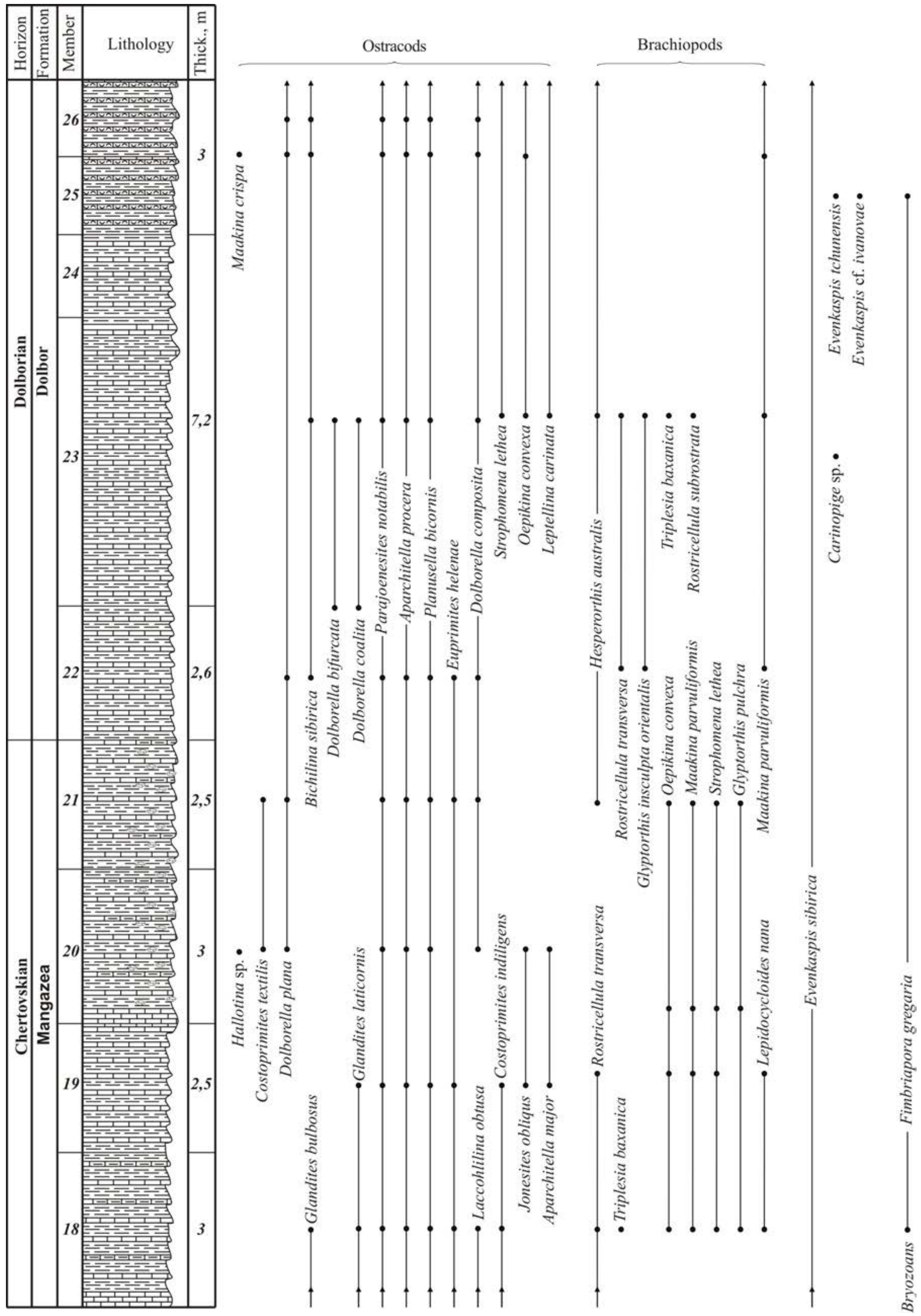

Fig. 17. Continued.

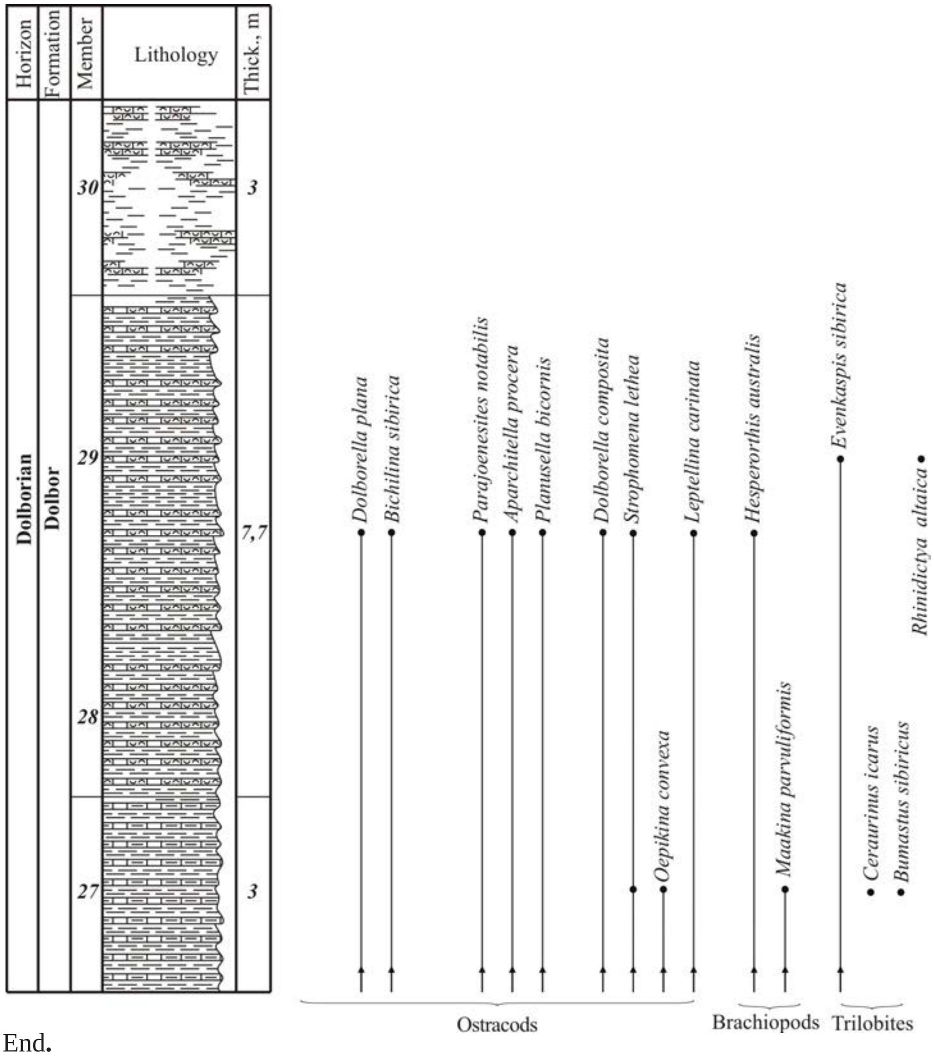

Fig. 17. The End.

Fig. 18. General view on the upstream end of the Outcrop I on the left bank of the Stolbovaya River, 5 km from its mouth. Top of the Baykit Sandstone, Ust'Stolbovaya and Mangazea formations.

Fig. 19. General view on the Outcrop II on the left bank of the Stolbovaya River, 0,5 km upstream from the Outcrop I. Ust'Stolbovaya and Mangazea formations. Note the position of the "Marker bed" and lower K-Bentonite layer.

Fig. 20. Closer view on the lower part of the outcrop. Vikhorevian, Kirensko-Kudrinian, Volginian, Chertovskian and Baksian Regional stages.

Fig. 21. Boundary between Chertovskian and Baksian Regional stages.

Fig. 22. Sequence boundary (transgressive surface) at the top of Baykit Sandstone. Note ripple marks and trace fossils.

Fig. 23. Phosphate pudding conglomerate of the Chertovskian Regional Stage.

25–26. Thinly and rhythmically alternating mudstones and organogenic limestone. Numerous organic remains include: brachiopods *Hesperorthis australis* Nikif., *H. euenkiensis tnutabilis* Nikif., *Glyptorthis katangaensis* Nikif., *Maakina kulinnensis* Andr., *Opikina parvula* Cooper, *Strophomena* ex. gr. *lethea* Nikif., *Rostricellula* sp., bryozoans *Fimbriopora gregaria* (Schm.), rugoses *Streptelastna* sp., *Kenophyllum subcylindricum* Dyb., trilobites *Evenkaspis tchunensis* Z. Max., *E.* cf. *ivanovae* Kram. **3.0 m**

27. Mudstones, silty, with clayey limestone interbeds. Organic residues in limestones are prolific: *Hesperorthis australis* Nikif., *Opikina parvula* Cooper, rugoses *Kenophyllum subcylindricum* Dyb., trilobites *Ceraurinus icarus* (Bill.), *Bumastus cf. sibiricus* Z. Max. **3.0 m**

28-29. Mudstones, thinly interbedded with organogenic limestones. Brachiopods are abundant *Glyptorthis katangaensis* Nikif., *Hesperorthis australis* Nikif., *Opikina parvula* Cooper, *Strophomena lethea* Nikif., other encountered fauna includes bryozoans *Rhinidictya altaica* Jar., trilobites *Evenkaspis sibirica* (Schm.). **7.7 m**

30. A poorly exposed member of rocks identical to those in the previous layers. **3.0 m**

Outcrop-III (Figs 24–27) – The Stolbovaya River, right bank, 3 km below the Kulinna River mouth. The steep bank overhanging the water edge exhibits:

1. Alternation of mudstones, bluish-grey, and limestones, containing organogenic and diverse organic remains: brachiopods *Glyptorthis*. **1.0 m**

2–3. Alternating mudstones and limestones, crystalline and clayey. The limestones contain numerous flat argillite pebbles. Numerous and diverse organic remains include: brachiopods *Glyptorhis katangaensis* Nikif., *Leptellina* sp., *Rostricellula* sp., trilobites *Evenkaspis* sp., ostracods *Glandites bulbosus* V. Ivan.? *Parajonesites notabilis* V. Ivan., *Parenthatia* sp., *Planusella bicornis* V. Ivan. **5.0 m**

4. Alternation of mudstones and limestones. The role of limestones tends to reduce, in as much as they become dominantly clayey up the section. Organic residues are abundant: *Hesperorthis australis* NiKif., *Leptellina* sp., *Opikina parvula* Cooper, *Rostricellula* sp., *Triplesia baxanica* Nikif., *T. dolbonca* Nikif., rugoses *Kenophyllum subcylindricum* Dyb., trilobites *Evenkaspis* sp., *Carinopyge* cf. *abscisa* Z. Max. **4.0 m**

5. Mudstones-siltstones member. Limestones are rare to nonexistent. *Opikina parvula* Cooper, *Kenophyllum subcylindricum* Dyb., *Evenkaspis* sp. have been identified. **2.8 m**

6–7. Mudstones, nonuniform, green, calcareous in interlayers, with individual limestones beds. The observed sporadic aggregates are organic remains of: brachiopods *Glyptorthis katangaensis* Nikif., *G. pulchra* Wang, *Hesperorthis australis* Nikif., *Opikina parvula* Cooper, *O. gibbosa* Andr., *Rostricellula* ex. gr. *subrostrata* Nikif., *Strophomena lethea* Nikif. and trilobites *Evenkaspis* sp. **4.1 m**

8–10. Mudstones, grey and greenish-grey, with thin limestone interbeds. The remains of brachiopods *Glyptorthis pulchra* Wang, *Hesperorthis australis* Nikif., *Rostricellula* sp., *Triplesia baxanica* Nikif., *Opikina parvula* Cooper, bryozoans *Nicholsonella pulchra* Ulr., rugoses *Streptelastna* sp., trilobites, ostracods, crinoids are encountered. **7.4 m**

11–12. Mudstones are greenish to dark grey, with thin and sparse limestones interbeds, which contain brachiopods *Glyptorthis pulchra* Wang, *Hesperorthis evenkiensis mutabilis* Nikif., *Opikina gibbosa* Andr., *O. parvula* Cooper, *Rostricellula* sp., *Triplesia dolborica* Nikif. **6.5 m**

13. Light grey calcareous sandstones (0.1 m) at the base contains crinoid columnal segments, which passes up into light greenish-grey marls with rare brachiopods *Maakina kulinnensis* Andr., *Rostricellula* ex. gr. *subrostrata* Nikif., and trilobites. **1.0 m**

14. Marls, non-stratified, greenish-grey, with scattered minute pebbles and rare organic remains of *Hesperorthis australis* Nikif., *Maakina* cf. *kulinnensis* Andr., *Rostricellula* ex. gr. *subrostrata* Nikif., *Rostricellula* sp. **1.5 m**

15. Marls, non-stratified, greenish- and bluish-grey. The encountered fossil fauna includes: brachiopods *Glyptorthis pulchra* Wang, *Maakina kulinnensis* Andr., *Opikina parvula* Cooper, *Rostricellula* ex. gr. *subrostrata* Nikif., *Triplesia baxanica* Nikif., rugoses *Cyrtophyllum dengum* Lind., trilobites *Ceraurinus icarus* (Bill.), small colonies of tabulates, bivalves, crinoids. **4.0 m**

16. Marls and siltstones are bluish- and greenish-grey. Bachiopods *Boreadorthis asiatica* Nikif., *Opikina gibbosa* Andr., *Rostricellula* ex. gr. *subrostrata* Nikif., *Strophomena lethea* Nikif., *Triplesia dolborica* Nikif., bivalves, and crinoids continue to occur. **1.8 m**

17. Marls and siltstone are green and yellowish-grey. Individual interlayers are enriched with pebbles and organic remains, which yielded brachiopods *Boreadorthis asiatica* Nikif, *Hesperorthis evenkiensis mutabilis* Nikif., *Glyptorthis pulchra* Wang, *Strophomena lethea* Nikif., *Triplesia baxanica* Nikif., and trilobites *Bumastus* sp. **1.8 m**

18–19. Siltstones, green, spotty, with calcareous interlayers. Rare limestones interbeds are rich in organic remains: brachiopods *Hesperorthis evenkiensis mutabilis* Nikif., *Opikina gibbosa* Andr., *Rostricellula* ex. gr. *subrostrata* Nikif., *Strophomena lethea* Nikif., *Triplesia baxanica* Nikif., rugoses *Cyrtophyllum dengum* Lind. **4.3 m**

20. Clayey interlayer. Bentonite. **0.02–0.03 m**

21. Siltstones, which grade into marls or loose calcareous light grey sandstones containing pebbles of argillite. **1.8 m**

22. Siltstones, green, with light grey crystalline limestone interbeds. Numerous pebbles, locally forming lenticular aggregates throughout the bed. Marl interbeds are common in the overlying portion. Fossil finds are represented by brachiopods *Boreadorthis asiatica* Nikif., *Glyptorthis pulchra* Wang, *Hesperorthis australis* Nikif., *Maakina* cf. *kulinnensis* Andr., *Opikina gibbosa* Andr., *Strophomena lethea* Nikif., rugoses *Cyrtophyllum dengum* Lind., bivalves, and crinoid columnal segments. **3.2 m**

23. Siltstones, dark green, non-stratified, with rare poorly preserved organic remains. **4.0–5.0 m**

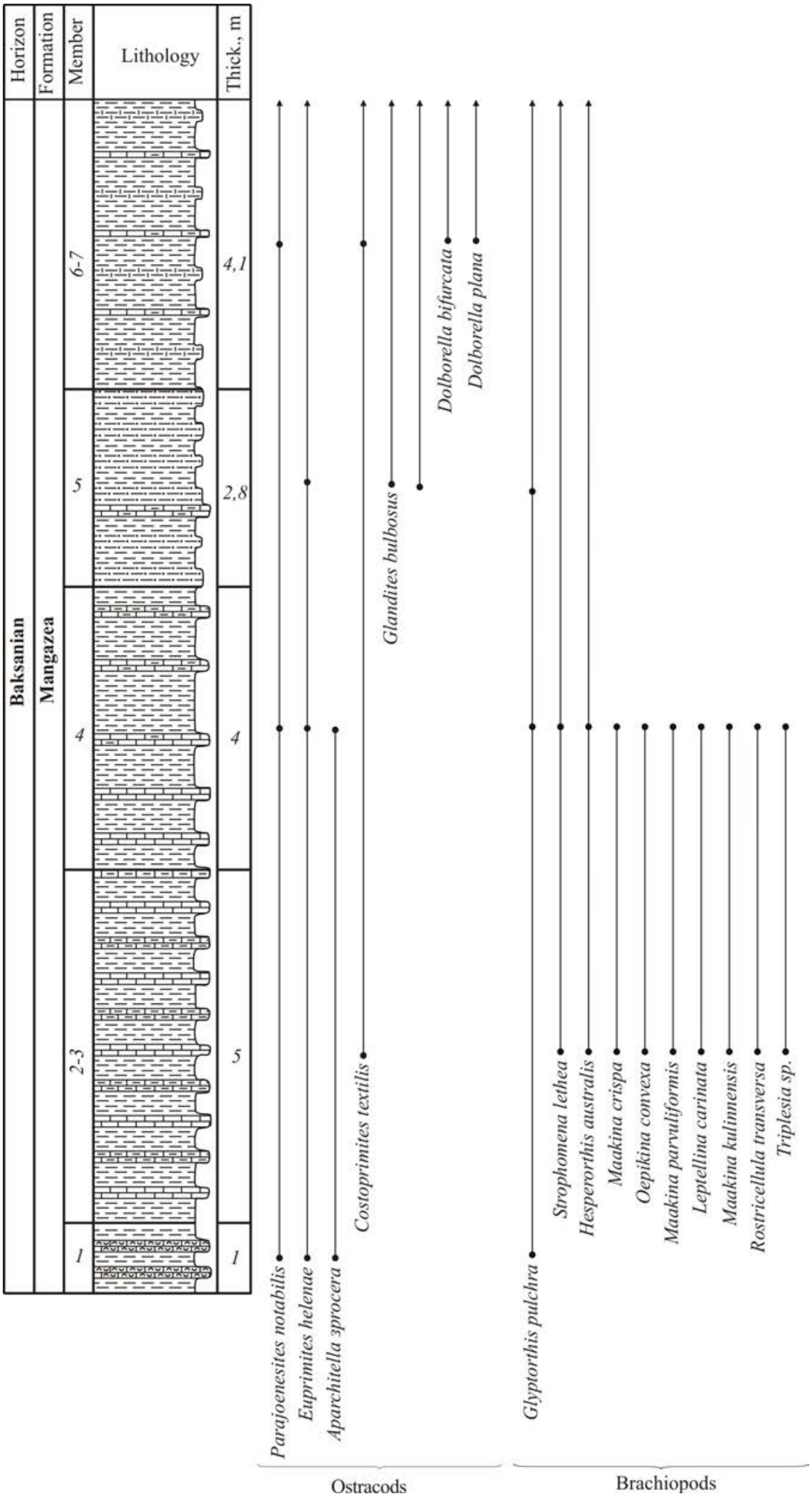

Fig. 24. Lithology and ranges of fossil taxa from the **Outcrop-III** – the Stolbovaya River, right bank, 3 km below the Kulinna River mouth.

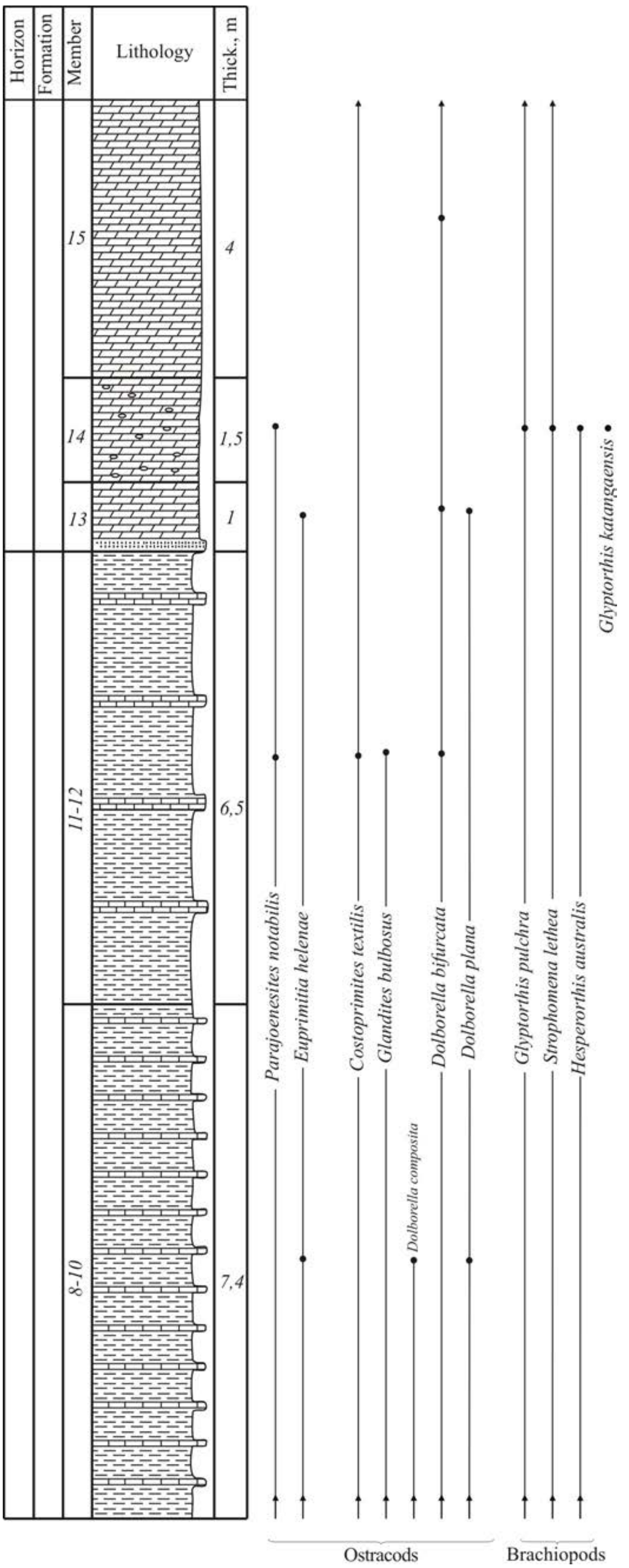

Fig. 24. Continued**.**

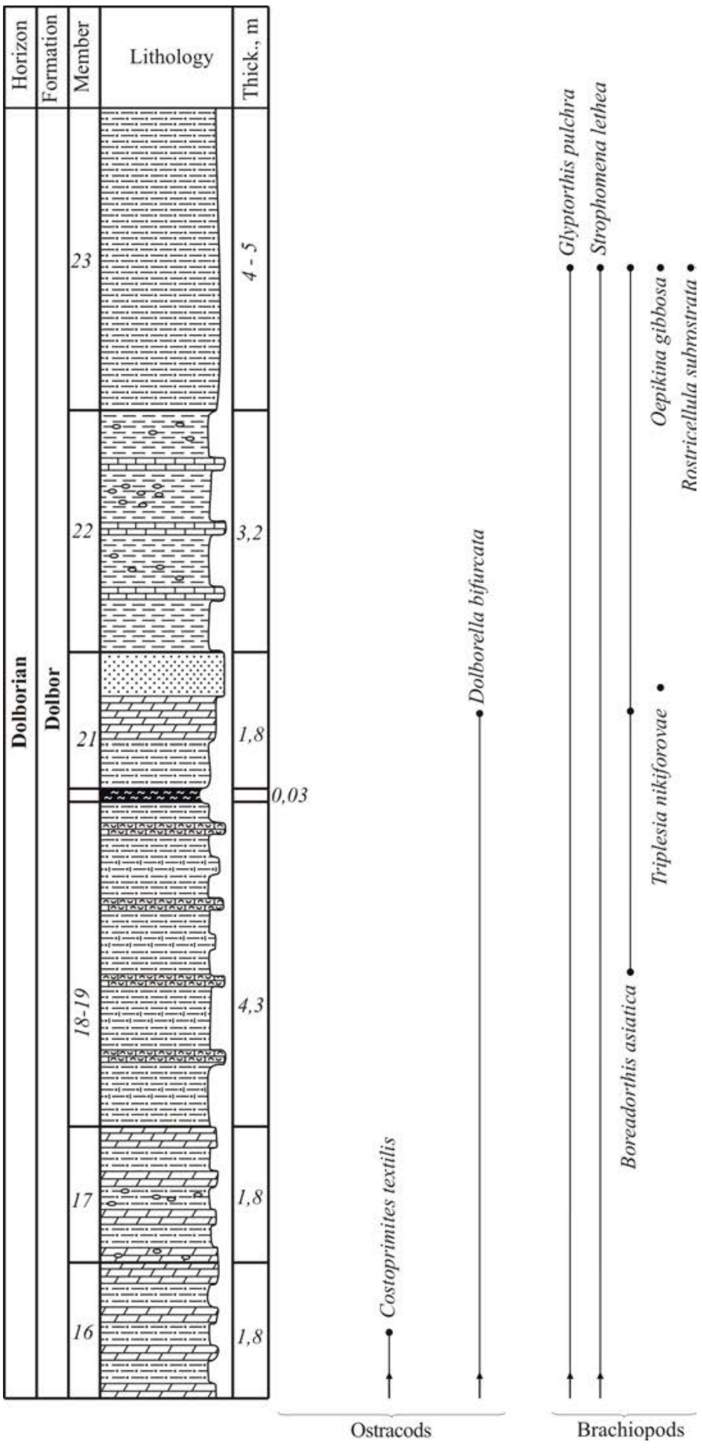

Fig. 24. The End.

Fig. 25. General view on the Outcrop III on the right bank of the Stolbovaya River, 5 km upstream from the Outcrop -II. Mangazea and Dolbor formations.

Fig. 26. Closer view to the lower part of the outcrop with the carbonate tempestites of the upper Mangazea Formation.

Fig. 27. Lenses of incised valley fills in the Mangazea Formation.

Outcrop-IV (Figs 28–30) – The Stolbovaya River, left bank, 1 km below the Kulinny River mouth.
The steep bank overhanging the water edge exhibits:

1–5. Mudstones, nonuniform, green, calcareous in interlayers, with individual limestones beds. The observed sporadic aggregates of organic remains, *inter alia* the finds of rugoses *Kenopliyllum subcylindricum* Dyb., *Lambeophyllum* sp., *Streptelasma* ex. gr. *foerstei* Troedss., trilobites *Bumastus* sp., *Ceratevenkaspis* cf. *armata* Kram., *Ceraurinus* sp., *Evencaspis* sp., and ostracods *Costoprimites indiligens* V. Ivan., *Glandites gulbosus* V. Ivan., *Parajonesites notabilis* V. Ivan., *Planusella* sp. **15.5 m**

6–14. Marls, non-stratified, greenish- and bluish-grey. Trilobites *Jsotellus maximus sibiricus* Z. Max. are encountered. **25.2 m**

15. Siltstones, yellowish-green, calcareous. Fossil finds include remains of brachiopods, crinoids. **3.3 m**

16. Limestones, clayey, with thin interlayers of greenish-grey mudstones. Brachiopods, bryozoans are less common. **1.0 m**

17. Slight outcroppings of siltstones, yellowish-green, calcareous. **3.0 m**

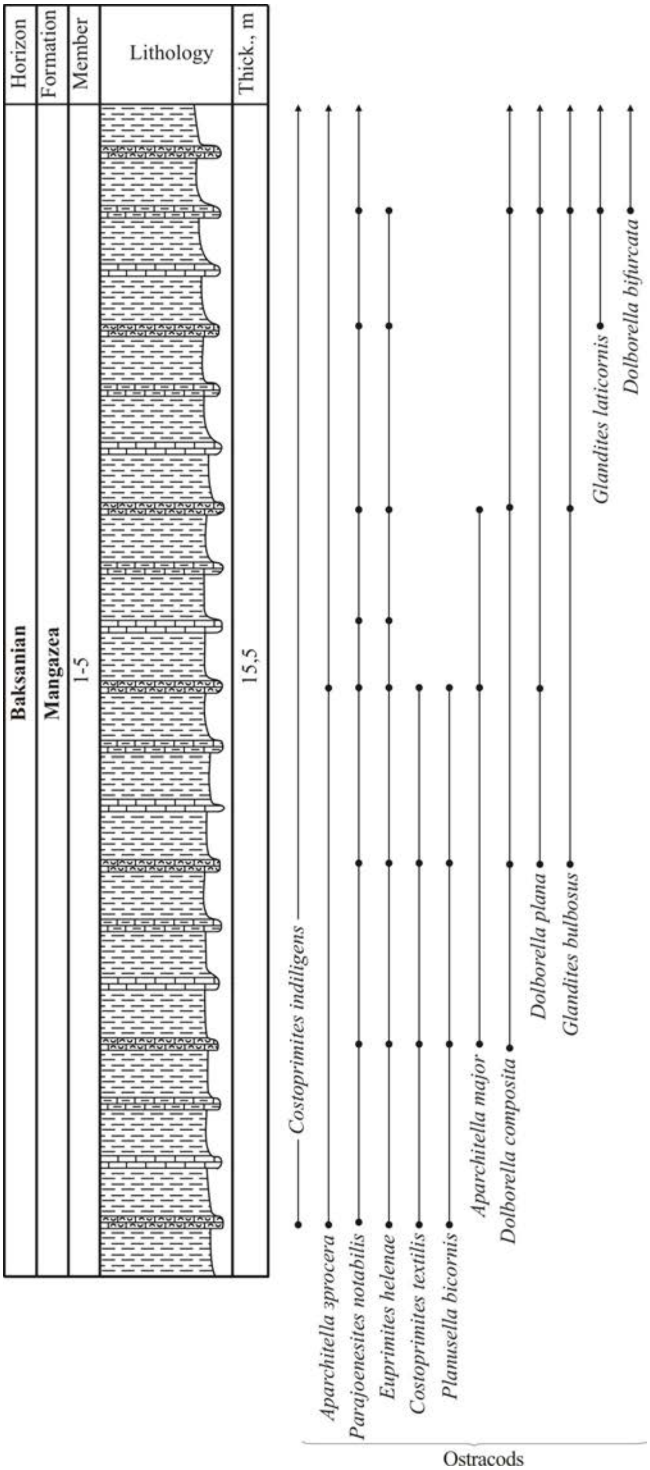

Fig. 28. Lithology and ranges of fossil taxa from the **Outcrop-IV**- the Stolbovaya River, left bank, 1 km below the Kulinny River mouth.

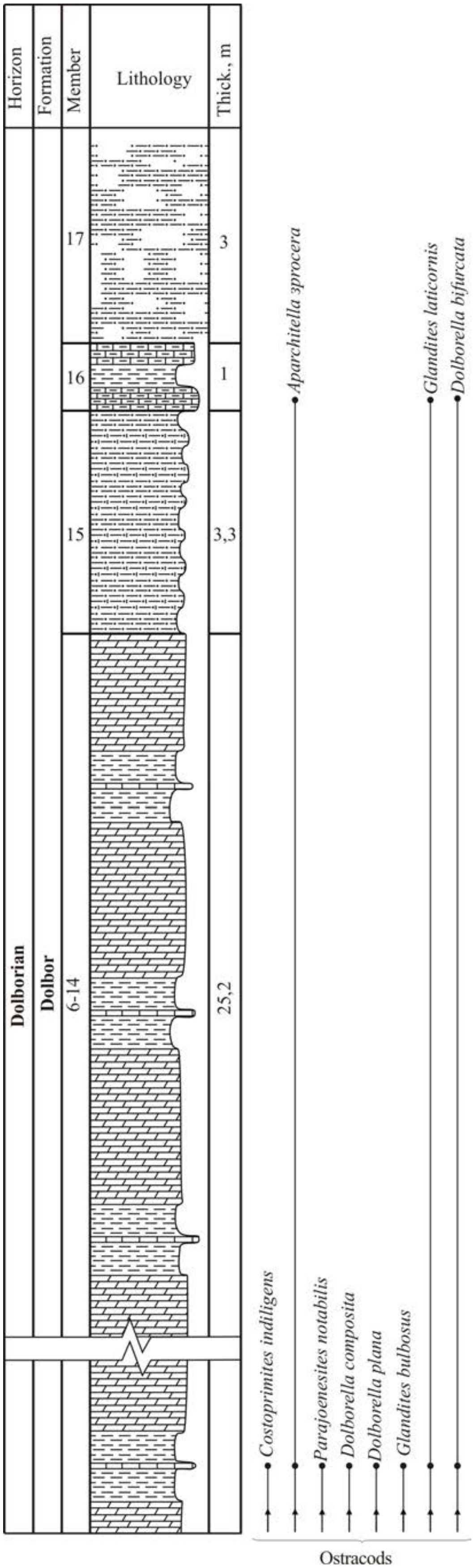

Fig. 24. The End.

Fig. 29. General view on the Outcrop IV on the left bank of the Stolbovaya River, 3 km upstream from the Outcrop IV. Mangazea and Dolbor formations.

Fig. 30. Normal fault in the Dolborian deposits.

Outcrop –V (Figs 31–34) – The Podkamennaya Tunguska River, right bank, 3.5 km above Kuzmovka Village. The flat lying part of the bank is composed by:

1. Alternating thin interlayers of limestones, dark grey, fine-grained, containing minute black phosphate pebbles, and grey siltstones. **0.15 m**

2. Mudstones are grey, thin-laminated, with fine-particulate dark detritus occurring in aggregates. **0.07 m**

3. Limestones, fine-grained, dark grey, locally with pyrite inclusions; numerous ostracods, rare poorly preserved brachiopods. **0.05 m**

4–5. Mudstones, dark grey, fine-grained, with small scales of mica and dark detritus largely concentrated along bedding planes. The encountered lenticular inclusions of coarser silty rocks contain numerous ostracods. **0.6 m**

6. Mudstones, greenish-grey and brownish-grey, with small concretions and thin intercalations of calcareous rocks. Ostracods *Aparchitella* sp., *Fidelitella* sp., *Primitia* ex gr. *abundans* V. Ivan., *Quadrilobella* sp., are prolific in the lower part, where nautiloids *Tunguskoceras*? sp. are not rare. **0.4 m**

7. Mudstones, variegated, with solitary thin interlayers of grey fine-crystalline limestones containing minute phosphate pebbles. Ostracods, nautiloids have been reported. **0,4 m**

8. Mudstones, red-coloured, with aggregates of small scales of mica. Ostracods *Fidelitella simplex* V. Ivan., *Quadrilobella* sp., *Aparchitella* sp. are fairly frequent. **0.2 m**

9. Mudstones, variegated, enclosing calcareous nodules. Ostracods *Aparchitella* sp., *Fidelitella simplex* V. Ivan., *Quadrilobella arpilobata* V. Ivan. are abundant. **0.8 m**

10. Mudstones, red-coloured. These are often ostracod-bearing (*Fidelitella simplex* V. Ivan., наутилоидеи *Metactinoceras* sp., *Ormoceras kusmovkense* Bal., *Tofangoceras* sp.). **0.3 m**

11. Mudstones, motley, brownish and green, with ostracods. **0.4 m**

12. Mudstones, red, with rare ostracods. **0.2 m**

13. Mudstones, green, with small scales of mica. **0.1 m**

14. Mudstones, red-coloured. **0.15 m**

Upwards, the slope is beginning to sharply increase in steepness, with scree-covered toe. Scree. **3.0 m**

15. Conglomerate layer containing a large number of phosphate pebbles. General background is dark grey. **0.5 m**

16–17. Siltstones, dark grey to almost black, with minute phosphate pebbles. Pyrite is not rare. Indistinct imprints of brachiopod shells. **2.3 m**

18. Mudstones, red-coloured, with minute phosphate pebbles. **0.2 m**

19. Siltstones, calcareous, green, alternating with interlayers of red and variegated argillite. Ostracods *Costoprimites indiligens* V. Ivan., *Euprimites helenae* V. Ivan. encounter occasionally. **1.3 m**

20–21. A thin interbed of pelitomorphic green limestones is succeeded by green mudstones with thin discontinuous limestone (grey fine-crystalline organogenic) interbeds. Organic remains are abundant and belong to various groups: bryozoans *Hemotrypa mundula* Ulr., *Trematopora* sp., *Pachydictya* cf. *miranda* Nekh., trilobites *Ceraurinus icarus* (Bill.), *Evenkaspis sibirica* (Schm.), *Monorakos* sp., ostracods *Aparchitella* ex gr. *procera* V. Ivan., *Coelochilina* sp., *Costoprimites indiligens* V. Ivan., *C. textilis* V. Ivan., *Jonesites obliquus* V. Ivan., *Laccochilina* sp., *Euprimites helenae* V. Ivan., as well as brachiopods, gastropods, crinoids. **3.2 m**.

22. Alternation of mudstones, green, crumbling into rubble, and limestones, grey and pinkish-grey, organogenic. Fossil are diverse and abundant. Trilobites *Monorakos* cf. *lopatini* (Schm.), *Monorakos* sp., and ostracods *Euprimites helenae* V. Ivan., *Costoprimites indiligens* V. Ivan., *Aparchitella* sp. have been identified. **6.7 m**

23. Oolite-like gravelites, red-coloured. **0.5 m**

24. Alternation of mudstones, enclosing minute phosphate pebbles and fine-particulate detritus occurring in aggregates, and limestones, grey to pink-grey, fine-crystalline and pelitomorphic, occasionally with phosphate pebbles. Fauna remains are numerous and diverse, which include the following identified species of bryozoans *Fimbriapora gregaria* (Schm.), and ostracods *Bolbinella* sp., *Glandites bulbosus* V. Ivan., *Euprimites helenae* V. Ivan., *Laccochilina* sp., *Parajonesites notabilis* V. Ivan., *Planusella bicornis* V. Ivan. **5.5 m**

25. The part of the rocks weakly outcropping upwards, is the same type as in the previous bed. **3.0–4.0 m.**

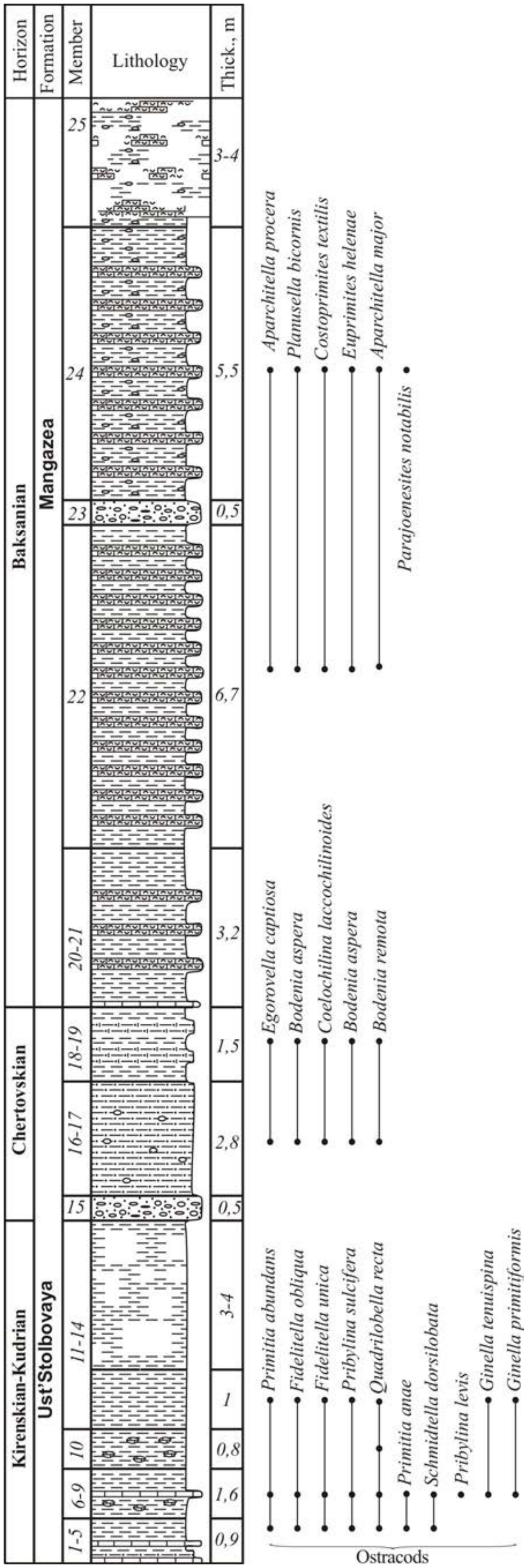

Fig. 31. Lithology and ranges of fossil taxa from the **Outcrop –V** - the Podkamennaya Tunguska River, right bank, 3.5 km above Kuzmovka Village.

Fig. 32. General view on the outcrop on the right bank of Podkamennaya Tunguska River, 3,5 km upstream Kuzmovka Village. Middle and Upper Ordovician deposits. Kirensk-Kidrinian, Chertovskian and Baksian regional stages. Ust'Stolbovaya and Mangazea formations.

Fig. 33. Closer view on the boundary between Chertovskian and Baksian Regional stages.

Fig. 34. Trace fossils *Balanoglossites*? in the micritic limestone bed of the Mangazea Formation.

Outcrop-VI (Figs 35–36) – The Podkamennaya Tunguska River, left bank, 2–3 km below Kuzmovka Village. In the sloping part of the coast and in its low steep slope there lie:

In the sloping part, the low steep bank exhibits:

1. Limestones, greenish-grey, enclosing abundant minute phosphate pebbles. The upper part is composed by siltstones, which yielded organic remains, such as bryozoans *Fimbriapora gregaria* (Schm.), trilobites *Isotelus maximus* Z. Max., ostracods *Euprimites helenae* V. Ivan., *Jonesites obliquus* V. Ivan. **1.3 m**

2. Mudstones, green, fine-rubbly, alternating with thin-bedded grey crystalline organogenic limestone containing abundant and diverse organic remains, identified as bryozoans *Eurydictya moyerensis* Nekh., ostracods *Euprimites helenae* V. Ivan., *Glandites bulbosus* V. Ivan., *Jonesites obliquus* V. Ivan., *Paraionesites notabilis* V. Ivan. Individual limestone interbeds are enriched in small dark phosphate pebbles, irregular in shape. The role of limestones is considerably reduced in the topmost part, with organic remains tending to disappear. **3.0 m**

3. Mudstones, green, silty, with solitary thin beds of organogenic limestones. Most common are bryozoans, and ostracods *Euprimites helenae* V. Ivan., *Glatidites bulbosus* V. Ivan. **1.8 m**

4. Mudstones, green to greenish-grey, with rare concretions and discontinuous interlayers of pelitomorphic limestones. **1.9 m**

5. Limestones, grey, coarse-crystalline, organogenic, with abundant colonies of ramifying bryozoans, while remains of brachiopods and trilobites *Carinopyge abscissa* Z. Max., *Isotellus maximus sibiricus* Z. Max. are much less common. **0.35 m**

6–7. Mudstones, dark green, with rare nodules and discontinuous limestone interbeds, often pelitomorphic, sometimes crystalline. **1.4 m**

8. Closely alternating limestones, grey, organogenic and pelitomorphic, and mudstones, dark grey, thinly-laminated, enriched in fine detritus. Limestones interbeds often have lenticular structure. **1.1 m**

9. Mudstones, dark green, crumbling into rubble, with abundant detritus. Thin interbeds of grey and pinkish-grey organogenic limestones are common. **6 m**

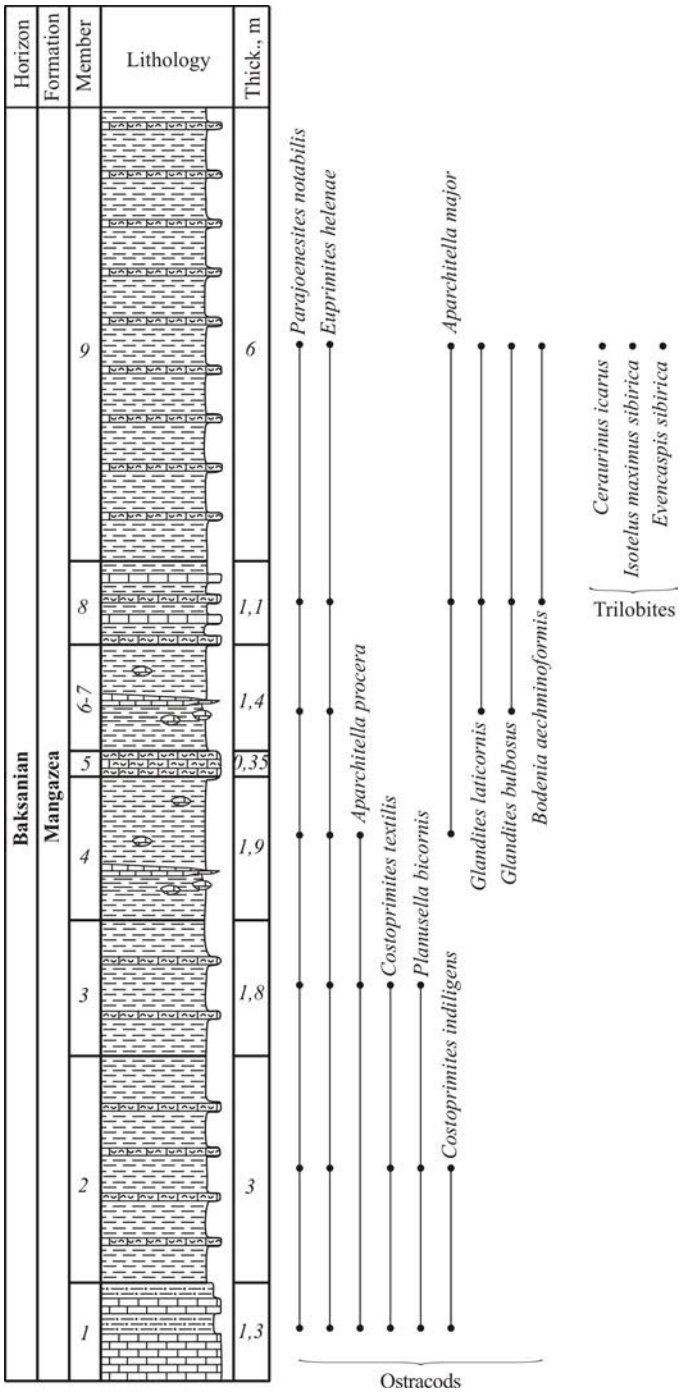

Fig. 35. Litology and ranges of fossil taxa from the **Outcrop-VI** – the Podkamennaya Tunguska River, left bank, 2–3 km below Kuzmovka Village.

Fig. 36. General view on the outcrop on the left bank of Podkamennaya Tunguska River, 3,5 km downstream of Kuzmovka Village. Mangazea Formation.

The outcrops near Gurievsky rivulet give the opportunity to study Baykit Sandstone and trace fossils which it contains including giant trilobite burrows (Kushlina & Dronov, 2011).

The Middle Ordovician Baykit Sandstone is exposed on the south-western margin of the Tungus Basin (Tungus Syneclise) mainly along the Podkamennaya Tunguska River and its tributaries. It constitutes a distinctive sedimentary body extending for over 600 km along the river valley (Figs 37–42). The succession consists of monotonous light grey and yellowish, sometimes pink or reddish coarsely bedded and frequently massive quartz sandstones. At certain levels a well developed cross-stratification and locally, especially near the base, conglomerates are typical. Thickness of the unit varies from 12m to 80-100m (Markov, 1970). The Baykit Sandstone (Baykit Formation) includes deposits of the Vikhorevian and Mukteian regional stages which correspond to the mid-Darriwilian of the Global Scale (Bergström et al., 2009). Baykit Sandstone is bounded at the base and at the top by regional unconformities and represents a complete depositional sequence. The monotonous composition of the sporadically exposed Baykit Sandstone prevents identification of depositional systems tracts. The Baykit depositional sequence roughly correlates with the Kunda depositional sequence of the Russian Platform (Dronov et al., 2009; Kanygin et al., 2010).

The *Rusophycus* trace fossils were found on the basal surface of the overturned fallen blocks of quartz sandstones in the locality on the right bank of the Podkamennaya Tunguska River about 3 km downstream from the mouth of the Stolbovaya River (Fig.1). Unfortunately the *Rusophycus* specimens were not found *in situ* but were present in talus material located at the base of the outcrop. Judging from lithology the block of rocks fell down approximately from the level about 10m from the base of the Baykit Sandstone.

Markov (1970) studied the Baykit Sandstone almost in all the territory of its exposures concluding that it was shallow marine in origin. Remnants of fauna are scarce but at some levels phosphatic shells of *Angarella* and lingulid brachiopods as well as usually very poorly preserved nautiloids and gastropods could be found. Trace fossils assemblage within the formation includes *Skolithos, Rusophycus, Planolites* and *Kouphichnium*. The later one seems to demonstrate tracks on subaerial exposed surfaces. Polygonal desiccation cracks are usual on some levels. Cross-stratification is very common. Sometimes herringbone cross-stratification could be found indicating bidirectional current orientation, although one current direction is usually dominant. Different types of ripples and current lineations provide an evidence of frequently active bottom currents. Integrating palaeontological, ichnological and sedimento-

Fig. 37. General view on the outcrop of Baykit Sandstone on the right bank of the Podkamennaya Tunguska River.

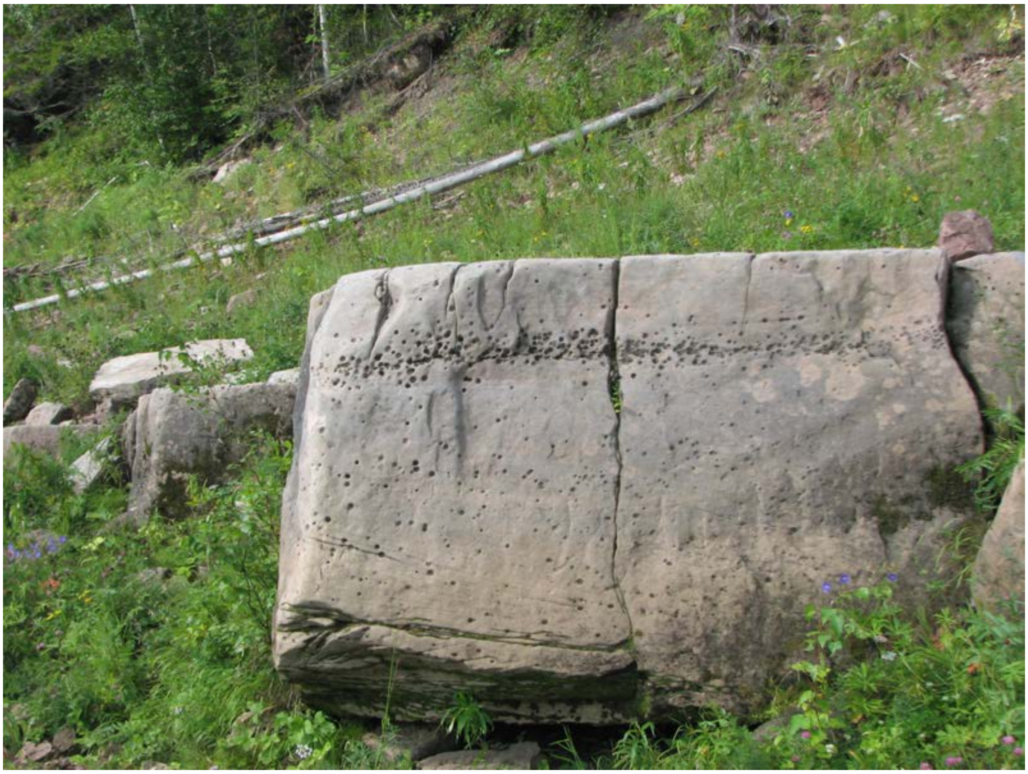

Fig. 38. Cross-stratification in the bed of Baykit Sandstone.

Fig. 39. Walking traces of limulides (*Kouphichnium*) at the upper bedding plane of sandstone bed of Baykit Formation.

Fig. 40. Closer view on the same block with horseshoe-like trilobite burrows (*Rusophycus*) and ripple marks at the bottoms of tidal distributary channels.

Fig. 41. Two closely spaced burrows of giant trilobites with well preserved scratch marks showing 3 claws of endopodites.

Fig. 42. The same burrows cleaned form grass, soil and moss.

logical data one can conclude that Baykit Sandstone was formed in near shore tide-dominated environment. It contains intertidal, supratidal and shallow subtidal strata.

The two best preserved *Rusophycus* specimens are located very close to each other on the sole of an 20 cm massive fine-grained quartz sandstone as a large positive feature (positive hyporelief) of broadly convex outline. Both specimens have a long elliptical outline. The length of one of them is 32 cm while width is 20 cm. The other one has length 31 cm and width 21 cm. Consequently the trace fossils were with a length: width ratio of approximately 3:2. Depth is about 12 cm. Unlike most *Cruziana* and *Rusophycus* our specimens do not demonstrate clear bilobate structure with a median (groove) axis. They seem to represent deep resting burrows or nests, dug in a slightly head-down position. Endopodal scratches up to 4-5 cm long are clearly visible on the front side of the burrows. They are three-clawed fingerprints in which the lateral scratches are stronger than the median one. Maximal distance between lateral claw scratch marks of one endopodite appendage is about 15 mm. Minimal distance is about 4 mm. Impressions of the cephalon edge are also well preserved on the steep or undercut front slope. No imprints of segments, pygidia, pleural spines or other parts of trilobite have been detected.

On the sole of the other big (3x9 m) fallen block of the quartz sandstone from the same locality 11 more poorly preserved *Rusophycus* burrows have been found. They are slightly different in morphology and represented mainly by bilobate horseshoe-like structures with different orientation. No scratch marks preserved on these burrows probably due to softer consistency of the sediment at the time of burrowing. Length of the structures varies from 36 to 53 cm with width variations from 19 to 24 cm. Depth does not usually exceed 6 cm. Despite their slightly different morphology length and width of the *Rusophycus* with scratch marks and the ones without them (horseshoe-like modifications) are very close to each other. That means they could be made by the same animals. Some more examples of the horseshoe-like *Rusophycus* can be found on the basal bedding planes of the fallen blocks of quartz sandstones about 0,5 km upstream and downstream the River from the main locality.

The Ordovician large *Rusophycus* are known from Canada and Australia. Hoffman (1979) has recorded *Rusophycus carleyi* from the Middle Ordovician Chazy Group 31 cm in length and 21 cm in width which is exactly the size of one of our specimens. Draper (1980) has recorded forms resembling both *R. dilate* and *R. carleyi* from the Early Ordovician of Mithaka Formation of the Georgina Basin (Australia) up to 31 cm in length. The largest Silurian recordings are by Osgood (1970) who noted *Rusophycus* up to 25 cm in length from the Clinton Group in Cincinnati and Tansathien and Pickerill (1986) who reported about *Rusophycus* 35 cm in length and 18 cm in width from the Arisaig Group of Nova Scotia. Giant *Cruziana* up to 23 cm in width has been also recorded from the Triassic Beaufort Group of South Africa (Shone, 1978).

While there is still controversy as to whether trilobites were responsible for producing all marine *Cruziana* and *Rusophycus* (see Whittington, 1980) it is almost universally accepted that in most cases they were responsible for that. The discovery of trilobites preserved *in situ* within *Rusophycus* (Osgood, 1970; Draper, 1980) together with closely comparable morphological features preserved in some *Rusophycus* when compared to the ventral morphology of trilobites leaves little doubt that trilobites were responsible for their production. Since the *Rusophycus* impressions correspond closely to the dimension of the trilobite which made them one can deduce that large trilobites at least 30 cm in length and 20 cm in width were inhabitants of the Siberian epicontinental seas in the Middle Ordovician. The problem however is that no such a big trilobites have been reported from the Ordovician of Siberian Platform. Judging from the broken fragments the largest exemplars rarely exceeded 20 cm (maximum 24 cm) in length and no more than 10–12 cm in width. These trilobites are from the family Asaphidae (Maksimova, 1962). It is of course dangerous to speculate on producers of trace fossils when no positive evidence is preserved. But Asaphidae trilobites seem to be a reasonable guess.

According to morphological analysis of trilobite skeletons the largest trilobites most probably were predators (Fortey and Owens, 1999). The *Rusophycus* trace fossil attributed to trilobites usually interpreted as a result of the producing organism resting, hunting or seeking protection (Osgood, 1970; Bergström, 1973). But the Siberian large *Rusophycus* with scratching marks seems to represent burrows dug for the reception of eggs. Similar interpretation was suggested by Fenton and Fenton (1937) for the Lower Cambrian burrow *Cruziana (Rusophycus) jenningsi*. The front (anterior) portions of each of the two traces bears horizontal ridges which seem to represent impressions made by a cephalon pushed forward and from side to side. The regularity, symmetry and depth of the burrows are inconsistent with functions of feeding or hunting. The fact that there are two burrows indicates that they are not accidental. They may be compared with the burrows that modern Limulus digs in sand on a beach as receptacles for its eggs. The horseshoe-like morphological type *Rusophycus* (Pl.1. Figs 1a, b) represents a different function. These trace fossils seem to be dig out by the trilobites seeking shelter from the strong currents during a tide activity.

Rusophycus and *Cruziana* with 3-clawed scratch marks are known from the Upper Cambrian – Upper Ordovician strata (Seilacher, 2007). This seems to be a maximum precision for global *Cruziana* stratigraphy nowadays. Regional *Cruziana* stratigraphy could be more precise but on Siberian Platform we still do not have enough findings of these trace fossils to establish a regional scale. As for trilobite body fossils in the Siberian Ordovician, they are mainly endemics (Maksimova, 1962). Up to now the Lower Paleozoic trilobite burrows with very few exceptions have been reported only from the fragments of ancient Gondwana continent (Seilacher, 2007). This fact has been even used for palinspastic purposes in order to identify terranes of Gondwanan origin that happen to dock at other paleocontinents (Seilacher and Crimes, 1969).The giant specimens of *Rusophycus* documented herein suggest that caution must be exercised with respect to palaeogeographic reconstructions based on trilobite burrows.

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